

# **MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family**

## **User's Guide**



Literature Number: SLAU367O  
October 2012–Revised December 2017

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## Read This First

### About This Manual

This manual describes the modules and peripherals of the MSP430FR58xx and MSP430FR59xx family of devices. Each description presents the module or peripheral in a general sense. Not all features and functions of all modules or peripherals may be present on all devices. In addition, modules or peripherals may differ in their exact implementation between device families, or may not be fully implemented on an individual device or device family.

Pin functions, internal signal connections, and operational parameters differ from device to device. Consult the device-specific data sheet for these details.

### Related Documentation From Texas Instruments

For related documentation, see the MSP430 web site: <http://www.ti.com/msp430>

### FCC Warning

This equipment is intended for use in a laboratory test environment only. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to subpart J of part 15 of FCC rules, which are designed to provide reasonable protection against radio frequency interference. Operation of this equipment in other environments may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

### Notational Conventions

Program examples are shown in a special typeface; for example:

```
MOV #255,R10
XOR @R5,R6
```

### Glossary

Abbreviation	Description
ACLK	Auxiliary clock
ADC	Analog-to-digital converter
BOR	Brownout reset
BSL	Bootloader; see <a href="http://www.ti.com/msp430">www.ti.com/msp430</a> for application reports
CPU	Central processing unit
DAC	Digital-to-analog converter
DCO	Digitally controlled oscillator
dst	Destination
FLL	Frequency locked loop
GIE Modes	General interrupt enable
INT(N/2)	Integer portion of N/2
I/O	Input/output
ISR	Interrupt service routine
LSB	Least-significant bit
LSD	Least-significant digit
LPM	Low-power mode; also named PM for power mode

Abbreviation	Description
MAB	Memory address bus
MCLK	Master clock
MDB	Memory data bus
MSB	Most-significant bit
MSD	Most-significant digit
NMI	(Non)-Maskable interrupt; also split to UNMI (user NMI) and SNMI (system NMI)
PC	Program counter
PM	Power mode
POR	Power-on reset
PUC	Power-up clear
RAM	Random access memory
SCG	System clock generator
SFR	Special function register
SMCLK	Subsystem master clock
SNMI	System NMI
SP	Stack pointer
SR	Status register
src	Source
TOS	Top of stack
UNMI	User NMI
WDT	Watchdog timer
z16	16-bit address space

## Register Bit Conventions

Each register is shown with a key indicating the accessibility of the each individual bit and the initial condition:

**Register Bit Accessibility and Initial Condition**

Key	Bit Accessibility
rw	Read/write
r	Read only
r0	Read as 0
r1	Read as 1
w	Write only
w0	Write as 0
w1	Write as 1
(w)	No register bit implemented; writing a 1 results in a pulse. The register bit always reads as 0.
h0	Cleared by hardware
h1	Set by hardware
-0,-1	Condition after PUC
-(0),-(1)	Condition after POR
-[0],-[1]	Condition after BOR
-{0},-{1}	Condition after brownout

## Trademarks

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## **System Resets, Interrupts, and Operating Modes, System Control Module (SYS)**

The system control module (SYS) is available on all devices. The basic features of SYS are:

- Brownout reset (BOR) and power on reset (POR) handling
- Power up clear (PUC) handling
- (Non)maskable interrupt (SNMI or UNMI) event source selection and management
- User data-exchange mechanism through the JTAG mailbox (JMB)
- Bootloader (BSL) entry mechanism
- Configuration management (device descriptors)
- Interrupt vector generators for reset and NMIs

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## 1.1 System Control Module (SYS) Introduction

SYS is responsible for the interaction between various modules throughout the system. The functions that SYS provides are not inherent to the modules themselves. Address decoding, bus arbitration, interrupt event consolidation, and reset generation are some examples of the many functions that SYS provides.

## 1.2 System Reset and Initialization

The system reset circuitry is shown in [Figure 1-1](#) and sources a brownout reset (BOR), a power-on reset (POR), and a power-up clear (PUC). Different events trigger these reset signals and different initial conditions exist depending on which signal was generated.

A BOR is a device reset. A BOR is generated only by the following events:

- Powering up the device
- Low signal on the  $\overline{RST}/NMI$  pin when configured in the reset mode
- Wake-up event from LPMx.5 (that is, LPM3.5 or LPM4.5) mode
- $SVS_H$  low condition, when enabled (see the [PMM and SVS](#) chapter for details)
- Software BOR event (see the [PMM and SVS](#) chapter for details)

A POR is always generated when a BOR is generated, but a BOR is not generated by a POR. The following events trigger a POR:

- BOR signal
- Software POR event (see the [PMM and SVS](#) chapter for details)

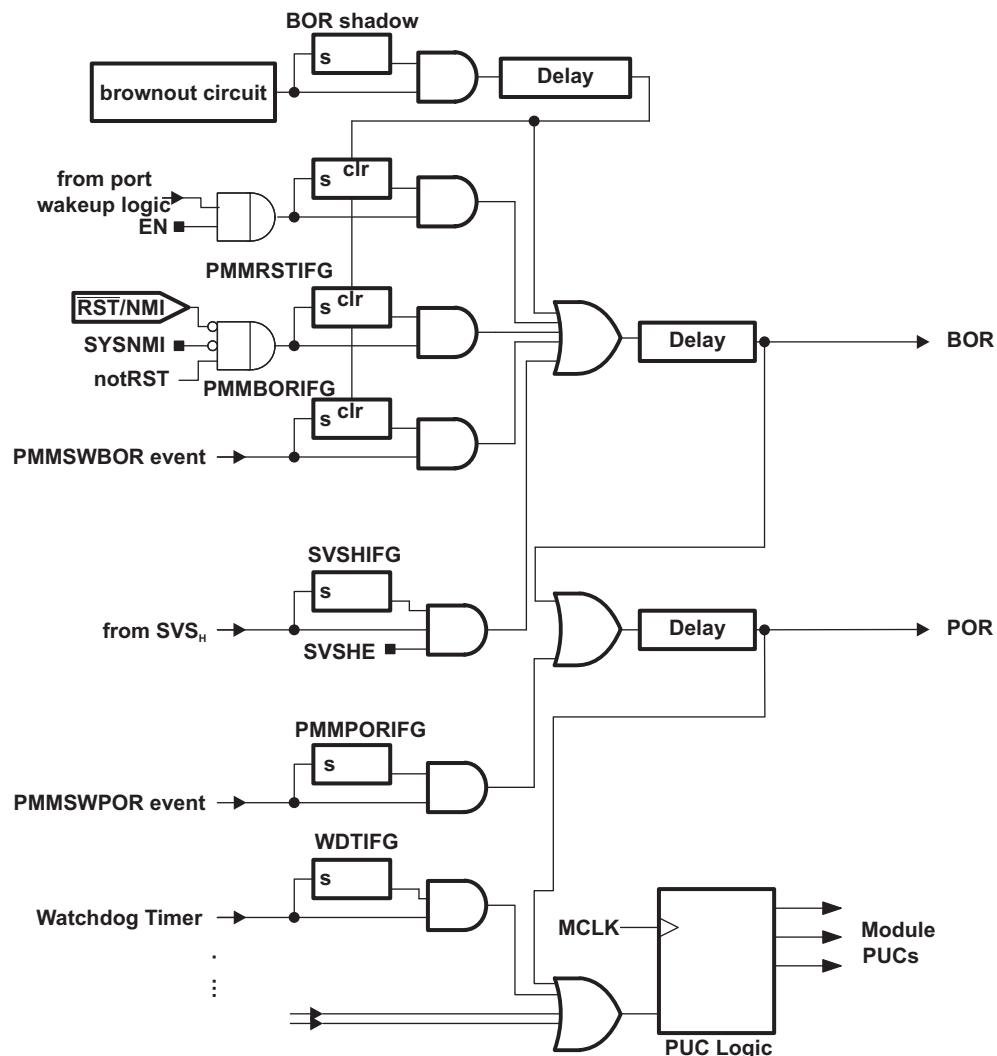
A PUC is always generated when a POR is generated, but a POR is not generated by a PUC. The following events trigger a PUC:

- POR signal
- Watchdog timer expiration when watchdog mode only (see the [WDT\\_A](#) chapter for details)
- Watchdog timer password violation (see the [WDT\\_A](#) chapter for details)
- FRAM memory password violation (see the [FRAM Controller](#) chapter for details)
- Power Management Module password violation (see the [PMM and SVS](#) chapter for details)
- Memory Protection Unit password violation (see the [MPU](#) chapter for details)
- Memory segment violation (see the [MPU](#) chapter for details)
- Clock System password violation (see the [Clock System](#) chapter for details)
- Fetch from peripheral area
- Uncorrectable FRAM bit error detection

---

**NOTE:** The number and type of resets available may vary from device to device. See the device-specific data sheet for all reset sources available.

---



**Figure 1-1. BOR, POR, and PUC Reset Circuit**

### 1.2.1 Device Initial Conditions After System Reset

After a BOR, the initial device conditions are:

- The  $\overline{\text{RST}}/\text{NMI}$  pin is configured in the reset mode. See [Section 1.7](#) for details on configuring the  $\overline{\text{RST}}/\text{NMI}$  pin.
- I/O pins are switched to input mode as described in the [Digital I/O](#) chapter.
- Other peripheral modules and registers are initialized as described in their respective chapters.
- Status register (SR) is reset.
- The watchdog timer powers up active in watchdog mode.
- Program counter (PC) is loaded with the boot code address and boot code execution begins at that address. See [Section 1.10](#) for more information regarding the boot code. Upon completion of the boot code, the PC is loaded with the address contained at the SYSRSTIV reset location (0FFFEh).

After a system reset, user software must initialize the device for the application requirements. The following must occur:

- Initialize the stack pointer (SP), typically to the top of RAM when available, otherwise FRAM location.
- Initialize the watchdog to the requirements of the application.
- Configure peripheral modules to the requirements of the application.

---

**NOTE:** A device that is unprogrammed or blank is defined as having its reset vector value, residing at memory address FFFEh, equal to FFFFh. Upon system reset of a blank device, the device automatically enters operating mode LPM4. See [Section 1.4](#) for information on operating modes and [Section 1.3.6](#) for details on interrupt vectors.

---

## 1.3 Interrupts

The interrupt priorities are fixed and defined by the arrangement of the modules in the connection chain as shown in [Figure 1-2](#). Interrupt priorities determine what interrupt is taken when more than one interrupt is pending simultaneously.

There are three types of interrupts:

- System reset
- (Non)maskable
- Maskable

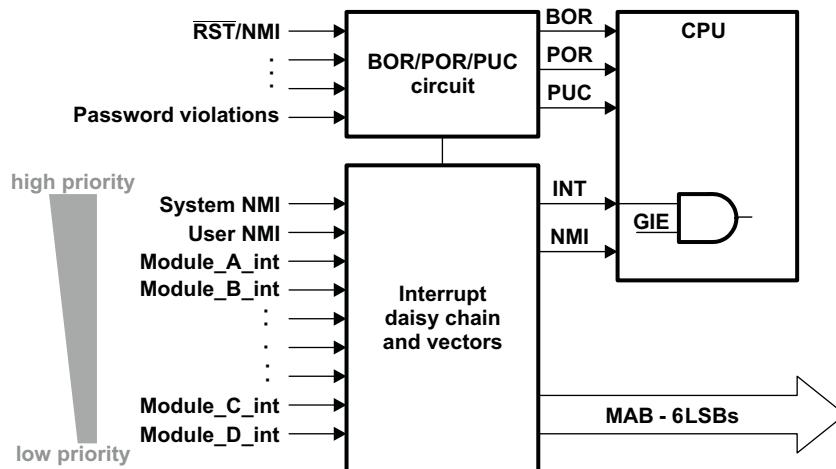


Figure 1-2. Interrupt Priority

---

**NOTE:** The types of interrupt sources available and their respective priorities change from device to device. See the device-specific data sheet for all interrupt sources and their priorities.

---

### 1.3.1 (Non)Maskable Interrupts (NMIs)

In general, NMIs are not masked by the general interrupt enable (GIE) bit. Two levels of NMIs are supported — system NMI (SNMI) and user NMI (UNMI). The NMI sources are enabled by individual interrupt enable bits. When an NMI interrupt is accepted, other NMIs of that level are automatically disabled to prevent nesting of consecutive NMIs of the same level. Program execution begins at the address stored in the NMI vector as shown in [Section 1.3.6](#). To allow software backward compatibility to users of earlier MSP430 families, the software may, but does not need to, reenable NMI sources. The block diagram for NMI sources is shown in [Section 1.3](#).

A UNMI interrupt can be generated by following sources:

- An edge on the  $\overline{RST}/NMI$  pin when configured in NMI mode
- An oscillator fault occurs

A SNMI interrupt can be generated by following sources:

- FRAM errors (see the [FRAM Controller](#) chapter for details)
- Vacant memory access
- JTAG mailbox (JMB) event

---

**NOTE:** The number and types of NMI sources may vary from device to device. See the device-specific data sheet for all NMI sources available.

---

### 1.3.2 SNMI Timing

Consecutive SNMIs that occur at a higher rate than they can be handled (interrupt storm) allow the main program to execute one instruction after the SNMI handler is finished with a RETI instruction, before the SNMI handler is executed again. Consecutive SNMIs are not interrupted by UNMIs in this case. This avoids a blocking behavior on high SNMI rates.

### 1.3.3 Maskable Interrupts

Maskable interrupts are caused by peripherals with interrupt capability. Each maskable interrupt source can be disabled individually by an interrupt enable bit, or all maskable interrupts can be disabled by the general interrupt enable (GIE) bit in the status register (SR).

Each individual peripheral interrupt is discussed in its respective module chapter in this manual.

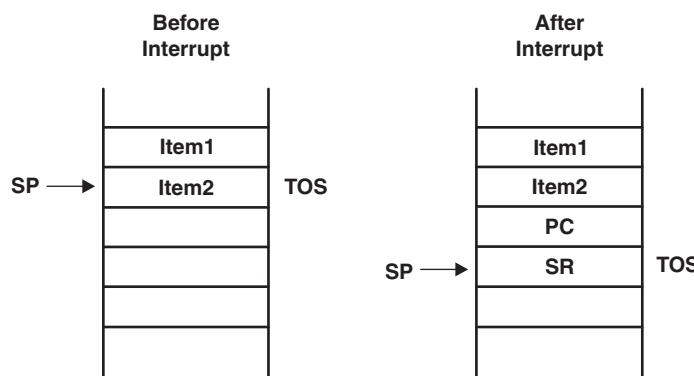
### 1.3.4 Interrupt Processing

When an interrupt is requested from a peripheral and the peripheral interrupt enable bit and GIE bit are set, the interrupt service routine is requested. Only the individual enable bit must be set for (non)-maskable interrupts (NMI) to be requested.

#### 1.3.4.1 Interrupt Acceptance

The interrupt latency is six cycles, starting with the acceptance of an interrupt request, and lasting until the start of execution of the first instruction of the interrupt service routine, as shown in [Figure 1-3](#). The interrupt logic executes the following:

1. Any currently executing instruction is completed.
2. The PC, which points to the next instruction, is pushed onto the stack.
3. The SR is pushed onto the stack.
4. The interrupt with the highest priority is selected if multiple interrupts occurred during the last instruction and are pending for service.
5. The interrupt request flag resets automatically on single-source flags. Multiple source flags remain set for servicing by software.
6. All bits of SR are cleared except SCG0, thereby terminating any low-power mode. Because the GIE bit is cleared, further interrupts are disabled.
7. The content of the interrupt vector is loaded into the PC; the program continues with the interrupt service routine at that address.



**Figure 1-3. Interrupt Processing**

---

#### NOTE: Enable and Disable Interrupt

Due to the pipelined CPU architecture, setting the general interrupt enable (GIE) requires special care.

- The instruction immediately after the enable interrupts instruction (EINT) is always executed, even if an interrupt service request is pending.
- Include at least one instruction between the clear of an interrupt enable or interrupt flag and the EINT instruction. For example: Insert a NOP instruction in front of the EINT instruction.
- Include at least one instruction between DINT and the start of an code sequence that requires protection from interrupts. For example: Insert a NOP instruction after the DINT.
- Never clear the general interrupt enable (GIE) immediately after setting it. Insert at least one instruction in between such sequence.

The rules above apply to all instructions that set or clear the general interrupt enable bit. Not following these rules might result in unexpected CPU execution.

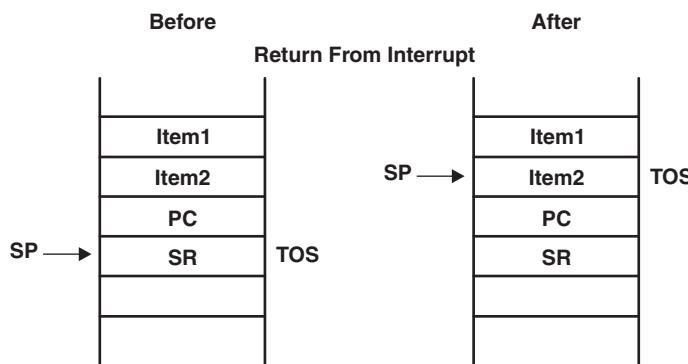
### 1.3.4.2 Return From Interrupt

The interrupt handling routine terminates with the instruction:

```
RETI //return from an interrupt service routine
```

The return from the interrupt takes five cycles to execute the following actions and is illustrated in [Figure 1-4](#).

1. The SR with all previous settings pops from the stack. All previous settings of GIE, CPUOFF, and so on are now in effect, regardless of the settings used during the interrupt service routine.
2. The PC pops from the stack and begins execution where it was interrupted.



**Figure 1-4. Return From Interrupt**

### 1.3.5 Interrupt Nesting

Interrupt nesting is enabled if the GIE bit is set inside an interrupt service routine. When interrupt nesting is enabled, any interrupt occurring during an interrupt service routine interrupts the routine, regardless of the interrupt priorities.

### 1.3.6 Interrupt Vectors

The interrupt vectors are located in the address range 0FFFFh to OFF80h, for a maximum of 64 interrupt sources. A vector is programmed by the user and points to the start location of the corresponding interrupt service routine. [Table 1-1](#) is an example of the interrupt vectors available. See the device-specific data sheet for the complete interrupt vector list.

**Table 1-1. Interrupt Sources, Flags, and Vectors**

Interrupt Source	Interrupt Flag	System Interrupt	Word Address	Priority
Reset: power up, external reset watchdog, FRAM password	... WDTIFG FRCTLWP	... Reset	0FFF Eh	... Highest
System NMI: JTAG Mailbox	JMBINIFG, JMBOUTIFG	(Non)maskable	0FFF Ch	...
User NMI: NMI oscillator fault	... NMIIIFG OFIFG	... (Non)maskable (Non)maskable	0FFF Ah	... ...
Device specific			0FFF8 h	...
...			...	...
Watchdog timer	WDTIFG	Maskable	...	...
...			...	...
Device specific			...	...
Reserved		Maskable	...	Lowest

Some interrupt enable bits and interrupt flags, as well as control bits for the RST/NMI pin, are located in the special function registers (SFR). The SFR are located in the peripheral address range and are byte and word accessible. See the device-specific data sheet for the SFR configuration.

#### 1.3.6.1 Alternate Interrupt Vectors

On devices that contain RAM, it is possible to use the RAM as an alternate location for the interrupt vector locations. Setting the SYSRIVECT bit to '1' in SYSCtrl causes the interrupt vectors to be remapped to the top of RAM. The total RAM size varies depending on the device configurations and could include one or multiple RAM sections. The alternate location is always the highest address of the entire RAM space available in the device. Note that the SYSRIVECT bit is automatically cleared on a BOR, so the default reset vector location (0FFEh) will be used after a BOR before setting the SYSRIVECT bit to '1'.

#### 1.3.7 SYS *Interrupt Vector Generators*

SYS collects all system NMI (SNMI) sources, user NMI (UNMI) sources, and BOR, POR, or PUC (reset) sources of all the other modules. They are combined into three interrupt vectors. The interrupt vector registers SYSRSTIV, SYSSNIV, SYSUNIV are used to determine which flags requested an interrupt or a reset. The interrupt with the highest priority of a group, when enabled, generates a number in the corresponding SYSRSTIV, SYSSNIV, SYSUNIV register. This number can be directly added to the program counter, causing a branch to the appropriate portion of the interrupt service routine. Disabled interrupts do not affect the SYSRSTIV, SYSSNIV, SYSUNIV values. Reading SYSRSTIV, SYSSNIV, SYSUNIV register automatically resets the highest pending interrupt flag of that register. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. Writing to the SYSRSTIV, SYSSNIV, SYSUNIV register automatically resets all pending interrupt flags of the group.

### 1.3.7.1 SYSSNIV Software Example

The following software example shows the recommended use of SYSSNIV. The SYSSNIV value is added to the PC to automatically jump to the appropriate routine. For SYSRSTIV and SYSUNIV, a similar software approach can be used. The following is an example for a generic device. Vectors can change in priority for a given device. The device-specific data sheet should be referenced for the vector locations. All vectors should be coded symbolically to allow for easy portability of code.

```

SNI_ISR:    ADD    &SYSSNIV,PC    ; Add offset to jump table
             RETI           ; Vector 0: No interrupt
             JMP    DBD_ISR     ; Vector 2: DBDIFG
             JMP    ACCTIM_ISR   ; Vector 4: ACCTIMIFG
             JMP    RSVD1_ISR    ; Vector 6: Reserved for future usage.
             JMP    RSVD2_ISR    ; Vector 8: Reserved for future usage.
             JMP    RSVD3_ISR    ; Vector 10: Reserved for future usage.
             JMP    RSVD4_ISR    ; Vector 12: Reserved for future usage.
             JMP    ACCV_ISR     ; Vector 14: ACCVIFG
             JMP    VMA_ISR      ; Vector 16: VMAIFG
             JMP    JMBI_ISR     ; Vector 18: JMBINIFG
             JMP    JMBO_ISR     ; Vector 20: JMBOUTIFG
             JMP    SBD_ISR      ; Vector 22: SBDIFG

DBD_ISR:          ; Vector 2: DBDIFG
...
RETI           ; Task_2 starts here
; Return
ACCTIM_ISR:       ; Vector 4
...
RETI           ; Task_4 starts here
; Return
RSVD1_ISR:        ; Vector 6
...
RETI           ; Task_6 starts here
; Return
RSVD2_ISR:        ; Vector 8
...
RETI           ; Task_8 starts here
; Return
RSVD3_ISR:        ; Vector 10
...
RETI           ; Task_10 starts here
; Return
RSVD4_ISR:        ; Vector 12
...
RETI           ; Task_12 starts here
; Return
ACCV_ISR:         ; Vector 14
...
RETI           ; Task_14 starts here
; Return
VMA_ISR:          ; Vector 16
...
RETI           ; Task_16 starts here
; Return
JMBI_ISR:         ; Vector 18
...
RETI           ; Task_18 starts here
; Return
JMBO_ISR:         ; Vector 20
...
RETI           ; Task_20 starts here
; Return
SBD_ISR:          ; Vector 22
...
RETI           ; Task_22 starts here
; Return

```

## 1.4 Operating Modes

The MSP430 family is designed for ultralow-power applications and uses different operating modes shown in [Figure 1-5](#).

The operating modes take into account three different needs:

- Ultra-low power
- Speed and data throughput
- Minimization of individual peripheral current consumption

The low-power modes LPM0 through LPM4 are configured with the CPUOFF, OSCOFF, SCG0, and SCG1 bits in the SR. The advantage of including the CPUOFF, OSCOFF, SCG0, and SCG1 mode-control bits in the SR is that the present operating mode is saved onto the stack during an interrupt service routine. Program flow returns to the previous operating mode if the saved SR value is not altered during the interrupt service routine. Program flow can be returned to a different operating mode by manipulating the saved SR value on the stack inside of the interrupt service routine. When setting any of the mode-control bits, the selected operating mode takes effect immediately. Peripherals operating with any disabled clock are disabled until the clock becomes active. Peripherals may also be disabled with their individual control register settings. All I/O port pins, RAM, and registers are unchanged. Wakeup from LPM0 through LPM4 is possible through all enabled interrupts.

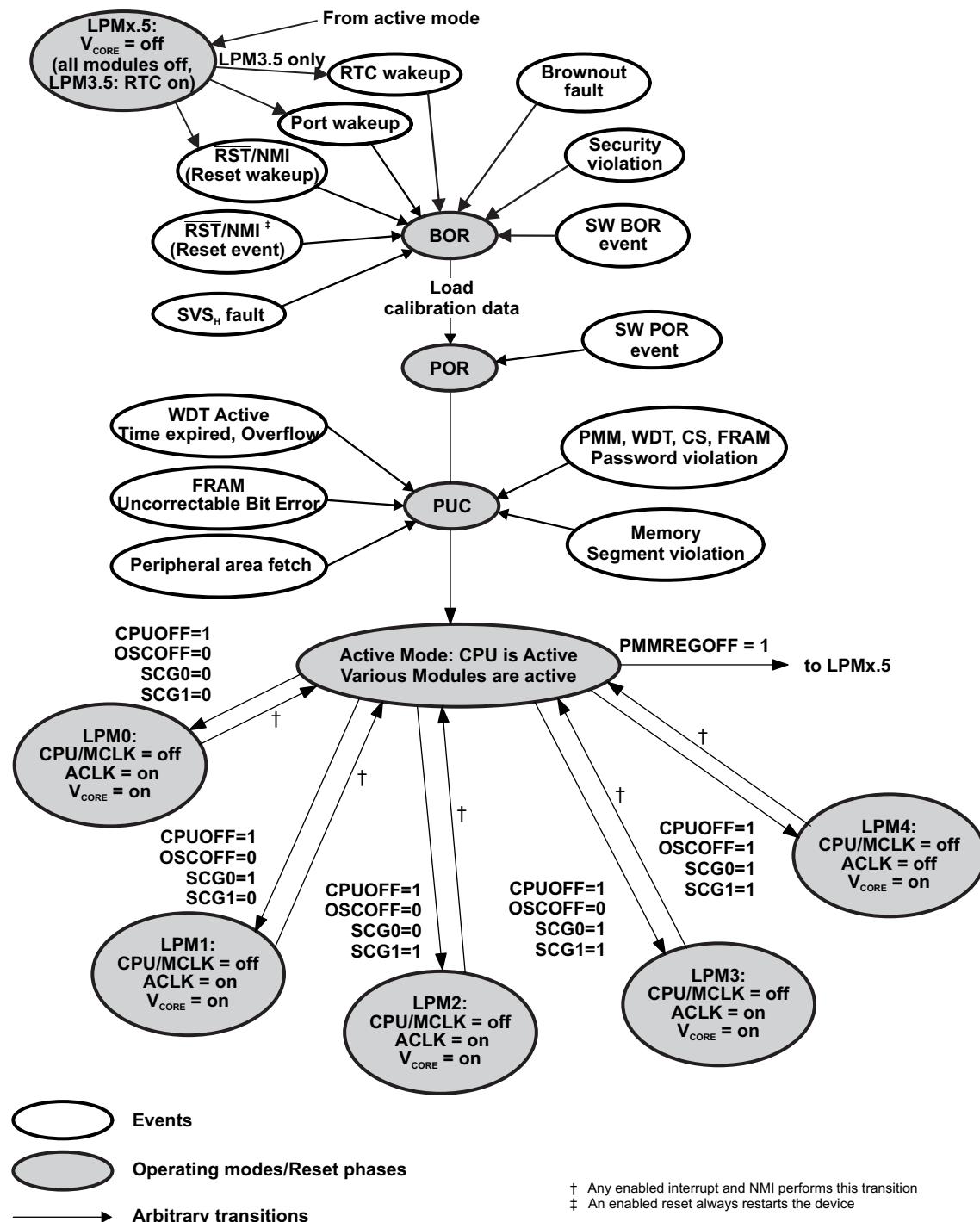
When LPMx.5 (LPM3.5 or LPM4.5) is entered, the voltage regulator of the Power Management Module (PMM) is disabled. All RAM and register contents are lost. Although the I/O register contents are lost, the I/O pin states are locked upon LPMx.5 entry. See the [Digital I/O](#) chapter for further details. Wakeup from LPM4.5 is possible through a power sequence, a RST event, or from specific I/O. Wakeup from LPM3.5 is possible through a power sequence, a RST event, RTC event, or from specific I/O.

---

**NOTE:** The TEST/SBWTCK pin is used to enable the connection of external development tools with the device through Spy-Bi-Wire or JTAG debug protocols. The connection is usually enabled when the TEST/SBWTCK is high. When the connection is enabled the device enters a debug mode. In the debug mode the entry and wake-up times to and from low power modes may be different compared to normal operation. Pay careful attention to the real-time behavior when using low power modes with the device connected to a development tool!

See the [EEM](#) chapter for further details.

---


**Figure 1-5. Operation Modes**

**Table 1-2. Operation Modes**

<b>SCG1<sup>(1)</sup></b>	<b>SCG0</b>	<b>OSCOFF<sup>(1)</sup></b>	<b>CPUOFF<sup>(1)</sup></b>	<b>Mode</b>	<b>CPU and Clocks Status<sup>(2)</sup></b>
0	0	0	0	Active	CPU, MCLK are active. ACLK is active. SMCLK optionally active (SMCLKOFF = 0). DCO is enabled if sources ACLK, MCLK, or SMCLK (SMCLKOFF = 0). DCO bias is enabled if DCO is enabled or DCO sources MCLK or SMCLK (SMCLKOFF = 0).
0	0	0	1	LPM0	CPU, MCLK are disabled. ACLK is active. SMCLK optionally active (SMCLKOFF = 0). DCO is enabled if sources ACLK or SMCLK (SMCLKOFF = 0). DCO bias is enabled if DCO is enabled or DCO sources MCLK or SMCLK (SMCLKOFF = 0).
0	1	0	1	LPM1	CPU, MCLK are disabled. ACLK is active. SMCLK optionally active (SMCLKOFF = 0). DCO is enabled if sources ACLK or SMCLK (SMCLKOFF = 0). DCO bias is enabled if DCO is enabled or DCO sources MCLK or SMCLK (SMCLKOFF = 0).
1	0	0	1	LPM2	CPU, MCLK are disabled. ACLK is active. SMCLK is disabled.
1	1	0	1	LPM3	CPU, MCLK are disabled. ACLK is active. SMCLK is disabled.
1	1	1	1	LPM4	CPU and all clocks are disabled.
1	1	1	1	LPM3.5	When PMMREGOFF = 1, regulator is disabled. No memory retention. In this mode, RTC operation is possible when configured properly. See the <i>RTC</i> module for further details.
1	1	1	1	LPM4.5	When PMMREGOFF = 1, regulator is disabled. No memory retention. In this mode, all clock sources are disabled; that is, no RTC operation is possible.

<sup>(1)</sup> This bit is automatically reset when exiting low-power modes. See [Section 1.4.2](#) for details.

<sup>(2)</sup> The low-power modes and, hence, the system clocks can be affected by the clock request system. See the [Clock System](#) chapter for details.

#### 1.4.1 Low-Power Modes and Clock Requests

A peripheral module requests its clock sources automatically from the clock system (CS) module if it is required for its proper operation, regardless of the current power mode of operation. Refer to the "Operation From Low-Power Modes, Requested by Peripheral Modules" section in the [Clock System](#) chapter.

Because of the clock request mechanism the system might not reach the low-power modes requested by the bits set in the CPU's status register SR as listed in [Table 1-3](#).

**Table 1-3. Requested vs Actual LPM**

Requested LPM (SR Bits according to <a href="#">Table 1-2</a> )	Actual LPM...		
	If No Clock Requested	If Only ACLK Requested	If SMCLK Requested
LPM0	LPM0	LPM0	LPM0
LPM1	LPM1	LPM1	LPM1
LPM2	LPM2	LPM2	LPM0
LPM3	LPM3	LPM3	LPM1
LPM4	LPM4	LPM3	LPM1

### 1.4.2 Entering and Exiting Low-Power Modes LPM0 Through LPM4

An enabled interrupt event wakes the device from low-power operating modes LPM0 through LPM4. The program flow for exiting LPM0 through LPM4 is:

- Enter interrupt service routine
    - The PC and SR are stored on the stack.
    - The CPUOFF, SCG1, and OSCOFF bits are automatically reset.
  - Options for returning from the interrupt service routine
    - The original SR is popped from the stack, restoring the previous operating mode.
    - The SR bits stored on the stack can be modified within the interrupt service routine returning to a different operating mode when the RETI instruction is executed.
- ```

; Enter LPM0 Example
    BIS    #GIE+CPUOFF,SR           ; Enter LPM0
; ...
;   ; Program stops here
;

; Exit LPM0 Interrupt Service Routine
    BIC    #CPUOFF,0(SP)          ; Exit LPM0 on RETI
    RETI

;

; Enter LPM3 Example
    BIS    #GIE+CPUOFF+SCG1+SCG0,SR      ; Enter LPM3
; ...
;   ; Program stops here
;

; Exit LPM3 Interrupt Service Routine
    BIC    #CPUOFF+SCG1+SCG0,0(SP)        ; Exit LPM3 on RETI
    RETI

;

; Enter LPM4 Example
    BIS    #GIE+CPUOFF+OSCOFF+SCG1+SCG0,SR      ; Enter LPM4
; ...
;   ; Program stops here
;

; Exit LPM4 Interrupt Service Routine
    BIC    #CPUOFF+OSCOFF+SCG1+SCG0,0(SP)        ; Exit LPM4 on RETI
    RETI

```

### 1.4.3 Low-Power Modes LPM3.5 and LPM4.5 (LPMx.5)

The low-power modes LPM3.5 and LPM4.5 (LPMx.5<sup>(1)</sup>) give the lowest power consumption on a device. In LPMx.5, the core LDO of the device is switched off. This has the following effects:

- Most of the modules are powered down.
  - In LPM3.5, only modules powered by the RTC LDO continue to operate. At least an RTC module is connected to the RTC LDO. Refer to the device's data sheet for other modules (if any) that are connected to the RTC LDO.
  - In LPM4.5 the RTC LDO and the connected modules are switched off.
- The register content of all modules and the CPU is lost.
- The SRAM content is lost.
- A wake-up from LPMx.5 causes a complete reset of the core.
- The application must initialize the complete device after a wake-up from LPMx.5.

The wake-up time from LPMx.5 is much longer than the wake-up time from any other power mode (see the device-specific data sheet). This is because the core domain must power up and the device internal initialization must be done. In addition, the application must be initialized again. Therefore, use LPMx.5 only when the application is in LPMx.5 for a long time.

<sup>(1)</sup> The abbreviation "LPMx.5" is used in this document to indicate both LPM3.5 and LPM4.5.

Compute Through Power Loss (CTPL) is a utility API set that leverages FRAM to enable ease of use with LPMx.5 low-power modes and provides a powerful shutdown mode that allows an application to save and restore critical system components when a power loss is detected. Visit [FRAM embedded software utilities for MSP ultra-low-power microcontrollers](#) for details.

#### 1.4.3.1 Enter LPMx.5

Do the following steps to enter LPMx.5:

1. Store any information that must be available after wakeup from LPMx.5 in FRAM.
2. For LPM4.5 set all ports to general-purpose I/Os (PxSEL0 = 00h and PxSEL1 = 00h).  
For LPM3.5 if the LF crystal oscillator is used do not change the settings for the I/Os shared with the LF-crystal-oscillator. These pins must be configured as LFXIN and LFXOUT. Set all other port pins to general-purpose I/Os with PxSEL0 and PxSEL1 bits equal to 0.
3. Set the port pin direction and output bits as necessary for the application.
4. To enable a wakeup from an I/O do the following:
  - a. Select the wakeup edge (PxIES)
  - b. Clear the interrupt flag (PxIFG)
  - c. Set the interrupt enable bit (PxIE)
5. For LPM3.5 the modules that stay active must be enabled. For example, the RTC must be enabled if necessary. Only modules connected to the RTC LDO can stay active.
6. For LPM3.5 if necessary enable any interrupt sources from these modules as wakeup sources. Refer to the corresponding module chapter.
7. Disable the watchdog timer WDT if it is enabled and in watchdog mode. If the WDT is enabled and in watchdog mode, the device does not enter LPMx.5.
8. Clear the GIE bit:  
`BIC #GIE, SR`

9. Do the following steps to set the PMMREGOFF bit in the PMMCTL0 register:

- a. Write the correct PMM password to get write access to the PMM control registers.

`MOV.B #PMMPW_H, &PMMCTL0_H`

- b. Set PMMREGOFF bit in the PMMCTL0 register.

`BIS.B #PMMREGOFF, &PMMCTL0_L`

- c. Optionally, disable the SVS during LPMx.5 by clearing the SVSHE bit in PMMCTL0.

`BIC.B #SVSHE, &PMMCTL0_L`

- d. Write an incorrect PMM password to disable the write access to the PMM control registers.

`MOV.B #000h, &PMMCTL0_H`

10. Enter LPMx.5 with the following instruction:

`BIS #CPUOFF+OSCOFF+SCG0+SCG1, SR`

After this process, the device enters LPM3.5 if modules connected to the RTC LDO are enabled, and it enters LPM4.5 if none of the modules connected to the RTC LDO are enabled.

#### 1.4.3.2 Exit and Wake up From LPM3.5

The following conditions cause an exit from LPM3.5:

- A wake-up event on an I/O if configured and enabled. The interrupt flag of the corresponding port pin is set (PxIFG). The PMMLPM5IFG bit is set.
- A wake-up event from a module connected to the RTC LDO if enabled. The corresponding interrupt flag in the module is set. The PMMLPM5IFG bit is set.
- A wake-up signal from the RST pin.
- A power cycle. Either the SVSHIFG or none of the PMMIFGs is set.

Any exit from LPM3.5 causes a BOR. The program execution starts at the address the reset vector points to. PMMLPM5IFG = 1 indicates a wakeup from LPM3.5, or the System Reset Vector Word register (SYSRSTIV) can be used to decode the reset condition (see the device data sheet).

After the wakeup from LPM3.5, the state of the I/Os and the modules connected to the RTC LDO are locked and remain unchanged until the application clears the LOCKLPM5 bit in the PM5CTL0 register.

Do the following steps after a wakeup from LPM3.5:

1. Initialize the registers of the modules connected to the RTC LDO exactly the same way as they were configured before the device entered LPM3.5 but do not enable the interrupts.
2. Initialize the port registers exactly the same way as they were configured before the device entered LPM3.5 but do not enable port interrupts.
3. If the LF-crystal-oscillator was used in LPM3.5 the corresponding I/Os must be configured as LFXIN and LFXOUT. The LF-crystal-oscillator must be enabled in the clock system (see the clock system CS chapter).
4. Clear the LOCKLPM5 bit in the PM5CTL0 register.
5. Enable port interrupts as necessary.
6. Enable module interrupts.
7. After enabling the port and module interrupts the wake-up interrupt will be serviced as a normal interrupt.

#### 1.4.3.3 Exit and Wake up From LPM4.5

The following conditions will cause an exit from LPM4.5:

- A wakeup event on an I/O if configured and enabled. The interrupt flag of the corresponding port pin is set (PxIFG). The PMMLPM5IFG bit is set.
- A wakeup from the RST pin.
- A power-cycle. Either the SVSHIFG or none of the PMMIFGs is set.

Any exit from LPM4.5 causes a BOR. The program execution starts at the address the reset vector points to. PMMLPM5IFG = 1 indicates a wakeup from LPM4.5, or the System Reset Vector Word register (SYSRSTIV) can be used to decode the reset condition (see the device data sheet).

After the wake-up from LPM4.5 the state of the I/Os are locked and remain unchanged until the application clears the LOCKLPM5 bit in the PM5CTL0 register.

Do the following steps after a wakeup from LPM4.5:

1. Initialize the port registers exactly the same way as they were configured before the device entered LPM4.5, but do not enable port interrupts.
2. Clear the LOCKLPM5 bit in the PM5CTL0 register.
3. Enable port interrupts as necessary.
4. After enabling the port interrupts the wake-up interrupt will be serviced as a normal interrupt.

If a crystal oscillator is needed after a wakeup from LPM4.5, configure the corresponding pins and start the oscillator after clearing the LOCKLPM5 bit.

## 1.5 Principles for Low-Power Applications

Often, the most important factor for reducing power consumption is using the device clock system to maximize the time in LPM3 or LPM4 modes whenever possible.

- Use interrupts to wake the processor and control program flow.
- Peripherals should be switched on only when needed.
- Use low-power integrated peripheral modules in place of software driven functions. For example, Timer\_A and Timer\_B can automatically generate PWM and capture external timing with no CPU resources.
- Calculated branching and fast table lookups should be used in place of flag polling and long software calculations.

- Avoid frequent subroutine and function calls due to overhead.
- For longer software routines, single-cycle CPU registers should be used.

If the application has low duty cycle and slow response time events, maximizing time in LPMx.5 can further reduce power consumption significantly.

## 1.6 Connection of Unused Pins

The correct termination of all unused pins is listed in [Table 1-4](#).

**Table 1-4. Connection of Unused Pins<sup>(1)</sup>**

| Pin                                          | Potential                           | Comment                                                                                                                                                                                                   |
|----------------------------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AVCC                                         | DV <sub>CC</sub>                    |                                                                                                                                                                                                           |
| AVSS                                         | DV <sub>SS</sub>                    |                                                                                                                                                                                                           |
| Px.0 to Px.7                                 | Open                                | Switched to port function, output direction (PxDIR.n = 1)                                                                                                                                                 |
| $\overline{\text{RST}}/\text{NMI}$           | DV <sub>CC</sub> or V <sub>CC</sub> | 47-k $\Omega$ pullup or internal pullup selected with 2.2-nF (10-nF <sup>(2)</sup> ) pulldown                                                                                                             |
| PJ.0/TDO<br>PJ.1/TDI<br>PJ.2/TMS<br>PJ.3/TCK | Open                                | The JTAG pins are shared with general-purpose I/O function (PJ.x). If not being used, these should be switched to port function, output direction. When used as JTAG pins, these pins should remain open. |
| TEST                                         | Open                                | This pin always has an internal pulldown enabled.                                                                                                                                                         |

<sup>(1)</sup> Any unused pin with a secondary function that is shared with general-purpose I/O should follow the Px.0 to Px.7 unused pin connection guidelines.

<sup>(2)</sup> The pulldown capacitor should not exceed 2.2 nF when using devices in Spy-Bi-Wire mode or in 4-wire JTAG mode with TI tools like FET interfaces or GANG programmers. If JTAG or Spy-Bi-Wire access is not needed, up to a 10-nF pulldown capacitor may be used.

## 1.7 Reset Pin ( $\overline{\text{RST}}/\text{NMI}$ ) Configuration

The reset pin can be configured as a reset function (default) or as an NMI function through the Special Function Register (SFR), SFRRPCR. Setting SYSNMI causes the  $\overline{\text{RST}}/\text{NMI}$  pin to be configured as an external NMI source. The external NMI is edge sensitive and its edge is selectable by SYSNMIIES. Setting the NMIIIE enables the interrupt of the external NMI. Upon an external NMI event, the NMIIIFG is set.

The  $\overline{\text{RST}}/\text{NMI}$  pin can have either a pullup or pulldown present or not. SYSRSTUP selects either pullup or pulldown, and SYSRSTRE causes the pullup or pulldown to be enabled or not. If the  $\overline{\text{RST}}/\text{NMI}$  pin is unused, it is required to have either the internal pullup selected and enabled or an external resistor connected to the  $\overline{\text{RST}}/\text{NMI}$  pin as shown in [Table 1-4](#).

There is a digital filter that suppresses short pulses on the reset pin to avoid unintended resets of the device. The minimum reset pulse duration is specified in the device data sheet. The filter is active only if the pin is configured in its reset function. The filter is disabled if the pin is used as an external NMI source.

## 1.8 Configuring JTAG Pins

The JTAG pins are shared with general-purpose I/O pins. After a BOR, the SYSJTAGPIN bit in the SYSCTL register is cleared. With SYSJTAGPIN cleared, the pins with JTAG functionality are configured as general-purpose I/O. In this case only a special sequences on the TEST and RST/NMI pins enables the JTAG functionality. As long as the TEST pin is pulled to DVCC, the pins remain in their JTAG functionality. If the TEST pin is released to DVSS, the shared JTAG pins revert to general-purpose I/Os.

If SYSJTAGPIN = 1, the JTAG pins are permanently configured to 4-wire JTAG mode and remain in this mode until another BOR occurs. Use this feature early in your software if the MSP430 is part of a JTAG chain. Note, that this also disables the Spy-Bi-Wire mode.

The SYSJTAGPIN is a write only once function. Clearing it by software is not possible.

## 1.9 Vacant Memory Space

Vacant memory is nonexistent memory space. Accesses to vacant memory space generate a system (non)maskable interrupt (SNMI) when enabled (VMAIE = 1). Reads from vacant memory results in the value 3FFFh. In the case of a fetch, this is taken as JMP \$. Fetch accesses from vacant peripheral space result in a PUC. After the boot code is executed, the boot code memory behaves like vacant memory space and causes an NMI on access.

## 1.10 Boot Code

The boot code loads factory stored calibration values of the oscillator and reference voltages. In addition, it checks for a bootloader (BSL) entry sequence. The boot code is always executed after a BOR.

## 1.11 Bootloader (BSL)

The BSL is software that is executed after start-up when a certain BSL entry condition is applied. The BSL lets the user communicate with the embedded memory in the microcontroller during the prototyping phase, final production, and in service. All memory mapped resources, the programmable memory, the data memory (RAM), and the peripherals, can be modified by the BSL as required.

A basic BSL program is provided by TI and resides in ROM at memory space 01000h through 017FFh. The BSL supports the commonly used UART protocol with RS232 interfacing, allowing flexible use of both hardware and software. Depending on the device, additional BSL communication interfaces are supported. For details of the available and configured BSL communication interfaces, see [Section 1.14.3.5](#).

To use the BSL, a specific BSL entry sequence must be applied to the RST/NMI and TEST pins. A correct entry sequence causes SYSBSLIND to be set. An added sequence of commands initiates the desired function. A bootloader session can be exited by continuing operation at a defined user program address or by applying the standard reset sequence. Access to the device memory through the BSL is protected against misuse by a user-defined password.

Two BSL signatures, BSL Signature 1 (memory location 0FF84h) and BSL Signature 2 (memory location 0FF86h) reside in FRAM and can be used to control the behavior of the BSL. Writing 05555h to BSL Signature 1 or BSL Signature 2 disables the BSL function and any access to the BSL memory space causes a vacant memory access as described in [Section 1.9](#). Most BSL commands require the BSL to be unlocked by a user-defined password. An incorrect password erases the device memory as a security feature. Writing 0AAAAh to both BSL Signature 1 and BSL Signature 2 disables this security feature. This causes a password error to be returned by the BSL, but the device memory is not erased. In this case, unlimited password attempts are possible.

For more details, see the [MSP430FR57xx, MSP430FR58xx, MSP430FR59xx, MSP430FR68xx, and MSP430FR69xx Bootloader \(BSL\) User's Guide](#).

Some JTAG commands are still possible after the device is secured, including the BYPASS command (see IEEE Std 1149-2001) and the JMB\_EXCHANGE command, which allows access to the JTAG Mailbox System (see [Section 1.12](#) for details).

## 1.12 JTAG Mailbox (JMB) System

The SYS module provides the capability to exchange user data through the regular JTAG test/debug interface. The idea behind the JMB is to have a direct interface to the CPU during debugging, programming, and test that is identical for all devices of this family and uses only few or no user application resources. The JTAG interface was chosen because it is available on all devices and is a dedicated resource for debugging, programming, and test.

Applications of the JMB are:

- Providing entry password for device lock or unlock protection
- Run-time data exchange (RTDX)

### 1.12.1 JMB Configuration

The JMB supports two transfer modes: 16-bit and 32-bit. Setting JMBMODE enables 32-bit transfer mode. Clearing JMBMODE enables 16-bit transfer mode.

### 1.12.2 JMBOUT0 and JMBOUT1 Outgoing Mailbox

Two 16-bit registers are available for outgoing messages to the JTAG port. JMBOUT0 is only used when using 16-bit transfer mode (JMBMODE = 0). JMBOUT1 is used in addition to JMBOUT0 when using 32-bit transfer mode (JMBMODE = 1). When the application wishes to send a message to the JTAG port, it writes data to JMBOUT0 for 16-bit mode, or JMBOUT0 and JMBOUT1 for 32-bit mode.

JMBOUT0FG and JMBOUT1FG are read only flags that indicate the status of JMBOUT0 and JMBOUT1, respectively. When JMBOUT0FG is set, JMBOUT0 has been read by the JTAG port and is ready to receive new data. When JMBOUT0FG is reset, the JMBOUT0 is not ready to receive new data. JMBOUT1FG behaves similarly.

### 1.12.3 JMBIN0 and JMBIN1 Incoming Mailbox

Two 16-bit registers are available for incoming messages from the JTAG port. Only JMBIN0 is used when in 16-bit transfer mode (JMBMODE = 0). JMBIN1 is used in addition to JMBIN0 when using 32-bit transfer mode (JMBMODE = 1). When the JTAG port wishes to send a message to the application, it writes data to JMBIN0 for 16-bit mode, or JMBIN0 and JMBIN1 for 32-bit mode.

JMBIN0FG and JMBIN1FG are flags that indicate the status of JMBIN0 and JMBIN1, respectively. When JMBIN0FG is set, JMBIN0 has data that is available for reading. When JMBIN0FG is reset, no new data is available in JMBIN0. JMBIN1FG behaves similarly.

JMBIN0FG and JMBIN1FG can be configured to clear automatically by clearing JMBCLR0OFF and JMBCLR1OFF, respectively. Otherwise, these flags must be cleared by software.

### 1.12.4 JMB NMI Usage

The JMB handshake mechanism can be configured to use interrupts to avoid unnecessary polling if desired. In 16-bit mode, JMBOUTIFG is set when JMBOUT0 has been read by the JTAG port and is ready to receive data. In 32-bit mode, JMBOUTIFG is set when both JMBOUT0 and JMBOUT1 has been read by the JTAG port and are ready to receive data. If JMBOUTIE is set, these events cause a system NMI. In 16-bit mode, JMBOUTIFG is cleared automatically when data is written to JMBOUT0. In 32-bit mode, JMBOUTIFG is cleared automatically when data is written to both JMBOUT0 and JMBOUT1. In addition, the JMBOUTIFG can be cleared when reading SYSSNIV. Clearing JMBOUTIE disables the NMI interrupt.

In 16-bit mode, JMBINIFG is set when JMBIN0 is available for reading. In 32-bit mode, JMBINIFG is set when both JMBIN0 and JMBIN1 are available for reading. If JMBOUTIE is set, these events cause a system NMI. In 16-bit mode, JMBINIFG is cleared automatically when JMBIN0 is read. In 32-bit mode, JMBINIFG is cleared automatically when both JMBIN0 and JMBIN1 are read. In addition, the JMBINIE can be cleared when reading SYSSNIV. Clearing JMBINIE disables the NMI interrupt.

## 1.13 JTAG and SBW Lock Mechanism Using the Electronic Fuse

A device can be protected from unauthorized access by restricting accessibility of JTAG commands that can be transferred to the device by the JTAG and SBW interface. This is achieved by programming the electronic fuse. When the device is protected, the JTAG and SBW interface still remains functional, but JTAG commands that give direct access into the device are completely disabled. There are two ways to lock the device. Both of these require the programming of two signatures that reside in FRAM. JTAG Signature 1 (memory location 0FF80h) and JTAG Signature 2 (memory location 0FF82h) control the behavior of the device locking mechanism.

---

**NOTE:** When a device has been protected, Texas Instruments cannot access the device for a customer return. Access is only possible if a BSL is provided with its corresponding key or an unlock mechanism is provided by the customer.

---

### 1.13.1 JTAG and SBW Lock Without Password

A device can be locked by writing 05555h to both JTAG Signature 1 and JTAG Signature 2. In this case, the JTAG and SBW interfaces grant access to a limited JTAG command set that restricts accessibility into the device. The only way to unlock the device in this case is to use the BSL to overwrite the JTAG signatures with anything other than 05555h or 0AAAAh. Some JTAG commands are still possible after the device is secured, including the BYPASS command (see IEEE1149-2001 Standard) and the JMB\_EXCHANGE command, which allows access to the JTAG Mailbox System (see [Section 1.12](#) for details).

---

**NOTE:** Signatures that have been entered do not take effect until the next BOR event has occurred, at which time the signatures are checked.

---

### 1.13.2 JTAG and SBW Lock With Password

A device can also be locked by writing 0AAAAh to JTAG Signature 1 and writing JTAG Signature 2 with any value except 05555h. In this case, JTAG and SBW interfaces grant access to a limited JTAG command set that restricts accessibility into the device as in [Section 1.13.1](#), but an additional mechanism is available that can unlock the device with a user-defined password. In this case, JTAG Signature 2 represents a user-defined length in words of the user defined password. For example, a password length of four words would require writing 0004h to JTAG Signature 2. The starting location of the password is fixed at location 0FF88h. As an example, for a password of length 4, the password memory locations would reside at 0FF88h, 0FF8Ah, 0FF8Ch, and 0FF8Eh.

The password is not checked after each BOR; it is checked only if a specific signature is present in the JTAG incoming mailbox. If the JTAG incoming mailbox contains 0A55Ah and 01E1Eh in JMBIN0 and JMBIN1, respectively, the device is expecting a password to be applied. The entered password is compared to the password that is stored in the device password memory locations. If they match, the device unlocks the JTAG and SBW to the complete JTAG command set until the next BOR event occurs.

---

**NOTE:** Memory locations 0FF80h through 0FFFFh may also be used for interrupt vector address locations (see the device-specific data sheet). Therefore, if using the password mechanism for JTAG and SBW lock, which uses address locations 0FF88h and higher, these locations may also have interrupt vector addresses assigned to them. Therefore, the same values assigned for any interrupt vector addresses must also be used as password values.

---

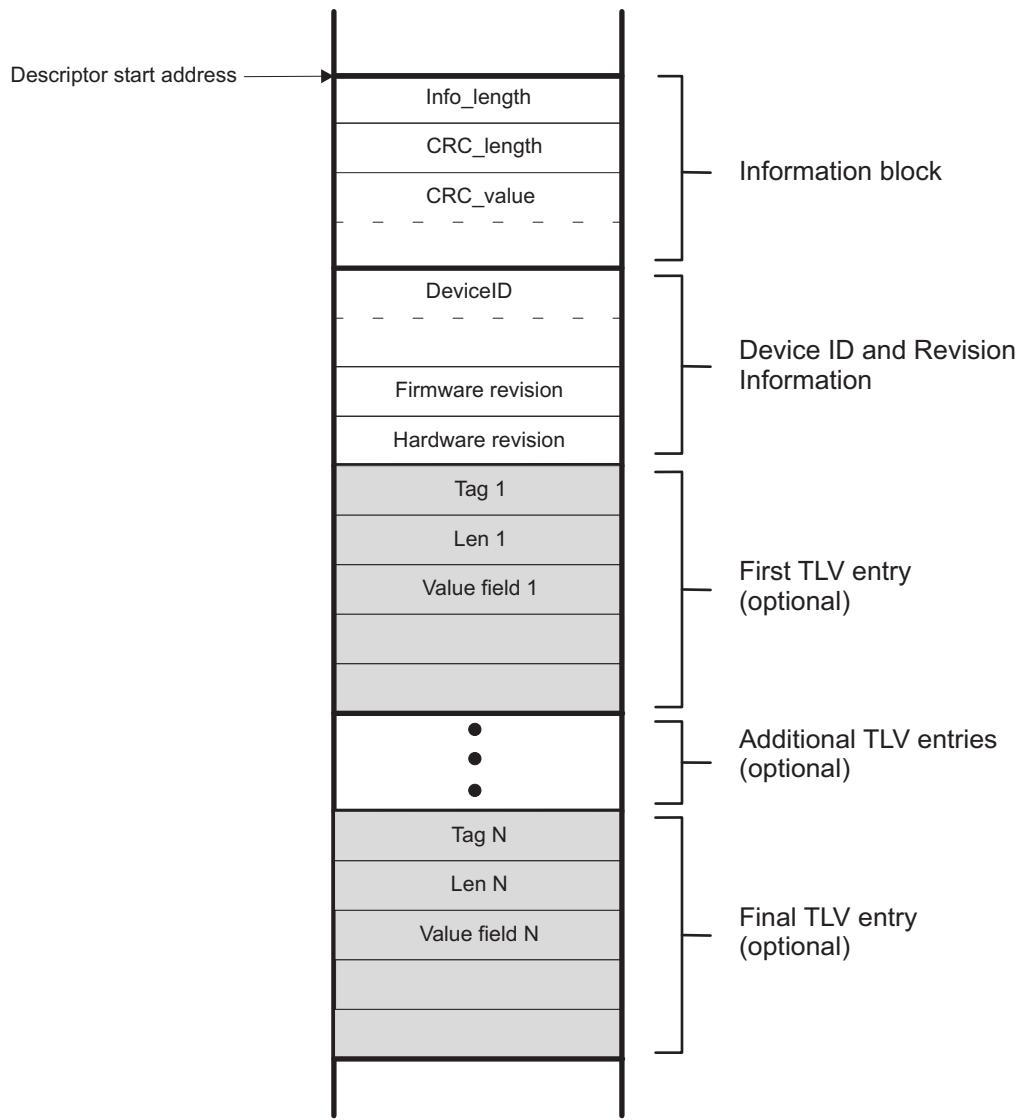
---

**NOTE:** Signatures that have been entered do not take effect until the next BOR event has occurred, at which time the signatures are checked. For example, entering a correct password that grants entry into the device followed by an incorrect password without a BOR sequence may still grant access to the device.

---

## 1.14 Device Descriptor Table

Each device provides a data structure in memory that allows an unambiguous identification of the device. The validity of the device descriptor can be verified by cyclic redundancy check (CRC). [Figure 1-6](#) shows the logical order and structure of the device descriptor table. The complete device descriptor table and its contents can be found in the device-specific data sheet.



**Figure 1-6. Devices Descriptor Table**

#### 1.14.1 Identifying Device Type

The value read at address 00FF0h identifies the family branch of the device. All values starting with 80h indicate a hierarchical structure consisting of the information block and a TLV tag-length-value (TLV) structure containing the various descriptors. Any other value than 80h read at address location 00FF0h indicates the device is of an older family and contains a flat descriptor beginning at location 0FF0h. The information block (see [Figure 1-6](#)) contains the device ID, die revisions, firmware revisions, and other manufacturer and tool related information.

The length of the descriptors represented by Info\_length is computed as shown in [Equation 1](#):

$$\text{Length} = 2^{\text{Info\_length}} \text{ in 32-bit words} \quad (1)$$

For example, if Info\_length = 5, then the length of the descriptors equals 128 bytes.

### 1.14.2 TLV Descriptors

The TLV descriptors follow the information block. Because the information block is always a fixed length, the start location of the TLV descriptors is fixed for a given device family. For the MSP430FR57xx family, this location is 01A08h. See the device-specific data sheet for the complete TLV structure and what descriptors are available.

The TLV descriptors are unique to their respective TLV block and are always followed by the descriptor block length.

Each TLV descriptor contains a tag field that identifies the descriptor type. [Table 1-5](#) shows the currently supported tags.

**Table 1-5. Tag Values**

| Short Name | Value   | Description                                                                                    |
|------------|---------|------------------------------------------------------------------------------------------------|
| LDTAG      | 01h     | Legacy descriptor (1xx, 2xx, 4xx families)                                                     |
| PDTAG      | 02h     | Peripheral discovery descriptor                                                                |
| Reserved   | 03h     | Reserved for future use                                                                        |
| Reserved   | 04h     | Reserved for future use                                                                        |
| BLANK      | 05h     | Blank descriptor                                                                               |
| Reserved   | 06h     | Reserved for future use                                                                        |
| Reserved   | 07h     | Reserved for future use                                                                        |
| Reserved   | 08h     | Unique Die Record                                                                              |
| Reserved   | 09h-0Fh | Reserved for future use                                                                        |
| Reserved   | 10h     | Reserved                                                                                       |
| ADC12CAL   | 11h     | ADC12 calibration (see <a href="#">Section 1.14.3.2</a> and <a href="#">Section 1.14.3.3</a> ) |
| REFCAL     | 12h     | REF calibration (see <a href="#">Section 1.14.3.1</a> )                                        |
| ADC10CAL   | 13h     | ADC10 calibration (see <a href="#">Section 1.14.3.2</a> and <a href="#">Section 1.14.3.3</a> ) |
| Reserved   | 14h     | Reserved for future use                                                                        |
| RANDTAG    | 15h     | Random Number Seed (see <a href="#">Section 1.14.3.4</a> )                                     |
| Reserved   | 16h-1Bh | Reserved for future use                                                                        |
| BSLTAG     | 1Ch     | BSL Configuration                                                                              |
| Reserved   | 1Dh-FDh | Reserved for future use                                                                        |
| TAGEEXT    | FEh     | Tag extender                                                                                   |

Each tag field is unique to its respective descriptor and is always followed by a length field. The length field is one byte if the tag value is 01h through 0FDh and represents the length of the descriptor in bytes. If the tag value equals 0FEh (TAGEEXT), the next byte extends the tag values, and the following two bytes represent the length of the descriptor in bytes. In this way, a user can search through the TLV descriptor table for a particular tag value, using a routine similar to the following pseudo code:

```
// Identify the descriptor ID (d_ID_value) for the TLV descriptor of interest:  
descriptor_address = TLV_START address;  
  
while ( value at descriptor_address != d_ID_value && descriptor_address != TLV_TAGEND &&  
descriptor_address < TLV_END)  
{  
    // Point to next descriptor  
    descriptor_address = descriptor_address + (length of the current TLV block) + 2;  
}  
  
if (value at descriptor_address == d_ID_value) {  
    // Appropriate TLV descriptor has been found!  
    Return length of descriptor & descriptor_address as the location of the TLV descriptor  
} else {  
    // No TLV descriptor found with a matching d_ID_value  
    Return a failing condition  
}
```

### 1.14.3 Calibration Values

The TLV structure contains calibration values that can be used to improve the measurement capability of various functions. The calibration values available on a given device are shown in the TLV structure of the device-specific data sheet.

#### 1.14.3.1 REF Calibration

[Table 1-6](#) shows the REF calibration tags.

**Table 1-6. REF Calibration Tags**

|                 |           |                       |
|-----------------|-----------|-----------------------|
| REF Calibration | TAG       | 12h                   |
|                 | Length    | 06h                   |
|                 | Low Byte  | CAL_ADC_12VREF_FACTOR |
|                 | High Byte |                       |
|                 | Low Byte  | CAL_ADC_20VREF_FACTOR |
|                 | High Byte |                       |
|                 | Low Byte  | CAL_ADC_25VREF_FACTOR |
|                 | High Byte |                       |

The calibration data for the REF module consists of three words, one word for each reference voltage available (1.2 V, 2.0 V, and 2.5 V). The reference voltages are measured at room temperature. The measured values are normalized by 1.2 V, 2.0 V, or 2.5 V before being stored into the TLV structure, as shown in [Equation 2](#):

$$\begin{aligned} \text{CAL\_ADC\_12VREF\_FACTOR} &= \frac{V_{\text{REF+}}}{1.2V} \times 2^{15} \\ \text{CAL\_ADC\_20VREF\_FACTOR} &= \frac{V_{\text{REF+}}}{2.0V} \times 2^{15} \\ \text{CAL\_ADC\_25VREF\_FACTOR} &= \frac{V_{\text{REF+}}}{2.5V} \times 2^{15} \end{aligned} \quad (2)$$

In this way, a conversion result is corrected by multiplying it with the CAL\_12VREF\_FACTOR (or CAL\_20VREF\_FACTOR, CAL\_25VREF\_FACTOR) and dividing the result by  $2^{15}$  as shown in [Equation 3](#) for each of the respective reference voltages:

$$\begin{aligned} \text{ADC(corrected)} &= \text{ADC(raw)} \times \text{CAL\_ADC12VREF\_FACTOR} \times \frac{1}{2^{15}} \\ \text{ADC(corrected)} &= \text{ADC(raw)} \times \text{CAL\_ADC20VREF\_FACTOR} \times \frac{1}{2^{15}} \\ \text{ADC(corrected)} &= \text{ADC(raw)} \times \text{CAL\_ADC25VREF\_FACTOR} \times \frac{1}{2^{15}} \end{aligned} \quad (3)$$

In the following example, the integrated 1.2-V reference voltage is used during a conversion.

- Conversion result: 0x0100 = 256 decimal
- Reference voltage calibration factor (CAL\_12VREF\_FACTOR) : 0x7BBB

The following steps show how the ADC conversion result can be corrected:

- Multiply the conversion result by 2 (this step simplifies the final division):  $0x0100 \times 0x0002 = 0x0200$
- Multiply the result by CAL\_12VREF\_FACTOR:  $0x200 \times 0x7FEE = 0x00F7_7600$
- Divide the result by  $2^{16}$ :  $0x00F7_7600 / 0x0001_0000 = 0x0000_00F7 = 247$  decimal

#### 1.14.3.2 ADC Offset and Gain Calibration

[Table 1-7](#) shows the ADC calibration tags.

**Table 1-7. ADC Calibration Tags**

|                    |           |                          |
|--------------------|-----------|--------------------------|
| ADC<br>Calibration | TAG       | ADC10: 13h<br>ADC12: 11h |
|                    | Length    | 10h                      |
|                    | Low Byte  | CAL_ADC_GAIN_FACTOR      |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_OFFSET           |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_12T30            |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_12T85            |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_20T30            |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_20T85            |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_25T30            |
|                    | High Byte |                          |
|                    | Low Byte  | CAL_ADC_25T85            |
|                    | High Byte |                          |

The offset of the ADC at room temperature is determined and stored as a twos-complement number in the TLV structure. The offset error correction is done by adding the CAL\_ADC\_OFFSET to the conversion result.

$$ADC(\text{offset\_corrected}) = ADC(\text{raw}) + \text{CAL\_ADC\_OFFSET} \quad (4)$$

The gain of the ADC at room temperature with an external reference voltage of 2.5 V is calculated by [Equation 5](#):

$$\text{CAL\_ADC\_GAIN\_FACTOR} = \frac{1}{\text{GAIN}} \times 2^{15} \quad (5)$$

The conversion result is gain corrected by multiplying it with the CAL\_ADC\_GAIN\_FACTOR and dividing the result by  $2^{15}$ :

$$ADC(\text{gain\_corrected}) = ADC(\text{raw}) \times \text{CAL\_ADC\_GAIN\_FACTOR} \times \frac{1}{2^{15}} \quad (6)$$

If both gain and offset are corrected, the gain correction is done first:

$$ADC(\text{gain\_corrected}) = ADC(\text{raw}) \times \text{CAL\_ADC\_GAIN\_FACTOR} \times \frac{1}{2^{15}}$$

$$ADC(\text{final}) = ADC(\text{gain\_corrected}) + \text{CAL\_ADC\_OFFSET} \quad (7)$$

### 1.14.3.3 Temperature Sensor Calibration

The temperature sensor calibration data is part of the ADC tag as shown in [Table 1-7](#).

The temperature sensor is calibrated using the internal voltage references. Each reference voltage (1.2 V, 2.0 V, or 2.5 V) contains a measured value for two temperatures ( $30^{\circ}\text{C} \pm 3^{\circ}\text{C}$  and  $85^{\circ}\text{C} \pm 3^{\circ}\text{C}$ ) and are stored in the TLV structure. The characteristic equation of the temperature sensor voltage, in millivolts is:

$$V_{\text{SENSE}} = TC_{\text{SENSOR}} \times \text{Temp} + V_{\text{SENSOR}} \quad (8)$$

The temperature coefficient,  $TC_{\text{SENSOR}}$  in mV/ $^{\circ}\text{C}$ , represents the slope of the equation.  $V_{\text{SENSOR}}$ , in mV, represents the y-intercept of the equation. Temp, in  $^{\circ}\text{C}$ , is the temperature of interest.

The temperature (Temp, °C) can be computed as follows for each of the reference voltages used in the ADC measurement:

$$\text{Temp } [{}^{\circ}\text{C}] = (\text{ADC(raw)} - \text{CAL\_ADC\_12T30}) \times \left( \frac{85 - 30}{\text{CAL\_ADC\_12T85} - \text{CAL\_ADC\_12T30}} \right) + 30$$

$$\text{Temp } [{}^{\circ}\text{C}] = (\text{ADC(raw)} - \text{CAL\_ADC\_20T30}) \times \left( \frac{85 - 30}{\text{CAL\_ADC\_20T85} - \text{CAL\_ADC\_20T30}} \right) + 30$$

$$\text{Temp } [{}^{\circ}\text{C}] = (\text{ADC(raw)} - \text{CAL\_ADC\_25T30}) \times \left( \frac{85 - 30}{\text{CAL\_ADC\_25T85} - \text{CAL\_ADC\_25T30}} \right) + 30 \quad (9)$$

#### 1.14.3.4 Random Number Seed

[Table 1-8](#) shows the tags used for the random number seed.

**Table 1-8. Random Number Tags**

|               |          |                            |
|---------------|----------|----------------------------|
| Random Number | TAG      | 15h                        |
|               | Length   | 10h                        |
|               | 16 bytes | 128-bit random number seed |

The random number stored as a seed for a deterministic random number generator is programmed during test of the device. It is generated on the test system using a cryptographic random number generator.

#### 1.14.3.5 BSL Configuration

[Table 1-9](#) shows the tags used for the BSL configuration. The BSL configuration stores the communication interface selection and corresponding communication interface settings. The Tag is optional for devices only providing the basic UART BSL interface. The TAG length field is variable and determinated by the length of the configuration option field BSL\_CIF\_CONFIG. The BSL configuration cannot be changed by the user.

**Table 1-9. BSL Configuration Tags**

|                   |           |                                                               |
|-------------------|-----------|---------------------------------------------------------------|
| BSL Configuration | TAG       | 1Ch                                                           |
|                   | Length    | Depends on the BSL_COM_IF value (actual: 02h for UART or I2C) |
|                   | Low Byte  | BSL_COM_IF                                                    |
|                   | High Byte | BSL_CIF_CONFIG[0]                                             |
|                   | Low Byte  | BSL_CIF_CONFIG[1] (optional)                                  |
|                   | High Byte | BSL_CIF_CONFIG[2] (optional)                                  |
|                   | Low Byte  | BSL_CIF_CONFIG[3] (optional)                                  |
|                   | High Byte | BSL_CIF_CONFIG[4] (optional)                                  |
|                   | :         | :                                                             |
|                   | :         | :                                                             |
|                   | High Byte | BSL_CIF_CONFIG[n] (optional)                                  |

**Table 1-10. BSL\_COM\_IF Values**

| BSL_COM_IF | Description                                 | Length   |
|------------|---------------------------------------------|----------|
| 00h        | UART interface selected                     | 02h      |
| 01h        | I2C interface selected                      | 02h      |
| 02h to FFh | Reserved for future communication interface | reserved |

[Table 1-10](#) shows the defined value for the BSL\_COM\_IF field. Depending on the selected communication interface, the subsequent bytes in the BSL config tag are interpreted to configure the communication interface. The interpretation is shown in [Table 1-11](#). Unused bytes in BSL\_CIF\_CONFIG are defined as 00h.

**Table 1-11. BSL\_CIF\_CONFIG Values**

| BSL_CIF_CONFIG_IF[n] | UART [BSL_COM_IF == 00h] | I2C [ BSL_COM_IF == 01h]             |
|----------------------|--------------------------|--------------------------------------|
| 0                    | 00h                      | I2C address (valid values: 0 to 7Fh) |
| 1 to FFh             | N/A                      | N/A                                  |

[Table 1-11](#) shows the defined configuration options for the given BSL communication interface.

## 1.15 SFR Registers

The SFRs are listed in [Table 1-12](#). The base address for the SFRs is 00100h. Many of the bits inside the SFRs are described in other chapters throughout this user's guide. These bits are marked with a note and a reference. See the specific chapter of the respective module for details.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 1-12. SFR Registers**

| Offset | Acronym          | Register Name     | Type       | Access | Reset | Section                        |
|--------|------------------|-------------------|------------|--------|-------|--------------------------------|
| 00h    | SFRIE1           | Interrupt Enable  | Read/write | Word   | 0000h | <a href="#">Section 1.15.1</a> |
| 00h    | SFRIE1_L (IE1)   |                   | Read/write | Byte   | 00h   |                                |
| 01h    | SFRIE1_H (IE2)   |                   | Read/write | Byte   | 00h   |                                |
| 02h    | SFRIFG1          | Interrupt Flag    | Read/write | Word   | 0082h | <a href="#">Section 1.15.2</a> |
| 02h    | SFRIFG1_L (IFG1) |                   | Read/write | Byte   | 82h   |                                |
| 03h    | SFRIFG1_H (IFG2) |                   | Read/write | Byte   | 00h   |                                |
| 04h    | SFRRPCR          | Reset Pin Control | Read/write | Word   | 001Ch | <a href="#">Section 1.15.3</a> |
| 04h    | SFRRPCR_L        |                   | Read/write | Byte   | 1Ch   |                                |
| 05h    | SFRRPCR_H        |                   | Read/write | Byte   | 00h   |                                |

### 1.15.1 SFRIE1 Register

Interrupt Enable Register

**Figure 1-7. SFRIE1 Register**

|          |         |          |       |       |          |                     |                      |
|----------|---------|----------|-------|-------|----------|---------------------|----------------------|
| 15       | 14      | 13       | 12    | 11    | 10       | 9                   | 8                    |
| Reserved |         |          |       |       |          |                     |                      |
| r0       | r0      | r0       | r0    | r0    | r0       | r0                  | r0                   |
| 7        | 6       | 5        | 4     | 3     | 2        | 1                   | 0                    |
| JMBOUTIE | JMBINIE | Reserved | NMIIE | VMAIE | Reserved | OFIE <sup>(1)</sup> | WDTIE <sup>(2)</sup> |
| rw-0     | rw-0    | r-0      | rw-0  | rw-0  | r0       | rw-0                | rw-0                 |

<sup>(1)</sup> See the [Clock System](#) chapter for details.

<sup>(2)</sup> See the [WDT\\_A](#) chapter for details.

**Table 1-13. SFRIE1 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                     |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                    |
| 7    | JMBOUTIE | RW   | 0h    | JTAG mailbox output interrupt enable<br>0b = Interrupts disabled<br>1b = Interrupts enabled                                                                                                                                                                                                                                                                                                     |
| 6    | JMBINIE  | RW   | 0h    | JTAG mailbox input interrupt enable<br>0b = Interrupts disabled<br>1b = Interrupts enabled                                                                                                                                                                                                                                                                                                      |
| 5    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                    |
| 4    | NMIIE    | RW   | 0h    | NMI pin interrupt enable<br>0b = Interrupts disabled<br>1b = Interrupts enabled                                                                                                                                                                                                                                                                                                                 |
| 3    | VMAIE    | RW   | 0h    | Vacant memory access interrupt enable<br>0b = Interrupts disabled<br>1b = Interrupts enabled                                                                                                                                                                                                                                                                                                    |
| 2    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                    |
| 1    | OFIE     | RW   | 0h    | Oscillator fault interrupt enable<br>0b = Interrupts disabled<br>1b = Interrupts enabled                                                                                                                                                                                                                                                                                                        |
| 0    | WDTIE    | RW   | 0h    | Watchdog timer interrupt enable. This bit enables the WDTIFG interrupt for interval timer mode. It is not necessary to set this bit for watchdog mode. Because other bits in SFRIE1 may be used for other modules, it is recommended to set or clear this bit using BIS.B or BIC.B instructions, rather than MOV.B or CLR.B instruction.<br>0b = Interrupts disabled<br>1b = Interrupts enabled |

### 1.15.2 SFRIFG1 Register

Interrupt Flag Register

**Figure 1-8. SFRIFG1 Register**

|           |          |          |        |        |          |                      |                       |
|-----------|----------|----------|--------|--------|----------|----------------------|-----------------------|
| 15        | 14       | 13       | 12     | 11     | 10       | 9                    | 8                     |
| Reserved  |          |          |        |        |          |                      |                       |
| r0        | r0       | r0       | r0     | r0     | r0       | r0                   | r0                    |
| 7         | 6        | 5        | 4      | 3      | 2        | 1                    | 0                     |
| JMBOUTIFG | JMBINIFG | Reserved | NMIIFG | VMAIFG | Reserved | OFIFG <sup>(1)</sup> | WDTIFG <sup>(2)</sup> |
| rw-(1)    | rw-(0)   | r0       | rw-0   | rw-0   | r0       | rw-(1)               | rw-0                  |

<sup>(1)</sup> See the [Clock System](#) chapter for details.

<sup>(2)</sup> See the [WDT\\_A](#) chapter for details.

**Table 1-14. SFRIFG1 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|-----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 7    | JMBOUTIFG | RW   | 1h    | <p>JTAG mailbox output interrupt flag</p> <p>0b = No interrupt pending. When in 16-bit mode (JMBMODE = 0), this bit is cleared automatically when JMBO0 has been written with a new message to the JTAG module by the CPU. When in 32-bit mode (JMBMODE = 1), this bit is cleared automatically when both JMBO0 and JMBO1 have been written with new messages to the JTAG module by the CPU. This bit is also cleared when the associated vector in SYSUNIV has been read.</p> <p>1b = Interrupt pending, JMBO registers are ready for new messages. In 16-bit mode (JMBMODE = 0), JMBO0 has been received by the JTAG module and is ready for a new message from the CPU. In 32-bit mode (JMBMODE = 1), JMBO0 and JMBO1 have been received by the JTAG module and are ready for new messages from the CPU.</p> |
| 6    | JMBINIFG  | RW   | 0h    | <p>JTAG mailbox input interrupt flag</p> <p>0b = No interrupt pending. When in 16-bit mode (JMBMODE = 0), this bit is cleared automatically when JMBI0 is read by the CPU. When in 32-bit mode (JMBMODE = 1), this bit is cleared automatically when both JMBI0 and JMBI1 have been read by the CPU. This bit is also cleared when the associated vector in SYSUNIV has been read</p> <p>1b = Interrupt pending, a message is waiting in the JMBIN registers. In 16-bit mode (JMBMODE = 0) when JMBI0 has been written by the JTAG module. In 32-bit mode (JMBMODE = 1) when JMBI0 and JMBI1 have been written by the JTAG module.</p>                                                                                                                                                                          |
| 5    | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 4    | NMIIFG    | RW   | 0h    | <p>NMI pin interrupt flag</p> <p>0b = No interrupt pending</p> <p>1b = Interrupt pending</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 3    | VMAIFG    | RW   | 0h    | <p>Vacant memory access interrupt flag</p> <p>0b = No interrupt pending</p> <p>1b = Interrupt pending</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 2    | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 1    | OFIFG     | RW   | 1h    | <p>Oscillator fault interrupt flag</p> <p>0b = No interrupt pending</p> <p>1b = Interrupt pending</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 0    | WDTIFG    | RW   | 0h    | <p>Watchdog timer interrupt flag. In watchdog mode, WDTIFG clears itself upon a watchdog timeout event. The SYSRSTIV can be read to determine if the reset was caused by a watchdog timeout event. In interval mode, WDTIFG is reset automatically by servicing the interrupt, or can be reset by software. Because other bits in SFRIFG1 may be used for other modules, it is recommended to set or clear WDTIFG by using BIS.B or BIC.B instructions, rather than MOV.B or CLR.B instructions.</p> <p>0b = No interrupt pending</p> <p>1b = Interrupt pending</p>                                                                                                                                                                                                                                             |

### 1.15.3 SFRRPCR Register

Reset Pin Control Register

**Figure 1-9. SFRRPCR Register**

|          |    |    |                        |    |          |          |           |
|----------|----|----|------------------------|----|----------|----------|-----------|
| 15       | 14 | 13 | 12                     | 11 | 10       | 9        | 8         |
| Reserved |    |    |                        |    |          |          |           |
| r0       | r0 | r0 | r0                     | r0 | r0       | r0       | r0        |
| 7        | 6  | 5  | 4                      | 3  | 2        | 1        | 0         |
| Reserved |    |    | Reserved               |    | SYSRSTRE | SYSRSTUP | SYSNMIIES |
| r0       | r0 | r0 | r(w <sup>(1)</sup> )-1 |    | rw-1     | rw-1     | rw-0      |
|          |    |    |                        |    |          |          | rw-0      |

<sup>(1)</sup> On some devices this bit can be written, but it must always be written as 1.

**Table 1-15. SFRRPCR Register Description**

| Bit  | Field     | Type                 | Reset | Description                                                                                                                                                                                                                                            |
|------|-----------|----------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-5 | Reserved  | R                    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                           |
| 4    | Reserved  | R(W <sup>(1)</sup> ) | 1h    | Reserved. Must be written as 1.                                                                                                                                                                                                                        |
| 3    | SYSRSTRE  | RW                   | 1h    | Reset pin resistor enable<br>0b = Pullup or pulldown resistor at the RST/NMI pin is disabled.<br>1b = Pullup or pulldown resistor at the RST/NMI pin is enabled.                                                                                       |
| 2    | SYSRSTUP  | RW                   | 1h    | Reset resistor pin pullup or pulldown<br>0b = Pulldown is selected.<br>1b = Pullup is selected.                                                                                                                                                        |
| 1    | SYSNMIIES | RW                   | 0h    | NMI edge select. This bit selects the interrupt edge for the NMI when SYSNMI = 1. Modifying this bit can trigger an NMI. Modify this bit when SYSNMI = 0 to avoid triggering an accidental NMI.<br>0b = NMI on rising edge<br>1b = NMI on falling edge |
| 0    | SYSNMI    | RW                   | 0h    | NMI select. This bit selects the function for the RST/NMI pin.<br>0b = Reset function<br>1b = NMI function                                                                                                                                             |

<sup>(1)</sup> On some devices this bit can be written, but it must always be written as 1.

## 1.16 SYS Registers

The SYS configuration registers are listed in [Table 1-16](#) and the base address is 00180h. A detailed description of each register and its bits is also provided. Each register starts at a word boundary. Either word or byte data can be written to the SYS configuration registers.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 1-16. SYS Registers**

| Offset | Acronym    | Register Name               | Type       | Access | Reset | Section                        |
|--------|------------|-----------------------------|------------|--------|-------|--------------------------------|
| 00h    | SYSCTL     | System Control              | Read/write | Word   | 0000h | <a href="#">Section 1.16.1</a> |
| 00h    | SYSCTL_L   |                             | Read/write | Byte   | 00h   |                                |
| 01h    | SYSCTL_H   |                             | Read/write | Byte   | 00h   |                                |
| 06h    | SYSJMBC    | JTAG Mailbox Control        | Read/write | Word   | 000Ch | <a href="#">Section 1.16.2</a> |
| 06h    | SYSJMBC_L  |                             | Read/write | Byte   | 0Ch   |                                |
| 07h    | SYSJMBC_H  |                             | Read/write | Byte   | 00h   |                                |
| 08h    | SYSJMBI0   | JTAG Mailbox Input 0        | Read/write | Word   | 0000h | <a href="#">Section 1.16.3</a> |
| 08h    | SYSJMBI0_L |                             | Read/write | Byte   | 00h   |                                |
| 09h    | SYSJMBI0_H |                             | Read/write | Byte   | 00h   |                                |
| 0Ah    | SYSJMBI1   | JTAG Mailbox Input 1        | Read/write | Word   | 0000h | <a href="#">Section 1.16.4</a> |
| 0Ah    | SYSJMBI1_L |                             | Read/write | Byte   | 00h   |                                |
| 0Bh    | SYSJMBI1_H |                             | Read/write | Byte   | 00h   |                                |
| 0Ch    | SYSJMBO0   | JTAG Mailbox Output 0       | Read/write | Word   | 0000h |                                |
| 0Ch    | SYSJMBO0_L |                             | Read/write | Byte   | 00h   |                                |
| 0Dh    | SYSJMBO0_H |                             | Read/write | Byte   | 00h   |                                |
| 0Eh    | SYSJMBO1   | JTAG Mailbox Output 1       | Read/write | Word   | 0000h | <a href="#">Section 1.16.6</a> |
| 0Eh    | SYSJMBO1_L |                             | Read/write | Byte   | 00h   |                                |
| 0Fh    | SYSJMBO1_H |                             | Read/write | Byte   | 00h   |                                |
| 1Ah    | SYSUNIV    | User NMI Vector Generator   | Read       | Word   | 0000h | <a href="#">Section 1.16.7</a> |
| 1Ch    | SYSSNIV    | System NMI Vector Generator | Read       | Word   | 0000h | <a href="#">Section 1.16.8</a> |
| 1Eh    | SYSRSTIV   | Reset Vector Generator      | Read       | Word   | 0002h | <a href="#">Section 1.16.9</a> |

### 1.16.1 SYSCTL Register

SYS Control Register

**Figure 1-10. SYSCTL Register**

|          |            |           |     |          |          |    |        |
|----------|------------|-----------|-----|----------|----------|----|--------|
| 15       | 14         | 13        | 12  | 11       | 10       | 9  | 8      |
| Reserved |            |           |     |          |          |    |        |
| r0       | r0         | r0        | r0  | r0       | r0       | r0 | r0     |
| 7        |            |           |     |          |          |    |        |
|          |            |           |     |          |          |    |        |
| 7        | 6          | 5         | 4   | 3        | 2        | 1  | 0      |
|          |            |           |     |          |          |    |        |
| Reserved | SYSJTAGPIN | SYSBSLIND |     | Reserved | SYSPMMPE |    |        |
| r0       | r0         | rw-[0]    | r-0 | r0       | rw-[0]   | r0 | rw-[0] |

**Table 1-17. SYSCTL Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 7-6  | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 5    | SYSJTAGPIN | RW   | 0h    | Dedicated JTAG pins enable. Setting this bit disables the shared functionality of the JTAG pins and permanently enables the JTAG function. This bit can only be set once. Once it is set it remains set until a BOR occurs.<br>0b = Shared JTAG pins (JTAG mode selectable using SBW sequence)<br>1b = Dedicated JTAG pins (explicit 4-wire JTAG mode selection)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 4    | SYSBSLIND  | R    | 0h    | BSL entry indication. This bit indicates a BSL entry sequence detected on the Spy-Bi-Wire pins.<br>0b = No BSL entry sequence detected<br>1b = BSL entry sequence detected                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 3    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 2    | SYSPMMPE   | RW   | 0h    | PMM access protect. This controls the accessibility of the PMM control registers. Once set to 1, it only can be cleared by a BOR.<br>0b = Access from anywhere in memory<br>1b = Access only from the BSL segments                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 1    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 0    | SYSRIVECT  | RW   | 0h    | RAM-based interrupt vectors<br>0b = Interrupt vectors generated with end address TOP of lower 64K FRAM FFFFh<br>1b = Interrupt vectors generated with end address TOP of RAM, when RAM available.<br>Note: On devices that contain RAM, it is possible to use the RAM as an alternate location for the interrupt vector locations. Setting the SYSRIVECT bit to '1' in SYSCTL causes the interrupt vectors to be remapped to the top of RAM. The total RAM size varies depending on the device configurations and could include one or multiple RAM sections. The alternate location is always the highest address of the entire RAM space available in the device. Note that the SYSRIVECT bit is automatically cleared on a BOR, so the default reset vector location (0FFEh) will be used after a BOR before setting the SYSRIVECT bit to '1'. On devices with LEA, the highest RAM address may be part of the LEA shared RAM. Care must be taken to avoid address conflicts if LEA is used in this case. |

### 1.16.2 SYSJMBC Register

JTAG Mailbox Control Register

**Figure 1-11. SYSJMBC Register**

|            |            |          |         |           |           |          |          |
|------------|------------|----------|---------|-----------|-----------|----------|----------|
| 15         | 14         | 13       | 12      | 11        | 10        | 9        | 8        |
| Reserved   |            |          |         |           |           |          |          |
| r0         | r0         | r0       | r0      | r0        | r0        | r0       | r0       |
| 7          | 6          | 5        | 4       | 3         | 2         | 1        | 0        |
| JMBCLR1OFF | JMBCLR0OFF | Reserved | JMBM0DE | JMBOUT1FG | JMBOUT0FG | JMBIN1FG | JMBIN0FG |
| rw-(0)     | rw-(0)     | r0       | rw-0    | r-(1)     | r-(1)     | rw-(0)   | rw-(0)   |

**Table 1-18. SYSJMBC Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                  |
|------|------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                 |
| 7    | JMBCLR1OFF | RW   | 0h    | Incoming JTAG Mailbox 1 flag auto-clear disable<br>0b = JMBIN1FG cleared on read of JMBIN register<br>1b = JMBIN1FG cleared by software                                                                                                                                                                                                      |
| 6    | JMBCLR0OFF | RW   | 0h    | Incoming JTAG Mailbox 0 flag auto-clear disable<br>0b = JMBIN0FG cleared on read of JMBIN register<br>1b = JMBIN0FG cleared by software                                                                                                                                                                                                      |
| 5    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                 |
| 4    | JMBMODE    | RW   | 0h    | This bit defines the operation mode of JMB for JMBI0, JMBI1, JMBO0, and JMBO1. Before switching this bit, pad and flush out any partial content to avoid data drops.<br>0b = 16-bit transfers using JMBO0 and JMBI0 only<br>1b = 32-bit transfers using JMBO0 with JMBO1 and JMBI0 with JMBI1                                                |
| 3    | JMBOUT1FG  | R    | 1h    | Outgoing JTAG Mailbox 1 flag. This bit is cleared automatically when a message is written to the upper byte of JMBO1 or as word access (by the CPU, DMA,...) and is set after the message was read through JTAG.<br>0b = JMBO1 is not ready to receive new data.<br>1b = JMBO1 is ready to receive new data.                                 |
| 2    | JMBOUT0FG  | R    | 1h    | Outgoing JTAG Mailbox 0 flag. This bit is cleared automatically when a message is written to the upper byte of JMBO0 or as word access (by the CPU, DMA,...) and is set after the message was read through JTAG.<br>0b = JMBO0 is not ready to receive new data.<br>1b = JMBO0 is ready to receive new data.                                 |
| 1    | JMBIN1FG   | RW   | 0h    | Incoming JTAG Mailbox 1 flag. This bit is set when a new message (provided through JTAG) is available in JMBI1. This flag is cleared automatically on read of JMBI1 when JMBCLR1OFF = 0 (auto clear mode). On JMBCLR1OFF = 1, JMBIN1FG needs to be cleared by software.<br>0b = JMBI1 has no new data.<br>1b = JMBI1 has new data available. |
| 0    | JMBIN0FG   | RW   | 0h    | Incoming JTAG Mailbox 0 flag. This bit is set when a new message (provided through JTAG) is available in JMBI0. This flag is cleared automatically on read of JMBI0 when JMBCLR0OFF = 0 (auto clear mode). On JMBCLR0OFF = 1, JMBIN0FG needs to be cleared by software.<br>0b = JMBI0 has no new data.<br>1b = JMBI0 has new data available. |

### 1.16.3 SYSJMBI0 Register

JTAG Mailbox Input 0 Register

**Figure 1-12. SYSJMBI0 Register**

|       |      |      |      |      |      |      |      |
|-------|------|------|------|------|------|------|------|
| 15    | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| MSGHI |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| MSGLO |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 1-19. SYSJMBI0 Register Description**

| Bit  | Field | Type | Reset | Description                             |
|------|-------|------|-------|-----------------------------------------|
| 15-8 | MSGHI | RW   | 0h    | JTAG mailbox incoming message high byte |
| 7-0  | MSGLO | RW   | 0h    | JTAG mailbox incoming message low byte  |

### 1.16.4 SYSJMBI1 Register

JTAG Mailbox Input 1 Register

**Figure 1-13. SYSJMBI1 Register**

|       |      |      |      |      |      |      |      |
|-------|------|------|------|------|------|------|------|
| 15    | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| MSGHI |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| MSGLO |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 1-20. SYSJMBI1 Register Description**

| Bit  | Field | Type | Reset | Description                             |
|------|-------|------|-------|-----------------------------------------|
| 15-8 | MSGHI | RW   | 0h    | JTAG mailbox incoming message high byte |
| 7-0  | MSGLO | RW   | 0h    | JTAG mailbox incoming message low byte  |

### 1.16.5 SYSJMBO0 Register

JTAG Mailbox Output 0 Register

**Figure 1-14. SYSJMBO0 Register**

| 15    | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------|------|------|------|------|------|------|------|
| MSGHI |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| MSGLO |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 1-21. SYSJMBO0 Register Description**

| Bit  | Field | Type | Reset | Description                             |
|------|-------|------|-------|-----------------------------------------|
| 15-8 | MSGHI | RW   | 0h    | JTAG mailbox outgoing message high byte |
| 7-0  | MSGLO | RW   | 0h    | JTAG mailbox outgoing message low byte  |

### 1.16.6 SYSJMBO1 Register

JTAG Mailbox Output 1 Register

**Figure 1-15. SYSJMBO1 Register**

| 15    | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------|------|------|------|------|------|------|------|
| MSGHI |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| MSGLO |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 1-22. SYSJMBO1 Register Description**

| Bit  | Field | Type | Reset | Description                             |
|------|-------|------|-------|-----------------------------------------|
| 15-8 | MSGHI | RW   | 0h    | JTAG mailbox outgoing message high byte |
| 7-0  | MSGLO | RW   | 0h    | JTAG mailbox outgoing message low byte  |

### **1.16.7 SYSUNIV Register**

User NMI Vector Register

**Figure 1-16. SYSUNIV Register**

| 15      | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
|---------|----|----|-----|-----|-----|-----|----|
| SYSUNIV |    |    |     |     |     |     |    |
| r0      | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| SYSUNIV |    |    |     |     |     |     |    |
| r0      | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 1-23. SYSUNIV Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                |
|------|---------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | SYSUNIV | R    | 0h    | User NMI vector. Generates a value that can be used as address offset for fast interrupt service routine handling. Writing to this register clears all pending user NMI flags.<br>See the device-specific data sheet for a list of values. |

### **1.16.8 SYSSNIV Register**

System NMI Vector Register

**Figure 1-17. SYSSNIV Register**

| 15      | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
|---------|----|----|-----|-----|-----|-----|----|
| SYSSNIV |    |    |     |     |     |     |    |
| r0      | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| SYSSNIV |    |    |     |     |     |     |    |
| r0      | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 1-24. SYSSNIV Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                    |
|------|---------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | SYSSNIV | R    | 0h    | System NMI vector. Generates a value that can be used as address offset for fast interrupt service routine handling. Writing to this register clears all pending system NMI flags.<br>See the device-specific data sheet for a list of values. |

### 1.16.9 SYSRSTIV Register

Reset Interrupt Vector Register

**Figure 1-18. SYSRSTIV Register**

|          |    |                  |                  |                  |                  |                  |    |
|----------|----|------------------|------------------|------------------|------------------|------------------|----|
| 15       | 14 | 13               | 12               | 11               | 10               | 9                | 8  |
| SYSRSTIV |    |                  |                  |                  |                  |                  |    |
| r0       | r0 | r0               | r0               | r0               | r0               | r0               | r0 |
| SYSRSTIV |    |                  |                  |                  |                  |                  |    |
| r0       | r0 | r <sup>(1)</sup> | r0 |

<sup>(1)</sup> Reset value depends on reset source.

**Table 1-25. SYSRSTIV Register Description**

| Bit  | Field    | Type | Reset                   | Description                                                                                                                                                                                                                                                                                               |
|------|----------|------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | SYSRSTIV | R    | 02h-03Eh <sup>(1)</sup> | Reset interrupt vector. Generates a value that can be used as address offset for fast interrupt service routine handling to identify the last cause of a reset (BOR, POR, PUC) . Writing to this register clears all pending reset source flags. See the device-specific data sheet for a list of values. |

<sup>(1)</sup> Reset value depends on reset source.

## **Power Management Module (PMM) and Supply Voltage Supervisor (SVS)**

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This chapter describes the operation of the Power Management Module (PMM) and Supply Voltage Supervisor (SVS). The PMM is family specific.

| Topic                                                | Page |
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| 2.2 PMM Operation .....                              | 85   |
| 2.3 PMM Registers.....                               | 88   |

## 2.1 Power Management Module (PMM) Introduction

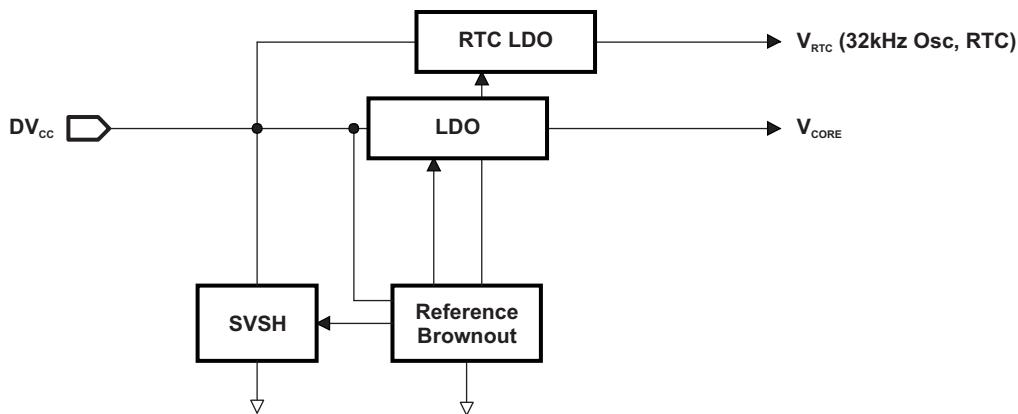
PMM features include:

- Wide supply voltage ( $DV_{CC}$ ) range: 1.8 V to 3.6 V
- Generation of voltage for the device core ( $V_{CORE}$ )
- Supply voltage supervisor (SVS) for  $DV_{CC}$
- Brownout reset (BOR)
- Software accessible power-fail indicators
- I/O protection during power-fail condition

The PMM manages all functions related to the power supply and its supervision for the device. Its primary functions are first to generate a supply voltage for the core logic, and second, provide several mechanisms for the supervision of the voltage applied to the device ( $DV_{CC}$ ).

The PMM uses an integrated low-dropout voltage regulator (LDO) to produce a secondary core voltage ( $V_{CORE}$ ) from the primary one applied to the device ( $DV_{CC}$ ). In general,  $V_{CORE}$  supplies the CPU, memories, and the digital modules, while  $DV_{CC}$  supplies the I/Os and analog modules. The  $V_{CORE}$  output is maintained using a dedicated voltage reference. The input or primary side of the regulator is referred to in this chapter as its high side. The output or secondary side is referred to in this chapter as its low side.

Figure 2-1 shows the block diagram of the PMM.



**Figure 2-1. PMM Block Diagram**

## 2.2 PMM Operation

### 2.2.1 $V_{CORE}$ and the Regulator

$DV_{CC}$  can be powered from a wide input voltage range, but the core logic of the device must be kept at a voltage lower than what this range allows. For this reason, a regulator (LDO) has been integrated into the PMM. The regulator derives the necessary core voltage ( $V_{CORE}$ ) from  $DV_{CC}$ .

The regulator supports different load settings to optimize power. The hardware controls the load settings automatically, according to the following criteria:

- Selected and active power modes
- Selected and active clocks
- Clock frequencies according to Clock System (CS) settings
- JTAG is active

In addition to the main LDO, an ultra-low-power regulator (RTC LDO) provides a regulated voltage to the real-time clock module (including the 32-kHz crystal oscillator) and other ultra-low-power modules that remain active during LPM3.5 when the main LDO is off.

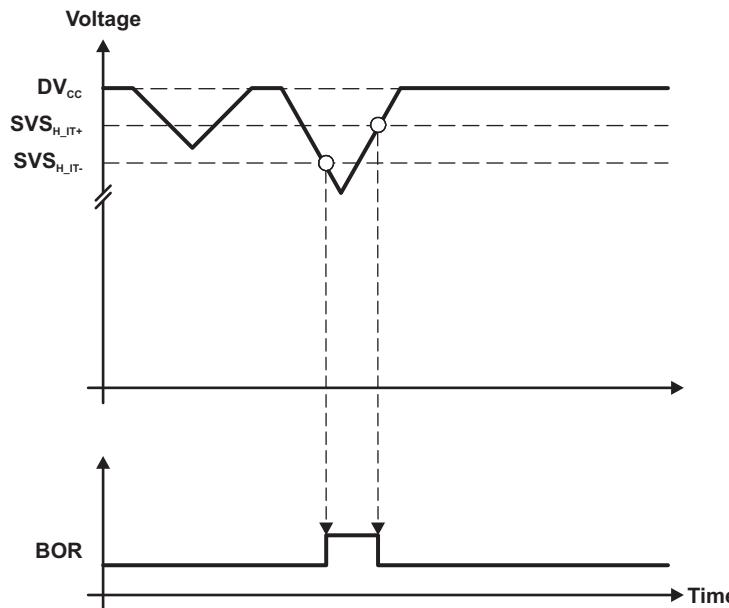
### 2.2.2 Supply Voltage Supervisor

The high-side supervisor (SVSH) oversees  $DV_{CC}$ . It is activate in all power modes by default. To disable the SVSH in LPM3, LPM4, LPM3.5, and LPM4.5, set SVSHE = 0.

#### 2.2.2.1 SVS Thresholds

As [Figure 2-2](#) shows, there is hysteresis built into the supervision thresholds, such that the thresholds in force depend on whether the voltage rail is going up or down.

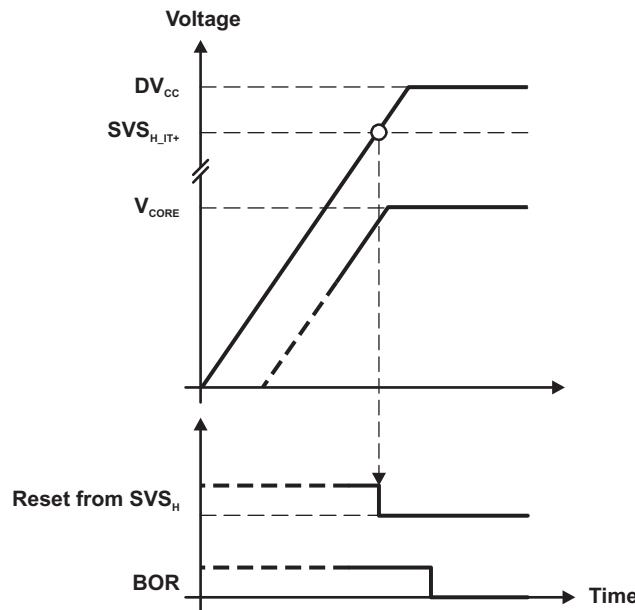
The behavior of the SVS according to these thresholds is best portrayed graphically. [Figure 2-2](#) shows how the supervisors respond to various supply failure conditions.



**Figure 2-2. Voltage Failure and Resulting PMM Actions**

### 2.2.3 Supply Voltage Supervisor - Power-Up

When the device is powering up, the SVSH function is enabled by default. Initially,  $DV_{CC}$  is low, and therefore the PMM holds the device in BOR reset. When the SVSH level is met, after a short delay the BOR reset is released. [Figure 2-3](#) shows this process.



**Figure 2-3. PMM Action at Device Power-Up**

### 2.2.4 LPM3.5 and LPM4.5

LPM3.5 and LPM4.5 are additional low-power modes in which the core voltage regulator of the PMM is completely disabled, providing additional power savings. Because there is no power supplied to  $V_{CORE}$  during LPMx.5, the CPU and all digital modules including RAM are unpowered. This essentially disables the entire device and thus the contents of the registers and RAM are lost. Any essential values should be stored to FRAM before entering LPMx.5.

To enable LPMx.5 the PMMREGOFF bit in the PMMCTL0 register must be set.

The LOCKLPM5 bit in the PM5CTL0 register locks the I/O configuration and other LPMx.5 relevant configurations after a wakeup from LPMx.5 until all the registers are configured again.

LPM3.5 and LPM4.5 can be configured with active SVS ( $SVSHE = 1$ ) or with SVS disabled ( $SVSHE = 0$ ). Disabling the SVS results in lower power consumption, whereas enabling it provides the ability to detect supply drops and getting a "wake-up" due to the supply drop below the SVS threshold. Note, the "wake-up" due to a supply failure would not be flagged as a LPMx.5 wake-up but as a SVS reset event. In LPM4.5 enabling the SVS results additionally in an about 4 times faster start-up time than with disabled SVS.

Refer to [Section 1.4.3](#) for complete descriptions and uses of LPMx.5.

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**NOTE:** In watchdog mode, the WDT\_A prevents LPMx.5. Refer to [Section 24.2.5](#).

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### 2.2.5 Brownout Reset (BOR)

The primary function of the brownout reset (BOR) circuit occurs when the device is powering up. It is functional very early in the power-up ramp, generating a BOR that initializes the system. It also functions when no SVS is enabled and a brownout condition occurs. It sustains this reset until the input power is sufficient for the logic, for proper reset of the system.

In an application, it may be desired to cause a BOR through software. Setting PMMSWBOR causes a software-driven BOR. PMMBORIFG is set accordingly. Note that a BOR also initiates a POR and PUC. PMMBORIFG can be cleared by software or by reading SYSRSTIV. Similarly, it is possible to cause a POR through software by setting PMMSWPOR. PMMPORIFG is set accordingly. A POR also initiates a PUC. PMMPORIFG can be cleared by software or by reading SYSRSTIV. Both PMMSWBOR and PMMSWPOR are self clearing. See the SYS module for complete descriptions of BOR, POR, and PUC resets.

### 2.2.6 *RST/NMI*

The external *RST/NMI* terminal is pulled low on a BOR reset condition. The *RST/NMI* can be used as reset source for the rest of the application.

### 2.2.7 *PMM Interrupts*

Interrupt flags generated by the PMM are routed to the system NMI interrupt vector generator register, SYSSNIV. When the PMM causes a reset, a value is generated in the system reset interrupt vector generator register, SYSRSTIV, corresponding to the source of the reset. These registers are defined within the SYS module. More information on the relationship between the PMM and SYS modules is available in the SYS chapter.

### 2.2.8 *Port I/O Control*

The PMM provides a means of ensuring that I/O pins cannot behave in uncontrolled fashion during an undervoltage event. During these times, outputs are disabled, both normal drive and the weak pullup or pulldown function. If the CPU is functioning normally, and then an undervoltage event occurs, any pin configured as an input has its PxIN register value locked in at the point the event occurs, until voltage is restored. During the undervoltage event, external voltage changes on the pin are not registered internally. This helps prevent erratic behavior from occurring.

## 2.3 PMM Registers

The PMM registers are listed in [Table 2-1](#). The base address of the PMM module can be found in the device-specific data sheet. The address offset of each PMM register is given in [Table 2-1](#).

The password defined in the PMMCTL0 register controls access to all PMM registers except PM5CTL0. PM5CTL0 can be accessed without a password. After the correct password is written, the write access is enabled (this includes byte access to the PMMCTL0 lower byte). The write access is disabled by writing a wrong password in byte mode to the PMMCTL0 upper byte. Word accesses to PMMCTL0 with a wrong password triggers a PUC. A write access to a register other than PMMCTL0 while write access is not enabled causes a PUC.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 2-1. PMM Registers**

| Offset | Acronym   | Register Name                   | Type                      | Access | Reset | Section                       |
|--------|-----------|---------------------------------|---------------------------|--------|-------|-------------------------------|
| 00h    | PMMCTL0   | PMM control register 0          | Read/write                | Word   | 9640h | <a href="#">Section 2.3.1</a> |
| 00h    | PMMCTL0_L |                                 | Read/write                | Byte   | 40h   |                               |
| 01h    | PMMCTL0_H |                                 | Read/write                | Byte   | 96h   |                               |
| 02h    | PMMCTL1   | PMM control register 1          | Read/write <sup>(1)</sup> | Word   | 9600h | <a href="#">Section 2.3.2</a> |
| 02h    | PMMCTL1_L |                                 | Read <sup>(1)</sup>       | Byte   | 00h   |                               |
| 03h    | PMMCTL1_H |                                 | Read <sup>(1)</sup>       | Byte   | 96h   |                               |
| 0Ah    | PMMIFG    | PMM interrupt flag register     | Read/write                | Word   | 0000h | <a href="#">Section 2.3.3</a> |
| 0Ah    | PMMIFG_L  |                                 | Read/write                | Byte   | 00h   |                               |
| 0Bh    | PMMIFG_H  |                                 | Read/write                | Byte   | 00h   |                               |
| 10h    | PM5CTL0   | Power mode 5 control register 0 | Read/write                | Word   | 0001h | <a href="#">Section 2.3.4</a> |
| 10h    | PM5CTL0_L |                                 | Read/write                | Byte   | 01h   |                               |
| 11h    | PM5CTL0_H |                                 | Read/write                | Byte   | 00h   |                               |

<sup>(1)</sup> PMMCTL1 can be written as word only.

### 2.3.1 PMMCTL0 Register (offset = 00h) [reset = 9640h]

Power Management Module Control Register 0

**Figure 2-4. PMMCTL0 Register**

|                 |        |          |           |          |          |          |      |
|-----------------|--------|----------|-----------|----------|----------|----------|------|
| 15              | 14     | 13       | 12        | 11       | 10       | 9        | 8    |
| PMMPW           |        |          |           |          |          |          |      |
| rw-1            | rw-0   | rw-0     | rw-1      | rw-0     | rw-1     | rw-1     | rw-0 |
| 7 6 5 4 3 2 1 0 |        |          |           |          |          |          |      |
| Reserved        | SVSHE  | Reserved | PMMREGOFF | PMMSWPOR | PMMSWBOR | Reserved |      |
| rw-[0]          | rw-[1] | r0       | rw-[0]    | rw-(0)   | rw-[0]   | r0       | r0   |

**Table 2-2. PMMCTL0 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                    |
|------|-----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | PMMPW     | RW   | 96h   | PMM password. Always reads as 096h. Must be written with 0A5h to unlock the PMM registers.                                                                                                     |
| 7    | Reserved  | RW   | 0h    | Reserved. Must be written with 0.                                                                                                                                                              |
| 6    | SVSHE     | RW   | 1h    | High-side SVS enable.<br>0b = High-side SVS (SVSH) is disabled in LPM2, LPM3, LPM4, LPM3.5, and LPM4.5. SVSH is always enabled in active mode, LPM0, and LPM1.<br>1b = SVSH is always enabled. |
| 5    | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                   |
| 4    | PMMREGOFF | RW   | 0h    | Regulator off<br>0b = Regulator remains on when going into LPM3 or LPM4<br>1b = Regulator is turned off when going to LPM3 or LPM4. System enters LPM3.5 or LPM4.5, respectively.              |
| 3    | PMMSWPOR  | RW   | 0h    | Software POR. Setting this bit to 1 triggers a POR. This bit is self clearing.<br>0b = Normal operation<br>1b = Set to 1 to trigger a POR                                                      |
| 2    | PMMSWBOR  | RW   | 0h    | Software brownout reset. Setting this bit to 1 triggers a BOR. This bit is self clearing.<br>0b = Normal operation<br>1b = Set to 1 to trigger a BOR                                           |
| 1-0  | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                   |

### 2.3.2 PMMCTL1 Register (offset = 02h) [reset = 9600h]

Power Management Module Control Register 1

**Figure 2-5. PMMCTL1 Register**

|          |        |        |        |        |        |        |      |
|----------|--------|--------|--------|--------|--------|--------|------|
| 15       | 14     | 13     | 12     | 11     | 10     | 9      | 8    |
| Reserved |        |        |        |        |        |        |      |
| rw-1     | rw-0   | rw-0   | rw-1   | rw-0   | rw-1   | rw-1   | rw-0 |
| Reserved |        |        |        |        |        |        |      |
| rw-[0]   | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] | r0   |

**Table 2-3. PMMCTL1 Register Description**

| Bit  | Field    | Type | Reset | Description                      |
|------|----------|------|-------|----------------------------------|
| 15-0 | Reserved | R    | 9600h | Reserved. Always reads as 9600h. |

### 2.3.3 PMMIFG Register (offset = 0Ah) [reset = 0000h]

Power Management Module Interrupt Flag Register

**Figure 2-6. PMMIFG Register**

| 15          | 14       | 13      | 12 | 11       | 10        | 9         | 8         |
|-------------|----------|---------|----|----------|-----------|-----------|-----------|
| PMMILPM5IFG | Reserved | SVSHIFG |    | Reserved | PMMPORIFG | PMMRSTIFG | PMMBORIFG |
| rw-{0}      | r0       | rw-{0}  | r0 | r0       | rw-[0]    | rw-{0}    | rw-{0}    |
| 7           | 6        | 5       | 4  | 3        | 2         | 1         | 0         |
| Reserved    |          |         |    |          |           |           |           |
| r0          | r0       | r0      | r0 | r0       | r0        | r0        | r0        |

**Table 2-4. PMMIFG Register Description**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------|-------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | PMMILPM5IFG | RW   | 0h    | <p>LPMx.5 flag.</p> <p>This bit has a specific reset conditions. This bit is only set if the system was in LPMx.5 before.</p> <p>The bit is cleared by software or by reading the reset vector word. A power failure on the DVCC domain triggered by the high-side SVS (if enabled) or the brownout clears the bit.</p> <p>0b = Reset not due to wake-up from LPMx.5<br/>1b = Reset due to wake-up from LPMx.5</p> |
| 14    | Reserved    | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                       |
| 13    | SVSHIFG     | RW   | 0h    | <p>High-side SVS interrupt flag.</p> <p>This bit has a specific reset conditions.</p> <p>The SVSHIFG interrupt flag is only set if the SVSH is the reset source; that is, if DVCC dropped below the high-side SVS levels but remained above the brownout levels. The bit is cleared by software or by reading the reset vector word SYSRSTIV.</p> <p>0b = Reset not due to SVSH<br/>1b = Reset due to SVSH</p>     |
| 12-11 | Reserved    | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                       |
| 10    | PMMPORIFG   | RW   | 0h    | <p>PMM software POR interrupt flag.</p> <p>This bit has a specific reset conditions. This interrupt flag is only set if a software POR (PMMSWPOR) is triggered.</p> <p>The bit is cleared by software or by reading the reset vector word.</p> <p>0b = Reset not due to PMMSWPOR<br/>1b = Reset due to PMMSWPOR</p>                                                                                                |
| 9     | PMMRSTIFG   | RW   | 0h    | <p>PMM reset pin interrupt flag.</p> <p>This bit has a specific reset conditions. This interrupt flag is only set if the RST/NMI pin is the reset source.</p> <p>The bit is cleared by software or by reading the reset vector word.</p> <p>0b = Reset not due to reset pin<br/>1b = Reset due to reset pin</p>                                                                                                    |
| 8     | PMMBORIFG   | RW   | 0h    | <p>PMM software brownout reset interrupt flag.</p> <p>This bit has a specific reset conditions. This interrupt flag is only set if a software BOR (PMMSWBOR) is triggered.</p> <p>The bit is cleared by software or by reading the reset vector word.</p> <p>0b = Reset not due to PMMSWBOR<br/>1b = Reset due to PMMSWBOR</p>                                                                                     |
| 7-0   | Reserved    | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                       |

### 2.3.4 PM5CTL0 Register (offset = 10h) [reset = 0001h]

Power Mode 5 Control Register 0

**Figure 2-7. PM5CTL0 Register**

|          |    |    |    |    |    |    |        |
|----------|----|----|----|----|----|----|--------|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8      |
| Reserved |    |    |    |    |    |    |        |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0     |
| 7        | 6  | 5  | 4  | 3  | 2  | 1  | 0      |
| Reserved |    |    |    |    |    |    |        |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | rw-{1} |

**Table 2-5. PM5CTL0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 0    | LOCKLPM5 | RW   | 1h    | <p>Locks I/O pin and other LPMx.5 relevant (for example, RTC) configurations upon exit from LPMx.5.</p> <p>This bit is set by hardware and must be cleared by software. It cannot be set by software.</p> <p>After a power cycle I/O pins are locked in high-impedance state with input Schmitt triggers disabled until LOCKLPM5 is cleared by the user software.</p> <p>After a wake-up from LPMx.5 I/O pins and other LPMx.5 relevant (for example, RTC) configurations are locked in their states configured before LPMx.5 entry until LOCKLPM5 is cleared by the user software.</p> <p>0b = I/O pin and LPMx.5 configurations unlocked.</p> <p>1b = I/O pin and LPMx.5 configuration remains locked.</p> |

## **Clock System (CS) Module**

This chapter describes the operation of the clock system, which is implemented in all devices.

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| 3.2 <b>Clock System Operation .....</b>    | <b>96</b>  |
| 3.3 <b>CS Registers .....</b>              | <b>103</b> |

### 3.1 Clock System Introduction

The clock system module supports low system cost and low power consumption. Using three system clock signals, the user can select the best balance of performance and power consumption. The clock module can be configured to operate without any external components, with one or two external crystals, or with resonators, under full software control.

The clock system module includes the following clock sources:

- LFXTCLK: Low-frequency oscillator that can be used either with low-frequency 32768-Hz watch crystals, standard crystals, resonators, or external clock sources in the 50 kHz or below range. When in bypass mode, LFXTCLK can be driven with an external square wave signal.
- VLOCLK: Internal very-low-power low-frequency oscillator with 10-kHz typical frequency
- DCOCLK: Internal digitally controlled oscillator (DCO) with selectable frequencies
- MODCLK: Internal low-power oscillator with 5-MHz typical frequency. LFMODCLK is MODCLK divided by 128.
- HFXTCLK: High-frequency oscillator that can be used with standard crystals or resonators in the 4-MHz to 24-MHz range. When in bypass mode, HFXTCLK can be driven with an external square wave signal.

Four system clock signals are available from the clock module:

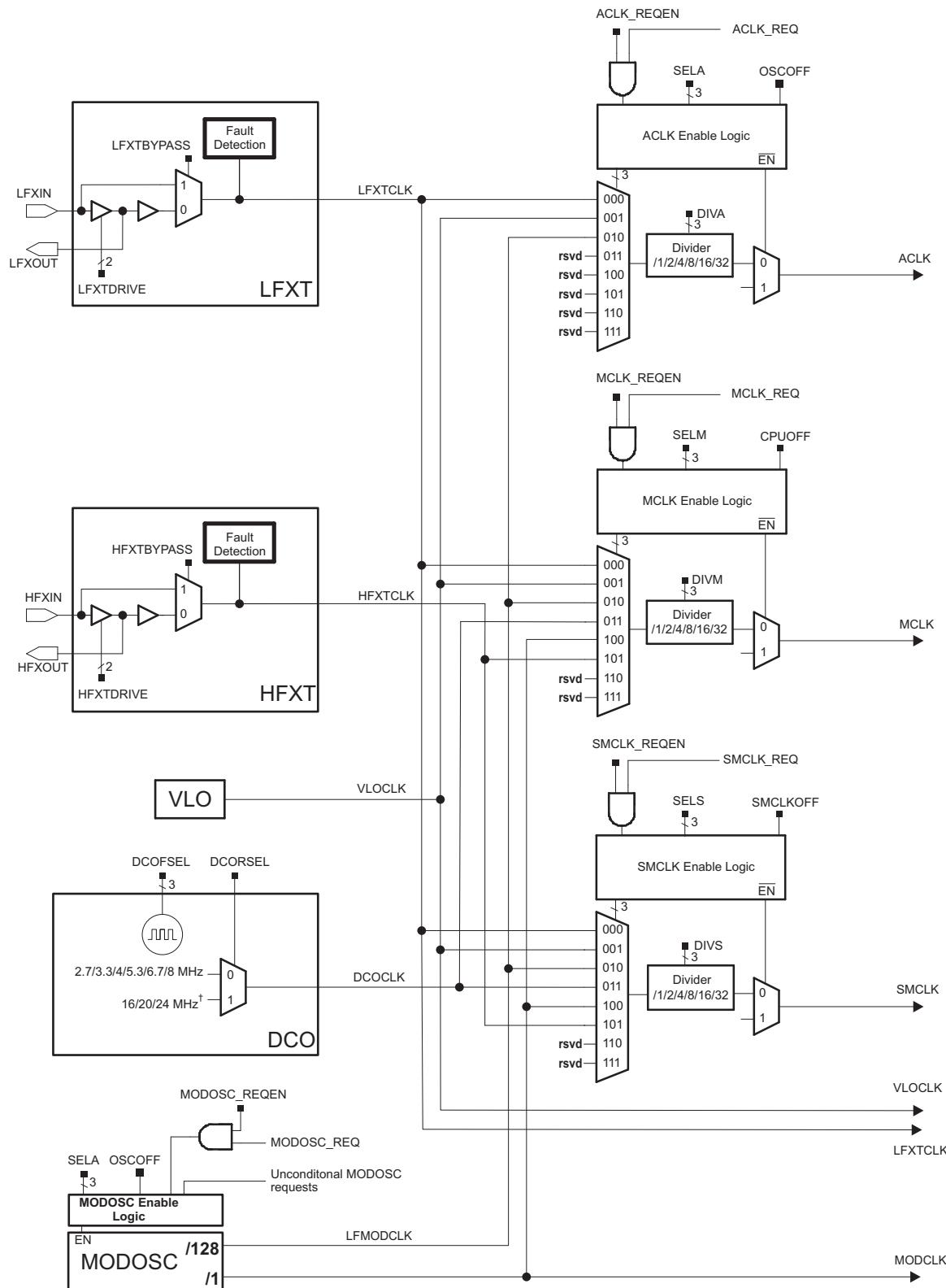
- ACLK: Auxiliary clock. The ACLK is software selectable as LFXTCLK, VLOCLK, or LFMODCLK. ACLK can be divided by 1, 2, 4, 8, 16, or 32. ACLK is software selectable by individual peripheral modules.
- MCLK: Master clock. MCLK is software selectable as LFXTCLK, VLOCLK, LFMODCLK, DCOCLK, MODCLK, or HFXTCLK. MCLK can be divided by 1, 2, 4, 8, 16, or 32. MCLK is used by the CPU and system.
- SMCLK: Subsystem master clock. SMCLK is software selectable as LFXTCLK, VLOCLK, LFMODCLK, DCOCLK, MODCLK, or HFXTCLK. SMCLK is software selectable by individual peripheral modules.
- MODCLK: Module clock. MODCLK may also be used by various peripheral modules and is sourced by MODOSC.
- VLOCLK: VLO clock. VLOCLK may also be used directly by various peripheral modules and is sourced by VLO.

---

**NOTE:** Not all devices contain both LFXT and HFXT clock sources. See the device-specific data sheet for availability.

---

Figure 3-1 shows the block diagram of the clock system module.



† Not available on all devices

**Figure 3-1. Clock System Block Diagram**

### 3.2 Clock System Operation

After PUC, the CS module default configuration is:

- LFXT is selected as the oscillator source for LFXTCLK. LFXTCLK is selected for ACLK (SELAx = 0) and ACLK is undivided (DIVAx = 0).
- DCOCLK is selected for MCLK and SMCLK (SELMx = SELSx = 3) and each are divided by 8 (DIVMx = DIVSx = 3).
- LFXIN and LFXOUT pins are set to general-purpose I/Os and LFXT remains disabled until the I/O ports are configured for LFXT operation.
- HFXIN and HFXOUT pins are set to general-purpose I/Os and HFXT is disabled.

As previously stated, LFXT is selected by default, but LFXT is disabled. The crystal pins (LFXIN, LFXOUT) are shared with general-purpose I/Os. To enable LFXT, the PSEL bits associated with the crystal pins must be set. When a 32768-Hz crystal is used for LFXTCLK, the fault control logic immediately causes ACLK to be sourced by LFMODCLK, and MCLK and SMCLK to be sourced by MODCLK, because LFXT is not stable immediately (see [Section 3.2.8](#)).

Status register control bits (SCG0, SCG1, OSCOFF, and CPUOFF) configure the MCU operating modes and enable or disable portions of the clock system module (see the *System Resets, Interrupts, and Operating Modes* chapter). Registers CSCTL0 to CSCTL6 configure the CS module.

The CS module can be configured or reconfigured by software at any time during program execution. The CS control registers are password protected to prevent inadvertent access.

#### 3.2.1 CS Module Features for Low-Power Applications

Conflicting requirements typically exist in battery-powered applications:

- Low clock frequency for energy conservation and time keeping
- High clock frequency for fast response times and fast burst processing capabilities
- Clock stability over operating temperature and supply voltage
- Low-cost applications with less-constrained clock accuracy requirements

The CS module addresses these conflicting requirements by allowing the user to select from the three available clock signals: ACLK, MCLK, and SMCLK. A flexible clock distribution and divider system is provided to fine tune the individual clock requirements.

#### 3.2.2 LFXT Oscillator

The LFXT oscillator supports ultra-low-current consumption using a 32768-Hz watch crystal. A watch crystal connects to LFXIN and LFXOUT and requires external capacitors on both terminals. These capacitors should be sized according to the crystal or resonator specifications. Different crystal or resonator ranges are supported by LFXT by choosing the proper LFXTDRIVE settings.

The LFXT pins are shared with general-purpose I/O ports. At power up, the LFXT clock defaults to "on" and is the source for ACLK. However, at power-up the LFXT pins default to general-purpose I/O mode, therefore, the LFXT clock remains disabled until the pins associated with LFXT are configured for LFXT operation. The configuration of the shared I/O is determined by the PSEL bit associated with LFXIN and the LFXTBYPASS bit. Setting the PSEL bit causes the LFXIN and LFXOUT ports to be configured for LFXT operation. If LFXTBYPASS is also set, LFXT is configured for bypass mode of operation, and the oscillator that is associated with LFXT is powered down. In bypass mode of operation, LFXIN can accept an external square-wave clock input signal, and LFXOUT is configured as a general-purpose I/O. The PSEL bit associated with LFXOUT is a don't care.

If the PSEL bit associated with LFXIN is cleared, both LFXIN and LFXOUT ports are configured as general-purpose I/Os, and LFXT is disabled.

LFXT is enabled under any of the following conditions:

- LFXT is a source for ACLK (SELAx = 0) and in active mode (AM) through LPM3 (OSCOFF = 0)
- LFXT is a source for MCLK (SELMx = 0) and in active mode (AM) (CPUOFF = 0)
- LFXT is a source for SMCLK (SELsx = 0) and in active mode (AM) through LPM1 (SMCLKOFF = 0)

- LFXTOFF = 0. LFXT enabled in active mode (AM) through LPM4.
- LFXT is selected as the source for RTC, RTC is enabled (RTCHOLD = 0), and LPMx.5 is entered.

**NOTE:** If LFXT is disabled when entering into a low-power mode, it is not fully enabled and stable upon exit from the low-power mode, because its enable time is much longer than the wake-up time. If the application requires or desires to keep LFXT enabled during a low-power mode, the LFXTOFF bit can be cleared before entering the low-power mode. This causes LFXT to remain enabled.

### 3.2.3 HFXT Oscillator

The HFXT high-frequency oscillator can be used with standard crystals or resonators in the 4 MHz to 24 MHz range. The HFXTDRIVE bits select the drive capability of HFXT. HFXTDRIVE bits can be used to provide optimal settings for a given crystal characteristic. HFXT sources HFXTCLK. The HFFREQ bits must be set for the appropriate frequency range of operation as shown in [Table 3-1](#) in crystal or bypass modes of operation.

**Table 3-1. HFFREQ Settings**

| HFXT Frequency Range | HFFREQ[1:0] |
|----------------------|-------------|
| 0 to 4 MHz           | 00          |
| > 4 MHz to 8 MHz     | 01          |
| > 8 MHz to 16 MHz    | 10          |
| > 16 MHz to 24 MHz   | 11          |

**NOTE:** The HFXT HFFREQ bit settings are also used to control the Power Management Module and must match the intended frequency of operation for proper functioning of the device as listed in [Table 3-1](#). In addition, these bits should be configured properly before use of HFXT in either crystal or bypass modes of operation.

The HFXT pins are shared with general-purpose I/O ports. At power up, the default operation is HFXT crystal operation. However, HFXT remains disabled until the ports shared with HFXT are configured for HFXT operation. The configuration of the shared I/O is determined by the PSEL bit associated with HFXIN and the HFXTBYPASS bit. Setting the PSEL bit causes the HFXIN and HFXOUT ports to be configured for HFXT operation. If HFXTBYPASS is also set, HFXT is configured for bypass mode of operation, and the oscillator associated with HFXT is powered down. In bypass mode of operation, HFXIN can accept an external square-wave clock input signal, and HFXOUT is configured as a general-purpose I/O. The PSEL bit that is associated with HFXOUT is a don't care.

If the PSEL bit associated with HFXIN is cleared, both HFXIN and HFXOUT ports are configured as general-purpose I/Os, and HFXT is disabled.

HFXT is enabled under any of the following conditions:

- HFXT is a source for MCLK (SELMx = 5) and in active mode (AM) (CPUOFF = 0)
- HFXT is a source for SMCLK (SELSx = 5) and in active mode (AM) through LPM1 (SMCLKOFF = 0)
- HFXTOFF = 0. HFXT enabled in active mode (AM) through LPM4.

**NOTE:** If HFXT is disabled when entering into a low-power mode, it is not fully enabled and stable upon exit from the low-power mode, because its enable time is much longer than the wake-up time. If the application requires or desires to keep HFXT enabled during a low-power mode, the HFXTOFF bit can be cleared before entering the low-power mode. This causes HFXT to remain enabled.

### 3.2.4 Internal Very-Low-Power Low-Frequency Oscillator (VLO)

The internal VLO provides a typical frequency of 10 kHz (see the device-specific data sheet for parameters) without requiring a crystal. The VLO provides for a low-cost ultra-low-power clock source for applications that do not require an accurate time base. To conserve power, VLO is powered down when not needed and enabled only when required.

VLO is enabled under any of the following conditions:

- VLO is a source for ACLK (SELAx = 1) and in active mode (AM) through LPM3 (OSCOFF = 0)
- VLO is a source for MCLK (SELMx = 1) and in active mode (AM) (CPUOFF = 0)
- VLO is a source for SMCLK (SELSx = 1) and in active mode (AM) through LPM1 (SMCLKOFF = 0)
- VLOOFF = 0. VLO enabled in active mode (AM) through LPM4.
- VLO is selected as the source for RTC, RTC is enabled (RTCHOLD = 0), and LPMx.5 is entered.

### 3.2.5 Module Oscillator (MODOSC)

The CS module also supports an internal oscillator, MODOSC, that can be used by ACLK, MCLK, or SMCLK, as well as by other modules in the system. It is also used as a fail-safe clock source as described in [Section 3.2.8](#). The MODOSC sources MODCLK and LFMODCLK.

To conserve power, MODOSC is powered down when not needed and is enabled only when required. When the MODOSC source is required, the respective module requests it. MODOSC is enabled based on unconditional and conditional requests. Setting MODOSCREQEN enables conditional requests. Unconditional requests are always enabled. It is not necessary to set MODOSCREQEN for modules that utilize unconditional requests; for example, ADC or fail-safe.

MODOSC is enabled under any of the following conditions:

- LFMODCLK is a source for ACLK (SELAx = 2) and in active mode (AM) through LPM3 (OSCOFF = 0)
- LFMODCLK or MODCLK is a source for MCLK (SELMx = 2, 4) and in active mode (AM) (CPUOFF = 0)
- LFMODCLK or MODCLK is a source for SMCLK (SELSx = 2, 4) and in active mode (AM) through LPM1 (SMCLKOFF = 0)
- During a fault detection (when fault detection enabled) and LFXT or HFXT is active.
- Unconditional requests from modules that require MODCLK; for example, ADC conversion clock when selected as the source.
- LFMODCLK is used as the fail-safe source for the WDT in watchdog mode. Should the selected source for ACLK or SMCLK not be available, the WDT automatically switches to LFMODCLK as its clock source.

The ADC12 may optionally use MODOSC as a clock source for its conversion clock. The user chooses the ADC12OSC as the conversion clock source. During a conversion, the ADC12 module issues an unconditional request for the ADC12OSC clock source. Upon doing so, the MODOSC source is enabled, if not already enabled from other modules' previous requests.

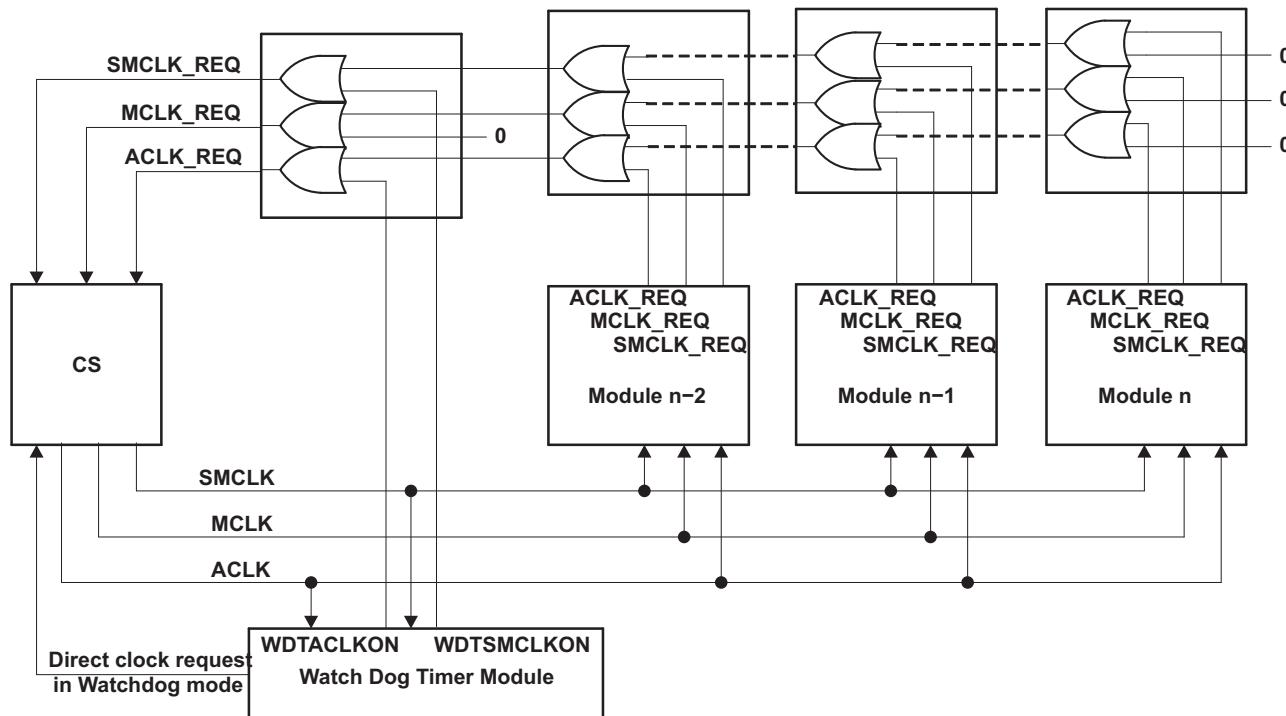
### 3.2.6 Digitally Controlled Oscillator (DCO)

The DCO is an integrated digitally controlled oscillator. The DCO has three frequency settings determined by the DCOFSEL bits. Each frequency is trimmed at the factory. The DCO can be used as a source for MCLK or SMCLK. See the device-specific data sheet for DCO characteristics.

The DCO frequency can be changed at any time, but care should be taken to ensure no other system clock frequency constraints are exceeded with the new frequency selection. Any change in the DCOFSEL or DCORSEL bits causes the DCOCLK to be held for four clock cycles before releasing the new value into the system. This allows for the DCO to settle properly.

### 3.2.7 Operation From Low-Power Modes, Requested by Peripheral Modules

A peripheral module requests its clock sources automatically from the CS module if required for its proper operation, regardless of the current power mode of operation, as shown in Figure 3-2.



**Figure 3-2. Module Request Clock System**

A peripheral module asserts one of three possible clock request signals based on its control bits: ACLK\_REQ, MCLK\_REQ, or SMCLK\_REQ. These request signals are based on the configuration and clock selection of the respective module. For example, if a timer selects ACLK as its clock source and the timer is enabled, the timer generates an ACLK\_REQ signal to the CS system. The CS, in turn, enables ACLK regardless of the power mode settings.

Any clock request from a peripheral module causes its respective clock off signal to be overridden, but does not change the setting of the clock off control bit. For example, a peripheral module may require ACLK that is currently disabled by the OSCOFF bit (OSCOFF = 1). The module can request ACLK by generating an ACLK\_REQ. This causes the OSCOFF bit to have no effect, thereby allowing ACLK to be available to the requesting peripheral module. The OSCOFF bit remains at its current setting (OSCOFF = 1).

If the requested source is not active, the software NMI handler must take care of the required actions. For the previous example, if ACLK was sourced by LFXT and LFXT was not enabled, an oscillator fault condition occurs, and the software must handle the event. The watchdog, due to its security requirement, actively selects the LFMODCLK source if the originally selected clock source is not available.

Due to the clock request feature, care must be taken in the application when entering low-power modes to save power. Although the device enters the selected low-power mode, a clock request causes more current consumption than the specified values in the data sheet. By default, the clock request feature is enabled. The feature can be disabled for each system clock by clearing ACLKREQEN, MCLKREQEN, or SMCLKREQEN for the respective clocks. This does not disable fail-safe clock requests; for example, those of the watchdog timer or the clock system itself.

The function of the ACLKREQEN, MCLKREQEN, and SMCLKREQEN bits are dependent upon which power mode is selected; that is, they do not have an effect across all power modes. For example, ACLKREQEN is used to enable or disable ACLK requests. It is effective only in LPM4, because ACLK is always active in all other modes (AM, LPM0, LPM1, LPM2, LPM3). SMCLKREQEN is used to enable or disable SMCLK requests. When SMCLKOFF = 0 and in AM, LPM0, or LPM1, it is a don't care, because SMCLK is always on in these cases. For SMCLKOFF = 0 and in LPM2, LPM3, and LPM4, SMCLKREQEN can be used to enable or disable SMCLK requests, because SMCLK is normally off in these modes. When SMCLKOFF = 1, SMCLKREQEN can be used to enable or disable SMCLK requests, because SMCLK is normally off in all power modes under this condition. This is summarized in [Table 3-2](#).

**Table 3-2. System Clocks, Power Modes, and Clock Requests**

| Mode   | System Clocks                     |                                   |                                   |                                   |                                    |                                    |                                    |                                    |
|--------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|
|        | MCLK                              |                                   | ACLK                              |                                   | SMCLK                              |                                    |                                    |                                    |
|        | MCLKREQEN = 0 and Clock Requested | MCLKREQEN = 1 and Clock Requested | ACLKREQEN = 0 and Clock Requested | ACLKREQEN = 1 and Clock Requested | SMCLKREQEN = 0 and Clock Requested | SMCLKREQEN = 1 and Clock Requested | SMCLKREQEN = 0 and Clock Requested | SMCLKREQEN = 1 and Clock Requested |
| AM     | Active                            | Active                            | Active                            | Active                            | Active                             | Active                             | Disabled                           | Active                             |
| LPM0   | Disabled                          | Active                            | Active                            | Active                            | Active                             | Active                             | Disabled                           | Active                             |
| LPM1   | Disabled                          | Active                            | Active                            | Active                            | Active                             | Active                             | Disabled                           | Active                             |
| LPM2   | Disabled                          | Active                            | Active                            | Active                            | Disabled                           | Active                             | Disabled                           | Active                             |
| LPM3   | Disabled                          | Active                            | Active                            | Active                            | Disabled                           | Active                             | Disabled                           | Active                             |
| LPM4   | Disabled                          | Active                            | Disabled                          | Active                            | Disabled                           | Active                             | Disabled                           | Active                             |
| LPM3.5 | Disabled                          | Disabled                          | Disabled <sup>(1)</sup>           | Disabled                          | Disabled                           | Disabled                           | Disabled                           | Disabled                           |
| LPM4.5 | Disabled                          | Disabled                          | Disabled                          | Disabled                          | Disabled                           | Disabled                           | Disabled                           | Disabled                           |

<sup>(1)</sup> LFXTCLK is available directly as the clock source to the RTC module.

### 3.2.8 CS Module Fail-Safe Operation

The CS module incorporates an oscillator-fault fail-safe feature. This feature detects an oscillator fault for LFXT and HFXT as shown in [Figure 3-3](#). The available fault conditions are:

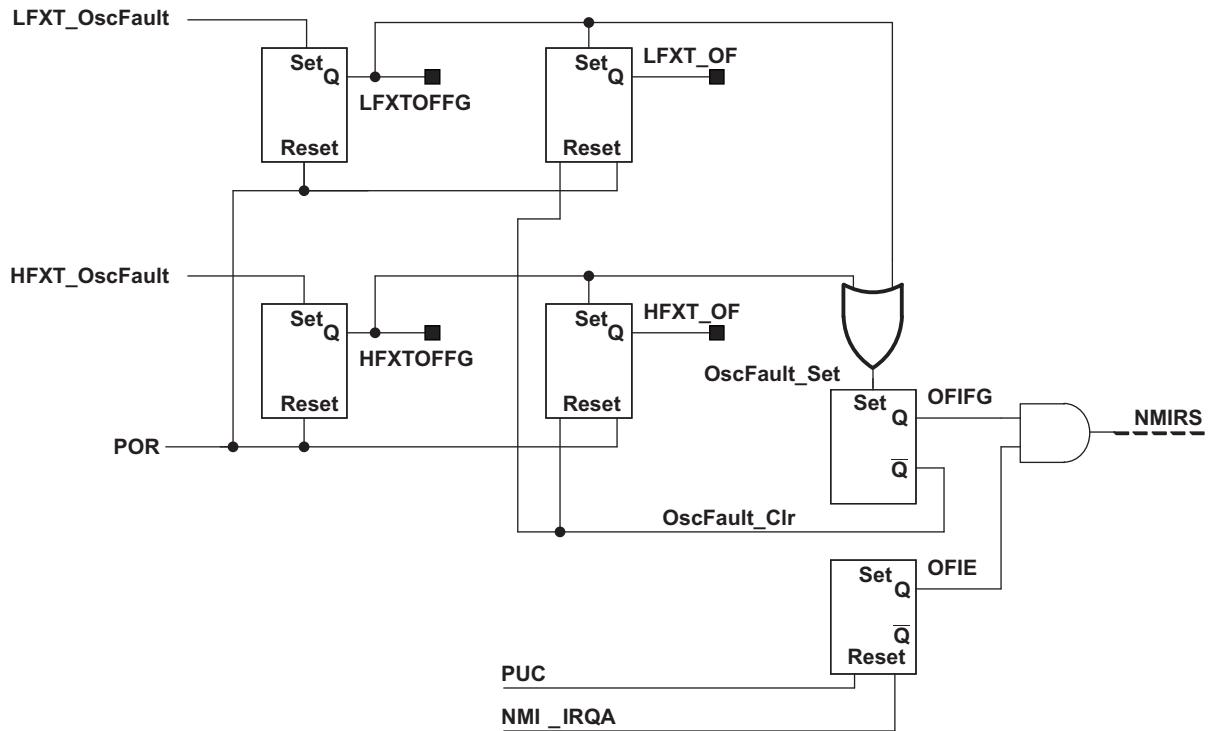
- Low-frequency oscillator fault (LFXTOFFG) for LFXT
- High-frequency oscillator fault (HFXTTOFFG) for HFXT
- External clock signal faults for all bypass modes; that is, LFXTBYPASS = 1 or HFXTBYPASS = 1

The crystal oscillator fault bits LFXTOFFG and HFXTTOFFG are set if the corresponding crystal oscillator is turned on and not operating properly. Once set, the fault bits remain set until reset in software, even if the fault condition no longer exists. If the user clears the fault bits and the fault condition still exists, the fault bits are automatically set; otherwise, they remain cleared.

The OFIFG oscillator-fault interrupt flag is set and latched at POR or when any oscillator fault (LFXTOFFG or HFXTTOFFG) is detected. When OFIFG is set and OFIE is set, the OFIFG requests a user NMI. When the interrupt is granted, the OFIE is not reset automatically as it is in previous MSP430 families. It is no longer required to reset the OFIE. NMI entry and exit circuitry removes this requirement. The OFIFG flag must be cleared by software. The source of the fault can be identified by checking the individual fault bits.

If LFXT is sourcing any system clock (ACLK, MCLK, or SMCLK) and a fault is detected, the system clock is automatically switched to LFMODCLK for its clock source. The LFXT fault logic works in all power modes, including LPM3.5. Similarly, if HFXT is sourcing MCLK or SMCLK, and a fault is detected, the system clock is automatically switched to MODCLK for its clock source. By default, the HFXT fault logic works in all power modes except LPM3.5 or LPM4.5, because high-frequency operation in these modes is not supported. The fail-safe logic does not change the respective SELA, SELM, and SELS bit settings.

The fail-safe mechanism behaves the same in normal and bypass modes. Reconfigure the CS settings and follow the instructions in [Section 1.4.3](#) after wakeup from LPM3.5 or LPM4.5, because all CS registers are reset to default values.



**Figure 3-3. Oscillator Fault Logic**

---

**NOTE: Fault conditions**

**LFXT\_OscFault:** When the fault detection logic is enabled ( $\text{ENLFXTD} = 1$ ), this signal is set after the LFXT oscillator has stopped operation and is cleared after operation resumes. The fault condition causes  $\text{LFXTOFFG}$  to be set and remain set. If the user clears  $\text{LFXTOFFG}$  and the fault condition still exists,  $\text{LFXTOFFG}$  remains set.

**HFXT\_OscFault:** When the fault detection logic is enabled ( $\text{ENHFXTD} = 1$ ), this signal is set after the HFXT oscillator has stopped operation and is cleared after operation resumes. The fault condition causes  $\text{HFXTOFFG}$  to be set and remain set. If the user clears  $\text{HFXTOFFG}$  and the fault condition still exists,  $\text{HFXTOFFG}$  remains set.

---

**NOTE: Fault logic**

As long as a fault condition still exists, the  $\text{OFIFG}$  remains set. The application must take special care when clearing the  $\text{OFIFG}$  signal. If no fault condition remains when the  $\text{OFIFG}$  signal is cleared, the clock logic switches back to the original user settings before the fault condition.

---

**NOTE:** The LFXT startup includes a counter that ensures that 1024 valid clock cycles have passed before  $\text{LFXT}_\text{OscFault}$  signal is cleared. A valid cycle is any cycle that meets the frequency requirement ( $f_{\text{Fault,LF}}$ ) as outlined in the device specific data sheet. Any crystal fault restarts the counter. It is recommended that the counter always be enabled, however the counter can be disabled by clearing  $\text{ENSTFCNT1}$ .

Similarly, HFXT startup also includes a counter that ensures that 1024 valid clock cycles have passed before  $\text{HFXT}_\text{OscFault}$  signal is cleared. This counter can be disabled by clearing  $\text{ENSTFCNT2}$ .

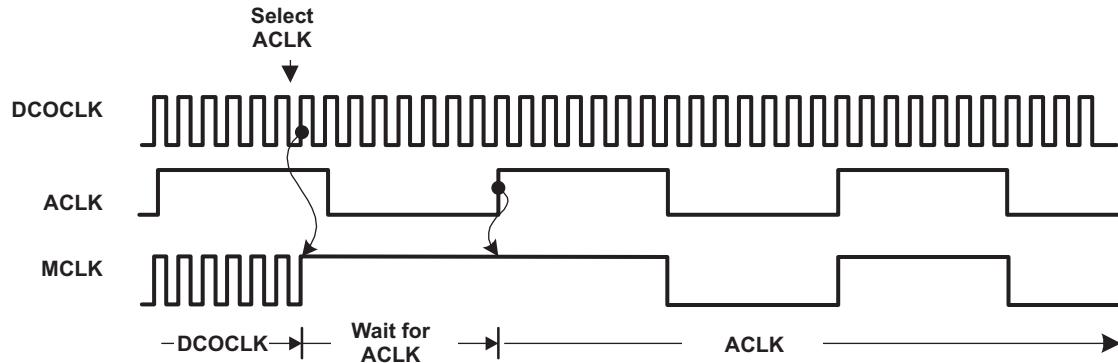
The disabling of the counters is valid for bypass and normal modes of operation.

---

### 3.2.9 Synchronization of Clock Signals

When switching ACLK, MCLK, or SMCLK from one clock source to the another, the switch is synchronized to avoid critical race conditions (see [Figure 3-4](#)):

- The current clock cycle continues until the next rising edge.
- The clock remains high until the next rising edge of the new clock.
- The new clock source is selected and continues with a full high period.



**Figure 3-4. Switch MCLK From DCOCLK to LFXTCLK**

### 3.3 CS Registers

The CS module registers are listed in [Table 3-3](#). The base address can be found in the device-specific data sheet.

The password defined in CSCTL0 controls access to the CS registers. After the correct password is written, the write access to the CS registers is enabled. Write access is disabled by writing an incorrect password in byte mode to the CSCTL0 upper byte.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 3-3. CS Registers**

| Offset | Acronym  | Register Name          | Type       | Access | Reset | Section                       |
|--------|----------|------------------------|------------|--------|-------|-------------------------------|
| 00h    | CSCTL0   | Clock System Control 0 | Read/write | Word   | 9600h | <a href="#">Section 3.3.1</a> |
| 00h    | CSCTL0_L |                        | Read/write | Byte   | 00h   |                               |
| 01h    | CSCTL0_H |                        | Read/write | Byte   | 96h   |                               |
| 02h    | CSCTL1   | Clock System Control 1 | Read/write | Word   | 000Ch | <a href="#">Section 3.3.2</a> |
| 02h    | CSCTL1_L |                        | Read/write | Byte   | 0Ch   |                               |
| 03h    | CSCTL1_H |                        | Read/write | Byte   | 00h   |                               |
| 04h    | CSCTL2   | Clock System Control 2 | Read/write | Word   | 0033h | <a href="#">Section 3.3.3</a> |
| 04h    | CSCTL2_L |                        | Read/write | Byte   | 33h   |                               |
| 05h    | CSCTL2_H |                        | Read/write | Byte   | 00h   |                               |
| 06h    | CSCTL3   | Clock System Control 3 | Read/write | Word   | 0033h | <a href="#">Section 3.3.4</a> |
| 06h    | CSCTL3_L |                        | Read/write | Byte   | 33h   |                               |
| 07h    | CSCTL3_H |                        | Read/write | Byte   | 00h   |                               |
| 08h    | CSCTL4   | Clock System Control 4 | Read/write | Word   | CDC9h | <a href="#">Section 3.3.5</a> |
| 08h    | CSCTL4_L |                        | Read/write | Byte   | C9h   |                               |
| 09h    | CSCTL4_H |                        | Read/write | Byte   | CDh   |                               |
| 0Ah    | CSCTL5   | Clock System Control 5 | Read/write | Word   | 00C0h | <a href="#">Section 3.3.6</a> |
| 0Ah    | CSCTL5_L |                        | Read/write | Byte   | C0h   |                               |
| 0Bh    | CSCTL5_H |                        | Read/write | Byte   | 00h   |                               |
| 0Ch    | CSCTL6   | Clock System Control 6 | Read/write | Word   | 0007h | <a href="#">Section 3.3.7</a> |
| 0Ch    | CSCTL6_L |                        | Read/write | Byte   | 07h   |                               |
| 0Dh    | CSCTL6_H |                        | Read/write | Byte   | 00h   |                               |

### 3.3.1 CSCTL0 Register

Clock System Control 0 Register

**Figure 3-5. CSCTL0 Register**

|          |      |      |      |      |      |      |      |
|----------|------|------|------|------|------|------|------|
| 15       | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| CSKEY    |      |      |      |      |      |      |      |
| rw-1     | rw-0 | rw-0 | rw-1 | rw-0 | rw-1 | rw-1 | rw-0 |
| 7        | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
| Reserved |      |      |      |      |      |      |      |
| r0       | r0   | r0   | r0   | r0   | r0   | r0   | r0   |

**Table 3-4. CSCTL0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | CSKEY    | RW   | 96h   | CSKEY password. Must always be written with A5h; a PUC is generated if any other value is written. Always reads as 96h. After the correct password is written, all CS registers are available for writing. |
| 7-0  | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                               |

### 3.3.2 CSCTL1 Register

Clock System Control 1 Register

**Figure 3-6. CSCTL1 Register**

|          |         |          |    |        |         |        |          |
|----------|---------|----------|----|--------|---------|--------|----------|
| 15       | 14      | 13       | 12 | 11     | 10      | 9      | 8        |
| Reserved |         |          |    |        |         |        |          |
| r0       | r0      | r0       | r0 | r0     | r0      | r0     | r0       |
| 7        | 6       | 5        | 4  | 3      | 2       | 1      | 0        |
| Reserved | DCORSEL | Reserved |    |        | DCOFSEL |        | Reserved |
| r0       | rw-[0]  | r0       | r0 | rw-[1] | rw-[1]  | rw-[0] | r0       |

**Table 3-5. CSCTL1 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-7 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 6    | DCORSEL  | RW   | 0h    | DCO range select. For high-speed devices, this bit can be written by the user. For low-speed devices, it is always 0. See description of DCOFSEL bit for details.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 5-4  | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 3-1  | DCOFSEL  | RW   | 6h    | DCO frequency select. Selects frequency settings for the DCO. Values shown below are approximate. Refer to the device-specific data sheet.<br>000b = If DCORSEL = 0: 1 MHz; If DCORSEL = 1: 1 MHz<br>001b = If DCORSEL = 0: 2.67 MHz; If DCORSEL = 1: 5.33 MHz<br>010b = If DCORSEL = 0: 3.5 MHz; If DCORSEL = 1: 7 MHz<br>011b = If DCORSEL = 0: 4 MHz; If DCORSEL = 1: 8 MHz<br>100b = If DCORSEL = 0: 5.33 MHz; If DCORSEL = 1: 16 MHz<br>101b = If DCORSEL = 0: 7 MHz; If DCORSEL = 1: 21 MHz<br>110b = If DCORSEL = 0: 8 MHz; If DCORSEL = 1: 24 MHz<br>111b = If DCORSEL = 0: Reserved. Defaults to 8 MHz. It is not recommended to use this setting; If DCORSEL = 1: Reserved. Defaults to 24 MHz. It is not recommended to use this setting |
| 0    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

### 3.3.3 CSCTL2 Register

Clock System Control 2 Register

**Figure 3-7. CSCTL2 Register**

|          |      |      |      |          |      |      |      |
|----------|------|------|------|----------|------|------|------|
| 15       | 14   | 13   | 12   | 11       | 10   | 9    | 8    |
| Reserved |      |      |      |          |      | SELA |      |
| r0       | r0   | r0   | r0   | r0       | rw-0 | rw-0 | rw-0 |
| 7        | 6    | 5    | 4    | 3        | 2    | 1    | 0    |
| Reserved | SELS |      |      | Reserved | SELM |      |      |
| r0       | rw-0 | rw-1 | rw-1 | r0       | rw-0 | rw-1 | rw-1 |

**Table 3-6. CSCTL2 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 10-8  | SELA     | RW   | 0h    | Selects the ACLK source<br>000b = LFXTCLK when LFXT available, otherwise VLOCLK.<br>001b = VLOCLK<br>010b = LFMODCLK<br>011b = Reserved. Defaults to LFMODCLK. Not recommended for use to ensure future compatibility.<br>100b = Reserved. Defaults to LFMODCLK. Not recommended for use to ensure future compatibility.<br>101b = Reserved. Defaults to LFMODCLK. Not recommended for use to ensure future compatibility.<br>110b = Reserved. Defaults to LFMODCLK. Not recommended for use to ensure future compatibility.<br>111b = Reserved. Defaults to LFMODCLK. Not recommended for use to ensure future compatibility. |
| 7     | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 6-4   | SELS     | RW   | 3h    | Selects the SMCLK source<br>000b = LFXTCLK when LFXT available, otherwise VLOCLK.<br>001b = VLOCLK<br>010b = LFMODCLK<br>011b = DCOCLK<br>100b = MODCLK<br>101b = HFXTCLK when HFXT available, otherwise DCOCLK.<br>110b = Reserved. Defaults to HFXTCLK. Not recommended for use to ensure future compatibility.<br>111b = Reserved. Defaults to HFXTCLK. Not recommended for use to ensure future compatibility.                                                                                                                                                                                                             |
| 3     | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 2-0   | SELM     | RW   | 3h    | Selects the MCLK source<br>000b = LFXTCLK when LFXT available, otherwise VLOCLK<br>001b = VLOCLK<br>010b = LFMODCLK<br>011b = DCOCLK<br>100b = MODCLK<br>101b = HFXTCLK when HFXT available, otherwise DCOCLK<br>110b = Reserved. Defaults to HFXTCLK. Not recommended for use to ensure future compatibility.<br>111b = Reserved. Defaults to HFXTCLK. Not recommended for use to ensure future compatibility.                                                                                                                                                                                                                |

### 3.3.4 CSCTL3 Register

Clock System Control 3 Register

**Figure 3-8. CSCTL3 Register**

|          |      |      |      |    |          |      |      |
|----------|------|------|------|----|----------|------|------|
| 15       | 14   | 13   | 12   | 11 | 10       | 9    | 8    |
| Reserved |      |      |      |    |          | DIVA |      |
| r0       | r0   | r0   | r0   | r0 | rw-0     | rw-0 | rw-0 |
| 7        | 6    | 5    | 4    | 3  | 2        | 1    | 0    |
| Reserved |      | DIVS |      |    | Reserved | DIVM |      |
| r0       | rw-0 | rw-1 | rw-1 | r0 | rw-0     | rw-1 | rw-1 |

**Table 3-7. CSCTL3 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                      |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                     |
| 10-8  | DIVA     | RW   | 0h    | ACLK source divider. Divides the frequency of the ACLK clock source.<br>000b = /1<br>001b = /2<br>010b = /4<br>011b = /8<br>100b = /16<br>101b = /32<br>110b = Reserved. Defaults to /32. Not recommended for use to ensure future compatibility.<br>111b = Reserved. Defaults to /32. Not recommended for use to ensure future compatibility.   |
| 7     | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                     |
| 6-4   | DIVS     | RW   | 3h    | SMCLK source divider. Divides the frequency of the SMCLK clock source.<br>000b = /1<br>001b = /2<br>010b = /4<br>011b = /8<br>100b = /16<br>101b = /32<br>110b = Reserved. Defaults to /32. Not recommended for use to ensure future compatibility.<br>111b = Reserved. Defaults to /32. Not recommended for use to ensure future compatibility. |
| 3     | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                     |
| 2-0   | DIVM     | RW   | 3h    | MCLK source divider. Divides the frequency of the MCLK clock source.<br>000b = /1<br>001b = /2<br>010b = /4<br>011b = /8<br>100b = /16<br>101b = /32<br>110b = Reserved. Defaults to /32. Not recommended for use to ensure future compatibility.<br>111b = Reserved. Defaults to /32. Not recommended for use to ensure future compatibility.   |

### 3.3.5 CSCTL4 Register

Clock System Control 4 Register

**Figure 3-9. CSCTL4 Register**

| 15        | 14       | 13         | 12     | 11       | 10       | 9       | 8    |
|-----------|----------|------------|--------|----------|----------|---------|------|
| HFXTDRIVE | Reserved | HFXTBYPASS |        | HFFREQ   | Reserved | HFXTOFF |      |
| rw-1      | rw-1     | r0         | rw-0   | rw-1     | rw-1     | r0      | rw-1 |
| 7         | 6        | 5          | 4      | 3        | 2        | 1       | 0    |
| LFXTDRIVE | Reserved | LFXTBYPASS | VLOOFF | Reserved | SMCLKOFF | LFXTOFF |      |
| rw-1      | rw-1     | rw-0       | rw-0   | rw-1     | r0       | rw-0    | rw-1 |

**Table 3-8. CSCTL4 Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                 |
|-------|------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | HFXTDRIVE  | RW   | 3h    | The HFXT oscillator current can be adjusted to its drive needs. This in combination with the HFFREQ bits can be used for optimizing crystal power based on crystal characteristics.<br>00b = Lowest current consumption<br>01b = Increased drive strength HFXT oscillator<br>10b = Increased drive strength HFXT oscillator<br>11b = Maximum drive strength HFXT oscillator |
| 13    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                |
| 12    | HFXTBYPASS | RW   | 0h    | HFXT bypass select<br>0b = HFXT sourced from external crystal<br>1b = HFXT sourced from external clock signal                                                                                                                                                                                                                                                               |
| 11-10 | HFFREQ     | RW   | 3h    | The HFXT frequency selection. These bits must be set to the appropriate frequency for crystal or bypass modes of operation.<br>00b = 0 to 4 MHz<br>01b = Greater than 4 MHz to 8 MHz<br>10b = Greater than 8 MHz to 16 MHz<br>11b = Greater than 16 MHz to 24 MHz                                                                                                           |
| 9     | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                |
| 8     | HFXTOFF    | RW   | 1h    | Turns off the HFXT oscillator<br>0b = HFXT is on if HFXT is selected through the port selection and HFXT is not in bypass mode of operation<br>1b = HFXT is off if it is not used as a source for ACLK, MCLK, or SMCLK                                                                                                                                                      |
| 7-6   | LFXTDRIVE  | RW   | 3h    | The LFXT oscillator current can be adjusted to its drive needs.<br>00b = Lowest drive strength and current consumption LFXT oscillator<br>01b = Increased drive strength LFXT oscillator<br>10b = Increased drive strength LFXT oscillator<br>11b = Maximum drive strength and maximum current consumption LFXT oscillator                                                  |
| 5     | Reserved   | RW   | 0h    | Reserved. Must be written as zero.                                                                                                                                                                                                                                                                                                                                          |
| 4     | LFXTBYPASS | RW   | 0h    | LFXT bypass select<br>0b = LFXT sourced from external crystal<br>1b = LFXT sourced from external clock signal                                                                                                                                                                                                                                                               |
| 3     | VLOOFF     | RW   | 1h    | VLO off. This bit turns off the VLO.<br>0b = VLO is on<br>1b = VLO is off if it is not used as a source for ACLK, MCLK, or SMCLK or if not used as a source for the RTC in LPM3.5                                                                                                                                                                                           |
| 2     | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                |
| 1     | SMCLKOFF   | RW   | 0h    | SMCLK off. This bit turns off the SMCLK.<br>0b = SMCLK on<br>1b = SMCLK off                                                                                                                                                                                                                                                                                                 |

**Table 3-8. CSCTL4 Register Description (continued)**

| Bit | Field   | Type | Reset | Description                                                                                                                                                                                                                     |
|-----|---------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0   | LFXTOFF | RW   | 1h    | LFXT off. This bit turns off the LFXT.<br>0b = LFXT is on if LFXT is selected through the port selection and LFXT is not in bypass mode of operation<br>1b = LFXT is off if it is not used as a source for ACLK, MCLK, or SMCLK |

### 3.3.6 CSCTL5 Register

Clock System Control 5 Register

**Figure 3-10. CSCTL5 Register**

|           |           |    |          |    |    |          |          |
|-----------|-----------|----|----------|----|----|----------|----------|
| 15        | 14        | 13 | 12       | 11 | 10 | 9        | 8        |
| Reserved  |           |    |          |    |    |          |          |
| r0        | r0        | 0  | r0       | r0 | r0 | r0       | r0       |
| 7         | 6         | 5  | 4        | 3  | 2  | 1        | 0        |
| ENSTFCNT2 | ENSTFCNT1 |    | Reserved |    |    | HFXTOFFG | LFXTOFFG |
| rw-(1)    | rw-(1)    | r0 | r0       | r0 | r0 | rw-(0)   | rw-(1)   |

**Table 3-9. CSCTL5 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                  |
|------|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                 |
| 7    | ENSTFCNT2 | RW   | 1h    | Enable start counter for HFXT when available.<br>0b = Startup fault counter disabled. Counter is cleared.<br>1b = Startup fault counter enabled                                                                                                                                                                                                              |
| 6    | ENSTFCNT1 | RW   | 1h    | Enable start counter for LFXT.<br>0b = Startup fault counter disabled. Counter is cleared.<br>1b = Startup fault counter enabled                                                                                                                                                                                                                             |
| 5-2  | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                 |
| 1    | HFXTOFFG  | RW   | 0h    | HFXT oscillator fault flag. If this bit is set, the OFIFG flag is also set. HFXTOFFG is set if a HFXT fault condition exists. HFXTOFFG can be cleared through software. If the HFXT fault condition still remains, HFXTOFFG is set.<br>0b = No fault condition occurred after the last reset<br>1b = HFXT fault; an HFXT fault occurred after the last reset |
| 0    | LFXTOFFG  | RW   | 1h    | LFXT oscillator fault flag. If this bit is set, the OFIFG flag is also set. LFXTOFFG is set if a LFXT fault condition exists. LFXTOFFG can be cleared through software. If the LFXT fault condition still remains, LFXTOFFG is set.<br>0b = No fault condition occurred after the last reset<br>1b = LFXT fault; an LFXT fault occurred after the last reset |

### 3.3.7 CSCTL6 Register

Clock System Control 6 Register

**Figure 3-11. CSCTL6 Register**

|          |    |    |    |             |            |           |           |
|----------|----|----|----|-------------|------------|-----------|-----------|
| 15       | 14 | 13 | 12 | 11          | 10         | 9         | 8         |
| Reserved |    |    |    |             |            |           |           |
| r0       | r0 | r0 | r0 | r0          | r0         | r0        | r0        |
| 7        | 6  | 5  | 4  | 3           | 2          | 1         | 0         |
| Reserved |    |    |    | MODCLKREQEN | SMCLKREQEN | MCLKREQEN | ACLKREQEN |
| r0       | r0 | r0 | r0 | rw-(0)      | rw-(1)     | rw-(1)    | rw-(1)    |

**Table 3-10. CSCTL6 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                |
|------|-------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | Reserved    | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                               |
| 3    | MODCLKREQEN | RW   | 0h    | MODCLK clock request enable. Setting this enables conditional module requests for MODCLK.<br>0b = MODCLK conditional requests are disabled<br>1b = MODCLK conditional requests are enabled |
| 2    | SMCLKREQEN  | RW   | 1h    | SMCLK clock request enable. Setting this enables conditional module requests for SMCLK.<br>0b = SMCLK conditional requests are disabled<br>1b = SMCLK conditional requests are enabled     |
| 1    | MCLKREQEN   | RW   | 1h    | MCLK clock request enable. Setting this enables conditional module requests for MCLK.<br>0b = MCLK conditional requests are disabled<br>1b = MCLK conditional requests are enabled         |
| 0    | ACLKREQEN   | RW   | 1h    | ACLK clock request enable. Setting this enables conditional module requests for ACLK.<br>0b = ACLK conditional requests are disabled<br>1b = ACLK conditional requests are enabled         |

This chapter describes the extended MSP430X 16-bit RISC CPU (CPUX) with 1MB memory access, its addressing modes, and instruction set.

---

**NOTE:** The MSP430X CPUX implemented on this device family, formally called CPUXV2, has in some cases, slightly different cycle counts from the MSP430X CPUX implemented on the 2xx and 4xx families.

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| Topic                                     | Page |
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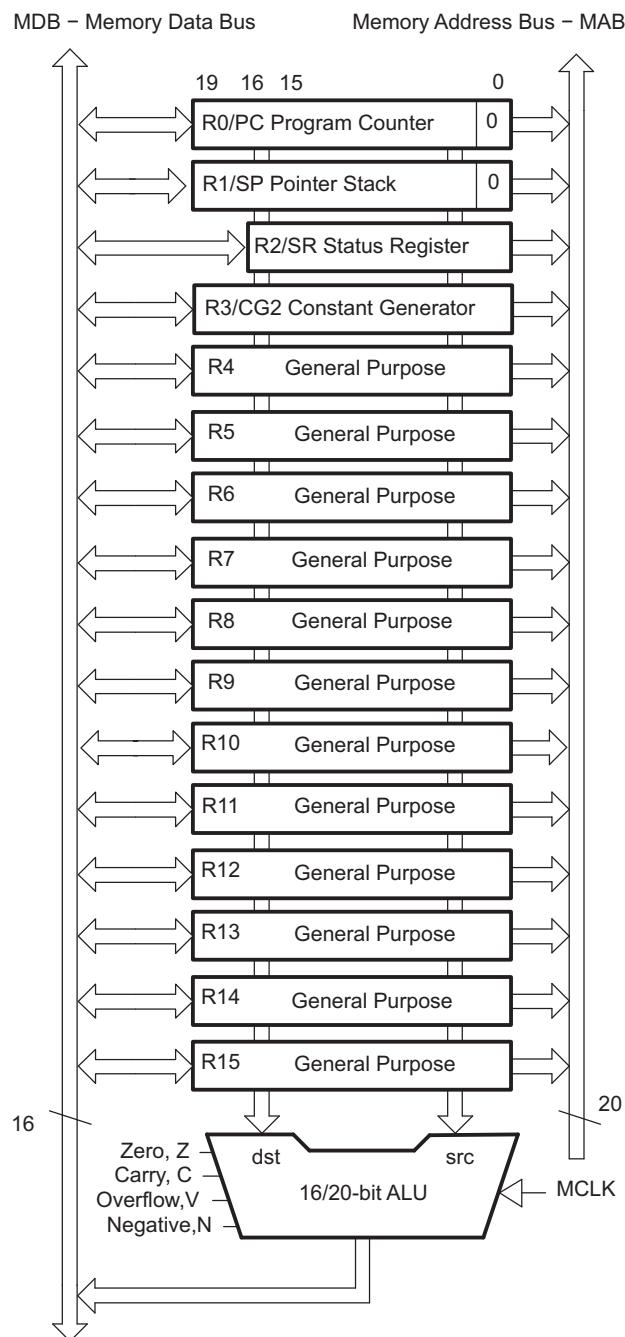
## 4.1 MSP430X CPU (CPUX) Introduction

The MSP430X CPU incorporates features specifically designed for modern programming techniques, such as calculated branching, table processing, and the use of high-level languages such as C. The MSP430X CPU can address a 1MB address range without paging. The MSP430X CPU is completely backward compatible with the MSP430 CPU.

The MSP430X CPU features include:

- RISC architecture
- Orthogonal architecture
- Full register access including program counter (PC), status register (SR), and stack pointer (SP)
- Single-cycle register operations
- Large register file reduces fetches to memory.
- 20-bit address bus allows direct access and branching throughout the entire memory range without paging.
- 16-bit data bus allows direct manipulation of word-wide arguments.
- Constant generator provides the six most often used immediate values and reduces code size.
- Direct memory-to-memory transfers without intermediate register holding
- Byte, word, and 20-bit address-word addressing

The block diagram of the MSP430X CPU is shown in [Figure 4-1](#).



**Figure 4-1. MSP430X CPU Block Diagram**

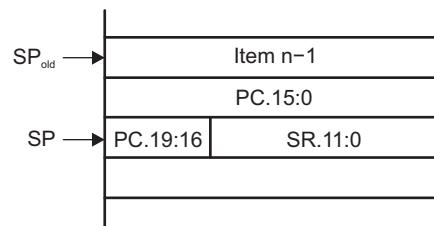
## 4.2 Interrupts

The MSP430X has the following interrupt structure:

- Vectored interrupts with no polling necessary
- Interrupt vectors are located downward from address 0FFEh.

The interrupt vectors contain 16-bit addresses that point into the lower 64KB memory. This means all interrupt handlers must start in the lower 64KB memory.

During an interrupt, the program counter (PC) and the status register (SR) are pushed onto the stack as shown in [Figure 4-2](#). The MSP430X architecture stores the complete 20-bit PC value efficiently by appending the PC bits 19:16 to the stored SR value automatically on the stack. When the RETI instruction is executed, the full 20-bit PC is restored making return from interrupt to any address in the memory range possible.



**Figure 4-2. PC Storage on the Stack for Interrupts**

## 4.3 CPU Registers

The CPU incorporates 16 registers (R0 through R15). Registers R0, R1, R2, and R3 have dedicated functions. Registers R4 through R15 are working registers for general use.

### 4.3.1 Program Counter (PC)

The 20-bit Program Counter (PC, also called R0) points to the next instruction to be executed. Each instruction uses an even number of bytes (2, 4, 6, or 8 bytes), and the PC is incremented accordingly. Instruction accesses are performed on word boundaries, and the PC is aligned to even addresses. [Figure 4-3](#) shows the PC.



**Figure 4-3. Program Counter**

The PC can be addressed with all instructions and addressing modes. A few examples:

```

MOV.W #LABEL,PC ; Branch to address LABEL (lower 64KB)

MOVA #LABEL,PC ; Branch to address LABEL (1MB memory)

MOV.W LABEL,PC ; Branch to address in word LABEL
; (lower 64KB)

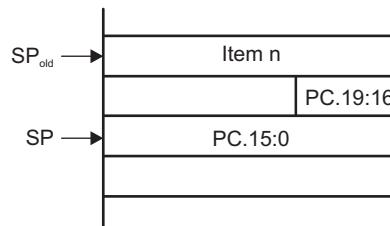
MOV.W @R14,PC ; Branch indirect to address in
; R14 (lower 64KB)

ADDA #4,PC ; Skip two words (1MB memory)

```

The BR and CALL instructions reset the upper four PC bits to 0. Only addresses in the lower 64KB address range can be reached with the BR or CALL instruction. When branching or calling, addresses beyond the lower 64KB range can only be reached using the BRA or CALLA instructions. Also, any instruction to directly modify the PC does so according to the used addressing mode. For example, MOV.W #value,PC clears the upper four bits of the PC, because it is a .W instruction.

The PC is automatically stored on the stack with CALL (or CALLA) instructions and during an interrupt service routine. [Figure 4-4](#) shows the storage of the PC with the return address after a CALLA instruction. A CALL instruction stores only bits 15:0 of the PC.



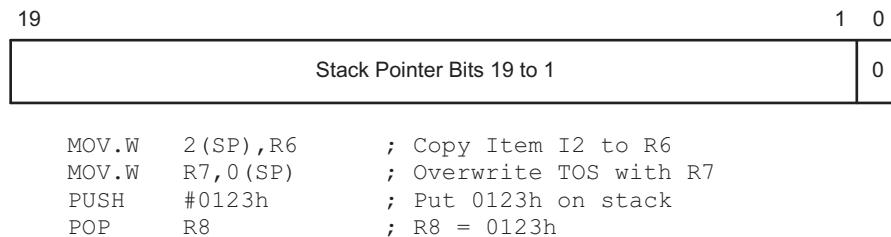
**Figure 4-4. PC Storage on the Stack for CALLA**

The RETA instruction restores bits 19:0 of the PC and adds 4 to the stack pointer (SP). The RET instruction restores bits 15:0 to the PC and adds 2 to the SP.

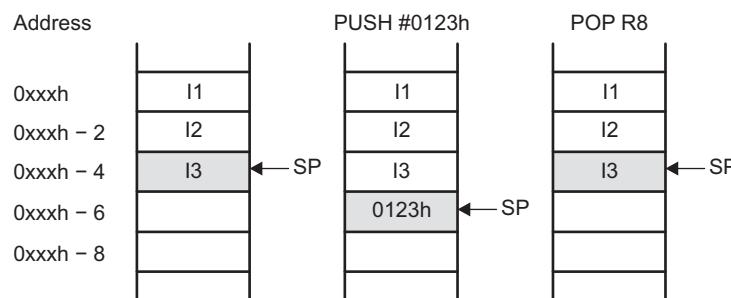
### 4.3.2 Stack Pointer (SP)

The 20-bit Stack Pointer (SP, also called R1) is used by the CPU to store the return addresses of subroutine calls and interrupts. It uses a predecrement, postincrement scheme. In addition, the SP can be used by software with all instructions and addressing modes. [Figure 4-5](#) shows the SP. The SP is initialized into RAM by the user, and is always aligned to even addresses.

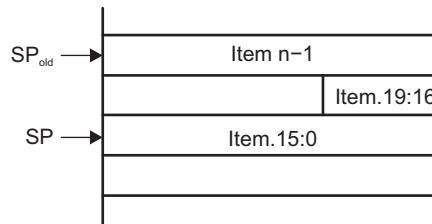
Figure 4-6 shows the stack usage. Figure 4-7 shows the stack usage when 20-bit address words are pushed.



**Figure 4-5. Stack Pointer**



**Figure 4-6. Stack Usage**



**Figure 4-7. PUSHX.A Format on the Stack**

The special cases of using the SP as an argument to the PUSH and POP instructions are described and shown in Figure 4-8.



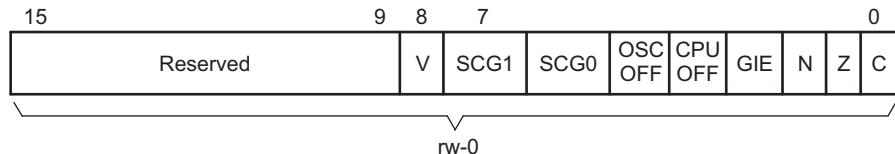
The stack pointer is changed after a PUSH SP instruction.

The stack pointer is not changed after a POP SP instruction. The POP SP instruction places SP1 into the stack pointer SP ( $SP_2 = SP_1$ )

**Figure 4-8. PUSH SP, POP SP Sequence**

### 4.3.3 Status Register (SR)

The 16-bit Status Register (SR, also called R2), used as a source or destination register, can only be used in register mode addressed with word instructions. The remaining combinations of addressing modes are used to support the constant generator. [Figure 4-9](#) shows the SR bits. Do not write 20-bit values to the SR. Unpredictable operation can result.



**Figure 4-9. SR Bits**

[Table 4-1](#) describes the SR bits.

**Table 4-1. SR Bit Description**

| Bit      | Description                                                                                                                                                                                       |                                                                                                  |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Reserved | Reserved                                                                                                                                                                                          |                                                                                                  |
| V        | Overflow. This bit is set when the result of an arithmetic operation overflows the signed-variable range.<br><br>ADD(.B), ADDX(.B,.A),<br>ADDC(.B), ADDCX(.B.A),<br>ADDA                          | Set when:<br>positive + positive = negative<br>negative + negative = positive<br>otherwise reset |
|          | SUB(.B), SUBX(.B,.A),<br>SUBC(.B), SUBCX(.B,.A),<br>SUBA, CMP(.B),<br>CMPX(.B,.A), CMPA                                                                                                           | Set when:<br>positive - negative = negative<br>negative - positive = positive<br>otherwise reset |
| SCG1     | System clock generator 1. This bit may be used to enable or disable functions in the clock system depending on the device family; for example, DCO bias enable or disable.                        |                                                                                                  |
| SCG0     | System clock generator 0. This bit may be used to enable or disable functions in the clock system depending on the device family; for example, FLL enable or disable.                             |                                                                                                  |
| OSCOFF   | Oscillator off. When this bit is set, it turns off the LFXT1 crystal oscillator when LFXT1CLK is not used for MCLK or SMCLK. In FRAM devices, CPUOFF must be 1 to disable the crystal oscillator. |                                                                                                  |
| CPUOFF   | CPU off. When this bit is set, it turns off the CPU and requests a low-power mode according to the settings of bits OSCOFF, SCG0, and SCG1.                                                       |                                                                                                  |
| GIE      | General interrupt enable. When this bit is set, it enables maskable interrupts. When it is reset, all maskable interrupts are disabled.                                                           |                                                                                                  |
| N        | Negative. This bit is set when the result of an operation is negative and cleared when the result is positive.                                                                                    |                                                                                                  |
| Z        | Zero. This bit is set when the result of an operation is 0 and cleared when the result is not 0.                                                                                                  |                                                                                                  |
| C        | Carry. This bit is set when the result of an operation produced a carry and cleared when no carry occurred.                                                                                       |                                                                                                  |

---

**NOTE:** Bit manipulations of the SR should be done by the following instructions: MOV, BIS, and BIC.

---

#### 4.3.4 Constant Generator Registers (CG1 and CG2)

Six commonly-used constants are generated with the constant generator registers R2 (CG1) and R3 (CG2), without requiring an additional 16-bit word of program code. The constants are selected with the source register addressing modes (As), as described in [Table 4-2](#).

**Table 4-2. Values of Constant Generators CG1, CG2**

| Register | As | Constant           | Remarks               |
|----------|----|--------------------|-----------------------|
| R2       | 00 | –                  | Register mode         |
| R2       | 01 | (0)                | Absolute address mode |
| R2       | 10 | 00004h             | +4, bit processing    |
| R2       | 11 | 00008h             | +8, bit processing    |
| R3       | 00 | 00000h             | 0, word processing    |
| R3       | 01 | 00001h             | +1                    |
| R3       | 10 | 00002h             | +2, bit processing    |
| R3       | 11 | FFh, FFFFh, FFFFFh | -1, word processing   |

The constant generator advantages are:

- No special instructions required
- No additional code word for the six constants
- No code memory access required to retrieve the constant

The assembler uses the constant generator automatically if one of the six constants is used as an immediate source operand. Registers R2 and R3, used in the constant mode, cannot be addressed explicitly; they act as source-only registers.

##### 4.3.4.1 Constant Generator – Expanded Instruction Set

The RISC instruction set of the MSP430 has only 27 instructions. However, the constant generator allows the MSP430 assembler to support 24 additional emulated instructions. For example, the single-operand instruction:

CLR dst

is emulated by the double-operand instruction with the same length:

MOV R3,dst

where the #0 is replaced by the assembler, and R3 is used with As = 00.

INC dst

is replaced by:

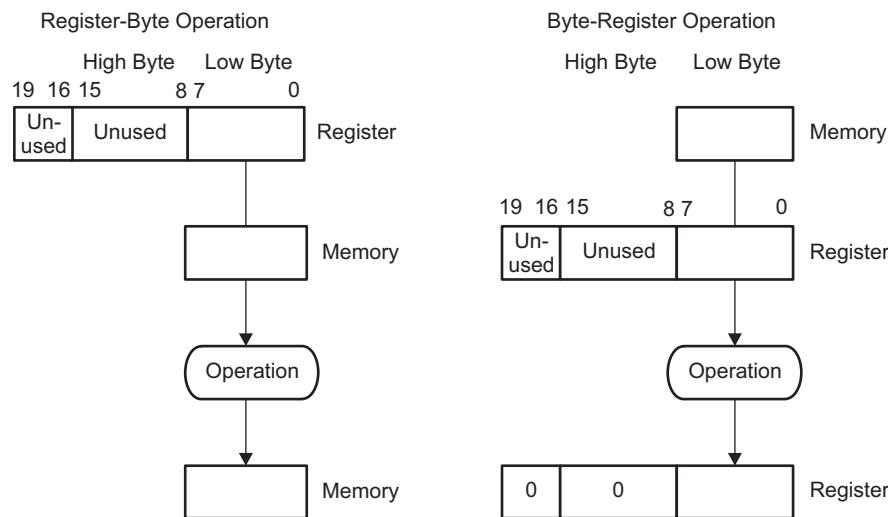
ADD #1,dst

#### 4.3.5 General-Purpose Registers (R4 to R15)

The 12 CPU registers (R4 to R15) contain 8-bit, 16-bit, or 20-bit values. Any byte-write to a CPU register clears bits 19:8. Any word-write to a register clears bits 19:16. The only exception is the SXT instruction. The SXT instruction extends the sign through the complete 20-bit register.

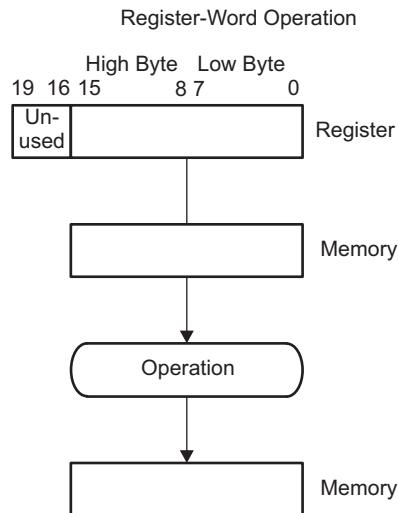
[Figure 4-10](#) through [Figure 4-14](#) show the handling of byte, word, and address-word data. Note the reset of the leading most significant bits (MSBs) if a register is the destination of a byte or word instruction.

[Figure 4-10](#) shows byte handling (8-bit data, .B suffix). The handling is shown for a source register and a destination memory byte and for a source memory byte and a destination register.



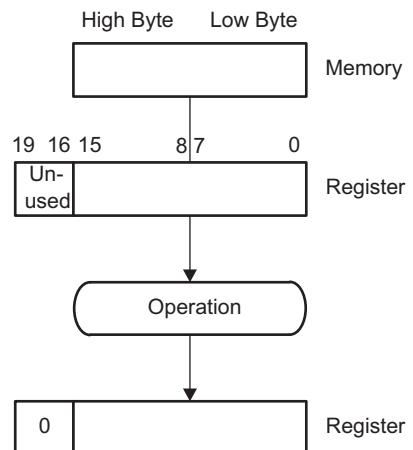
**Figure 4-10. Register-Byte and Byte-Register Operation**

[Figure 4-11](#) and [Figure 4-12](#) show 16-bit word handling (.W suffix). The handling is shown for a source register and a destination memory word and for a source memory word and a destination register.

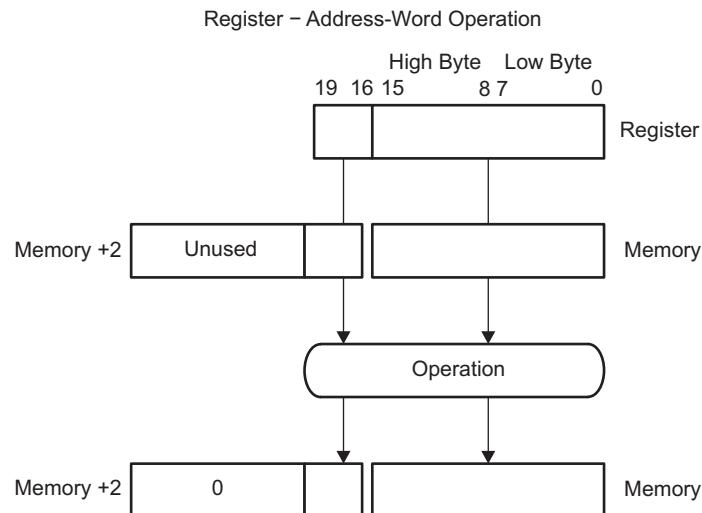


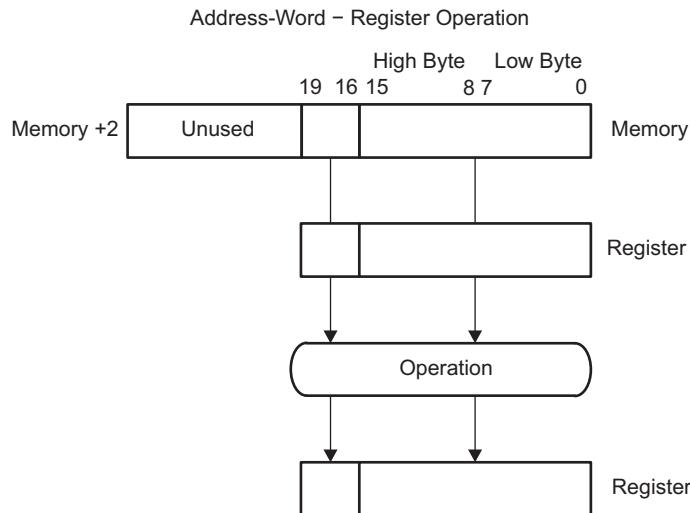
**Figure 4-11. Register-Word Operation**

## Word Register Operation

**Figure 4-12. Word-Register Operation**

[Figure 4-13](#) and [Figure 4-14](#) show 20-bit address-word handling (.A suffix). The handling is shown for a source register and a destination memory address-word and for a source memory address-word and a destination register.

**Figure 4-13. Register – Address-Word Operation**



**Figure 4-14. Address-Word – Register Operation**

#### 4.4 Addressing Modes

Seven addressing modes for the source operand and four addressing modes for the destination operand use 16-bit or 20-bit addresses (see [Table 4-3](#)). The MSP430 and MSP430X instructions are usable throughout the entire 1MB memory range.

**Table 4-3. Source and Destination Addressing**

| As, Ad | Addressing Mode        | Syntax | Description                                                                                                                                                                                             |
|--------|------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 00, 0  | Register               | Rn     | Register contents are operand.                                                                                                                                                                          |
| 01, 1  | Indexed                | X(Rn)  | (Rn + X) points to the operand. X is stored in the next word, or stored in combination of the preceding extension word and the next word.                                                               |
| 01, 1  | Symbolic               | ADDR   | (PC + X) points to the operand. X is stored in the next word, or stored in combination of the preceding extension word and the next word. Indexed mode X(PC) is used.                                   |
| 01, 1  | Absolute               | &ADDR  | The word following the instruction contains the absolute address. X is stored in the next word, or stored in combination of the preceding extension word and the next word. Indexed mode X(SR) is used. |
| 10, –  | Indirect Register      | @Rn    | Rn is used as a pointer to the operand.                                                                                                                                                                 |
| 11, –  | Indirect Autoincrement | @Rn+   | Rn is used as a pointer to the operand. Rn is incremented afterwards by 1 for .B instructions, by 2 for .W instructions, and by 4 for .A instructions.                                                  |
| 11, –  | Immediate              | #N     | N is stored in the next word, or stored in combination of the preceding extension word and the next word. Indirect autoincrement mode @PC+ is used.                                                     |

The seven addressing modes are explained in detail in the following sections. Most of the examples show the same addressing mode for the source and destination, but any valid combination of source and destination addressing modes is possible in an instruction.

---

**NOTE: Use of Labels EDE, TONI, TOM, and LEO**

Throughout MSP430 documentation, EDE, TONI, TOM, and LEO are used as generic labels. They are only labels and have no special meaning.

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#### **4.4.1 Register Mode**

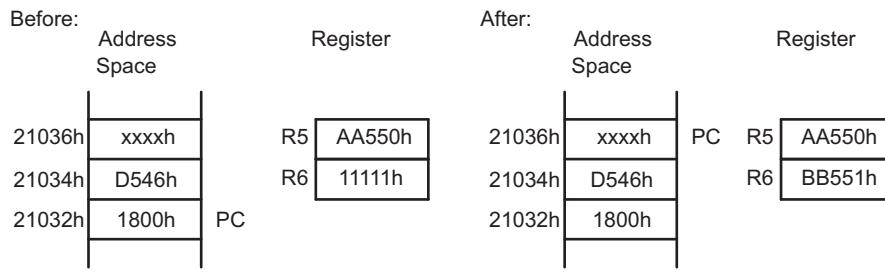
|                         |                                                                                                                                                                                                                                            |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Operation:              | The operand is the 8-, 16-, or 20-bit content of the used CPU register.                                                                                                                                                                    |
| Length:                 | One, two, or three words                                                                                                                                                                                                                   |
| Comment:                | Valid for source and destination                                                                                                                                                                                                           |
| Byte operation:         | Byte operation reads only the eight least significant bits (LSBs) of the source register Rsrc and writes the result to the eight LSBs of the destination register Rdst. The bits Rdst.19:8 are cleared. The register Rsrc is not modified. |
| Word operation:         | Word operation reads the 16 LSBs of the source register Rsrc and writes the result to the 16 LSBs of the destination register Rdst. The bits Rdst.19:16 are cleared. The register Rsrc is not modified.                                    |
| Address-word operation: | Address-word operation reads the 20 bits of the source register Rsrc and writes the result to the 20 bits of the destination register Rdst. The register Rsrc is not modified                                                              |
| SXT exception:          | The SXT instruction is the only exception for register operation. The sign of the low byte in bit 7 is extended to the bits Rdst.19:8.                                                                                                     |
| Example:                | <pre>BIS.W R5,R6 ;</pre> <p>This instruction logically ORs the 16-bit data contained in R5 with the 16-bit contents of R6. R6.19:16 is cleared.</p>                                                                                        |



**Example:** BISX.A R5 ,R6 ;

This instruction logically ORs the 20-bit data contained in R5 with the 20-bit contents of R6.

The extension word contains the A/L bit for 20-bit data. The instruction word uses byte mode with bits A/L:B/W = 01. The result of the instruction is:



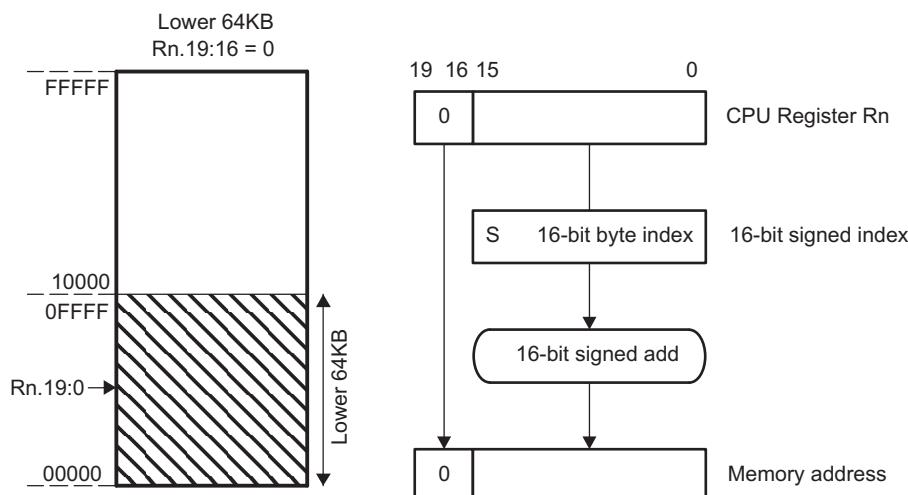
#### 4.4.2 Indexed Mode

The Indexed mode calculates the address of the operand by adding the signed index to a CPU register. The Indexed mode has four addressing possibilities:

- MSP430 instruction with Indexed mode in lower 64KB memory (see [Section 4.4.2.1](#))
- MSP430 instruction with Indexed mode addressing memory above the lower 64KB memory (see [Section 4.4.2.2](#))
- MSP430X instruction with Indexed mode (see [Section 4.4.2.3](#))
- MSP430X address instructions with Indexed mode (see [Section 4.4.2.4](#))

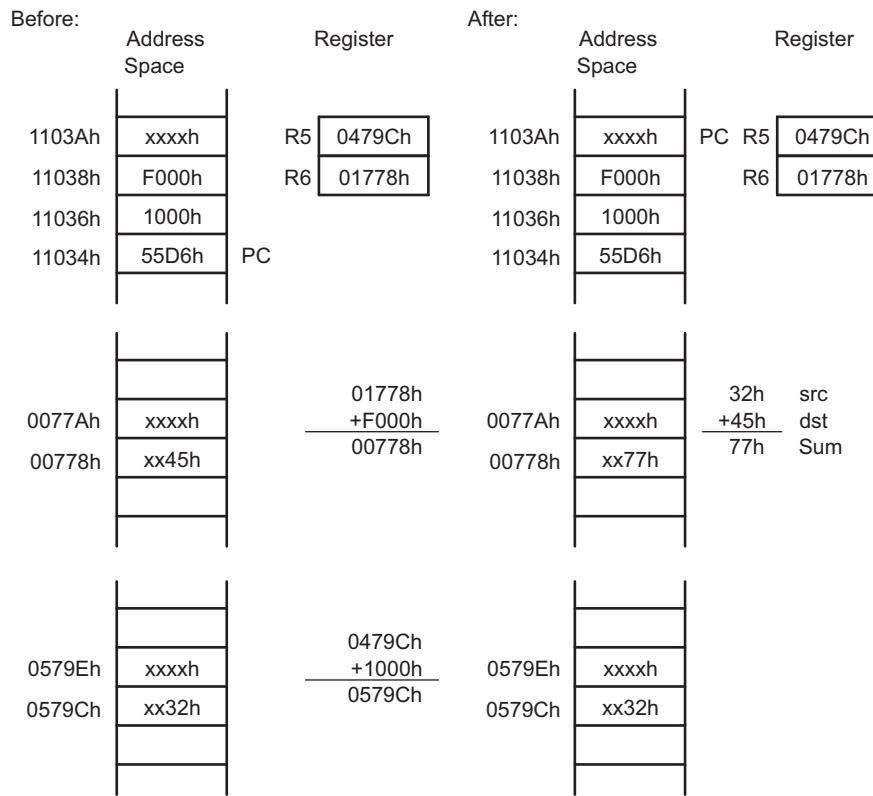
##### 4.4.2.1 MSP430 Instruction With Indexed Mode in Lower 64KB Memory

If the CPU register Rn points to an address in the lower 64KB of the memory range, the calculated memory address bits 19:16 are cleared after the addition of the CPU register Rn and the signed 16-bit index. This means the calculated memory address is always located in the lower 64KB and does not overflow or underflow out of the lower 64KB memory space. The RAM and the peripheral registers can be accessed this way and existing MSP430 software is usable without modifications as shown in [Figure 4-15](#).



**Figure 4-15. Indexed Mode in Lower 64KB**

|              |                                                                                                                                                                                                                                                                                                                              |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length:      | Two or three words                                                                                                                                                                                                                                                                                                           |
| Operation:   | The signed 16-bit index is located in the next word after the instruction and is added to the CPU register Rn. The resulting bits 19:16 are cleared giving a truncated 16-bit memory address, which points to an operand address in the range 00000h to 0FFFFh. The operand is the content of the addressed memory location. |
| Comment:     | Valid for source and destination. The assembler calculates the register index and inserts it.                                                                                                                                                                                                                                |
| Example:     | <pre>ADD.B 1000h(R5), 0F000h(R6);</pre> This instruction adds the 8-bit data contained in source byte 1000h(R5) and the destination byte 0F000h(R6) and places the result into the destination byte. Source and destination bytes are both located in the lower 64KB due to the cleared bits 19:16 of registers R5 and R6.   |
| Source:      | The byte pointed to by R5 + 1000h results in address 0479Ch + 1000h = 0579Ch after truncation to a 16-bit address.                                                                                                                                                                                                           |
| Destination: | The byte pointed to by R6 + F000h results in address 01778h + F000h = 00778h after truncation to a 16-bit address.                                                                                                                                                                                                           |



#### 4.4.2.2 MSP430 Instruction With Indexed Mode in Upper Memory

If the CPU register Rn points to an address above the lower 64KB memory, the Rn bits 19:16 are used for the address calculation of the operand. The operand may be located in memory in the range  $Rn \pm 32KB$ , because the index, X, is a signed 16-bit value. In this case, the address of the operand can overflow or underflow into the lower 64KB memory space (see [Figure 4-16](#) and [Figure 4-17](#)).

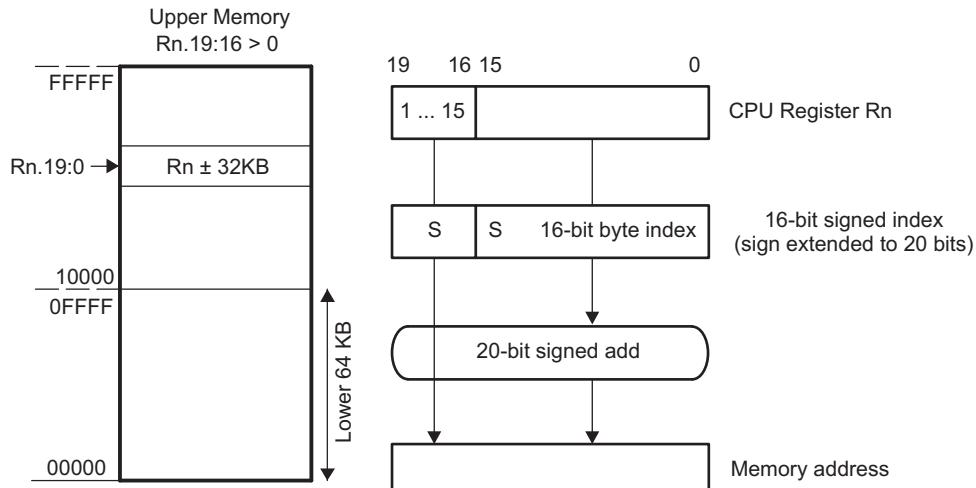
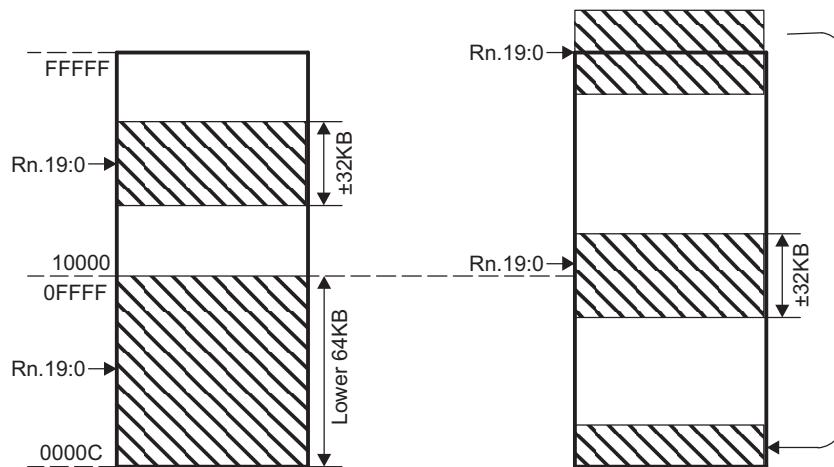
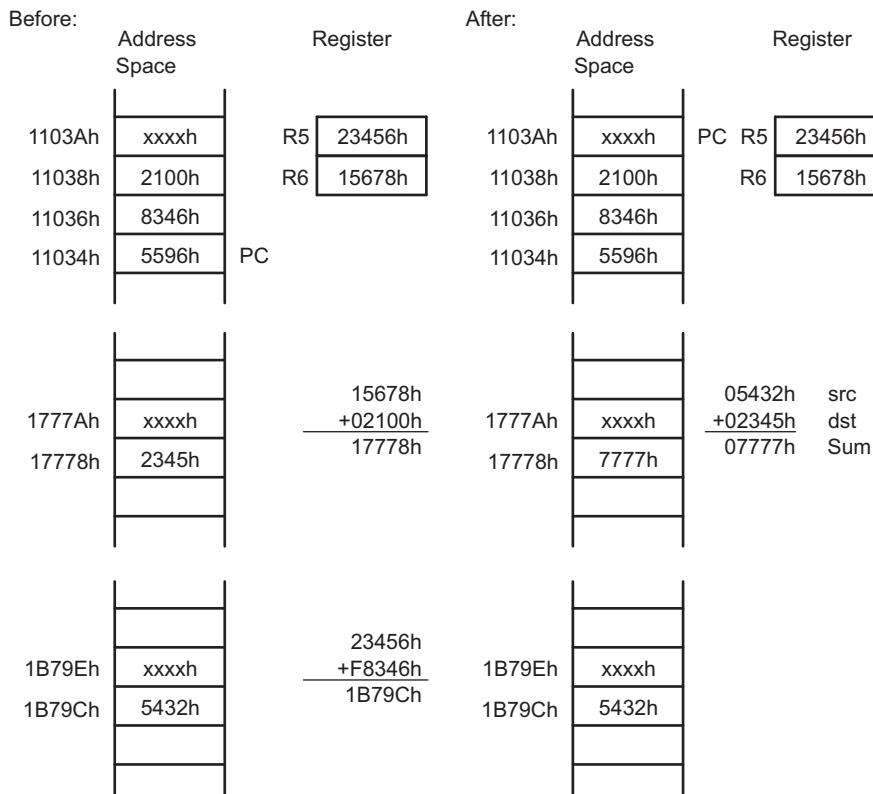


Figure 4-16. Indexed Mode in Upper Memory



**Figure 4-17. Overflow and Underflow for Indexed Mode**

|              |                                                                                                                                                                                                                                                                         |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length:      | Two or three words                                                                                                                                                                                                                                                      |
| Operation:   | The sign-extended 16-bit index in the next word after the instruction is added to the 20 bits of the CPU register Rn. This delivers a 20-bit address, which points to an address in the range 0 to FFFFFh. The operand is the content of the addressed memory location. |
| Comment:     | Valid for source and destination. The assembler calculates the register index and inserts it.                                                                                                                                                                           |
| Example:     | ADD.W 8346h(R5),2100h(R6) ;<br>This instruction adds the 16-bit data contained in the source and the destination addresses and places the 16-bit result into the destination. Source and destination operand can be located in the entire address range.                |
| Source:      | The word pointed to by R5 + 8346h. The negative index 8346h is sign extended, which results in address 23456h + F8346h = 1B79Ch.                                                                                                                                        |
| Destination: | The word pointed to by R6 + 2100h results in address 15678h + 2100h = 17778h.                                                                                                                                                                                           |



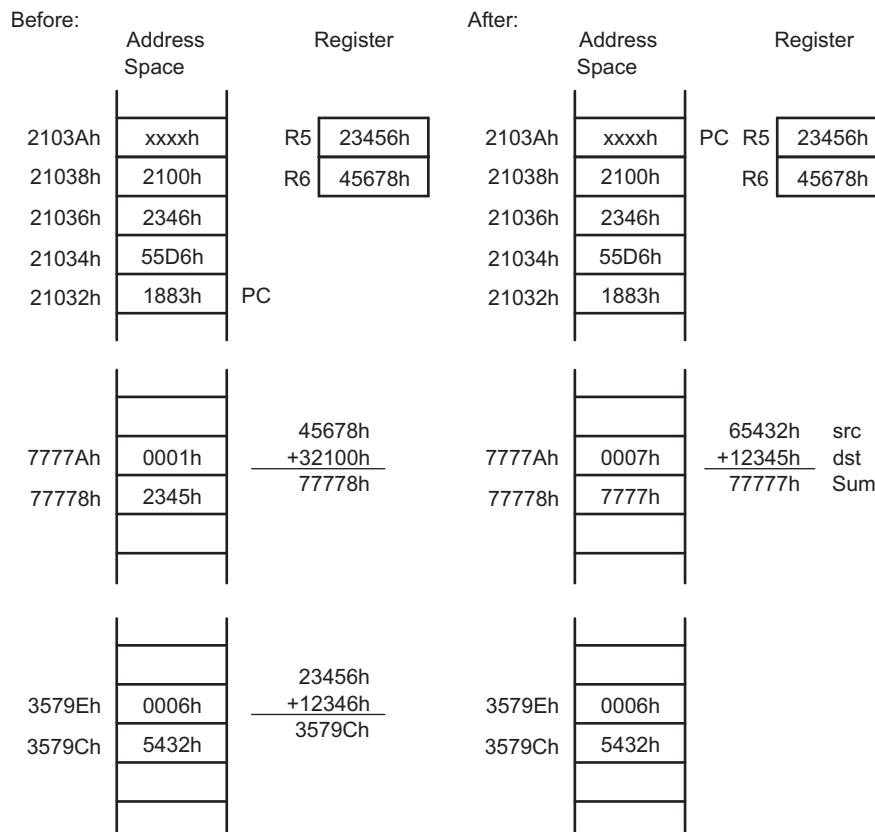
**Figure 4-18. Example for Indexed Mode**

#### 4.4.2.3 MSP430X Instruction With Indexed Mode

When using an MSP430X instruction with Indexed mode, the operand can be located anywhere in the range of  $Rn + 19$  bits.

|              |                                                                                                                                                                                                                                                        |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length:      | Three or four words                                                                                                                                                                                                                                    |
| Operation:   | The operand address is the sum of the 20-bit CPU register content and the 20-bit index. The 4 MSBs of the index are contained in the extension word; the 16 LSBs are contained in the word following the instruction. The CPU register is not modified |
| Comment:     | Valid for source and destination. The assembler calculates the register index and inserts it.                                                                                                                                                          |
| Example:     | <pre>ADDX.A 12346h(R5),32100h(R6) ;</pre> This instruction adds the 20-bit data contained in the source and the destination addresses and places the result into the destination.                                                                      |
| Source:      | Two words pointed to by $R5 + 12346h$ which results in address $23456h + 12346h = 3579Ch$ .                                                                                                                                                            |
| Destination: | Two words pointed to by $R6 + 32100h$ which results in address $45678h + 32100h = 77778h$ .                                                                                                                                                            |

The extension word contains the MSBs of the source index and of the destination index and the A/L bit for 20-bit data. The instruction word uses byte mode due to the 20-bit data length with bits A/L:B/W = 01.



#### 4.4.2.4 MSP430X Address Instructions With Indexed Mode

When using an MSP430X Address Instruction with Indexed mode, the operand is located in memory in the range  $Rn \pm 32KB$ , because the index, X, is a signed 16-bit value.

- Length:** Two words  
**Operation:** The sign-extended 16-bit index in the next word after the instruction is added to the 20 bits of the CPU register  $Rn$ . This delivers a 20-bit address, which points to an address in the range 0 to FFFFFh. The operand is the content of the addressed memory location.  
**Comment:** Valid for source and destination. The assembler calculates the register index and inserts it.  
**Example:** MOVA 8002h(R5),R6 ; // R5 = 0x100  
 This instruction loads the 20-bit data contained in the source address into destination register.  
**Source:** Two words pointed to by  $R5 + 8002h$  and  $R5 + 8002h + 2h$  which results in address  $00100h + F8002h (+2h) = F8102h$  and  $F8104h$ .  
**Destination:** Register R6

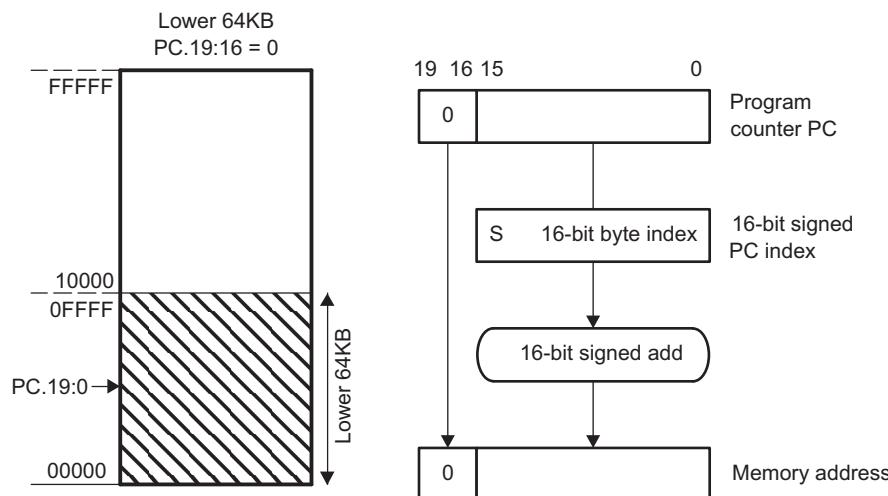
#### 4.4.3 Symbolic Mode

The Symbolic mode calculates the address of the operand by adding the signed index to the PC. The Symbolic mode has three addressing possibilities:

- Symbolic mode in lower 64KB of memory
- MSP430 instruction with Symbolic mode addressing memory above the lower 64KB of memory.
- MSP430X instruction with Symbolic mode

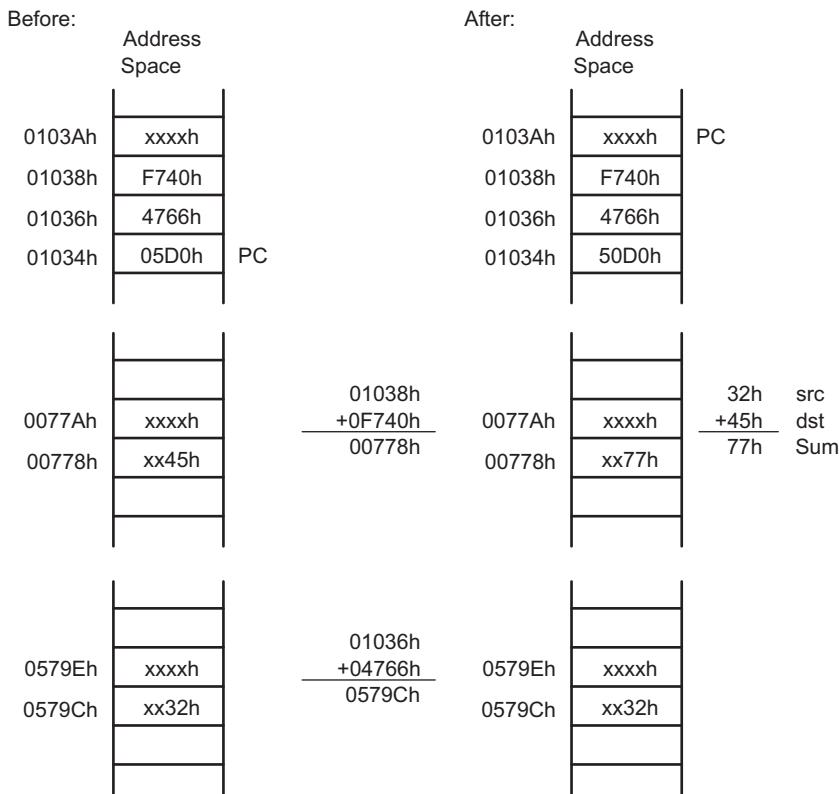
##### 4.4.3.1 Symbolic Mode in Lower 64KB

If the PC points to an address in the lower 64KB of the memory range, the calculated memory address bits 19:16 are cleared after the addition of the PC and the signed 16-bit index. This means the calculated memory address is always located in the lower 64KB and does not overflow or underflow out of the lower 64KB memory space. The RAM and the peripheral registers can be accessed this way and existing MSP430 software is usable without modifications as shown in [Figure 4-19](#).



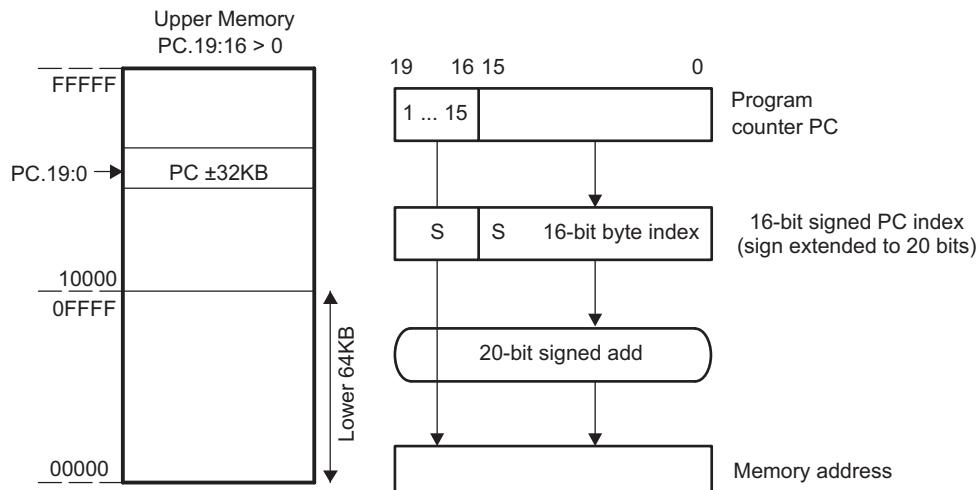
**Figure 4-19. Symbolic Mode Running in Lower 64KB**

|              |                                                                                                                                                                                                                                                                                                              |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Operation:   | The signed 16-bit index in the next word after the instruction is added temporarily to the PC. The resulting bits 19:16 are cleared giving a truncated 16-bit memory address, which points to an operand address in the range 00000h to 0FFFFh. The operand is the content of the addressed memory location. |
| Length:      | Two or three words                                                                                                                                                                                                                                                                                           |
| Comment:     | Valid for source and destination. The assembler calculates the PC index and inserts it.                                                                                                                                                                                                                      |
| Example:     | ADD.B EDE,TONI ;                                                                                                                                                                                                                                                                                             |
|              | This instruction adds the 8-bit data contained in source byte EDE and destination byte TONI and places the result into the destination byte TONI. Bytes EDE and TONI and the program are located in the lower 64KB.                                                                                          |
| Source:      | Byte EDE located at address 0579Ch, pointed to by PC + 4766h, where the PC index 4766h is the result of 0579Ch – 01036h = 04766h. Address 01036h is the location of the index for this example.                                                                                                              |
| Destination: | Byte TONI located at address 00778h, pointed to by PC + F740h, is the truncated 16-bit result of 00778h – 1038h = FF740h. Address 01038h is the location of the index for this example.                                                                                                                      |

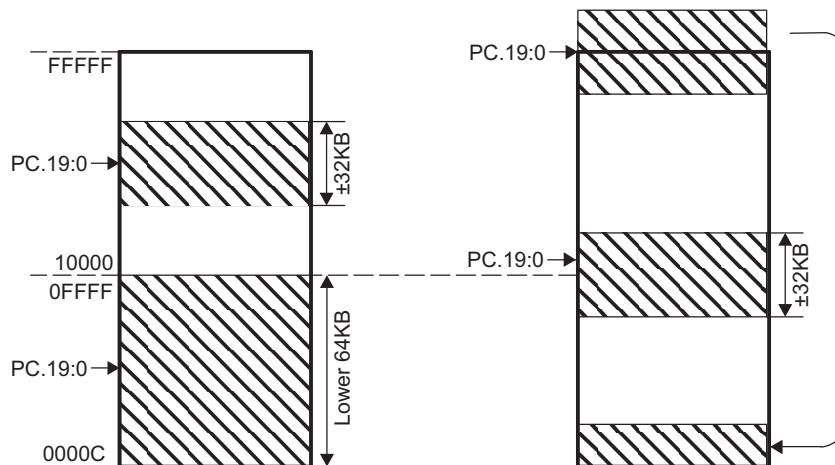


#### 4.4.3.2 MSP430 Instruction With Symbolic Mode in Upper Memory

If the PC points to an address above the lower 64KB memory, the PC bits 19:16 are used for the address calculation of the operand. The operand may be located in memory in the range  $PC \pm 32KB$ , because the index, X, is a signed 16-bit value. In this case, the address of the operand can overflow or underflow into the lower 64KB memory space as shown in [Figure 4-20](#) and [Figure 4-21](#).

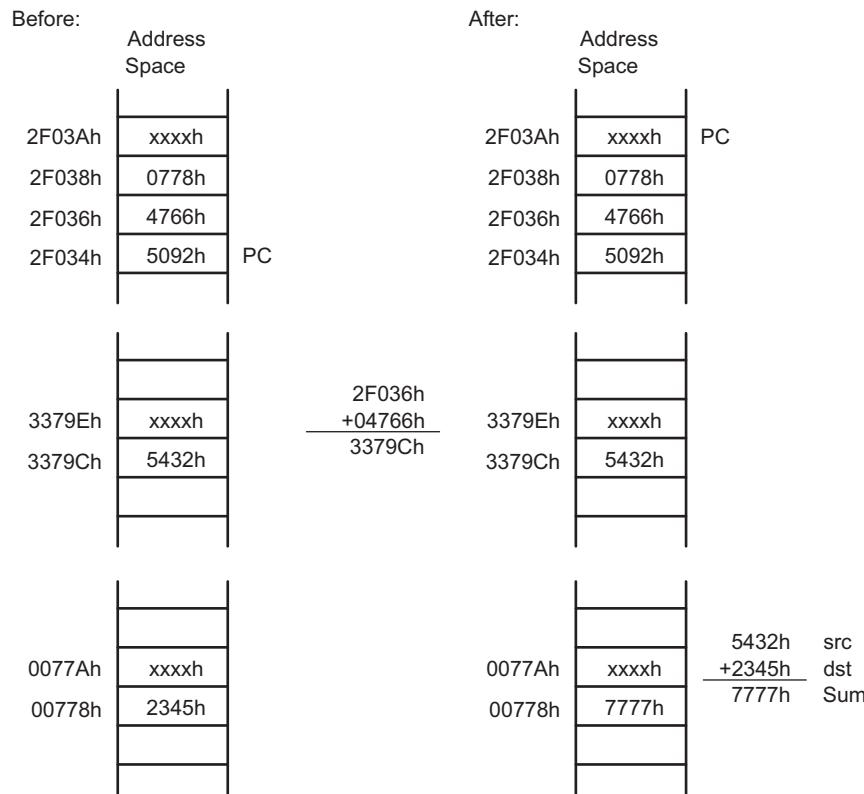


**Figure 4-20. Symbolic Mode Running in Upper Memory**



**Figure 4-21. Overflow and Underflow for Symbolic Mode**

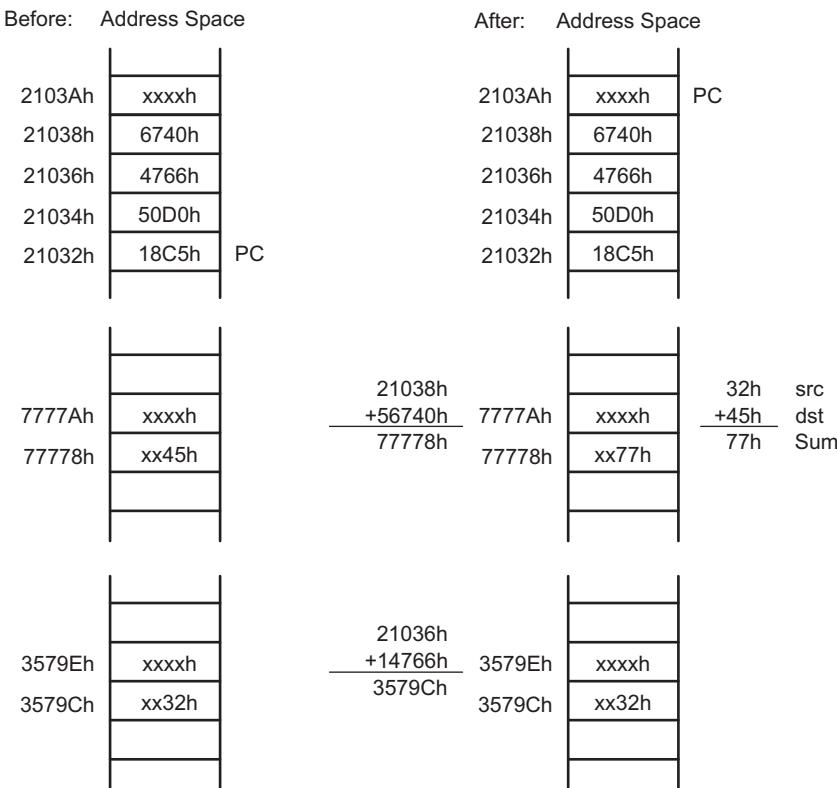
|              |                                                                                                                                                                                                                                                             |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length:      | Two or three words                                                                                                                                                                                                                                          |
| Operation:   | The sign-extended 16-bit index in the next word after the instruction is added to the 20 bits of the PC. This delivers a 20-bit address, which points to an address in the range 0 to FFFFh. The operand is the content of the addressed memory location.   |
| Comment:     | Valid for source and destination. The assembler calculates the PC index and inserts it                                                                                                                                                                      |
| Example:     | <pre>ADD.W EDE ,&amp;TONI ;</pre> This instruction adds the 16-bit data contained in source word EDE and destination word TONI and places the 16-bit result into the destination word TONI. For this example, the instruction is located at address 2F034h. |
| Source:      | Word EDE at address 3379Ch, pointed to by PC + 4766h, which is the 16-bit result of $3379Ch - 2F036h = 04766h$ . Address 2F036h is the location of the index for this example.                                                                              |
| Destination: | Word TONI located at address 00778h pointed to by the absolute address 00778h                                                                                                                                                                               |



#### 4.4.3.3 MSP430X Instruction With Symbolic Mode

When using an MSP430X instruction with Symbolic mode, the operand can be located anywhere in the range of PC + 19 bits.

|              |                                                                                                                                                                                                     |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length:      | Three or four words                                                                                                                                                                                 |
| Operation:   | The operand address is the sum of the 20-bit PC and the 20-bit index. The 4 MSBs of the index are contained in the extension word; the 16 LSBs are contained in the word following the instruction. |
| Comment:     | Valid for source and destination. The assembler calculates the register index and inserts it.                                                                                                       |
| Example:     | <pre>ADDX.B EDE,TONI ;</pre> <p>This instruction adds the 8-bit data contained in source byte EDE and destination byte TONI and places the result into the destination byte TONI.</p>               |
| Source:      | Byte EDE located at address 3579Ch, pointed to by PC + 14766h, is the 20-bit result of 3579Ch – 21036h = 14766h. Address 21036h is the address of the index in this example.                        |
| Destination: | Byte TONI located at address 77778h, pointed to by PC + 56740h, is the 20-bit result of 77778h – 21038h = 56740h. Address 21038h is the address of the index in this example.                       |



#### 4.4.4 Absolute Mode

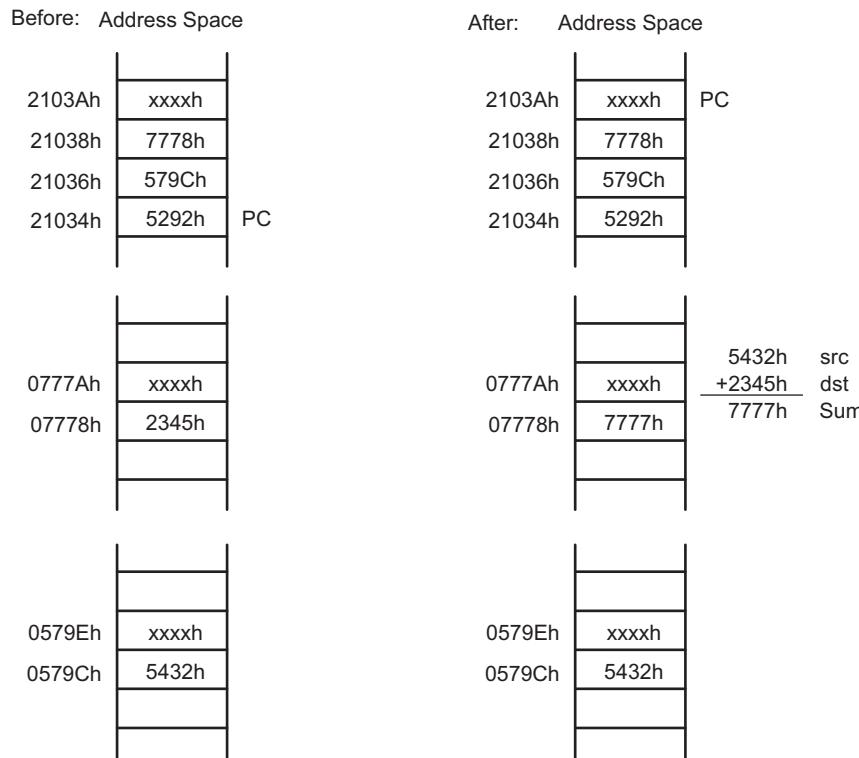
The Absolute mode uses the contents of the word following the instruction as the address of the operand. The Absolute mode has two addressing possibilities:

- Absolute mode in lower 64KB memory
- MSP430X instruction with Absolute mode

##### 4.4.4.1 Absolute Mode in Lower 64KB

If an MSP430 instruction is used with Absolute addressing mode, the absolute address is a 16-bit value and, therefore, points to an address in the lower 64KB of the memory range. The address is calculated as an index from 0 and is stored in the word following the instruction. The RAM and the peripheral registers can be accessed this way and existing MSP430 software is usable without modifications.

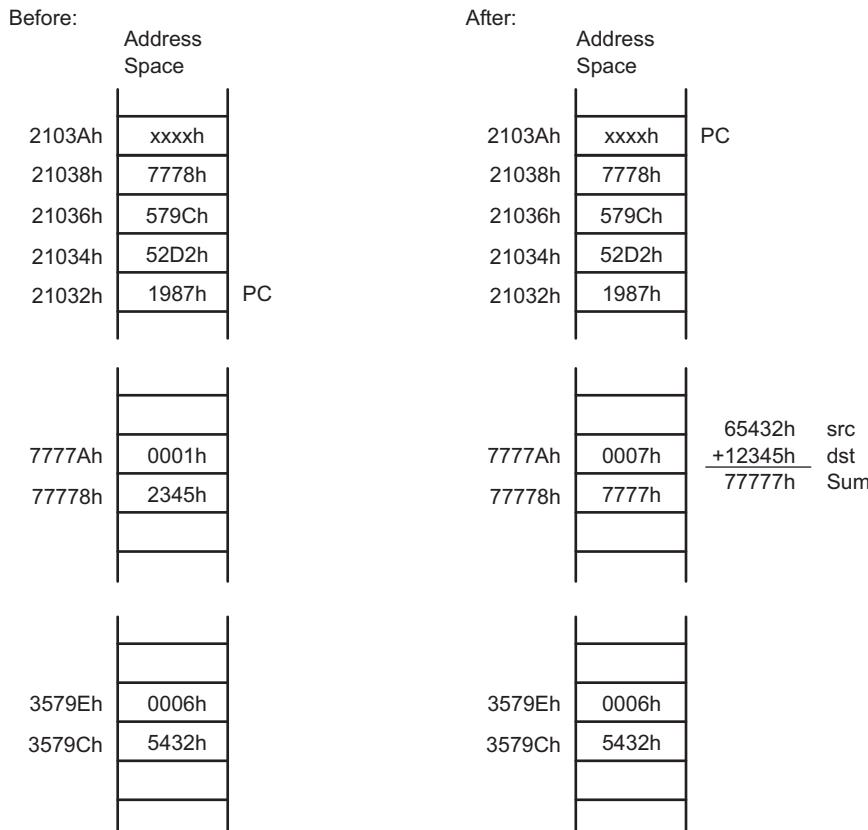
|              |                                                                                                                                                                     |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length:      | Two or three words                                                                                                                                                  |
| Operation:   | The operand is the content of the addressed memory location.                                                                                                        |
| Comment:     | Valid for source and destination. The assembler calculates the index from 0 and inserts it.                                                                         |
| Example:     | ADD.W &EDE ,&TONI ;<br>This instruction adds the 16-bit data contained in the absolute source and destination addresses and places the result into the destination. |
| Source:      | Word at address EDE                                                                                                                                                 |
| Destination: | Word at address TONI                                                                                                                                                |



#### 4.4.4.2 MSP430X Instruction With Absolute Mode

If an MSP430X instruction is used with Absolute addressing mode, the absolute address is a 20-bit value and, therefore, points to any address in the memory range. The address value is calculated as an index from 0. The 4 MSBs of the index are contained in the extension word, and the 16 LSBs are contained in the word following the instruction.

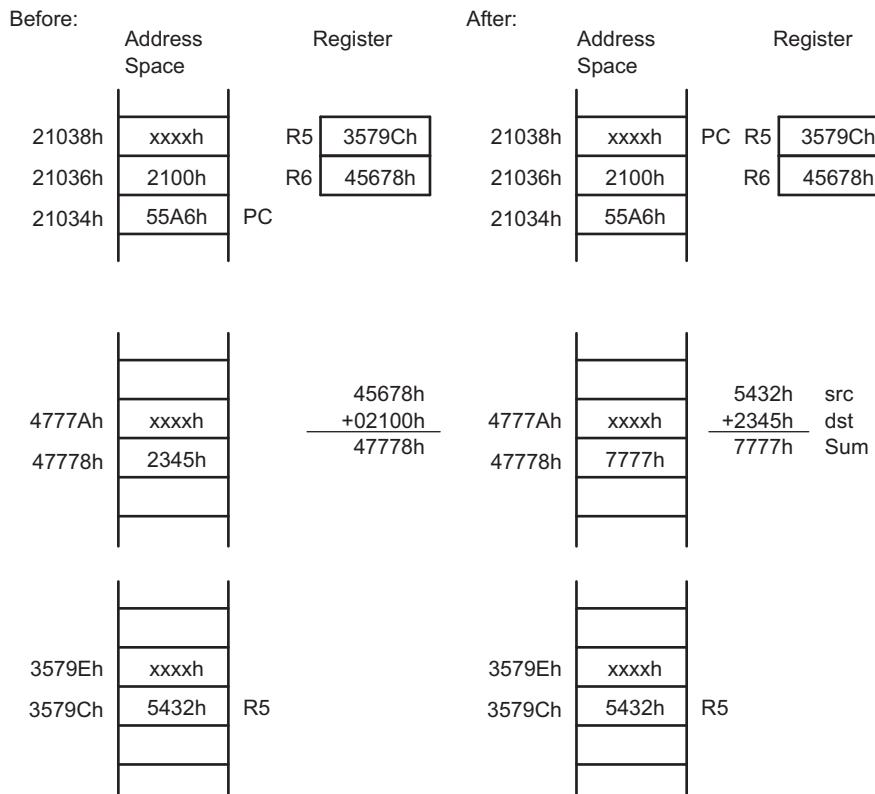
- Length: Three or four words  
 Operation: The operand is the content of the addressed memory location.  
 Comment: Valid for source and destination. The assembler calculates the index from 0 and inserts it.  
 Example: ADDX.A &EDE,&TONI ;  
           This instruction adds the 20-bit data contained in the absolute source and destination addresses and places the result into the destination.  
 Source: Two words beginning with address EDE  
 Destination: Two words beginning with address TONI



#### 4.4.5 Indirect Register Mode

The Indirect Register mode uses the contents of the CPU register Rsrc as the source operand. The Indirect Register mode always uses a 20-bit address.

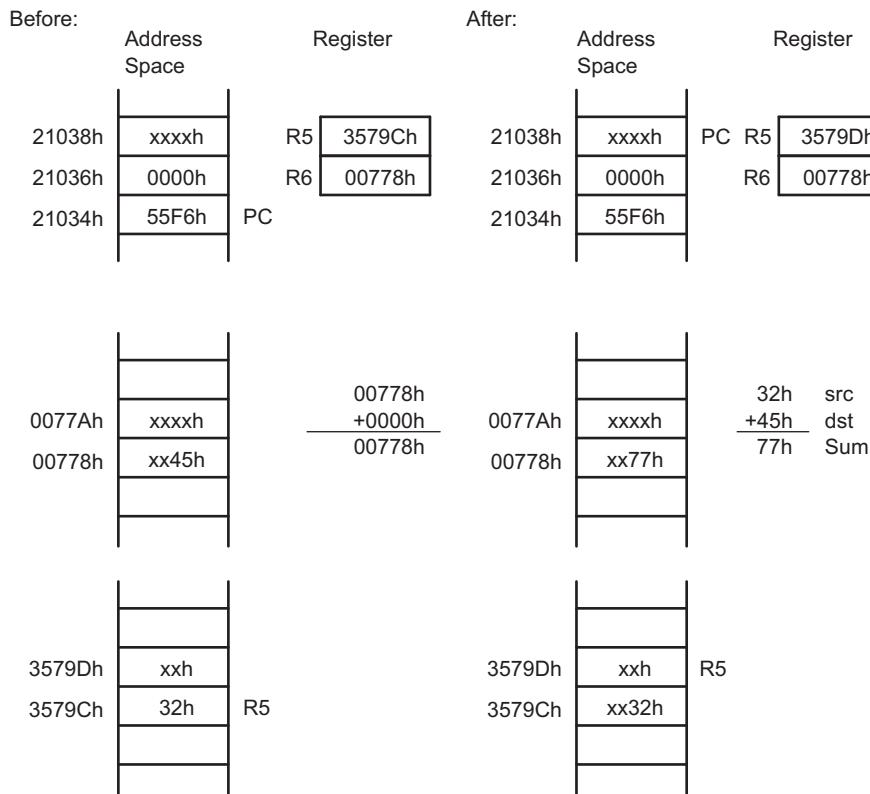
- Length:** One, two, or three words  
**Operation:** The operand is the content the addressed memory location. The source register Rsrc is not modified.  
**Comment:** Valid only for the source operand. The substitute for the destination operand is 0(Rdst).  
**Example:** ADDX.W @R5,2100h(R6)  
 This instruction adds the two 16-bit operands contained in the source and the destination addresses and places the result into the destination.  
**Source:** Word pointed to by R5. R5 contains address 3579Ch for this example.  
**Destination:** Word pointed to by R6 + 2100h, which results in address 45678h + 2100h = 7778h



#### 4.4.6 Indirect Autoincrement Mode

The Indirect Autoincrement mode uses the contents of the CPU register Rsrc as the source operand. Rsrc is then automatically incremented by 1 for byte instructions, by 2 for word instructions, and by 4 for address-word instructions immediately after accessing the source operand. If the same register is used for source and destination, it contains the incremented address for the destination access. Indirect Autoincrement mode always uses 20-bit addresses.

- Length:** One, two, or three words  
**Operation:** The operand is the content of the addressed memory location.  
**Comment:** Valid only for the source operand  
**Example:** ADD.B @R5+, 0(R6)  
 This instruction adds the 8-bit data contained in the source and the destination addresses and places the result into the destination.  
**Source:** Byte pointed to by R5. R5 contains address 3579Ch for this example.  
**Destination:** Byte pointed to by R6 + 0h, which results in address 0778h for this example



#### 4.4.7 Immediate Mode

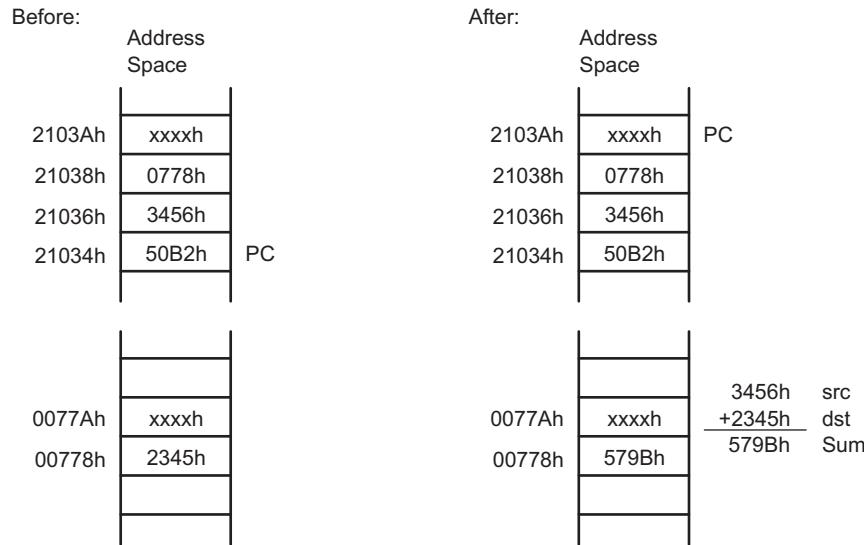
The Immediate mode allows accessing constants as operands by including the constant in the memory location following the instruction. The PC is used with the Indirect Autoincrement mode. The PC points to the immediate value contained in the next word. After the fetching of the immediate operand, the PC is incremented by 2 for byte, word, or address-word instructions. The Immediate mode has two addressing possibilities:

- 8-bit or 16-bit constants with MSP430 instructions
- 20-bit constants with MSP430X instruction

##### 4.4.7.1 MSP430 Instructions With Immediate Mode

If an MSP430 instruction is used with Immediate addressing mode, the constant is an 8- or 16-bit value and is stored in the word following the instruction.

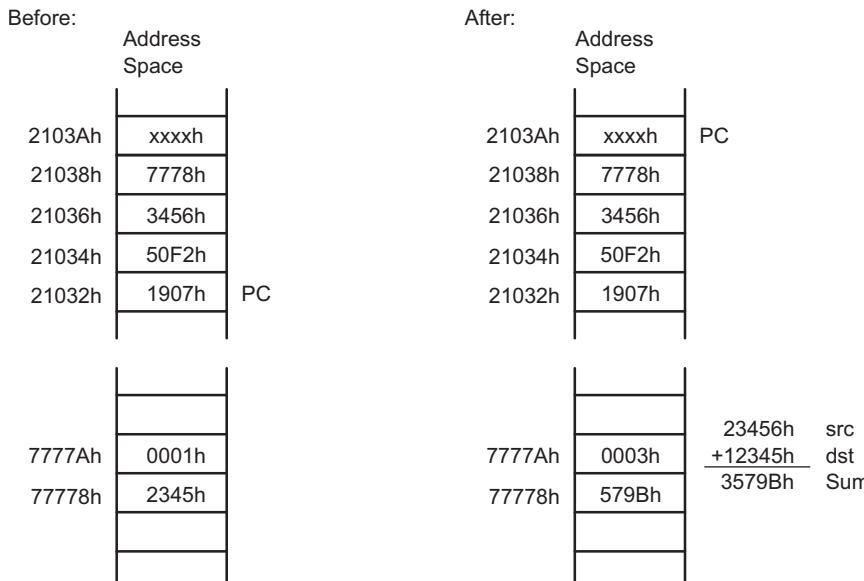
|              |                                                                                                                  |
|--------------|------------------------------------------------------------------------------------------------------------------|
| Length:      | Two or three words. One word less if a constant of the constant generator can be used for the immediate operand. |
| Operation:   | The 16-bit immediate source operand is used together with the 16-bit destination operand.                        |
| Comment:     | Valid only for the source operand                                                                                |
| Example:     | ADD #3456h,&TONI                                                                                                 |
|              | This instruction adds the 16-bit immediate operand 3456h to the data in the destination address TONI.            |
| Source:      | 16-bit immediate value 3456h                                                                                     |
| Destination: | Word at address TONI                                                                                             |



#### 4.4.7.2 MSP430X Instructions With Immediate Mode

If an MSP430X instruction is used with Immediate addressing mode, the constant is a 20-bit value. The 4 MSBs of the constant are stored in the extension word, and the 16 LSBs of the constant are stored in the word following the instruction.

- Length:** Three or four words. One word less if a constant of the constant generator can be used for the immediate operand.  
**Operation:** The 20-bit immediate source operand is used together with the 20-bit destination operand.  
**Comment:** Valid only for the source operand  
**Example:** ADDX.A #23456h,&TONI ;  
 This instruction adds the 20-bit immediate operand 23456h to the data in the destination address TONI.  
**Source:** 20-bit immediate value 23456h  
**Destination:** Two words beginning with address TONI



## 4.5 MSP430 and MSP430X Instructions

MSP430 instructions are the 27 implemented instructions of the MSP430 CPU. These instructions are used throughout the 1MB memory range unless their 16-bit capability is exceeded. The MSP430X instructions are used when the addressing of the operands or the data length exceeds the 16-bit capability of the MSP430 instructions.

There are three possibilities when choosing between an MSP430 and MSP430X instruction:

- To use only the MSP430 instructions – The only exceptions are the CALLA and the RETA instruction. This can be done if a few, simple rules are met:
  - Place all constants, variables, arrays, tables, and data in the lower 64KB. This allows the use of MSP430 instructions with 16-bit addressing for all data accesses. No pointers with 20-bit addresses are needed.
  - Place subroutine constants immediately after the subroutine code. This allows the use of the symbolic addressing mode with its 16-bit index to reach addresses within the range of PC + 32KB.
- To use only MSP430X instructions – The disadvantages of this method are the reduced speed due to the additional CPU cycles and the increased program space due to the necessary extension word for any double-operand instruction.
- Use the best fitting instruction where needed.

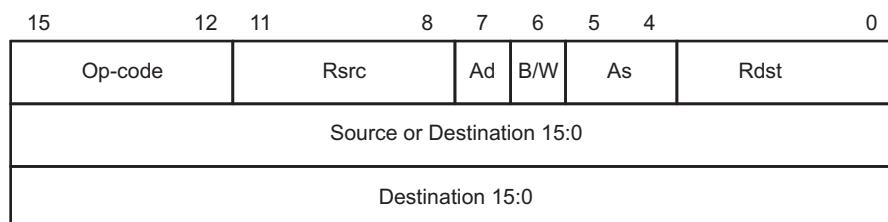
[Section 4.5.1](#) lists and describes the MSP430 instructions, and [Section 4.5.2](#) lists and describes the MSP430X instructions.

### 4.5.1 MSP430 Instructions

The MSP430 instructions can be used, regardless if the program resides in the lower 64KB or beyond it. The only exceptions are the instructions CALL and RET, which are limited to the lower 64KB address range. CALLA and RETA instructions have been added to the MSP430X CPU to handle subroutines in the entire address range with no code size overhead.

#### 4.5.1.1 MSP430 Double-Operand (Format I) Instructions

[Figure 4-22](#) shows the format of the MSP430 double-operand instructions. Source and destination words are appended for the Indexed, Symbolic, Absolute, and Immediate modes. [Table 4-4](#) lists the 12 MSP430 double-operand instructions.



**Figure 4-22. MSP430 Double-Operand Instruction Format**

**Table 4-4. MSP430 Double-Operand Instructions**

| <b>Mnemonic</b> | <b>S-Reg,<br/>D-Reg</b> | <b>Operation</b>                | <b>Status Bits<sup>(1)</sup></b> |          |          |          |
|-----------------|-------------------------|---------------------------------|----------------------------------|----------|----------|----------|
|                 |                         |                                 | <b>V</b>                         | <b>N</b> | <b>Z</b> | <b>C</b> |
| MOV(.B)         | src,dst                 | src → dst                       | —                                | —        | —        | —        |
| ADD(.B)         | src,dst                 | src + dst → dst                 | *                                | *        | *        | *        |
| ADDC(.B)        | src,dst                 | src + dst + C → dst             | *                                | *        | *        | *        |
| SUB(.B)         | src,dst                 | dst + .not.src + 1 → dst        | *                                | *        | *        | *        |
| SUBC(.B)        | src,dst                 | dst + .not.src + C → dst        | *                                | *        | *        | *        |
| CMP(.B)         | src,dst                 | dst - src                       | *                                | *        | *        | *        |
| DADD(.B)        | src,dst                 | src + dst + C → dst (decimally) | *                                | *        | *        | *        |
| BIT(.B)         | src,dst                 | src .and. dst                   | 0                                | *        | *        | —        |
| BIC(.B)         | src,dst                 | .not.src .and. dst → dst        | —                                | —        | —        | —        |
| BIS(.B)         | src,dst                 | src .or. dst → dst              | —                                | —        | —        | —        |
| XOR(.B)         | src,dst                 | src .xor. dst → dst             | *                                | *        | *        | —        |
| AND(.B)         | src,dst                 | src .and. dst → dst             | 0                                | *        | *        | —        |

<sup>(1)</sup> \* = Status bit is affected.

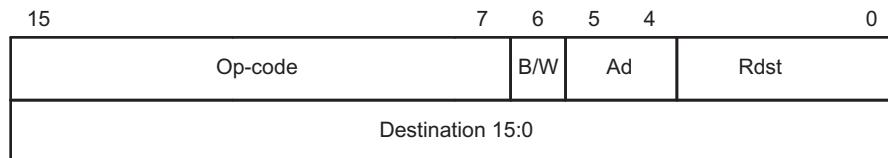
— = Status bit is not affected.

0 = Status bit is cleared.

1 = Status bit is set.

#### 4.5.1.2 MSP430 Single-Operand (Format II) Instructions

Figure 4-23 shows the format for MSP430 single-operand instructions, except RETI. The destination word is appended for the Indexed, Symbolic, Absolute, and Immediate modes. Table 4-5 lists the seven single-operand instructions.

**Figure 4-23. MSP430 Single-Operand Instructions****Table 4-5. MSP430 Single-Operand Instructions**

| <b>Mnemonic</b> | <b>S-Reg,<br/>D-Reg</b> | <b>Operation</b>                                                             | <b>Status Bits<sup>(1)</sup></b> |          |          |          |
|-----------------|-------------------------|------------------------------------------------------------------------------|----------------------------------|----------|----------|----------|
|                 |                         |                                                                              | <b>V</b>                         | <b>N</b> | <b>Z</b> | <b>C</b> |
| RRC(.B)         | dst                     | C → MSB →.....LSB → C                                                        | 0                                | *        | *        | *        |
| RRA(.B)         | dst                     | MSB → MSB →....LSB → C                                                       | 0                                | *        | *        | *        |
| PUSH(.B)        | src                     | SP - 2 → SP, src → SP                                                        | —                                | —        | —        | —        |
| SWPB            | dst                     | bit 15...bit 8 ↔ bit 7...bit 0                                               | —                                | —        | —        | —        |
| CALL            | dst                     | Call subroutine in lower 64KB                                                | —                                | —        | —        | —        |
| RETI            |                         | TOS → SR, SP + 2 → SP<br>TOS → PC,SP + 2 → SP                                | *                                | *        | *        | *        |
| SXT             | dst                     | Register mode: bit 7 → bit 8...bit 19<br>Other modes: bit 7 → bit 8...bit 15 | 0                                | *        | *        | —        |

<sup>(1)</sup> \* = Status bit is affected.

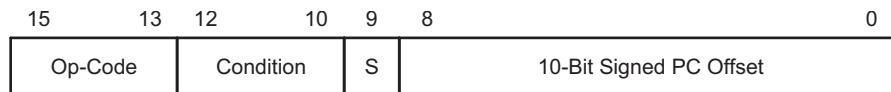
— = Status bit is not affected.

0 = Status bit is cleared.

1 = Status bit is set.

#### 4.5.1.3 Jump Instructions

Figure 4-24 shows the format for MSP430 and MSP430X jump instructions. The signed 10-bit word offset of the jump instruction is multiplied by two, sign-extended to a 20-bit address, and added to the 20-bit PC. This allows jumps in a range of -511 to +512 words relative to the PC in the full 20-bit address space. Jumps do not affect the status bits. Table 4-6 lists and describes the eight jump instructions.



**Figure 4-24. Format of Conditional Jump Instructions**

**Table 4-6. Conditional Jump Instructions**

| Mnemonic | S-Reg,<br>D-Reg | Operation                            |
|----------|-----------------|--------------------------------------|
| JEQ, JZ  | Label           | Jump to label if zero bit is set     |
| JNE, JNZ | Label           | Jump to label if zero bit is reset   |
| JC       | Label           | Jump to label if carry bit is set    |
| JNC      | Label           | Jump to label if carry bit is reset  |
| JN       | Label           | Jump to label if negative bit is set |
| JGE      | Label           | Jump to label if (N .XOR. V) = 0     |
| JL       | Label           | Jump to label if (N .XOR. V) = 1     |
| JMP      | Label           | Jump to label unconditionally        |

#### 4.5.1.4 Emulated Instructions

In addition to the MSP430 and MSP430X instructions, emulated instructions are instructions that make code easier to write and read, but do not have op-codes themselves. Instead, they are replaced automatically by the assembler with a core instruction. There is no code or performance penalty for using emulated instructions. The emulated instructions are listed in Table 4-7.

**Table 4-7. Emulated Instructions**

| Instruction  | Explanation               | Emulation       | Status Bits <sup>(1)</sup> |   |   |   |
|--------------|---------------------------|-----------------|----------------------------|---|---|---|
|              |                           |                 | V                          | N | Z | C |
| ADC(.B) dst  | Add Carry to dst          | ADDC(.B) #0,dst | *                          | * | * | * |
| BR dst       | Branch indirectly dst     | MOV dst,PC      | -                          | - | - | - |
| CLR(.B) dst  | Clear dst                 | MOV(.B) #0,dst  | -                          | - | - | - |
| CLRC         | Clear Carry bit           | BIC #1,SR       | -                          | - | - | 0 |
| CLRN         | Clear Negative bit        | BIC #4,SR       | -                          | 0 | - | - |
| CLRZ         | Clear Zero bit            | BIC #2,SR       | -                          | - | 0 | - |
| DADC(.B) dst | Add Carry to dst decimaly | DADD(.B) #0,dst | *                          | * | * | * |
| DEC(.B) dst  | Decrement dst by 1        | SUB(.B) #1,dst  | *                          | * | * | * |
| DECD(.B) dst | Decrement dst by 2        | SUB(.B) #2,dst  | *                          | * | * | * |
| DINT         | Disable interrupt         | BIC #8,SR       | -                          | - | - | - |
| EINT         | Enable interrupt          | BIS #8,SR       | -                          | - | - | - |
| INC(.B) dst  | Increment dst by 1        | ADD(.B) #1,dst  | *                          | * | * | * |
| INCD(.B) dst | Increment dst by 2        | ADD(.B) #2,dst  | *                          | * | * | * |

<sup>(1)</sup> \* = Status bit is affected.

- = Status bit is not affected.

0 = Status bit is cleared.

1 = Status bit is set.

**Table 4-7. Emulated Instructions (continued)**

| Instruction | Explanation                            | Emulation         | Status Bits <sup>(1)</sup> |   |   |   |
|-------------|----------------------------------------|-------------------|----------------------------|---|---|---|
|             |                                        |                   | V                          | N | Z | C |
| INV(.B) dst | Invert dst                             | XOR (.B) #-1,dst  | *                          | * | * | * |
| NOP         | No operation                           | MOV R3,R3         | -                          | - | - | - |
| POP dst     | Pop operand from stack                 | MOV @SP+,dst      | -                          | - | - | - |
| RET         | Return from subroutine                 | MOV @SP+,PC       | -                          | - | - | - |
| RLA(.B) dst | Shift left dst arithmetically          | ADD (.B) dst,dst  | *                          | * | * | * |
| RLC(.B) dst | Shift left dst logically through Carry | ADDC (.B) dst,dst | *                          | * | * | * |
| SBC(.B) dst | Subtract Carry from dst                | SUBC (.B) #0,dst  | *                          | * | * | * |
| SETC        | Set Carry bit                          | BIS #1,SR         | -                          | - | - | 1 |
| SETN        | Set Negative bit                       | BIS #4,SR         | -                          | 1 | - | - |
| SETZ        | Set Zero bit                           | BIS #2,SR         | -                          | - | 1 | - |
| TST(.B) dst | Test dst (compare with 0)              | CMP (.B) #0,dst   | 0                          | * | * | 1 |

#### 4.5.1.5 MSP430 Instruction Execution

The number of CPU clock cycles required for an instruction depends on the instruction format and the addressing modes used – not the instruction itself. The number of clock cycles refers to MCLK.

##### 4.5.1.5.1 Instruction Cycles and Length for Interrupt, Reset, and Subroutines

Table 4-8 lists the length and the CPU cycles for reset, interrupts, and subroutines.

**Table 4-8. Interrupt, Return, and Reset Cycles and Length**

| Action                                                             | Execution Time<br>(MCLK Cycles) | Length of Instruction<br>(Words) |
|--------------------------------------------------------------------|---------------------------------|----------------------------------|
| Return from interrupt RETI                                         | 5                               | 1                                |
| Return from subroutine RET                                         | 4                               | 1                                |
| Interrupt request service (cycles needed before first instruction) | 6                               | -                                |
| WDT reset                                                          | 4                               | -                                |
| Reset (RST/NMI)                                                    | 4                               | -                                |

##### 4.5.1.5.2 Format II (Single-Operand) Instruction Cycles and Lengths

Table 4-9 lists the length and the CPU cycles for all addressing modes of the MSP430 single-operand instructions.

**Table 4-9. MSP430 Format II Instruction Cycles and Length**

| Addressing Mode | No. of Cycles         |      |      | Length of Instruction | Example     |
|-----------------|-----------------------|------|------|-----------------------|-------------|
|                 | RRA, RRC<br>SWPB, SXT | PUSH | CALL |                       |             |
| Rn              | 1                     | 3    | 4    | 1                     | SWPB R5     |
| @Rn             | 3                     | 3    | 4    | 1                     | RRC @R9     |
| @Rn+            | 3                     | 3    | 4    | 1                     | SWPB @R10+  |
| #N              | N/A                   | 3    | 4    | 2                     | CALL #LABEL |
| X(Rn)           | 4                     | 4    | 5    | 2                     | CALL 2(R7)  |
| EDE             | 4                     | 4    | 5    | 2                     | PUSH EDE    |
| &EDE            | 4                     | 4    | 6    | 2                     | SXT &EDE    |

#### 4.5.1.5.3 Jump Instructions Cycles and Lengths

All jump instructions require one code word and take two CPU cycles to execute, regardless of whether the jump is taken or not.

#### 4.5.1.5.4 Format I (Double-Operand) Instruction Cycles and Lengths

Table 4-10 lists the length and CPU cycles for all addressing modes of the MSP430 Format I instructions.

**Table 4-10. MSP430 Format I Instructions Cycles and Length**

| Addressing Mode |             | No. of Cycles    | Length of Instruction | Example          |
|-----------------|-------------|------------------|-----------------------|------------------|
| Source          | Destination |                  |                       |                  |
| Rn              | Rm          | 1                | 1                     | MOV R5,R8        |
|                 | PC          | 3                | 1                     | BR R9            |
|                 | x(Rm)       | 4 <sup>(1)</sup> | 2                     | ADD R5,4(R6)     |
|                 | EDE         | 4 <sup>(1)</sup> | 2                     | XOR R8,EDE       |
|                 | &EDE        | 4 <sup>(1)</sup> | 2                     | MOV R5,&EDE      |
| @Rn             | Rm          | 2                | 1                     | AND @R4,R5       |
|                 | PC          | 4                | 1                     | BR @R8           |
|                 | x(Rm)       | 5 <sup>(1)</sup> | 2                     | XOR @R5,8(R6)    |
|                 | EDE         | 5 <sup>(1)</sup> | 2                     | MOV @R5,EDE      |
|                 | &EDE        | 5 <sup>(1)</sup> | 2                     | XOR @R5,&EDE     |
| @Rn+            | Rm          | 2                | 1                     | ADD @R5+,R6      |
|                 | PC          | 4                | 1                     | BR @R9+          |
|                 | x(Rm)       | 5 <sup>(1)</sup> | 2                     | XOR @R5,8(R6)    |
|                 | EDE         | 5 <sup>(1)</sup> | 2                     | MOV @R9+,EDE     |
|                 | &EDE        | 5 <sup>(1)</sup> | 2                     | MOV @R9+,&EDE    |
| #N              | Rm          | 2                | 2                     | MOV #20,R9       |
|                 | PC          | 3                | 2                     | BR #2AEh         |
|                 | x(Rm)       | 5 <sup>(1)</sup> | 3                     | MOV #0300h,0(SP) |
|                 | EDE         | 5 <sup>(1)</sup> | 3                     | ADD #33,EDE      |
|                 | &EDE        | 5 <sup>(1)</sup> | 3                     | ADD #33,&EDE     |
| x(Rn)           | Rm          | 3                | 2                     | MOV 2(R5),R7     |
|                 | PC          | 5                | 2                     | BR 2(R6)         |
|                 | TONI        | 6 <sup>(1)</sup> | 3                     | MOV 4(R7),TONI   |
|                 | x(Rm)       | 6 <sup>(1)</sup> | 3                     | ADD 4(R4),6(R9)  |
|                 | &TONI       | 6 <sup>(1)</sup> | 3                     | MOV 2(R4),&TONI  |
| EDE             | Rm          | 3                | 2                     | AND EDE,R6       |
|                 | PC          | 5                | 2                     | BR EDE           |
|                 | TONI        | 6 <sup>(1)</sup> | 3                     | CMP EDE,TONI     |
|                 | x(Rm)       | 6 <sup>(1)</sup> | 3                     | MOV EDE,0(SP)    |
|                 | &TONI       | 6 <sup>(1)</sup> | 3                     | MOV EDE,&TONI    |
| &EDE            | Rm          | 3                | 2                     | MOV &EDE,R8      |
|                 | PC          | 5                | 2                     | BR &EDE          |
|                 | TONI        | 6 <sup>(1)</sup> | 3                     | MOV &EDE,TONI    |
|                 | x(Rm)       | 6 <sup>(1)</sup> | 3                     | MOV &EDE,0(SP)   |
|                 | &TONI       | 6 <sup>(1)</sup> | 3                     | MOV &EDE,&TONI   |

<sup>(1)</sup> MOV, BIT, and CMP instructions execute in one fewer cycle.

#### 4.5.2 MSP430X Extended Instructions

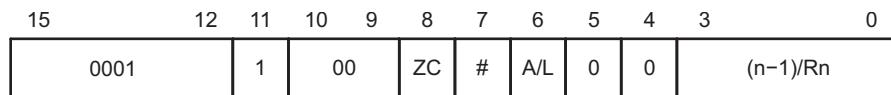
The extended MSP430X instructions give the MSP430X CPU full access to its 20-bit address space. Most MSP430X instructions require an additional word of op-code called the extension word. Some extended instructions do not require an additional word and are noted in the instruction description. All addresses, indexes, and immediate numbers have 20-bit values when preceded by the extension word.

There are two types of extension words:

- Register or register mode for Format I instructions and register mode for Format II instructions
- Extension word for all other address mode combinations

##### 4.5.2.1 Register Mode Extension Word

The register mode extension word is shown in [Figure 4-25](#) and described in [Table 4-11](#). An example is shown in [Figure 4-27](#).



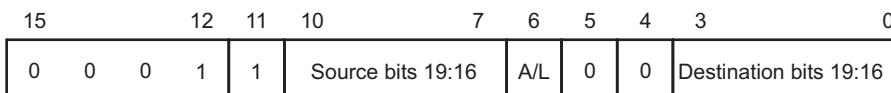
**Figure 4-25. Extension Word for Register Modes**

**Table 4-11. Description of the Extension Word Bits for Register Mode**

| Bit   | Description                                                                                                                                        |                                                                                                                                              |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| 15:11 | Extension word op-code. Op-codes 1800h to 1FFFh are extension words.                                                                               |                                                                                                                                              |
| 10:9  | Reserved                                                                                                                                           |                                                                                                                                              |
| ZC    | Zero carry                                                                                                                                         |                                                                                                                                              |
| 0     | A/L                                                                                                                                                | The executed instruction uses the status of the carry bit C.                                                                                 |
| 1     | #                                                                                                                                                  | The executed instruction uses the carry bit as 0. The carry bit is defined by the result of the final operation after instruction execution. |
| #     | B/W                                                                                                                                                | Repetition                                                                                                                                   |
| 0     | 0                                                                                                                                                  | The number of instruction repetitions is set by extension word bits 3:0.                                                                     |
| 1     | 1                                                                                                                                                  | The number of instruction repetitions is defined by the value of the four LSBs of Rn. See description for bits 3:0.                          |
| A/L   | Data length extension. Together with the B/W bits of the following MSP430 instruction, the AL bit defines the used data length of the instruction. |                                                                                                                                              |
|       | A/L                                                                                                                                                | Comment                                                                                                                                      |
| 0     | 0                                                                                                                                                  | Reserved                                                                                                                                     |
| 0     | 1                                                                                                                                                  | 20-bit address word                                                                                                                          |
| 1     | 0                                                                                                                                                  | 16-bit word                                                                                                                                  |
| 1     | 1                                                                                                                                                  | 8-bit byte                                                                                                                                   |
| 5:4   | Reserved                                                                                                                                           |                                                                                                                                              |
| 3:0   | Repetition count                                                                                                                                   |                                                                                                                                              |
| # = 0 | These four bits set the repetition count n. These bits contain n – 1.                                                                              |                                                                                                                                              |
| # = 1 | These four bits define the CPU register whose bits 3:0 set the number of repetitions. Rn.3:0 contain n – 1.                                        |                                                                                                                                              |

##### 4.5.2.2 Non-Register Mode Extension Word

The extension word for non-register modes is shown in [Figure 4-26](#) and described in [Table 4-12](#). An example is shown in [Figure 4-28](#).



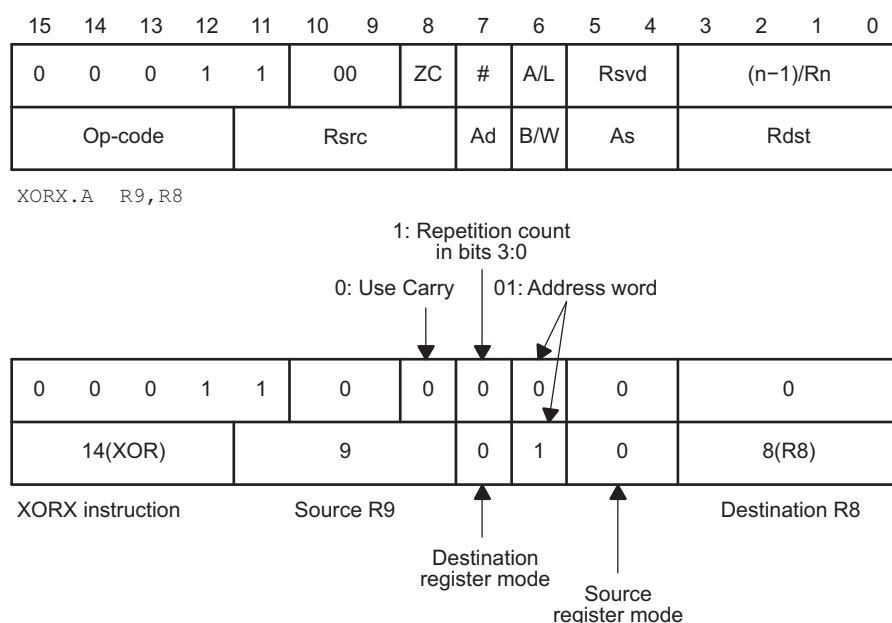
**Figure 4-26. Extension Word for Non-Register Modes**

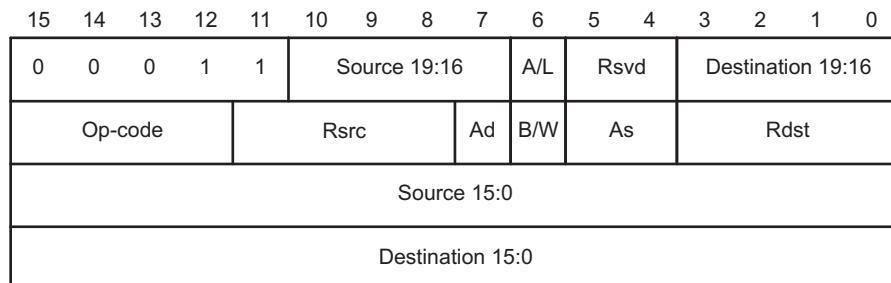
**Table 4-12. Description of Extension Word Bits for Non-Register Modes**

| Bit                    | Description                                                                                                                                                           |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15:11                  | Extension word op-code. Op-codes 1800h to 1FFFh are extension words.                                                                                                  |
| Source Bits 19:16      | The four MSBs of the 20-bit source. Depending on the source addressing mode, these four MSBs may belong to an immediate operand, an index, or to an absolute address. |
| A/L                    | Data length extension. Together with the B/W bits of the following MSP430 instruction, the AL bit defines the used data length of the instruction.                    |
|                        | <b>A/L    B/W    Comment</b>                                                                                                                                          |
| 0    0                 | Reserved                                                                                                                                                              |
| 0    1                 | 20-bit address word                                                                                                                                                   |
| 1    0                 | 16-bit word                                                                                                                                                           |
| 1    1                 | 8-bit byte                                                                                                                                                            |
| 5:4                    | Reserved                                                                                                                                                              |
| Destination Bits 19:16 | The four MSBs of the 20-bit destination. Depending on the destination addressing mode, these four MSBs may belong to an index or to an absolute address.              |

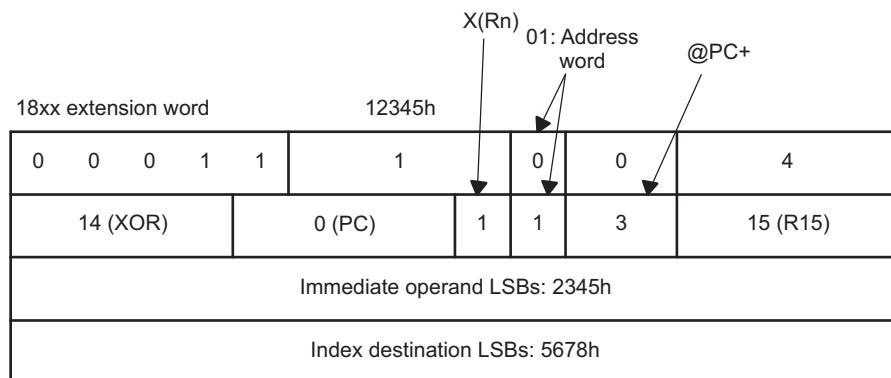
**NOTE: B/W and A/L bit settings for SWPBX and SXTX**

| A/L    | B/W |                 |
|--------|-----|-----------------|
| 0    0 |     | SWPBX.A, SXTX.A |
| 0    1 |     | N/A             |
| 1    0 |     | SWPB.W, SXTX.W  |
| 1    1 |     | N/A             |

**Figure 4-27. Example for Extended Register or Register Instruction**



XORX.A #12345h, 45678h (R15)

**Figure 4-28. Example for Extended Immediate or Indexed Instruction**

#### 4.5.2.3 Extended Double-Operand (Format I) Instructions

All 12 double-operand instructions have extended versions as listed in [Table 4-13](#).

**Table 4-13. Extended Double-Operand Instructions**

| Mnemonic       | Operands | Operation                     | Status Bits <sup>(1)</sup> |   |   |   |
|----------------|----------|-------------------------------|----------------------------|---|---|---|
|                |          |                               | V                          | N | Z | C |
| MOVX( .B, .A)  | src,dst  | src → dst                     | —                          | — | — | — |
| ADDX( .B, .A)  | src,dst  | src + dst → dst               | *                          | * | * | * |
| ADDCX( .B, .A) | src,dst  | src + dst + C → dst           | *                          | * | * | * |
| SUBX( .B, .A)  | src,dst  | dst + .not/src + 1 → dst      | *                          | * | * | * |
| SUBCX( .B, .A) | src,dst  | dst + .not/src + C → dst      | *                          | * | * | * |
| CMPX( .B, .A)  | src,dst  | dst – src                     | *                          | * | * | * |
| DADDX( .B, .A) | src,dst  | src + dst + C → dst (decimal) | *                          | * | * | * |
| BITX( .B, .A)  | src,dst  | src .and. dst                 | 0                          | * | * | Z |
| BICX( .B, .A)  | src,dst  | .not/src .and. dst → dst      | —                          | — | — | — |
| BISX( .B, .A)  | src,dst  | src .or. dst → dst            | —                          | — | — | — |
| XORX( .B, .A)  | src,dst  | src .xor. dst → dst           | *                          | * | * | Z |
| ANDX( .B, .A)  | src,dst  | src .and. dst → dst           | 0                          | * | * | Z |

(1) \* = Status bit is affected.

— = Status bit is not affected.

0 = Status bit is cleared.

1 = Status bit is set.

The four possible addressing combinations for the extension word for Format I instructions are shown in Figure 4-29.

| 15       | 14 | 13 | 12 | 11  | 10        | 9 | 8  | 7  | 6   | 5  | 4 | 3         | 0 |  |  |  |  |  |  |  |  |
|----------|----|----|----|-----|-----------|---|----|----|-----|----|---|-----------|---|--|--|--|--|--|--|--|--|
| 0        | 0  | 0  | 1  | 1   | 0         | 0 | ZC | #  | A/L | 0  | 0 | n-1/Rn    |   |  |  |  |  |  |  |  |  |
| Op-code  |    |    |    | src |           |   |    | 0  | B/W | 0  | 0 | dst       |   |  |  |  |  |  |  |  |  |
|          |    |    |    |     |           |   |    |    |     |    |   |           |   |  |  |  |  |  |  |  |  |
| 0        | 0  | 0  | 1  | 1   | src.19:16 |   |    |    | A/L | 0  | 0 | 0         | 0 |  |  |  |  |  |  |  |  |
| Op-code  |    |    |    | src |           |   |    | Ad | B/W | As |   | dst       |   |  |  |  |  |  |  |  |  |
| src.15:0 |    |    |    |     |           |   |    |    |     |    |   |           |   |  |  |  |  |  |  |  |  |
| 0        | 0  | 0  | 1  | 1   | 0         | 0 | 0  | 0  | A/L | 0  | 0 | dst.19:16 |   |  |  |  |  |  |  |  |  |
| Op-code  |    |    |    | src |           |   |    | Ad | B/W | As |   | dst       |   |  |  |  |  |  |  |  |  |
| dst.15:0 |    |    |    |     |           |   |    |    |     |    |   |           |   |  |  |  |  |  |  |  |  |
| 0        | 0  | 0  | 1  | 1   | src.19:16 |   |    |    | A/L | 0  | 0 | dst.19:16 |   |  |  |  |  |  |  |  |  |
| Op-code  |    |    |    | src |           |   |    | Ad | B/W | As |   | dst       |   |  |  |  |  |  |  |  |  |
| src.15:0 |    |    |    |     |           |   |    |    |     |    |   |           |   |  |  |  |  |  |  |  |  |
| dst.15:0 |    |    |    |     |           |   |    |    |     |    |   |           |   |  |  |  |  |  |  |  |  |

**Figure 4-29. Extended Format I Instruction Formats**

If the 20-bit address of a source or destination operand is located in memory, not in a CPU register, then two words are used for this operand as shown in Figure 4-30.

| 15        | 14                | 13    | 12    | 11    | 10    | 9     | 8     | 7     | 6     | 5     | 4     | 3     | 2     | 1     | 0 |
|-----------|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---|
| Address+2 | 0                 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0 |
| Address   | Operand LSBs 15:0 |       |       |       |       |       |       |       |       |       |       |       |       |       |   |

**Figure 4-30. 20-Bit Addresses in Memory**

#### 4.5.2.4 Extended Single-Operand (Format II) Instructions

Extended MSP430X Format II instructions are listed in [Table 4-14](#).

**Table 4-14. Extended Single-Operand Instructions**

| <b>Mnemonic</b> | <b>Operands</b> | <b>Operation</b>                                               | <b>n</b> | <b>Status Bits<sup>(1)</sup></b> |          |          |          |
|-----------------|-----------------|----------------------------------------------------------------|----------|----------------------------------|----------|----------|----------|
|                 |                 |                                                                |          | <b>n</b>                         | <b>V</b> | <b>N</b> | <b>Z</b> |
| CALLA           | dst             | Call indirect to subroutine (20-bit address)                   |          | —                                | —        | —        | —        |
| POPM.A          | #n,Rdst         | Pop n 20-bit registers from stack                              | 1 to 16  | —                                | —        | —        | —        |
| POPM.W          | #n,Rdst         | Pop n 16-bit registers from stack                              | 1 to 16  | —                                | —        | —        | —        |
| PUSHM.A         | #n,Rsrc         | Push n 20-bit registers to stack                               | 1 to 16  | —                                | —        | —        | —        |
| PUSHM.W         | #n,Rsrc         | Push n 16-bit registers to stack                               | 1 to 16  | —                                | —        | —        | —        |
| PUSHX(.B,.A)    | src             | Push 8-, 16-, or 20-bit source to stack                        |          | —                                | —        | —        | —        |
| RRCM(.A)        | #n,Rdst         | Rotate right Rdst n bits through carry (16-, 20-bit register)  | 1 to 4   | 0                                | *        | *        | *        |
| RRUM(.A)        | #n,Rdst         | Rotate right Rdst n bits unsigned (16-, 20-bit register)       | 1 to 4   | 0                                | *        | *        | *        |
| RRAM(.A)        | #n,Rdst         | Rotate right Rdst n bits arithmetically (16-, 20-bit register) | 1 to 4   | 0                                | *        | *        | *        |
| RLAM(.A)        | #n,Rdst         | Rotate left Rdst n bits arithmetically (16-, 20-bit register)  | 1 to 4   | *                                | *        | *        | *        |
| RRCX(.B,.A)     | dst             | Rotate right dst through carry (8-, 16-, 20-bit data)          | 1        | 0                                | *        | *        | *        |
| RRUX(.B,.A)     | Rdst            | Rotate right dst unsigned (8-, 16-, 20-bit)                    | 1        | 0                                | *        | *        | *        |
| RRAX(.B,.A)     | dst             | Rotate right dst arithmetically                                | 1        | 0                                | *        | *        | *        |
| SWPBX(.A)       | dst             | Exchange low byte with high byte                               | 1        | —                                | —        | —        | —        |
| SXTX(.A)        | Rdst            | Bit7 → bit8 ... bit19                                          | 1        | 0                                | *        | *        | Z        |
| SXTX(.A)        | dst             | Bit7 → bit8 ... MSB                                            | 1        | 0                                | *        | *        | Z        |

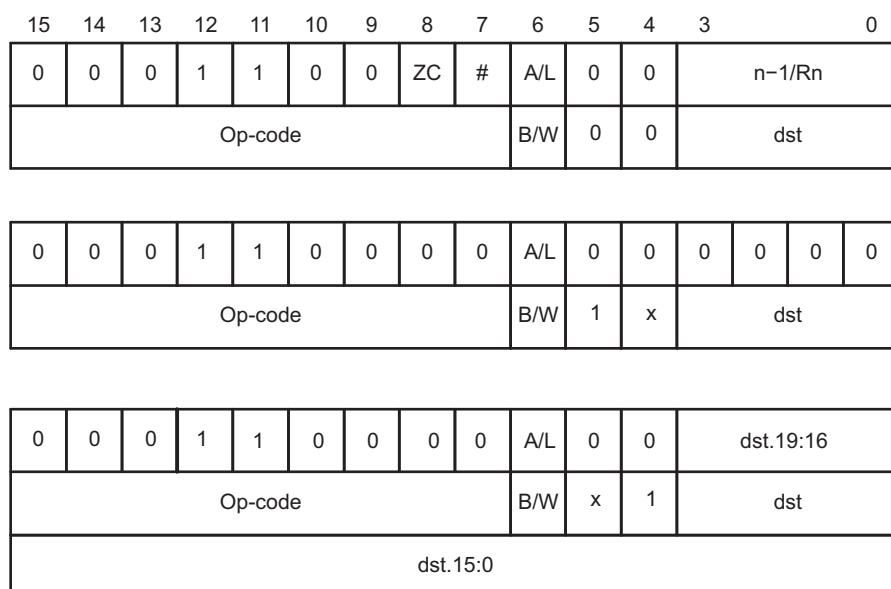
(1) \* = Status bit is affected.

— = Status bit is not affected.

0 = Status bit is cleared.

1 = Status bit is set.

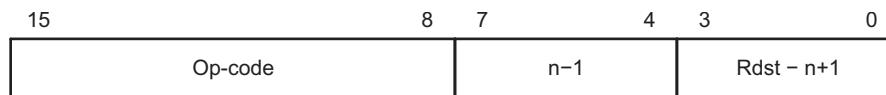
The three possible addressing mode combinations for Format II instructions are shown in [Figure 4-31](#).



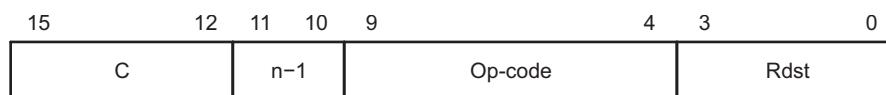
**Figure 4-31. Extended Format II Instruction Format**

#### 4.5.2.4.1 Extended Format II Instruction Format Exceptions

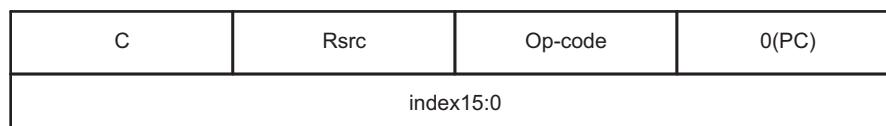
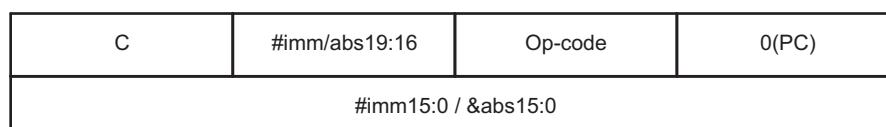
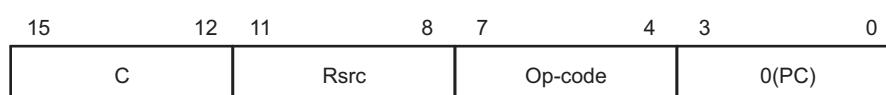
Exceptions for the Format II instruction formats are shown in [Figure 4-32](#) through [Figure 4-35](#).



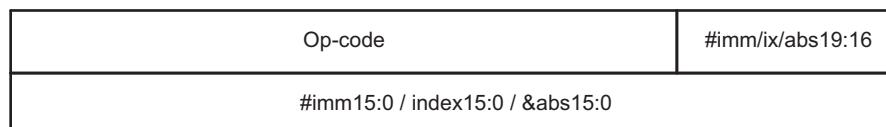
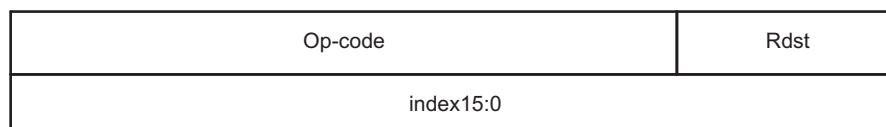
**Figure 4-32. PUSHM and POPM Instruction Format**



**Figure 4-33. RRCM, RRAM, RRUM, and RLAM Instruction Format**



**Figure 4-34. BRA Instruction Format**



**Figure 4-35. CALLA Instruction Format**

#### 4.5.2.5 Extended Emulated Instructions

The extended instructions together with the constant generator form the extended emulated instructions. [Table 4-15](#) lists the emulated instructions.

**Table 4-15. Extended Emulated Instructions**

| Instruction       | Explanation                            | Emulation             |
|-------------------|----------------------------------------|-----------------------|
| ADCX( .B,.A) dst  | Add carry to dst                       | ADDCX( .B,.A) #0,dst  |
| BRA dst           | Branch indirect dst                    | MOVA dst,PC           |
| RETA              | Return from subroutine                 | MOVA @SP+,PC          |
| CLRA Rdst         | Clear Rdst                             | MOV #0,Rdst           |
| CLRX( .B,.A) dst  | Clear dst                              | MOVX( .B,.A) #0,dst   |
| DADCX( .B,.A) dst | Add carry to dst decimaly              | DADDX( .B,.A) #0,dst  |
| DECX( .B,.A) dst  | Decrement dst by 1                     | SUBX( .B,.A) #1,dst   |
| DECDA Rdst        | Decrement Rdst by 2                    | SUBA #2,Rdst          |
| DECDX( .B,.A) dst | Decrement dst by 2                     | SUBX( .B,.A) #2,dst   |
| INCX( .B,.A) dst  | Increment dst by 1                     | ADDX( .B,.A) #1,dst   |
| INCDA Rdst        | Increment Rdst by 2                    | ADDA #2,Rdst          |
| INCDX( .B,.A) dst | Increment dst by 2                     | ADDX( .B,.A) #2,dst   |
| INVX( .B,.A) dst  | Invert dst                             | XORX( .B,.A) #-1,dst  |
| RLAX( .B,.A) dst  | Shift left dst arithmetically          | ADDX( .B,.A) dst,dst  |
| RLCX( .B,.A) dst  | Shift left dst logically through carry | ADDCX( .B,.A) dst,dst |
| SBCX( .B,.A) dst  | Subtract carry from dst                | SUBCX( .B,.A) #0,dst  |
| TSTA Rdst         | Test Rdst (compare with 0)             | CMPA #0,Rdst          |
| TSTX( .B,.A) dst  | Test dst (compare with 0)              | CMPX( .B,.A) #0,dst   |
| POPX dst          | Pop to dst                             | MOVX( .B,.A) @SP+,dst |

#### 4.5.2.6 MSP430X Address Instructions

MSP430X address instructions are instructions that support 20-bit operands but have restricted addressing modes. The addressing modes are restricted to the Register mode and the Immediate mode, except for the MOVA instruction as listed in [Table 4-16](#). Restricting the addressing modes removes the need for the additional extension-word op-code improving code density and execution time. Address instructions should be used any time an MSP430X instruction is needed with the corresponding restricted addressing mode.

**Table 4-16. Address Instructions, Operate on 20-Bit Register Data**

| Mnemonic | Operands                                                                                                                                     | Operation                                 | Status Bits <sup>(1)</sup> |   |   |   |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------------------|---|---|---|
|          |                                                                                                                                              |                                           | V                          | N | Z | C |
| ADDA     | Rsrc, Rdst<br>#imm20, Rdst                                                                                                                   | Add source to destination register        | *                          | * | * | * |
| MOVA     | Rsrc, Rdst<br>#imm20, Rdst<br>z16(Rsrc), Rdst<br>EDE, Rdst<br>&abs20, Rdst<br>@Rsrc, Rdst<br>@Rsrc+, Rdst<br>Rsrc, z16(Rdst)<br>Rsrc, &abs20 | Move source to destination                | -                          | - | - | - |
| CMPA     | Rsrc, Rdst<br>#imm20, Rdst                                                                                                                   | Compare source to destination register    | *                          | * | * | * |
| SUBA     | Rsrc, Rdst<br>#imm20, Rdst                                                                                                                   | Subtract source from destination register | *                          | * | * | * |

<sup>(1)</sup> \* = Status bit is affected.  
 - = Status bit is not affected.  
 0 = Status bit is cleared.  
 1 = Status bit is set.

#### 4.5.2.7 MSP430X Instruction Execution

The number of CPU clock cycles required for an MSP430X instruction depends on the instruction format and the addressing modes used, not the instruction itself. The number of clock cycles refers to MCLK.

##### 4.5.2.7.1 MSP430X Format II (Single-Operand) Instruction Cycles and Lengths

[Table 4-17](#) lists the length and the CPU cycles for all addressing modes of the MSP430X extended single-operand instructions.

**Table 4-17. MSP430X Format II Instruction Cycles and Length**

| Instruction | Execution Cycles, Length of Instruction (Words) |      |      |      |                      |      |      |
|-------------|-------------------------------------------------|------|------|------|----------------------|------|------|
|             | Rn                                              | @Rn  | @Rn+ | #N   | X(Rn)                | EDE  | &EDE |
| RRAM        | n, 1                                            | —    | —    | —    | —                    | —    | —    |
| RRCM        | n, 1                                            | —    | —    | —    | —                    | —    | —    |
| RRUM        | n, 1                                            | —    | —    | —    | —                    | —    | —    |
| RLAM        | n, 1                                            | —    | —    | —    | —                    | —    | —    |
| PUSHM       | 2+n, 1                                          | —    | —    | —    | —                    | —    | —    |
| PUSHM.A     | 2+2n, 1                                         | —    | —    | —    | —                    | —    | —    |
| POPM        | 2+n, 1                                          | —    | —    | —    | —                    | —    | —    |
| POPM.A      | 2+2n, 1                                         | —    | —    | —    | —                    | —    | —    |
| CALLA       | 5, 1                                            | 6, 1 | 6, 1 | 5, 2 | 5 <sup>(1)</sup> , 2 | 7, 2 | 7, 2 |
| RRAX.(B)    | 1+n, 2                                          | 4, 2 | 4, 2 | —    | 5, 3                 | 5, 3 | 5, 3 |
| RRAX.A      | 1+n, 2                                          | 6, 2 | 6, 2 | —    | 7, 3                 | 7, 3 | 7, 3 |
| RRCX.(B)    | 1+n, 2                                          | 4, 2 | 4, 2 | —    | 5, 3                 | 5, 3 | 5, 3 |
| RRCX.A      | 1+n, 2                                          | 6, 2 | 6, 2 | —    | 7, 3                 | 7, 3 | 7, 3 |
| PUSHX.(B)   | 4, 2                                            | 4, 2 | 4, 2 | 4, 3 | 5 <sup>(1)</sup> , 3 | 5, 3 | 5, 3 |
| PUSHX.A     | 5, 2                                            | 6, 2 | 6, 2 | 5, 3 | 7 <sup>(1)</sup> , 3 | 7, 3 | 7, 3 |
| POPX.(B)    | 3, 2                                            | —    | —    | —    | 5, 3                 | 5, 3 | 5, 3 |
| POPX.A      | 4, 2                                            | —    | —    | —    | 7, 3                 | 7, 3 | 7, 3 |

<sup>(1)</sup> Add one cycle when Rn = SP

#### 4.5.2.7.2 MSP430X Format I (Double-Operand) Instruction Cycles and Lengths

Table 4-18 lists the length and CPU cycles for all addressing modes of the MSP430X extended Format I instructions.

**Table 4-18. MSP430X Format I Instruction Cycles and Length**

| Addressing Mode |                   | No. of Cycles    |                   | Length of Instruction | Examples          |
|-----------------|-------------------|------------------|-------------------|-----------------------|-------------------|
| Source          | Destination       | .B/W             | .A                | .B/W/A                |                   |
| Rn              | Rm <sup>(1)</sup> | 2                | 2                 | 2                     | BITX.B R5,R8      |
|                 | PC                | 4                | 4                 | 2                     | ADDX R9,PC        |
|                 | x(Rm)             | 5 <sup>(2)</sup> | 7 <sup>(3)</sup>  | 3                     | ANDX.A R5,4(R6)   |
|                 | EDE               | 5 <sup>(2)</sup> | 7 <sup>(3)</sup>  | 3                     | XORX R8,EDE       |
|                 | &EDE              | 5 <sup>(2)</sup> | 7 <sup>(3)</sup>  | 3                     | BITX.W R5,&EDE    |
| @Rn             | Rm                | 3                | 4                 | 2                     | BITX @R5,R8       |
|                 | PC                | 5                | 6                 | 2                     | ADDX @R9,PC       |
|                 | x(Rm)             | 6 <sup>(2)</sup> | 9 <sup>(3)</sup>  | 3                     | ANDX.A @R5,4(R6)  |
|                 | EDE               | 6 <sup>(2)</sup> | 9 <sup>(3)</sup>  | 3                     | XORX @R8,EDE      |
|                 | &EDE              | 6 <sup>(2)</sup> | 9 <sup>(3)</sup>  | 3                     | BITX.B @R5,&EDE   |
| @Rn+            | Rm                | 3                | 4                 | 2                     | BITX @R5+,R8      |
|                 | PC                | 5                | 6                 | 2                     | ADDX.A @R9+,PC    |
|                 | x(Rm)             | 6 <sup>(2)</sup> | 9 <sup>(3)</sup>  | 3                     | ANDX @R5+,4(R6)   |
|                 | EDE               | 6 <sup>(2)</sup> | 9 <sup>(3)</sup>  | 3                     | XORX.B @R8+,EDE   |
|                 | &EDE              | 6 <sup>(2)</sup> | 9 <sup>(3)</sup>  | 3                     | BITX @R5+,&EDE    |
| #N              | Rm                | 3                | 3                 | 3                     | BITX #20,R8       |
|                 | PC <sup>(4)</sup> | 4                | 4                 | 3                     | ADDX.A #FE000h,PC |
|                 | x(Rm)             | 6 <sup>(2)</sup> | 8 <sup>(3)</sup>  | 4                     | ANDX #1234,4(R6)  |
|                 | EDE               | 6 <sup>(2)</sup> | 8 <sup>(3)</sup>  | 4                     | XORX #A5A5h,EDE   |
|                 | &EDE              | 6 <sup>(2)</sup> | 8 <sup>(3)</sup>  | 4                     | BITX.B #12,&EDE   |
| x(Rn)           | Rm                | 4                | 5                 | 3                     | BITX 2(R5),R8     |
|                 | PC <sup>(4)</sup> | 6                | 7                 | 3                     | SUBX.A 2(R6),PC   |
|                 | TONI              | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | ANDX 4(R7),4(R6)  |
|                 | x(Rm)             | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | XORX.B 2(R6),EDE  |
|                 | &TONI             | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | BITX 8(SP),&EDE   |
| EDE             | Rm                | 4                | 5                 | 3                     | BITX.B EDE,R8     |
|                 | PC <sup>(4)</sup> | 6                | 7                 | 3                     | ADDX.A EDE,PC     |
|                 | TONI              | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | ANDX EDE,4(R6)    |
|                 | x(Rm)             | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | ANDX EDE,TONI     |
|                 | &TONI             | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | BITX EDE,&TONI    |
| &EDE            | Rm                | 4                | 5                 | 3                     | BITX &EDE,R8      |
|                 | PC <sup>(4)</sup> | 6                | 7                 | 3                     | ADDX.A &EDE,PC    |
|                 | TONI              | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | ANDX.B &EDE,4(R6) |
|                 | x(Rm)             | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | XORX &EDE,TONI    |
|                 | &TONI             | 7 <sup>(2)</sup> | 10 <sup>(3)</sup> | 4                     | BITX &EDE,&TONI   |

<sup>(1)</sup> Repeat instructions require n + 1 cycles, where n is the number of times the instruction is executed.

<sup>(2)</sup> Reduce the cycle count by one for MOV, BIT, and CMP instructions.

<sup>(3)</sup> Reduce the cycle count by two for MOV, BIT, and CMP instructions.

<sup>(4)</sup> Reduce the cycle count by one for MOV, ADD, and SUB instructions.

#### **4.5.2.7.3 MSP430X Address Instruction Cycles and Lengths**

**Table 4-19** lists the length and the CPU cycles for all addressing modes of the MSP430X address instructions.

**Table 4-19. Address Instruction Cycles and Length**

| Addressing Mode |             | Execution Time<br>(MCLK Cycles) |                      | Length of Instruction<br>(Words) |                      | Example         |
|-----------------|-------------|---------------------------------|----------------------|----------------------------------|----------------------|-----------------|
| Source          | Destination | MOVA<br>BRA                     | CMPA<br>ADDA<br>SUBA | MOVA                             | CMPA<br>ADDA<br>SUBA |                 |
| Rn              | Rn          | 1                               | 1                    | 1                                | 1                    | CMPA R5,R8      |
|                 | PC          | 3                               | 3                    | 1                                | 1                    | SUBA R9,PC      |
|                 | x(Rm)       | 4                               | —                    | 2                                | —                    | MOVA R5,4(R6)   |
|                 | EDE         | 4                               | —                    | 2                                | —                    | MOVA R8,EDE     |
|                 | &EDE        | 4                               | —                    | 2                                | —                    | MOVA R5,&EDE    |
|                 | @Rn         | 3                               | —                    | 1                                | —                    | MOVA @R5,R8     |
| @Rn+            | Rm          | 3                               | —                    | 1                                | —                    | MOVA @R9,PC     |
|                 | PC          | 5                               | —                    | 1                                | —                    | MOVA @R9+,PC    |
|                 | Rm          | 3                               | —                    | 1                                | —                    | MOVA @R5+,R8    |
| #N              | Rm          | 2                               | 3                    | 2                                | 2                    | CMPA #20,R8     |
|                 | PC          | 3                               | 3                    | 2                                | 2                    | SUBA #FE000h,PC |
| x(Rn)           | Rm          | 4                               | —                    | 2                                | —                    | MOVA 2(R5),R8   |
|                 | PC          | 6                               | —                    | 2                                | —                    | MOVA 2(R6),PC   |
| EDE             | Rm          | 4                               | —                    | 2                                | —                    | MOVA EDE,R8     |
|                 | PC          | 6                               | —                    | 2                                | —                    | MOVA EDE,PC     |
| &EDE            | Rm          | 4                               | —                    | 2                                | —                    | MOVA &EDE,R8    |
|                 | PC          | 6                               | —                    | 2                                | —                    | MOVA &EDE,PC    |

## 4.6 Instruction Set Description

Table 4-20 shows all available instructions:

**Table 4-20. Instruction Map of MSP430X**

|      | 000 | 040       | 080      | 0C0 | 100 | 140       | 180 | 1C0 | 200          | 240        | 280  | 2C0 | 300  | 340       | 380 | 3C0 |
|------|-----|-----------|----------|-----|-----|-----------|-----|-----|--------------|------------|------|-----|------|-----------|-----|-----|
| 0xxx |     |           |          |     |     |           |     |     |              |            |      |     |      |           |     |     |
| 10xx | RRC | RRC.<br>B | SWP<br>B |     | RRA | RRA.<br>B | SXT |     | PUS<br>H     | PUS<br>H.B | CALL |     | RETI | CALL<br>A |     |     |
| 14xx |     |           |          |     |     |           |     |     |              |            |      |     |      |           |     |     |
| 18xx |     |           |          |     |     |           |     |     |              |            |      |     |      |           |     |     |
| 1Cxx |     |           |          |     |     |           |     |     |              |            |      |     |      |           |     |     |
| 20xx |     |           |          |     |     |           |     |     | JNE, JNZ     |            |      |     |      |           |     |     |
| 24xx |     |           |          |     |     |           |     |     | JEQ, JZ      |            |      |     |      |           |     |     |
| 28xx |     |           |          |     |     |           |     |     | JNC          |            |      |     |      |           |     |     |
| 2Cxx |     |           |          |     |     |           |     |     | JC           |            |      |     |      |           |     |     |
| 30xx |     |           |          |     |     |           |     |     | JN           |            |      |     |      |           |     |     |
| 34xx |     |           |          |     |     |           |     |     | JGE          |            |      |     |      |           |     |     |
| 38xx |     |           |          |     |     |           |     |     | JL           |            |      |     |      |           |     |     |
| 3Cxx |     |           |          |     |     |           |     |     | JMP          |            |      |     |      |           |     |     |
| 4xxx |     |           |          |     |     |           |     |     | MOV, MOV.B   |            |      |     |      |           |     |     |
| 5xxx |     |           |          |     |     |           |     |     | ADD, ADD.B   |            |      |     |      |           |     |     |
| 6xxx |     |           |          |     |     |           |     |     | ADDC, ADDC.B |            |      |     |      |           |     |     |
| 7xxx |     |           |          |     |     |           |     |     | SUBC, SUBC.B |            |      |     |      |           |     |     |
| 8xxx |     |           |          |     |     |           |     |     | SUB, SUB.B   |            |      |     |      |           |     |     |
| 9xxx |     |           |          |     |     |           |     |     | CMP, CMP.B   |            |      |     |      |           |     |     |
| Axxx |     |           |          |     |     |           |     |     | DADD, DADD.B |            |      |     |      |           |     |     |
| Bxxx |     |           |          |     |     |           |     |     | BIT, BIT.B   |            |      |     |      |           |     |     |
| Cxxx |     |           |          |     |     |           |     |     | BIC, BIC.B   |            |      |     |      |           |     |     |
| Dxxx |     |           |          |     |     |           |     |     | BIS, BIS.B   |            |      |     |      |           |     |     |
| Exxx |     |           |          |     |     |           |     |     | XOR, XOR.B   |            |      |     |      |           |     |     |
| Fxxx |     |           |          |     |     |           |     |     | AND, AND.B   |            |      |     |      |           |     |     |

#### 4.6.1 Extended Instruction Binary Descriptions

Detailed MSP430X instruction binary descriptions are shown in the following tables.

| Instruction | Instruction Group |    |    |   | src or data.19:16 |            |  |   | Instruction Identifier |   |   |  | dst        |  |                     |
|-------------|-------------------|----|----|---|-------------------|------------|--|---|------------------------|---|---|--|------------|--|---------------------|
|             | 15                | 12 | 11 |   | 8                 | 7          |  | 4 | 3                      |   | 0 |  |            |  |                     |
| MOVA        | 0                 | 0  | 0  | 0 |                   | src        |  | 0 | 0                      | 0 | 0 |  | dst        |  | MOVA @Rsrc,Rdst     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 0 | 0                      | 0 | 1 |  | dst        |  | MOVA @Rsrc+,Rdst    |
|             | 0                 | 0  | 0  | 0 |                   | &abs.19:16 |  | 0 | 0                      | 1 | 0 |  | dst        |  | MOVA &abs20,Rdst    |
|             | &abs.15:0         |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 0 | 0                      | 1 | 1 |  | dst        |  | MOVA z16(Rsrc),Rdst |
|             | x.15:0            |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 0 | 1                      | 1 | 0 |  | &abs.19:16 |  | MOVA Rsrc,&abs20    |
|             | &abs.15:0         |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 0 | 1                      | 1 | 1 |  | dst        |  | MOVA Rsrc,z16(Rdst) |
|             | x.15:0            |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | imm.19:16  |  | 1 | 0                      | 0 | 0 |  | dst        |  | MOVA #imm20,Rdst    |
| CMPA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | imm.19:16  |  | 1 | 0                      | 0 | 1 |  | dst        |  | CMPA #imm20,Rdst    |
| ADDA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | imm.19:16  |  | 1 | 0                      | 1 | 0 |  | dst        |  | ADDA #imm20,Rdst    |
| SUBA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | imm.19:16  |  | 1 | 0                      | 1 | 1 |  | dst        |  | SUBA #imm20,Rdst    |
| MOVA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 1 | 1                      | 0 | 0 |  | dst        |  | MOVA Rsrc,Rdst      |
| CMPA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 1 | 1                      | 0 | 1 |  | dst        |  | CMPA Rsrc,Rdst      |
| ADDA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 1 | 1                      | 1 | 0 |  | dst        |  | ADDA Rsrc,Rdst      |
| SUBA        | imm.15:0          |    |    |   |                   |            |  |   |                        |   |   |  |            |  |                     |
|             | 0                 | 0  | 0  | 0 |                   | src        |  | 1 | 1                      | 1 | 1 |  | dst        |  | SUBA Rsrc,Rdst      |

| Instruction | Instruction Group |    |    |    | Bit Loc. | Inst. ID | Instruction Identifier |   |   |   | dst |   |     |                |
|-------------|-------------------|----|----|----|----------|----------|------------------------|---|---|---|-----|---|-----|----------------|
|             | 15                | 12 | 11 | 10 |          |          | 9                      | 8 | 7 |   | 4   | 3 | 0   |                |
| RRCM.A      | 0                 | 0  | 0  | 0  | n - 1    | 0        | 0                      | 0 | 1 | 0 | 0   |   | dst | RRCM.A #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 0        | 1                      | 0 | 1 | 0 | 0   |   | dst | RRAM.A #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 1        | 0                      | 0 | 1 | 0 | 0   |   | dst | RLAM.A #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 1        | 1                      | 0 | 1 | 0 | 0   |   | dst | RRUM.A #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 0        | 0                      | 0 | 1 | 0 | 1   |   | dst | RRCM.W #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 0        | 1                      | 0 | 0 | 1 | 0   |   | dst | RRAM.W #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 1        | 0                      | 0 | 1 | 0 | 1   |   | dst | RLAM.W #n,Rdst |
|             | 0                 | 0  | 0  | 0  | n - 1    | 1        | 1                      | 0 | 1 | 0 | 1   |   | dst | RRUM.W #n,Rdst |

| Instruction | Instruction Identifier |    |    |   |   |   |   |   |       |   |   |   | dst         |   |   |   |                 |
|-------------|------------------------|----|----|---|---|---|---|---|-------|---|---|---|-------------|---|---|---|-----------------|
|             | 15                     | 12 | 11 | 8 | 7 | 6 | 5 | 4 | 3     | 0 |   |   |             |   |   |   |                 |
| RETI        | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 0     | 0 | 0 | 0 | 0           | 0 | 0 | 0 |                 |
| CALLA       | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 0     | 1 | 0 | 0 | dst         |   |   |   | CALLA Rdst      |
|             | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 0     | 1 | 0 | 1 | dst         |   |   |   | CALLA x(Rdst)   |
|             | x.15:0                 |    |    |   |   |   |   |   |       |   |   |   |             |   |   |   |                 |
|             | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 0     | 1 | 1 | 0 | dst         |   |   |   | CALLA @Rdst     |
|             | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 0     | 1 | 1 | 1 | dst         |   |   |   | CALLA @Rdst+    |
|             | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 1     | 0 | 0 | 0 | &abs.19:16  |   |   |   | CALLA &abs20    |
|             | &abs.15:0              |    |    |   |   |   |   |   |       |   |   |   |             |   |   |   |                 |
|             | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 1     | 0 | 0 | 1 | x.19:16     |   |   |   | CALLA EDE       |
|             | x.15:0                 |    |    |   |   |   |   |   |       |   |   |   |             |   |   |   | CALLA x(PC)     |
|             | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 1     | 0 | 1 | 1 | imm.19:16   |   |   |   | CALLA #imm20    |
|             | imm.15:0               |    |    |   |   |   |   |   |       |   |   |   |             |   |   |   |                 |
| Reserved    | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 1     | 0 | 1 | 0 | x           | x | x | x |                 |
| Reserved    | 0                      | 0  | 0  | 1 | 0 | 0 | 1 | 1 | 1     | 1 | x | x | x           | x | x | x |                 |
| PUSHM.A     | 0                      | 0  | 0  | 1 | 0 | 1 | 0 | 0 | n - 1 |   |   |   | dst         |   |   |   | PUSHM.A #n,Rdst |
| PUSHM.W     | 0                      | 0  | 0  | 1 | 0 | 1 | 0 | 1 | n - 1 |   |   |   | dst         |   |   |   | PUSHM.W #n,Rdst |
| POPM.A      | 0                      | 0  | 0  | 1 | 0 | 1 | 1 | 0 | n - 1 |   |   |   | dst - n + 1 |   |   |   | POPM.A #n,Rdst  |
| POPM.W      | 0                      | 0  | 0  | 1 | 0 | 1 | 1 | 1 | n - 1 |   |   |   | dst - n + 1 |   |   |   | POPM.W #n,Rdst  |

#### 4.6.2 MSP430 Instructions

The MSP430 instructions are listed and described on the following pages.

#### 4.6.2.1 ADC

|                    |                                                                                                                                                                                                                                                                                               |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * <b>ADC.W</b>     | Add carry to destination                                                                                                                                                                                                                                                                      |
| * <b>ADC.B</b>     | Add carry to destination                                                                                                                                                                                                                                                                      |
| <b>Syntax</b>      | ADC dst or                                   ADC.W dst<br>ADC.B dst                                                                                                                                                                                                                           |
| <b>Operation</b>   | dst + C → dst                                                                                                                                                                                                                                                                                 |
| <b>Emulation</b>   | ADDC #0, dst<br>ADDC.B #0, dst                                                                                                                                                                                                                                                                |
| <b>Description</b> | The carry bit (C) is added to the destination operand. The previous contents of the destination are lost.                                                                                                                                                                                     |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if result is zero, reset otherwise<br>C: Set if dst was incremented from 0FFFFh to 0000, reset otherwise<br>Set if dst was incremented from 0FFh to 00, reset otherwise<br>V: Set if an arithmetic overflow occurs, otherwise reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                     |
| <b>Example</b>     | The 16-bit counter pointed to by R13 is added to a 32-bit counter pointed to by R12.                                                                                                                                                                                                          |

```
ADD    @R13,0(R12)      ; Add LSDs
ADC    2(R12)          ; Add carry to MSD
```

|                |                                                                                     |
|----------------|-------------------------------------------------------------------------------------|
| <b>Example</b> | The 8-bit counter pointed to by R13 is added to a 16-bit counter pointed to by R12. |
|----------------|-------------------------------------------------------------------------------------|

```
ADD.B  @R13,0(R12)      ; Add LSDs
ADC.B  1(R12)          ; Add carry to MSD
```

#### 4.6.2.2 ADD

|                    |                                                                                                                                                                                                                                                                                                                                |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ADD[.W]</b>     | Add source word to destination word                                                                                                                                                                                                                                                                                            |
| <b>ADD.B</b>       | Add source byte to destination byte                                                                                                                                                                                                                                                                                            |
| <b>Syntax</b>      | ADD src,dst or ADD.W src,dst<br>ADD.B src,dst                                                                                                                                                                                                                                                                                  |
| <b>Operation</b>   | src + dst → dst                                                                                                                                                                                                                                                                                                                |
| <b>Description</b> | The source operand is added to the destination operand. The previous content of the destination is lost.                                                                                                                                                                                                                       |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB of the result, reset otherwise<br>V: Set if the result of two positive operands is negative, or if the result of two negative numbers is positive, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | Ten is added to the 16-bit counter CNTR located in lower 64 K.                                                                                                                                                                                                                                                                 |

```
ADD.W #10,&CNTR ; Add 10 to 16-bit counter
```

|                |                                                                                                                      |
|----------------|----------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address in R5) is added to R6. The jump to label TONI is performed on a carry. |
|----------------|----------------------------------------------------------------------------------------------------------------------|

```
ADD.W @R5,R6 ; Add table word to R6. R6.19:16 = 0
JC    TONI   ; Jump if carry
...               ; No carry
```

|                |                                                                                                                                                                                |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is added to R6. The jump to label TONI is performed if no carry occurs. The table pointer is auto-incremented by 1. R6.19:8 = 0 |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
ADD.B @R5+,R6 ; Add byte to R6. R5 + 1. R6: 000xxh
JNC   TONI   ; Jump if no carry
...               ; Carry occurred
```

### 4.6.2.3 ADDC

|                    |                                                                                                                                                                                                                                                                                                                                |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ADDC.W</b>      | Add source word and carry to destination word                                                                                                                                                                                                                                                                                  |
| <b>ADDC.B</b>      | Add source byte and carry to destination byte                                                                                                                                                                                                                                                                                  |
| <b>Syntax</b>      | ADDC src,dst or ADDC.W src,dst<br>ADDC.B src,dst                                                                                                                                                                                                                                                                               |
| <b>Operation</b>   | src + dst + C → dst                                                                                                                                                                                                                                                                                                            |
| <b>Description</b> | The source operand and the carry bit C are added to the destination operand. The previous content of the destination is lost.                                                                                                                                                                                                  |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB of the result, reset otherwise<br>V: Set if the result of two positive operands is negative, or if the result of two negative numbers is positive, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | Constant value 15 and the carry of the previous instruction are added to the 16-bit counter CNTR located in lower 64 K.                                                                                                                                                                                                        |

```
ADDC.W      #15,&CNTR      ; Add 15 + C to 16-bit CNTR
```

|                |                                                                                                                                              |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) and the carry C are added to R6. The jump to label TONI is performed on a carry. R6.19:16 = 0 |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------|

```
ADDC.W      @R5,R6      ; Add table word + C to R6
JC          TONI       ; Jump if carry
...          ...        ; No carry
```

|                |                                                                                                                                                                                                     |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) and the carry bit C are added to R6. The jump to label TONI is performed if no carry occurs. The table pointer is auto-incremented by 1. R6.19:8 = 0 |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
ADDC.B      @R5+,R6     ; Add table byte + C to R6. R5 + 1
JNC         TONI       ; Jump if no carry
...          ...        ; Carry occurred
```

#### 4.6.2.4 AND

|                    |                                                                                                                                                                                                  |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>AND[.W]</b>     | Logical AND of source word with destination word                                                                                                                                                 |
| <b>AND.B</b>       | Logical AND of source byte with destination byte                                                                                                                                                 |
| <b>Syntax</b>      | AND src,dst or AND.W src,dst<br>AND.B src,dst                                                                                                                                                    |
| <b>Operation</b>   | src .and. dst → dst                                                                                                                                                                              |
| <b>Description</b> | The source operand and the destination operand are logically ANDed. The result is placed into the destination. The source operand is not affected.                                               |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if the result is not zero, reset otherwise. C = (.not. Z)<br>V: Reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                        |
| <b>Example</b>     | The bits set in R5 (16-bit data) are used as a mask (AA55h) for the word TOM located in the lower 64 K. If the result is zero, a branch is taken to label TONI. R5.19:16 = 0                     |

```

MOV #AA55h,R5      ; Load 16-bit mask to R5
AND R5 ,&TOM       ; TOM .and. R5 -> TOM
JZ TONI            ; Jump if result 0
...

```

or shorter:

```

AND #AA55h,&TOM    ; TOM .and. AA55h -> TOM
JZ TONI            ; Jump if result 0

```

|                |                                                                                                                                               |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is logically ANDed with R6. R5 is incremented by 1 after the fetching of the byte. R6.19:8 = 0 |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|

```
AND.B @R5+,R6      ; AND table byte with R6. R5 + 1
```

#### 4.6.2.5 BIC

|                    |                                                                                                                                                             |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BIC[.W]</b>     | Clear bits set in source word in destination word                                                                                                           |
| <b>BIC.B</b>       | Clear bits set in source byte in destination byte                                                                                                           |
| <b>Syntax</b>      | BIC src,dst or BIC.W src,dst<br>BIC.B src,dst                                                                                                               |
| <b>Operation</b>   | (.not. src) .and. dst → dst                                                                                                                                 |
| <b>Description</b> | The inverted source operand and the destination operand are logically ANDed. The result is placed into the destination. The source operand is not affected. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                                    |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                   |
| <b>Example</b>     | The bits 15:14 of R5 (16-bit data) are cleared. R5.19:16 = 0                                                                                                |

```
BIC #0C000h,R5      ; Clear R5.19:14 bits
```

|                |                                                                                          |
|----------------|------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is used to clear bits in R7. R7.19:16 = 0 |
|----------------|------------------------------------------------------------------------------------------|

```
BIC.W @R5,R7      ; Clear bits in R7 set in @R5
```

|                |                                                                                |
|----------------|--------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is used to clear bits in Port1. |
|----------------|--------------------------------------------------------------------------------|

```
BIC.B @R5,&P1OUT    ; Clear I/O port P1 bits set in @R5
```

#### **4.6.2.6 BIS**

|                    |                                                                                                                                                   |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BIS[.W]</b>     | Set bits set in source word in destination word                                                                                                   |
| <b>BIS.B</b>       | Set bits set in source byte in destination byte                                                                                                   |
| <b>Syntax</b>      | <code>BIS src,dst</code> or <code>BIS.W src,dst</code><br><code>BIS.B src,dst</code>                                                              |
| <b>Operation</b>   | <code>src .or. dst → dst</code>                                                                                                                   |
| <b>Description</b> | The source operand and the destination operand are logically ORed. The result is placed into the destination. The source operand is not affected. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                          |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                         |
| <b>Example</b>     | Bits 15 and 13 of R5 (16-bit data) are set to one. $R5.19:16 = 0$                                                                                 |

```
BIS      #A000h,R5          ; Set R5 bits
```

|                |                                                                                          |
|----------------|------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is used to set bits in R7. $R7.19:16 = 0$ |
|----------------|------------------------------------------------------------------------------------------|

```
BIS.W    @R5+,R7          ; Set bits in R7
```

|                |                                                                                                                 |
|----------------|-----------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is used to set bits in Port1. R5 is incremented by 1 afterwards. |
|----------------|-----------------------------------------------------------------------------------------------------------------|

```
BIS.B    @R5+,&P1OUT       ; Set I/O port P1 bits. R5 + 1
```

#### 4.6.2.7 BIT

|                    |                                                                                                                                                                                                               |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BIT[.W]</b>     | Test bits set in source word in destination word                                                                                                                                                              |
| <b>BIT.B</b>       | Test bits set in source byte in destination byte                                                                                                                                                              |
| <b>Syntax</b>      | BIT src,dst or BIT.W src,dst<br>BIT.B src,dst                                                                                                                                                                 |
| <b>Operation</b>   | src .and. dst                                                                                                                                                                                                 |
| <b>Description</b> | The source operand and the destination operand are logically ANDed. The result affects only the status bits in SR.<br>Register mode: the register bits Rdst.19:16 (.W) resp. Rdst. 19:8 (.B) are not cleared! |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if the result is not zero, reset otherwise. C = (.not. Z)<br>V: Reset              |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                     |
| <b>Example</b>     | Test if one (or both) of bits 15 and 14 of R5 (16-bit data) is set. Jump to label TONI if this is the case. R5.19:16 are not affected.                                                                        |

```
BIT      #C000h,R5      ; Test R5.15:14 bits
JNZ     TONI           ; At least one bit is set in R5
...                 ; Both bits are reset
```

|                |                                                                                                                                                      |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is used to test bits in R7. Jump to label TONI if at least one bit is set. R7.19:16 are not affected. |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------|

```
BIT.W    @R5+,R7        ; Test bits in R7
JC      TONI           ; At least one bit is set
...                 ; Both are reset
```

|                |                                                                                                                                                             |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is used to test bits in output Port1. Jump to label TONI if no bit is set. The next table byte is addressed. |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
BIT.B    @R5+,&P1OUT    ; Test I/O port P1 bits. R5 + 1
JNC     TONI           ; No corresponding bit is set
...                 ; At least one bit is set
```

#### 4.6.2.8 BR, BRANCH

|                         |                                                                                                                                                                                |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* BR,<br/>BRANCH</b> | Branch to destination in lower 64K address space                                                                                                                               |
| <b>Syntax</b>           | BR dst                                                                                                                                                                         |
| <b>Operation</b>        | dst → PC                                                                                                                                                                       |
| <b>Emulation</b>        | MOV dst,PC                                                                                                                                                                     |
| <b>Description</b>      | An unconditional branch is taken to an address anywhere in the lower 64K address space. All source addressing modes can be used. The branch instruction is a word instruction. |
| <b>Status Bits</b>      | Status bits are not affected.                                                                                                                                                  |
| <b>Example</b>          | Examples for all addressing modes are given.                                                                                                                                   |

```

BR      #EXEC      ; Branch to label EXEC or direct branch (for example #0A4h)
          ; Core instruction MOV @PC+,PC

BR      EXEC       ; Branch to the address contained in EXEC
          ; Core instruction MOV X(PC),PC
          ; Indirect address

BR      &EXEC      ; Branch to the address contained in absolute
          ; address EXEC
          ; Core instruction MOV X(0),PC
          ; Indirect address

BR      R5         ; Branch to the address contained in R5
          ; Core instruction MOV R5,PC
          ; Indirect R5

BR      @R5        ; Branch to the address contained in the word
          ; pointed to by R5.
          ; Core instruction MOV @R5,PC
          ; Indirect, indirect R5

BR      @R5+       ; Branch to the address contained in the word pointed
          ; to by R5 and increment pointer in R5 afterwards.
          ; The next time-S/W flow uses R5 pointer-it can
          ; alter program execution due to access to
          ; next address in a table pointed to by R5
          ; Core instruction MOV @R5,PC
          ; Indirect, indirect R5 with autoincrement

BR      X(R5)     ; Branch to the address contained in the address
          ; pointed to by R5 + X (for example table with address
          ; starting at X). X can be an address or a label
          ; Core instruction MOV X(R5),PC
          ; Indirect, indirect R5 + X

```

#### 4.6.2.9 CALL

|                    |                                                                                                                                                                                                                                                |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CALL</b>        | Call a subroutine in lower 64 K                                                                                                                                                                                                                |
| <b>Syntax</b>      | CALL dst                                                                                                                                                                                                                                       |
| <b>Operation</b>   | <p>dst → tmp 16-bit dst is evaluated and stored</p> <p>SP – 2 → SP</p> <p>PC → @SP updated PC with return address to TOS</p> <p>tmp → PC saved 16-bit dst to PC</p>                                                                            |
| <b>Description</b> | A subroutine call is made from an address in the lower 64 K to a subroutine address in the lower 64 K. All seven source addressing modes can be used. The call instruction is a word instruction. The return is made with the RET instruction. |
| <b>Status Bits</b> | Status bits are not affected.<br>PC.19:16 cleared (address in lower 64 K)                                                                                                                                                                      |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                      |
| <b>Examples</b>    | Examples for all addressing modes are given.<br><br>Immediate Mode: Call a subroutine at label EXEC (lower 64 K) or call directly to address.                                                                                                  |

```
CALL #EXEC           ; Start address EXEC
CALL #0AA04h         ; Start address 0AA04h
```

Symbolic Mode: Call a subroutine at the 16-bit address contained in address EXEC. EXEC is located at the address (PC + X) where X is within PC ± 32 K.

```
CALL EXEC           ; Start address at @EXEC. z16(PC)
```

Absolute Mode: Call a subroutine at the 16-bit address contained in absolute address EXEC in the lower 64 K.

```
CALL &EXEC          ; Start address at @EXEC
```

Register mode: Call a subroutine at the 16-bit address contained in register R5.15:0.

```
CALL R5             ; Start address at R5
```

Indirect Mode: Call a subroutine at the 16-bit address contained in the word pointed to by register R5 (20-bit address).

```
CALL @R5            ; Start address at @R5
```

#### 4.6.2.10 CLR

|                    |                                     |
|--------------------|-------------------------------------|
| * CLR[.W]          | Clear destination                   |
| * CLR.B            | Clear destination                   |
| <b>Syntax</b>      | CLR dst or<br>CLR.B dst             |
| <b>Operation</b>   | $0 \rightarrow \text{dst}$          |
| <b>Emulation</b>   | MOV #0,dst<br>MOV.B #0,dst          |
| <b>Description</b> | The destination operand is cleared. |
| <b>Status Bits</b> | Status bits are not affected.       |
| <b>Example</b>     | RAM word TONI is cleared.           |

CLR      TONI      ; 0 -> TONI

**Example**    Register R5 is cleared.

CLR      R5

**Example**    RAM byte TONI is cleared.

CLR.B    TONI      ; 0 -> TONI

#### 4.6.2.11 CLRC

|                    |                                                                                              |
|--------------------|----------------------------------------------------------------------------------------------|
| * <b>CLRC</b>      | Clear carry bit                                                                              |
| <b>Syntax</b>      | CLRC                                                                                         |
| <b>Operation</b>   | $0 \rightarrow C$                                                                            |
| <b>Emulation</b>   | BIC #1,SR                                                                                    |
| <b>Description</b> | The carry bit (C) is cleared. The clear carry instruction is a word instruction.             |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Cleared<br>V: Not affected                          |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                    |
| <b>Example</b>     | The 16-bit decimal counter pointed to by R13 is added to a 32-bit counter pointed to by R12. |

```
CLRC          ; C=0: defines start
DADD  @R13,0(R12)    ; add 16-bit counter to low word of 32-bit counter
DADC  2(R12)        ; add carry to high word of 32-bit counter
```

#### 4.6.2.12 CLRN

**\* CLRN** Clear negative bit

**Syntax** CLRN

**Operation**  $0 \rightarrow N$

or

$(.\text{NOT}.\text{src} .\text{AND}. \text{dst} \rightarrow \text{dst})$

**Emulation** BIC #4,SR

**Description** The constant 04h is inverted (0FFFh) and is logically ANDed with the destination operand. The result is placed into the destination. The clear negative bit instruction is a word instruction.

**Status Bits** N: Reset to 0

Z: Not affected

C: Not affected

V: Not affected

**Mode Bits** OSCOFF, CPUOFF, and GIE are not affected.

**Example** The negative bit in the SR is cleared. This avoids special treatment with negative numbers of the subroutine called.

```

CLRN
CALL    SUBR
.....
.....
SUBR    JN      SUBRET      ; If input is negative: do nothing and return
.....
.....
.....
SUBRET   RET

```

#### 4.6.2.13 CLRZ

|                    |                                                                                                                                                                                          |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* CLRZ</b>      | Clear zero bit                                                                                                                                                                           |
| <b>Syntax</b>      | CLRZ                                                                                                                                                                                     |
| <b>Operation</b>   | $0 \rightarrow Z$<br>or<br>$(\text{NOT}.\text{src} \cdot \text{AND. dst} \rightarrow \text{dst})$                                                                                        |
| <b>Emulation</b>   | BIC #2,SR                                                                                                                                                                                |
| <b>Description</b> | The constant 02h is inverted (0FFFDh) and logically ANDed with the destination operand. The result is placed into the destination. The clear zero bit instruction is a word instruction. |
| <b>Status Bits</b> | N: Not affected<br>Z: Reset to 0<br>C: Not affected<br>V: Not affected                                                                                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                |
| <b>Example</b>     | The zero bit in the SR is cleared.                                                                                                                                                       |

CLRZ

Indirect, Auto-Increment mode: Call a subroutine at the 16-bit address contained in the word pointed to by register R5 (20-bit address) and increment the 16-bit address in R5 afterwards by 2. The next time the software uses R5 as a pointer, it can alter the program execution due to access to the next word address in the table pointed to by R5.

CALL @R5+ ; Start address at @R5. R5 + 2

Indexed mode: Call a subroutine at the 16-bit address contained in the 20-bit address pointed to by register (R5 + X); for example, a table with addresses starting at X. The address is within the lower 64KB. X is within  $\pm 32\text{KB}$ .

CALL X(R5) ; Start address at @(R5+X). z16(R5)

#### 4.6.2.14 CMP

|                    |                                                                                                                                                                                              |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CMP[.W]</b>     | Compare source word and destination word                                                                                                                                                     |
| <b>CMP.B</b>       | Compare source byte and destination byte                                                                                                                                                     |
| <b>Syntax</b>      | CMP src,dst or CMP.W src,dst<br>CMP.B src,dst                                                                                                                                                |
| <b>Operation</b>   | $(\text{not}.\text{src}) + 1 + \text{dst}$<br>or<br>$\text{dst} - \text{src}$                                                                                                                |
| <b>Description</b> | The source operand is subtracted from the destination operand. This is made by adding the 1s complement of the source + 1 to the destination. The result affects only the status bits in SR. |

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Status Bits</b> | Register mode: the register bits Rdst.19:16 (.W) resp. Rdst. 19:8 (.B) are not cleared.<br>N: Set if result is negative ( $\text{src} > \text{dst}$ ), reset if positive ( $\text{src} \leq \text{dst}$ )<br>Z: Set if result is zero ( $\text{src} = \text{dst}$ ), reset otherwise ( $\text{src} \neq \text{dst}$ )<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow). |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

**Mode Bits** OSCOFF, CPUOFF, and GIE are not affected.

**Example** Compare word EDE with a 16-bit constant 1800h. Jump to label TONI if EDE equals the constant. The address of EDE is within PC + 32 K.

```
CMP      #01800h,EDE      ; Compare word EDE with 1800h
JEQ      TONI            ; EDE contains 1800h
...
; Not equal
```

**Example** A table word pointed to by (R5 + 10) is compared with R7. Jump to label TONI if R7 contains a lower, signed 16-bit number. R7.19:16 is not cleared. The address of the source operand is a 20-bit address in full memory range.

```
CMP.W    10(R5),R7        ; Compare two signed numbers
JL      TONI            ; R7 < 10(R5)
...
; R7 >= 10(R5)
```

**Example** A table byte pointed to by R5 (20-bit address) is compared to the value in output Port1. Jump to label TONI if values are equal. The next table byte is addressed.

```
CMP.B    @R5+,&P1OUT      ; Compare P1 bits with table. R5 + 1
JEQ      TONI            ; Equal contents
...
; Not equal
```

#### 4.6.2.15 DADC

|                    |                                                                                                                                                                                                                  |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* DADC.W</b>    | Add carry decimal to destination                                                                                                                                                                                 |
| <b>* DADC.B</b>    | Add carry decimal to destination                                                                                                                                                                                 |
| <b>Syntax</b>      | DADC dst or<br>DADC.B dst                                                                                                                                                                                        |
| <b>Operation</b>   | dst + C → dst (decimally)                                                                                                                                                                                        |
| <b>Emulation</b>   | DADD #0, dst<br>DADD.B #0, dst                                                                                                                                                                                   |
| <b>Description</b> | The carry bit (C) is added decimal to the destination.                                                                                                                                                           |
| <b>Status Bits</b> | N: Set if MSB is 1<br>Z: Set if dst is 0, reset otherwise<br>C: Set if destination increments from 9999 to 0000, reset otherwise<br>Set if destination increments from 99 to 00, reset otherwise<br>V: Undefined |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                        |
| <b>Example</b>     | The four-digit decimal number contained in R5 is added to an eight-digit decimal number pointed to by R8.                                                                                                        |

```

CLRC          ; Reset carry
              ; next instruction's start condition is defined
DADD  R5,0(R8)    ; Add LSDs + C
DADC  2(R8)      ; Add carry to MSD

```

|                |                                                                                                        |
|----------------|--------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The two-digit decimal number contained in R5 is added to a four-digit decimal number pointed to by R8. |
|----------------|--------------------------------------------------------------------------------------------------------|

```

CLRC          ; Reset carry
              ; next instruction's start condition is defined
DADD.B R5,0(R8)    ; Add LSDs + C
DADC  1(R8)      ; Add carry to MSDs

```

#### 4.6.2.16 DADD

|                    |                                                                                                                                                                                                                                                                                                                                                               |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* DADD.W</b>    | Add source word and carry decimal to destination word                                                                                                                                                                                                                                                                                                         |
| <b>* DADD.B</b>    | Add source byte and carry decimal to destination byte                                                                                                                                                                                                                                                                                                         |
| <b>Syntax</b>      | DADD src,dst or DADD.W src,dst<br><br>DADD.B src,dst                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | $src + dst + C \rightarrow dst$ (decimally)                                                                                                                                                                                                                                                                                                                   |
| <b>Description</b> | The source operand and the destination operand are treated as two (.B) or four (.W) binary coded decimals (BCD) with positive signs. The source operand and the carry bit C are added decimal to the destination operand. The source operand is not affected. The previous content of the destination is lost. The result is not defined for non-BCD numbers. |
| <b>Status Bits</b> | N: Set if MSB of result is 1 (word > 7999h, byte > 79h), reset if MSB is 0<br><br>Z: Set if result is zero, reset otherwise<br><br>C: Set if the BCD result is too large (word > 9999h, byte > 99h), reset otherwise<br><br>V: Undefined                                                                                                                      |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                     |
| <b>Example</b>     | Decimal 10 is added to the 16-bit BCD counter DECCNTR.                                                                                                                                                                                                                                                                                                        |

```
DADD #10h,&DECCNTR ; Add 10 to 4-digit BCD counter
```

|                |                                                                                                                                                                                                                     |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The eight-digit BCD number contained in 16-bit RAM addresses BCD and BCD+2 is added decimal to an eight-digit BCD number contained in R4 and R5 (BCD+2 and R5 contain the MSDs). The carry C is added, and cleared. |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
CLRC ; Clear carry
DADD.W &BCD,R4 ; Add LSDs. R4.19:16 = 0
DADD.W &BCD+2,R5 ; Add MSDs with carry. R5.19:16 = 0
JC OVERFLOW ; Result >9999,9999: go to error routine
... ; Result ok
```

|                |                                                                                                                                                                     |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The two-digit BCD number contained in word BCD (16-bit address) is added decimal to a two-digit BCD number contained in R4. The carry C is added, also. R4.19:8 = 0 |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
CLRC ; Clear carry
DADD.B &BCD,R4 ; Add BCD to R4 decimal.
R4: 0,00ddh
```

#### 4.6.2.17 DEC

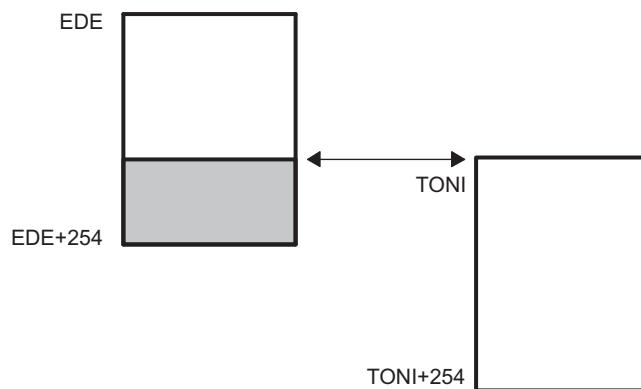
|                    |                                                                                                                                                                                                                                                                                                                                                |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * DEC.W            | Decrement destination                                                                                                                                                                                                                                                                                                                          |
| * DEC.B            | Decrement destination                                                                                                                                                                                                                                                                                                                          |
| <b>Syntax</b>      | DEC dst or<br>DEC.B dst                                                                                                                                                                                                                                                                                                                        |
| <b>Operation</b>   | $dst - 1 \rightarrow dst$                                                                                                                                                                                                                                                                                                                      |
| <b>Emulation</b>   | SUB #1,dst<br>SUB.B #1,dst                                                                                                                                                                                                                                                                                                                     |
| <b>Description</b> | The destination operand is decremented by one. The original contents are lost.                                                                                                                                                                                                                                                                 |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if dst contained 1, reset otherwise<br>C: Reset if dst contained 0, set otherwise<br>V: Set if an arithmetic overflow occurs, otherwise reset.<br>Set if initial value of destination was 08000h, otherwise reset.<br>Set if initial value of destination was 080h, otherwise reset. |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | R10 is decremented by 1.                                                                                                                                                                                                                                                                                                                       |

```
DEC      R10          ; Decrement R10
```

```
; Move a block of 255 bytes from memory location starting with EDE to
; memory location starting with TONI. Tables should not overlap: start of
; destination address TONI must not be within the range EDE to EDE+0FEh
```

```
MOV      #EDE,R6
MOV      #255,R10
L$1    MOV.B   @R6+,TONI-EDE-1(R6)
DEC      R10
JNZ      L$1
```

Do not transfer tables using the routine above with the overlap shown in [Figure 4-36](#).



**Figure 4-36. Decrement Overlap**

#### 4.6.2.18 DECD

|                    |                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* DECD.W</b>    | Double-decrement destination                                                                                                                                                                                                                                                                                                                                     |
| <b>* DECD.B</b>    | Double-decrement destination                                                                                                                                                                                                                                                                                                                                     |
| <b>Syntax</b>      | DECD dst or<br>DECD.B dst                                                                                                                                                                                                                                                                                                                                        |
| <b>Operation</b>   | $dst - 2 \rightarrow dst$                                                                                                                                                                                                                                                                                                                                        |
| <b>Emulation</b>   | SUB #2,dst<br>SUB.B #2,dst                                                                                                                                                                                                                                                                                                                                       |
| <b>Description</b> | The destination operand is decremented by two. The original contents are lost.                                                                                                                                                                                                                                                                                   |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if dst contained 2, reset otherwise<br>C: Reset if dst contained 0 or 1, set otherwise<br>V: Set if an arithmetic overflow occurs, otherwise reset<br>Set if initial value of destination was 08001 or 08000h, otherwise reset<br>Set if initial value of destination was 081 or 080h, otherwise reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                        |
| <b>Example</b>     | R10 is decremented by 2.                                                                                                                                                                                                                                                                                                                                         |

```
DECD      R10           ; Decrement R10 by two
```

```
; Move a block of 255 bytes from memory location starting with EDE to
; memory location starting with TONI.
; Tables should not overlap: start of destination address TONI must not
; be within the range EDE to EDE+0FEh
```

```
MOV      #EDE,R6
MOV      #255,R10
L$1    MOV.B   @R6+,TONI-EDE-2(R6)
        DECD   R10
        JNZ    L$1
```

|                |                                               |
|----------------|-----------------------------------------------|
| <b>Example</b> | Memory at location LEO is decremented by two. |
|----------------|-----------------------------------------------|

```
DECD.B   LEO           ; Decrement MEM(LEO)
```

Decrement status byte STATUS by two

```
DECD.B   STATUS
```

#### 4.6.2.19 DINT

|                    |                                                                                                                                                                                               |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* DINT</b>      | Disable (general) interrupts                                                                                                                                                                  |
| <b>Syntax</b>      | DINT                                                                                                                                                                                          |
| <b>Operation</b>   | $0 \rightarrow GIE$<br>or<br>$(0FFF7h .AND. SR \rightarrow SR / .NOT.src .AND. dst \rightarrow dst)$                                                                                          |
| <b>Emulation</b>   | BIC #8,SR                                                                                                                                                                                     |
| <b>Description</b> | All interrupts are disabled.<br>The constant 08h is inverted and logically ANDed with the SR. The result is placed into the SR.                                                               |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                 |
| <b>Mode Bits</b>   | GIE is reset. OSCOFF and CPUOFF are not affected.                                                                                                                                             |
| <b>Example</b>     | The general interrupt enable (GIE) bit in the SR is cleared to allow a nondisrupted move of a 32-bit counter. This ensures that the counter is not modified during the move by any interrupt. |

```

DINT           ; All interrupt events using the GIE bit are disabled
NOP           ; Required due to pipelined CPU architecture
MOV COUNTHI,R5 ; Copy counter
MOV COUNTLO,R6
EINT           ; All interrupt events using the GIE bit are enabled

```

---

**NOTE: Disable interrupt**

Due to the pipelined CPU architecture, clearing the general interrupt enable (GIE) requires special care.

- Include at least one instruction between DINT and the start of a code sequence that requires protection from interrupts. For example: Insert a NOP instruction after the DINT.
- Never clear the general interrupt enable (GIE) immediately after setting it. Insert at least one instruction in between such sequence.

The rules above apply to all instructions that clear the general interrupt enable bit. Not following these rules might result in unexpected CPU execution.

---

#### 4.6.2.20 EINT

|                    |                                                                                                                   |
|--------------------|-------------------------------------------------------------------------------------------------------------------|
| <b>* EINT</b>      | Enable (general) interrupts                                                                                       |
| <b>Syntax</b>      | EINT                                                                                                              |
| <b>Operation</b>   | 1 → GIE<br>or<br>(0008h .OR. SR → SR / .src .OR. dst → dst)                                                       |
| <b>Emulation</b>   | BIS #8,SR                                                                                                         |
| <b>Description</b> | All interrupts are enabled.<br>The constant #08h and the SR are logically ORed. The result is placed into the SR. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                     |
| <b>Mode Bits</b>   | GIE is set. OSCOFF and CPUOFF are not affected.                                                                   |
| <b>Example</b>     | The general interrupt enable (GIE) bit in the SR is set.                                                          |

```

PUSH.B    &P1IN
BIC.B    @SP,&P1IFG ; Reset only accepted flags
NOP          ; Required due to pipelined CPU architecture
EINT         ; Preset port 1 interrupt flags stored on stack
              ; other interrupts are allowed
BIT     #Mask,@SP
JEQ     MaskOK      ; Flags are present identically to mask: jump
.....
MaskOK  BIC     #Mask,@SP
.....
INCD    SP          ; Housekeeping: inverse to PUSH instruction
              ; at the start of interrupt subroutine. Corrects
              ; the stack pointer.
RETI

```

---

**NOTE: Enable interrupt**

Due to the pipelined CPU architecture, setting the general interrupt enable (GIE) requires special care.

- The instruction immediately after the enable interrupts instruction (EINT) is always executed, even if an interrupt service request is pending.
- Include at least one instruction between the clear of an interrupt enable or interrupt flag and the EINT instruction. For example: Insert a NOP instruction in front of the EINT instruction.
- Never clear the general interrupt enable (GIE) immediately after setting it. Insert at least one instruction in between such sequence.

The rules above apply to all instructions that set the general interrupt enable bit. Not following these rules might result in unexpected CPU execution.

---

#### 4.6.2.21 INC

|                    |                                                                                                                                                                                                                                                                                                                                                    |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * INC[.W]          | Increment destination                                                                                                                                                                                                                                                                                                                              |
| * INC.B            | Increment destination                                                                                                                                                                                                                                                                                                                              |
| <b>Syntax</b>      | INC dst or<br>INC.B dst                                                                                                                                                                                                                                                                                                                            |
| <b>Operation</b>   | dst + 1 → dst                                                                                                                                                                                                                                                                                                                                      |
| <b>Emulation</b>   | ADD #1,dst                                                                                                                                                                                                                                                                                                                                         |
| <b>Description</b> | The destination operand is incremented by one. The original contents are lost.                                                                                                                                                                                                                                                                     |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if dst contained 0FFFFh, reset otherwise<br>Set if dst contained 0FFh, reset otherwise<br>C: Set if dst contained 0FFFFh, reset otherwise<br>Set if dst contained 0FFh, reset otherwise<br>V: Set if dst contained 07FFFh, reset otherwise<br>Set if dst contained 07Fh, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                          |
| <b>Example</b>     | The status byte, STATUS, of a process is incremented. When it is equal to 11, a branch to OVFL is taken.                                                                                                                                                                                                                                           |

```

INC.B    STATUS
CMP.B    #11,STATUS
JEQ     OVFL

```

#### 4.6.2.22 INCD

|                    |                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * <b>INCD[.W]</b>  | Double-increment destination                                                                                                                                                                                                                                                                                                                                                         |
| * <b>INCD.B</b>    | Double-increment destination                                                                                                                                                                                                                                                                                                                                                         |
| <b>Syntax</b>      | INCD dst or<br>INCD.B dst                                                                                                                                                                                                                                                                                                                                                            |
| <b>Operation</b>   | dst + 2 → dst                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Emulation</b>   | ADD #2,dst                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Description</b> | The destination operand is incremented by two. The original contents are lost.                                                                                                                                                                                                                                                                                                       |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if dst contained 0FFEh, reset otherwise<br>Set if dst contained 0FEh, reset otherwise<br>C: Set if dst contained 0FFEh or 0FFFFh, reset otherwise<br>Set if dst contained 0FEh or 0FFh, reset otherwise<br>V: Set if dst contained 07FFEh or 07FFFh, reset otherwise<br>Set if dst contained 07Eh or 07Fh, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                            |
| <b>Example</b>     | The item on the top of the stack (TOS) is removed without using a register.                                                                                                                                                                                                                                                                                                          |

```
.....
PUSH    R5      ; R5 is the result of a calculation, which is stored
          ; in the system stack
INCD    SP      ; Remove TOS by double-increment from stack
          ; Do not use INCD.B, SP is a word-aligned register
RET
```

|                |                                                         |
|----------------|---------------------------------------------------------|
| <b>Example</b> | The byte on the top of the stack is incremented by two. |
| INCD.B         | 0(SP) ; Byte on TOS is increment by two                 |

#### 4.6.2.23 INV

|                    |                                                                                                                                                                                                                                                                                         |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * <b>INV[.W]</b>   | Invert destination                                                                                                                                                                                                                                                                      |
| * <b>INV.B</b>     | Invert destination                                                                                                                                                                                                                                                                      |
| <b>Syntax</b>      | INV dst or<br>INV.B dst                                                                                                                                                                                                                                                                 |
| <b>Operation</b>   | .not.dst → dst                                                                                                                                                                                                                                                                          |
| <b>Emulation</b>   | XOR #0FFFFh,dst<br>XOR.B #0FFh,dst                                                                                                                                                                                                                                                      |
| <b>Description</b> | The destination operand is inverted. The original contents are lost.                                                                                                                                                                                                                    |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if dst contained 0FFFFh, reset otherwise<br>Set if dst contained 0FFh, reset otherwise<br>C: Set if result is not zero, reset otherwise (= .NOT. Zero)<br>V: Set if initial destination operand was negative, otherwise reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                               |
| <b>Example</b>     | Content of R5 is negated (twos complement).                                                                                                                                                                                                                                             |

```

MOV    #00AEh,R5      ;           R5 = 000AEh
INV    R5              ; Invert R5,       R5 = 0FF51h
INC    R5              ; R5 is now negated,   R5 = 0FF52h

```

|                   |                                        |
|-------------------|----------------------------------------|
| <b>Example</b>    | Content of memory byte LEO is negated. |
| MOV.B #0AEh,LEO ; | MEM(LEO) = 0AEh                        |

```

INV.B LEO            ; Invert LEO,      MEM(LEO) = 051h
INC.B LEO            ; MEM(LEO) is negated, MEM(LEO) = 052h

```

#### 4.6.2.24 JC, JHS

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JC</b>          | Jump if carry                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>JHS</b>         | Jump if higher or same (unsigned)                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Syntax</b>      | JC label<br>JHS label                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | If C = 1: PC + (2 × Offset) → PC<br>If C = 0: execute the following instruction                                                                                                                                                                                                                                                                                                                                                                |
| <b>Description</b> | The carry bit C in the SR is tested. If it is set, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means a jump in the range -511 to +512 words relative to the PC in the full memory range. If C is reset, the instruction after the jump is executed.<br>JC is used for the test of the carry bit C.<br>JHS is used for the comparison of unsigned numbers. |
| <b>Status Bits</b> | Status bits are not affected                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | The state of the port 1 pin P1IN.1 bit defines the program flow.                                                                                                                                                                                                                                                                                                                                                                               |

```
BIT.B #2,&P1IN      ; Port 1, bit 1 set? Bit -> C
JC    Label1       ; Yes, proceed at Label1
...
           ; No, continue
```

**Example** If R5 ≥ R6 (unsigned), the program continues at Label2.

```
CMP  R6,R5        ; Is R5 >= R6? Info to C
JHS  Label2       ; Yes, C = 1
...
           ; No, R5 < R6. Continue
```

**Example** If R5 ≥ 12345h (unsigned operands), the program continues at Label2.

```
CMPA #12345h,R5   ; Is R5 >= 12345h? Info to C
JHS  Label2       ; Yes, 12344h < R5 <= F,FFFFh. C = 1
...
           ; No, R5 < 12345h. Continue
```

#### 4.6.2.25 JEQ, JZ

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JEQ</b>         | Jump if equal                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>JZ</b>          | Jump if zero                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Syntax</b>      | JEQ label<br>JZ label                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Operation</b>   | If Z = 1: PC + (2 × Offset) → PC<br>If Z = 0: execute following instruction                                                                                                                                                                                                                                                                                                                                                          |
| <b>Description</b> | The zero bit Z in the SR is tested. If it is set, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means a jump in the range -511 to +512 words relative to the PC in the full memory range. If Z is reset, the instruction after the jump is executed.<br>JZ is used for the test of the zero bit Z.<br>JEQ is used for the comparison of operands. |
| <b>Status Bits</b> | Status bits are not affected                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Example</b>     | The state of the P2IN.0 bit defines the program flow.                                                                                                                                                                                                                                                                                                                                                                                |

```
BIT.B #1,&P2IN      ; Port 2, bit 0 reset?  
JZ Label1        ; Yes, proceed at Label1  
...              ; No, set, continue
```

**Example** If R5 = 15000h (20-bit data), the program continues at Label2.

```
CMPA #15000h,R5    ; Is R5 = 15000h? Info to SR  
JEQ Label2        ; Yes, R5 = 15000h. Z = 1  
...              ; No, R5 not equal 15000h. Continue
```

**Example** R7 (20-bit counter) is incremented. If its content is zero, the program continues at Label4.

```
ADDA #1,R7        ; Increment R7  
JZ Label4        ; Zero reached: Go to Label4  
...              ; R7 not equal 0. Continue here.
```

#### 4.6.2.26 JGE

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JGE</b>         | Jump if greater or equal (signed)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Syntax</b>      | JGE label                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Operation</b>   | If (N .xor. V) = 0: PC + (2 × Offset) → PC<br>If (N .xor. V) = 1: execute following instruction                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Description</b> | The negative bit N and the overflow bit V in the SR are tested. If both bits are set or both are reset, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means a jump in the range -511 to +512 words relative to the PC in full Memory range. If only one bit is set, the instruction after the jump is executed.<br><br>JGE is used for the comparison of signed operands: also for incorrect results due to overflow, the decision made by the JGE instruction is correct.<br><br>Note that JGE emulates the nonimplemented JP (jump if positive) instruction if used after the instructions AND, BIT, RRA, SXTX, and TST. These instructions clear the V bit. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Example</b>     | If byte EDE (lower 64 K) contains positive data, go to Label1. Software can run in the full memory range.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

```
TST.B    &EDE           ; Is EDE positive? V <- 0
JGE      Label1         ; Yes, JGE emulates JP
...
          ; No, 80h <= EDE <= FFh
```

|                |                                                                                                                                                                   |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | If the content of R6 is greater than or equal to the memory pointed to by R7, the program continues a Label5. Signed data. Data and program in full memory range. |
| CMP            | @R7,R6           ; Is R6 >= @R7?                                                                                                                                  |

```
JGE      Label5         ; Yes, go to Label5
...
          ; No, continue here
```

|                |                                                                                                       |
|----------------|-------------------------------------------------------------------------------------------------------|
| <b>Example</b> | If R5 $\geq$ 12345h (signed operands), the program continues at Label2. Program in full memory range. |
| CMPA           | #12345h,R5       ; Is R5 $\geq$ 12345h?                                                               |

```
JGE      Label2         ; Yes, 12344h < R5 <= 7FFFFh
...
          ; No, 80000h <= R5 < 12345h
```

#### 4.6.2.27 JL

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JL</b>          | Jump if less (signed)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Syntax</b>      | JL label                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Operation</b>   | If $(N \text{ xor. } V) = 1$ : $\text{PC} + (2 \times \text{Offset}) \rightarrow \text{PC}$<br>If $(N \text{ xor. } V) = 0$ : execute following instruction                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Description</b> | The negative bit N and the overflow bit V in the SR are tested. If only one is set, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means a jump in the range -511 to +512 words relative to the PC in full memory range. If both bits N and V are set or both are reset, the instruction after the jump is executed.<br><br>JL is used for the comparison of signed operands: also for incorrect results due to overflow, the decision made by the JL instruction is correct. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Example</b>     | If byte EDE contains a smaller, signed operand than byte TONI, continue at Label1. The address EDE is within $\text{PC} \pm 32 \text{ K}$ .                                                                                                                                                                                                                                                                                                                                                                                                                     |

```
CMP.B    &TONI,EDE      ; Is EDE < TONI
JL       Label1        ; Yes
...
           ; No, TONI <= EDE
```

|                |                                                                                                                                                                |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | If the signed content of R6 is less than the memory pointed to by R7 (20-bit address), the program continues at Label5. Data and program in full memory range. |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
CMP     @R7,R6        ; Is R6 < @R7?
JL      Label5        ; Yes, go to Label5
...
           ; No, continue here
```

|                |                                                                                                             |
|----------------|-------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | If $R5 < 12345h$ (signed operands), the program continues at Label2. Data and program in full memory range. |
|----------------|-------------------------------------------------------------------------------------------------------------|

```
CMPA   #12345h,R5    ; Is R5 < 12345h?
JL     Label2        ; Yes, 80000h <= R5 < 12345h
...
           ; No, 12344h < R5 <= 7FFFFh
```

#### 4.6.2.28 JMP

|                    |                                                                                                                                                                                                                                                                                                                                             |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JMP</b>         | Jump unconditionally                                                                                                                                                                                                                                                                                                                        |
| <b>Syntax</b>      | JMP label                                                                                                                                                                                                                                                                                                                                   |
| <b>Operation</b>   | PC + (2 × Offset) → PC                                                                                                                                                                                                                                                                                                                      |
| <b>Description</b> | The signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means an unconditional jump in the range -511 to +512 words relative to the PC in the full memory. The JMP instruction may be used as a BR or BRA instruction within its limited range relative to the PC. |
| <b>Status Bits</b> | Status bits are not affected                                                                                                                                                                                                                                                                                                                |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                   |
| <b>Example</b>     | The byte STATUS is set to 10. Then a jump to label MAINLOOP is made. Data in lower 64 K, program in full memory range.                                                                                                                                                                                                                      |

```
MOV.B #10,&STATUS      ; Set STATUS to 10
JMP     MAINLOOP       ; Go to main loop
```

|                |                                                                                                                                                                 |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The interrupt vector TAIIV of Timer_A3 is read and used for the program flow. Program in full memory range, but interrupt handlers always starts in lower 64 K. |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
ADD    &TAIIV,PC        ; Add Timer_A interrupt vector to PC
RETI
JMP    IHCCR1          ; No Timer_A interrupt pending
JMP    IHCCR2          ; Timer block 1 caused interrupt
JMP    IHCCR2          ; Timer block 2 caused interrupt
RETI              ; No legal interrupt, return
```

#### 4.6.2.29 JN

|                    |                                                                                                                                                                                                                                                                                                                                                     |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JN</b>          | Jump if negative                                                                                                                                                                                                                                                                                                                                    |
| <b>Syntax</b>      | JN label                                                                                                                                                                                                                                                                                                                                            |
| <b>Operation</b>   | If N = 1: PC + (2 × Offset) → PC<br>If N = 0: execute following instruction                                                                                                                                                                                                                                                                         |
| <b>Description</b> | The negative bit N in the SR is tested. If it is set, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit program PC. This means a jump in the range -511 to +512 words relative to the PC in the full memory range. If N is reset, the instruction after the jump is executed. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                       |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | The byte COUNT is tested. If it is negative, program execution continues at Label0. Data in lower 64 K, program in full memory range.                                                                                                                                                                                                               |

```
TST.B    &COUNT      ; Is byte COUNT negative?
JN       Label0       ; Yes, proceed at Label0
...
; COUNT >= 0
```

|                |                                                                                                                 |
|----------------|-----------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | R6 is subtracted from R5. If the result is negative, program continues at Label2. Program in full memory range. |
|----------------|-----------------------------------------------------------------------------------------------------------------|

```
SUB     R6,R5      ; R5 - R6 -> R5
JN       Label2       ; R5 is negative: R6 > R5 (N = 1)
...
; R5 >= 0. Continue here.
```

|                |                                                                                                                                  |
|----------------|----------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | R7 (20-bit counter) is decremented. If its content is below zero, the program continues at Label4. Program in full memory range. |
|----------------|----------------------------------------------------------------------------------------------------------------------------------|

```
SUBA   #1,R7      ; Decrement R7
JN       Label4       ; R7 < 0: Go to Label4
...
; R7 >= 0. Continue here.
```

#### 4.6.2.30 JNC, JLO

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JNC</b>         | Jump if no carry                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>JLO</b>         | Jump if lower (unsigned)                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Syntax</b>      | JNC label<br>JLO label                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | If C = 0: PC + (2 × Offset) → PC<br>If C = 1: execute following instruction                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Description</b> | The carry bit C in the SR is tested. If it is reset, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means a jump in the range -511 to +512 words relative to the PC in the full memory range. If C is set, the instruction after the jump is executed.<br>JNC is used for the test of the carry bit C.<br>JLO is used for the comparison of unsigned numbers. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Example</b>     | If byte EDE < 15, the program continues at Label2. Unsigned data. Data in lower 64 K, program in full memory range.                                                                                                                                                                                                                                                                                                                             |

```
CMP.B #15,&EDE      ; Is EDE < 15? Info to C
JLO Label2         ; Yes, EDE < 15. C = 0
...                ; No, EDE >= 15. Continue
```

|                |                                                                                                                |
|----------------|----------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The word TONI is added to R5. If no carry occurs, continue at Label0. The address of TONI is within PC ± 32 K. |
|----------------|----------------------------------------------------------------------------------------------------------------|

```
ADD TONI,R5        ; TONI + R5 -> R5. Carry -> C
JNC Label0         ; No carry
...                ; Carry = 1: continue here
```

### 4.6.2.31 JNZ, JNE

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>JNZ</b>         | Jump if not zero                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>JNE</b>         | Jump if not equal                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Syntax</b>      | JNZ label<br>JNE label                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Operation</b>   | If Z = 0: PC + (2 × Offset) → PC<br>If Z = 1: execute following instruction                                                                                                                                                                                                                                                                                                                                                           |
| <b>Description</b> | The zero bit Z in the SR is tested. If it is reset, the signed 10-bit word offset contained in the instruction is multiplied by two, sign extended, and added to the 20-bit PC. This means a jump in the range -511 to +512 words relative to the PC in the full memory range. If Z is set, the instruction after the jump is executed.<br>JNZ is used for the test of the zero bit Z.<br>JNE is used for the comparison of operands. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Example</b>     | The byte STATUS is tested. If it is not zero, the program continues at Label3. The address of STATUS is within PC ± 32 K.                                                                                                                                                                                                                                                                                                             |

```
TST.B STATUS      ; Is STATUS = 0?  
JNZ Label3       ; No, proceed at Label3  
...              ; Yes, continue here
```

|                |                                                                                                        |
|----------------|--------------------------------------------------------------------------------------------------------|
| <b>Example</b> | If word EDE ≠ 1500, the program continues at Label2. Data in lower 64 K, program in full memory range. |
|----------------|--------------------------------------------------------------------------------------------------------|

```
CMP #1500,&EDE    ; Is EDE = 1500? Info to SR  
JNE Label2        ; No, EDE not equal 1500.  
...              ; Yes, R5 = 1500. Continue
```

|                |                                                                                                                                |
|----------------|--------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | R7 (20-bit counter) is decremented. If its content is not zero, the program continues at Label4. Program in full memory range. |
|----------------|--------------------------------------------------------------------------------------------------------------------------------|

```
SUBA #1,R7        ; Decrement R7  
JNZ Label4        ; Zero not reached: Go to Label4  
...              ; Yes, R7 = 0. Continue here.
```

#### 4.6.2.32 MOV

|                    |                                                                                      |
|--------------------|--------------------------------------------------------------------------------------|
| <b>MOV[.W]</b>     | Move source word to destination word                                                 |
| <b>MOV.B</b>       | Move source byte to destination byte                                                 |
| <b>Syntax</b>      | MOV src,dst or MOV.W src,dst<br>MOV.B src,dst                                        |
| <b>Operation</b>   | src → dst                                                                            |
| <b>Description</b> | The source operand is copied to the destination. The source operand is not affected. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected             |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                            |
| <b>Example</b>     | Move a 16-bit constant 1800h to absolute address-word EDE (lower 64 K)               |

```
MOV      #01800h,&EDE           ; Move 1800h to EDE
```

|                |                                                                                                                                                                |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The contents of table EDE (word data, 16-bit addresses) are copied to table TOM. The length of the tables is 030h words. Both tables reside in the lower 64 K. |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
Loop    MOV      #EDE,R10          ; Prepare pointer (16-bit address)
        MOV      @R10+,TOM-EDE-2(R10) ; R10 points to both tables.
   ; R10+2
        CMP      #EDE+60h,R10       ; End of table reached?
        JLO      Loop               ; Not yet
   ; Copy completed
        ...
```

|                |                                                                                                                                                                                                      |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The contents of table EDE (byte data, 16-bit addresses) are copied to table TOM. The length of the tables is 020h bytes. Both tables may reside in full memory range, but must be within R10 ± 32 K. |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
Loop    MOVA   #EDE,R10          ; Prepare pointer (20-bit)
        MOV     #20h,R9            ; Prepare counter
        MOV.B  @R10+,TOM-EDE-1(R10); R10 points to both tables.
   ; R10+1
        DEC     R9                ; Decrement counter
        JNZ     Loop               ; Not yet done
   ; Copy completed
        ...
```

#### 4.6.2.33 NOP

|                    |                                                                                                                                                    |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| * <b>NOP</b>       | No operation                                                                                                                                       |
| <b>Syntax</b>      | NOP                                                                                                                                                |
| <b>Operation</b>   | None                                                                                                                                               |
| <b>Emulation</b>   | MOV #0, R3                                                                                                                                         |
| <b>Description</b> | No operation is performed. The instruction may be used for the elimination of instructions during the software check or for defined waiting times. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                      |

#### 4.6.2.34 POP

|                    |                                                                                                                       |
|--------------------|-----------------------------------------------------------------------------------------------------------------------|
| <b>* POP[.W]</b>   | Pop word from stack to destination                                                                                    |
| <b>* POP.B</b>     | Pop byte from stack to destination                                                                                    |
| <b>Syntax</b>      | POP dst<br>POP.B dst                                                                                                  |
| <b>Operation</b>   | $\text{@SP} \rightarrow \text{temp}$<br>$\text{SP} + 2 \rightarrow \text{SP}$<br>$\text{temp} \rightarrow \text{dst}$ |
| <b>Emulation</b>   | MOV @SP+,dst or MOV.W @SP+,dst<br>MOV.B @SP+,dst                                                                      |
| <b>Description</b> | The stack location pointed to by the SP (TOS) is moved to the destination. The SP is incremented by two afterwards.   |
| <b>Status Bits</b> | Status bits are not affected.                                                                                         |
| <b>Example</b>     | The contents of R7 and the SR are restored from the stack.                                                            |

```
POP    R7      ; Restore R7
POP    SR      ; Restore status register
```

|                |                                                          |
|----------------|----------------------------------------------------------|
| <b>Example</b> | The contents of RAM byte LEO is restored from the stack. |
|----------------|----------------------------------------------------------|

```
POP.B  LEO     ; The low byte of the stack is moved to LEO.
```

|                |                                                |
|----------------|------------------------------------------------|
| <b>Example</b> | The contents of R7 is restored from the stack. |
|----------------|------------------------------------------------|

```
POP.B  R7      ; The low byte of the stack is moved to R7,
                 ; the high byte of R7 is 00h
```

|                |                                                                                     |
|----------------|-------------------------------------------------------------------------------------|
| <b>Example</b> | The contents of the memory pointed to by R7 and the SR are restored from the stack. |
|----------------|-------------------------------------------------------------------------------------|

```
POP.B  0(R7)   ; The low byte of the stack is moved to the
                 ; the byte which is pointed to by R7
                 ; Example: R7 = 203h
                 ;           Mem(R7) = low byte of system stack
                 ; Example: R7 = 20Ah
                 ;           Mem(R7) = low byte of system stack
POP    SR      ; Last word on stack moved to the SR
```

---

**NOTE: System stack pointer**

The system SP is always incremented by two, independent of the byte suffix.

---

#### 4.6.2.35 PUSH

|                    |                                                                                                                                                                                 |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>PUSH[.W]</b>    | Save a word on the stack                                                                                                                                                        |
| <b>PUSH.B</b>      | Save a byte on the stack                                                                                                                                                        |
| <b>Syntax</b>      | PUSH dst or<br>PUSH.B dst                                                                                                                                                       |
| <b>Operation</b>   | SP - 2 → SP<br>dst → @SP                                                                                                                                                        |
| <b>Description</b> | The 20-bit SP SP is decremented by two. The operand is then copied to the RAM word addressed by the SP. A pushed byte is stored in the low byte; the high byte is not affected. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                       |
| <b>Example</b>     | Save the two 16-bit registers R9 and R10 on the stack                                                                                                                           |

```
PUSH    R9      ; Save R9 and R10 xxxxh
PUSH    R10     ; YYYYh
```

|                |                                                                                                |
|----------------|------------------------------------------------------------------------------------------------|
| <b>Example</b> | Save the two bytes EDE and TONI on the stack. The addresses EDE and TONI are within PC ± 32 K. |
|----------------|------------------------------------------------------------------------------------------------|

```
PUSH.B  EDE      ; Save EDE   xxXXh
PUSH.B  TONI     ; Save TONI  xxYYh
```

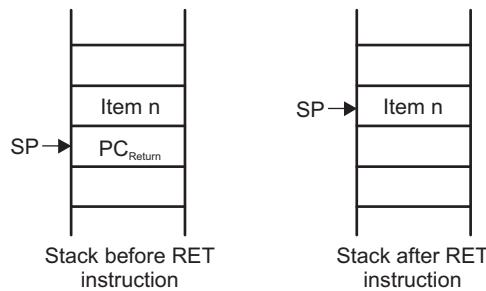
#### 4.6.2.36 RET

|                    |                                                                                                                                                                                                                           |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* RET</b>       | Return from subroutine                                                                                                                                                                                                    |
| <b>Syntax</b>      | RET                                                                                                                                                                                                                       |
| <b>Operation</b>   | $@SP \rightarrow PC.15:0$ Saved PC to PC.15:0. $PC.19:16 \leftarrow 0$<br>$SP + 2 \rightarrow SP$                                                                                                                         |
| <b>Description</b> | The 16-bit return address (lower 64 K), pushed onto the stack by a CALL instruction is restored to the PC. The program continues at the address following the subroutine call. The four MSBs of the PC.19:16 are cleared. |
| <b>Status Bits</b> | Status bits are not affected.<br>PC.19:16: Cleared                                                                                                                                                                        |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                 |
| <b>Example</b>     | Call a subroutine SUBR in the lower 64 K and return to the address in the lower 64 K after the CALL.                                                                                                                      |

```

CALL    #SUBR      ; Call subroutine starting at SUBR
...
SUBR   PUSH     R14      ; Save R14 (16 bit data)
...
POP     R14      ; Restore R14
RET      ; Return to lower 64 K

```



**Figure 4-37. Stack After a RET Instruction**

#### 4.6.2.37 RETI

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RETI</b>        | Return from interrupt                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Syntax</b>      | RETI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Operation</b>   | $\begin{array}{ll} @SP \rightarrow SR.15:0 & \text{Restore saved SR with PC.19:16} \\ SP + 2 \rightarrow SP & \\ @SP \rightarrow PC.15:0 & \text{Restore saved PC.15:0} \\ SP + 2 \rightarrow SP & \text{Housekeeping} \end{array}$                                                                                                                                                                                                                                                                                                                                                      |
| <b>Description</b> | <p>The SR is restored to the value at the beginning of the interrupt service routine. This includes the four MSBs of the PC.19:16. The SP is incremented by two afterward.</p> <p>The 20-bit PC is restored from PC.19:16 (from same stack location as the status bits) and PC.15:0. The 20-bit PC is restored to the value at the beginning of the interrupt service routine. The program continues at the address following the last executed instruction when the interrupt was granted. The SP is incremented by two afterward. No interrupt flags are modified by this command.</p> |
| <b>Status Bits</b> | <p>N: Restored from stack</p> <p>C: Restored from stack</p> <p>Z: Restored from stack</p> <p>V: Restored from stack</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are restored from stack.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Example</b>     | Interrupt handler in the lower 64 K. A 20-bit return address is stored on the stack.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

```

INTRPT PUSHM.A #2,R14      ; Save R14 and R13 (20-bit data)
...           ; Interrupt handler code
POP.M.A    #2,R14      ; Restore R13 and R14 (20-bit data)
RETI          ; Return to 20-bit address in full memory range

```

#### 4.6.2.38 RLA

\* **RLA[.W]**      Rotate left arithmetically

\* **RLA.B**      Rotate left arithmetically

**Syntax**      RLA dst or                                    RLA.W dst

                      RLA.B dst

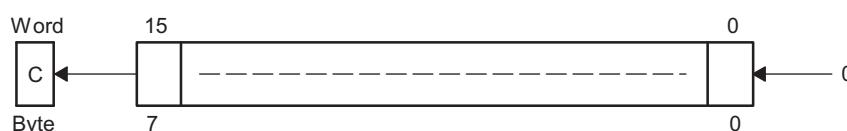
**Operation**     C  $\leftarrow$  MSB  $\leftarrow$  MSB-1 .... LSB+1  $\leftarrow$  LSB  $\leftarrow$  0

**Emulation**     ADD dst,dst

                      ADD.B dst,dst

**Description**     The destination operand is shifted left one position as shown in [Figure 4-38](#). The MSB is shifted into the carry bit (C) and the LSB is filled with 0. The RLA instruction acts as a signed multiplication by 2.

An overflow occurs if dst  $\geq$  04000h and dst < 0C000h before operation is performed; the result has changed sign.



**Figure 4-38. Destination Operand—Arithmetic Shift Left**

An overflow occurs if dst  $\geq$  040h and dst < 0C0h before the operation is performed; the result has changed sign.

**Status Bits**    N: Set if result is negative, reset if positive

Z: Set if result is zero, reset otherwise

C: Loaded from the MSB

V: Set if an arithmetic overflow occurs; the initial value is 04000h  $\leq$  dst < 0C000h, reset otherwise

Set if an arithmetic overflow occurs; the initial value is 040h  $\leq$  dst < 0C0h, reset otherwise

**Mode Bits**    OSCOFF, CPUOFF, and GIE are not affected.

**Example**      R7 is multiplied by 2.

```
RLA    R7      ; Shift left R7  (x 2)
```

**Example**      The low byte of R7 is multiplied by 4.

```
RLA.B   R7      ; Shift left low byte of R7  (x 2)
RLA.B   R7      ; Shift left low byte of R7  (x 4)
```

**NOTE: RLA substitution**

The assembler does not recognize the instructions:

RLA @R5+

RLA.B @R5+

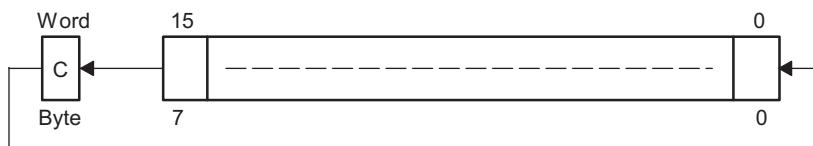
RLA(.B) @R5

They must be substituted by:

```
ADD  @R5+, -2(R5)    ADD.B  @R5+, -1(R5)    ADD(.B) @R5
```

### 4.6.2.39 RLC

|                    |                                                                                                                                                                                          |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * <b>RLC[.W]</b>   | Rotate left through carry                                                                                                                                                                |
| * <b>RLC.B</b>     | Rotate left through carry                                                                                                                                                                |
| <b>Syntax</b>      | RLC dst or RLC.W dst<br>RLC.B dst                                                                                                                                                        |
| <b>Operation</b>   | $C \leftarrow MSB \leftarrow MSB-1 \dots LSB+1 \leftarrow LSB \leftarrow C$                                                                                                              |
| <b>Emulation</b>   | ADDC dst,dst                                                                                                                                                                             |
| <b>Description</b> | The destination operand is shifted left one position as shown in <a href="#">Figure 4-39</a> . The carry bit (C) is shifted into the LSB, and the MSB is shifted into the carry bit (C). |



**Figure 4-39. Destination Operand—Carry Left Shift**

|                    |                                                                                                                                                                                                                                                                                                                                             |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the MSB<br>V: Set if an arithmetic overflow occurs; the initial value is $04000h \leq dst < 0C000h$ , reset otherwise<br>Set if an arithmetic overflow occurs; the initial value is $040h \leq dst < 0C0h$ , reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                   |
| <b>Example</b>     | R5 is shifted left one position.                                                                                                                                                                                                                                                                                                            |

```
RLC      R5          ; (R5 x 2) + C -> R5
```

**Example** The input P1IN.1 information is shifted into the LSB of R5.

```
BIT.B    #2,&P1IN      ; Information -> Carry
RLC      R5          ; Carry=P0in.1 -> LSB of R5
```

**Example** The MEM(LEO) content is shifted left one position.

```
RLC.B    LEO         ; Mem(LEO) x 2 + C -> Mem(LEO)
```

**NOTE: RLA substitution**

The assembler does not recognize the instructions:

```
RLC    @R5+           RLC.B   @R5+           RLC(.B) @R5
```

They must be substituted by:

```
ADDC   @R5+, -2(R5)   ADDC.B  @R5+, -1(R5)   ADDC(.B) @R5
```

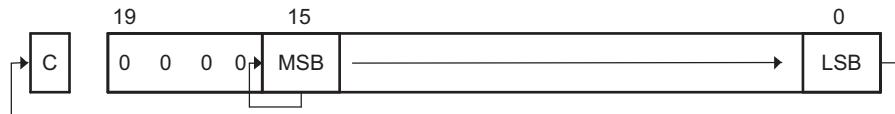
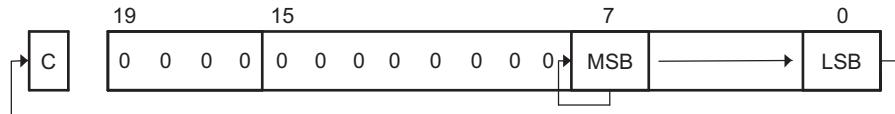
#### 4.6.2.40 RRA

|                    |                                                                                                                                                                                                                                                                                                                                            |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRA[.W]</b>     | Rotate right arithmetically destination word                                                                                                                                                                                                                                                                                               |
| <b>RRA.B</b>       | Rotate right arithmetically destination byte                                                                                                                                                                                                                                                                                               |
| <b>Syntax</b>      | RRA.B dst or RRA.W dst                                                                                                                                                                                                                                                                                                                     |
| <b>Operation</b>   | MSB → MSB → MSB-1 → ... LSB+1 → LSB → C                                                                                                                                                                                                                                                                                                    |
| <b>Description</b> | The destination operand is shifted right arithmetically by one bit position as shown in <a href="#">Figure 4-40</a> . The MSB retains its value (sign). RRA operates equal to a signed division by 2. The MSB is retained and shifted into the MSB-1. The LSB+1 is shifted into the LSB. The previous LSB is shifted into the carry bit C. |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset otherwise (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the LSB<br>V: Reset                                                                                                                                                                                       |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                  |
| <b>Example</b>     | The signed 16-bit number in R5 is shifted arithmetically right one position.                                                                                                                                                                                                                                                               |

RRA      R5 ; R5/2 -> R5

**Example**      The signed RAM byte EDE is shifted arithmetically right one position.

RRA.B    EDE ; EDE/2 -> EDE



**Figure 4-40. Rotate Right Arithmetically RRA.B and RRA.W**

#### 4.6.2.41 RRC

|                    |                                                                                                                                                                                             |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRC[.W]</b>     | Rotate right through carry destination word                                                                                                                                                 |
| <b>RRC.B</b>       | Rotate right through carry destination byte                                                                                                                                                 |
| <b>Syntax</b>      | <code>RRC dst or</code> <code>RRC.W dst</code><br><code>RRC.B dst</code>                                                                                                                    |
| <b>Operation</b>   | $C \rightarrow \text{MSB} \rightarrow \text{MSB-1} \rightarrow \dots \text{LSB+1} \rightarrow \text{LSB} \rightarrow C$                                                                     |
| <b>Description</b> | The destination operand is shifted right by one bit position as shown in <a href="#">Figure 4-41</a> . The carry bit C is shifted into the MSB and the LSB is shifted into the carry bit C. |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset otherwise (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the LSB<br>V: Reset                                        |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                   |
| <b>Example</b>     | RAM word EDE is shifted right one bit position. The MSB is loaded with 1.                                                                                                                   |

```
SETC          ; Prepare carry for MSB
RRC  EDE      ; EDE = EDE >> 1 + 8000h
```



**Figure 4-41. Rotate Right Through Carry RRC.B and RRC.W**

#### 4.6.2.42 SBC

|                    |                                                                                                                                                                                                                                                                              |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * <b>SBC.W</b>     | Subtract borrow (.NOT. carry) from destination                                                                                                                                                                                                                               |
| * <b>SBC.B</b>     | Subtract borrow (.NOT. carry) from destination                                                                                                                                                                                                                               |
| <b>Syntax</b>      | SBC dst or<br>SBC.B dst                                                                                                                                                                                                                                                      |
| <b>Operation</b>   | $dst + 0FFFFh + C \rightarrow dst$<br>$dst + 0FFh + C \rightarrow dst$                                                                                                                                                                                                       |
| <b>Emulation</b>   | SUBC #0,dst<br>SUBC.B #0,dst                                                                                                                                                                                                                                                 |
| <b>Description</b> | The carry bit (C) is added to the destination operand minus one. The previous contents of the destination are lost.                                                                                                                                                          |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB of the result, reset otherwise<br>Set to 1 if no borrow, reset if borrow<br>V: Set if an arithmetic overflow occurs, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                    |
| <b>Example</b>     | The 16-bit counter pointed to by R13 is subtracted from a 32-bit counter pointed to by R12.                                                                                                                                                                                  |

```
SUB    @R13,0(R12)      ; Subtract LSDs
SBC    2(R12)          ; Subtract carry from MSD
```

|                |                                                                                            |
|----------------|--------------------------------------------------------------------------------------------|
| <b>Example</b> | The 8-bit counter pointed to by R13 is subtracted from a 16-bit counter pointed to by R12. |
|                | SUB.B  @R13,0(R12)      ; Subtract LSDs SBC.B  1(R12)          ; Subtract carry from MSD   |

---

**NOTE: Borrow implementation**

The borrow is treated as a .NOT. carry:

| Borrow | Carry Bit |
|--------|-----------|
| Yes    | 0         |
| No     | 1         |

---

#### 4.6.2.43 SETC

|                    |                                                                                                                   |
|--------------------|-------------------------------------------------------------------------------------------------------------------|
| <b>* SETC</b>      | Set carry bit                                                                                                     |
| <b>Syntax</b>      | SETC                                                                                                              |
| <b>Operation</b>   | $1 \rightarrow C$                                                                                                 |
| <b>Emulation</b>   | BIS #1,SR                                                                                                         |
| <b>Description</b> | The carry bit (C) is set.                                                                                         |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Set<br>V: Not affected                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                         |
| <b>Example</b>     | Emulation of the decimal subtraction:<br>Subtract R5 from R6 decimal.<br>Assume that R5 = 03987h and R6 = 04137h. |

```

DSUB  ADD    #06666h,R5      ; Move content R5 from 0-9 to 6-0Fh
                  ; R5 = 03987h + 06666h = 09FEDh
      INV    R5      ; Invert this (result back to 0-9)
                  ; R5 = .NOT. R5 = 06012h
      SETC
      DADD  R5,R6      ; Prepare carry = 1
                  ; Emulate subtraction by addition of:
                  ; (010000h - R5 - 1)
                  ; R6 = R6 + R5 + 1
                  ; R6 = 0150h

```

#### 4.6.2.44 SETN

|                    |                                                                 |
|--------------------|-----------------------------------------------------------------|
| * <b>SETN</b>      | Set negative bit                                                |
| <b>Syntax</b>      | SETN                                                            |
| <b>Operation</b>   | $1 \rightarrow N$                                               |
| <b>Emulation</b>   | BIS #4,SR                                                       |
| <b>Description</b> | The negative bit (N) is set.                                    |
| <b>Status Bits</b> | N: Set<br>Z: Not affected<br>C: Not affected<br>V: Not affected |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                       |

#### 4.6.2.45 SETZ

|                    |                                                                 |
|--------------------|-----------------------------------------------------------------|
| * <b>SETZ</b>      | Set zero bit                                                    |
| <b>Syntax</b>      | SETZ                                                            |
| <b>Operation</b>   | $1 \rightarrow N$                                               |
| <b>Emulation</b>   | BIS #2,SR                                                       |
| <b>Description</b> | The zero bit (Z) is set.                                        |
| <b>Status Bits</b> | N: Not affected<br>Z: Set<br>C: Not affected<br>V: Not affected |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                       |

#### 4.6.2.46 SUB

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SUB[.W]</b>     | Subtract source word from destination word                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>SUB.B</b>       | Subtract source byte from destination byte                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Syntax</b>      | SUB src,dst or SUB.W src,dst<br>SUB.B src,dst                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Operation</b>   | (.not.src) + 1 + dst → dst or dst - src → dst                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Description</b> | The source operand is subtracted from the destination operand. This is made by adding the 1s complement of the source + 1 to the destination. The source operand is not affected, the result is written to the destination operand.                                                                                                                                                                                                                                                 |
| <b>Status Bits</b> | N: Set if result is negative (src > dst), reset if positive (src ≤ dst)<br>Z: Set if result is zero (src = dst), reset otherwise (src ≠ dst)<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow) |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | A 16-bit constant 7654h is subtracted from RAM word EDE.                                                                                                                                                                                                                                                                                                                                                                                                                            |

```
SUB #7654h, &EDE ; Subtract 7654h from EDE
```

|                |                                                                                                                                                                            |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is subtracted from R7. Afterwards, if R7 contains zero, jump to label TONI. R5 is then auto-incremented by 2. R7.19:16 = 0. |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
SUB @R5+,R7 ; Subtract table number from R7. R5 + 2
JZ TONI ; R7 = @R5 (before subtraction)
          ; R7 <> @R5 (before subtraction)
...
```

|                |                                                                                                                                           |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | Byte CNT is subtracted from byte R12 points to. The address of CNT is within PC ± 32K. The address R12 points to is in full memory range. |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------|

```
SUB.B CNT,0(R12) ; Subtract CNT from @R12
```

#### 4.6.2.47 SUBC

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SUBC.W</b>      | Subtract source word with carry from destination word                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>SUBC.B</b>      | Subtract source byte with carry from destination byte                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Syntax</b>      | SUBC src,dst or SUBC.W src,dst<br>SUBC.B src,dst                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Operation</b>   | $(\text{.not}.src) + C + dst \rightarrow dst$ or $dst - (\text{src} - 1) + C \rightarrow dst$                                                                                                                                                                                                                                                                                                                                                           |
| <b>Description</b> | The source operand is subtracted from the destination operand. This is done by adding the 1s complement of the source + carry to the destination. The source operand is not affected, the result is written to the destination operand. Used for 32, 48, and 64-bit operands.                                                                                                                                                                           |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow) |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Example</b>     | A 16-bit constant 7654h is subtracted from R5 with the carry from the previous instruction. R5.19:16 = 0                                                                                                                                                                                                                                                                                                                                                |
|                    | <pre>SUBC.W #7654h,R5      ; Subtract 7654h + C from R5</pre>                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | A 48-bit number (3 words) pointed to by R5 (20-bit address) is subtracted from a 48-bit counter in RAM, pointed to by R7. R5 points to the next 48-bit number afterwards. The address R7 points to is in full memory range.                                                                                                                                                                                                                             |
|                    | <pre>SUB    @R5+,0(R7)      ; Subtract LSBs. R5 + 2 SUBC   @R5+,2(R7)      ; Subtract MIDs with C. R5 + 2 SUBC   @R5+,4(R7)      ; Subtract MSBs with C. R5 + 2</pre>                                                                                                                                                                                                                                                                                   |

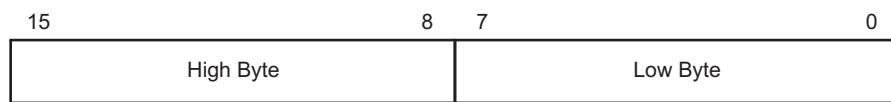
|                |                                                                                                                                          |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | Byte CNT is subtracted from the byte, R12 points to. The carry of the previous instruction is used. The address of CNT is in lower 64 K. |
|                | <pre>SUBC.B &amp;CNT,0(R12)    ; Subtract byte CNT from @R12</pre>                                                                       |

#### 4.6.2.48 SWPB

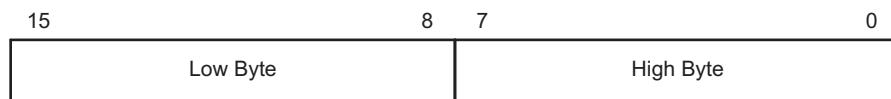
|                    |                                                                                                     |
|--------------------|-----------------------------------------------------------------------------------------------------|
| <b>SWPB</b>        | Swap bytes                                                                                          |
| <b>Syntax</b>      | SWPB dst                                                                                            |
| <b>Operation</b>   | dst.15:8 ↔ dst.7:0                                                                                  |
| <b>Description</b> | The high and the low byte of the operand are exchanged. PC.19:16 bits are cleared in register mode. |
| <b>Status Bits</b> | Status bits are not affected                                                                        |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                           |
| <b>Example</b>     | Exchange the bytes of RAM word EDE (lower 64 K)                                                     |

```
MOV    #1234h, &EDE      ; 1234h -> EDE
SWPB   &EDE            ; 3412h -> EDE
```

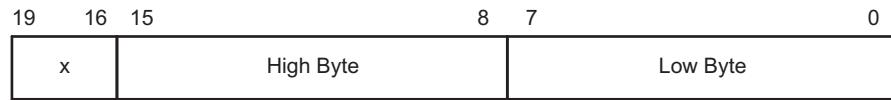
Before SWPB



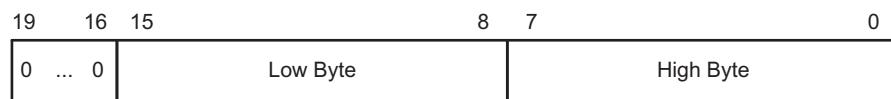
After SWPB

**Figure 4-42. Swap Bytes in Memory**

Before SWPB



After SWPB

**Figure 4-43. Swap Bytes in a Register**

#### 4.6.2.49 SXT

|                    |                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SXT</b>         | Extend sign                                                                                                                                                                                                                                                                                                                                                     |
| <b>Syntax</b>      | SXT dst                                                                                                                                                                                                                                                                                                                                                         |
| <b>Operation</b>   | dst.7 → dst.15:8, dst.7 → dst.19:8 (register mode)                                                                                                                                                                                                                                                                                                              |
| <b>Description</b> | Register mode: the sign of the low byte of the operand is extended into the bits Rdst.19:8.<br>Rdst.7 = 0: Rdst.19:8 = 000h afterwards<br>Rdst.7 = 1: Rdst.19:8 = FFFh afterwards<br><br>Other modes: the sign of the low byte of the operand is extended into the high byte.<br>dst.7 = 0: high byte = 00h afterwards<br>dst.7 = 1: high byte = FFh afterwards |
| <b>Status Bits</b> | N: Set if result is negative, reset otherwise<br>Z: Set if result is zero, reset otherwise<br>C: Set if result is not zero, reset otherwise (C = .not.Z)<br>V: Reset                                                                                                                                                                                            |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                       |
| <b>Example</b>     | The signed 8-bit data in EDE (lower 64 K) is sign extended and added to the 16-bit signed data in R7.                                                                                                                                                                                                                                                           |

```

MOV.B  &EDE,R5      ; EDE -> R5. 00XXh
SXT    R5          ; Sign extend low byte to R5.19:8
ADD    R5,R7       ; Add signed 16-bit values

```

|                |                                                                                              |
|----------------|----------------------------------------------------------------------------------------------|
| <b>Example</b> | The signed 8-bit data in EDE (PC +32 K) is sign extended and added to the 20-bit data in R7. |
|----------------|----------------------------------------------------------------------------------------------|

```

MOV.B  EDE,R5      ; EDE -> R5. 00XXh
SXT    R5          ; Sign extend low byte to R5.19:8
ADDA   R5,R7       ; Add signed 20-bit values

```

#### 4.6.2.50 TST

|                    |                                                                                                                                    |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------|
| <b>* TST[.W]</b>   | Test destination                                                                                                                   |
| <b>* TST.B</b>     | Test destination                                                                                                                   |
| <b>Syntax</b>      | TST dst or<br>TST.B dst                                                                                                            |
| <b>Operation</b>   | dst + 0FFFFh + 1<br>dst + 0FFh + 1                                                                                                 |
| <b>Emulation</b>   | CMP #0,dst<br>CMP.B #0,dst                                                                                                         |
| <b>Description</b> | The destination operand is compared with zero. The status bits are set according to the result. The destination is not affected.   |
| <b>Status Bits</b> | N: Set if destination is negative, reset if positive<br>Z: Set if destination contains zero, reset otherwise<br>C: Set<br>V: Reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                          |
| <b>Example</b>     | R7 is tested. If it is negative, continue at R7NEG; if it is positive but not zero, continue at R7POS.                             |

```

TST      R7          ; Test R7
JN       R7NEG       ; R7 is negative
JZ       R7ZERO      ; R7 is zero
R7POS   .....       ; R7 is positive but not zero
R7NEG   .....       ; R7 is negative
R7ZERO  .....       ; R7 is zero

```

|                |                                                                                                                        |
|----------------|------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The low byte of R7 is tested. If it is negative, continue at R7NEG; if it is positive but not zero, continue at R7POS. |
|----------------|------------------------------------------------------------------------------------------------------------------------|

```

TST.B    R7          ; Test low byte of R7
JN       R7NEG       ; Low byte of R7 is negative
JZ       R7ZERO      ; Low byte of R7 is zero
R7POS   .....       ; Low byte of R7 is positive but not zero
R7NEG   .....       ; Low byte of R7 is negative
R7ZERO  .....       ; Low byte of R7 is zero

```

#### 4.6.2.51 XOR

|                    |                                                                                                                                                                                                                                                           |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>XOR[.W]</b>     | Exclusive OR source word with destination word                                                                                                                                                                                                            |
| <b>XOR.B</b>       | Exclusive OR source byte with destination byte                                                                                                                                                                                                            |
| <b>Syntax</b>      | <code>XOR src,dst</code> or <code>XOR.W src,dst</code><br><code>XOR.B src,dst</code>                                                                                                                                                                      |
| <b>Operation</b>   | <code>src .xor. dst → dst</code>                                                                                                                                                                                                                          |
| <b>Description</b> | The source and destination operands are exclusively ORed. The result is placed into the destination. The source operand is not affected. The previous content of the destination is lost.                                                                 |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if result is not zero, reset otherwise (C = .not. Z)<br>V: Set if both operands are negative before execution, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                 |
| <b>Example</b>     | Toggle bits in word CNTR (16-bit data) with information (bit = 1) in address-word TONI. Both operands are located in lower 64 K.                                                                                                                          |

```
XOR    &TONI ,&CNTR      ; Toggle bits in CNTR
```

**Example** A table word pointed to by R5 (20-bit address) is used to toggle bits in R6. R6.19:16 = 0.

```
XOR    @R5 ,R6      ; Toggle bits in R6
```

**Example** Reset to zero those bits in the low byte of R7 that are different from the bits in byte EDE. R7.19:8 = 0. The address of EDE is within PC ± 32 K.

```
XOR.B  EDE ,R7      ; Set different bits to 1 in R7.  
INV.B  R7      ; Invert low byte of R7, high byte is 0h
```

#### 4.6.3 Extended Instructions

The extended MSP430X instructions give the MSP430X CPU full access to its 20-bit address space. MSP430X instructions require an additional word of op-code called the extension word. All addresses, indexes, and immediate numbers have 20-bit values when preceded by the extension word. The MSP430X extended instructions are listed and described in the following pages.

#### 4.6.3.1 ADCX

- \* **ADCX.A** Add carry to destination address-word
- \* **ADCX.[W]** Add carry to destination word
- \* **ADCX.B** Add carry to destination byte

**Syntax**

```
ADCX.A dst
ADCX dst or ADCX.W dst
ADCX.B dst
```

**Operation**  $dst + C \rightarrow dst$

**Emulation** ADDCX.A #0,dst

ADDCX #0,dst

ADDCX.B #0,dst

**Description** The carry bit (C) is added to the destination operand. The previous contents of the destination are lost.

**Status Bits** N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)

Z: Set if result is zero, reset otherwise

C: Set if there is a carry from the MSB of the result, reset otherwise

V: Set if the result of two positive operands is negative, or if the result of two negative numbers is positive, reset otherwise

**Mode Bits** OSCOFF, CPUOFF, and GIE are not affected.

**Example** The 40-bit counter, pointed to by R12 and R13, is incremented.

```
INCX.A    @R12      ; Increment lower 20 bits
ADCX.A    @R13      ; Add carry to upper 20 bits
```

#### 4.6.3.2 ADDX

|                    |                                                                                                                                                                                                                                                                                                                                |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ADDX.A</b>      | Add source address-word to destination address-word                                                                                                                                                                                                                                                                            |
| <b>ADDX.[W]</b>    | Add source word to destination word                                                                                                                                                                                                                                                                                            |
| <b>ADDX.B</b>      | Add source byte to destination byte                                                                                                                                                                                                                                                                                            |
| <b>Syntax</b>      | ADDX.A src,dst<br>ADDX src,dst OR ADDX.W src,dst<br>ADDX.B src,dst                                                                                                                                                                                                                                                             |
| <b>Operation</b>   | $src + dst \rightarrow dst$                                                                                                                                                                                                                                                                                                    |
| <b>Description</b> | The source operand is added to the destination operand. The previous contents of the destination are lost. Both operands can be located in the full address space.                                                                                                                                                             |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB of the result, reset otherwise<br>V: Set if the result of two positive operands is negative, or if the result of two negative numbers is positive, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | Ten is added to the 20-bit pointer CNTR located in two words CNTR (LSBs) and CNTR+2 (MSBs).                                                                                                                                                                                                                                    |

```
ADDX.A #10,CNTR ; Add 10 to 20-bit pointer
```

|                |                                                                                                                         |
|----------------|-------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word (16-bit) pointed to by R5 (20-bit address) is added to R6. The jump to label TONI is performed on a carry. |
|----------------|-------------------------------------------------------------------------------------------------------------------------|

```
ADDX.W @R5,R6 ; Add table word to R6
JC TONI ; Jump if carry
... ; No carry
```

|                |                                                                                                                                                                    |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is added to R6. The jump to label TONI is performed if no carry occurs. The table pointer is auto-incremented by 1. |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
ADDX.B @R5+,R6 ; Add table byte to R6. R5 + 1. R6: 000xxh
JNC TONI ; Jump if no carry
... ; Carry occurred
```

Note: Use ADDA for the following two cases for better code density and execution.

```
ADDX.A Rsrc,Rdst
ADDX.A #imm20,Rdst
```

#### 4.6.3.3 ADDCX

|                    |                                                                                                                                                                                                                                                                                                                                |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ADDCX.A</b>     | Add source address-word and carry to destination address-word                                                                                                                                                                                                                                                                  |
| <b>ADDCX.[W]</b>   | Add source word and carry to destination word                                                                                                                                                                                                                                                                                  |
| <b>ADDCX.B</b>     | Add source byte and carry to destination byte                                                                                                                                                                                                                                                                                  |
| <b>Syntax</b>      | ADDCX.A src,dst<br>ADDCX src,dst or ADDCX.W src,dst<br>ADDCX.B src,dst                                                                                                                                                                                                                                                         |
| <b>Operation</b>   | $\text{src} + \text{dst} + C \rightarrow \text{dst}$                                                                                                                                                                                                                                                                           |
| <b>Description</b> | The source operand and the carry bit C are added to the destination operand. The previous contents of the destination are lost. Both operands may be located in the full address space.                                                                                                                                        |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB of the result, reset otherwise<br>V: Set if the result of two positive operands is negative, or if the result of two negative numbers is positive, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | Constant 15 and the carry of the previous instruction are added to the 20-bit counter CNTR located in two words.                                                                                                                                                                                                               |

```
ADDCX.A #15,&CNTR ; Add 15 + C to 20-bit CNTR
```

|                |                                                                                                                                 |
|----------------|---------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) and the carry C are added to R6. The jump to label TONI is performed on a carry. |
|----------------|---------------------------------------------------------------------------------------------------------------------------------|

```
ADDCX.W @R5,R6 ; Add table word + C to R6
JC    TONI      ; Jump if carry
...               ; No carry
```

|                |                                                                                                                                                                                         |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) and the carry bit C are added to R6. The jump to label TONI is performed if no carry occurs. The table pointer is auto-incremented by 1. |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
ADDCX.B @R5+,R6 ; Add table byte + C to R6. R5 + 1
JNC   TONI      ; Jump if no carry
...               ; Carry occurred
```

#### 4.6.3.4 ANDX

|                    |                                                                                                                                                                                                            |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ANDX.A</b>      | Logical AND of source address-word with destination address-word                                                                                                                                           |
| <b>ANDX.[W]</b>    | Logical AND of source word with destination word                                                                                                                                                           |
| <b>ANDX.B</b>      | Logical AND of source byte with destination byte                                                                                                                                                           |
| <b>Syntax</b>      | ANDX.A src,dst<br>ANDX src,dst OR ANDX.W src,dst<br>ANDX.B src,dst                                                                                                                                         |
| <b>Operation</b>   | src .and. dst → dst                                                                                                                                                                                        |
| <b>Description</b> | The source operand and the destination operand are logically ANDed. The result is placed into the destination. The source operand is not affected. Both operands may be located in the full address space. |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if the result is not zero, reset otherwise. C = (.not. Z)<br>V: Reset           |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                  |
| <b>Example</b>     | The bits set in R5 (20-bit data) are used as a mask (AAA55h) for the address-word TOM located in two words. If the result is zero, a branch is taken to label TONI.                                        |

```

MOVA    #AAA55h,R5      ; Load 20-bit mask to R5
ANDX.A  R5,TOM          ; TOM .and. R5 -> TOM
JZ      TONI             ; Jump if result 0
...
            ; Result > 0

```

or shorter:

```

ANDX.A  #AAA55h,TOM      ; TOM .and. AAA55h -> TOM
JZ      TONI             ; Jump if result 0

```

|                |                                                                                                                                     |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is logically ANDed with R6. R6.19:8 = 0. The table pointer is auto-incremented by 1. |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------|

```
ANDX.B  @R5+,R6          ; AND table byte with R6. R5 + 1
```

#### 4.6.3.5 BICX

|                    |                                                                                                                                                                                                                     |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BICX.A</b>      | Clear bits set in source address-word in destination address-word                                                                                                                                                   |
| <b>BICX.[W]</b>    | Clear bits set in source word in destination word                                                                                                                                                                   |
| <b>BICX.B</b>      | Clear bits set in source byte in destination byte                                                                                                                                                                   |
| <b>Syntax</b>      | BICX.A src,dst<br>BICX src,dst OR BICX.W src,dst<br>BICX.B src,dst                                                                                                                                                  |
| <b>Operation</b>   | (.not. src) .and. dst → dst                                                                                                                                                                                         |
| <b>Description</b> | The inverted source operand and the destination operand are logically ANDed. The result is placed into the destination. The source operand is not affected. Both operands may be located in the full address space. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                                                                                            |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                           |
| <b>Example</b>     | The bits 19:15 of R5 (20-bit data) are cleared.                                                                                                                                                                     |

```
BICX.A #0F8000h,R5 ; Clear R5.19:15 bits
```

**Example** A table word pointed to by R5 (20-bit address) is used to clear bits in R7. R7.19:16 = 0.

```
BICX.W @R5,R7 ; Clear bits in R7
```

**Example** A table byte pointed to by R5 (20-bit address) is used to clear bits in output Port1.

```
BICX.B @R5,&P1OUT ; Clear I/O port P1 bits
```

#### 4.6.3.6 BISX

|                    |                                                                                                                                                                                                           |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BISX.A</b>      | Set bits set in source address-word in destination address-word                                                                                                                                           |
| <b>BISX.[W]</b>    | Set bits set in source word in destination word                                                                                                                                                           |
| <b>BISX.B</b>      | Set bits set in source byte in destination byte                                                                                                                                                           |
| <b>Syntax</b>      | <code>BISX.A src,dst</code><br><code>BISX src,dst OR BISX.W src,dst</code><br><code>BISX.B src,dst</code>                                                                                                 |
| <b>Operation</b>   | <code>src .or. dst → dst</code>                                                                                                                                                                           |
| <b>Description</b> | The source operand and the destination operand are logically ORed. The result is placed into the destination. The source operand is not affected. Both operands may be located in the full address space. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                                                                                  |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                 |
| <b>Example</b>     | Bits 16 and 15 of R5 (20-bit data) are set to one.                                                                                                                                                        |

```
BISX.A      #018000h,R5      ; Set R5.16:15 bits
```

**Example** A table word pointed to by R5 (20-bit address) is used to set bits in R7.

```
BISX.W      @R5,R7          ; Set bits in R7
```

**Example** A table byte pointed to by R5 (20-bit address) is used to set bits in output Port1.

```
BISX.B      @R5,&P1OUT       ; Set I/O port P1 bits
```

#### 4.6.3.7 BITX

|                    |                                                                                                                                                                                                  |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BITX.A</b>      | Test bits set in source address-word in destination address-word                                                                                                                                 |
| <b>BITX.[W]</b>    | Test bits set in source word in destination word                                                                                                                                                 |
| <b>BITX.B</b>      | Test bits set in source byte in destination byte                                                                                                                                                 |
| <b>Syntax</b>      | BITX.A src,dst<br>BITX src,dst OR BITX.W src,dst<br>BITX.B src,dst                                                                                                                               |
| <b>Operation</b>   | src .and. dst → dst                                                                                                                                                                              |
| <b>Description</b> | The source operand and the destination operand are logically ANDed. The result affects only the status bits. Both operands may be located in the full address space.                             |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if the result is not zero, reset otherwise. C = (.not. Z)<br>V: Reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                        |
| <b>Example</b>     | Test if bit 16 or 15 of R5 (20-bit data) is set. Jump to label TONI if so.                                                                                                                       |

```
BITX.A    #018000h,R5      ; Test R5.16:15 bits
JNZ      TONI             ; At least one bit is set
...                  ; Both are reset
```

|                |                                                                                                                           |
|----------------|---------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is used to test bits in R7. Jump to label TONI if at least one bit is set. |
|----------------|---------------------------------------------------------------------------------------------------------------------------|

```
BITX.W    @R5,R7          ; Test bits in R7: C = .not.Z
JC       TONI             ; At least one is set
...                  ; Both are reset
```

|                |                                                                                                                                                            |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is used to test bits in input Port1. Jump to label TONI if no bit is set. The next table byte is addressed. |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
BITX.B    @R5+,&P1IN        ; Test input P1 bits. R5 + 1
JNC      TONI             ; No corresponding input bit is set
...                  ; At least one bit is set
```

#### 4.6.3.8 CLRX

- \* **CLRX.A** Clear destination address-word
- \* **CLRX.[W]** Clear destination word
- \* **CLRX.B** Clear destination byte

**Syntax**      CLRX.A dst

          CLRX dst or

          CLRX.W dst

          CLRX.B dst

**Operation**    0 → dst

**Emulation**    MOVX.A #0,dst

          MOVX #0,dst

          MOVX.B #0,dst

**Description**     The destination operand is cleared.

**Status Bits**   Status bits are not affected.

**Mode Bits**     OSCOFF, CPUOFF, and GIE are not affected.

**Example**       RAM address-word TONI is cleared.

```
CLRX.A    TONI    ; 0 -> TONI
```

#### 4.6.3.9 CMPX

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CMPX.A</b>      | Compare source address-word and destination address-word                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>CMPX.[W]</b>    | Compare source word and destination word                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>CMPX.B</b>      | Compare source byte and destination byte                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Syntax</b>      | CMPX.A src,dst<br>CMPX src,dst OR CMPX.W src,dst<br>CMPX.B src,dst                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Operation</b>   | (.not. src) + 1 + dst or dst - src                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Description</b> | The source operand is subtracted from the destination operand by adding the 1s complement of the source + 1 to the destination. The result affects only the status bits. Both operands may be located in the full address space.                                                                                                                                                                                                                                                    |
| <b>Status Bits</b> | N: Set if result is negative (src > dst), reset if positive (src ≤ dst)<br>Z: Set if result is zero (src = dst), reset otherwise (src ≠ dst)<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow) |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | Compare EDE with a 20-bit constant 18000h. Jump to label TONI if EDE equals the constant.                                                                                                                                                                                                                                                                                                                                                                                           |

```
CMPX.A #018000h,EDE      ; Compare EDE with 18000h
JEQ    TONI                ; EDE contains 18000h
...                  ; Not equal
```

|                |                                                                                                                                       |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is compared with R7. Jump to label TONI if R7 contains a lower, signed, 16-bit number. |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------|

```
CMPX.W @R5,R7            ; Compare two signed numbers
JL     TONI                ; R7 < @R5
...                  ; R7 >= @R5
```

|                |                                                                                                                                                                     |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table byte pointed to by R5 (20-bit address) is compared to the input in I/O Port1. Jump to label TONI if the values are equal. The next table byte is addressed. |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
CMPX.B @R5+,&P1IN        ; Compare P1 bits with table. R5 + 1
JEQ    TONI                ; Equal contents
...                  ; Not equal
```

Note: Use CMPA for the following two cases for better density and execution.

```
CMPA   Rsrc,Rdst
CMPA   #imm20,Rdst
```

#### **4.6.3.10 DADCX**

- \* **DADCX.A** Add carry decimaly to destination address-word
  - \* **DADCX.[W]** Add carry decimaly to destination word
  - \* **DADCX.B** Add carry decimaly to destination byte

## Syntax

DADCX.A dst  
DADCX dst or DADCX.W dst  
DADCX.B dst

## Operation

$\text{dst} + C \rightarrow \text{dst}$  (decimally)

Emulation

DADDX.A #0,dst

DADDX #0,dst

DADDX B #0 dst

## Description

The carry bit ( $C$ ) is added decimaly to the destination

## Description

N: Set if MSB of result is 1 (address-word > 79999h, word > 7999h, byte > 79h), reset if MSB is 0

7: Set if result is zero, reset otherwise

C: Set if the BCD result is too large (address-word > 99999h, word > 9999h, byte > 99h), reset otherwise.

v: Undefined

## Mode Bits

OSCOFF, CPUOFF, and GIE are not affected.

### **Example**

The 40-bit counter, pointed to by R12 and R13, is incremented decimaly.

DADDX.A #1,0(R12) ; Increment lower 20 bits  
DADCX A 0(R13) ; Add carry to upper 20 bits

#### 4.6.3.11 DADDX

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>DADDX.A</b>     | Add source address-word and carry decimal to destination address-word                                                                                                                                                                                                                                                                                                                                                               |
| <b>DADDX.[W]</b>   | Add source word and carry decimal to destination word                                                                                                                                                                                                                                                                                                                                                                               |
| <b>DADDX.B</b>     | Add source byte and carry decimal to destination byte                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Syntax</b>      | DADDX.A src,dst<br>DADDX src,dst or DADDX.W src,dst<br>DADDX.B src,dst                                                                                                                                                                                                                                                                                                                                                              |
| <b>Operation</b>   | $src + dst + C \rightarrow dst$ (decimally)                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Description</b> | The source operand and the destination operand are treated as two (.B), four (.W), or five (.A) binary coded decimals (BCD) with positive signs. The source operand and the carry bit C are added decimal to the destination operand. The source operand is not affected. The previous contents of the destination are lost. The result is not defined for non-BCD numbers. Both operands may be located in the full address space. |
| <b>Status Bits</b> | N: Set if MSB of result is 1 (address-word > 79999h, word > 7999h, byte > 79h), reset if MSB is 0.<br>Z: Set if result is zero, reset otherwise<br>C: Set if the BCD result is too large (address-word > 99999h, word > 9999h, byte > 99h), reset otherwise<br>V: Undefined                                                                                                                                                         |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | Decimal 10 is added to the 20-bit BCD counter DECCNTR located in two words.                                                                                                                                                                                                                                                                                                                                                         |

```
DADDX.A #10h,&DECCNTR ; Add 10 to 20-bit BCD counter
```

|                |                                                                                                                                                                              |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The eight-digit BCD number contained in 20-bit addresses BCD and BCD+2 is added decimal to an eight-digit BCD number contained in R4 and R5 (BCD+2 and R5 contain the MSDs). |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
CLRC ; Clear carry
DADDX.W BCD,R4 ; Add LSDs
DADDX.W BCD+2,R5 ; Add MSDs with carry
JC OVERFLOW ; Result >99999999: go to error routine
... ; Result ok
```

|                |                                                                                                                      |
|----------------|----------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The two-digit BCD number contained in 20-bit address BCD is added decimal to a two-digit BCD number contained in R4. |
|----------------|----------------------------------------------------------------------------------------------------------------------|

```
CLRC ; Clear carry
DADDX.B BCD,R4 ; Add BCD to R4 decimal.
; R4: 000ddh
```

#### 4.6.3.12 DECX

- \* **DECX.A** Decrement destination address-word
- \* **DECX.[W]** Decrement destination word
- \* **DECX.B** Decrement destination byte

**Syntax** DECX.A dst

DECX dst or DECX.W dst  
DECX.B dst

**Operation** dst - 1 → dst

**Emulation** SUBX.A #1,dst  
SUBX #1,dst  
SUBX.B #1,dst

**Description** The destination operand is decremented by one. The original contents are lost.

**Status Bits** N: Set if result is negative, reset if positive

Z: Set if dst contained 1, reset otherwise

C: Reset if dst contained 0, set otherwise

V: Set if an arithmetic overflow occurs, otherwise reset

**Mode Bits** OSCOFF, CPUOFF, and GIE are not affected.

**Example** RAM address-word TONI is decremented by one.

```
DECX.A    TONI      ; Decrement TONI
```

#### 4.6.3.13 DECDX

- \* **DECDX.A** Double-decrement destination address-word
- \* **DECDX.[W]** Double-decrement destination word
- \* **DECDX.B** Double-decrement destination byte

**Syntax** DECDX.A dst

DECDX dst or DECDX.W dst

DECDX.B dst

**Operation** dst - 2 → dst

**Emulation** SUBX.A #2,dst

SUBX #2,dst

SUBX.B #2,dst

**Description** The destination operand is decremented by two. The original contents are lost.

**Status Bits** N: Set if result is negative, reset if positive

Z: Set if dst contained 2, reset otherwise

C: Reset if dst contained 0 or 1, set otherwise

V: Set if an arithmetic overflow occurs, otherwise reset

**Mode Bits** OSCOFF, CPUOFF, and GIE are not affected.

**Example** RAM address-word TONI is decremented by two.

```
DECDX.A    TONI      ; Decrement TONI
```

#### 4.6.3.14 INCX

- \* **INCX.A** Increment destination address-word
- \* **INCX.[W]** Increment destination word
- \* **INCX.B** Increment destination byte

**Syntax**      INCX.A dst

                INCX dst or                            INCX.W dst  
                 INCX.B dst

**Operation**    dst + 1 → dst

**Emulation**    ADDX.A #1,dst  
                   ADDX #1,dst  
                   ADDX.B #1,dst

**Description**     The destination operand is incremented by one. The original contents are lost.

**Status Bits**    N: Set if result is negative, reset if positive  
                   Z: Set if dst contained 0FFFFh, reset otherwise  
                       Set if dst contained 0FFFh, reset otherwise  
                       Set if dst contained 0FFh, reset otherwise  
                   C: Set if dst contained 0FFFFh, reset otherwise  
                       Set if dst contained 0FFFh, reset otherwise  
                       Set if dst contained 0FFh, reset otherwise  
                   V: Set if dst contained 07FFFh, reset otherwise  
                       Set if dst contained 07FFFh, reset otherwise  
                       Set if dst contained 07Fh, reset otherwise

**Mode Bits**    OSCOFF, CPUOFF, and GIE are not affected.

**Example**       RAM address-word TONI is incremented by one.

```
INCX.A    TONI      ; Increment TONI (20-bits)
```

#### 4.6.3.15 INCDX

- \* **INCDX.A** Double-increment destination address-word
- \* **INCDX.[W]** Double-increment destination word
- \* **INCDX.B** Double-increment destination byte

**Syntax**

```
INCDX.A dst
INCDX dst or           INCDX.W dst
INCDX.B dst
```

**Operation**

$dst + 2 \rightarrow dst$

**Emulation**

ADDX.A #2,dst

ADDX #2,dst

ADDX.B #2,dst

**Description**

The destination operand is incremented by two. The original contents are lost.

**Status Bits**

- N: Set if result is negative, reset if positive
- Z: Set if dst contained 0FFFFEh, reset otherwise
  - Set if dst contained 0FFEh, reset otherwise
  - Set if dst contained 0FEh, reset otherwise
- C: Set if dst contained 0FFFFEh or 0FFFFFFh, reset otherwise
  - Set if dst contained 0FFEh or 0FFh, reset otherwise
  - Set if dst contained 0FEh or 0Fh, reset otherwise
- V: Set if dst contained 07FFFEh or 07FFFFFFh, reset otherwise
  - Set if dst contained 07FFEh or 07FFFh, reset otherwise
  - Set if dst contained 07Eh or 07Fh, reset otherwise

**Mode Bits**

OSCOFF, CPUOFF, and GIE are not affected.

**Example**

RAM byte LEO is incremented by two; PC points to upper memory.

```
INCDX.B    LEO      ; Increment LEO by two
```

#### 4.6.3.16 INVX

- \* **INVX.A**      Invert destination
- \* **INVX.[W]**    Invert destination
- \* **INVX.B**      Invert destination

**Syntax**            INVX.A dst

                      INVX dst or                            INVX.W dst  
                       INVX.B dst

**Operation**        .NOT.dst → dst

**Emulation**        XORX.A #0FFFFFh,dst  
                       XORX #0FFFFFh,dst  
                       XORX.B #0FFh,dst

**Description**        The destination operand is inverted. The original contents are lost.

**Status Bits**      N: Set if result is negative, reset if positive  
                       Z: Set if dst contained 0FFFFFh, reset otherwise  
                       Set if dst contained 0FFFh, reset otherwise  
                       Set if dst contained 0FFh, reset otherwise

C: Set if result is not zero, reset otherwise (= .NOT. Zero)

V: Set if initial destination operand was negative, otherwise reset

**Mode Bits**        OSCOFF, CPUOFF, and GIE are not affected.

**Example**          20-bit content of R5 is negated (twos complement).

```
INVX.A    R5      ; Invert R5
INCX.A    R5      ; R5 is now negated
```

**Example**          Content of memory byte LEO is negated. PC is pointing to upper memory.

```
INVX.B    LEO     ; Invert LEO
INCX.B    LEO     ; MEM(LEO) is negated
```

#### 4.6.3.17 MOVX

|                    |                                                                                                                                              |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>MOVX.A</b>      | Move source address-word to destination address-word                                                                                         |
| <b>MOVX.[W]</b>    | Move source word to destination word                                                                                                         |
| <b>MOVX.B</b>      | Move source byte to destination byte                                                                                                         |
| <b>Syntax</b>      | MOVX.A src,dst<br>MOVX src,dst or MOVX.W src,dst<br>MOVX.B src,dst                                                                           |
| <b>Operation</b>   | src → dst                                                                                                                                    |
| <b>Description</b> | The source operand is copied to the destination. The source operand is not affected. Both operands may be located in the full address space. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                     |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                    |
| <b>Example</b>     | Move a 20-bit constant 18000h to absolute address-word EDE                                                                                   |

```
MOVX.A #018000h,&EDE ; Move 18000h to EDE
```

|                |                                                                                                                         |
|----------------|-------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The contents of table EDE (word data, 20-bit addresses) are copied to table TOM. The length of the table is 030h words. |
|----------------|-------------------------------------------------------------------------------------------------------------------------|

```
Loop MOVA #EDE,R10 ; Prepare pointer (20-bit address)
      MOVX.W @R10+,TOM-EDE-2(R10) ; R10 points to both tables.
                                    ; R10+2
      CMPA #EDE+60h,R10 ; End of table reached?
      JLO Loop ; Not yet
      ... ; Copy completed
```

|                |                                                                                                                         |
|----------------|-------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | The contents of table EDE (byte data, 20-bit addresses) are copied to table TOM. The length of the table is 020h bytes. |
|----------------|-------------------------------------------------------------------------------------------------------------------------|

```
Loop MOVA #EDE,R10 ; Prepare pointer (20-bit)
      MOV #20h,R9 ; Prepare counter
      MOVX.W @R10+,TOM-EDE-2(R10) ; R10 points to both tables.
                                    ; R10+1
      DEC R9 ; Decrement counter
      JNZ Loop ; Not yet done
      ... ; Copy completed
```

Ten of the 28 possible addressing combinations of the MOVX.A instruction can use the MOVA instruction. This saves two bytes and code cycles. Examples for the addressing combinations are:

|                    |                  |                     |
|--------------------|------------------|---------------------|
| MOVX.A Rsrc,Rdst   | MOVA Rsrc,Rdst   | ; Reg/Reg           |
| MOVX.A #imm20,Rdst | MOVA #imm20,Rdst | ; Immediate/Reg     |
| MOVX.A &abs20,Rdst | MOVA &abs20,Rdst | ; Absolute/Reg      |
| MOVX.A @Rsrc,Rdst  | MOVA @Rsrc,Rdst  | ; Indirect/Reg      |
| MOVX.A @Rsrc+,Rdst | MOVA @Rsrc+,Rdst | ; Indirect,Auto/Reg |
| MOVX.A Rsrc,&abs20 | MOVA Rsrc,&abs20 | ; Reg/Absolute      |

The next four replacements are possible only if 16-bit indexes are sufficient for the addressing:

|        |                       |      |                       |                |
|--------|-----------------------|------|-----------------------|----------------|
| MOVX.A | <i>z20(Rsrc),Rdst</i> | MOVA | <i>z16(Rsrc),Rdst</i> | ; Indexed/Reg  |
| MOVX.A | <i>Rsrc,z20(Rdst)</i> | MOVA | <i>Rsrc,z16(Rdst)</i> | ; Reg/Indexed  |
| MOVX.A | <i>symb20,Rdst</i>    | MOVA | <i>symb16,Rdst</i>    | ; Symbolic/Reg |
| MOVX.A | <i>Rsrc,symb20</i>    | MOVA | <i>Rsrc,symb16</i>    | ; Reg/Symbolic |

#### 4.6.3.18 POPM

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>POPM.A</b>      | Restore n CPU registers (20-bit data) from the stack                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>POPM.[W]</b>    | Restore n CPU registers (16-bit data) from the stack                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Syntax</b>      | POPM.A #n,Rdst $1 \leq n \leq 16$<br>POPM.W #n,Rdst or POPM #n,Rdst $1 \leq n \leq 16$                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Operation</b>   | POPM.A: Restore the register values from stack to the specified CPU registers. The SP is incremented by four for each register restored from stack. The 20-bit values from stack (two words per register) are restored to the registers.<br>POPM.W: Restore the 16-bit register values from stack to the specified CPU registers. The SP is incremented by two for each register restored from stack. The 16-bit values from stack (one word per register) are restored to the CPU registers.<br>Note : This instruction does not use the extension word. |
| <b>Description</b> | POPM.A: The CPU registers pushed on the stack are moved to the extended CPU registers, starting with the CPU register (Rdst – n + 1). The SP is incremented by (n × 4) after the operation.<br>POPM.W: The 16-bit registers pushed on the stack are moved back to the CPU registers, starting with CPU register (Rdst – n + 1). The SP is incremented by (n × 2) after the instruction. The MSBs (Rdst.19:16) of the restored CPU registers are cleared.                                                                                                  |
| <b>Status Bits</b> | Status bits are not affected, except SR is included in the operation.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Example</b>     | Restore the 20-bit registers R9, R10, R11, R12, R13 from the stack                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

```
POPM.A #5,R13 ; Restore R9, R10, R11, R12, R13
```

**Example**      Restore the 16-bit registers R9, R10, R11, R12, R13 from the stack.

```
POPM.W #5,R13 ; Restore R9, R10, R11, R12, R13
```

#### 4.6.3.19 PUSHM

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>PUSHM.A</b>     | Save n CPU registers (20-bit data) on the stack                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>PUSHM.[W]</b>   | Save n CPU registers (16-bit words) on the stack                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Syntax</b>      | PUSHM.A #n,Rdst $1 \leq n \leq 16$<br>PUSHM.W #n,Rdst Or PUSHM #n,Rdst $1 \leq n \leq 16$                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Operation</b>   | PUSHM.A: Save the 20-bit CPU register values on the stack. The SP is decremented by four for each register stored on the stack. The MSBs are stored first (higher address).<br>PUSHM.W: Save the 16-bit CPU register values on the stack. The SP is decremented by two for each register stored on the stack.                                                                                                                                                                                  |
| <b>Description</b> | PUSHM.A: The n CPU registers, starting with Rdst backwards, are stored on the stack. The SP is decremented by $(n \times 4)$ after the operation. The data (Rn.19:0) of the pushed CPU registers is not affected.<br>PUSHM.W: The n registers, starting with Rdst backwards, are stored on the stack. The SP is decremented by $(n \times 2)$ after the operation. The data (Rn.19:0) of the pushed CPU registers is not affected.<br>Note : This instruction does not use the extension word. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Example</b>     | Save the five 20-bit registers R9, R10, R11, R12, R13 on the stack                                                                                                                                                                                                                                                                                                                                                                                                                             |

```
PUSHM.A    #5,R13      ; Save R13, R12, R11, R10, R9
```

|                |                                                                    |
|----------------|--------------------------------------------------------------------|
| <b>Example</b> | Save the five 16-bit registers R9, R10, R11, R12, R13 on the stack |
|                |                                                                    |

```
PUSHM.W    #5,R13      ; Save R13, R12, R11, R10, R9
```

#### 4.6.3.20 POPX

- \* **POPX.A** Restore single address-word from the stack
- \* **POPX.[W]** Restore single word from the stack
- \* **POPX.B** Restore single byte from the stack

**Syntax**

```
POPX.A dst
POPX dst or          POPX.W dst
POPX.B dst
```

**Operation**

Restore the 8-, 16-, 20-bit value from the stack to the destination. 20-bit addresses are possible. The SP is incremented by two (byte and word operands) and by four (address-word operand).

**Emulation**

The item on TOS is written to the destination operand. Register mode, Indexed mode, Symbolic mode, and Absolute mode are possible. The SP is incremented by two or four.

Note: the SP is incremented by two also for byte operations.

**Status Bits**

Status bits are not affected.

**Mode Bits**

OSCOFF, CPUOFF, and GIE are not affected.

**Example**

Write the 16-bit value on TOS to the 20-bit address &EDE

```
POPX.W    &EDE      ; Write word to address EDE
```

**Example**      Write the 20-bit value on TOS to R9

```
POPX.A    R9       ; Write address-word to R9
```

#### 4.6.3.21 PUSHX

|                    |                                                                                                                                                                                                                     |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>PUSHX.A</b>     | Save single address-word to the stack                                                                                                                                                                               |
| <b>PUSHX.[W]</b>   | Save single word to the stack                                                                                                                                                                                       |
| <b>PUSHX.B</b>     | Save single byte to the stack                                                                                                                                                                                       |
| <b>Syntax</b>      | PUSHX.A src<br>PUSHX src or<br>PUSHX.B src                                                                                                                                                                          |
| <b>Operation</b>   | Save the 8-, 16-, 20-bit value of the source operand on the TOS. 20-bit addresses are possible. The SP is decremented by two (byte and word operands) or by four (address-word operand) before the write operation. |
| <b>Description</b> | The SP is decremented by two (byte and word operands) or by four (address-word operand). Then the source operand is written to the TOS. All seven addressing modes are possible for the source operand.             |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                       |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                           |
| <b>Example</b>     | Save the byte at the 20-bit address &EDE on the stack                                                                                                                                                               |

```
PUSHX.B    &EDE      ; Save byte at address EDE
```

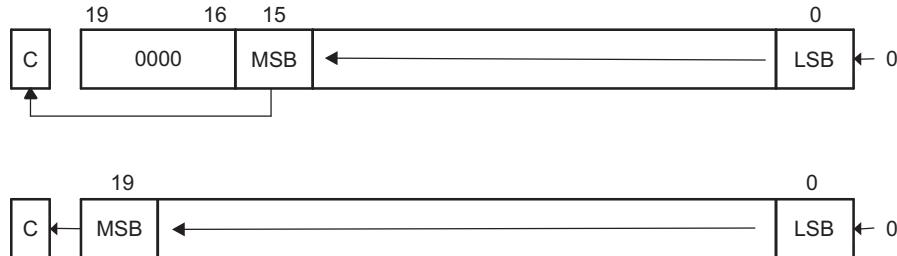
**Example**      Save the 20-bit value in R9 on the stack.

```
PUSHX.A    R9      ; Save address-word in R9
```

#### 4.6.3.22 RLAM

|                              |                                                                                                                                                                                                                                                                                                                                                      |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RLAM.A</b>                | Rotate left arithmetically the 20-bit CPU register content                                                                                                                                                                                                                                                                                           |
| <b>RLAM.[W]</b>              | Rotate left arithmetically the 16-bit CPU register content                                                                                                                                                                                                                                                                                           |
| <b>Syntax</b>                | RLAM.A #n,Rdst $1 \leq n \leq 4$<br>RLAM.W #n,Rdst or RLAM #n,Rdst $1 \leq n \leq 4$                                                                                                                                                                                                                                                                 |
| <b>Operation Description</b> | $C \leftarrow MSB \leftarrow MSB-1 \dots LSB+1 \leftarrow LSB \leftarrow 0$<br>The destination operand is shifted arithmetically left one, two, three, or four positions as shown in <a href="#">Figure 4-44</a> . RLAM works as a multiplication (signed and unsigned) with 2, 4, 8, or 16. The word instruction RLAM.W clears the bits Rdst.19:16. |
|                              | Note : This instruction does not use the extension word.                                                                                                                                                                                                                                                                                             |
| <b>Status Bits</b>           | N: Set if result is negative<br>.A: Rdst.19 = 1, reset if Rdst.19 = 0<br>.W: Rdst.15 = 1, reset if Rdst.15 = 0<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the MSB (n = 1), MSB-1 (n = 2), MSB-2 (n = 3), MSB-3 (n = 4)<br>V: Undefined                                                                                           |
| <b>Mode Bits</b>             | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                            |
| <b>Example</b>               | The 20-bit operand in R5 is shifted left by three positions. It operates equal to an arithmetic multiplication by 8.                                                                                                                                                                                                                                 |

RLAM.A    #3,R5        ; R5 = R5 x 8



**Figure 4-44. Rotate Left Arithmetically—RLAM.[W] and RLAM.A**

#### 4.6.3.23 RLAX

- \* **RLAX.A**
- \* **RLAX.[W]**
- \* **RLAX.B**

**Syntax**      RLAX.A dst

                RLAX dst or                            RLAX.W dst  
                 RLAX.B dst

**Operation**     C  $\leftarrow$  MSB  $\leftarrow$  MSB-1 .... LSB+1  $\leftarrow$  LSB  $\leftarrow$  0

**Emulation**     ADDX.A dst,dst

                ADDX dst,dst  
                 ADDX.B dst,dst

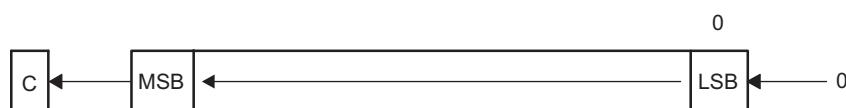
**Description**      The destination operand is shifted left one position as shown in [Figure 4-45](#). The MSB is shifted into the carry bit (C) and the LSB is filled with 0. The RLAX instruction acts as a signed multiplication by 2.

**Status Bits**     N: Set if result is negative, reset if positive  
                      Z: Set if result is zero, reset otherwise  
                      C: Loaded from the MSB  
                      V: Set if an arithmetic overflow occurs: the initial value is  $040000h \leq dst < 0C0000h$ ; reset otherwise  
                      Set if an arithmetic overflow occurs: the initial value is  $04000h \leq dst < 0C000h$ ; reset otherwise  
                      Set if an arithmetic overflow occurs: the initial value is  $040h \leq dst < 0C0h$ ; reset otherwise

**Mode Bits**      OSCOFF, CPUOFF, and GIE are not affected.

**Example**        The 20-bit value in R7 is multiplied by 2

RLAX.A    R7       ; Shift left R7 (20-bit)



**Figure 4-45. Destination Operand-Arithmetic Shift Left**

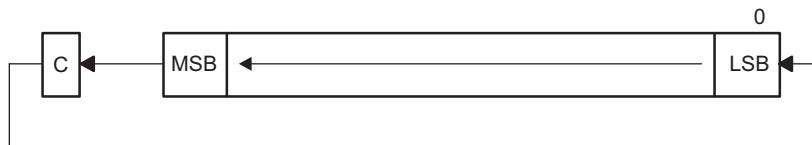
#### 4.6.3.24 RLCX

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * RLCX.A           | Rotate left through carry address-word                                                                                                                                                                                                                                                                                                                                                                                                                   |
| * RLCX.[W]         | Rotate left through carry word                                                                                                                                                                                                                                                                                                                                                                                                                           |
| * RLCX.B           | Rotate left through carry byte                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Syntax</b>      | RLCX.A dst<br>RLCX dst or RLCX.W dst<br>RLCX.B dst                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Operation</b>   | $C \leftarrow MSB \leftarrow MSB-1 \dots LSB+1 \leftarrow LSB \leftarrow C$                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Emulation</b>   | ADDCX.A dst,dst<br>ADDCX dst,dst<br>ADDCX.B dst,dst                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Description</b> | The destination operand is shifted left one position as shown in <a href="#">Figure 4-46</a> . The carry bit (C) is shifted into the LSB and the MSB is shifted into the carry bit (C).                                                                                                                                                                                                                                                                  |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the MSB<br>V: Set if an arithmetic overflow occurs: the initial value is $040000h \leq dst < 0C0000h$ ; reset otherwise<br>Set if an arithmetic overflow occurs: the initial value is $04000h \leq dst < 0C000h$ ; reset otherwise<br>Set if an arithmetic overflow occurs: the initial value is $040h \leq dst < 0C0h$ ; reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Example</b>     | The 20-bit value in R5 is shifted left one position.                                                                                                                                                                                                                                                                                                                                                                                                     |

RLCX.A R5 ;  $(R5 \times 2) + C \rightarrow R5$

**Example** The RAM byte LEO is shifted left one position. PC is pointing to upper memory.

RLCX.B LEO ;  $RAM(LEO) \times 2 + C \rightarrow RAM(LEO)$



**Figure 4-46. Destination Operand-Carry Left Shift**

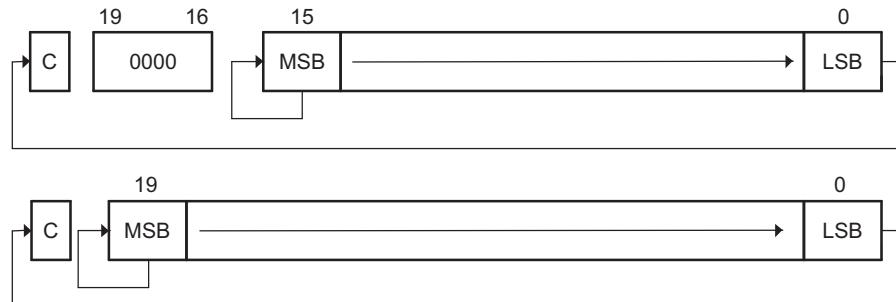
#### 4.6.3.25 RRAM

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRAM.A</b>      | Rotate right arithmetically the 20-bit CPU register content                                                                                                                                                                                                                                                                                                                                                                   |
| <b>RRAM.[W]</b>    | Rotate right arithmetically the 16-bit CPU register content                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Syntax</b>      | RRAM.A #n,Rdst $1 \leq n \leq 4$<br>RRAM.W #n,Rdst or RRAM #n,Rdst $1 \leq n \leq 4$                                                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | MSB → MSB → MSB-1 ... LSB+1 → LSB → C                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Description</b> | The destination operand is shifted right arithmetically by one, two, three, or four bit positions as shown in <a href="#">Figure 4-47</a> . The MSB retains its value (sign). RRAM operates equal to a signed division by 2, 4, 8, or 16. The MSB is retained and shifted into MSB-1. The LSB+1 is shifted into the LSB, and the LSB is shifted into the carry bit C. The word instruction RRAM.W clears the bits Rdst.19:16. |
| <b>Status Bits</b> | Note : This instruction does not use the extension word.<br>N: Set if result is negative<br>.A: Rdst.19 = 1, reset if Rdst.19 = 0<br>.W: Rdst.15 = 1, reset if Rdst.15 = 0<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the LSB (n = 1), LSB+1 (n = 2), LSB+2 (n = 3), or LSB+3 (n = 4)<br>V: Reset                                                                                                         |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Example</b>     | The signed 20-bit number in R5 is shifted arithmetically right two positions.                                                                                                                                                                                                                                                                                                                                                 |

```
RRAM.A #2,R5 ; R5/4 -> R5
```

**Example** The signed 20-bit value in R15 is multiplied by 0.75.  $(0.5 + 0.25) \times R15$ .

```
PUSHM.A #1,R15 ; Save extended R15 on stack
RRAM.A #1,R15 ; R15 y 0.5 -> R15
ADDX.A @SP+,R15 ; R15 y 0.5 + R15 = 1.5 y R15 -> R15
RRAM.A #1,R15 ; (1.5 y R15) y 0.5 = 0.75 y R15 -> R15
```



**Figure 4-47. Rotate Right Arithmetically RRAM.[W] and RRAM.A**

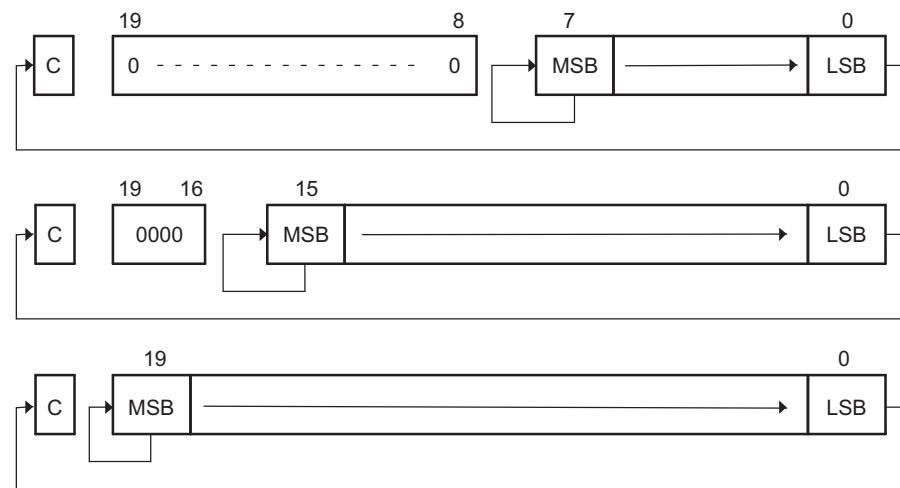
#### **4.6.3.26 RRAX**

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRA</b> X.A     | Rotate right arithmetically the 20-bit operand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>RRA</b> X.[W]   | Rotate right arithmetically the 16-bit operand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>RRA</b> X.B     | Rotate right arithmetically the 8-bit operand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Syntax</b>      | <pre> RRA A Rdst RRA W Rdst RRA Rdst RRA B Rdst  RRA A dst RRA dst or           RRA W dst RRA B dst </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | $MSB \rightarrow MSB \rightarrow MSB-1 \dots LSB+1 \rightarrow LSB \rightarrow C$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Description</b> | Register mode for the destination: the destination operand is shifted right by one bit position as shown in <a href="#">Figure 4-48</a> . The MSB retains its value (sign). The word instruction RRA.W clears the bits Rdst.19:16, the byte instruction RRA.B clears the bits Rdst.19:8. The MSB retains its value (sign), the LSB is shifted into the carry bit. RRA here operates equal to a signed division by 2.<br><br>All other modes for the destination: the destination operand is shifted right arithmetically by one bit position as shown in <a href="#">Figure 4-49</a> . The MSB retains its value (sign), the LSB is shifted into the carry bit. RRA here operates equal to a signed division by 2. All addressing modes, with the exception of the Immediate mode, are possible in the full memory. |
| <b>Status Bits</b> | <p>N: Set if result is negative, reset if positive<br/>           .A: dst.19 = 1, reset if dst.19 = 0<br/>           .W: dst.15 = 1, reset if dst.15 = 0<br/>           .B: dst.7 = 1, reset if dst.7 = 0</p> <p>Z: Set if result is zero, reset otherwise</p> <p>C: Loaded from the LSB</p> <p>V: Reset</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | The signed 20-bit number in R5 is shifted arithmetically right four positions.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

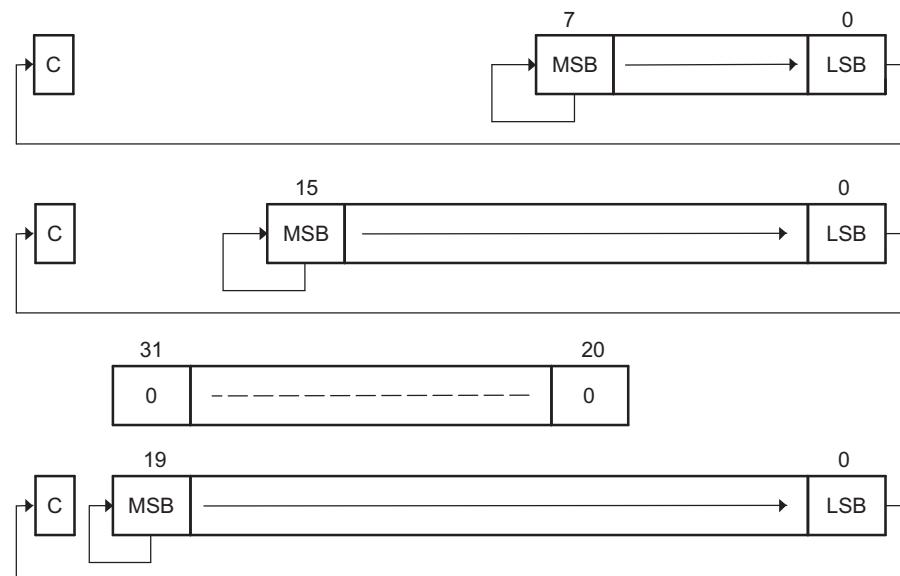
RPT #4  
RRAX.A R5 ; R5/16 -> R5

**Example** The signed 8-bit value in EDE is multiplied by 0.5.

RRAX.B      &EDE      ; EDE / 2 -> EDE



**Figure 4-48. Rotate Right Arithmetically RRAX(.B,.A) – Register Mode**



**Figure 4-49. Rotate Right Arithmetically RRAX(.B,.A) – Non-Register Mode**

#### 4.6.3.27 RRCM

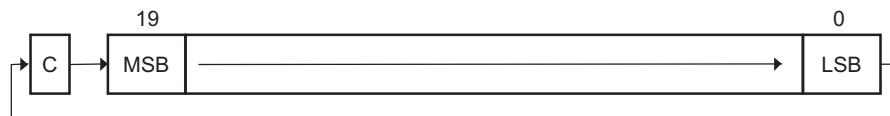
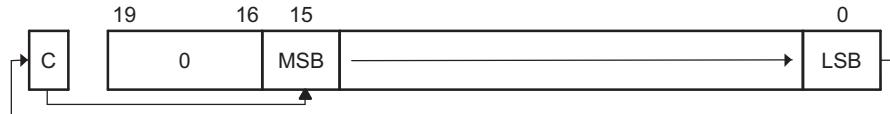
|                              |                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRCM.A</b>                | Rotate right through carry the 20-bit CPU register content                                                                                                                                                                                                                                                                                                              |
| <b>RRCM.[W]</b>              | Rotate right through carry the 16-bit CPU register content                                                                                                                                                                                                                                                                                                              |
| <b>Syntax</b>                | RRCM.A #n,Rdst $1 \leq n \leq 4$<br>RRCM.W #n,Rdst or RRCM #n,Rdst $1 \leq n \leq 4$                                                                                                                                                                                                                                                                                    |
| <b>Operation Description</b> | C → MSB → MSB-1 ... LSB+1 → LSB → C<br>The destination operand is shifted right by one, two, three, or four bit positions as shown in <a href="#">Figure 4-50</a> . The carry bit C is shifted into the MSB, the LSB is shifted into the carry bit. The word instruction RRCM.W clears the bits Rdst.19:16.<br>Note : This instruction does not use the extension word. |
| <b>Status Bits</b>           | N: Set if result is negative<br>.A: Rdst.19 = 1, reset if Rdst.19 = 0<br>.W: Rdst.15 = 1, reset if Rdst.15 = 0<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the LSB (n = 1), LSB+1 (n = 2), LSB+2 (n = 3), or LSB+3 (n = 4)<br>V: Reset                                                                                                               |
| <b>Mode Bits</b>             | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                               |

**Example** The address-word in R5 is shifted right by three positions. The MSB–2 is loaded with 1.

```
SETC          ; Prepare carry for MSB-2
RRCM.A #3,R5    ; R5 = R5 >> 3 + 20000h
```

**Example** The word in R6 is shifted right by two positions. The MSB is loaded with the LSB. The MSB–1 is loaded with the contents of the carry flag.

```
RRCM.W #2,R6      ; R6 = R6 >> 2. R6.19:16 = 0
```



**Figure 4-50. Rotate Right Through Carry RRCM[.W] and RRCM.A**

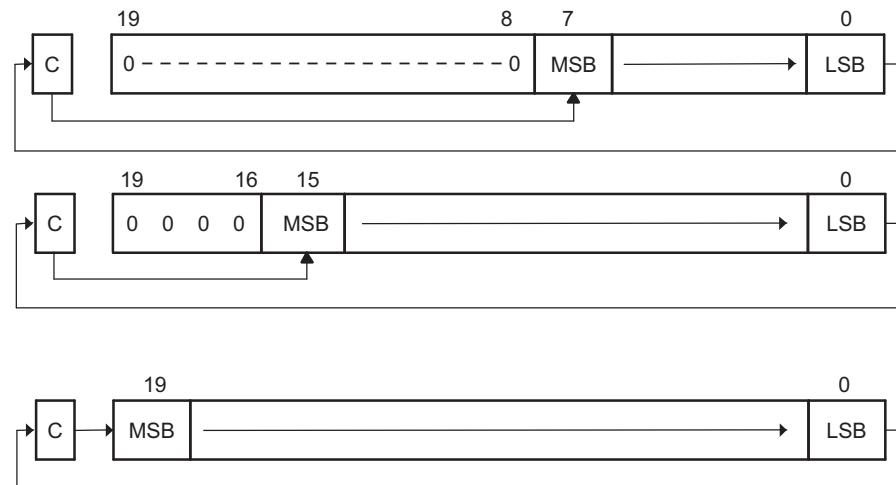
#### 4.6.3.28 RRCX

|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRCX.A</b>                | Rotate right through carry the 20-bit operand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>RRCX.[W]</b>              | Rotate right through carry the 16-bit operand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>RRCX.B</b>                | Rotate right through carry the 8-bit operand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Syntax</b>                | <pre>RRCX.A Rdst RRCX.W Rdst RRCX Rdst RRCX.B Rdst  RRCX.A dst RRCX dst or           RRCX.W dst RRCX.B dst</pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Operation Description</b> | <p><b>C → MSB → MSB-1 ... LSB+1 → LSB → C</b></p> <p>Register mode for the destination: the destination operand is shifted right by one bit position as shown in <a href="#">Figure 4-51</a>. The word instruction RRCX.W clears the bits Rdst.19:16, the byte instruction RRCX.B clears the bits Rdst.19:8. The carry bit C is shifted into the MSB, the LSB is shifted into the carry bit.</p> <p>All other modes for the destination: the destination operand is shifted right by one bit position as shown in <a href="#">Figure 4-52</a>. The carry bit C is shifted into the MSB, the LSB is shifted into the carry bit. All addressing modes, with the exception of the Immediate mode, are possible in the full memory.</p> |
| <b>Status Bits</b>           | <p>N: Set if result is negative</p> <p>.A: dst.19 = 1, reset if dst.19 = 0</p> <p>.W: dst.15 = 1, reset if dst.15 = 0</p> <p>.B: dst.7 = 1, reset if dst.7 = 0</p> <p>Z: Set if result is zero, reset otherwise</p> <p>C: Loaded from the LSB</p> <p>V: Reset</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Mode Bits</b>             | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>               | The 20-bit operand at address EDE is shifted right by one position. The MSB is loaded with 1.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

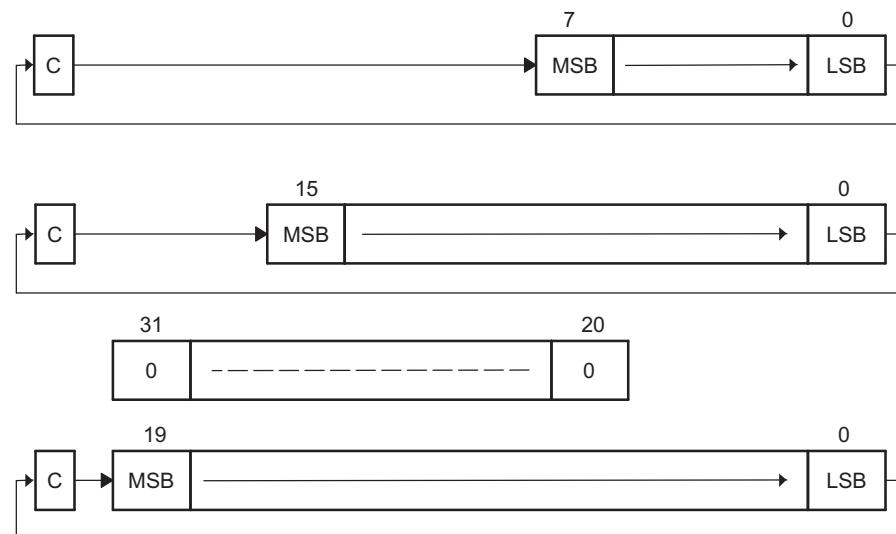
```
SETC          ; Prepare carry for MSB
RRCX.A      EDE      ; EDE = EDE >> 1 + 80000h
```

**Example**      The word in R6 is shifted right by 12 positions.

```
RPT      #12
RRCX.W  R6      ; R6 = R6 » 12. R6.19:16 = 0
```



**Figure 4-51. Rotate Right Through Carry RRCX(.B,.A) – Register Mode**



**Figure 4-52. Rotate Right Through Carry RRCX(.B,.A) – Non-Register Mode**

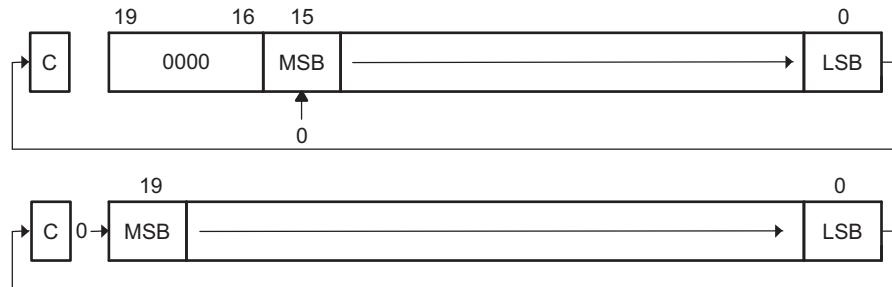
#### 4.6.3.29 RRUM

|                              |                                                                                                                                                                                                                                                                                                                                                          |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRUM.A</b>                | Rotate right through carry the 20-bit CPU register content                                                                                                                                                                                                                                                                                               |
| <b>RRUM.[W]</b>              | Rotate right through carry the 16-bit CPU register content                                                                                                                                                                                                                                                                                               |
| <b>Syntax</b>                | RRUM.A #n,Rdst $1 \leq n \leq 4$<br>RRUM.W #n,Rdst or RRUM #n,Rdst $1 \leq n \leq 4$                                                                                                                                                                                                                                                                     |
| <b>Operation Description</b> | 0 → MSB → MSB-1 ... LSB+1 → LSB → C<br>The destination operand is shifted right by one, two, three, or four bit positions as shown in <a href="#">Figure 4-53</a> . Zero is shifted into the MSB, the LSB is shifted into the carry bit. RRUM works like an unsigned division by 2, 4, 8, or 16. The word instruction RRUM.W clears the bits Rdst.19:16. |
| <b>Status Bits</b>           | Note : This instruction does not use the extension word.<br>N: Set if result is negative<br>.A: Rdst.19 = 1, reset if Rdst.19 = 0<br>.W: Rdst.15 = 1, reset if Rdst.15 = 0<br>Z: Set if result is zero, reset otherwise<br>C: Loaded from the LSB (n = 1), LSB+1 (n = 2), LSB+2 (n = 3), or LSB+3 (n = 4)<br>V: Reset                                    |
| <b>Mode Bits</b>             | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                |
| <b>Example</b>               | The unsigned address-word in R5 is divided by 16.                                                                                                                                                                                                                                                                                                        |

```
RRUM.A #4,R5 ; R5 = R5 >> 4. R5/16
```

**Example** The word in R6 is shifted right by one bit. The MSB R6.15 is loaded with 0.

```
RRUM.W #1,R6 ; R6 = R6/2. R6.19:15 = 0
```

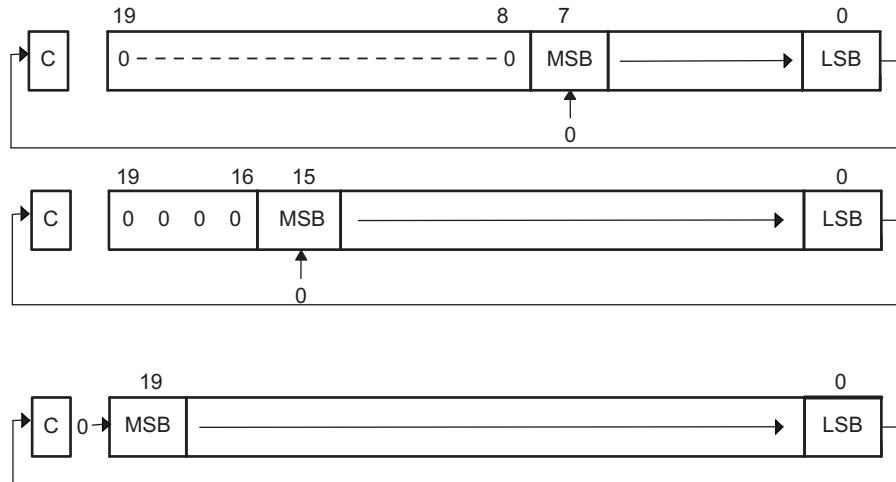


**Figure 4-53. Rotate Right Unsigned RRUM.[W] and RRUM.A**

#### 4.6.3.30 RRUX

|                    |                                                                                                                                                                                                                                                                                                                                  |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RRUX.A</b>      | Shift right unsigned the 20-bit CPU register content                                                                                                                                                                                                                                                                             |
| <b>RRUX.[W]</b>    | Shift right unsigned the 16-bit CPU register content                                                                                                                                                                                                                                                                             |
| <b>RRUX.B</b>      | Shift right unsigned the 8-bit CPU register content                                                                                                                                                                                                                                                                              |
| <b>Syntax</b>      | <pre>RRUX.A Rdst RRUX.W Rdst RRUX Rdst RRUX.B Rdst</pre>                                                                                                                                                                                                                                                                         |
| <b>Operation</b>   | $C=0 \rightarrow MSB \rightarrow MSB-1 \dots LSB+1 \rightarrow LSB \rightarrow C$                                                                                                                                                                                                                                                |
| <b>Description</b> | RRUX is valid for register mode only: the destination operand is shifted right by one bit position as shown in <a href="#">Figure 4-54</a> . The word instruction RRUX.W clears the bits Rdst.19:16. The byte instruction RRUX.B clears the bits Rdst.19:8. Zero is shifted into the MSB, the LSB is shifted into the carry bit. |
| <b>Status Bits</b> | <p>N: Set if result is negative<br/>         .A: dst.19 = 1, reset if dst.19 = 0<br/>         .W: dst.15 = 1, reset if dst.15 = 0<br/>         .B: dst.7 = 1, reset if dst.7 = 0</p> <p>Z: Set if result is zero, reset otherwise</p> <p>C: Loaded from the LSB</p> <p>V: Reset</p>                                              |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                        |
| <b>Example</b>     | The word in R6 is shifted right by 12 positions.                                                                                                                                                                                                                                                                                 |

```
RPT      #12
RRUX.W  R6      ; R6 = R6 >> 12. R6.19:16 = 0
```



**Figure 4-54. Rotate Right Unsigned RRUX(.B,.A) – Register Mode**

#### 4.6.3.31 SBCX

|                    |                                                                                                                                                                                                                                                                              |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* SBCX.A</b>    | Subtract borrow (.NOT. carry) from destination address-word                                                                                                                                                                                                                  |
| <b>* SBCX.[W]</b>  | Subtract borrow (.NOT. carry) from destination word                                                                                                                                                                                                                          |
| <b>* SBCX.B</b>    | Subtract borrow (.NOT. carry) from destination byte                                                                                                                                                                                                                          |
| <b>Syntax</b>      | SBCX.A dst<br>SBCX dst or SBCX.W dst<br>SBCX.B dst                                                                                                                                                                                                                           |
| <b>Operation</b>   | dst + 0FFFFh + C → dst<br>dst + 0FFFFh + C → dst<br>dst + 0FFh + C → dst                                                                                                                                                                                                     |
| <b>Emulation</b>   | SBCX.A #0,dst<br>SBCX #0,dst<br>SBCX.B #0,dst                                                                                                                                                                                                                                |
| <b>Description</b> | The carry bit (C) is added to the destination operand minus one. The previous contents of the destination are lost.                                                                                                                                                          |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB of the result, reset otherwise<br>Set to 1 if no borrow, reset if borrow<br>V: Set if an arithmetic overflow occurs, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                    |
| <b>Example</b>     | The 8-bit counter pointed to by R13 is subtracted from a 16-bit counter pointed to by R12.                                                                                                                                                                                   |

```
SUBX.B    @R13,0(R12)      ; Subtract LSDs
SBCX.B    1(R12)          ; Subtract carry from MSD
```

---

**NOTE: Borrow implementation**

The borrow is treated as a .NOT. carry:

---

| Borrow | Carry Bit |
|--------|-----------|
| Yes    | 0         |
| No     | 1         |

---

#### 4.6.3.32 SUBX

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SUBX.A</b>      | Subtract source address-word from destination address-word                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>SUBX.[W]</b>    | Subtract source word from destination word                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>SUBX.B</b>      | Subtract source byte from destination byte                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Syntax</b>      | SUBX.A src,dst<br>SUBX src,dst or SUBX.W src,dst<br>SUBX.B src,dst                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Operation</b>   | $(\text{not. src}) + 1 + \text{dst} \rightarrow \text{dst}$ or $\text{dst} - \text{src} \rightarrow \text{dst}$                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Description</b> | The source operand is subtracted from the destination operand. This is done by adding the 1s complement of the source + 1 to the destination. The source operand is not affected. The result is written to the destination operand. Both operands may be located in the full address space.                                                                                                                                                                                                                                                                       |
| <b>Status Bits</b> | N: Set if result is negative ( $\text{src} > \text{dst}$ ), reset if positive ( $\text{src} \leq \text{dst}$ )<br>Z: Set if result is zero ( $\text{src} = \text{dst}$ ), reset otherwise ( $\text{src} \neq \text{dst}$ )<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow) |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Example</b>     | A 20-bit constant 87654h is subtracted from EDE (LSBs) and EDE+2 (MSBs).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

```
SUBX.A #87654h,EDE ; Subtract 87654h from EDE+2 | EDE
```

|                |                                                                                                                                                                                  |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A table word pointed to by R5 (20-bit address) is subtracted from R7. Jump to label TONI if R7 contains zero after the instruction. R5 is auto-incremented by two. R7.19:16 = 0. |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
SUBX.W @R5+,R7 ; Subtract table number from R7. R5 + 2
JZ TONI ; R7 = @R5 (before subtraction)
... ; R7 <> @R5 (before subtraction)
```

|                |                                                                                                                    |
|----------------|--------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | Byte CNT is subtracted from the byte R12 points to in the full address space. Address of CNT is within PC ± 512 K. |
|----------------|--------------------------------------------------------------------------------------------------------------------|

```
SUBX.B CNT,0(R12) ; Subtract CNT from @R12
```

Note: Use SUBA for the following two cases for better density and execution.

```
SUBX.A Rsrc,Rdst
SUBX.A #imm20,Rdst
```

### 4.6.3.33 SUBCX

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SUBCX.A</b>     | Subtract source address-word with carry from destination address-word                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>SUBCX.[W]</b>   | Subtract source word with carry from destination word                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>SUBCX.B</b>     | Subtract source byte with carry from destination byte                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Syntax</b>      | SUBCX.A src,dst<br>SUBCX src,dst or SUBCX.W src,dst<br>SUBCX.B src,dst                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Operation</b>   | $(\text{not. src}) + C + \text{dst} \rightarrow \text{dst}$ or $\text{dst} - (\text{src} - 1) + C \rightarrow \text{dst}$                                                                                                                                                                                                                                                                                                                                |
| <b>Description</b> | The source operand is subtracted from the destination operand. This is made by adding the 1s complement of the source + carry to the destination. The source operand is not affected, the result is written to the destination operand. Both operands may be located in the full address space.                                                                                                                                                          |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow). |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Example</b>     | A 20-bit constant 87654h is subtracted from R5 with the carry from the previous instruction.                                                                                                                                                                                                                                                                                                                                                             |

```
SUBCX.A #87654h,R5 ; Subtract 87654h + C from R5
```

|                |                                                                                                                                                                                  |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | A 48-bit number (3 words) pointed to by R5 (20-bit address) is subtracted from a 48-bit counter in RAM, pointed to by R7. R5 auto-increments to point to the next 48-bit number. |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```
SUBX.W @R5+,0(R7) ; Subtract LSBs. R5 + 2
SUBCX.W @R5+,2(R7) ; Subtract MIDs with C. R5 + 2
SUBCX.W @R5+,4(R7) ; Subtract MSBs with C. R5 + 2
```

|                |                                                                                                                      |
|----------------|----------------------------------------------------------------------------------------------------------------------|
| <b>Example</b> | Byte CNT is subtracted from the byte R12 points to. The carry of the previous instruction is used. 20-bit addresses. |
|----------------|----------------------------------------------------------------------------------------------------------------------|

```
SUBCX.B &CNT,0(R12) ; Subtract byte CNT from @R12
```

#### 4.6.3.34 SWPBX

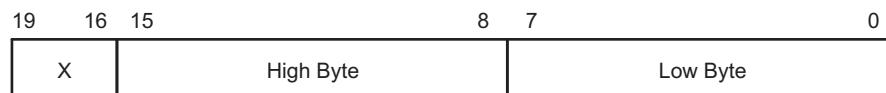
|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SWPBX.A</b>     | Swap bytes of lower word                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>SWPBX.[W]</b>   | Swap bytes of word                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Syntax</b>      | SWPBX.A dst<br>SWPBX dst or SWPBX.W dst                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Operation</b>   | dst.15:8 ↔ dst.7:0                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Description</b> | Register mode: Rn.15:8 are swapped with Rn.7:0. When the .A extension is used, Rn.19:16 are unchanged. When the .W extension is used, Rn.19:16 are cleared.<br>Other modes: When the .A extension is used, bits 31:20 of the destination address are cleared, bits 19:16 are left unchanged, and bits 15:8 are swapped with bits 7:0. When the .W extension is used, bits 15:8 are swapped with bits 7:0 of the addressed word. |
| <b>Status Bits</b> | Status bits are not affected.                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Example</b>     | Exchange the bytes of RAM address-word EDE                                                                                                                                                                                                                                                                                                                                                                                      |

```
MOVX.A    #23456h, &EDE      ; 23456h -> EDE
SWPBX.A   EDE                ; 25634h -> EDE
```

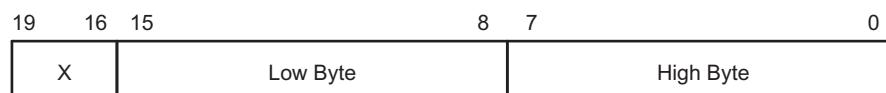
**Example** Exchange the bytes of R5

```
MOVA      #23456h, R5        ; 23456h -> R5
SWPBX.W   R5                ; 05634h -> R5
```

Before SWPBX.A



After SWPBX.A



**Figure 4-55. Swap Bytes SWPBX.A Register Mode**

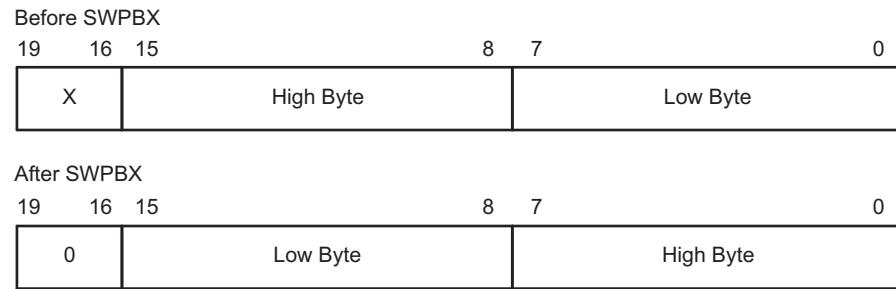
Before SWPBX.A



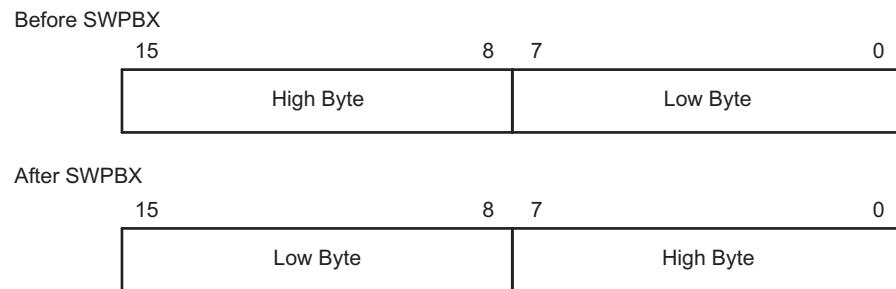
After SWPBX.A



**Figure 4-56. Swap Bytes SWPBX.A In Memory**



**Figure 4-57. Swap Bytes SWPBX[.W] Register Mode**



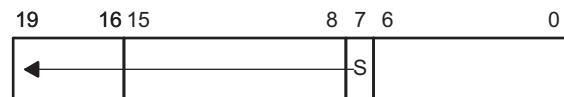
**Figure 4-58. Swap Bytes SWPBX[.W] In Memory**

#### **4.6.3.35 SXTX**

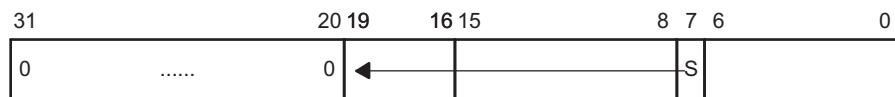
|                    |                                                                                                                                                                                                                                                                                                                                 |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SXTX.A</b>      | Extend sign of lower byte to address-word                                                                                                                                                                                                                                                                                       |
| <b>SXTX.[W]</b>    | Extend sign of lower byte to word                                                                                                                                                                                                                                                                                               |
| <b>Syntax</b>      | SXTX.A dst                                                                                                                                                                                                                                                                                                                      |
|                    | SXTX dst or SXTX.W dst                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | dst.7 → dst.15:8, Rdst.7 → Rdst.19:8 (Register mode)                                                                                                                                                                                                                                                                            |
| <b>Description</b> | Register mode: The sign of the low byte of the operand (Rdst.7) is extended into the bits Rdst.19:8.<br>Other modes: SXTX.A: the sign of the low byte of the operand (dst.7) is extended into dst.19:8. The bits dst.31:20 are cleared.<br>SXTX.[W]: the sign of the low byte of the operand (dst.7) is extended into dst.15:8. |
| <b>Status Bits</b> | N: Set if result is negative, reset otherwise<br>Z: Set if result is zero, reset otherwise<br>C: Set if result is not zero, reset otherwise (C = .not.Z)<br>V: Reset                                                                                                                                                            |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                       |
| <b>Example</b>     | The signed 8-bit data in EDE.7:0 is sign extended to 20 bits: EDE.19:8. Bits 31:20 located in EDE+2 are cleared.                                                                                                                                                                                                                |

SXTX.A &EDE ; Sign extended EDE -> EDE+2/EDE

SXTX.A Rdst



SXTX.A dst

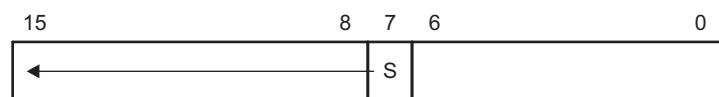


**Figure 4-59.** Sign Extend SXTX.A

SXTX[.W] Rdst



SXTX[.W] dst



**Figure 4-60. Sign Extend SXTX[.W]**

#### 4.6.3.36 TSTX

|                    |                                                                                                                                                    |            |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>* TSTX.A</b>    | Test destination address-word                                                                                                                      |            |
| <b>* TSTX.[W]</b>  | Test destination word                                                                                                                              |            |
| <b>* TSTX.B</b>    | Test destination byte                                                                                                                              |            |
| <b>Syntax</b>      | TSTX.A dst                                                                                                                                         | TSTX.W dst |
|                    | TSTX dst or                                                                                                                                        |            |
|                    | TSTX.B dst                                                                                                                                         |            |
| <b>Operation</b>   | dst + 0FFFFh + 1                                                                                                                                   |            |
|                    | dst + 0FFFh + 1                                                                                                                                    |            |
|                    | dst + 0FFh + 1                                                                                                                                     |            |
| <b>Emulation</b>   | CMPX.A #0,dst                                                                                                                                      |            |
|                    | CMPX #0,dst                                                                                                                                        |            |
|                    | CMPX.B #0,dst                                                                                                                                      |            |
| <b>Description</b> | The destination operand is compared with zero. The status bits are set according to the result. The destination is not affected.                   |            |
| <b>Status Bits</b> | N: Set if destination is negative, reset if positive<br>Z: Set if destination contains zero, reset otherwise<br>C: Set<br>V: Reset                 |            |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                          |            |
| <b>Example</b>     | RAM byte LEO is tested; PC is pointing to upper memory. If it is negative, continue at LEONEG; if it is positive but not zero, continue at LEOPOS. |            |

```

TSTX.B    LEO          ; Test LEO
JN        LEONEG       ; LEO is negative
JZ        LEOZERO      ; LEO is zero
LEOPOS   .....        ; LEO is positive but not zero
LEONEG   .....        ; LEO is negative
LEOZERO  .....        ; LEO is zero

```

#### 4.6.3.37 XORX

|                    |                                                                                                                                                                                                                                                                    |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>XORX.A</b>      | Exclusive OR source address-word with destination address-word                                                                                                                                                                                                     |
| <b>XORX.[W]</b>    | Exclusive OR source word with destination word                                                                                                                                                                                                                     |
| <b>XORX.B</b>      | Exclusive OR source byte with destination byte                                                                                                                                                                                                                     |
| <b>Syntax</b>      | XORX.A src,dst<br>XORX src,dst or XORX.W src,dst<br>XORX.B src,dst                                                                                                                                                                                                 |
| <b>Operation</b>   | src .xor. dst → dst                                                                                                                                                                                                                                                |
| <b>Description</b> | The source and destination operands are exclusively ORed. The result is placed into the destination. The source operand is not affected. The previous contents of the destination are lost. Both operands may be located in the full address space.                |
| <b>Status Bits</b> | N: Set if result is negative (MSB = 1), reset if positive (MSB = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if result is not zero, reset otherwise (carry = .not. Zero)<br>V: Set if both operands are negative (before execution), reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                          |
| <b>Example</b>     | Toggle bits in address-word CNTR (20-bit data) with information in address-word TONI (20-bit address)                                                                                                                                                              |

```
XORX.A    TONI,&CNTR      ; Toggle bits in CNTR
```

**Example** A table word pointed to by R5 (20-bit address) is used to toggle bits in R6.

```
XORX.W    @R5,R6        ; Toggle bits in R6. R6.19:16 = 0
```

**Example** Reset to zero those bits in the low byte of R7 that are different from the bits in byte EDE (20-bit address)

```
XORX.B    EDE,R7        ; Set different bits to 1 in R7  
INV.B     R7            ; Invert low byte of R7. R7.19:8 = 0.
```

#### 4.6.4 Address Instructions

MSP430X address instructions are instructions that support 20-bit operands but have restricted addressing modes. The addressing modes are restricted to the Register mode and the Immediate mode, except for the MOVA instruction. Restricting the addressing modes removes the need for the additional extension-word op-code improving code density and execution time. The MSP430X address instructions are listed and described in the following pages.

#### 4.6.4.1 ADDA

|                    |                                                                                                                                                                                                                                                                                                                                    |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ADDA</b>        | Add 20-bit source to a 20-bit destination register                                                                                                                                                                                                                                                                                 |
| <b>Syntax</b>      | ADDA Rsrc,Rdst<br>ADDA #imm20,Rdst                                                                                                                                                                                                                                                                                                 |
| <b>Operation</b>   | $\text{src} + \text{Rdst} \rightarrow \text{Rdst}$                                                                                                                                                                                                                                                                                 |
| <b>Description</b> | The 20-bit source operand is added to the 20-bit destination CPU register. The previous contents of the destination are lost. The source operand is not affected.                                                                                                                                                                  |
| <b>Status Bits</b> | N: Set if result is negative (Rdst.19 = 1), reset if positive (Rdst.19 = 0)<br>Z: Set if result is zero, reset otherwise<br>C: Set if there is a carry from the 20-bit result, reset otherwise<br>V: Set if the result of two positive operands is negative, or if the result of two negative numbers is positive, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                          |
| <b>Example</b>     | R5 is increased by 0A4320h. The jump to TONI is performed if a carry occurs.                                                                                                                                                                                                                                                       |

```
ADDA #0A4320h,R5      ; Add A4320h to 20-bit R5
JC    TONI             ; Jump on carry
...                  ; No carry occurred
```

#### 4.6.4.2 BRA

|                    |                                                                                                                                                                                                                                                                                                                                     |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* BRA</b>       | Branch to destination                                                                                                                                                                                                                                                                                                               |
| <b>Syntax</b>      | BRA dst                                                                                                                                                                                                                                                                                                                             |
| <b>Operation</b>   | dst → PC                                                                                                                                                                                                                                                                                                                            |
| <b>Emulation</b>   | MOVA dst,PC                                                                                                                                                                                                                                                                                                                         |
| <b>Description</b> | An unconditional branch is taken to a 20-bit address anywhere in the full address space. All seven source addressing modes can be used. The branch instruction is an address-word instruction. If the destination address is contained in a memory location X, it is contained in two ascending words: X (LSBs) and (X + 2) (MSBs). |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                                                                                                                                                                                                            |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                           |
| <b>Examples</b>    | Examples for all addressing modes are given.<br>Immediate mode: Branch to label EDE located anywhere in the 20-bit address space or branch directly to address.                                                                                                                                                                     |

```
BRA      #EDE          ; MOVA    #imm20,PC
BRA      #01AA04h
```

Symbolic mode: Branch to the 20-bit address contained in addresses EXEC (LSBs) and EXEC+2 (MSBs). EXEC is located at the address (PC + X) where X is within ±32 K. Indirect addressing.

```
BRA      EXEC          ; MOVA    z16(PC),PC
```

Note: If the 16-bit index is not sufficient, a 20-bit index may be used with the following instruction.

```
MOVX.A  EXEC,PC       ; 1M byte range with 20-bit index
```

Absolute mode: Branch to the 20-bit address contained in absolute addresses EXEC (LSBs) and EXEC+2 (MSBs). Indirect addressing.

```
BRA      &EXEC         ; MOVA    &abs20,PC
```

Register mode: Branch to the 20-bit address contained in register R5. Indirect R5.

```
BRA      R5            ; MOVA    R5,PC
```

Indirect mode: Branch to the 20-bit address contained in the word pointed to by register R5 (LSBs). The MSBs have the address (R5 + 2). Indirect, indirect R5.

```
BRA      @R5           ; MOVA    @R5,PC
```

Indirect, Auto-Increment mode: Branch to the 20-bit address contained in the words pointed to by register R5 and increment the address in R5 afterwards by 4. The next time the software flow uses R5 as a pointer, it can alter the program execution due to access to the next address in the table pointed to by R5. Indirect, indirect R5.

```
BRA      @R5+           ; MOVA    @R5+, PC. R5 + 4
```

Indexed mode: Branch to the 20-bit address contained in the address pointed to by register (R5 + X) (for example, a table with addresses starting at X). (R5 + X) points to the LSBs, (R5 + X + 2) points to the MSBs of the address. X is within R5 ± 32 K. Indirect, indirect (R5 + X).

```
BRA      X(R5)          ; MOVA    z16(R5), PC
```

Note: If the 16-bit index is not sufficient, a 20-bit index X may be used with the following instruction:

```
MOVX.A   X(R5), PC     ; 1M byte range with 20-bit index
```

#### 4.6.4.3 CALLA

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CALLA</b>       | Call a subroutine                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Syntax</b>      | CALLA dst                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | <p>dst → tmp 20-bit dst is evaluated and stored</p> <p>SP – 2 → SP</p> <p>PC.19:16 → @SP updated PC with return address to TOS (MSBs)</p> <p>SP – 2 → SP</p> <p>PC.15:0 → @SP updated PC to TOS (LSBs)</p> <p>tmp → PC saved 20-bit dst to PC</p>                                                                                                                                                                                  |
| <b>Description</b> | A subroutine call is made to a 20-bit address anywhere in the full address space. All seven source addressing modes can be used. The call instruction is an address-word instruction. If the destination address is contained in a memory location X, it is contained in two ascending words, X (LSBs) and (X + 2) (MSBs). Two words on the stack are needed for the return address. The return is made with the instruction RETA. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                                                                                                                                                                                                                                                                                                           |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Examples</b>    | Examples for all addressing modes are given.<br><br>Immediate mode: Call a subroutine at label EXEC or call directly an address.                                                                                                                                                                                                                                                                                                   |

```
CALLA #EXEC          ; Start address EXEC
CALLA #01AA04h       ; Start address 01AA04h
```

Symbolic mode: Call a subroutine at the 20-bit address contained in addresses EXEC (LSBs) and EXEC+2 (MSBs). EXEC is located at the address (PC + X) where X is within ±32 K. Indirect addressing.

```
CALLA EXEC          ; Start address at @EXEC. z16(PC)
```

Absolute mode: Call a subroutine at the 20-bit address contained in absolute addresses EXEC (LSBs) and EXEC+2 (MSBs). Indirect addressing.

```
CALLA &EXEC         ; Start address at @EXEC
```

Register mode: Call a subroutine at the 20-bit address contained in register R5. Indirect R5.

```
CALLA R5            ; Start address at @R5
```

Indirect mode: Call a subroutine at the 20-bit address contained in the word pointed to by register R5 (LSBs). The MSBs have the address (R5 + 2). Indirect, indirect R5.

```
CALLA @R5           ; Start address at @R5
```

Indirect, Auto-Increment mode: Call a subroutine at the 20-bit address contained in the words pointed to by register R5 and increment the 20-bit address in R5 afterwards by 4. The next time the software flow uses R5 as a pointer, it can alter the program execution due to access to the next word address in the table pointed to by R5. Indirect, indirect R5.

```
CALLA    @R5+           ; Start address at @R5. R5 + 4
```

Indexed mode: Call a subroutine at the 20-bit address contained in the address pointed to by register (R5 + X); for example, a table with addresses starting at X. (R5 + X) points to the LSBs, (R5 + X + 2) points to the MSBs of the word address. X is within R5 ± 32 K. Indirect, indirect (R5 + X).

```
CALLA    X(R5)          ; Start address at @(R5+X). z16(R5)
```

#### 4.6.4.4 CLRA

|                    |                                      |
|--------------------|--------------------------------------|
| * <b>CLRA</b>      | Clear 20-bit destination register    |
| <b>Syntax</b>      | CLRA Rdst                            |
| <b>Operation</b>   | $0 \rightarrow \text{Rdst}$          |
| <b>Emulation</b>   | MOVA #0, Rdst                        |
| <b>Description</b> | The destination register is cleared. |
| <b>Status Bits</b> | Status bits are not affected.        |
| <b>Example</b>     | The 20-bit value in R10 is cleared.  |

```
CLRA    R10      ; 0 -> R10
```

#### 4.6.4.5 CMPA

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CMPA</b>        | Compare the 20-bit source with a 20-bit destination register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Syntax</b>      | CMPA Rsrc,Rdst<br>CMPA #imm20,Rdst                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Operation</b>   | $(\text{not. src}) + 1 + \text{Rdst} \text{ or } \text{Rdst} - \text{src}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Description</b> | The 20-bit source operand is subtracted from the 20-bit destination CPU register. This is made by adding the 1s complement of the source + 1 to the destination register. The result affects only the status bits.                                                                                                                                                                                                                                                                                                                                                |
| <b>Status Bits</b> | N: Set if result is negative ( $\text{src} > \text{dst}$ ), reset if positive ( $\text{src} \leq \text{dst}$ )<br>Z: Set if result is zero ( $\text{src} = \text{dst}$ ), reset otherwise ( $\text{src} \neq \text{dst}$ )<br>C: Set if there is a carry from the MSB, reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow) |

**Mode Bits** OSCOFF, CPUOFF, and GIE are not affected.

**Example** A 20-bit immediate operand and R6 are compared. If they are equal, the program continues at label EQUAL.

```
CMPA #12345h,R6      ; Compare R6 with 12345h
JEQ EQUAL            ; R6 = 12345h
...                  ; Not equal
```

**Example** The 20-bit values in R5 and R6 are compared. If R5 is greater than (signed) or equal to R6, the program continues at label GRE.

```
CMPA R6,R5          ; Compare R6 with R5 (R5 - R6)
JGE GRE             ; R5 >= R6
...                  ; R5 < R6
```

#### 4.6.4.6 DECDA

|                    |                                                                                                                                                                                                                |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* DECDA</b>     | Double-decrement 20-bit destination register                                                                                                                                                                   |
| <b>Syntax</b>      | DECDA Rdst                                                                                                                                                                                                     |
| <b>Operation</b>   | Rdst – 2 → Rdst                                                                                                                                                                                                |
| <b>Emulation</b>   | SUBA #2,Rdst                                                                                                                                                                                                   |
| <b>Description</b> | The destination register is decremented by two. The original contents are lost.                                                                                                                                |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if Rdst contained 2, reset otherwise<br>C: Reset if Rdst contained 0 or 1, set otherwise<br>V: Set if an arithmetic overflow occurs, otherwise reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                      |
| <b>Example</b>     | The 20-bit value in R5 is decremented by 2.                                                                                                                                                                    |

```
DECDA    R5          ; Decrement R5 by two
```

#### 4.6.4.7 INCDA

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* INCDA</b>     | Double-increment 20-bit destination register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Syntax</b>      | INCDA Rdst                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Operation</b>   | Rdst + 2 → Rdst                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Emulation</b>   | ADDA #2,Rdst                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Description</b> | The destination register is incremented by two. The original contents are lost.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Status Bits</b> | N: Set if result is negative, reset if positive<br>Z: Set if Rdst contained 0FFFFEh, reset otherwise<br>Set if Rdst contained 0FFEh, reset otherwise<br>Set if Rdst contained 0FEh, reset otherwise<br>C: Set if Rdst contained 0FFFFEh or 0FFFFFh, reset otherwise<br>Set if Rdst contained 0FFEh or 0FFFh, reset otherwise<br>Set if Rdst contained 0FEh or 0FFh, reset otherwise<br>V: Set if Rdst contained 07FFEh or 07FFFFh, reset otherwise<br>Set if Rdst contained 07FEh or 07FFFh, reset otherwise<br>Set if Rdst contained 07Eh or 07Fh, reset otherwise |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Example</b>     | The 20-bit value in R5 is incremented by two.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

```
INCDA    R5      ; Increment R5 by two
```

#### 4.6.4.8 MOVA

|                    |                                                                                                                                                    |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>MOVA Syntax</b> | Move the 20-bit source to the 20-bit destination                                                                                                   |
|                    | MOVA Rsrc,Rdst                                                                                                                                     |
|                    | MOVA #imm20,Rdst                                                                                                                                   |
|                    | MOVA z16(Rsrc),Rdst                                                                                                                                |
|                    | MOVA EDE,Rdst                                                                                                                                      |
|                    | MOVA &abs20,Rdst                                                                                                                                   |
|                    | MOVA @Rsrc,Rdst                                                                                                                                    |
|                    | MOVA @Rsrc+,Rdst                                                                                                                                   |
|                    | MOVA Rsrc,z16(Rdst)                                                                                                                                |
|                    | MOVA Rsrc,&abs20                                                                                                                                   |
| <b>Operation</b>   | src → Rdst<br>Rsrc → dst                                                                                                                           |
| <b>Description</b> | The 20-bit source operand is moved to the 20-bit destination. The source operand is not affected. The previous content of the destination is lost. |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                           |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                          |
| <b>Examples</b>    | Copy 20-bit value in R9 to R8                                                                                                                      |
| MOVA               | R9,R8 ; R9 → R8                                                                                                                                    |
|                    | Write 20-bit immediate value 12345h to R12                                                                                                         |
| MOVA               | #12345h,R12 ; 12345h → R12                                                                                                                         |
|                    | Copy 20-bit value addressed by (R9 + 100h) to R8. Source operand in addresses (R9 + 100h) LSBs and (R9 + 102h) MSBs.                               |
| MOVA               | 100h(R9),R8 ; Index: + 32 K. 2 words transferred                                                                                                   |
|                    | Move 20-bit value in 20-bit absolute addresses EDE (LSBs) and EDE+2 (MSBs) to R12                                                                  |
| MOVA               | &EDE,R12 ; &EDE → R12. 2 words transferred                                                                                                         |
|                    | Move 20-bit value in 20-bit addresses EDE (LSBs) and EDE+2 (MSBs) to R12. PC index ± 32 K.                                                         |
| MOVA               | EDE,R12 ; EDE → R12. 2 words transferred                                                                                                           |
|                    | Copy 20-bit value R9 points to (20 bit address) to R8. Source operand in addresses @R9 LSBs and @(R9 + 2) MSBs.                                    |
| MOVA               | @R9,R8 ; @R9 → R8. 2 words transferred                                                                                                             |

Copy 20-bit value R9 points to (20 bit address) to R8. R9 is incremented by four afterwards. Source operand in addresses @R9 LSBs and @(R9 + 2) MSBs.

MOVA @R9+,R8 ; @R9 -> R8. R9 + 4. 2 words transferred.

Copy 20-bit value in R8 to destination addressed by (R9 + 100h). Destination operand in addresses @(R9 + 100h) LSBs and @(R9 + 102h) MSBs.

MOVA R8,100h(R9) ; Index: +- 32 K. 2 words transferred

Move 20-bit value in R13 to 20-bit absolute addresses EDE (LSBs) and EDE+2 (MSBs)

MOVA R13,&EDE ; R13 -> EDE. 2 words transferred

Move 20-bit value in R13 to 20-bit addresses EDE (LSBs) and EDE+2 (MSBs). PC index ± 32 K.

MOVA R13,EDE ; R13 -> EDE. 2 words transferred

#### 4.6.4.9 RETA

|                    |                                                                                                                                                                                                                                                                                                              |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* RETA</b>      | Return from subroutine                                                                                                                                                                                                                                                                                       |
| <b>Syntax</b>      | RETA                                                                                                                                                                                                                                                                                                         |
| <b>Operation</b>   | <p><math>\text{@SP} \rightarrow \text{PC.15:0 LSBs (15:0) of saved PC to PC.15:0}</math></p> <p><math>\text{SP + 2} \rightarrow \text{SP}</math></p> <p><math>\text{@SP} \rightarrow \text{PC.19:16 MSBs (19:16) of saved PC to PC.19:16}</math></p> <p><math>\text{SP + 2} \rightarrow \text{SP}</math></p> |
| <b>Emulation</b>   | MOVA @SP+, PC                                                                                                                                                                                                                                                                                                |
| <b>Description</b> | The 20-bit return address information, pushed onto the stack by a CALLA instruction, is restored to the PC. The program continues at the address following the subroutine call. The SR bits SR.11:0 are not affected. This allows the transfer of information with these bits.                               |
| <b>Status Bits</b> | N: Not affected<br>Z: Not affected<br>C: Not affected<br>V: Not affected                                                                                                                                                                                                                                     |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                    |
| <b>Example</b>     | Call a subroutine SUBR from anywhere in the 20-bit address space and return to the address after the CALLA                                                                                                                                                                                                   |

```

CALLA    #SUBR      ; Call subroutine starting at SUBR
...
SUBR    PUSHM.A    #2,R14   ; Save R14 and R13 (20 bit data)
        ...
        POPM.A     #2,R14   ; Restore R13 and R14 (20 bit data)
        RETA          ; Return (to full address space)

```

#### 4.6.4.10 SUBA

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SUBA</b>        | Subtract 20-bit source from 20-bit destination register                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Syntax</b>      | SUBA Rsrc,Rdst<br>SUBA #imm20,Rdst                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Operation</b>   | (.not.src) + 1 + Rdst → Rdst or Rdst - src → Rdst                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Description</b> | The 20-bit source operand is subtracted from the 20-bit destination register. This is made by adding the 1s complement of the source + 1 to the destination. The result is written to the destination register, the source is not affected.                                                                                                                                                                                                                                                   |
| <b>Status Bits</b> | N: Set if result is negative (src > dst), reset if positive (src ≤ dst)<br>Z: Set if result is zero (src = dst), reset otherwise (src ≠ dst)<br>C: Set if there is a carry from the MSB (Rdst.19), reset otherwise<br>V: Set if the subtraction of a negative source operand from a positive destination operand delivers a negative result, or if the subtraction of a positive source operand from a negative destination operand delivers a positive result, reset otherwise (no overflow) |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Example</b>     | The 20-bit value in R5 is subtracted from R6. If a carry occurs, the program continues at label TONI.                                                                                                                                                                                                                                                                                                                                                                                         |

```

SUBA R5,R6      ; R6 - R5 -> R6
JC   TONI       ; Carry occurred
...             ; No carry

```

#### 4.6.4.11 TSTA

|                    |                                                                                                                                                      |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>* TSTA</b>      | Test 20-bit destination register                                                                                                                     |
| <b>Syntax</b>      | TSTA Rdst                                                                                                                                            |
| <b>Operation</b>   | dst + 0FFFFFh + 1<br>dst + 0FFFFh + 1<br>dst + 0FFh + 1                                                                                              |
| <b>Emulation</b>   | CMPA #0,Rdst                                                                                                                                         |
| <b>Description</b> | The destination register is compared with zero. The status bits are set according to the result. The destination register is not affected.           |
| <b>Status Bits</b> | N: Set if destination register is negative, reset if positive<br>Z: Set if destination register contains zero, reset otherwise<br>C: Set<br>V: Reset |
| <b>Mode Bits</b>   | OSCOFF, CPUOFF, and GIE are not affected.                                                                                                            |
| <b>Example</b>     | The 20-bit value in R7 is tested. If it is negative, continue at R7NEG; if it is positive but not zero, continue at R7POS.                           |

```

TSTA    R7          ; Test R7
JN      R7NEG       ; R7 is negative
JZ      R7ZERO      ; R7 is zero
R7POS   .....       ; R7 is positive but not zero
R7NEG   .....       ; R7 is negative
R7ZERO  .....       ; R7 is zero

```

## **32-Bit Hardware Multiplier (MPY32)**

This chapter describes the 32-bit hardware multiplier (MPY32). The MPY32 module is implemented in all devices.

| Topic                                                        | Page |
|--------------------------------------------------------------|------|
| 5.1    32-Bit Hardware Multiplier (MPY32) Introduction ..... | 268  |
| 5.2    MPY32 Operation.....                                  | 270  |
| 5.3    MPY32 Registers .....                                 | 282  |

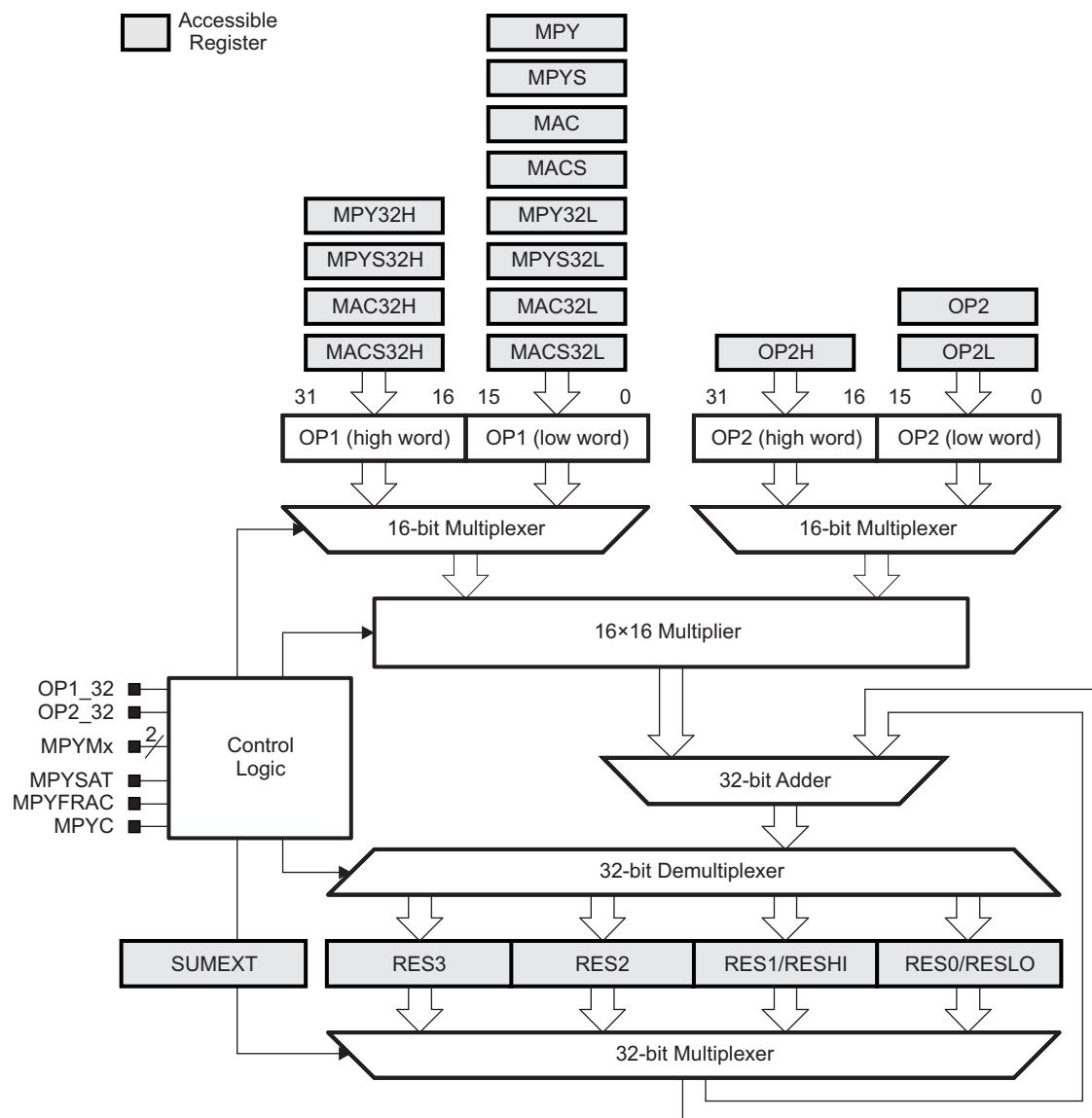
## 5.1 32-Bit Hardware Multiplier (MPY32) Introduction

The MPY32 is a peripheral and is not part of the CPU. This means its activities do not interfere with the CPU activities. The multiplier registers are peripheral registers that are loaded and read with CPU instructions.

The MPY32 supports:

- Unsigned multiply
- Signed multiply
- Unsigned multiply accumulate
- Signed multiply accumulate
- 8-bit, 16-bit, 24-bit, and 32-bit operands
- Saturation
- Fractional numbers
- 8-bit and 16-bit operation compatible with 16-bit hardware multiplier
- 8-bit and 24-bit multiplications without requiring a "sign extend" instruction

The MPY32 block diagram is shown in [Figure 5-1](#).



**Figure 5-1. MPY32 Block Diagram**

## 5.2 MPY32 Operation

The MPY32 supports 8-bit, 16-bit, 24-bit, and 32-bit operands with unsigned multiply, signed multiply, unsigned multiply-accumulate, and signed multiply-accumulate operations. The size of the operands are defined by the address the operand is written to and if it is written as word or byte. The type of operation is selected by the address the first operand is written to.

The hardware multiplier has two 32-bit operand registers – operand one (OP1) and operand two (OP2), and a 64-bit result register accessible through registers RES0 to RES3. For compatibility with the  $16 \times 16$  hardware multiplier, the result of a 8-bit or 16-bit operation is accessible through RESLO, RESHI, and SUMEXT, as well. RESLO stores the low word of the  $16 \times 16$ -bit result, RESHI stores the high word of the result, and SUMEXT stores information about the result.

The result of a 8-bit or 16-bit operation is ready in three MCLK cycles and can be read with the next instruction after writing to OP2, except when using an indirect addressing mode to access the result. When using indirect addressing for the result, a NOP is required before the result is ready.

The result of a 24-bit or 32-bit operation can be read with successive instructions after writing OP2 or OP2H starting with RES0, except when using an indirect addressing mode to access the result. When using indirect addressing for the result, a NOP is required before the result is ready.

**Table 5-1** summarizes when each word of the 64-bit result is available for the various combinations of operand sizes. With a 32-bit-wide second operand, OP2L and OP2H must be written. Depending on when the two 16-bit parts are written, the result availability may vary; thus, the table shows two entries, one for OP2L written and one for OP2H written. The worst case defines the actual result availability.

**Table 5-1. Result Availability (MPYFRAC = 0, MPYSAT = 0)**

| Operation<br>(OP1 × OP2) | Result Ready in MCLK Cycles |      |      |      |          | After        |
|--------------------------|-----------------------------|------|------|------|----------|--------------|
|                          | RES0                        | RES1 | RES2 | RES3 | MPYC Bit |              |
| 8/16 × 8/16              | 3                           | 3    | 4    | 4    | 3        | OP2 written  |
| 24/32 × 8/16             | 3                           | 5    | 6    | 7    | 7        | OP2 written  |
| 8/16 × 24/32             | 3                           | 5    | 6    | 7    | 7        | OP2L written |
|                          | N/A                         | 3    | 4    | 4    | 4        | OP2H written |
| 24/32 × 24/32            | 3                           | 8    | 10   | 11   | 11       | OP2L written |
|                          | N/A                         | 3    | 5    | 6    | 6        | OP2H written |

### 5.2.1 Operand Registers

Operand one (OP1) has 12 registers (see [Table 5-2](#)) used to load data into the multiplier and also select the multiply mode. Writing the low word of the first operand to a given address selects the type of multiply operation to be performed, but does not start any operation. When writing a second word to a high-word register with suffix 32H, the multiplier assumes a 32-bit-wide OP1, otherwise, 16 bits are assumed. The last address written prior to writing OP2 defines the width of the first operand. For example, if MPY32L is written first followed by MPY32H, all 32 bits are used and the data width of OP1 is set to 32 bits. If MPY32H is written first followed by MPY32L, the multiplication ignores MPY32H and assumes a 16-bit-wide OP1 using the data written into MPY32L.

Repeated multiply operations may be performed without reloading OP1 if the OP1 value is used for successive operations. It is not necessary to rewrite the OP1 value to perform the operations.

**Table 5-2. OP1 Registers**

| OP1 Register | Operation                                               |
|--------------|---------------------------------------------------------|
| MPY          | Unsigned multiply – operand bits 0 up to 15             |
| MPYS         | Signed multiply – operand bits 0 up to 15               |
| MAC          | Unsigned multiply accumulate – operand bits 0 up to 15  |
| MACS         | Signed multiply accumulate – operand bits 0 up to 15    |
| MPY32L       | Unsigned multiply – operand bits 0 up to 15             |
| MPY32H       | Unsigned multiply – operand bits 16 up to 31            |
| MPYS32L      | Signed multiply – operand bits 0 up to 15               |
| MPYS32H      | Signed multiply – operand bits 16 up to 31              |
| MAC32L       | Unsigned multiply accumulate – operand bits 0 up to 15  |
| MAC32H       | Unsigned multiply accumulate – operand bits 16 up to 31 |
| MACS32L      | Signed multiply accumulate – operand bits 0 up to 15    |
| MACS32H      | Signed multiply accumulate – operand bits 16 up to 31   |

Writing the second operand to the OP2 initiates the multiply operation. Writing OP2 starts the selected operation with a 16-bit-wide second operand together with the values stored in OP1. Writing OP2L starts the selected operation with a 32-bit-wide second operand and the multiplier expects a the high word to be written to OP2H. Writing to OP2H without a preceding write to OP2L is ignored.

**Table 5-3. OP2 Registers**

| OP2 Register | Operation                                                               |
|--------------|-------------------------------------------------------------------------|
| OP2          | Start multiplication with 16-bit-wide OP2 – operand bits 0 up to 15     |
| OP2L         | Start multiplication with 32-bit-wide OP2 – operand bits 0 up to 15     |
| OP2H         | Continue multiplication with 32-bit-wide OP2 – operand bits 16 up to 31 |

For 8-bit or 24-bit operands, the operand registers can be accessed with byte instructions. Accessing the multiplier with a byte instruction during a signed operation automatically causes a sign extension of the byte within the multiplier module. For 24-bit operands, only the high word should be written as byte. If the 24-bit operands are sign-extended as defined by the register, that is used to write the low word to, because this register defines if the operation is unsigned or signed.

The high-word of a 32-bit operand remains unchanged when changing the size of the operand to 16 bit, either by modifying the operand size bits or by writing to the respective operand register. During the execution of the 16-bit operation, the content of the high-word is ignored.

**NOTE: Changing of first or second operand during multiplication**

By default, changing OP1 or OP2 while the selected multiply operation is being calculated renders any results invalid that are not ready at the time the new operands are changed. Writing OP2 or OP2L aborts any ongoing calculation and starts a new operation. Results that are not ready at that time are also invalid for following MAC or MACS operations.

To avoid this behavior, the MPYDLYWRDEN bit can be set to 1. Then, all writes to any MPY32 registers are delayed with MPYDLY32 = 0 until the 64-bit result is ready or with MPYDLY32 = 1 until the 32-bit result is ready. For MAC and MACS operations, the complete 64-bit result should always be ready.

See [Table 5-1](#) for how many CPU cycles are needed until a certain result register is ready and valid for each of the different modes.

### 5.2.2 Result Registers

The multiplication result is always 64 bits wide. It is accessible through registers RES0 to RES3. Used with a signed operation, MPYS or MACS, the results are appropriately sign extended. If the result registers are loaded with initial values before a MACS operation, the user software must take care that the written value is properly sign extended to 64 bits.

**NOTE: Changing of result registers during multiplication**

The result registers must not be modified by the user software after writing the second operand into OP2 or OP2L until the initiated operation is completed.

In addition to RES0 to RES3, for compatibility with the 16x16 hardware multiplier, the 32-bit result of a 8-bit or 16-bit operation is accessible through RESLO, RESHI, and SUMEXT. In this case, the result low register RESLO holds the lower 16 bits of the calculation result and the result high register RESHI holds the upper 16 bits. RES0 and RES1 are identical to RESLO and RESHI, respectively, in usage and access of calculated results.

The sum extension register SUMEXT contents depend on the multiply operation and are listed in [Table 5-4](#). If all operands are 16 bits wide or less, the 32-bit result is used to determine sign and carry. If one of the operands is larger than 16 bits, the 64-bit result is used.

The MPYC bit reflects the multiplier's carry as listed in [Table 5-4](#) and, thus, can be used as 33rd or 65th bit of the result, if fractional or saturation mode is not selected. With MAC or MACS operations, the MPYC bit reflects the carry of the 32-bit or 64-bit accumulation and is not taken into account for successive MAC and MACS operations as the 33rd or 65th bit.

**Table 5-4. SUMEXT and MPYC Contents**

| Mode | SUMEXT                                                                                                                   | MPYC                                                                                                |
|------|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| MPY  | SUMEXT is always 0000h.                                                                                                  | MPYC is always 0.                                                                                   |
| MPYS | SUMEXT contains the extended sign of the result.<br>00000h = Result was positive or zero<br>0FFFFh = Result was negative | MPYC contains the sign of the result.<br>0 = Result was positive or zero<br>1 = Result was negative |
| MAC  | SUMEXT contains the carry of the result.<br>0000h = No carry for result<br>0001h =                                       | MPYC contains the carry of the result.<br>0 = No carry for result<br>1 = Result has a carry         |
| MACS | SUMEXT contains the extended sign of the result.<br>00000h = Result was positive or zero<br>0FFFFh = Result was negative | MPYC contains the carry of the result.<br>0 = No carry for result<br>1 = Result has a carry         |

### 5.2.2.1 MACS Underflow and Overflow

The multiplier does not automatically detect underflow or overflow in MACS mode. For example, working with 16-bit input data and 32-bit results (that is, using only RESLO and RESHI), the available range for positive numbers is 0 to 07FFF FFFFh and for negative numbers is 0FFFF FFFFh to 08000 0000h. An underflow occurs when the sum of two negative numbers yields a result that is in the range for a positive number. An overflow occurs when the sum of two positive numbers yields a result that is in the range for a negative number.

The SUMEXT register contains the sign of the result in both cases described above, 0FFFFh for a 32-bit overflow and 0000h for a 32-bit underflow. The MPYC bit in MPY32CTL0 can be used to detect the overflow condition. If the carry is different from the sign reflected by the SUMEXT register, an overflow or underflow occurred. User software must handle these conditions appropriately.

### 5.2.3 Software Examples

Examples for all multiplier modes follow. All 8x8 modes use the absolute address for the registers, because the assembler does not allow .B access to word registers when using the labels from the standard definitions file.

There is no sign extension necessary in software. Accessing the multiplier with a byte instruction during a signed operation automatically causes a sign extension of the byte within the multiplier module.

```
; 32x32 Unsigned Multiply
    MOV      #01234h,&MPY32L      ; Load low word of 1st operand
    MOV      #01234h,&MPY32H      ; Load high word of 1st operand
    MOV      #05678h,&OP2L       ; Load low word of 2nd operand
    MOV      #05678h,&OP2H       ; Load high word of 2nd operand
;   ...                           ; Process results

; 16x16 Unsigned Multiply
    MOV      #01234h,&MPY         ; Load 1st operand
    MOV      #05678h,&OP2         ; Load 2nd operand
;   ...                           ; Process results

; 8x8 Unsigned Multiply. Absolute addressing.
    MOV.B   #012h,&MPY_B        ; Load 1st operand
    MOV.B   #034h,&OP2_B        ; Load 2nd operand
;   ...                           ; Process results

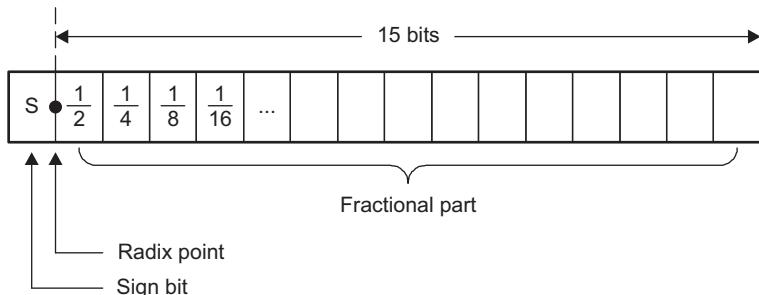
; 32x32 Signed Multiply
    MOV      #01234h,&MPYS32L    ; Load low word of 1st operand
    MOV      #01234h,&MPYS32H    ; Load high word of 1st operand
    MOV      #05678h,&OP2L       ; Load low word of 2nd operand
    MOV      #05678h,&OP2H       ; Load high word of 2nd operand
;   ...                           ; Process results

; 16x16 Signed Multiply
    MOV      #01234h,&MPYS        ; Load 1st operand
    MOV      #05678h,&OP2         ; Load 2nd operand
;   ...                           ; Process results

; 8x8 Signed Multiply. Absolute addressing.
    MOV.B   #012h,&MPYS_B       ; Load 1st operand
    MOV.B   #034h,&OP2_B        ; Load 2nd operand
;   ...                           ; Process results
```

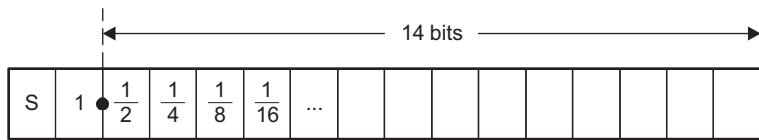
## 5.2.4 Fractional Numbers

The MPY32 provides support for fixed-point signal processing. In fixed-point signal processing, fractional numbers are numbers that have a fixed number of digits after (and sometimes also before) the radix point. To classify different ranges of binary fixed-point numbers, a Q-format is used. Different Q-formats represent different locations of the radix point. Figure 5-2 shows the format of a signed Q15 number using 16 bits. Every bit after the radix point has a resolution of  $1/2$ , and the most significant bit (MSB) is used as the sign bit. The most negative number is 08000h and the maximum positive number is 07FFFh. This gives a range from  $-1.0$  to  $0.999969482 \approx 1.0$  for the signed Q15 format with 16 bits.



**Figure 5-2. Q15 Format Representation**

The range can be increased by shifting the radix point to the right as shown in Figure 5-3. The signed Q14 format with 16 bits gives a range from  $-2.0$  to  $1.999938965 \approx 2.0$ .



**Figure 5-3. Q14 Format Representation**

The benefit of using 16-bit signed Q15 or 32-bit signed Q31 numbers with multiplication is that the product of two numbers in the range from  $-1.0$  to  $1.0$  is always in that same range.

### 5.2.4.1 Fractional Number Mode

Multiplying two fractional numbers using the default multiplication mode with MPYFRAC = 0 and MPYSAT = 0 gives a result with two sign bits. For example, if two 16-bit Q15 numbers are multiplied, a 32-bit result in Q30 format is obtained. To convert the result into Q15 format manually, the first 15 trailing bits and the extended sign bit must be removed. However, when the fractional mode of the multiplier is used, the redundant sign bit is automatically removed, yielding a result in Q31 format for the multiplication of two 16-bit Q15 numbers. Reading the result register RES1 gives the result as 16-bit Q15 number. The 32-bit Q31 result of a multiplication of two 32-bit Q31 numbers is accessed by reading registers RES2 and RES3.

The fractional mode is enabled with MPYFRAC = 1 in register MPY32CTL0. The actual content of the result registers is not modified when MPYFRAC = 1. When the result is accessed using software, the value is left shifted one bit, resulting in the final Q formatted result. This allows user software to switch between reading both the shifted (fractional) and the unshifted result. The fractional mode should only be enabled when required and disabled after use.

In fractional mode, the SUMEXT register contains the sign extended bits 32 and 33 of the shifted result for  $16 \times 16$ -bit operations and bits 64 and 65 for  $32 \times 32$ -bit operations – not only bits 32 or 64, respectively.

The MPYC bit is not affected by the fractional mode. It always reads the carry of the nonfractional result.

```
; Example using
; Fractional 16x16 multiplication
BIS      #MPYFRAC,&MPY32CTL0    ; Turn on fractional mode
MOV      &FRACT1,&MPYS          ; Load 1st operand as Q15
MOV      &FRACT2,&OP2           ; Load 2nd operand as Q15
MOV      &RES1,&PROD            ; Save result as Q15
BIC      #MPYFRAC,&MPY32CTL0    ; Back to normal mode
```

**Table 5-5. Result Availability in Fractional Mode (MPYFRAC = 1, MPYSAT = 0)**

| Operation<br>(OP1 × OP2) | Result Ready in MCLK Cycles |      |      |      |          | After        |
|--------------------------|-----------------------------|------|------|------|----------|--------------|
|                          | RES0                        | RES1 | RES2 | RES3 | MPYC Bit |              |
| 8/16 × 8/16              | 3                           | 3    | 4    | 4    | 3        | OP2 written  |
| 24/32 × 8/16             | 3                           | 5    | 6    | 7    | 7        | OP2 written  |
| 8/16 × 24/32             | 3                           | 5    | 6    | 7    | 7        | OP2L written |
|                          | N/A                         | 3    | 4    | 4    | 4        | OP2H written |
| 24/32 × 24/32            | 3                           | 8    | 10   | 11   | 11       | OP2L written |
|                          | N/A                         | 3    | 5    | 6    | 6        | OP2H written |

#### 5.2.4.2 Saturation Mode

The multiplier prevents overflow and underflow of signed operations in saturation mode. The saturation mode is enabled with MPYSAT = 1 in register MPY32CTL0. If an overflow occurs, the result is set to the most-positive value available. If an underflow occurs, the result is set to the most-negative value available. This is useful to reduce mathematical artifacts in control systems on overflow and underflow conditions. The saturation mode should only be enabled when required and disabled after use.

The actual content of the result registers is not modified when MPYSAT = 1. When the result is accessed using software, the value is automatically adjusted to provide the most-positive or most-negative result when an overflow or underflow has occurred. The adjusted result is also used for successive multiply-and-accumulate operations. This allows user software to switch between reading the saturated and the nonsaturated result.

With 16×16 operations, the saturation mode only applies to the least significant 32 bits; that is, the result registers RES0 and RES1. Using the saturation mode in MAC or MACS operations that mix 16×16 operations with 32×32, 16×32, or 32×16 operations leads to unpredictable results.

With 32×32, 16×32, and 32×16 operations, the saturated result can only be calculated when RES3 is ready.

Enabling the saturation mode does not affect the content of the SUMEXT register nor the content of the MPYC bit.

```
; Example using
; Fractional 16x16 multiply accumulate with Saturation
; Turn on fractional and saturation mode:
BIS      #MPYSAT+MPYFRAC,&MPY32CTL0
MOV      &A1,&MPYS          ; Load A1 for 1st term
MOV      &K1,&OP2           ; Load K1 to get A1*K1
MOV      &A2,&MACS            ; Load A2 for 2nd term
MOV      &K2,&OP2           ; Load K2 to get A2*K2
MOV      &RES1,&PROD            ; Save A1*K1+A2*K2 as result
BIC      #MPYSAT+MPYFRAC,&MPY32CTL0    ; turn back to normal
```

Table 5-6. Result Availability in Saturation Mode (MPYSAT = 1)

| Operation<br>(OP1 × OP2) | Result Ready in MCLK Cycles |      |      |      |          | After        |
|--------------------------|-----------------------------|------|------|------|----------|--------------|
|                          | RES0                        | RES1 | RES2 | RES3 | MPYC Bit |              |
| 8/16 × 8/16              | 3                           | 3    | N/A  | N/A  | 3        | OP2 written  |
| 24/32 × 8/16             | 7                           | 7    | 7    | 7    | 7        | OP2 written  |
| 8/16 × 24/32             | 7                           | 7    | 7    | 7    | 7        | OP2L written |
|                          | 4                           | 4    | 4    | 4    | 4        | OP2H written |
| 24/32 × 24/32            | 11                          | 11   | 11   | 11   | 11       | OP2L written |
|                          | 6                           | 6    | 6    | 6    | 6        | OP2H written |

Figure 5-4 shows the flow for 32-bit saturation used for 16×16 bit multiplications and the flow for 64-bit saturation used in all other cases. Primarily, the saturated results depends on the carry bit MPYC and the MSB of the result. Secondly, if the fractional mode is enabled, it depends also on the two MSBs of the unshifted result, that is, the result that is read with fractional mode disabled.

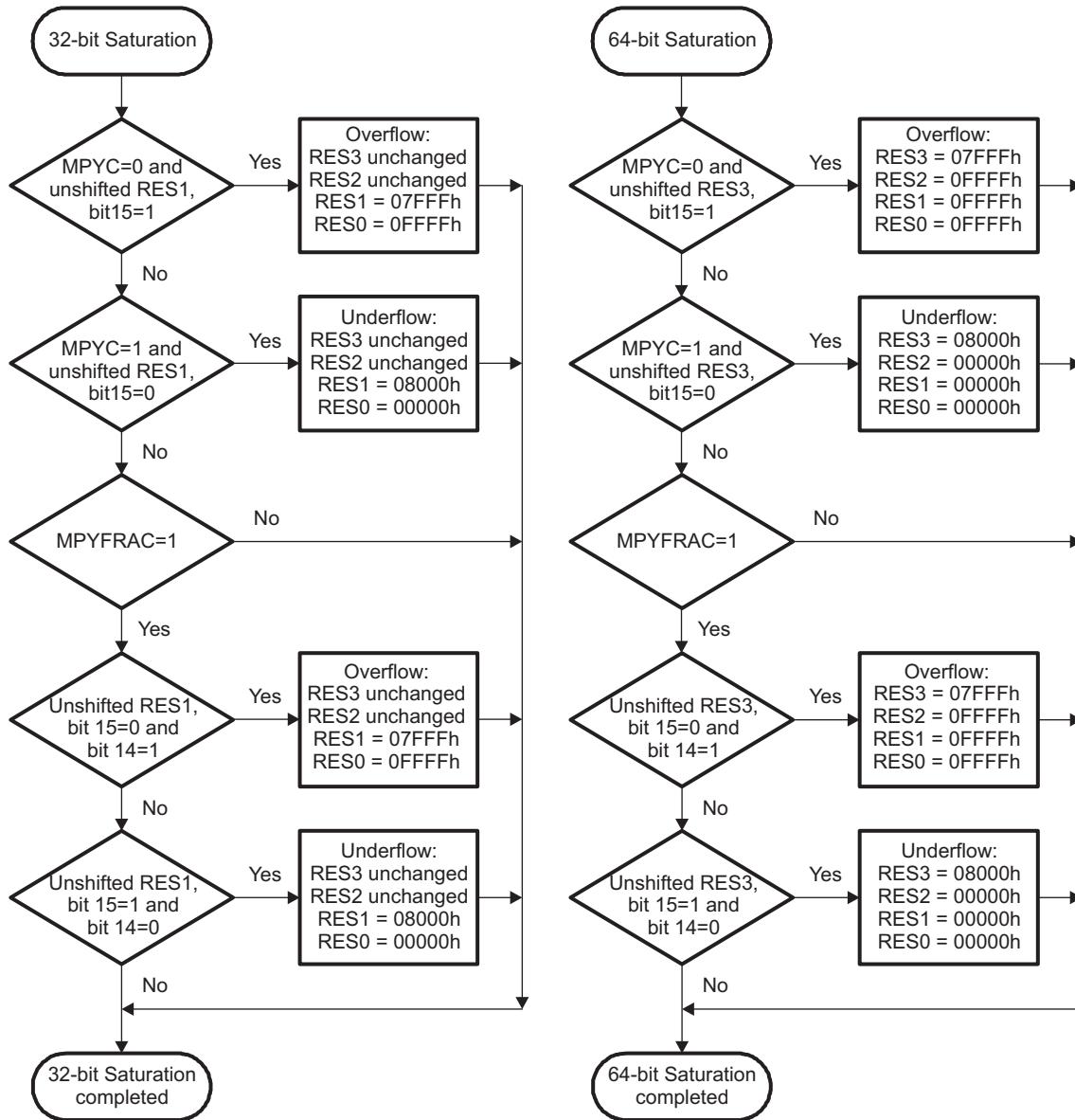


Figure 5-4. Saturation Flow Chart

**NOTE: Saturation in fractional mode**

In case of multiplying  $-1.0 \times -1.0$  in fractional mode, the result of  $+1.0$  is out of range, thus, the saturated result gives the most positive result.

When using multiply-and-accumulate operations, the accumulated values are saturated as if MPYFRAC = 0; only during read accesses to the result registers the values are saturated taking the fractional mode into account. This provides additional dynamic range during the calculation and only the end result is then saturated if needed.

The following example illustrates a special case showing the saturation function in fractional mode. It also uses the 8-bit functionality of the MPY32 module.

```
; Turn on fractional and saturation mode,
; clear all other bits in MPY32CTL0:
MOV      #MPYSAT+MPYFRAC ,&MPY32CTL0
;Pre-load result registers to demonstrate overflow
MOV      #0,&RES3          ;
MOV      #0,&RES2          ;
MOV      #07FFFh,&RES1        ;
MOV      #0FA60h,&RES0        ;
MOV.B    #050h,&MACS_B       ; 8-bit signed MAC operation
MOV.B    #012h,&OP2_B        ; Start 16x16 bit operation
MOV      &RES0,R6           ; R6 = 0FFFFh
MOV      &RES1,R7           ; R7 = 07FFFh
```

The result is saturated because already the result not converted into a fractional number shows an overflow. The multiplication of the two positive numbers 00050h and 00012h gives 005A0h. 005A0h added to 07FFF FA60h results in 8000 059Fh, without MPYC being set. Because the MSB of the unmodified result RES1 is 1 and MPYC = 0, the result is saturated according [Figure 5-4](#).

**NOTE: Validity of saturated result**

The saturated result is valid only if the registers RES0 to RES3, the size of OP1 and OP2, and MPYC are not modified.

If the saturation mode is used with a preloaded result, user software must ensure that MPYC in the MPY32CTL0 register is loaded with the sign bit of the written result; otherwise, the saturation mode erroneously saturates the result.

### **5.2.5 Putting It All Together**

[Figure 5-5](#) shows the complete multiplication flow, depending on the various selectable modes for the MPY32 module.

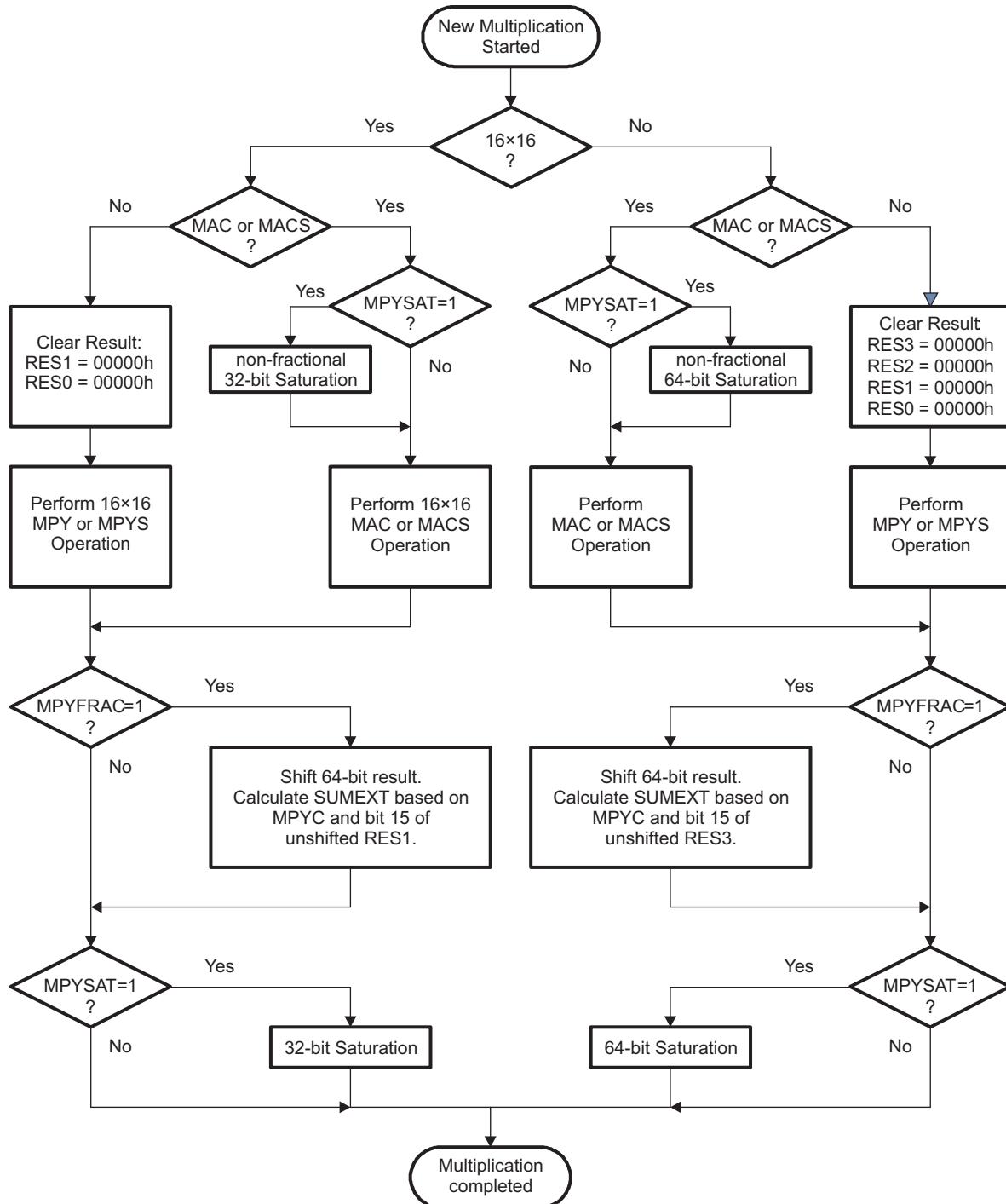


Figure 5-5. Multiplication Flow Chart

Given the separation in processing of 16-bit operations (32-bit results) and 32-bit operations (64-bit results) by the module, it is important to understand the implications when using MAC/MACS operations and mixing 16-bit operands or results with 32-bit operands or results. User software must address these points during use when mixing these operations. The following code illustrates the issue.

```
; Mixing 32x24 multiplication with 16x16 MACS operation
MOV      #MPYSAT,&MPY32CTL0    ; Saturation mode
MOV      #052C5h,&MPY32L       ; Load low word of 1st operand
MOV      #06153h,&MPY32H       ; Load high word of 1st operand
MOV      #001ABh,&OP2L        ; Load low word of 2nd operand
MOV.B   #023h,&OP2H_B        ; Load high word of 2nd operand
                                ;... 5 NOPs required
MOV      &RES0,R6            ; R6 = 00E97h
MOV      &RES1,R7            ; R7 = 0A6EAh
MOV      &RES2,R8            ; R8 = 04F06h
MOV      &RES3,R9            ; R9 = 0000Dh
                                ; Note that MPYC = 0!
MOV      #0CCC3h,&MACS        ; Signed MAC operation
MOV      #0FFB6h,&OP2          ; 16x16 bit operation
MOV      &RESLO,R6            ; R6 = 0FFFFh
MOV      &RESHI,R7            ; R7 = 07FFFh
```

The second operation gives a saturated result because the 32-bit value used for the 16x16-bit MACS operation was already saturated when the operation was started; the carry bit MPYC was 0 from the previous operation, but the MSB in result register RES1 is set. As one can see in the flow chart, the content of the result registers are saturated for multiply-and-accumulate operations after starting a new operation based on the previous results, but depending on the size of the result (32 bit or 64 bit) of the newly initiated operation.

The saturation before the multiplication can cause issues if the MPYC bit is not properly set as the following code shows.

```
;Pre-load result registers to demonstrate overflow
MOV      #0,&RES3           ;
MOV      #0,&RES2           ;
MOV      #0,&RES1           ;
MOV      #0,&RES0           ;
; Saturation mode and set MPYC:
MOV      #MPYSAT+MPYC,&MPY32CTL0
MOV.B   #082h,&MACS_B       ; 8-bit signed MAC operation
MOV.B   #04Fh,&OP2_B        ; Start 16x16 bit operation
MOV      &RES0,R6            ; R6 = 00000h
MOV      &RES1,R7            ; R7 = 08000h
```

Even though the result registers were loaded with all zeros, the final result is saturated. This is because the MPYC bit was set, causing the result used for the multiply-and-accumulate to be saturated to 08000 0000h. Adding a negative number to it would again cause an underflow, thus, the final result is also saturated to 08000 0000h.

### 5.2.6 Indirect Addressing of Result Registers

When using indirect or indirect autoincrement addressing mode to access the result registers and the multiplier requires three cycles until result availability according to [Table 5-1](#), at least one instruction is needed between loading the second operand and accessing the result registers:

```
; Access multiplier 16x16 results with indirect addressing
MOV #RES0,R5          ; RES0 address in R5 for indirect
MOV &OPER1,&MPY      ; Load 1st operand
MOV &OPER2,&OP2      ; Load 2nd operand
NOP                  ; Need one cycle
MOV @R5+,&xxx        ; Move RES0
MOV @R5,&xxx         ; Move RES1
```

In case of a 32x16 multiplication, there is also one instruction required between reading the first result register RES0 and the second result register RES1:

```
; Access multiplier 32x16 results with indirect addressing
MOV #RES0,R5          ; RES0 address in R5 for indirect
MOV &OPER1L,&MPY32L   ; Load low word of 1st operand
MOV &OPER1H,&MPY32H   ; Load high word of 1st operand
MOV &OPER2,&OP2      ; Load 2nd operand (16 bits)
NOP                  ; Need one cycle
MOV @R5+,&xxx        ; Move RES0
NOP                  ; Need one additional cycle
MOV @R5,&xxx         ; Move RES1
                                ; No additional cycles required!
MOV @R5,&xxx         ; Move RES2
```

### 5.2.7 Using Interrupts

If an interrupt occurs after writing OP, but before writing OP2, and the multiplier is used in servicing that interrupt, the original multiplier mode selection is lost and the results are unpredictable. To avoid this, disable interrupts before using the MPY32, do not use the MPY32 in interrupt service routines, or use the save and restore functionality of the MPY32.

```
; Disable interrupts before using the hardware multiplier
DINT                 ; Disable interrupts
NOP                  ; Required for DINT
MOV #xxh,&MPY        ; Load 1st operand
MOV #xxh,&OP2        ; Load 2nd operand
EINT                 ; Interrupts may be enabled before
                      ; processing results if result
                      ; registers are stored and restored in
                      ; interrupt service routines
```

### 5.2.7.1 Save and Restore

If the multiplier is used in interrupt service routines, its state can be saved and restored using the MPY32CTL0 register. The following code example shows how the complete multiplier status can be saved and restored to allow interruptible multiplications together with the usage of the multiplier in interrupt service routines. Because the state of the MPYSAT and MPYFRAC bits are unknown, they should be cleared before the registers are saved as shown in the code example.

```
; Interrupt service routine using multiplier
MPY_USING_ISR
    PUSH    &MPY32CTL0      ; Save multiplier mode, etc.
    BIC     #MPYSAT+MPYFRAC,&MPY32CTL0
                ; Clear MPYSAT+MPYFRAC
    PUSH    &RES3          ; Save result 3
    PUSH    &RES2          ; Save result 2
    PUSH    &RES1          ; Save result 1
    PUSH    &RES0          ; Save result 0
    PUSH    &MPY32H         ; Save operand 1, high word
    PUSH    &MPY32L         ; Save operand 1, low word
    PUSH    &OP2H           ; Save operand 2, high word
    PUSH    &OP2L           ; Save operand 2, low word
    ;
    ...
                ; Main part of ISR
                ; Using standard MPY routines
    ;
    POP     &OP2L           ; Restore operand 2, low word
    POP     &OP2H           ; Restore operand 2, high word
                ; Starts dummy multiplication but
                ; result is overwritten by
                ; following restore operations:
    POP     &MPY32L         ; Restore operand 1, low word
    POP     &MPY32H         ; Restore operand 1, high word
    POP     &RES0          ; Restore result 0
    POP     &RES1          ; Restore result 1
    POP     &RES2          ; Restore result 2
    POP     &RES3          ; Restore result 3
    POP     &MPY32CTL0       ; Restore multiplier mode, etc.
    reti               ; End of interrupt service routine
```

### 5.2.8 Using DMA

In devices with a DMA controller, the multiplier can trigger a transfer when the complete result is available. The DMA controller needs to start reading the result with MPY32RES0 successively up to MPY32RES3. Not all registers need to be read. The trigger timing is such that the DMA controller starts reading MPY32RES0 when its ready, and that the MPY32RES3 can be read exactly in the clock cycle when it is available to allow the fastest access through the DMA. The signal into the DMA controller is 'Multiplier ready' (see the *DMA Controller* chapter for details).

### 5.3 MPY32 Registers

MPY32 registers are listed in [Table 5-7](#). The base address can be found in the device-specific data sheet. The address offsets are listed in [Table 5-7](#).

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 5-7. MPY32 Registers**

| Offset | Acronym   | Register Name                                     | Type       | Access | Reset     |
|--------|-----------|---------------------------------------------------|------------|--------|-----------|
| 00h    | MPY       | 16-bit operand one – multiply                     | Read/write | Word   | Undefined |
| 00h    | MPY_L     |                                                   | Read/write | Byte   | Undefined |
| 01h    | MPY_H     |                                                   | Read/write | Byte   | Undefined |
| 00h    | MPY_B     | 8-bit operand one – multiply                      | Read/write | Byte   | Undefined |
| 02h    | MPYS      | 16-bit operand one – signed multiply              | Read/write | Word   | Undefined |
| 02h    | MPYS_L    |                                                   | Read/write | Byte   | Undefined |
| 03h    | MPYS_H    |                                                   | Read/write | Byte   | Undefined |
| 02h    | MPYS_B    | 8-bit operand one – signed multiply               | Read/write | Byte   | Undefined |
| 04h    | MAC       | 16-bit operand one – multiply accumulate          | Read/write | Word   | Undefined |
| 04h    | MAC_L     |                                                   | Read/write | Byte   | Undefined |
| 05h    | MAC_H     |                                                   | Read/write | Byte   | Undefined |
| 04h    | MAC_B     | 8-bit operand one – multiply accumulate           | Read/write | Byte   | Undefined |
| 06h    | MACS      | 16-bit operand one – signed multiply accumulate   | Read/write | Word   | Undefined |
| 06h    | MACS_L    |                                                   | Read/write | Byte   | Undefined |
| 07h    | MACS_H    |                                                   | Read/write | Byte   | Undefined |
| 06h    | MACS_B    | 8-bit operand one – signed multiply accumulate    | Read/write | Byte   | Undefined |
| 08h    | OP2       | 16-bit operand two                                | Read/write | Word   | Undefined |
| 08h    | OP2_L     |                                                   | Read/write | Byte   | Undefined |
| 09h    | OP2_H     |                                                   | Read/write | Byte   | Undefined |
| 08h    | OP2_B     | 8-bit operand two                                 | Read/write | Byte   | Undefined |
| 0Ah    | RESLO     | 16x16-bit result low word                         | Read/write | Word   | Undefined |
| 0Ah    | RESLO_L   |                                                   | Read/write | Byte   | Undefined |
| 0Ch    | RESHI     | 16x16-bit result high word                        | Read/write | Word   | Undefined |
| 0Eh    | SUMEXT    | 16x16-bit sum extension register                  | Read       | Word   | Undefined |
| 10h    | MPY32L    | 32-bit operand 1 – multiply – low word            | Read/write | Word   | Undefined |
| 10h    | MPY32L_L  |                                                   | Read/write | Byte   | Undefined |
| 11h    | MPY32L_H  |                                                   | Read/write | Byte   | Undefined |
| 12h    | MPY32H    | 32-bit operand 1 – multiply – high word           | Read/write | Word   | Undefined |
| 12h    | MPY32H_L  |                                                   | Read/write | Byte   | Undefined |
| 13h    | MPY32H_H  |                                                   | Read/write | Byte   | Undefined |
| 12h    | MPY32H_B  | 24-bit operand 1 – multiply – high byte           | Read/write | Byte   | Undefined |
| 14h    | MPYS32L   | 32-bit operand 1 – signed multiply – low word     | Read/write | Word   | Undefined |
| 14h    | MPYS32L_L |                                                   | Read/write | Byte   | Undefined |
| 15h    | MPYS32L_H |                                                   | Read/write | Byte   | Undefined |
| 16h    | MPYS32H   | 32-bit operand 1 – signed multiply – high word    | Read/write | Word   | Undefined |
| 16h    | MPYS32H_L |                                                   | Read/write | Byte   | Undefined |
| 17h    | MPYS32H_H |                                                   | Read/write | Byte   | Undefined |
| 16h    | MPYS32H_B | 24-bit operand 1 – signed multiply – high byte    | Read/write | Byte   | Undefined |
| 18h    | MAC32L    | 32-bit operand 1 – multiply accumulate – low word | Read/write | Word   | Undefined |

**Table 5-7. MPY32 Registers (continued)**

| Offset | Acronym     | Register Name                                             | Type       | Access | Reset     |
|--------|-------------|-----------------------------------------------------------|------------|--------|-----------|
| 18h    | MAC32L_L    |                                                           | Read/write | Byte   | Undefined |
| 19h    | MAC32L_H    |                                                           | Read/write | Byte   | Undefined |
| 1Ah    | MAC32H      | 32-bit operand 1 – multiply accumulate – high word        | Read/write | Word   | Undefined |
| 1Ah    | MAC32H_L    |                                                           | Read/write | Byte   | Undefined |
| 1Bh    | MAC32H_H    |                                                           | Read/write | Byte   | Undefined |
| 1Ah    | MAC32H_B    | 24-bit operand 1 – multiply accumulate – high byte        | Read/write | Byte   | Undefined |
| 1Ch    | MACS32L     | 32-bit operand 1 – signed multiply accumulate – low word  | Read/write | Word   | Undefined |
| 1Ch    | MACS32L_L   |                                                           | Read/write | Byte   | Undefined |
| 1Dh    | MACS32L_H   |                                                           | Read/write | Byte   | Undefined |
| 1Eh    | MACS32H     | 32-bit operand 1 – signed multiply accumulate – high word | Read/write | Word   | Undefined |
| 1Eh    | MACS32H_L   |                                                           | Read/write | Byte   | Undefined |
| 1Fh    | MACS32H_H   |                                                           | Read/write | Byte   | Undefined |
| 1Eh    | MACS32H_B   | 24-bit operand 1 – signed multiply accumulate – high byte | Read/write | Byte   | Undefined |
| 20h    | OP2L        | 32-bit operand 2 – low word                               | Read/write | Word   | Undefined |
| 20h    | OP2L_L      |                                                           | Read/write | Byte   | Undefined |
| 21h    | OP2L_H      |                                                           | Read/write | Byte   | Undefined |
| 22h    | OP2H        | 32-bit operand 2 – high word                              | Read/write | Word   | Undefined |
| 22h    | OP2H_L      |                                                           | Read/write | Byte   | Undefined |
| 23h    | OP2H_H      |                                                           | Read/write | Byte   | Undefined |
| 22h    | OP2H_B      | 24-bit operand 2 – high byte                              | Read/write | Byte   | Undefined |
| 24h    | RES0        | 32x32-bit result 0 – least significant word               | Read/write | Word   | Undefined |
| 24h    | RES0_L      |                                                           | Read/write | Byte   | Undefined |
| 26h    | RES1        | 32x32-bit result 1                                        | Read/write | Word   | Undefined |
| 28h    | RES2        | 32x32-bit result 2                                        | Read/write | Word   | Undefined |
| 2Ah    | RES3        | 32x32-bit result 3 – most significant word                | Read/write | Word   | Undefined |
| 2Ch    | MPY32CTL0   | MPY32 control register 0                                  | Read/write | Word   | Undefined |
| 2Ch    | MPY32CTL0_L |                                                           | Read/write | Byte   | Undefined |
| 2Dh    | MPY32CTL0_H |                                                           | Read/write | Byte   | 00h       |

The registers listed in [Table 5-8](#) are treated equally.

**Table 5-8. Alternative Registers**

| Register                                        | Alternative 1    | Alternative 2          |
|-------------------------------------------------|------------------|------------------------|
| 16-bit operand one – multiply                   | MPY              | MPY32L                 |
| 8-bit operand one – multiply                    | MPY_B or MPY_L   | MPY32L_B or MPY32L_L   |
| 16-bit operand one – signed multiply            | MPYS             | MPYS32L                |
| 8-bit operand one – signed multiply             | MPYS_B or MPYS_L | MPYS32L_B or MPYS32L_L |
| 16-bit operand one – multiply accumulate        | MAC              | MAC32L                 |
| 8-bit operand one – multiply accumulate         | MAC_B or MAC_L   | MAC32L_B or MAC32L_L   |
| 16-bit operand one – signed multiply accumulate | MACS             | MACS32L                |
| 8-bit operand one – signed multiply accumulate  | MACS_B or MACS_L | MACS32L_B or MACS32L_L |
| 16x16-bit result low word                       | RESLO            | RES0                   |
| 16x16-bit result high word                      | RESHI            | RES1                   |

### 5.3.1 MPY32CTL0 Register

32-Bit Hardware Multiplier Control 0 Register

**Figure 5-6. MPY32CTL0 Register**

|           |           |       |        |         |          |            |      |
|-----------|-----------|-------|--------|---------|----------|------------|------|
| 15        | 14        | 13    | 12     | 11      | 10       | 9          | 8    |
| Reserved  |           |       |        |         | MPYDLY32 | MPYDLYWRTE |      |
| r-0       | r-0       | r-0   | r-0    | r-0     | r-0      | rw-0       | rw-0 |
| 7         | 6         | 5     | 4      | 3       | 2        | 1          | 0    |
| MPYOP2_32 | MPYOP1_32 | MPYMX | MPYSAT | MPYFRAC | Reserved | MPYC       |      |
| rw        | rw        | rw    | rw     | rw-0    | rw-0     | rw-0       | rw   |

**Table 5-9. MPY32CTL0 Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                             |
|-------|------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                            |
| 9     | MPYDLY32   | RW   | 0h    | Delayed write mode<br>0b = Writes are delayed until 64-bit result (RES0 to RES3) is available.<br>1b = Writes are delayed until 32-bit result (RES0 to RES1) is available.                                                                                                                                                              |
| 8     | MPYDLYWRTE | RW   | 0h    | Delayed write enable<br>All writes to any MPY32 register are delayed until the 64-bit (MPYDLY32 = 0) or 32-bit (MPYDLY32 = 1) result is ready.<br>0b = Writes are not delayed.<br>1b = Writes are delayed.                                                                                                                              |
| 7     | MPYOP2_32  | RW   | 0h    | Multiplier bit width of operand 2<br>0b = 16 bits<br>1b = 32 bits                                                                                                                                                                                                                                                                       |
| 6     | MPYOP1_32  | RW   | 0h    | Multiplier bit width of operand 1<br>0b = 16 bits<br>1b = 32 bits                                                                                                                                                                                                                                                                       |
| 5-4   | MPYMX      | RW   | 0h    | Multiplier mode<br>00b = MPY – Multiply<br>01b = MPYS – Signed multiply<br>10b = MAC – Multiply accumulate<br>11b = MACS – Signed multiply accumulate                                                                                                                                                                                   |
| 3     | MPYSAT     | RW   | 0h    | Saturation mode<br>0b = Saturation mode disabled<br>1b = Saturation mode enabled                                                                                                                                                                                                                                                        |
| 2     | MPYFRAC    | RW   | 0h    | Fractional mode<br>0b = Fractional mode disabled<br>1b = Fractional mode enabled                                                                                                                                                                                                                                                        |
| 1     | Reserved   | RW   | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                            |
| 0     | MPYC       | RW   | 0h    | Carry of the multiplier. It can be considered as 33rd or 65th bit of the result if fractional or saturation mode is not selected, because the MPYC bit does not change when switching to saturation or fractional mode.<br>It is used to restore the SUMEXT content in MAC mode.<br>0b = No carry for result<br>1b = Result has a carry |

## FRAM Controller Overview

### 6.1 FRAM Controller Overview

Table 6-1 summarizes the differences between the FRCTL and FRCTL\_A modules. See the full feature descriptions in the [FRCTL chapter](#) and [FRCTL\\_A chapter](#) for details. A device can includes only one FRAM controller, either FRCTL or FRCTL\_A. See the functional block diagram in the device-specific data sheet to determine the supported FRAM controller (if FRCTL\_A is not specified in the block diagram, the device supports FRCTL).

**Table 6-1. FRAM Controller Overview**

| Feature            |                                                       | FRCTL                                                                            | FRCTL_A                                                                 |
|--------------------|-------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Wait state control | Automatic wait state mode                             | No                                                                               | Yes                                                                     |
|                    | User wait state mode                                  | Yes                                                                              | Yes                                                                     |
|                    |                                                       | Control Bits: NWAITS[2:0]                                                        | Control Bits: NWAITS[3:0]                                               |
|                    |                                                       | Timing violation interrupt:<br>ACCTEIFG bit and a reset (PUC);<br>always enabled | Timing violation interrupt:<br>ACCTEIFG bit; enabled by the ACCTEIE bit |
| Write protection   | MPU (see <a href="#">Chapter 9</a> )                  | Yes                                                                              | Yes                                                                     |
|                    | Temporary protection - whole FRAM memory              | No                                                                               | Yes (WPROT bit)                                                         |
| Power control      | FRAM on or off in AM                                  | FRPWR bit                                                                        | FRPWR bit                                                               |
|                    | FRAM power status when the device wakes up from a LPM | FRLPMPWR bit                                                                     | FRPWR bit                                                               |

## ***FRAM Controller (FRCTL)***

This chapter describes the operation of the FRAM controller.

| Topic                              | Page |
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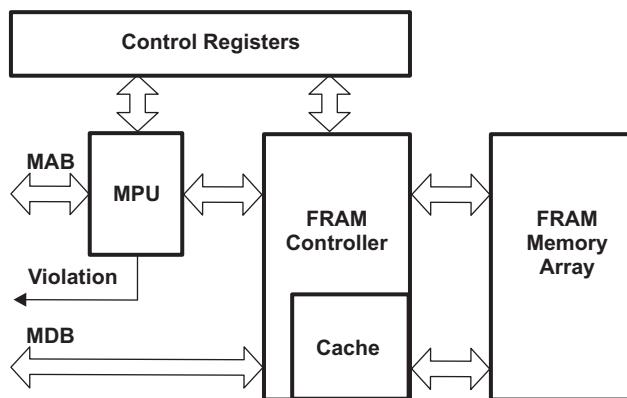
## 7.1 FRAM Introduction

FRAM is a nonvolatile memory that reads and writes like standard SRAM. The MSP430 FRAM features include:

- Byte or word write access
- Automatic and programmable wait state control with independent wait state settings for access and cycle times
- Error correction code with bit error correction, extended bit error detection and flag indicators
- Cache for fast read
- Power control for disabling FRAM if it is not used

For important software design information regarding FRAM, including but not limited to partitioning the memory layout according to application-specific code, constant, and data space requirements, the use of FRAM to optimize application energy consumption, and the use of the memory protection unit (MPU) to maximize application robustness by protecting the program code against unintended write accesses, see [MSP430™ FRAM Technology – How To and Best Practices](#).

Figure 7-1 shows the block diagram of the FRAM Controller.



**Figure 7-1. FRAM Controller Block Diagram**

## 7.2 FRAM Organization

The FRAM can be arranged into segments by the Memory Protection Unit (MPU). See [Chapter 9, Memory Protection Unit](#), for details. The address space is linear with the exception of the User Information Memory and the Device Descriptor Information (TLV).

## 7.3 FRCTL Module Operation

The FRAM can be read in a similar fashion to SRAM and needs no special requirements. Similarly, any writes to unprotected segments can be written in the same fashion as SRAM. All writes to user protected segments are handled as described in [Chapter 9, Memory Protection Unit](#).

An FRAM read always requires a write back to the same memory location with the same information read. This write back is part of the FRAM module itself and requires no user interaction. These write backs are different from the normal write access from application code.

The FRAM module has built-in error correction code (ECC) logic that can correct bit errors and detect multiple bit errors. Two flags are available that indicate the presence of an error. The CBDIFG is set when a correctable bit error has been detected. If CBDIE is also set, a System NMI event (SYSNMI) occurs. The UBDIFG is set when a multiple bit error that is not correctable has been detected. If UBDIE is also set, a System NMI event (SYSNMI) occurs. Upon correctable or uncorrectable bit errors, the program vectors to the SYSSNIV if the NMI is enabled. If desired, a System Reset event (SYSRST) can be generated by setting the UBDRSTEN bit. If an uncorrectable error is detected, a PUC is initiated and the program vectors to the SYSRSTIV.

## 7.4 Programming FRAM Devices

There are three options for programming an MSP430 FRAM device. All options support in-system programming.

- Program with JTAG or the Spy-Bi-Wire interface
- Program with the BSL
- Program with a custom solution

### 7.4.1 Programming FRAM With JTAG or Spy-Bi-Wire

Devices can be programmed through the JTAG port or the Spy-Bi-Wire port. The JTAG interface requires access to TDI, TDO, TMS, TCK, TEST, ground, and optionally VCC and  $\overline{RST}/NMI$ . Spy-Bi-Wire interface requires access to TEST,  $\overline{RST}/NMI$ , ground and optionally VCC. For more details, see [MSP430 Programming With the JTAG Interface](#).

### 7.4.2 Programming FRAM With the Bootloader (BSL)

Every device contains a BSL stored in ROM. The BSL enables users to read or program the FRAM or RAM using a UART serial interface. Access to the FRAM through the BSL is protected by a 256-bit user-defined password. For more details, see the [MSP430FR57xx, MSP430FR58xx, MSP430FR59xx, MSP430FR68xx, and MSP430FR69xx Bootloader \(BSL\) User's Guide](#).

### 7.4.3 Programming FRAM With a Custom Solution

The ability of the CPU to write to its own FRAM allows for in-system and external custom programming solutions. The user can choose to provide data to the device through any means available (for example, UART or SPI). User-developed software can receive the data and program the FRAM. Because this type of solution is developed by the user, it can be completely customized to fit the application needs for programming or updating the FRAM.

## 7.5 Wait State Control

The system clock for the CPU or DMA can exceed the FRAM access and cycle time requirements. For these scenarios, a wait state generator mechanism is implemented. The *Recommended Operating Conditions* of the device-specific data sheet list the frequency ranges with the required wait state settings. The number of wait states is controlled by the NWAITS[2:0] bits in the FRCTL0 register.

To increase the system clock frequency beyond the maximum frequency allowed by the current wait state setting, the following steps are required:

1. Increase the number of wait states by configuring NWAITS[2:0] according to the target frequency.
2. Increase the frequency to the new target.

To decrease the system clock frequency to a range that supports fewer wait states, the following steps are required:

1. Decrease frequency to the new target.
2. Decrease number of wait states by configuring NWAITS[2:0] according to the new frequency setting.

To ensure memory integrity, a mechanism is implemented to reset the device with a PUC if the system clock frequency and the wait state settings violate the FRAM access timing.

---

**NOTE: Wait State Settings**

- The device starts with zero wait states.
  - Correct wait state settings must be ensured, otherwise a PUC might be generated to avoid erratic FRAM accesses.
-

### 7.5.1 Wait State and Cache Hit

The FRAM controller contains a cache with two cache sets. Each of these cache sets contains two lines that are preloaded with four words (64 bits) during one access cycle. An intelligent logic selects one of the cache lines to preload FRAM data and preserves recently accessed data in the other cache. If one of the four words stored in one of the cache lines is requested (a cache hit), no FRAM access occurs; instead, a cache request occurs. No wait state is needed for a cache request, and the data is accessed with full system speed. However, if none of the words that are available in the cache are requested (a cache miss), the wait state controls the CPU to ensure proper FRAM access.

## 7.6 FRAM ECC

The FRAM supports bit error correction and uncorrectable bit error detection. The UBDIFG FRAM uncorrectable bit error flag is set if an uncorrectable bit error has been detected in the FRAM error detection logic. The CBDIFG FRAM correctable bit error flag is set if a correctable bit error has been detected and corrected. UBDRSTEN enables a power up clear (PUC) reset. If an uncorrectable bit error is detected, UBDIE enables a NMI event if an uncorrectable bit error is detected. CBDIE enables an NMI event if a marginal correctable bit error is detected and corrected.

## 7.7 FRAM Write Back

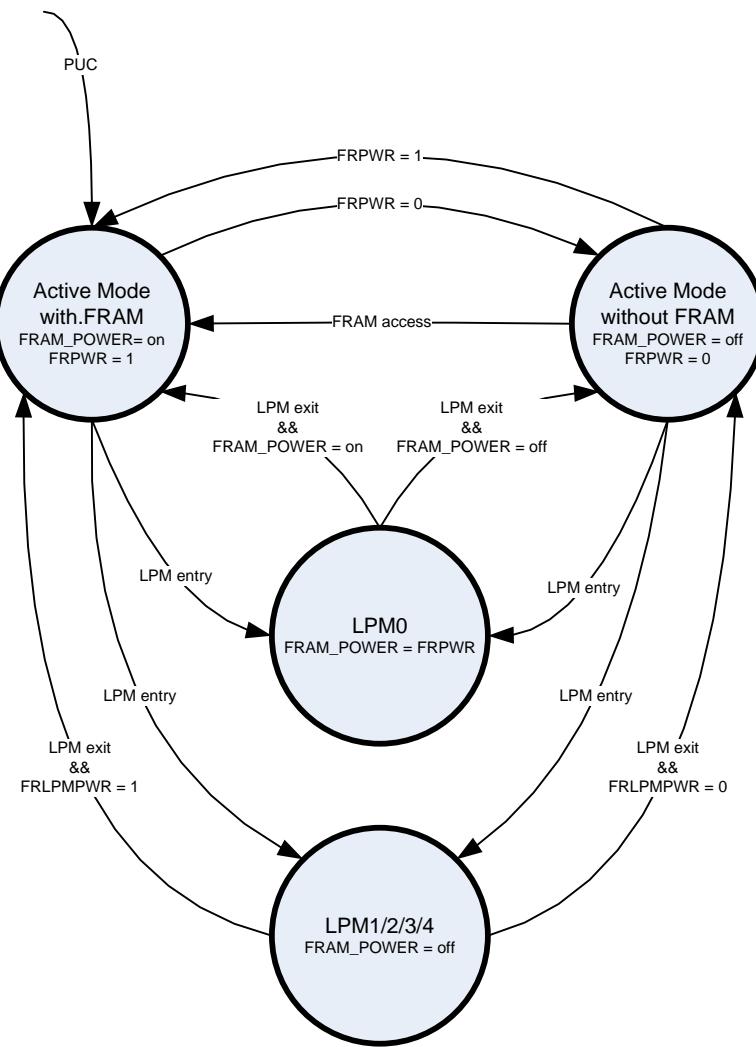
All reads from FRAM requires a write back of the previously read content. This write back is performed under all circumstances without any interaction from a user.

## 7.8 FRAM Power Control

The FRAM controller can disable the power supply for the FRAM array. By setting FRPWR = 0, the FRAM array supply is disabled. Register accesses in the FRAM controller are still possible. Memory accesses pointing into the FRAM address space automatically reset the FRPWR = 1 and re-enable the power supply of the FRAM. A second control bit, FRLPMPWR, delays the power-up of the FRAM after LPM exit. With FRLPMPWR = 1, the FRAM is activated directly on exit from LPM. FRLPMPWR = 0 delays the activation of the FRAM to the first access into the FRAM address space. For LPM0, the FRAM power state during LPM0 is determined from the previous state in active mode. If FRAM power is disabled, a memory access automatically inserts wait states to ensure sufficient timing for the FRAM power-up and access. Access to FRAM that can be served from cache does not change the power state of the FRAM power control.

A PUC reset forces the state machine to Active mode with FRAM enabled. The CPU must execute from RAM to clear the FRPWR bit for turning off power to FRAM.

Figure 7-2 shows the activation flow of the FRAM controller.



**Figure 7-2. FRAM Power Control Diagram**

## 7.9 FRAM Cache

The FRAM controller implements a read cache to provide a speed benefit when running the CPU at higher speeds than the FRAM supports without wait states. The cache implemented is a 2-way associative cache with 4 cache lines of 64 bit size. Memory read accesses on consecutive addresses can be executed without wait states when they are within the same cache line.

## 7.10 FRCTL Registers

The FRCTL registers and their address offsets are listed in [Table 7-1](#). The base address of the FRCTL module can be found in the device-specific data sheet.

The password defined in the FRCTL0 register controls access to all FRCTL registers. When the correct password is written, write access to the registers is enabled. The write access is disabled by writing a wrong password in byte mode to the FRCTL upper byte. Word accesses to FRCTL with a wrong password triggers a PUC. A write access to a register other than FRCTL while write access is not enabled causes a PUC.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 7-1. FRCTL Registers**

| Offset | Acronym | Register Name             | Type       | Access | Reset | Section                        |
|--------|---------|---------------------------|------------|--------|-------|--------------------------------|
| 00h    | FRCTL0  | FRAM Controller Control 0 | Read/write | Word   | 9600h | <a href="#">Section 7.10.1</a> |
| 00h    |         | FRCTL0_L                  | Read/Write | Byte   | 00h   |                                |
| 01h    |         | FRCTL0_H                  | Read/Write | Byte   | 96h   |                                |
| 04h    | GCCTL0  | General Control 0         | Read/write | Word   | 0006h | <a href="#">Section 7.10.2</a> |
| 04h    |         | GCCTL0_L                  | Read/Write | Byte   | 06h   |                                |
| 05h    |         | GCCTL0_H                  | Read/Write | Byte   | 00h   |                                |
| 06h    | GCCTL1  | General Control 1         | Read/write | Word   | 0000h | <a href="#">Section 7.10.3</a> |
| 06h    |         | GCCTL1_L                  | Read/Write | Byte   | 00h   |                                |
| 07h    |         | GCCTL1_H                  | Read/Write | Byte   | 00h   |                                |

### 7.10.1 FRCTL0 Register

FRAM Controller Control Register 0

**Figure 7-3. FRCTL0 Register**

|          |        |        |        |     |          |     |     |
|----------|--------|--------|--------|-----|----------|-----|-----|
| 15       | 14     | 13     | 12     | 11  | 10       | 9   | 8   |
| FRCTLPW  |        |        |        |     |          |     |     |
| rw       | rw     | rw     | rw     | rw  | rw       | rw  | rw  |
| 7        | 6      | 5      | 4      | 3   | 2        | 1   | 0   |
| Reserved | NWAITS |        |        |     | Reserved |     |     |
| r-0      | rw-[0] | rw-[0] | rw-[0] | r-0 | r-0      | r-0 | r-0 |

**Table 7-2. FRCTL0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                            |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | FRCTLPW  | RW   | 96h   | FRCTLPW password. Always reads as 96h.<br>To enable write access to the FRCTL registers, write A5h. A word write of any other value causes a PUC.<br>After a correct password is written and register access is enabled, write a wrong password in byte mode to disable the access. In this case, no PUC is generated. |
| 7    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                           |
| 6-4  | NWAITS   | RW   | 0h    | Wait state control. Specifies number of wait states (0 to 7) required for an FRAM access (cache miss). 0 implies no wait states.                                                                                                                                                                                       |
| 3    | Reserved | R    | 0h    | Reserved. Must be written as 0.                                                                                                                                                                                                                                                                                        |
| 2-0  | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                           |

### 7.10.2 GCCTL0 Register

General Control Register 0

**Figure 7-4. GCCTL0 Register**

|          |        |        |          |          |       |          |          |
|----------|--------|--------|----------|----------|-------|----------|----------|
| 15       | 14     | 13     | 12       | 11       | 10    | 9        | 8        |
| Reserved |        |        |          |          |       |          |          |
| r-0      | r-0    | r-0    | r-0      | r-0      | r-0   | r-0      | r-0      |
| 7        | 6      | 5      | 4        | 3        | 2     | 1        | 0        |
| UBDRSTEN | UBDIE  | CBDIE  | Reserved | Reserved | FRPWR | FRLPMPWR | Reserved |
| rw-[0]   | rw-[0] | rw-[0] | r-0      | rw-0     | rw-1  | rw-1     | r-0      |

**Table 7-3. GCCTL0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                             |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                            |
| 7    | UBDRSTEN | RW   | 0h    | Enable power up clear (PUC) reset if FRAM uncorrectable bit error detected. The bits UBDRSTEN and UBDIE are mutual exclusive and are not allowed to be set simultaneously. Only one error handling can be selected at one time.<br>0b = PUC not initiated on uncorrectable bit detection flag.<br>1b = PUC initiated on uncorrectable bit detection flag. Generates vector in SYSRSTIV. |
| 6    | UBDIE    | RW   | 0h    | Enable NMI event if uncorrectable bit error detected. The bits UBDRSTEN and UBDIE are mutual exclusive and are not allowed to be set simultaneously. Only one error handling can be selected at one time.<br>0b = Uncorrectable bit detection interrupt disabled.<br>1b = Uncorrectable bit detection interrupt enabled. Generates vector in SYSSNIV.                                   |
| 5    | CBDIE    | RW   | 0h    | Enable NMI event if correctable bit error detected.<br>0b = Correctable bit detection interrupt disabled.<br>1b = Correctable bit detection interrupt enabled. Generates vector in SYSSNIV.                                                                                                                                                                                             |
| 4    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                            |
| 3    | Reserved | RW   | 0h    | Reserved. Must be written as 0.                                                                                                                                                                                                                                                                                                                                                         |
| 2    | FRPWR    | RW   | 1h    | FRAM power control.<br>Writing to the register enables or disables the FRAM power supply. The read of the register returns the actual state of the FRAM power supply, also reflecting a possible delay after enabling the power supply. FRPWR = 1 indicates that the FRAM power is up and ready.<br>0b = FRAM power supply disabled<br>1b = FRAM power supply enabled                   |
| 1    | FRLPMPWR | RW   | 1h    | Enables FRAM auto power up after LPM<br>0b = FRAM startup is delayed to the first FRAM access after LPM exit<br>1b = FRAM is powered up instantly with LPM exit.                                                                                                                                                                                                                        |
| 0    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                            |

### 7.10.3 GCCTL1 Register

General Control Register 1

**Figure 7-5. GCCTL1 Register**

|          |     |     |     |          |        |        |          |
|----------|-----|-----|-----|----------|--------|--------|----------|
| 15       | 14  | 13  | 12  | 11       | 10     | 9      | 8        |
| Reserved |     |     |     |          |        |        |          |
| r-0      | r-0 | r-0 | r-0 | r-0      | r-0    | r-0    | r-0      |
| 7        | 6   | 5   | 4   | 3        | 2      | 1      | 0        |
| Reserved |     |     |     | ACCTEIFG | UBDIFG | CBDIFG | Reserved |
| r-0      | r-0 | r-0 | r-0 | rw-0     | rw-[0] | rw-[0] | r-0      |

**Table 7-4. GCCTL1 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 3    | ACCTEIFG | RW   | 0h    | <p>Access time error flag. This flag is set and a reset PUC is generated if a wrong setting for NWAITS is set and the FRAM access time is violated. This bit is cleared by software or by reading the system reset vector word SYSRSTIV if it is the highest pending flag. This bit is write 0 only, write 1 has no effect.</p> <p><b>Note:</b> The ACCTEIFG bit may be set in debug mode when the system frequency is configured to be greater than 8 MHz, regardless of the wait states (NWAITS). In the case, it is not an FRAM access violation. The ACCTEIFG bit does not trigger a PUC or change the SYSRSTIV register value. The ACCTEIFG bit is cleared only by writing 0. It is recommended to use SYSRESTIV register to check FRAM access violation error to avoid confusion.</p> |
| 2    | UBDIFG   | RW   | 0h    | <p>FRAM uncorrectable bit error flag. This interrupt flag is set if an uncorrectable bit error has been detected in the FRAM memory error detection logic. This bit is cleared by software or by reading the system NMI vector word SYSSNIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.</p> <p>0b = No interrupt pending<br/>1b = Interrupt pending. Can be cleared by user or by reading SYSSNIV.</p>                                                                                                                                                                                                                                                                                                                                 |
| 1    | CBDIFG   | RW   | 0h    | <p>FRAM correctable bit error flag. This interrupt flag is set if a correctable bit error has been detected and corrected in the FRAM memory error detection logic. This bit is cleared by software or by reading the system NMI vector word SYSSNIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.</p> <p>0b = No interrupt pending<br/>1b = Interrupt pending. Can be cleared by user or by reading SYSSNIV</p>                                                                                                                                                                                                                                                                                                                         |
| 0    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

## ***FRAM Controller A (FRCTL\_A)***

This chapter describes the operation of the FRAM controller A (FRCTL\_A) . The FRCTL\_A and FRCTL are almost identical in terms of the features that they support. For a summary of the differences between the two modules, see the *FRAM Controller Overview* chapter.

| Topic                                                     | Page       |
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## 8.1 FRAM Controller A (FRCTL\_A) Introduction

The FRAM Controller A includes the following features :

- Byte (8 bit) or word (16 bit) write access
- Automatic and programmable wait state control with independent wait state settings for access and cycle times
- Timing violation detection to ensure proper interrupt handling with incorrect wait state setting
- Error correction code with bit error correction, extended bit error detection, and flag indicators
- Cache for energy-efficient read
- Power control for disabling FRAM when it is not in use, including automatic wake up

For important software design information regarding FRAM, including but not limited to partitioning the memory layout according to application-specific code, constant, and data space requirements, the use of FRAM to optimize application energy consumption, and the use of the memory protection unit (MPU) to maximize application robustness by protecting the program code against unintended write accesses, see [MSP430™ FRAM Technology – How To and Best Practices](#).

Figure 8-1 shows the block diagram of the FRCTL\_A.

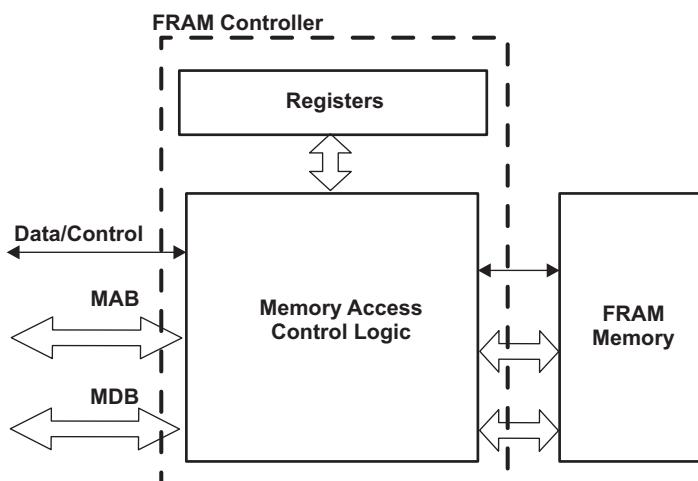


Figure 8-1. FRCTL\_A Block Diagram

## 8.2 FRAM Controller A (FRCTL\_A) Operation

FRAM is a nonvolatile memory that eliminates the slow writing barrier of flash memory. The read and write operations of FRAM is just like the way that the standard SRAM works. The FRAM features SRAM-like operation with nonvolatility.

### 8.2.1 FRCTL\_A Error Detection

The FRAM module has a built-in error correction code (ECC) block that can correct bit errors and detect multiple bit errors. Two flags, the CBDIFG and UBDIFG bits, are used to report the status of errors.

The correctable bit detection interrupt flag (CBDIFG) is set when a correctable bit error is detected. In this case, the error generates a system NMI (SYSNMI) if the correctable bit detection interrupt enable bit (CBDIE) is set.

The uncorrectable bit detection interrupt flag (UBDIFG) is set when a multiple bit error, which is not correctable, is detected. In this case, cache is flushed and either a system NMI (SYSNMI), if the uncorrectable bit detection interrupt enable bit (UBDIE) is set, or a power-up-clear (PUC) reset, if the uncorrectable bit detection reset enable bit (UBDRSTEN) is set, can be generated.

The UBDRSTEN bit and the UBDIE bit are mutually exclusive. The UBDRSTEN bit has a higher priority—if both bits are set, the UBDIE bit is ignored and the UBDRSTEN bit remains active.

## 8.2.2 Programming FRAM Memory Devices

There are three options for programming an MSP430 FRAM device. All options support in-system programming.

- Program with JTAG or the Spy-Bi-Wire interface
- Program with the BSL
- Program with a custom solution

### 8.2.2.1 Programming FRAM Memory With JTAG or Spy-Bi-Wire

Devices can be programmed through the JTAG port or the Spy-Bi-Wire port. The JTAG interface requires access to TDI, TDO, TMS, TCK, TEST, ground, and optionally V<sub>CC</sub> and RST/NMI. Spy-Bi-Wire interface requires access to TEST, RST/NMI, ground and optionally V<sub>CC</sub>. For more details, see the [MSP430 Programming With the JTAG Interface](#).

### 8.2.2.2 Programming FRAM Memory With the Bootstrap Loader (BSL)

Every device contains a BSL stored in ROM. The BSL enables users to read or program the FRAM or RAM using a UART serial interface. Access to the FRAM through the BSL is protected by a 256-bit user-defined password. For more details, see the [MSP430 Programming With the Bootloader \(BSL\)](#).

### 8.2.2.3 Programming FRAM Memory With a Custom Solution

The ability of the CPU to write to its own FRAM allows for in-system and external custom programming solutions. The user can choose to provide data to the device through any means available (for example, UART or SPI). User-developed software can receive the data and program the FRAM. Because this type of solution is developed by the user, it can be completely customized to fit the application needs for programming or updating the FRAM.

## 8.2.3 Access Control

### 8.2.3.1 Write Protection

The WPROT bit can be used to protect the contents of FRAM from being unintentionally modified. When the WPROT is set, reading is allowed, but no writing to FRAM memory is allowed. If a write access is attempted with WPROT = 1, the WPIFG (write protection flag) bit is set. In this case, the error generates a system NMI (SYSNMI) if the WPIE (write protection interrupt enable) bit is set. Note that writing-to-FRAM is also blocked when the ACCTEIFG bit is set due to a timing violation. The WPIFG bit is set when a write access is attempted with ACCTEIFG = 1.

The WPROT bit protects the entire FRAM from unintended writes regardless of MPU configurations, so this bit should be used as temporary protection. To protect a portion of the FRAM permanently, use the MPU module (see [Chapter 9, Memory Protection Unit](#)). Write protection is disabled after BOR (WPROT = 0).

### 8.2.3.2 Two Wait State Modes

FRAM memory has limited access speed (see the device data sheet for details), but that does not limit the speed of CPU and DMA in the device. When the running speed of the CPU and DMA exceeds the FRAM access speed, a wait state control mechanism is implemented. The FRAM controller A (FRCTL\_A) supports two wait state modes, user wait state mode and automatic wait state mode.

### 8.2.3.3 User Wait State Mode

User wait state mode and automatic wait state mode are mutually exclusive. User wait state mode is automatically enabled after device reset (BOR), but the wait state mode can be switched to automatic wait state mode by setting the AUTO bit. The FRAM access speed can be maximized in user wait state mode by writing an optimized wait state number to NWAITS[3:0]. However, incorrect wait state numbers may cause a timing violation error. Thus, the application must write a proper wait state to NWAITS[3:0] before accessing FRAM. See [Table 8-1](#) for optimized wait states with different system frequencies.

### 8.2.3.4 Timing Violation Detection

In user wait state mode (AUTO = 0), if NWAITS[3:0] bit has been configured with an incorrect wait state, a timing violation can occur when accessing FRAM. Upon detecting a timing violation, the FRAM controller responses to the timing violation event with three actions:

- Sets the access timer error flag (ACCTEIFG)
- Ignores the NWAITS[3:0] bits and internally applies the maximum wait state (15) (the NWAITS[3:0] bits are not changed)
- Flushes the cache
- Disables write access to FRAM regardless of the WPROT bit (the WPROT bit is not changed)

The FRAM controller A (FRCTL\_A) keeps the maximum wait state and blocks write access if the ACCTEIFG bit is set in order to avoid further timing violations. It is recommended to configure the NWAITS[3:0] bits based on the table shown in [Table 8-1](#) and complete any necessary actions prior to clearing the ACCTEIFG bit. When the ACCTEIFG bit is cleared, the FRAM controller A (FRCTL\_A) takes the value written to NWAITS[3:0] bits as wait state and enables write access to the FRAM if the WPROT bit is cleared. The timing violation (ACCTEIFG) generates a system NMI (SYSNMI) if the access time error interrupt enable (ACCTIE) bit is set.

### 8.2.3.5 Automatic Wait State Mode

Automatic wait state mode is enabled when the AUTO bit is set. In this mode, the FRAM controller A (FRCTL\_A) takes a control of choosing a wait state. So, it is not required for user to configure NWAITS[3:0] bits. The value written to NWAITS[3:0] has no influence in this mode. In order to determine the wait state automatically, the FRAM controller A (FRCTL\_A) adds a delay so that no maximum FRAM access speed is reached and no timing violation is guaranteed. See [Table 8-1](#) for wait state numbers in automatic mode with different system frequencies.

**Table 8-1. FRAM memory Access Speed**

| System Bus Frequency | Required Wait States |                | FRAM Access Speed (Without Cache Hit) |                |
|----------------------|----------------------|----------------|---------------------------------------|----------------|
|                      | User Mode            | Automatic Mode | User Mode                             | Automatic Mode |
| 4 MHz                | 0                    | 3              | 4 MHz                                 | 1 MHz          |
| 8 MHz                | 0                    | 3              | 8 MHz                                 | 2 MHz          |
| 10 MHz               | 1                    | 3              | 5 MHz                                 | 2.5 MHz        |
| 12 MHz               | 1                    | 3              | 6 MHz                                 | 3 MHz          |
| 14 MHz               | 1                    | 3              | 7 MHz                                 | 3.5 MHz        |
| 16 MHz               | 1                    | 3              | 8 MHz                                 | 4 MHz          |
| 24 MHz               | 2                    | 3              | 8 MHz                                 | 6 MHz          |
| 32 MHz               | 3                    | 4              | 8 MHz                                 | 6.4 MHz        |

### 8.2.3.6 Wait State and Cache Hit

The FRAM controller A (FRCTL\_A) has a cache that contains four 64-bit lines. The cache keeps up to 32 bytes ( $4 \times 64$  bit) from the latest accesses to FRAM. When a read is requested, the FRAM controller A (FRCTL\_A) first determines if the requested data is in the cache. If a match is found (a cache hit), then the data is read from the cache and no physical FRAM memory access occurs. In this case, no wait state is required and the data is accessed at the full system bus speed. If no match is found (no cache hit), then the data is read from FRAM memory and the new data replaces one of the four 64-bit lines in the cache.

### 8.2.3.7 Wait State in Debug Mode

When the device is in debug mode, no wait state is applied. The NWAITS[3:0] has no influence in debug mode. In debug mode (for example, during JTAG access to FRAM), the device system clock is controlled externally and can be stopped at any time, thus FRAM access needs to be completed without wait state cycles. The running speed of the CPU and DMA never exceeds the maximum FRAM access speed limit in debug mode.

## 8.3 FRAM ECC

The FRAM controller can correct bit errors and detect uncorrectable multiple-bit errors. When a correctable error occurs, the error is automatically corrected and CBDIFG bit (correctable bit error detection flag) is set. In this case, a system NMI can be generated if CBDIE bit is set. When an uncorrectable error occurs, UCBDIFG (uncorrectable bit error detection flag) bit is set. In this case, the uncorrectable bit error can generate either a system NMI if UBDIE bit is set or a system reset (PUC) if UBDRSTEN bit is set.

The UBDRSTEN bit and the UBDIE bit are mutually exclusive. The UBDRSTEN bit has a higher priority, so the UBDIE bit is ignored when both bits are set.

## 8.4 FRAM Power Control

To achieve maximum power efficiency of FRAM operations, the FRAM controller A (FRCTL\_A) supports a power control mode. There are three inputs that influence the power state of FRAM: the FRPWR bit, FRAM access (read or write), and the device power mode.

[Table 8-2](#) summarizes how FRAM power modes are controlled by the source. [Figure 8-2](#) shows the flow of FRAM power mode transitions.

While the device is in active mode(AM), FRAM power is controlled by the FRPWR bit and FRAM access. When the FRPWR is set, FRAM goes to ACTIVE mode regardless of FRAM access. When the FRPWR is cleared by the CPU and there is no access to FRAM, the FRAM goes into INACTIVE mode so that the FRAM does not consume power.

INACTIVE mode can be used if FRAM access is not required for a significant amount of time. For example, short tasks can be executed from RAM, so while CPU runs from RAM, FRAM can be powered off. When the FRAM is in the INACTIVE mode, wake-up is automatic. An access to FRAM (read or write) wakes up the FRAM before performing the access. In this case, the FRPWR bit is set automatically by the FRAM controller A (FRCTL\_A).

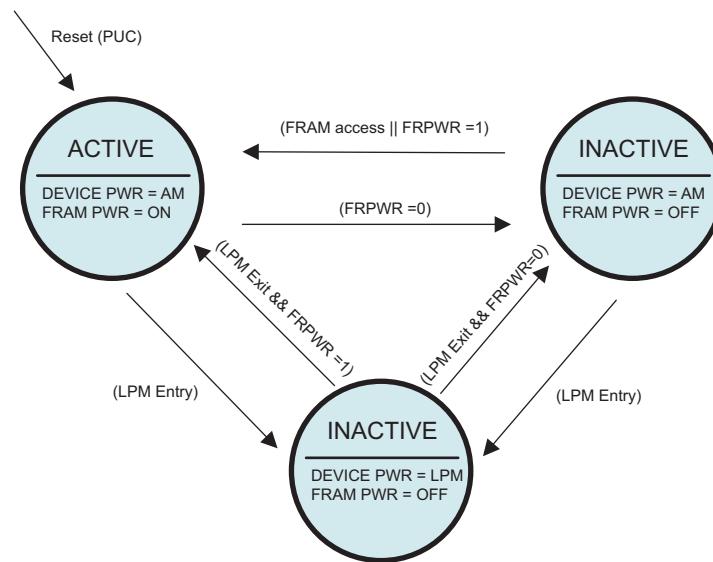
Care must be taken when using the FRPWR bit. When the FRAM is powered off, there is a wake-up time delay before the FRAM can be accessed again. The delay should be considered to avoid affecting system performance. See the device data sheet for the delay time.

When the device enters LPM0, LPM1, LPM2, LPM3, or LPM4, the FRAM also enters INACTIVE mode regardless of FRPWR bit status, however FRPWR bit determines the power status when the device wakes up from a LPM. When the device wakes up from a low-power mode to active mode (AM), FRAM Controller A (FRCTL\_A) immediately wakes up FRAM memory if the FRPWR is set. If the FRPWR bit is cleared, FRAM memory remains in INACTIVE mode until an access to FRAM occurs (read or write). The latter case can be used to reduce the device power consumption if the device wakes up only for a short amount of time, and the task during device active mode can be executed from RAM with no need to access FRAM memory. See [Table 8-2](#) and [Figure 8-2](#) for details.

**Table 8-2. FRAM Power Mode Transition**

| Power Control Source                 |               |             | FRAM Power State (Start) | FRAM Power State (End)                  |
|--------------------------------------|---------------|-------------|--------------------------|-----------------------------------------|
| Device Power Mode                    | FRPWR Bit     | FRAM Access |                          |                                         |
| AM                                   | 1 (after PUC) | Don't care  | ACTIVE                   | ACTIVE                                  |
| AM                                   | 1 → 0         | No          | ACTIVE                   | INACTIVE                                |
| AM                                   | 0             | No → Yes    | INACTIVE                 | ACTIVE (FRPWR bit is set automatically) |
| AM                                   | 0 → 1         | No          | INACTIVE                 | ACTIVE                                  |
| AM → LPM0, LPM1, LPM2, LPM3, or LPM4 | Don't care    | No          | Don't care               | INACTIVE                                |
| LPM0                                 | Don't care    | No → Yes    | Don't care               | ACTIVE (FRPWR bit is set automatically) |
| LPM0, LPM1, LPM2, LPM3, or LPM4 → AM | 1             | No          | INACTIVE                 | ACTIVE                                  |
| LPM0, LPM1, LPM2, LPM3, or LPM4 → AM | 0             | No          | INACTIVE                 | INACTIVE                                |

Figure 8-2 shows the flow of the FRAM power transitions.



**Figure 8-2. FRAM Power Control Diagram**

## 8.5 FRAM Cache

The FRAM controller A (FRCTL\_A) has a cache that contains four 64-bit lines. One of the 64-bit lines is preloaded during one access cycle and the cache can keep up to 32 bytes ( $4 \times 64$  bit) from the latest accesses to FRAM memory. When an FRAM read is requested, the FRAM controller A (FRCTL\_A) first checks cache. If the requested data is found in cache (a cache hit), then the data is read from the cache and no physical FRAM access occurs. In this case, no wait state is required and the data is accessed at the full system bus speed.

## 8.6 FRCTL\_A Registers

**Table 8-3** lists the memory-mapped registers for the FRCTL\_A. All register offset addresses not listed in **Table 8-3** should be considered as reserved locations and the register contents should not be modified.

The password defined in the FRCTL0 register controls access to all FRAM Controller A registers. When the correct password is written, write access to the registers is enabled. The write access is disabled by writing a wrong password in byte mode to FRCTL0 upper byte. Word accesses to FRCTL0 with a wrong password triggers a PUC. A write access to a register other than FRCTL0 while write access is not enabled causes a PUC.

**Note 1:** The correct password (A5h) is written to the FRCTLPW bits by the bootcode during the device boot-up process; therefore, the FRCTL0 (low byte), GCCTL0, and GCCTL1 registers are unlocked after the device is powered up or reset (BOR) or after LPMx.5 wakeup.

**Note 2:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

**Table 8-3. FRCTL\_A Registers**

| Offset | Acronym | Register Name                        | Type       | Reset | Section                       |
|--------|---------|--------------------------------------|------------|-------|-------------------------------|
| 0h     | FRCTL0  | FRAM Controller A Control Register 0 | Read-Write | 9600h | <a href="#">Section 8.6.1</a> |
| 4h     | GCCTL0  | General Control Register 0           | Read-Write | 4h    | <a href="#">Section 8.6.2</a> |
| 6h     | GCCTL1  | General Control Register 1           | Read-Write | 0h    | <a href="#">Section 8.6.3</a> |

### 8.6.1 FRCTL0 Register (Offset = 0h) [reset = 9600h]

FRCTL0 is shown in [Figure 8-3](#) and described in [Table 8-4](#).

[Return to Summary Table.](#)

FRAM Controller A Control Register 0

**Figure 8-3. FRCTL0 Register**

|         |    |    |        |    |          |   |        |
|---------|----|----|--------|----|----------|---|--------|
| 15      | 14 | 13 | 12     | 11 | 10       | 9 | 8      |
| FRCTLPW |    |    |        |    |          |   |        |
| R/W-96h |    |    |        |    |          |   |        |
| 7       | 6  | 5  | 4      | 3  | 2        | 1 | 0      |
| NWAITS  |    |    | AUTO   |    | Reserved |   | WPROT  |
| R/W-0h  |    |    | R/W-0h |    | R-0h     |   | R/W-0h |

**Table 8-4. FRCTL0 Register Field Descriptions**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------|---------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | FRCTLPW | R/W  | 96h   | <p>FRCTLPW password. Always read as 96h.</p> <p><b>Note:</b> The correct password (A5h) is written to the FRCTLPW bits by the bootcode during the device boot-up process; therefore, the FRCTL0 (low byte), GCCTL0, and GCCTL1 registers are unlocked after the device is powered up or reset (BOR) or after LPMx.5 wakeup.</p> <p>96h (R) = FRPW : Read value while locked</p> <p>A5h (W) = FWPW : Must be written as A5h or a PUC is generated on word write. After a correct password is written and register access is enabled, a wrong password write in byte mode disables the access and no PUC is generated.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 7-4  | NWAITS  | R/W  | 0h    | <p>Wait state generator access time control when AUTO =0.</p> <p>Each wait state adds a N integer multiple increase of the IFCLK period where N = 0 through 15. N = 0 implies no wait states. When a timing violation is detected, the Access Time Error Flag (ACCTEIFG) is set and the maximum wait state, 15, is automatically applied to the NWAITS[3:0] to avoid further timing violation. While the ACCTEIFG bit is set, the NWAITS[3:0] cannot be overwritten and writing to the FRAM memory is prohibited regardless of the WPROT bit. Only reading is allowed. The ACCTEIFG bit must be cleared prior to applying a new value to NWAITS[3:0] or writing access to the FRAM memory. The timing violation (ACCTEIFG) can generate a system NMI (SYSNMI) if the Access Time Error Interrupt Enable (ACCTEIE) bit is set. When a timing violation occurs for reading, the data from FRAM memory could be incorrect, thus proper error handling is recommended before proceeding.</p> <p>Reset type: BOR</p> <p>0h (R/W) = FRAM wait states: 0</p> <p>1h (R/W) = FRAM wait states: 1</p> <p>2h (R/W) = FRAM wait states: 2</p> <p>3h (R/W) = FRAM wait states: 3</p> <p>4h (R/W) = FRAM wait states: 4</p> <p>5h (R/W) = FRAM wait states: 5</p> <p>6h (R/W) = FRAM wait states: 6</p> <p>7h (R/W) = FRAM wait states: 7</p> <p>8h (R/W) = FRAM wait states: 8</p> <p>9h (R/W) = FRAM wait states: 9</p> <p>Ah (R/W) = FRAM wait states: 10</p> <p>Bh (R/W) = FRAM wait states: 11</p> <p>Ch (R/W) = FRAM wait states: 12</p> <p>Dh (R/W) = FRAM wait states: 13</p> <p>Eh (R/W) = FRAM wait states: 14</p> <p>Fh (R/W) = FRAM wait states: 15</p> |

**Table 8-4. FRCTL0 Register Field Descriptions (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | AUTO     | R/W  | 0h    | <p>Enable automatic Wait State Mode.</p> <p>Reset type: BOR</p> <p>0h (R/W) = AUTO_0 : User Wait State Mode. The NWAITS[3:0] is used for the FRAM wait state.</p> <p>1h (R/W) = AUTO_1 : Auto mode. The NWAITS[3:0] is ignored. Wait states are generated automatically by the internal FRAM controller state machine.</p>                                                                                                                                                                                                                                                                                                                                                                                                            |
| 2-1 | Reserved | R    | 0h    | <p>Reserved. Always read 0.</p> <p>Reset type: PUC</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 0   | WPROT    | R/W  | 0h    | <p>Write Protection Enable.</p> <p>This bit is set after BOR. This bit must be cleared before accessing FRAM for write. This bit does not block read operation. Note that the WPROT bit protects the entire FRAM memory from unintended write, so it should be used as temporary protection. If it is desired to protect a portion of the FRAM memory permanently, it should be done via MPU segments. See the MPU module for details.</p> <p>Reset type: BOR</p> <p>0h (R/W) = WPROT_0 : Disable Write Protection. Write to FRAM memory is allowed.</p> <p>1h (R/W) = WPROT_1 : Enable Write Protection. Write to FRAM memory is not allowed. If a write access is attempted, the WPIFG (Write Protection Flag) bit will be set.</p> |

### 8.6.2 GCCTL0 Register (Offset = 4h) [reset = 4h]

GCCTL0 is shown in [Figure 8-4](#) and described in [Table 8-5](#).

[Return to Summary Table.](#)

General Control Register 0

**Figure 8-4. GCCTL0 Register**

|          |        |        |        |         |        |          |      |
|----------|--------|--------|--------|---------|--------|----------|------|
| 15       | 14     | 13     | 12     | 11      | 10     | 9        | 8    |
| Reserved |        |        |        |         |        |          |      |
| R-0h     |        |        |        |         |        |          |      |
| 7        | 6      | 5      | 4      | 3       | 2      | 1        | 0    |
| UBDRSTEN | UBDIE  | CBDIE  | WPIE   | ACCTEIE | FRPWR  | Reserved |      |
| R/W-0h   | R/W-0h | R/W-0h | R/W-0h | R/W-0h  | R/W-1h |          | R-0h |

**Table 8-5. GCCTL0 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved. Always read 0.<br>Reset type: PUC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 7    | UBDRSTEN | R/W  | 0h    | Enable Power Up Clear (PUC) reset for the uncorrectable bit error detection flag (UBDIFG).<br><br>The UBDRSTEN and UBDIE must be mutual exclusive. The FRAM controller does not allow the status of both bits are being set. Writing 1 to one of the bits will automatically clear the other bit.<br>Reset type: BOR<br>0h (R/W) = UBDRSTEN_0 : PUC not initiated on uncorrectable bit error detection flag.<br>1h (R/W) = UBDRSTEN_1 : PUC initiated on uncorrectable bit error detection flag. Generates vector in SYSRSTIV. Clear the UBDIE bit. |
| 6    | UBDIE    | R/W  | 0h    | Enable NMI event for the uncorrectable bit error detection flag (UBDIFG).<br><br>The UBDRSTEN and UBDIE must be mutual exclusive. The FRAM controller does not allow the status of both bits are being set. Writing 1 to one of the bits will automatically clear the other bit.<br>Reset type: BOR<br>0h (R/W) = UBDIE_0 : Disable NMI for the uncorrectable bit error detection flag (UBDIFG).<br>1h (R/W) = UBDIE_1 : Enable NMI for the uncorrectable bit error detection flag (UBDIFG). Generates vector in SYSSNIV. Clear the UBDRSTEN bit.   |
| 5    | CBDIE    | R/W  | 0h    | Enable NMI event for the correctable bit error detection flag (CBDIFG).<br>Reset type: BOR<br>0h (R/W) = CBDIE_0 : Disable NMI for the correctable bit error detection flag (CBDIFG).<br>1h (R/W) = CBDIE_1 : Disable NMI for the correctable bit error detection flag (CBDIFG). Generates vector in SYSSNIV.                                                                                                                                                                                                                                       |
| 4    | WPIE     | R/W  | 0h    | Enable NMI event for the Write Protection Detection flag (WPIFG).<br>Reset type: BOR<br>0h (R/W) = WPIE_0 : Disable NMI for the Write Protection Detection flag (WPIFG).<br>1h (R/W) = WPIE_1 : Enable NMI for the Write Protection Detection flag (WPIFG). Generates vector in SYSSNIV.                                                                                                                                                                                                                                                            |

**Table 8-5. GCCTL0 Register Field Descriptions (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | ACCTEIE  | R/W  | 0h    | <p>Enable NMI event for the Access time error flag (ACCTEIFG).<br/>           Reset type: BOR</p> <p>0h (R/W) = ACCTEIE_0 : Disable NMI for the Access time error flag (ACCTEIFG).</p> <p>1h (R/W) = ACCTEIE_1 : Enable NMI for the Access time error flag (ACCTEIFG). Generates vector in SYSSNIV.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 2   | FRPWR    | R/W  | 1h    | <p>FRAM Memory Power Control Request</p> <p>While the device is in AM (Active mode), the FRAM memory power is controlled by the FRPWR bit and FRAM access. When the FRPWR is set, the FRAM memory is in ACTIVE mode. When the FRPWR is cleared by CPU, the FRAM memory goes into INACTIVE mode so that the FRAM memory does not consume power. The INACTIVE mode can be used if no FRAM access is required for a significant amount of time. Once the FRAM memory is in the INACTIVE mode, wake-up is automatic. An access to FRAM (read or write) will wake up the FRAM memory before performing the access. In this case, the FRPWR bit is set automatically by the FRAM controller. When the device enters LPM0/1/2/3/4 modes, the FRAM memory also enters INACTIVE mode regardless of the FRPWR bit status. When the device wakes up from LPM0/1/2/3/4, the FRAM memory will be immediately powered up (ACTIVE mode) if the FRPWR is set, but if the FRPWR bit is cleared, the FRAM memory will remain in INACTIVE mode until the FRAM memory is actually accessed (read or write). The latter case can be used to save the device power consumption in case the device wakes up only for a short amount of time, and the task during the wake-up can be executed from RAM, so no need of FRAM access.</p> <p>Reset type: PUC</p> <p>0h (R/W) = FRPWR_0 : Enable INACTIVE mode.</p> <p>1h (R/W) = FRPWR_1 : Enable ACTIVE mode.</p> |
| 1-0 | Reserved | R    | 0h    | <p>Reserved. Always read 0.</p> <p>Reset type: PUC</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

### 8.6.3 GCCTL1 Register (Offset = 6h) [reset = 0h]

GCCTL1 is shown in [Figure 8-5](#) and described in [Table 8-6](#).

[Return to Summary Table.](#)

General Control Register 1

**Figure 8-5. GCCTL1 Register**

|          |    |    |        |          |        |        |          |
|----------|----|----|--------|----------|--------|--------|----------|
| 15       | 14 | 13 | 12     | 11       | 10     | 9      | 8        |
| Reserved |    |    |        |          |        |        |          |
| R-0h     |    |    |        |          |        |        |          |
| 7        | 6  | 5  | 4      | 3        | 2      | 1      | 0        |
| Reserved |    |    | WPIFG  | ACCTEIFG | UBDIFG | CBDIFG | Reserved |
| R-0h     |    |    | R/W-0h | R/W-0h   | R/W-0h | R/W-0h | R-0h     |

**Table 8-6. GCCTL1 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-5 | Reserved | R    | 0h    | Reserved. Always read 0.<br>Reset type: PUC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 4    | WPIFG    | R/W  | 0h    | Write Protection Detection flag. This flag is set when a write access is attempted while the WPROT bit is set. This bit can generate a system NMI if the WPIE bit is set (see the GCCTL0 register). This bit can be cleared by writing 0 directly or by reading the system reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only, write 1 has no effect.<br>Reset type: BOR<br>0h (R/W) = WPIFG_0 : No interrupt pending.<br>1h (R/W) = Interrupt pending. Can be cleared by writing 0 or by reading SYSSNIV when it is the highest pending interrupt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 3    | ACCTEIFG | R/W  | 0h    | Access time error flag. This flag is set when a timing violation is detected, which indicates that NWAITS[3:0] is improperly configured. When a timing violation is detected, the maximum wait state will be automatically applied to the NWAITS[3:0] to avoid further timing violation. While the ACCTEIFG bit is set, the NWAIS[3:0] cannot be overwritten and the FRAM memory write access is prohibited regardless of the WPROT bit. The ACCTEIFG bit must be cleared prior to applying a new value to NWAITS[3:0] or writing access to the FRAM memory. The timing violation (ACCTEIFG) can generate a system NMI (SYSNMI) if the Access Time Error Interrupt Enable (ACCTIE) bit is set. This bit can be cleared by writing 0 directly or by reading the system reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only, write 1 has no effect.<br>Reset type: BOR<br>0h (R/W) = ACCTEIFG_0 : No interrupt pending.<br>1h (R/W) = ACCTEIFG_1 : Interrupt pending. Can be cleared by writing 0 or by reading SYSSNIV when it is the highest pending interrupt. |
| 2    | UBDIFG   | R/W  | 0h    | FRAM uncorrectable bit error detection flag. This flag is set when an uncorrectable bit error is detected in the FRAM memory error detection logic. This bit can generate either a system NMI or a system reset (PUC). If the UBDIE bit is set, then this bit generates a system NMI, if the UBDRSTEN bit is set, then this bit generates a system reset (PUC) - see the GCCTL0 register. This bit can be cleared by writing 0 directly or by reading the system NMI vector word SYSSNIV when it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.<br>Reset type: BOR<br>0h (R/W) = UBDIFG_0 : No interrupt pending.<br>1h (R/W) = UBDIFG_1 : Interrupt pending. Can be cleared by writing 0 or by reading SYSSNIV when it is the highest pending interrupt.                                                                                                                                                                                                                                                                                                        |

**Table 8-6. GCCTL1 Register Field Descriptions (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------|--------------|-------------|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1          | CBDIFG       | R/W         | 0h           | <p>FRAM correctable bit error detection flag. This flag is set when a correctable bit error is detected and corrected in the FRAM memory error detection logic. This bit can generate a system NMI if the CBDIE bit is set (see the GCCTL0 register). This bit can be cleared by software or by reading the system NMI vector word SYSSNIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.</p> <p>Reset type: BOR</p> <p>0h (R/W) = CBDIFG_0 : No interrupt is pending</p> <p>1h (R/W) = CBDIFG_1 : Interrupt pending. Can be cleared by writing 0 or by reading SYSSNIV if it is the highest pending interrupt.</p> |
| 0          | Reserved     | R           | 0h           | <p>Reserved. Always read 0.</p> <p>Reset type: PUC</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

## ***Memory Protection Unit (MPU)***

This chapter describes the operation of the Memory Protection Unit (MPU). The MPU is family specific.

| Topic                                                      | Page       |
|------------------------------------------------------------|------------|
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| 9.2 <b>MPU Segments</b> .....                              | <b>310</b> |
| 9.3 <b>MPU Access Management Settings</b> .....            | <b>314</b> |
| 9.4 <b>MPU Violations</b> .....                            | <b>315</b> |
| 9.5 <b>MPU Lock</b> .....                                  | <b>315</b> |
| 9.6 <b>How to Enable MPU and IPE Segments</b> .....        | <b>315</b> |
| 9.7 <b>MPU Registers</b> .....                             | <b>318</b> |

## 9.1 Memory Protection Unit (MPU) Introduction

The MPU protects against accidental writes to designated read-only memory segments or execution of code from a constant memory segment. Clearing the MPUENA bit disables the MPU, and the complete memory is accessible for read, write, and execute operations. After a BOR, the complete memory is accessible without restrictions to read, write, and execute operations.

The Memory Protection Unit features include:

- Configuration of main memory into three variable-sized segments
- Access rights for each segment can be set independently
- Fixed-size constant user information memory segment with selectable access rights
- Protection of MPU registers by password

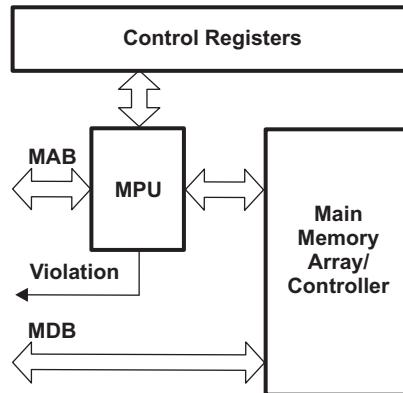
---

**NOTE:** After BOR, no segmentation is initiated, and the main memory and information memory are accessible by read, write, and execute operations.

---

For important software design information regarding FRAM, including but not limited to partitioning the memory layout according to application-specific code, constant, and data space requirements, the use of FRAM to optimize application energy consumption, and the use of the memory protection unit (MPU) to maximize application robustness by protecting the program code against unintended write accesses, see [MSP430™ FRAM Technology – How To and Best Practices](#).

Figure 9-1 shows an overview of the Memory Protection Unit.



**Figure 9-1. Memory Protection Unit Overview**

## 9.2 MPU Segments

### 9.2.1 Main Memory Segments

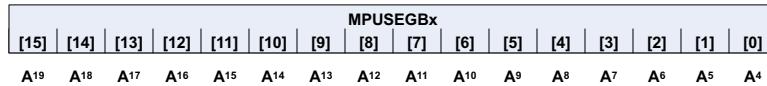
The MPU can logically divide the main memory into three segments. The size of each segment is defined by setting the borders between adjacent segments. To configure three segments, a lower border (B1) and a higher border (B2) are positioned by control register bits MPUSEGB1[15:0] and MPUSEGB2[15:0], respectively, in the MPUSEGBx registers. The position of both borders is limited to the 16 most significant bits of the memory address space (20-bit). Therefore, the segment borders registers are equivalent to the memory address bus, shifted right by 4 bits (see [Figure 9-2](#)).

[Table 9-1](#) shows the minimum segment size. Depending on the total memory size, some of the border register bits must be written as zero. [Table 9-1](#) summarizes the user-selectable bits and fixed bits for different memory sizes (see the device-specific data sheet for total memory size). [Figure 9-3](#) and [Figure 9-4](#) show fixed bits of the segment register when memory size is 128KB and 256KB respectively.

The beginning of segment 1 is the lowest available address for the main memory as defined in the device-specific data sheet. The lower border (B1) defines the end of segment 1 and the beginning of segment 2. The higher border (B2) defines the end of segment 2 and beginning of segment 3. The end of segment 3 is the highest main memory address as defined in the device-specific data sheet. For example, devices with up to 64KB of FRAM, the highest memory address is 013FFFh. Segment 2 includes the address defined by the lower border (B1) but excludes the higher border (B2).

The address bus (MAB) is analyzed by the MPU using the 16 most significant bits along with the current border settings.

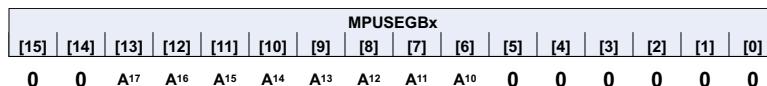
- If the significant address bits are lower than MPUSEGB1[15:0], segment 1 is selected.
- If the significant address bits are equal to or greater than MPUSEGB1[15:0] and less than MPUSEGB2[15:0], segment 2 is selected.
- If the significant address bits are equal to or greater than MPUSEGB2[15:0], segment 3 is selected.



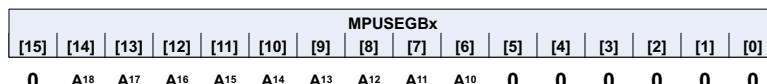
**Figure 9-2. Segment Border Register**

**Table 9-1. Address Comparator Bit Selection**

| FRAM Size            | Index of Used MSB Address Bus (n) | User-Selectable Border Register Bits | Fixed Border Register Bits (zero) | Segment Size (bytes) |
|----------------------|-----------------------------------|--------------------------------------|-----------------------------------|----------------------|
| 32KB < size ≤ 128KB  | 17-bit                            | [13:6]                               | [15:14] and [5:0]                 | 1k                   |
| 128KB < size ≤ 256KB | 18-bit                            | [14:6]                               | [15] and [5:0]                    | 1k                   |



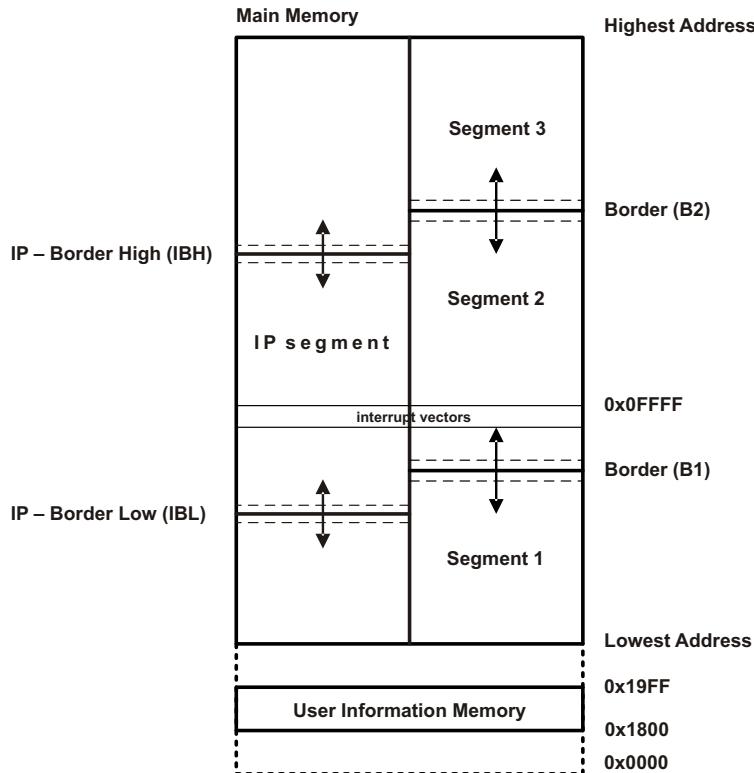
**Figure 9-3. Example of Segment Border Register Fixed Bits When FRAM Size = 128KB**



**Figure 9-4. Example of Segment Border Register Fixed Bits When FRAM Size = 256KB**

**NOTE:** The same result is calculated during MAB analysis of segment membership independent of whether the higher value is in MPUSEGB1[15:0] or MPUSEGB2[15:0]. If MPUSEGB1[15:0] = MPUSEGB2[15:0], Segment 2 is not available and the main memory only contains 2 segments.

Figure 9-5 shows an example segmentation of the main memory.



**Figure 9-5. Segmentation of Main Memory**

### 9.2.2 IP Encapsulation Segment

The MPU can protect an address range in the main memory from unconditional external access. The size of this segment is defined by setting the upper and lower borders of this segment. To configure the segments, a lower (IBL) border and a higher (IBH) border are positioned by control register bits MPUIPSEG<sub>B</sub>[15:0] and MPUIPSEG<sub>B</sub>[15:0], respectively, in the MPUIPSEG<sub>B</sub> register. The position of both borders follows the same mechanism as described in for the main segments.

The beginning of the IP encapsulation segment (IPE-segment) (IBL) is defined by the lower value of either the MPUIPSEG<sub>B</sub>[15:0] or MPUIPSEG<sub>B</sub>[15:0] register. The end of the IPE-segment (IBH) is defined by the higher value of either the MPUIPSEG<sub>B</sub>[15:0] or MPUIPSEG<sub>B</sub>[15:0] register. All memory locations addressed by the 16 most significant bits of the address bus (MAB) equal to or greater than the lower border (IBL) and less than IBH are protected.

Only program code executed from the IPE-segment can access data stored in this segment. The access rights are evaluated with each code access. Each code access outside of the IP-protected area deactivates the data access into the IPE-segment. JTAG or DMA cannot access the IPE-segment. The interrupt vector table is always open for read and write accesses (for details see [Section 9.4.1](#)).

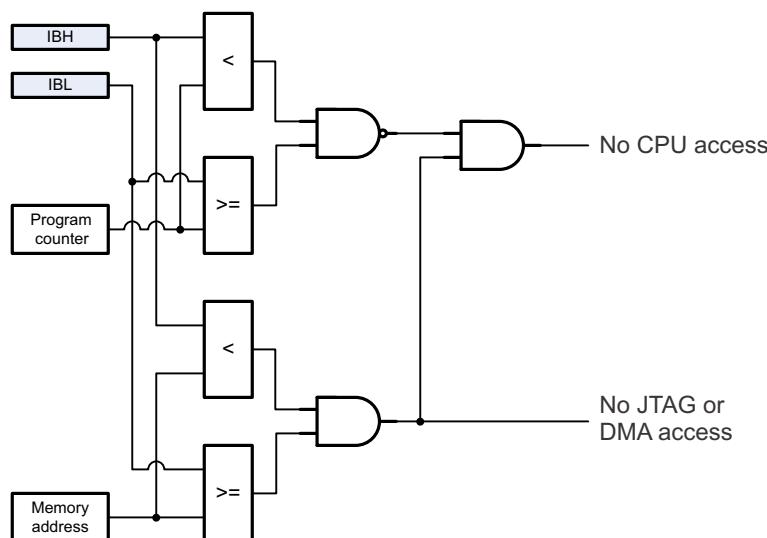
To execute code from the IPE-segment, branch into that segment or call functions stored in that segment. Interrupt service routines can be executed from the IPE-segment, too.

[Table 9-2](#) summarizes the possible combinations of code execution and memory access types and the resulting access rights.

An unauthorized access to the IPE-segment returns a value equivalent to the instruction "JMP \$" and triggers an interrupt. In addition, the generation of a PUC can be configured.

**Table 9-2. IP Encapsulation Access Rights**

| IBL ≤ Memory Address < IBH       | IBL ≤ Program Counter < IBH | JTAG or DMA Access | CPU Access |
|----------------------------------|-----------------------------|--------------------|------------|
| 0FF80h ≤ Memory Address < 0FFFFh | –                           | Read/Write         | Read/Write |
| False                            | False                       | Yes                | Yes        |
| False                            | True                        | Yes                | Yes        |
| True                             | False                       | No                 | No         |
| True                             | True                        | No                 | Yes        |



**Figure 9-6. IP Encapsulation Access Rights Equivalent Schematic**

---

**NOTE:** IP Encapsulation area access rights do not override MPU segment rights. The IP Encapsulation rights are evaluated and if the access is granted, access rights as described in [Section 9.3](#) are applied.

---

**NOTE: Code fetch from the first 8 bytes in IPE-segment does not enable data access.**

The first 8 bytes within the IPE-segment do not enable data access within the IPE-segment if code is executed from that area. The start of an IPE-segment is reserved for a data structure describing the IPE-segment boundaries.

---

shows the segmentation of the main memory.

### 9.2.3 Segment Border Setting

[Section 9.2.1](#) describes the procedure of setting borders for segmentation of the main memory. This section describes how the values in MPUSEGBx[15:0] and MPUIPSEGBx[15:0] bits need to be set to achieve the desired borders for different memory sizes. The bits of the MUSBx[15:0] bits represent the 16 most significant bits of the border address that can be selected.

The setting of the MPUSEGBx[15:0] bits forms a border between two segments of main memory space. For the following examples, the segment with the higher address range formed by this border is called the higher segment. The segment with the lower address range is called the lower segment.

The lowest address in the higher segment can be calculated with the following formula:

Given:

Segment Border Address (BA) or register value MPUSEGBx

Hence follows:

$$\text{MPUSEGBx} = (\text{BA}) \gg 4$$

$$\text{BA} = (\text{MPUSEGBx} \ll 4)$$

Examples:

$$\text{Segment border address} = 0x0F000 \rightarrow \text{MPUSEGBx} = (0x0F000 \gg 4) = 0x0F00$$

$$\text{Segment border address} = 0x13000 \rightarrow \text{MPUSEGBx} = (0x13000 \gg 4) = 0x1300$$

$$\text{MPUSEGBx} = 0x1100 \rightarrow \text{segment border address} = (0x1100 \ll 4) = 0x1100$$

**Table 9-3. MPU Border Selection Example 64KB  
(004000h to 013FFFh)**

| Border Address          | MPUSEGBx[15:0] |
|-------------------------|----------------|
| (outside)               | 0000h          |
| :                       | :              |
| (outside)               | 03C0h          |
| 04000h                  | 0400h          |
| 04400h                  | 0440h          |
| 04800h                  | 0480h          |
| 04C00h                  | 04C0h          |
| 05000h                  | 0500h          |
| :                       | :              |
| 0F000h                  | 0F00h          |
| 0F400h                  | 0F40h          |
| 0F800h                  | 0F80h          |
| 0FC00h                  | 0FC0h          |
| 10000h                  | 1000h          |
| 10400h                  | 1040h          |
| :                       | :              |
| 13000h                  | 1300h          |
| 13400h                  | 1340h          |
| 13800h                  | 1380h          |
| 13C00h                  | 13C0h          |
| 14000h (top of memory ) | 1400h          |
| (outside)               | 1440h          |
| :                       | :              |
| (outside)               | 3F80h          |
| (outside)               | 3FC0h          |

---

**NOTE:** Depending on the memory size settings for MPUSEGBx[4:0], the calculation may result in a lower address space than is available. For those settings, a lower segment does not exist, and the higher segment starts with the first available memory address (see memory organization in device-specific data sheet).

---

#### 9.2.4 IP Encapsulation Border Settings

The setting of the boundaries for the IP Encapsulation segment follows the same principle as the Main Segment settings.

### 9.2.5 Information Memory

The information memory is a partition of memory that is 512 bytes in size. The information memory can be used to store application-specific information (such as IDs or version numbers), or it can be used for executable code. It is located at address 01800h to 019FFh.

## 9.3 MPU Access Management Settings

Each segment described in and [Section 9.2.5](#) can have read, write, and execute access rights set independently.

The MPUSAM register allows setting the access rights for the four segments (information memory segment, three main memory segments). MPUSEGxRE enables read access for segment x, MPUSEGxWE enables write access for segment x, and MPUSEGxE enables code execution from segment x. JTAG and DMA accesses are treated as read or write data accesses and are evaluated according to the corresponding access bits.

[Table 9-4](#) shows the different settings of MPUSEGxE, MPUSEGxWE, and MPUSEGxRE. Not all settings lead to a different memory protection. For example, as shown, if the execution bit MPUSEGxE is set to 1, read access is automatically allowed independent of the setting of MPUSEGxRE. Also, setting the MPUSEGxWE bit to 1 enables the read option.

---

**NOTE:** Combinations that are not shown in [Table 9-4](#) should be avoided because they may be used in future versions of the MPU.

---

**Table 9-4. Segment Access Rights**

| MPUSEGxE | MPUSEGxWE | MPUSEGxRE | Execute Rights | Write Rights | Read Rights |
|----------|-----------|-----------|----------------|--------------|-------------|
| 0        | 0         | 0         | No             | No           | No          |
| 0        | 0         | 1         | No             | No           | Yes         |
| 0        | 1         | 1         | No             | Yes          | Yes         |
| 1        | 0         | 1         | Yes            | No           | Yes         |
| 1        | 1         | 1         | Yes            | Yes          | Yes         |

---

**NOTE: Discontinuity instructions at segment boundaries**

Do not fill code segments to the last word with program code, because program discontinuity instructions like jump or branch instructions, RET, CALL, ... at a segment boundary can trigger an access right violation.

The CPU prefetches instructions beyond the one currently being executed. The MPU interprets the prefetch as read and instruction fetch accesses. For example if there is a JMP instruction (or any another discontinuity instruction) at the segment boundary, the CPU prefetches from the neighboring segment. This causes an access right violation if instruction fetches are not allowed within the neighboring segment.

---

## 9.4 MPU Violations

### 9.4.1 Interrupt Vector Table and Reset Vector

The interrupt vector table and the reset vector are located at addresses 0FF80h to 0FFFFh. It is possible to define a segment that includes this address space with restricted access rights. If an interrupt or a reset occurs, and this segment is read protected, the MPU automatically allows access to the Interrupt Vector memory space 0FF80h to 0FFFFh. Write rights are granted depending on MPU segment access management register MPUSAM. Only the interrupt vector table is read accessible. Access to the interrupt routine itself is not automatically enabled.

If the interrupt vector table is inside of the IP Encapsulation, the execute right is always prohibited. Code fetches at the addresses 0FF80h to 0FFFFh are always denied if IPE-segments include that memory range.

Table 9-5 shows the access right to the interrupt vector table for all possible cases.

**Table 9-5. Access Rights to IVT<sup>(1)</sup>**

| Condition                            | Read |     |      | Execute | Write |     |      |
|--------------------------------------|------|-----|------|---------|-------|-----|------|
|                                      | CPU  | DMA | JTAG |         | CPU   | DMA | JTAG |
| IVT belongs to ...                   |      |     |      |         |       |     |      |
| an MPU segment (main memory segment) | O    | O   | O    | O       | C     | C   | C    |
| the IPE-segment                      | O    | O   | O    | X       | O     | O   | O    |
| an MPU segment and the IPE-segment   | O    | O   | O    | X       | C     | C   | C    |

<sup>(1)</sup> O = Allowed, X = Not allowed, C = Depends on MPU segment access management register MPUSAM

---

**NOTE:** Only the interrupt table and the reset vector are opened on an interrupt or reset occurrence. If the application protects the segment that contains the interrupt routine itself from execution rights, a violation occurs.

---

### 9.4.2 Violation Handling

The handling of access rights violations can be selected for each segment with the MPUSEGxVS bit in the MPUSAM register. By default (MPUSEGxVS = 0), any access right violation causes a nonmaskable interrupt (NMI). Setting MPUSEGxVS = 1, causes a PUC to occur. In either case, the illegal instruction on a protected memory segment is not executed. Upon an access rights violation, the data bus content (MDB) is driven with 03FFFh until next valid data is available.

## 9.5 MPU Lock

The MPU registers can be protected from write access by setting the MPULOCK bit. Write access is not possible on all MPU registers except MPUCTL1, MPUIPC0, and MPUIPSEGbx until a BOR occurs. MPULOCK cannot be cleared manually.

MPUIPLOCK allows to separately lock the MPUIPC0 and MPUIPSEGbx registers. Write access is not possible on these registers until a BOR occurs. MPUIPLOCK cannot be cleared manually.

## 9.6 How to Enable MPU and IPE Segments

Both MPU and IPE-segments can be enabled at any time through the control registers. However, in typical applications, it may be required to initiate MPU segments or the IPE-segment before beginning the application program, thus the following features are offered as more secure and convenient methods.

1. Code Composer Studio for MSP430 offers an easy-to-use graphical interface to configure MPU segments and the IPE-segment. See the [Code Composer Studio for MSP430 User's Guide](#). When using the methods outlined in the document, no further user setup is required.
2. For the IPE-segment, when using the method described in the [Code Composer Studio for MSP430 User's Guide](#), the compiler and linker handle the structure generation and initialization automatically - [Section 9.6.1](#) describes what happens behind the scenes in this case, and further user setup is not required.

## 9.6.1 IP Encapsulation (IPE) Instantiation Using IPE Signatures

The boot code can preload user-defined setting before the start of application code. This ensures that the encapsulation is active before any user-controlled accesses to the memory can be performed.

### 9.6.1.1 IP Encapsulation Signatures

Two IPE signatures, IPE Signature 1 (memory location 0FF88h) and IPE Signature 2 (memory location 0FF8Ah), reside in FRAM and can be used to control the initialization of the IP Encapsulation. Write 0xAAAA to IPE Signature 1 to trigger the evaluation of the IPE Signature 2 as the IPE structure pointer. The following code for CCS is an example:

```
#define IPE_SIG_VALID 0xFF88
    // IPE signature valid flag
#define IPE_STR_PTR_SRC 0xFF8A
    // Source for pointer (nibble address) to MPU IPE structure

#pragma RETAIN(ipe_signalValid)
#pragma location=IPE_SIG_VALID
const unsigned int ipe_signalValid = 0xAAAA;

// Locate your IPE structure and it should be placed
// on the top of the IPE memory. In this example, IPE structure
// is at 0xD000
#pragma RETAIN(IPE_stringPointerSourceSource)
#pragma location=IPE_STR_PTR_SRC
const unsigned int IPE_stringPointerSourceSource = (__INSERT_IPE_STRUCT_ADDRESS_(0xD000) >> 4;
```

**Table 9-6. IPE Signatures**

| Signature       | Address | Symbolic Name   | Description                                              |
|-----------------|---------|-----------------|----------------------------------------------------------|
| IPE Signature 1 | 0FF88h  | IPE_SIG_VALID   | IPE signature valid flag                                 |
| IPE Signature 2 | 0FF8Ah  | IPE_STR_PTR_SRC | Source for pointer (nibble address) to MPU IPE structure |

### 9.6.1.1.1 Trapdoor Mechanism for IP Structure Pointer Transfer

The bootcode performs a sequence to ensure the integrity of the IPE structure pointer. On bootcode execution, a valid IPE Signature 1 triggers the transfer of the IPE Signature 2 (IPE structure pointer source) to a secured nonvolatile system data area (saved IPE structure pointer). This transfer only happens once if no previous secured IPE structure pointer exist. Subsequent of a successful transfer of the IPE structure pointer, the IPE Signatures can be overwritten by any value without compromising the existing IP Encapsulation.

**NOTE:** Memory locations for IPE Signatures are shared with the JTAG password. This gives the limitation that the first word of the JTAG password cannot be set to 0AAAH for a nonprotected device, because this would unintentionally trigger the trapdoor mechanism.

### 9.6.1.2 IP Encapsulation Init Structure

By evaluating the saved IPE structure pointer, the bootcode can program the IP Encapsulation related register by transferring the values defined in the IP Encapsulation init structure to the corresponding fields in the MPU control registers. The definition of the structure can be seen in [Table 9-7](#). The check code is calculated as an odd bit interleaved parity of the previous three words. As an example, see the following code for CCS:

```
// IPE data structures definition, reusable for ALL projects
#define IPE_MPUIPLOCK 0x0080
#define IPE_MPUIPENA 0x0040
#define IPE_MPUIPPUC 0x0020
#define IPE_SEGREG(a) (a >> 4)
#define IPE_BIP(a,b,c) (a ^ b ^ c ^ 0xFFFF)
#define IPE_FILLSTRUCT(a,b,c)
```

```

{a,IPE SEGREG(b),IPE SEGREG(c),IPE_BIP(a,IPE SEGREG(b),IPE SEGREG(c))}

typedef struct IPE_Init_Structure {
    unsigned int MPUIPC0 ;
    unsigned int MPUIPB2 ;
    unsigned int MPUIPB1 ;
    unsigned int MPUCHECK ;
} IPE_Init_Structure;           // this struct should be placed inside IPB1/IPB2 boundaries

// This is the project dependant part

#define IPE_START 0x0D000      // This defines the Start of the IP protected area
#define IPE_END    0x0F000      // This defines the End of the IP protected area

// define borders of protected code
// ipestruct is defined in a adopted linker control file
// ipestruct is the section for protected data;
#pragma RETAIN(ipe_configStructure)
#pragma DATA_SECTION(ipe_configStructure,".ipestruct");

const IPE_Init_Structure ipe_configStructure = IPE_FILLSTRUCT(IPE_MPUIPLOCK + IPE_MPUIPENA,
   IPE_END,IPE_START);

```

**Table 9-7. IPE\_Init\_Structure**

| Field Name | Address Offset | Length | Description                                                              |
|------------|----------------|--------|--------------------------------------------------------------------------|
| MPUIPC0    | 0h             | word   | Control setting for IP Encapsulation. Value is written to MPUIPC0        |
| MPUIPB2    | 2h             | word   | Upper border of IP Encapsulation segment. Value is written to MPUIPSEG2. |
| MPUIPB1    | 4h             | word   | Lower border of IP Encapsulation segment. Value is written to MPUIPSEG1. |
| MPUCHECK   | 6h             | word   | Odd bit interleaved parity                                               |

---

**NOTE:** Although the user is free to select the location for the IPE Init Structure, protection against unwanted modification is given only if the structure is placed inside of the protected area checked by the structure itself. This allows a reconfiguration from within the protected area but prevents malicious modification from outside.

---

### 9.6.2 IP Encapsulation Removal

After successful instantiation of an IP protected memory area, a mass erase erases only the memory area outside of the IP Encapsulation. To perform an erase of all memory locations in main memory and to remove the IPE structure pointer, a special erase sequence must be performed. For more details, see the [MSP430 Programming With the JTAG Interface](#). For details on how to initiate this erasure from the IDE, see the [Code Composer Studio for MSP430 User's Guide](#).

---

**NOTE:** An invalid IP Encapsulation init structure or a saved IPE structure pointer with an invalid target (not pointing to a valid IP Encapsulation init structure) causes an erase of all nonvolatile memory segments including the IP Encapsulation segments and the init structure during bootcode execution. This setup error leads to a completely unprogrammed device after the next bootcode execution. This mechanism ensures that no exposure of IP code can happen by a misconfiguration or a memory corruption.

---

## 9.7 MPU Registers

The MPU registers are listed in [Table 9-8](#). The base address of the MPU module can be found in the device-specific data sheet. The address offset of each MPU register is given in [Table 9-8](#). The password defined in the MPUCCTL0 register controls access to all MPU registers. Once the correct password is written, the write access is enabled. The write access is disabled by writing a wrong password in byte mode to the MPUCCTL0 upper byte. Word accesses to MPUCCTL0 with a wrong password triggers a PUC. A write access to a register other than MPUCCTL0 while write access is not enabled causes a PUC. This behavior is independent from MPULOCK bit settings. Password write is always enabled to allow consecutive access to MPUCCTL1 and independent configuration of MPU and IP-Encapsulation registers.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 9-8. MPU Registers**

| Offset | Acronym     | Register Name                                                     | Type        | Access | Reset | Section                       |
|--------|-------------|-------------------------------------------------------------------|-------------|--------|-------|-------------------------------|
| 00h    | MPUCCTL0    | Memory Protection Unit Control 0                                  | Read/write  | Word   | 9600h | <a href="#">Section 9.7.1</a> |
| 00h    | MPUCCTL0_L  |                                                                   | Read/Write  | Byte   | 00h   |                               |
| 01h    | MPUCCTL0_H  |                                                                   | Read/Write  | Byte   | 96h   |                               |
| 02h    | MPUCCTL1    | Memory Protection Unit Control 1                                  | Read/write  | Word   | 0000h | <a href="#">Section 9.7.2</a> |
| 02h    | MPUCCTL1_L  |                                                                   | Read/Write  | Byte   | 00h   |                               |
| 03h    | MPUCCTL1_H  |                                                                   | Read/Write  | Byte   | 00h   |                               |
| 04h    | MPUSEGB2    | Memory Protection Unit Segmentation Border 2 Register             | Read/write  | Word   | 0000h |                               |
| 04h    | MPUSEGB2_L  |                                                                   | Read/Write  | Byte   | 00h   |                               |
| 05h    | MPUSEGB2_H  |                                                                   | Read/Write  | Byte   | 00h   |                               |
| 06h    | MPUSEGB1    | Memory Protection Unit Segmentation Border 1 Register             | Read/W/rite | Word   | 0000h |                               |
| 06h    | MPUSEGB1_L  |                                                                   | Read/Write  | Byte   | 00h   |                               |
| 07h    | MPUSEGB1_H  |                                                                   | Read/W/rite | Byte   | 00h   |                               |
| 08h    | MPUSAM      | Memory Protection Unit Segmentation Access Management Register    | Read/write  | Word   | 7777h | <a href="#">Section 9.7.5</a> |
| 08h    | MPUSAM_L    |                                                                   | Read/Write  | Byte   | 77h   |                               |
| 09h    | MPUSAM_H    |                                                                   | Read/W/rite | Byte   | 77h   |                               |
| 0Ah    | MPUIPC0     | Memory Protection Unit IP Control 0 Register                      | Read/Write  | Word   | 0000h | <a href="#">Section 9.7.6</a> |
| 0Ah    | MPUIPC0_L   |                                                                   | Read/W/rite | Byte   | 00h   |                               |
| 0Bh    | MPUIPC0_H   |                                                                   | Read/W/rite | Byte   | 00h   |                               |
| 0Ch    | MPUIPSEG2   | Memory Protection Unit IP Encapsulation Segment Border 2 Register | Read/W/rite | Word   | 0000h |                               |
| 0Ch    | MPUIPSEG2_L |                                                                   | Read/W/rite | Byte   | 00h   |                               |
| 0Dh    | MPUIPSEG2_H |                                                                   | Read/W/rite | Byte   | 00h   |                               |
| 0Eh    | MPUIPSEG1   | Memory Protection Unit IP Encapsulation Segment Border 1 Register | Read/W/rite | Word   | 0000h |                               |
| 0Eh    | MPUIPSEG1_L |                                                                   | Read/W/rite | Byte   | 00h   |                               |
| 0Fh    | MPUIPSEG1_H |                                                                   | Read/W/rite | Byte   | 00h   |                               |

### 9.7.1 MPUCTL0 Register

Memory Protection Unit Control 0 Register

**Figure 9-7. MPUCTL0 Register**

| 15       | 14   | 13   | 12       | 11   | 10       | 9      | 8      |
|----------|------|------|----------|------|----------|--------|--------|
| MPUPW    |      |      |          |      |          |        |        |
| rw-1     | rw-0 | rw-0 | rw-1     | rw-0 | rw-1     | rw-1   | rw-0   |
| 7        |      |      |          |      |          |        |        |
|          |      |      |          |      |          |        |        |
| Reserved |      |      | MPUSEGIE |      | Reserved |        |        |
| r-0      | r-0  | r-0  | rw-[0]   | r-0  | r-0      | rw-[0] | rw-[0] |

**Table 9-9. MPUCTL0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                              |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | MPUPW    | RW   | 96h   | MPU Password. Always reads as 096h. Must be written as 0A5h; writing any other value with a word write generates a PUC. After a correct password is written and MPU register access is enabled, a wrong password write in byte mode disables the access and no PUC is generated. This behavior is independent from MPULOCK bit settings. |
| 7-5  | Reserved | R    | 0h    | Reserved. Always read 0.                                                                                                                                                                                                                                                                                                                 |
| 4    | MPUSEGIE | RW   | 0h    | Enable NMI Event if a Segment violation is detected in any Segment.<br>0b = Segment violation interrupt disabled<br>1b = Segment violation interrupt enabled                                                                                                                                                                             |
| 3-2  | Reserved | R    | 0h    | Reserved. Always read 0.                                                                                                                                                                                                                                                                                                                 |
| 1    | MPULOCK  | RW   | 0h    | MPU Lock. If this bit is set, access to all MPU Registers except MPUCTL1, MPUIPC0, and MPUIPSEGx are locked and they are read only until a BOR occurs. BOR sets MPULOCK to 0.<br>0b = Open<br>1b = Locked                                                                                                                                |
| 0    | MPUENA   | RW   | 0h    | MPU Enable. This bit enables the MPU operation. The enable bit can be set any time with word write and a correct password, if MPULOCK is not set<br>0b = Disabled<br>1b = Enabled                                                                                                                                                        |

## 9.7.2 MPUCTL1 Register

Memory Protection Unit Control 1 Register

**Figure 9-8. MPUCTL1 Register**

| 15       | 14  | 13  | 12          | 11         | 10         | 9          | 8          |
|----------|-----|-----|-------------|------------|------------|------------|------------|
| Reserved |     |     |             |            |            |            |            |
| r-0      | r-0 | r-0 | r-0         | r-0        | r-0        | r-0        | r-0        |
| 7        | 6   | 5   | 4           | 3          | 2          | 1          | 0          |
| Reserved |     |     | MPUSEG1PIFG | MPUSEGIIFG | MPUSEG3IFG | MPUSEG2IFG | MPUSEG1IFG |
| r-0      | r-0 | r-0 | rw-[0]      | rw-[0]     | rw-[0]     | rw-[0]     | rw-[0]     |

**Table 9-10. MPUCTL1 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                       |
|------|-------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-5 | Reserved    | R    | 0h    | Reserved. Always read 0.                                                                                                                                                                                                                                                                                                                                                          |
| 4    | MPUSEG1PIFG | RW   | 0h    | IP Encapsulation Access Violation Interrupt Flag. This bit is set if an access violation in the IP Encapsulation memory segment is detected. This bit is cleared by software or by reading the reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 3    | MPUSEGIIFG  | RW   | 0h    | User Information Memory Violation Interrupt Flag. This bit is set if an access violation in User Information Memory is detected. This bit is cleared by software or by reading the reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.<br>0b = No interrupt pending<br>1b = Interrupt pending             |
| 2    | MPUSEG3IFG  | RW   | 0h    | Main Memory Segment 3 Violation Interrupt Flag. This bit is set if an access violation in Main Memory Segment 3 is detected. This bit is cleared by software or by reading the reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.<br>0b = No interrupt pending<br>1b = Interrupt pending                 |
| 1    | MPUSEG2IFG  | RW   | 0h    | Main Memory Segment 2 Violation Interrupt Flag. This bit is set if an access violation in Main Memory Segment 2 is detected. This bit is cleared by software or by reading the reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.<br>0b = No interrupt pending<br>1b = Interrupt pending                 |
| 0    | MPUSEG1IFG  | RW   | 0h    | Main Memory Segment 1 Violation Interrupt Flag. This bit is set if an access violation in Main Memory Segment 1 is detected. This bit is cleared by software or by reading the reset vector word SYSRSTIV if it is the highest pending interrupt flag. This bit is write 0 only and write 1 has no effect.<br>0b = No interrupt pending<br>1b = Interrupt pending                 |

### 9.7.3 MPUSEGB2 Register

Memory Protection Unit Segmentation Border 2 Register

**Figure 9-9. MPUSEGB2 Register**

| 15              | 14            | 13     | 12     | 11     | 10     | 9      | 8      |
|-----------------|---------------|--------|--------|--------|--------|--------|--------|
| <b>MPUSEGB2</b> |               |        |        |        |        |        |        |
| r-0             | rw-[0] or r-0 | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] |
| <b>MPUSEGB2</b> |               |        |        |        |        |        |        |
| rw-[0]          | rw-[0]        | r-0    | r-0    | r-0    | r-0    | r-0    | r-0    |

**Table 9-11. MPUSEGB2 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | MPUSEGB2 | RW   | 0h    | <p>MPU Segment Border 2 address line equivalents.</p> <p><b>FRAM size ≤ 128KB:</b></p> <p>MPUSEGB2[15:14] = MPU Segment Border 2 address line 19-18 equivalents. Must be written as zero.</p> <p>MPUSEGB2[13:6] = MPU Segment Border 2 address lines 17-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB1 is also 0, only Segment 3 is active).</p> <p>MPUSEGB2[5:0] = MPU Segment Border 2 address line 9-4 equivalents. Must be written as zero.</p> <p><b>128KB &lt; FRAM size ≤ 256KB:</b></p> <p>MPUSEGB2[15] = MPU Segment Border 2 address line 19 equivalents. Must be written as zero.</p> <p>MPUSEGB2[14:6] = MPU Segment Border 2 address lines 18-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB1 is also 0, only Segment 3 is active).</p> <p>MPUSEGB2[5:0] = MPU Segment Border 2 address line 9-4 equivalents. Must be written as zero.</p> |

### 9.7.4 MPUSEGB1 Register

Memory Protection Unit Segmentation Border 1 Register

**Figure 9-10. MPUSEGB1 Register**

|          |               |        |        |        |        |        |        |
|----------|---------------|--------|--------|--------|--------|--------|--------|
| 15       | 14            | 13     | 12     | 11     | 10     | 9      | 8      |
| MPUSEGB1 |               |        |        |        |        |        |        |
| r-0      | rw-[0] or r-0 | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] |
| MPUSEGB1 |               |        |        |        |        |        |        |
| 7        | 6             | 5      | 4      | 3      | 2      | 1      | 0      |
| rw-[0]   | rw-[0]        | r-0    | r-0    | r-0    | r-0    | r-0    | r-0    |

**Table 9-12. MPUSEGB1 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | MPUSEGB1 | RW   | 0h    | <p>MPU Segment Border 1 address line equivalents.</p> <p><b>FRAM size ≤ 128KB:</b></p> <p>MPUSEGB1[15:14] = MPU Segment Border 1 address line 19-18 equivalents. Must be written as zero.</p> <p>MPUSEGB1[13:6] = MPU Segment Border 1 address lines 17-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB2 is also 0, only Segment 3 is active).</p> <p>MPUSEGB1[5:0] = MPU Segment Border 1 address line 9-4 equivalents. Must be written as zero.</p> <p><b>128KB &lt; FRAM size ≤ 256KB:</b></p> <p>MPUSEGB1[15] = MPU Segment Border 1 address line 19 equivalents. Must be written as zero.</p> <p>MPUSEGB1[14:6] = MPU Segment Border 1 address lines 18-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB2 is also 0, only Segment 3 is active).</p> <p>MPUSEGB1[5:0] = MPU Segment Border 1 address line 9-4 equivalents. Must be written as zero.</p> |

### 9.7.5 MPUSAM Register

Memory Protection Unit Segmentation Access Management Register

**Figure 9-11. MPUSAM Register**

| 15        | 14        | 13        | 12        | 11        | 10        | 9         | 8         |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| MPUSEGIVS | MPUSEGIXE | MPUSEGIWE | MPUSEGIRE | MPUSEG3VS | MPUSEG3XE | MPUSEG3WE | MPUSEG3RE |
| rw-[0]    | rw-[1]    | rw-[1]    | rw-[1]    | rw-[0]    | rw-[1]    | rw-[1]    | rw-[1]    |
| 7         | 6         | 5         | 4         | 3         | 2         | 1         | 0         |
| MPUSEG2VS | MPUSEG2XE | MPUSEG2WE | MPUSEG2RE | MPUSEG1VS | MPUSEG1XE | MPUSEG1WE | MPUSEG1RE |
| rw-[0]    | rw-[1]    | rw-[1]    | rw-[1]    | rw-[0]    | rw-[1]    | rw-[1]    | rw-[1]    |

**Table 9-13. MPUSAM Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                     |
|-----|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15  | MPUSEGIVS | RW   | 0h    | MPU User Information Memory Segment Violation Select. This bit selects if additional to the interrupt flag a PUC must be executed on illegal access to User Information Memory<br>0b = Violation in User Information Memory asserts the MPUSEGIIFG bit and executes a SNMI if enabled by MPUSEGIE =1<br>1b = Violation in User Information Memory asserts the MPUSEGIIFG bit and executes a PUC |
| 14  | MPUSEGIXE | RW   | 1h    | MPU User Information Memory Segment Execute Enable. If set, this bit enables execution on User Information Memory<br>0b = Execute code on User Information Memory causes a violation<br>1b = Execute code on User Information Memory is allowed                                                                                                                                                 |
| 13  | MPUSEGIWE | RW   | 1h    | MPU User Information Memory Segment Write Enable. If set, this bit enables write access on User Information Memory<br>0b = Write on User Information Memory causes a violation<br>1b = Write on User Information Memory is allowed                                                                                                                                                              |
| 12  | MPUSEGIRE | RW   | 1h    | MPU User Information Memory Segment Read Enable. If set, this bit enables read access on User Information Memory<br>0b = Read on User Information Memory causes a violation if MPUSEGIWE=MPUSEGIXE=0<br>1b = Read on User Information Memory is allowed                                                                                                                                         |
| 11  | MPUSEG3VS | RW   | 0h    | MPU Main Memory Segment 3 Violation Select. This bit selects if additional to the interrupt flag a PUC must be executed on illegal access to Main Memory segment 3<br>0b = Violation in Main Memory Segment 3 asserts the MPUSEG3IFG bit and executes a SNMI if enabled by MPUSEGIE =1<br>1b = Violation in Main Memory Segment 3 asserts the MPUSEG3IFG bit and executes a PUC                 |
| 10  | MPUSEG3XE | RW   | 1h    | MPU Main Memory Segment 3 Execute Enable. If set this bit enables execution on Main Memory segment 3<br>0b = Execute code on Main Memory Segment 3 causes a violation<br>1b = Execute code on Main Memory Segment 3 is allowed                                                                                                                                                                  |
| 9   | MPUSEG3WE | RW   | 1h    | MPU Main Memory Segment 3 Write Enable. If set this bit enables write access on Main Memory segment 3<br>0b = Write on Main Memory Segment 3 causes a violation<br>1b = Write on Main Memory Segment 3 is allowed                                                                                                                                                                               |
| 8   | MPUSEG3RE | RW   | 1h    | MPU Main Memory Segment 3 Read Enable. If set this bit enables read access on Main Memory segment 3<br>0b = Read on Main Memory Segment 3 causes a violation if MPUSEG3WE = MPUSEG3XE = 0<br>1b = Read on Main Memory Segment 3 is allowed                                                                                                                                                      |

**Table 9-13. MPUSAM Register Description (continued)**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                     |
|-----|-----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | MPUSEG2VS | RW   | 0h    | MPU Main Memory Segment 2 Violation Select. This bit selects if additional to the interrupt flag a PUC must be executed on illegal access to Main Memory segment 2<br>0b = Violation in Main Memory Segment 2 asserts the MPUSEG2IFG bit and executes a SNMI if enabled by MPUSEGIE =1<br>1b = Violation in Main Memory Segment 2 asserts the MPUSEG2IFG bit and executes a PUC |
| 6   | MPUSEG2XE | RW   | 1h    | MPU Main Memory Segment 2 Execute Enable. If set this bit enables execution on Main Memory segment 2<br>0b = Execute code on Main Memory Segment 2 causes a violation<br>1b = Execute code on Main Memory Segment 2 is allowed                                                                                                                                                  |
| 5   | MPUSEG2WE | RW   | 1h    | MPU Main Memory Segment 2 Write Enable. If set this bit enables write access on Main Memory segment 2<br>0b = Write on Main Memory Segment 2 causes a violation<br>1b = Write on Main Memory Segment 2 is allowed                                                                                                                                                               |
| 4   | MPUSEG2RE | RW   | 1h    | MPU Main Memory Segment 2 Read Enable. If set this bit enables read access on Main Memory segment 2<br>0b = Read on Main Memory Segment 2 causes a violation if MPUSEG2WE = MPUSEG2XE = 0<br>1b = Read on Main Memory Segment 2 is allowed                                                                                                                                      |
| 3   | MPUSEG1VS | RW   | 0h    | MPU Main Memory Segment 1 Violation Select. This bit selects if additional to the interrupt flag a PUC must be executed illegal access to Main Memory segment 1<br>0b = Violation in Main Memory Segment 1 asserts the MPUSEG1IFG bit and executes a SNMI if enabled by MPUSEGIE = 1<br>1b = Violation in Main Memory Segment 1 asserts the MPUSEG1IFG bit and executes a PUC   |
| 2   | MPUSEG1XE | RW   | 1h    | MPU Main Memory Segment 1 Execute Enable. If set this bit enables execution on Main Memory segment 1<br>0b = Execute code on Main Memory Segment 1 causes a violation<br>1b = Execute code on Main Memory Segment 1 is allowed                                                                                                                                                  |
| 1   | MPUSEG1WE | RW   | 1h    | MPU Main Memory Segment 1 Write Enable. If set this bit enables write access on Main Memory segment 1<br>0b = Write on Main Memory Segment 1 causes a violation<br>1b = Write on Main Memory Segment 1 is allowed                                                                                                                                                               |
| 0   | MPUSEG1RE | RW   | 1h    | MPU Main Memory Segment 1 Read Enable. If set this bit enables read access on Main Memory segment 1<br>0b = Read on Main Memory Segment 1 causes a violation if MPUSEG1WE = MPUSEG1XE = 0<br>1b = Read on Main Memory Segment 1 is allowed                                                                                                                                      |

### 9.7.6 MPUIPC0 Register

Memory Protection Unit IP Control 0 Register

**Figure 9-12. MPUIPC0 Register**

|           |          |         |     |          |     |     |     |
|-----------|----------|---------|-----|----------|-----|-----|-----|
| 15        | 14       | 13      | 12  | 11       | 10  | 9   | 8   |
| Reserved  |          |         |     |          |     |     |     |
| r-0       | r-0      | r-0     | r-0 | r-0      | r-0 | r-0 | r-0 |
| 7         | 6        | 5       | 4   | 3        | 2   | 1   | 0   |
| MPUIPLOCK | MPUIPENA | MPUIPVS |     | Reserved |     |     |     |
| rw[0]     | rw-[0]   | rw-[0]  | r-0 | r-0      | r-0 | r-0 | r-0 |

**Table 9-14. MPUIPC0 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                       |
|------|-----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved  | R    | 0h    | Reserved. Always read 0.                                                                                                                                                                                                                                                                                                                          |
| 7    | MPUIPLOCK | RW   | 0h    | MPU IP Encapsulation Lock. If this bit is set, access to MPUIPC0 and MPUIPSEG <sub>B</sub> registers is locked, and they are read-only until a BOR occurs.<br>BOR sets the bit to 0.<br>0b = Open<br>1b = Locked                                                                                                                                  |
| 6    | MPUIPENA  | RW   | 0h    | MPU IP Encapsulation Enable. This bit enables the MPU IP Encapsulation operation. The enable bit can be set any time with word write and a correct password, if MPUIPLOCK is not set<br>0b = Disabled<br>1b = Enabled                                                                                                                             |
| 5    | MPUIPVS   | RW   | 0h    | MPU IP Encapsulation segment Violation Select. This bit selects whether or not a PUC occurs on illegal access to the IPE-segment.<br>0b = Violation in Main Memory Segment 1 asserts the MPUSEGIPIFG bit and executes a SNMI if enabled by MPUSEGIE = 1<br>1b = Violation in Main Memory Segment 1 asserts the MPUSEGIPIFG bit and executes a PUC |
| 4-0  | Reserved  | R    | 0h    | Reserved. Always read 0.                                                                                                                                                                                                                                                                                                                          |

### 9.7.7 MPUIPSEGB2 Register

Memory Protection Unit IP Encapsulation Segmentation Border 2 Register

**Figure 9-13. MPUIPSEGB2 Register**

| 15         | 14            | 13     | 12     | 11     | 10     | 9      | 8      |
|------------|---------------|--------|--------|--------|--------|--------|--------|
| MPUIPSEGB2 |               |        |        |        |        |        |        |
| r-0        | rw-[0] or r-0 | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] |
| MPUIPSEGB2 |               |        |        |        |        |        |        |
| rw-[0]     | rw-[0]        | r-0    | r-0    | r-0    | r-0    | r-0    | r-0    |

**Table 9-15. MPUIPSEGB2 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | MPUIPSEGB2 | RW   | 0h    | <p>MPU IP Segment Border 2 address line equivalents.</p> <p><b>FRAM size ≤ 128KB:</b></p> <p>MPUIPSEGB2[15:14] = MPU IP Segment Border 2 address line 19-18 equivalents. Must be written as zero.</p> <p>MPUIPSEGB2[13:6] = MPU IP Segment Border 2 address lines 17-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB1 is also 0, only Segment 3 is active).</p> <p>MPUIPSEGB2[5:0] = MPU IP Segment Border 2 address line 9-4 equivalents. Must be written as zero.</p> <p><b>128KB &lt; FRAM size ≤ 256KB:</b></p> <p>MPUIPSEGB2[15] = MPU IP Segment Border 2 address line 19 equivalents. Must be written as zero.</p> <p>MPUIPSEGB2[14:6] = MPU IP Segment Border 2 address lines 18-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB1 is also 0, only Segment 3 is active).</p> <p>MPUIPSEGB2[5:0] = MPU IP Segment Border 2 address line 9-4 equivalents. Must be written as zero.</p> |

### **9.7.8 MPUIPSEGB1 Register**

Memory Protection Unit IP Encapsulation Segmentation Border 1 Register

**Figure 9-14. MPUIPSEGB1 Register**

|            |               |        |        |        |        |        |        |
|------------|---------------|--------|--------|--------|--------|--------|--------|
| 15         | 14            | 13     | 12     | 11     | 10     | 9      | 8      |
| MPUIPSEGB1 |               |        |        |        |        |        |        |
| r-0        | rw-[0] or r-0 | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] | rw-[0] |
| MPUIPSEGB1 |               |        |        |        |        |        |        |
| 7          | 6             | 5      | 4      | 3      | 2      | 1      | 0      |
| rw-[0]     | rw-[0]        | r-0    | r-0    | r-0    | r-0    | r-0    | r-0    |

**Table 9-16. MPUIPSEGB1 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------|------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | MPUIPSEGB1 | RW   | 0h    | <p>MPU Segment Border 1 address line equivalents.</p> <p><b>FRAM size ≤ 128KB:</b></p> <p>MPUIPSEGB1[15:14] = MPU Segment Border 1 address line 19-18 equivalents. Must be written as zero.</p> <p>MPUIPSEGB1[13:6] = MPU Segment Border 1 address lines 17-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB2 is also 0, only Segment 3 is active).</p> <p>MPUIPSEGB1[5:0] = MPU Segment Border 1 address line 9-4 equivalents. Must be written as zero.</p> <p><b>128KB &lt; FRAM size ≤ 256KB:</b></p> <p>MPUIPSEGB1[15] = MPU Segment Border 1 address line 19 equivalents. Must be written as zero.</p> <p>MPUIPSEGB1[14:6] = MPU Segment Border 1 address lines 18-10. After BOR, the bits are set to 0 (if MPU is enabled and MPUSEGB2 is also 0, only Segment 3 is active).</p> <p>MPUIPSEGB1[5:0] = MPU Segment Border 1 address line 9-4 equivalents. Must be written as zero.</p> |

## ***RAM Controller (RAMCTL)***

The RAM controller (RAMCTL) allows control of the power-down behavior of the RAM.

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## 10.1 RAM Controller (RAMCTL) Introduction

The RAM Controller allows reduction of the leakage current during LPM3 and LPM4. The RAM is partitioned in one to four sectors, depending on the device. See the device-specific data sheet for sector allocation and size.

## 10.2 RAMCTL Operation

Each sector  $y$  is controlled by a sector off control bit (RCRSyOFF0) in the RAM Controller Control Register 0 (RCCTL0). By default, the RAM content is retained in LPM3 and LPM4 (RCRSyOFF0 = 0).

By setting the RAM sector's control bit RCRSyOFF0 to 1, the respective RAM sector is powered down completely during LPM3 and LPM4 and all RAM content within the sector  $y$  is lost after a wake-up from LPM3 or LPM4. After wake-up the RAM can be accessed normally.

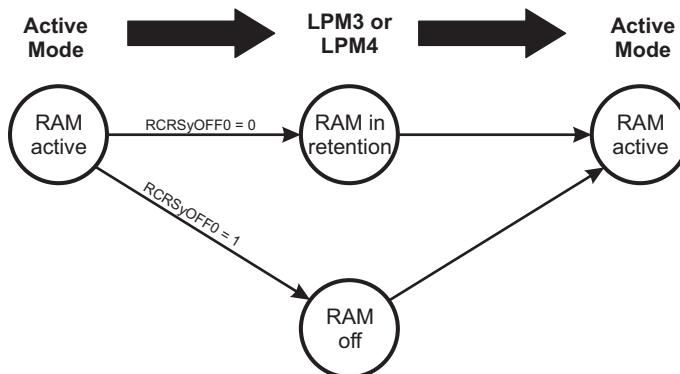
[Figure 10-1](#) shows the possible transitions when entering LPM3 or LPM4 and when waking up from LPM3 or LPM4.

---

**NOTE:** After a wake-up from LPM3 and LPM4 with RCRSyOFF0 = 1, the content of powered down sectors is lost and completely undefined. Any potentially required re-initialization must be implemented in software.

---

The RCCTL0 register is protected with a key. The RCCTL0 register content can be modified only if the correct key is written during a word write. Byte write accesses or write accesses with a wrong key are ignored.



**Figure 10-1. RAM Power Mode Transitions Into and Out of LPM3 or LPM4**

### 10.2.1 Considerations for Complete Power Down

Using the power-down feature requires special care in devices with only one RAM sector or if all sectors are powered down. Usually the program stack is located in RAM; therefore, using the power-down (with RCRSyOFF0 = 1) destroys the stack content when entering LPM3 or LPM4. This is acceptable if the stack is empty when entering LPM3 or LPM4; otherwise, the stack must be located in a different memory (for example, FRAM).

### 10.2.2 DACCESSIE and DACCESSIFG Bits in RCCTL1 Register

This section applies only to the devices that include both the USS and the LEA modules. The LEA RAM can be accessed by CPU, DMA, or DTC. Among the three bus master sources, the DTC has the highest priority. The DTC is the data transfer controller in the SDHS, which is a submodule of the USS module. The DTC transfers data from the SDHS directly to the LEA RAM. It is highly recommended not to access LEA RAM while the DTC is active. If CPU or DMA accesses the LEA RAM while the DTC is accessing the same memory:

- A write access from CPU or DMA is ignored

- A read access from CPU or DMA returns with 0x3FFF
- A instruction fetch access from CPU results in executing a jump \$ instruction (0x3FFF)
- A read or write access from CPU or DMA causes the DACCESSIFG bit to be set

This conflict does not affect the access by the DTC. The DACCESS interrupt can be enabled or disabled by the DACCESSIE bit. If DACCESSIE = 1 and DACCESSIFG = 1, then a user NMI is generated (DACCESSIFG). See the device-specific data sheet for the user NMI information.

## 10.3 RAMCTL Registers

Table 10-1 lists the memory-mapped registers for the RAMCTL. All register offset addresses not listed in Table 10-1 should be considered as reserved locations and the register contents should not be modified.

**Table 10-1. RAMCTL Registers**

| Offset | Acronym | Register Name            | Type       | Reset | Section                        |
|--------|---------|--------------------------|------------|-------|--------------------------------|
| 0h     | CTL0    | RAM Controller Control 0 | read-write | 6900h | <a href="#">Section 10.3.1</a> |
| 2h     | CTL1    | RAM Controller Control 1 | read-write | 0h    | <a href="#">Section 10.3.2</a> |

### 10.3.1 CTL0 Register (Offset = 0h) [reset = 6900h]

CTL0 is shown in [Figure 10-2](#) and described in [Table 10-2](#).

[Return to Summary Table.](#)

RAM Controller Control 0

**Figure 10-2. CTL0 Register**

|         |    |        |    |         |    |        |   |
|---------|----|--------|----|---------|----|--------|---|
| 15      | 14 | 13     | 12 | 11      | 10 | 9      | 8 |
| KEY     |    |        |    |         |    |        |   |
| R/W-69h |    |        |    |         |    |        |   |
| 7       | 6  | 5      | 4  | 3       | 2  | 1      | 0 |
| RS3OFF  |    | RS2OFF |    | RS1OFFx |    | RS0OFF |   |
| R/W-0h  |    | R/W-0h |    | R/W-0h  |    | R/W-0h |   |

**Table 10-2. CTL0 Register Field Descriptions**

| Bit  | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------|--------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | KEY    | R/W  | 69h   | RAM controller key. Always reads as 69h. Must be written as 5Ah; any other write is ignored.<br>5Ah (W) = 0x5A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 7-6  | RS3OFF | R/W  | 0h    | RAM controller RAM sector 3 off.<br>0h (R/W) = Contents of this RAM sector are retained in LPM3 and LPM4.<br>1h (R/W) = Turns off this RAM sector in LPM3 and LPM4, re-activates it on wake-up.<br>All data of this RAM sector is lost after wakeup from LPM3 and LPM4. See the device-specific data sheet to find the number of available sectors, the address range, and the size of each RAM sector.<br>2h (R/W) = Turns off this RAM sector entering LPM3 and LPM4, the RAM sector remains off after wake-up. All data of this RAM sector is lost. See the devicespecific data sheet to find the number of available sectors, the address range, and the size of each RAM sector. |
| 5-4  | RS2OFF | R/W  | 0h    | RAM controller RAM sector 2 off.<br>0h (R/W) = Contents of this RAM sector are retained in LPM3 and LPM4.<br>1h (R/W) = Turns off this RAM sector in LPM3 and LPM4, re-activates it on wake-up.<br>All data of this RAM sector is lost after wakeup from LPM3 and LPM4. See the device-specific data sheet to find the number of available sectors, the address range, and the size of each RAM sector.<br>2h (R/W) = Turns off this RAM sector entering LPM3 and LPM4, the RAM sector remains off after wake-up. All data of this RAM sector is lost. See the devicespecific data sheet to find the number of available sectors, the address range, and the size of each RAM sector. |

**Table 10-2. CTL0 Register Field Descriptions (continued)**

| Bit | Field   | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----|---------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3-2 | RS1OFFx | R/W  | 0h    | <p>RAM controller RAM sector 1 off.</p> <p>0h (R/W) = Contents of this RAM sector are retained in LPM3 and LPM4.</p> <p>1h (R/W) = Turns off this RAM sector in LPM3 and LPM4, re-activates it on wake-up.</p> <p>All data of this RAM sector is lost after wakeup from LPM3 and LPM4. See the device-specific data sheet to find the number of available sectors, the address range, and the size of each RAM sector.</p> <p>2h (R/W) = Turns off this RAM sector entering LPM3 and LPM4, the RAM sector remains off after wake-up. All data of this RAM sector is lost. See the devicespecific data sheet to find the number of available sectors, the address range, and the size of each RAM sector.</p> |
| 1-0 | RS0OFF  | R/W  | 0h    | <p>RAM controller RAM sector 0 off</p> <p>0h (R/W) = Contents of this RAM sector are retained in LPM3 and LPM4.</p> <p>1h (R/W) = Turns off this RAM sector in LPM3 and LPM4, re-activates it on wake-up.</p> <p>All data of this RAM sector is lost after wakeup from LPM3 and LPM4. See the device-specific data sheet to find the number of available sectors, the address range, and the size of each RAM sector.</p> <p>2h (R/W) = Turns off this RAM sector entering LPM3 and LPM4, the RAM sector remains off after wake-up. All data of this RAM sector is lost. See the devicespecific data sheet to find the number of available sectors, the address range, and the size of each RAM sector.</p>  |

### 10.3.2 CTL1 Register (Offset = 2h) [reset = 0h]

CTL1 is shown in [Figure 10-3](#) and described in [Table 10-3](#).

[Return to Summary Table.](#)

RAM Controller Control 1

**Figure 10-3. CTL1 Register**

|          |    |    |    |    |    |   |            |
|----------|----|----|----|----|----|---|------------|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8          |
| Reserved |    |    |    |    |    |   | DACCESSIE  |
| R-0h     |    |    |    |    |    |   | R/W-0h     |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0          |
| Reserved |    |    |    |    |    |   | DACCESSIFG |
| R-0h     |    |    |    |    |    |   | R/W-0h     |

**Table 10-3. CTL1 Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-9 | Reserved   | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 8    | DACCESSIE  | R/W  | 0h    | <p>DACCESS Interrupt enable bit.<br/>           DACCESS Interrupt can be enabled or disabled by DACCESSIE bit.<br/>           If DACCESSIE =1 and DACCESSIFG =1, then an User NMI is generated. See the device specific datasheet for details.<br/>           0h (R/W) = Disable NMI for DACCESS Interrupt<br/>           1h (R/W) = Enable NMI for DACCESS Interrupt</p>                                                                                                                                                                                                                         |
| 7-1  | Reserved   | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 0    | DACCESSIFG | R/W  | 0h    | <p>DACCESS Interrupt Flag. LEA RAM can be accessed by CPU, DMA, or DTC. DTC has the highest priority. If CPU or DMA accesses LEA RAM while DTC is accessing the LEA RAM, the access by CPU or DMA is ignored and DACCESSIFG bit is set. It does not affect the access by DTC. DACCESS Interrupt can be enabled or disabled by DACCESSIE bit. If DACCESSIE =1 and DACCESSIFG =1, then an User NMI is generated (DACCESSIFG). See the device specific datasheet for details.<br/>           0h (R/W) = DACCESS Interrupt is not pending<br/>           1h (R/W) = DACCESS Interrupt is pending.</p> |

## DMA Controller

The direct memory access (DMA) controller module transfers data from one address to another, without CPU intervention. This chapter describes the operation of the DMA controller.

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| 11.1 Direct Memory Access (DMA) Introduction ..... | 336  |
| 11.2 DMA Operation.....                            | 338  |
| 11.3 DMA Registers .....                           | 350  |

## 11.1 Direct Memory Access (DMA) Introduction

The DMA controller transfers data from one address to another, without CPU intervention, across the entire address range. For example, the DMA controller can move data from the ADC conversion memory to RAM.

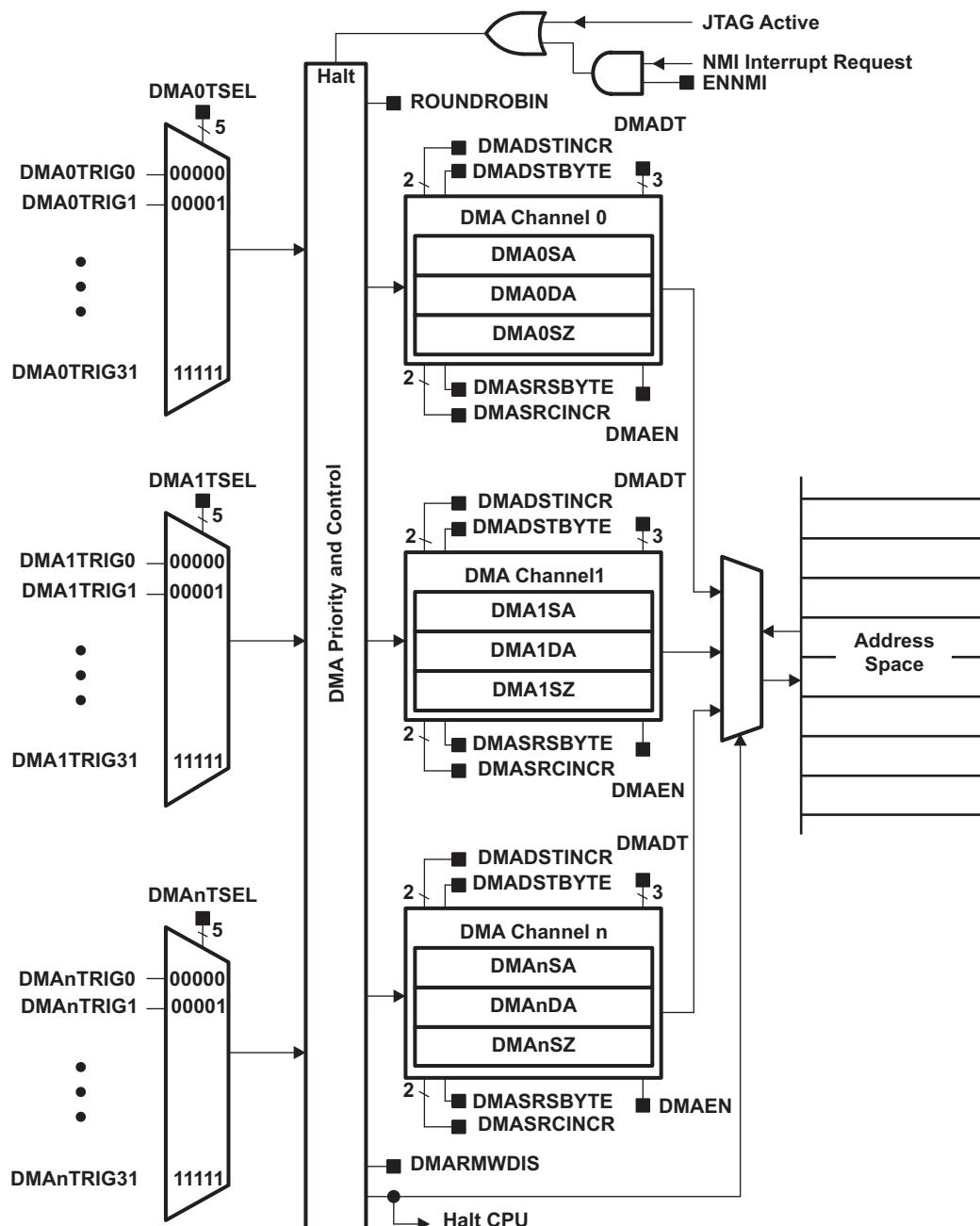
Devices that contain a DMA controller can have up to eight DMA channels available. Therefore, depending on the number of DMA channels available, some features described in this chapter are not applicable to all devices. See the device-specific data sheet for the number of channels that are supported.

Using the DMA controller can increase the throughput of peripheral modules. It can also reduce system power consumption by allowing the CPU to remain in a low-power mode, without having to awaken to move data to or from a peripheral.

DMA controller features include:

- Up to eight independent transfer channels
- Configurable DMA channel priorities
- Requires only two MCLK clock cycles per transfer
- Byte, word, or mixed byte and word transfer capability
- Block sizes up to 65535 bytes or words
- Configurable transfer trigger selections
- Selectable-edge or level-triggered transfer
- Four addressing modes
- Single, block, or burst-block transfer modes

The DMA controller block diagram is shown in [Figure 11-1](#).



**Figure 11-1. DMA Controller Block Diagram**

## 11.2 DMA Operation

The DMA controller is configured with user software. The setup and operation of the DMA is discussed in the following sections.

### 11.2.1 DMA Addressing Modes

The DMA controller has four addressing modes. The addressing mode for each DMA channel is independently configurable. For example, channel 0 may transfer between two fixed addresses, while channel 1 transfers between two blocks of addresses. The addressing modes are shown in [Figure 11-2](#). The addressing modes are:

- Fixed address to fixed address
- Fixed address to block of addresses
- Block of addresses to fixed address
- Block of addresses to block of addresses

The addressing modes are configured with the DMASRCINCR and DMADSTINCR control bits. The DMASRCINCR bits select if the source address is incremented, decremented, or unchanged after each transfer. The DMADSTINCR bits select if the destination address is incremented, decremented, or unchanged after each transfer.

Transfers may be byte to byte, word to word, byte to word, or word to byte. When transferring word to byte, only the lower byte of the source word transfers. When transferring byte to word, the upper byte of the destination word is cleared when the transfer occurs.

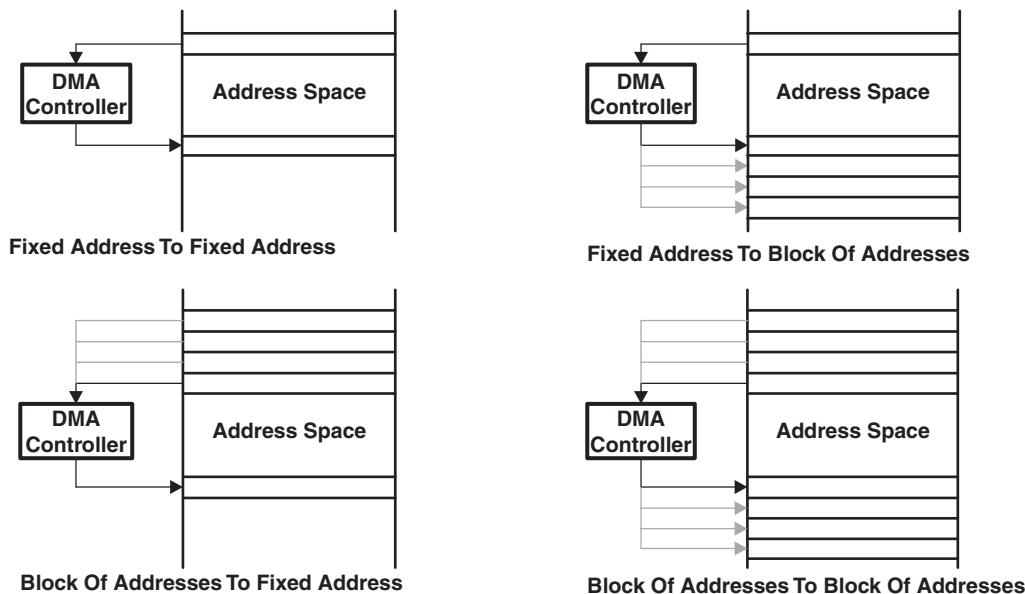


Figure 11-2. DMA Addressing Modes

### 11.2.2 DMA Transfer Modes

The DMA controller has six transfer modes selected by the DMADT bits as listed in [Table 11-1](#). Each channel is individually configurable for its transfer mode. For example, channel 0 may be configured in single transfer mode, while channel 1 is configured for burst-block transfer mode, and channel 2 operates in repeated block mode. The transfer mode is configured independently from the addressing mode. Any addressing mode can be used with any transfer mode.

Two types of data can be transferred selectable by the DMAxCTL DSTBYTE and SRCBYTE fields. The source and destination locations can be either byte or word data. It is also possible to transfer byte to byte, word to word, or any combination.

**Table 11-1. DMA Transfer Modes**

| DMADT    | Transfer Mode                 | Description                                                                                                               |
|----------|-------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| 000      | Single transfer               | Each transfer requires a trigger. DMAEN is automatically cleared when DMAxSZ transfers have been made.                    |
| 001      | Block transfer                | A complete block is transferred with one trigger. DMAEN is automatically cleared at the end of the block transfer.        |
| 010, 011 | Burst-block transfer          | CPU activity is interleaved with a block transfer. DMAEN is automatically cleared at the end of the burst-block transfer. |
| 100      | Repeated single transfer      | Each transfer requires a trigger. DMAEN remains enabled.                                                                  |
| 101      | Repeated block transfer       | A complete block is transferred with one trigger. DMAEN remains enabled.                                                  |
| 110, 111 | Repeated burst-block transfer | CPU activity is interleaved with a block transfer. DMAEN remains enabled.                                                 |

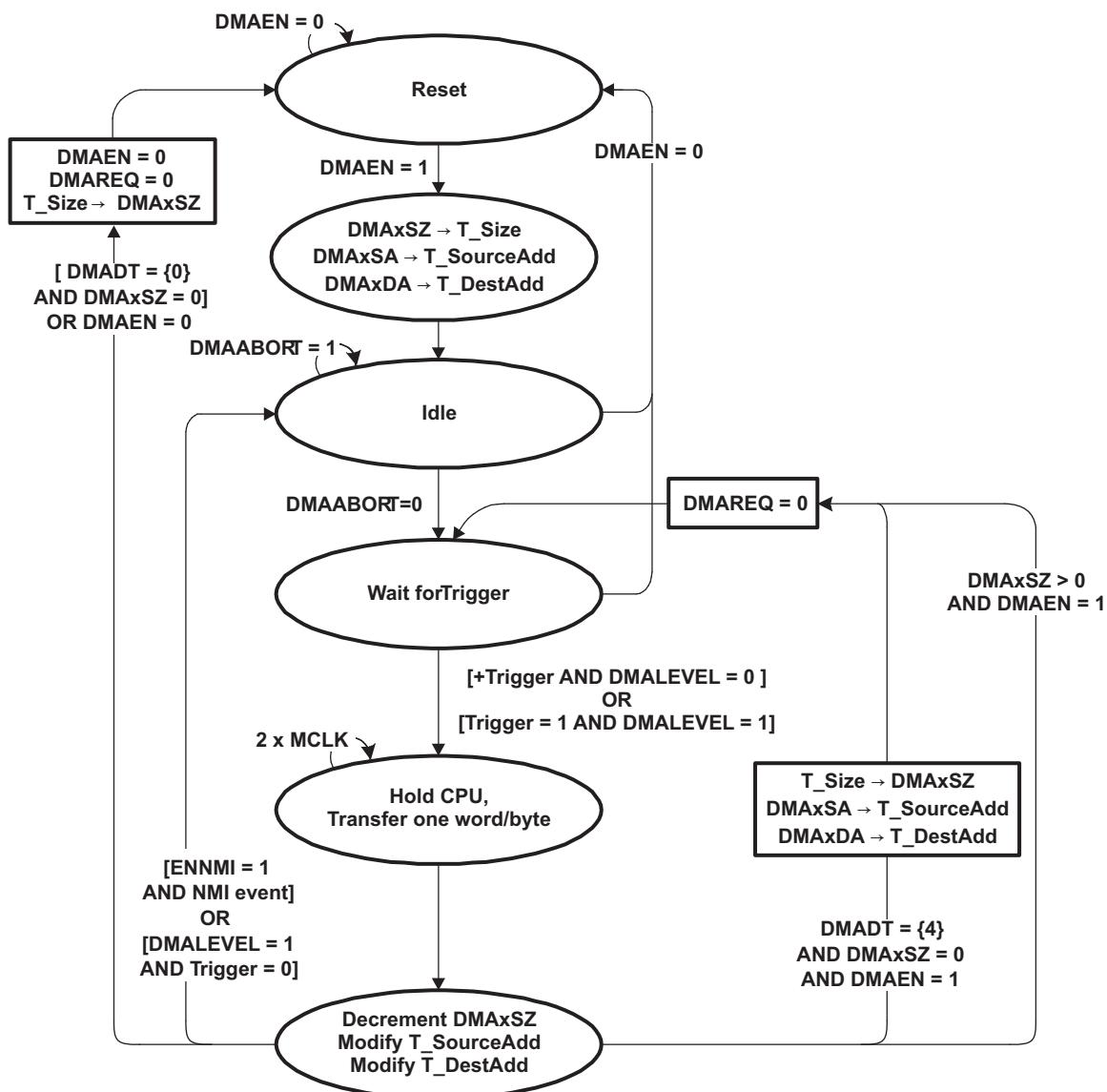
### 11.2.2.1 Single Transfer

In single transfer mode, each byte or word transfer requires a separate trigger. The single transfer state diagram is shown in [Figure 11-3](#).

The DMAxSZ register defines the number of transfers to be made. The DMADSTINCR and DMASRCINCR bits select if the destination address and the source address are incremented or decremented after each transfer. If DMAxSZ = 0, no transfers occur.

The DMAxSA, DMAxDA, and DMAxSZ registers are copied into temporary registers. The temporary values of DMAxSA and DMAxDA are incremented or decremented after each transfer. The DMAxSZ register is decremented after each transfer. When the DMAxSZ register decrements to zero, it is reloaded from its temporary register and the corresponding DMAIFG flag is set. When DMADT = 0, the DMAEN bit is cleared automatically when DMAxSZ decrements to zero and must be set again for another transfer to occur.

In repeated single transfer mode, the DMA controller remains enabled with DMAEN = 1, and a transfer occurs every time a trigger occurs.



**Figure 11-3. DMA Single Transfer State Diagram**

### 11.2.2.2 Block Transfer

In block transfer mode, a transfer of a complete block of data occurs after one trigger. When DMADT = 1, the DMAEN bit is cleared after the completion of the block transfer and must be set again before another block transfer can be triggered. After a block transfer has started, another trigger signal that occurs during the block transfer is ignored. The block transfer state diagram is shown in [Figure 11-4](#).

The DMAxSZ register defines the size of the block, and the DMADSTINCR and DMASRCINCR bits select if the destination address and the source address are incremented or decremented after each transfer of the block. If DMAxSZ = 0, no transfers occur.

The DMAxSA, DMAxDA, and DMAxSZ registers are copied into temporary registers. The temporary values of DMAxSA and DMAxDA are incremented or decremented after each transfer in the block. The DMAxSZ register is decremented after each transfer of the block and shows the number of transfers remaining in the block. When the DMAxSZ register decrements to zero, it is reloaded from its temporary register and the corresponding DMAIFG flag is set.

During a block transfer, the CPU is halted until the complete block has been transferred. The block transfer takes  $(2 \times \text{MCLK} \times \text{DMAxSZ})$  clock cycles to complete. CPU execution resumes with its previous state after the block transfer is complete.

In repeated block transfer mode, the DMAEN bit remains set after completion of the block transfer. The next trigger after the completion of a repeated block transfer starts another block transfer.

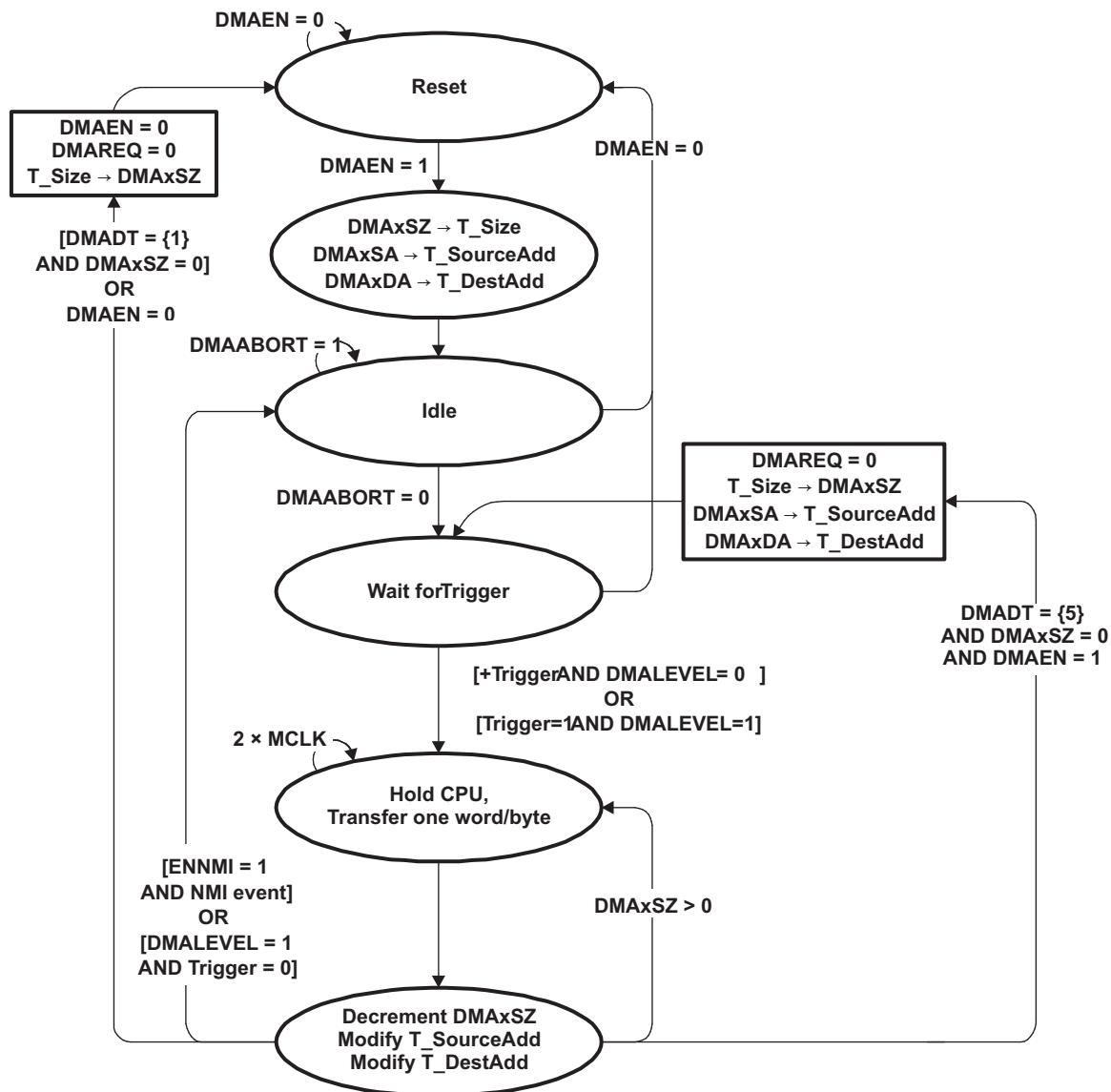


Figure 11-4. DMA Block Transfer State Diagram

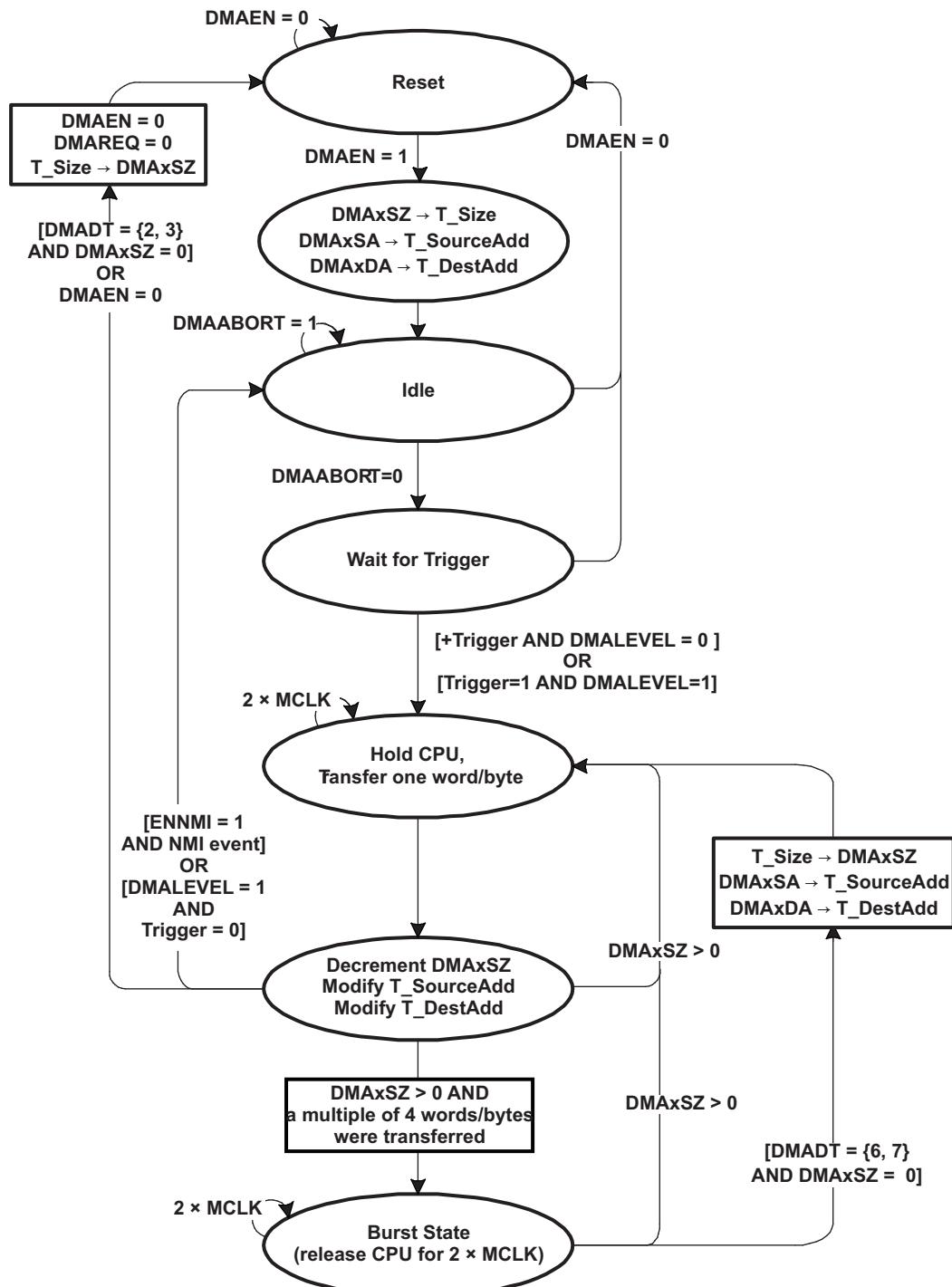
### 11.2.2.3 Burst-Block Transfer

In burst-block mode, transfers are block transfers with CPU activity interleaved. The CPU executes two MCLK cycles after every four byte or word transfers of the block, resulting in 20% CPU execution capacity. After the burst-block, CPU execution resumes at 100% capacity and the DMAEN bit is cleared. DMAEN must be set again before another burst-block transfer can be triggered. After a burst-block transfer has been triggered, further trigger signals occurring during the burst-block transfer are ignored. The burst-block transfer state diagram is shown in [Figure 11-5](#).

The DMAxSZ register defines the size of the block, and the DMADSTINCR and DMASRCINCR bits select if the destination address and the source address are incremented or decremented after each transfer of the block. If DMAxSZ = 0, no transfers occur.

The DMAxSA, DMAxDA, and DMAxSZ registers are copied into temporary registers. The temporary values of DMAxSA and DMAxDA are incremented or decremented after each transfer in the block. The DMAxSZ register is decremented after each transfer of the block and shows the number of transfers remaining in the block. When the DMAxSZ register decrements to zero, it is reloaded from its temporary register and the corresponding DMAIFG flag is set.

In repeated burst-block mode, the DMAEN bit remains set after completion of the burst-block transfer and no further trigger signals are required to initiate another burst-block transfer. Another burst-block transfer begins immediately after completion of a burst-block transfer. In this case, the transfers must be stopped by clearing the DMAEN bit, or by an (non)maskable interrupt (NMI) when ENNMI is set. In repeated burst-block mode the CPU executes at 20% capacity continuously until the repeated burst-block transfer is stopped.



**Figure 11-5. DMA Burst-Block Transfer State Diagram**

### 11.2.3 Initiating DMA Transfers

Each DMA channel is independently configured for its trigger source with the DMAxTSEL. The DMAxTSEL bits should be modified only when the DMACTLx DMAEN bit is 0. Otherwise, unpredictable DMA triggers may occur. [Table 11-2](#) describes the trigger operation for each type of module. See the device-specific data sheet for the list of triggers available, along with their respective DMAxTSEL values.

When selecting the trigger, the trigger must not have already occurred, or the transfer does not take place.

#### 11.2.3.1 Edge-Sensitive Triggers

When DMALEVEL = 0, edge-sensitive triggers are used, and the rising edge of the trigger signal initiates the transfer. In single-transfer mode, each transfer requires its own trigger. When using block or burst-block modes, only one trigger is required to initiate the block or burst-block transfer.

#### 11.2.3.2 Level-Sensitive Triggers

When DMALEVEL = 1, level-sensitive triggers are used. For proper operation, level-sensitive triggers can only be used when external trigger DMAE0 is selected as the trigger. DMA transfers are triggered as long as the trigger signal is high and the DMAEN bit remains set.

The trigger signal must remain high for a block or burst-block transfer to complete. If the trigger signal goes low during a block or burst-block transfer, the DMA controller is held in its current state until the trigger goes back high or until the DMA registers are modified by software. If the DMA registers are not modified by software, when the trigger signal goes high again, the transfer resumes from where it was when the trigger signal went low.

When DMALEVEL = 1, transfer modes selected when DMADT = {0, 1, 2, 3} are recommended, because the DMAEN bit is automatically reset after the configured transfer.

### 11.2.4 Halting Executing Instructions for DMA Transfers

The DMARMWDIS bit controls when the CPU is halted for DMA transfers. When DMARMWDIS = 0, the CPU is halted immediately and the transfer begins when a trigger is received. In this case, it is possible that CPU read-modify-write operations can be interrupted by a DMA transfer. When DMARMWDIS = 1, the CPU finishes the currently executing read-modify-write operation before the DMA controller halts the CPU and the transfer begins (see [Table 11-2](#)).

**Table 11-2. DMA Trigger Operation**

| Module   | Operation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DMA      | A transfer is triggered when the DMAREQ bit is set. The DMAREQ bit is automatically reset when the transfer starts.<br>A transfer is triggered when the DMAxIFG flag is set. DMA0IFG triggers channel 1, DMA1IFG triggers channel 2, and DMA2IFG triggers channel 0. None of the DMAxIFG flags are automatically reset when the transfer starts.<br>A transfer is triggered by the external trigger DMAEO.                                                                                                  |
| Timer_A  | A transfer is triggered when the TAxCRC0 CCIFG flag is set. The TAxCRC0 CCIE bit is set, the TAxCRC0 CCIFG flag is automatically reset when the transfer starts. If the TAxCRC0 CCIE bit is set, the TAxCRC0 CCIFG flag does not trigger a transfer.<br>A transfer is triggered when the TAxCRC2 CCIFG flag is set. The TAxCRC2 CCIFG flag is automatically reset when the transfer starts. If the TAxCRC2 CCIE bit is set, the TAxCRC2 CCIFG flag does not trigger a transfer.                             |
| Timer_B  | A transfer is triggered when the TBxCRC0 CCIFG flag is set. The TBxCRC0 CCIFG flag is automatically reset when the transfer starts. If the TBxCRC0 CCIE bit is set, the TBxCRC0 CCIFG flag does not trigger a transfer.<br>A transfer is triggered when the TBxCRC2 CCIFG flag is set. The TBxCRC2 CCIFG flag is automatically reset when the transfer starts. If the TBxCRC2 CCIE bit is set, the TBxCRC2 CCIFG flag does not trigger a transfer.                                                          |
| eUSCI_Ax | A transfer is triggered when eUSCI_Ax receives new data. UCAXRXIFG is automatically reset when the transfer starts. If UCAXRXIE is set, the UCAXRXIFG does not trigger a transfer.<br>A transfer is triggered when eUSCI_Ax is ready to transmit new data. UCAXTXIFG is automatically reset when the transfer starts. If UCAXTXIE is set, the UCAXTXIFG does not trigger a transfer.                                                                                                                        |
| eUSCI_Bx | A transfer is triggered when eUSCI_Bx receives new data. UCBxRXIFG is automatically reset when the transfer starts. If UCBxRXIE is set, the UCBxRXIFG does not trigger a transfer.<br>A transfer is triggered when eUSCI_Bx is ready to transmit new data. UCBxTXIFG is automatically reset when the transfer starts. If UCBxTXIE is set, the UCBxTXIFG does not trigger a transfer.                                                                                                                        |
| ADC12_B  | A transfer is triggered by an ADC12IFG flag. When single-channel conversions are performed, the corresponding ADC12IFG is the trigger. When sequences are used, the ADC12IFG for the last conversion in the sequence is the trigger. A transfer is triggered when the conversion is completed and the ADC12IFG is set. Setting the ADC12IFG with software does not trigger a transfer. All ADC12IFG flags are automatically reset when the associated ADC12MEMx register is accessed by the DMA controller. |
| MPY      | A transfer is triggered when the hardware multiplier is ready for a new operand.                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Reserved | No transfer is triggered.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

### 11.2.5 Stopping DMA Transfers

There are two ways to stop DMA transfers in progress:

- A single, block, or burst-block transfer may be stopped with an NMI, if the ENNMI bit is set in register DMACTL1.
- A burst-block transfer may be stopped by clearing the DMAEN bit.

### 11.2.6 DMA Channel Priorities

The default DMA channel priorities are DMA0 through DMA7. If two or three triggers happen simultaneously or are pending, the channel with the highest priority completes its transfer (single, block, or burst-block transfer) first, then the second priority channel, then the third priority channel. Transfers in progress are not halted if a higher-priority channel is triggered. The higher-priority channel waits until the transfer in progress completes before starting.

The DMA channel priorities are configurable with the ROUNDROBIN bit. When the ROUNDROBIN bit is set, the channel that completes a transfer becomes the lowest priority. The order of the priority of the channels always stays the same, DMA0-DMA1-DMA2, for example, for three channels. When the ROUNDROBIN bit is cleared, the channel priority returns to the default priority.

| DMA Priority   | Transfer Occurs | New DMA Priority |
|----------------|-----------------|------------------|
| DMA0-DMA1-DMA2 | DMA1            | DMA2-DMA0-DMA1   |
| DMA2-DMA0-DMA1 | DMA2            | DMA0-DMA1-DMA2   |
| DMA0-DMA1-DMA2 | DMA0            | DMA1-DMA2-DMA0   |

### 11.2.7 DMA Transfer Cycle Time

The DMA controller requires one or two MCLK clock cycles to synchronize before each single transfer or complete block or burst-block transfer. Each byte or word transfer requires two MCLK cycles after synchronization, and one cycle of wait time after the transfer. Because the DMA controller uses MCLK, the DMA cycle time is dependent on the MSP430 operating mode and clock system setup.

If the MCLK source is active but the CPU is off, the DMA controller uses the MCLK source for each transfer, without reenabling the CPU. If the MCLK source is off, the DMA controller temporarily restarts MCLK, sourced with DCOCLK, for the single transfer or complete block or burst-block transfer. The CPU remains off and, after the transfer completes, MCLK is turned off. The maximum DMA cycle time for all operating modes is shown in [Table 11-3](#).

**Table 11-3. Maximum Single-Transfer DMA Cycle Time**

| CPU Operating Mode Clock Source             | Maximum DMA Cycle Time                   |
|---------------------------------------------|------------------------------------------|
| Active mode MCLK = DCOCLK                   | 4 MCLK cycles                            |
| Active mode MCLK = LFXT1CLK                 | 4 MCLK cycles                            |
| Low-power mode LPM0 or LPM1 MCLK = DCOCLK   | 5 MCLK cycles                            |
| Low-power mode LPM3 or LPM4 MCLK = DCOCLK   | 5 MCLK cycles + 5 $\mu$ s <sup>(1)</sup> |
| Low-power mode LPM0 or LPM1 MCLK = LFXT1CLK | 5 MCLK cycles                            |
| Low-power mode LPM3 MCLK = LFXT1CLK         | 5 MCLK cycles                            |
| Low-power mode LPM4 MCLK = LFXT1CLK         | 5 MCLK cycles + 5 $\mu$ s <sup>(1)</sup> |

<sup>(1)</sup> The additional 5  $\mu$ s are needed to start the DCOCLK. It is the  $t_{(LPMx)}$  parameter in the data sheet.

### 11.2.8 Using DMA With System Interrupts

DMA transfers are not interruptible by system interrupts. System interrupts remain pending until the completion of the transfer. NMIs can interrupt the DMA controller if the ENNMI bit is set.

System interrupt service routines are interrupted by DMA transfers. If an interrupt service routine or other routine must execute with no interruptions, the DMA controller should be disabled before executing the routine.

### 11.2.9 DMA Controller Interrupts

Each DMA channel has its own DMAIFG flag. Each DMAIFG flag is set in any mode when the corresponding DMAxSZ register counts to zero. If the corresponding DMAIE and GIE bits are set, an interrupt request is generated.

All DMAIFG flags are prioritized, with DMA0IFG being the highest, and combined to source a single interrupt vector. The highest-priority enabled interrupt generates a number in the DMAIV register. This number can be evaluated or added to the program counter (PC) to automatically enter the appropriate software routine. Disabled DMA interrupts do not affect the DMAIV value.

Any access, read or write, of the DMAIV register automatically resets the highest pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. For example, assume that DMA0 has the highest priority. If the DMA0IFG and DMA2IFG flags are set when the interrupt service routine accesses the DMAIV register, DMA0IFG is reset automatically. After the RETI instruction of the interrupt service routine is executed, the DMA2IFG generates another interrupt.

### 11.2.9.1 DMAIV Software Example

The following software example shows the recommended use of DMAIV and the handling overhead for an eight channel DMA controller. The DMAIV value is added to the PC to automatically jump to the appropriate routine.

The numbers at the right margin show the necessary CPU cycles for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself.

|          |            | Cycles                                                |
|----------|------------|-------------------------------------------------------|
| DMA_HND  | ...        |                                                       |
| ADD      | &DMAIV, PC | ; Interrupt latency 6<br>; Add offset to Jump table 3 |
| RETI     |            | ; Vector 0: No interrupt 5                            |
| JMP      | DMA0_HND   | ; Vector 2: DMA channel 0 2                           |
| JMP      | DMA1_HND   | ; Vector 4: DMA channel 1 2                           |
| JMP      | DMA2_HND   | ; Vector 6: DMA channel 2 2                           |
| JMP      | DMA3_HND   | ; Vector 8: DMA channel 3 2                           |
| JMP      | DMA4_HND   | ; Vector 10: DMA channel 4 2                          |
| JMP      | DMA5_HND   | ; Vector 12: DMA channel 5 2                          |
| JMP      | DMA6_HND   | ; Vector 14: DMA channel 6 2                          |
| JMP      | DMA7_HND   | ; Vector 16: DMA channel 7 2                          |
| DMA7_HND |            | ; Vector 16: DMA channel 7                            |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA6_HND |            | ; Vector 14: DMA channel 6                            |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA5_HND |            | ; Vector 12: DMA channel 5                            |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA4_HND |            | ; Vector 10: DMA channel 4                            |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA3_HND |            | ; Vector 8: DMA channel 3                             |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA2_HND |            | ; Vector 6: DMA channel 2                             |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA1_HND |            | ; Vector 4: DMA channel 1                             |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |
| DMA0_HND |            | ; Vector 2: DMA channel 0                             |
| ...      |            | ; Task starts here                                    |
| RETI     |            | ; Back to main program 5                              |

### 11.2.10 Using the eUSCI\_B I<sup>2</sup>C Module With the DMA Controller

The eUSCI\_B I<sup>2</sup>C module provides two trigger sources for the DMA controller. The eUSCI\_B I<sup>2</sup>C module can trigger a transfer when new I<sup>2</sup>C data is received and the when the transmit data is needed.

### 11.2.11 Using ADC12 With the DMA Controller

MSP430 devices with an integrated DMA controller can automatically move data from any ADC12MEMx register to another location. DMA transfers are done without CPU intervention and independently of any low-power modes. The DMA controller increases throughput of the ADC12 module, and enhances low-power applications allowing the CPU to remain off while data transfers occur.

DMA transfers can be triggered from any ADC12IFG flag. When CONSEQx = {0,2}, the ADC12IFG flag for the ADC12MEMx used for the conversion can trigger a DMA transfer. When CONSEQx = {1,3}, the ADC12IFG flag for the last ADC12MEMx in the sequence can trigger a DMA transfer. Any ADC12IFG flag is automatically cleared when the DMA controller accesses the corresponding ADC12MEMx.

## 11.3 DMA Registers

The DMA module registers are listed in [Table 11-4](#). The base addresses can be found in the device-specific data sheet. Each channel starts at its respective base address. The address offsets are listed in [Table 11-4](#).

**Table 11-4. DMA Registers**

| Offset | Acronym | Register Name                     | Type       | Access               | Reset     | Section                         |
|--------|---------|-----------------------------------|------------|----------------------|-----------|---------------------------------|
| 00h    | DMACTL0 | DMA Control 0                     | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.1</a>  |
| 02h    | DMACTL1 | DMA Control 1                     | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.2</a>  |
| 04h    | DMACTL2 | DMA Control 2                     | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.3</a>  |
| 06h    | DMACTL3 | DMA Control 3                     | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.4</a>  |
| 08h    | DMACTL4 | DMA Control 4                     | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.5</a>  |
| 0Eh    | DMAIV   | DMA Interrupt Vector              | Read only  | Word                 | 0000h     | <a href="#">Section 11.3.10</a> |
| 00h    | DMA0CTL | DMA Channel 0 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA0SA  | DMA Channel 0 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA0DA  | DMA Channel 0 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |
| 0Ah    | DMA0SZ  | DMA Channel 0 Transfer Size       | Read/write | Word                 | undefined | <a href="#">Section 11.3.9</a>  |
| 00h    | DMA1CTL | DMA Channel 1 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA1SA  | DMA Channel 1 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA1DA  | DMA Channel 1 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |
| 0Ah    | DMA1SZ  | DMA Channel 1 Transfer Size       | Read/write | Word                 | undefined | <a href="#">Section 11.3.9</a>  |
| 00h    | DMA2CTL | DMA Channel 2 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA2SA  | DMA Channel 2 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA2DA  | DMA Channel 2 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |
| 0Ah    | DMA2SZ  | DMA Channel 2 Transfer Size       | Read/write | Word                 | undefined | <a href="#">Section 11.3.9</a>  |
| 00h    | DMA3CTL | DMA Channel 3 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA3SA  | DMA Channel 3 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA3DA  | DMA Channel 3 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |
| 0Ah    | DMA3SZ  | DMA Channel 3 Transfer Size       | Read/write | Word                 | undefined | <a href="#">Section 11.3.9</a>  |
| 00h    | DMA4CTL | DMA Channel 4 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA4SA  | DMA Channel 4 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA4DA  | DMA Channel 4 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |
| 0Ah    | DMA4SZ  | DMA Channel 4 Transfer Size       | Read/write | Word                 | undefined | <a href="#">Section 11.3.9</a>  |
| 00h    | DMA5CTL | DMA Channel 5 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA5SA  | DMA Channel 5 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA5DA  | DMA Channel 5 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |
| 0Ah    | DMA5SZ  | DMA Channel 5 Transfer Size       | Read/write | Word                 | undefined | <a href="#">Section 11.3.9</a>  |
| 00h    | DMA6CTL | DMA Channel 6 Control             | Read/write | Word                 | 0000h     | <a href="#">Section 11.3.6</a>  |
| 02h    | DMA6SA  | DMA Channel 6 Source Address      | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.7</a>  |
| 06h    | DMA6DA  | DMA Channel 6 Destination Address | Read/write | Word,<br>double word | undefined | <a href="#">Section 11.3.8</a>  |

**Table 11-4. DMA Registers (continued)**

| <b>Offset</b> | <b>Acronym</b> | <b>Register Name</b>              | <b>Type</b> | <b>Access</b>        | <b>Reset</b> | <b>Section</b>                 |
|---------------|----------------|-----------------------------------|-------------|----------------------|--------------|--------------------------------|
| 0Ah           | DMA6SZ         | DMA Channel 6 Transfer Size       | Read/write  | Word                 | undefined    | <a href="#">Section 11.3.9</a> |
| 00h           | DMA7CTL        | DMA Channel 7 Control             | Read/write  | Word                 | 0000h        | <a href="#">Section 11.3.6</a> |
| 02h           | DMA7SA         | DMA Channel 7 Source Address      | Read/write  | Word,<br>double word | undefined    | <a href="#">Section 11.3.7</a> |
| 06h           | DMA7DA         | DMA Channel 7 Destination Address | Read/write  | Word,<br>double word | undefined    | <a href="#">Section 11.3.8</a> |
| 0Ah           | DMA7SZ         | DMA Channel 7 Transfer Size       | Read/write  | Word                 | undefined    | <a href="#">Section 11.3.9</a> |

### 11.3.1 DMACTL0 Register

DMA Control 0 Register

**Figure 11-6. DMACTL0 Register**

| 15       | 14 | 13       | 12     | 11     | 10     | 9      | 8      |
|----------|----|----------|--------|--------|--------|--------|--------|
| Reserved |    | DMA1TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| 7        | 6  | 5        | 4      | 3      | 2      | 1      | 0      |
| Reserved |    | DMA0TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 11-5. DMACTL0 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                            |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 12-8  | DMA1TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA1TRIG0<br>00001b = DMA1TRIG1<br>00010b = DMA1TRIG2<br>⋮<br>11110b = DMA1TRIG30<br>11111b = DMA1TRIG31 |
| 7-5   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 4-0   | DMA0TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA0TRIG0<br>00001b = DMA0TRIG1<br>00010b = DMA0TRIG2<br>⋮<br>11110b = DMA0TRIG30<br>11111b = DMA0TRIG31 |

### **11.3.2 DMACTL1 Register**

DMA Control 1 Register

**Figure 11-7. DMACTL1 Register**

| 15       | 14 | 13       | 12     | 11     | 10     | 9      | 8      |
|----------|----|----------|--------|--------|--------|--------|--------|
| Reserved |    | DMA3TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| 7        | 6  | 5        | 4      | 3      | 2      | 1      | 0      |
| Reserved |    | DMA2TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 11-6. DMACTL1 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                            |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 12-8  | DMA3TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA3TRIG0<br>00001b = DMA3TRIG1<br>00010b = DMA3TRIG2<br>⋮<br>11110b = DMA3TRIG30<br>11111b = DMA3TRIG31 |
| 7-5   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 4-0   | DMA2TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA2TRIG0<br>00001b = DMA2TRIG1<br>00010b = DMA2TRIG2<br>⋮<br>11110b = DMA2TRIG30<br>11111b = DMA2TRIG31 |

### 11.3.3 DMACTL2 Register

DMA Control 2 Register

**Figure 11-8. DMACTL2 Register**

| 15       | 14 | 13       | 12     | 11     | 10     | 9      | 8      |
|----------|----|----------|--------|--------|--------|--------|--------|
| Reserved |    | DMA5TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| 7        | 6  | 5        | 4      | 3      | 2      | 1      | 0      |
| Reserved |    | DMA4TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 11-7. DMACTL2 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                            |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 12-8  | DMA5TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA5TRIG0<br>00001b = DMA5TRIG1<br>00010b = DMA5TRIG2<br>⋮<br>11110b = DMA5TRIG30<br>11111b = DMA5TRIG31 |
| 7-5   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 4-0   | DMA4TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA4TRIG0<br>00001b = DMA4TRIG1<br>00010b = DMA4TRIG2<br>⋮<br>11110b = DMA4TRIG30<br>11111b = DMA4TRIG31 |

### **11.3.4 DMACTL3 Register**

DMA Control 3 Register

**Figure 11-9. DMACTL3 Register**

| 15       | 14 | 13       | 12     | 11     | 10     | 9      | 8      |
|----------|----|----------|--------|--------|--------|--------|--------|
| Reserved |    | DMA7TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| 7        | 6  | 5        | 4      | 3      | 2      | 1      | 0      |
| Reserved |    | DMA6TSEL |        |        |        |        |        |
| r0       | r0 | r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 11-8. DMACTL3 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                            |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 12-8  | DMA7TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA7TRIG0<br>00001b = DMA7TRIG1<br>00010b = DMA7TRIG2<br>⋮<br>11110b = DMA7TRIG30<br>11111b = DMA7TRIG31 |
| 7-5   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                           |
| 4-0   | DMA6TSEL | RW   | 0h    | DMA trigger select. These bits select the DMA transfer trigger. See the device-specific data sheet for number of channels and trigger assignment.<br>00000b = DMA6TRIG0<br>00001b = DMA6TRIG1<br>00010b = DMA6TRIG2<br>⋮<br>11110b = DMA6TRIG30<br>11111b = DMA6TRIG31 |

### 11.3.5 DMACTL4 Register

DMA Control 4 Register

**Figure 11-10. DMACTL4 Register**

|          |    |    |    |    |           |           |        |
|----------|----|----|----|----|-----------|-----------|--------|
| 15       | 14 | 13 | 12 | 11 | 10        | 9         | 8      |
| Reserved |    |    |    |    |           |           |        |
| r0       | r0 | r0 | r0 | r0 | r0        | r0        | r0     |
| 7        | 6  | 5  | 4  | 3  | 2         | 1         | 0      |
| Reserved |    |    |    |    | DMARMWDIS | ROUNDRBIN | ENNMI  |
| r0       | r0 | r0 | r0 | r0 | rw-(0)    | rw-(0)    | rw-(0) |

**Table 11-9. DMACTL4 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                        |
|------|-----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                       |
| 2    | DMARMWDIS | RW   | 0h    | Read-modify-write disable. When set, this bit inhibits any DMA transfers from occurring during CPU read-modify-write operations.<br>0b = DMA transfers can occur during read-modify-write CPU operations.<br>1b = DMA transfers inhibited during read-modify-write CPU operations                  |
| 1    | ROUNDRBIN | RW   | 0h    | Round robin. This bit enables the round-robin DMA channel priorities.<br>0b = DMA channel priority is DMA0-DMA1-DMA2 - ..... -DMA7.<br>1b = DMA channel priority changes with each transfer.                                                                                                       |
| 0    | ENNMI     | RW   | 0h    | Enable NMI. This bit enables the interruption of a DMA transfer by an NMI. When an NMI interrupts a DMA transfer, the current transfer is completed normally, further transfers are stopped and DMAABORT is set.<br>0b = NMI does not interrupt DMA transfer<br>1b = NMI interrupts a DMA transfer |

### 11.3.6 DMAxCTL Register

DMA Channel x Control Register

**Figure 11-11. DMAxCTL Register**

| 15         | 14         | 13       | 12     | 11         | 10     | 9          | 8      |
|------------|------------|----------|--------|------------|--------|------------|--------|
| Reserved   | DMADT      |          |        | DMADSTINCR |        | DMASRCINCR |        |
| r0         | rw-(0)     | rw-(0)   | rw-(0) | rw-(0)     | rw-(0) | rw-(0)     | rw-(0) |
| 7          | 6          | 5        | 4      | 3          | 2      | 1          | 0      |
| DMADSTBYTE | DMASRCBYTE | DMALEVEL | DMAEN  | DMAIFG     | DMAIE  | DMAABORT   | DMAREQ |
| rw-(0)     | rw-(0)     | rw-(0)   | rw-(0) | rw-(0)     | rw-(0) | rw-(0)     | rw-(0) |

**Table 11-10. DMAxCTL Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 14-12 | DMADT      | RW   | 0h    | DMA transfer mode<br>000b = Single transfer<br>001b = Block transfer<br>010b = Burst-block transfer<br>011b = Burst-block transfer<br>100b = Repeated single transfer<br>101b = Repeated block transfer<br>110b = Repeated burst-block transfer<br>111b = Repeated burst-block transfer                                                                                                                                                                                                                                                                                                                                                    |
| 11-10 | DMADSTINCR | RW   | 0h    | DMA destination increment. This bit selects automatic incrementing or decrementing of the destination address after each byte or word transfer. When DMADSTBYTE = 1, the destination address increments or decrements by one. When DMADSTBYTE = 0, the destination address increments or decrements by two. The DMAxDA is copied into a temporary register and the temporary register is incremented or decremented. DMAxDA is not incremented or decremented.<br>00b = Destination address is unchanged<br>01b = Destination address is unchanged<br>10b = Destination address is decremented<br>11b = Destination address is incremented |
| 9-8   | DMASRCINCR | RW   | 0h    | DMA source increment. This bit selects automatic incrementing or decrementing of the source address for each byte or word transfer. When DMASRCBYTE = 1, the source address increments or decrements by one. When DMASRCBYTE = 0, the source address increments/decrements by two. The DMAxSA is copied into a temporary register and the temporary register is incremented or decremented. DMAxSA is not incremented or decremented.<br>00b = Source address is unchanged<br>01b = Source address is unchanged<br>10b = Source address is decremented<br>11b = Source address is incremented                                              |
| 7     | DMADSTBYTE | RW   | 0h    | DMA destination byte. This bit selects the destination as a byte or word.<br>0b = Word<br>1b = Byte                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 6     | DMASRCBYTE | RW   | 0h    | DMA source byte. This bit selects the source as a byte or word.<br>0b = Word<br>1b = Byte                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 5     | DMALEVEL   | RW   | 0h    | DMA level. This bit selects between edge-sensitive and level-sensitive triggers.<br>0b = Edge sensitive (rising edge)<br>1b = Level sensitive (high level)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 4     | DMAEN      | RW   | 0h    | DMA enable<br>0b = Disabled<br>1b = Enabled                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

**Table 11-10. DMAXCTL Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                             |
|-----|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | DMAIFG   | RW   | 0h    | DMA interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                               |
| 2   | DMAIE    | RW   | 0h    | DMA interrupt enable<br>0b = Disabled<br>1b = Enabled                                                                                                   |
| 1   | DMAABORT | RW   | 0h    | DMA abort. This bit indicates if a DMA transfer was interrupted by an NMI.<br>0b = DMA transfer not interrupted<br>1b = DMA transfer interrupted by NMI |
| 0   | DMAREQ   | RW   | 0h    | DMA request. Software-controlled DMA start. DMAREQ is reset automatically.<br>0b = No DMA start<br>1b = Start DMA                                       |

### **11.3.7 DMAxSA Register**

DMA Source Address Register

**Figure 11-12. DMAxSA Register**

|          |    |    |    |        |    |    |    |
|----------|----|----|----|--------|----|----|----|
| 31       | 30 | 29 | 28 | 27     | 26 | 25 | 24 |
| Reserved |    |    |    |        |    |    |    |
| r0       | r0 | r0 | r0 | r0     | r0 | r0 | r0 |
| 23       | 22 | 21 | 20 | 19     | 18 | 17 | 16 |
| Reserved |    |    |    | DMAxSA |    |    |    |
| r0       | r0 | r0 | r0 | rw     | rw | rw | rw |
| 15       | 14 | 13 | 12 | 11     | 10 | 9  | 8  |
| DMAxSA   |    |    |    |        |    |    |    |
| rw       | rw | rw | rw | rw     | rw | rw | rw |
| 7        | 6  | 5  | 4  | 3      | 2  | 1  | 0  |
| DMAxSA   |    |    |    |        |    |    |    |
| rw       | rw | rw | rw | rw     | rw | rw | rw |

**Table 11-11. DMAxSA Register Description**

| Bit   | Field    | Type | Reset     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------|----------|------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 31-20 | Reserved | R    | 0h        | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 19-0  | DMAxSA   | RW   | undefined | DMA source address. The source address register points to the DMA source address for single transfers or the first source address for block transfers. The source address register remains unchanged during block and burst-block transfers. There are two words for the DMAxSA register. Bits 31-20 are reserved and always read as zero. Reading or writing bits 19-16 requires the use of extended instructions. When writing to DMAxSA with word instructions, bits 19-16 are cleared. |

### 11.3.8 DMAxDA Register

DMA Destination Address Register

**Figure 11-13. DMAxDA Register**

|          |    |    |    |        |    |    |    |
|----------|----|----|----|--------|----|----|----|
| 31       | 30 | 29 | 28 | 27     | 26 | 25 | 24 |
| Reserved |    |    |    |        |    |    |    |
| r0       | r0 | r0 | r0 | r0     | r0 | r0 | r0 |
| 23       | 22 | 21 | 20 | 19     | 18 | 17 | 16 |
| Reserved |    |    |    | DMAxDA |    |    |    |
| r0       | r0 | r0 | r0 | rw     | rw | rw | rw |
| 15       | 14 | 13 | 12 | 11     | 10 | 9  | 8  |
| DMAxDA   |    |    |    |        |    |    |    |
| rw       | rw | rw | rw | rw     | rw | rw | rw |
| 7        | 6  | 5  | 4  | 3      | 2  | 1  | 0  |
| DMAxDA   |    |    |    |        |    |    |    |
| rw       | rw | rw | rw | rw     | rw | rw | rw |

**Table 11-12. DMAxDA Register Description**

| Bit   | Field    | Type | Reset     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------|----------|------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 31-20 | Reserved | R    | 0h        | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 19-0  | DMAxDA   | RW   | undefined | DMA destination address. The destination address register points to the DMA destination address for single transfers or the first destination address for block transfers. The destination address register remains unchanged during block and burst-block transfers. There are two words for the DMAxDA register. Bits 31–20 are reserved and always read as zero. Reading or writing bits 19–16 requires the use of extended instructions. When writing to DMAxDA with word instructions, bits 19–16 are cleared. |

### 11.3.9 DMAxSZ Register

DMA Size Address Register

**Figure 11-14. DMAxSZ Register**

|        |    |    |    |    |    |    |    |
|--------|----|----|----|----|----|----|----|
| 15     | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| DMAxSZ |    |    |    |    |    |    |    |
| rw     | rw | rw | rw | rw | rw | rw | rw |
| 7      | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| DMAxSZ |    |    |    |    |    |    |    |
| rw     | rw | rw | rw | rw | rw | rw | rw |

**Table 11-13. DMAxSZ Register Description**

| Bit  | Field  | Type | Reset     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|--------|------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | DMAxSZ | RW   | undefined | <p>DMA size. The DMA size register defines the number of byte or word data per block transfer. DMAxSZ register decrements with each word or byte transfer. When DMAxSZ decrements to 0, it is immediately and automatically reloaded with its previously initialized value.</p> <p>0000h = Transfer is disabled.<br/>     0001h = One byte or word is transferred.<br/>     0002h = Two bytes or words are transferred.<br/>     ...<br/>     FFFFh = 65535 bytes or words are transferred.</p> |

### 11.3.10 DMAIV Register

DMA Interrupt Vector Register

**Figure 11-15. DMAIV Register**

|       |    |       |       |       |       |       |    |
|-------|----|-------|-------|-------|-------|-------|----|
| 15    | 14 | 13    | 12    | 11    | 10    | 9     | 8  |
| DMAIV |    |       |       |       |       |       |    |
| r0    | r0 | r0    | r0    | r0    | r0    | r0    | r0 |
| DMAIV |    |       |       |       |       |       |    |
| r0    | r0 | r-(0) | r-(0) | r-(0) | r-(0) | r-(0) | r0 |

**Table 11-14. DMAIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------|-------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | DMAIV | R    | 0h    | DMA interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: DMA channel 0; Interrupt Flag: DMA0IFG; Interrupt Priority: Highest<br>04h = Interrupt Source: DMA channel 1; Interrupt Flag: DMA1IFG<br>06h = Interrupt Source: DMA channel 2; Interrupt Flag: DMA2IFG<br>08h = Interrupt Source: DMA channel 3; Interrupt Flag: DMA3IFG<br>0Ah = Interrupt Source: DMA channel 4; Interrupt Flag: DMA4IFG<br>0Ch = Interrupt Source: DMA channel 5; Interrupt Flag: DMA5IFG<br>0Eh = Interrupt Source: DMA channel 6; Interrupt Flag: DMA6IFG<br>10h = Interrupt Source: DMA channel 7; Interrupt Flag: DMA7IFG; Interrupt Priority: Lowest |

## Digital I/O

This chapter describes the operation of the digital I/O ports in all devices.

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## 12.1 Digital I/O Introduction

The digital I/O features include:

- Independently programmable individual I/Os
- Any combination of input or output
- Individually configurable P1 and P2 interrupts. Some devices may include additional port interrupts.
- Independent input and output data registers
- Individually configurable pullup or pulldown resistors

Devices within the family may have up to twelve digital I/O ports implemented (P1 to P11 and PJ). Most ports contain eight I/O lines; however, some ports may contain less (see the device-specific data sheet for ports available). Each I/O line is individually configurable for input or output direction, and each can be individually read or written. Each I/O line is individually configurable for pullup or pulldown resistors.

Ports P1 and P2 always have interrupt capability. Each interrupt for the P1 and P2 I/O lines can be individually enabled and configured to provide an interrupt on a rising or falling edge of an input signal. All P1 I/O lines source a single interrupt vector ([P1IV](#)), and all P2 I/O lines source a different single interrupt vector ([P2IV](#)). Additional ports with interrupt capability may be available (see the device-specific data sheet for details) and contain their own respective interrupt vectors.

Individual ports can be accessed as byte-wide ports or can be combined into word-wide ports and accessed by word formats. Port pairs P1 and P2, P3 and P4, P5 and P6, P7 and P8, and so on, are associated with the names PA, PB, PC, PD, and so on, respectively. All port registers are handled in this manner with this naming convention except for the interrupt vector registers, [P1IV](#) and [P2IV](#); that is, PAIV does not exist.

When writing to port PA with word operations, all 16 bits are written to the port. When writing to the lower byte of port PA using byte operations, the upper byte remains unchanged. Similarly, writing to the upper byte of port PA using byte instructions leaves the lower byte unchanged. When writing to a port that contains less than the maximum number of bits possible, the unused bits are don't care. Ports PB, PC, PD, PE, and PF behave similarly.

Reading port PA using word operations causes all 16 bits to be transferred to the destination. Reading the lower or upper byte of port PA (P1 or P2) and storing to memory using byte operations causes only the lower or upper byte to be transferred to the destination, respectively. Reading of port PA and storing to a general-purpose register using byte operations writes the byte that is transferred to the least significant byte of the register. The upper significant byte of the destination register is cleared automatically. Ports PB, PC, PD, PE, and PF behave similarly. When reading from ports that contain fewer than the maximum bits possible, unused bits are read as zeros (similarly for port PJ).

## 12.2 Digital I/O Operation

The digital I/O are configured with user software. The setup and operation of the digital I/O are discussed in the following sections.

### 12.2.1 Input Registers (*PxIN*)

Each bit in each PxIN register reflects the value of the input signal at the corresponding I/O pin when the pin is configured as I/O function. These registers are read only.

- Bit = 0: Input is low
- Bit = 1: Input is high

---

**NOTE: Writing to read-only registers PxIN**

Writing to these read-only registers results in increased current consumption while the write attempt is active.

---

### 12.2.2 Output Registers (*PxOUT*)

Each bit in each PxOUT register is the value to be output on the corresponding I/O pin when the pin is configured as I/O function, output direction.

- Bit = 0: Output is low
- Bit = 1: Output is high

If the pin is configured as I/O function, input direction and the pullup or pulldown resistor are enabled; the corresponding bit in the PxOUT register selects pullup or pulldown.

- Bit = 0: Pin is pulled down
- Bit = 1: Pin is pulled up

### 12.2.3 Direction Registers (*PxDIR*)

Each bit in each PxDIR register selects the direction of the corresponding I/O pin, regardless of the selected function for the pin. PxDIR bits for I/O pins that are selected for other functions must be set as required by the other function.

- Bit = 0: Port pin is switched to input direction
- Bit = 1: Port pin is switched to output direction

### 12.2.4 Pullup or Pulldown Resistor Enable Registers (*PxREN*)

Each bit in each PxREN register enables or disables the pullup or pulldown resistor of the corresponding I/O pin. The corresponding bit in the PxOUT register selects if the pin contains a pullup or pulldown.

- Bit = 0: Pullup or pulldown resistor disabled
- Bit = 1: Pullup or pulldown resistor enabled

Table 12-1 summarizes the use of PxDIR, PxREN, and PxOUT for proper I/O configuration.

**Table 12-1. I/O Configuration**

| PxDIR | PxREN | PxOUT | I/O Configuration            |
|-------|-------|-------|------------------------------|
| 0     | 0     | x     | Input                        |
| 0     | 1     | 0     | Input with pulldown resistor |
| 0     | 1     | 1     | Input with pullup resistor   |
| 1     | x     | x     | Output                       |

### 12.2.5 Function Select Registers ( $PxSEL0$ , $PxSEL1$ )

Port pins are often multiplexed with other peripheral module functions. See the device-specific data sheet to determine pin functions. Each port pin uses two bits to select the pin function – I/O port or one of the three possible peripheral module function. [Table 12-2](#) shows how to select the various module functions. See the device-specific data sheet to determine pin functions. Each  $PxSEL$  bit is used to select the pin function – I/O port or peripheral module function.

**Table 12-2. I/O Function Selection**

| <b><math>PxSEL1</math></b> | <b><math>PxSEL0</math></b> | <b>I/O Function</b>                   |
|----------------------------|----------------------------|---------------------------------------|
| 0                          | 0                          | General purpose I/O is selected       |
| 0                          | 1                          | Primary module function is selected   |
| 1                          | 0                          | Secondary module function is selected |
| 1                          | 1                          | Tertiary module function is selected  |

Setting the  $PxSEL1$  or  $PxSEL0$  bits to a module function does not automatically set the pin direction. Other peripheral module functions may require the  $PxDIR$  bits to be configured according to the direction needed for the module function. See the pin schematics in the device-specific data sheet.

When a port pin is selected as an input to peripheral modules, the input signal to those peripheral modules is a latched representation of the signal at the device pin. While  $PxSEL1$  and  $PxSEL0$  is other than 00, the internal input signal follows the signal at the pin for all connected modules. However, if  $PxSEL1$  and  $PxSEL0 = 00$ , the input to the peripherals maintain the value of the input signal at the device pin before the  $PxSEL1$  and  $PxSEL0$  bits were reset.

Because the  $PxSEL1$  and  $PxSEL0$  bits do not reside in contiguous addresses, changing both bits at the same time is not possible. For example, an application might need to change P1.0 from general purpose I/O to the tertiary module function residing on P1.0. Initially,  $P1SEL1 = 00h$  and  $P1SEL0 = 00h$ . To change the function, it would be necessary to write both  $P1SEL1 = 01h$  and  $P1SEL0 = 01h$ . This is not possible without first passing through an intermediate configuration, and this configuration may not be desirable from an application standpoint. The  $PxSELC$  complement register can be used to handle such situations. The  $PxSELC$  register always reads 0. Each set bit of the  $PxSELC$  register complements the corresponding respective bit of the  $PxSEL1$  and  $PxSEL0$  registers. In the example, with  $P1SEL1 = 00h$  and  $P1SEL0 = 00h$  initially, writing  $P1SELC = 01h$  causes  $P1SEL1 = 01h$  and  $P1SEL0 = 01h$  to be written simultaneously.

---

**NOTE: Interrupts are disabled when  $PxSEL1 = 1$  or  $PxSEL0 = 1$**

When any  $PxSEL$  bit is set, the corresponding pin interrupt function is disabled. Therefore, signals on these pins do not generate interrupts, regardless of the state of the corresponding  $PxIE$  bit.

---

### 12.2.6 Port Interrupts

At least each pin in ports P1 and P2 have interrupt capability, configured with the  $PxIFG$ ,  $PxIE$ , and  $PxIES$  registers. Some devices may contain additional port interrupts besides P1 and P2. See the device-specific data sheet to determine which port interrupts are available.

All  $Px$  interrupt flags are prioritized, with  $PxIFG.0$  being the highest, and combined to source a single interrupt vector. The highest priority enabled interrupt generates a number in the  $PxIV$  register. This number can be evaluated or added to the program counter to automatically enter the appropriate software routine. Disabled  $Px$  interrupts do not affect the  $PxIV$  value. The  $PxIV$  registers are word or byte access.

Each  $PxIFG$  bit is the interrupt flag for its corresponding I/O pin, and the flag is set when the selected input signal edge occurs at the pin. All  $PxIFG$  interrupt flags request an interrupt when their corresponding  $PxIE$  bit and the GIE bit are set. Software can also set each  $PxIFG$  flag, providing a way to generate a software-initiated interrupt.

- Bit = 0: No interrupt is pending
- Bit = 1: An interrupt is pending

Only transitions, not static levels, cause interrupts. If any PxIFG flag becomes set during a Px interrupt service routine or is set after the RETI instruction of a Px interrupt service routine is executed, the set PxIFG flag generates another interrupt. This ensures that each transition is acknowledged.

---

**NOTE: PxIFG flags when changing PxOUT, PxDIR, or PxREN**

Writing to PxOUT, PxDIR, or PxREN can result in setting the corresponding PxIFG flags.

---

Any access (read or write) of the lower byte of the PxIV register, either word or byte access, automatically resets the highest pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt.

For example, assume that P1IFG.0 has the highest priority. If the P1IFG.0 and P1IFG.2 flags are set when the interrupt service routine accesses the P1IV register, P1IFG.0 is reset automatically. After the RETI instruction of the interrupt service routine is executed, the P1IFG.2 generates another interrupt.

#### 12.2.6.1 P1IV Software Example

The following software example shows the recommended use of P1IV and the handling overhead. The P1IV value is added to the PC to automatically jump to the appropriate routine. The code to handle any other PxIV register is similar.

The numbers at the right margin show the number of CPU cycles that are required for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles but not the task handling itself.

|          |          |                            | Cycles |
|----------|----------|----------------------------|--------|
| P1_HND   | ...      | ; Interrupt latency        | 6      |
| ADD      | &P1IV,PC | ; Add offset to Jump table | 3      |
| RETI     |          | ; Vector 0: No interrupt   | 5      |
| JMP      | P1_0_HND | ; Vector 2: Port 1 bit 0   | 2      |
| JMP      | P1_1_HND | ; Vector 4: Port 1 bit 1   | 2      |
| JMP      | P1_2_HND | ; Vector 6: Port 1 bit 2   | 2      |
| JMP      | P1_3_HND | ; Vector 8: Port 1 bit 3   | 2      |
| JMP      | P1_4_HND | ; Vector 10: Port 1 bit 4  | 2      |
| JMP      | P1_5_HND | ; Vector 12: Port 1 bit 5  | 2      |
| JMP      | P1_6_HND | ; Vector 14: Port 1 bit 6  | 2      |
| JMP      | P1_7_HND | ; Vector 16: Port 1 bit 7  | 2      |
| P1_7_HND |          | ; Vector 16: Port 1 bit 7  |        |
| ...      |          | ; Task starts here         |        |
| RETI     |          | ; Back to main program     | 5      |
| P1_6_HND |          | ; Vector 14: Port 1 bit 6  |        |
| ...      |          | ; Task starts here         |        |
| RETI     |          | ; Back to main program     | 5      |
| P1_5_HND |          | ; Vector 12: Port 1 bit 5  |        |
| ...      |          | ; Task starts here         |        |
| RETI     |          | ; Back to main program     | 5      |
| P1_4_HND |          | ; Vector 10: Port 1 bit 4  |        |
| ...      |          | ; Task starts here         |        |
| RETI     |          | ; Back to main program     | 5      |
| P1_3_HND |          | ; Vector 8: Port 1 bit 3   |        |
| ...      |          | ; Task starts here         |        |
| RETI     |          | ; Back to main program     | 5      |
| P1_2_HND |          | ; Vector 6: Port 1 bit 2   |        |
| ...      |          | ; Task starts here         |        |
| RETI     |          | ; Back to main program     | 5      |
| P1_1_HND |          | ; Vector 4: Port 1 bit 1   |        |
| ...      |          | ; Task starts here         |        |

---

```

RETI          ; Back to main program      5
P1_0_HND    ; Vector 2: Port 1 bit 0
...
RETI          ; Task starts here
              ; Back to main program      5

```

---

### 12.2.6.2 Interrupt Edge Select Registers (PxIES)

Each PxIES bit selects the interrupt edge for the corresponding I/O pin.

- Bit = 0: Respective PxIFG flag is set on a low-to-high transition
- Bit = 1: Respective PxIFG flag is set on a high-to-low transition

---

**NOTE: Writing to PxIES**

Writing to [P1IES](#) or [P2IES](#) for each corresponding I/O can result in setting the corresponding interrupt flags.

| PxIES | PxIN | PxIFG       |
|-------|------|-------------|
| 0 → 1 | 0    | Will be set |
| 0 → 1 | 1    | Unchanged   |
| 1 → 0 | 0    | Unchanged   |
| 1 → 0 | 1    | Will be set |

---

### 12.2.6.3 Interrupt Enable Registers (PxIE)

Each PxIE bit enables the associated PxIFG interrupt flag.

- Bit = 0: The interrupt is disabled
- Bit = 1: The interrupt is enabled

## 12.3 I/O Configuration

### 12.3.1 Configuration After Reset

After a BOR reset, all port pins are high-impedance with Schmitt triggers and their module functions disabled to prevent any cross currents. The application must initialize all port pins including unused ones ([Section 12.3.2](#)) as input high impedance, input with pulldown, input with pullup, output high, or output low according to the application needs by configuring PxDIR, PxREN, PxOUT, and PxIES accordingly. This initialization takes effect as soon as the LOCKLPM5 bit in the PM5CTL register (described in the PMM chapter) is cleared; until then, the I/Os remain in their high-impedance state with Schmitt trigger inputs disabled. Note that this is usually the same I/O initialization that is required after a wake-up from LPMx.5. After clearing LOCKLPM5 all interrupt flags should be cleared (note, this is different to the wake-up from LPMx.5 flow). Then port interrupts can be enabled by setting the corresponding PxIE bits.

After a POR or PUC reset all port pins are configured as inputs with their module function being disabled. Also here to prevent floating inputs all port pins including unused ones ([Section 12.3.2](#)) should be configured according to the application needs as early as possible during the initialization procedure.

Note, the same I/O initialization procedure can be used for all reset cases and wake-up from LPMx.5 - except for PxIFG:

1. Initialize Ports: PxDIR, PxREN, PxOUT, and PxIES
2. Clear LOCKLPM5
3. If not wake-up from LPMx.5: clear all PxIFGs to avoid erroneous port interrupts
4. Enable port interrupts in PxIE

### 12.3.2 Configuration of Unused Port Pins

To prevent a floating input and to reduce power consumption, unused I/O pins should be configured as I/O function, output direction, and left unconnected on the PC board. The value of the PxOUT bit is don't care, because the pin is unconnected. Alternatively, the integrated pullup or pulldown resistor can be enabled by setting the PxREN bit of the unused pin to prevent a floating input. See the *System Resets, Interrupts, and Operating Modes, System Control Module (SYS)* chapter for termination of unused pins.

---

**NOTE: Configuring port PJ and shared JTAG pins:**

The application should make sure that port PJ is configured properly to prevent a floating input. Because port PJ is shared with the JTAG function, floating inputs may not be noticed when in an emulation environment. Port J is initialized to high-impedance inputs by default.

---

### 12.3.3 Configuration for LPMx.5 Low-Power Modes

---

**NOTE: See , Entering and Exiting Low-Power Modes LPMx.5, in the *System Resets, Interrupts, and Operating Modes, System Control Module (SYS)* chapter for details about LPMx.5 low-power modes.**

See the device-specific data sheet to determine which LPMx.5 low-power modes are available and which modules can operate in LPM3.5, if any.

With regard to the digital I/O, the following description is applicable to both LPM3.5 and LPM4.5.

---

Upon entering LPMx.5 (LPM3.5 or LPM4.5) the LDO of the PMM module is disabled, which removes the supply voltage from the core of the device. This causes all I/O register configurations to be lost, thus the configuration of I/O pins must be handled differently to ensure that all pins in the application behave in a controlled manner upon entering and exiting LPMx.5. Properly setting the I/O pins is critical to achieve the lowest possible power consumption in LPMx.5, and to prevent an uncontrolled input or output I/O state in the application. The application has complete control of the I/O pin conditions that are necessary to prevent unwanted spurious activity upon entry and exit from LPMx.5.

Before entering LPMx.5 the following operations are required for the I/Os:

- Set all I/Os to general-purpose I/Os (PxSEL0 = 000h and PxSEL1 = 000h) and configure as needed. Each I/O can be set to input high impedance, input with pulldown, input with pullup, output high, or output low. It is critical that no inputs are left floating in the application; otherwise, excess current may be drawn in LPMx.5.

Configuring the I/O in this manner ensures that each pin is in a safe condition before entering LPMx.5.

- Optionally, configure input interrupt pins for wake-up from LPMx.5. To wake the device from LPMx.5, a general-purpose I/O port must contain an input port with interrupt and wakeup capability. Not all inputs with interrupt capability offer wakeup from LPMx.5. See the device-specific data sheet for availability. To wake up the device, a port pin must be configured properly before entering LPMx.5. Each port should be configured as general-purpose input. Pulldowns or pullups can be applied if required. Setting the PxIES bit of the corresponding register determines the edge transition that wakes the device. Last, the PxIE for the port must be enabled, as well as the general interrupt enable.

---

**NOTE: It is not possible to wake up from a port interrupt if its respective port interrupt flag is already asserted. It is recommended that the flag be cleared before entering LPMx.5. It is also recommended that GIE = 1 be set before entry into LPMx.5. Any pending flags in this case could then be serviced before LPMx.5 entry.**

This completes the operations required for the I/Os before entering LPMx.5.

During LPMx.5 the I/O pin states are held and locked based on the settings before LPMx.5 entry. Note that only the pin conditions are retained. All other port configuration register settings such as PxDIR, PxREN, PxOUT, PxIES, and PxIE contents are lost.

Upon exit from LPMx.5, all peripheral registers are set to their default conditions but the I/O pins remain locked while LOCKLPM5 remains set. Keeping the I/O pins locked ensures that all pin conditions remain stable when entering the active mode, regardless of the default I/O register settings.

When back in active mode, the I/O configuration and I/O interrupt configuration such as PxDIR, PxREN, PxOUT, and PxIES should be restored to the values before entering LPMx.5. The LOCKLPM5 bit can then be cleared, which releases the I/O pin conditions and I/O interrupt configuration. Any changes to the port configuration registers while LOCKLPM5 is set have no effect on the I/O pins.

After enabling the I/O interrupts by configuring PxIE, the I/O interrupt that caused the wakeup can be serviced as indicated by the PxIFG flags. These flags can be used directly, or the corresponding PxIV register may be used. Note that the PxIFG flag cannot be cleared until the LOCKLPM5 bit has been cleared.

---

**NOTE:** It is possible that multiple events occurred on various ports. In these cases, multiple PxIFG flags are set, and it cannot be determined which port caused the I/O wakeup.

---

## 12.4 Digital I/O Registers

The digital I/O registers are listed in [Table 12-3](#). The base addresses can be found in the device-specific data sheet. Each port grouping begins at its base address. The address offsets are given in [Table 12-3](#).

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 12-3. Digital I/O Registers**

| Offset | Acronym               | Register Name                | Type       | Access | Reset     | Section                         |
|--------|-----------------------|------------------------------|------------|--------|-----------|---------------------------------|
| 0Eh    | P1IV                  | Port 1 Interrupt Vector      | Read only  | Word   | 0000h     | <a href="#">Section 12.4.1</a>  |
| 0Eh    | P1IV_L                |                              | Read only  | Byte   | 00h       |                                 |
| 0Fh    | P1IV_H                |                              | Read only  | Byte   | 00h       |                                 |
| 1Eh    | P2IV                  | Port 2 Interrupt Vector      | Read only  | Word   | 0000h     | <a href="#">Section 12.4.2</a>  |
| 1Eh    | P2IV_L                |                              | Read only  | Byte   | 00h       |                                 |
| 1Fh    | P2IV_H                |                              | Read only  | Byte   | 00h       |                                 |
| 2Eh    | P3IV                  | Port 3 Interrupt Vector      | Read only  | Word   | 0000h     | <a href="#">Section 12.4.3</a>  |
| 2Eh    | P3IV_L                |                              | Read only  | Byte   | 00h       |                                 |
| 2Fh    | P3IV_H                |                              | Read only  | Byte   | 00h       |                                 |
| 3Eh    | P4IV                  | Port 4 Interrupt Vector      | Read only  | Word   | 0000h     | <a href="#">Section 12.4.4</a>  |
| 3Eh    | P4IV_L                |                              | Read only  | Byte   | 00h       |                                 |
| 3Fh    | P4IV_H                |                              | Read only  | Byte   | 00h       |                                 |
| 00h    | P1IN<br>or PAIN_L     | Port 1 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 02h    | P1OUT<br>or PAOUT_L   | Port 1 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 04h    | P1DIR<br>or PADIR_L   | Port 1 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 06h    | P1REN<br>or PAREN_L   | Port 1 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Ah    | P1SEL0<br>or PASEL0_L | Port 1 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Ch    | P1SEL1<br>or PASEL1_L | Port 1 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 16h    | P1SELC<br>or PASELC_L | Port 1 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 18h    | P1IES<br>or PAIES_L   | Port 1 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Ah    | P1IE<br>or PAIE_L     | Port 1 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Ch    | P1IFG<br>or PAIFG_L   | Port 1 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym               | Register Name                | Type       | Access | Reset     | Section                         |
|--------|-----------------------|------------------------------|------------|--------|-----------|---------------------------------|
| 01h    | P2IN<br>or PAINT_H    | Port 2 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 03h    | P2OUT<br>or PAOUT_H   | Port 2 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 05h    | P2DIR<br>or PADIR_H   | Port 2 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 07h    | P2REN<br>or PAREN_H   | Port 2 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Bh    | P2SEL0<br>or PASEL0_H | Port 2 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Dh    | P2SEL1<br>or PASEL1_H | Port 2 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 17h    | P2SELC<br>or PBSELC_L | Port 2 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 19h    | P2IES<br>or PAIES_H   | Port 2 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Bh    | P2IE<br>or PAIE_H     | Port 2 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Dh    | P2IFG<br>or PAIFG_H   | Port 2 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |
| 00h    | P3IN<br>or PBIN_L     | Port 3 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 02h    | P3OUT<br>or PBOUT_L   | Port 3 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 04h    | P3DIR<br>or PBDIR_L   | Port 3 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 06h    | P3REN<br>or PBREN_L   | Port 3 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Ah    | P3SEL0<br>or PBSEL0_L | Port 3 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Ch    | P3SEL1<br>or PBSEL1_L | Port 3 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 16h    | P3SELC<br>or PBSELC_L | Port 3 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 18h    | P3IES<br>or PBIES_L   | Port 3 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Ah    | P3IE<br>or PBIE_L     | Port 3 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Ch    | P3IFG<br>or PBIFG_L   | Port 3 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym               | Register Name                | Type       | Access | Reset     | Section                         |
|--------|-----------------------|------------------------------|------------|--------|-----------|---------------------------------|
| 01h    | P4IN<br>or PBIN_H     | Port 4 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 03h    | P4OUT<br>or PBOUT_H   | Port 4 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 05h    | P4DIR<br>or PBDIR_H   | Port 4 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 07h    | P4REN<br>or PBREN_H   | Port 4 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Bh    | P4SEL0<br>or PBSEL0_H | Port 4 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Dh    | P4SEL1<br>or PBSEL1_H | Port 4 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 17h    | P4SELC<br>or PBSELC_L | Port 4 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 19h    | P4IES<br>or PBIES_H   | Port 4 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Bh    | P4IE<br>or PBIE_H     | Port 4 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Dh    | P4IFG<br>or PBIFG_H   | Port 4 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |
| 00h    | P5IN<br>or PCIN_L     | Port 5 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 02h    | P5OUT<br>or PCOUT_L   | Port 5 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 04h    | P5DIR<br>or PCDIR_L   | Port 5 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 06h    | P5REN<br>or PCREN_L   | Port 5 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Ah    | P5SEL0<br>or PCSEL0_L | Port 5 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Ch    | P5SEL1<br>or PCSEL1_L | Port 5 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 16h    | P5SELC<br>or PCSELC_L | Port 5 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 18h    | P5IES<br>or PCIES_L   | Port 5 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Ah    | P5IE<br>or PCIE_L     | Port 5 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Ch    | P5IFG<br>or PCIFG_L   | Port 5 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym               | Register Name                | Type       | Access | Reset     | Section                         |
|--------|-----------------------|------------------------------|------------|--------|-----------|---------------------------------|
| 01h    | P6IN<br>or PCIN_H     | Port 6 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 03h    | P6OUT<br>or PCOUT_H   | Port 6 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 05h    | P6DIR<br>or PCDIR_H   | Port 6 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 07h    | P6REN<br>or PCREN_H   | Port 6 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Bh    | P6SEL0<br>or PCSEL0_H | Port 6 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Dh    | P6SEL1<br>or PCSEL1_H | Port 6 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 17h    | P6SELC<br>or PCSELC_L | Port 6 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 19h    | P6IES<br>or PCIES_H   | Port 6 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Bh    | P6IE<br>or PCIE_H     | Port 6 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Dh    | P6IFG<br>or PCIFG_H   | Port 6 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |
| 00h    | P7IN<br>or PDIN_L     | Port 7 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 02h    | P7OUT<br>or PDOUT_L   | Port 7 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 04h    | P7DIR<br>or PDDIR_L   | Port 7 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 06h    | P7REN<br>or PDREN_L   | Port 7 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Ah    | P7SEL0<br>or PDSEL0_L | Port 7 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Ch    | P7SEL1<br>or PDSEL1_L | Port 7 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 16h    | P7SELC<br>or PDSELC_L | Port 7 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 18h    | P7IES<br>or PDIES_L   | Port 7 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Ah    | P7IE<br>or PDIE_L     | Port 7 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Ch    | P7IFG<br>or PDIFG_L   | Port 7 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym               | Register Name                | Type       | Access | Reset     | Section                         |
|--------|-----------------------|------------------------------|------------|--------|-----------|---------------------------------|
| 01h    | P8IN<br>or PDIN_H     | Port 8 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 03h    | P8OUT<br>or PDOUT_H   | Port 8 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 05h    | P8DIR<br>or PDDIR_H   | Port 8 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 07h    | P8REN<br>or PDREN_H   | Port 8 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Bh    | P8SEL0<br>or PDSEL0_H | Port 8 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Dh    | P8SEL1<br>or PDSEL1_H | Port 8 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 17h    | P8SELC<br>or PDSELC_L | Port 8 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 19h    | P8IES<br>or PDIES_H   | Port 8 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Bh    | P8IE<br>or PDIE_H     | Port 8 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Dh    | P8IFG<br>or PDIFG_H   | Port 8 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |
| 00h    | P9IN<br>or PEIN_L     | Port 9 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 02h    | P9OUT<br>or PEOUT_L   | Port 9 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 04h    | P9DIR<br>or PEDIR_L   | Port 9 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 06h    | P9REN<br>or PEREN_L   | Port 9 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Ah    | P9SEL0<br>or PESEL0_L | Port 9 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Ch    | P9SEL1<br>or PESEL1_L | Port 9 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 16h    | P9SELC<br>or PESELC_L | Port 9 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 18h    | P9IES<br>or PEIES_L   | Port 9 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Ah    | P9IE<br>or PEIE_L     | Port 9 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Ch    | P9IFG<br>or PEIFG_L   | Port 9 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym                | Register Name                 | Type       | Access | Reset     | Section                         |
|--------|------------------------|-------------------------------|------------|--------|-----------|---------------------------------|
| 01h    | P10IN<br>or PEIN_H     | Port 10 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 03h    | P10OUT<br>or PEOUT_H   | Port 10 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 05h    | P10DIR<br>or PEDIR_H   | Port 10 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 07h    | P10REN<br>or PEREN_H   | Port 10 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Bh    | P10SEL0<br>or PESEL0_H | Port 10 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Dh    | P10SEL1<br>or PESEL1_H | Port 10 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 17h    | P10SELC<br>or PESELC_L | Port 10 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 19h    | P10IES<br>or PEIES_H   | Port 10 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Bh    | P10IE<br>or PEIE_H     | Port 10 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Dh    | P10IFG<br>or PEIFG_H   | Port 10 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |
| 00h    | P11IN<br>or PFIN_L     | Port 11 Input                 | Read only  | Byte   | undefined | <a href="#">Section 12.4.5</a>  |
| 02h    | P11OUT<br>or PFOUT_L   | Port 11 Output                | Read/write | Byte   | undefined | <a href="#">Section 12.4.6</a>  |
| 04h    | P11DIR<br>or PFDIR_L   | Port 11 Direction             | Read/write | Byte   | 00h       | <a href="#">Section 12.4.7</a>  |
| 06h    | P11REN<br>or PFREN_L   | Port 11 Resistor Enable       | Read/write | Byte   | 00h       | <a href="#">Section 12.4.8</a>  |
| 0Ah    | P11SEL0<br>or PFSEL0_L | Port 11 Select 0              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.9</a>  |
| 0Ch    | P11SEL1<br>or PFSEL1_L | Port 11 Select 1              | Read/write | Byte   | 00h       | <a href="#">Section 12.4.10</a> |
| 16h    | P11SELC<br>or PFSELC_L | Port 11 Complement Selection  | Read/write | Byte   | 00h       | <a href="#">Section 12.4.11</a> |
| 18h    | P11IES<br>or PFIES_L   | Port 11 Interrupt Edge Select | Read/write | Byte   | undefined | <a href="#">Section 12.4.12</a> |
| 1Ah    | P11IE<br>or PFIE_L     | Port 11 Interrupt Enable      | Read/write | Byte   | 00h       | <a href="#">Section 12.4.13</a> |
| 1Ch    | P11IFG<br>or PFIFG_L   | Port 11 Interrupt Flag        | Read/write | Byte   | 00h       | <a href="#">Section 12.4.14</a> |

**Table 12-3. Digital I/O Registers (continued)**

| <b>Offset</b> | <b>Acronym</b> | <b>Register Name</b>         | <b>Type</b> | <b>Access</b> | <b>Reset</b> | <b>Section</b> |
|---------------|----------------|------------------------------|-------------|---------------|--------------|----------------|
| 00h           | PAIN           | Port A Input                 | Read only   | Word          | undefined    |                |
| 00h           | PAIN_L         |                              | Read only   | Byte          | undefined    |                |
| 01h           | PAIN_H         |                              | Read only   | Byte          | undefined    |                |
| 02h           | PAOUT          | Port A Output                | Read/write  | Word          | undefined    |                |
| 02h           | PAOUT_L        |                              | Read/write  | Byte          | undefined    |                |
| 03h           | PAOUT_H        |                              | Read/write  | Byte          | undefined    |                |
| 04h           | PADIR          | Port A Direction             | Read/write  | Word          | 0000h        |                |
| 04h           | PADIR_L        |                              | Read/write  | Byte          | 00h          |                |
| 05h           | PADIR_H        |                              | Read/write  | Byte          | 00h          |                |
| 06h           | PAREN          | Port A Resistor Enable       | Read/write  | Word          | 0000h        |                |
| 06h           | PAREN_L        |                              | Read/write  | Byte          | 00h          |                |
| 07h           | PAREN_H        |                              | Read/write  | Byte          | 00h          |                |
| 0Ah           | PASEL0         | Port A Select 0              | Read/write  | Word          | 0000h        |                |
| 0Ah           | PASEL0_L       |                              | Read/write  | Byte          | 00h          |                |
| 0Bh           | PASEL0_H       |                              | Read/write  | Byte          | 00h          |                |
| 0Ch           | PASEL1         | Port A Select 1              | Read/write  | Word          | 0000h        |                |
| 0Ch           | PASEL1_L       |                              | Read/write  | Byte          | 00h          |                |
| 0Dh           | PASEL1_H       |                              | Read/write  | Byte          | 00h          |                |
| 16h           | PASELC         | Port A Complement Select     | Read/write  | Word          | 0000h        |                |
| 16h           | PASELC_L       |                              | Read/write  | Byte          | 00h          |                |
| 17h           | PASELC_H       |                              | Read/write  | Byte          | 00h          |                |
| 18h           | PAIES          | Port A Interrupt Edge Select | Read/write  | Word          | undefined    |                |
| 18h           | PAIES_L        |                              | Read/write  | Byte          | undefined    |                |
| 19h           | PAIES_H        |                              | Read/write  | Byte          | undefined    |                |
| 1Ah           | PAIE           | Port A Interrupt Enable      | Read/write  | Word          | 0000h        |                |
| 1Ah           | PAIE_L         |                              | Read/write  | Byte          | 00h          |                |
| 1Bh           | PAIE_H         |                              | Read/write  | Byte          | 00h          |                |
| 1Ch           | PAIFG          | Port A Interrupt Flag        | Read/write  | Word          | 0000h        |                |
| 1Ch           | PAIFG_L        |                              | Read/write  | Byte          | 00h          |                |
| 1Dh           | PAIFG_H        |                              | Read/write  | Byte          | 00h          |                |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym  | Register Name                | Type       | Access | Reset     | Section |
|--------|----------|------------------------------|------------|--------|-----------|---------|
| 00h    | PBIN     | Port B Input                 | Read only  | Word   | undefined |         |
| 00h    | PBIN_L   |                              | Read only  | Byte   | undefined |         |
| 01h    | PBIN_H   |                              | Read only  | Byte   | undefined |         |
| 02h    | PBOUT    | Port B Output                | Read/write | Word   | undefined |         |
| 02h    | PBOUT_L  |                              | Read/write | Byte   | undefined |         |
| 03h    | PBOUT_H  |                              | Read/write | Byte   | undefined |         |
| 04h    | PBDIR    | Port B Direction             | Read/write | Word   | 0000h     |         |
| 04h    | PBDIR_L  |                              | Read/write | Byte   | 00h       |         |
| 05h    | PBDIR_H  |                              | Read/write | Byte   | 00h       |         |
| 06h    | PBREN    | Port B Resistor Enable       | Read/write | Word   | 0000h     |         |
| 06h    | PBREN_L  |                              | Read/write | Byte   | 00h       |         |
| 07h    | PBREN_H  |                              | Read/write | Byte   | 00h       |         |
| 0Ah    | PBSEL0   | Port B Select 0              | Read/write | Word   | 0000h     |         |
| 0Ah    | PBSEL0_L |                              | Read/write | Byte   | 00h       |         |
| 0Bh    | PBSEL0_H |                              | Read/write | Byte   | 00h       |         |
| 0Ch    | PBSEL1   | Port B Select 1              | Read/write | Word   | 0000h     |         |
| 0Ch    | PBSEL1_L |                              | Read/write | Byte   | 00h       |         |
| 0Dh    | PBSEL1_H |                              | Read/write | Byte   | 00h       |         |
| 16h    | PBSELC   | Port B Complement Select     | Read/write | Word   | 0000h     |         |
| 16h    | PBSELC_L |                              | Read/write | Byte   | 00h       |         |
| 17h    | PBSELC_H |                              | Read/write | Byte   | 00h       |         |
| 18h    | PBIOS    | Port B Interrupt Edge Select | Read/write | Word   | undefined |         |
| 18h    | PBIOS_L  |                              | Read/write | Byte   | undefined |         |
| 19h    | PBIOS_H  |                              | Read/write | Byte   | undefined |         |
| 1Ah    | PBIE     | Port B Interrupt Enable      | Read/write | Word   | 0000h     |         |
| 1Ah    | PBIE_L   |                              | Read/write | Byte   | 00h       |         |
| 1Bh    | PBIE_H   |                              | Read/write | Byte   | 00h       |         |
| 1Ch    | PBIFG    | Port B Interrupt Flag        | Read/write | Word   | 0000h     |         |
| 1Ch    | PBIFG_L  |                              | Read/write | Byte   | 00h       |         |
| 1Dh    | PBIFG_H  |                              | Read/write | Byte   | 00h       |         |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym  | Register Name                | Type       | Access | Reset     | Section |
|--------|----------|------------------------------|------------|--------|-----------|---------|
| 00h    | PCIN     | Port C Input                 | Read only  | Word   | undefined |         |
| 00h    | PCIN_L   |                              | Read only  | Byte   | undefined |         |
| 01h    | PCIN_H   |                              | Read only  | Byte   | undefined |         |
| 02h    | PCOUT    | Port C Output                | Read/write | Word   | undefined |         |
| 02h    | PCOUT_L  |                              | Read/write | Byte   | undefined |         |
| 03h    | PCOUT_H  |                              | Read/write | Byte   | undefined |         |
| 04h    | PCDIR    | Port C Direction             | Read/write | Word   | 0000h     |         |
| 04h    | PCDIR_L  |                              | Read/write | Byte   | 00h       |         |
| 05h    | PCDIR_H  |                              | Read/write | Byte   | 00h       |         |
| 06h    | PCREN    | Port C Resistor Enable       | Read/write | Word   | 0000h     |         |
| 06h    | PCREN_L  |                              | Read/write | Byte   | 00h       |         |
| 07h    | PCREN_H  |                              | Read/write | Byte   | 00h       |         |
| 0Ah    | PCSEL0   | Port C Select 0              | Read/write | Word   | 0000h     |         |
| 0Ah    | PCSEL0_L |                              | Read/write | Byte   | 00h       |         |
| 0Bh    | PCSEL0_H |                              | Read/write | Byte   | 00h       |         |
| 0Ch    | PCSEL1   | Port C Select 1              | Read/write | Word   | 0000h     |         |
| 0Ch    | PCSEL1_L |                              | Read/write | Byte   | 00h       |         |
| 0Dh    | PCSEL1_H |                              | Read/write | Byte   | 00h       |         |
| 16h    | PCSELC   | Port C Complement Select     | Read/write | Word   | 0000h     |         |
| 16h    | PCSELC_L |                              | Read/write | Byte   | 00h       |         |
| 17h    | PCSELC_H |                              | Read/write | Byte   | 00h       |         |
| 18h    | PCIES    | Port C Interrupt Edge Select | Read/write | Word   | undefined |         |
| 18h    | PCIES_L  |                              | Read/write | Byte   | undefined |         |
| 19h    | PCIES_H  |                              | Read/write | Byte   | undefined |         |
| 1Ah    | PCIE     | Port C Interrupt Enable      | Read/write | Word   | 0000h     |         |
| 1Ah    | PCIE_L   |                              | Read/write | Byte   | 00h       |         |
| 1Bh    | PCIE_H   |                              | Read/write | Byte   | 00h       |         |
| 1Ch    | PCIFG    | Port C Interrupt Flag        | Read/write | Word   | 0000h     |         |
| 1Ch    | PCIFG_L  |                              | Read/write | Byte   | 00h       |         |
| 1Dh    | PCIFG_H  |                              | Read/write | Byte   | 00h       |         |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym  | Register Name                | Type       | Access | Reset     | Section |
|--------|----------|------------------------------|------------|--------|-----------|---------|
| 00h    | PDIN     | Port D Input                 | Read only  | Word   | undefined |         |
| 00h    | PDIN_L   |                              | Read only  | Byte   | undefined |         |
| 01h    | PDIN_H   |                              | Read only  | Byte   | undefined |         |
| 02h    | PDOUT    | Port D Output                | Read/write | Word   | undefined |         |
| 02h    | PDOUT_L  |                              | Read/write | Byte   | undefined |         |
| 03h    | PDOUT_H  |                              | Read/write | Byte   | undefined |         |
| 04h    | PDDR     | Port D Direction             | Read/write | Word   | 0000h     |         |
| 04h    | PDDR_L   |                              | Read/write | Byte   | 00h       |         |
| 05h    | PDDR_H   |                              | Read/write | Byte   | 00h       |         |
| 06h    | PDREN    | Port D Resistor Enable       | Read/write | Word   | 0000h     |         |
| 06h    | PDREN_L  |                              | Read/write | Byte   | 00h       |         |
| 07h    | PDREN_H  |                              | Read/write | Byte   | 00h       |         |
| 0Ah    | PDSEL0   | Port D Select 0              | Read/write | Word   | 0000h     |         |
| 0Ah    | PDSEL0_L |                              | Read/write | Byte   | 00h       |         |
| 0Bh    | PDSEL0_H |                              | Read/write | Byte   | 00h       |         |
| 0Ch    | PDSEL1   | Port D Select 1              | Read/write | Word   | 0000h     |         |
| 0Ch    | PDSEL1_L |                              | Read/write | Byte   | 00h       |         |
| 0Dh    | PDSEL1_H |                              | Read/write | Byte   | 00h       |         |
| 16h    | PDSELC   | Port D Complement Select     | Read/write | Word   | 0000h     |         |
| 16h    | PDSELC_L |                              | Read/write | Byte   | 00h       |         |
| 17h    | PDSELC_H |                              | Read/write | Byte   | 00h       |         |
| 18h    | PDIES    | Port D Interrupt Edge Select | Read/write | Word   | undefined |         |
| 18h    | PDIES_L  |                              | Read/write | Byte   | undefined |         |
| 19h    | PDIES_H  |                              | Read/write | Byte   | undefined |         |
| 1Ah    | PDIE     | Port D Interrupt Enable      | Read/write | Word   | 0000h     |         |
| 1Ah    | PDIE_L   |                              | Read/write | Byte   | 00h       |         |
| 1Bh    | PDIE_H   |                              | Read/write | Byte   | 00h       |         |
| 1Ch    | PDIFG    | Port D Interrupt Flag        | Read/write | Word   | 0000h     |         |
| 1Ch    | PDIFG_L  |                              | Read/write | Byte   | 00h       |         |
| 1Dh    | PDIFG_H  |                              | Read/write | Byte   | 00h       |         |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym  | Register Name                | Type       | Access | Reset     | Section |
|--------|----------|------------------------------|------------|--------|-----------|---------|
| 00h    | PEIN     | Port E Input                 | Read only  | Word   | undefined |         |
| 00h    | PEIN_L   |                              | Read only  | Byte   | undefined |         |
| 01h    | PEIN_H   |                              | Read only  | Byte   | undefined |         |
| 02h    | PEOUT    | Port E Output                | Read/write | Word   | undefined |         |
| 02h    | PEOUT_L  |                              | Read/write | Byte   | undefined |         |
| 03h    | PEOUT_H  |                              | Read/write | Byte   | undefined |         |
| 04h    | PEDIR    | Port E Direction             | Read/write | Word   | 0000h     |         |
| 04h    | PEDIR_L  |                              | Read/write | Byte   | 00h       |         |
| 05h    | PEDIR_H  |                              | Read/write | Byte   | 00h       |         |
| 06h    | PEREN    | Port E Resistor Enable       | Read/write | Word   | 0000h     |         |
| 06h    | PEREN_L  |                              | Read/write | Byte   | 00h       |         |
| 07h    | PEREN_H  |                              | Read/write | Byte   | 00h       |         |
| 0Ah    | PESEL0   | Port E Select 0              | Read/write | Word   | 0000h     |         |
| 0Ah    | PESEL0_L |                              | Read/write | Byte   | 00h       |         |
| 0Bh    | PESEL0_H |                              | Read/write | Byte   | 00h       |         |
| 0Ch    | PESEL1   | Port E Select 1              | Read/write | Word   | 0000h     |         |
| 0Ch    | PESEL1_L |                              | Read/write | Byte   | 00h       |         |
| 0Dh    | PESEL1_H |                              | Read/write | Byte   | 00h       |         |
| 16h    | PESELC   | Port E Complement Select     | Read/write | Word   | 0000h     |         |
| 16h    | PESELC_L |                              | Read/write | Byte   | 00h       |         |
| 17h    | PESELC_H |                              | Read/write | Byte   | 00h       |         |
| 18h    | PEIES    | Port E Interrupt Edge Select | Read/write | Word   | undefined |         |
| 18h    | PEIES_L  |                              | Read/write | Byte   | undefined |         |
| 19h    | PEIES_H  |                              | Read/write | Byte   | undefined |         |
| 1Ah    | PEIE     | Port E Interrupt Enable      | Read/write | Word   | 0000h     |         |
| 1Ah    | PEIE_L   |                              | Read/write | Byte   | 00h       |         |
| 1Bh    | PEIE_H   |                              | Read/write | Byte   | 00h       |         |
| 1Ch    | PEIFG    | Port E Interrupt Flag        | Read/write | Word   | 0000h     |         |
| 1Ch    | PEIFG_L  |                              | Read/write | Byte   | 00h       |         |
| 1Dh    | PEIFG_H  |                              | Read/write | Byte   | 00h       |         |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym   | Register Name                | Type       | Access | Reset     | Section |
|--------|-----------|------------------------------|------------|--------|-----------|---------|
| 00h    | PFIN      | Port F Input                 | Read only  | Word   | undefined |         |
| 00h    | PFIN_L    |                              | Read only  | Byte   | undefined |         |
| 01h    | PFIN_H    |                              | Read only  | Byte   | undefined |         |
| 02h    | PFOUT     | Port F Output                | Read/write | Word   | undefined |         |
| 02h    | PFOUT_L   |                              | Read/write | Byte   | undefined |         |
| 03h    | PFOUT_H   |                              | Read/write | Byte   | undefined |         |
| 04h    | PFDIR     | Port F Direction             | Read/write | Word   | 0000h     |         |
| 04h    | PFDIR_L   |                              | Read/write | Byte   | 00h       |         |
| 05h    | PFDIR_H   |                              | Read/write | Byte   | 00h       |         |
| 06h    | PFREN     | Port F Resistor Enable       | Read/write | Word   | 0000h     |         |
| 06h    | PFREN_L   |                              | Read/write | Byte   | 00h       |         |
| 07h    | PFREN_H   |                              | Read/write | Byte   | 00h       |         |
| 0Ah    | PFSEL0    | Port F Select 0              | Read/write | Word   | 0000h     |         |
| 0Ah    | PFSEL0_L  |                              | Read/write | Byte   | 00h       |         |
| 0Bh    | PFSEL0_H  |                              | Read/write | Byte   | 00h       |         |
| 0Ch    | PFSEL1    | Port F Select 1              | Read/write | Word   | 0000h     |         |
| 0Ch    | PFSEL1_L  |                              | Read/write | Byte   | 00h       |         |
| 0Dh    | PFSEL1_H  |                              | Read/write | Byte   | 00h       |         |
| 16h    | PFSEL_C   | Port F Complement Select     | Read/write | Word   | 0000h     |         |
| 16h    | PFSEL_C_L |                              | Read/write | Byte   | 00h       |         |
| 17h    | PFSEL_C_H |                              | Read/write | Byte   | 00h       |         |
| 18h    | PFIES     | Port F Interrupt Edge Select | Read/write | Word   | undefined |         |
| 18h    | PFIES_L   |                              | Read/write | Byte   | undefined |         |
| 19h    | PFIES_H   |                              | Read/write | Byte   | undefined |         |
| 1Ah    | PFIE      | Port F Interrupt Enable      | Read/write | Word   | 0000h     |         |
| 1Ah    | PFIE_L    |                              | Read/write | Byte   | 00h       |         |
| 1Bh    | PFIE_H    |                              | Read/write | Byte   | 00h       |         |
| 1Ch    | PFIFG     | Port F Interrupt Flag        | Read/write | Word   | 0000h     |         |
| 1Ch    | PFIFG_L   |                              | Read/write | Byte   | 00h       |         |
| 1Dh    | PFIFG_H   |                              | Read/write | Byte   | 00h       |         |

**Table 12-3. Digital I/O Registers (continued)**

| Offset | Acronym  | Register Name            | Type       | Access | Reset     | Section |
|--------|----------|--------------------------|------------|--------|-----------|---------|
| 00h    | PJIN     | Port J Input             | Read only  | Word   | undefined |         |
| 00h    | PJIN_L   |                          | Read only  | Byte   | undefined |         |
| 01h    | PJIN_H   |                          | Read only  | Byte   | undefined |         |
| 02h    | PJOUT    | Port J Output            | Read/write | Word   | undefined |         |
| 02h    | PJOUT_L  |                          | Read/write | Byte   | undefined |         |
| 03h    | PJOUT_H  |                          | Read/write | Byte   | undefined |         |
| 04h    | PJDIR    | Port J Direction         | Read/write | Word   | 0000h     |         |
| 04h    | PJDIR_L  |                          | Read/write | Byte   | 00h       |         |
| 05h    | PJDIR_H  |                          | Read/write | Byte   | 00h       |         |
| 06h    | PJREN    | Port J Resistor Enable   | Read/write | Word   | 0000h     |         |
| 06h    | PJREN_L  |                          | Read/write | Byte   | 00h       |         |
| 07h    | PJREN_H  |                          | Read/write | Byte   | 00h       |         |
| 0Ah    | PJSEL0   | Port J Select 0          | Read/write | Word   | 0000h     |         |
| 0Ah    | PJSEL0_L |                          | Read/write | Byte   | 00h       |         |
| 0Bh    | PJSEL0_H |                          | Read/write | Byte   | 00h       |         |
| 0Ch    | PJSEL1   | Port J Select 1          | Read/write | Word   | 0000h     |         |
| 0Ch    | PJSEL1_L |                          | Read/write | Byte   | 00h       |         |
| 0Dh    | PJSEL1_H |                          | Read/write | Byte   | 00h       |         |
| 16h    | PJSELC   | Port J Complement Select | Read/write | Word   | 0000h     |         |
| 16h    | PJSELC_L |                          | Read/write | Byte   | 00h       |         |
| 17h    | PJSELC_H |                          | Read/write | Byte   | 00h       |         |

### 12.4.1 P1IV Register

Port 1 Interrupt Vector Register

**Figure 12-1. P1IV Register**

|      |    |    |     |     |     |     |    |
|------|----|----|-----|-----|-----|-----|----|
| 15   | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| P1IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| P1IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 12-4. P1IV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | P1IV  | R    | 0h    | Port 1 interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Port 1.0 interrupt; Interrupt Flag: P1IFG.0; Interrupt Priority: Highest<br>04h = Interrupt Source: Port 1.1 interrupt; Interrupt Flag: P1IFG.1<br>06h = Interrupt Source: Port 1.2 interrupt; Interrupt Flag: P1IFG.2<br>08h = Interrupt Source: Port 1.3 interrupt; Interrupt Flag: P1IFG.3<br>0Ah = Interrupt Source: Port 1.4 interrupt; Interrupt Flag: P1IFG.4<br>0Ch = Interrupt Source: Port 1.5 interrupt; Interrupt Flag: P1IFG.5<br>0Eh = Interrupt Source: Port 1.6 interrupt; Interrupt Flag: P1IFG.6<br>10h = Interrupt Source: Port 1.7 interrupt; Interrupt Flag: P1IFG.7; Interrupt Priority: Lowest |

### 12.4.2 P2IV Register

Port 2 Interrupt Vector Register

**Figure 12-2. P2IV Register**

|      |    |    |     |     |     |     |    |
|------|----|----|-----|-----|-----|-----|----|
| 15   | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| P2IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| P2IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 12-5. P2IV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | P2IV  | R    | 0h    | Port 2 interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Port 2.0 interrupt; Interrupt Flag: P2IFG.0; Interrupt Priority: Highest<br>04h = Interrupt Source: Port 2.1 interrupt; Interrupt Flag: P2IFG.1<br>06h = Interrupt Source: Port 2.2 interrupt; Interrupt Flag: P2IFG.2<br>08h = Interrupt Source: Port 2.3 interrupt; Interrupt Flag: P2IFG.3<br>0Ah = Interrupt Source: Port 2.4 interrupt; Interrupt Flag: P2IFG.4<br>0Ch = Interrupt Source: Port 2.5 interrupt; Interrupt Flag: P2IFG.5<br>0Eh = Interrupt Source: Port 2.6 interrupt; Interrupt Flag: P2IFG.6<br>10h = Interrupt Source: Port 2.7 interrupt; Interrupt Flag: P2IFG.7; Interrupt Priority: Lowest |

### 12.4.3 P3IV Register

Port 3 Interrupt Vector Register

**Figure 12-3. P3IV Register**

|      |    |    |     |     |     |     |    |
|------|----|----|-----|-----|-----|-----|----|
| 15   | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| P3IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| P3IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 12-6. P3IV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | P3IV  | R    | 0h    | Port 3 interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Port 3.0 interrupt; Interrupt Flag: P3IFG.0; Interrupt Priority: Highest<br>04h = Interrupt Source: Port 3.1 interrupt; Interrupt Flag: P3IFG.1<br>06h = Interrupt Source: Port 3.2 interrupt; Interrupt Flag: P3IFG.2<br>08h = Interrupt Source: Port 3.3 interrupt; Interrupt Flag: P3IFG.3<br>0Ah = Interrupt Source: Port 3.4 interrupt; Interrupt Flag: P3IFG.4<br>0Ch = Interrupt Source: Port 3.5 interrupt; Interrupt Flag: P3IFG.5<br>0Eh = Interrupt Source: Port 3.6 interrupt; Interrupt Flag: P3IFG.6<br>10h = Interrupt Source: Port 3.7 interrupt; Interrupt Flag: P3IFG.7; Interrupt Priority: Lowest |

### 12.4.4 P4IV Register

Port 4 Interrupt Vector Register

**Figure 12-4. P4IV Register**

|      |    |    |     |     |     |     |    |
|------|----|----|-----|-----|-----|-----|----|
| 15   | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| P4IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| P4IV |    |    |     |     |     |     |    |
| r0   | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 12-7. P4IV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | P4IV  | R    | 0h    | Port 4 interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Port 4.0 interrupt; Interrupt Flag: P4IFG.0; Interrupt Priority: Highest<br>04h = Interrupt Source: Port 4.1 interrupt; Interrupt Flag: P4IFG.1<br>06h = Interrupt Source: Port 4.2 interrupt; Interrupt Flag: P4IFG.2<br>08h = Interrupt Source: Port 4.3 interrupt; Interrupt Flag: P4IFG.3<br>0Ah = Interrupt Source: Port 4.4 interrupt; Interrupt Flag: P4IFG.4<br>0Ch = Interrupt Source: Port 4.5 interrupt; Interrupt Flag: P4IFG.5<br>0Eh = Interrupt Source: Port 4.6 interrupt; Interrupt Flag: P4IFG.6<br>10h = Interrupt Source: Port 4.7 interrupt; Interrupt Flag: P4IFG.7; Interrupt Priority: Lowest |

### 12.4.5 PxIN Register

Port x Input Register

**Figure 12-5. PxIN Register**

| 7    | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|------|---|---|---|---|---|---|---|
| PxIN |   |   |   |   |   |   |   |
| r    | r | r | r | r | r | r | r |

**Table 12-8. PxIN Register Description**

| Bit | Field | Type | Reset     | Description                                             |
|-----|-------|------|-----------|---------------------------------------------------------|
| 7-0 | PxIN  | R    | Undefined | Port x input<br>0b = Input is low<br>1b = Input is high |

### 12.4.6 PxOUT Register

Port x Output Register

**Figure 12-6. PxOUT Register**

| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|-------|----|----|----|----|----|----|----|
| PxOUT |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

**Table 12-9. PxOUT Register Description**

| Bit | Field | Type | Reset     | Description                                                                                                                                                                                                               |
|-----|-------|------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxOUT | RW   | Undefined | Port x output<br>When I/O configured to output mode:<br>0b = Output is low.<br>1b = Output is high.<br>When I/O configured to input mode and pullups/pulldowns enabled:<br>0b = Pulldown selected<br>1b = Pullup selected |

### 12.4.7 PxDIR Register

Port x Direction Register

**Figure 12-7. PxDIR Register**

| 7     | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|-------|------|------|------|------|------|------|------|
| PxDIR |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 12-10. P1DIR Register Description**

| Bit | Field | Type | Reset | Description                                                                         |
|-----|-------|------|-------|-------------------------------------------------------------------------------------|
| 7-0 | PxDIR | RW   | 0h    | Port x direction<br>0b = Port configured as input<br>1b = Port configured as output |

#### 12.4.8 PxREN Register

Port x Pullup or Pulldown Resistor Enable Register

**Figure 12-8. PxREN Register**

| 7     | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|-------|------|------|------|------|------|------|------|
| PxREN |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 12-11. PxREN Register Description**

| Bit | Field | Type | Reset | Description                                                                                                                                                                                                             |
|-----|-------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxREN | RW   | 0h    | Port x pullup or pulldown resistor enable. When the port is configured as an input, setting this bit enables or disables the pullup or pulldown.<br>0b = Pullup or pulldown disabled<br>1b = Pullup or pulldown enabled |

#### 12.4.9 PxSEL0 Register

Port x Function Selection Register 0

**Figure 12-9. PxSEL0 Register**

| 7      | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|--------|------|------|------|------|------|------|------|
| PxSEL0 |      |      |      |      |      |      |      |
| rw-0   | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 12-12. PxSEL0 Register Description**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                   |
|-----|--------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxSEL0 | RW   | 0h    | Port function selection. Each bit corresponds to one channel on Port x.<br>The values of each bit position in PxSEL1 and PxSEL0 are combined to specify the function. For example, if P1SEL1.5 = 1 and P1SEL0.5 = 0, then the secondary module function is selected for P1.5.<br>See PxSEL1 for the definition of each value. |

#### 12.4.10 PxSEL1 Register

Port x Function Selection Register 1

**Figure 12-10. PxSEL1 Register**

| 7      | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|--------|------|------|------|------|------|------|------|
| PxSEL1 |      |      |      |      |      |      |      |
| rw-0   | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 12-13. PxSEL1 Register Description**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----|--------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxSEL1 | RW   | 0h    | Port function selection. Each bit corresponds to one channel on Port x.<br>The values of each bit position in PxSEL1 and PxSEL0 are combined to specify the function. For example, if P1SEL1.5 = 1 and P1SEL0.5 = 0, then the secondary module function is selected for P1.5.<br>00b = General-purpose I/O is selected<br>01b = Primary module function is selected<br>10b = Secondary module function is selected<br>11b = Tertiary module function is selected |

### 12.4.11 PxSELC Register

Port x Complement Selection

**Figure 12-11. PxSELC Register**

| 7      | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|--------|------|------|------|------|------|------|------|
| PxSELC |      |      |      |      |      |      |      |
| rw-0   | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 12-14. PxSELC Register Description**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                    |
|-----|--------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxSELC | RW   | 0h    | Port selection complement.<br>Each bit that is set in PxSELC complements the corresponding respective bit of both the PxSEL1 and PxSEL0 registers; that is, for each bit set in PxSELC, the corresponding bits in both PxSEL1 and PxSEL0 are both changed at the same time. Always reads as 0. |

### 12.4.12 PxIES Register

Port x Interrupt Edge Select Register

**Figure 12-12. PxIES Register**

| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|-------|----|----|----|----|----|----|----|
| PxIES |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

**Table 12-15. PxIES Register Description**

| Bit | Field | Type | Reset     | Description                                                                                                                                  |
|-----|-------|------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxIES | RW   | Undefined | Port x interrupt edge select<br>0b = PxIFG flag is set with a low-to-high transition<br>1b = PxIFG flag is set with a high-to-low transition |

### 12.4.13 PxIE Register

Port x Interrupt Enable Register

**Figure 12-13. PxIE Register**

| 7    | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|------|------|------|------|------|------|------|------|
| PxIE |      |      |      |      |      |      |      |
| rw-0 |

**Table 12-16. PxIE Register Description**

| Bit | Field | Type | Reset | Description                                                                                                        |
|-----|-------|------|-------|--------------------------------------------------------------------------------------------------------------------|
| 7-0 | PxIE  | RW   | 0h    | Port x interrupt enable<br>0b = Corresponding port interrupt disabled<br>1b = Corresponding port interrupt enabled |

### **12.4.14 PxIFG Register**

Port x Interrupt Flag Register

**Figure 12-14. PxIFG Register**

| 7     | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|-------|------|------|------|------|------|------|------|
| PxIFG |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 12-17. PxIFG Register Description**

| Bit | Field | Type | Reset     | Description                                                                          |
|-----|-------|------|-----------|--------------------------------------------------------------------------------------|
| 7-0 | PxIFG | RW   | Undefined | Port x interrupt flag<br>0b = No interrupt is pending.<br>1b = Interrupt is pending. |

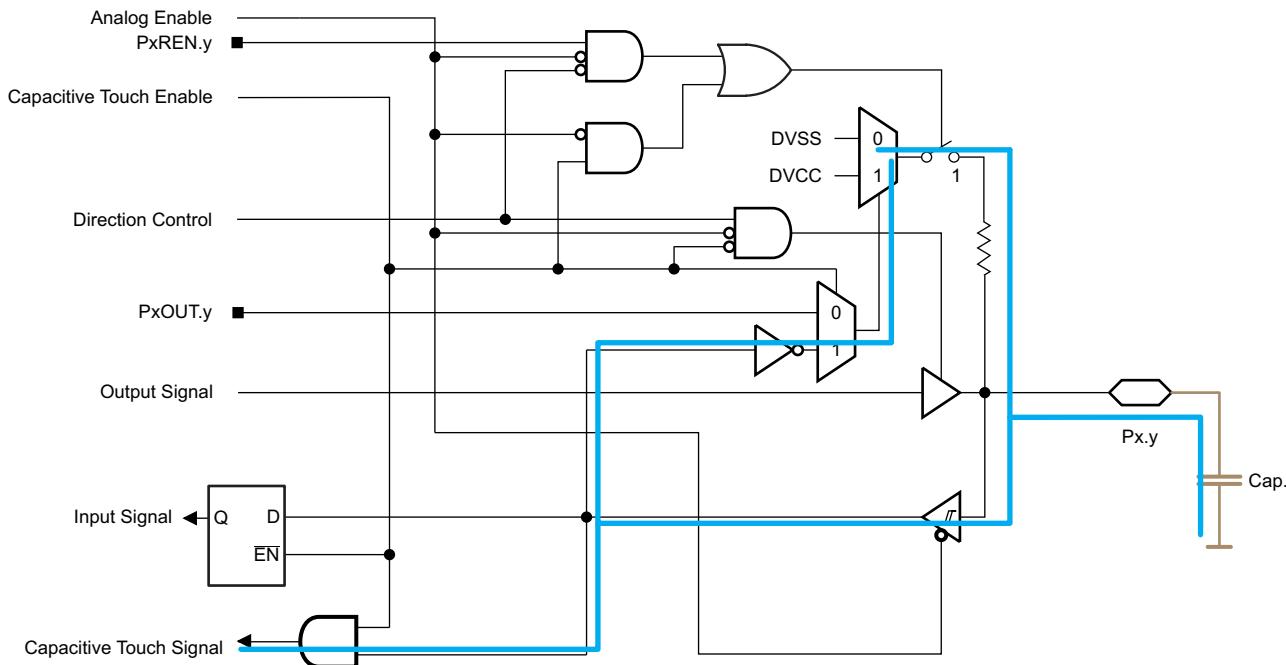
## ***Capacitive Touch I/O***

This chapter describes the functionality of the Capacitive Touch I/Os and related control.

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| 13.1 Capacitive Touch I/O Introduction ..... | 391  |
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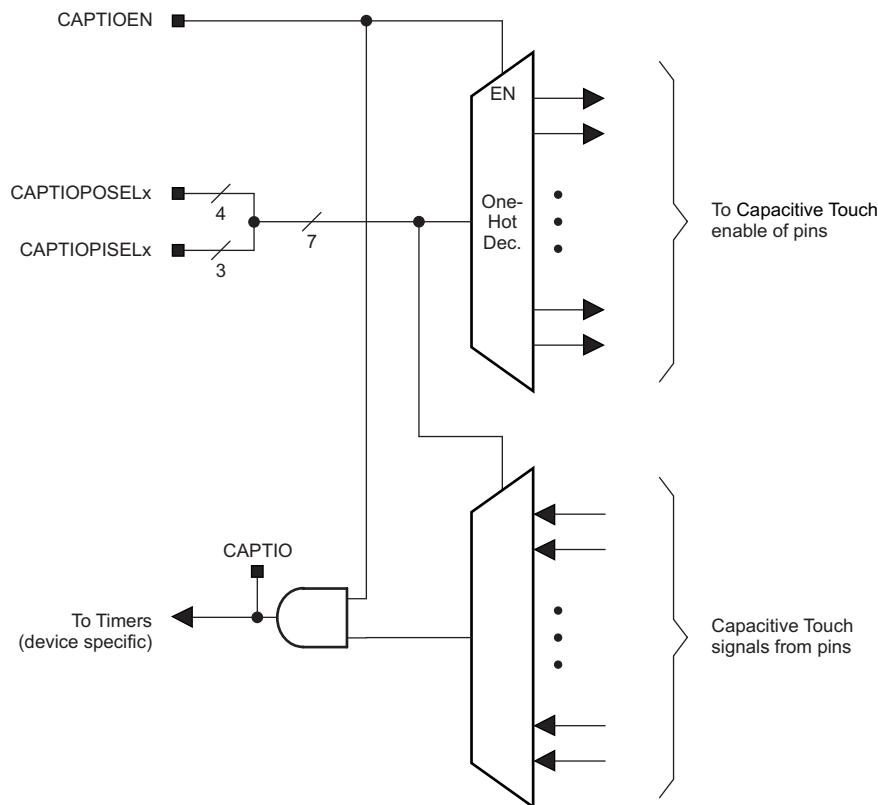
### 13.1 Capacitive Touch I/O Introduction

The Capacitive Touch I/O module allows implementation of a simple capacitive touch sense application. The module uses the integrated pullup and pulldown resistors and an external capacitor to form an oscillator by feeding back the inverted input voltage sensed by the input Schmitt triggers to the pullup and pulldown control. [Figure 13-1](#) shows the capacitive touch I/O principle



**Figure 13-1. Capacitive Touch I/O Principle**

Figure 13-2 shows the block diagram of the Capacitive Touch I/O module.



**Figure 13-2. Capacitive Touch I/O Block Diagram**

### 13.2 Capacitive Touch I/O Operation

Enable the Capacitive Touch I/O functionality with CAPTIOEN = 1 and select a port pin using CAPTIPOSEL<sub>x</sub> and CAPTIPISEL<sub>x</sub>. The selected port pin is switched into the Capacitive Touch state, and the resulting oscillating signal is provided to be measured by a timer. The connected timers are device-specific (see the device-specific data sheet).

It is possible to scan to successive port pins by incrementing the low byte of the Capacitive Touch I/O control register CAPTIOCTL\_L by 2.

### 13.3 CapTouch Registers

The Capacitive Touch I/O registers and their address offsets are listed in [Table 13-1](#). In a given device, multiple Capacitive Touch I/O registers might be available. The base address of each Capacitive Touch I/O module can be found in the device-specific data sheet.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 13-1. CapTouch Registers**

| Offset | Acronym      | Register Name                           | Type       | Access | Reset | Section                        |
|--------|--------------|-----------------------------------------|------------|--------|-------|--------------------------------|
| 0Eh    | CAPTIOxCTL   | Capacitive Touch I/O x control register | Read/write | Word   | 0000h | <a href="#">Section 13.3.1</a> |
| 0Eh    | CAPTIOxCTL_L |                                         | Read/write | Byte   | 00h   |                                |
| 0Fh    | CAPTIOxCTL_H |                                         | Read/write | Byte   | 00h   |                                |

### 13.3.1 CAPTIOxCTL Register (offset = 0Eh) [reset = 0000h]

Capacitive Touch I/O x Control Register

**Figure 13-3. CAPTIOxCTL Register**

| 15           | 14   | 13   | 12       | 11           | 10   | 9    | 8    |
|--------------|------|------|----------|--------------|------|------|------|
|              |      |      | Reserved |              |      |      |      |
| r0           | r0   | r0   | r0       | r0           | r0   | r-0  | rw-0 |
| 7            | 6    | 5    | 4        | 3            | 2    | 1    | 0    |
| CAPTIOPOSELx |      |      |          | CAPTIOPISELx |      |      |      |
| rw-0         | rw-0 | rw-0 | rw-0     | rw-0         | rw-0 | rw-0 | r0   |

**Table 13-2. CAPTIOxCTL Register Description**

| Bit   | Field        | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------|--------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | Reserved     | R    | 0h    | Reserved. Always reads 0.                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 9     | CAPTIO       | R    | 0h    | Capacitive Touch I/O state. Reports the current state of the selected Capacitive Touch I/O. Reads 0, if Capacitive Touch I/O disabled.<br>0b = Current state 0 or Capacitive Touch I/O is disabled<br>1b = Current state 1                                                                                                                                                                                                                                            |
| 8     | CAPTIONEN    | RW   | 0h    | Capacitive Touch I/O enable<br>0b = All Capacitive Touch I/Os are disabled. Signal toward timers is 0.<br>1b = Selected Capacitive Touch I/O is enabled                                                                                                                                                                                                                                                                                                               |
| 7-4   | CAPTIOPOSELx | RW   | 0h    | Capacitive Touch I/O port select. Selects port Px. Selecting a port pin that is not available on the device in use gives unpredictable results.<br>0000b = Px = PJ<br>0001b = Px = P1<br>0010b = Px = P2<br>0011b = Px = P3<br>0100b = Px = P4<br>0101b = Px = P5<br>0110b = Px = P6<br>0111b = Px = P7<br>1000b = Px = P8<br>1001b = Px = P9<br>1010b = Px = P10<br>1011b = Px = P11<br>1100b = Px = P12<br>1101b = Px = P13<br>1110b = Px = P14<br>1111b = Px = P15 |
| 3-1   | CAPTIOPISELx | RW   | 0h    | Capacitive Touch I/O pin select. Selects the pin within selected port Px (see CAPTIOPOSELx). Selecting a port pin that is not available on the device in use gives unpredictable results.<br>000b = Px.0<br>001b = Px.1<br>010b = Px.2<br>011b = Px.3<br>100b = Px.4<br>101b = Px.5<br>110b = Px.6<br>111b = Px.7                                                                                                                                                     |
| 0     | Reserved     | R    | 0h    | Reserved. Always reads 0.                                                                                                                                                                                                                                                                                                                                                                                                                                             |

## AES256 Accelerator

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The AES256 accelerator module performs Advanced Encryption Standard (AES) encryption or decryption in hardware. It supports key lengths of 128 bits, 192 bits, and 256 bits. This chapter describes the AES256 accelerator.

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| 14.2 AES Accelerator Operation .....   | 397  |
| 14.3 AES Accelerator Registers .....   | 414  |

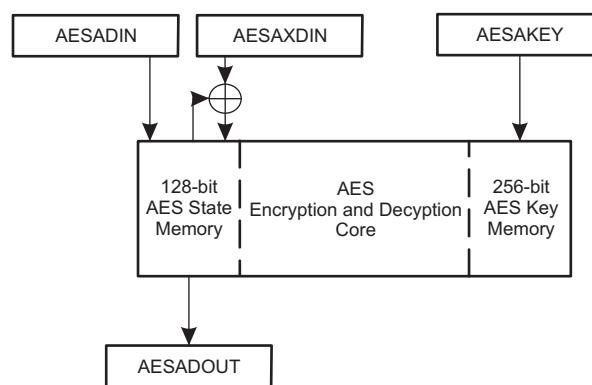
## 14.1 AES Accelerator Introduction

The AES accelerator module performs encryption and decryption of 128-bit data with 128-, 192-, or 256-bit keys according to the advanced encryption standard (AES) (FIPS PUB 197) in hardware.

The AES accelerator features are:

- AES encryption
  - 128 bit in 168 cycles
  - 192 bit in 204 cycles
  - 256 bit in 234 cycles
- AES decryption
  - 128 bit in 168 cycles
  - 192 bit in 206 cycles
  - 256 bit in 234 cycles
- On-the-fly key expansion for encryption and decryption
- Offline key generation for decryption
- Shadow register storing the initial key for all key lengths
- DMA support for ECB, CBC, OFB, and CFB cipher modes
- Byte and word access to key, input data, and output data
- AES ready interrupt flag

The AES accelerator block diagram is shown in [Figure 14-1](#).



**Figure 14-1. AES Accelerator Block Diagram**

## 14.2 AES Accelerator Operation

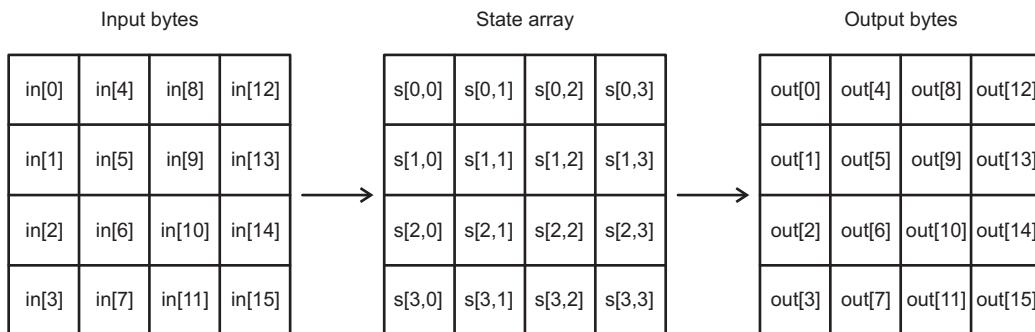
The AES accelerator is configured with user software. The bit AESKLx determines if AES128, AES192, or AES256 is going to be performed. There are four different operation modes available, selectable by the AESOPx bits (see [Table 14-1](#)).

**Table 14-1. AES Operation Modes Overview**

| AESOPx | AESKLx | Operation                                              | Clock Cycles |
|--------|--------|--------------------------------------------------------|--------------|
| 00     | 00     | AES128 encryption                                      | 168          |
|        | 01     | AES192 encryption                                      | 204          |
|        | 10     | AES256 encryption                                      | 234          |
| 01     | 00     | AES128 decryption (with initial roundkey) is performed | 215          |
|        | 01     | AES192 decryption (with initial roundkey) is performed | 255          |
|        | 10     | AES256 decryption (with initial roundkey) is performed | 292          |
| 10     | 00     | AES128 encryption key schedule is performed            | 53           |
|        | 01     | AES192 encryption key schedule is performed            | 57           |
|        | 10     | AES256 encryption key schedule is performed            | 68           |
| 11     | 00     | AES128 (with last roundkey) decryption is performed    | 168          |
|        | 01     | AES192 (with last roundkey) decryption is performed    | 206          |
|        | 10     | AES256 (with last roundkey) decryption is performed    | 234          |

The execution time of the different modes of operation is shown in [Table 14-1](#). While the AES module is operating, the AESBUSY bit is 1. As soon as the operation has finished, the AESRDYIFG bit is set.

Internally, the AES algorithm's operations are performed on a two-dimensional array of bytes called the State. The State consists of four rows of bytes, each containing four bytes, independently if AES128, AES192, or AES256 is performed. The input is assigned to the State array as shown in [Figure 14-2](#), with in[0] being the first data byte written into one of the AES accelerators input registers (AESADIN, AESAXDIN, and AESXIN). The encrypt or decrypt operations are then conducted on the State array, after which its final values can be read from the output with out[0] being the first data byte read from the AES accelerator data output register (AESADOUT).



**Figure 14-2. AES State Array Input and Output**

If an encryption is to be performed, the initial state is called plaintext. If a decryption is to be performed, the initial state is called ciphertext.

The module allows word and byte access to all data registers—AESAKEY, AESADIN, AESAXDIN, AESXIN, and AESADOUT. Word and byte access cannot be mixed while reading from or writing into one of the registers. However, it is possible to write one of the registers using byte access and another using word access.

**NOTE: General Access Restrictions**

While the AES accelerator is busy (AESBUSY = 1):

- AESADOUT always reads as zero.
- The AESDOUTCNTx counter, the AESDOUTRD flag, and the AESDINWR flag are reset.
- Any attempt to change AESOPx, AESKLx, AESDINWR, or AESKEYWR is ignored.
- Writing to AESAKEY, AESADIN, AESAXDIN, or AESAXIN aborts the current operation, the complete module is reset (except for the AESRDYIE, AESOPx, and AESKLx), and the AES error flag AESERRFG is set.

AESADIN, AESAXDIN, AESAXIN, and AESAKEY are write-only registers and always read as zero.

Writing data into AESADIN, AESAXDIN, or AESAXIN influences the content of the corresponding output data; for example, writing in[0] alters out[0], writing in[1] alters out[1], and so on. However, interleaved operation is possible; for example, first reading out[0] and then writing in[0], and continuing with reading out[1] and then writing in[1], and so on. This interleaved operation must be either byte or word access on in[x] and out[x].

**Access Restriction With Cipher Modes Enabled (AESCMEN = 1)**

When cipher modes are enabled (AESCMEN = 1) and a cipher block operation is being processed (AESBLKCNTx > 0), writes to the following bits are ignored, independent of AESBUSY: AESCMEN, AESCMx, AESKLx, AESOPx, and AESBLKCNTx. Writing to AESAKEY aborts the cipher block mode operation if AESBUSY = 1, and the complete module is reset (except for AESRDYIE, AESOPx, and AESKLx).

#### **14.2.1 Load the Key (128-Bit, 192-Bit, or 256-Bit Key Length)**

The key can be loaded by writing to the AESAKEY register or by setting AESKEYWR. Depending on the selected key length (AESKLx), a different number of bits must be loaded:

- If AESKLx = 00, the 128-bit key must be loaded using either 16 byte-writes or 8 word-writes to AESAKEY.
- If AESKLx = 01, the 192-bit key must be loaded using either 24 byte-writes or 12 word-writes to AESAKEY.
- If AESKLx = 10, the 256-bit key must be loaded using either 32 byte-writes or 16 word-writes to AESAKEY.

The key memory is reset after changing the AESKLx.

If a key was loaded previously without changing AESOPx, the AESKEYWR flag is cleared with the first write access to AESAKEY.

If the conversion is triggered without writing a new key, the last key is used. The key must always be written before writing the data.

#### **14.2.2 Load the Data (128-Bit State)**

The state can be loaded by writing to AESADIN, AESAXDIN, or AESAXIN with 16 byte writes or 8 word writes. Do not mix byte and word mode when writing the state. Writing to a mixture of AESADIN, AESAXDIN, and AESAXIN using the same byte or word data format is allowed. When the 16th byte or 8th word of the state is written, AESDINWR is set.

When writing to AESADIN, the corresponding byte or word of the state is overwritten. If AESADIN is used to write the last byte or word of the state, encryption or decryption starts automatically.

When writing to AESAXDIN, the corresponding byte or word is XORed with the current byte or word of the state. If AESAXDIN is used to write the last byte or word of the state, encryption or decryption starts automatically.

Writing to AESAXIN has the same behavior as writing to AESAXDIN: the corresponding byte or word is XORed with the current byte or word of the state; however, writing the last byte or word of the state using AESAXIN does not start encryption or decryption.

#### 14.2.3 Read the Data (128-Bit State)

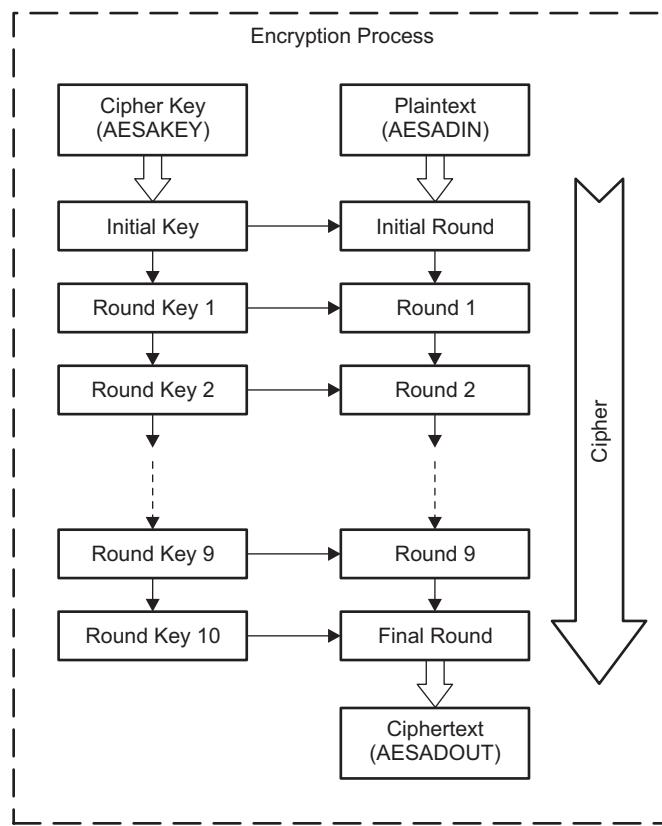
The state can be read if AESBUSY = 0 using 16 byte reads or 8 word reads from AESADOUT. When all 16 bytes are read, the AESDOUTRD flag indicates completion.

#### 14.2.4 Trigger an Encryption or Decryption

The AES module's encrypt or decrypt operations are triggered if the state was completely written in the AESADIN or AESAXDIN registers. Alternatively, the bit AESDINWR can be set to trigger an operation if AESCMEN = 0.

### **14.2.5 Encryption**

Figure 14-3 shows the encryption process with the cipher being a series of transformations that convert the plaintext written into the AESADIN register to a ciphertext that can be read from the AESADOUT register using the cipher key provided in the AESAKEY register.



**Figure 14-3. AES Encryption Process for 128-Bit Key**

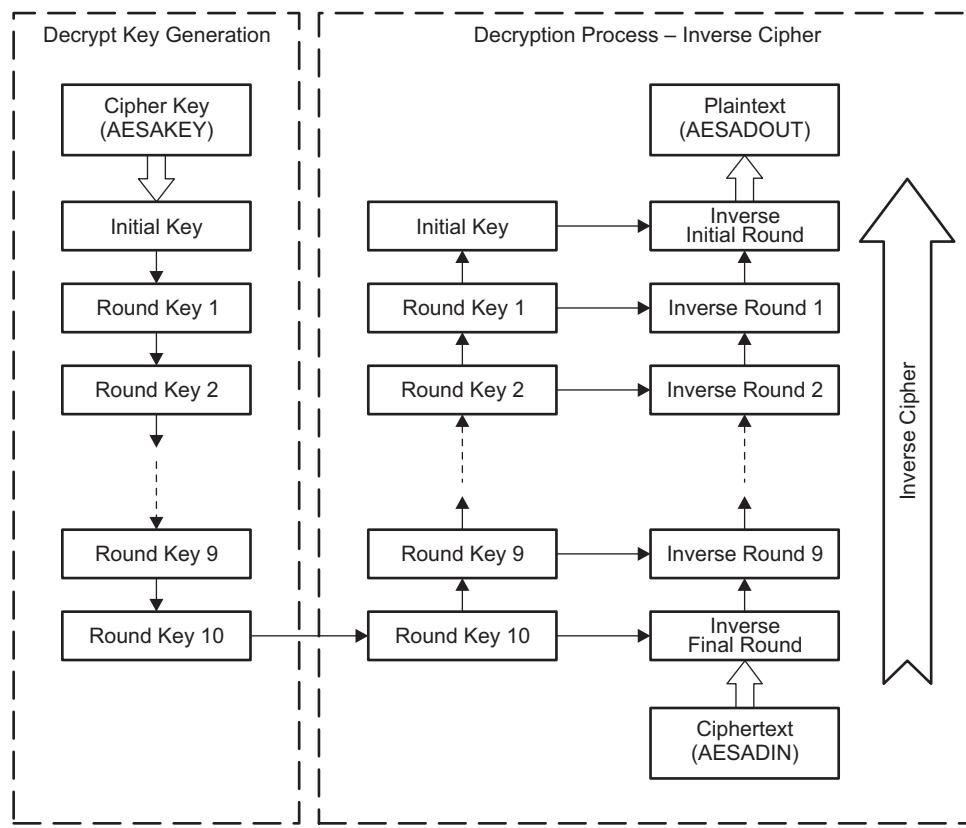
To perform encryption:

1. Set AESOPx = 00 to select encryption. Changing the AESOPx bits clears the AESKEYWR flag, and a new key must be loaded in the next step.
  2. Load the key as described in [Section 14.2.1](#).
  3. Load the state (data) as described in [Section 14.2.2](#). After the data is loaded, the AES module starts the encryption.
  4. After the encryption is ready, the result can be read from AESADOUT as described in [Section 14.2.3](#).
  5. To encrypt additional data with the same key loaded in step 2, write the new data into AESADIN after the results of the operation on the previous data were read from AESADOUT. When an additional 16 data bytes are written, the module automatically starts the encryption using the key loaded in step 2.

When implementing, for example, the output feedback (OFB) cipher block chaining mode, setting the AESDINWR flag triggers the next encryption, and the module starts the encryption using the output data from the previous encryption as the input data.

#### 14.2.6 Decryption

Figure 14-4 shows the decryption process with the inverse cipher being a series of transformations that convert the ciphertext written into the AESADIN register to a plaintext that can be read from the AESADOUT register using the cipher key provided in the AESAKEY register.



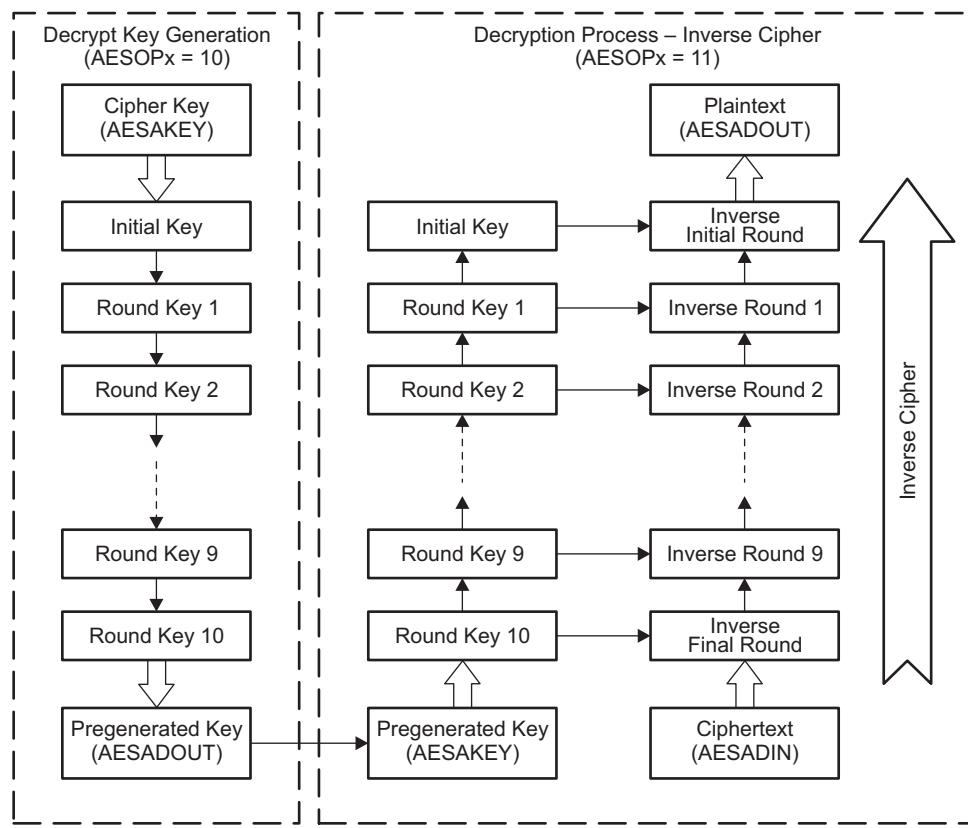
**Figure 14-4. AES Decryption Process Using AESOPx = 01 for 128-Bit Key**

The steps to perform decryption are:

1. Set AESOPx = 01 to select decryption using the same key used for encryption. Set AESOPx = 11 if the first-round key required for decryption (the last roundkey) is already generated and will be loaded in step 2. Changing the AESOPx bits clears the AESKEYWR flag, and a new key must be loaded in step 2.
2. Load the key according to [Section 14.2.1](#).
3. Load the state (data) according to [Section 14.2.2](#). After the data is loaded, the AES module starts the decryption.
4. After the decryption is ready, the result can be read from AESADOUT according to [Section 14.2.3](#).
5. If additional data should be decrypted with the same key loaded in step 2, new data can be written into AESADIN after the results of the operation on the previous data were read from AESADOUT. When additional 16 data bytes are written, the module automatically starts the decryption using the key loaded in step 2.

### 14.2.7 Decryption Key Generation

Figure 14-5 shows the decryption process with a pregenerated decryption key. In this case, the decryption key is calculated first with AESOPx = 10, then the precalculated key can be used together with the decryption operation AESOPx = 11.



**Figure 14-5. AES Decryption Process Using AESOPx = 10 and 11 for 128-bit Key**

To generate the decryption key independent from the actual decryption:

1. Set AESOPx = 10 to select decryption key generation. Changing the AESOPx bits clears the AESKEYWR flag, and a new key must be loaded in step 2.
2. Load the key as described in [Section 14.2.1](#). The generation of the first round key required for decryption is started immediately.
3. While the AES module is performing the key generation, the AESBUSY bit is 1. 53 CPU clock cycles are required to complete the key generation for a 128-bit key (for other key lengths, see [Table 14-1](#)). After its completion, the AESRDYIFG is set, and the result can be read from AESADOUT. When all 16 bytes are read, the AESDOUTRD flag indicates completion.

The AESRDYIFG flag is cleared when reading AESADOUT or writing to AESAKEY or AESADIN.

4. If data should be decrypted with the generated key, AESOPx must be set to 11. Then the generated key must be loaded or, if it was just generated with AESOPx = 10, set the AESKEYWR flag by software to indicate that the key is already valid.
5. See [Section 14.2.6](#) for instructions on the decryption steps, starting from step 3 (load data).

#### 14.2.8 AES Key Buffer

The AES128, AES192, or AES256 algorithm operates not only on the state but also on the key. To avoid the need of reloading the key for each encryption or decryption, a key buffer is included in the AES accelerator.

#### 14.2.9 Using the AES Accelerator With Low-Power Modes

The AES accelerator module provides automatic clock activation for MCLK for use with low-power modes. When the AES accelerator is busy, it automatically activates MCLK, regardless of the control-bit settings for the clock source. The clock remains active until the AES accelerator completes its operation.

The interrupt flag AESRDYIFG is reset after a PUC or with AESSWRST = 1. AESRDYIE is reset after a PUC but is not reset by AESSWRST = 1.

#### 14.2.10 AES Accelerator Interrupts

The AESRDYIFG interrupt flag is set when the AES module completes the selected operation on the provided data. An interrupt request is generated if AESRDYIE and GIE are also set. AESRDYIFG is automatically reset if the AES interrupt is serviced, if AESADOUT is read, or if AESADIN or AESAKEY are written. AESRDYIFG is reset after a PUC or with AESSWRST = 1. AESRDYIE is reset after a PUC but is not reset by AESSWRST = 1.

#### 14.2.11 DMA Operation and Implementing Block Cipher Modes

DMA operation, meaning the implementation of the cipher modes Electronic code book (ECB), Cipher block chaining (CBC), Output feedback (OFB), and Cipher feedback (CFB) using the DMA, supports easy and fast encryption and decryption of more than 128 bits.

When DMA cipher mode support is enabled by setting the AESCMEN bit, the AES256 module triggers 'AES trigger 0', 'AES trigger 1', and 'AES trigger 2' (also called 'AES trigger 0-2') in a certain order to execute different block cipher modes together with the DMA module.

For example, when using ECB encryption with AESCMEN = 1, 'AES trigger 0' is triggered eight times for DMA word access to read out AESADOUT, and then 'AES trigger 1' is triggered eight times to fill the next data into AESADIN. Because the AES modules generates a trigger for each word or byte the single transfer mode of the DMA must be used.

**Table 14-2** shows the behavior of the 'AES trigger 0-2' for the different cipher modes selected by AESCMx.

**Table 14-2. 'AES trigger 0-2' Operation When AESCMEN = 1**

| AESCMx    | AESOPx                 | 'AES trigger 0'                                                                 | 'AES trigger 1'                                                                                                                    | 'AES trigger 2'                                                                                     |
|-----------|------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| 00<br>ECB | 00<br>encryption       | Set after encryption ready, set again until 128 bit are read from AESADOUT      | Set to load the first block and set after 'AES trigger 0' was served the last time, set again until 128 bit are written to AESADIN | not set                                                                                             |
|           | 01 or 11<br>decryption | Set after decryption ready, set again until 128 bit are read from AESADOUT      | Set to load the first block and set after 'AES trigger 0' was served the last time, set again until 128 bit are written to AESADIN | not set                                                                                             |
| 01<br>CBC | 00<br>encryption       | Set after encryption ready, set again until 128 bit are read from AESADOUT      | Set after 'AES trigger 0' was served the last time, set again until 128 bit are written to AESAXDIN                                | not set                                                                                             |
|           | 01 or 11<br>decryption | Set after decryption ready, set again until 128 bit are written to from AESAXIN | Set after 'AES trigger 0' was served the last time, set again until 128 bit are read from AESADOUT                                 | Set after 'AES trigger 1' was served the last time, set again until 128 bit are written to AESADIN  |
| 10<br>OFB | 00<br>encryption       | Set after encryption ready, set again until 128 bit are written to AESAXIN      | Set after 'AES trigger 0' was served the last time, set again until 128 bit are read from AESADOUT                                 | Set after 'AES trigger 1' was served the last time, set again until 128 bit are written to AESAXDIN |
|           | 01 or 11<br>decryption | Set after decryption ready, set again until 128 bit are written to AESAXIN      | Set after 'AES trigger 0' was served the last time, set again until 128 bit are read from AESADOUT                                 | Set after 'AES trigger 1' was served the last time, set again until 128 bit are written to AESAXDIN |
| 11<br>CFB | 00<br>encryption       | Set after encryption ready, set again until 128 bit are written to AESAXIN      | Set after 'AES trigger 0' was served the last time, set again until 128 bit are read from AESADOUT                                 | not set                                                                                             |
|           | 01 or 11<br>decryption | Set after decryption ready, set again until 128 bit are written to AESAXIN      | Set after 'AES trigger 0' was served the last time, set again until 128 bit are read from AESADOUT                                 | Set after 'AES trigger 1' was served the last time, set again until 128 bit are written to AESADIN  |

The retrigerring of the 'AES trigger 0-2' until 128-bit of data are written or read from the corresponding register supports both byte and word access for writing and reading the state through the DMA.

For AESCMEN = 0, no DMA triggers are generated.

The following sections explain the configuration of the AES module for automatic cipher mode execution using DMA.

It is assumed that the key is written by software (or by a separate DMA transfer) before writing the first block to the AES state. The key shadow register always restores the original key, so that there is no need to reload it. The AESAKEY register should not be written after AESBLKCNTx is written to a non-zero value.

The number of blocks to be encrypted or decrypted must be programmed into the AESBLKCNTx bits before writing the first data. Writing a non-zero value into AESBLKCNTx starts the cipher mode sequence and, thus, AESBLKCNTx must be written after the DMA channels are configured.

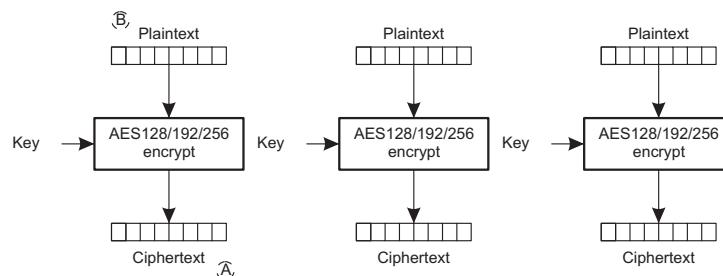
Throughout these sections, the different DMA channels are called DMA\_A, DMA\_B, and so on. In the figures, these letters appear in dotted circles showing which operation is going to be executed by which DMA channel. The DMA counter must be loaded with a multiple of 8 for word mode or a multiple of 16 for byte mode and the single transfer mode of the DMA must be selected. The DMA priorities of DMA\_A, DMA\_B, and DMA\_C do not play any role but static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

#### 14.2.11.1 Electronic Codebook (ECB) Mode

The electronic codebook block cipher mode is the most simple cipher mode. The data is divided into 128-bit blocks and encrypted and decrypted separately.

The disadvantage of the ECB is that the same 128-bit plaintext is always encrypted to the same ciphertext, whereas the other modes encrypt each block differently, partly dependent on the already executed encryptions.

##### 14.2.11.1.1 ECB Encryption



**Figure 14-6. ECB Encryption**

To implement the ECB encryption without CPU interaction, two DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-3. AES and DMA Configuration for ECB Encryption**

| AES CMEN | AES CMx | AES OPx | DMA_A<br>Triggered by 'AES trigger 0' | DMA_B<br>Triggered by 'AES trigger 1'                               |
|----------|---------|---------|---------------------------------------|---------------------------------------------------------------------|
| 1        | 00      | 00      | Read ciphertext from AESADOUT         | Write plaintext to AESADIN, which also triggers the next encryption |

The following pseudo code snippet shows the implementation of the ECB encryption in software:

```

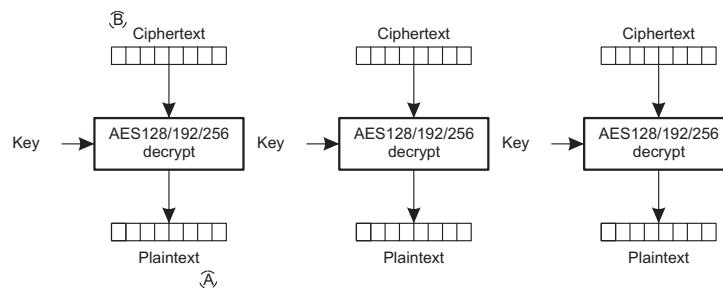
ECB_Encryption(key, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Configure AES for block cipher:
    AESCMEN= 1; AESCMx= ECB; AESOPx= 00;

    Write key into AESAKEY;
    Setup DMA:
        DMA0: Triggered by AES trigger 0,
            Source: AESADOUT, Destination: ciphertext,
            Size: num_blocks*8 words, Single Transfer mode
        DMA1: Triggered by AES trigger 1,
            Source: plaintext, Destination: AESADIN,
            Size: num_blocks*8 words, Single Transfer mode

    Start encryption:
    AESBLKCNT= num_blocks;

    End of encryption: DMA0IFG=1
}
  
```

#### 14.2.11.1.2 ECB Decryption



**Figure 14-7. ECB Decryption**

To implement the ECB decryption without CPU interaction, two DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-4. AES DMA Configuration for ECB Decryption**

| AES CMEN | AES CMx | AES OPx  | DMA_A Triggered by 'AES trigger 0' | DMA_B Triggered by 'AES trigger 1'                                   |
|----------|---------|----------|------------------------------------|----------------------------------------------------------------------|
| 1        | 00      | 01 or 11 | Read plaintext from AESADOUT       | Write ciphertext to AESADIN, which also triggers the next decryption |

The following pseudo code snippet shows the implementation of the ECB decryption in software:

```

ECB_Decryption(key, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Generate Decrypt Key
    Configure AES:
        AESCMEN= 0; AESOPx= 10;
        Write key into AESKEY;
        Wait until key generation completed.

    Configure AES for block cipher:
        AESCMEN= 1; AESCMx= ECB; AESOPx= 11;
        AESKEYWR= 1; // Use previously generated key

    Setup DMA:
        DMA0: Triggered by AES trigger 0,
            Source: AESADOUT, Destination: plaintext,
            Size: num_blocks*8 words, Single Transfer mode
        DMA1: Triggered by AES trigger 1,
            Source: ciphertext, Destination: AESADIN,
            Size: num_blocks*8 words, Single Transfer mode

    Start decryption:
        AESBLKCNT= num_blocks;

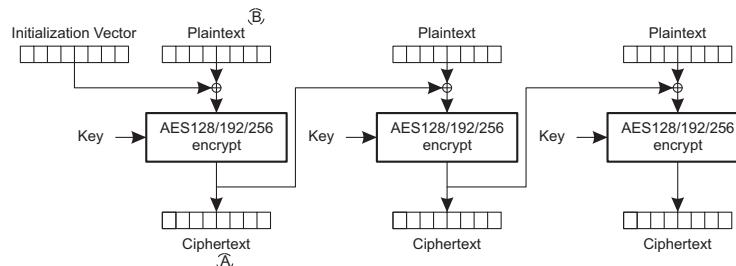
    End of decryption: DMA0IFG=1
}
  
```

### 14.2.11.2 Cipher Block Chaining (CBC) Mode

The cipher block chaining cipher mode always performs an XOR on the ciphertext of the previous block with the current block. Therefore, the encryption of each block depends not only on the key but also on the previous encryption.

#### 14.2.11.2.1 CBC Encryption

For encryption, the initialization vector must be loaded by software (or by a separate DMA transfer) into AESXIN before the DMA can be enabled to write the first 16 bytes of the plaintext into AESAXDIN



**Figure 14-8. CBC Encryption**

To implement the CBC encryption without CPU interaction, two DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-5. AES and DMA Configuration for CBC Encryption**

| AES CMEN | AES CMx | AES OPx | DMA_A Triggered by 'AES trigger 0' | DMA_B Triggered by 'AES trigger 1'                                   |
|----------|---------|---------|------------------------------------|----------------------------------------------------------------------|
| 1        | 01      | 00      | Read ciphertext from AESADOUT      | Write plaintext to AESAXDIN, which also triggers the next encryption |

The following pseudo code snippet shows the implementation of the CBC encryption in software:

```
CBC_Encryption(key, IV, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Reset AES Module (clears internal state memory):
    AECSRST= 1;
    Configure AES for block cipher:
    AESCMEN= 1; AESCMx= CBC; AESOPx= 00;

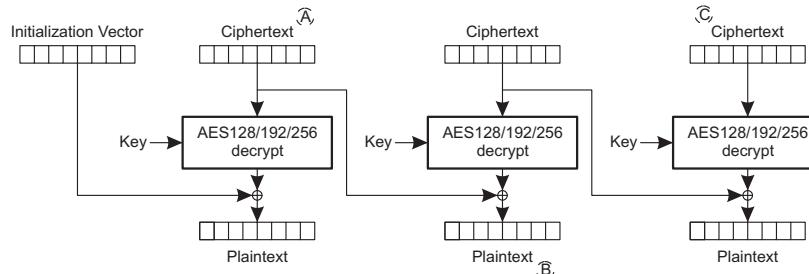
    Write key into AESKEY;
    Write IV into AESXIN; // Does not trigger encryption.
                           // Assumes that state is reset (=> XORing with Zeros).
    Setup DMA:
        DMA0: Triggered by AES trigger 0,
              Source: AESADOUT, Destination: ciphertext,
              Size: num_blocks*8 words, Single Transfer mode
        DMA1: Triggered by AES trigger 1,
              Source: plaintext, Destination: AESAXDIN,
              Size: num_blocks*8 words, Single Transfer mode

    Start encryption:
    AESBLKCNT= num_blocks;

    End of encryption: DMA0IFG=1
}
```

### 14.2.11.2.2 CBC Decryption

For CBC decryption, the first block of data needs some special handling because the output must be XORed with the Initialization Vector. For that purpose, the DMA triggered by 'AES trigger 0' must be configured to read the data from the Initialization Vector first and then must be reconfigured to read from the ciphertext.



**Figure 14-9. CBC Decryption**

To implement the CBC decryption without CPU interaction, three DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-6. AES and DMA Configuration for CBC Decryption**

| AES CMEN | AES CMx | AES OPx  | DMA_A Triggered by 'AES trigger 0'             | DMA_B Triggered by 'AES trigger 1' | DMA_C Triggered by 'AES trigger 2'                                       |
|----------|---------|----------|------------------------------------------------|------------------------------------|--------------------------------------------------------------------------|
| 1        | 01      | 01 or 11 | Write the previous ciphertext block to AESAXIN | Read plaintext from AESADOUT       | Write next plaintext to AESADIN, which also triggers the next decryption |

The following pseudo code snippet shows the implementation of the CBC decryption in software:

```

CBC_Decryption(key, IV, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Generate Decrypt Key:
    Configure AES:
        AESCMEN= 0; AESOPx= 10;
        Write key into AESAKEY;
        Wait until key generation completed;

    Configure AES for block cipher:
        AESCMEN= 1; AESCMx= CBC; AESOPx= 11;
        AESKEYWR= 1; // Use previously generated key

    Setup DMA:
        DMA0: Triggered by AES trigger 0,
              Source: IV, Destination: AESAXIN,
              Size: 8 words, Single Transfer mode
        DMA1: Triggered by AES trigger 1,
              Source: AESADOUT, Destination: plaintext,
              Size: num_blocks*8 words, Single Transfer mode
        DMA2: Triggered by AES trigger 2,
              Source: ciphertext, Destination: AESADIN,
              Size: num_blocks*8 words, Single Transfer mode

    Start decryption:
        AESBLKCNT= num_blocks;

    Wait until first block is decrypted: DMA0IFG=1;

    Setup DMA0 for further blocks:
        DMA0: // Write previous cipher text into AES module
              Triggered by AES trigger 0,

```

```
Source: ciphertext, Destination: AESAXIN,  
Size: (num_blocks-1)*8 words, Single Transfer mode
```

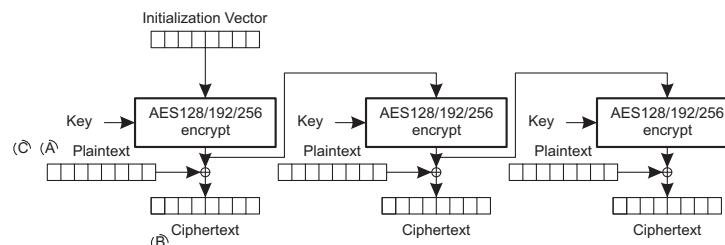
```
End of decryption: DMA1IFG=1  
}
```

### 14.2.11.3 Output Feedback (OFB) Mode

The output feedback cipher mode continuously encrypts the initialization vector. The ciphertext is generated by XORing the corresponding plaintext with the encrypted initialization vector.

The initialization vector must be loaded by software (or by a separate DMA transfer).

#### 14.2.11.3.1 OFB Encryption



**Figure 14-10. OFB Encryption**

To implement the OFB encryption without CPU interaction, three DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-7. AES and DMA Configuration for OFB Encryption**

| AES CMEN | AES CMx | AES OPx | DMA_A<br>Triggered by 'AES trigger 0'               | DMA_B<br>Triggered by 'AES trigger 1' | DMA_C<br>Triggered by 'AES trigger 2'                                                         |
|----------|---------|---------|-----------------------------------------------------|---------------------------------------|-----------------------------------------------------------------------------------------------|
| 1        | 10      | 00      | Write the plaintext of the current block to AESAXIN | Read ciphertext from AESADOUT         | Write the plaintext of the current block to AESAXDIN, which also triggers the next encryption |

The following pseudo code snippet shows the implementation of the OFB encryption in software:

```

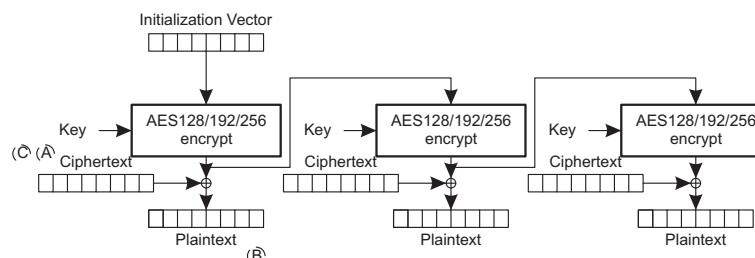
OFB_Encryption(Key, IV, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Reset AES Module (clears internal state memory):
    AESSWRST= 1;
    Configure AES:
    AESCMEN= 1; AESCMx= OFB; AESOPx= 00;

    Write Key into AESAKEY;
    Write IV into AESAXIN; // Does not trigger encryption.
                           // Assumes that state is reset (=> XORing with Zeros).
    Setup DMA:
    DMA0: Triggered by AES trigger 0,
          Source: plaintext, Destination: AESAXIN,
          Size: num_blocks*8 words, Single Transfer mode
    DMA1: Triggered by AES trigger 1,
          Source: AESADOUT, Destination: ciphertext,
          Size: num_blocks*8 words, Single Transfer mode
    DMA2: Triggered by AES trigger 2,
          Source: plaintext, Destination: AESAXDIN,
          Size: num_blocks*8 words, Single Transfer mode

    Start encryption:
    AESBLKCNT= num_blocks;
    Trigger encryption by setting AESDINWR= 1;

    End of encryption: DMA1IFG=1
}
  
```

#### 14.2.11.3.2 OFB Decryption



**Figure 14-11. OFB Decryption**

To implement the OFB decryption without CPU interaction, three DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-8. AES and DMA Configuration for OFB Decryption**

| AES CMEN | AES CMx | AES OPx                    | DMA_A<br>Triggered by 'AES trigger 0'                | DMA_B<br>Triggered by 'AES trigger 1' | DMA_C<br>Triggered by 'AES trigger 2'                                                          |
|----------|---------|----------------------------|------------------------------------------------------|---------------------------------------|------------------------------------------------------------------------------------------------|
| 1        | 10      | 01 or<br><sup>(1)</sup> 11 | Write the ciphertext of the current block to AESAXIN | Read plaintext from AESADOUT          | Write the ciphertext of the current block to AESAXDIN, which also triggers the next encryption |

<sup>(1)</sup> Note, in this cipher mode, the decryption also uses AES encryption on block level, thus the key used for decryption is identical with the key used for encryption; therefore, no decryption key generation is required.

The following pseudo code snippet shows the implementation of the OFB decryption in software:

```

OFB_Decryption(Key, IV, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Reset AES Module (clears internal state memory):
    AECSRST= 1;
    Configure AES:
    AESCMEN= 1; AESCMx= OFB; AESOPx= 01;

    Write Key into AESAKEY;
    Write IV into AESAXIN; // Does not trigger encryption.
                           // Assumes that state is reset (=> XORing with Zeros).

    Setup DMA:
    DMA0: Triggered by AES trigger 0,
          Source: ciphertext, Destination: AESAXIN,
          Size: num_blocks*8 words, Single Transfer mode
    DMA1: Triggered by AES trigger 1,
          Source: AESADOUT, Destination: plaintext,
          Size: num_blocks*8 words, Single Transfer mode
    DMA2: Triggered by AES trigger 2,
          Source: ciphertext, Destination: AESAXDIN,
          Size: num_blocks*8 words, Single Transfer mode

    Start decryption:
    AESBLKCNT= num_blocks;
    Trigger decryption by setting AESDINWR= 1;

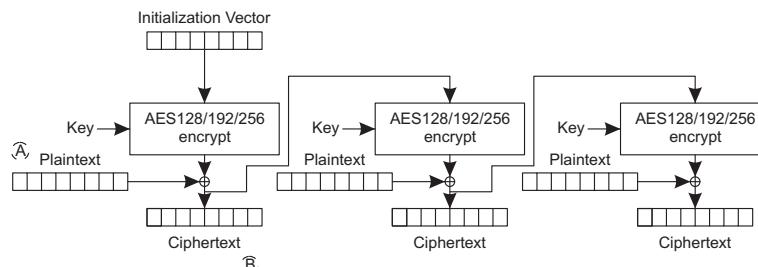
    End of decryption: DMA1IFG=1
}
  
```

#### 14.2.11.4 Cipher Feedback (CFB) Mode

In the cipher feedback cipher mode, the plaintext of the new block is XORed to the last encryption result. The result of the encryption is the input for the new encryption.

The initialization vector must be loaded by software (or by a separate DMA transfer).

##### 14.2.11.4.1 CFB Encryption



**Figure 14-12. CFB Encryption**

To implement the CFB encryption without CPU interaction, two DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-9. AES and DMA Configuration for CFB Encryption**

| AES CMEN | AES CMx | AES OPx | DMA_A Triggered by 'AES trigger 0'                  | DMA_B Triggered by 'AES trigger 1'                                         |
|----------|---------|---------|-----------------------------------------------------|----------------------------------------------------------------------------|
| 1        | 11      | 00      | Write the plaintext of the current block to AESAXIN | Read the ciphertext from AESADOUT, which also triggers the next encryption |

The following pseudo code snippet shows the implementation of the CFB encryption in software:

```

CFB_Encryption(Key, IV, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Reset AES Module (clears internal state memory):
    AECSRST= 1;
    Configure AES:
    AESCMEN= 1; AESCMx= CFB; AESOPx= 00;

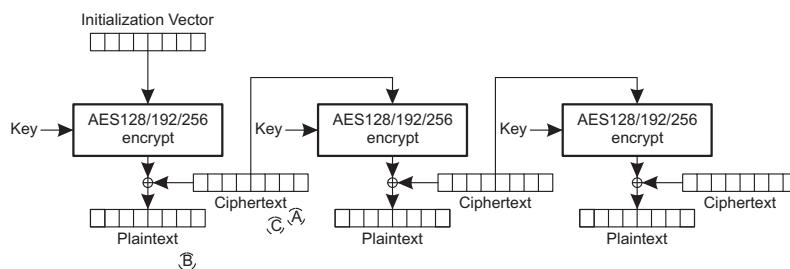
    Write Key into AESAKEY;
    Write IV into AESAXIN; // Does not trigger encryption.
                           // Assumes that state is reset (=> XORing with Zeros).
    Setup DMA:
    DMA0: Triggered by AES trigger 0,
          Source: plaintext, Destination: AESAXIN,
          Size: num_blocks*8 words, Single Transfer mode
    DMA1: Triggered by AES trigger 1,
          Source: AESADOUT, Destination: ciphertext,
          Size: num_blocks*8 words, Single Transfer mode

    Start encryption:
    AESBLKcnt= num_blocks;
    Trigger encryption by setting AESDINWR= 1;

    End of encryption: DMA1IFG=1
}

```

#### 14.2.11.4.2 CFB Decryption



**Figure 14-13. CFB Decryption**

To implement the CFB decryption without CPU interaction, three DMA channels are needed. Static DMA priorities must be enabled. The DMA triggers must be configured as level-sensitive triggers.

**Table 14-10. AES and DMA Configuration for CFB Decryption**

| AES CMEN | AES CMx | AES OPx                 | DMA_A<br>Triggered by 'AES trigger 0'                | DMA_B<br>Triggered by 'AES trigger 1' | DMA_C<br>Triggered by 'AES trigger 2'                                                         |
|----------|---------|-------------------------|------------------------------------------------------|---------------------------------------|-----------------------------------------------------------------------------------------------|
| 1        | 11      | 01 or 11 <sup>(1)</sup> | Write the ciphertext of the current block to AESAXIN | Read the plaintext from AESADOUT      | Write the ciphertext of the current block to AESADIN, which also triggers the next encryption |

<sup>(1)</sup> Note, in this cipher mode, the decryption also uses AES encryption on block level thus the key used for decryption is identical with the key used for encryption; therefore, no decryption key generation is required.

The following pseudo code snippets shows the implementation of the CFB encryption and decryption in software:

```

CFB_Decryption(Key, IV, plaintext, ciphertext, num_blocks)
// Pseudo Code
{
    Reset AES Module (clears internal state memory):
    AESWRST= 1;
    Configure AES:
    AESCMEN= 1; AESCMx= CFB; AESOPx= 01;

    Write Key into AESAKEY;
    Write IV into AESAXIN; // Does not trigger encryption.
                           // Assumes that state is reset (=> XORing with Zeros).
    Setup DMA:
    DMA0: Triggered by AES trigger 0,
           Source: ciphertext, Destination: AESAXIN,
           Size: num_blocks*8 words, Single Transfer mode
    DMA1: Triggered by AES trigger 1,
           Source: AESADOUT, Destination: plaintext,
           Size: num_blocks*8 words, Single Transfer mode
    DMA2: Triggered by AES trigger 2,
           Source: ciphertext, Destination: AESADIN,
           Size: num_blocks*8 words, Single Transfer mode

    Start decryption:
    AESBLKCNT= num_blocks;
    Trigger decryption by setting AESDINWR= 1;

    End of decryption: DMA1IFG=1
}

```

## 14.3 AES Accelerator Registers

[Table 14-11](#) shows the memory-mapped registers for the AES256 module with their address offsets. See the device-specific data sheet for the base memory address of these registers. All other register offset addresses not listed in [Table 14-11](#) should be considered as reserved locations, and the register contents should not be modified.

**Table 14-11. AES256 Registers**

| Offset | Acronym  | Register Name                                       | Type       | Access | Reset | Section                        |
|--------|----------|-----------------------------------------------------|------------|--------|-------|--------------------------------|
| 00h    | AESACTL0 | AES accelerator control register 0                  | Read/write | Word   | 00h   | <a href="#">Section 14.3.1</a> |
| 02h    | AESACTL1 | AES accelerator control register 1                  | Read/write | Word   | 00h   | <a href="#">Section 14.3.2</a> |
| 04h    | AESASTAT | AES accelerator status register                     | Read only  | Word   | 00h   | <a href="#">Section 14.3.3</a> |
| 06h    | AESAKEY  | AES accelerator key register                        | Read/write | Word   | 00h   | <a href="#">Section 14.3.4</a> |
| 08h    | AESADIN  | AES accelerator data in register                    | Write only | Word   | 00h   | <a href="#">Section 14.3.5</a> |
| 0Ah    | AESADOUT | AES accelerator data out register                   | Read/write | Word   | 00h   | <a href="#">Section 14.3.6</a> |
| 0Ch    | AESAXDIN | AES accelerator XORed data in register              | Write only | Word   | 00h   | <a href="#">Section 14.3.7</a> |
| 0Eh    | AESAXIN  | AES accelerator XORed data in register (no trigger) | Write only | Word   | 00h   | <a href="#">Section 14.3.8</a> |

### 14.3.1 AESACTL0 Register

AES Accelerator Control Register 0

**Figure 14-14. AESACTL0 Register**

| 15       | 14       | 13 | 12       | 11       | 10       | 9      | 8         |
|----------|----------|----|----------|----------|----------|--------|-----------|
| AESCMEN  | Reserved |    | AESRDYIE | AESERRFG | Reserved |        | AESRDYIFG |
| rw-0     | r0       | r0 | rw-0     | rw-0     | r0       | r0     | rw-0      |
| 7        | 6        | 5  | 4        | 3        | 2        | 1      | 0         |
| AESSWRST | AESCMx   |    | Reserved | AESKLx   |          | AESOPx |           |
| rw-0     | r0       | r0 | r0       | rw-0     | r0       | rw-0   | rw-0      |

Writes are ignored when AESCMEN = 1 and AESBLKCNTx > 0.

**Table 14-12. AESACTL0 Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                         |
|-------|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | AESCMEN   | RW   | 0h    | AESCMEN enables the support of the cipher modes ECB, CBC, OFB and CFB together with the DMA. Writes are ignored when AESCMEN = 1 and AESBLKCNTx > 0.<br>0 = No DMA triggers are generated<br>1 = DMA cipher mode support operation is enabled and the corresponding DMA triggers are generated.                                     |
| 14-13 | Reserved  | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                            |
| 12    | AESRDYIE  | RW   | 0h    | AES ready interrupt enable. AESRDYIE is not reset by AESSWRST = 1.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                                             |
| 11    | AESERRFG  | RW   | 0h    | AES error flag. AESAKEY or AESADIN were written while an AES operation was in progress. The bit must be cleared by software.<br>0b = No error<br>1b = Error occurred                                                                                                                                                                |
| 10-9  | Reserved  | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                            |
| 8     | AESRDYIFG | RW   | 0h    | AES ready interrupt flag. Set when the selected AES operation was completed and the result can be read from AESADOUT. Automatically cleared when AESADOUT is read or AESAKEY or AESADIN is written.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                          |
| 7     | AESSWRST  | RW   | 0h    | AES software reset. Immediately resets the complete AES accelerator module even when busy except for the AESRDYIE, the AESKLx and the AESOPx bits. It also clears the (internal) state memory.<br>The AESSWRST bit is automatically reset and is always read as zero.<br>0b = No reset<br>1b = Reset AES accelerator module         |
| 6-5   | AESCMx    | RW   | 0h    | AES cipher mode select. These bits are ignored for AESCMEN = 0. Writes are ignored when AESCMEN = 1 and AESBLKCNTx > 0.<br>00b = ECB<br>01b = CBC<br>10b = OFB<br>11b = CFB                                                                                                                                                         |
| 4     | Reserved  | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                            |
| 3-2   | AESKLx    | RW   | 0h    | AES key length. These bits define which of the 3 AES standards is performed. The AESKLx bits are not reset by AESSWRST = 1. Writes are ignored when AESCMEN = 1 and AESBLKCNTx > 0.<br>00b = AES128. The key size is 128 bit.<br>01b = AES192. The key size is 192 bit.<br>10b = AES256. The key size is 256 bit.<br>11b = Reserved |

**Table 14-12. AESACTL0 Register Description (continued)**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                          |
|-----|--------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-0 | AESOPx | RW   | 0h    | <p>AES operation. The AESOPx bits are not reset by AECCRST = 1. Writes are ignored when AESCMEN = 1 and AESBLKCNTx &gt; 0.</p> <p>00b = Encryption<br/>     01b = Decryption. The provided key is the same key used for encryption.<br/>     10b = Generate first round key required for decryption.<br/>     11b = Decryption. The provided key is the first round key required for decryption.</p> |

### **14.3.2 AESACTL1 Register**

AES Accelerator Control Register 1

**Figure 14-15. AESACTL1 Register**

|            |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|
| 15         | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| Reserved   |      |      |      |      |      |      |      |
| r0         | r0   | r0   | r0   | r0   | r0   | r0   | r0   |
| 7          | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
| AESBLKCNTx |      |      |      |      |      |      |      |
| rw-0       | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

Writes are ignored when AESCMEN = 1 and AESBLKCNTx > 0.

**Table 14-13. AESACTL1 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                         |
|------|------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved   | R    | 0h    | Reserved. Always reads 0.                                                                                                                                                                                                                                                           |
| 7-0  | AESBLKCNTx | RW   | 0h    | Cipher Block Counter. Number of blocks to be encrypted or decrypted with block cipher modes enabled (AESCMEN = 1). Ignored if AESCMEN = 0.<br>The block counter decrements with each performed encryption or decryption.<br>Writes are ignored when AESCMEN = 1 and AESBLKCNTx > 0. |

### 14.3.3 AESASTAT Register

AES Accelerator Status Register

**Figure 14-16. AESASTAT Register**

| 15          | 14  | 13  | 12  | 11         | 10       | 9       | 8       |
|-------------|-----|-----|-----|------------|----------|---------|---------|
| AESDOUTCNTx |     |     |     | AESDINCNTx |          |         |         |
| r-0         | r-0 | r-0 | r-0 | r-0        | r-0      | r-0     | r-0     |
| 7           | 6   | 5   | 4   | 3          | 2        | 1       | 0       |
| AESKEYCNTx  |     |     |     | AESDOUTRD  | AESDINWR | AEKEYWR | AESBUSY |
| r-0         | r-0 | r-0 | r-0 | r-0        | rw-0     | rw-0    | r-0     |

**Table 14-14. AESASTAT Register Description**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------|-------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | AESDOUTCNTx | R    | 0h    | Bytes read from AESADOUT. Reset when AESDOUTRD is reset.<br>If AESDOUTCNTx = 0 and AESDOUTRD = 0, no bytes were read.<br>If AESDOUTCNTx = 0 and AESDOUTRD = 1, all bytes were read.                                                                                                                                                                                                                                                                                                                               |
| 11-8  | AESDINCNTx  | R    | 0h    | Bytes written to AESADIN, AESAXDIN or AESAXIN. Reset when AESDINWR is reset.<br>If AESDINCNTx = 0 and AESDINWR = 0, no bytes were written.<br>If AESDINCNTx = 0 and AESDINWR = 1, all bytes were written.                                                                                                                                                                                                                                                                                                         |
| 7-4   | AESKEYCNTx  | R    | 0h    | Bytes written to AESAKEY for AESKLx = 00, words written to AESAKEY if AESKLx = 01, 10, 11. Reset when AEKEYWR is reset.<br>If AESKEYCNTx = 0 and AEKEYWR = 0, no bytes were written.<br>If AESKEYCNTx = 0 and AEKEYWR = 1, all bytes were written.                                                                                                                                                                                                                                                                |
| 3     | AESDOUTRD   | R    | 0h    | All 16 bytes read from AESADOUT. AESDOUTRD is reset by PUC, AECSRST, an error condition, changing AESOPx, changing AESKLx, when the AES accelerator is busy, and when the output data is read again.<br>0 = Not all bytes read<br>1 = All bytes read                                                                                                                                                                                                                                                              |
| 2     | AESDINWR    | RW   | 0h    | All 16 bytes written to AESADIN, AESAXDIN or AESAXIN. Changing its state by software also resets the AESDINCNTx bits.<br>AESDINWR is reset by PUC, AECSRST, an error condition, changing AESOPx, changing AESKLx, the start to (over)write the data, and when the AES accelerator is busy. Because it is reset when AESOPx or AESKLx is changed it can be set by software again to indicate that the current data is still valid.<br>0 = Not all bytes written<br>1 = All bytes written                           |
| 1     | AEKEYWR     | RW   | 0h    | All 16 bytes written to AESAKEY. This bit can be modified by software but it must not be reset by software (1→0) if AESCMEN=1. Changing its state by software also resets the AESKEYCNTx bits.<br>AEKEYWR is reset by PUC, AECSRST, an error condition, changing AESOPx, changing AESKLx, and the start to (over)write a new key. Because it is reset when AESOPx is changed it can be set by software again to indicate that the loaded key is still valid<br>0 = Not all bytes written<br>1 = All bytes written |
| 0     | AESBUSY     | R    | 0h    | AES accelerator module busy; encryption, decryption, or key generation in progress.<br>0 = Not busy<br>1 = Busy                                                                                                                                                                                                                                                                                                                                                                                                   |

#### **14.3.4 AESAKEY Register**

AES Accelerator Key Register

**Figure 14-17. AESAKEY Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| AESKEY1x |     |     |     |     |     |     |     |
| w-0      | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |
| 7        | 6   | 5   | 4   | 3   | 2   | 1   | 0   |
| AESKEY0x |     |     |     |     |     |     |     |
| w-0      | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |

**Table 14-15. AESAKEY Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                             |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | AESKEY1x | W    | 0h    | AES key byte n+1 when AESAKEY is written as word. Do not use these bits for byte access. Do not mix word and byte access. Always reads as zero. The key is reset by PUC or by AESSWRST = 1.             |
| 7-0  | AESKEY0x | W    | 0h    | AES key byte n when AESAKEY is written as word. AES next key byte when AESAKEY_L is written as byte. Do not mix word and byte access. Always reads as zero. The key is reset by PUC or by AESSWRST = 1. |

### 14.3.5 AESADIN Register

AES Accelerator Data In Register

**Figure 14-18. AESADIN Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| AESDIN1x |     |     |     |     |     |     |     |
| w-0      | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |
| 7        | 6   | 5   | 4   | 3   | 2   | 1   | 0   |
| AESDIN0x |     |     |     |     |     |     |     |
| w-0      | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |

**Table 14-16. AESADIN Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                         |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | AESDIN1x | W    | 0h    | AES data in byte n+1 when AESADIN is written as word. Do not use these bits for byte access. Do not mix word and byte access. Always reads as zero.                 |
| 7-0  | AESDIN0x | W    | 0h    | AES data in byte n when AESADIN is written as word. AES next data in byte when AESADIN_L is written as byte. Do not mix word and byte access. Always reads as zero. |

#### **14.3.6 AESADOUT Register**

AES Accelerator Data Out Register

**Figure 14-19. AESADOUT Register**

|           |     |     |     |     |     |     |     |
|-----------|-----|-----|-----|-----|-----|-----|-----|
| 15        | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| AESDOUT1x |     |     |     |     |     |     |     |
| r-0       | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| 7         | 6   | 5   | 4   | 3   | 2   | 1   | 0   |
| AESDOUT0x |     |     |     |     |     |     |     |
| r-0       | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |

**Table 14-17. AESADOUT Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                 |
|------|-----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | AESDOUT1x | R    | 0h    | AES data out byte n+1 when AESADOUT is read as word. Do not use these bits for byte access. Do not mix word and byte access.                |
| 7-0  | AESDOUT0x | R    | 0h    | AES data out byte n when AESADOUT is read as word. AES next data out byte when AESADOUT_L is read as byte. Do not mix word and byte access. |

#### 14.3.7 AESAXDIN Register

AES Accelerator XORed Data In Register

**Figure 14-20. AESAXDIN Register**

|           |     |     |     |     |     |     |     |
|-----------|-----|-----|-----|-----|-----|-----|-----|
| 15        | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| AESXDIN1x |     |     |     |     |     |     |     |
| w-0       | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |
| 7         | 6   | 5   | 4   | 3   | 2   | 1   | 0   |
| AESXDIN0x |     |     |     |     |     |     |     |
| w-0       | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |

**Table 14-18. AESAXDIN Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                           |
|------|-----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | AESXDIN1x | W    | 0h    | AES data in byte n+1 when AESAXDIN is written as word. Do not use these bits for byte access. Do not mix word and byte access. Always reads as zero.                  |
| 7-0  | AESXDIN0x | W    | 0h    | AES data in byte n when AESAXDIN is written as word. AES next data in byte when AESAXDIN_L is written as byte. Do not mix word and byte access. Always reads as zero. |

### **14.3.8 AESAXIN Register**

AES Accelerator XORed Data In Register (No Trigger)

**Figure 14-21. AESAXIN Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| AESXIN1x |     |     |     |     |     |     |     |
| w-0      | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |
| 7        | 6   | 5   | 4   | 3   | 2   | 1   | 0   |
| AESXIN0x |     |     |     |     |     |     |     |
| w-0      | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 | w-0 |

**Table 14-19. AESAXIN Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                         |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | AESXIN1x | W    | 0h    | AES data in byte n+1 when AESAXIN is written as word. Do not use these bits for byte access. Do not mix word and byte access. Always reads as zero.                 |
| 7-0  | AESXIN0x | W    | 0h    | AES data in byte n when AESAXIN is written as word. AES next data in byte when AESAXIN_L is written as byte. Do not mix word and byte access. Always reads as zero. |

## CRC Module

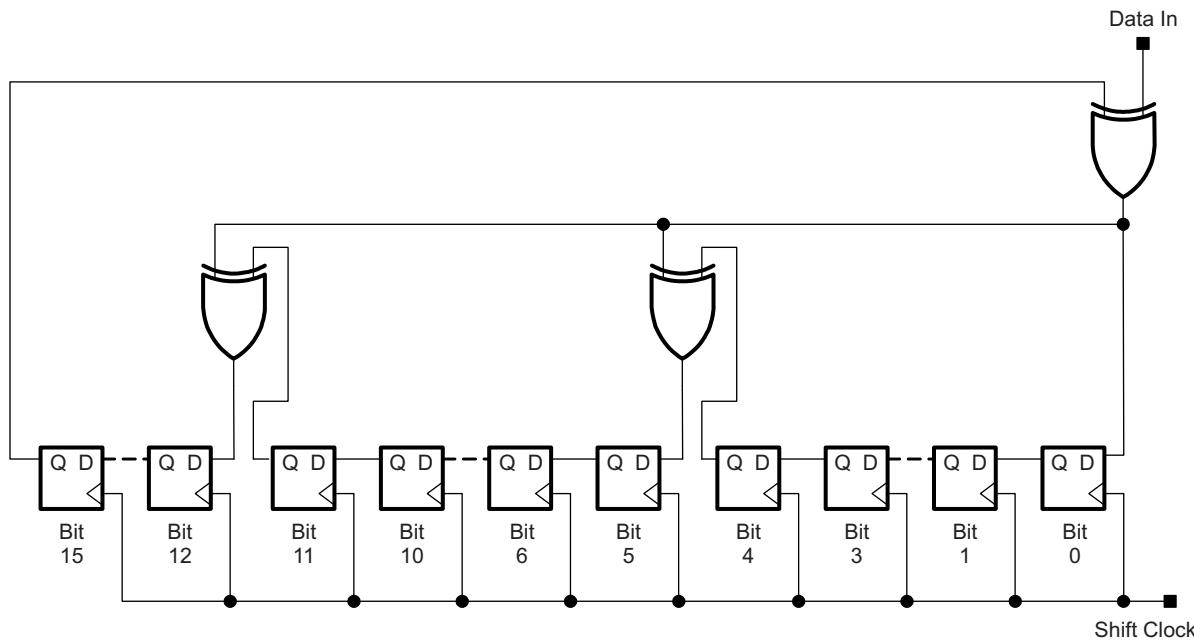
The cyclic redundancy check (CRC) module provides a signature for a given data sequence. This chapter describes the operation and use of the CRC module.

| Topic                                                       | Page |
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## 15.1 Cyclic Redundancy Check (CRC) Module Introduction

The CRC module produces a signature for a given sequence of data values. The signature is generated through a feedback path from data bits 0, 4, 11, and 15 (see Figure 15-1). The CRC signature is based on the polynomial given in the CRC-CCITT-BR polynomial (see Equation 10).

$$f(x) = x^{16} + x^{12} + x^5 + 1 \quad (10)$$



**Figure 15-1. LFSR Implementation of CRC-CCITT Standard, Bit 0 is the MSB of the Result**

Identical input data sequences result in identical signatures when the CRC is initialized with a fixed seed value, whereas different sequences of input data, in general, result in different signatures.

## 15.2 CRC Standard and Bit Order

The definitions of the various CRC standards were done in the era of main frame computers, and by convention bit 0 was treated as the MSB. Today, as in most microcontrollers such as the MSP430, bit 0 normally denotes the LSB. In Figure 15-1, the bit convention shown is as given in the original standards (bit 0 is the MSB). The fact that bit 0 is treated for some as LSB, and for others as MSB, continues to cause confusion. The CRC16 module therefore provides a bit reversed register pair for CRC16 operations to support both conventions.

## 15.3 CRC Checksum Generation

The CRC generator is first initialized by writing a 16-bit word (seed) to the CRC Initialization and Result (CRCINIRES) register. Any data that should be included into the CRC calculation must be written to the CRC Data Input (CRCDI or CRCDIRB) register in the same order that the original CRC signature was calculated. The actual signature can be read from the CRCINIRES register to compare the computed checksum with the expected checksum.

Signature generation describes a method of how the result of a signature operation can be calculated. The calculated signature, which is computed by an external tool, is called checksum in the following text. The checksum is stored in the product's memory and is used to check the correctness of the CRC operation result.

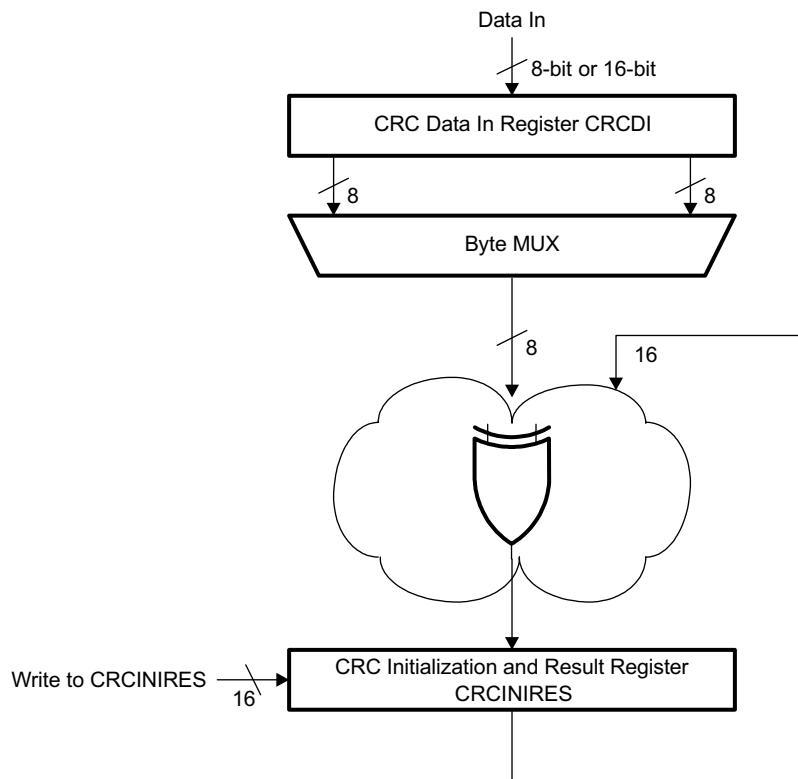
### 15.3.1 CRC Implementation

To allow parallel processing of the CRC, the linear feedback shift register (LFSR) functionality is implemented with an XOR tree. This implementation shows the identical behavior as the LFSR approach after 8 bits of data are shifted in when the LSB is 'shifted' in first. The generation of a signature calculation has to be started by writing a seed to the CRCINIRES register to initialize the register. Software or hardware (for example, the DMA) can transfer data to the CRCDI or CRCDIRB register (for example, from memory). The value in CRCDI or CRCDIRB is then included into the signature, and the result is available in the signature result registers at the next read access (CRCINIRES and CRCRESR). The signature can be generated using word or byte data.

If a word data is processed, the lower byte at the even address is used at the first clock (MCLK) cycle. During the second clock cycle, the higher byte is processed. Thus, it takes two clock cycles to process word data, while it takes only one clock (MCLK) cycle to process byte data.

Data bytes written to CRCDIRB in word mode or the data byte in byte mode are bit-wise reversed before the CRC engine adds them to the signature. The bits among each byte are reversed. Data bytes written to CRCDI in word mode or the data byte in byte mode are not bit reversed before use by the CRC engine.

If the checksum itself (with reversed bit order) is included into the CRC operation (as data written to CRCDI or CRCDIRB), the result in the CRCINIRES and CRCRESR registers must be zero.



**Figure 15-2. Implementation of CRC-CCITT Using the CRCDI and CRCINIRES Registers**

### 15.3.2 Assembler Examples

[Example 15-1](#) demonstrates the operation of the on-chip CRC.

#### Example 15-1. General Assembler Example

```

...
PUSH  R4          ; Save registers
PUSH  R5
MOV   #StartAddress,R4  ; StartAddress < EndAddress
MOV   #EndAddress,R5
MOV   &INIT, &CRCINIRES ; INIT to CRCINIRES
L1   MOV   @R4+,&CRCDI  ; Item to Data In register
      CMP   R5,R4        ; End address reached?
      JLO   L1            ; No
      MOV   &Check_Sum,&CRCDI ; Yes, Include checksum
      TST   &CRCINIRES   ; Result = 0?
      JNZ   CRC_ERROR    ; No, CRCRES <> 0: error
      ...                ; Yes, CRCRES=0:
                          ; information ok.
      POP   R5          ; Restore registers
      POP   R4

```

The details of the implemented CRC algorithm are shown by the data sequences in [Example 15-2](#) using word or byte accesses and the CRC data-in as well as the CRC data-in reverse byte registers.

**Example 15-2. Reference Data Sequence**

```

...
mov      #0FFFFh,&CRCINIRES ; initialize CRC
mov.b   #00031h,&CRCDI_L    ; "1"
mov.b   #00032h,&CRCDI_L    ; "2"
mov.b   #00033h,&CRCDI_L    ; "3"
mov.b   #00034h,&CRCDI_L    ; "4"
mov.b   #00035h,&CRCDI_L    ; "5"
mov.b   #00036h,&CRCDI_L    ; "6"
mov.b   #00037h,&CRCDI_L    ; "7"
mov.b   #00038h,&CRCDI_L    ; "8"
mov.b   #00039h,&CRCDI_L    ; "9"

cmp      #089F6h,&CRCINIRES ; compare result
           ; CRCRESR contains 06F91h
jeq     &Success          ; no error
br      &Error            ; to error handler
mov      #0FFFFh,&CRCINIRES ; initialize CRC
mov.w   #03231h,&CRCDI      ; "1" & "2"
mov.w   #03433h,&CRCDI      ; "3" & "4"
mov.w   #03635h,&CRCDI      ; "5" & "6"
mov.w   #03837h,&CRCDI      ; "7" & "8"
mov.b   #039h,  &CRCDI_L    ; "9"

cmp      #089F6h,&CRCINIRES ; compare result
           ; CRCRESR contains 06F91h
jeq     &Success          ; no error
br      &Error            ; to error handler
...

mov      #0FFFFh,&CRCINIRES ; initialize CRC
mov.b   #00031h,&CRCDIRB_L  ; "1"
mov.b   #00032h,&CRCDIRB_L  ; "2"
mov.b   #00033h,&CRCDIRB_L  ; "3"
mov.b   #00034h,&CRCDIRB_L  ; "4"
mov.b   #00035h,&CRCDIRB_L  ; "5"
mov.b   #00036h,&CRCDIRB_L  ; "6"
mov.b   #00037h,&CRCDIRB_L  ; "7"
mov.b   #00038h,&CRCDIRB_L  ; "8"
mov.b   #00039h,&CRCDIRB_L  ; "9"

cmp      #029B1h,&CRCINIRES ; compare result
           ; CRCRESR contains 08D94h
jeq     &Success          ; no error
br      &Error            ; to error handler
...

mov      #0FFFFh,&CRCINIRES ; initialize CRC
mov.w   #03231h,&CRCDIRB    ; "1" & "2"
mov.w   #03433h,&CRCDIRB    ; "3" & "4"
mov.w   #03635h,&CRCDIRB    ; "5" & "6"
mov.w   #03837h,&CRCDIRB    ; "7" & "8"
mov.b   #039h,  &CRCDIRB_L  ; "9"

cmp      #029B1h,&CRCINIRES ; compare result
           ; CRCRESR contains 08D94h
jeq     &Success          ; no error
br      &Error            ; to error handler

```

## 15.4 CRC Registers

The CRC module registers are listed in [Table 15-1](#). The base address can be found in the device-specific data sheet. The address offset is given in [Table 15-1](#).

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 15-1. CRC Registers**

| Offset | Acronym     | Register Name                 | Type       | Access | Reset | Section                        |
|--------|-------------|-------------------------------|------------|--------|-------|--------------------------------|
| 00h    | CRCIDI      | CRC Data In                   | Read/write | Word   | 0000h | <a href="#">Section 15.4.1</a> |
| 00h    | CRCIDI_L    |                               | Read/write | Byte   | 00h   |                                |
| 01h    | CRCIDI_H    |                               | Read/write | Byte   | 00h   |                                |
| 02h    | CRCDIRB     | CRC Data In Reverse Byte      | Read/write | Word   | 0000h | <a href="#">Section 15.4.2</a> |
| 02h    | CRCDIRB_L   |                               | Read/write | Byte   | 00h   |                                |
| 03h    | CRCDIRB_H   |                               | Read/write | Byte   | 00h   |                                |
| 04h    | CRCINIRES   | CRC Initialization and Result | Read/write | Word   | FFFFh | <a href="#">Section 15.4.3</a> |
| 04h    | CRCINIRES_L |                               | Read/write | Byte   | FFh   |                                |
| 05h    | CRCINIRES_H |                               | Read/write | Byte   | FFh   |                                |
| 06h    | CRCRESR     | CRC Result Reverse            | Read only  | Word   | FFFFh | <a href="#">Section 15.4.4</a> |
| 06h    | CRCRESR_L   |                               | Read/write | Byte   | FFh   |                                |
| 07h    | CRCRESR_H   |                               | Read/write | Byte   | FFh   |                                |

### 15.4.1 CRCDI Register

CRC Data In Register

**Figure 15-3. CRCDI Register**

| 15    | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------|------|------|------|------|------|------|------|
| CRCDI |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRCDI |      |      |      |      |      |      |      |
| rw-0  | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 15-2. CRCDI Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                         |
|------|-------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRCDI | RW   | 0h    | CRC data in. Data written to the CRCDI register is included to the present signature in the CRCINIRES register according to the CRC-CCITT standard. |

### 15.4.2 CRCDIRB Register

CRC Data In Reverse Register

**Figure 15-4. CRCDIRB Register**

| 15      | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|---------|------|------|------|------|------|------|------|
| CRCDIRB |      |      |      |      |      |      |      |
| rw-0    | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRCDIRB |      |      |      |      |      |      |      |
| rw-0    | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 15-3. CRCDIRB Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                              |
|------|---------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRCDIRB | RW   | 0h    | CRC data in reverse byte. Data written to the CRCDIRB register is included to the present signature in the CRCINIRES and CRCRESR registers according to the CRC-CCITT standard. Reading the register returns the register CRCDI content. |

### 15.4.3 CRCINIRES Register

CRC Initialization and Result Register

**Figure 15-5. CRCINIRES Register**

| 15        | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-----------|------|------|------|------|------|------|------|
| CRCINIRES |      |      |      |      |      |      |      |
| rw-1      | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |
| CRCINIRES |      |      |      |      |      |      |      |
| rw-1      | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |

**Table 15-4. CRCINIRES Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                         |
|------|-----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRCINIRES | RW   | FFFFh | CRC initialization and result. This register holds the current CRC result (according to the CRC-CCITT standard). Writing to this register initializes the CRC calculation with the value written to it. The value just written can be read from CRCINIRES register. |

### 15.4.4 CRCRESR Register

CRC Reverse Result Register

**Figure 15-6. CRCRESR Register**

| 15      | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
|---------|-----|-----|-----|-----|-----|-----|-----|
| CRCRESR |     |     |     |     |     |     |     |
| r-1     | r-1 | r-1 | r-1 | r-1 | r-1 | r-1 | r-1 |
| CRCRESR |     |     |     |     |     |     |     |
| r-1     | r-1 | r-1 | r-1 | r-1 | r-1 | r-1 | r-1 |

**Table 15-5. CRCRESR Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                     |
|------|---------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRCRESR | R    | FFFFh | CRC reverse result. This register holds the current CRC result (according to the CRC-CCITT standard). The order of bits is reverse (for example, CRCINIRES[15] = CRCRESR[0]) to the order of bits in the CRCINIRES register (see example code). |

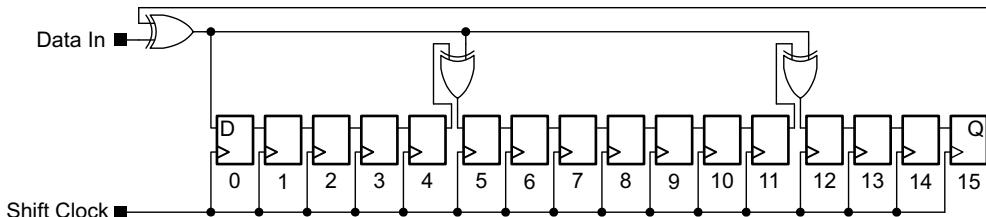
## CRC32 Module

The 16-bit or 32-bit cyclic redundancy check (CRC32) module provides a signature for a given data sequence. This chapter describes the operation and use of the CRC32 module.

| Topic                                                          | Page |
|----------------------------------------------------------------|------|
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| 16.2 CRC Checksum Generation .....                             | 433  |
| 16.3 CRC32 Register Descriptions.....                          | 436  |

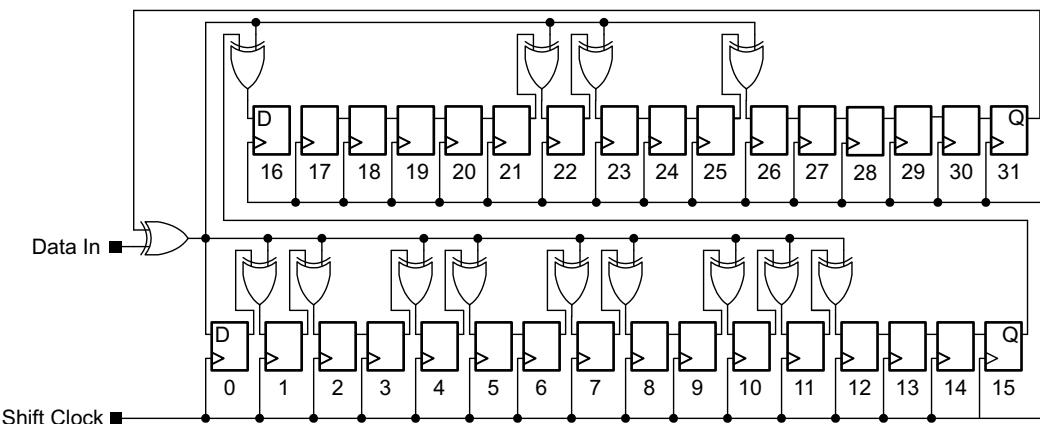
## 16.1 Cyclic Redundancy Check (CRC32) Module Introduction

The CRC module produces signatures for a given sequences of data values. These signatures are defined bit serial in various standard specifications. For CRC16-CCITT, a feedback path from data bits 4, 11, and 15 is generated (see [Figure 16-1](#)). This CRC signature is based on the polynomial given in the CRC-CCITT with  $f(x)=x^{16}+x^{12}+x^5+1$ .



**Figure 16-1. LFSR Implementation of CRC-CCITT as Defined in Standard (Bit 0 is MSB)**

For CRC32-IS3309 a feedback path from data bits 0, 1, 3, 4, 6, 7, 9, 10, 11, 15, 21, 22, 26 and 31 is generated (see [Figure 16-2](#)). This CRC signature is based on the polynomial given in the CRC32-ISO3309 with  $f(x)=x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^8+x^7+x^5+x^4+x^2+x+1$ .



**Figure 16-2. LFSR Implementation of CRC32-ISO3309 as Defined in Standard (Bit 0 is MSB)**

Identical input data sequences result in identical signatures when the CRC is initialized with a fixed seed value. Different sequences of input data, in general, result in different signatures for a given CRC function.

The CRC32 module supports 16-bit and 32-bit CRC generation. They are independent from each other and supported by two dedicated register sets.

## 16.2 CRC Checksum Generation

The CRC generators are initialized by writing the "seed" to the CRC Initialization and Result (CRC16INIRES or CRC32INIRES) registers. Any data that should be included in the CRC calculation must be written to the CRC Data Input (CRC16DI or CRC32DI) registers in the same order that the original CRC signatures were calculated. The actual signature can be read from the CRC16INIRES or CRC32INIRES registers to compare the computed checksum with the expected checksum. Signature generation describes a method of how the result of a signature operation can be calculated. The calculated signature, which is computed by an external tool, is called checksum in the following text. The checksum is stored in the product's memory and is used to check the correctness of the CRC operation result.

### 16.2.1 CRC Standard and Bit Order

The various CRC standards were defined in the era of main frame computers. At that time, Bit 0 was treated as the MSB. Now, Bit 0 is typically the LSB (as the value of Bit N = 2N). In [Figure 16-1](#) and [Figure 16-2](#), the bit references are used as given in the original standards. The MSP430 microcontrollers treat Bit 0 as the LSB, as is typical in modern CPUs and MCUs.

This sometimes causes confusion, because Bit 0 has been treated as the LSB in some cases and as the MSB in other cases. Therefore, the CRC32 module provides a bit-reversed register pair for CRC16 and CRC32 operations to support both conventions.

### 16.2.2 CRC Implementation

To allow faster processing of the CRC, the linear feedback shift register (LFSR) functionality is implemented with a set of XOR trees. This implementation shows the identical behavior as the LFSR approach. After a set of 8, 16, or 32 bits is provided to the CRC32 module by writing to the CRC16DI or CRC32DI registers, a calculation for the whole set of input bits is performed. For this calculation, the CPU or the DMA can write to the memory-mapped data input registers. After the last value is written to CRC16DI or CRC32DIRB, the signature can be read from the CRC16INIRES or CRC32INIRES registers. The CRC16 and CRC32 generators accept byte- and word-wide access to the input registers CRC16DI and CRC32DI.

For bit-reversed conventions, write the data bytes to the CRC16DIRB or CRC32DIRB register.

Initialization is done by writing to the CRC, and CRC engine adds them to the signature. The bits among each byte are reversed. Data bytes written to CRCDI in word mode or the data byte in byte mode are not bit reversed before use by the CRC engine. If the checksum itself (with reversed bit order) is included in the CRC operation (as data written to CRCDI or CRCDIRB), the result in the CRCINIRES and CRCRESR register must be zero.

### 16.2.3 Assembler Examples

#### 16.2.3.1 General Assembler Example

This example demonstrates the operation of the on-chip CRC.

```

PUSH  R4          ; Save registers
PUSH  R5
MOV   #StartAddress,R4    ; StartAddress < EndAddress
MOV   #EndAddress,R5
MOV   &INIT,&CRCINIRES  ; INIT to CRCINIRES
L1   MOV   @R4+,&CRCDI   ; Item to Data In register
      CMP   R5,R4        ; End address reached?
      JLO   L1           ; No
      MOV   &Check_Sum,&CRCDI ; Yes, Include checksum
      TST   &CRCINIRES   ; Result = 0?
      JNZ   CRC_ERROR    ; No, CRCRES <> 0: error
      ...               ; Yes, CRCRES=0:
                        ; information ok.
      POP   R5          ; Restore registers
      POP   R4

```

### 16.2.3.2 Reference Data Sequence

The details of the implemented CRC algorithm is shown by the following data sequences using word or byte accesses and the CRC data-in as well as the CRC data-in reverse byte registers:

```

mov #0FFFFh,&CRCINIRES ; initialize CRC
mov.b #00031h,&CRCDI_L ; "1"
mov.b #00032h,&CRCDI_L ; "2"
mov.b #00033h,&CRCDI_L ; "3"
mov.b #00034h,&CRCDI_L ; "4"
mov.b #00035h,&CRCDI_L ; "5"
mov.b #00036h,&CRCDI_L ; "6"
mov.b #00037h,&CRCDI_L ; "7"
mov.b #00038h,&CRCDI_L ; "8"
mov.b #00039h,&CRCDI_L ; "9"
cmp #089F6h,&CRCINIRES ; compare result
; CRCRESR contains 06F91h
jeq Success ; no error
br &Error ; to error handler
...
mov #0FFFFh,&CRCINIRES ; initialize CRC
mov.w #03231h,&CRCDI ; "1" & "2"
mov.w #03433h,&CRCDI ; "3" & "4"
mov.w #03635h,&CRCDI ; "5" & "6"
mov.w #03837h,&CRCDI ; "7" & "8"
mov.b #039h, &CRCDI_L ; "9"
cmp #089F6h,&CRCINIRES ; compare result
; CRCRESR contains 06F91h
jeq Success ; no error
br &Error ; to error handler
...
mov #0FFFFh,&CRCINIRES ; initialize CRC
mov.b #00031h,&CRCDIRB_L ; "1"
mov.b #00032h,&CRCDIRB_L ; "2"
mov.b #00033h,&CRCDIRB_L ; "3"
mov.b #00034h,&CRCDIRB_L ; "4"
mov.b #00035h,&CRCDIRB_L ; "5"
mov.b #00036h,&CRCDIRB_L ; "6"
mov.b #00037h,&CRCDIRB_L ; "7"
mov.b #00038h,&CRCDIRB_L ; "8"
mov.b #00039h,&CRCDIRB_L ; "9"
cmp #029B1h,&CRCINIRES ; compare result
; CRCRESR contains 08D94h
jeq Success ; no error
br &Error ; to error handler
...
mov #0FFFFh,&CRCINIRES ; initialize CRC
mov.w #03231h,&CRCDIRB ; "1" & "2"
mov.w #03433h,&CRCDIRB ; "3" & "4"
mov.w #03635h,&CRCDIRB ; "5" & "6"
mov.w #03837h,&CRCDIRB ; "7" & "8"
mov.b #039h, &CRCDIRB_L ; "9"
cmp #029B1h,&CRCINIRES ; compare result
; CRCRESR contains 08D94h
jeq Success ; no error
br &Error ; to error handler
...

```

## 16.3 CRC32 Register Descriptions

### 16.3.1 CRC32 Registers

The CRC32 module registers with their address offsets are shown in [Table 16-1](#). The base address for the CRC32 module registers can be found in the device-specific data sheet.

**Table 16-1. CRC32 Registers**

| Offset | Acronym       | Register Name                   | Type       | Access | Reset | Section                           |
|--------|---------------|---------------------------------|------------|--------|-------|-----------------------------------|
| 0002h  | CRC32DIW1     | CRC32 Data Input                | read/write | word   | 0000h | <a href="#">Section 16.3.1.2</a>  |
| 0000h  | CRC32DIW0     |                                 |            | word   | 0000h | <a href="#">Section 16.3.1.1</a>  |
| 0000h  | CRC32DIB0     |                                 |            | byte   | 00h   |                                   |
| 0004h  | CRC32DIRBW1   | CRC32 Data In Reverse           | read/write | word   | 0000h | <a href="#">Section 16.3.1.4</a>  |
| 0006h  | CRC32DIRBW0   |                                 |            | word   | 0000h | <a href="#">Section 16.3.1.3</a>  |
| 0007h  | CRC32DIRBB0   |                                 |            | byte   | 00h   |                                   |
| 000Ah  | CRC32INIRESW1 | CRC32 Initialization and Result | read/write | word   | FFFFh | <a href="#">Section 16.3.1.6</a>  |
| 0008h  | CRC32INIRESW0 |                                 |            | word   | FFFFh | <a href="#">Section 16.3.1.5</a>  |
| 000Bh  | CRC32RESB3    |                                 |            | byte   | FFh   |                                   |
| 000Ah  | CRC32RESB2    |                                 |            | byte   | FFh   |                                   |
| 0009h  | CRC32RESB1    |                                 |            | byte   | FFh   |                                   |
| 0008h  | CRC32RESB0    |                                 |            | byte   | FFh   |                                   |
| 000Ch  | CRC32RESRW1   | CRC32 Result Reverse            | read/write | word   | FFFFh | <a href="#">Section 16.3.1.8</a>  |
| 000Eh  | CRC32RESRW0   |                                 |            | word   | FFFFh | <a href="#">Section 16.3.1.7</a>  |
| 000Ch  | CRC32RESRB3   |                                 |            | byte   | FFh   |                                   |
| 000Dh  | CRC32RESRB2   |                                 |            | byte   | FFh   |                                   |
| 000Eh  | CRC32RESRB1   |                                 |            | byte   | FFh   |                                   |
| 000Fh  | CRC32RESRB0   |                                 |            | byte   | FFh   |                                   |
| 0010h  | CRC16DIW0     | CRC16 Data Input                | read/write | word   | 0000h | <a href="#">Section 16.3.1.9</a>  |
| 0010h  | CRC16DIB0     |                                 |            | byte   | 00h   |                                   |
| 0016h  | CRC16DIRBW0   | CRC16 Data In Reverse           | read/write | word   | 0000h | <a href="#">Section 16.3.1.10</a> |
| 0017h  | CRC16DIRBB0   |                                 |            | byte   | 00h   |                                   |
| 0018h  | CRC16INIRESW0 | CRC16 Init and Result           | read/write | word   | FFFFh | <a href="#">Section 16.3.1.11</a> |
| 0019h  | CRC16INIRESB1 |                                 |            | byte   | FFh   |                                   |
| 0018h  | CRC16INIRESB0 |                                 |            | byte   | FFh   |                                   |
| 001Eh  | CRC16RESRW0   | CRC16 Result Reverse            | read/write | word   | FFFFh | <a href="#">Section 16.3.1.12</a> |
| 001Fh  | CRC16RESRB0   |                                 |            | byte   | FFh   |                                   |
| 001Eh  | CRC16RESRB1   |                                 |            | byte   | FFh   |                                   |

### 16.3.1.1 CRC32DIW0 Register

Data Input Register Word\_0 for 32-Bit CRCs

Data written to this register is taken into CRC32 signature calculations. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-3. CRC32DIW0 Register**

| 15        | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-----------|------|------|------|------|------|------|------|
| CRC32DIW0 |      |      |      |      |      |      |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC32DIW0 |      |      |      |      |      |      |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-2. CRC32DIW0 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                             |
|------|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32DIW0 | RW   | 0h    | CRC32 data in word 0. Data written to the CRC32DILW0 register is included to the present signature in the CRC32INIRES register according to the CRC32-ISO3309 standard. |

### 16.3.1.2 CRC32DIW1 Register

Data Input Register Word\_1 for 32-Bit CRCs

Data written to this register is taken into CRC32 signature calculations. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-4. CRC32DIW1 Register**

| 15        | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-----------|------|------|------|------|------|------|------|
| CRC32DIW1 |      |      |      |      |      |      |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC32DIW1 |      |      |      |      |      |      |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-3. CRC32DIW1 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                             |
|------|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32DIW1 | RW   | 0h    | CRC32 data in word 1. Data written to the CRC32DILW1 register is included to the present signature in the CRC32INIRES register according to the CRC32-ISO3309 standard. |

### 16.3.1.3 CRC32DIRBW0 Register

Data In Register Word\_0 with Reversed Bit Order for 32-Bit CRCs

Data written to this register is taken into CRC32 signature calculations. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-5. CRC32DIRBW0 Register**

| 15          | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------------|------|------|------|------|------|------|------|
| CRC32DIRBW0 |      |      |      |      |      |      |      |
| rw-0        | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC32DIRBW0 |      |      |      |      |      |      |      |
| rw-0        | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-4. CRC32DIRBW0 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                      |
|------|-------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32DIRBW0 | RW   | 0h    | CRC32 data in word 0 as bit reversed pattern. Data written to the CRC32DIRBW0 register is included to the present signature in the CRC32INIRES register according to the CRC32-ISO3309 standard. |

### 16.3.1.4 CRC32DIRBW1 Register

Data In Register Word\_1 with Reversed Bit Order for 32-Bit CRCs

Data written to this register is taken into CRC32 signature calculations. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-6. CRC32DIRBW1 Register**

| 15          | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------------|------|------|------|------|------|------|------|
| CRC32DIRBW1 |      |      |      |      |      |      |      |
| rw-0        | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC32DIRBW1 |      |      |      |      |      |      |      |
| rw-0        | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-5. CRC32DIRBW1 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                     |
|------|-------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32DIRBW1 | RW   | 0h    | CRC32 data in word1 as bit reversed pattern. Data written to the CRC32DIRBW1 register is included to the present signature in the CRC32INIRES register according to the CRC32-ISO3309 standard. |

### 16.3.1.5 CRC32INIRESW0 Register

Data Initialization and Result Register Word\_0 for 32-Bit CRCs

Data written to this register represents the seed for the CRC calculation. This register always reflects the latest signature of the values collected so far. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-7. CRC32INIRESW0 Register**

| 15            | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|---------------|------|------|------|------|------|------|------|
| CRC32INIRESW0 |      |      |      |      |      |      |      |
| rw-0          | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC32INIRESW0 |      |      |      |      |      |      |      |
| rw-0          | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-6. CRC32INIRESW0 Register Description**

| Bit  | Field         | Type | Reset | Description                                                                                                                                                                                                                                          |
|------|---------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32INIRESW0 | RW   | 0h    | CRC32 data initialization and result word0. Data written to the CRC32INIRESW0 register is used as the seed for the CRC calculation according to the CRC32-ISO3309 standard. Reading this register returns the current result of the CRC calculation. |

### 16.3.1.6 CRC32INIRESW1 Register

Data Initialization and Result Register Word\_1 for 32-Bit CRCs

Data written to this register represents the seed for the CRC calculation. This register always reflects the latest signature of the values collected so far. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-8. CRC32INIRESW1 Register**

| 15            | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|---------------|------|------|------|------|------|------|------|
| CRC32INIRESW1 |      |      |      |      |      |      |      |
| rw-0          | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC32INIRESW1 |      |      |      |      |      |      |      |
| rw-0          | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-7. CRC32INIRESW1 Register Description**

| Bit  | Field         | Type | Reset | Description                                                                                                                                                                                                                                          |
|------|---------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32INIRESW1 | RW   | 0h    | CRC32 data initialization and result word1. Data written to the CRC32INIRESW1 register is used as the seed for the CRC calculation according to the CRC32-ISO3309 standard. Reading this register returns the current result of the CRC calculation. |

### 16.3.1.7 CRC32RESRW0 Register

Data Result Register Word\_0 as Bit Reversed for 32-Bit CRCs

Data written to this register represents the seed for the CRC calculation. This register always reflects the latest signature of the values collected so far. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-9. CRC32RESRW0 Register**

| 15          | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------------|------|------|------|------|------|------|------|
| CRC32RESRW0 |      |      |      |      |      |      |      |
| rw-1        | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |
| CRC32RESRW0 |      |      |      |      |      |      |      |
| rw-1        | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |

**Table 16-8. CRC32RESRW0 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                                                 |
|------|-------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32RESRW0 | RW   | FFh   | CRC32 bit reverse initialization and result word0. This register holds the current CRC32 result (according to the CRC32-ISO3309 standard). The order of bits is reverse to the order of bits in the CRC32INIRESW1 register. |

### 16.3.1.8 CRC32RESRW1 Register

Data Result Register Word1 as Bit Reversed for 32-Bit CRCs

Data written to this register represents the seed for the CRC calculation. This register always reflects the latest signature of the values collected so far. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-10. CRC32RESRW1 Register**

| 15          | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------------|------|------|------|------|------|------|------|
| CRC32RESRW1 |      |      |      |      |      |      |      |
| rw-1        | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |
| CRC32RESRW1 |      |      |      |      |      |      |      |
| rw-1        | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |

**Table 16-9. CRC32RESRW1 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                                                 |
|------|-------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC32RESRW1 | RW   | FFh   | CRC32 bit reverse initialization and result word1. This register holds the current CRC32 result (according to the CRC32-ISO3309 standard). The order of bits is reverse to the order of bits in the CRC32INIRESW0 register. |

### 16.3.1.9 CRC16DIW0 Register

Data In Register for 16-Bit CRCs

Data written to this register is taken into CRC16 signature calculations. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-11. CRC16DIW0 Register**

| 15        | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-----------|------|------|------|------|------|------|------|
| CRC16DIW0 |      |      |      |      |      |      |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC16DIW0 |      |      |      |      |      |      |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-10. CRC16DIL0 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                  |
|------|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC16DIW0 | RW   | 0h    | CRC16 data in. Data written to the CRC16DIW0 register is included to the present signature in the CRC16NIRES register according to the CRC16-CCITT standard. |

### 16.3.1.10 CRC16DIRBW0 Register

Data In Register with Reversed Bit Order for 16-Bit CRCs

Data written to this register is taken into CRC16 signature calculations. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-12. CRC16DIRBW0 Register**

| 15          | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|-------------|------|------|------|------|------|------|------|
| CRC16DIRBW0 |      |      |      |      |      |      |      |
| rw-0        | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| CRC16DIRBW0 |      |      |      |      |      |      |      |
| rw-0        | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 16-11. CRC16DIRBW0 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                                                                         |
|------|-------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC16DIRBW0 | RW   | 0h    | CRC16 data in reverse byte. Data written to the CRC16DIRBW0 register is included to the present signature in the CRC16NIRES and CRC16RESR registers according to the CRC-CCITT standard. Reading the register returns the register CRC16DI content. |

### 16.3.1.11 CRC16INIRESW0 Register

Data Initialization and Result Register for 16-Bit CRCs

Data written to this register represents the seed for the CRC calculation. This register always reflects the latest signature of the values collected so far. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-13. CRC16INIRESW0 Register**

| 15            | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|---------------|------|------|------|------|------|------|------|
| CRC16INIRESW0 |      |      |      |      |      |      |      |
| rw-1          | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |
| CRC16INIRESW0 |      |      |      |      |      |      |      |
| rw-1          | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |

**Table 16-12. CRC16INIRESW0 Register Description**

| Bit  | Field         | Type | Reset | Description                                                                                                                                                                                                     |
|------|---------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC16INIRESW0 | RW   | FFh   | CRC16 initialization and result. This register holds the current CRC16 result (according to the CRC16-CCITT standard). Writing to this register initializes the CRC16 calculation with the value written to it. |

### 16.3.1.12 CRC16RESRW0 Register

Data Result Register with Reversed Bits for 16-Bit CRCs

Data written to this register represents the seed for the CRC calculation. This register always reflects the latest signature of the values collected so far. This register can be accessed 8-bit wide and 16-bit wide.

**Figure 16-14. CRC16RESRW0 Register**

| 15          | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
|-------------|----|----|----|----|----|----|----|
| CRC16RESRW0 |    |    |    |    |    |    |    |
| r0          | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| CRC16RESRW0 |    |    |    |    |    |    |    |
| r0          | r0 | r0 | r0 | r0 | r0 | r0 | r0 |

**Table 16-13. CRC16RESRW0 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                  |
|------|-------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CRC16RESRW0 | RW   | FFh   | CRC16 reverse result. This register holds the current CRC16 result (according to the CRC16-CCITT standard). The order of bits is reverse to the order of bits in the CRC16INIRESW0 register. |

## **Low-Energy Accelerator (LEA) for Signal Processing**

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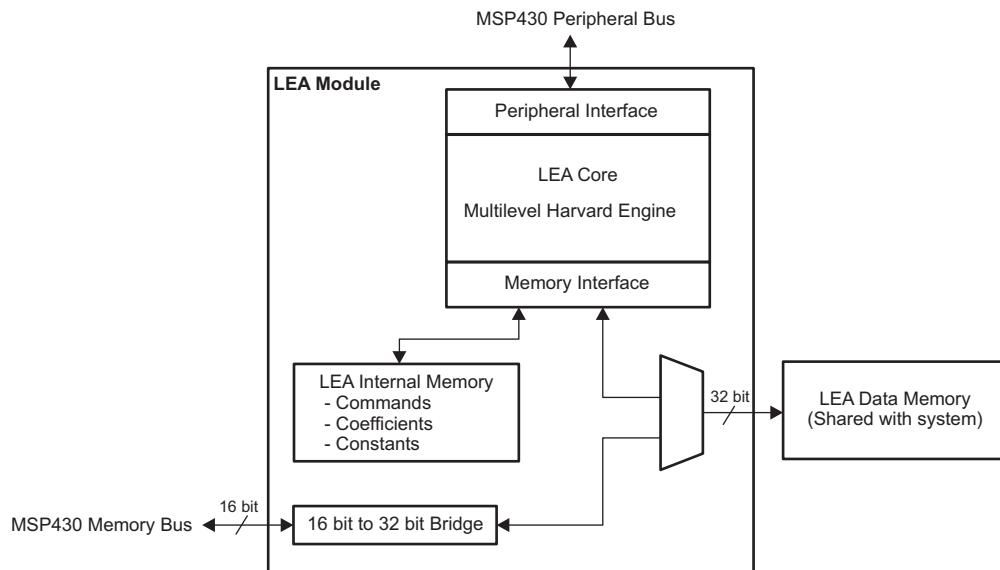
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The LEA (low-energy accelerator) module is an execution unit for vector-based signal processing operations. This chapter introduces the LEA.

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## 17.1 LEA Introduction

The LEA is a 32-bit hardware engine designed for operations that involve vector-based signal processing, such as FIR, IIR, and FFT without CPU intervention. The LEA supports multiple commands, which are issued by CPU. The LEA offers incomparable performance and energy consumption when performing vector-based digital signal processing computations; for performance benchmarks comparing LEA to using the CPU or other processors, see [Benchmarking the Signal Processing Capabilities of the Low-Energy Accelerator on MSP430™ MCUs](#).



**Figure 17-1. LEA System Block Diagram**

## 17.2 LEA Operation

The LEA begins executing the selected operation when the CPU writes a LEA command to the LEA command register when the LEA is in idle mode. Before writing the command, the CPU must configure the LEA argument registers with the pointers to the parameter blocks for the designated operation. The LEA performs the operation without CPU intervention and triggers an interrupt when the operation is complete.

The LEA accesses the LEA data memory, which is used for input data, output data, and the parameter blocks. The LEA data memory is also accessible by the CPU and the DMA, so that the output data of the LEA operation can be moved to other memory location by the CPU or the DMA (see [Figure 17-1](#)). The CPU and the LEA can run simultaneously and independently unless they access the same system memory (RAM). See the device-specific data sheet for details about LEA availability and LEA data memory size.

The LEA supports a variety of commands that are used to perform vector-based mathematical operations. [Table 17-1](#) lists the command groups that are available.

**Table 17-1. LEA Command Groups**

| Group    | Purpose or Use                                                            |
|----------|---------------------------------------------------------------------------|
| Group 1  | Basic pointwise vector and matrix operations                              |
| Group 2  | Basic vector MAC operations (windowing, scaling, general)                 |
| Group 3  | MAC, pointwise FIR, correlation, convolution                              |
| Group 4  | Basic minimum/maximum vector search operations on 16-bit data             |
| Group 5  | Generic minimum/maximum search operations on 32-bit data                  |
| Group 6  | Generic minimum/maximum search operations on dual 16-bit data and complex |
| Group 7  | Block based FIR, correlation, convolution                                 |
| Group 8  | Taylor functions and operations on pointwise vectors and matrices         |
| Group 9  | FFT and iFFT bank filtering (DIT type)                                    |
| Group 10 | Bit-reversed carry propagated presort for DIT-FFTs                        |
| Group 11 | FFT post operation for real points                                        |
| Group 12 | Vector and matrix deinterleave and sort functions                         |
| Group A  | Programming structure and rearrange functions                             |
| Group B  | Special functions for math, matrix, and DSP                               |

### 17.2.1 Use the LEA in Programs

How the LEA operates is briefly described in [Section 17.2](#). It is not necessary to understand how the LEA works or the details of the LEA registers. The [Digital Signal Processing \(DSP\) Library for MSP Microcontrollers](#) offers easy-to-use APIs that use the functions of the LEA and provide a high-level environment to use the LEA in various applications. The DSP Library is a set of highly optimized API functions to perform many common signal processing operations on fixed-point numbers for MSP430 microcontrollers. The APIs automatically enable and use the LEA module if the LEA is available in the target device, and apply the optimal configurations to the LEA registers with the correct sequence. If the LEA is not available, the CPU is selected to perform the operations.

The full LEA commands are supported by the DSP Library APIs, which are listed in the [DSP Library API Guide](#), [Low-Energy Accelerator \(LEA\) Frequently Asked Questions \(FAQ\)](#), and [Benchmarking the Signal Processing Capabilities of the Low-Energy Accelerator on MSP430™ MCUs](#).

The following sequence of operations is an example of performing a vector-based algorithm using the LEA, DMA, ADC, and SPI.

1. The CPU sets up the DMA controller, ADC, and SPI.
2. A DMA channel collects samples from the ADC converter at a defined sampling rate and transfers data to the LEA memory.
3. After a block of data has been collected, the CPU enables one or a series of operations of the LEA using the APIs in the [Digital Signal Processing \(DSP\) Library for MSP Microcontrollers](#) to perform the required algorithm (for example, FIR, IIR, correlation, or FFT).
4. When the algorithm is complete, another DMA channel transfers the result of that algorithm to the SPI.
5. The SPI transfers the data to an external device.

### 17.2.2 Where to Get the DSP Library

The [Digital Signal Processing \(DSP\) Library for MSP Microcontrollers](#) can be downloaded separately, but TI recommends installing [MSPWare](#), which includes the DSP Library with user's guides, code examples, training, and other design resources for all MSP devices. Table 17-2 lists the versions of the DSP Library and MSPWare that support the LEA.

**Table 17-2. DSP Library and MSPWare Versions for the LEA**

| Link                                                                             | Version             |
|----------------------------------------------------------------------------------|---------------------|
| <a href="#">Digital Signal Processing (DSP) Library for MSP Microcontrollers</a> | 1.20.00.xx or later |
| <a href="#">MSP430Ware</a>                                                       | 3.60 or later       |

### 17.2.3 Where to Start

1. Visit the [LEA landing page](#) where all of the technical documents, training videos, software examples, hardware designs, and tools for the LEA are listed.
2. See [Low-Energy Accelerator \(LEA\) Frequently Asked Questions \(FAQ\)](#) for the questions about the LEA.
3. See the [DSP Library API Guide](#) and [DSP Library Example Projects](#) for detailed information about the DSP Library APIs and examples.

## 17.3 LEA Registers

As mentioned in [Section 17.2.1](#), the DSP Library APIs are designed to apply the optimal configurations to the LEA registers for the selected operations. Direct access to LEA registers is not supported, and TI recommends using the [Digital Signal Processing \(DSP\) Library for MSP Microcontrollers](#) for the operations that the LEA module supports.

## ***Ultrasonic Sensing Solution (USS, USS\_A)***

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This chapter describes the operation of the USS and the USS\_A module.

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## 18.1 Introduction

The USS module is designed for analog-to-digital (ADC) converter based ultrasonic sensing technology in various measurement applications. [Figure 18-1](#) shows the block diagram of the USS module. The USS is a sophisticated system that consists of the following four submodules. USS\_A is an extended variant of the original USS module and features SAPH\_A instead of the SAPH module. Because USS\_A is a superset of USS, USS\_A is specifically named only when describing feature that differ between USS and USS\_A.

- **UUPS:** Generates reference voltages, currents, and operation voltage for the USS module, and controls the power-up and power-down sequences of the USS module. See [UUPS](#) for details.
- **HSPLL:** Generates a low-jitter clock (68 MHz to 80 MHz) from the USSXT oscillator for the USS module. See [HSPLL](#) for details.
- **SAPH (part of USS):** Consists of a pulse generator, a low-impedance output driver, an input multiplexer, and an acquisition sequencer. See [SAPH](#) for details.
- **SAPH\_A (part of USS\_A):** Consists of an extended pulse generator, a low-impedance output driver, an input multiplexer, an acquisition sequencer and external bias terminals. See [SAPH\\_A](#) for details.
- **SDHS:** High-speed sigma-delta analog-to-digital converter with a dedicated data transfer controller. See [SDHS](#) for details

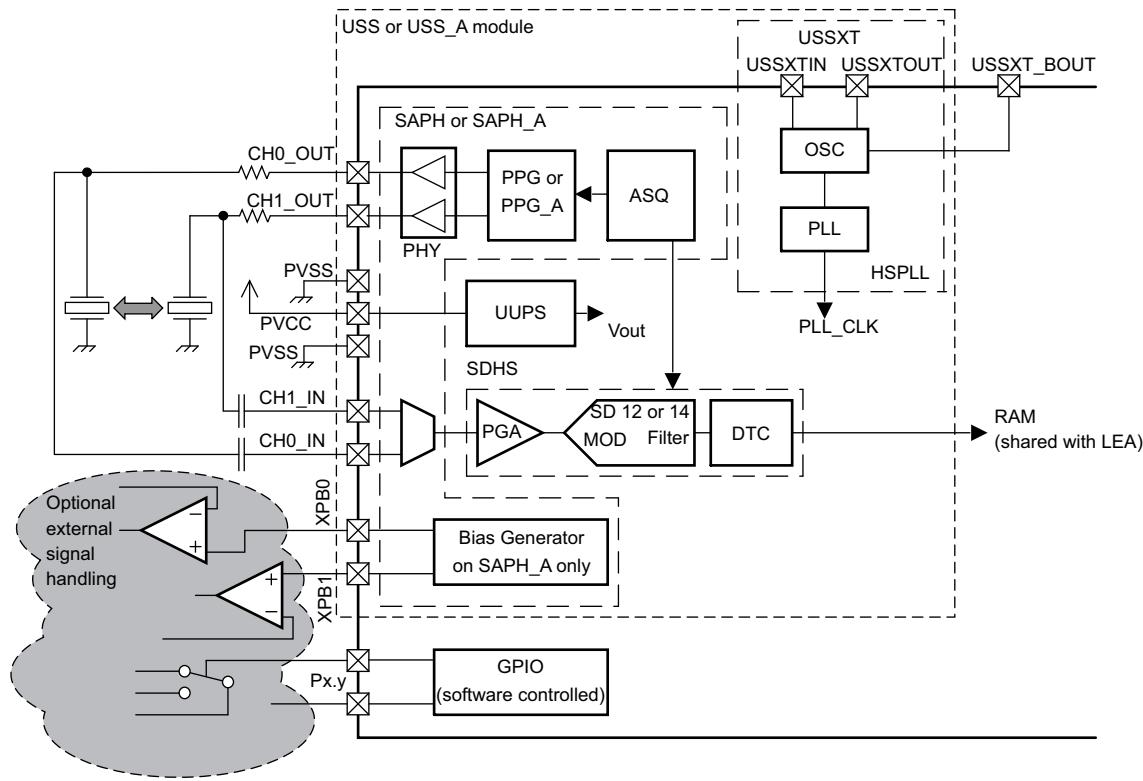
The submodules have different roles, and together they enable high-precision data acquisition for ultrasonic technology in various applications. The USS module has a dedicated power management module, UUPS, which generates operating voltage, reference voltages, and reference currents for other submodules. The USS module also has a dedicated clock module, HSPLL, which generates a very-low-jitter clock (68 MHz to 80 MHz) from the USSXT oscillator. The SAPH or SAPH\_A module controls the signal flow including excitation pulse generation through a low-impedance driver (3-4 Ω, typical), internal bias voltages for Tx and Rx sides, and the input multiplexer. The SDHS is a high-speed analog-to-digital converter to sample the input signals and transfer the output data to the target memory location. The Low Energy Accelerator (LEA), if available, processes the data transferred by the SDHS.

The USS module supports three operation modes for data acquisition sequence: auto mode, register mode and ultra low power bias mode.

In auto mode, the entire measurement sequence is automatically controlled by the ASQ block. Control by ASQ enables ultra-low power consumption during the measurement and frees the CPU from data acquisition, so that ultrasonic application software can be executed in parallel with data acquisition with minimum intervention.

In register mode, the measurement sequence is fully controlled by user software. The register mode can be used during development and for special tasks like diagnostics.

In ultra low power bias mode the ASQ sequencer performs an extended power sequence dedicated for the ultra low power utility meter market.



**Figure 18-1. USS and USS\_A Block Diagram**

**NOTE:** Naming convention for register names and bit fields:

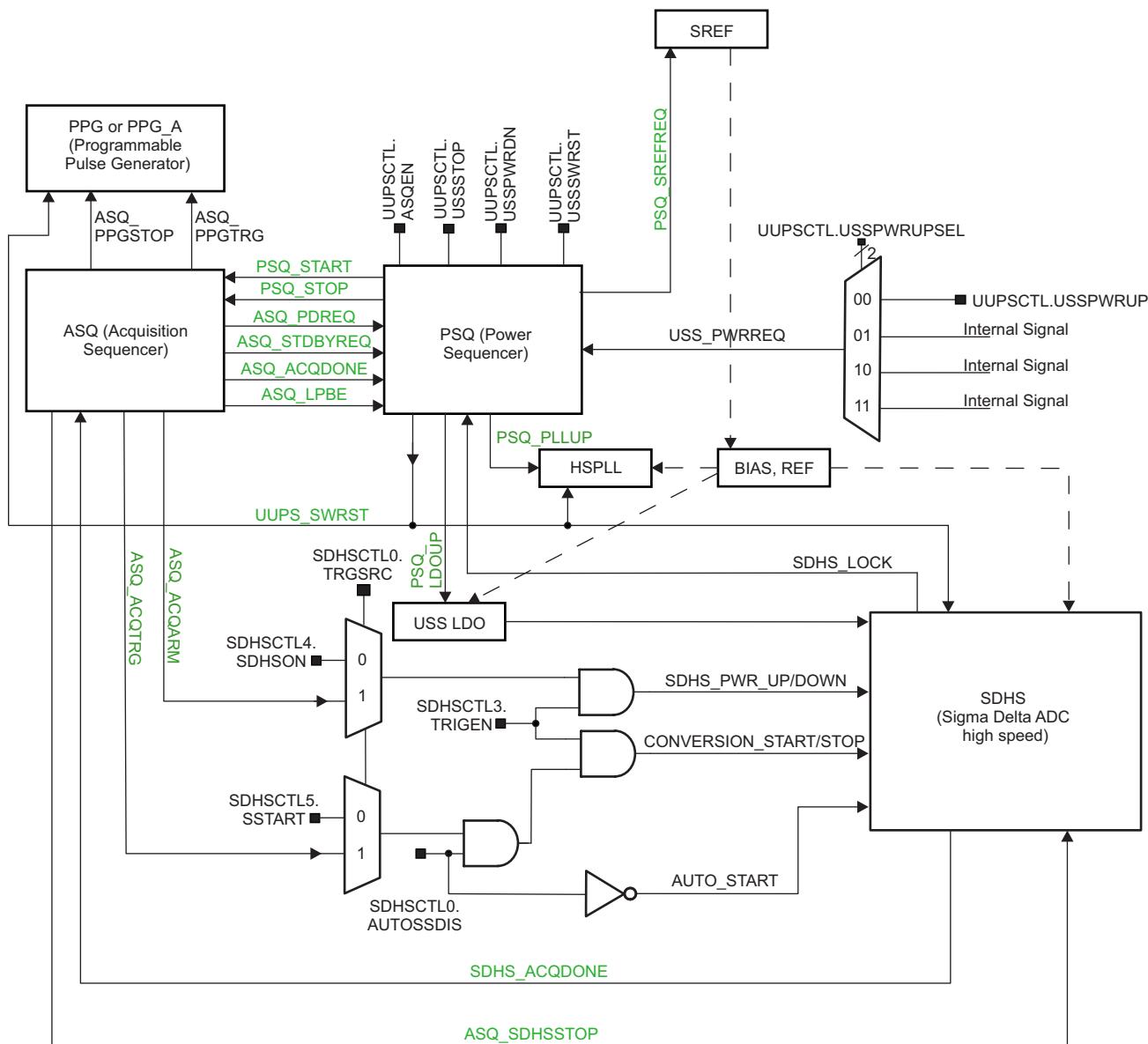
ModuleName.RegisterName or ModuleName.RegisterName.BitField

## 18.2 Operation of the USS Module

This section describes how the USS submodules are connected and controlled together. For details of each submodule, see the following chapters:

- [UUPS](#)
- [HSPLL](#)
- [SAPH or SAPH\\_A](#)
- [SDHS](#)

[Figure 18-2](#) shows control signals that connect the submodules.



## Figure 18-2. USS and USS\_A Submodule Connections

**NOTE:** In Figure 18-2, the control signals between submodules are shown in green. The naming convention for these signal is SourceSubmoduleName\_CommandToDestination.

Example 1: PSQ\_START: The signal is from PSQ to tell the receiver submodule to START (start measurement)

Example 2: ASQ\_ACQTRG: The signal is from ASQ to tell the receiver submodule to ACQTRG (acquisition trigger).

### 18.2.1 Auto Mode and Register Mode

The USS or USS\_A module can perform the full data acquisition sequence with minimum involvement of CPU, which enables ultra-low power consumption during the measurement and frees the CPU from data acquisition, so that the ultrasonic application software can be executed in parallel to data acquisition with minimum intervention. The USS or USS\_A module also support register mode, in which each measurement sequence is controlled by user software. Register mode can be used during development and for special tasks like diagnostics.

To enable the auto mode, apply the configurations in [Table 18-1](#) before turning on the USS or USS\_A module.

**Table 18-1. Auto Mode and Register Mode**

| Auto Mode Configuration                      | Action                                                            | Register Mode                                |
|----------------------------------------------|-------------------------------------------------------------------|----------------------------------------------|
| UUPSCTL.SWRST = 0                            | Take USS submodules out of reset (once after reset)               | UUPSCTL.SWRST = 0                            |
| SAPHMCNF.LPBE = 0                            | Enable auto mode or register mode (on mode changes)               | SAPHMCNF.LPBE = 0                            |
| UUPSCTL.LBHDEL = 0, 1, 2, or 3               | Set optimal start-up hold-off delay or leave at default           | UUPSCTL.LBHDEL = 0, 1, 2, or 3               |
| SAPHMCNF.BIMP = 0, 1, 2, or 3                | Set optimal bias impedance or leave at default                    | SAPHMCNF.BIMP = 0, 1, 2, or 3                |
| UUPSCTL.ASQEN = 1                            | PSQ to trigger ASQ when power is up (PSQ_START) (on mode changes) | UUPSCTL.ASQEN = 0                            |
| SAPHASCTL0.TRIGSEL = 1                       | ASQ is triggered by PSQ (on mode changes)                         | SAPHASCTL0.TRIGSEL = 0                       |
| SAPHOSEL.PCH0SEL = 1<br>SAPHOSEL.PCH1SEL = 1 | Drive output drivers to GND (on mode changes)                     | SAPHOSEL.PCH0SEL = 0<br>SAPHOSEL.PCH1SEL = 0 |
| SAPHBCTL.ASQBSW = 1                          | Tx bias, Rx bias control (on mode changes)                        | SAPHBCTL.ASQBSW = 0                          |
| SAPHPGCTL.PGSEL = 1                          | Select output channel in PPG (on mode changes)                    | SAPHPGCTL.PGSEL = 0                          |
| SAPHPGCTL.TRSEL = 1                          | Trigger PPG (on mode changes)                                     | SAPHPGCTL.TRSEL = 0                          |
| SAPHICTL0.MUXCTL = 1                         | Input channel selection (on mode changes)                         | SAPHICTL0.MUXCTL = 0                         |
| SDHSCTL0.TRGSRC = 1                          | SDHS power up and conversion trigger source (on mode changes)     | SDHSCTL0.TRGSRC = 0                          |
| SDHSCTL0.AUTOSSDIS = 1                       | SDHS conversion trigger (on mode changes)                         | SDHSCTL0.AUTOSSDIS = 0 or 1                  |
| SDHSCTL2.SMPCTLOFF = 0<br>(optional)         | Total sample size is preprogrammed (on mode changes)              | SDHSCTL2.SMPCTLOFF = 0 or 1                  |
| SDHSCTL2.DTCOFF = 0                          | Data transfer by DTC (on mode changes)                            | SDHSCTL2.DTCOFF = 0 or 1                     |

#### 18.2.1.1 Six Time Mark Events in Auto Mode

In auto mode, the six time mark registers generate important timing events during measurement. [Table 21-3](#) describes the time mark events.

**Table 18-2. Time Mark Events**

| Time Mark                                      | Action by ASQ                                             |
|------------------------------------------------|-----------------------------------------------------------|
| PSQ_START= 0 → 1                               | Apply Tx Bias                                             |
| ASQ time counter = Value in SAPHATM_A register | Trigger PPG to generate excitation pulses and stop pulses |
| ASQ time counter = Value in SAPHATM_B register | Turn on the SDHS                                          |
| ASQ time counter = Value in SAPHATM_C register | Apply Rx Bias                                             |
| ASQ time counter = Value in SAPHATM_D register | Start sampling the input signal (trigger the SDHS)        |
| ASQ time counter = Value in SAPHATM_E register | Restart the time counter for the next measurement         |
| ASQ time counter = Value in SAPHATM_F register | Time-out                                                  |

#### 18.2.1.2 How to Start in Auto Mode

In auto mode, the entire measurement sequence is executed by the PSQ and the ASQ. The start-up sequence is simple but the following order must be used:

1. Applied desired configurations to USS registers (all submodules). Make sure to apply the auto mode (see [Table 18-1](#)).
2. Set the following bits to 1: SAPHPGCTL.PPGEN, SAPHASCTL0.ASQTEN, SAPHMCNF.LPBE and SDHSCTL3.TRIGEN
3. Assert the USS\_PWRREQ signal (see [Table 18-3](#)).

**Table 18-3. USS\_PWRREQ Signal Source**

| UUPSCTL.USSPWRUPSEL | Selected Trigger Source | Comment                         |
|---------------------|-------------------------|---------------------------------|
| 0                   | UUPSCTL.USSPWRUP = 1    | Default, write only             |
| 1                   | Internal signal         | See device-specific data sheet. |
| 2                   | Internal signal         | See device-specific data sheet. |
| 3                   | Internal signal         | See device-specific data sheet. |

## 18.2.2 Control Signals

### Start-up signal, USS\_PWRREQ

USS\_PWRREQ = 0 → 1 is the signal that powers up the USS module and starts a new measurement. If the USS module is already powered up, then the PSQ initiates a new measurement immediately. UUPSCTL.USSPWRUPSEL determines the source of the USS\_PWRREQ signal. When the PSQ detects USS\_PWRREQ signal, no additional event is accepted by the PSQ until the measurement is complete. UUPSCTL.USS\_BUSY indicates whether or not the USS module is in a power transition or performing a measurement. While UUPSCTL.USS\_BUSY = 1, the PSQ ignores the USS\_PWRREQ signal (0 → 1).

### Reset and Low Power Bias Mode control signals

On device Power Up the all USS submodules are kept in reset state. Set UUPSCTL.SWRST = 0 to release reset and put the module into operation mode.

The operation mode has to be selected before the USS is powered up. For Auto mode and Register Mode set SAPHMCNF.LPBE=0.

To select Low Power Bias Mode set SAPHMCNF.LPBE=1. SAPHMCNF.LPBE shall only be changed while the PSQ is in OFF state.

- **USS\_SWRST:** SW reset signal to all USS submodules.
- **ASQ\_LPBE:** Enables Low Power Bias operation mode here the ASQ takes has full control over the input multiplexer and channel selection.

### Power-up control signals

When USS\_PWRREQ = 0 → 1 is detected, the PSQ starts the power-up sequence if the USS module has not been powered up (UUPSCTL.UPSTATE = 0). The PSQ requests the required reference voltage and currents, then enables the USS LDO and enables HSPLL. When the PLL is locked, generate the PSQ\_START signal to ASQ.

- **PSQ\_SREFREQ:** Request signal to the share reference module.
- **PSQ\_LDOUP:** Enables the USS LDO after the reference voltage and currents from BIAS\_REF module are settled.
- **PSQ\_PLLUP:** Enables HSPLL when UUPSCTL.LDORDY = 1.
- **PSQ\_START:** PSQ to ASQ to start a new measurement sequence. The PSQ asserts the signal when IREF\_MOD, USS LDO, and HSPLL are fully settled and UUPSCTL.ASQEN bit = 1.
- **PSQ\_STOP:** PSQ to ASQ to stop the existing measurement immediately. The PSQ asserts the signal when UUPSCTL.USSPWRDN = 1 or UUPSCTL.USSSTOP = 1.

### Measurement control signals

When USS\_START = 0 → 1 is detected, the ASQ starts a new measurement sequence based on the timing information in the time mark registers (SAPHATM\_A to SAPHATM\_F).

- **ASQ\_PPGTRG:** ASQ to PPG to generate excitation pulses.

- **ASQ\_ACQARM:** ASQ to SDHS to power up the SDHS module.
- **ASQ\_ACQTRG:** ASQ to SDHS to start data conversion and transfer output data to target memory.
- **SHDS\_ACQDONE:** SDHS to ASQ to acknowledge that the preconfigured sample size has been captured.

### Power-down control states and signals

When the desired measurement sequences finish execution, the power-down process starts. There are three power states that can be chosen:

- **READY:** The USS module is fully powered up (no changes in power state).
- **STANDBY:** The USS module is powered off, but required reference voltage is kept on for faster wakeup.
- **OFF:** The USS module is fully powered off.

The ASQ asserts ASQ\_ACQDONE to acknowledge the PSQ that the measurement is compete.

Depending on the selected power state, ASQ\_PDREQ or ASQ\_STBYREQ can be asserted along with the ASQ\_ACQDONE signal.

- **ASQ\_PDREQ:** Goes to OFF state.
- **ASQ\_STBYREQ:** Goes to STANDBY state.
- **ASQ\_ASQDONE:** Indicates that the measurement is complete. If neither ASQ\_PDREQ nor ASQ\_STBYREQ is asserted, then stay in READY state.

### Emergency measurement stop control signals

While the USS module is active, the current measurement sequence can be stopped at any time:

- **PSQ\_STOP:** PSQ to ASQ to stop the current measurement immediately (when UUPSCTL.USSSTOP = 1 or UUPSCTL.USSPWRDN = 1).
- **ASQ\_PPGSTOP:** ASQ to PPG to stop pulse generation if the PPG is active.
- **ASQ\_SDHSSTOP:** ASQ to SDHS to stop the data conversion and turn off the SDHS if the SDHS is active.

**Table 18-4. Control Signals Among USS Submodules**

| Source           | Signal      | Receiver             | Function                                                                 | Condition to Generate the Signal                              |
|------------------|-------------|----------------------|--------------------------------------------------------------------------|---------------------------------------------------------------|
| UUPSCTL.SWRST    | USS_SWRST   | ASQ, PPG, SAPH, SDHS | Software reset to all USS submodules                                     | UUPSCTL.SWRST = 1                                             |
| SAPHMCNF.LPBE    | ASQ_LPBE    | PSQ                  | Indication to enter low-power bias mode                                  | SAPHMCNF.LPBE = 1                                             |
| UUPSCTL.USSPWRUP | USS_PWRREQ  | PSQ                  | 1. Power up the USS module                                               | UUPSCTL.USSPWRUP = 0 → 1                                      |
| Internal signal  |             |                      | 2. Assert PSQ_START if UUPSCTL.ASQEN = 1                                 | See device-specific data sheet                                |
| Internal signal  |             |                      | 3. If UUPSCTL.USS_BUSY = 1 or UUPSCTL.UPSTATE = 2, the signal is ignored | See device-specific data sheet                                |
| Internal signal  |             |                      |                                                                          | See device-specific data sheet                                |
| PSQ              | PSQ_SREFREQ | SREF                 | Shared reference request                                                 | USS_PWRREQ: 0 → 1 (valid)                                     |
|                  | PSQ_LDOUP   | USS LDO              | Enable USS LDO                                                           | SREF is ready                                                 |
|                  | PSQ_PLLUP   | HSPLL                | Enable HSPLL                                                             | UUPSCTL.LDORDY = 1                                            |
|                  | PSQ_START   | ASQ                  | Start a new measurement                                                  | UUPSCTL.UPSTATE = 3                                           |
|                  | PSQ_STOP    |                      | Stop the current measurement immediately                                 | UUPSCTL.USSPWRDN = 1, UUPSCTL.USSSTOP = 1 or Enter debug mode |

**Table 18-4. Control Signals Among USS Submodules (continued)**

| Source | Signal       | Receiver | Function                                                             | Condition to Generate the Signal                                       |
|--------|--------------|----------|----------------------------------------------------------------------|------------------------------------------------------------------------|
| ASQ    | ASQ_PPGTRG   | PPG      | Start pulse generation                                               | SAPHATM_A register                                                     |
|        | ASQ_PPGSTOP  |          | Stop pulse generation immediately                                    | PSQ_STOP = 1 and PPG is active                                         |
|        | ASQ_ACQARM   | SDHS     | Power up SDHS                                                        | SAPHATM_B register                                                     |
|        | ASQ_ACQTRG   |          | Conversion start                                                     | SAPHATM_D register                                                     |
|        | ASQ_SDHSSTOP |          | Conversion stop and power off                                        | PSQ_STOP = 1                                                           |
|        | ASQ_PDREQ    | PSQ      | USS power down, PSQ can receive a new USS_PWRREQ signal              | If SAPHASCTL1.ESOFF = 1 and SAPHASCTL1.STDBY = 0 when SDHS_ACQDONE = 1 |
|        | ASQ_STDBYREQ |          | USS standby, USS power down, PSQ can receive a new USS_PWRREQ signal | If SAPHASCTL1.ESOFF = 1 and SAPHASCTL1.STDBY = 1 when SDHS_ACQDONE = 1 |
|        | ASQ_ACQDONE  |          | PSQ can receive a new USS_PWRREQ signal                              | SDHS_ACQDONE = 1                                                       |
| SDHS   | SDHS_ACQDONE | ASQ      | Signal to ASQ that SDHS data conversion is complete                  | When the preconfigured sample size has been captured                   |

### 18.3 Debug Features

When the device enters debug mode, the USS module automatically stops the existing measurement, and all interrupts are suppressed. The debugger can read or write any USS registers, but SDHSCTL4.SDHSON and SDHSCTL5.SSTART are not functional. The PSQ ignores the USS\_PWRREQ signal.

## ***Universal USS Power Supply (UUPS)***

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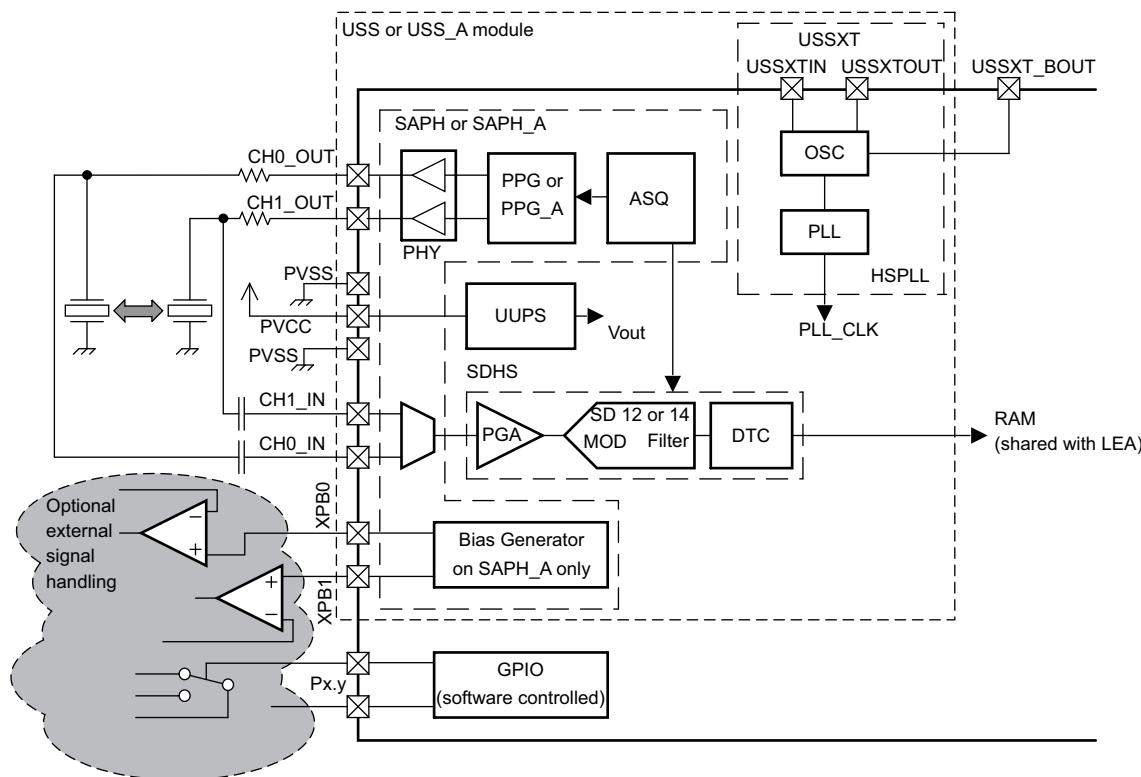
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This chapter describes the operation of the UUPS module.

| Topic                                                   | Page |
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## 19.1 Introduction

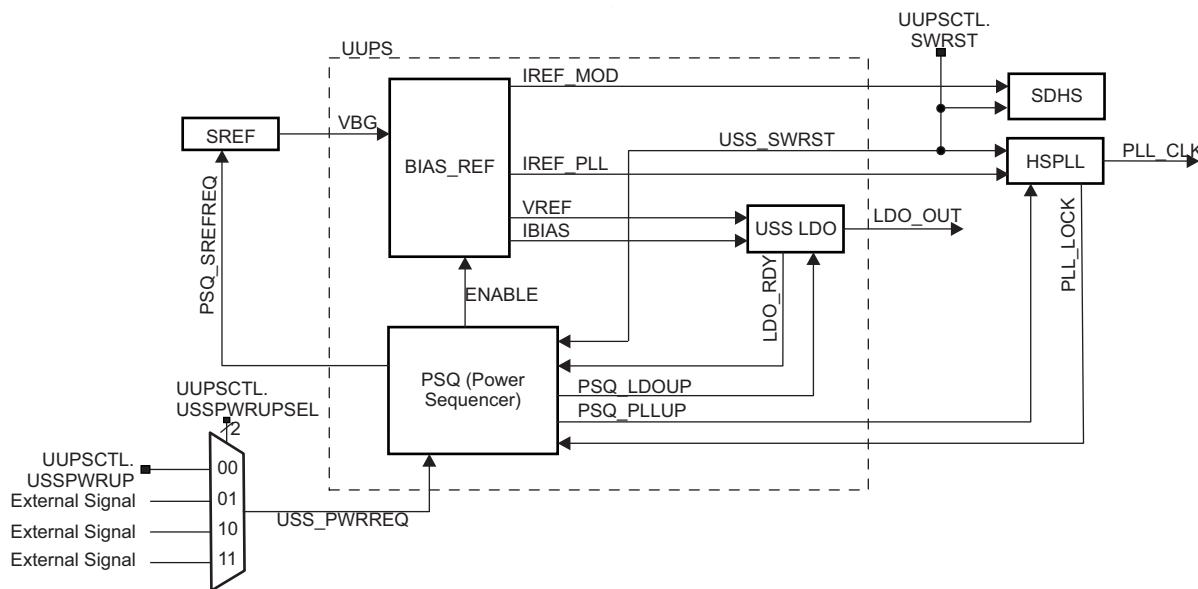
The Universal USS Power Supply (UUPS) is one of the submodules in the Ultrasonic Sensing Solution (USS) module. The USS module is designed for ADC-based ultrasonic sensing technology in various measurement applications. [Figure 19-2](#) shows the block diagram of the USS module.



**Figure 19-1. USS/USS\_A Block Diagram**

The UUPS module consists of three blocks: the power sequencer (PSQ), the reference generator (BIAS\_REF), and the USS LDO (see [Figure 19-2](#)).

- PSQ block: Controls the power-up and power-down sequences of the USS module.
- BIAS\_REF block: Generates required reference voltages and currents for the SDHS, HSPLL, and USS LDO.
- USS\_LDO block: Generates regulated 1.6 V, which is used by the USS submodules.



**Figure 19-2. UUPS Block Diagram**

The signal names in [Figure 19-2](#) are for information only to show how each block is connected inside the UUPS module. These signals are not under user control.

**NOTE:** Naming convention for register names and bit fields:

- UUPS registers: RegisterName or RegisterName.BitField
- Other module registers: ModuleNameRegisterName or ModuleNameRegisterName.BitField

## 19.2 USS Power-up Sequence

The Power Sequencer (PSQ) block controls the USS module power-up and power-down sequences. The PSQ powers up the USS module when the USS\_PWRREQ signal is asserted (see [Figure 19-2](#)). The USS\_PWRREQ signal can be generated from four different sources. When UUPSCTL.USSPWRUPSEL = 0, writing 1 to UUPSCTL.USSPWRUP generates the USS\_PWRREQ signal and starts the USS power-up sequences. The other sources may or may not be available; see the device-specific data sheet for the internal signal sources (search for UUPSCTL.USSPWRUPSEL). The power states of the USS module can be monitored by reading UUPSCTL.UPSTATE.

The order of the USS power-up sequence is:

1. The USS\_PWRREQ is asserted when the USS module is powered off (UUPSCTL.UPSTATE = 0, indicating that the USS module is in OFF state).
2. The PSQ sends a request to the shared reference (SREF) to generate VBG and starts an internal timer (UUPSCTL.UPSTATE = 2, indicating that the USS power state is in transition).
3. The PSQ enables the BIAS\_REF block when the VBG is ready (UUPSCTL.UPSTATE = 2).
4. The PSQ turns on the USS\_LDO when the required reference voltages and currents are ready (UUPSCTL.UPSTATE = 2).
5. The PSQ waits for the LDORDY signal which can be monitored by reading UUPSCTL.LDORDY (UUPSCTL.UPSTATE = 2).
6. The PSQ enables the HSPLL module when LDORDY = 1 (UUPSCTL.UPSTATE = 2).
7. The PSQ waits for the PLL\_LOCK signal from the HSPLL module. The PLL\_LOCK can be monitored by reading HSPLLCTL.PLL\_LOCK (UUPSCTL.UPSTATE = 2).
8. The PSQ sets UUPSCTL.UPSTATE = 3 to indicate that the USS is fully powered and ready to start a

new measurement.

9. If the PSQ internal timer reaches its time-out limit before the PLL\_LOCK signal is asserted, UUPSRIS.PTMOUT is set to 1. The time-out is not programmable and can vary depending on the PLL output clock frequency. The maximum delay is 160  $\mu$ s plus the configured "holdoff time" (~300us max).

#### CAUTION

The application must turn on the USSXT oscillator (HSPLLUXSXTLCTL.OSCEN = 1) and wait for a sufficient time to let the oscillator start (this depends on the crystal or resonator characteristics) before powering up the USS module. The USSXT oscillator is not controlled by the PSQ. The PSQ assumes that the oscillator output is already available and stable in frequency and amplitude).

### 19.3 USS Power States

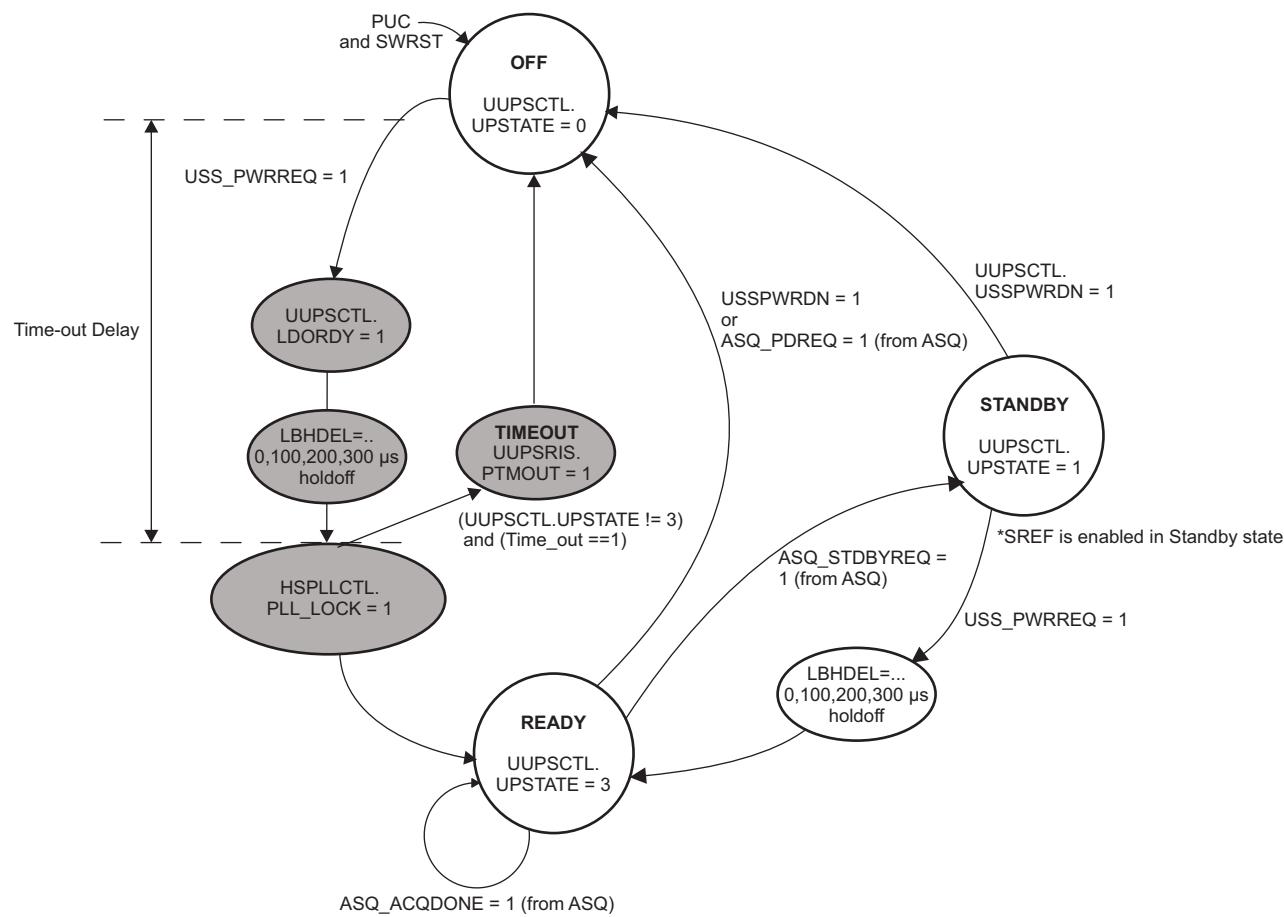
The following power states are supported by the UUPS module.

- **OFF:** The USS module is powered off (UUPSCTL.UPSTATE = 0).
- **TRANSITION:** The USS module is in transition state (UUPSCTL.UPSTATE = 2).
- **READY:** The USS module is fully powered up and ready (UUPSCTL.UPSTATE = 3).
- **STANDBY:** The USS module is powered off, but the SREF remains on for fast wakeup (UUPSCTL.UPSTATE = 1).
- **TIMEOUT:** The power-up sequence is taking more than expected time. The USS module goes back to OFF state and the PTMOUT (power time-out) interrupt is generated if enabled (UUPSCTL.UPSTATE bits = 0).

**Table 19-1. USS Power State**

| Power State | State Register<br>(UUPSCTL.UPSTATE) | Description                                                                                                                                                                                                                                                                 |
|-------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| OFF         | 0                                   | The USS module is fully powered off.                                                                                                                                                                                                                                        |
| TRANSITION  | 2                                   | In transition. A new trigger to the PSQ is ignored.                                                                                                                                                                                                                         |
| READY       | 3                                   | The USS module is fully powered up.                                                                                                                                                                                                                                         |
| STANDBY     | 1                                   | The USS module is powered off, but SREF is enable for fast wakeup.                                                                                                                                                                                                          |
| TIMEOUT     | 0                                   | The USS power-up sequence has not been properly ended. The USS module goes back to OFF state and UUPSRIS.PTMOUT is set to 1.<br>Note: A time-out should not happen during normal operating conditions. Make sure that the USSXT oscillator is enabled and working properly. |

Figure 19-3 shows the USS module power states and their relationships to each other.



**Figure 19-3. USS Power State Control Flow**

Table 19-2 lists the signals that cause UUPS power state transitions.

**Table 19-2. USS Power States and State Changes**

| Current Power State | Next State | UUPSCtrl.UPSTATE | Trigger Signal                          |
|---------------------|------------|------------------|-----------------------------------------|
| OFF                 | READY      | 0 → 2 → 3        | USS_PWRREQ = 0 → 1                      |
| READY               | STANDBY    | 3 → 2 → 1        | ASQ_STDBYREQ = 0 → 1 (generated by ASQ) |
| READY               | OFF        | 3 → 2 → 0        | ASQ_PDREQ = 0 → 1 (generated by ASQ)    |
| READY               | OFF        | 3 → 2 → 0        | UUPSCtrl.USSPWRDN = 0 → 1               |
| STANDBY             | OFF        | 1 → 2 → 0        | UUPSCtrl.USSPWRDN = 0 → 1               |
| STANDBY             | READY      | 1 → 2 → 3        | USS_PWRREQ = 0 → 1                      |

The USS power state and the device power mode have a relationship as listed in Table 19-3. When the USS module is in READY state, keep the device in LPM0 or AM mode, because the USS module uses resources from the core domain of the device. If the device is in other low-power modes, the measurement performance degrades significantly.

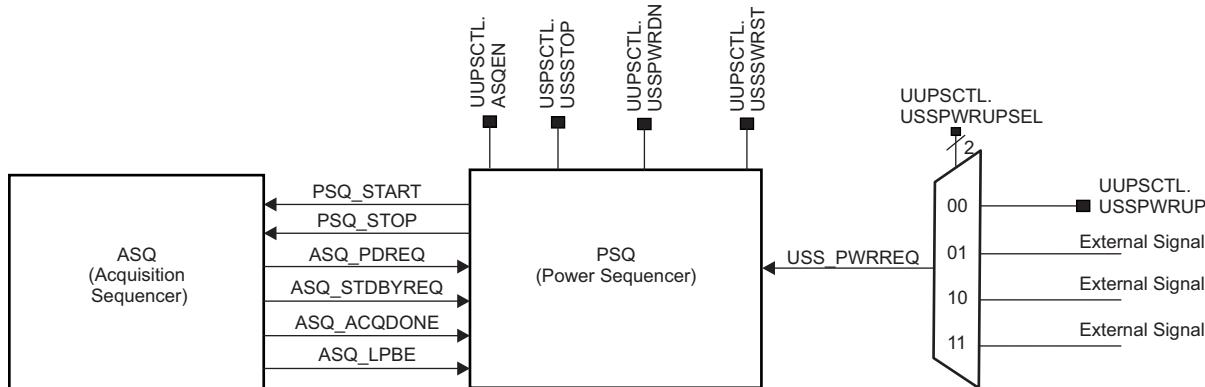
The transition from STANDBY to READY can be extended by a user selectable holdoff delay. This method is used in ultra low bias mode to suppress the PLL operation while the system is still settling. Depending on the transducers and other external circuits some considerable power savings can be achieved.

**Table 19-3. Device Power Modes and USS Power States**

| USS Power State Change | Device Power Mode                 |
|------------------------|-----------------------------------|
| READY                  | LPM0 or higher                    |
| STANDBY                | LPM3 or higher<br>(PMMREGOFF = 0) |

## 19.4 Interface to the ASQ (Acquisition Sequencer)

Figure 19-4 shows the interface signals between the PSQ and the ASQ (see [Chapter 21](#) for details).


**Figure 19-4. USS Power Control**


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**NOTE:** The control signals in [Table 19-4](#) are internal only, and cannot be read or written by user software.

---

**Table 19-4. Internal Control Signals**

| Control Signal | Description                                                                           | Condition to be Triggered                                                              |
|----------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| USS_PWRREQ     | PSQ to power up the USS module and generate PSQ_START to the ASQ if UUPSCTL.ASQEN = 1 | Trigger one of the sources selected by UUPSCTL.USSPWRUPSEL                             |
| PSQ_START      | ASQ to start a new measurement process if SAPHASCTL0.TRIGSEL = 1                      | UUPSCTL.UPSTATE = 0 → 2 → 3 and UUPSCTL.ASQEN = 1                                      |
| PSQ_STOP       | ASQ to stop the current measurement process                                           | UUPSCTL.USSSTOP = 0 → 1                                                                |
| ASQ_ACQDONE    | Acknowledge PSQ that ASQ has completed the measurements                               | The measurements have been completed                                                   |
| ASQ_STDBYREQ   | PSQ to enter STANDBY state                                                            | The measurements have been completed and SAPHASCTL1.ESOFF = 1 and SAPHASCTL1.STDBY = 1 |
| ASQ_PDREQ      | PSQ to power off the USS module                                                       | The measurements have been completed and SAPHASCTL1.ESOFF = 1 and SAPHASCTL1.STDBY = 0 |

### 19.4.1 Start New Measurements

If UUPSCTL.ASQEN = 1, the PSQ block automatically sends the PSQ\_START signal to the ASQ when the USS module is fully powered up. The ASQ starts new measurement sequences upon receiving the PSQ\_START signal if SAPHASCTL0.TRIGSEL = 1. In this case, the full measurement sequence can be performed without any CPU intervention, and the USS\_PWRREQ is the only trigger signal the USS module needs externally. The PSQ and ASQ must be configured independently (see [Figure 19-4](#)). The ASQ can be triggered by user software by writing SAPHASQTRIG.ASQTRIG = 1 when SAPHASCTL0.TRIGSEL = 0.

Figure 19-4 shows the interface signals between the PSQ and the ASQ (see Chapter 21 for details). If UUPSCTL.ASQEN = 1, the PSQ block sends the PSQ\_START signal to the ASQ when the USS module reaches READY state from OFF state. Then, the ASQ starts new measurement sequences upon receiving the PSQ\_START signal if SAPHASCTL0.TRIGSEL = 1. In this case, the full measurement sequences can be performed without any CPU intervention. The USS\_PWRREQ is the only trigger signal the USS needs to take externally. The PSQ and ASQ must be configured independently (see Figure 19-4). The ASQ can be triggered manually by user software by writing SAPHASQTRIG.ASQTRIG = 1 when SAPHASCTL0.TRIGSEL = 0.

**Table 19-5. ASQ Trigger**

| ASQ Auto Trigger Mode | PSQ Configuration | ASQ Configuration      | How to Trigger ASQ                                                                                              |
|-----------------------|-------------------|------------------------|-----------------------------------------------------------------------------------------------------------------|
| Yes                   | UUPSCTL.ASQEN = 1 | SAPHASCTL0.TRIGSEL = 1 | The PSQ sends a trigger signal (PSQ_START) to the ASQ when the USS gets to READY state                          |
| No                    | UUPSCTL.ASQEN = 0 | SAPHASCTL0.TRIGSEL = 1 | This configuration is not supported                                                                             |
| No                    | UUPSCTL.ASQEN = 1 | SAPHASCTL0.TRIGSEL = 0 | The PSQ_START signal generated by the PSQ is ignored. The ASQ is triggered by writing 1 to SAPHASQTRIG.ASQTRIG. |
| No                    | UUPSCTL.ASQEN = 0 | SAPHASCTL0.TRIGSEL = 0 | The ASQ is triggered by writing 1 to SAPHASQTRIG.ASQTRIG.                                                       |

#### 19.4.2 Stop Measurement Before Completion

While the USS module is performing a measurement, the PSQ can stop the current measurement process using any of these methods:

- **Write 1 to UUPSCTL.USSSTOP:** The PSQ asserts the PSQ\_STOP signal to the ASQ, then the ASQ starts the process to gracefully stop the current measurement. When the measurement is fully stopped, the ASQ asserts the ASQ\_ACQDONE signal to the PSQ. No changes are made to the USS power state. The UUPSCTL.USSSTOP bit is cleared when the stop request has been completed. If this bit is set to 1 when the ASQ is idle, it is cleared immediately.
- **Enable Debug mode:** When debug entry is detected, the PSQ asserts, the PSQ asserts the PSQ\_STOP signal to the ASQ, then the ASQ starts the process to stop the current measurement gracefully. When the measurement is fully stopped, the ASQ asserts the ASQ\_ACQDONE signal to the PSQ. No changes to the USS power state.
- **Write 1 to UUPSCTL.USSPWRDN:** The PSQ asserts the PSQ\_STOP signal to the ASQ, then the ASQ starts the process to gracefully stop the current measurement. When the measurement is fully stopped, the ASQ asserts the ASQ\_ACQDONE signal, then the PSQ powers off the USS module. The UUPSCTL.USSPWRDN bit is cleared when the power down request has been completed. If this bit is set to 1 when the USS module is powered off (OFF state), it is cleared immediately.

### 19.4.3 USS Power State After Completion of Measurements

The USS power state after completion of the measurement can be programmed to one of the following states:

- **READY:** No changes to the USS power state. The USS module is ready for the next measurement.
- **STANDBY:** The USS module is powered off but, the SREF block is enabled for fast wakeup.
- **OFF:** The USS module is fully powered off.

[Figure 19-4](#) lists the configuration to select one of the power states after measurement completion.

**Table 19-6. Power States After Measurement Completion**

| Configuration Before Starting a New Measurement | Final USS Power State After Measurement Completion |
|-------------------------------------------------|----------------------------------------------------|
| SAPHASCTL1.ESOFF = 0                            | READY                                              |
| SAPHASCTL1.ESOFF = 1 and SAPHASCTL1.STDBY = 1   | STANDBY                                            |
| SAPHASCTL1.ESOFF = 1 and SAPHASCTL1.STDBY = 0   | OFF                                                |

### 19.4.4 UUPSCTL.USSPWRUP Bit and UUPSCTL.USS\_BUSY Bit

[Figure 19-2](#) shows that the USS\_PWRREQ signal can be generated from a maximum of four different sources (see the device-specific data sheet for implementation). When UUPSCTL.USSPWRUPSEL = 0, UUPSCTL.USSPWRUP is selected. In the case, writing 1 to UUPSCTL.USSPWRUP asserts the USS\_PWRREQ signal to the PSQ, then the PSQ starts the power-up sequences, and then the PSQ can trigger the PSQ to perform new measurements (if UUPSCTL.ASQEN = 1 and SAPHASCTL0.TRIGSEL = 1). Writing 1 to UUPSCTL.USSPWRUP is invalid and ignored if the power is in TRANSITION state (UUPSCTL.UPSTATE = 2) or the ASQ is performing a measurement sequence (UUPSCTL.USS\_BUSY = 1), because the current power sequence or the measurement sequence should be completed before taking a new request.

The UUPSCTL.USS\_BUSY bit can be used to monitor the USS module status. When a valid USS\_PWRREQ signal is detected, the PSQ sets the UUPSCTL.USS\_BUSY bit to 1 to indicate that the PSQ is in busy state and is not ready to take a new USS\_PWRREQ signal. Do not generate a new USS\_PWRREQ while UUPSCTL.USS\_BUSY = 1. The UUPSCTL.USS\_BUSY is set to 1 when any one of the following conditions is satisfied:

- UUPSCTL.UPSTATE = 2 (power state = TRANSITION)
- The ASQ is performing a measurement sequence (the internal signal, ASQ\_ACQDONE = 0).
- The SDHS is sampling data (SDHSCTL5.SDHS\_LCK = 1) even when the measurement is not under ASQ control (register mode).

## 19.5 Interrupts

The UUPS module supports the following interrupts:

- **STPBYDB interrupt:** The USS module has been interrupted by debug mode. This interrupt is reported when debug halt mode is entered when UUPSRIS.USS\_BUSY = 1 or UUPSRIS.UPSTATE = 3. The interrupt indicates that any existing activities have been (or will be) stopped due to entering debug mode:
  - If UUPSRIS.USS\_BUSY = 1 and UUPSRIS.STPBYDB = 1, then the USS module is stopping the current activities.
  - If UUPSRIS.USS\_BUSY = 0 and UUPSRIS.STPBYDB = 1, then the USS module is idle.
- **PTMOUT interrupt:** This interrupt is reported when the power-up sequence takes more time than expected. The USS module is powered off and the UUPSRIS.PTMOUT is set to 1.
- **PREQIG interrupt:** This interrupt is reported when a new USS\_PWRREQ is detected before completing the previous measurement. Two conditions of the USS\_PWRREQ signal cannot be detected:
  1. After detecting a valid USS\_PWRREQ signal, another USS\_PWRREQ is applied within 3 MODOSC clock cycles.
  2. After UUPSRIS.PREQIG is cleared, a USS\_PWRREQ signal is applied within 6 MODOSC clock cycles + 2 system clock cycles.

## 19.6 Debug Mode

The USS module stops activities when the device enters debug mode. The following actions are performed when entering debug mode.

- Assert the PSQ\_STOP signal to the ASQ to stop the current measurement sequence.
- Set UUPSRIS.STPBYDB to 1 to indicate that the current measurement has been interrupted.
- Clear UUPSRIS.USS\_BUSY bit to zero upon receiving the ASQ\_ACQDONE from the ASQ.
- Ignore the USS\_PWRREQ signal (writing 1 to UUPSRIS.USSPWRUP in debug mode has no effect).

## 19.7 UUPS Registers

Table 19-7 lists the memory-mapped registers for the UUPS. All register offset addresses not listed in Table 19-7 should be considered as reserved locations and the register contents should not be modified.

**Table 19-7. UUPS Registers**

| Offset | Acronym    | Register Name                    | Type       | Reset | Section                        |
|--------|------------|----------------------------------|------------|-------|--------------------------------|
| 0h     | UUPSIIDX   | Interrupt Index Register         | read-only  | 0     | <a href="#">Section 19.7.1</a> |
| 2h     | UUPSMIS    | Masked Interrupt Status Register | read-only  | 0h    | <a href="#">Section 19.7.2</a> |
| 4h     | UUPSRIS    | Raw Interrupt Status Register    | read-only  | 0h    | <a href="#">Section 19.7.3</a> |
| 6h     | UUPSIMSC   | Interrupt Mask Register          | read-write | 0h    | <a href="#">Section 19.7.4</a> |
| 8h     | UUPSICR    | Interrupt Clear Register.        | write-only | 0h    | <a href="#">Section 19.7.5</a> |
| Ah     | UUPSISR    | Interrupt Flag Set Register.     | write-only | 0h    | <a href="#">Section 19.7.6</a> |
| Ch     | UUPSDESCLO | UUPS Descriptor Register L.      | read-only  | 110h  | <a href="#">Section 19.7.7</a> |
| Eh     | UUPSDESCHI | UUPS Descriptor Register H.      | read-only  | BA10h | <a href="#">Section 19.7.8</a> |
| 10h    | UUPSCTL    | UUPS Control                     | read-write | 800h  | <a href="#">Section 19.7.9</a> |

### 19.7.1 UUPSIIDX Register (Offset = 0h) [reset = 0h]

UUPSIIDX is shown in [Figure 19-5](#) and described in [Table 19-8](#).

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Interrupt Index Register.

Note: This register is word accessible. A byte access is also allowed but not recommended. Either high byte or low byte access alone can clear the pending interrupt flag.

**Figure 19-5. UUPSIIDX Register**

|      |    |    |    |    |    |   |          |
|------|----|----|----|----|----|---|----------|
| 15   | 14 | 13 | 12 | 11 | 10 | 9 | 8        |
| IIDX |    |    |    |    |    |   |          |
| R-   |    |    |    |    |    |   |          |
| 7    | 6  | 5  | 4  | 3  | 2  | 1 | 0        |
| IIDX |    |    |    |    |    |   | RESERVED |
| R-   |    |    |    |    |    |   | R-       |

**Table 19-8. UUPSIIDX Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | IIDX     | R    |       | <p>UUPS Interrupt Vector Value. Read only. It generates a value that can be used as address offset for fast interrupt service routine handling. On each read, only one interrupt is indicated. On a read, the current interrupt (highest priority) is automatically cleared by the hardware and the corresponding interrupt flag in RIS and MIS are cleared as well. After a read from the CPU (not from the debug interface), the register must be updated with the next highest priority interrupt, if none are pending, then it should display 0h.</p> <p>If the interrupt displayed by the IIDX register (highest priority pending interrupt) is cleared in the ICR through a software write of 1 in the corresponding bit field, the IIDX register shall be updated and the next priority interrupt (if any) be displayed.</p> <p>Reset type: PUC</p> <p>0h (R) = No Interrupt pending</p> <p>1h (R) = Interrupt Source: PTMOUT; Interrupt Priority: Highest</p> <p>2h (R) = Interrupt Source: PREQIG</p> <p>3h (R) = Interrupt Source: STPBYDB</p> <p>4h (R) = Reserved; Interrupt Priority: Lowest</p> |
| 0    | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

### 19.7.2 UUPSMIS Register (Offset = 2h) [reset = 0h]

UUPSMIS is shown in [Figure 19-6](#) and described in [Table 19-9](#).

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Masked Interrupt Status Register.

Implementation note: UUPSMIS = (RIS and IMSC) when read.

**Figure 19-6. UUPSMIS Register**

|          |    |    |    |      |         |        |        |
|----------|----|----|----|------|---------|--------|--------|
| 15       | 14 | 13 | 12 | 11   | 10      | 9      | 8      |
| RESERVED |    |    |    |      |         |        |        |
| R-0h     |    |    |    |      |         |        |        |
| 7        | 6  | 5  | 4  | 3    | 2       | 1      | 0      |
| RESERVED |    |    |    |      | STPBYDB | PREQIG | PTMOUT |
| R-0h     |    |    |    | R-0h | R-0h    | R-0h   | R-0h   |

**Table 19-9. UUPSMIS Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                           |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | RESERVED | R    | 0h    | Reserved                                                                                                                                              |
| 2    | STPBYDB  | R    | 0h    | USS has been interrupted by debug mode Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending |
| 1    | PREQIG   | R    | 0h    | UUPS Power Request Ignored Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending             |
| 0    | PTMOUT   | R    | 0h    | UUPS Power Up Time Out Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending                 |

### 19.7.3 UUPSRIS Register (Offset = 4h) [reset = 0h]

UUPSRIS is shown in [Figure 19-7](#) and described in [Table 19-10](#).

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Raw Interrupt Status Register. Read Only Register.

The UUPSRIS register allows the user to implement a poll scheme instead of an interrupt (as the interrupt does not need to be enabled)

Note that the UUPSRIS flag can be cleared by writing to the ICR register bit.

**Figure 19-7. UUPSRIS Register**

|          |    |    |    |    |         |        |        |
|----------|----|----|----|----|---------|--------|--------|
| 15       | 14 | 13 | 12 | 11 | 10      | 9      | 8      |
| RESERVED |    |    |    |    |         |        |        |
| R-0h     |    |    |    |    |         |        |        |
| 7        | 6  | 5  | 4  | 3  | 2       | 1      | 0      |
| RESERVED |    |    |    |    | STPBYDB | PREQIG | PTMOUT |
| R-0h     |    |    |    |    | R-0h    | R-0h   | R-0h   |

**Table 19-10. UUPSRIS Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 2    | STPBYDB  | R    | 0h    | <p>USS has been interrupted by debug mode. Read Only. This interrupt flag is set when debug halt mode is entered when USS_BUSY = 1 or UPSTATE = 3. The interrupt indicates that any existing activity of USS will be or has been stopped due to entering debug halt.</p> <p>If USS_BUSY = 1 and STPBYDB = 1, then USS is in the middle of stopping the existing activities.</p> <p>If USS_BUSY = 0 and STPBYDB = 1, then USS is in idle state.</p> <p>Reset type: PUC</p> <p>0h (R) = USS has not been interrupted by debug halt mode.</p> <p>1h (R) = USS has been interrupted by debug halt mode.</p>                                                                                                                      |
| 1    | PREQIG   | R    | 0h    | <p>Power Request Ignored Raw Interrupt Status bit. Read Only. This interrupt flag is set when USS_PWRREQ is detected before completing the previous measurement.</p> <p>Note: There are two conditions that a USS_PWRREQ signal cannot be detected. See below.</p> <ol style="list-style-type: none"> <li>After detecting a valid USS_PWRREQ signal, another USS_PWRREQ is applied within 3 MODOSC clock period.</li> <li>After RIS.PREQIG bit is cleared (either by ICR or reading IIDX register), a USS_PWRREQ signal is applied within 6 MODOSC clock + 2 System clock period.</li> </ol> <p>Reset type: PUC</p> <p>0h (R) = No USS_PWRREQ signal has been ignored</p> <p>1h (R) = USS_PWRREQ signal has been ignored</p> |
| 0    | PTMOUT   | R    | 0h    | <p>UUPS Power Up Time Out Raw Interrupt Status bit. Read Only</p> <p>Reset type: PUC</p> <p>0h (R) = Time out during power up has not occurred</p> <p>1h (R) = Time out during power up has occurred</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

### 19.7.4 UUPSIMSC Register (Offset = 6h) [reset = 0h]

UUPSIMSC is shown in [Figure 19-8](#) and described in [Table 19-11](#).

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Interrupt Mask Register.

This is a read and write register. On a read, it returns the current state of the mask on the relevant interrupt. On a write of 1 to a particular bit, it sets the corresponding mask of that interrupt. A write of 0 clears the mask.

**Figure 19-8. UUPSIMSC Register**

|          |    |    |    |    |         |        |        |
|----------|----|----|----|----|---------|--------|--------|
| 15       | 14 | 13 | 12 | 11 | 10      | 9      | 8      |
| RESERVED |    |    |    |    |         |        |        |
| R-0h     |    |    |    |    |         |        |        |
| 7        | 6  | 5  | 4  | 3  | 2       | 1      | 0      |
| RESERVED |    |    |    |    | STPBYDB | PREQIG | PTMOUT |
| R-0h     |    |    |    |    | R/W-0h  | R/W-0h | R/W-0h |

**Table 19-11. UUPSIMSC Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                              |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                 |
| 2    | STPBYDB  | R/W  | 0h    | USS has been interrupted by debug mode Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R) = STPBYDB Interrupt is disabled<br>1h (R) = STPBYDB Interrupt is enabled                     |
| 1    | PREQIG   | R/W  | 0h    | Power Request Ignored Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Power Request Ignore Interrupt is disabled.<br>1h (R/W) = Power Request Ignore Interrupt is enabled.      |
| 0    | PTMOUT   | R/W  | 0h    | UUPS Power Up Time Out Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = UUPS Power Up Time Out Interrupt is disabled.<br>1h (R/W) = UUPS Power Up Time Out Interrupt is enabled. |

### **19.7.5 UUPSICR Register (Offset = 8h) [reset = 0h]**

UUPSICR is shown in [Figure 19-9](#) and described in [Table 19-12](#).

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Interrupt Clear Register. Write 1 to clear the corresponding RIS bit. Read as zero.

**Figure 19-9. UUPSICR Register**

|          |    |    |    |    |         |        |        |
|----------|----|----|----|----|---------|--------|--------|
| 15       | 14 | 13 | 12 | 11 | 10      | 9      | 8      |
| RESERVED |    |    |    |    |         |        |        |
| R-0h     |    |    |    |    |         |        |        |
| 7        | 6  | 5  | 4  | 3  | 2       | 1      | 0      |
| RESERVED |    |    |    |    | STPBYDB | PREQIG | PTMOUT |
| R-0h     |    |    |    |    | W-0h    | W-0h   | W-0h   |

**Table 19-12. UUPSICR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                    |
|------|----------|------|-------|--------------------------------------------------------------------------------|
| 15-3 | RESERVED | R    | 0h    | Reserved                                                                       |
| 2    | STPBYDB  | W    | 0h    | USS has been interrupted by debug mode Interrupt Clear bit.<br>Reset type: PUC |
| 1    | PREQIG   | W    | 0h    | Power Request Ignored Interrupt Clear bit. Write 1 to Clear RIS.PREQIG bit.    |
| 0    | PTMOUT   | W    | 0h    | UUPS Power Up Time Out Interrupt Clear bit. Write 1 to clear RIS.PTMOUT bit.   |

### 19.7.6 UUPSISR Register (Offset = Ah) [reset = 0h]

UUPSISR is shown in [Figure 19-10](#) and described in [Table 19-13](#).

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Interrupt Flag Set Register. Read as zero.

**Figure 19-10. UUPSISR Register**

|          |    |    |    |         |        |        |      |
|----------|----|----|----|---------|--------|--------|------|
| 15       | 14 | 13 | 12 | 11      | 10     | 9      | 8    |
| RESERVED |    |    |    |         |        |        |      |
| R-0h     |    |    |    |         |        |        |      |
| 7        | 6  | 5  | 4  | 3       | 2      | 1      | 0    |
| RESERVED |    |    |    | STPBYDB | PREQIG | PTMOUT |      |
| R-0h     |    |    |    | W-0h    | W-0h   | W-0h   | W-0h |

**Table 19-13. UUPSISR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                |
|------|----------|------|-------|--------------------------------------------------------------------------------------------|
| 15-3 | RESERVED | R    | 0h    | Reserved                                                                                   |
| 2    | STPBYDB  | W    | 0h    | USS has been interrupted by debug mode Interrupt Set bit.<br>Reset type: PUC               |
| 1    | PREQIG   | W    | 0h    | Power Request Ignored Interrupt Set bit. Write 1 to set RIS.PREQIG bit                     |
| 0    | PTMOUT   | W    | 0h    | UUPS Power Up Time Out Interrupt Set bit. Write 1 to set RIS.PTMOUT bit<br>Reset type: PUC |

### 19.7.7 UUPSDESCLO Register (Offset = Ch) [reset = 110h]

UUPSDESCLO is shown in [Figure 19-11](#) and described in [Table 19-14](#).

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UUPS Descriptor Register L.

**Figure 19-11. UUPSDESCLO Register**

| 15         | 14 | 13 | 12 | 11      | 10 | 9    | 8 |
|------------|----|----|----|---------|----|------|---|
| FEATUREVER |    |    |    | INSTNUM |    |      |   |
| R-0h       |    |    |    |         |    | R-1h |   |
| 7          | 6  | 5  | 4  | 3       | 2  | 1    | 0 |
| MAJREV     |    |    |    | MINREV  |    |      |   |
| R-1h       |    |    |    |         |    | R-0h |   |

**Table 19-14. UUPSDESCLO Register Field Descriptions**

| Bit   | Field      | Type | Reset | Description                                                                                                         |
|-------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------|
| 15-12 | FEATUREVER | R    | 0h    | Feature Set for the module<br>Reset type: PUC                                                                       |
| 11-8  | INSTNUM    | R    | 1h    | Instance Number within the device. This will be a parameter to the RTL for modules that can have multiple instances |
| 7-4   | MAJREV     | R    | 1h    | Major Revision<br>Reset type: PUC                                                                                   |
| 3-0   | MINREV     | R    | 0h    | Minor Revision<br>Reset type: PUC                                                                                   |

### 19.7.8 UUPSDESCHI Register (Offset = Eh) [reset = BA10h]

UUPSDESCHI is shown in [Figure 19-12](#) and described in [Table 19-15](#).

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UUPS Descriptor Register H.

**Figure 19-12. UUPSDESCHI Register**

|          |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|----------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MODULEID |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R-BA10h  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 19-15. UUPSDESCHI Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                           |
|------|----------|------|-------|---------------------------------------|
| 15-0 | MODULEID | R    | BA10h | Module Identifier.<br>Reset type: PUC |

### 19.7.9 UUPSCTL Register (Offset = 10h) [reset = 800h]

UUPSCTL is shown in [Figure 19-13](#) and described in [Table 19-16](#).

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UUPS Control Register

**Figure 19-13. UUPSCTL Register**

| 15       | 14       | 13       | 12     | 11       | 10          | 9        | 8 |
|----------|----------|----------|--------|----------|-------------|----------|---|
| USSSTOP  | USSPWRDN |          | LBHDEL | ASQEN    | USSPWRUPSEL | USSPWRUP |   |
| R/W-0h   | R/W-0h   |          | R/W-0h | R/W-1h   | R/W-0h      | W-0h     |   |
| 7        | 6        | 5        | 4      | 3        | 2           | 1        | 0 |
| USSSWRST |          | RESERVED |        | USS_BUSY | UPSTATE     | LDORDY   |   |
| R/W-0h   |          | R-0h     |        | R-0h     | R-0h        | R-0h     |   |

**Table 19-16. UUPSCTL Register Field Descriptions**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------|-------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | USSSTOP     | R/W  | 0h    | Force to stop the current measurement. This bit is self cleared. No change to the power state. This bit is cleared when the stop request has been completed. Note that if this bit is set to '1' when the ASQ is idle, it is cleared immediately.<br><br>Reset type: PUC<br>0h (R/W) = No action<br>1h (R/W) = Stop the current measurement.                                                                                                                                                                                                                                           |
| 14    | USSPWRDN    | R/W  | 0h    | Force to power down the USS module. This bit is self cleared. Writing '0' has no effect. This bit is cleared when the powerdown request has been completed. Note that if this bit is set to '1' when the USS module is in OFF state, it is cleared immediately.<br><br>Reset type: PUC<br>0h (R/W) = No action<br>1h (R/W) = Stop the current measurement and power off the USS module.                                                                                                                                                                                                |
| 13-12 | LBHDEL      | R/W  | 0h    | Low power bias hold off delay. These bits define the duration of the hold off delay for the low power bias mode ( SAPHMCNF.LPBE=1). The hold off delay is inserted from "OFF state" to "READY state" and from "STANDBY state" to "READY state". Set these bits to zero to avoid extra delay in Register Mode and Auto Mode.<br><br>Reset type: PUC<br>0h (R/W) = no additional delay<br>1h (R/W) = additional hold off delay of ~100us (512 REFCLKs)<br>2h (R/W) = additional hold off delay of ~200us (1024 REFCLKs)<br>3h (R/W) = additional hold off delay of ~300us (1536 REFCLKs) |
| 11    | ASQEN       | R/W  | 1h    | Enable the PSQ_START signal to the ASQ.<br><br>Note: This bit must be correctly configured before asserting the USS_PWRREQ signal.<br><br>Reset type: PUC<br>0h (R/W) = Do not generate the PSQ_START signal event to ASQ.<br>1h (R/W) = Generate the PSQ_START signal event to the ASQ.                                                                                                                                                                                                                                                                                               |
| 10-9  | USSPWRUPSEL | R/W  | 0h    | USS Power Up trigger source select.<br><br>Reset type: PUC<br>0h (R/W) = CTL.USSPWRUP bit<br>1h (R/W) = Ext. trigger (see the device specific datasheet)<br>2h (R/W) = Ext. trigger (see the device-specific data sheet)<br>3h (R/W) = Ext. trigger (see the device-specific data sheet)                                                                                                                                                                                                                                                                                               |

**Table 19-16. UUPSLT Register Field Descriptions (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 8   | USSPWRUP | W    | 0h    | <p>Power up the USS module. This bit is self cleared. Writing '0' has no effect.</p> <p>Note: This bit is read as zero.</p> <p>Reset type: PUC</p> <p>0h (R/W) = No action</p> <p>1h (R/W) = Power up the USS module and generate the PSQ_START to the ASQ if CTL.ASQEN = 1.</p> <p>Note: This bit becomes invalid in debug mode.</p>                                                                                                                                                                                                                   |
| 7   | USSSWRST | R/W  | 0h    | <p>Software reset</p> <p>Reset type: PUC</p> <p>0h (R/W) = Disabled. USS (and sub modules) reset released for operation</p> <p>1h (R/W) = Enabled. USS (and sub modules) logic held in reset state</p>                                                                                                                                                                                                                                                                                                                                                  |
| 6-4 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 3   | USS_BUSY | R    | 0h    | <p>USS Busy bit. Read Only. This bit is set to '1' if one of the following conditions is met.</p> <p>1) CTL.UPSTATE = 2</p> <p>2) ASQ is in the middle of performing a measurement process</p> <p>3) SDHS.CTL5.SDHS_LOCK = 1.</p> <p>Reset type: PUC</p> <p>0h (R) = The USS module is not busy.</p> <p>1h (R) = The USS module is busy.</p>                                                                                                                                                                                                            |
| 2-1 | UPSTATE  | R    | 0h    | <p>USS Power state bits. Read Only Note: Due to the synchronization issue with 2 bits, there is a very short time window that an invalid value can be read while power transition. In case an accurate state information is needed, a simple verification would be required - Read the register twice in a row and check if the two values are the same.</p> <p>Reset type: PUC</p> <p>0h (R) = USS is in OFF state</p> <p>1h (R) = USS is in STANDBY state</p> <p>2h (R) = USS power state is in transition.</p> <p>3h (R) = USS is in READY state</p> |
| 0   | LDORDY   | R    | 0h    | <p>USS LDO is ready.</p> <p>Reset type: PUC</p> <p>0h (R) = USS LDO is powered down or in transition state</p> <p>1h (R) = USS LDO is powered on</p>                                                                                                                                                                                                                                                                                                                                                                                                    |

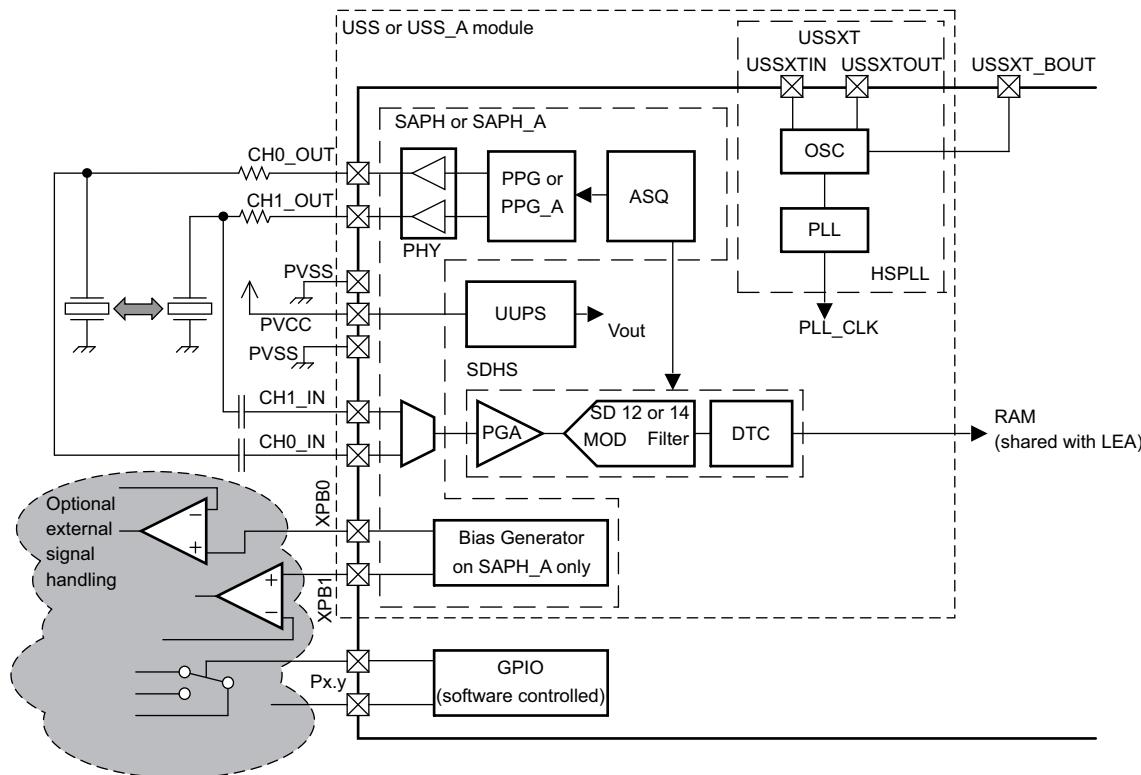
## ***High-Speed PLL (HSPLL)***

This chapter describes the operation of the HSPLL module.

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## 20.1 Introduction

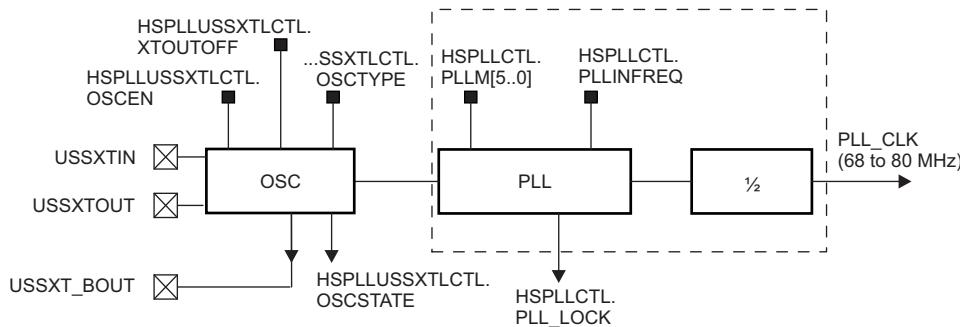
The High-Speed PLL (HSPLL) is one of the submodules in the Ultrasonic Sensing Solution (USS) module. The USS module is designed for analog-to-digital converter (ADC) based ultrasonic sensing technology in various measurement applications. [Figure 20-1](#) shows the block diagram of the USS module.



**Figure 20-1. USS or USS\_A Block Diagram**

The HSPLL module is the dedicated clock generation module for the USS module. To measure the flow speed using ultrasonic technology, the USS module requires a very low-jitter clock to achieve very high accuracy between upstream and downstream measurements. The HSPLL consists of two blocks, OSC and PLL. The output clock of the PLL is in the range of 68 MHz to 80 MHz. [Figure 20-2](#) shows the HSPLL block diagram.

- OSC (oscillator) block: Generates a clock of 4 MHz or 8 MHz from USSXT (crystal or ceramic resonator).
- PLL (phase-locked loop): Generates a clock in the range of 68 MHz to 80 MHz from the output of the OSC.



**Figure 20-2. HSPLL Block Diagram**

The control bits of the OSC are grouped in the HSPLLUSSXTCTL register, and the control bits of the PLL are grouped in the HSPLLCTL register.

---

**NOTE:** Naming conventions in this document for register names and bit fields:

- HSPLL registers: RegisterName or RegisterName.BitField
  - Other module registers: ModuleNameRegisterName or ModuleNameRegisterName.BitField
- 

## 20.2 OSC Control Register (HSPLLUSSXTCTL)

As shown in [Figure 20-2](#), the PLL takes the input clock from OSC block. The OSC block supports both crystal resonators and ceramic resonators with a frequency range of 4 MHz to 8 MHz. The OSC does not support a bypass mode, so do not attempt to feed an external clock to the USSXTIN pin. Ensure that the oscillator is enabled and fully stable before enabling the USS module.

### 20.2.1 OSCEN Bit

The HSPLLUSSXTCTL.OSCEN bit enables or disables the oscillator. The output of the oscillator is gated by default. When the oscillator is enabled, it drives the external resonator and waits for a predefined counter value before enabling the output of the oscillator to feed a stable clock to the PLL. One of the two predefined counter values can be selected by HSPLLUSSXTLCTL.OSCTYPE.

### 20.2.2 OSCTYPE Bit

The oscillator supports both crystal resonators and ceramic resonators. The resonators have different start-up times, so the correct setting must be applied before enabling the OSC (by writing 1 to HSPLLUSSXTCTL.OSCEN). Ceramic resonators have faster wake-up time than crystal resonators. For a crystal resonator, TI recommends setting HSPLLUSSXTCTL.OSCTYPE to 0 (gating counter = 4096). For a ceramic resonator, TI recommends setting HSPLLUSSXTCTL.OSCTYPE to 1 (gating counter = 512).

### 20.2.3 OSCSTATE Bit

The HSPLLUSSXTLCTL.OSCSTATE bit is set after the predefined cycle count has been reached after the oscillator is enabled. This bit can be used to check whether the oscillator has started. The power-up sequence of the USS module is fully controlled by the PSQ (see [Chapter 19](#)). However, the oscillator must be enabled and stable before powering up the USS module. The application must turn on the USSXT oscillator (HSPLLUSSXTLCTL.OSCEN = 1) and wait until the oscillator output is available (HSPLLUSSXTLCTL.OSCSTATE = 1) before powering up the USS module. The OSCSTATE bit indicates sufficient signal strength, not signal quality of the oscillator output.

#### CAUTION

The application must turn on the USSXT oscillator (HSPLLUSSXTLCTL.OSCEN = 1) and wait for a sufficient time to let the oscillator start (this depends on the crystal and resonator characteristics) before powering up the USS module (see [Section 20.4.1](#)). The USSXT oscillator is not controlled by the PSQ. The PSQ assumes that the oscillator output is already available (see [Chapter 20](#)).

### 20.2.4 XTOUTOFF Bit

An application may be required to monitor the clock from the oscillator or to use the clock as the source of another subsystem. To meet these requirements, the buffered output clock from the oscillator can be enabled on the USSXT\_BOUT pin by setting HSPLLUSSXTLCTL.XTOUTOFF = 0. The clock on the USSXT\_BOUT pin can be monitored or used as a clock source. Never use the USSXTOUT pin for monitoring or for a clock source.

## 20.3 PLL Control (CTL) Register

The PLL block takes its input from the oscillator (4 MHz to 8 MHz) and generates the output clock in the range of 68 MHz to 80 MHz. The PLL block does not have a separate power control. It is fully controlled by the Power Sequencer (PSQ). When the USS module is in OFF state (UUPSCTL.UPSTATE = 0) or STANDBY state (UUPSCTL.UPSTATE = 1), the PLL block is turned off and does not consume power. See [Chapter 19](#) for details. The output of the PLL block is divided by half to keep a 50-50 duty cycle at the final output. The maximum frequency at the final output must be limited to 80 MHz.

### 20.3.1 PLLM[5:0] Bits

The PLL output frequency is determined as :

- PLL output clock frequency = input clock frequency  $\times$  (PLLM + 1)
- The final output clock frequency = PLL output clock frequency / 2

The input clock to the PLL block must be 4 MHz to 8 MHz. Choose a HSPLLCTL.PLLM[5:0] value so that the final output clock is in the range of 68 MHz to 80 MHz. Set HSPLLCTL.PLLM[5:0] to the desired value before powering up the USS module and do not change the value while the USS module is on.

### 20.3.2 PLLINREQ Bit

The PLL can be optimized for the best performance based on its input frequency. The HSPLLCTL.PLLINREQ bit divides the input frequency range into two categories ( $\leq 6$  MHz and  $> 6$  MHz) and optimizes the PLL block for the specified input range and output frequency.

### 20.3.3 PLL\_LOCK Bit

The HSPLLCTL.PLL\_LOCK bit indicates whether or not the PLL output clock is stable.

HSPLLCTL.PLL\_LOCK is set to 1 when the PLL output frequency reaches the desired frequency and becomes stable. The lock signal is also used by the PSQ during its power-up sequence. When the PLL output is changed from locked to unlocked, the PLL unlock interrupt bit (HSPLLRIS.PLLUNLOCK) is set. When the PLL unlock interrupt occurs, TI recommends turning off the USS module, and then checking the USSXT oscillator to make sure it is operating correctly before enabling the USS module again.

### 20.3.4 USSXT Control Register

[Figure 20-2](#) show that the PLL has one input clock source, the USSXT oscillator. The oscillator supports both crystal resonators and ceramic resonators with the range of 4 MHz to 8 MHz. The oscillator must be enabled and fully stable before the PLL is enabled.

## 20.4 Start-up Sequence of the USSXT Oscillator

The PLL block is automatically enabled and disabled by the Power Sequencer (PSQ) during the power-up and power-down sequences of the USS module. The USSXT oscillator must be enabled and stabled before the application enables the USS module. The application must start the USS XT oscillator and wait until it is stable before powering up the USS module, as described in the following sequence:

1. Configure HSPLLUSSXTLCTL.OSCTYPE bit correctly based on the resonator type (0 for a crystal resonator, 1 for a ceramic resonator).
2. Write 1 to the HSPLLUSSXTLCTL.USSXTEN bit.
3. Wait for the start-up time. The device can enter a low-power mode while waiting for a TIMER interrupt.
4. Read the HSPLLUSSXTLCTL.OSCSTATE bit to check if the USSXT started.
5. Now the USSXT is running. The USS module can be powered up.

---

**NOTE:** All of the USS submodules must be configured properly before powering up the USS module.

---

#### 20.4.1 USSXT Start-up Behavior

The USSXT oscillator is designed to generate an even running output clock in frequency and amplitude while still allowing fast start-up. Therefore, the crystal or resonator is given more degrees of freedom during start-up. Some crystals and resonators use the distributed capacitance and inductance of the PCB traces and package as tank circuits and tend to oscillate on its harmonic frequencies during power up. Increasing the value of the serial resistance between USSXTOUT and crystal or resonator prevents such oscillation conditions at those higher frequencies. The maximum time for crystals and resonators is give in the data sheet. USSXT\_BOUT can be used to monitor USSXT start-up and operation. Use USSXT\_BOUT as system clock (for example, through HFXTIN) only after USSXT is completely started and has settled.

### 20.5 Interrupts

The HSPLL module supports one interrupt:

- **PLLUNLOCK interrupt:** When the PLL output status changes from locked to unlocked, HSPLLRI.S.PLLUNLOCK is set to 1.

## 20.6 HSPLL Registers

Table 20-1 lists the memory-mapped registers for the HSPLL. All register offset addresses not listed in Table 20-1 should be considered as reserved locations and the register contents should not be modified.

**Table 20-1. HSPLL Registers**

| Offset | Acronym        | Register Name                     | Type       | Reset | Section         |
|--------|----------------|-----------------------------------|------------|-------|-----------------|
| 0h     | HSPLLIIDX      | Interrupt Index Register          | read-only  | 0     | Section 20.6.1  |
| 2h     | HSPLLMIS       | Masked Interrupt Status Register. | read-only  | 0h    | Section 20.6.2  |
| 4h     | HSPLLRISS      | Raw Interrupt Status Register     | read-only  | 0h    | Section 20.6.3  |
| 6h     | HSPLLIMSC      | Interrupt Mask Register           | read-write | 0h    | Section 20.6.4  |
| 8h     | HSPLLICR       | Interrupt Flag Clear Register.    | write-only | 0h    | Section 20.6.5  |
| Ah     | HSPLLISR       | Interrupt Flag Set Register.      | write-only | 0h    | Section 20.6.6  |
| Ch     | HSPLLDESCLO    | HSPLL Descriptor Register L.      | read-only  | 110h  | Section 20.6.7  |
| Eh     | HSPLLDESCHI    | HSPLL Descriptor Register H.      | read-only  | BD10h | Section 20.6.8  |
| 10h    | HSPLLCTL       | HSPLL Control Register            | read-write | 4000h | Section 20.6.9  |
| 12h    | HSPLLUSSXTLCTL | USSXT Control Register            | read-write | 100h  | Section 20.6.10 |

### 20.6.1 HSPLLIIDX Register (Offset = 0h) [reset = 0h]

HSPLLIIDX is shown in [Figure 20-3](#) and described in [Table 20-2](#).

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Interrupt Index Register.

Note: This register is word accessible. A byte access is also allowed but not recommended. Either high byte or low byte access alone can clear the pending interrupt flag.

**Figure 20-3. HSPLLIIDX Register**

|      |    |    |    |    |    |   |          |
|------|----|----|----|----|----|---|----------|
| 15   | 14 | 13 | 12 | 11 | 10 | 9 | 8        |
| IIDX |    |    |    |    |    |   |          |
| R-   |    |    |    |    |    |   |          |
| 7    | 6  | 5  | 4  | 3  | 2  | 1 | 0        |
| IIDX |    |    |    |    |    |   | RESERVED |
| R-   |    |    |    |    |    |   | R-       |

**Table 20-2. HSPLLIIDX Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | IIDX     | R    |       | <p>HSPLL Interrupt Vector Value. Read only. It generates a value that can be used as address offset for fast interrupt service routine handling. On each read, only one interrupt is indicated. On a read, the current interrupt (highest priority) is automatically cleared by the hardware and the corresponding interrupt flag in RIS and MISC are cleared as well. After a read from the CPU (not from the debug interface), the register must be updated with the next highest priority interrupt, if none are pending, then it should display 0h.</p> <p>If the interrupt displayed by the I IDX register (highest priority pending interrupt) is cleared in the MISC through a software write of 1 in the corresponding bit field, the I IDX register shall be updated and the next priority interrupt (if any) be displayed.</p> <p>Reset type: PUC<br/>           0h (R) = No Interrupt pending<br/>           1h (R) = Interrupt Source: PLLUNLOCK; Interrupt Priority: Highest<br/>           2h (R) = Reserved; Interrupt Priority: Lowest</p> |
| 0    | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

### 20.6.2 HSPLLMIS Register (Offset = 2h) [reset = 0h]

HSPLLMIS is shown in [Figure 20-4](#) and described in [Table 20-3](#).

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Masked Interrupt Status Register.

**Figure 20-4. HSPLLMIS Register**

|          |    |    |    |    |    |           |   |
|----------|----|----|----|----|----|-----------|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9         | 8 |
| RESERVED |    |    |    |    |    |           |   |
| R-0h     |    |    |    |    |    |           |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1         | 0 |
| RESERVED |    |    |    |    |    | PLLUNLOCK |   |
| R-0h     |    |    |    |    |    |           |   |

**Table 20-3. HSPLLMIS Register Field Descriptions**

| Bit  | Field     | Type | Reset | Description                                                                                                                 |
|------|-----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED  | R    | 0h    | Reserved                                                                                                                    |
| 0    | PLLUNLOCK | R    | 0h    | HSPLL Unlock Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending |

### **20.6.3 HSPLLRIS Register (Offset = 4h) [reset = 0h]**

HSPLLRIS is shown in [Figure 20-5](#) and described in [Table 20-4](#).

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Raw Interrupt Status Register. Read Only Register.

The HSPLLRIS register allows the user to implement a poll scheme instead of an interrupt (as the interrupt does not need to be enabled). Note that the HSPLLRIS flag can be cleared by writing to the MISC register bit even if the corresponding IM bit is not enabled.

**Figure 20-5. HSPLLRIS Register**

|          |    |    |    |    |    |           |   |
|----------|----|----|----|----|----|-----------|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9         | 8 |
| RESERVED |    |    |    |    |    |           |   |
| R-0h     |    |    |    |    |    |           |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1         | 0 |
| RESERVED |    |    |    |    |    | PLLUNLOCK |   |
| R-0h     |    |    |    |    |    |           |   |

**Table 20-4. HSPLLRIS Register Field Descriptions**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                    |
|------|-----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED  | R    | 0h    | Reserved                                                                                                                                                                                                                                       |
| 0    | PLLUNLOCK | R    | 0h    | PLL Unlock Raw Interrupt Status bit. Read Only. This bit is set when PLL output changes from lock to unlock status.<br>Reset type: PUC<br>0h (R) = PLL status has not been changed<br>1h (R) = PLL status has been changed from Lock to Unlock |

#### 20.6.4 HSPLLIMSC Register (Offset = 6h) [reset = 0h]

HSPLLIMSC is shown in [Figure 20-6](#) and described in [Table 20-5](#).

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Interrupt Mask Register. Note: writing '1' enables the corresponding interrupt.

**Figure 20-6. HSPLLIMSC Register**

|          |    |    |    |    |    |           |   |  |  |
|----------|----|----|----|----|----|-----------|---|--|--|
| 15       | 14 | 13 | 12 | 11 | 10 | 9         | 8 |  |  |
| RESERVED |    |    |    |    |    |           |   |  |  |
| R-0h     |    |    |    |    |    |           |   |  |  |
| 7        | 6  | 5  | 4  | 3  | 2  | 1         | 0 |  |  |
| RESERVED |    |    |    |    |    | PLLUNLOCK |   |  |  |
| R-0h     |    |    |    |    |    |           |   |  |  |
| R/W-0h   |    |    |    |    |    |           |   |  |  |

**Table 20-5. HSPLLIMSC Register Field Descriptions**

| Bit  | Field     | Type | Reset | Description                                                                                                                                    |
|------|-----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED  | R    | 0h    | Reserved                                                                                                                                       |
| 0    | PLLUNLOCK | R/W  | 0h    | PLL Unlock Interrupt Mask bit.<br>Reset type: PUC<br>0h (R/W) = PLL Unlock Interrupt is disabled<br>1h (R/W) = PLL Unlock Interrupt is enabled |

### **20.6.5 HSPLLICR Register (Offset = 8h) [reset = 0h]**

HSPLLICR is shown in [Figure 20-7](#) and described in [Table 20-6](#).

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Interrupt Flag Clear Register. Read as zero.

**Figure 20-7. HSPLLICR Register**

|          |    |    |    |    |    |           |   |  |  |
|----------|----|----|----|----|----|-----------|---|--|--|
| 15       | 14 | 13 | 12 | 11 | 10 | 9         | 8 |  |  |
| RESERVED |    |    |    |    |    |           |   |  |  |
| R-0h     |    |    |    |    |    |           |   |  |  |
| 7        | 6  | 5  | 4  | 3  | 2  | 1         | 0 |  |  |
| RESERVED |    |    |    |    |    | PLLUNLOCK |   |  |  |
| R-0h     |    |    |    |    |    |           |   |  |  |
| W-0h     |    |    |    |    |    |           |   |  |  |

**Table 20-6. HSPLLICR Register Field Descriptions**

| Bit  | Field     | Type | Reset | Description                                                                           |
|------|-----------|------|-------|---------------------------------------------------------------------------------------|
| 15-1 | RESERVED  | R    | 0h    | Reserved                                                                              |
| 0    | PLLUNLOCK | W    | 0h    | PLL Unlock Interrupt Clear bit. Write 1 to clear RIS.PLLUNLOCK bit<br>Reset type: PUC |

### 20.6.6 HSPLLISR Register (Offset = Ah) [reset = 0h]

HSPLLISR is shown in [Figure 20-8](#) and described in [Table 20-7](#).

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Interrupt Flag Set Register. Read as zero.

**Figure 20-8. HSPLLISR Register**

|          |    |    |    |    |    |           |   |
|----------|----|----|----|----|----|-----------|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9         | 8 |
| RESERVED |    |    |    |    |    |           |   |
| R-0h     |    |    |    |    |    |           |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1         | 0 |
| RESERVED |    |    |    |    |    | PLLUNLOCK |   |
| R-0h     |    |    |    |    |    | W-0h      |   |

**Table 20-7. HSPLLISR Register Field Descriptions**

| Bit  | Field     | Type | Reset | Description                                                                       |
|------|-----------|------|-------|-----------------------------------------------------------------------------------|
| 15-1 | RESERVED  | R    | 0h    | Reserved                                                                          |
| 0    | PLLUNLOCK | W    | 0h    | PLL Unlock Interrupt Set bit. Write 1 to set RIS.PLLUNLOCK bit<br>Reset type: PUC |

### **20.6.7 HSPLLDESCLO Register (Offset = Ch) [reset = 110h]**

HSPLLDESCLO is shown in [Figure 20-9](#) and described in [Table 20-8](#).

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HSPLL Descriptor Register L.

**Figure 20-9. HSPLLDESCLO Register**

| 15         | 14 | 13 | 12 | 11      | 10 | 9    | 8 |
|------------|----|----|----|---------|----|------|---|
| FEATUREVER |    |    |    | INSTNUM |    |      |   |
| R-0h       |    |    |    |         |    | R-1h |   |
| 7          | 6  | 5  | 4  | 3       | 2  | 1    | 0 |
| MAJREV     |    |    |    | MINREV  |    |      |   |
| R-1h       |    |    |    |         |    | R-0h |   |

**Table 20-8. HSPLLDESCLO Register Field Descriptions**

| Bit   | Field      | Type | Reset | Description                                                                                                         |
|-------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------|
| 15-12 | FEATUREVER | R    | 0h    | Feature Set for the module<br>Reset type: PUC                                                                       |
| 11-8  | INSTNUM    | R    | 1h    | Instance Number within the device. This will be a parameter to the RTL for modules that can have multiple instances |
| 7-4   | MAJREV     | R    | 1h    | Major Revision<br>Reset type: PUC                                                                                   |
| 3-0   | MINREV     | R    | 0h    | Minor Revision<br>Reset type: PUC                                                                                   |

### 20.6.8 HSPLLDESCHI Register (Offset = Eh) [reset = BD10h]

HSPLLDESCHI is shown in [Figure 20-10](#) and described in [Table 20-9](#).

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HSPLL Descriptor Register H.

**Figure 20-10. HSPLLDESCHI Register**

|          |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|----------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MODULEID |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R-BD10h  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 20-9. HSPLLDESCHI Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                           |
|------|----------|------|-------|---------------------------------------|
| 15-0 | MODULEID | R    | BD10h | Module Identifier.<br>Reset type: PUC |

### **20.6.9 HSPLLCTL Register (Offset = 10h) [reset = 4000h]**

HSPLLCTL is shown in [Figure 20-11](#) and described in [Table 20-10](#).

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HSPLL Control Register

**Figure 20-11. HSPLLCTL Register**

|          |    |    |    |          |    |           |   |
|----------|----|----|----|----------|----|-----------|---|
| 15       | 14 | 13 | 12 | 11       | 10 | 9         | 8 |
| PLLM     |    |    |    | RESERVED |    | PLLINFREQ |   |
| R/W-10h  |    |    |    | R-0h     |    | R/W-0h    |   |
| 7        | 6  | 5  | 4  | 3        | 2  | 1         | 0 |
| RESERVED |    |    |    | PLL_LOCK |    | R-0h      |   |
| R-0h     |    |    |    |          |    |           |   |

**Table 20-10. HSPLLCTL Register Field Descriptions**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------|-----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | PLLM      | R/W  | 10h   | PLL Multiplier. default value = 16. Valid data range: 16 ~ 39.<br>The input clock to the PLL block must be 4MHz ~ 8MHz. Care needs to be taken to choose PLLM[5:0] value that the final output clock must be in range of 68MHz ~ 80MHz. Note that PLLM[5:0] needs to be configured with the desired value before powering up the USS module and must not be changed while the USS module is on.<br><br>10h (R/W) = 16<br>11h (R/W) = 17<br>12h (R/W) = 18<br>13h (R/W) = 19<br>14h (R/W) = 20<br>15h (R/W) = 21<br>16h (R/W) = 22<br>17h (R/W) = 23<br>18h (R/W) = 24<br>19h (R/W) = 25<br>1Ah (R/W) = 26<br>1Bh (R/W) = 27<br>1Ch (R/W) = 28<br>1Dh (R/W) = 29<br>1Eh (R/W) = 30<br>1Fh (R/W) = 31<br>20h (R/W) = 32<br>21h (R/W) = 33<br>22h (R/W) = 34<br>23h (R/W) = 35<br>24h (R/W) = 36<br>25h (R/W) = 37<br>26h (R/W) = 38<br>27h (R/W) = 39 |
| 9     | RESERVED  | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 8     | PLLINFREQ | R/W  | 0h    | PLL Input Frequency Selection.<br>0h (R/W) = Input frequency is equal to 6MHz or lower than 6MHz<br>1h (R/W) = Input frequency is higher than 6MHz                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 7-1   | RESERVED  | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

**Table 20-10. HSPLLCTL Register Field Descriptions (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                        |
|-----|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0   | PLL_LOCK | R    | 0h    | <p>PLL Lock Status.</p> <p>Note: When PLL output is changed from locked status to unlock status, PLL Unlock Interrupt bit (RIS.PLLUNLOCK) is set. It is recommended to enable the interrupt while performing a measurement.</p> <p>Reset type: PUC</p> <p>0h (R) = PLL is not running or not locked<br/>1h (R) = PLL is locked</p> |

### 20.6.10 HSPLLUSSXTLCTL Register (Offset = 12h) [reset = 100h]

HSPLLUSSXTLCTL is shown in [Figure 20-12](#) and described in [Table 20-11](#).

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USSXT Control Register.

HSPLL has a dedicated XTAL which generates the input frequency of the HSPLL.

**Figure 20-12. HSPLLUSSXTLCTL Register**

|          |    |    |    |          |    |          |   |
|----------|----|----|----|----------|----|----------|---|
| 15       | 14 | 13 | 12 | 11       | 10 | 9        | 8 |
| RESERVED |    |    |    | OSCTYPE  |    | XTOUTOFF |   |
| R-0h     |    |    |    | R/W-0h   |    | R/W-1h   |   |
| 7        | 6  | 5  | 4  | 3        | 2  | 1        | 0 |
| RESERVED |    |    |    | OSCSTATE |    | USSXTEN  |   |
| R-0h     |    |    |    | R-0h     |    | R/W-0h   |   |

**Table 20-11. HSPLLUSSXTLCTL Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 9     | OSCTYPE  | R/W  | 0h    | <p>Oscillator Type.<br/>           The oscillator output clock is gated until it is fully stabilized after power up in order to provide a stable clock frequency to HSPLL.<br/>           0h (R) = XTAL : Gating Counter Length: 4096. It is recommended to use this configuration for crystal resonators.<br/>           Note: the counter counts the oscillator clock, so total time can be calculated as Time = 4096 x 1/Oscillator Clock Frequency.<br/>           1h (R) = CERAMIC : Gating Counter Length: 512. It is recommended to use this configuration for ceramic resonators.<br/>           Note: the counter counts the oscillator clock, so total time can be calculated as Time = 512x 1/Oscillator Clock Frequency.</p> |
| 8     | XTOUTOFF | R/W  | 1h    | <p>USSXT Buffered Output OFF<br/>           0h (R/W) = Enable USSXT buffered output<br/>           1h (R/W) = Disable USSXT buffered output. Default.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 7-2   | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 1     | OSCSTATE | R    | 0h    | <p>Oscillator start indication. This bit indicates that the oscillator started and has sufficient signal strength (not signal quality)<br/>           0h (R) = Oscillator is either not enabled or in the middle of start-up transition.<br/>           1h (R) = Oscillator has started but is not stable yet. Wait for sufficient time for stabilization.</p>                                                                                                                                                                                                                                                                                                                                                                           |
| 0     | USSXTEN  | R/W  | 0h    | <p>USSXT Enable.<br/>           Reset type: PUC<br/>           0h (R) = Disable USSXT Oscillator<br/>           1h (R) = Enable USSXT Oscillator</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

## **Sequencer for Acquisition, Programmable Pulse Generator, and Physical Interface (SAPH, SAPH\_A)**

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This chapter describes the operation of the SAPH module.

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| 21.2 Programmable Pulse Generator (PPG or PPG_A) Block ..... | 494  |
| 21.3 Physical Interface (PHY) Block .....                    | 501  |
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## 21.1 Introduction

The sequencer for acquisition, programmable pulse generator, and physical interface (SAPH or SAPH\_A) is one of the submodules in the Ultrasonic Sensing Solution (USS or USS\_A) module. The USS module is designed for analog-to-digital converter (ADC) based ultrasonic sensing technology in various measurement applications. See [Chapter 18](#) for details.

The SAPH module features the PPG generator, and the SAPH\_A module features the PPG\_A generator. The SAPH\_A is a superset of SAPH; therefore, SAPH\_A is specifically named only when necessary to distinguish from the SAPH module.

The SAPH or SAPH\_A consist of three blocks (see [Figure 21-1](#)):

- Acquisition Sequencer (ASQ)
- Programmable Pulse Generator (PPG or PPG\_A)
- Physical Interface (PHY)

SAPH\_A provides additional bias voltages for optional external signal conditioning like low-noise amplifiers (LNAs) and booster amplifiers.

- PPG or PPG\_A block: Generates pulses at different frequencies.
- PHY block: Controls output channels and input channels of the USS module.
- ASQ block: The entire measurement sequence can be controlled by user software (called register mode) or by ASQ without any CPU intervention (called auto mode). The auto mode helps reduce the measurement power consumption, because the CPU can stay in LPM0 during measurement.
- External bias generator on SAPH\_A

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**NOTE:** Naming convention for register names and bit fields:

- SAPH registers: RegisterName or RegisterName.BitField
  - Other module registers: ModuleNameRegisterName or ModuleNameRegisterName.BitField
  - Code written for USS and SAPH modules is also accepted by USS\_A and SAPH\_A modules. The register names are resolved automatically.
- 

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**NOTE:** Before writing to any SAPH register with an offset address greater than 0x0F, unlock the registers by writing 0x45B to the KEY register. The unlock must be performed only once. Writing any other value to the KEY register locks the registers. Read accesses are always allowed.

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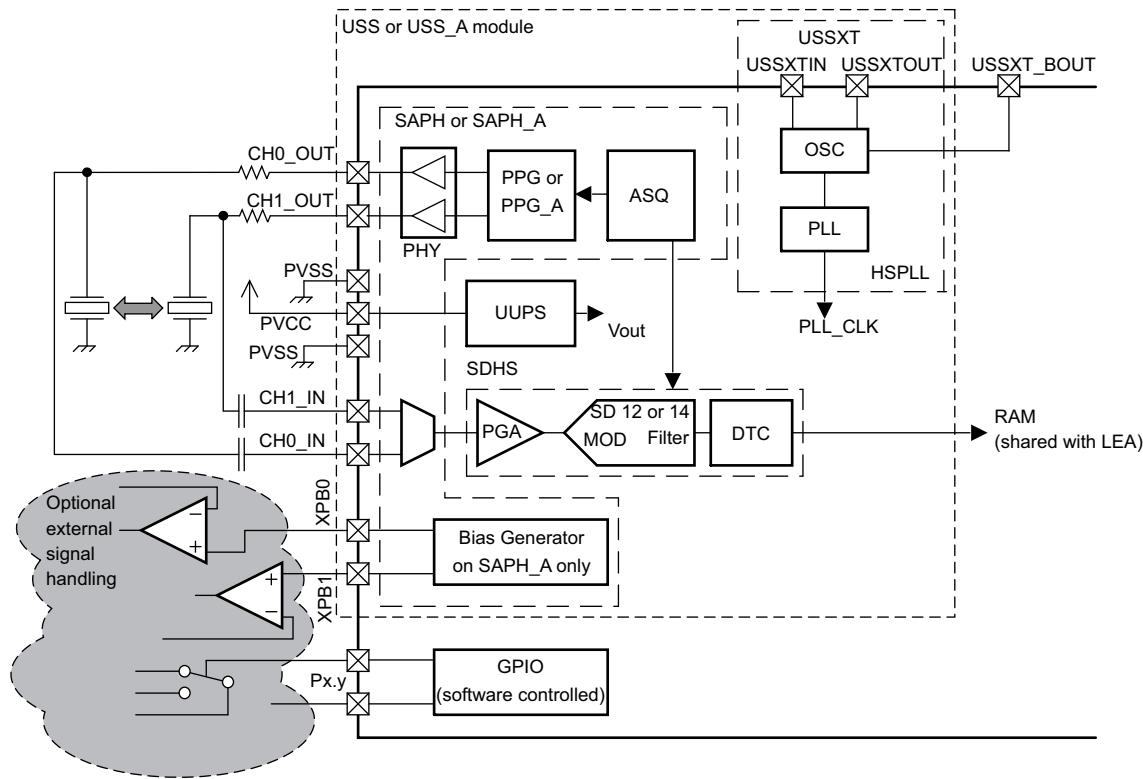


Figure 21-1. USS or USS\_A Block Diagram

## 21.2 Programmable Pulse Generator (PPG or PPG\_A) Block

Figure 21-2 shows the conceptual block diagram of the programmable pulse generator (PPG). In italics the extended elements of PPG\_A.

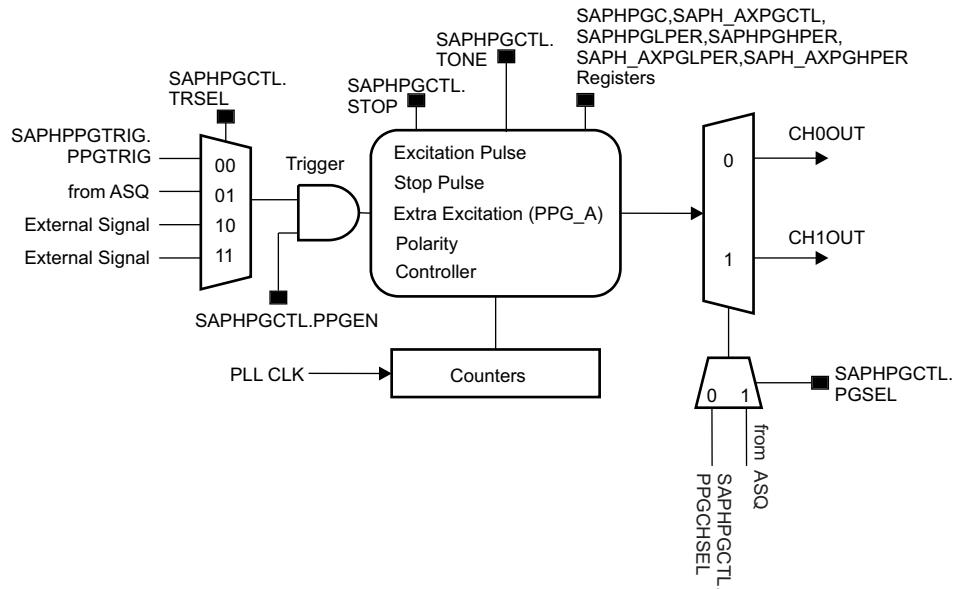


Figure 21-2. PPG or PPG\_A Block Diagram

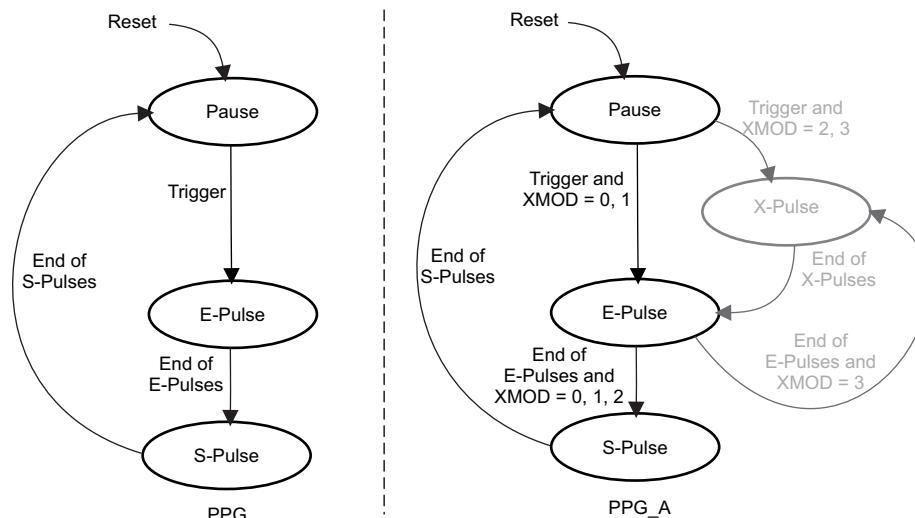
### 21.2.1 Pulse Generation

The PPG offers flexible pulse generation profiles for single tone generation at different frequencies. The PPG\_A is an extended variant of the PPG and extends the profiles with dual tone, trill tone, and multi tone (chirp).

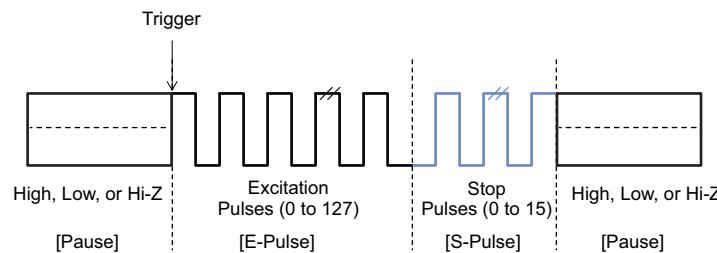
### 21.2.2 Single Tone Generation

The output pulses consists of four different phases: *Pause*, *Excitation*, *Stop*, and *Pause again*. A state machine in PPG and PPG\_A controls the flow. On PPG\_A set SAPPH\_AXPGCTL.XMOD = 0 for single tone generation. When the PPG or PPG\_A is triggered, it leaves the Pause phase and generates excitation pulses followed by stop pulses, then goes to Pause phase again (see [Figure 21-3](#), [Figure 21-4](#) and [Figure 21-5](#)). The stop pulses have a 180° phase shift compared to the excitation pulses. The PPG generates up to 127 excitation pulses and up to 15 stop pulses, which are controlled by the SAPHPGC.EPULS and SAPHPGC.SPULS bits, respectively. The pulse polarity is programmable in the SAPHPGC.PPOL bit. The signal polarity for Pause can be programmed to be logical high, logical low, or high impedance through the SAPHPGC.PLEV and SAPHPGC.PHIZ bits.

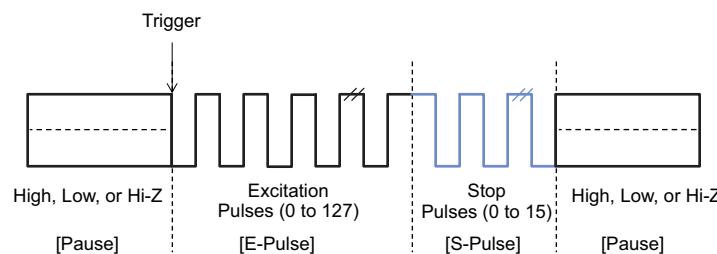
The PPG can be triggered by writing 1 to the SAPHPGTRIG.PPGTRIG bit when SAPHPGCTL.TRSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPHPGCTL.TRSEL = 1 (auto mode). To avoid unintended pulse outputs, keep SAPHPGCTL.PPGEN = 0 while updating the PPG registers. After the PPG registers are updated, write 1 to the SAPHPGCTL.PPGEN bit before triggering the PPG. The SAPHPGCTL.PPGEN bit must be set before triggering the PPG. The output channel is determined by the SAPHPGCTL.PPGCHSEL bit when SAPHPGCTL.PGSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPHPGCTL.PGSEL = 1 (auto mode). Another layer of output control is inside the PHY, so both blocks must be configured properly (see [Section 21.3](#)). The PPG or PPG\_A automatically stops when it completes generating the pulses. To stop generating pulses before completion, regardless of operation mode, write 1 to SAPHPGCTL.STOP. The PPG immediately stops generating pulses. The SAPHPGCTL.STOP bit is automatically cleared to zero.



**Figure 21-3. PPG or PPG\_A Internal State Diagrams for Single Tone**



**Figure 21-4. PPG Single Tone Generation With SAPHPGC.PPOL = 0  
(Starts With High Polarity)**

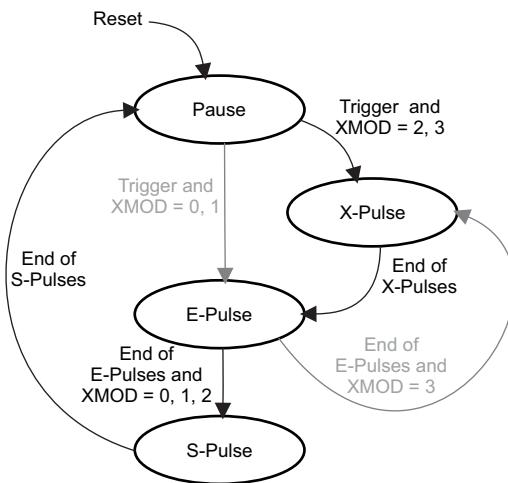


**Figure 21-5. PPG Single Tone Generation With SAPHPGC.PPOL = 1  
(Starts With Low Polarity)**

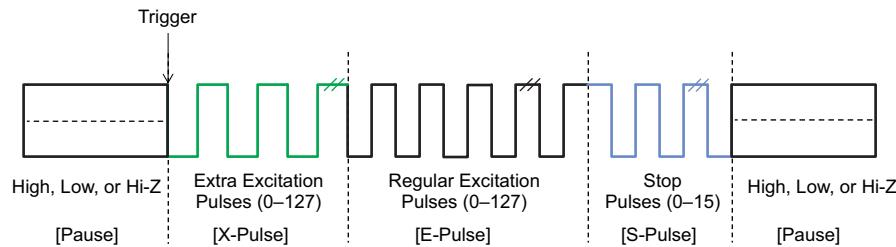
### 21.2.3 Dual Tone Generation

The output pulses consists of five different phases: *Pause*, *Extra\_Excitation*, *Regular\_Excitation*, *Stop*, and *Pause* again. A state machine in PPG\_A controls the flow. Set SAPH\_AXPGCTL.XMOD = 2 for dual tone generation. When the PPG\_A is triggered, it leaves the Pause phase, generates excitation pulses with a frequency defined by SAPH\_AXPGHPER/SAPH\_AXPGLPER, then excitation pulses with a frequency defined by SAPH\_APGHPER/SAPH\_APGLPER followed by stop pulses, then goes to Pause phase again (see [Figure 21-6](#) and [Figure 21-7](#)). The stop pulses have a 180° phase shift compared to the regular excitation pulses. The stop pulses have same frequency as the regular excitation pulses. The PPG generates up to 127 extra excitation pulses, up to 127 regular excitation pulses and up to 15 stop pulses, which are controlled by the SAPH\_AXPGCTL.XPULS, SAPH\_APGC.EPULS and SAPH\_APGC.SPULS bits, respectively. The pulse polarity is programmable in the SAPH\_APGC.PPOL bit. The signal polarity of Pause can be programmed to be logical high, logical low, or high impedance through the SAPH\_APGC.PLEV and SAPH\_APGC.PHIZ bits.

The PPG\_A can be triggered by writing 1 to the SAPH\_APPGTRIG.PPGTRIG bit when SAPH\_APGCTL.TRSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPH\_APGCTL.TRSEL = 1 (auto mode). To avoid unintended pulse outputs, keep SAPH\_APGCTL.PPGEN = 0 while updating the PPG\_A registers. After the PPG\_A registers are updated, write 1 to the SAPH\_APGCTL.PPGEN bit before triggering the PPG\_A. The SAPH\_APGCTL.PPGEN bit must be set before triggering the PPG\_A. The output channel is determined by the SAPH\_APGCTL.PPGCHSEL bit when SAPH\_APGCTL.PGSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPH\_APGCTL.PGSEL = 1 (auto mode). Another layer of output control is inside the PHY, so both blocks must be configured properly (see [Section 21.3](#)). The PPG\_A automatically stops when it completes generating the pulses. To stop generating pulses before completion, regardless of operation mode, write 1 to SAPH\_APGCTL.STOP. The PPG\_A immediately stops generating pulses. The SAPH\_APGCTL.STOP bit is automatically cleared to zero.



**Figure 21-6. PPG\_A State Diagram for Dual Tone**



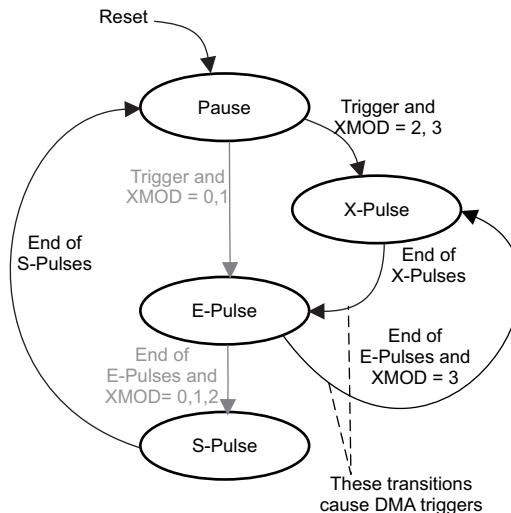
**Figure 21-7. PPG\_A Dual Tone Generation With SAPHPGC.PPOL = 1  
(Starts With Low Polarity)**

#### 21.2.4 Trill Tone Generation

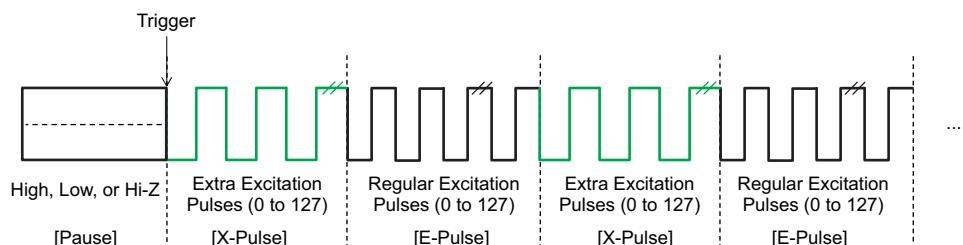
The output pulses consists of multiple phases: *Pause*, a software defined set of *Extra\_Excitation* and *Regular\_Excitation* phases, *Stop*, and *Pause* again. A state machine in PPG\_A controls the flow. Set SAPH\_AXPGCTL.XMOD = 3 for trill tone generation. When the PPG\_A is triggered, it leaves *Pause* phase and generates extra excitation pulses with a frequency defined by SAPH\_AXPGHPER/SAPH\_AXPLPER, then regular excitation pulses with a frequency defined by SAPH\_APGHPER/SAPH\_APGLPER. While XMOD = 3 the extra excitation pulses followed by the regular excitation pulses is repeated. Software is required to change SAPH\_AXPGCTL.XMOD = 2 to terminate the trill. The last regular excitation pulses are followed by stop pulses. Then PPG\_A goes to *Pause* phase again (see [Figure 21-8](#) and [Figure 21-9](#)). The stop pulses have a 180° phase shift compared to the last regular excitation pulses. The stop pulses have same frequency as the last regular excitation pulses. The PPG generates up to 127 extra excitation pulses, up to 127 regular excitation pulses and up to 15 stop pulses, which are controlled by the SAPH\_AXPGCTL.XPULS, SAPH\_APGC.EPULS and SAPH\_APGC.SPULS bits, respectively. The pulse polarity is programmable in the SAPH\_APGC.PPOL bit. The signal polarity of *Pause* can be programmed to be logical high, logical low, or high impedance through the SAPH\_APGC.PLEV and SAPH\_APGC.PHIZ bits.

The PPG\_A can be triggered by writing 1 to the SAPH\_APPGTRIG.PPGTRIG bit when SAPH\_APGCTL.TRSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPH\_APGCTL.TRSEL = 1 (auto mode). To avoid unintended pulse outputs, keep SAPH\_APGCTL.PPGEN = 0 when preparing the PPG\_A registers. After the PPG\_A registers are prepared, write 1 to the SAPH\_APGCTL.PPGEN bit before triggering the PPG\_A. The SAPH\_APGCTL.PPGEN bit must be set before triggering the PPG\_A. The output channel is determined by the SAPH\_APGCTL.PPGCHSEL bit when SAPH\_APGCTL.PGSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPH\_APGCTL.PGSEL = 1 (auto mode). Another layer of output control is inside the PHY, so both blocks must be configured properly (see [Section 21.3](#)). After software sets XMOD = 2 by directly writing or using the DMA, the PPG\_A automatically stops when it completes

generating the pulses. Setting XMOD = 2 must be done when entering the last X-Pulse state. The current PPG\_A state is indicated in SAPH\_AXPGCTL.XSTAT. Leave at least 6 CPU clocks time margin for synchronizing. To stop generating pulses before completion, regardless of operation mode, write 1 to SAPH\_APGCTL.STOP. The PPG\_A immediately stops generating pulses. The SAPH\_APGCTL.STOP bit is automatically cleared to zero.



**Figure 21-8. PPG\_A State Diagram for Trill Tone**

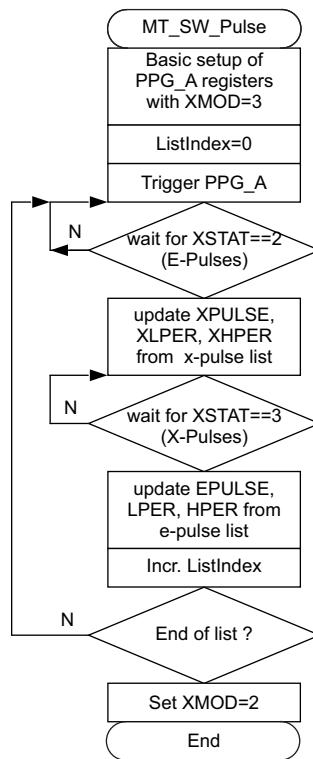


**Figure 21-9. PPG\_A Trill Tone Generation With SAPHPGC.PPOL = 1  
(Starts With Low Polarity)**

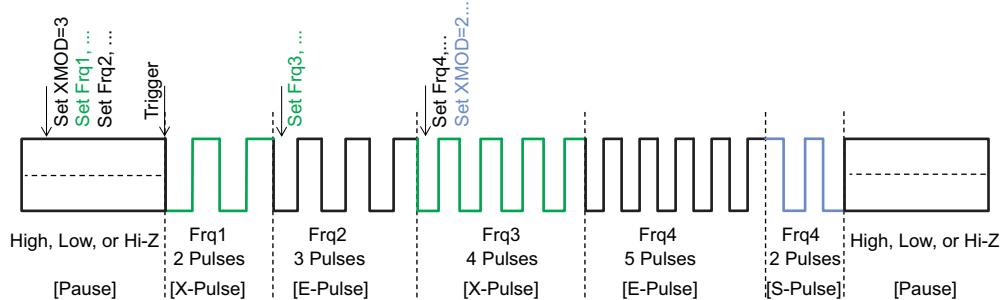
### 21.2.5 Multi Tone Generation

The output pulses consists of multiple phases: *Pause*, a software defined set of *Extra\_Excitation* and *Regular\_Excitation* phases, *Stop*, and *Pause* again. A state machine in PPG\_A controls the flow. Set SAPH\_AXPGCTL.XMOD = 3 like for trill tone generation. When the PPG\_A is triggered, it leaves the *Pause* phase, generates extra excitation pulses with a frequency defined by SAPH\_AXPGHPER/SAPH\_AXPGLPER, then regular excitation pulses with a frequency defined by SAPH\_APGHPER/SAPH\_APGLPER. While XMOD = 3 the extra excitation pulses followed by the regular excitation pulses is repeated. Software is required to change the following: SAPH\_AXPGHPER, SAPH\_AXPGLPER, SAPH\_AXPGCTL.XPULS, SAPHPGHPER, SAPHPGLPER, SAPHPGCTL.EPULS, SAPHPGCTL.SPULS, in a well timed manner. This can be done by direct register access or by DMA accesses. Finally setting SAPH\_AXPGCTL.XMOD = 2 to terminates the multi tone. The last regular excitation pulses are followed by stop pulses. Then PPG\_A goes to *Pause* phase again (see [Figure 21-10](#) and [Figure 21-9](#)). The stop pulses have a 180° phase shift compared to the last regular excitation pulses. The stop pulses have same frequency as the last regular excitation pulses. The PPG generates up to 127 extra excitation pulses, up to 127 regular excitation pulses and up to 15 stop pulses, which are controlled by the SAPH\_AXPGCTL.XPULS, SAPH\_APGC.EPULS and SAPH\_APGC.SPULS bits, respectively. The pulse polarity is programmable in the SAPH\_APGC.PPOL bit. The signal polarity of *Pause* can be programmed to be logical high, logical low, or high impedance through the SAPH\_APGC.PLEV and SAPH\_APGC.PHIZ bits.

The PPG\_A can be triggered by writing 1 to the SAPH\_APPGTRIG.PPGTRIG bit when SAPH\_APGCTL.TRSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPH\_APGCTL.TRSEL = 1 (auto mode). To avoid unintended pulse outputs, keep SAPH\_APGCTL.PPGEN = 0 while preparing the PPG\_A registers. After the PPG\_A registers are prepared, write 1 to the SAPH\_APGCTL.PPGEN bit before triggering the PPG\_A. The SAPH\_APGCTL.PPGEN bit must be set before triggering the PPG\_A. The output channel is determined by the SAPH\_APGCTL.PPGCHSEL bit when SAPH\_APGCTL.PGSEL = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPH\_APGCTL.PGSEL = 1 (auto mode). Another layer of output control is inside the PHY, so both blocks must be configured properly (see [Section 21.3](#)). After software sets XMOD = 2 by directly writing or using the DMA, the PPG\_A automatically stops when it completes generating the pulses. Setting XMOD = 2 must be done when entering the last X-Pulse state. The current PPG\_A state is indicated in SAPH\_AXPGCTL.XSTAT. Leave at least 6 CPU clocks time margin for synchronizing. To stop generating pulses before completion, regardless of operation mode, write 1 to SAPH\_APGCTL.STOP. The PPG\_A immediately stops generating pulses. The SAPH\_APGCTL.STOP bit is automatically cleared to zero.



**Figure 21-10. PPG\_A Software Flow Chart for Multi Tone**



**Figure 21-11. PPG\_A Multi Tone Generation With SAPHPGC.PPOL = 1  
(Starts With Low Polarity)**

### 21.2.6 Excitation Pulse Frequency on PPG or PPG\_A

The excitation pulse frequency is determined by the PPG clock frequency and the SAPHPGLPER.LPER and SAPHPGHPER.HPER bits. The high duration of a regular excitation pulse and low duration of a regular excitation pulse are determined by SAPHPGHPER.HPER (8 bits) and SAPHPGLPER.LPER (8 bits), respectively. Thus:

- Excitation pulse frequency = HSPLL frequency / ( SAPHPGHPER.HPER + SAPHPGLPER.LPER)

### 21.2.7 Extra Excitation Pulse Frequency on PPG\_A

The pulse frequency for the X-Pulses is determined by the PPG\_A clock frequency and the SAPH\_AXPGLPER.XLPER and SAPH\_AXPGHPER.XHPER bits. The high duration of an extra excitation pulse and low duration of an extra excitation pulse are determined by SAPH\_AXPGHPER.XHPER (8 bits) and SAPH\_AXPGLPER.XLPER (8 bits), respectively. Thus:

- X-Pulse frequency = HSPLL frequency / ( SAPH\_AXPGHPER.XHPER + SAPH\_AXPGLPER.XLPER)

### 21.2.8 Test Tone Generation

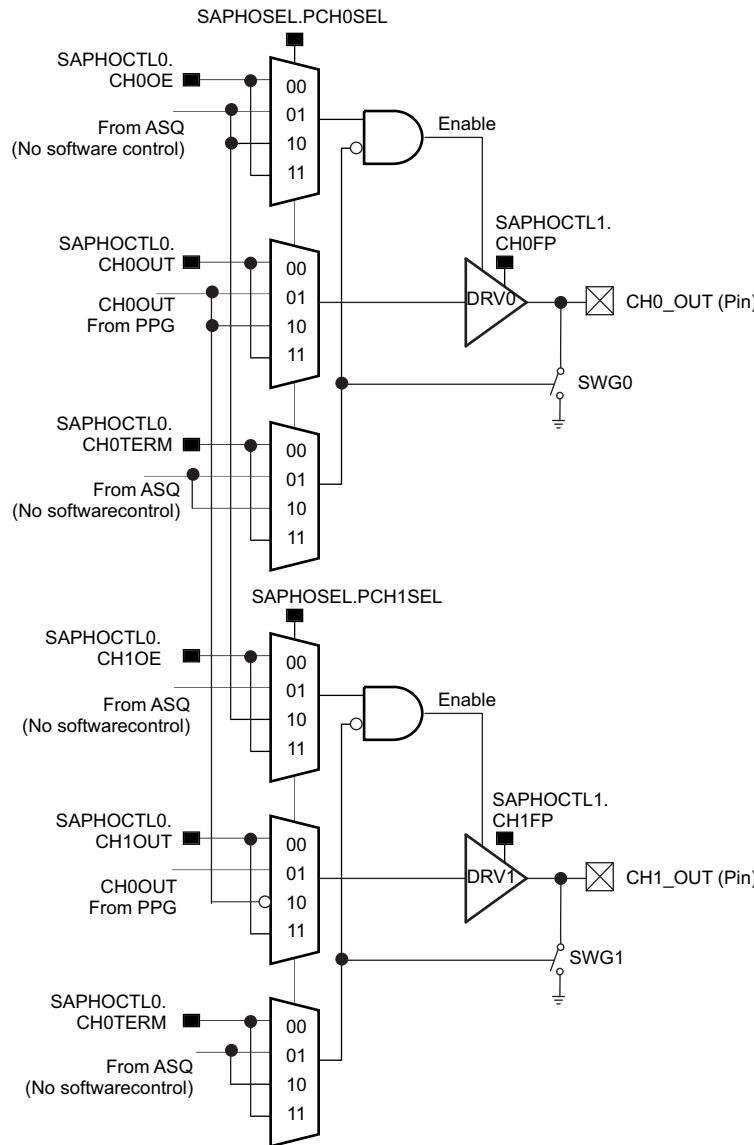
To start the PPG test tone generation, write SAPHPGCTL.TONE = 1. While SAPHPGCTL.TONE = 1, the PPG consistently generates excitation pulses (no stop pulse). In this case, SAPHPGC.EPULSE and SAPHPCG.SPULSE are ignored. To terminate the PPG test tone generation, write SAPHPGCTL.TONE = 0.

## 21.3 Physical Interface (PHY) Block

The PHY controls the input and output pins of the USS module. The USS module has dedicated pins (CH0\_OUT, CH0\_IN, CH1\_OUT, CH1\_IN, two PVSS, and PVCC), which are controlled by the USS module, not by the digital I/O module.

### 21.3.1 Output Channels (CH0\_OUT and CH1\_OUT)

Figure 21-12 shows the functional block diagram for the output channels, CH0\_OUT and CH1\_OUT.



**Figure 21-12. PHY Output Pins**

The output pins (CH0\_OUT and CH1\_OUT) can be used as general I/O pins when SAPHOSEL.PCH0SEL = 0 or 3. In this case, the polarity of the two pins is controlled by SAPHOCTL0.CH0OUT and SAPHOCTL0.CH1OUT, and the pins are enabled or disabled (Hi-Z) by SAPHOCTL0.CH0OE and SAPHOCTL0.CH1OE. The pins can be connected to GND through the SWG0 and SWG1 switches by SAPHOCTL0.CH0TERM and SAPHOCTL0.CH1TERM, respectively.

When SAPHOSEL.PCH0SEL = 1, the output pins work as single output drivers. The pulses generated by PPG are output on the selected pin. This is the typical use case for the flow measurement application.

When SAPHOSEL.PCH0SEL = 2, the two output pins working as differential output drivers. The pulses generated by PPG are output on both pins differentially.

When SAPHOSEL.PCH0SEL = 1 or 2, the two pins are controlled by the PPG block and ASQ block. The pins are automatically enabled when PPG generates pulses. The SWG0 and SWG1 switches are controlled by ASQ as part of measurement sequence (see [Section 21.4](#)).

The drive strength of DRV0 and DRV1 are maximized when SAPHOCTL1.CH0FP = 1 and SAPHOCTL1.CH1FP = 1, respectively. The drive strength of the pins are determined by SAPHCH0PUT, SAPHCH0PDT, SAPHCH1PUT, and SAPHCH1PDT when SAPHOCTL1.CH0FP = 0 and SAPHOCTL1.CH1FP = 0, respectively (see [Section 21.3.2](#)).

When SAPHOSEL.PCH0SEL = 1 or 2, the two pins are controlled by the PPG block and ASQ block. The pins are automatically enabled when PPG generates pulses. The SWG0 and SWG1 switches are controlled by ASQ as part of measurement sequence (see [Section 21.4](#)).

### 21.3.2 Trim Registers for the Output Drivers and Termination Resistors

The output channels (CH0\_OUT and CH1\_OUT) have low-impedance output drivers (DRV0 and DRV1) and termination switches (SWG0 and SWG1). To support the impedance-matching requirement in application environments using ultrasonic technology, programmability is offered to the output drive strength of the drivers (DRV0 and DRV1) and the termination switches (SWG0 and SWG1). The drivers are based on inverter architecture, which consists of PMOS and NMOS. Thus, three trim registers are offered for each channel (see [Table 21-1](#) for details).

During manufacturing, optimal impedance of the drivers and termination switches are determined and their trim values are stored to the device boot data memory (not user accessible). The output impedance of DRV0 and DRV1 are trimmed to match each other (with the lowest possible value), and the termination switches (SWG0 and SWG1) are trimmed to match the impedance of each driver. During the boot process, the trim values are written to the trim registers by bootcode. The default trim values may be different from device to device. Programmability is offered if different impedance values are preferred in a specific application environment.

**Table 21-1. Trim Registers**

| Register          | Description                                             | Trim Range (Typical) <sup>(1)</sup>                                            |
|-------------------|---------------------------------------------------------|--------------------------------------------------------------------------------|
| SAPHCH0PUT.CH0PUT | PMOS trim bits (4 bits) for the channel 0 output driver | 15 = lowest ( $\approx 2.5 \Omega$ )<br>0 = highest<br>Each step $\approx 3\%$ |
| SAPHCH0PDT.CH0PDT | NMOS trim bits (4 bits) for the channel 0 output driver | 15 = lowest ( $\approx 2.5 \Omega$ )<br>0 = highest<br>Each step $\approx 3\%$ |
| SAPHCH0TT         | Termination switch trim bits (4 bits) for channel 0     | 15 = lowest ( $\approx 2.5 \Omega$ )<br>0 = highest<br>Each step $\approx 3\%$ |
| SAPHCH1PUT.CH1PUT | PMOS trim bits (4 bits) for the channel 1 output driver | 15 = lowest ( $\approx 2.5 \Omega$ )<br>0 = highest<br>Each step $\approx 3\%$ |
| SAPHCH1PDT.CH1PDT | NMOS trim bits (4 bits) for the channel 1 output driver | 15 = lowest ( $\approx 2.5 \Omega$ )<br>0 = highest<br>Each step $\approx 3\%$ |
| SAPHCH1TT         | Termination switch trim bits (4 bits) for channel 1     | 15 = lowest ( $\approx 2.5 \Omega$ )<br>0 = highest<br>Each step $\approx 3\%$ |

<sup>(1)</sup> See the device-specific data sheet for details.

The trim registers are written with the default values during every boot up; thus, if different trim values are preferred, the values must be written to the trim registers by software after every boot.

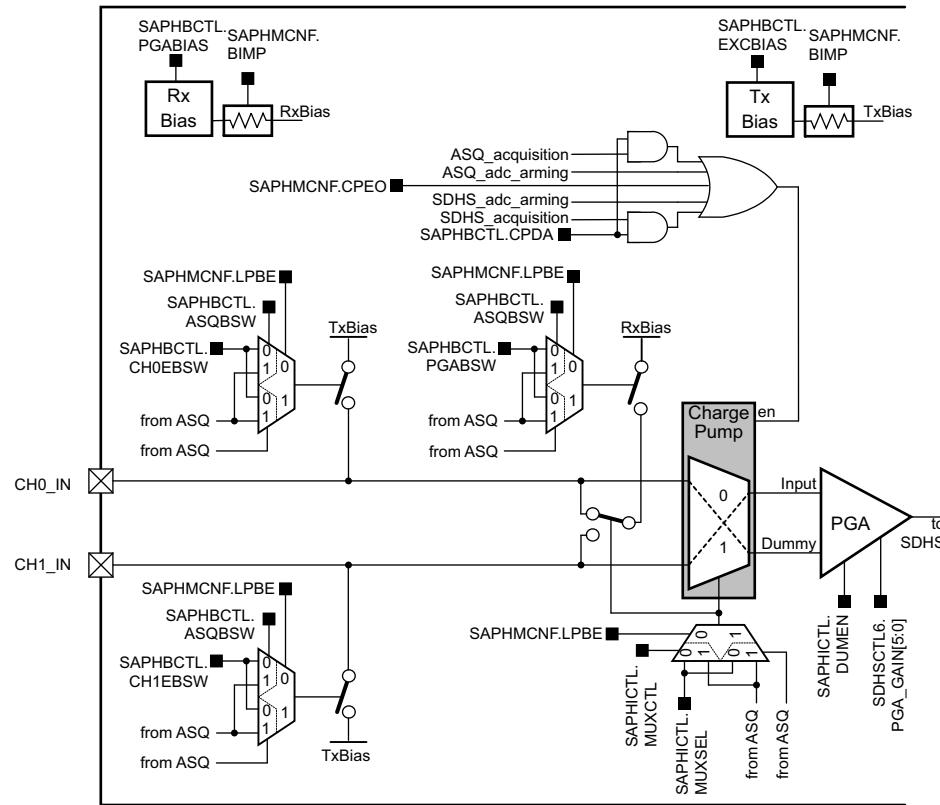
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**NOTE:** To avoid unintended writes to the trim registers, the SAPHTACTL.UNLOCK bit can block write access to the trim registers. The trim registers are locked when SAPHTACTL.UNLOCK = 0.

---

### 21.3.3 Input Channels (CH0\_IN and CH1\_IN)

Figure 21-13 shows the functional block diagram for the input channels, CH0\_IN and CH1\_IN.



**Figure 21-13. SAPH or SAPH\_A Analog Input Signal Chain**

The PGA uses only one input channel at a time, and the input channel is selected by SAPHICTL0.MUXSEL when SAPHICTL0.MUXCTL = 0 and SAPHMCNF.LPBE = 0 (register mode) or by the acquisition sequencer (ASQ) when SAPHICTL0.MUXCTL = 1 and SAPHMCNF.LPBE = 0 (auto mode). Register mode uses the SAPHOCTL0, SAPHOCTL1, SAPHOSEL, and SAPHBCTL registers to control the signal chain. Auto mode uses the SAPHASCTL0, SAPHASCTL1, SAPHAPOL, SAPHAPLEV and SAPHAHZ registers to control the signal chain.

In Ultra Low Power Bias mode (SAPHMCNF=1) both register sets are and the multiplexer selection is controlled by the ASQ.

The PGA has two input channels, but one of the channels is a dummy input, which has the same input impedance of the real input. The dummy input is designed to meet the impedance match requirement between transmit mode and receive mode of one channel. The dummy impedance is enabled when SAPHICTL0.DUMEN = 1 (default).

The input multiplexer is powered by a charge pump, which generates 3.2 V from the USS LDO voltage (1.6 V). The charge pump is turned on while the SAPHMCNF.CPEO=1 and during the preparation/arming for SDHS acquisition. If desired, the charge pump is turned off while capturing the Rx signal through the SDHS to reduce noise (SAPHBCTL.CPDA = 0); however, if signal capture is more than 300  $\mu$ s, the charge pump should remain on (SAPHBCTL.CPDA = 1). Configure SAPHBCTL.CPDA before starting a measurement sequence. The clock of the charge pump is generated from a divided SDHS modulator frequency to maintain coherence during acquisition.

The impedance of the bias voltages TxBias and RxBias can be programmed with SAPHMCNF.BIMP . This allows to find the best fit for the reactant behavior of transducers on bias voltage changes (shorter ringing).

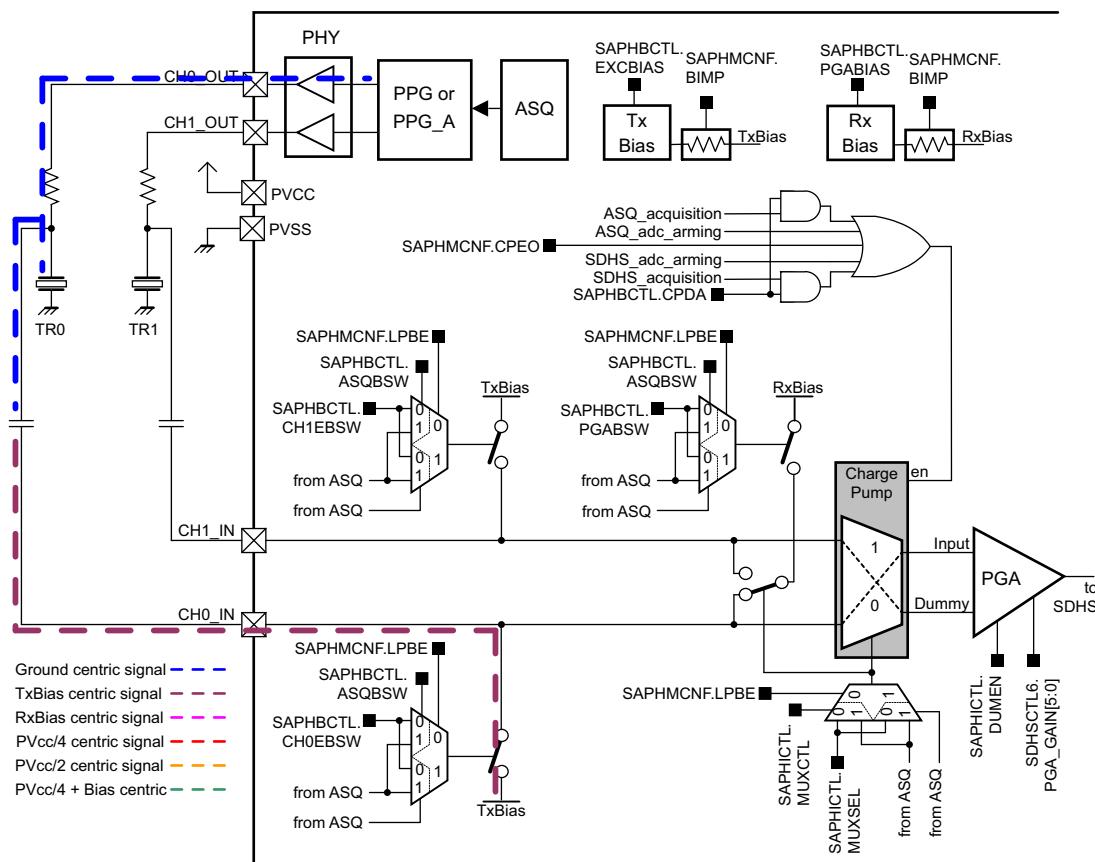
**Table 21-2. Supply to the Rx Multiplexer**

| Register                    | Description                                                    | Recommended Data Capture Time (Typical) |
|-----------------------------|----------------------------------------------------------------|-----------------------------------------|
| SAPHBCTL.CPDA = 0 (default) | The charge pump is automatically off when data capture begins. | <300 µs                                 |
| SAPHBCTL.CPDA = 1           | The charge pump remains on during data capture.                | ≥300 µs                                 |

### 21.3.3.1 Tx Bias and Rx Bias

During a measurement sequence, bias voltages must be applied appropriately to the transmit signal and receive signal. In auto mode, the entire measurement sequence including applying appropriate bias voltages is fully controlled by the ASQ. In register mode, the application must apply the correct bias voltages during a measurement sequence. [Figure 21-13](#) shows the two bias voltage sources, Tx bias and Rx bias. The Tx bias must be applied to the output channel before generating excitation pulses. The Rx bias must be applied to the input channel before capturing the input signal. A typical measurement sequence is as follows [assuming that excitation (Tx) at CH0 and reception (Rx) at CH1]:

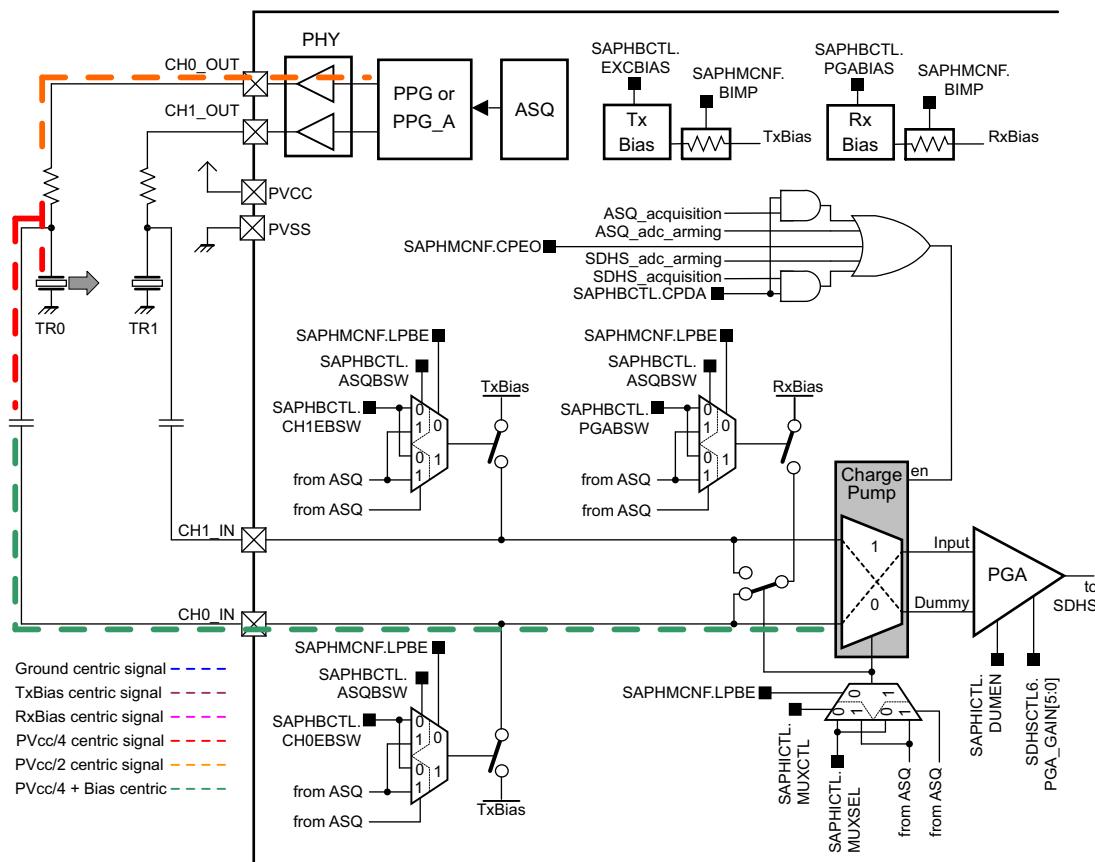
1. Before generating excitation pulses and stop pulses, apply the Tx bias to CH0\_IN while CH0\_OUT is connected to GND through the SWG0 switch (see [Figure 21-14](#) and [Figure 21-12](#)).



NOTE: Apply Tx bias to CH0\_IN while CH0\_OUT is connected to GND through SWG0.

**Figure 21-14. Before Excitation**

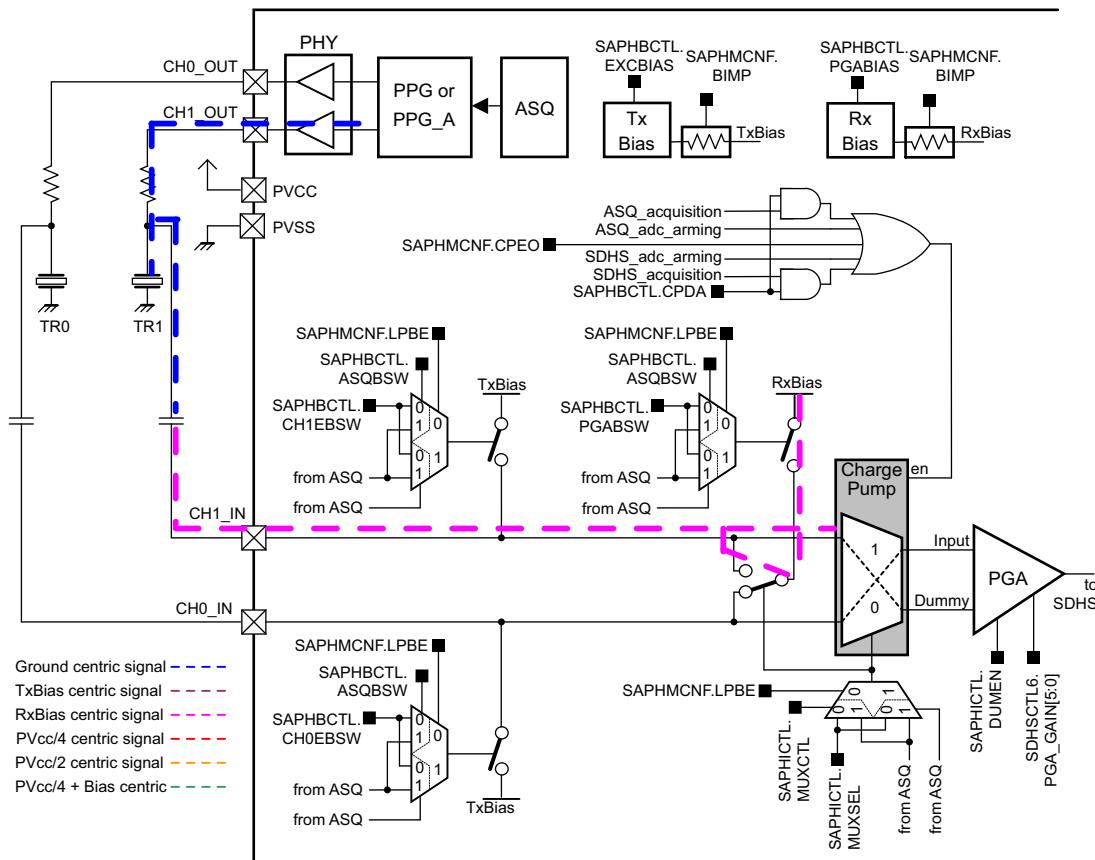
2. Generate excitation pulses and stop pulses through CH0\_OUT, and CH0\_IN is connected to PGA dummy load to meet the impedance-matching requirement. The pulses are driven to the transducer 0 (TR0) (see [Figure 21-15](#)).



NOTE: Excitation pulses are driven on CH0\_OUT, and CH0\_IN is connected to the PGA dummy input.

**Figure 21-15. Excitation**

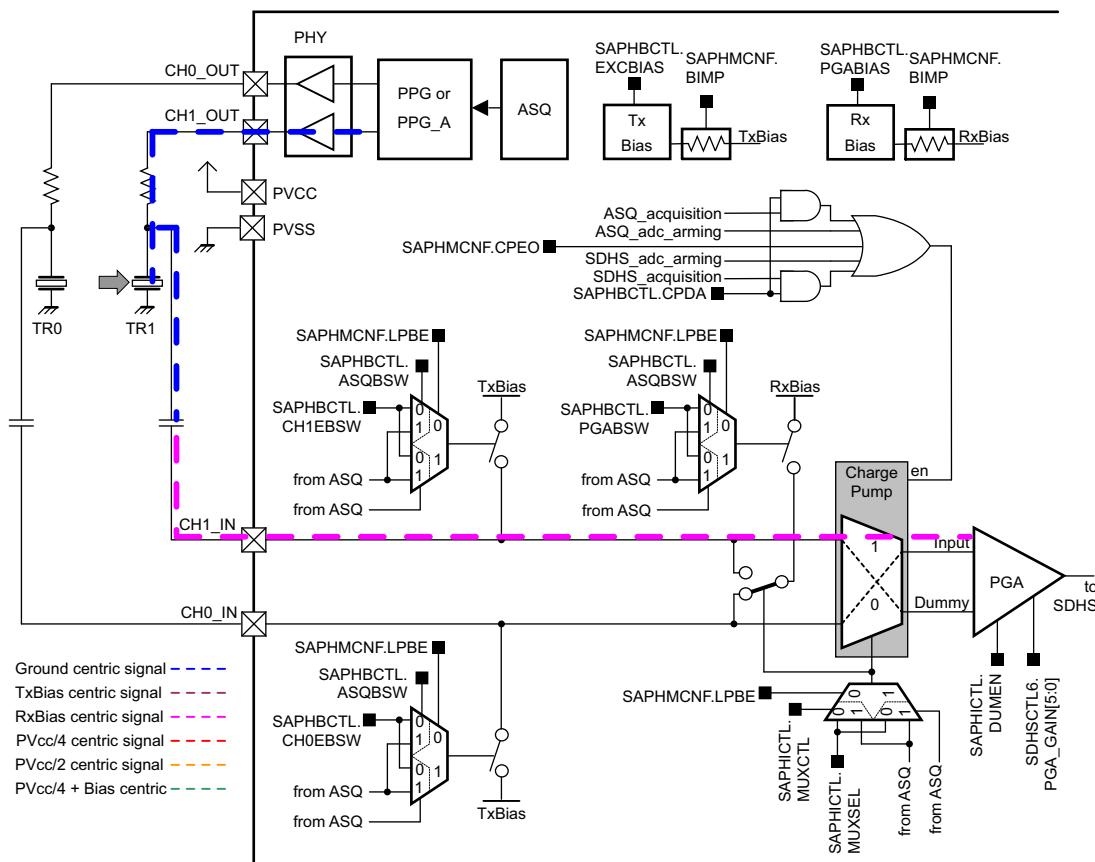
3. Wait for almost the complete estimated time of flight (TOF) between the transducer 0 (TR0) and the transducer 1 (TR1). The delay must be less than TOF to capture the beginning of the arriving pulse train.
4. Before the signal arrives at the transducer 1 (TR1), power on the SDHS ADC so that the SDHS is fully settled before sampling data.
5. Before the signal arrives at the transducer 1 (TR1), apply the Rx bias to CH1\_IN while CH1\_OUT is connected to GND through the SWG1 switch (see [Figure 21-16](#) and [Figure 21-12](#)).



NOTE: Apply Rx bias to CH1\_IN while CH1\_OUT is connect to GND through SWG1.

**Figure 21-16. Before Reception**

- Trigger the SDHS to sample the arrived signal at the transducer 1 (TR1): CH1\_IN is connected to PGA input for data capturing. CH1\_OUT is connected to GND through the SWG1 switch (see [Figure 21-17](#)).



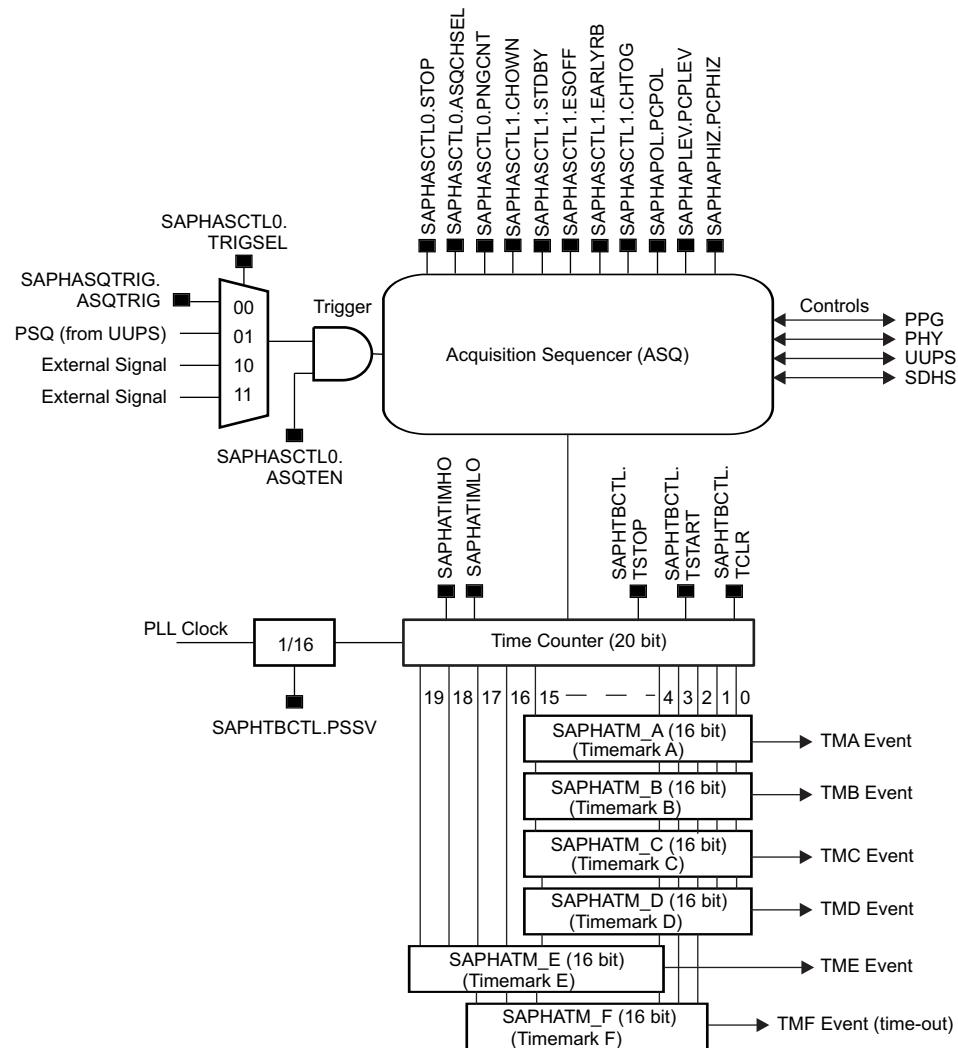
NOTE: CH1\_IN is connected to the PGA input, and CH1\_OUT is connected to GND through the SWG1 switch.

**Figure 21-17. Reception**

The Tx bias voltage and the Rx bias voltage are programmable independently by SAPHBCTL.EXCBIAS and SAPHBCTL.PGABIAS, respectively.

## 21.4 Acquisition Sequencer (ASQ)

The entire measurement sequence can be controlled by user software (called register mode), by ASQ without any CPU intervention (called auto mode) or by ASQ without any CPU intervention (called ultra low power bias mode). The auto mode helps reduce the measurement power consumption, because the CPU can stay in LPM0 during the measurement sequences. The ASQ is a state machine that can be used to control the entire measurement sequence. [Figure 21-17](#) shows the ASQ block diagram. In auto mode a mixed operation of register control and ASQ control is possible for various signal chain elements. In ultra low power bias mode all control is obtained by the ASQ.



**Figure 21-18. ASQ Block Diagram**

#### 21.4.1 Time Counter

Figure 21-17 shows that the ASQ has a 20-bit time counter running at 1/16 of the PLL clock. The counter value can be read from the read-only registers, SAPHTIMLO (low 16 bits) and SAPHTIMHI (high 4 bits). The time counter is controlled by the ASQ during measurement in auto mode; however, the time counter can be forced to stop (SAPHTBCTL.TSTOP = 1), reset (SAPHTBCTL.TCLR = 1), and start (SAPHTBCTL.TSTART = 1) by user software if necessary. Controlling the time counter by user software is not recommended while ASQ is actively controlling the measurement sequences, because these changes interfere with the measurement timings.

### 21.4.2 Six Time Mark Events

The six time mark registers are to generate important timing events during measurement in auto mode. See [Table 21-3](#) for details about the time mark events.

**Table 21-3. Time Mark Events**

| Register                               | Time Counter Bits | Event Name  | Action Done by ASQ                                        |
|----------------------------------------|-------------------|-------------|-----------------------------------------------------------|
| SAPHASQTRIG.ASQTRIG or signal from PSQ | N/A               | ASQ Trigger | Apply Rx bias                                             |
| SAPHATM_A                              | [15: 0]           | TMA         | Trigger PPG to generate excitation pulses and stop pulses |
| SAPHATM_B                              | [15: 0]           | TMB         | Turn on the SDHS                                          |
| SAPHATM_C                              | [15: 0]           | TMC         | Apply Rx bias                                             |
| SAPHATM_D                              | [15: 0]           | TMD         | Start sampling the input signal (trigger the SDHS)        |
| SAPHATM_E                              | [19: 4]           | TME         | Restart the time counter for the next measurement         |
| SAPHATM_F                              | [17: 2]           | TMF         | Time-out                                                  |

The order of the time mark events is determined by the counter values written to the SAPHATM\_x registers.

- Time mark event period = PLL clock  $\times$  1/16  $\times$  value in the time mark registers (for TMA, TMB, TMC, and TMD)
- TME event period = PLL clock  $\times$  1/16  $\times$  value in the time mark register  $\times$  16
- TMF event period = PLL clock  $\times$  1/16  $\times$  value in the time mark register  $\times$  4

### 21.4.3 Triggering the ASQ

There are two ways to start the ASQ. One is user software trigger by writing 1 to SAPHASQTRIG.ASQTRIG, and the other is auto trigger by the PSQ from the UUPS module after the USS power up is complete. When SAPHASCTL0.TRIGSEL = 0, SAPHASQTRIG.ASQTRIG is selected as the trigger source of the ASQ. When SAPHASCTL0.TRIGSEL = 1, the signal from the PSQ is selected as the trigger source of the ASQ. In this case, configure all USS registers before turning on the USS module, so that the entire measurement process can be fully automated by the PSQ and ASQ.

To avoid undesired ASQ triggers, keep SAPHASCTL0.ASQTEN = 0 while configuring ASQ registers. After updating the ASQ registers, write SAPHASCTL0.ASQTEN = 1 before triggering the ASQ. The SAPHASCTL0.ASQTEN bit must be set before triggering the ASQ.

#### 21.4.4 Auto Mode and Register Mode

The entire measurement sequence can be controlled by user software (called register mode) or by the ASQ without any CPU intervention (called auto mode). See [Table 21-4](#) for differences. Configuration of each submodule is the same and is not listed in [Table 21-4](#).

**Table 21-4. Auto Mode and Register Mode**

| Action                                              | Auto Mode                  | Control Register in Auto Mode                                 | Register Mode              | Control Register in Register Mode       |
|-----------------------------------------------------|----------------------------|---------------------------------------------------------------|----------------------------|-----------------------------------------|
| Take USS submodules out of reset (once after reset) | UUPSCTL.SWRST = 0          | UUPSCTL.SWRST                                                 | UUPSCTL.SWRST = 0          | UUPSCTL.SWRST                           |
| Enable auto mode or register mode (on mode changes) | SAPHMCNF.LPBE = 0          | SAPHMCNF.LPBE                                                 | SAPHMCNF.LPBE = 0          | SAPHMCNF.LPBE                           |
| Set TxBias and RxBias impedance                     | SAPHMCNF.BIMP = 0, 1, 2, 3 | SAPHMCNF.BIMP                                                 | SAPHMCNF.BIMP = 0, 1, 2, 3 | SAPHMCNF.BIMP                           |
| Drive output drivers to GND                         | SAPHOSEL.PCH0SEL = 1       | N/A (automatic)                                               | SAPHOSEL.PCH0SEL = 0       | SAPHOCTL0.CH0TERM,<br>SAPHOCTL0.CH1TERM |
| Tx bias                                             | SAPHBCTL.ASQBSW = 1        | N/A (automatic)                                               | SAPHBCTL.ASQBSW = 0        | SAPHBCTL.CH0EBSW,<br>SAPHBCTL.CH1EBSW   |
| Select output channel in PPG                        | SAPHPGCTL.PGSEL = 1        | SAPHASCTL0.ASQCHSEL,<br>SAPHASCTL1.CHTOG                      | SAPHPGCTL.PGSEL = 0        | SAPHPGCTL.PPGCHSEL                      |
| Trigger PPG                                         | SAPHPGCTL.TRSEL = 1        | SAPHATM_A                                                     | SAPHPGCTL.TRSEL = 0        | SAPHPPGTRIG.PPGTRIG                     |
| Input channel selection                             | SAPHICTL0.MUXCTL = 1       | SAPHASCTL0.ASQCHSEL,<br>SAPHASCTL1.CHTOG,<br>SAPHASCTL1.CHOWN | SAPHICTL0.MUXCTL = 0       | SAPHICTL0.MUXSEL                        |
| Turn on the SDHS                                    | SDHSCTL0.TRGSRC = 1        | SAPHATM_B                                                     | SDHSCTL0.TRGSRC = 0        | SDHSCTL4.SDHSON                         |
| Rx bias                                             | SAPHBCTL.ASQBSW = 1        | SAPHATM_C or<br>SAPHASCTL1.EARLYRB                            | SAPHBCTL.ASQBSW = 0        | SAPHBCTL.PGABSW,<br>SAPHICTL0.MUXSEL    |
| SDHS conversion start                               | SDHSCTL0.TRGSRC = 1        | SAPHATM_D                                                     | SDHSCTL0.TRGSRC = 0        | SDHSCTL5.SSTART                         |
| The number of measurement                           | Triggering ASQ             | SAPHASCTL0.PNGCNT (up to 4)                                   | No ASQ trigger             | N/A                                     |

The order of the time mark events is determined by the counter values written to the SAPHATM\_x registers.

## 21.5 Ultra-Low-Power Bias Mode

The ultra-low bias power mode suppresses the PLL operation during the hold-off delay phase on USS startup. Because the PLL and its clock tree operate at a high frequency, considerable energy savings can be achieved. Common utility flow meters that enter LPM3 or LPM3.5 between the measurements with turned off USSXT benefit in particular from that mode.

[Figure 21-19](#) shows a typical use case with register mode or auto mode. The timing axis and the amplitudes in the diagram are not to scale. Following a very short summary of that theoretical use cases.... .

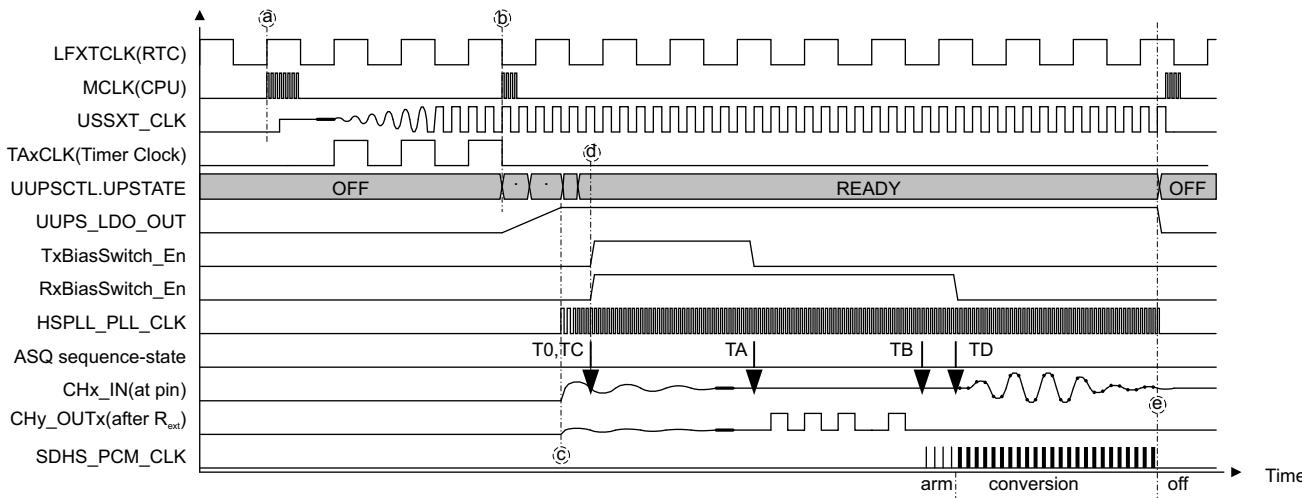
After an RTC event at (a), the system wakes up from LPMx, runs boot code, configures the USS trimming, and enters application code. This turns on USSXT, prepares time-out on TimerA that is running from LFXTCLK, then the CPU enters LPMx.

At (b), the TimerA service routine starts the UUPS, and the CPU enters LPMx again.

At (c), the transducers and external circuits may show ringing due to power up and bias voltage enable. The signals settle then.

At (d) the HSPLL generates a clock with almost no remaining phase variations. Near TA, the transducers have settled and the regular sequence is started by generating pulses. At TB, well before the arrival of the signal, the SDHS and its clock is enabled. At TD, the data acquisition starts.

At (e), the sequence is completed. The interrupt service routine performs calculations and sets the system to LPMx again.



**Figure 21-19. Auto Mode and Register Mode Example**

[Figure 21-20](#) shows a the use case with ultra-low-power bias mode. The timing axis and the amplitudes in the diagram are not to scale. The following is a short summary of that theoretical use case:

After an RTC event at (a), the system wakes up from LPMx, runs boot code, configures the USS trimming, and enters application code. This turns on USSXT, prepares time-out on TimerA that is running from LFXTCLK, and then the CPU enters LPMx.

At (b), the TimerA service routine starts the UUPS with hold-off delay, and the CPU enters LPMx again. The UUPS state machine starts up with suppressed HSPLL.

At (c), the transducers and external circuits may show ringing due to power up and bias voltages. The signals settle then.

At (d), the HSPLL generates a clock with almost no remaining phase variations. Near TA, the transducers have settled and the regular sequence is started by generating pulses. At TB, well before the arrival of the signal, the SDHS and its clock are enabled. At TD, the data acquisition starts.

At (e), the sequence is completed. The interrupt service routine perform calculations and sets the system to LPMx again.

The ASQ.mux control signal switches between both control register sets during power up. Both register sets require same values of the corresponding control bits for a smooth bias generation and handover.

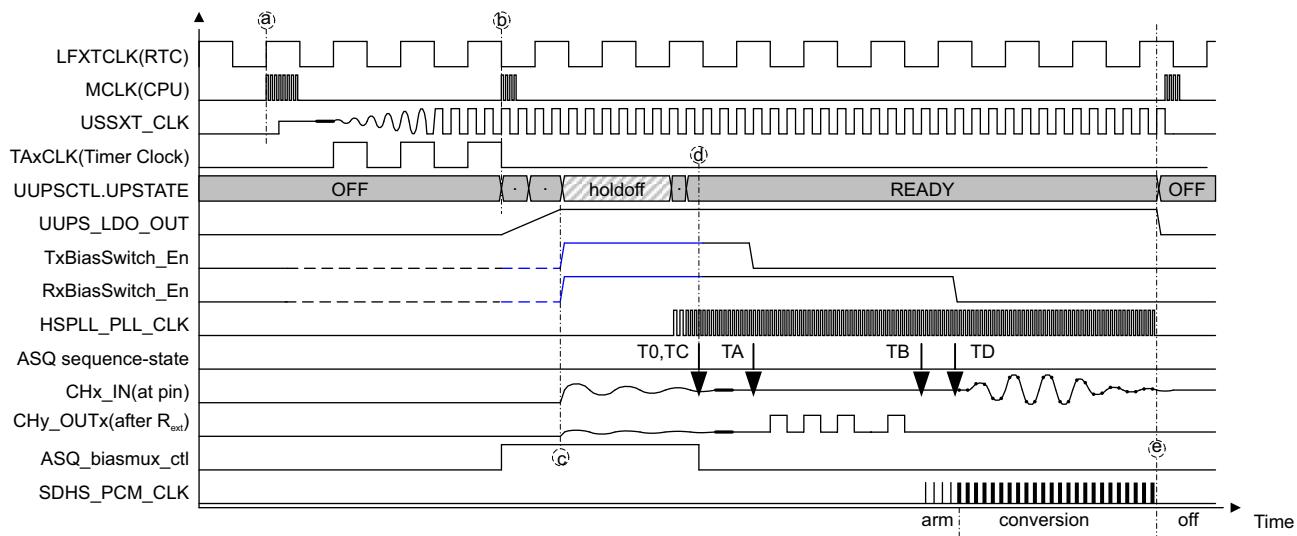


Figure 21-20. Ultra-Low-Power Bias Mode Example

## 21.6 Interrupts Triggers

The SAPH or SAPH\_A module supports four interrupts:

- **PNGDN interrupt:** The interrupt occurs when the PPG completes pulse generation.
- **SEQDN interrupt:** The interrupt occurs when ASQ completes all of the measurements programmed in SAPHASCTL0.PNGCNT. For example, when SAPHASCTL0.PNGCNT = 3, four measurements are performed. The interrupt indicates that all four measurements have been completed.

---

**NOTE:** After ASQ is triggered, if the current measurement is interrupted by entering debug halt mode (UUPSRIS.STPBYDB = 1), the SEQDN interrupt is also reported.

- 
- **TMFTO interrupt:** This interrupt is valid when ASQ is active (auto mode). The interrupt indicates that the time counter in ASQ has reached to TIMEMARK\_F (time-out).
  - **DATAERR interrupt:** This interrupt indicates that either WINHI interrupt or WINLO interrupt has occurred in SDHS. See [Chapter 22](#) for details.

## 21.7 DMA Triggers

The SAPH\_A module supports a DMA trigger. The trigger is fired when the PPG\_A state machine transitions from S\_Pulse to X\_Pulse and when the PPG\_A state machine transitions from X\_Pulse to S\_Pulse.

## 21.8 SAPH and SAPH\_A Registers

**Table 21-5** lists the memory-mapped registers for SAPH/SAPH\_A. All register offset addresses not listed in **Table 21-5** should be considered as reserved locations and the register contents should not be modified.

**Table 21-5. SAPH Registers**

| Offset | Acronym                    | Register Name                             | Type       | Reset | Section         |
|--------|----------------------------|-------------------------------------------|------------|-------|-----------------|
| 0h     | SAPHIDX<br>SAPH_AIIDX      | Interrupt Index                           | read-only  | 0h    | Section 21.8.1  |
| 2h     | SAPHMIS<br>SAPH_AMIS       | Masked Interrupt Status                   | read-only  | 0h    | Section 21.8.2  |
| 4h     | SAPHRIS<br>SAPH_ARIS       | Raw Interrupt Status                      | read-only  | 0h    | Section 21.8.3  |
| 6h     | SAPHIMSC<br>SAPH_AIMSC     | Interrupt Mask                            | read-write | 0h    | Section 21.8.4  |
| 8h     | SAPHICR<br>SAPH_AICR       | Interrupt Clear                           | write-only | 0h    | Section 21.8.5  |
| Ah     | SAPHISR<br>SAPH_AISR       | Interrupt Set                             | write-only | 0h    | Section 21.8.6  |
| Ch     | SAPHDESCLO<br>SAPH_ADESCLO | Module-Descriptor Low Word                | read-only  | 10h   | Section 21.8.7  |
| Eh     | SAPHDESCHI<br>SAPH_ADESCHI | Module-Descriptor High Word               | read-only  | 5553h | Section 21.8.8  |
| 10h    | SAPHKEY<br>SAPH_AKEY       | Key                                       | write-only | 0h    | Section 21.8.9  |
| 12h    | SAPHOCTL0<br>SAPH_AOCTL0   | Physical Interface Output Control #0      | read-write | 0h    | Section 21.8.10 |
| 14h    | SAPHOCTL1<br>SAPH_AOCTL1   | Physical Interface Output Control #1      | read-write | 0h    | Section 21.8.11 |
| 16h    | SAPHOSEL<br>SAPH_AOSEL     | Physical Interface Output Function Select | read-write | 5h    | Section 21.8.12 |
| 20h    | SAPHCH0PUT<br>SAPH_ACH0PUT | Channel 0 Pull UpTrim Register            | read-write | 0h    | Section 21.8.13 |
| 22h    | SAPHCH0PDT<br>SAPH_ACH0PDT | Channel 0 Pull DownTrim Register          | read-write | 0h    | Section 21.8.14 |
| 24h    | SAPHCH0TT<br>SAPH_ACH0TT   | Channel 0 Termination Trim                | read-write | 0h    | Section 21.8.15 |
| 26h    | SAPHCH1PUT<br>SAPH_ACH1PUT | Channel 1 Pull UpTrim                     | read-write | 0h    | Section 21.8.16 |
| 28h    | SAPHCH1PDT<br>SAPH_ACH1PDT | Channel 1 Pull DownTrim                   | read-write | 0h    | Section 21.8.17 |
| 2Ah    | SAPHCH1TT<br>SAPH_ACH1TT   | Channel 1 Termination Trim                | read-write | 0h    | Section 21.8.18 |
| 2Ch    | SAPHMCNF<br>SAPH_AMCNF     | Mode Configuration Register               | read-write | 2h    | Section 21.8.19 |
| 2Eh    | SAPHTACTL<br>SAPH_ATACTL   | Trim Access Control                       | read-write | 0h    | Section 21.8.20 |
| 30h    | SAPHICTL0<br>SAPH_AICTL0   | Physical Interface Input Control #0       | read-write | 90h   | Section 21.8.21 |
| 34h    | SAPH_ABCTL<br>SAPHBCTL     | Bias Control                              | read-write | A1h   | Section 21.8.22 |
| 40h    | SAPHPGC<br>SAPH_APGC       | PPG Count                                 | read-write | 0h    | Section 21.8.23 |
| 42h    | SAPHPLPER<br>SAPH_APGLPER  | Pulse Generator Low Period                | read-write | 0h    | Section 21.8.24 |
| 44h    | SAPHPGHPER<br>SAPH_APGHPER | Pulse Generator High Period               | read-write | 0h    | Section 21.8.25 |

**Table 21-5. SAPH Registers (continued)**

| Offset | Acronym                      | Register Name                    | Type       | Reset | Section         |
|--------|------------------------------|----------------------------------|------------|-------|-----------------|
| 46h    | SAPHPGCTL<br>SAPH_APGCT      | PPG Control                      | read-write | 11h   | Section 21.8.26 |
| 48h    | SAPHPPGTRIG<br>SAPH_APPGTRIG | PPG Software Trigger             | write-only | 0h    | Section 21.8.27 |
| 4Ah    | SAPH_AXPGCTL                 | Extended Pulse Control Register  | read-write | 0h    | Section 21.8.28 |
| 4Ch    | SAPH_AXPGLPER                | Extra Pulse Low Period Register  | read-write | 0h    | Section 21.8.29 |
| 4Eh    | SAPH_AXPGHPER                | Extra Pulse High Period Register | read-write | 0h    | Section 21.8.30 |
| 60h    | SAPHASCTL0<br>SAPH_AASCTL0   | A-SEQ control register 0         | read-write | 0h    | Section 21.8.31 |
| 62h    | SAPHASCTL1<br>SAPH_AASCTL1   | A-SEQ control register 1         | read-write | 0h    | Section 21.8.32 |
| 64h    | SAPHASQTRIG<br>APH_AASQTRIG  | ASQ Software Trigger             | write-only | 0h    | Section 21.8.33 |
| 66h    | SAPHAPOL<br>SAPH_AAPOL       | ASQ ping output polarity         | read-write | 0h    | Section 21.8.34 |
| 68h    | SAPHAPLEV<br>SAPH_AAPLEV     | ASQ ping pause level             | read-write | 0h    | Section 21.8.35 |
| 6Ah    | SAPHAPHIZ<br>SAPH_AAPHIZ     | ASQ ping pause impedance         | read-write | 0h    | Section 21.8.36 |
| 6Eh    | SAPHATM_A<br>SAPH_AATM_A     | A-SEQ start to 1st ping          | read-write | 0h    | Section 21.8.37 |
| 70h    | SAPHATM_B<br>SAPH_AATM_B     | ASQ start to ADC arm             | read-write | 0h    | Section 21.8.38 |
| 72h    | SAPHATM_C<br>SAPH_AATM_C     | Count for the TIMEMARK C Event   | read-write | 0h    | Section 21.8.39 |
| 74h    | SAPHATM_D<br>SAPH_AATM_D     | ASQ start to ADC trig            | read-write | 0h    | Section 21.8.40 |
| 76h    | SAPHATM_E<br>SAPH_AATM_E     | ASQ start to restart             | read-write | 0h    | Section 21.8.41 |
| 78h    | SAPHATM_F<br>SAPH_AATM_F     | ASQ start to timeout             | read-write | 0h    | Section 21.8.42 |
| 7Ah    | SAPHTBCTL<br>SAPH_ATBCTL     | Time Base Control                | read-write | 0h    | Section 21.8.43 |
| 7Ch    | SAPHATIMLO<br>APH_AATIMLO    | Acquisition Timer Low Part       | read-only  | 0h    | Section 21.8.44 |
| 7Eh    | SAPHATIMHI<br>SAPH_AATIMHI   | Acquisition Timer High Part      | read-only  | 0h    | Section 21.8.45 |

### **21.8.1 SAPHIIDX/SAPH\_AIIDX Register (Offset = 0h) [reset = 0h]**

SAPHIDX/SAPH\_AIIDX is shown in [Figure 21-21](#) and described in [Table 21-6](#).

[Return to Summary Table.](#)

Interrupt Index Register

**Figure 21-21. SAPHIIDX/SAPH\_AIIDX Register**

|          |    |    |    |       |    |          |   |
|----------|----|----|----|-------|----|----------|---|
| 15       | 14 | 13 | 12 | 11    | 10 | 9        | 8 |
| RESERVED |    |    |    |       |    |          |   |
| R-0h     |    |    |    |       |    |          |   |
| 7        | 6  | 5  | 4  | 3     | 2  | 1        | 0 |
| RESERVED |    |    |    | IIDX  |    | RESERVED |   |
| R-0h     |    |    |    | RH-0h |    | R-0h     |   |

**Table 21-6. SAPHIIDX/SAPH\_AIIDX Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 3-1  | IIDX     | RH   | 0h    | This register provides the highest priority enabled interrupt index.<br>Reset type: PUC<br>0h (R/W) = NONE : no interrupts pending<br>1h (R/W) = DATAERR : This interrupt indicates that either WINHI interrupt or WINLO interrupt has occurred in SDHS.<br>2h (R/W) = TMFTO : This interrupt is valid when ASQ is active (auto mode). The interrupt indicates that the time counter in ASQ has reached to TIMEMARK_F (timeout).<br>3h (R/W) = SEQDN : This interrupt is valid when ASQ is active (auto mode). The interrupt occurs when ASQ completes all of the measurements programmed in SAPHASCTL0.PNGCNT. For example, when SAPHASCTL0.PNGCNT = 3, total four measurements are performed. The interrupt indicates that all of the four measurements have been completed.<br>4h (R/W) = PNGDN : This interrupt is valid when ASQ is active (auto mode). The interrupt occurs when ASQ completes one measurement sequence. For example, when SAPHASCTL0.PNGCNT = 3, total four measurements are performed. The interrupt indicates that one measurement has been completed. |
| 0    | RESERVED | R    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

### 21.8.2 SAPHMIS/SAPH\_AMIS Register (Offset = 2h) [reset = 0h]

SAPHMIS/SAPH\_AMIS is shown in [Figure 21-22](#) and described in [Table 21-7](#).

[Return to Summary Table.](#)

Masked Interrupt Status Register

**Figure 21-22. SAPHMIS/SAPH\_AMIS Register**

|          |    |    |    |       |       |       |         |
|----------|----|----|----|-------|-------|-------|---------|
| 15       | 14 | 13 | 12 | 11    | 10    | 9     | 8       |
| RESERVED |    |    |    |       |       |       |         |
| R-0h     |    |    |    |       |       |       |         |
| 7        | 6  | 5  | 4  | 3     | 2     | 1     | 0       |
| RESERVED |    |    |    | PNGDN | SEQDN | TMFTO | DATAERR |
| R-0h     |    |    |    | RH-0h | RH-0h | RH-0h | RH-0h   |

**Table 21-7. SAPHMIS/SAPH\_AMIS Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R    | 0h    |                                                                                                                                                                                                                                                                                                                                            |
| 3    | PNGDN    | RH   | 0h    | This interrupt is valid when ASQ is active (auto mode). The interrupt occurs when ASQ completes one measurement sequence. For example, when SAPHASCTL0.PNGCNT = 3, total four measurements are performed. The interrupt indicates that one measurement has been completed.<br>Reset type: PUC                                              |
| 2    | SEQDN    | RH   | 0h    | This interrupt is valid when ASQ is active (auto mode). The interrupt occurs when ASQ completes all of the measurements programmed in SAPHASCTL0.PNGCNT. For example, when SAPHASCTL0.PNGCNT = 3, total four measurements are performed. The interrupt indicates that all of the four measurements have been completed.<br>Reset type: PUC |
| 1    | TMFTO    | RH   | 0h    | This bit indicates a TIMEMARK F (timeout) event has happened.<br>Reset type: PUC                                                                                                                                                                                                                                                           |
| 0    | DATAERR  | RH   | 0h    | This interrupt indicates that either WINHI interrupt or WINLO interrupt has occurred in SDHS.<br>Reset type: PUC                                                                                                                                                                                                                           |

### 21.8.3 SAPHRIS/SAPH\_ARIS Register (Offset = 4h) [reset = 0h]

SAPHRIS/SAPH\_ARIS is shown in [Figure 21-23](#) and described in [Table 21-8](#).

[Return to Summary Table.](#)

Raw Interrupt Status Register

**Figure 21-23. SAPHRIS/SAPH\_ARIS Register**

| 15       | 14    | 13 | 12 | 11       | 10    | 9     | 8       |
|----------|-------|----|----|----------|-------|-------|---------|
| RESERVED | DAV   |    |    | RESERVED |       |       |         |
| R-0h     | RH-0h |    |    | R-0h     |       |       |         |
| 7        | 6     | 5  | 4  | 3        | 2     | 1     | 0       |
| RESERVED |       |    |    | PNGDN    | SEQDN | TMFTO | DATAERR |
| R-0h     |       |    |    | RH-0h    | RH-0h | RH-0h | R-0h    |

**Table 21-8. SAPHRIS/SAPH\_ARIS Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | RESERVED | R    | 0h    |                                                                                                                                                                                                                                                                                                                                                     |
| 14   | DAV      | RH   | 0h    | This bit indicates a DMA access violation<br>Reset type: PUC                                                                                                                                                                                                                                                                                        |
| 13-4 | RESERVED | R    | 0h    |                                                                                                                                                                                                                                                                                                                                                     |
| 3    | PNGDN    | RH   | 0h    | This interrupt is valid when ASQ is active (auto mode). The interrupt occurs when<br>ASQ completes one measurement sequence. For example, when<br>SAPHASCTL0.PNGCNT = 3, total four measurements are performed. The interrupt indicates that one measurement has been completed.<br>Reset type: PUC                                                 |
| 2    | SEQDN    | RH   | 0h    | This interrupt is valid when ASQ is active (auto mode). The interrupt occurs when<br>ASQ completes all of the measurements programmed in<br>SAPHASCTL0.PNGCNT. For example, when<br>SAPHASCTL0.PNGCNT = 3, total four measurements are performed. The interrupt indicates that all of the four measurements have been completed.<br>Reset type: PUC |
| 1    | TMFTO    | RH   | 0h    | This bit indicates a TIMEMARK F (timeout) event has happened.<br>Reset type: PUC                                                                                                                                                                                                                                                                    |
| 0    | DATAERR  | R    | 0h    | This interrupt indicates that either WINHI interrupt or WINLO interrupt has occurred in SDHS.<br>Reset type: PUC                                                                                                                                                                                                                                    |

#### 21.8.4 SAPHIMSC/SAPH\_AIMSC Register (Offset = 6h) [reset = 0h]

SAPHIMSC/SAPH\_AIMSC is shown in [Figure 21-24](#) and described in [Table 21-9](#).

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Interrupt Mask Register

**Figure 21-24. SAPHIMSC/SAPH\_AIMSC Register**

| 15       | 14 | 13    | 12     | 11     | 10     | 9       | 8 |
|----------|----|-------|--------|--------|--------|---------|---|
| RESERVED |    |       |        |        |        |         |   |
| R/W-0h   |    |       |        |        |        |         |   |
| 7        | 6  | 5     | 4      | 3      | 2      | 1       | 0 |
| RESERVED |    | DAV   | PNGDN  | SEQDN  | TMFTO  | DATAERR |   |
| R/W-0h   |    | RH-0h | R/W-0h | R/W-0h | R/W-0h | R/W-0h  |   |

**Table 21-9. SAPHIMSC/SAPH\_AIMSC Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                             |
|------|----------|------|-------|-------------------------------------------------------------------------|
| 15-5 | RESERVED | R/W  | 0h    |                                                                         |
| 4    | DAV      | RH   | 0h    | This bit indicates a DMA access violation<br>Reset type: PUC            |
| 3    | PNGDN    | R/W  | 0h    | This bit enables the PNGDN interrupt<br>Reset type: PUC                 |
| 2    | SEQDN    | R/W  | 0h    | This bit enables the SEQDN interrupt<br>Reset type: PUC                 |
| 1    | TMFTO    | R/W  | 0h    | This bit enables the TIMEMARK F (timeout) interrupt.<br>Reset type: PUC |
| 0    | DATAERR  | R/W  | 0h    | This bit enables the DATAERR interrupt.<br>Reset type: PUC              |

### **21.8.5 SAPHICR/SAPH\_AICR Register (Offset = 8h) [reset = 0h]**

SAPHICR/SAPH\_AICR is shown in [Figure 21-25](#) and described in [Table 21-10](#).

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Interrupt Clear Register

**Figure 21-25. SAPHICR/SAPH\_AICR Register**

| 15       | 14      | 13 | 12 | 11       | 10      | 9       | 8       |
|----------|---------|----|----|----------|---------|---------|---------|
| RESERVED | DAV     |    |    | RESERVED |         |         |         |
| W-0h     | HW1C-0h |    |    | W-0h     |         |         |         |
| 7        | 6       | 5  | 4  | 3        | 2       | 1       | 0       |
| RESERVED |         |    |    | PNGDN    | SEQDN   | TMFTO   | DATAERR |
| W-0h     |         |    |    | HW1C-0h  | HW1C-0h | HW1C-0h | HW1C-0h |

**Table 21-10. SAPHICR/SAPH\_AICR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                    |
|------|----------|------|-------|------------------------------------------------------------------------------------------------|
| 15   | RESERVED | W    | 0h    |                                                                                                |
| 14   | DAV      | HW1C | 0h    | Writing one this bit to clear any previous DMA access violations                               |
| 13-4 | RESERVED | W    | 0h    |                                                                                                |
| 3    | PNGDN    | HW1C | 0h    | Writing one this bit to clear the pending PNGDN interrupt.<br>Reset type: PUC                  |
| 2    | SEQDN    | HW1C | 0h    | Writing one this bit to clear the pending SEQDN interrupt.<br>Reset type: PUC                  |
| 1    | TMFTO    | HW1C | 0h    | Writing one this bit to clear the pending TIMEMARK F (timeout)<br>interrupt<br>Reset type: PUC |
| 0    | DATAERR  | HW1C | 0h    | Writing one this bit to clear the pending DATAERR interrupt.<br>Reset type: PUC                |

### 21.8.6 SAPHISR/SAPH\_AISR Register (Offset = Ah) [reset = 0h]

SAPHISR/SAPH\_AISR is shown in [Figure 21-26](#) and described in [Table 21-11](#).

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Interrupt Set Register

**Figure 21-26. SAPHISR/SAPH\_AISR Register**

| 15       | 14      | 13 | 12 | 11       | 10      | 9       | 8       |
|----------|---------|----|----|----------|---------|---------|---------|
| RESERVED | DAV     |    |    | RESERVED |         |         |         |
| W-0h     | HW1S-0h |    |    | W-0h     |         |         |         |
| 7        | 6       | 5  | 4  | 3        | 2       | 1       | 0       |
| RESERVED |         |    |    | PNGDN    | SEQDN   | TMFTO   | DATAERR |
| W-0h     |         |    |    | HW1S-0h  | HW1S-0h | HW1S-0h | HW1S-0h |

**Table 21-11. SAPHISR/SAPH\_AISR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                       |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------|
| 15   | RESERVED | W    | 0h    |                                                                                                   |
| 14   | DAV      | HW1S | 0h    | Writing one this bit to set RIS.DAV by software.<br>Reset type: PUC                               |
| 13-4 | RESERVED | W    | 0h    |                                                                                                   |
| 3    | PNGDN    | HW1S | 0h    | Writing one this bit to generate a PNGDN interrupt by software.<br>Reset type: PUC                |
| 2    | SEQDN    | HW1S | 0h    | Writing one this bit to generate a SEQDN interrupt by software.<br>Reset type: PUC                |
| 1    | TMFTO    | HW1S | 0h    | Writing one this bit to generate a TIMEMARK F (timeout) interrupt by software.<br>Reset type: PUC |
| 0    | DATAERR  | HW1S | 0h    | Writing one this bit generates a DATAERR interrupt by software.<br>Reset type: PUC                |

### **21.8.7 SAPHDESCLO/SAPH\_ADESCLO Register (Offset = Ch) [reset = 10h]**

SAPHDESCLO/SAPH\_ADESCLO is shown in [Figure 21-27](#) and described in [Table 21-12](#).

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Module-Descriptor Low Word

**Figure 21-27. SAPHDESCLO/SAPH\_ADESCLO Register**

| 15         | 14 | 13 | 12 | 11      | 10 | 9 | 8 |
|------------|----|----|----|---------|----|---|---|
| FEATUREVER |    |    |    | INSTNUM |    |   |   |
| R-0h       |    |    |    | R-0h    |    |   |   |
| 7          | 6  | 5  | 4  | 3       | 2  | 1 | 0 |
| MAJREV     |    |    |    | MINREV  |    |   |   |
| R-1h       |    |    |    | R-0h    |    |   |   |

**Table 21-12. SAPHDESCLO/SAPH\_ADESCLO Register Field Descriptions**

| Bit   | Field      | Type | Reset | Description     |
|-------|------------|------|-------|-----------------|
| 15-12 | FEATUREVER | R    | 0h    | Feature Version |
| 11-8  | INSTNUM    | R    | 0h    | Instance Number |
| 7-4   | MAJREV     | R    | 1h    | Major Revision  |
| 3-0   | MINREV     | R    | 0h    | Minor Revision  |

### 21.8.8 SAPHDESCHI/SAPH\_ADESCHI Register (Offset = Eh) [reset = 5553h]

SAPHDESCHI/SAPH\_ADESCHI is shown in [Figure 21-28](#) and described in [Table 21-13](#).

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Module Descriptor High Word

**Figure 21-28. SAPHDESCHI/SAPH\_ADESCHI Register**

|          |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|----------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| ModuleID |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R-5553h  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-13. SAPHDESCHI/SAPH\_ADESCHI Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description       |
|------|----------|------|-------|-------------------|
| 15-0 | ModuleID | R    | 5553h | SAPH's Identifier |

### **21.8.9 SAPHKEY/SAPH\_AKEY Register (Offset = 10h) [reset = 0h]**

SAPHKEY/SAPH\_AKEY is shown in [Figure 21-29](#) and described in [Table 21-14](#).

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SAPH Key register

**Figure 21-29. SAPHKEY/SAPH\_AKEY Register**

|      |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15   | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| KEY  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| W-0h |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-14. SAPHKEY/SAPH\_AKEY Register Field Descriptions**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|-------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | KEY   | W    | 0h    | <p>This field must be written with 0x454B using a word write to unlock the SAPH registers for write accesses. Writing a value other than 0x454B locks the SAPH registers again. The KEY register only locks/unlocks the SAPH registers with offset address of 0xF or higher. SAPHIDX, SAPHMIS, SAPHRIS, SAPHIMSC, SAPHICR, SAPHSRR, SAPHDESCLO, and SAPHDESCHI registers are not affected and the registers are not locked.</p> <p>Note: This register is write only. Reading always returns with zero.<br/>454Bh (W) = 0x454B</p> |

### 21.8.10 SAPHOCTL0/SAPH\_AOCTL0 Register (Offset = 12h) [reset = 0h]

SAPHOCTL0/SAPH\_AOCTL0 is shown in [Figure 21-30](#) and described in [Table 21-15](#).

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Physical Interface Output Control #0

**Figure 21-30. SAPHOCTL0/SAPH\_AOCTL0 Register**

|          |    |    |    |        |    |        |   |
|----------|----|----|----|--------|----|--------|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9      | 8 |
| RESERVED |    |    |    | CH1OUT |    | CH0OUT |   |
| R/W-0h   |    |    |    | R/W-0h |    | R/W-0h |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1      | 0 |
| RESERVED |    |    |    | CH1OE  |    | CH0OE  |   |
| R/W-0h   |    |    |    | R/W-0h |    | R/W-0h |   |

**Table 21-15. SAPHOCTL0/SAPH\_AOCTL0 Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                        |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                    |
| 9     | CH1OUT   | R/W  | 0h    | CH1_OUT Value. When SAPHOSEL.PCH1SEL =0 and SAPHOCTL0.CH1OE=1, this bit represents the logical value on the CH1 terminal.<br>0 = low<br>1 = high<br>Reset type: PUC<br>0h (R/W) = Ch1 is set to low signal<br>1h (R/W) = Ch1 is set to high signal |
| 8     | CH0OUT   | R/W  | 0h    | CH0_OUT Value. When SAPHOSEL.PCH0SEL =0 and SAPHOCTL0.CH0OE=1, this bit represents the logical value on the CH0 terminal.<br>0 = low<br>1 = high<br>Reset type: PUC<br>0h (R/W) = Ch0 is set to low signal<br>1h (R/W) = Ch0 is set to high signal |
| 7-2   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                    |
| 1     | CH1OE    | R/W  | 0h    | CH1_OUT Enable. When SAPHOSEL.PCH1SEL =0, this bit enables the output CH1 when set to 1. When SAPHOSEL.PCH1SEL != 0, this bit is invalid.<br>Reset type: PUC<br>0h (R/W) = Ch1 Output is HiZ<br>1h (R/W) = CH1 Output is driving                   |
| 0     | CH0OE    | R/W  | 0h    | CH0_OUT Enable. When SAPHOSEL.PCH0SEL =0, this bit enables the output CH0 when set to 1. When SAPHOSEL.PCH0SEL != 0, this bit is invalid.<br>Reset type: PUC<br>0h (R/W) = Ch0 Output is HiZ<br>1h (R/W) = CH0 Output is driving                   |

### 21.8.11 SAPHOCTL1/SAPH\_AOCTL1 Register (Offset = 14h) [reset = 0h]

SAPHOCTL1/SAPH\_AOCTL1 is shown in [Figure 21-31](#) and described in [Table 21-16](#).

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Physical Interface Output Control #1

**Figure 21-31. SAPHOCTL1/SAPH\_AOCTL1 Register**

|          |    |    |    |         |    |         |   |
|----------|----|----|----|---------|----|---------|---|
| 15       | 14 | 13 | 12 | 11      | 10 | 9       | 8 |
| RESERVED |    |    |    | CH1FP   |    | CH0FP   |   |
| R/W-0h   |    |    |    | R/W-0h  |    | R/W-0h  |   |
| 7        | 6  | 5  | 4  | 3       | 2  | 1       | 0 |
| RESERVED |    |    |    | CH1TERM |    | CH0TERM |   |
| R/W-0h   |    |    |    | R/W-0h  |    | R/W-0h  |   |

**Table 21-16. SAPHOCTL1/SAPH\_AOCTL1 Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 9     | CH1FP    | R/W  | 0h    | DRV1 (output driver on the CH1_OUT) full strength enable.<br>0 = The DRV1 output impedance is determined by SAPHCH1PUT and SAPHCH1PDT registers.<br>1 = The DRV1 has lowest output impedance.<br>Reset type: PUC<br>0h (R/W) = Ch1 Output is set to normal strength<br>1h (R/W) = Ch1 Output is set to maximum strength                                                                                         |
| 8     | CH0FP    | R/W  | 0h    | DRV0 (output driver on the CH0_OUT) full strength enable.<br>0 = The DRV0 output impedance is determined by SAPHCH0PUT and SAPHCH0PDT registers.<br>1 = The DRV0 has lowest output impedance.<br>Reset type: PUC<br>0h (R/W) = Ch0 Output is set to normal strength<br>1h (R/W) = Ch0 Output is set to maximum strength                                                                                         |
| 7-2   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 1     | CH1TERM  | R/W  | 0h    | CH1 termination switch (SWG1) enable. When SAPHOSEL.PCH1SEL =0, this bit controls the SWG1 switch.<br>0 = SWG1 is off.<br>1 = SWG1 is on. The CH1_OUT is disabled and connected to PVSS via SWG1 switch. No need to change SAPHOCTL0.CH1OE status.<br>Reset type: PUC<br>0h (R/W) = CH1 Output is defined by SAPHOCTL0.CH1OUT and SAPHOCTL0.CH1OE<br>1h (R/W) = CH1 Output is set low with termination strength |
| 0     | CH0TERM  | R/W  | 0h    | CH0 termination switch (SWG0) enable. When SAPHOSEL.PCH0SEL =0, this bit controls the SWG0 switch.<br>0 = SWG0 is off.<br>1 = SWG0 is on. The CH0_OUT is disabled and connected to PVSS via SWG0 switch. No need to change SAPHOCTL0.CH0OE status.<br>Reset type: PUC<br>0h (R/W) = CH0 Output is defined by SAPHOCTL0.CH0OUT and SAPHOCTL0.CH0OE<br>1h (R/W) = CH0 Output is set low with termination strength |

### 21.8.12 SAPHOSEL/SAPH\_AOSEL Register (Offset = 16h) [reset = 5h]

SAPHOCTL1/SAPH\_AOSEL is shown in [Figure 21-32](#) and described in [Table 21-17](#).

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Physical Interface Output Function Select

**Figure 21-32. SAPHOSEL/SAPH\_AOSEL Register**

|          |    |    |    |         |         |   |   |
|----------|----|----|----|---------|---------|---|---|
| 15       | 14 | 13 | 12 | 11      | 10      | 9 | 8 |
| RESERVED |    |    |    |         |         |   |   |
| R/W-0h   |    |    |    |         |         |   |   |
| 7        | 6  | 5  | 4  | 3       | 2       | 1 | 0 |
| RESERVED |    |    |    | PCH1SEL | PCH0SEL |   |   |
| R/W-0h   |    |    |    | R/W-1h  | R/W-1h  |   |   |

**Table 21-17. SAPHOSEL/SAPH\_AOSEL Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 3-2  | PCH1SEL  | R/W  | 1h    | <p>Output functional select for CH0_OUT.<br/>           Reset type: PUC<br/>           0h (R/W) = GPIO : CH1_OUT is used as a GPO pin. It is controlled by SAPHOCTL0.CH1OUT and SAPHOCTL0.CH1OE.<br/>           1h (R/W) = PPGSE : CH1_OUT is driven by the PPG.<br/>           2h (R/W) = CH1_OUT is driven by the PPG as differential output along with CH0_OUT. (CH0_OUT and CH1_OUT are always opposite polarity)<br/>           3h (R/W) = CH1_OUT is used as a GPO pin. It is controlled by SAPHOCTL0.CH1OUT and SAPHOCTL0.CH1OE.</p> |
| 1-0  | PCH0SEL  | R/W  | 1h    | <p>Output functional select for CH0_OUT.<br/>           Reset type: PUC<br/>           0h (R/W) = GPIO : CH0_OUT is used as a GPO pin. It is controlled by SAPHOCTL0.CH0OUT and SAPHOCTL0.CH0OE.<br/>           1h (R/W) = PPGSE : CH0_OUT is driven by the PPG.<br/>           2h (R/W) = CH0_OUT is driven by the PPG as differential output along with CH1_OUT. (CH0_OUT and CH1_OUT are always opposite polarity)<br/>           3h (R/W) = CH0_OUT is used as a GPO pin. It is controlled by SAPHOCTL0.CH0OUT and SAPHOCTL0.CH0OE.</p> |

### **21.8.13 SAPHCH0PUT/SAPH\_ACH0PUT Register (Offset = 20h) [reset = 0h]**

SAPHCH0PUT/SAPH\_ACH0PUT is shown in [Figure 21-33](#) and described in [Table 21-18](#).

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DRV0 (CH0\_OUT driver) Trim Register for pull-up.

**Figure 21-33. SAPHCH0PUT/SAPH\_ACH0PUT Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | CH0PUT |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-18. SAPHCH0PUT/SAPH\_ACH0PUT Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                           |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                       |
| 3-0  | CH0PUT   | R/W  | 0h    | DRV0 pull up trim register. Write access is allowed only when SAPHTACTL.UNLOCK=1. For secure the trim value, it is recommended to keep SAPHTACTL.UNLOCK=0 during normal operation.<br>Reset type: BOR |

### 21.8.14 SAPHCH0PDT/SAPH\_ACH0PDT Register (Offset = 22h) [reset = 0h]

SAPHCH0PDT/SAPH\_ACH0PDT is shown in Figure 21-34 and described in Table 21-19.

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DRV0 (CH0\_OUT driver) Trim Register for pull-down.

**Figure 21-34. SAPHCH0PDT/SAPH\_ACH0PDT Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | CH0PDT |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-19. SAPHCH0PDT/SAPH\_ACH0PDT Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                             |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                         |
| 3-0  | CH0PDT   | R/W  | 0h    | DRV0 pull down trim register. Write access is allowed only when SAPHTACTL.UNLOCK=1. For secure the trim value, it is recommended to keep SAPHTACTL.UNLOCK=0 during normal operation.<br>Reset type: BOR |

### 21.8.15 SAPHCH0TT/SAPH\_ACH0TT Register (Offset = 24h) [reset = 0h]

SAPHCH0TT/SAPH\_ACH0TT is shown in [Figure 21-35](#) and described in [Table 21-20](#).

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SWG0 (CH0\_OUT termination switch) Trim Register.

**Figure 21-35. SAPHCH0TT/SAPH\_ACH0TT Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | CH0TT  |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-20. SAPHCH0TT/SAPH\_ACH0TT Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                   |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                               |
| 3-0  | CH0TT    | R/W  | 0h    | SWG0 trim register. Write access is allowed only when SAPHTACTL.UNLOCK=1. For secure the trim value, it is recommended to keep SAPHTACTL.UNLOCK=0 during normal operation.<br>Reset type: BOR |

### 21.8.16 SAPHCH1PUT /SAPH\_ACH1PUT Register (Offset = 26h) [reset = 0h]

SAPHCH1PUT/SAPH\_ACH1PUT is shown in [Figure 21-36](#) and described in [Table 21-21](#).

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DRV1 (CH1\_OUT driver) Trim Register for pull-up.

**Figure 21-36. SAPHCH1PUT/SAPH\_ACH1PUT Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | CH1PUT |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-21. SAPHCH1PUT/SAPH\_ACH1PUT Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                           |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                       |
| 3-0  | CH1PUT   | R/W  | 0h    | DRV1 pull up trim register. Write access is allowed only when SAPHTACTL.UNLOCK=1. For secure the trim value, it is recommended to keep SAPHTACTL.UNLOCK=0 during normal operation.<br>Reset type: BOR |

### **21.8.17 SAPHCH1PDT/SAPH\_ACH1PDT Register (Offset = 28h) [reset = 0h]**

SAPHCH1PDT/SAPH\_ACH1PDT is shown in [Figure 21-37](#) and described in [Table 21-22](#).

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DRV1 (CH1\_OUT driver) Trim Register for pull-down.

**Figure 21-37. SAPHCH1PDT/SAPH\_ACH1PDT Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | CH1PDT |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-22. SAPHCH1PDT/SAPH\_ACH1PDT Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                             |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                         |
| 3-0  | CH1PDT   | R/W  | 0h    | DRV1 pull down trim register. Write access is allowed only when SAPHTACTL.UNLOCK=1. For secure the trim value, it is recommended to keep SAPHTACTL.UNLOCK=0 during normal operation.<br>Reset type: BOR |

### 21.8.18 SAPHCH1TT/SAPH\_ACH1TT Register (Offset = 2Ah) [reset = 0h]

SAPHCH1TT/SAPH\_ACH1TT is shown in [Figure 21-38](#) and described in [Table 21-23](#).

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SWG1 (CH1\_OUT termination switch) Trim Register.

**Figure 21-38. SAPHCH1TT/SAPH\_ACH1TT Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | CH1TT  |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-23. SAPHCH1TT/SAPH\_ACH1TT Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                  |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                              |
| 3-0  | CH1TT    | R/W  | 0h    | SWG1 trim register. Write access is allowed only when SAPHTACTL.UNLOCK=1. For secure the trim value, it is recommended to keep SAPHTACTLUNLOCK=0 during normal operation.<br>Reset type: BOR |

### 21.8.19 SAPHMCNF/SAPH\_AMCNF Register (Offset = 2Ch) [reset = 2h]

SAPHMCNF/SAPH\_AMCNF is shown in [Figure 21-39](#) and described in [Table 21-24](#).

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Mode Configuration Register. This bit needs to be unlocked via SAPH\_AKEY for changes

**Figure 21-39. SAPHMCNF/SAPH\_AMCNF Register**

|          |    |    |    |        |        |   |        |
|----------|----|----|----|--------|--------|---|--------|
| 15       | 14 | 13 | 12 | 11     | 10     | 9 | 8      |
| RESERVED |    |    |    | LPBE   | RSV1   |   | CPEO   |
| R/W-0h   |    |    |    | R/W-0h | R/W-0h |   | R/W-0h |
| 7        | 6  | 5  | 4  | 3      | 2      | 1 | 0      |
| RESERVED |    |    |    | RSV0   | BIMP   |   |        |
| R/W-0h   |    |    |    | R/W-0h | R/W-2h |   |        |

**Table 21-24. SAPHMCNF/SAPH\_AMCNF Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 11    | LPBE     | R/W  | 0h    | LPBE, low power bias mode enable. This bit enables the low power bias operation mode. The selection of the operation mode shall only be changed while the PSQ is in OFF state (changes during other states of the PSQ causes corrupt measurement results and irregular triggers of sub modules ba ASQ)<br>Reset type: BOR<br>0h (R/W) = For manual bias mode and regular ASQ bias mode. In this configuration the user controls by the ASQBSW has full control over the TxBias and RxBias switches.<br>1h (R/W) = Low power bias mode. In this mode the ASQ uses the CHxEBSW and PGABSW as auxiliary values to achieve faster channel setting on reactive input loads. The ASQ has full controls over the bias switch multiplexer. |
| 10-9  | RSV1     | R/W  | 0h    | Reserved for future use<br>Reset type: BOR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 8     | CPEO     | R/W  | 0h    | Charge pump explicitly on. This bit enables the charge pump of the input multiplexer.<br>Reset type: BOR<br>0h (R/W) = Charge pump is turned on by SDHS and ASQ related requests only.<br>1h (R/W) = Charge pump is turned on regardless of SDHS and ASQ related charge pump requests.                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 7-4   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 3-2   | RSV0     | R/W  | 0h    | Reserved for future use<br>Reset type: BOR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 1-0   | BIMP     | R/W  | 2h    | Bias generator Impedance configuration. These bits define the impedance of the buffers for RxBias and TxBias. While for resistive loads the lowest impedance shows the fastest settling; is this not the case for reactive loads.<br>Reset type: BOR<br>0h (R/W) = Buffer impedance 500 ohms for RxBias and 450 ohms for TxBias<br>1h (R/W) = Buffer impedance 900 ohms for RxBias and 850 ohms for TxBias<br>2h (R/W) = Buffer impedance 1500 ohms for RxBias and 1450 ohms for TxBias<br>3h (R/W) = Buffer impedance 2950 Ohms for RxBias and 2900 Ohms for TxBias                                                                                                                                                               |

### 21.8.20 SAPHTACTL/SAPH\_ATACTL Register (Offset = 2Eh) [reset = 0h]

SAPHTACTL/SAPH\_ATACTL is shown in [Figure 21-40](#) and described in [Table 21-25](#).

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Trim Access Control Register

**Figure 21-40. SAPHTACTL/SAPH\_ATACTL Register**

|          |    |    |    |          |    |        |   |
|----------|----|----|----|----------|----|--------|---|
| 15       | 14 | 13 | 12 | 11       | 10 | 9      | 8 |
| RESERVED |    |    |    |          |    |        |   |
| R/W-0h   |    |    |    |          |    |        |   |
| 7        | 6  | 5  | 4  | 3        | 2  | 1      | 0 |
| RESERVED |    |    |    | RESERVED |    | UNLOCK |   |
| R/W-0h   |    |    |    | R-0h     |    | R/W-0h |   |

**Table 21-25. SAPHTACTL/SAPH\_ATACTL Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                  |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | RESERVED | R/W  | 0h    |                                                                                                                                                              |
| 2-1  | RESERVED | R    | 0h    | Reserved                                                                                                                                                     |
| 0    | UNLOCK   | R/W  | 0h    | When UNLOCK = 1, the trim registers are allowed to be updated (SAPHCH0PUT, SAPHCH0PDT, SAPHCH0TT, SAPHCH1PUT, SAPHCH1PDT, and SAPHCH1TT).<br>Reset type: PUC |

### 21.8.21 SAPHICTL0 /SAPH\_AICTL0 Register (Offset = 30h) [reset = 90h]

SAPHICTL0/SAPH\_AICTL0 is shown in [Figure 21-41](#) and described in [Table 21-26](#).

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Physical Interface Input Control #0

**Figure 21-41. SAPHICTL0/SAPH\_AICTL0 Register**

| 15       | 14       | 13     | 12     | 11       | 10 | 9       | 8       |
|----------|----------|--------|--------|----------|----|---------|---------|
| RESERVED |          | XPBSW1 | XPBSW0 | RESERVED |    | XPB1FEN | XPB0FEN |
| R/W-0h   |          | R/W-0h | R/W-0h | R/W-0h   |    | R/W-0h  | R/W-0h  |
| 7        | 6        | 5      | 4      | 3        | 2  | 1       | 0       |
| DUMEN    | RESERVED |        | MUXCTL |          |    | MUXSEL  |         |
| R/W-1h   |          | R/W-0h | R/W-1h |          |    | R/W-0h  |         |

**Table 21-26. SAPHICTL0/SAPH\_AICTL0 Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                    |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                |
| 13    | XPBSW1   | R/W  | 0h    | External PGA Bias Switch 1 control<br>Reset type: PUC<br>0h (R/W) = External bias switch is open (no bias driven)<br>1h (R/W) = External bias switch is closed (bias is driven)                                |
| 12    | XPBSW0   | R/W  | 0h    | External PGA Bias Switch 0 control<br>Reset type: PUC<br>0h (R/W) = External bias switch is open (no bias driven)<br>1h (R/W) = External bias switch is closed (bias is driven)                                |
| 11-10 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                |
| 9     | XPB1FEN  | R/W  | 0h    | XPB1 Pin Function Enable<br>Reset type: PUC<br>0h (R/W) = XPB1 pin function disabled<br>1h (R/W) = XPB1 pin function enabled                                                                                   |
| 8     | XPB0FEN  | R/W  | 0h    | XPB0 Pin Function Enable<br>Reset type: PUC<br>0h (R/W) = XPB0 pin function disabled<br>1h (R/W) = XPB0 pin function enabled                                                                                   |
| 7     | DUMEN    | R/W  | 1h    | PGA dummy load enable on the deselected multiplexer inputs.<br>Reset type: PUC<br>0h (R/W) = PGA dummy input load is Hi-Z.<br>1h (R/W) = PGA dummy input load matches the PGA input impedance.                 |
| 6-5   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                |
| 4     | MUXCTL   | R/W  | 1h    | Input Multiplexer Control source<br>Reset type: PUC<br>0h (R/W) = The input multiplexer is controlled by SAPHICTL0.MUXSEL (register mode)<br>1h (R/W) = The input multiplexer is controlled by ASQ (auto mode) |

**Table 21-26. SAPHICTL0/SAPH\_AICTL0 Register Field Descriptions (continued)**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-----|--------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3-0 | MUXSEL | R/W  | 0h    | <p>Input Multiplexer Channel Select<br/>         Reset type: PUC</p> <p>0h (R/W) = CH0IN : Channel 0 is selected for input<br/>         1h (R/W) = CH1IN : Channel 1 is selected for input<br/>         2h (R/W) = reserved for future channels<br/>         3h (R/W) = reserved for future channels<br/>         4h (R/W) = reserved for future channels<br/>         5h (R/W) = reserved for future channels<br/>         6h (R/W) = reserved for future channels<br/>         7h (R/W) = reserved for future channels<br/>         8h (R/W) = no channel is selected<br/>         9h (R/W) = no channel is selected<br/>         Ah (R/W) = no channel is selected<br/>         Bh (R/W) = no channel is selected<br/>         Ch (R/W) = no channel is selected<br/>         Dh (R/W) = no channel is selected<br/>         Eh (R/W) = no channel is selected<br/>         Fh (R/W) = no channel is selected</p> |

### 21.8.22 SAPHBCTL/SAPH\_ABCTL Register (Offset = 34h) [reset = A1h]

SAPHBCTL/SAPH\_ABCTL is shown in [Figure 21-42](#) and described in [Table 21-27](#).

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Bias Control Register

**Figure 21-42. SAPHBCTL/SAPH\_ABCTL Register**

|          |    |         |    |        |         |         |        |
|----------|----|---------|----|--------|---------|---------|--------|
| 15       | 14 | 13      | 12 | 11     | 10      | 9       | 8      |
| RESERVED |    |         |    |        | CH1EBSW | CH0EBSW |        |
| R/W-0h   |    |         |    |        | R/W-0h  | R/W-0h  |        |
| 7        | 6  | 5       | 4  | 3      | 2       | 1       | 0      |
| PGABIAS  |    | EXCBIAS |    | CPDA   | LILC    | PGABSW  | ASQBSC |
| R/W-2h   |    | R/W-2h  |    | R/W-0h | R/W-0h  | R/W-0h  | R/W-1h |

**Table 21-27. SAPHBCTL/SAPH\_ABCTL Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                            |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                        |
| 9     | CH1EBSW  | R/W  | 0h    | Channel 1 Tx bias Switch Control. Note that the Tx bias voltage is determined by SAPHBCTL.EXCBIAS.<br>Reset type: PUC<br>0h (R/W) = Tx bias switch to CH1 is open.<br>1h (R/W) = Tx bias switch to CH1 is closed (enabled).                            |
| 8     | CH0EBSW  | R/W  | 0h    | Channel 0 Tx bias Switch Control. Note that the Tx bias voltage is determined by SAPHBCTL.EXCBIAS.<br>Reset type: PUC<br>0h (R/W) = Tx bias switch to CH0 is open.<br>1h (R/W) = Tx bias switch to CH0 is closed (enabled).                            |
| 7-6   | PGABIAS  | R/W  | 2h    | PGA bias (Rx bias) Voltage Select<br>Reset type: PUC<br>0h (R/W) = 0.75V nominal<br>1h (R/W) = 0.8V nominal<br>2h (R/W) = 0.9V nominal<br>3h (R/W) = 0.95V nominal                                                                                     |
| 5-4   | EXCBIAS  | R/W  | 2h    | Excitation bias (Rx bias) Voltage Select<br>Reset type: PUC<br>0h (R/W) = 0.2V nominal<br>1h (R/W) = 0.3V nominal<br>2h (R/W) = 0.4V nominal<br>3h (R/W) = 0.6V nominal                                                                                |
| 3     | CPDA     | R/W  | 0h    | Enable the power supply (Charge Pump) for the the input multiplexer during data acquisition.<br>Reset type: PUC<br>0h (R/W) = Turn off the charge pump during data acquisition.<br>1h (R/W) = Keep turning on the charge pump during data acquisition. |
| 2     | LILC     | R/W  | 0h    | LILC test feature. Leave at 0 for proper operation<br>Reset type: PUC<br>0h (R/W) = LILC is disabled.<br>1h (R/W) = LILC is enabled.                                                                                                                   |
| 1     | PGABSW   | R/W  | 0h    | Rx bias (PGA bias) switch control. Note that the channel to apply the Rx bias is determined by SAPHICL0.MUXSEL.<br>Reset type: PUC<br>0h (R/W) = Rx bias switch is open.<br>1h (R/W) = Rx bias switch is closed (enabled).                             |

**Table 21-27. SAPHBCTL/SAPH\_ABCTL Register Field Descriptions (continued)**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                   |
|-----|--------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0   | ASQBSC | R/W  | 1h    | <p>Tx bias and Rx bias switches control source select<br/>           Reset type: PUC</p> <p>0h (R/W) = Bias switches are controlled by SAPHBCTL.CH0EBSW,<br/>           SAPHBCTL.CH1EBSW, SAPHBCTL.PGABSW bits (register mode).<br/>           1h (R/W) = Bias switches are controlled by ASQ (auto mode)</p> |

### 21.8.23 SAPHPGC/SAPH\_APAGC Register (Offset = 40h) [reset = 0h]

SAPHPGC/SAPH\_APAGC is shown in Figure 21-43 and described in Table 21-28.

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PPG Count Register

**Figure 21-43. SAPHPGC/SAPH\_APAGC Register**

| 15       | 14     | 13     | 12       | 11     | 10     | 9 | 8 |
|----------|--------|--------|----------|--------|--------|---|---|
| PHIZ     | PLEV   | PPOL   | RESERVED |        | SPULS  |   |   |
| R/W-0h   | R/W-0h | R/W-0h | R/W-0h   |        | R/W-0h |   |   |
| 7        | 6      | 5      | 4        | 3      | 2      | 1 | 0 |
| RESERVED |        |        |          | EPULS  |        |   |   |
|          |        |        |          | R/W-0h |        |   |   |

**Table 21-28. SAPHPGC/SAPH\_APAGC Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                               |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | PHIZ     | R/W  | 0h    | Hi-Z enable to PPG output during inactive.<br>Reset type: PUC<br>0h (R/W) = PPG output during inactive is determined by SAPHPGC.PLEV bit.<br>1h (R/W) = PPG output is in Hi-Z during inactive regardless of SAPHPGC.PLEV bit.                                                                             |
| 14   | PLEV     | R/W  | 0h    | PPG output level during inactive. This bit affects the status of PPG output before and after excitations. Note that this bit is only valid when SAPHPGC.PHIZ =0.<br>Reset type: PUC<br>0h (R/W) = PPG output is low during inactive<br>1h (R/W) = PPG output is high during inactive                      |
| 13   | PPOL     | R/W  | 0h    | Pulse Polarity. This bit defines the polarity of the first excitation pulse.<br>Reset type: PUC<br>0h (R/W) = The excitation begins with logical high phase. The stop begins with logical low phase.<br>1h (R/W) = The excitation begins with logical low phase. The stop begins with logical high phase. |
| 12   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                           |
| 11-8 | SPULS    | R/W  | 0h    | Stop Pulse Count; This bit field defines the number of stop pulses. Minimum value is zero. Stop pulses have the inverted polarity of excitation pulses.<br>Reset type: PUC                                                                                                                                |
| 7    | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                           |
| 6-0  | EPULS    | R/W  | 0h    | Excitation Pulse Count. This bit field defines the number of excitation pulses. Minimum value is zero.<br>Reset type: PUC                                                                                                                                                                                 |

### 21.8.24 SAPHPGLPER/SAPH\_APGLPER Register (Offset = 42h) [reset = 0h]

SAPHPGLPER/SAPH\_APGLPER is shown in Figure 21-44 and described in Table 21-29.

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PPG output pulse low period.

**Figure 21-44. SAPHPGLPER/SAPH\_APGLPER Register**

|          |    |    |    |    |    |   |   |
|----------|----|----|----|----|----|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| RESERVED |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| LPER     |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |

**Table 21-29. SAPHPGLPER/SAPH\_APGLPER Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                        |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                    |
| 7-0  | LPER     | R/W  | 0h    | Low phase period of PPG excitation pulses. This value defines the length of the low phase of the pulses. The minimum count is two regardless of the value set in this register.<br>Reset type: PUC |

### **21.8.25 SAPHPGHPER/SAPH\_APGHPER Register (Offset = 44h) [reset = 0h]**

SAPHPGHPER/SAPH\_APGHPER is shown in [Figure 21-45](#) and described in [Table 21-30](#).

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PPG output pulse high period.

**Figure 21-45. SAPHPGHPER/SAPH\_APGHPER Register**

|          |    |    |    |    |    |   |   |
|----------|----|----|----|----|----|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| RESERVED |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| HPER     |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |

**Table 21-30. SAPHPGHPER/SAPH\_APGHPER Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                          |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                      |
| 7-0  | HPER     | R/W  | 0h    | High phase period of PPG excitation pulses. This value defines the length of the high phase of the pulses. The minimum count is two regardless of the value set in this register.<br>Reset type: PUC |

### 21.8.26 SAPHPGCTL/SAPH\_APGCTL Register (Offset = 46h) [reset = 11h]

SAPHPGCTL/SAPH\_APGCTL is shown in [Figure 21-46](#) and described in [Table 21-31](#).

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PPG Control Register

**Figure 21-46. SAPHPGCTL/SAPH\_APGCTL Register**

| 15       | 14      | 13     | 12       | 11       | 10       | 9        | 8 |
|----------|---------|--------|----------|----------|----------|----------|---|
| STOP     | TONE    | PSCEN  | RESERVED | RESERVED | PPGEN    | RESERVED |   |
| R/W-0h   | RH/W-0h | R/W-0h | R/W-0h   | R-0h     | R/W-0h   | R/W-0h   |   |
| 7        | 6       | 5      | 4        | 3        | 2        | 1        | 0 |
| RESERVED |         | TRSEL  |          | RESERVED | PPGCHSEL | PGSEL    |   |
| R/W-0h   |         | R/W-1h |          | R/W-0h   | R/W-0h   | R/W-1h   |   |

**Table 21-31. SAPHPGCTL/SAPH\_APGCTL Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                          |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | STOP     | R/W  | 0h    | Writing one to this bit stops the PPG to generate pulses. This bit is cleared automatically.<br>Reset type: PUC                                                                                                                                                                                                                                                                      |
| 14    | TONE     | RH/W | 0h    | Tone generation enable. The frequency of the test tone is determined by LPER and HPER. The test tone persists while SAPHPGCTL.TONE = 1 & SAPHPGCTL.STOP=0. Either writing 0 to SAPHPGCTL.TONE or writing 1 to SAPHPGCTL.STOP stops tone generation.<br>Reset type: PUC<br>0h (R/W) = ENABLE : Test tone generation is enabled.                                                       |
| 13    | PSCEN    | R/W  | 0h    | Test feature: Keep this bit zero for proper operation.<br>Reset type: PUC<br>0h (R/W) = disabled<br>1h (R/W) = enabled; PPG is clocked with 1/4 of PLL_CLK without phase control                                                                                                                                                                                                     |
| 12    | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                      |
| 11-10 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                             |
| 9     | PPGEN    | R/W  | 0h    | PPGEN PPG trigger enable. This bit can be used to indicates that the configuration of the pulse generator is complete. The PPG can only be started when this bit is set to 1 regardless of its trigger source. It is recommended to keep this bit zero while updating PPG registers.<br>Reset type: PUC<br>0h (R/W) = PPG trigger is disabled.<br>1h (R/W) = PPG trigger is enabled. |
| 8-6   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                      |
| 5-4   | TRSEL    | R/W  | 1h    | PPG Trigger source select.<br>Reset type: PUC<br>0h (R/W) = Writing 1 to PPGTRIG.PPGTRIG to trigger the PPG (start pulse generation).<br>1h (R/W) = PPG trigger is controlled by the ASQ.<br>2h (R/W) = Ext. Signal (See device specific datasheet)<br>3h (R/W) = Ext. Signal (See device specific datasheet)                                                                        |
| 3-2   | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                      |
| 1     | PPGCHSEL | R/W  | 0h    | PPG output channel select when SAPHPGCTL.PGSEL = 0.<br>Reset type: PUC<br>0h (R/W) = CH0 is selected<br>1h (R/W) = CH1 is selected                                                                                                                                                                                                                                                   |

**Table 21-31. SAPHPGCTL/SAPH\_APGCTL Register Field Descriptions (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                                                            |
|------------|--------------|-------------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0          | PGSEL        | R/W         | 1h           | PPG output channel select source.<br>Reset type: PUC<br>0h (R/W) = PPG output channel is selected by SAPHPGCTL.PPGCHSEL bit (register mode).<br>1h (R/W) = PPG output channel is selected by ASQ (auto mode). |

### 21.8.27 SAPHPPGTRIG/SAPH\_APPGTRIG Register (Offset = 48h) [reset = 0h]

SAPHPPGTRIG/SAPH\_APPGTRIG is shown in Figure 21-47 and described in Table 21-32.

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PPG Software Trigger Register

**Figure 21-47. SAPHPPGTRIG/SAPH\_APPGTRIG Register**

|          |    |    |    |    |    |         |   |
|----------|----|----|----|----|----|---------|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9       | 8 |
| RESERVED |    |    |    |    |    |         |   |
| W-0h     |    |    |    |    |    |         |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1       | 0 |
| RESERVED |    |    |    |    |    | PPGTRIG |   |
| W-0h     |    |    |    |    |    |         |   |

**Table 21-32. SAPHPPGTRIG/SAPH\_APPGTRIG Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                             |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED | W    | 0h    |                                                                                                                                                         |
| 0    | PPGTRIG  | W    | 0h    | Writing '1' to this bit triggers the PPG to generate pulses when SAPHPGCTL.TRSEL =0.<br>Note: This bit is write only. Reading always returns with zero. |

### 21.8.28 SAPH\_AXPGCTL Register (Offset = 4Ah) [reset = 0h]

SAPH\_AXPGCTL is shown in [Figure 21-48](#) and described in [Table 21-33](#).

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Extended Pulse Control Register

**Figure 21-48. SAPH\_AXPGCTL Register**

| 15       | 14     | 13     | 12 | 11       | 10 | 9     | 8 |
|----------|--------|--------|----|----------|----|-------|---|
| RESERVED | ETY    | XMOD   |    | RESERVED |    | XSTAT |   |
| R/W-0h   | R/W-0h | R/W-0h |    | R/W-0h   |    | RH-0h |   |
| 7        | 6      | 5      | 4  | 3        | 2  | 1     | 0 |
| RESERVED |        |        |    | XPULS    |    |       |   |
| R/W-0h   |        |        |    | R/W-0h   |    |       |   |

**Table 21-33. SAPH\_AXPGCTL Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                       |
|-------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                   |
| 14    | ETY      | R/W  | 0h    | Event type. Selects the type of the event generated in SAPH_AXPGCTL.XMOD=3<br>Reset type: PUC<br>0h (R/W) = Timer count event<br>1h (R/W) = DMA trigger event                                                                                                                                                                     |
| 13-12 | XMOD     | R/W  | 0h    | Extended Mode Select<br>Reset type: PUC<br>0h (R/W) = Single tone generation (Pause-E-S-Pause)<br>1h (R/W) = reserved<br>2h (R/W) = Dual Tone Generation (Pause-X-E-S-Pause)<br>3h (R/W) = Dual Tone Loop (...X-E-X-E... triggers events)                                                                                         |
| 11-10 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                   |
| 9-8   | XSTAT    | RH   | 0h    | Phase Status of PPG_A<br>Reset type: PUC<br>0h (R) = PPG_A in Pause Phase<br>1h (R) = PPG_A in Stop Phase<br>2h (R) = PPG_A in Regular Excitation phase<br>3h (R) = PPG_A in Extra Excitation Phase                                                                                                                               |
| 7     | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                   |
| 6-0   | XPULS    | R/W  | 0h    | XPULS Extra Pulse Count; This bit field defines the count of extra excitation pulses excited. If set to zero no extra excitation pulses are generated. Directly after the start the regular excitation phase is entered. Any other number will generate up the number of excitation pulses set by this field .<br>Reset type: PUC |

### 21.8.29 SAPH\_AXPGLPER Register (Offset = 4Ch) [reset = 0h]

SAPH\_AXPGLPER is shown in [Figure 21-49](#) and described in [Table 21-34](#).

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Extra Pulse Low Period Register

**Figure 21-49. SAPH\_AXPGLPER Register**

|          |    |    |    |    |    |   |   |
|----------|----|----|----|----|----|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| RESERVED |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| XLPER    |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |

**Table 21-34. SAPH\_AXPGLPER Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                             |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                         |
| 7-0  | XLPER    | R/W  | 0h    | XLPER low phase period of the extra pulses. This value defines the length of the low phase of the extra pulses in units of high speed clocks. The minimum count is two regardless of the value set in this register.<br>Reset type: PUC |

### **21.8.30 SAPH\_AXPGHPER Register (Offset = 4Eh) [reset = 0h]**

SAPH\_AXPGHPER is shown in [Figure 21-50](#) and described in [Table 21-35](#).

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Extra Pulse High Period Register

**Figure 21-50. SAPH\_AXPGHPER Register**

|          |    |    |    |    |    |   |   |
|----------|----|----|----|----|----|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| RESERVED |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| XHPER    |    |    |    |    |    |   |   |
| R/W-0h   |    |    |    |    |    |   |   |

**Table 21-35. SAPH\_AXPGHPER Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                      |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                  |
| 7-0  | XHPER    | R/W  | 0h    | XHPER high phase period of the extra pulses. This value defines the length of the high phase of the pulses in units of high speed clocks. The minimum count is two regardless of the value set in this register. Reset type: PUC |

### 21.8.31 SAPHASCTL0/SAPH\_AASCTL0 Register (Offset = 60h) [reset = 0h]

SAPHASCTL0/SAPH\_AASCTL0 is shown in [Figure 21-51](#) and described in [Table 21-36](#).

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A-SEQ control register 0

**Figure 21-51. SAPHASCTL0/SAPH\_AASCTL0 Register**

| 15       | 14       | 13       | 12 | 11       | 10     | 9        | 8 |
|----------|----------|----------|----|----------|--------|----------|---|
| RESERVED | ERABRT   | RESERVED |    | TRIGSEL  | ASQTEN | RESERVED |   |
| R-0h     | R/W-0h   | R-0h     |    | R/W-0h   | R/W-0h | R/W-0h   |   |
| 7        | 6        | 5        | 4  | 3        | 2      | 1        | 0 |
| ASQSTOP  | RESERVED | ASQCHSEL |    | RESERVED |        | PNGCNT   |   |
| R/W-0h   | R-0h     | R/W-0h   |    | R/W-0h   |        | R/W-0h   |   |

**Table 21-36. SAPHASCTL0/SAPH\_AASCTL0 Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 13    | ERABRT   | R/W  | 0h    | Stop ASQ when the DATAERR interrupt occurs when the measurements controlled by ASQ (auto mode). Note that it is not possible to resume the measurement from where it was stopped. When ASQ is triggered again, the measurement sequence starts from the beginning.<br>Reset type: PUC<br>0h (R/W) = Continue the measurements until completion regardless of the DATAERR interrupt.<br>1h (R/W) = Stop the ASQ upon the DATAERR interrupt. |
| 12    | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 11-10 | TRIGSEL  | R/W  | 0h    | ASQ trigger select.<br>Reset type: PUC<br>0h (R/W) = SWTRIG : Writing '1' to ASQTRIG.ASQTRIG<br>1h (R/W) = PSQ : The PSQ is selected to start the ASQ.<br>2h (R/W) = Timer : Ext. Signal (See device specific datasheet)<br>3h (R/W) = Ext. Signal (See device specific datasheet)                                                                                                                                                         |
| 9     | ASQTEN   | R/W  | 0h    | ASQ Trigger Enable. This bit can be used to indicate that the configuration of the ASQ is complete. The ASQ can only be triggered when this bit is set to '1' regardless of its trigger source. It is recommended to keep this bit zero while updating ASQ registerds.<br>Reset type: PUC<br>0h (R/W) = ASQ trigger is disabled.<br>1h (R/W) = ASQ trigger is enabled.                                                                     |
| 8     | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 7     | ASQSTOP  | R/W  | 0h    | Stop the ASQ. Writing '1' to this bit stops the measurement sequence controlled by the ASQ. This bit is self cleared.<br>Reset type: PUC                                                                                                                                                                                                                                                                                                   |
| 6-5   | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                   |

**Table 21-36. SAPHASCTL0/SAPH\_AASCTL0 Register Field Descriptions (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4   | ASQCHSEL | R/W  | 0h    | <p>This bit selects the channel to start with when ASQ controls the measurement sequences.</p> <p>Reset type: PUC</p> <p>0h (R/W) = CH0 is selected to start with.</p> <p>If SAPHASCTL0.PNGCNT = 3 and SAPHASCTL1.CHTOG =1, then the channel selection would be CH0 -&gt; CH1 -&gt; CH0 -&gt; CH1.</p> <p>If SAPHASCTL0.PNGCNT = 3 and SAPHASCTL1.CHTOG =0, then the channel selection would be CH0 -&gt; CH0 -&gt; CH0 -&gt; CH0.</p> <p>1h (R/W) = CH1 is selected to start with.</p> <p>If SAPHASCTL0.PNGCNT = 3 and SAPHASCTL1.CHTOG =0, then the channel selection would be CH1 -&gt; CH1 -&gt; CH1 -&gt; CH1.</p> <p>If SAPHASCTL0.PNGCNT = 3 and SAPHASCTL1.CHTOG =1, then the channel selection would be CH1 -&gt; CH0 -&gt; CH1 -&gt; CH0.</p> |
| 3-2 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 1-0 | PNGCNT   | R/W  | 0h    | <p>The total number of measurements to be performed.</p> <p>0 = 1 measurement will be performed (Min)</p> <p>1 = 2 measurements will be performed</p> <p>2 = 3 measurements will be performed</p> <p>3 = 4 measurements will be performed (Max)</p> <p>Note: This bit field is static, does not reflect the currently remaining measurement numbers.</p> <p>Reset type: PUC</p>                                                                                                                                                                                                                                                                                                                                                                         |

### 21.8.32 SAPHASCTL1/SAPH\_AASCTL1 Register (Offset = 62h) [reset = 0h]

SAPHASCTL1/SAPH\_AASCTL1 is shown in [Figure 21-52](#) and described in [Table 21-37](#).

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A-SEQ control register 1

**Figure 21-52. SAPHASCTL1/SAPH\_AASCTL1 Register**

|          |          |    |        |          |          |          |        |
|----------|----------|----|--------|----------|----------|----------|--------|
| 15       | 14       | 13 | 12     | 11       | 10       | 9        | 8      |
| RESERVED |          |    | CHOWN  | STDBY    | RESERVED | ESOFF    |        |
| R-0h     |          |    | R/W-0h | R/W-0h   | R/W-0h   | R/W-0h   |        |
| 7        | 6        | 5  | 4      | 3        | 2        | 1        | 0      |
| EARLYRB  | RESERVED |    | CHACT  | RESERVED | RESERVED | RESERVED | CHTOG  |
| R/W-0h   | R-0h     |    | R-0h   | R/W-0h   | R-0h     | R-0h     | R/W-0h |

**Table 21-37. SAPHASCTL1/SAPH\_AASCTL1 Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 11    | CHOWN    | R/W  | 0h    | In general, if CH0 is selected for Tx, CH1 is selected for Rx. However, when this bit is set to '1', the Tx channel and Rx channel are identical. This bit can be used for debugging purpose.<br>Reset type: PUC<br>0h (R/W) = Tx channel and Rx channel are not the same (This is the typical configuration).<br>1h (R/W) = Tx channel and Rx channel are identical.                                                      |
| 10    | STDBY    | R/W  | 0h    | ASQ can send a request signal to the PSQ (Power Sequencer) of the USS module when the OFF request is received (See SAPHASCTL1.ESOFF and the UUPS module).<br>Reset type: PUC<br>0h (R/W) = PWROFF : The ASQ sends a power down request to the PSQ (Power Sequencer) when the OFF request is received.<br>1h (R/W) = STDBY : The ASQ sends a standby request to the PSQ (Power Sequencer) when the OFF request is received. |
| 9     | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 8     | ESOFF    | R/W  | 0h    | Enable the OFF request when ASQ completes all of the measurement sequences.<br>Reset type: PUC<br>0h (R/W) = OFF request is disabled. The ASQ does not send a request about USS power mode to the PSQ.<br>1h (R/W) = OFF request is generated after sequence                                                                                                                                                               |
| 7     | EARLYRB  | R/W  | 0h    | Early Receive Bias Control. The Rx bias is applied at the TIMEMARK C, but when this bit is set to '1', the Rx bias is applied at the TIMEMARK A.<br>Reset type: PUC<br>0h (R/W) = Rx bias is applied to the Rx channel by the TIMEMARK C<br>1h (R/W) = Rx bias is applied to the Rx channel by the TIMEMARK A                                                                                                              |
| 6-5   | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 4     | CHACT    | R    | 0h    | Read Only bit. This bit indicates the currently selected Tx channel.<br>Reset type: PUC                                                                                                                                                                                                                                                                                                                                    |
| 3     | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 2     | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 1     | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                   |

**Table 21-37. SAPHASCTL1/SAPH\_AASCTL1 Register Field Descriptions (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                           |
|------------|--------------|-------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0          | CHTOG        | R/W         | 0h           | Channel toggle enable at each PNGDN interrupt.<br>Reset type: PUC<br>0h (R/W) = Channel toggle is disabled.<br>1h (R/W) = Channel toggle is enabled at each PNGDN interrupt. |

### 21.8.33 SAPHASQTRIG/SAPH\_AASQTRIG Register (Offset = 64h) [reset = 0h]

SAPHASQTRIG/SAPH\_AASQTRIG is shown in Figure 21-53 and described in Table 21-38.

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ASQ Software Trigger Register

**Figure 21-53. SAPHASQTRIG/SAPH\_AASQTRIG Register**

| 7        | 6 | 5 | 4 | 3 | 2 | 1       | 0 |
|----------|---|---|---|---|---|---------|---|
| RESERVED |   |   |   |   |   | ASQTRIG |   |
| W-0h     |   |   |   |   |   | W-0h    |   |

**Table 21-38. SAPHASQTRIG/SAPH\_AASQTRIG Register Field Descriptions**

| Bit | Field    | Type | Reset | Description                                                                                                                             |
|-----|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 7-1 | RESERVED | W    | 0h    |                                                                                                                                         |
| 0   | ASQTRIG  | W    | 0h    | Writing '1' to this bit trigger the ASQ when SAPHASCTL0.TRIGSEL = 0.<br>Note: This bit is write only. Reading always returns with zero. |

### 21.8.34 SAPHAPOL/SAPH\_AAPOL Register (Offset = 66h) [reset = 0h]

SAPHAPOL/SAPH\_AAPOL is shown in [Figure 21-54](#) and described in [Table 21-39](#).

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The PPG output pulse polarity when ASQ is controlling the measurement.

**Figure 21-54. SAPHAPOL/SAPH\_AAPOL Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | PCPOL  |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-39. SAPHAPOL/SAPH\_AAPOL Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                          |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 3-0  | PCPOL    | R/W  | 0h    | Bit 0 defines the PPG pulse polarity for the first measurement.<br>Bit 1 defines the PPG pulse polarity for the second measurement.<br>Bit 2 defines the PPG pulse polarity for the third measurement.<br>Bit 3 defines the PPG pulse polarity for the fourth measurement.<br>0 = PPG output pulses starts with logical high polarity.<br>1 = PPG output pulses starts with logical low polarity.<br>Reset type: PUC |

### 21.8.35 SAPHAPLEV /SAPH\_AAPLEV Register (Offset = 68h) [reset = 0h]

SAPHAPLEV/SAPH\_AAPLEV is shown in [Figure 21-55](#) and described in [Table 21-40](#).

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The PPG output level at pause when ASQ is controlling the measurement.

**Figure 21-55. SAPHAPLEV/SAPH\_AAPLEV Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | PCPLEV |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-40. SAPHAPLEV/SAPH\_AAPLEV Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 3-0  | PCPLEV   | R/W  | 0h    | <p>Bit 0 defines the PPG output level at pause for the first measurement when PCPHIZ bit 0 = 0.</p> <p>Bit 1 defines the PPG output level at pause for the second measurement when PCPHIZ bit 1 = 0.</p> <p>Bit 2 defines the PPG output level at pause for the third measurement when PCPHIZ bit 2 = 0.</p> <p>Bit 3 defines the PPG output level at pause for the fourth measurement when PCPHIZ bit 3 = 0.</p> <p>0 = Logical Low.<br/>1 = Logical High.</p> <p>Reset type: PUC</p> |

### 21.8.36 SAPHAPHIZ/SAPH\_AAPHIZ Register (Offset = 6Ah) [reset = 0h]

SAPHAPHIZ/SAPH\_AAPHIZ is shown in [Figure 21-56](#) and described in [Table 21-41](#).

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The PPG output status at pause when ASQ is controlling the measurement.

**Figure 21-56. SAPHAPHIZ/SAPH\_AAPHIZ Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R/W-0h   |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | PCPHIZ |    |   |   |
| R/W-0h   |    |    |    | R/W-0h |    |   |   |

**Table 21-41. SAPHAPHIZ/SAPH\_AAPHIZ Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 3-0  | PCPHIZ   | R/W  | 0h    | <p>Bit 0 defines the PPG output status at pause for the first measurement.</p> <p>Bit 1 defines the PPG output status at pause for the second measurement.</p> <p>Bit 2 defines the PPG output status at pause for the third measurement.</p> <p>Bit 3 defines the PPG output status at pause for the fourth measurement.</p> <p>0 = PPG ouput level is determined by SAPHAPLEV.PCPLEV bits</p> <p>1 = Hi-z. regardless of SAPHAPLEV.PCPLEV bits</p> <p>Reset type: PUC</p> |

### 21.8.37 SAPHATM\_A/SAPH\_AATM\_A Register (Offset = 6Eh) [reset = 0h]

SAPHATM\_A/SAPH\_AATM\_A is shown in [Figure 21-57](#) and described in [Table 21-42](#).

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Count for the TIMEMARK A Event

**Figure 21-57. SAPHATM\_A/SAPH\_AATM\_A Register**

|            |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TIMEMARK_A |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-42. SAPHATM\_A/SAPH\_AATM\_A Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                              |
|------|------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TIMEMARK_A | R/W  | 0h    | <p>This value is used to generate the TIMEMARK A event by comparing with the ASQ timer counter value. TIMEMARK_A value [15:0] are compared to ASQ Timer Counter [15:0]</p> <p>TIMEMARK A event is to trigger the PPG. Before this event, the Tx bias is applied to the transmit channel, so make sure to provide enough time to settle the Tx bias. The minimum value is two.</p> <p>Reset type: PUC</p> |

### **21.8.38 SAPHATM\_B/SAPH\_AATM\_B Register (Offset = 70h) [reset = 0h]**

SAPHATM\_B/SAPH\_AATM\_B is shown in [Figure 21-58](#) and described in [Table 21-43](#).

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Count for the TIMEMARK B Event

**Figure 21-58. SAPHATM\_B/SAPH\_AATM\_B Register**

|            |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TIMEMARK_B |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-43. SAPHATM\_B/SAPH\_AATM\_B Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TIMEMARK_B | R/W  | 0h    | <p>This value is used to generate the TIMEMARK B event by comparing with the ASQ timer counter value. TIMEMARK_B value [15:0] are compared to ASQ Timer Counter [15:0]</p> <p>TIMEMARK B event is to turn on the SDHS (ADC converter). The SDHS starts sampling input signal at the TIMEMARK D event. The time between B and D is for the SDHS settling time. The minimum value is two.</p> <p>Reset type: PUC</p> |

### 21.8.39 SAPHATM\_C/SAPH\_AATM\_C Register (Offset = 72h) [reset = 0h]

SAPHATM\_C/SAPH\_AATM\_C is shown in [Figure 21-59](#) and described in [Table 21-44](#).

[Return to Summary Table.](#)

Count for the TIMEMARK C Event

**Figure 21-59. SAPHATM\_C/SAPH\_AATM\_C Register**

|            |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TIMEMARK_C |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-44. SAPHATM\_C/SAPH\_AATM\_C Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TIMEMARK_C | R/W  | 0h    | <p>This value is used to generate the TIMEMARK C event by comparing with the ASQ timer counter value. TIMEMARK_C value [15:0] are compared to ASQ Timer Counter [15:0]</p> <p>TIMEMARK C event is to apply Rx bias to the PGA input channel. The Rx bias should be applied before the signal arrives at the input channel. The time between C and D is for the Rx bias settling time. The minimum value is two.</p> <p>Reset type: PUC</p> |

### **21.8.40 SAPHATM\_D/SAPH\_AATM\_D Register (Offset = 74h) [reset = 0h]**

SAPHATM\_D/SAPH\_AATM\_D is shown in [Figure 21-60](#) and described in [Table 21-45](#).

[Return to Summary Table.](#)

Count for the TIMEMARK D Event

**Figure 21-60. SAPHATM\_D/SAPH\_AATM\_D Register**

|            |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TIMEMARK_D |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-45. SAPHATM\_D/SAPH\_AATM\_D Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                             |
|------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TIMEMARK_D | R/W  | 0h    | <p>This value is used to generate the TIMEMARK D event by comparing with the ASQ timer counter value. TIMEMARK_D value [15:0] are compared to ASQ Timer Counter [15:0]</p> <p>TIMEMARK D event is to trigger the SDHS to start sampling on the input signal. The time between D and E is for the total data sampling time + transfer time via DTC. The minimum value is two.</p> <p>Reset type: PUC</p> |

### 21.8.41 SAPHATM\_E/SAPH\_AATM\_E Register (Offset = 76h) [reset = 0h]

SAPHATM\_E/SAPH\_AATM\_E is shown in [Figure 21-61](#) and described in [Table 21-46](#).

[Return to Summary Table.](#)

Count for the TIMEMARK E Event

**Figure 21-61. SAPHATM\_E/SAPH\_AATM\_E Register**

|            |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TIMEMARK_E |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-46. SAPHATM\_E/SAPH\_AATM\_E Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                               |
|------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TIMEMARK_E | R/W  | 0h    | <p>This value is used to generate the TIMEMARK E event by comparing with the ASQ timer counter value. TIMEMARK_E value [15:0] are compared to ASQ Timer Counter [19:4]</p> <p>TIMEMARK E event is to resume the measurement sequence. The ASQ time counter is reset. The minimum value is two.</p> <p>Reset type: PUC</p> |

### 21.8.42 SAPHATM\_F/SAPH\_AATM\_F Register (Offset = 78h) [reset = 0h]

SAPHATM\_F/SAPH\_AATM\_F is shown in [Figure 21-62](#) and described in [Table 21-47](#).

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Count for the TIMEMARK F Event

**Figure 21-62. SAPHATM\_F/SAPH\_AATM\_F Register**

|            |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TIMEMARK_F |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-47. SAPHATM\_F/SAPH\_AATM\_F Register Field Descriptions**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TIMEMARK_F | R/W  | 0h    | <p>This value is used to generate the TIMEMARK F event by comparing with the ASQ timer counter value. TIMEMARK_F value [15:0] are compared to ASQ Timer Counter [17:2]</p> <p>TIMEMARK F event is to check out if the measurement is completed within this time limit. The ASQ time counter is reset. The TMFTO interrupt is generated if a measurement has not been completed until the event occurs. The event will abort all of the pre-programmed measurement sequences. The minimum value is two.</p> <p>Note: TIMEMAR_E should be programmed to be longer than TIMEMARK_F.</p> <p>Reset type: PUC</p> |

### 21.8.43 SAPHTBCTL/SAPH\_ATBCTL Register (Offset = 7Ah) [reset = 0h]

SAPHTBCTL/SAPH\_ATBCTL is shown in [Figure 21-63](#) and described in [Table 21-48](#).

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Time Base Control Register

**Figure 21-63. SAPHTBCTL/SAPH\_ATBCTL Register**

| 15     | 14 | 13       | 12 | 11       | 10 | 9        | 8 |
|--------|----|----------|----|----------|----|----------|---|
| PSTAT  |    | RESERVED |    | RESERVED |    | RESERVED |   |
| R-0h   |    | R/W-0h   |    | R-0h     |    | R-0h     |   |
| 7      | 6  | 5        | 4  | 3        | 2  | 1        | 0 |
| PSSV   |    | RESERVED |    | TSTOP    |    | TSTART   |   |
| R/W-0h |    | R/W-0h   |    | W-0h     |    | W-0h     |   |
|        |    |          |    |          |    |          |   |

**Table 21-48. SAPHTBCTL/SAPH\_ATBCTL Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | PSTAT    | R    | 0h    | These bits reflect the current power state of the USS module. These bits are also reflected in "energy trace" of the debug tools. As simple unidirectional measurement sequence would show the sequence: "0,1,2,1,3,1,0"<br><br>Reset type: PUC<br>0h (R/W) = ASQ inactive or waiting for trigger (ASQ timer not running)<br>1h (R/W) = ASQ timer running (ASQ timer tuning)<br>2h (R/W) = PPG during ping process<br>3h (R/W) = ADC during acquisition process |
| 13-10 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 9     | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 8     | RESERVED | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 7-4   | PSSV     | R/W  | 0h    | ASQ pre-scaler shift. The value written to the PSSV bits shifts the start point of the ASQ's pre-scaler. Note that the value only affects the first cycle of the pre-scaler.<br><br>0 = No shift<br>1 = The pre-scaler starts 1 clock later<br>2 = The pre-scaler starts 2 clocks later<br>...<br>15 = The pre-scaler starts 15 clocks later<br><br>Reset type: PUC                                                                                             |
| 3     | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 2     | TSTOP    | W    | 0h    | The ASQ time counter stop. Writing '1' to this bit stops the counter. This bit is self cleared. TSTOP, TSTART, and TCLR bits are offered for only debugging purpose. It is not recommend to use this bit while ASQ is active.<br><br>Note: This bit is write only. Reading always returns with zero.                                                                                                                                                            |
| 1     | TSTART   | W    | 0h    | The ASQ time counter start. Writing '1' to this bit starts the counter. This bit is self cleared. TSTOP, TSTART, and TCLR bits are offered for only debugging purpose. It is not recommend to use this bit while ASQ is active.<br><br>Note: This bit is write only. Reading always returns with zero.                                                                                                                                                          |
| 0     | TCLR     | W    | 0h    | The ASQ time counter clear. Writing '1' to this bit clears the the counter value. The counter must be stopped prior to be cleared. This bit is self cleared. TSTOP, TSTART, and TCLR bits are offered for only debugging purpose. It is not recommend to use this bit while ASQ is active.<br><br>Note: This bit is write only. Reading always returns with zero.                                                                                               |

### **21.8.44 SAPHATIMLO/SAPH\_AATIMLO Register (Offset = 7Ch) [reset = 0h]**

SAPHATIMLO/SAPH\_AATIMLO is shown in [Figure 21-64](#) and described in [Table 21-49](#).

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ASQ Time Counter Low Part [15:0]

**Figure 21-64. SAPHATIMLO/SAPH\_AATIMLO Register**

|        |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|--------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15     | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| ATIMLO |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R-0h   |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 21-49. SAPHATIMLO/SAPH\_AATIMLO Register Field Descriptions**

| Bit  | Field  | Type | Reset | Description                                                                                                |
|------|--------|------|-------|------------------------------------------------------------------------------------------------------------|
| 15-0 | ATIMLO | R    | 0h    | ASQ Timer Counter low part. The reading this register returns the counter value [15:0].<br>Reset type: PUC |

### 21.8.45 SAPHATIMHI/SAPH\_AATIMHI Register (Offset = 7Eh) [reset = 0h]

SAPHATIMHI/SAPH\_AATIMHI is shown in [Figure 21-65](#) and described in [Table 21-50](#).

[Return to Summary Table.](#)

ASQ Time Counter High Part[19:16]

**Figure 21-65. SAPHATIMHI/SAPH\_AATIMHI Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| RESERVED |    |    |    |        |    |   |   |
| R-0h     |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| RESERVED |    |    |    | ATIMHI |    |   |   |
| R-0h     |    |    |    | R-0h   |    |   |   |

**Table 21-50. SAPHATIMHI /SAPH\_AATIMHI Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                  |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------|
| 15-4 | RESERVED | R    | 0h    |                                                                                                              |
| 3-0  | ATIMHI   | R    | 0h    | ASQ Timer Counter high part. The reading this register returns the counter value [19:16].<br>Reset type: PUC |

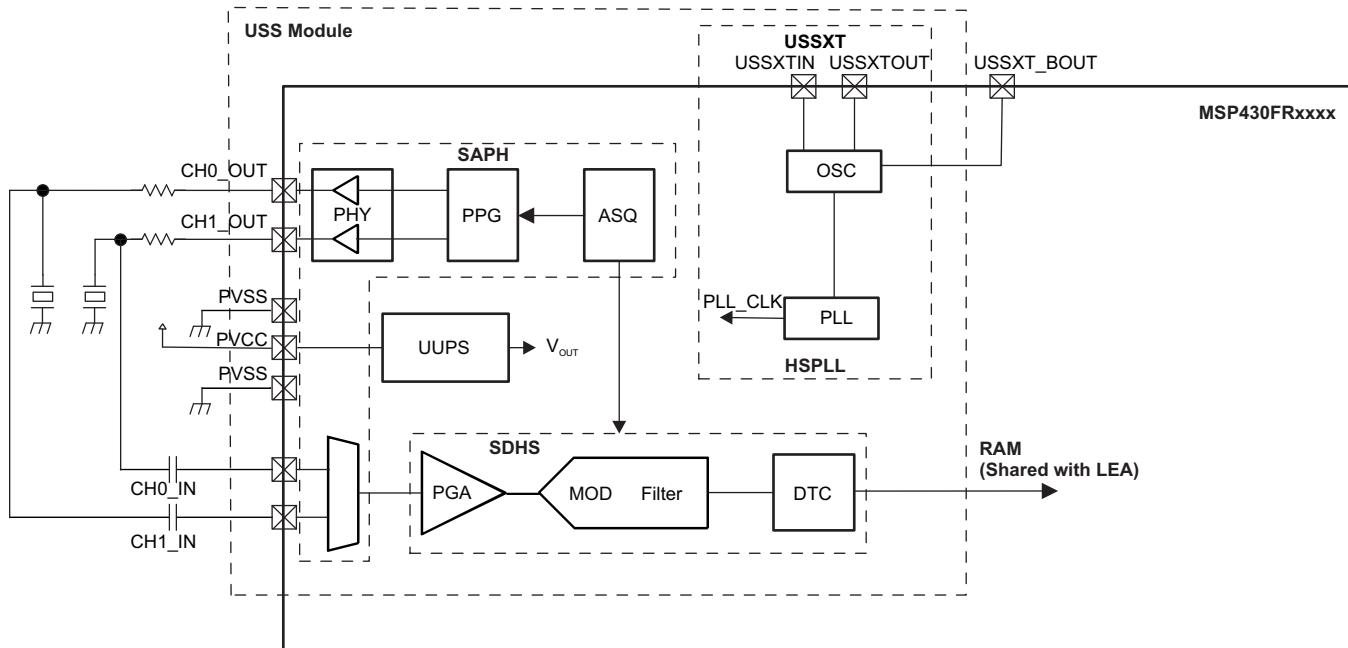
## **Sigma-Delta High Speed (SDHS)**

This chapter describes the operation of the SDHS module.

| Topic                                | Page |
|--------------------------------------|------|
| 22.1 Introduction .....              | 566  |
| 22.2 SDHS Functional Operation ..... | 566  |
| 22.3 Interrupts.....                 | 591  |
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| 22.5 SDHS Registers.....             | 592  |

## 22.1 Introduction

The Sigma-Delta High Speed (SDHS) is a high-performance high-speed 12-bit analog-to-digital converter (ADC). The SDHS is one of the submodules in the Ultrasonic Sensing Solution (USS) module. The USS module is designed for ADC-based ultrasonic sensing technology in various measurement applications. Figure 22-1 shows the block diagram of the USS module.



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**Figure 22-1. USS Block Diagram**

The SDHS module consists of three blocks: the programmable gain amplifier (PGA), the sigma-delta high speed (SDHS), and the data transfer controller (DTC) (see Figure 22-1).

- PGA block: Applies a gain to the input signal before the SDHS.
- SDHS block: ADC converts that converts the input signal to digital data at the programmed sampling rate.
- DTC block: Transfers the output data from the SDHS to the LEA RAM for data processing.

**NOTE:** Naming convention for register names and bit fields:

- SDHS registers: RegisterName or RegisterName.BitField
- Other module registers: ModuleNameRegisterName or ModuleNameRegisterName.BitField

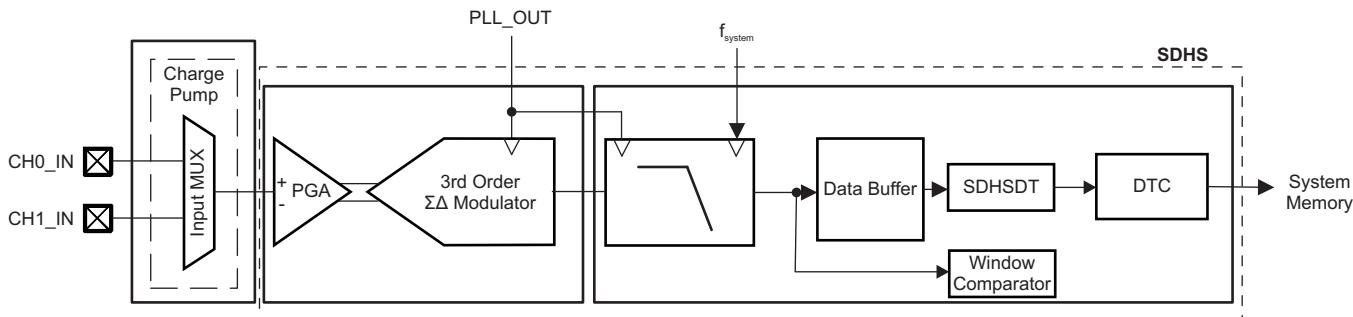
## 22.2 SDHS Functional Operation

The SDHS is a high-performance high-speed ADC that supports output data rates up to 8 Msps.

Figure 22-2 shows the SDHS block diagram. The converter consists of a third-order sigma-delta modulator and digital decimation filters. The decimation filters are CIC filters with selectable oversampling ratios of 10, 20, 40, 80, or 160.

Features of the SDHS include:

- Third-order sigma-delta architecture
- High-speed data conversion rate up to 8 Msps
- Low-pass filter with selectable oversampling ratios of 10, 20, 40, 80, or 160



**Figure 22-2. SDHS Block Diagram**

### 22.2.1 Input Multiplexer

The input multiplexer is mentioned for completeness here, but is part of the physical interface (PHY). See the PHY module (the SAPH module) for details on how to select the input channels, how bias is provided, and what other features are available on a given device.

### 22.2.2 Third-Order Modulator

The sigma-delta ADC consists of two parts: modulator and digital filter. A third-order modulator is used in SDHS. The modulator performs oversampling up to 80 MHz against the analog input signal and feeds the digital filter a pulse code modulated (PCM) data stream. The digital filter averages the bitstreams from the modulator over a given number of bits and generates output data at a reduced sampling rate, specified by the oversampling rate (OSR), for further data processing.

Averaging can be used to increase the signal-to-noise performance of a conversion (see [Figure 22-3 a and b](#)). With a conventional ADC, each factor-of-4 oversampling can improve the SNR by approximately 6 dB or 1 bit. To achieve a 16-bit resolution out of a simple 1-bit ADC would require an impractical oversampling rate of  $4^{15} = 1\,073\,741\,824$ . To overcome this limitation, the sigma-delta modulator implements a technique called noise shaping. Using a feedback loop and integrators, the quantization noise is pushed to higher frequencies and, thus, much lower oversampling rates are sufficient to achieve high resolutions (see [Figure 22-3 c](#)).

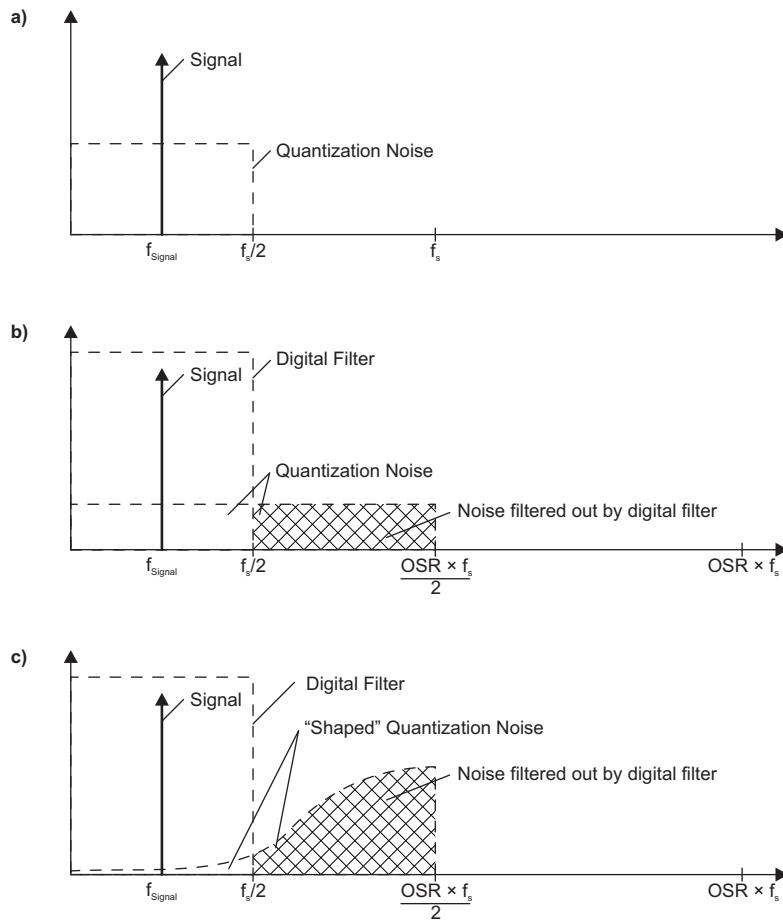


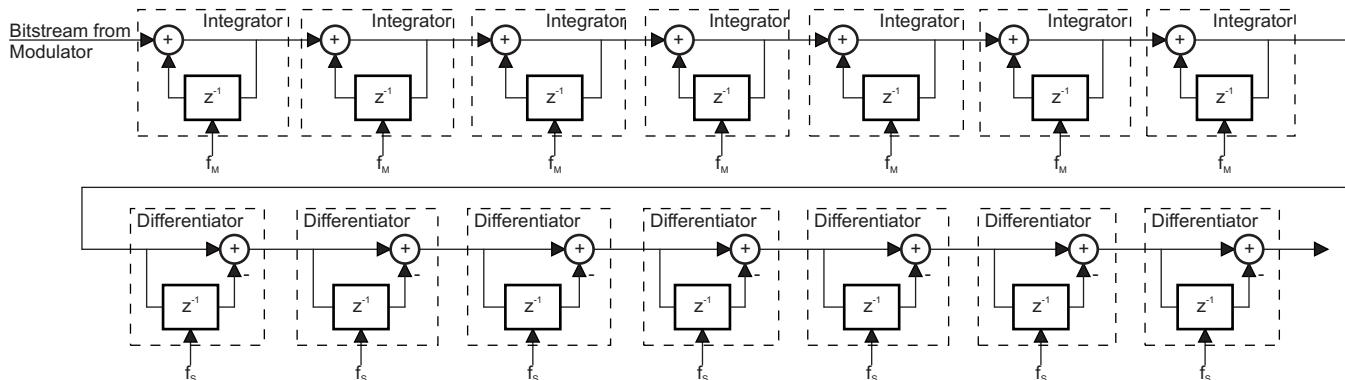
Figure 22-3. Sigma-Delta Principle

### 22.2.3 Digital Output

The SDHS digital filter processes the data stream from the modulator. The filter consists of two stages. The first stage is a 7<sup>th</sup>-order CIC filter (CIC<sup>7</sup>), which is always enabled and its decimation ratio is 10. The second-stage filter is a 1<sup>st</sup>-order CIC filter (CIC<sup>1</sup>) which is automatically enabled when the OSR ratio is greater than 10. The second-stage filter can have decimation ratio of 2, 4, 8, or 16. With an OSR ratio greater than 10, both of the CIC filters are enabled and cascaded. See [Figure 22-7](#) for details.

#### 22.2.3.1 CIC<sup>7</sup> Filter

[Figure 22-4](#) shows the structure of a CIC<sup>7</sup> filter, which is selected when SDHSCTL1.OSR = 10.



**Figure 22-4. CIC<sup>7</sup> Filter Structure**

The transfer function is described in the z-domain by [Equation 11](#).

$$H(z) = \left( \frac{1}{OSR} \times \frac{1 - z^{-OSR}}{1 - z^{-1}} \right)^7 \quad (11)$$

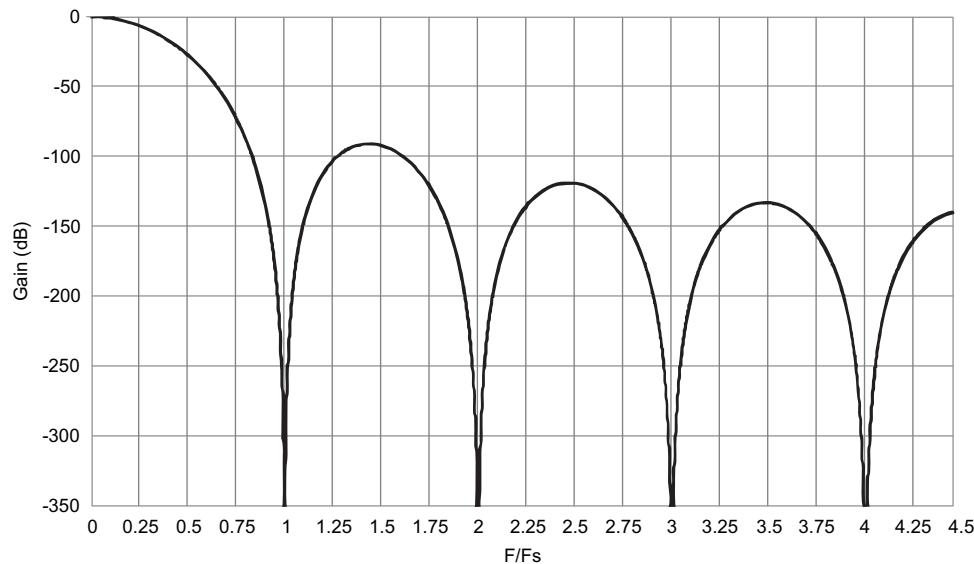
The transfer function is described in the frequency domain by [Equation 12](#).

$$H(f) = \left( \frac{\text{sinc}\left(\text{OSR}\pi\frac{f}{f_M}\right)}{\text{sinc}\left(\pi\frac{f}{f_M}\right)} \right)^7 = \left( \frac{1}{OSR} \times \frac{\sin\left(\text{OSR} \times \pi \times \frac{f}{f_M}\right)}{\sin\left(\pi \times \frac{f}{f_M}\right)} \right)^7$$

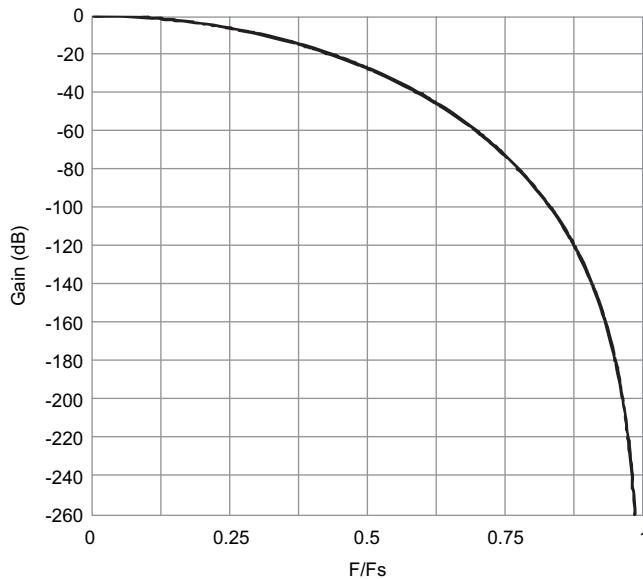
where

- OSR = The ratio of the modulator frequency  $f_M$  to the sample frequency  $f_s$
- (12)

[Figure 22-5](#) shows the filter frequency response beyond  $f_s$  (normalized), and [Figure 22-6](#) shows the filter frequency response within  $f_s$ . The first filter notch is always at  $f_s = f_M / OSR$ . The digital filter for the SDHS converter completes the decimation of the digital bit stream and outputs the new conversion result to the SDHSDT register at the sample frequency,  $f_s$ .



**Figure 22-5. SDHS Filter Frequency Response, SDHSCTL1.OSR = 10**



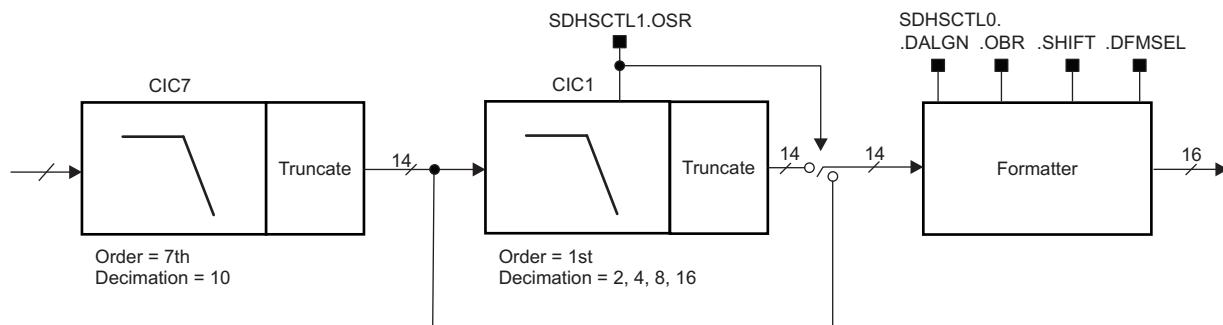
**Figure 22-6. SDHS Filter Frequency Response Within  $f_s$ , SDHSCTL1.OSR = 10**

### 22.2.3.2 CIC<sup>1</sup> Filter

The second-stage filter is a 1<sup>st</sup>-order CIC filter, which is automatically enabled when the OSR ratio is greater than 10. The second-stage filter can have decimation ratio of 2, 4, 8, or 16. By cascading the CIC<sup>7</sup> and CIC<sup>1</sup> filters, the OSR ratio can be 10, 20, 40, 80, or 160.

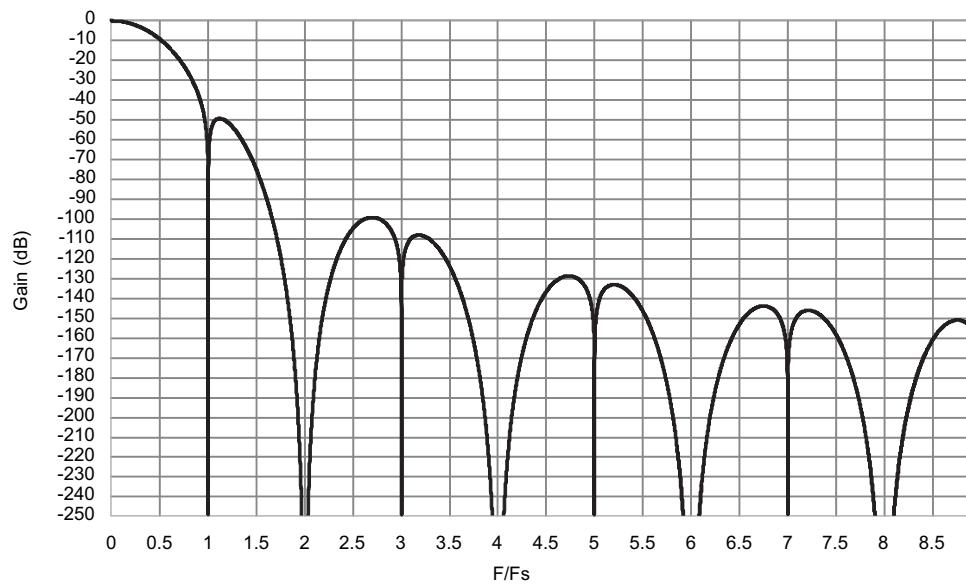
### 22.2.3.3 Digital Filter Output

Figure 22-7 shows the block diagram of the SDHS digital filter. The CIC<sup>7</sup> is a 7th-order CIC filter with decimation of 10. The CIC<sup>1</sup> is a 1<sup>st</sup>-order CIC filter with programmable decimation of 2, 4, 8, or 16. By cascading the two filters, OSR of 10, 20, 40, 80, or 160 is offered. The OSR ratio is configured by the SDHSCTL1.OSR bits. Each output of the CIC<sup>7</sup> and CIC<sup>1</sup> is truncated to 14 bits. The final output data is 16 bit, but the effective number of bits and data format are programmable through the SDHSCTL0.DALGN, SDHSCTL0.OBR, SDHSCTL0.SHIFT, and SDHSCTL0.DFMSEL bits.



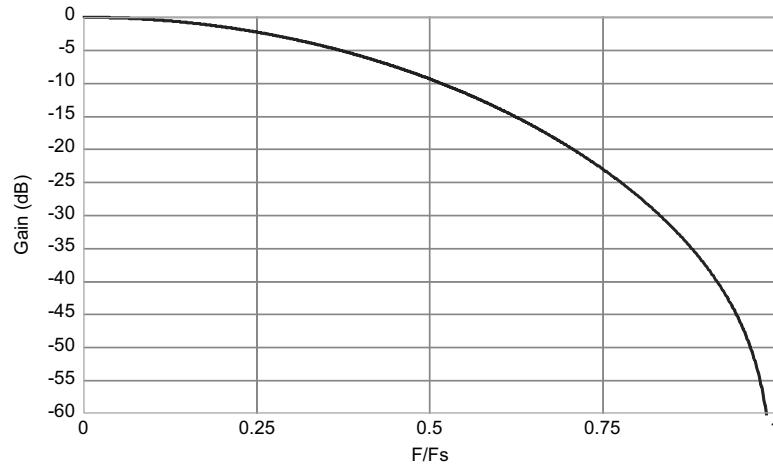
**Figure 22-7. Digital Filter Block Diagram**

The final frequency response of the SDHS digital filter is determined by SDHSCTL1.OSR bit. Figure 22-8 shows the frequency response of cascading CIC<sup>7</sup> and CIC<sup>1</sup> beyond  $f_s$  (normalized) when SDHSCTL1.OSR = 20.



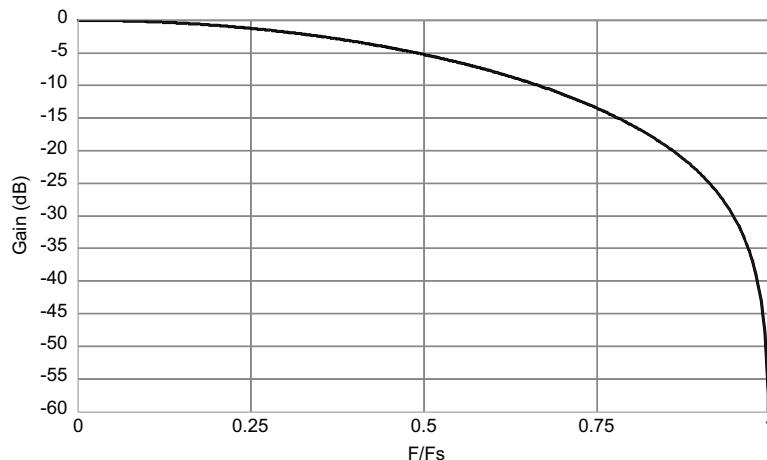
**Figure 22-8. SDHS Filter Frequency Response, SDHSCTL1.OSR = 20**

Figure 22-9 shows the frequency response of cascading CIC<sup>7</sup> and CIC<sup>1</sup> within  $f_s$  (normalized) when SDHSCTL1.OSR = 20.



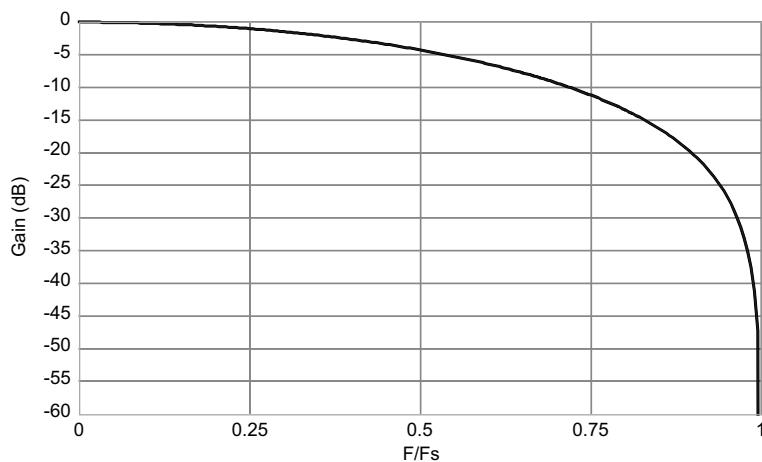
**Figure 22-9. SDHS Filter Frequency Response Within  $f_s$ , SDHSCTL1.OSR = 20**

Figure 22-10 shows the frequency response of cascading CIC<sup>7</sup> and CIC<sup>1</sup> within  $f_s$  (normalized) when SDHSCTL1.OSR = 40.



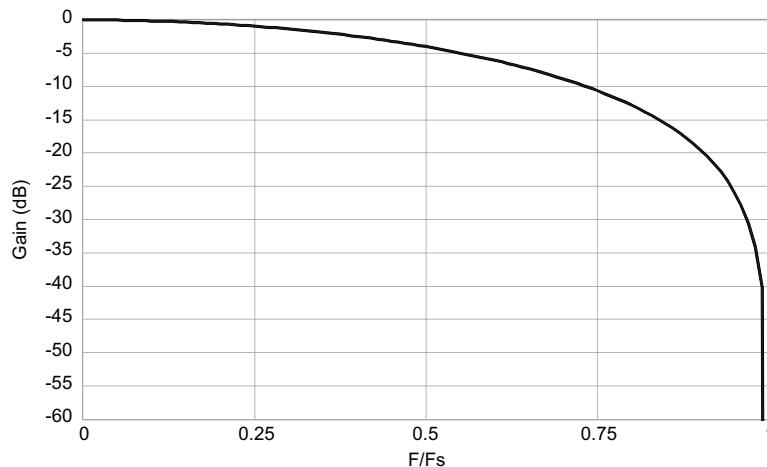
**Figure 22-10. SDHS Filter Frequency Response within  $f_s$ , SDHSCTL1.OSR = 40**

Figure 22-11 shows the frequency response of cascading CIC<sup>7</sup> and CIC<sup>1</sup> within  $f_s$  (normalized) when SDHSCTL1.OSR = 80.



**Figure 22-11. SDHS Filter Frequency Response within  $f_s$ , SDHSCTL1.OSR = 80**

Figure 22-12 shows the frequency response of cascading CIC<sup>7</sup> and CIC<sup>1</sup> within  $f_s$  (normalized) when SDHSCTL1.OSR = 160.



**Figure 22-12. SDHS Filter Frequency Response within  $f_s$ , SDHSCTL1.OSR = 160**

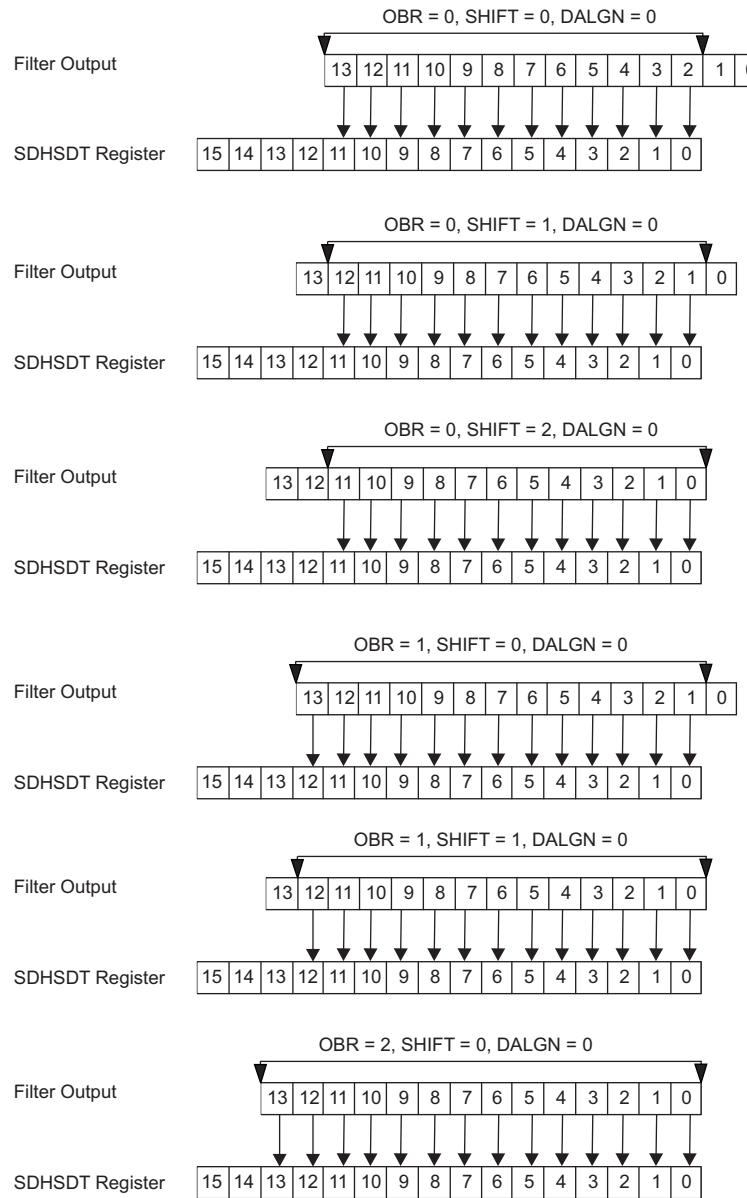
#### 22.2.3.4 Filter Output Data Formats

SDHS filter output can be configured as offset binary format (SDHSCTL0.DFMSEL = 1) or 2s complement format (SDHSCTL0.DFMSEL = 0). The output values range is between 0 to FS when offset binary format is selected, between  $-f_s/2$  and  $+f_s/2$  when 2s complement format is selected. See [Table 22-1](#) for the data range based on the configuration of SDHSCTL0.DFMSEL, SDHSCTL0.DALGN, and SDHSCTL0.OBR bits.

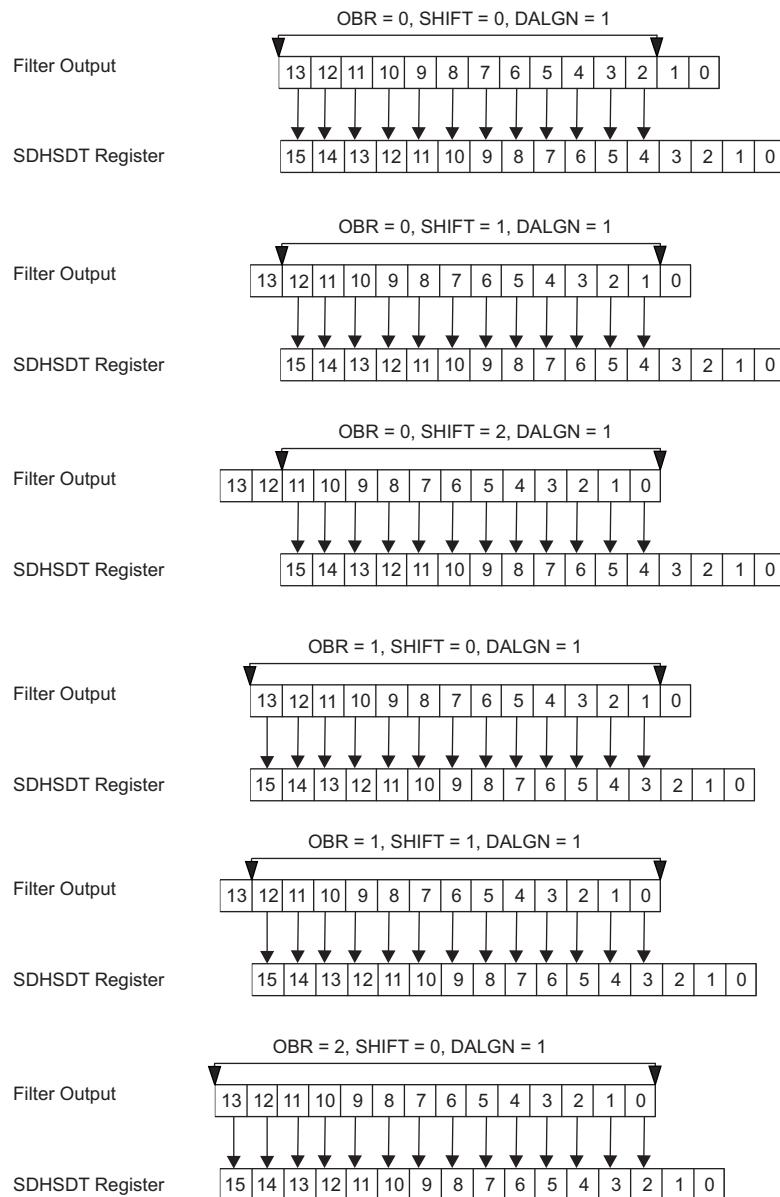
**Table 22-1. Data Format**

| Format<br>(SDHSCTL0.DF<br>MSEL Bit) | Alignment<br>(SDHSCTL0.DAL<br>GN Bit) | Analog<br>Input | Data Output<br>(SDHSCTL0.OBR = 0):<br>12 Bit | Data Output<br>(SDHSCTL0.OBR = 1):<br>13 Bit | Data Output<br>(SDHSCTL0.OBR = 2):<br>14 Bit |
|-------------------------------------|---------------------------------------|-----------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|
| 2s Complement<br>(0)                | Right Aligned (0)                     | $+f_s/2$        | 0x7FF                                        | 0xFFFF                                       | 0x1FFF                                       |
|                                     |                                       | 0               | 0                                            | 0                                            | 0                                            |
|                                     |                                       | $-f_s/2$        | 0x800                                        | 0x1000                                       | 0x2000                                       |
| Offset Binary (1)                   | Right Aligned (0)                     | $+f_s/2$        | 0xFFFF                                       | 0x1FFF                                       | 0x3FFF                                       |
|                                     |                                       | 0               | 0x800                                        | 0x1000                                       | 0x2000                                       |
|                                     |                                       | $-f_s/2$        | 0                                            | 0                                            | 0                                            |

The effective number of bits in the output data format is determined by SDHSCTL0.OBR and SDHSCTL0.SHIFT bits. [Figure 22-13](#) shows bits selection from the filter output to the SDHSCTL register with left alignment mode (SDHSCTL0.DALGN = 0). [Figure 22-14](#) shows bits selection from the filter output to the SDHSCTL register with right alignment mode (SDHSCTL0.DALGN = 1). Increasing the SDHSCTL0.SHIFT value is equivalent of multiplying the output data by 2 at every shift. Take care when using SDHSCTL0.SHIFT bits and ensure that signal overflow never happens after shifting.



**Figure 22-13. Bits Selection From Filter to the Data Register (SDHSCTL0.DALGN = 0)**



**Figure 22-14. Bits Selection From Filter to the Data Register (SDHSCTL0.DALGN = 1)**

#### 22.2.4 Data Transfer Controller (DTC) and Internal Data Buffer

The SDHS supports output data rates up to 8 Msps, which is faster than the system DMA can support, so the SDHS has a dedicated Data Transfer Controller (DTC) and an internal data buffer to support up to 8-MHz data transfer speed to the target memory.

Figure 22-14 shows the block diagram of the output data path. A conversion result from digital filter goes first to the internal data buffer. The buffer has 64-word depth. As soon as a new data is available in the buffer, the data is latched with the system clock (called synchronization to the system clock) and is written to SDHS DT register. Then the DTC reads the data from SDHS DT register and transfers to the destination memory location.

The DTC may require more than one sample period to transfer the data to system memory. Thus, the buffer depth is selected to achieve the 8-MHz data transfer speed when the system clock is equal to or higher than the SDHS output data rate. Take care when selecting SDHSCTL1.OSR bits or the system clock frequency. The system clock frequency must be equal to or greater than the SDHS output data rate, or a data overflow may occur.

- System clock frequency  $\geq$  SDHS output data rate
- SDHS output data rate = PLL output frequency / SDHSCTL1.OSR

The DTC is enabled by default but can be disabled when SDHSCTL2.DTCOFF = 1. When the DTC is disabled, the data in the SDHSDT register must be ready by CPU. If the SDHSDT register has not been read by CPU over 64 sample periods, the internal buffer becomes full and does not take any more new data. In the case, newly generated data is lost and causes the overflow interrupt (SDHSRIS.OVF).

---

**NOTE:** If data conversion is performed with SDHSCTL2.DTCOFF = 1, the data buffer may not be empty when the conversion stops. The CPU can continue to read the data until the buffer is empty. While the CPU is reading the data from the buffer after conversion is stopped, data format configurations (SDHSCTL0.DFMSEL, SDHSCTL0.DALGN, and SDHSCTL0.OBR bits) must not be changed.

---

The destination system memory is the LEA RAM, which is part of system memory. The DTC automatically recognize the base address of the LEA RAM in the target device. Only offset address needs to be configured to SDHSDTCDA register.

- Destination address = LEA RAM base address + offset address
- Offset address = SDHSDTCDA register value  $\times$  2 (for example, if SDHSDTCDA = 2, then the destination address = LEA base address + 4)

The SDHSDTCCA register value automatically increases by 1 at every data transfer, so the current target address can be monitored by reading SDHSDTCDA register. The maximum offset address is 64KB. The SDHSDTCDA register value resets when the offset address reaches the 64KB limit and starts from zero again.

---

**NOTE:** The DTC block supports up to 64KB of memory size; however, the available memory (LEA RAM) could be smaller than 64KB (see the device-specific data sheet). If the SDHSDTCDA register goes beyond the available memory space, data transferred to the outside of the available memory is lost. In this case, the DTC block does not overwrite data in other memory areas, because it accesses only the LEA RAM.

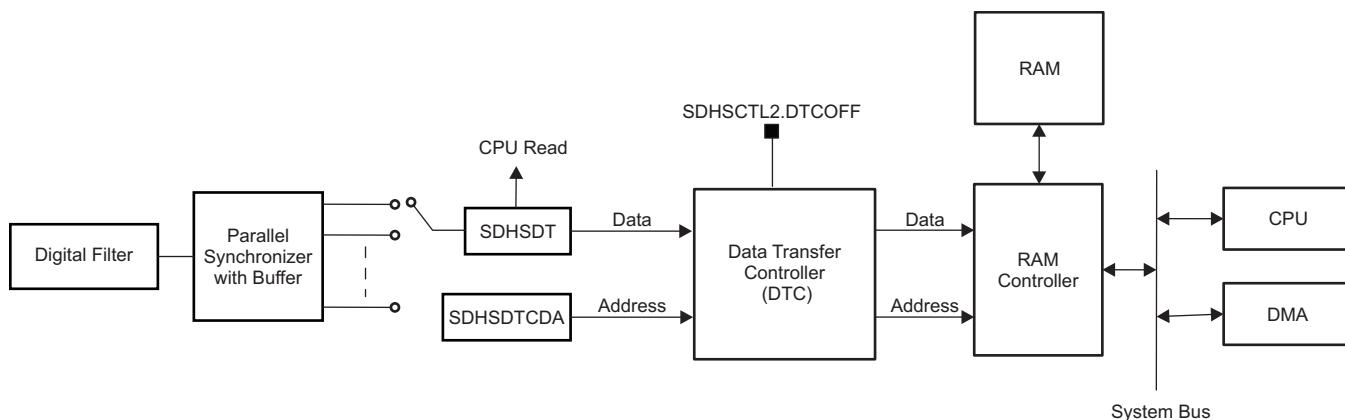
Take care not to go beyond the available memory address range. The DTC cannot detect if the offset address goes beyond the available LEA RAM. TI recommends using SDHSCTL2.SMPSZ[9:0], which controls the total number of samples.

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**NOTE:** While the DTC is transferring data to the destination memory, the memory is blocked from being accessed by CPU or DMA. If the CPU or DMA attempts to access the same memory, 0xFFFF is returned and an NMI is generated (DACCESSIFG).

---



**Figure 22-15. Data Output Path**

### 22.2.5 PGA Gain Control

The programmable gain amplifier (PGA) allows adjusting the input signal amplitude to satisfy the input range of the SDHS modulator. The input gain can be adjusted by SDHSCTL6.PGA\_GAIN[5:0]. See [Table 22-2](#) for the PGA gain table.

**Table 22-2. PGA Gain Table**

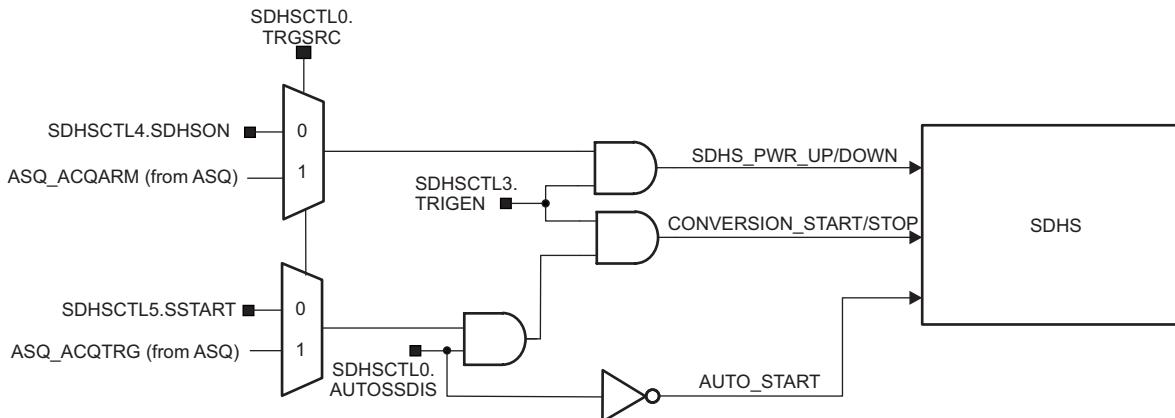
| SDHSCTL6.PGA_GAIN[5:0] Bits | PGA Gain (Typical) (dB) | Tolerance  | Shift (Entire Table) |
|-----------------------------|-------------------------|------------|----------------------|
| 00xxxxb                     | -6.5                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010000b                     | -6.5                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010001b                     | -6.5                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010010b                     | -5.5                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010011b                     | -4.6                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010100b                     | -4.1                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010101b                     | -3.3                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010110b                     | -2.3                    | $\pm 1$ dB | $\pm 1$ dB           |
| 010111b                     | -1.4                    | $\pm 1$ dB | $\pm 1$ dB           |
| 011000b                     | -0.8                    | $\pm 1$ dB | $\pm 1$ dB           |
| 011001b                     | 0.1                     | $\pm 1$ dB | $\pm 1$ dB           |
| 011010b                     | 1.0                     | $\pm 1$ dB | $\pm 1$ dB           |
| 011011b                     | 1.9                     | $\pm 1$ dB | $\pm 1$ dB           |
| 011100b                     | 2.6                     | $\pm 1$ dB | $\pm 1$ dB           |
| 011101b                     | 3.5                     | $\pm 1$ dB | $\pm 1$ dB           |
| 011110b                     | 4.4                     | $\pm 1$ dB | $\pm 1$ dB           |
| 011111b                     | 5.2                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100000b                     | 6.0                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100001b                     | 6.8                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100010b                     | 7.7                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100011b                     | 8.7                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100100b                     | 9.0                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100101b                     | 9.8                     | $\pm 1$ dB | $\pm 1$ dB           |
| 100110b                     | 10.7                    | $\pm 1$ dB | $\pm 1$ dB           |
| 100111b                     | 11.7                    | $\pm 1$ dB | $\pm 1$ dB           |
| 101000b                     | 12.2                    | $\pm 1$ dB | $\pm 1$ dB           |

Table 22-2. PGA Gain Table (continued)

| SDHSCTL6.PGA_GAI<br>N[5:0] Bits | PGA Gain<br>(Typical)<br>(dB) | Tolerance | Shift (Entire<br>Table) |
|---------------------------------|-------------------------------|-----------|-------------------------|
| 101001b                         | 13.0                          | ±1 dB     | ±1 dB                   |
| 101010b                         | 13.9                          | ±1 dB     | ±1 dB                   |
| 101011b                         | 14.9                          | ±1 dB     | ±1 dB                   |
| 101100b                         | 15.5                          | ±1 dB     | ±1 dB                   |
| 101101b                         | 16.3                          | ±1 dB     | ±1 dB                   |
| 101110b                         | 17.2                          | ±1 dB     | ±1 dB                   |
| 101111b                         | 18.2                          | ±1 dB     | ±1 dB                   |
| 110000b                         | 18.8                          | ±1 dB     | ±1 dB                   |
| 110001b                         | 19.6                          | ±1 dB     | ±1 dB                   |
| 110010b                         | 20.5                          | ±1 dB     | ±1 dB                   |
| 110011b                         | 21.5                          | ±1 dB     | ±1 dB                   |
| 110100b                         | 22.0                          | ±1 dB     | ±1 dB                   |
| 110101b                         | 22.8                          | ±1 dB     | ±1 dB                   |
| 110110b                         | 23.6                          | ±1 dB     | ±1 dB                   |
| 110111b                         | 24.6                          | ±1 dB     | ±1 dB                   |
| 111000b                         | 25.0                          | ±1 dB     | ±1 dB                   |
| 111001b                         | 25.8                          | ±1 dB     | ±1 dB                   |
| 111010b                         | 26.7                          | ±1 dB     | ±1 dB                   |
| 111011b                         | 27.7                          | ±1 dB     | ±1 dB                   |
| 111100b                         | 28.1                          | ±1 dB     | ±1 dB                   |
| 111101b                         | 28.9                          | ±1 dB     | ±1 dB                   |
| 111110b                         | 29.8                          | ±1 dB     | ±1 dB                   |
| 111111b                         | 30.8                          | ±1 dB     | ±1 dB                   |

## 22.2.6 SDHS Power and Conversion Control

The SDHS has two trigger sources for power and conversion. Figure 22-16 shows the connections of the power and conversion trigger signals to the SDHS. Table 22-3 lists the use cases of the trigger signals.



**Figure 22-16. SDHS Power and Conversion Trigger Source**

**Table 22-3. Control Signals for Power and Conversion**

| SDHSCTL3.TRI<br>GEN | SDHSCTL0.TRG<br>SRC | SDHSCTL0.AUT<br>OSSDIS | Trigger Signal                      |                                     |                                          |                                        |
|---------------------|---------------------|------------------------|-------------------------------------|-------------------------------------|------------------------------------------|----------------------------------------|
|                     |                     |                        | Power Up                            | Power Down                          | Conversion<br>Start                      | Conversion<br>Stop                     |
| 1                   | 0                   | 0                      | SDHSCTL4.SDH<br>SON = 0 → 1         | SDHSCTL4.SDH<br>SON = 1 → 0         | Start<br>automatically<br>after power up | See<br><a href="#">Section 22.2.12</a> |
| 1                   | 0                   | 1                      | SDHSCTL4.SDH<br>SON = 0 → 1         | SDHSCTL4.SDH<br>SON = 1 → 0         | SDHSCTL5.SST<br>ART = 0 → 1              | See<br><a href="#">Section 22.2.12</a> |
| 1                   | 1                   | 0                      | Not supported                       | Not supported                       | Not supported                            | Not supported                          |
| 1                   | 1                   | 1                      | ASQ_ACQARM<br>= 0 → 1 (from<br>ASQ) | ASQ_ACQARM<br>= 1 → 0 (from<br>ASQ) | ASQ_ACQTRIG<br>= 0 → 1 (from<br>ASQ)     | See<br><a href="#">Section 22.2.12</a> |
| 0                   | x                   | x                      | Not supported                       | Not supported                       | Not supported                            | Not supported                          |

### 22.2.6.1 SDHS in Auto Mode and Register Mode

The SDHS is one of the submodules in the USS module. The USS module is designed for ADC-based ultrasonic sensing technology in various measurement applications. The USS module has its own power module (see [USS](#)) to provide the required voltages to the USS submodules including the SDHS. The USS module supports two control modes, register mode and auto mode. In the register mode, the SDHS is controlled by its own registers. In the auto mode, the SDHS is controlled by the ASQ. See [SAPH](#) and [USS](#) for details.

**Table 22-4. USS Auto Mode and Register Mode**

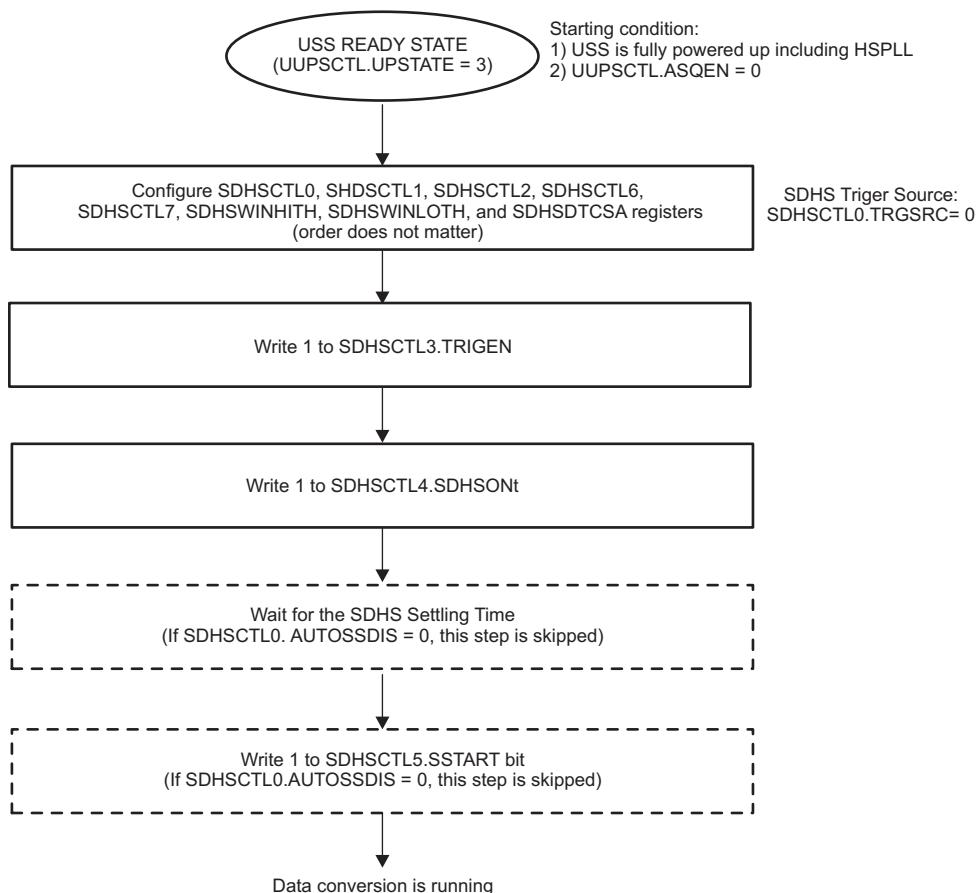
| USS Control Mode | Configuration for SDHS | Control by: SDHS Power up | Control by: SDHS<br>Conversion Start |
|------------------|------------------------|---------------------------|--------------------------------------|
| Register         | SDHSCTL0.TRGSRC = 0    | SDHSCTL4.SDHSON           | SDHSCTL5.SSTART                      |
| Auto             | SDHSCTL0.TRGSRC = 1    | ASQ (ASQ_ACQARM signal)   | ASQ (ASQ_ACQTRIG signal)             |

### 22.2.6.1.1 SDHS Configuration in Register Mode

In register mode (SDHSCTL0.TRGSRC = 0), the SDHS can be used as an stand-alone ADC converter. See the following sequence for the correct SDHS configuration:

1. Turn on the USS module and wait for UUPSCtrl.UPSTATE = 3.
2. Configure all registers except the SDHSCTL3, SDHSCTL4, and SDHSCTL5 registers (no specific order is required, SDHSCTL0.TRGSRC = 0).
3. Enable trigger sources: Set SDHSCTL3.TRIGEN = 1.
4. Power up the SDHS: Set SDHSCTL4.SDHSON = 1 (If SDHSCTL0.AUTOSSDIS = 1, then the remaining steps are not required).
5. Wait for the SDHS settling time (see [SDHS](#)).
6. Start conversion: Set SDHSCTL5.SSTART = 1.

[Figure 22-17](#) shows this configuration sequence.



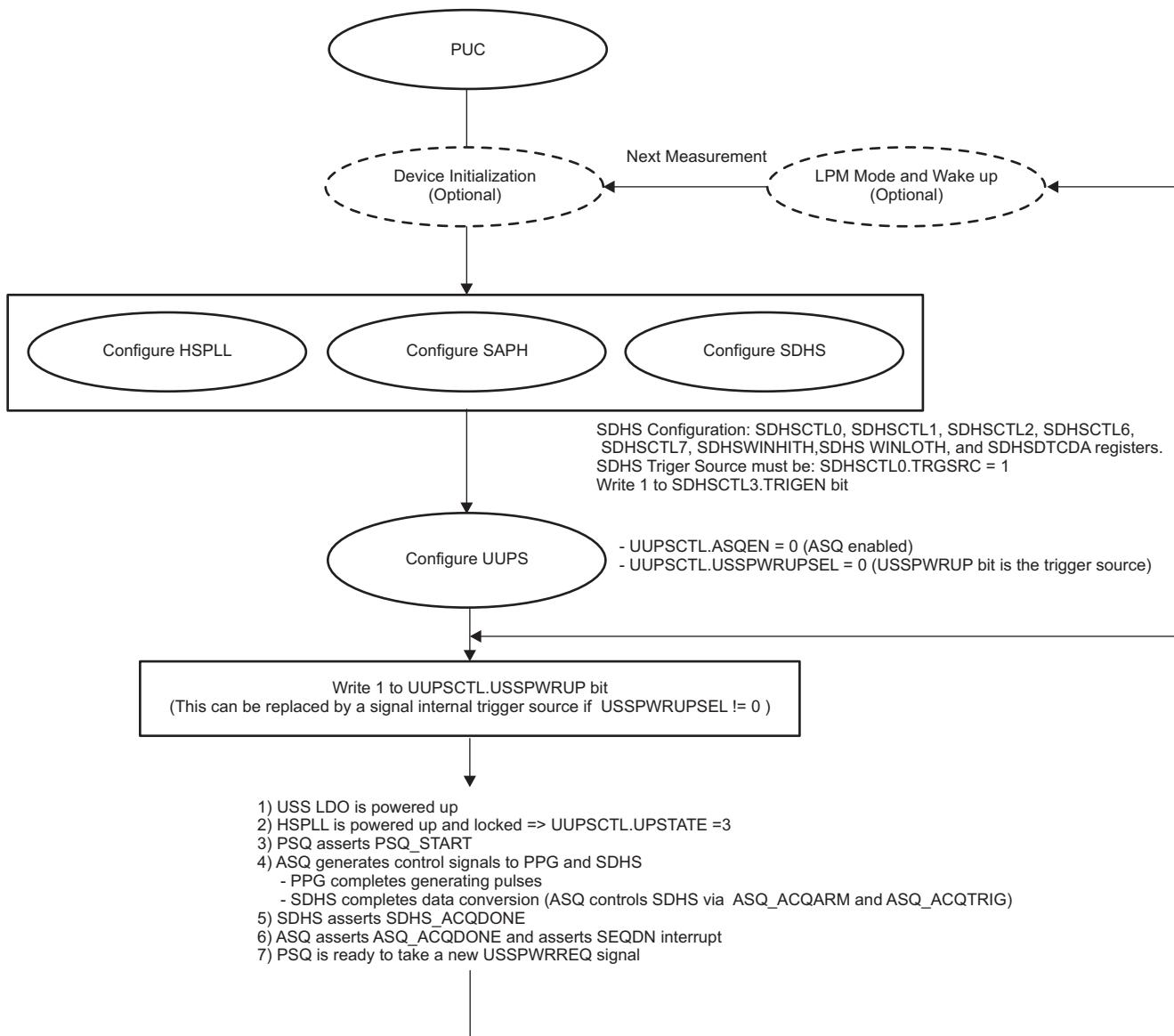
**Figure 22-17. SDHS Operation in Register Mode (SDHSCTL0.TRGSRC = 0)**

### 22.2.6.1.2 SDHS Configuration in Auto Mode

In auto mode (SDHSCTL0.TRGSRC = 1), the SDHS is fully controlled by the ASQ. See the following sequence for the correct SDHS configuration:

1. Configure all registers except SDHSCTL3, SDHSCTL4, and SDHSCTL5 (no specific order is required, SDHSCTL0.TRGSRC = 1).
2. Enable trigger sources: Set SDHSCTL3.TRIGEN = 1.
3. Turn on the USS module.

[Figure 22-18](#) shows an example of USS measurement in auto mode (see [USS](#) for details).



**Figure 22-18. SDHS Operation as Part of USS Measurement (SDHSCTL0.TRGSRC = 1)**

### 22.2.7 TRIGEN Bit and SDHS\_LOCK Bit

SDHSCTL3.TRIGEN has two functional roles:

- The first role is to enable the SDHS to receive the power trigger and conversion trigger signals (see [Figure 22-16](#)). SDHSCTL3.TRIGEN must be set to 1 before applying the trigger signals to the SDHS.
- The second role is to lock the SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSDTCD registers.

When SDHSCTL3.TRIGEN = 1, those registers cannot be modified. Thus, SDHSCTL3.TRIGEN must be set to 1 after updating the SDHS registers (except SDHSCTL3, SDHSCTL4, and SDHSCTL5) and before powering up the SDHS. See [Section 22.2.6.1.1](#) for an example of the SDHS register configuration sequence. SDHSCTL3.TRIGEN can be used as the power-up trigger signal (see [Figure 22-19](#) and [Figure 22-19](#)). However, this is not recommended when SDHSCTL0.AUTOSSDIS = 1, because the SDHS may not be fully settled before data conversion starts.

After the SDHS is triggered for power up, SDHSCTL5.SDHS\_LOCK is automatically set to 1. When SDHSCTL5.SDHS\_LOCK = 1, the SDHSCTL3 register is locked. Both SDHSCTL3.TRIGEN and SDHS\_LOCK protect the SDHS registers from inadvertent modifications while the SDHS is active. The PGA gain registers (SDHSCTL6) are not locked even after SDHS is powered up; however, take care when updating the PGA gain while SDHS is performing data conversion. Expect a transition period before the new gain is applied (see the device-specific data sheet for the PGA gain settling time).

**Table 22-5. SDHSCTL3.TRIGEN Bit and SDHSCTL5.SDHS\_LOCK Bit**

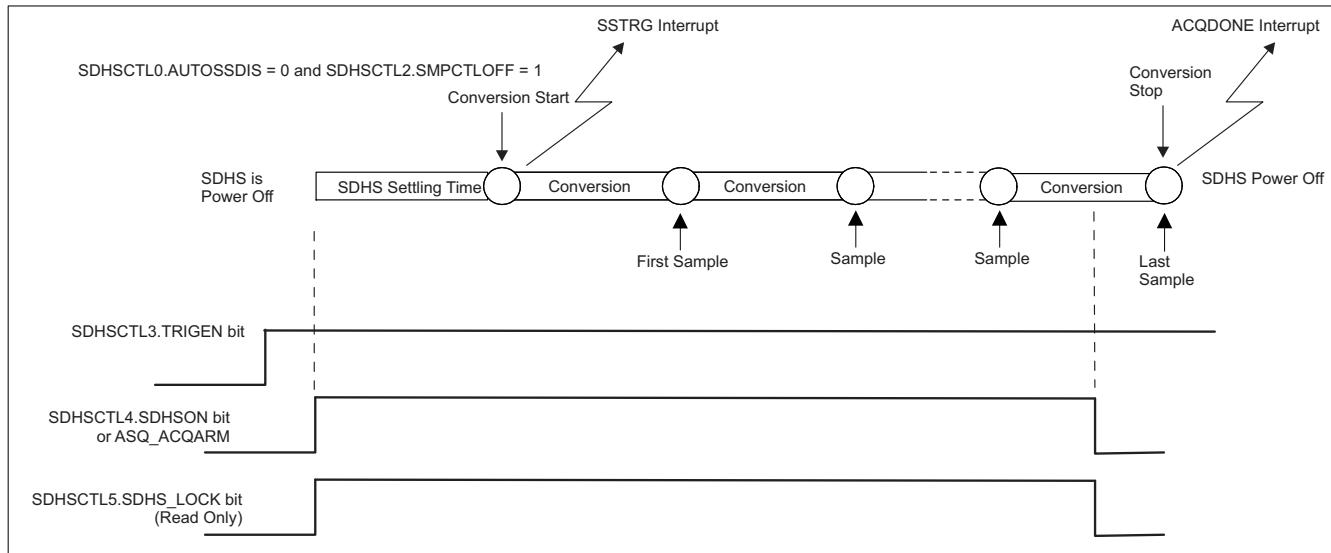
| Control Bit        | Type       | How to Set the Control Bit     | Registers Locked                                                               |
|--------------------|------------|--------------------------------|--------------------------------------------------------------------------------|
| SDHSCTL3.TRIGEN    | Read/Write | Write 1 to SDHSCTL3.TRIGEN bit | SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSDTCD |
| SDHSCTL5.SDHS_LOCK | Read Only  | When SDHS_PWR_UP is asserted   | SDHSCTL3                                                                       |

**Table 22-6. Timing of the SDHS\_LOCK bit**

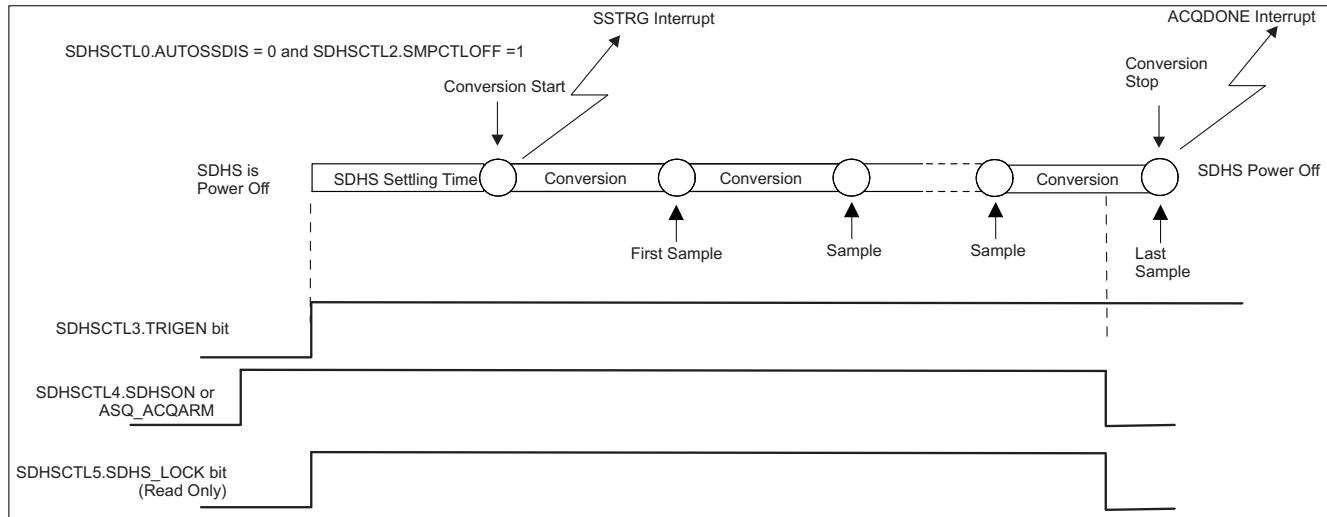
| Type                                        | SDHSCTL0.TRGSRC = 0               | SDHSCTL0.TRGSRC = 1                                           |
|---------------------------------------------|-----------------------------------|---------------------------------------------------------------|
| SDHS power trigger                          | SDHSCTL4.SDHSON = 1 (by software) | ASQ_ACQARM = 1 (from ASQ)                                     |
| Time to set SDHS_LOCK bit after the trigger | No delay                          | Delay = 4 × system clock period + 4 × (PLL clock period × 10) |

To update the SDHS registers, the SDHS must be powered off first, then write 0 to SDHSCTL3.TRIGEN. When the SDHS is powered off, SDHSCTL5.SDHS\_LOCK is automatically cleared to 0.

SDHS power up is synchronized to the trigger source

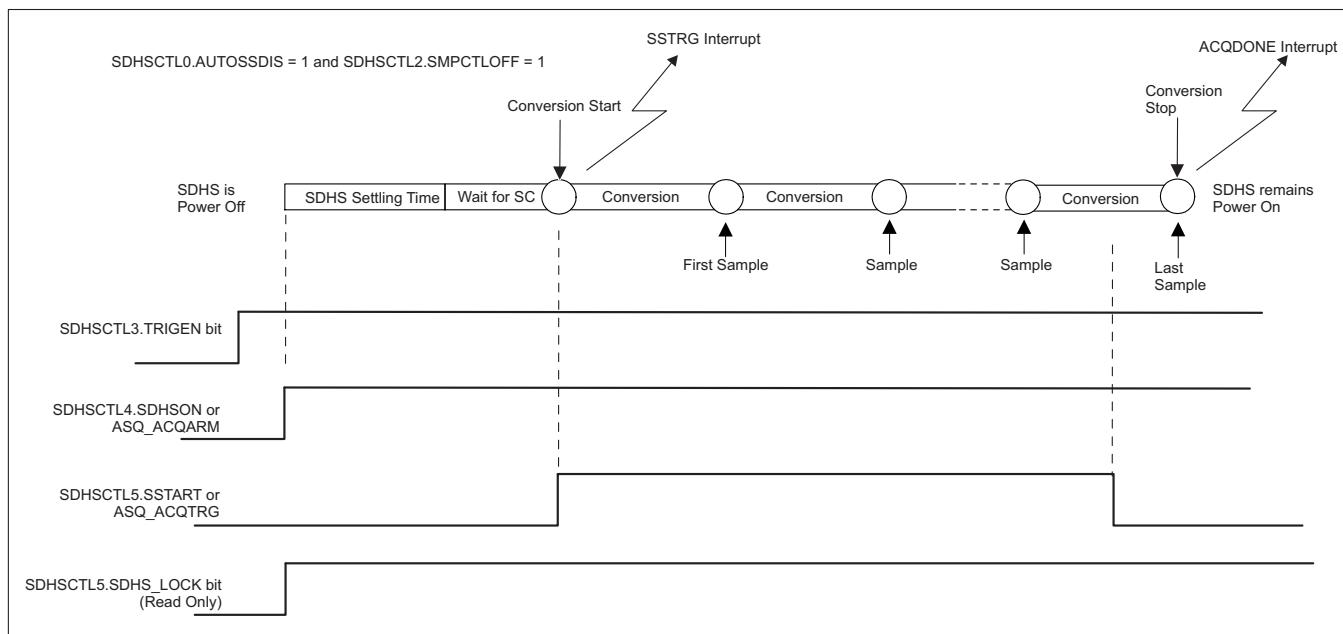


SDHS power up is synchronized to SDHSCTL3.TRIGEN bit

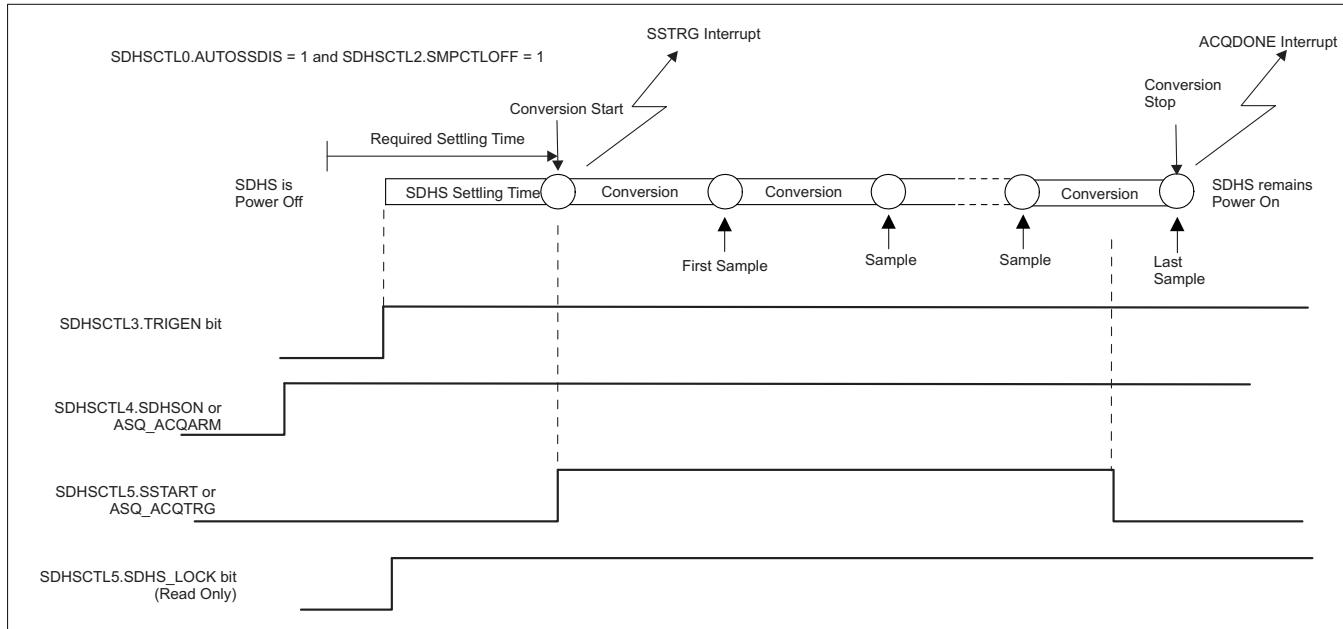


**Figure 22-19. Example Using SDHSCTL3.TRIGEN Bit (SDHSCTL0.AUTOSSDIS = 0)**

SDHS power up is synchronized to the trigger source



SDHS power up is synchronized to SDHSCtrl3.TRIGEN bit (not recommended)



**Figure 22-20. Example Using SDHSCtrl3.TRIGEN bit (SDHSCtrl0.AUTOSSDIS = 1)**

**NOTE:** In the following sections, it is assumed that SDHSCtrl3.TRIGEN is set to 1 before powering up the SDHS.

### 22.2.8 AUTOSSDIS (Auto Conversion Start Disable) Bit

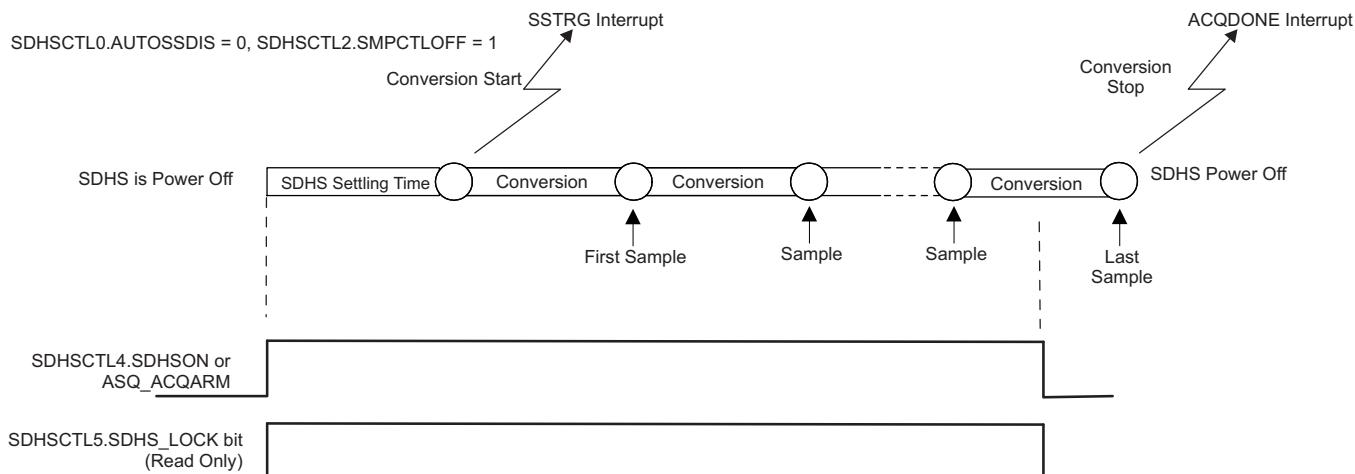
The SDHS supports two different ways to start data conversion after power up (see [Table 22-7](#)).

**Table 22-7. Conversion Control Mode**

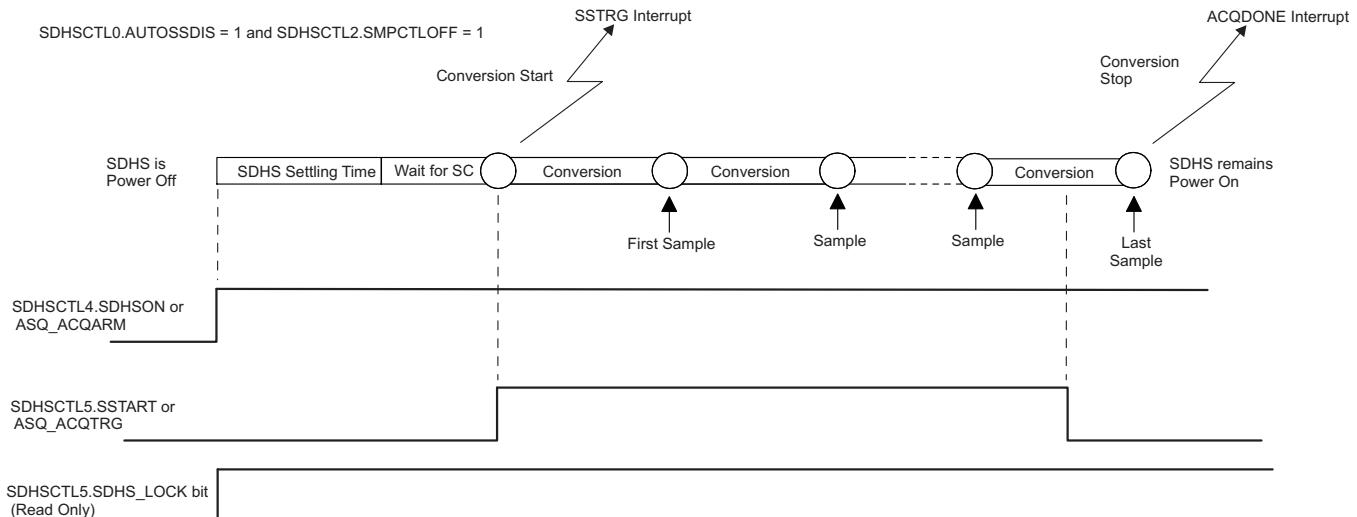
| Mode                            | Control | Power up SDHS             |                           | Conversion Start          |                           | Operation                                                                                                                                       |
|---------------------------------|---------|---------------------------|---------------------------|---------------------------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
|                                 |         | When SDHSCTL0.TR GSRC = 0 | When SDHSCTL0.TR GSRC = 1 | When SDHSCTL0.TR GSRC = 0 | When SDHSCTL0.TR GSRC = 1 |                                                                                                                                                 |
| Auto conversion start: disabled | 1       | SDHSCTL4.SDHSON = 1       | ASQ_ACQARM = 1 (from ASQ) | SDHSCTL5.SDHSLOCK = 1     | ASQ_ACQTRG = 1 (from ASQ) | Power up and conversion start are controlled separately. The SDHS settling time must be satisfied before asserting the conversion start signal. |
| Auto conversion start: enabled  | 0       | SDHSCTL4.SDHSON = 1       | ASQ_ACQARM = 1 (from ASQ) | Not Required              | Not Required              | Data conversion automatically begins after power up. The SDHS settling time is automatically applied.                                           |

When SDHSCTL0.AUTOSSDIS = 0, automatic conversion start is enabled. Conversion automatically starts after the SDHS is powered on. During power up, the SDHS settling time is monitored and when the SDHS is settled, conversion automatically begins. See [Figure 22-21](#) for the sequence of conversion start and stop in this mode.

When SDHSCTL0.AUTOSSDIS = 1, auto conversion start is disabled (default after reset). In this mode, power control and conversion control are separate (see [Figure 22-22](#)). This mode can be used when data conversion start time needs to be precisely controlled. It is important that the SDHS settling time must be satisfied before data conversion start signal is applied. If the data conversion start trigger signal is applied during the settling time, the SDHS data conversion is automatically delayed until the settling time has passed. SDHS settling time is the greater of the PGA settling time and SDHS modulator settling time. See the device-specific data sheet for the settling times.



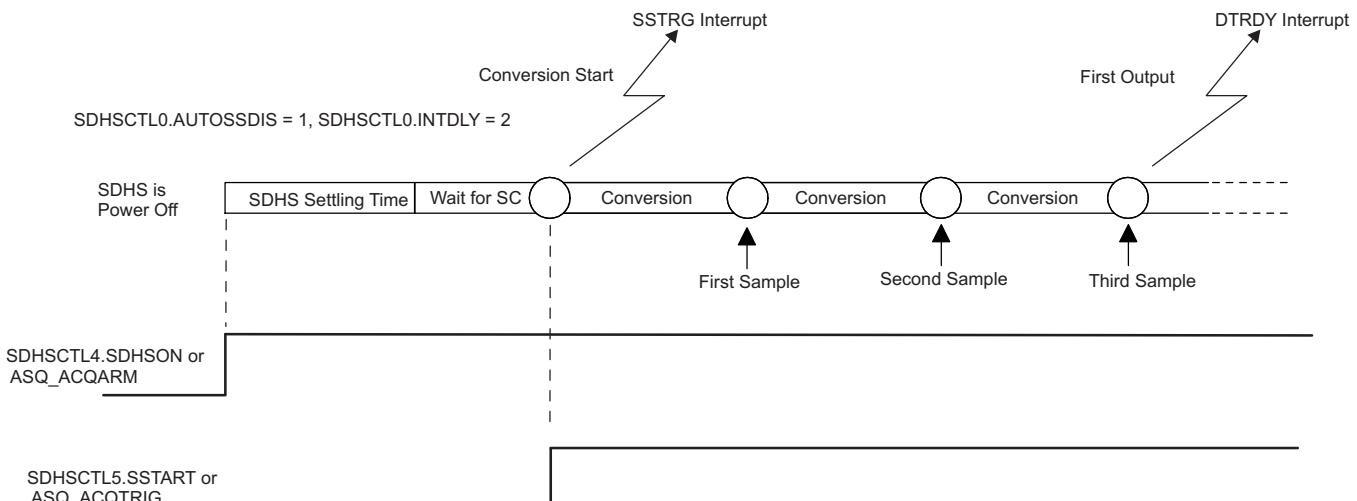
**Figure 22-21. Conversion Start and Stop When SDHSCTL0.AUTOSSDIS = 0**



**Figure 22-22. Conversion Start and Stop When SDHSCTL0.AUTOSSDIS = 1**

### 22.2.9 INTDLY (Interrupt Delay) bits

After conversion start, the position of the first output data to the internal data buffer and the first SDHSRIS.DTRDY interrupt can be adjusted by the SDHSCTL0.INTDLY delay. Any skipped data is permanently lost. The delay is applied each time conversion starts. The SDHSRIS.OVF (overflow) interrupt is not enabled for the selected number of delay samples. Figure 22-23 shows the first interrupt position when SDHSCTL0.INTDLY = 2. The window comparator feature is not applied to the skipped samples (see [Section 22.2.11](#) for the window comparator).



**Figure 22-23. First Interrupt Position With SDHSCTL0.INTDLY = 2**

By the nature of sigma-delta ADC converters, if a steep and abrupt input level change (like a step function) is applied, a few samples are needed before the full input level is reached at the output. The INTDLY can be used if the unsettled output data should be skipped. This skipping is not required for most applications. See [Table 22-8](#) for the output data settling time.

**Table 22-8. Conversion Control Mode**

| Input Change          | SDHSCTL1.OSR Bit | Fully Settled Output Sample From the Time a Step Function is Applied | SDHSCTL0.INTDLY Value |
|-----------------------|------------------|----------------------------------------------------------------------|-----------------------|
| Synchronous to $f_s$  | 10               | 5th sample                                                           | $\leq 4$              |
|                       | 20               | 3th sample                                                           | $\leq 2$              |
|                       | 40               | 2th sample                                                           | $\leq 1$              |
|                       | 80               | 1st sample                                                           | 0                     |
|                       | 160              | 1st sample                                                           | 0                     |
| Asynchronous to $f_s$ | 10               | 6th sample                                                           | $\leq 5$              |
|                       | 20               | 4th sample                                                           | $\leq 3$              |
|                       | 40               | 3rd sample                                                           | $\leq 2$              |
|                       | 80               | 2nd sample                                                           | $\leq 1$              |
|                       | 160              | 2nd sample                                                           | $\leq 1$              |

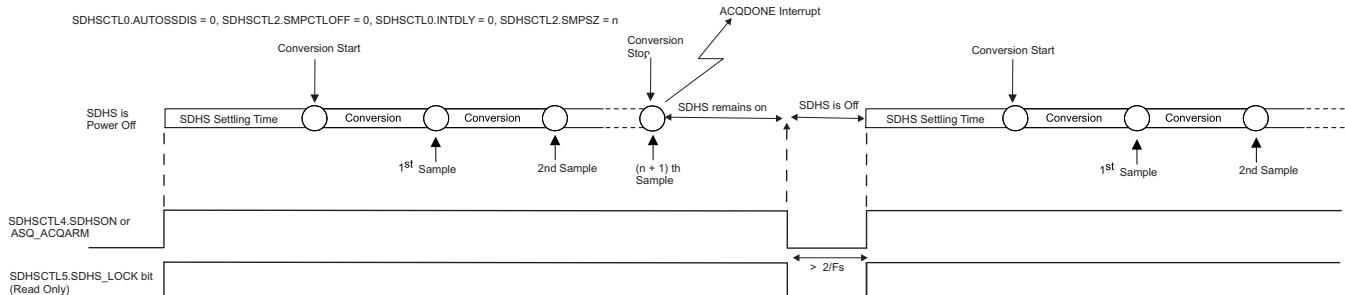
### 22.2.10 Total Sample Size

The total number of samples that the SDHS generates can be predefined by SDHSCTL2.SMPSZ when SDHSCTL2.SMPCTLOFF = 0. The value written to SDHSCTL2.SMPSZ includes the samples skipped by SDHSCTL0.INTDLY:

- Total number of samples SDHS generates = SMPSZ + 1 (when SDHSCTL2.SMPCTLOFF = 0)
- The number of samples that can be read or transferred = SMPSZ – INTDLY + 1 (when SDHSCTL2.SMPCTLOFF = 0)

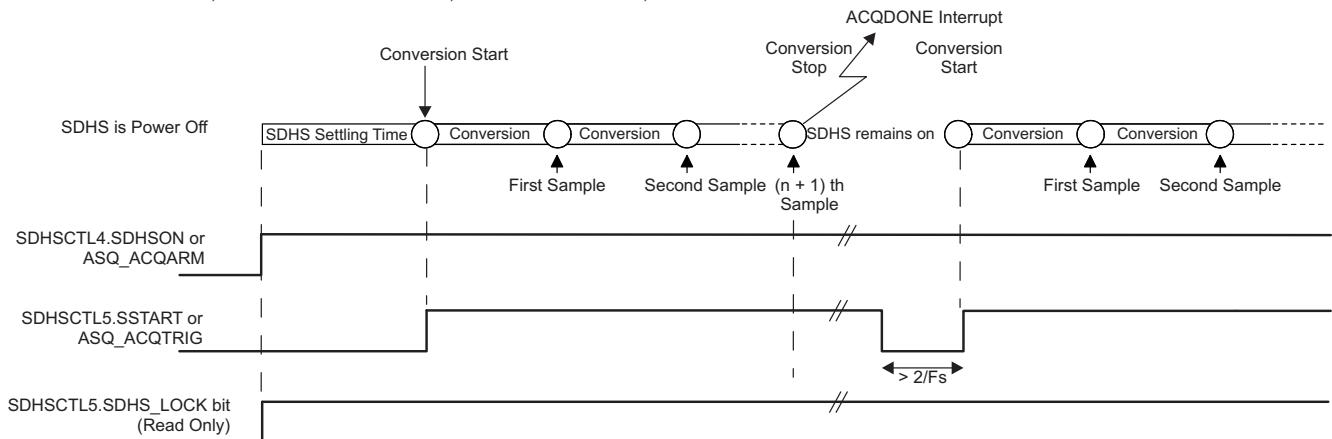
When SDHSCTL2.SMPCTLOFF = 0, the SDHS automatically stops data conversion after completing the number of samples configured in SDHSCTL2.SMPSZ. The SDHSCTL2.SMPSZ bit is ignored when SDHSCTL2.SMPCTLOFF = 1. In this case, the SDHS continues conversion until it is stopped by the trigger source. Take care when writing a value to SDHSCTL2.SMPSZ. If SDHSCTL2.SMPSZ – SDHSCTL0.INTDLY + 1  $\leq 0$ , no output data is generated. For example:

If SDHSCTL2.SMPSZ = 10 and SDHSCTL0.INTDLY = 2, then the number of available samples would be  $10 - 2 + 1 = 9$ .

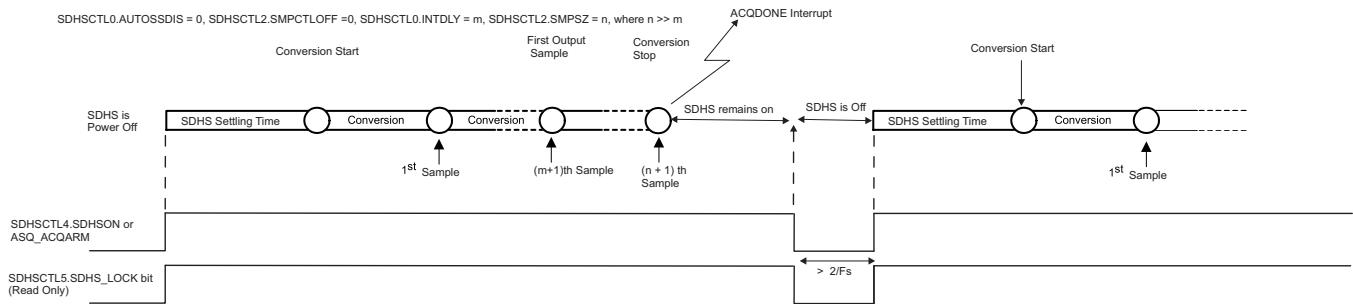


**Figure 22-24. SDHSCTL0.AUTOSSDIS = 0, SDHSCTL2.SMPCTLOFF = 0, SDHSCTL0.INTDLY = 0, Total Sample Size is Controlled by SDHSCTL2.SMPSZ**

SDHSCTL0.AUTOSSDIS = 1, SDHSCTL2.SMPCTLOFF = 0, SDHSCTL0.INTDLY = 0, SDHSCTL2.SMPSZ = n:



**Figure 22-25. SDHSCTL0.AUTOSSDIS = 1, SDHSCTL2.SMPCTLOFF = 0, SDHSCTL0.INTDLY = 0, Total Sample Size is Controlled by SDHSCTL2.SMPSZ**



**Figure 22-26. SDHSCTL0.AUTOSSDIS = 1, SDHSCTL2.SMPCTLOFF = 0, SDHSCTL0.INTDLY = m, Total Sample Size is Controlled by SDHSCTL2.SMPSZ**

When data conversion has stopped or SDHS has been powered down, 2 sample periods must pass before starting a new data conversion or turning SDHS on (see [Figure 22-24](#) and [Figure 22-25](#)).

- SDHS output sampling period = SDHSCTL1.OSR / PLL output clock frequency (= SDHS modulator sampling frequency).
- SDHS output sampling frequency = PLL output clock frequency (= SDHS modulator sampling frequency) / SDHSCTL1.OSR.

### 22.2.11 Window Comparator

The window comparator can monitor data range without CPU interventions. The window comparator is enabled by the SDHSCTL2.WINDMPEN bit. The comparator compares the latest conversion result against the value in the SDHWINHITH register and the SDHWINLOTH register, then asserts SDHSRIS.WINHI (window high interrupt flag) if the conversion result is higher than the value in SDHWINHITH register, or asserts SDHSRIS.WINLO (window low interrupt flag) if the conversion result is lower than the value in SDHWINLOTH register. The window comparison is always performed with the latest output data before it goes to the internal buffer (see [Section 22.2.4](#) for details about the internal buffer). The window comparison is functional even when the internal buffer is full; however, the internal buffer stops taking new data, so the sample that caused either the SDHSRIS.WINHI or SDHSRIS.WINLO interrupt cannot be read by the SDHSDT register. The application must ensure that the values in the SDHWINHITH and SDHWINLOTH registers are in the correct data format. The interrupt flags (WINHI and WINLO) must be reset by user software.

## 22.2.12 Conditions to Stop Data Conversion

**Table 22-9** lists the conditions that stop SDHS data conversion. The SDHSRIS.ACQDONE bit is set to 1 to indicate that data conversion has been stopped (either incomplete or complete). When the previous data conversion has been forced to stopped before completion, the SDHSRIS.ISTOP bit is set to 1 to indicate that data conversion has been interrupted (incomplete).

**Table 22-9. SDHS Conversion Stop Conditions**

| Stop Condition                                                                                                                                                                                                                     | SDHSCTL0.<br>TRGSRC | SDHSCTL0.<br>AUTOSSDIS | SDHSCTL2.<br>SMPCTLOFF | Result                   |           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|------------------------|------------------------|--------------------------|-----------|
| Number of samples =<br>SDHSCTL2.SMPSZ + 1                                                                                                                                                                                          | Don't care          | Don't care             | 0                      | SDHS power               | No change |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | No change |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |
|                                                                                                                                                                                                                                    | Don't care          | Don't care             | 1                      | Not supported            |           |
| The ASQ stops the SDHS operation<br>(ACQ_SDHSSTOP: 0 → 1) caused by:<br>• UUPSTCL.USSSTOP = 0 → 1<br>• UUPSTCL.USSPWRDN = 0 → 1<br>• SAPHASCTL0.STOP = 0 → 1<br>• Enter debug mode while the SDHS is<br>performing data conversion | Don't care          | Don't care             | Don't care             | SDHS power               | No change |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |
|                                                                                                                                                                                                                                    |                     |                        | 0                      | SDHS power               | Power off |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | Not supported            |           |
| SDHSCTL4.SDHSON: 1 → 0                                                                                                                                                                                                             | 0                   | Don't care             | 0                      | SDHS power               | Power off |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |
|                                                                                                                                                                                                                                    |                     |                        | 1                      | SDHS power               | Power off |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | No change |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |
|                                                                                                                                                                                                                                    | 1                   | Don't care             | Don't care             | Not supported            |           |
| ASQ_ACQARM: 1 → 0 (from ASQ)                                                                                                                                                                                                       | 0                   | Don't care             | 0                      | SDHS power               | Power off |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |
|                                                                                                                                                                                                                                    |                     |                        | 1                      | SDHS power               | Power off |
|                                                                                                                                                                                                                                    |                     |                        |                        | Data conversion          | Stop      |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ISTOP            | No change |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                                                                                                                                                    |                     |                        |                        | SDHSRIS.ACQDONE          | Assert    |

**Table 22-9. SDHS Conversion Stop Conditions (continued)**

| Stop Condition               | SDHSCTL0.<br>TRGSRC | SDHSCTL0.<br>AUTOSSDIS | SDHSCTL2.<br>SMPCTLOFF | Result     |                                    |
|------------------------------|---------------------|------------------------|------------------------|------------|------------------------------------|
| SDHSCTL5.SSTART: 1 → 0       | 0                   | 0                      | 0                      | Don't care | Not supported                      |
|                              |                     |                        | 1                      | 0          | SDHS power<br>No change            |
|                              |                     |                        |                        |            | Data conversion<br>Stop            |
|                              |                     |                        |                        |            | SDHSRIS.ISTOP<br>Assert            |
|                              |                     |                        |                        |            | SDHS_ACQDONE<br>(to ASQ)<br>Assert |
|                              |                     |                        | 1                      | 1          | SDHSRIS.ACQDONE<br>Assert          |
|                              |                     |                        |                        |            | SDHS power<br>No change            |
|                              |                     |                        |                        |            | Data conversion<br>Stop            |
|                              |                     |                        |                        |            | SDHSRIS.ISTOP<br>No change         |
|                              |                     |                        |                        |            | SDHS_ACQDONE<br>(to ASQ)<br>Assert |
|                              |                     |                        |                        |            | SDHSRIS.ACQDONE<br>Assert          |
| ASQ_ACQTRG: 1 → 0 (from ASQ) | 0                   | 0                      | 1                      | Don't care | Don't care                         |
|                              |                     |                        | 1                      | 0          | Not supported                      |
|                              |                     |                        |                        |            | Not supported                      |
|                              |                     |                        |                        |            | SDHS power<br>No change            |
|                              |                     |                        |                        |            | Data conversion<br>Stop            |
|                              |                     |                        | 1                      | 1          | SDHSRIS.ISTOP<br>Assert            |
|                              |                     |                        |                        |            | SDHS_ACQDONE<br>(to ASQ)<br>Assert |
|                              |                     |                        |                        |            | SDHSRIS.ACQDONE<br>Assert          |
|                              |                     |                        |                        |            | SDHS power<br>No change            |
|                              |                     |                        |                        |            | Data conversion<br>Stop            |
|                              |                     |                        |                        |            | SDHSRIS.ISTOP<br>No change         |
|                              |                     |                        |                        |            | SDHS_ACQDONE<br>(to ASQ)<br>Assert |
|                              |                     |                        |                        |            | SDHSRIS.ACQDONE<br>Assert          |

The stop conditions listed in [Table 22-9](#) can occur when data conversion has already completed or has not started. [Table 22-10](#) summarizes how the SDHS responds to the signals when no data conversion is ongoing.

**Table 22-10. SDHS Response to Conversion Stop Signals When Data Conversion is Not Running**

| Action                                                                                           | Conditions                             | Result                   |           |
|--------------------------------------------------------------------------------------------------|----------------------------------------|--------------------------|-----------|
| SDHSCTL4.SDHSON: 1 → 0<br>(SDHSCTL0.TRGSRC = 0) or<br>ASQ_ACQARM: 1 → 0<br>(SDHSCTL0.TRGSRC = 1) | SDHS is not performing data conversion | SDHS Power               | Power off |
|                                                                                                  |                                        | SDHSRIS.ISTOP bit        | No change |
|                                                                                                  |                                        | SDHS_ACQDONE<br>(to ASQ) | No change |
|                                                                                                  |                                        | RIS.ACQDONE              | No change |
| The ASQ stops the SDHS operation<br>(ACQ_SDHSSTOP: 0 → 1)                                        | SDHS is not performing data conversion | SDHS power               | No change |
|                                                                                                  |                                        | SDHSRIS.ISTOP bit        | No change |
|                                                                                                  |                                        | SDHS_ACQDONE<br>(to ASQ) | Assert    |
|                                                                                                  |                                        | SDHSRIS.ACQDONE          | No change |

## 22.3 Interrupts

The SDHS support the following interrupt sources:

- **SDHSRIS.OVF (data overflow interrupt):** When the internal buffer overflows, the SDHSRIS.OVF bit is asserted.
- **SDHSRIS.ACQDONE (acquisition done interrupt):** The SDHSRIS.ACQDONE is asserted when data conversion has been finished (either complete or incomplete).  
If SDHSCTL2.DTOFF = 0, then SDHSRIS.ACQDONE is asserted when the data buffer is empty (that is, the DTC completes the data transfer).  
If SDHSCTL2.DTCOFF = 1, then SDHSRIS.ACQDONE is asserted as the data conversion stops regardless of the data buffer status. In this case, user can continuously read SDHSDT register until the data buffer is empty. While reading the SDHSDT register, the data format configuration must not be changed (SDHSCTL0.DFMSEL, SDHSCTL0.DALGN, and SDHSCTL0.OBR).
- **SDHSRIS.SSTRG (start sampling trigger interrupt):** This bit indicates that the SDHS has started data conversion.
- **SDHSRIS.DTRDY (data ready interrupt):** This bit is asserted when a new data is available in the data buffer and remains asserted as long as the data buffer is not empty. The data read by CPU or DTC is removed from the data buffer. The SDHSRIS.DTRDY bit is deasserted when the data buffer becomes empty.
- **SDHSRIS.WINHI (window high interrupt):** This bit is asserted when a new output data is higher than the value in the SDHSWINHITH register.
- **SDHSRIS.WINHL (window low interrupt):** This bit is asserted when a new output data is lower than the value in the SDHSWINLOTH register.

In addition, the SDHSRIS.ISTOP (incomplete stop status) bit is asserted when the data conversion has been interrupted without completion. This bit is not an interrupt flag. It can be used as a status bit, not an interrupt flag.

### 22.3.1 IIDX, Interrupt Vector Generator

All SDHS interrupt sources are prioritized and combined to source a single interrupt vector. The SDHSIIDX register is used to determine which enabled SDHS interrupt sources have requested an interrupt. The SDHSIIDX register generates a value that can be used as address offset for fast interrupt service routine handling. On each read, only one interrupt is indicated. On a read, the current interrupt (highest priority) is automatically cleared by the hardware and the corresponding interrupt flag in SDHSRIS and SDHSMISC are also cleared. After a read from the CPU (not from the debug interface), the register must be updated with the next highest priority interrupt, if none are pending, then it reads as 0h. If the interrupt reported by the SDHSIIDX register (highest priority pending interrupt) is cleared in the SDHSICR by a software write of 1 in the corresponding bit field, the SDHSIIDX register is updated and the next priority interrupt (if any) is available.

## 22.4 Debug Mode

When the device is in debug mode, the SDHS cannot be enabled. Writes to the SDHSCTL4.SDHSON and SDHSCTL5.SSTART bits are prohibited. If the SDHS is already performing data conversion, the data conversion is stopped automatically and the SDHSRIS.ISTOP bit is asserted (see [Table 22-9](#)).

## 22.5 SDHS Registers

**Table 22-11** lists the memory-mapped registers for the SDHS. All register offset addresses not listed in **Table 22-11** should be considered as reserved locations and the register contents should not be modified.

Note 1: When SDHSCTL3.TRIGEN = 1, SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSSWINHITH, SDHSSWINLOTH, and SDHSDTCDA registers are locked. In other words, an attempt to update those registers will be ignored.

Note 2: When SDHSCTL5.SDHS\_LOCK = 1, SDHSCTL3 register is locked.

Note 3: SDHSCTL3.TRIGEN bit is a read-write bit, which is controlled by user program, whereas SDHSCTL5.SDHS\_LOCK bit a read-only bit, which is a status bit that indicates whether or not the SDHS is powered-up.

Note 4: SDHSCTL3.TRIGEN bit must be set to 1 before applying a power-up signal to SDHS (SDHSON bit or an external SDHS PWR UP signal)

Note 5:

When SDHSCTL0.TRGSRC = 0:

Once SDHSCTL4.SDHSON bit is written as 1, SDHSCTL5.SDHS\_LOCK bit is set immediately.

In order to update SDHS registers, clear SDHSCTL4.SDHSON bit first, and then SDHSCTL3.TRIGEN bit needs to be cleared.

When SDHSCTL0.TRGSRC = 1:

It takes up to 4 system clock cycles to set SDHSCTL5.SDHS\_LOCK bit after detecting an external SDHS PWR UP signal.

In order to update SDHS registers, the SDHS\_PWR\_UP signal should be de-asserted first, then SDHSCTL3.TRIGEN bit needs to be cleared to be zero.

**Table 22-11. SDHS Registers**

| Offset | Acronym      | Register Name                                   | Type       | Reset | Section                         |
|--------|--------------|-------------------------------------------------|------------|-------|---------------------------------|
| 0h     | SDHSIIDX     | Interrupt Index Register                        | read-only  | 0h    | <a href="#">Section 22.5.1</a>  |
| 2h     | SDHSMIS      | Masked Interrupt Status and Clear Register      | read-only  | 0h    | <a href="#">Section 22.5.2</a>  |
| 4h     | SDHSRIS      | Raw Interrupt Status Register                   | read-only  | 0h    | <a href="#">Section 22.5.3</a>  |
| 6h     | SDHSIMSC     | Interrupt Mask Register                         | read-write | 0h    | <a href="#">Section 22.5.4</a>  |
| 8h     | SDHSICR      | Interrupt Clear Register.                       | write-only | 0h    | <a href="#">Section 22.5.5</a>  |
| Ah     | SDHSISR      | Interrupt Set Register.                         | write-only | 0h    | <a href="#">Section 22.5.6</a>  |
| Ch     | SDHSDESCLO   | SDHS Descriptor Register L.                     | read-only  | 110h  | <a href="#">Section 22.5.7</a>  |
| Eh     | SDHSDESCHI   | SDHS Descriptor Register H.                     | read-only  | BB10h | <a href="#">Section 22.5.8</a>  |
| 10h    | SDHSCTL0     | SDHS Control Register 0                         | read-write | 8001h | <a href="#">Section 22.5.9</a>  |
| 12h    | SDHSCTL1     | SDHS Control Register 1                         | read-write | 0h    | <a href="#">Section 22.5.10</a> |
| 14h    | SDHSCTL2     | SDHS Control Register 2                         | read-write | 0h    | <a href="#">Section 22.5.11</a> |
| 16h    | SDHSCTL3     | SDHS Control Register 3                         | read-write | 0h    | <a href="#">Section 22.5.12</a> |
| 18h    | SDHSCTL4     | SDHS Control Register 4                         | read-write | 0h    | <a href="#">Section 22.5.13</a> |
| 1Ah    | SDHSCTL5     | SDHS Control Register 5                         | read-write | 0h    | <a href="#">Section 22.5.14</a> |
| 1Ch    | SDHSCTL6     | SDHS Control Register 6                         | read-write | 19h   | <a href="#">Section 22.5.15</a> |
| 1Eh    | SDHSCTL7     | SDHS Control Register 7                         | read-write | Fh    | <a href="#">Section 22.5.16</a> |
| 22h    | SDHSDT       | SDHS Data Converstion Register                  | read-only  | 0h    | <a href="#">Section 22.5.17</a> |
| 24h    | SDHSSWINHITH | SDHS Window Comparator High Threshold Register. | read-write | 0h    | <a href="#">Section 22.5.18</a> |
| 26h    | SDHSSWINLOTH | SDHS Window Comparator Low Threshold Register.  | read-write | 0h    | <a href="#">Section 22.5.19</a> |
| 28h    | SDHSDTCDA    | DTC destination address register                | read-write | 0h    | <a href="#">Section 22.5.20</a> |

### 22.5.1 SDHSIIDX Register (Offset = 0h) [reset = 0h]

SDHSIIDX is shown in [Figure 22-27](#) and described in [Table 22-12](#).

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Interrupt Index Register.

Note: This register is word accessible. A byte access is also allowed but not recommended. Either high byte or low byte access alone can clear the pending interrupt flag.

**Figure 22-27. SDHSIIDX Register**

|      |    |    |    |    |    |   |          |
|------|----|----|----|----|----|---|----------|
| 15   | 14 | 13 | 12 | 11 | 10 | 9 | 8        |
| IIDX |    |    |    |    |    |   |          |
| R-0h |    |    |    |    |    |   |          |
| 7    | 6  | 5  | 4  | 3  | 2  | 1 | 0        |
| IIDX |    |    |    |    |    |   | Reserved |
| R-0h |    |    |    |    |    |   | R-0h     |

**Table 22-12. SDHSIIDX Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | IIDX     | R    | 0h    | <p>SDHS Interrupt Vector Value. Read only. It generates a value that can be used as address offset for fast interrupt service routine handling. On each read, only one interrupt is indicated. On a read, the current interrupt (highest priority) is automatically de-asserted by the hardware and the corresponding bit in RIS and MISC are de-asserted as well. After a read from the CPU (not from the debug interface), the register is updated with the next highest priority interrupt, if none are pending, then it is read as zero.</p> <p>If the interrupt displayed by the SDHSIIDX register (highest priority pending interrupt) is cleared by writing '1' to a corresponding bit in the ICR register, the SDHSIIDX register shall be updated and the next priority interrupt (if any) is read.</p> <p>Reset type: PUC</p> <p>0h (R) = No Interrupt pending.</p> <p>1h (R) = Interrupt Source: SDHSRIS.OVF; Interrupt Priority: Highest</p> <p>2h (R) = Interrupt Source: SDHSRIS.ACQDONE</p> <p>3h (R) = Interrupt Source: SDHSRIS.SSTRG</p> <p>4h (R) = Interrupt Source: SDHSRIS.DTRDY</p> <p>5h (R) = Interrupt Source: SDHSRIS.WINHI</p> <p>6h (R) = Interrupt Source: SDHSRIS.WINLO</p> <p>7h (R) = Reserved; Interrupt</p> <p>8h (R) = Reserved; Interrupt Priority: Lowest</p> |
| 0    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

## 22.5.2 SDHSMIS Register (Offset = 2h) [reset = 0h]

SDHSMIS is shown in [Figure 22-28](#) and described in [Table 22-13](#).

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Masked Interrupt Status Register.

**Figure 22-28. SDHSMIS Register**

|          |       |       |       |       |         |      |      |
|----------|-------|-------|-------|-------|---------|------|------|
| 15       | 14    | 13    | 12    | 11    | 10      | 9    | 8    |
| Reserved |       |       |       |       |         |      |      |
| R-0h     |       |       |       |       |         |      |      |
| 7        | 6     | 5     | 4     | 3     | 2       | 1    | 0    |
| Reserved | WINLO | WINHI | DTRDY | SSTRG | ACQDONE | OVF  |      |
| R-0h     | R-0h  | R-0h  | R-0h  | R-0h  | R-0h    | R-0h | R-0h |

**Table 22-13. SDHSMIS Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                  |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------|
| 15-6 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                 |
| 5    | WINLO    | R    | 0h    | SDHS Window Low Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending               |
| 4    | WINHI    | R    | 0h    | SDHS Window High Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending              |
| 3    | DTRDY    | R    | 0h    | SDHS Data Ready Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending               |
| 2    | SSTRG    | R    | 0h    | SDHS Conversion Start Trigger Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending |
| 1    | ACQDONE  | R    | 0h    | Acquisition Done Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending              |
| 0    | OVF      | R    | 0h    | SDHS Data Overflow Masked Interrupt Status bit.<br>Reset type: PUC<br>0h (R) = No interrupt pending<br>1h (R) = Interrupt pending            |

### 22.5.3 SDHSRIS Register (Offset = 4h) [reset = 0h]

SDHSRIS is shown in [Figure 22-29](#) and described in [Table 22-14](#).

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Raw Interrupt Status Register. Read Only Register.

**Figure 22-29. SDHSRIS Register**

| 15       | 14 | 13    | 12    | 11       | 10    | 9       | 8    |
|----------|----|-------|-------|----------|-------|---------|------|
| ISTOP    |    |       |       | Reserved |       |         |      |
| R-0h     |    |       |       | R-0h     |       |         |      |
| 7        | 6  | 5     | 4     | 3        | 2     | 1       | 0    |
| Reserved |    | WINLO | WINHI | DTRDY    | SSTRG | ACQDONE | OVF  |
| R-0h     |    | R-0h  | R-0h  | R-0h     | R-0h  | R-0h    | R-0h |

**Table 22-14. SDHSRIS Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | ISTOP    | R    | 0h    | <p>Incomplete Stop Raw Interrupt Status bit. Read Only. This bit is asserted when data conversion has been interrupted and stopped before completing the number of samples defined in SDHSCTL2.SAMPSZ.</p> <p>This bit is offered only for polling the event by reading this bit. Interrupt is not available for this event. This bit must be de-asserted by writing '1' to SDHSICR.ISTOP bit.</p> <p>Reset type: PUC</p> <p>0h (R) = No ISTOP event</p> <p>1h (R) = Conversion has been interrupted and stopped before completing the number of samples defined in SDHSCTL2.SAMPSZ.</p> |
| 14-6 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 5    | WINLO    | R    | 0h    | <p>SDHS Window Low Raw Interrupt Status bit. Read Only. This bit is asserted when output data value is lower than the value in the SDHSWINLOTH register.</p> <p>Note:</p> <p>1) The window comparator is only enabled when SDHSCTL2.WINCPEN = 1.</p> <p>2) Note: It takes 4 system clock cycles + 4 sampling periods to update SDHSRIS.WINLO bit after the condition is detected.</p> <p>Reset type: PUC</p> <p>0h (R) = No new data is lower than the value in the SDHSWINLOTH register</p> <p>1h (R) = New data is low than the value in the SDHSWINLOTH register</p>                  |
| 4    | WINHI    | R    | 0h    | <p>SDHS Window High Raw Interrupt Status bit. Read Only. This bit is asserted when the output data value is higher than the value in the SDHSWINHITH register.</p> <p>Note:</p> <p>1) The window comparator is only enabled when SDHSCTL2.WINCPEN = 1.</p> <p>2) It takes 4 system clock cycles + 4 sampling periods to update SDHSRIS.WINHI after the condition is detected.</p> <p>Reset type: PUC</p> <p>0h (R) = No WINHI event</p> <p>1h (R) = The output data value is higher than the value in the SDHSWINHITH register</p>                                                       |

Table 22-14. SDHSRIS Register Field Descriptions (continued)

| Bit | Field   | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-----|---------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | DTRDY   | R    | 0h    | <p>SDHS Data Ready Raw Interrupt Status bit. Read Only. This bit is asserted when a new conversion data is available in the data buffer and remains set as long as the buffer is not empty regardless of the SDHS data conversion status.</p> <p>Note: the data buffer is automatically cleared when the data buffer becomes empty.</p> <p>Following two methods can be used to empty the data buffer after completing data conversion if necessary:</p> <ol style="list-style-type: none"> <li>1) When the DTC is enabled, no additional action is required. The DTC reads the data buffer until the data buffer becomes empty.</li> <li>2) When the DTC is disabled, then either read the SDHSDT register until this bit is cleared or enable the DTC so that the DTC empties the buffer. Either way, this bit will be cleared when the buffer becomes empty.</li> </ol> <p>Reset type: PUC<br/>           0h (R) = No DTRDY event<br/>           1h (R) = The data buffer has become empty.</p> |
| 2   | SSTRG   | R    | 0h    | <p>SDHS Conversion Start Trigger Raw Interrupt Status bit. Read Only.</p> <p>Reset type: PUC<br/>           0h (R) = No SSTRG event<br/>           1h (R) = Conversor Start signal has been asserted</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 1   | ACQDONE | R    | 0h    | <p>Acquisition Done Raw Interrupt Status bit. Read Only. This bit is not de-asserted by hardware. This bit is asserted when data conversion is ended (either complete or incomplete).</p> <p>If SDHSCTL2.DTOFF = 0, then this bit is asserted when data buffer becomes empty (i.e. when DTC completes the data transfer).</p> <p>If SDHSCTL2.DTCOFF = 1, then this bit is asserted immediately when data conversion stops regardless of the data buffer status. In this case, CPU can continuously read the SDHSDT register until the data buffer becomes empty.</p> <p>Reset type: PUC<br/>           0h (R) = No ACQDONE event<br/>           1h (R) = Data conversion has been finished (either complete or incomplete).</p>                                                                                                                                                                                                                                                                    |
| 0   | OVF     | R    | 0h    | <p>SDHS Data Overflow Raw Interrupt Status bit. Read Only. This bit is not automatically de-asserted by hardware.</p> <p>Reset type: PUC<br/>           0h (R) = No OVF event<br/>           1h (R) = When DTC is enabled (SDHSCTL2.DTCOFF = 0), DTC has dropped at least one sample. This indicates that the system clock needs to be increased.<br/>           When DTC is disabled (SDHSCTL2.DTCOFF = 1), At least one new sample has been overwritten to SDHSDT register before the previous value is read.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

## 22.5.4 SDHSIMSC Register (Offset = 6h) [reset = 0h]

SDHSIMSC is shown in [Figure 22-30](#) and described in [Table 22-15](#).

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Interrupt Mask Register.

**Figure 22-30. SDHSIMSC Register**

| 15       | 14     | 13     | 12     | 11       | 10      | 9      | 8      |
|----------|--------|--------|--------|----------|---------|--------|--------|
| ISTOP    |        |        |        | Reserved |         |        |        |
| R-0h     |        |        |        | R-0h     |         |        |        |
| 7        | 6      | 5      | 4      | 3        | 2       | 1      | 0      |
| Reserved | WINLO  | WINHI  | DTRDY  | SSTRG    | ACQDONE | OVF    |        |
| R-0h     | R/W-0h | R/W-0h | R/W-0h | R/W-0h   | R/W-0h  | R/W-0h | R/W-0h |

**Table 22-15. SDHSIMSC Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                     |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | ISTOP    | R    | 0h    | Incomplete Stop Interrupt Mask bit. Read Only. Note that this interrupt is always disabled. No interrupt will be generated.                     |
| 14-6 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                    |
| 5    | WINLO    | R/W  | 0h    | SDHS Window Low Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Interrupt is disabled<br>1h (R/W) = Interrupt is enabled               |
| 4    | WINHI    | R/W  | 0h    | SDHS Window High Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Interrupt is disabled<br>1h (R/W) = Interrupt is enabled              |
| 3    | DTRDY    | R/W  | 0h    | SDHS Data Ready Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Interrupt is disabled<br>1h (R/W) = Interrupt is enabled               |
| 2    | SSTRG    | R/W  | 0h    | SDHS Start Conversion Trigger Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Interrupt is disabled<br>1h (R/W) = Interrupt is enabled |
| 1    | ACQDONE  | R/W  | 0h    | Acquisition Done Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Interrupt is disabled<br>1h (R/W) = Interrupt is enabled              |
| 0    | OVF      | R/W  | 0h    | SDHS Data Overflow Interrupt Mask bit.<br><br>Reset type: PUC<br>0h (R/W) = Interrupt is disabled<br>1h (R/W) = Interrupt is enabled            |

### 22.5.5 SDHSICR Register (Offset = 8h) [reset = 0h]

SDHSICR is shown in [Figure 22-31](#) and described in [Table 22-16](#).

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Interrupt Clear Register. Writing '1' to clear the corresponding bit in SDHSRIS register. Read as zero.

Note: This register can be used to clear an interrupt source without reading the SDHSIIDX register.

**Figure 22-31. SDHSICR Register**

| 15       | 14 | 13    | 12    | 11       | 10    | 9       | 8    |
|----------|----|-------|-------|----------|-------|---------|------|
| ISTOP    |    |       |       | Reserved |       |         |      |
| W-0h     |    |       |       | R-0h     |       |         |      |
| 7        | 6  | 5     | 4     | 3        | 2     | 1       | 0    |
| Reserved |    | WINLO | WINHI | DTRDY    | SSTRG | ACQDONE | OVF  |
| R-0h     |    | W-0h  | W-0h  | W1S-0h   | W-0h  | W-0h    | W-0h |

**Table 22-16. SDHSICR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                          |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | ISTOP    | W    | 0h    | Incomplete Stop Interrupt Clear bit.                                                                                                                                                                                                                                                                 |
| 14-6 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                         |
| 5    | WINLO    | W    | 0h    | SDHS Window Low Interrupt Clear bit.                                                                                                                                                                                                                                                                 |
| 4    | WINHI    | W    | 0h    | SDHS Window High Interrupt Clear bit.<br>Reset type: PUC                                                                                                                                                                                                                                             |
| 3    | DTRDY    | W1S  | 0h    | SDHS Data Ready Interrupt Clear bit.<br>Note: SDHSRIS.DTRDY is automatically cleared by hardware when the data buffer is empty. This bit can be used to de-assert SDHSRIS.DTRDY only when SDHSRIS.DTRDY is asserted by writing '1' to SDHSISR.DTRDY and the data buffer is empty.<br>Reset type: PUC |
| 2    | SSTRG    | W    | 0h    | SDHS Converstion Start Trigger Interrupt Clear bit.                                                                                                                                                                                                                                                  |
| 1    | ACQDONE  | W    | 0h    | Acquisition Done Interrupt Clear bit.                                                                                                                                                                                                                                                                |
| 0    | OVF      | W    | 0h    | SDHS Data Overflow Interrupt Clear bit.                                                                                                                                                                                                                                                              |

### 22.5.6 SDHSISR Register (Offset = Ah) [reset = 0h]

SDHSISR is shown in [Figure 22-32](#) and described in [Table 22-17](#).

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Interrupt Set Register. Writing '1' to assert the corresponding bit in SDHSRIS register. Read as zero.

Note: This register can be used for debugging purpose to generate an interrupt manually.

**Figure 22-32. SDHSISR Register**

| 15       | 14 | 13    | 12    | 11       | 10    | 9       | 8    |
|----------|----|-------|-------|----------|-------|---------|------|
| ISTOP    |    |       |       | Reserved |       |         |      |
| W-0h     |    |       |       | R-0h     |       |         |      |
| 7        | 6  | 5     | 4     | 3        | 2     | 1       | 0    |
| Reserved |    | WINLO | WINHI | DTRDY    | SSTRG | ACQDONE | OVF  |
| R-0h     |    | W-0h  | W-0h  | W1S-0h   | W-0h  | W-0h    | W-0h |

**Table 22-17. SDHSISR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | ISTOP    | W    | 0h    | Incomplete Stop Interrupt Set bit.                                                                                                                                                                                                                                                                                                                                                                          |
| 14-6 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                |
| 5    | WINLO    | W    | 0h    | SDHS Window Low Interrupt Set bit.                                                                                                                                                                                                                                                                                                                                                                          |
| 4    | WINHI    | W    | 0h    | SDHS Window High Interrupt Set bit.<br>Reset type: PUC                                                                                                                                                                                                                                                                                                                                                      |
| 3    | DTRDY    | W1S  | 0h    | SDHS Data Ready Interrupt Set bit. Write 1 to set SDHSRIS.DTRDY bit.<br><br>Note: This bit can be used to test the interrupt when the data buffer is empty. In the case, SDHSRIS.DTRDY bit does not indicate actual status of the data buffer. Once SDHSRIS.DTRDY is asserted by SDHSISR.DTRDY, then it can be de-asserted by SDHSICR.DTRDY bit as long as the data buffer is empty.<br><br>Reset type: PUC |
| 2    | SSTRG    | W    | 0h    | SDHS Start Conversion Trigger Interrupt Set bit.                                                                                                                                                                                                                                                                                                                                                            |
| 1    | ACQDONE  | W    | 0h    | Acquisition Done Interrupt Set bit.                                                                                                                                                                                                                                                                                                                                                                         |
| 0    | OVF      | W    | 0h    | SDHS Data Overflow Interrupt Set bit.                                                                                                                                                                                                                                                                                                                                                                       |

### 22.5.7 SDHSDESCLO Register (Offset = Ch) [reset = 110h]

SDHSDESCLO is shown in [Figure 22-33](#) and described in [Table 22-18](#).

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SDHS Descriptor Register L.

**Figure 22-33. SDHSDESCLO Register**

| 15         | 14 | 13 | 12 | 11      | 10 | 9 | 8 |
|------------|----|----|----|---------|----|---|---|
| FEATUREVER |    |    |    | INSTNUM |    |   |   |
| R-0h       |    |    |    | R-1h    |    |   |   |
| 7          | 6  | 5  | 4  | 3       | 2  | 1 | 0 |
| MAJREV     |    |    |    | MINREV  |    |   |   |
| R-1h       |    |    |    | R-0h    |    |   |   |

**Table 22-18. SDHSDESCLO Register Field Descriptions**

| Bit   | Field      | Type | Reset | Description                                                                                                         |
|-------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------|
| 15-12 | FEATUREVER | R    | 0h    | Feature Set for the module<br>Reset type: PUC                                                                       |
| 11-8  | INSTNUM    | R    | 1h    | Instance Number within the device. This will be a parameter to the RTL for modules that can have multiple instances |
| 7-4   | MAJREV     | R    | 1h    | Major Revision<br>Reset type: PUC                                                                                   |
| 3-0   | MINREV     | R    | 0h    | Minor Revision<br>Reset type: PUC                                                                                   |

### **22.5.8 SDHSDESCHI Register (Offset = Eh) [reset = BB10h]**

SDHSDESCHI is shown in [Figure 22-34](#) and described in [Table 22-19](#).

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SDHS Descriptor Register H.

**Figure 22-34. SDHSDESCHI Register**

|          |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|----------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MODULEID |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R-BB10h  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 22-19. SDHSDESCHI Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                           |
|------|----------|------|-------|---------------------------------------|
| 15-0 | MODULEID | R    | BB10h | Module Identifier.<br>Reset type: PUC |

### 22.5.9 SDHSCTL0 Register (Offset = 10h) [reset = 8001h]

SDHSCTL0 is shown in [Figure 22-35](#) and described in [Table 22-20](#).

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SDHS Control Register 0.

When SDHSCTL3.TRGEN bit = 1 or SDHSCTL5.SDHS\_LOCK bit = 1, this register is locked. In that case, an attempt to update this registers will be ignored.

**Figure 22-35. SDHSCTL0 Register**

| 15     | 14       | 13     | 12 | 11     | 10 | 9         | 8 |
|--------|----------|--------|----|--------|----|-----------|---|
| TRGSRC | Reserved | SHIFT  |    | OBR    |    | DFMSEL    |   |
| R/W-1h | R-0h     | R/W-0h |    | R/W-0h |    | R/W-0h    |   |
| 7      | 6        | 5      | 4  | 3      | 2  | 1         | 0 |
| DALGN  | Reserved |        |    | INTDLY |    | AUTOSSDIS |   |
| R/W-0h | R-0h     |        |    | R/W-0h |    | R/W-1h    |   |

**Table 22-20. SDHSCTL0 Register Field Descriptions**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | TRGSRC   | R/W  | 1h    | SDHS trigger source select.<br>Reset type: PUC<br>0h (R/W) = Register control mode:<br>- SDHSCTL4.SDHSON is the source of the SHDS_PWR_UP/DOWN signal<br>- SDHSCTL5.SSTART is the source of the CONVERSION_START/STOP signal<br>1h (R/W) = ASQ control mode: The SDHS is controlled by the ASQ.<br>- ASQ_ACQARM signal from the ASQ is the source of the SHDS_PWR_UP/DOWN signal<br>- ASQ_ACQTRIG signal from the ASQ is the source of the CONVERSION_START/STOP signal |
| 14    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 13-12 | SHIFT    | R/W  | 0h    | MSB Shift.<br>Reset type: PUC<br>0h (R/W) = No Shift, MSB.<br>1h (R/W) = MSB - 1 (Shift left by 1 from filter out). If SDHSCTL0.OBR = 2, then this configuration is invalid. No shift is performed.<br>2h (R/W) = MSB - 2 (Shift left by 2 from filter out). If SDHSCTL0.OBR = 1, then this configuration is invalid. No shift is performed.<br>3h (R/W) = Reserved (No shift)                                                                                          |
| 11-10 | OBR      | R/W  | 0h    | Output Bit Resolution.<br>Reset type: PUC<br>0h (R/W) = 12-bit<br>1h (R/W) = 13-bit<br>2h (R/W) = 14-bit<br>3h (R/W) = Reserved (default: 12-bit)                                                                                                                                                                                                                                                                                                                       |
| 9-8   | DFMSEL   | R/W  | 0h    | Data format.<br>Reset type: PUC<br>0h (R/W) = 2's complement<br>1h (R/W) = Offset binary<br>2h (R/W) = Reserved (defaults to 0, 2s complement)<br>3h (R/W) = Reserved (defaults to 0, 2s complement)                                                                                                                                                                                                                                                                    |

**Table 22-20. SDHSCTL0 Register Field Descriptions (continued)**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----|-----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | DALGN     | R/W  | 0h    | Data alignment.<br>Reset type: PUC<br>0h (R/W) = Right-aligned.<br>1h (R/W) = Left-aligned.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 6-4 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 3-1 | INTDLY    | R/W  | 0h    | DTRDY Interrupt delay select. This register can be used to discard up to 7 samples after conversion start. Note that the skipped samples will be lost.<br>Reset type: PUC<br>0h (R/W) = No delay<br>1h (R/W) = 1 sample delay, 2nd sample is the first interrupt<br>2h (R/W) = 2 samples delay, 3rd sample is the first interrupt<br>3h (R/W) = 3 samples delay, 4rd sample is the first interrupt<br>4h (R/W) = 4 samples delay, 5th sample is the first interrupt<br>5h (R/W) = 5 samples delay, 6th sample is the first interrupt<br>6h (R/W) = 6 samples delay, 7th sample is the first interrupt<br>7h (R/W) = 7 samples delay, 8th sample is the first interrupt |
| 0   | AUTOSSDIS | R/W  | 1h    | SDHS Auto Sample Start Disable.<br>Reset type: PUC<br>0h (R/W) = Auto Sample start enabled. SDHS is powered up when the SHDS_PWR_UP applied, then data conversion is automatically started once the SDHS is fully powered up.<br>1h (R/W) = Auto Sample start disabled. (This configuration must be used when the ASQ controls the measurement sequences)<br>- SHDS_PWR_UP signal to turns on the SDHS<br>- CONVERSION_START signal to start data convesion                                                                                                                                                                                                            |

### 22.5.10 SDHSCTL1 Register (Offset = 12h) [reset = 0h]

SDHSCTL1 is shown in [Figure 22-36](#) and described in [Table 22-21](#).

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SDHS Control Register 1

When SDHSCTL3.TRGEN = 1 or SDHSCTL5.SDHS\_LOCK = 1, this register is locked. In that case, an attempt to update this registers will be ignored.

**Figure 22-36. SDHSCTL1 Register**

|          |    |    |    |        |    |   |   |
|----------|----|----|----|--------|----|---|---|
| 15       | 14 | 13 | 12 | 11     | 10 | 9 | 8 |
| Reserved |    |    |    |        |    |   |   |
| R-0h     |    |    |    |        |    |   |   |
| 7        | 6  | 5  | 4  | 3      | 2  | 1 | 0 |
| Reserved |    |    |    | OSR    |    |   |   |
| R-0h     |    |    |    | R/W-0h |    |   |   |

**Table 22-21. SDHSCTL1 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                               |
| 3-0  | OSR      | R/W  | 0h    | Over Sampling Rate. Output Data Rate = Input Clock Frequency / OSR.<br>Note: values not shown below are reserved.<br>Reset type: PUC<br>0h (R/W) = 10<br>1h (R/W) = 20<br>2h (R/W) = 40<br>3h (R/W) = 80<br>4h (R/W) = 160 |

### 22.5.11 SDHSCTL2 Register (Offset = 14h) [reset = 0h]

SDHSCTL2 is shown in [Figure 22-37](#) and described in [Table 22-22](#).

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SDHS Control Register 2

When SDHSCTL3.TRGEN = 1 or SDHSCTL5.SDHS\_LOCK = 1, this register is locked. In that case, an attempt to update this registers will be ignored.

**Figure 22-37. SDHSCTL2 Register**

| 15     | 14       | 13 | 12       | 11 | 10        | 9 | 8      |
|--------|----------|----|----------|----|-----------|---|--------|
| DTCOFF | WINCMPEN |    | Reserved |    | SMPCTLOFF |   | SMPSZ  |
| R/W-0h | R/W-0h   |    | R-0h     |    | R/W-0h    |   | R/W-0h |
| 7      | 6        | 5  | 4        | 3  | 2         | 1 | 0      |
|        |          |    | SMPSZ    |    |           |   |        |
|        |          |    | R/W-0h   |    |           |   |        |

**Table 22-22. SDHSCTL2 Register Field Descriptions**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | DTCOFF    | R/W  | 0h    | <p>Data Transfer Controller (DTC) Off.</p> <p>Reset type: PUC</p> <p>0h (R/W) = DTC enabled. The DTC automatically transfers the data from the SDHSCTL register to the address specified in the SDHSCTLDA register.</p> <p>1h (R/W) = DTC disabled. The data in the SDHSCTL register must be read by CPU, otherwise the overflow interrupt flag (SDHSRIS.OVF) will eventually be asserted.</p>                                                                                                                                      |
| 14    | WINCMPEN  | R/W  | 0h    | <p>Window Comparator Enable.</p> <p>Note:</p> <ul style="list-style-type: none"> <li>- For the samples skipped by SDHSCTL0.INTDLY, window comparison is not applied.</li> <li>- Window comparison is performed with the latest conversion result before it is pushed to the internal buffer.</li> <li>- Window comparison is still functional when the internal buffer is full.</li> </ul> <p>Reset type: PUC</p> <p>0h (R/W) = Window Comparator is disabled</p> <p>1h (R/W) = Window Comparator is enabled</p>                    |
| 13-11 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 10    | SMPCTLOFF | R/W  | 0h    | <p>Disable sampling size counting.</p> <p>Reset type: PUC</p> <p>0h (R/W) = Total sampling size is determined by SDHSCTL2.SMPSZ bits. The SDHS automatically stops data conversion.</p> <p>1h (R/W) = SDHSCTL2.SMPSZ bits are ignored. Conversion does not stop until the trigger source selected by TRGSRC bits is deasserted.</p>                                                                                                                                                                                                 |
| 9-0   | SMPSZ     | R/W  | 0h    | <p>Total Sample Size. Total Sample Size = SMPSZ + 1.</p> <p>Note that SDHSCTL2.SMPSZ includes the samples skipped by SDHSCTL0.INTDLY:</p> <ul style="list-style-type: none"> <li>- The total number of samples SDHS generates = SMPSZ + 1.</li> <li>- The number of samples SDHS generates via SDHSCTL register = SMPSZ - INTDLY + 1.</li> </ul> <p>Care must be taken when writing a value to SDHSCTL2.SMPSZ. If SDHSCTL2.SMPSZ - SDHSCTL0.INTDLY + 1 &lt;= 0, then no data output to SDHSCTL register.</p> <p>Reset type: PUC</p> |

### 22.5.12 SDHSCTL3 Register (Offset = 16h) [reset = 0h]

SDHSCTL3 is shown in [Figure 22-38](#) and described in [Table 22-23](#).

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SDHS Control Register 3

**Figure 22-38. SDHSCTL3 Register**

|          |    |    |    |    |    |        |   |  |  |
|----------|----|----|----|----|----|--------|---|--|--|
| 15       | 14 | 13 | 12 | 11 | 10 | 9      | 8 |  |  |
| RESERVED |    |    |    |    |    |        |   |  |  |
| R-0h     |    |    |    |    |    |        |   |  |  |
| 7        | 6  | 5  | 4  | 3  | 2  | 1      | 0 |  |  |
| RESERVED |    |    |    |    |    | TRIGEN |   |  |  |
| R-0h     |    |    |    |    |    |        |   |  |  |
| R/W-0h   |    |    |    |    |    |        |   |  |  |

**Table 22-23. SDHSCTL3 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 0    | TRIGEN   | R/W  | 0h    | <p>SDHS Trigger Enable bit. This bit enables SDHS Trigger Source and lock SDHS registers.</p> <p>Note:</p> <p>This bit is used to inform SDHS that register configuration has been completed. This bit must be written as 1 before applying SDHS_PWR_UP signal.</p> <p>Once this bit is asserted, SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSDTCD registers are locked (not allowed to be modified). This bit is locked once a SDHS_PWR_UP signal is applied. See SDHSCTL5.SDHS_LOCK for the sequence of SDHS register configuration.</p> <p>Reset type: PUC</p> <p>0h (R/W) = SDHS Trigger is disabled. Once this bit is de-asserted, SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSDTCD registers are unlocked (allowed to be modified).</p> <p>1h (R/W) = SDHS Trigger is enabled. Once this bit is asserted, SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSDTCD registers are locked (not allowed to be modified).</p> |

### **22.5.13 SDHSCTL4 Register (Offset = 18h) [reset = 0h]**

SDHSCTL4 is shown in [Figure 22-39](#) and described in [Table 22-24](#).

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SDHS Control Register 4

**Figure 22-39. SDHSCTL4 Register**

|          |    |    |    |    |    |        |   |  |  |
|----------|----|----|----|----|----|--------|---|--|--|
| 15       | 14 | 13 | 12 | 11 | 10 | 9      | 8 |  |  |
| RESERVED |    |    |    |    |    |        |   |  |  |
| R-0h     |    |    |    |    |    |        |   |  |  |
| 7        | 6  | 5  | 4  | 3  | 2  | 1      | 0 |  |  |
| RESERVED |    |    |    |    |    | SDHSON |   |  |  |
| R-0h     |    |    |    |    |    |        |   |  |  |
| R/W-0h   |    |    |    |    |    |        |   |  |  |

**Table 22-24. SDHSCTL4 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 0    | SDHSON   | R/W  | 0h    | <p>Turn on the SDHS module. When SDHSCTL0.TRGSRC =0, SDHS Power-up/down bit.</p> <p>Note:</p> <ul style="list-style-type: none"> <li>- When SDHSCTL0.AUTOSSDIS = 0 and SDHSCTL0.TRGSRC =0, the SDHSON bit only powers up the SDHS, does not start sampling.</li> <li>- When SDHSCTL0.AUTOSSDIS = 1 and SDHSCTL0.TRGSRC =0, the SDHSON powers up the SDHS and starts sampling when the SDHS is fully powered up.</li> <li>- When SDHSCTL0.TRGSRC = 1, this bit is invalid.</li> </ul> <p>Reset type: PUC</p> <p>0h (R/W) = Power down the SDHS module</p> <p>1h (R/W) = Power on the SDHS module</p> |

### 22.5.14 SDHSCTL5 Register (Offset = 1Ah) [reset = 0h]

SDHSCTL5 is shown in [Figure 22-40](#) and described in [Table 22-25](#).

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SDHS Control Register 5

**Figure 22-40. SDHSCTL5 Register**

|          |    |    |    |    |    |   |           |
|----------|----|----|----|----|----|---|-----------|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8         |
| Reserved |    |    |    |    |    |   | SDHS_LOCK |
| R-0h     |    |    |    |    |    |   | R-0h      |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0         |
| Reserved |    |    |    |    |    |   | SSTART    |
| R-0h     |    |    |    |    |    |   | R/W-0h    |

**Table 22-25. SDHSCTL5 Register Field Descriptions**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-9 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 8    | SDHS_LOCK | R    | 0h    | <p>SDHS register lock status bit. This bit is asserted when the SDHS has received the SDHS_PWR_UP signal. When this bit is asserted, SDHSCTL3 register is locked.</p> <p>Note:</p> <p>1) When SDHSCTL0.TRGSRC = 0:<br/> Once SDHSCTL4.SDHSON is written as 1, SDHSCTL5.SDHS_LOCK is asserted immediately.<br/> In order to update SDHS registers, clear SDHSCTL4.SDHSON first, and then SDHSCTL3.TRIGEN needs to be cleared.</p> <p>2) When SDHSCTL0.TRGSRC = 1:<br/> It takes up to 4 system clock cycles to assert SDHSCTL5.SDHS_LOCK after detecting the SDHS_PWR_UP signal (ASQ_ACQARM from the ASQ).<br/> In order to update SDHS registers, the SDHS_PWR_UP signal should be de-asserted first by the ASQ, then SDHSCTL3.TRIGEN needs to be cleared.</p> <p>3) SDHS register configuration sequence:<br/> a) After reset (or device power up), configure SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSCTCDA registers<br/> b) write '1' to SDHSCTL3.TRIGEN bit =&gt; SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSCTCDA registers are locked<br/> c) Apply a SDHS_PWR_UP signal =&gt; SDHSCTL3 register is locked<br/> d) Apply a CONVERSION_START signal if necessary</p> <p>Reset type: PUC<br/> 0h (R) = SDHSCTL3 register is unlocked.<br/> 1h (R) = SDHSCTL3 register is locked as well as SDHSCTL0, SDHSCTL1, SDHSCTL2, SDHSCTL7, SDHSWINHITH, SDHSWINLOTH, and SDHSCTCDA registers. Only read is allowed.</p> |
| 7-1  | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

**Table 22-25. SDHSCTL5 Register Field Descriptions (continued)**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----|--------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0   | SSTART | R/W  | 0h    | <p>Start data conversion.</p> <p>Note:</p> <ul style="list-style-type: none"> <li>- When SDHSCTL0.AUTOSSDIS = 0 and SDHSCTL0.TRGSRC =0, the SDHSON powers up the SDHS, the SSTART triggers data conversion. It is very important to wait for the SDHS settling time (34 usec) before asserting SSTART from the time of SDHSON = 0 -&gt; 1.</li> <li>- When SDHSCTL0.AUTOSSDIS = 1 and SDHSCTL0.TRGSRC =0, this bit is invalid.</li> <li>- When SDHSCTL0.TRGSRC = 1, this bit is invalid.</li> </ul> <p>Reset type: PUC</p> <p>0h (R/W) = Stop conversion<br/>1h (R/W) = Start conversion</p> |

### 22.5.15 SDHSCTL6 Register (Offset = 1Ch) [reset = 19h]

SDHSCTL6 is shown in [Figure 22-41](#) and described in [Table 22-26](#).

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SDHS Control Register 6

**Figure 22-41. SDHSCTL6 Register**

|          |    |          |    |    |    |   |   |  |
|----------|----|----------|----|----|----|---|---|--|
| 15       | 14 | 13       | 12 | 11 | 10 | 9 | 8 |  |
| Reserved |    |          |    |    |    |   |   |  |
| R-0h     |    |          |    |    |    |   |   |  |
| 7        | 6  | 5        | 4  | 3  | 2  | 1 | 0 |  |
| Reserved |    | PGA_GAIN |    |    |    |   |   |  |
| R-0h     |    |          |    |    |    |   |   |  |
| R/W-19h  |    |          |    |    |    |   |   |  |

**Table 22-26. SDHSCTL6 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                              |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------|
| 15-6 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                             |
| 5-0  | PGA_GAIN | R/W  | 19h   | PGA Gain Control bits. These bits control the Gain range of the analog amplifier. See PGA Gain Table for details.<br><br>Reset type: PUC |

### **22.5.16 SDHSCTL7 Register (Offset = 1Eh) [reset = Fh]**

SDHSCTL7 is shown in [Figure 22-42](#) and described in [Table 22-27](#).

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SDHS Control Register 7

**Figure 22-42. SDHSCTL7 Register**

|          |    |    |    |         |    |   |   |  |  |  |  |
|----------|----|----|----|---------|----|---|---|--|--|--|--|
| 15       | 14 | 13 | 12 | 11      | 10 | 9 | 8 |  |  |  |  |
| RESERVED |    |    |    |         |    |   |   |  |  |  |  |
| R-0h     |    |    |    |         |    |   |   |  |  |  |  |
| 7        | 6  | 5  | 4  | 3       | 2  | 1 | 0 |  |  |  |  |
| RESERVED |    |    |    | MODOPTI |    |   |   |  |  |  |  |
| R-0h     |    |    |    |         |    |   |   |  |  |  |  |
| R/W-Fh   |    |    |    |         |    |   |   |  |  |  |  |

**Table 22-27. SDHSCTL7 Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-5 | RESERVED | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 4-0  | MODOPTI  | R/W  | Fh    | <p>SDHS Modulator Optimization bits.</p> <p>In order to get the maximum performance of SDHS, it is recommended to configure this bits based on the PLL output frequency.</p> <p>See below for details:</p> <p>PLL output frequency (=Fmod) : MODOPTI bits</p> <p>77MHz &lt;= Fmod &lt;= 80MHz: 0xC</p> <p>74MHz &lt;= Fmod &lt; 77MHz: 0xD</p> <p>71MHz &lt;= Fmod &lt; 74MHz: 0xE</p> <p>68MHz &lt;= Fmod &lt; 71MHz: 0xF (Reset)</p> <p>Where Fmod = PLL output frequency</p> <p>Reset type: PUC</p> |

### 22.5.17 SDHSDT Register (Offset = 22h) [reset = 0h]

SDHSDT is shown in [Figure 22-43](#) and described in [Table 22-28](#).

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SDHS Data Conversion Register

**Figure 22-43. SDHSDT Register**

|        |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|--------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15     | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SDHSDT |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R-0h   |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 22-28. SDHSDT Register Field Descriptions**

| Bit  | Field  | Type | Reset | Description                         |
|------|--------|------|-------|-------------------------------------|
| 15-0 | SDHSDT | R    | 0h    | Conversion Data.<br>Reset type: PUC |

### **22.5.18 SDHSWINHITH Register (Offset = 24h) [reset = 0h]**

SDHSWINHITH is shown in Figure 22-44 and described in Table 22-29.

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SDHS Window Comparator High Threshold Register.

When SDHSCTL3.TRGEN = 1 or SDHSCTL5.SDHS\_LOCK = 1, this register is locked. In that case, an attempt to update this registers will be ignored.

**Figure 22-44. SDHSWINHITH Register**

|         |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|---------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15      | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| WINHITH |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 22-29. SDHSWINHITH Register Field Descriptions**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|---------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | WINHITH | R/W  | 0h    | <p>SDHS Window Comparator High Threshold Register.</p> <p>The user always needs to ensure that the values in this register is in the correct data format. When the conversion data is higher than the value specified in this register, WINHI interrupt flag is asserted. It only works during SDHS conversion is on-going.</p> <p>Note: Once the condition is detected, it takes 4 system clock cycles + 4 sampling periods to update SDHSRIS.WINHI due to synchronization requirement.</p> <p>Reset type: PUC</p> |

### 22.5.19 SDHSWINLOTH Register (Offset = 26h) [reset = 0h]

SDHSWINLOTH is shown in Figure 22-45 and described in Table 22-30.

[Return to Summary Table.](#)

SDHS Window Comparator Low Threshold Register.

When SDHSCTL3.TRGEN bit = 1 or SDHSCTL5.SDHS\_LOCK bit = 1, this register is locked. In that case, an attempt to update this registers will be ignored.

**Figure 22-45. SDHSWINLOTH Register**

|         |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|---------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15      | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| WINLOTH |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| R/W-0h  |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 22-30. SDHSWINLOTH Register Field Descriptions**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|---------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | WINLOTH | R/W  | 0h    | <p>SDHS Window Comparator Low Threshold Register.</p> <p>The user always needs to ensure that the values in this register is in the correct data format. When the conversion data is lower than the value specified in this register, WINLO interrupt flag is asserted. It only works during SDHS conversion is on-going.</p> <p>Note: Note: Once the condition is detected, it takes 4 system clock cycles + 4 sampling periods to update RIS.WINLO due to synchronization requirement.</p> <p>Reset type: PUC</p> |

### 22.5.20 SDHSDTCDA Register (Offset = 28h) [reset = 0h]

SDHSDTCDA is shown in [Figure 22-46](#) and described in [Table 22-31](#).

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DTC destination offset address. As DTC transfers data, this register value increases by 1 at every data transfer.

Note: When SDHSCTL3.TRGEN bit = 1 or SDHSCTL5.SDHS\_LOCK bit = 1, this register is locked. In that case, an attempt to update this registers will be ignored.

**Figure 22-46. SDHSDTCDA Register**

| 15       | 14 | 13    | 12 | 11     | 10 | 9 | 8 |
|----------|----|-------|----|--------|----|---|---|
| Reserved |    |       |    | DTCDA  |    |   |   |
| R-0h     |    |       |    | R/W-0h |    |   |   |
| 7        | 6  | 5     | 4  | 3      | 2  | 1 | 0 |
|          |    | DTCDA |    |        |    |   |   |
|          |    |       |    | R/W-0h |    |   |   |

**Table 22-31. SDHSDTCDA Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                           |
| 14-0 | DTCDA    | R/W  | 0h    | <p>DTC destination offset address. Destination location = base address + DTCDA x 2.</p> <p>The address offset for DTC destination memory. The size of the destination memory is up to 64KB. The address register value increases by 1 at every data transfer.</p> <p>Note: Care must be taken not to go beyond the available memory address range (specified by the device datasheet). The DTC is able to access the LEA RAM only.</p> |

## **Metering Test Interface (MTIF)**

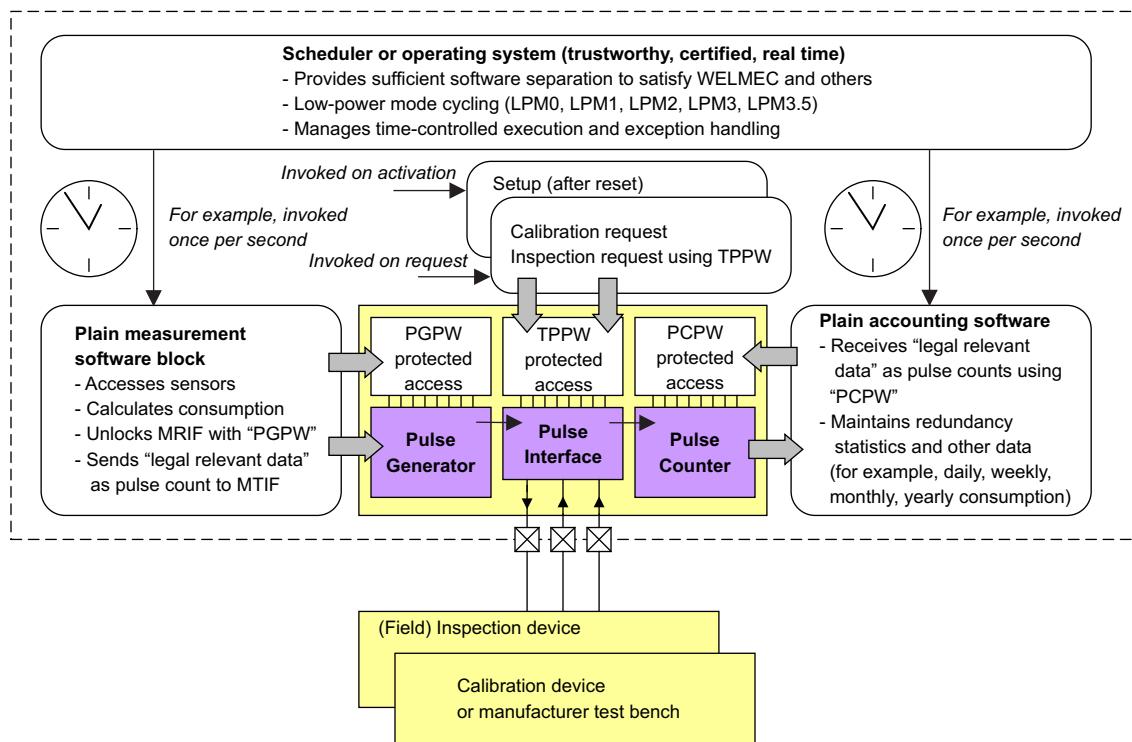
This chapter describes the MSP430 Metering Test Interface (MTIF) module.

| Topic                               | Page       |
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## 23.1 MTIF Introduction

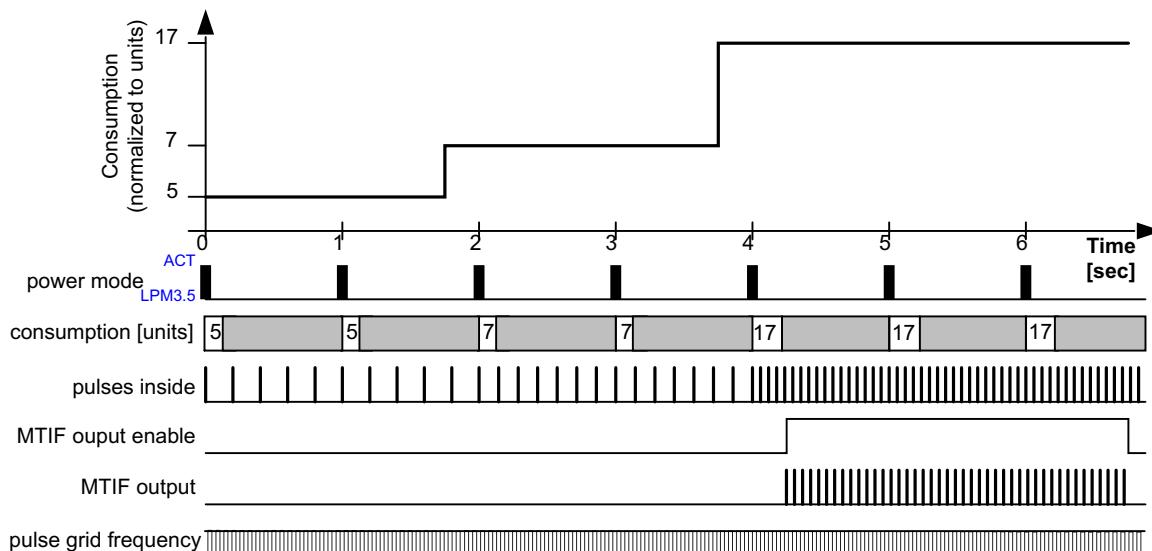
The Metering Test Interface (MTIF) is module is used to implement a simple pulse interface indicating the current consumption measured by the meter. MTIF provides three independent password-controlled access ports. One for the pulse generator, one for the pulse counter, and one for configuration and maintenance. Because all three passwords are different, a clear software separation can be achieved.

**Figure 23-1** shows an assumed software stack of a meter that is divided into smaller blocks, thus allowing certification. The measurement software block measures the consumption and delivers its values to the MTIF pulse generator. The accounting software picks up the pulses from the pulse counter and generates the consumption values and records them. During a field inspection or calibration, the MTIF pulses are brought out to the MTIF output pins without changing the operation mode of measurement software and accounting software. A scheduler or operating system can invoke measurement software and accounting software at independent rates. The pulses on the MTIF output pin are generated in the power modes AM, LPM0, LPM1, LPM2, LPM3 and LPM3.5.



**Figure 23-1. MTIF Use Case**

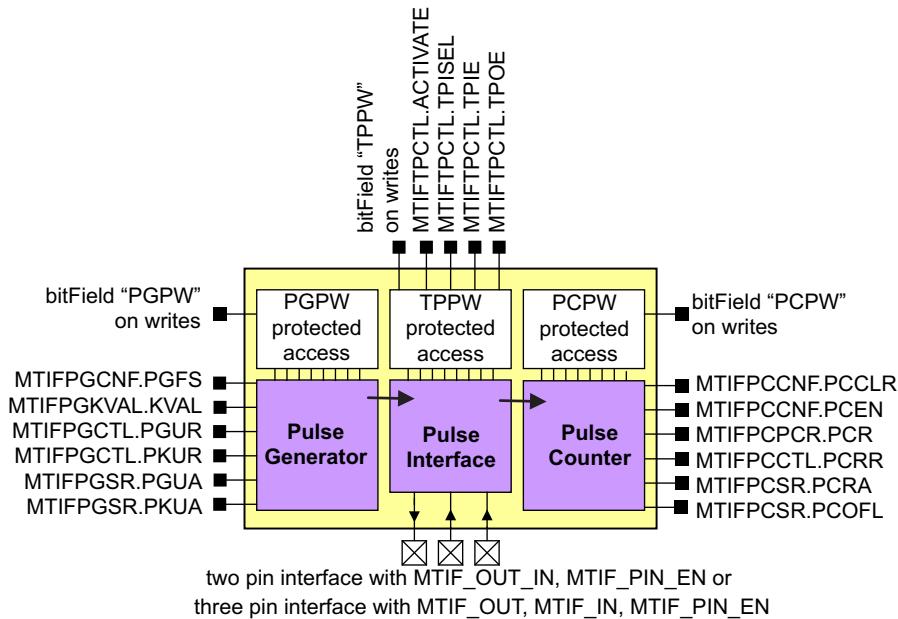
**Figure 23-2** shows the MTIF in its operation. At  $t = 0$  seconds, a consumption of 5 units is measured, this consumption increases stepwise, first to 7 units then to 17 units per second. The single measurement values are converted into pulses by the pulse generator, then transferred to and counted by the pulse counter. While the MTIF output is enabled, the pulse train is sent to the MTIF output.



**Figure 23-2. MTIF Pulse Diagram**

## 23.2 MTIF Operation

The MTIF module can be configured in active mode like any other MSP430 module. The inner core of MTIF operates as the RTC from a power domain that is still active in LPM3.5.



**Figure 23-3. MTIF Internal Interfaces**

### 23.2.1 MTIF and RTC\_C

MTIF and RTC share the same clock source, power, and resets. MTIF can therefore be kept synchronous with the RTC. With an RTC operated from 32.768 kHz, the MTIF can generate pulse rates from 8 to 1024 pulses per second.

### 23.2.2 Initialization of the MTIF

Before configuring the MTIF, the RTC module must be configured for operation. Choose the maximum pulse frequency for operation and select PGFS accordingly (see [Table 23-1](#)). In the following initialization example, a grid frequency of 256 Hz is chosen. The grid frequency is the frequency at which the inner state machines of the pulse generator and the pulse counter run. The width of pulses and the gaps are derived from this frequency. A frequency of 256 Hz allows a pulse rate of 128 pulses per seconds. The frame duration is 1 second. Within this second, up to 127 pulses can be generated. No pulse is generated in the update time slot.

[Table 23-2](#) summarizes the process of initializing MTIF. The MTIF requires a running RTC, therefore the RTC is initialized first. Next, the MTIF pulse generator, pins, and counter are configured. Optionally, the pulse counter can be cleared (regulations in some countries require that the counter can be cleared only once in a meter's lifetime).

**Table 23-1. PGFS Values**

| PGFS | Pulses Rate | Frame Duration | Update Time Slot        | Grid Frequency |
|------|-------------|----------------|-------------------------|----------------|
| 0    | 8           | 16 s           | 62 ms before frame end  | 16 Hz          |
| 1    | 16          | 8 s            | 31 ms before frame end  | 32 Hz          |
| 2    | 32          | 4 s            | 15 ms before frame end  | 64 Hz          |
| 3    | 64          | 2 s            | 8 ms before frame end   | 128 Hz         |
| 4    | 128         | 1 s            | 4 ms before frame end   | 256 Hz         |
| 5    | 256         | 500 ms         | 2 ms before frame end   | 512 Hz         |
| 6    | 512         | 250 ms         | 1 ms before frame end   | 1024 Hz        |
| 7    | 1024        | 125 ms         | 500 µs before frame end | 2048 Hz        |

**Table 23-2. MTIF Initialization**

| Order | Required                                                        | Comment                                                                 |
|-------|-----------------------------------------------------------------|-------------------------------------------------------------------------|
| 1     | Configure and enable the RTC                                    | See RTC module chapter for details                                      |
| 2     | Write to MTIFPGCNF (PGPW = 0x5A, PGFS = 5, PGCLR = 1, PGEN = 1) | Set grid frequency to 256 Hz, clear and enable the MTIF pulse generator |
| 3     | Write to MTIFPGCTL (PGPW = 0x5A, PGUR = 1)                      | Request update of grid frequency setting                                |
| 4     | Check for MTIFPGST.PGUA = 1                                     | Check for acknowledge of PGFS setting                                   |
| 5     | Write to MTIFPCCNF (PCPW = 0xA5, PCCLR = 1, PCEN = 1)           | Clear and enable MTIF pulse counter                                     |
| 6     | Write to MTIFTPCTL (TPPW = 0xC3, ACTIVATE = 1, TPOE = 1)        | Enable MTIF output enable pin to control MTIF output                    |

### 23.2.3 Setting the Pulse Rate

To set the pulse rate to  $n$  pulses per frame, write the required pulse count  $n$  into MTIFPGKVAL.KVAL =  $n$  with proper password and request an update by setting MTIFPGCTL.PKUR = 1 with password. The update occurs at the last time slot of the current frame. MTIFPGCTL.PKUA may be polled after for 1 to verify an update of MTIFPGKVAL.

[Table 23-3](#) shows a simple example to set the pulse rate.

**Table 23-3. Setting the Pulse Rate**

| Order | LPM3 operation                                | LPM3.5 operation                              | Comment                           |
|-------|-----------------------------------------------|-----------------------------------------------|-----------------------------------|
| 1     | Check if MTIFPGSR.PGUA = 0                    | Check if MTIFPGSR.PGUA = 0                    | Check if last request is complete |
| 2     | Write to MTIFPGKVAL(PGPW = 0x5A, KVAL = $n$ ) | Write to MTIFPGKVAL(PGPW = 0x5A, KVAL = $n$ ) | Set to $n$ pulses                 |
| 3     | Write to MTIFPGCTL (PCPW = 0x5A, PGUR = 1)    | Write to MTIFPGCTL (PCPW = 0x5A, PGUR = 1)    | Request update of pulse generator |
| 4     | Enter LPM3                                    | Enter LPM3.5                                  | Optional, when required           |

### 23.2.4 Reading Pulse Counter

To read the pulse counter perform a read request to update the pulse counter read register by writing MTIFPCCTL.PCRR = 1 with password, then wait for the acknowledge on MTIFPCST.PCRA for confirmation.

**Table 23-4. Reading the Pulse Rate**

| Order | LPM3 operation                                                                                | Comment                                                            |
|-------|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------|
| 1     | Check if MTIFPCSR.PCRA = 0                                                                    | Check if last request is complete                                  |
| 2     | Write to MTIFPCCTL (PGPW = 0xA5, PCRR = 1)                                                    | Request update of pulse counter read register                      |
| 3     | Wait for MTIFPCSR .PCRA = 1                                                                   | Wait until update request is acknowledged                          |
| 4     | Read MTIFPCR register                                                                         | Treat the count value as signed 16 bit value                       |
| 5     | Subtract the old (previous) value from new value; this is done after reading the PCSR.OFL bit | Calculate the difference with wrap around correction when negative |

MTIFPCSE.PCOFL indicates an wrap around of the pulse counter. MTIFPCSR.PCOFL can be considered as the 17<sup>th</sup> bit of the counter. XOR the previous read with the current read value to determine the overflow condition.

### 23.2.5 Synchronizing Pulse Generator Timing to Application

At the very first start up, perform an update request: set MTIFPGCTL.PGUR, poll MTIFPGSR.PGUA for changing, then read the RTC prescaler registers after the MTIFPGSR.PGUA change. The RTC prescaler value indicates the moment of the update slot for the selected frame rate. Alternatively, set the RTC prescaler registers after a MTIFPGSR.PGUA change for synchronization.

In most cases, the pulse generator frame rate and the measurement rate of the meter are kept the same. If the MTIFPGKVAL register is updated much faster than the pulse generator frame frequency, the value read during the update time slot is used for the next frame.

### 23.2.6 Various Resets During MTIF Operation

The MTIF module provides immunity against most system reset types. A power-up clear (PUC) resets the watchdog timer (WDT), and password violation resets do not cause any changes in setting, count, and behavior of the MTIF setting.

A power-on reset (POR) stops the RTC and low-frequency crystal and sets MTIFPGCNF.PGEN = 0 and MTIFPCCNF.PCEN = 0. After a POR, reactivate the module and settings and record the POR event as an error with a timestamp for later reference, if required by the application.

A POR (for example, after waking up from LPMx.5) resets the MTIF pin configuration, but the content of the pulse generator setting and the pulse counter are not affected. Reinitialize the MTIF pin configuration by software.

A BOR (resulting from a power supply drop) resets the MTIF module, including the pulse generating setting and pulse counter value.

A reset caused by the RST pin resets the MTIF module. To avoid this type of reset, select the NMI functionality on the RST/NMI pin. Restore SFRRPCR.SYSNMI on any other reset.

### 23.2.7 PUC Reset During Register Access

PUC resets can occur during register access of the pulse generator registers, pulse counter registers, or pin configuration registers. A PUC reset requires immediate action during the following reset start-up sequence, because the configuration and counter value may be corrupted. Alternatively, use software signatures in FRAM and Hoare\_Monitors to keep track of what was happening and resolve the situation.

The application can keep FRAM structures (in separate storage clusters) that contain "old\_value", "new\_value", "transaction\_number", and "transaction\_state". Record and update each phase of the transaction. This allows recovery after any reset on the next start-up.

### 23.2.8 Enabling the Pulse Generator and the Pulse Counter

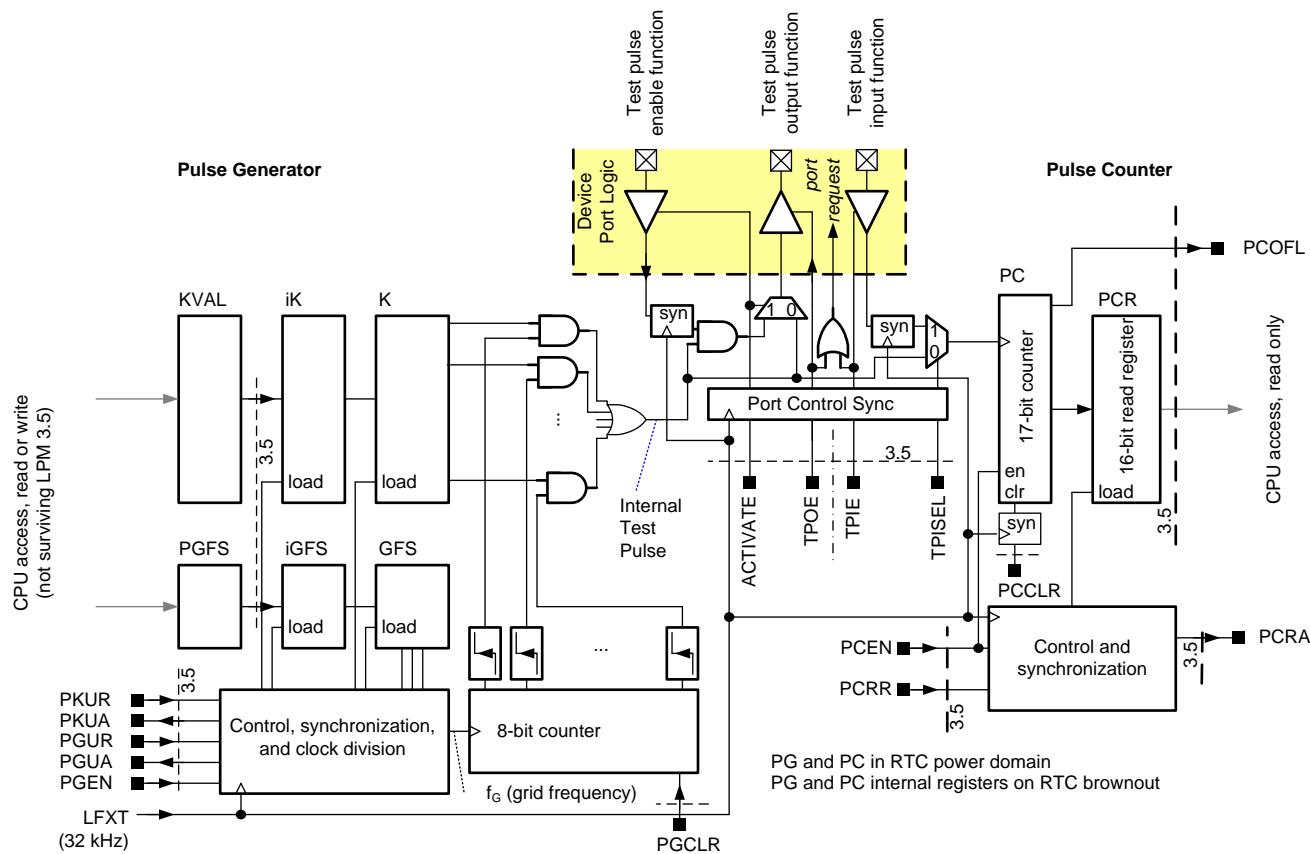
The configuration bits MTIFPGCNT.PGEN and MTIFPCCNF.PCEN are expected to be static during a regular metering operation. At start-up of the meter application, a reset caused by the RST pin after recovery from an power loss, the MTIF behaves as follows:

The prescaler of the pulse generator is cleared when the pulse generator is disabled. After the application enables MTIFPGCTL.PGEN, the pulse generation starts after 2 to 3 cycles (with the LF clock at 32 kHz). Even though the pulse counter may be cleared independent of MTIFPGCTL.PCEN, make sure that the counter is cleared either before or after 2 to 3 LFCLK cycles to avoid conflicts.

The pulse counter increments on high active pulses. Shorter pulses (artifacts) may be generated when enabling and disabling the MTIF output pin. A complete MTIFPCCTL.PCEN disable and enable cycle can cause up to two increments of the pulse counter when using the external pulse input pin.

### 23.3 MTIF Block Diagram

Figure 23-4 shows the interior of the MTIF module with an 3-pin MTIF I/O configuration. The dashed lines represent the power domain crossings to areas that are powered in LPM0 to LPM3.5.



**Figure 23-4. MTIF Block Diagram**

#### 23.3.1 Test Interface Input

The input does not feature any filter logic. To filter low-frequency contact bouncing, use an external RC filter. For higher ESD, EMI, and RFI tolerance, use appropriate shielding and filtering. The enable function of the test interface input is located in a separate register to fulfill the functional isolation requirement of various regulations.

The MTIF module supports one input and one output, which can be on separate pins or on a shared pin, depending on the specific device.

## 23.4 MTIF Registers

Table 23-5 lists the memory-mapped registers for the MTIF. All register offset addresses not listed in Table 23-5 should be considered as reserved locations and the register contents should not be modified.

**Table 23-5. MTIF Registers**

| Offset | Acronym    | Register Name                          | Type       | Reset | Section                        |
|--------|------------|----------------------------------------|------------|-------|--------------------------------|
| 0h     | MTIFPGCNF  | Pulse Generator Configuration Register | read-write | 6970h | <a href="#">Section 23.4.1</a> |
| 2h     | MTIFPGKVAL | Pulse Generator Value Register         | read-write | 6900h | <a href="#">Section 23.4.2</a> |
| 4h     | MTIFPGCTL  | Pulse Generator Control Register       | read-write | 6900h | <a href="#">Section 23.4.3</a> |
| 6h     | MTIFPGCSR  | Pulse Generator Status Register        | read-write | 0h    | <a href="#">Section 23.4.4</a> |
| 8h     | MTIFPCCNF  | Pulse Counter Configuration Register   | read-write | 9600h | <a href="#">Section 23.4.5</a> |
| Ah     | MTIFPCR    | Pulse Counter Value Register           | read-write |       | <a href="#">Section 23.4.6</a> |
| Ch     | MTIFPCCTL  | Pulse Counter Control Register         | read-write | 0h    | <a href="#">Section 23.4.7</a> |
| Eh     | MTIFPCCSR  | Pulse Counter Status Register          | read-write | 0h    | <a href="#">Section 23.4.8</a> |
| 10h    | MTIFTPCTL  | Measurement Test Port Control Register | read-write | F00h  | <a href="#">Section 23.4.9</a> |

### 23.4.1 MTIFPGCNF Register (Offset = 0h) [reset = 6970h]

MTIFPGCNF is shown in [Figure 23-5](#) and described in [Table 23-6](#).

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Pulse Generator Configuration Register

**Figure 23-5. MTIFPGCNF Register**

|          |    |        |    |          |           |          |        |
|----------|----|--------|----|----------|-----------|----------|--------|
| 15       | 14 | 13     | 12 | 11       | 10        | 9        | 8      |
| PGPW     |    |        |    |          |           |          |        |
| RH/W-69h |    |        |    |          |           |          |        |
| 7        | 6  | 5      | 4  | 3        | 2         | 1        | 0      |
| RESERVED |    | PGFS   |    | RESERVED | PGCLR     | RESERVED | PGEN   |
| R/W-0h   |    | R/W-7h |    | R/W-0h   | RH/W1S-0h | R/W-0h   | R/W-0h |

**Table 23-6. MTIFPGCNF Register Field Descriptions**

| Bit  | Field    | Type   | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|----------|--------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | PGPW     | RH/W   | 69h   | PG password. Always reads as 0x69. Must be written as 0x5A for register changes to be effective. This password differs from the pin configuration and pulse counter passwords.<br>Reset type: PUC<br>5Ah (W) = PGPW : Must be written as 0x5A for register changes to be effective.<br>69h (R) = PGPW_R : Read value while locked                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 7    | RESERVED | R/W    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 6-4  | PGFS     | R/W    | 7h    | PG pulse grid frequency select. This value determines at which time grid pulses are generated. The pulse generator frame frequency is an 1/256th of this (MTIFPGCNF.PGEN has to be one to perform a change).<br>Reset type: PUC<br>0h (R/W) = Pulse grid frequency is set to 8 Hz (nominal)<br>1h (R/W) = Pulse grid frequency is set to 16 Hz (nominal)<br>2h (R/W) = Pulse grid frequency is set to 32 Hz (nominal)<br>3h (R/W) = Pulse grid frequency is set to 64 Hz (nominal)<br>4h (R/W) = Pulse grid frequency is set to 128 Hz (nominal)<br>5h (R/W) = Pulse grid frequency is set to 256 Hz (nominal)<br>6h (R/W) = Pulse grid frequency is set to 512 Hz (nominal)<br>7h (R/W) = Pulse grid frequency is set to 1024 Hz (nominal) default |
| 3    | RESERVED | R/W    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 2    | PGCLR    | RH/W1S | 0h    | PG pulse counter clear. This bit allows to clear the pulse generator (MTIFPGCNF.PGEN has to be set to one to perform a clear). Note!: A clear request is being latched and released after the clear is executed. While MTIFPGCNF.PCEN =0 a time shift is generated. The clear occurs then after the clock is reenabled. This bit is for triggering only; its state cannot be read back<br>Reset type: PUC                                                                                                                                                                                                                                                                                                                                           |
| 1    | RESERVED | R/W    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 0    | PGEN     | R/W    | 0h    | PG sub module enable. This bit enables the PG sub module when set to one<br>Reset type: POR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

### 23.4.2 MTIFPGKVAL Register (Offset = 2h) [reset = 6900h]

MTIFPGKVAL is shown in [Figure 23-6](#) and described in [Table 23-7](#).

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Pulse Generator Value Register

**Figure 23-6. MTIFPGKVAL Register**

|          |        |    |    |    |    |   |   |
|----------|--------|----|----|----|----|---|---|
| 15       | 14     | 13 | 12 | 11 | 10 | 9 | 8 |
| PGPW     |        |    |    |    |    |   |   |
| R/W-69h  |        |    |    |    |    |   |   |
| 7        | 6      | 5  | 4  | 3  | 2  | 1 | 0 |
| RESERVED | KVAL   |    |    |    |    |   |   |
|          | R/W-0h |    |    |    |    |   |   |

**Table 23-7. MTIFPGKVAL Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                       |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | PGPW     | R/W  | 69h   | PG password. Always reads as 0x69. Must be written as 0x5A for register changes to be effective. This password differs from the pin configuration and pulse counter passwords.<br>Reset type: PUC<br>5Ah (W) = PGPW : Must be written as 0x5A for register changes to be effective.<br>69h (R) = PGPW_R : Read value while locked |
| 7    | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                   |
| 6-0  | KVAL     | R/W  | 0h    | Pulse Count Number. This register value determines how many pulses are generated within 256 periods of the pulse grid frequency (with password protection as in MTIFPGCNF).<br>MTIFPGCNF.PGEN has to be one to perform a change.<br>Reset type: PUC                                                                               |

### 23.4.3 MTIFPGCTL Register (Offset = 4h) [reset = 6900h]

MTIFPGCTL is shown in [Figure 23-7](#) and described in [Table 23-8](#).

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Pulse Generator Control Register

**Figure 23-7. MTIFPGCTL Register**

|          |    |    |    |           |      |           |   |
|----------|----|----|----|-----------|------|-----------|---|
| 15       | 14 | 13 | 12 | 11        | 10   | 9         | 8 |
| PGPW     |    |    |    |           |      |           |   |
| R/W-69h  |    |    |    |           |      |           |   |
| 7        | 6  | 5  | 4  | 3         | 2    | 1         | 0 |
| RESERVED |    |    |    |           | PGUR | PKUR      |   |
| R/W-0h   |    |    |    | RH/W1S-0h |      | RH/W1S-0h |   |

**Table 23-8. MTIFPGCTL Register Field Descriptions**

| Bit  | Field    | Type   | Reset | Description                                                                                                                                                                                                                                                                                                                       |
|------|----------|--------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | PGPW     | R/W    | 69h   | PG password. Always reads as 0x69. Must be written as 0x5A for register changes to be effective. This password differs from the pin configuration and pulse counter passwords.<br>Reset type: PUC<br>5Ah (W) = PGPW : Must be written as 0x5A for register changes to be effective.<br>69h (R) = PGPW_R : Read value while locked |
| 7-2  | RESERVED | R/W    | 0h    |                                                                                                                                                                                                                                                                                                                                   |
| 1    | PGUR     | RH/W1S | 0h    | Pulse Grid Frequency Update Request (with password protection as in MTIFPGCNF). The update of PGFS occurs during the frequency grid slot 0xff (e.g. in the last 4ms of a second with an pulse grid frequency of 256Hz)<br>Reset type: PUC                                                                                         |
| 0    | PKUR     | RH/W1S | 0h    | Pulse K-Count Update Request (with password protection as in MTIFPGCNF). The update of KVAL occurs during the frequency grid slot 0xff (e.g. in the last 4ms of a second with a pulse grid frequency of 256Hz)<br>Reset type: PUC                                                                                                 |

### 23.4.4 MTIFPGSR Register (Offset = 6h) [reset = 0h]

MTIFPGSR is shown in [Figure 23-8](#) and described in [Table 23-9](#).

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Pulse Generator Status Register

**Figure 23-8. MTIFPGSR Register**

|          |    |    |    |    |    |         |         |
|----------|----|----|----|----|----|---------|---------|
| 15       | 14 | 13 | 12 | 11 | 10 | 9       | 8       |
| RESERVED |    |    |    |    |    |         |         |
| R/W-0h   |    |    |    |    |    |         |         |
| 7        | 6  | 5  | 4  | 3  | 2  | 1       | 0       |
| RESERVED |    |    |    |    |    | PGUA    | PKUA    |
| R/W-0h   |    |    |    |    |    | RH/W-0h | RH/W-0h |

**Table 23-9. MTIFPGSR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                     |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-2 | RESERVED | R/W  | 0h    |                                                                                                                                                 |
| 1    | PGUA     | RH/W | 0h    | Pulse Grid Frequency Update Acknowledge. This acknowledges a MTIFPGSR.PGUR 2-3 LFCLK cycles after the PGFS has been updated.<br>Reset type: PUC |
| 0    | PKUA     | RH/W | 0h    | Pulse K-Count Update Acknowledge. This acknowledges a MTIFPGSR.PKUR 2-3 LFCLK cycles after the K-values have been updated.<br>Reset type: PUC   |

### 23.4.5 MTIFPCCNF Register (Offset = 8h) [reset = 9600h]

MTIFPCCNF is shown in [Figure 23-9](#) and described in [Table 23-10](#).

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Pulse Counter Configuration Register

**Figure 23-9. MTIFPCCNF Register**

|          |    |    |    |           |          |        |          |
|----------|----|----|----|-----------|----------|--------|----------|
| 15       | 14 | 13 | 12 | 11        | 10       | 9      | 8        |
| PCPW     |    |    |    |           |          |        |          |
| RH/W-96h |    |    |    |           |          |        |          |
| 7        | 6  | 5  | 4  | 3         | 2        | 1      | 0        |
| RESERVED |    |    |    | PCCLR     | RESERVED | PCEN   |          |
| R/W-0h   |    |    |    | RH/W1S-0h | R/W-0h   | R/W-0h | R/W1S-0h |

**Table 23-10. MTIFPCCNF Register Field Descriptions**

| Bit  | Field    | Type   | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|----------|--------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | PCPW     | RH/W   | 96h   | Pulse counter password. Always reads as 0x96. Must be written as 0xA5 for register changes to be effective. This password differs from the pin configuration and pulse generator passwords<br>Reset type: PUC<br>96h (R) = PCPW_R : Read value while locked<br>A5h (W) = PCPW : 0xA5                                                                                                                            |
| 7-3  | RESERVED | R/W    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 2    | PCCLR    | RH/W1S | 0h    | Pulse counter clear. This bit allows to clear the pulse counter when set to one (MTIFPCCNF.PCEN has to be one to perform a clear).<br>Note!: A clear request is being latched and released after the clear is executed. While MTIFPCCNF.PCEN=0 a time shift is generated. The clear occurs then after the clock is reenabled. This bit is for triggering only; its state cannot be read back<br>Reset type: PUC |
| 1    | RESERVED | R/W    | 0h    |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 0    | PCEN     | R/W1S  | 0h    | PC sub module enable. This bit enables the PC sub module when set to one<br>Reset type: POR                                                                                                                                                                                                                                                                                                                     |

### 23.4.6 MTIFPCR Register (Offset = Ah) [reset = 0h]

MTIFPCR is shown in [Figure 23-10](#) and described in [Table 23-11](#).

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Pulse Counter Value Register

**Figure 23-10. MTIFPCR Register**

|     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| 15  | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PCR |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |
| RH- |    |    |    |    |    |   |   |   |   |   |   |   |   |   |   |

**Table 23-11. MTIFPCR Register Field Descriptions**

| Bit  | Field | Type | Reset | Description                                                                                 |
|------|-------|------|-------|---------------------------------------------------------------------------------------------|
| 15-0 | PCR   | RH   | 0     | Pulse Counter value register. This register returns the count value from the pulse counter. |

### **23.4.7 MTIFPCCTL Register (Offset = Ch) [reset = 0h]**

MTIFPCCTL is shown in [Figure 23-11](#) and described in [Table 23-12](#).

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Pulse Counter Control Register

**Figure 23-11. MTIFPCCTL Register**

|          |    |    |    |    |    |           |   |
|----------|----|----|----|----|----|-----------|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9         | 8 |
| RESERVED |    |    |    |    |    |           |   |
| R/W-0h   |    |    |    |    |    |           |   |
| 7        | 6  | 5  | 4  | 3  | 2  | 1         | 0 |
| RESERVED |    |    |    |    |    | PCRR      |   |
| R/W-0h   |    |    |    |    |    | RH/W1S-0h |   |

**Table 23-12. MTIFPCCTL Register Field Descriptions**

| Bit  | Field    | Type   | Reset | Description                                                                                                                    |
|------|----------|--------|-------|--------------------------------------------------------------------------------------------------------------------------------|
| 15-1 | RESERVED | R/W    | 0h    |                                                                                                                                |
| 0    | PCRR     | RH/W1S | 0h    | Pulse Counter Read Request. Set this to request an update of MTIFPCR read register from the actual counter.<br>Reset type: PUC |

### 23.4.8 MTIFPCSR Register (Offset = Eh) [reset = 0h]

MTIFPCSR is shown in [Figure 23-12](#) and described in [Table 23-13](#).

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Pulse Counter Status Register

**Figure 23-12. MTIFPCSR Register**

|          |    |    |    |    |    |         |         |
|----------|----|----|----|----|----|---------|---------|
| 15       | 14 | 13 | 12 | 11 | 10 | 9       | 8       |
| RESERVED |    |    |    |    |    |         |         |
| R/W-0h   |    |    |    |    |    |         |         |
| 7        | 6  | 5  | 4  | 3  | 2  | 1       | 0       |
| RESERVED |    |    |    |    |    | PCOFL   | PCRA    |
| R/W-0h   |    |    |    |    |    | RH/W-0h | RH/W-0h |

**Table 23-13. MTIFPCSR Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                            |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-2 | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                        |
| 1    | PCOFL    | RH/W | 0h    | Pulse counter overflow. This bit indicates an overflow of the pulse counter when its value changes since the last read request procedure. It is basically the 17th bit of the counter<br>Reset type: PUC                                                                                                                               |
| 0    | PCRA     | RH/W | 0h    | Pulse counter read acknowledge. This acknowledges the update of the PCR register as response to the MTIFPCCTL.PCRR read request. Note!: A read request is being latched. A temporary disable (MTIFPCCNF.PCEN=0) allows a time shift. The read will then be performed and acknowledged after the clock is reenabled.<br>Reset type: PUC |

### 23.4.9 MTIFTPCTL Register (Offset = 10h) [reset = F00h]

MTIFTPCTL is shown in [Figure 23-13](#) and described in [Table 23-14](#).

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Measurement Test Port Control Register

**Figure 23-13. MTIFTPCTL Register**

|          |    |    |    |          |        |        |        |
|----------|----|----|----|----------|--------|--------|--------|
| 15       | 14 | 13 | 12 | 11       | 10     | 9      | 8      |
| TPPW     |    |    |    |          |        |        |        |
| RH/W-Fh  |    |    |    |          |        |        |        |
| 7        | 6  | 5  | 4  | 3        | 2      | 1      | 0      |
| RESERVED |    |    |    | ACTIVATE | TPISEL | TPIE   | TPOE   |
| R/W-0h   |    |    |    | R/W-0h   | R/W-0h | R/W-0h | R/W-0h |

**Table 23-14. MTIFTPCTL Register Field Descriptions**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                      |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | TPPW     | RH/W | Fh    | Test port password. Always reads as 0x0F. Must be written as 0xC3 for register changes to be effective. This password differs from the pulse generator and pulse counter passwords<br>Reset type: PUC<br>0Fh (R) = TPPW_R : Read value while locked<br>C3h (W) = TPPW : 0xC3                                                                                                     |
| 7-4  | RESERVED | R/W  | 0h    |                                                                                                                                                                                                                                                                                                                                                                                  |
| 3    | ACTIVATE | R/W  | 0h    | Test port terminal enable activation. This value determines if the testport output is enabled solely by software or by software and hardware.<br>Reset type: POR<br>0h (R/W) = The test port output is enabled solely by TPOE (enabled if MTIFTPCTL.TPOE=1)<br>1h (R/W) = The testport output requires both MTIFTPCTL.TPOE=1 and the MTPE_IN_ENABLE pin to be high to be enabled |
| 2    | TPISEL   | R/W  | 0h    | Test port input select for pulse counter. This value determines the source for the pulse counter.<br>Reset type: POR<br>0h (R/W) = The pulse generator is used as input<br>1h (R/W) = The test port input terminal is selected as input                                                                                                                                          |
| 1    | TPIE     | R/W  | 0h    | Test port input enable. This bit allows to enable the test input port<br>Reset type: POR                                                                                                                                                                                                                                                                                         |
| 0    | TPOE     | R/W  | 0h    | Test port output enable. This bit allows to enable the test pulse output when set to one<br>Reset type: POR                                                                                                                                                                                                                                                                      |

## ***Watchdog Timer (WDT\_A)***

The watchdog timer is a 32-bit timer that can be used as a watchdog or as an interval timer. This chapter describes the watchdog timer. The enhanced watchdog timer, WDT\_A, is implemented in all devices.

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## 24.1 WDT\_A Introduction

The primary function of the watchdog timer (WDT\_A) module is to perform a controlled system restart after a software problem occurs. If the selected time interval expires, a system reset is generated. If the watchdog function is not needed in an application, the module can be configured as an interval timer and can generate interrupts at selected time intervals.

Features of the watchdog timer module include:

- Eight software-selectable time intervals
- Watchdog mode
- Interval mode
- Password-protected access to Watchdog Timer Control (WDTCTL) register
- Selectable clock source
- Can be stopped to conserve power
- Clock fail-safe feature

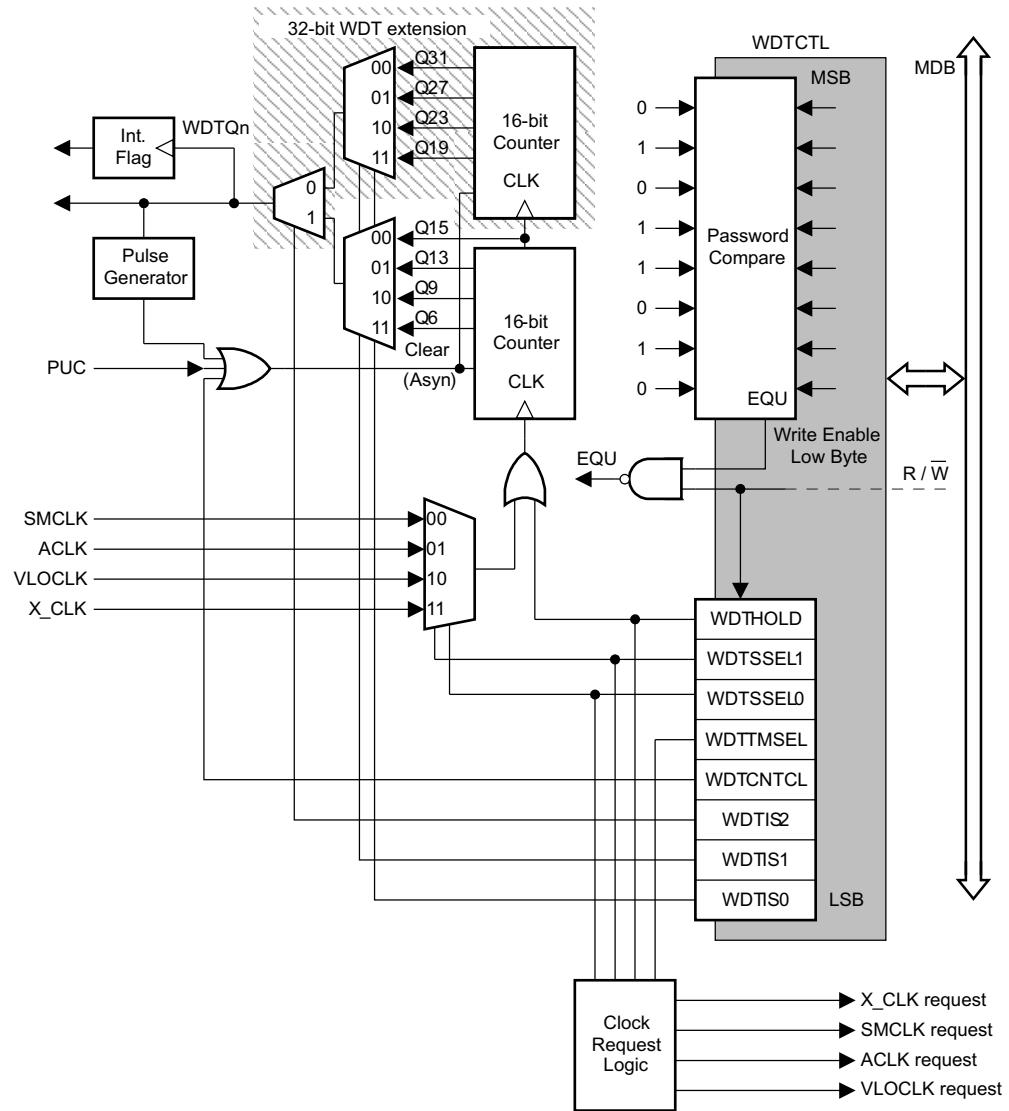
The watchdog timer block diagram is shown in [Figure 24-1](#).

---

**NOTE: Watchdog timer powers up active.**

After a PUC, the WDT\_A module is automatically configured in the watchdog mode with an initial approximately 32-ms reset interval using the SMCLK. The user must set up or halt the WDT\_A before the initial reset interval expires.

---



**Figure 24-1. Watchdog Timer Block Diagram**

## 24.2 WDT\_A Operation

The watchdog timer module can be configured as either a watchdog or interval timer with the WDTCTL register. WDTCTL is a 16-bit password-protected read/write register. Any read or write access must use word instructions, and write accesses must include the write password 05Ah in the upper byte. A write to WDTCTL with any value other than 05Ah in the upper byte is a password violation and causes a PUC system reset, regardless of timer mode. Any read of WDTCTL reads 069h in the upper byte. Byte reads on WDTCTL high or low part result in the value of the low byte. Writing byte wide to upper or lower parts of WDTCTL results in a PUC.

### 24.2.1 Watchdog Timer Counter (WDTCNT)

The WDTCNT is a 32-bit up counter that is not directly accessible by software. The WDTCNT is controlled and its time intervals are selected through the Watchdog Timer Control (WDTCTL) register. The WDTCNT can be sourced from SMCLK, ACLK, VLOCLK, and X\_CLK on some devices. The clock source is selected with the WDTSEL bits. The timer interval is selected with the WDTIS bits.

### 24.2.2 Watchdog Mode

After a PUC condition, the WDT module is configured in the watchdog mode with an initial 32-ms (approximate) reset interval using the SMCLK. The user must set up, halt, or clear the watchdog timer before this initial reset interval expires, or another PUC is generated. When the watchdog timer is configured to operate in watchdog mode, either writing to WDTCTL with an incorrect password or expiration of the selected time interval triggers a PUC. A PUC resets the watchdog timer to its default condition.

### 24.2.3 Interval Timer Mode

Setting the WDTMSEL bit to 1 selects the interval timer mode. This mode can be used to provide periodic interrupts. In interval timer mode, the WDTIFG flag is set at the expiration of the selected time interval. A PUC is not generated in interval timer mode at expiration of the selected timer interval, and the WDTIFG enable bit WDTIE remains unchanged.

When the WDTIE bit and the GIE bit are set, the WDTIFG flag requests an interrupt. The WDTIFG interrupt flag is automatically reset when its interrupt request is serviced, or may be reset by software. The interrupt vector address in interval timer mode is different from that in watchdog mode.

---

**NOTE: Modifying the watchdog timer**

The watchdog timer interval should be changed together with WDTCNTCL = 1 in a single instruction to avoid an unexpected immediate PUC or interrupt. The watchdog timer should be halted before changing the clock source to avoid a possible incorrect interval.

---

### 24.2.4 Watchdog Timer Interrupts

The watchdog timer uses two bits in the SFRs for interrupt control:

- WDT interrupt flag, WDTIFG, located in SFRIFG1.0
- WDT interrupt enable, WDTIE, located in SFRIE1.0

When using the watchdog timer in the watchdog mode, the WDTIFG flag sources a reset vector interrupt. The WDTIFG can be used by the reset interrupt service routine to determine if the watchdog caused the device to reset. If the flag is set, the watchdog timer initiated the reset condition, either by timing out or by a password violation. If WDTIFG is cleared, the reset was caused by a different source.

When using the watchdog timer in interval timer mode, the WDTIFG flag is set after the selected time interval and requests a watchdog timer interval timer interrupt if the WDTIE and the GIE bits are set. The interval timer interrupt vector is different from the reset vector used in watchdog mode. In interval timer mode, the WDTIFG flag is reset automatically when the interrupt is serviced, or can be reset with software.

### 24.2.5 Fail-Safe Features

The WDT\_A provides a fail-safe clocking feature, ensuring the clock to the WDT\_A cannot be disabled while in watchdog mode. This means the low-power modes may be affected by the choice for the WDT\_A clock.

In watchdog mode the WDT\_A prevents LPMx.5 because in LPMx.5 the WDT\_A cannot operate.

If SMCLK or ACLK fails as the WDT\_A clock source, LFMODCLK clock is automatically selected as the WDT\_A clock source.

When the WDT\_A module is used in interval timer mode, there are no fail-safe features.

### 24.2.6 Operation in Low-Power Modes

The devices have several low-power modes. Different clock signals are available in different low-power modes. The requirements of the application and the type of clocking that is used determine how the WDT\_A should be configured. For example, the WDT\_A should not be configured in watchdog mode with a clock source that is originally sourced from DCO, XT1 in high-frequency mode, or XT2 sourcing SMCLK or ACLK if the user wants to use low-power mode 3. In this case, SMCLK or ACLK would remain enabled, increasing the current consumption of LPM3. When the watchdog timer is not required, the WDTHOLD bit can be used to hold the WDTCNT, reducing power consumption.

Any write operation to WDTCTL must be a word operation with 05Ah (WDTPW) in the upper byte (see [Example 24-1](#)).

#### **Example 24-1. Writes to WDTCTL**

```
; Periodically clear an active watchdog
MOV #WDTPW+WDTIS2+WDTIS1+WDTCNTCL,&WDTCTL
;
; Change watchdog timer interval
MOV #WDTPW+WDTCNTCL+SSEL,&WDTCTL
;
; Stop the watchdog
MOV #WDTPW+WDTHOLD,&WDTCTL
;
; Change WDT to interval timer mode, clock/8192 interval
MOV #WDTPW+WDTCNTCL+WDTTMSEL+WDTIS2+WDTIS0,&WDTCTL
```

## 24.3 WDT\_A Registers

The watchdog timer module registers are listed in [Table 24-1](#). The base address for the watchdog timer module registers and special function registers (SFRs) can be found in the device-specific data sheets. The address offset is given in [Table 24-1](#).

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 24-1. WDT\_A Registers**

| Offset | Acronym  | Register Name          | Type       | Access | Reset | Section                        |
|--------|----------|------------------------|------------|--------|-------|--------------------------------|
| 0Ch    | WDTCTL   | Watchdog Timer Control | Read/write | Word   | 6904h | <a href="#">Section 24.3.1</a> |
| 0Ch    | WDTCTL_L |                        | Read/write | Byte   | 04h   |                                |
| 0Dh    | WDTCTL_H |                        | Read/write | Byte   | 69h   |                                |

### 24.3.1 WDTCTL Register

Watchdog Timer Control Register

**Figure 24-2. WDTCTL Register**

|         |        |         |          |       |       |      |      |
|---------|--------|---------|----------|-------|-------|------|------|
| 15      | 14     | 13      | 12       | 11    | 10    | 9    | 8    |
| WDTPW   |        |         |          |       |       |      |      |
| rw      | rw     | rw      | rw       | rw    | rw    | rw   | rw   |
| 7       | 6      | 5       | 4        | 3     | 2     | 1    | 0    |
| WDTHOLD | WDTSEL | WDTMSEL | WDTCNTCL |       | WDTIS |      |      |
| rw-0    | rw-0   | rw-0    | rw-0     | r0(w) | rw-1  | rw-0 | rw-0 |

**Table 24-2. WDTCTL Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | WDTPW    | RW   | 69h   | Watchdog timer password. Always read as 069h. Must be written as 05Ah, or a PUC is generated.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 7    | WDTHOLD  | RW   | 0h    | Watchdog timer hold. This bit stops the watchdog timer. Setting WDTHOLD = 1 when the WDT is not in use conserves power.<br>0b = Watchdog timer is not stopped<br>1b = Watchdog timer is stopped                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 6-5  | WDTSEL   | RW   | 0h    | Watchdog timer clock source select<br>00b = SMCLK<br>01b = ACLK<br>10b = VLOCLK<br>11b = X_CLK, same as VLOCLK if not defined differently in data sheet                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 4    | WDTMSEL  | RW   | 0h    | Watchdog timer mode select<br>0b = Watchdog mode<br>1b = Interval timer mode                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 3    | WDTCNTCL | RW   | 0h    | Watchdog timer counter clear. Setting WDTCNTCL = 1 clears the count value to 0000h. WDTCNTCL is automatically reset.<br>0b = No action<br>1b = WDTCNT = 0000h                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 2-0  | WDTIS    | RW   | 4h    | Watchdog timer interval select. These bits select the watchdog timer interval to set the WDTIFG flag or generate a PUC.<br>000b = Watchdog clock source / $2^{31}$ (18:12:16 at 32.768 kHz)<br>001b = Watchdog clock source / $2^{27}$ (01:08:16 at 32.768 kHz)<br>010b = Watchdog clock source / $2^{23}$ (00:04:16 at 32.768 kHz)<br>011b = Watchdog clock source / $2^{19}$ (00:00:16 at 32.768 kHz)<br>100b = Watchdog clock source / $2^{15}$ (1 s at 32.768 kHz)<br>101b = Watchdog clock source / $2^{13}$ (250 ms at 32.768 kHz)<br>110b = Watchdog clock source / $2^9$ (15.625 ms at 32.768 kHz)<br>111b = Watchdog clock source / $2^6$ (1.95 ms at 32.768 kHz) |

***Timer\_A***

Timer\_A is a 16-bit timer and counter with multiple capture/compare registers. There can be multiple Timer\_A modules on a given device (see the device-specific data sheet). This chapter describes the operation and use of the Timer\_A module.

| Topic                                  | Page       |
|----------------------------------------|------------|
| <b>25.1 Timer_A Introduction .....</b> | <b>640</b> |
| <b>25.2 Timer_A Operation.....</b>     | <b>642</b> |
| <b>25.3 Timer_A Registers .....</b>    | <b>654</b> |

## 25.1 Timer\_A Introduction

Timer\_A is a 16-bit timer/counter with up to seven capture/compare registers. Timer\_A can support multiple capture/comparisons, PWM outputs, and interval timing. Timer\_A also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

Timer\_A features include:

- Asynchronous 16-bit timer/counter with four operating modes
- Selectable and configurable clock source
- Up to seven configurable capture/compare registers
- Configurable outputs with pulse width modulation (PWM) capability
- Asynchronous input and output latching
- Interrupt vector register for fast decoding of all Timer\_A interrupts

The block diagram of Timer\_A is shown in [Figure 25-1](#).

---

**NOTE: Use of the word count**

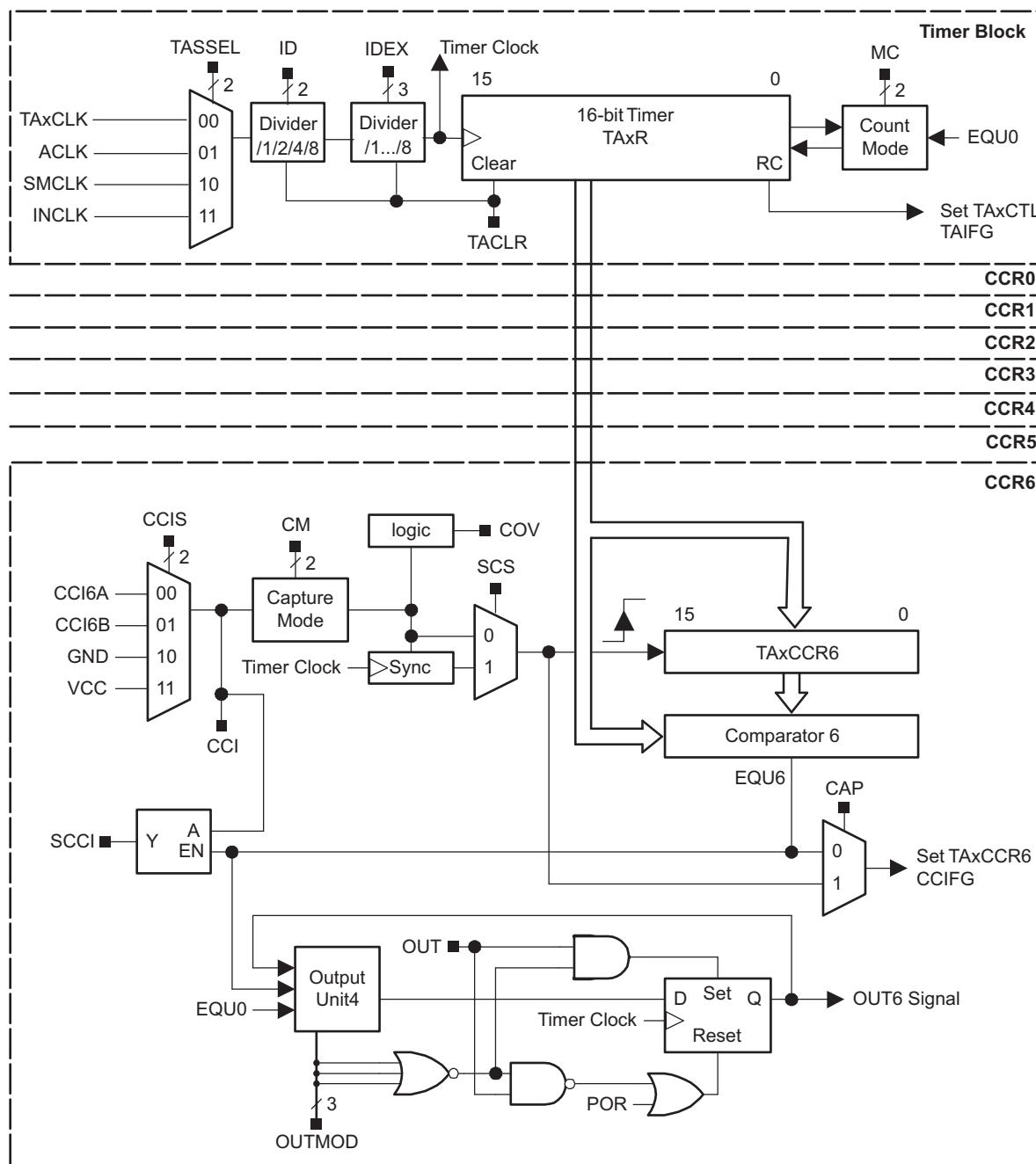
*Count* is used throughout this chapter. It means the counter must be in the process of counting for the action to take place. If a particular value is directly written to the counter, an associated action does not take place.

---

**NOTE: Nomenclature**

There may be multiple instantiations of Timer\_A on a given device. The prefix TAx is used, where x is greater than or equal to zero indicating the Timer\_A instantiation. For devices with one instantiation, x = 0. The suffix n, where n = 0 to 6, represents the specific capture/compare registers associated with the Timer\_A instantiation.

---



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**Figure 25-1. Timer\_A Block Diagram**

## 25.2 Timer\_A Operation

The Timer\_A module is configured with user software. The setup and operation of Timer\_A are discussed in the following sections.

### 25.2.1 16-Bit Timer Counter

The 16-bit timer/counter register, **TAXR**, increments or decrements (depending on mode of operation) with each rising edge of the clock signal. TAXR can be read or written with software. Additionally, the timer can generate an interrupt when it overflows.

TAR may be cleared by setting the TACLR bit. Setting TACLR also clears the clock divider counter logic (the divider setting remains unchanged) and count direction for up/down mode.

---

**NOTE: Modifying Timer\_A registers**

TI recommends stopping the timer before modifying its operation (with exception of the interrupt enable, interrupt flag, and TACLR) to avoid errant operating conditions.

When the timer clock is asynchronous to the CPU clock, any read from **TAXR** should occur while the timer is not operating or the results may be unpredictable. Alternatively, the timer may be read multiple times while operating, and a majority vote taken in software to determine the correct reading. Any write to **TAXR** takes effect immediately.

---

#### 25.2.1.1 Clock Source Select and Divider

The timer clock can be sourced from ACLK, SMCLK, or externally from TACLK or INCLK. The clock source is selected with the TASSEL bits. The selected clock source may be passed directly to the timer or divided by 2, 4, or 8, using the ID bits. The selected clock source can be further divided by 2, 3, 4, 5, 6, 7, or 8 using the TAIDEX bits. The timer clock divider logic is reset when TACLR is set.

---

**NOTE: Timer\_A dividers**

After programming ID or TAIDEX bits, set the TACLR bit. This clears the contents of **TAXR** and resets the clock divider logic to a defined state. The clock dividers are implemented as down counters. Therefore, when the TACLR bit is cleared, the timer clock immediately begins clocking at the first rising edge of the Timer\_A clock source selected with the TASSEL bits and continues clocking at the divider settings set by the ID and TAIDEX bits.

---

### 25.2.2 Starting the Timer

The timer may be started or restarted in the following ways:

- The timer counts when MC > { 0 } and the clock source is active.
- When the timer mode is either up or up/down, the timer may be stopped by writing 0 to **TAXCCR0**. The timer may then be restarted by writing a nonzero value to **TAXCCR0**. In this scenario, the timer starts incrementing in the up direction from zero.

### 25.2.3 Timer Mode Control

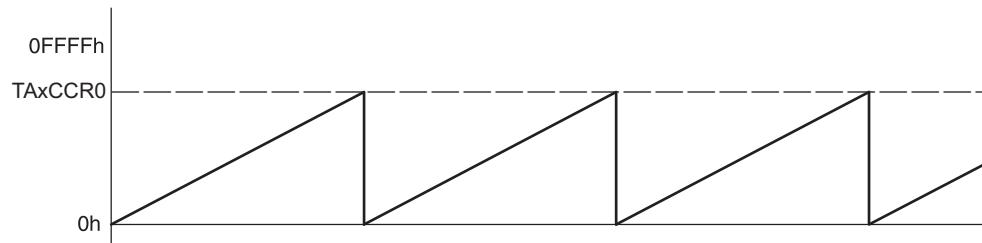
The timer has four modes of operation: stop, up, continuous, and up/down (see [Table 25-1](#)). The operating mode is selected with the MC bits.

**Table 25-1. Timer Modes**

| MC | Mode       | Description                                                                             |
|----|------------|-----------------------------------------------------------------------------------------|
| 00 | Stop       | The timer is halted.                                                                    |
| 01 | Up         | The timer repeatedly counts from zero to the value of TAxCCR0                           |
| 10 | Continuous | The timer repeatedly counts from zero to 0FFFFh.                                        |
| 11 | Up/down    | The timer repeatedly counts from zero up to the value of TAxCCR0 and back down to zero. |

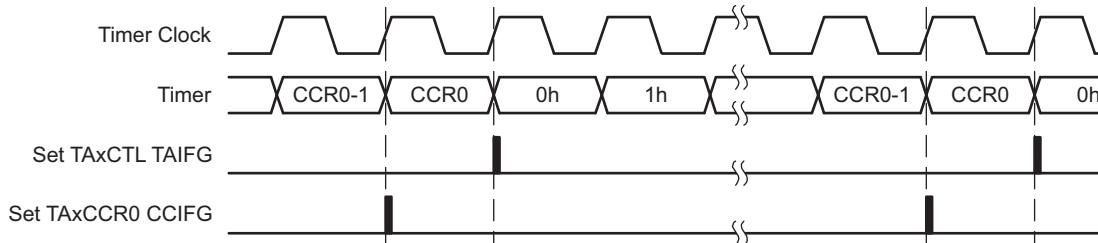
#### 25.2.3.1 Up Mode

The up mode is used if the timer period must be different from 0FFFFh counts. The timer repeatedly counts up to the value of compare register [TAxCCR0](#), which defines the period (see [Figure 25-2](#)). The number of timer counts in the period is TAxCCR0 + 1. When the timer value equals TAxCCR0, the timer restarts counting from zero. If up mode is selected when the timer value is greater than TAxCCR0, the timer immediately restarts counting from zero.



**Figure 25-2. Up Mode**

The [TAxCCR0](#) CCIFG interrupt flag is set when the timer *counts* to the TAxCCR0 value. The TAIFG interrupt flag is set when the timer *counts* from TAxCCR0 to zero. [Figure 25-3](#) shows the flag set cycle.



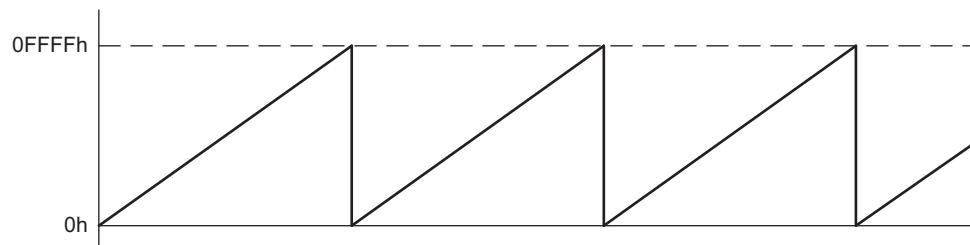
**Figure 25-3. Up Mode Flag Setting**

##### 25.2.3.1.1 Changing Period Register TAxCCR0

When changing [TAxCCR0](#) while the timer is running, if the new period is greater than or equal to the old period or greater than the current count value, the timer counts up to the new period. If the new period is less than the current count value, the timer rolls to zero. However, one additional count may occur before the counter rolls to zero.

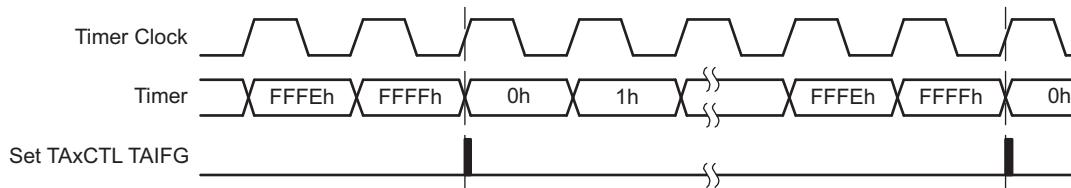
### 25.2.3.2 Continuous Mode

In the continuous mode, the timer repeatedly counts up to 0FFFFh and restarts from zero as shown in Figure 25-4. The capture/compare register **TAxCCR0** works the same way as the other capture/compare registers.



**Figure 25-4. Continuous Mode**

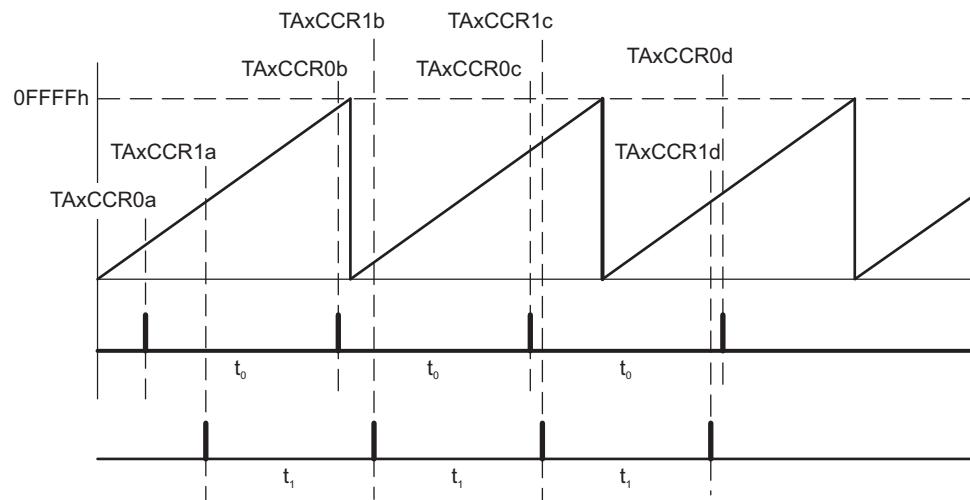
The TAIFG interrupt flag is set when the timer *counts* from 0FFFFh to zero. Figure 25-5 shows the flag set cycle.



**Figure 25-5. Continuous Mode Flag Setting**

### 25.2.3.3 Use of Continuous Mode

The continuous mode can be used to generate independent time intervals and output frequencies. Each time an interval is completed, an interrupt is generated. The next time interval is added to the TAxCCRn register in the interrupt service routine. Figure 25-6 shows two separate time intervals,  $t_0$  and  $t_1$ , being added to the capture/compare registers. In this usage, the time interval is controlled by hardware, not software, without impact from interrupt latency. Up to n (where n = 0 to 6), independent time intervals or output frequencies can be generated using capture/compare registers.

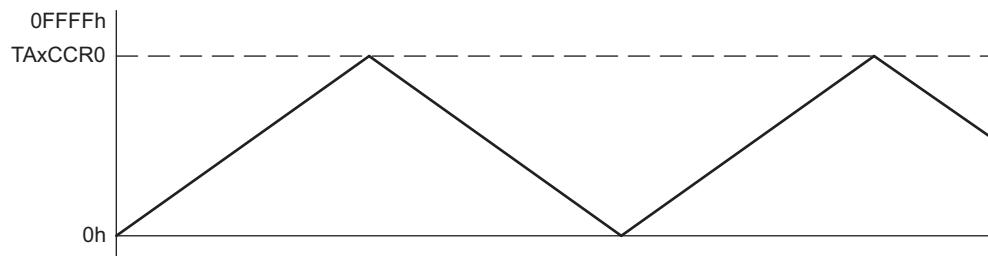


**Figure 25-6. Continuous Mode Time Intervals**

Time intervals can be produced with other modes as well, where **TAxCCR0** is used as the period register. Their handling is more complex since the sum of the old **TAxCCRn** data and the new period can be higher than the **TAxCCR0** value. When the previous **TAxCCRn** value plus  $t_x$  is greater than the **TAxCCR0** data, the **TAxCCR0** value must be subtracted to obtain the correct time interval.

#### 25.2.3.4 Up/Down Mode

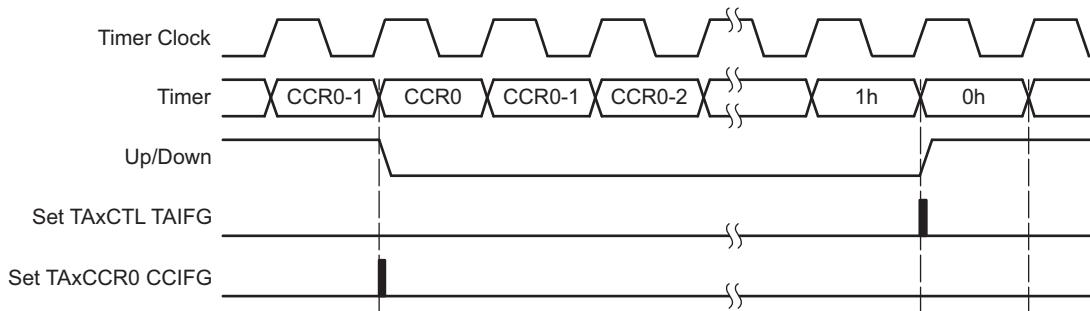
The up/down mode is used if the timer period must be different from 0FFFFh counts, and if symmetrical pulse generation is needed. The timer repeatedly counts up to the value of compare register **TAxCCR0** and back down to zero (see Figure 25-7). The period is twice the value in **TAxCCR0**.



**Figure 25-7. Up/Down Mode**

The count direction is latched. This allows the timer to be stopped and then restarted in the same direction it was counting before it was stopped. If this is not desired, the TACLR bit must be set to clear the direction. Setting TACLR also clears the TAR value and the clock divider counter logic (the divider setting remains unchanged).

In up/down mode, the **TAxCCR0** CCIFG interrupt flag and the TAIFG interrupt flag are set only once during a period, separated by one-half the timer period. The **TAxCCR0** CCIFG interrupt flag is set when the timer *counts* from **TAxCCR0-1** to **TAxCCR0**, and TAIFG is set when the timer completes *counting* down from 0001h to 0000h. Figure 25-8 shows the flag set cycle.



**Figure 25-8. Up/Down Mode Flag Setting**

##### 25.2.3.4.1 Changing Period Register **TAxCCR0**

When changing **TAxCCR0** while the timer is running and counting in the down direction, the timer continues its descent until it reaches zero. The new period takes effect after the counter counts down to zero.

When the timer is counting in the up direction, and the new period is greater than or equal to the old period or greater than the current count value, the timer counts up to the new period before counting down.

When the timer is counting in the up direction and the new period is less than the current count value, the timer begins counting down. However, one additional count may occur before the counter begins counting down.

### 25.2.3.5 Use of Up/Down Mode

The up/down mode supports applications that require dead times between output signals (see [Section 25.2.5](#)). For example, to avoid overload conditions, two outputs driving an H-bridge must never be in a high state simultaneously. In the example shown in [Figure 25-9](#), the  $t_{\text{dead}}$  is:

$$t_{\text{dead}} = t_{\text{timer}} \times (\text{TAxCCR1} - \text{TAxCCR2})$$

Where:

$t_{\text{dead}}$  = Time during which both outputs need to be inactive

$t_{\text{timer}}$  = Cycle time of the timer clock

TAxCCRn = Content of capture/compare register n

The TAxCCRn registers are not buffered. They update immediately when written to. Therefore, any required dead time is not maintained automatically.

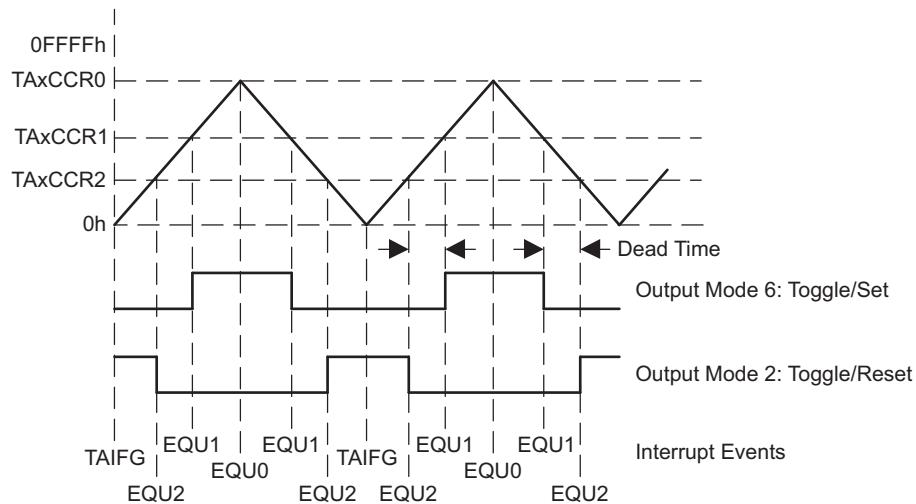


Figure 25-9. Output Unit in Up/Down Mode

### 25.2.4 Capture/Compare Blocks

Up to seven identical capture/compare blocks, TAxCCRn (where n = 0 to 7), are present in Timer\_A. Any of the blocks may be used to capture the timer data or to generate time intervals.

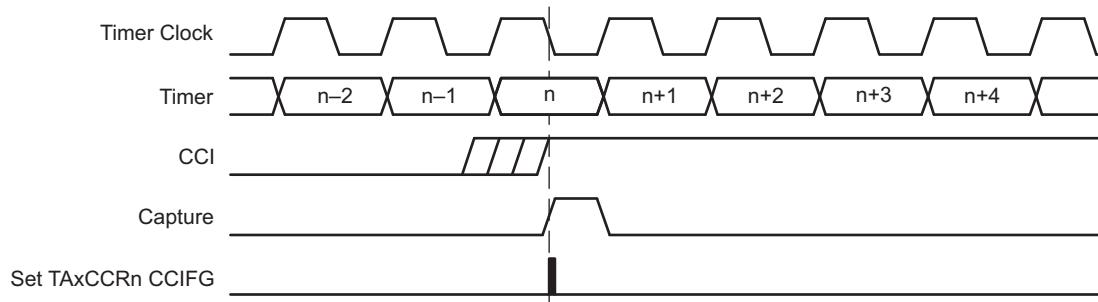
#### 25.2.4.1 Capture Mode

The capture mode is selected when CAP = 1. Capture mode is used to record time events. It can be used for speed computations or time measurements. The capture inputs CCIA and CCIB are connected to external pins or internal signals and are selected with the CCIS bits. The CM bits select the capture edge of the input signal as rising, falling, or both. A capture occurs on the selected edge of the input signal. If a capture occurs:

- The timer value is copied into the TAxCCRn register.
- The interrupt flag CCIFG is set.

The input signal level can be read at any time from the CCI bit. Devices may have different signals connected to CCIA and CCIB. See the device-specific data sheet for the connections of these signals.

The capture signal can be asynchronous to the timer clock and cause a race condition. Setting the SCS bit synchronizes the capture with the next timer clock. Setting the SCS bit to synchronize the capture signal with the timer clock is recommended (see [Figure 25-10](#)).

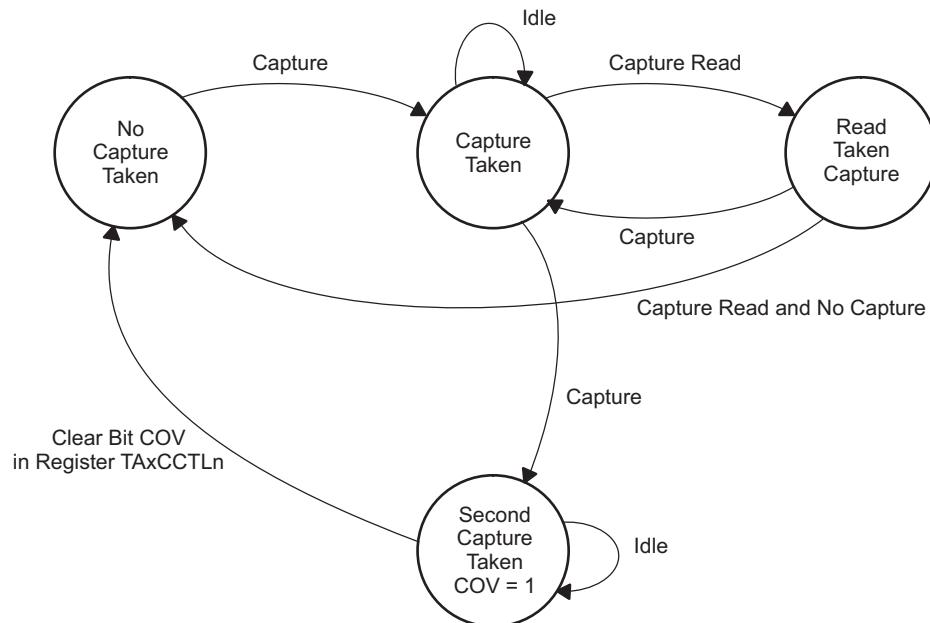


**Figure 25-10. Capture Signal (SCS = 1)**

**NOTE: Changing Capture Inputs**

Changing capture inputs while in capture mode may cause unintended capture events. To avoid this scenario, capture inputs should only be changed when capture mode is disabled (CM = {0} or CAP = 0).

Overflow logic is provided in each capture/compare register to indicate if a second capture was performed before the value from the first capture was read. Bit COV is set when this occurs as shown in [Figure 25-11](#). COV must be reset with software.



**Figure 25-11. Capture Cycle**

#### 25.2.4.1.1 Capture Initiated by Software

Captures can be initiated by software. The CMx bits can be set for capture on both edges. Software then sets CCIS1 = 1 and toggles bit CCIS0 to switch the capture signal between V<sub>CC</sub> and GND, initiating a capture each time CCIS0 changes state:

```
MOV #CAP+SCS+CCIS1+CM_3,&TA0CCTL1 ; Setup TA0CCTL1, synch. capture mode
                                    ; Event trigger on both edges of capture input.
XOR #CCIS0,&TA0CCTL1           ; TA0CCR1 = TA0R
```

**NOTE: Capture Initiated by Software**

In general, changing capture inputs while in capture mode may cause unintended capture events. For this scenario, switching the capture input between VCC and GND, disabling the capture mode is not required.

#### 25.2.4.2 Compare Mode

The compare mode is selected when CAP = 0. The compare mode is used to generate PWM output signals or interrupts at specific time intervals. When TA<sub>x</sub>R counts to the value in TA<sub>x</sub>CCR<sub>n</sub>, where n represents the specific capture/compare register.

- Interrupt flag CCIFG is set.
- Internal signal EQUn = 1.
- EQUn affects the output according to the output mode.
- The input signal CCI is latched into SCCI.

#### 25.2.5 Output Unit

Each capture/compare block contains an output unit. The output unit is used to generate output signals, such as PWM signals. Each output unit has eight operating modes that generate signals based on the EQU0 and EQUn signals.

##### 25.2.5.1 Output Modes

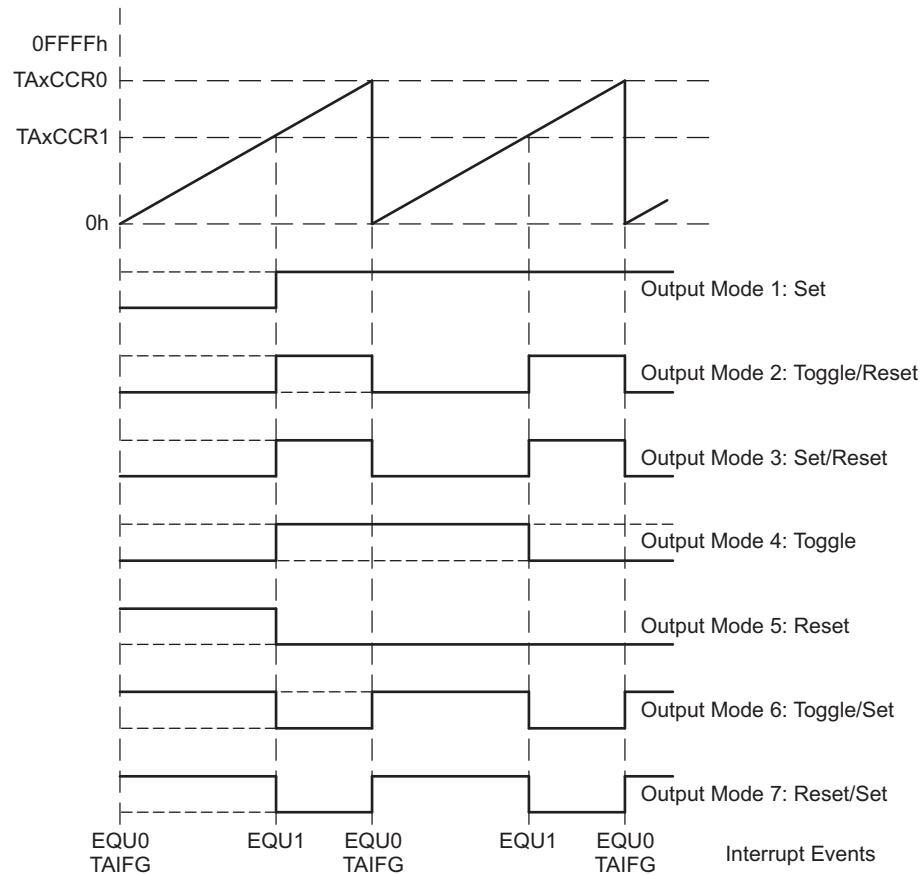
The output modes are defined by the OUTMOD bits and are described in [Table 25-2](#). The OUTn signal is changed with the rising edge of the timer clock for all modes except mode 0. Output modes 2, 3, 6, and 7 are not useful for output unit 0 because EQUn = EQU0.

**Table 25-2. Output Modes**

| OUTMODx | Mode         | Description                                                                                                                                                                                        |
|---------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 000     | Output       | The output signal OUTn is defined by the OUT bit. The OUTn signal updates immediately when OUT is updated.                                                                                         |
| 001     | Set          | The output is set when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. It remains set until a reset of the timer, or until another output mode is selected and affects the output. |
| 010     | Toggle/Reset | The output is toggled when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. It is reset when the timer counts to the TA <sub>x</sub> CCR0 value.                                    |
| 011     | Set/Reset    | The output is set when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. It is reset when the timer counts to the TA <sub>x</sub> CCR0 value.                                        |
| 100     | Toggle       | The output is toggled when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. The output period is double the timer period.                                                           |
| 101     | Reset        | The output is reset when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. It remains reset until another output mode is selected and affects the output.                            |
| 110     | Toggle/Set   | The output is toggled when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. It is set when the timer counts to the TA <sub>x</sub> CCR0 value.                                      |
| 111     | Reset/Set    | The output is reset when the timer counts to the TA <sub>x</sub> CCR <sub>n</sub> value. It is set when the timer counts to the TA <sub>x</sub> CCR0 value.                                        |

### 25.2.5.1.1 Output Example—Timer in Up Mode

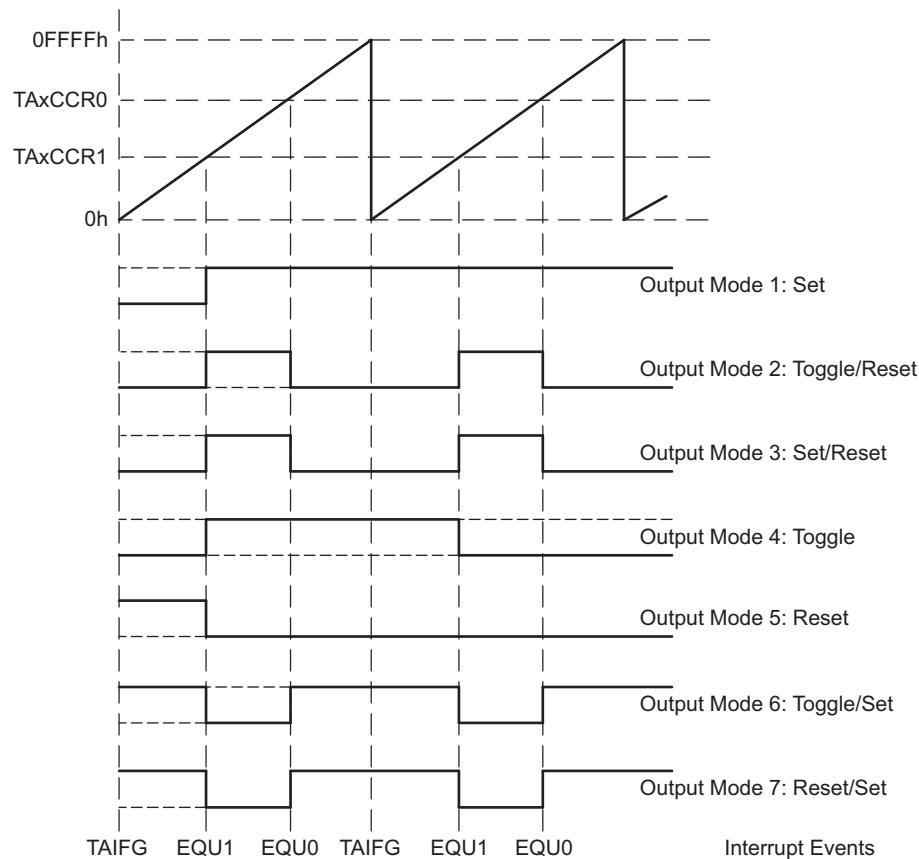
The OUTn signal is changed when the timer *counts* up to the TAxCCRn value and rolls from TAxCCR0 to zero, depending on the output mode. An example is shown in Figure 25-12 using TAxCCR0 and TAxCCR1.



**Figure 25-12. Output Example – Timer in Up Mode**

### 25.2.5.1.2 Output Example – Timer in Continuous Mode

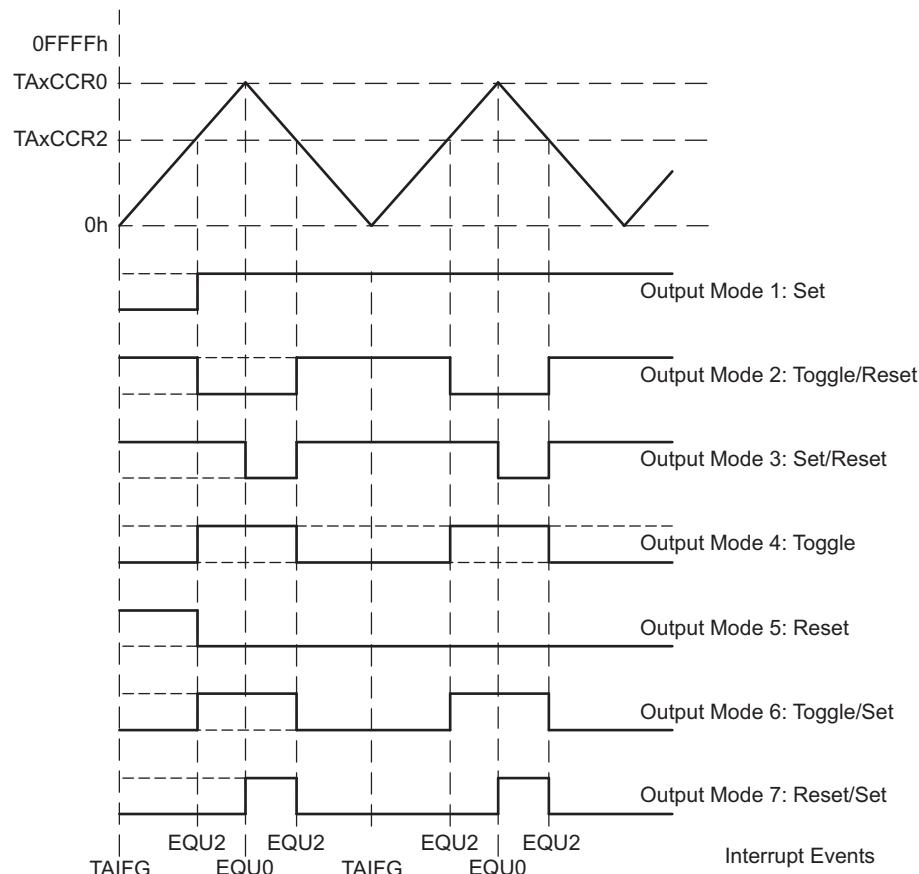
The OUTn signal is changed when the timer reaches the TAxCCRn and TAxCCR0 values, depending on the output mode. An example is shown in Figure 25-13 using TAxCCR0 and TAxCCR1.



**Figure 25-13. Output Example – Timer in Continuous Mode**

### 25.2.5.1.3 Output Example – Timer in Up/Down Mode

The OUTn signal changes when the timer equals TAxCRRn in either count direction and when the timer equals **TAxCCR0**, depending on the output mode. An example is shown in Figure 25-14 using TAxCCR0 and **TAxCCR2**.



**Figure 25-14. Output Example – Timer in Up/Down Mode**

**NOTE: Switching between output modes**

When switching between output modes, one of the OUTMOD bits should remain set during the transition, unless switching to mode 0. Otherwise, output glitching can occur, because a NOR gate decodes output mode 0. A safe method for switching between output modes is to use output mode 7 as a transition state:

```
BIS #OUTMOD_7,&TA0CCTL1      ; Set output mode=7
BIC #OUTMOD,&TA0CCTL1      ; Clear unwanted bits
```

## 25.2.6 Timer\_A Interrupts

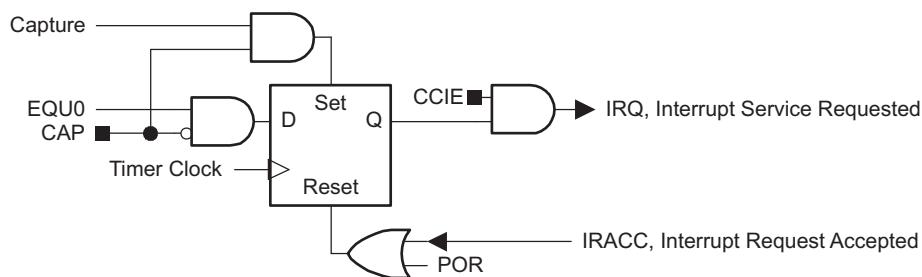
Two interrupt vectors are associated with the 16-bit Timer\_A module:

- **TAxCCR0** interrupt vector for TAxCCR0 CCIFG
- **TAxIV** interrupt vector for all other CCIFG flags and TAIFG

In capture mode, any CCIFG flag is set when a timer value is captured in the associated TAxCCRn register. In compare mode, any CCIFG flag is set if TAxR counts to the associated TAxCCRn value. Software may also set or clear any CCIFG flag. All CCIFG flags request an interrupt when their corresponding CCIE bit and the GIE bit are set.

### 25.2.6.1 TAxCCR0 Interrupt

The **TAxCCR0** CCIFG flag has the highest Timer\_A interrupt priority and has a dedicated interrupt vector as shown in [Figure 25-15](#). The TAxCCR0 CCIFG flag is automatically reset when the TAxCCR0 interrupt request is serviced.



**Figure 25-15. Capture/Compare TAxCCR0 Interrupt Flag**

### 25.2.6.2 TAxIV, Interrupt Vector Generator

The TAxCCRy CCIFG flags and TAIFG flags are prioritized and combined to source a single interrupt vector. The interrupt vector register **TAxIV** is used to determine which flag requested an interrupt.

The highest-priority enabled interrupt generates a number in the **TAxIV** register (see register description). This number can be evaluated or added to the program counter to automatically enter the appropriate software routine. Disabled Timer\_A interrupts do not affect the TAxIV value.

Any access, read or write, of the **TAxIV** register automatically resets the highest-pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. For example, if the **TAxCCR1** and **TAxCCR2** CCIFG flags are set when the interrupt service routine accesses the TAxIV register, TAxCCR1 CCIFG is reset automatically. After the RETI instruction of the interrupt service routine is executed, the TAxCCR2 CCIFG flag generates another interrupt.

### **25.2.6.2.1 TAxIV Software Example**

The following software example shows the recommended use of **TAxIV** and the handling overhead. The TAxIV value is added to the PC to automatically jump to the appropriate routine. The example assumes a single instantiation of the largest timer configuration available.

The numbers at the right margin show the necessary CPU cycles for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself. The latencies are:

- Capture/compare block TA0CCR0: 11 cycles
- Capture/compare blocks TA0CCR1, TA0CCR2, TA0CCR3, TA0CCR4, TA0CCR5, TA0CCR6: 16 cycles
- Timer overflow TA0IFG: 14 cycles

```
; Interrupt handler for TA0CCR0 CCIFG.                                Cycles
CCIFG_0_HND
;           ...          ; Start of handler Interrupt latency      6
        RETI                           5

; Interrupt handler for TA0IFG, TA0CCR1 through TA0CCR6 CCIFG.

TA0_HND    ...          ; Interrupt latency      6
        ADD     &TA0IV,PC   ; Add offset to Jump table      3
        RETI                           5
        JMP     CCIFG_1_HND ; Vector  2: TA0CCR1      2
        JMP     CCIFG_2_HND ; Vector  4: TA0CCR2      2
        JMP     CCIFG_3_HND ; Vector  6: TA0CCR3      2
        JMP     CCIFG_4_HND ; Vector  8: TA0CCR4      2
        JMP     CCIFG_5_HND ; Vector 10: TA0CCR5      2
        JMP     CCIFG_6_HND ; Vector 12: TA0CCR6      2

TA0IFG_HND          ; Vector 14: TA0IFG Flag
;           ...          ; Task starts here
        RETI                           5

CCIFG_6_HND          ; Vector 12: TA0CCR6
;           ...          ; Task starts here
        RETI                           5

CCIFG_5_HND          ; Vector 10: TA0CCR5
;           ...          ; Task starts here
        RETI                           5

CCIFG_4_HND          ; Vector  8: TA0CCR4
;           ...          ; Task starts here
        RETI                           5

CCIFG_3_HND          ; Vector  6: TA0CCR3
;           ...          ; Task starts here
        RETI                           5

CCIFG_2_HND          ; Vector  4: TA0CCR2
;           ...          ; Task starts here
        RETI                           5

CCIFG_1_HND          ; Vector  2: TA0CCR1
;           ...          ; Task starts here
        RETI                           5
```

## 25.3 Timer\_A Registers

Timer\_A registers are listed in [Table 25-3](#) for the largest configuration available. The base address can be found in the device-specific data sheet.

**Table 25-3. Timer\_A Registers**

| Offset | Acronym  | Register Name                      | Type       | Access | Reset | Section                        |
|--------|----------|------------------------------------|------------|--------|-------|--------------------------------|
| 00h    | TAxCTL   | Timer_Ax Control                   | Read/write | Word   | 0000h | <a href="#">Section 25.3.1</a> |
| 02h    | TAxCCTL0 | Timer_Ax Capture/Compare Control 0 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 04h    | TAxCCTL1 | Timer_Ax Capture/Compare Control 1 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 06h    | TAxCCTL2 | Timer_Ax Capture/Compare Control 2 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 08h    | TAxCCTL3 | Timer_Ax Capture/Compare Control 3 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 0Ah    | TAxCCTL4 | Timer_Ax Capture/Compare Control 4 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 0Ch    | TAxCCTL5 | Timer_Ax Capture/Compare Control 5 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 0Eh    | TAxCCTL6 | Timer_Ax Capture/Compare Control 6 | Read/write | Word   | 0000h | <a href="#">Section 25.3.3</a> |
| 10h    | TAxR     | Timer_Ax Counter                   | Read/write | Word   | 0000h | <a href="#">Section 25.3.2</a> |
| 12h    | TAxCCR0  | Timer_Ax Capture/Compare 0         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 14h    | TAxCCR1  | Timer_Ax Capture/Compare 1         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 16h    | TAxCCR2  | Timer_Ax Capture/Compare 2         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 18h    | TAxCCR3  | Timer_Ax Capture/Compare 3         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 1Ah    | TAxCCR4  | Timer_Ax Capture/Compare 4         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 1Ch    | TAxCCR5  | Timer_Ax Capture/Compare 5         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 1Eh    | TAxCCR6  | Timer_Ax Capture/Compare 6         | Read/write | Word   | 0000h | <a href="#">Section 25.3.4</a> |
| 2Eh    | TAxIV    | Timer_Ax Interrupt Vector          | Read only  | Word   | 0000h | <a href="#">Section 25.3.5</a> |
| 20h    | TAxEX0   | Timer_Ax Expansion 0               | Read/write | Word   | 0000h | <a href="#">Section 25.3.6</a> |

### 25.3.1 TAxCTL Register

Timer\_A Control Register

**Figure 25-16. TAxCTL Register**

| 15       | 14     | 13     | 12     | 11       | 10     | 9      | 8      |
|----------|--------|--------|--------|----------|--------|--------|--------|
| Reserved |        |        |        |          |        | TASSEL |        |
| rw-(0)   | rw-(0) | rw-(0) | rw-(0) | rw-(0)   | rw-(0) | rw-(0) | rw-(0) |
| 7        | 6      | 5      | 4      | 3        | 2      | 1      | 0      |
| ID       |        | MC     |        | Reserved | TACLR  | TAIE   | TAIFG  |
| rw-(0)   | rw-(0) | rw-(0) | rw-(0) | rw-(0)   | w-(0)  | rw-(0) | rw-(0) |

**Table 25-4. TAxCTL Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                          |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | Reserved | RW   | 0h    | Reserved                                                                                                                                                                                                                                                                                                             |
| 9-8   | TASSEL   | RW   | 0h    | Timer_A clock source select<br>00b = TAxCLK<br>01b = ACLK<br>10b = SMCLK<br>11b = INCLK                                                                                                                                                                                                                              |
| 7-6   | ID       | RW   | 0h    | Input divider. These bits along with the TAIDEX bits select the divider for the input clock.<br>00b = /1<br>01b = /2<br>10b = /4<br>11b = /8                                                                                                                                                                         |
| 5-4   | MC       | RW   | 0h    | Mode control. Setting MC = 00h when Timer_A is not in use conserves power.<br>00b = Stop mode: Timer is halted<br>01b = Up mode: Timer counts up to <a href="#">TAXCCR0</a><br>10b = Continuous mode: Timer counts up to 0FFFFh<br>11b = Up/down mode: Timer counts up to <a href="#">TAXCCR0</a> then down to 0000h |
| 3     | Reserved | RW   | 0h    | Reserved                                                                                                                                                                                                                                                                                                             |
| 2     | TACLR    | RW   | 0h    | Timer_A clear. Setting this bit clears TAR, the clock divider logic (the divider setting remains unchanged), and the count direction. The TACLR bit is automatically reset and is always read as zero.                                                                                                               |
| 1     | TAIE     | RW   | 0h    | Timer_A interrupt enable. This bit enables the TAIFG interrupt request.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                         |
| 0     | TAIFG    | RW   | 0h    | Timer_A interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                                                                                                                                        |

### 25.3.2 TAxR Register

Timer\_Ax Counter Register

**Figure 25-17. TAxR Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|--------|--------|--------|--------|--------|--------|--------|--------|
| TAXR   |        |        |        |        |        |        |        |
| rw-(0) |
| TAXR   |        |        |        |        |        |        |        |
| rw-(0) |

**Table 25-5. TAxR Register Description**

| Bit  | Field | Type | Reset | Description                                                  |
|------|-------|------|-------|--------------------------------------------------------------|
| 15-0 | TAXR  | RW   | 0h    | Timer_A register. The TAXR register is the count of Timer_A. |

### 25.3.3 TAxCCTLn Register

Timer\_Ax Capture/Compare Control n Register

**Figure 25-18. TAxCCTLn Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9        | 8      |
|--------|--------|--------|--------|--------|--------|----------|--------|
| CM     |        | CCIS   |        | SCS    | SCCI   | Reserved | CAP    |
| rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | r-(0)  | r-(0)    | rw-(0) |
| 7      | 6      | 5      | 4      | 3      | 2      | 1        | 0      |
|        | OUTMOD |        | CCIE   | CCI    | OUT    | COV      | CCIFG  |
| rw-(0) | rw-(0) | rw-(0) | rw-(0) | r      | rw-(0) | rw-(0)   | rw-(0) |

**Table 25-6. TAxCCTLn Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                  |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | CM       | RW   | 0h    | Capture mode<br>00b = No capture<br>01b = Capture on rising edge<br>10b = Capture on falling edge<br>11b = Capture on both rising and falling edges                                                                                          |
| 13-12 | CCIS     | RW   | 0h    | Capture/compare input select. These bits select the TAxCCR0 input signal. See the device-specific data sheet for specific signal connections.<br>00b = CCIXA<br>01b = CCIXB<br>10b = GND<br>11b = VCC                                        |
| 11    | SCS      | RW   | 0h    | Synchronize capture source. This bit is used to synchronize the capture input signal with the timer clock.<br>0b = Asynchronous capture<br>1b = Synchronous capture                                                                          |
| 10    | SCCI     | RW   | 0h    | Synchronized capture/compare input. The selected CCI input signal is latched with the EQUx signal and can be read from this bit.                                                                                                             |
| 9     | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                        |
| 8     | CAP      | RW   | 0h    | Capture mode<br>0b = Compare mode<br>1b = Capture mode                                                                                                                                                                                       |
| 7-5   | OUTMOD   | RW   | 0h    | Output mode. Modes 2, 3, 6, and 7 are not useful for TAxCCR0 because EQUx = EQU0.<br>000b = OUT bit value<br>001b = Set<br>010b = Toggle/reset<br>011b = Set/reset<br>100b = Toggle<br>101b = Reset<br>110b = Toggle/set<br>111b = Reset/set |
| 4     | CCIE     | RW   | 0h    | Capture/compare interrupt enable. This bit enables the interrupt request of the corresponding CCIFG flag.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                               |
| 3     | CCI      | R    | 0h    | Capture/compare input. The selected input signal can be read by this bit.                                                                                                                                                                    |
| 2     | OUT      | RW   | 0h    | Output. For output mode 0, this bit directly controls the state of the output.<br>0b = Output low<br>1b = Output high                                                                                                                        |

**Table 25-6. TAxCCTLn Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                        |
|------------|--------------|-------------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1          | COV          | RW          | 0h           | Capture overflow. This bit indicates a capture overflow occurred. COV must be reset with software.<br>0b = No capture overflow occurred<br>1b = Capture overflow occurred |
| 0          | CCIFG        | RW          | 0h           | Capture/compare interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                     |

### 25.3.4 TAxCRRn Register

Timer\_A Capture/Compare n Register

**Figure 25-19. TAxCRRn Register**

| 15      | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|---------|--------|--------|--------|--------|--------|--------|--------|
| TAxCRRn |        |        |        |        |        |        |        |
| rw-(0)  | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| TAxCRRn |        |        |        |        |        |        |        |
| 7       | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
| rw-(0)  | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 25-7. TAxCRRn Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                           |
|------|---------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TAxCCR0 | RW   | 0h    | Compare mode: TAxCRRn holds the data for the comparison to the timer value in the Timer_A Register, TAR.<br>Capture mode: The Timer_A Register, TAR, is copied into the TAxCRRn register when a capture is performed. |

### 25.3.5 TAIV Register

Timer\_Ax Interrupt Vector Register

**Figure 25-20. TAIV Register**

| 15   | 14 | 13 | 12 | 11    | 10    | 9     | 8  |
|------|----|----|----|-------|-------|-------|----|
| TAIV |    |    |    |       |       |       |    |
| r0   | r0 | r0 | r0 | r0    | r0    | r0    | r0 |
| TAIV |    |    |    |       |       |       |    |
| r0   | r0 | r0 | r0 | r-(0) | r-(0) | r-(0) | r0 |

**Table 25-8. TAIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------|-------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TAIV  | R    | 0h    | Timer_A interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Capture/compare 1; Interrupt Flag: <a href="#">TAxCCR1 CCIFG</a> ; Interrupt Priority: Highest<br>04h = Interrupt Source: Capture/compare 2; Interrupt Flag: <a href="#">TAxCCR2 CCIFG</a><br>06h = Interrupt Source: Capture/compare 3; Interrupt Flag: <a href="#">TAxCCR3 CCIFG</a><br>08h = Interrupt Source: Capture/compare 4; Interrupt Flag: <a href="#">TAxCCR4 CCIFG</a><br>0Ah = Interrupt Source: Capture/compare 5; Interrupt Flag: <a href="#">TAxCCR5 CCIFG</a><br>0Ch = Interrupt Source: Capture/compare 6; Interrupt Flag: <a href="#">TAxCCR6 CCIFG</a><br>0Eh = Interrupt Source: Timer overflow; Interrupt Flag: <a href="#">TAxCTL TAIFG</a> ; Interrupt Priority: Lowest |

### 25.3.6 TAxE0 Register

Timer\_Ax Expansion 0 Register

**Figure 25-21. TAxE0 Register**

|          |    |    |    |    |        |                       |        |
|----------|----|----|----|----|--------|-----------------------|--------|
| 15       | 14 | 13 | 12 | 11 | 10     | 9                     | 8      |
| Reserved |    |    |    |    |        |                       |        |
| r0       | r0 | r0 | r0 | r0 | r0     | r0                    | r0     |
| 7        | 6  | 5  | 4  | 3  | 2      | 1                     | 0      |
| Reserved |    |    |    |    |        | TAIDEX <sup>(1)</sup> |        |
| r0       | r0 | r0 | r0 | r0 | rw-(0) | rw-(0)                | rw-(0) |

<sup>(1)</sup> After programming TAIDEX bits and configuration of the timer, set TACLR bit to ensure proper reset of the timer divider logic.

**Table 25-9. TAxE0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                        |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                                              |
| 2-0  | TAIDEX   | RW   | 0h    | Input divider expansion. These bits along with the ID bits select the divider for the input clock.<br>000b = Divide by 1<br>001b = Divide by 2<br>010b = Divide by 3<br>011b = Divide by 4<br>100b = Divide by 5<br>101b = Divide by 6<br>110b = Divide by 7<br>111b = Divide by 8 |

***Timer\_B***

Timer\_B is a 16-bit timer/counter with multiple capture/compare registers. There can be multiple Timer\_B modules on a given device (see the device-specific data sheet). This chapter describes the operation and use of the Timer\_B module.

| Topic                                  | Page       |
|----------------------------------------|------------|
| <b>26.1 Timer_B Introduction .....</b> | <b>662</b> |
| <b>26.2 Timer_B Operation.....</b>     | <b>664</b> |
| <b>26.3 Timer_B Registers .....</b>    | <b>677</b> |

## 26.1 Timer\_B Introduction

Timer\_B is a 16-bit timer/counter with up to seven capture/compare registers. Timer\_B can support multiple capture/comparisons, PWM outputs, and interval timing. Timer\_B also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

Timer\_B features include:

- Asynchronous 16-bit timer/counter with four operating modes and four selectable lengths
- Selectable and configurable clock source
- Up to seven configurable capture/compare registers
- Configurable outputs with PWM capability
- Double-buffered compare latches with synchronized loading
- Interrupt vector register for fast decoding of all Timer\_B interrupts

The block diagram of Timer\_B is shown in [Figure 26-1](#).

---

**NOTE: Use of the word count**

*Count* is used throughout this chapter. It means the counter must be in the process of counting for the action to take place. If a particular value is directly written to the counter, an associated action does not take place.

---

**NOTE: Nomenclature**

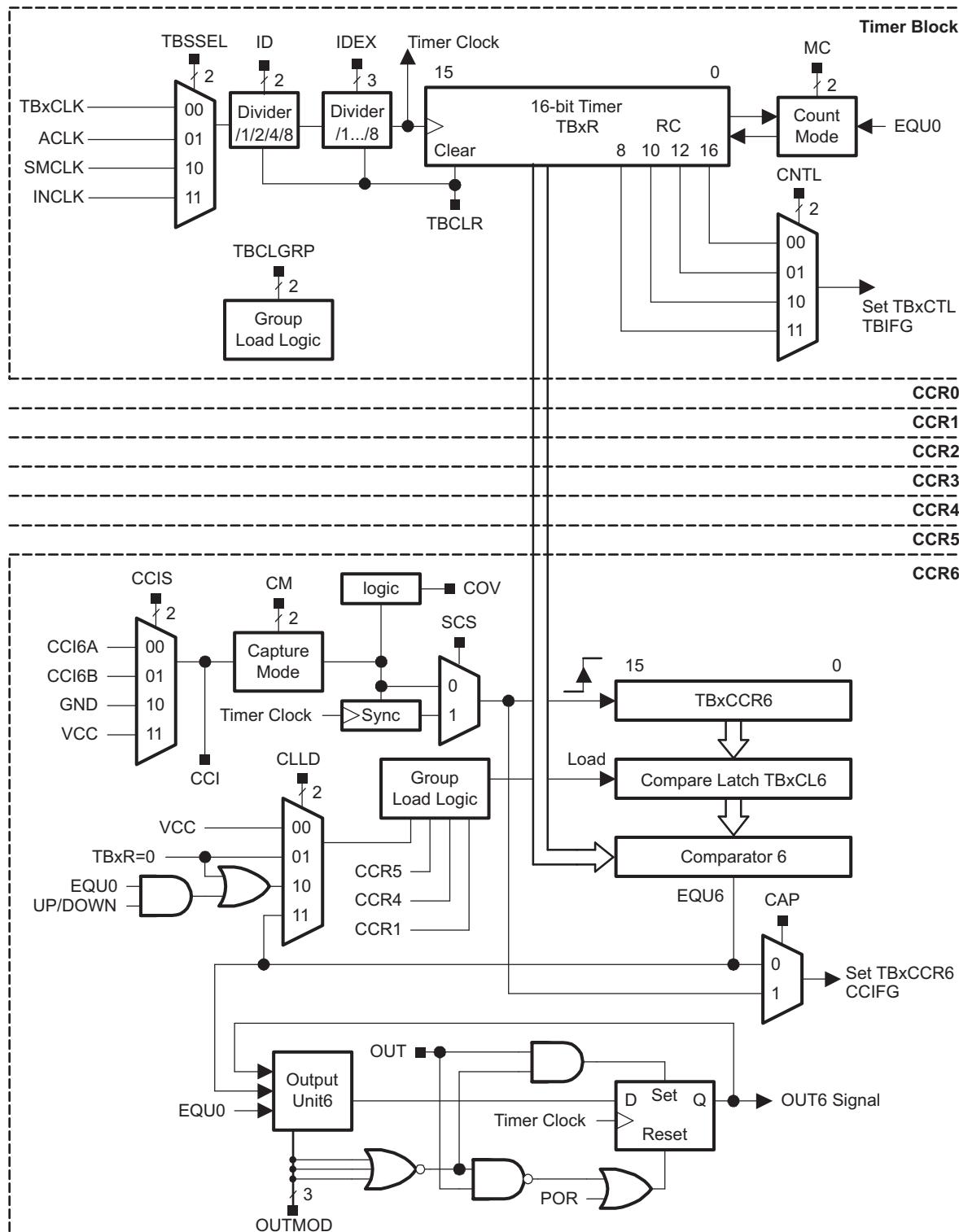
There may be multiple instantiations of Timer\_B on a given device. The prefix TB<sub>x</sub> is used, where *x* is greater than or equal to zero indicating the Timer\_B instantiation. For devices with one instantiation, *x* = 0. The suffix *n*, where *n* = 0 to 6, represents the specific capture/compare registers associated with the Timer\_B instantiation.

---

### 26.1.1 Similarities and Differences From Timer\_A

Timer\_B is identical to Timer\_A with the following exceptions:

- The length of Timer\_B is programmable to be 8, 10, 12, or 16 bits.
- Timer\_B TB<sub>x</sub>CCR<sub>n</sub> registers are double-buffered and can be grouped.
- All Timer\_B outputs can be put into a high-impedance state.
- The SCCI bit function is not implemented in Timer\_B.



**Figure 26-1. Timer\_B Block Diagram**

## 26.2 Timer\_B Operation

The Timer\_B module is configured with user software. The setup and operation of Timer\_B is discussed in the following sections.

### 26.2.1 16-Bit Timer Counter

The 16-bit timer/counter register, TBxR, increments or decrements (depending on mode of operation) with each rising edge of the clock signal. TBxR can be read or written with software. Additionally, the timer can generate an interrupt when it overflows.

TBxR may be cleared by setting the TBCLR bit. Setting TBCLR also clears the clock divider counter logic (the divider setting remains unchanged) and count direction for up/down mode.

---

**NOTE: Modifying Timer\_B registers**

TI recommends stopping the timer before modifying its operation (with exception of the interrupt enable, interrupt flag, and TBCLR) to avoid errant operating conditions.

When the timer clock is asynchronous to the CPU clock, any read from TBxR should occur while the timer is not operating or the results may be unpredictable. Alternatively, the timer may be read multiple times while operating, and a majority vote taken in software to determine the correct reading. Any write to TBxR takes effect immediately.

---

#### 26.2.1.1 TBxR Length

Timer\_B is configurable to operate as an 8-, 10-, 12-, or 16-bit timer with the CNTL bits. The maximum count value, TBxR<sub>(max)</sub>, for the selectable lengths is 0FFh, 03FFh, OFFFh, and 0FFFFh, respectively. Data written to the TBxR register in 8-, 10-, and 12-bit mode is right justified with leading zeros.

#### 26.2.1.2 Clock Source Select and Divider

The timer clock can be sourced from ACLK, SMCLK, or externally from TBxCLK or INCLK. The clock source is selected with the TBSSEL bits. The selected clock source may be passed directly to the timer or divided by 2, 4, or 8, using the ID bits. The selected clock source can be further divided by 2, 3, 4, 5, 6, 7, or 8 using the TBIDEX bits. The timer clock divider logic is reset when TBCLR is set.

---

**NOTE: Timer\_B dividers**

After programming ID or TBIDEX bits, set the TBCLR bit. This clears the contents of TBxR and resets the clock divider logic to a defined state. The clock dividers are implemented as down counters. Therefore, when the TBCLR bit is cleared, the timer clock immediately begins clocking at the first rising edge of the Timer\_B clock source selected with the TBSSEL bits and continues clocking at the divider settings set by the ID and TBIDEX bits.

---

## 26.2.2 Starting the Timer

The timer may be started or restarted in the following ways:

- The timer counts when MC > { 0 } and the clock source is active.
- When the timer mode is either up or up/down, the timer may be stopped by loading 0 to TBxCL0. The timer may then be restarted by loading a nonzero value to TBxCL0. In this scenario, the timer starts incrementing in the up direction from zero.

### 26.2.3 Timer Mode Control

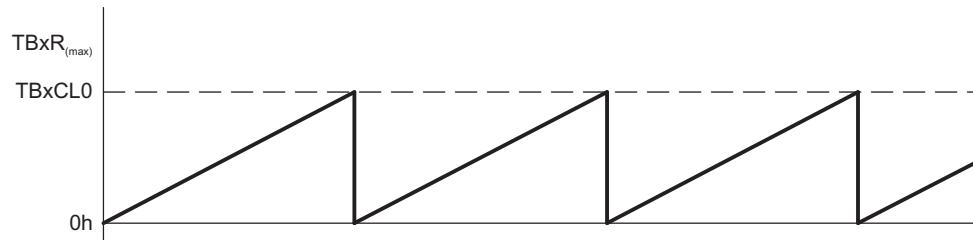
The timer has four modes of operation: stop, up, continuous, and up/down (see [Table 26-1](#)). The operating mode is selected with the MC bits.

**Table 26-1. Timer Modes**

| MC | Mode       | Description                                                                                 |
|----|------------|---------------------------------------------------------------------------------------------|
| 00 | Stop       | The timer is halted.                                                                        |
| 01 | Up         | The timer repeatedly counts from zero to the value of compare register TBxCL0.              |
| 10 | Continuous | The timer repeatedly counts from zero to the value selected by the CNTL bits.               |
| 11 | Up/down    | The timer repeatedly counts from zero up to the value of TBxCL0 and then back down to zero. |

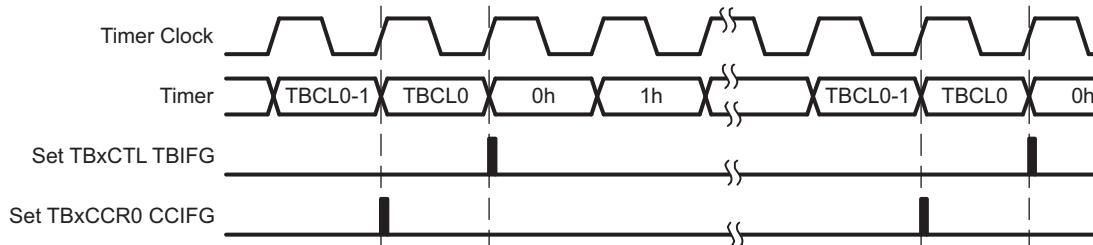
#### 26.2.3.1 Up Mode

The up mode is used if the timer period must be different from  $TBxR_{(max)}$  counts. The timer repeatedly counts up to the value of compare latch TBxCL0, which defines the period (see [Figure 26-2](#)). The number of timer counts in the period is  $TBxCL0 + 1$ . When the timer value equals TBxCL0, the timer restarts counting from zero. If up mode is selected when the timer value is greater than TBxCL0, the timer immediately restarts counting from zero.



**Figure 26-2. Up Mode**

The TBxCCR0 CCIFG interrupt flag is set when the timer *counts* to the TBxCL0 value. The TBIFG interrupt flag is set when the timer *counts* from TBxCL0 to zero. [Figure 26-3](#) shows the flag set cycle.



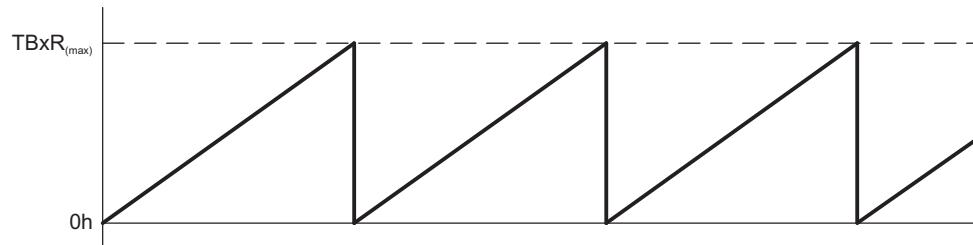
**Figure 26-3. Up Mode Flag Setting**

##### 26.2.3.1.1 Changing Period Register TBxCL0

When changing TBxCL0 while the timer is running and when the TBxCL0 load mode is *immediate*, if the new period is greater than or equal to the old period or greater than the current count value, the timer counts up to the new period. If the new period is less than the current count value, the timer rolls to zero. However, one additional count may occur before the counter rolls to zero.

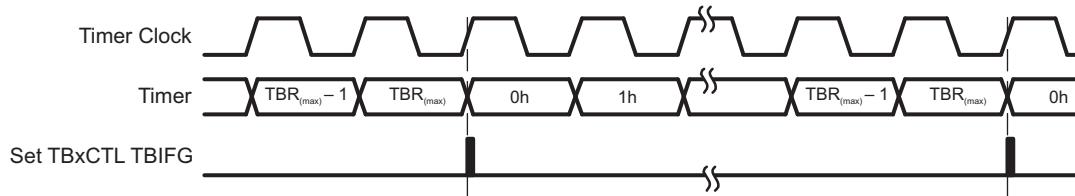
### 26.2.3.2 Continuous Mode

In continuous mode, the timer repeatedly counts up to  $TBxR_{(max)}$  and restarts from zero (see Figure 26-4). The compare latch  $TBxCL0$  works the same way as the other capture/compare registers.



**Figure 26-4. Continuous Mode**

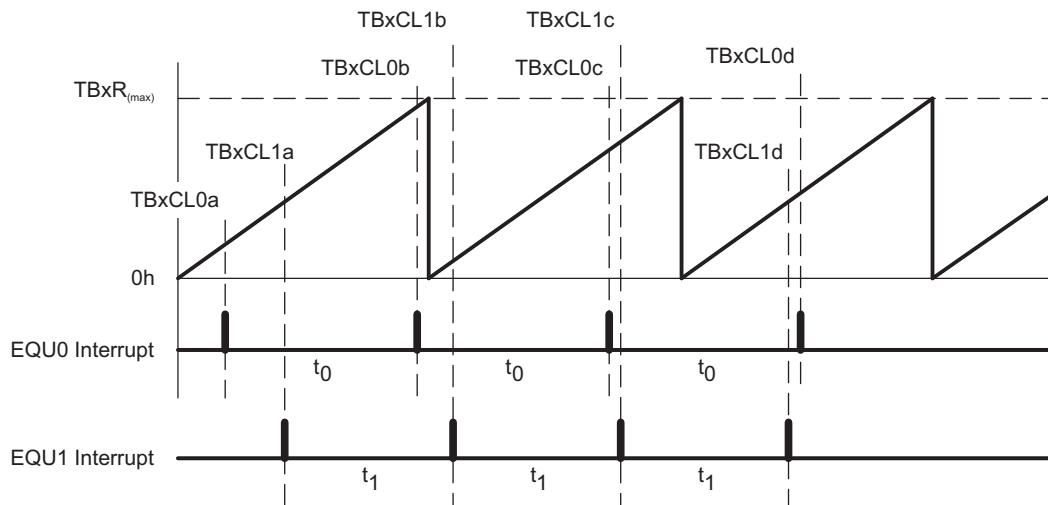
The  $TBIFG$  interrupt flag is set when the timer *counts* from  $TBxR_{(max)}$  to zero. Figure 26-5 shows the flag set cycle.



**Figure 26-5. Continuous Mode Flag Setting**

### 26.2.3.3 Use of Continuous Mode

The continuous mode can be used to generate independent time intervals and output frequencies. Each time an interval is completed, an interrupt is generated. The next time interval is added to the  $TBxCLn$  latch in the interrupt service routine. Figure 26-6 shows two separate time intervals,  $t_0$  and  $t_1$ , being added to the capture/compare registers. The time interval is controlled by hardware, not software, without impact from interrupt latency. Up to n (where  $n = 0$  to 7), independent time intervals or output frequencies can be generated using capture/compare registers.



**Figure 26-6. Continuous Mode Time Intervals**

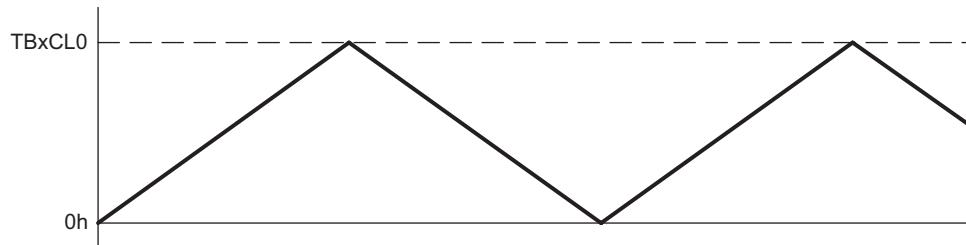
Time intervals can be produced with other modes as well, where TBxCL0 is used as the period register. Their handling is more complex, because the sum of the old TBxCLn data and the new period can be higher than the TBxCL0 value. When the sum of the previous TBxCLn value plus  $t_x$  is greater than the TBxCL0 data, the old TBxCL0 value must be subtracted to obtain the correct time interval.

#### 26.2.3.4 Up/Down Mode

The up/down mode is used if the timer period must be different from  $TBxR_{(max)}$  counts and if symmetrical pulse generation is needed. The timer repeatedly counts up to the value of compare latch TBxCL0, and back down to zero (see [Figure 26-7](#)). The period is twice the value in TBxCL0.

**NOTE:**  $TBxCL0 > TBxR_{(max)}$

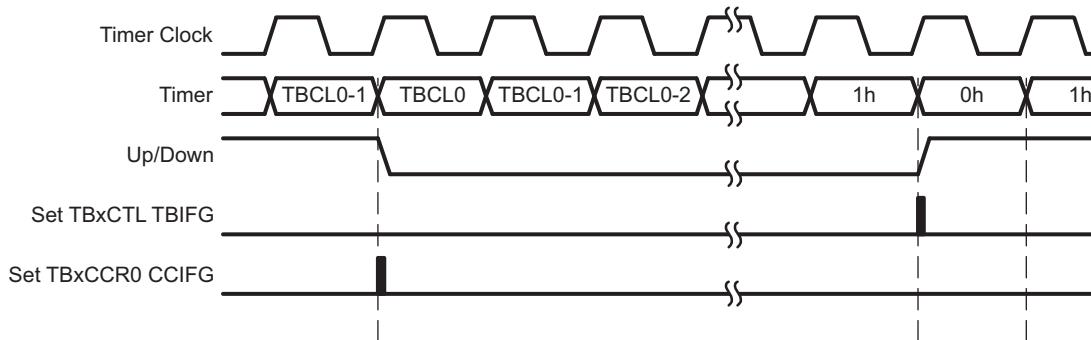
If  $TBxCL0 > TBxR_{(max)}$ , the counter operates as if it were configured for continuous mode. It does not count down from  $TBxR_{(max)}$  to zero.



**Figure 26-7. Up/Down Mode**

The count direction is latched. This allows the timer to be stopped and then restarted in the same direction it was counting before it was stopped. If this is not desired, the TBCLR bit must be used to clear the direction. Setting TBCLR also clears the TBxR value and the clock divider counter logic (the divider setting remains unchanged).

In up/down mode, the TBxCCR0 CCIFG interrupt flag and the TBIFG interrupt flag are set only once during the period, separated by one-half the timer period. The TBxCCR0 CCIFG interrupt flag is set when the timer *counts* from TBxCL0-1 to TBxCL0, and TBIFG is set when the timer completes *counting* down from 0001h to 0000h. [Figure 26-8](#) shows the flag set cycle.



**Figure 26-8. Up/Down Mode Flag Setting**

##### 26.2.3.4.1 Changing the Value of Period Register TBxCL0

When changing TBxCL0 while the timer is running and counting in the down direction, and when the TBxCL0 load mode is *immediate*, the timer continues its descent until it reaches zero. The new period takes effect after the counter counts down to zero.

If the timer is counting in the up direction when the new period is latched into TBxCL0, and the new period is greater than or equal to the old period or greater than the current count value, the timer counts up to the new period before counting down. When the timer is counting in the up direction, and the new period is less than the current count value when TBxCL0 is loaded, the timer begins counting down. However, one additional count may occur before the counter begins counting down.

### 26.2.3.5 Use of Up/Down Mode

The up/down mode supports applications that require dead times between output signals (see [Section 26.2.5](#)). For example, to avoid overload conditions, two outputs driving an H-bridge must never be in a high state simultaneously. In the example shown in [Figure 26-9](#), the  $t_{\text{dead}}$  is:

$$t_{\text{dead}} = t_{\text{timer}} \times (TBxCL1 - TBxCL3)$$

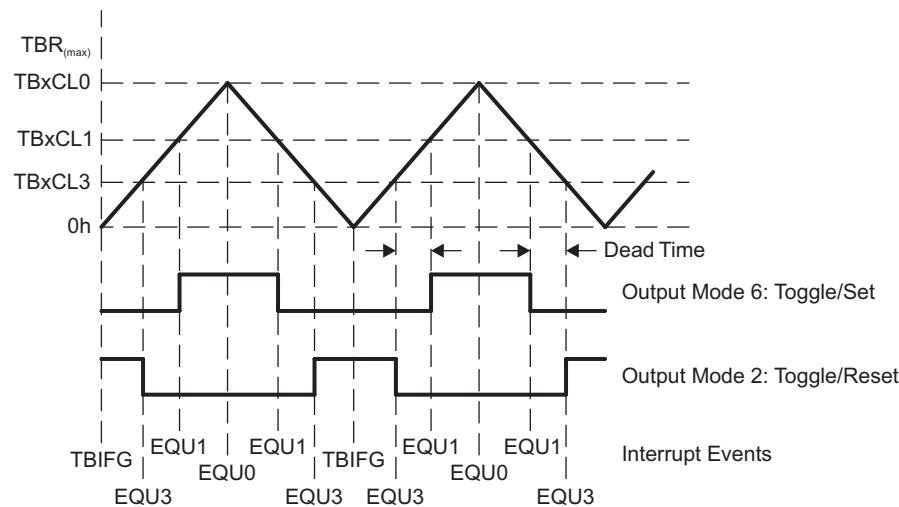
Where:

$t_{\text{dead}}$  = Time during which both outputs need to be inactive

$t_{\text{timer}}$  = Cycle time of the timer clock

TBxCLn = Content of compare latch n

The ability to simultaneously load grouped compare latches ensures the dead times.



**Figure 26-9. Output Unit in Up/Down Mode**

### 26.2.4 Capture/Compare Blocks

Up to seven identical capture/compare blocks, TBxCCRn (where n = 0 to 6), are present in Timer\_B. Any of the blocks may be used to capture the timer data or to generate time intervals.

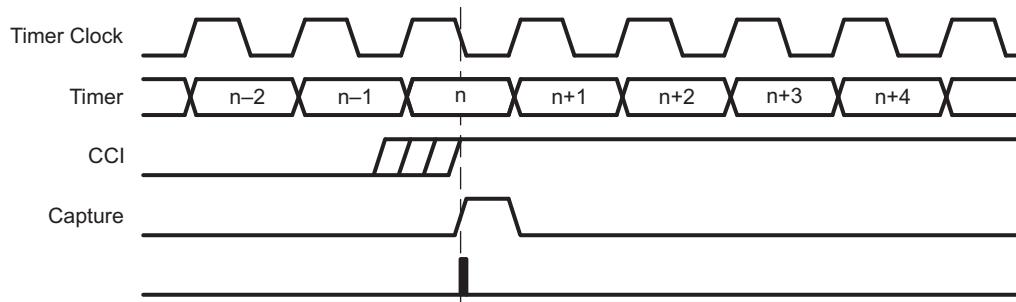
#### 26.2.4.1 Capture Mode

The capture mode is selected when CAP = 1. Capture mode is used to record time events. It can be used for speed computations or time measurements. The capture inputs CCIA and CCIB are connected to external pins or internal signals and are selected with the CCIS bits. The CM bits select the capture edge of the input signal as rising, falling, or both. A capture occurs on the selected edge of the input signal. If a capture is performed:

- The timer value is copied into the TBxCCRn register.
- The interrupt flag CCIFG is set.

The input signal level can be read at any time from the CCI bit. Devices may have different signals connected to CCIA and CCIB. See the device-specific data sheet for the connections of these signals.

The capture signal can be asynchronous to the timer clock and cause a race condition. Setting the SCS bit synchronizes the capture with the next timer clock. TI recommends setting the SCS bit to synchronize the capture signal with the timer clock (see [Figure 26-10](#)).



**Figure 26-10. Capture Signal (SCS = 1)**

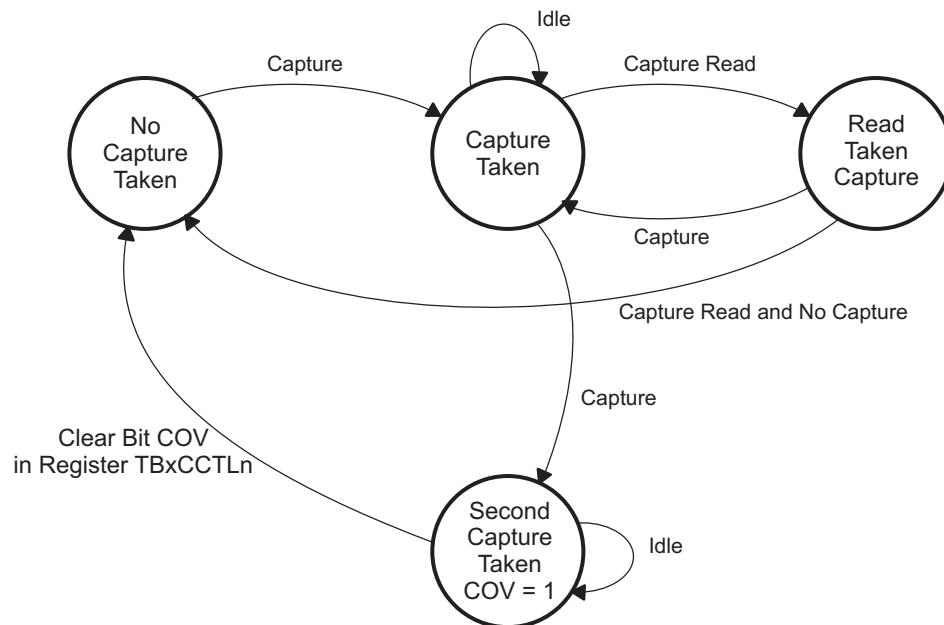
---

**NOTE: Changing Capture Inputs**

Changing capture inputs while in capture mode may cause unintended capture events. To avoid this scenario, capture inputs should only be changed when capture mode is disabled ( $CM = \{0\}$  or  $CAP = 0$ ).

---

Overflow logic is provided in each capture/compare register to indicate if a second capture was performed before the value from the first capture was read. Bit COV is set when this occurs (see [Figure 26-11](#)). COV must be reset with software.



**Figure 26-11. Capture Cycle**

#### 26.2.4.1.1 Capture Initiated by Software

Captures can be initiated by software. The CM bits can be set for capture on both edges. Software then sets bit CCIS1 = 1 and toggles bit CCIS0 to switch the capture signal between V<sub>CC</sub> and GND, initiating a capture each time CCIS0 changes state:

```
MOV      #CAP+SCS+CCIS1+CM_3 ,&TB0CCTL1    ; Setup TB0CCTL1
XOR      #CCIS0 ,&TB0CCTL1                ; TB0CCR1 = TB0R
```

**NOTE: Capture Initiated by Software**

In general, changing capture inputs while in capture mode may cause unintended capture events. For this scenario, switching the capture input between VCC and GND, disabling the capture mode is not required.

#### 26.2.4.2 Compare Mode

The compare mode is selected when CAP = 0. Compare mode is used to generate PWM output signals or interrupts at specific time intervals. When TBxR *counts* to the value in a TBxCn, where n represents the specific capture/compare latch:

- Interrupt flag CCIFG is set.
- Internal signal EQUn = 1.
- EQUn affects the output according to the output mode.

#### 26.2.4.2.1 Compare Latch TBxCn

The TBxCCRn compare latch, TBxCn, holds the data for the comparison to the timer value in compare mode. TBxCn is buffered by TBxCCRn. The buffered compare latch gives the user control over when a compare period updates. The user cannot directly access TBxCn. Compare data is written to each TBxCCRn and automatically transferred to TBxCn. The timing of the transfer from TBxCCRn to TBxCn is user selectable, with the CLLD bits as described in [Table 26-2](#).

**Table 26-2. TBxCn Load Events**

| CLLD | Description                                                                                                                                                                                                                     |
|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 00   | New data is transferred from TBxCCRn to TBxCn immediately when TBxCCRn is written to.                                                                                                                                           |
| 01   | New data is transferred from TBxCCRn to TBxCn when TBxR <i>counts</i> to 0.                                                                                                                                                     |
| 10   | New data is transferred from TBxCCRn to TBxCn when TBxR <i>counts</i> to 0 for up and continuous modes. New data is transferred from TBxCCRn to TBxCn when TBxR <i>counts</i> to the old TBxCLO value or to 0 for up/down mode. |
| 11   | New data is transferred from TBxCCRn to TBxCn when TBxR <i>counts</i> to the old TBxCn value.                                                                                                                                   |

### 26.2.4.2.2 Grouping Compare Latches

Multiple compare latches may be grouped together for simultaneous updates with the TBCLGRPx bits. When using groups, the CLLD bits of the lowest numbered TBxCCRn in the group determine the load event for each compare latch of the group, except when TBCLGRP = 3 (see [Table 26-3](#)). The CLLD bits of the controlling TBxCCRn must not be set to zero. When the CLLD bits of the controlling TBxCCRn are set to zero, all compare latches update immediately when their corresponding TBxCCRn is written; no compare latches are grouped.

Two conditions must exist for the compare latches to be loaded when grouped. First, all TBxCCRn registers of the group must be updated, even when new TBxCCRn data = old TBxCCRn data. Second, the load event must occur.

**Table 26-3. Compare Latch Operating Modes**

| TBCLGRPx | Grouping                                         | Update Control                |
|----------|--------------------------------------------------|-------------------------------|
| 00       | None                                             | Individual                    |
| 01       | TBxCL1+TBxCL2<br>TBxCL3+TBxCL4<br>TBxCL5+TBxCL6  | TBxCCR1<br>TBxCCR3<br>TBxCCR5 |
| 10       | TBxCL1+TBxCL2+TBxCL3<br>TBxCL4+TBxCL5+TBxCL6     | TBxCCR1<br>TBxCCR4            |
| 11       | TBxCL0+TBxCL1+TBxCL2+TBxCL3+TBxCL4+TBxCL5+TBxCL6 | TBxCCR1                       |

### 26.2.5 Output Unit

Each capture/compare block contains an output unit. The output unit is used to generate output signals, such as PWM signals. Each output unit has eight operating modes that generate signals based on the EQU0 and EQUn signals. The TBOUTH pin function can be used to put all Timer\_B outputs into a high-impedance state. When the TBOUTH pin function is selected for the pin (corresponding PSEL bit is set, and port configured as input) and when the pin is pulled high, all Timer\_B outputs are in a high-impedance state.

#### 26.2.5.1 Output Modes

The output modes are defined by the OUTMOD bits and are described in [Table 26-4](#). The OUTn signal is changed with the rising edge of the timer clock for all modes except mode 0. Output modes 2, 3, 6, and 7 are not useful for output unit 0 because EQUn = EQU0.

**Table 26-4. Output Modes**

| OUTMOD | Mode         | Description                                                                                                                                                                     |
|--------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 000    | Output       | The output signal OUTn is defined by the OUT bit. The OUTn signal updates immediately when OUT is updated.                                                                      |
| 001    | Set          | The output is set when the timer <i>counts</i> to the TBxCLn value. It remains set until a reset of the timer, or until another output mode is selected and affects the output. |
| 010    | Toggle/Reset | The output is toggled when the timer <i>counts</i> to the TBxCLn value. It is reset when the timer <i>counts</i> to the TBxCL0 value.                                           |
| 011    | Set/Reset    | The output is set when the timer <i>counts</i> to the TBxCLn value. It is reset when the timer <i>counts</i> to the TBxCL0 value.                                               |
| 100    | Toggle       | The output is toggled when the timer <i>counts</i> to the TBxCLn value. The output period is double the timer period.                                                           |
| 101    | Reset        | The output is reset when the timer <i>counts</i> to the TBxCLn value. It remains reset until another output mode is selected and affects the output.                            |
| 110    | Toggle/Set   | The output is toggled when the timer <i>counts</i> to the TBxCLn value. It is set when the timer <i>counts</i> to the TBxCL0 value.                                             |
| 111    | Reset/Set    | The output is reset when the timer <i>counts</i> to the TBxCLn value. It is set when the timer <i>counts</i> to the TBxCL0 value.                                               |

### 26.2.5.1.1 Output Example – Timer in Up Mode

The OUTn signal is changed when the timer *counts* up to the TBxCLn value, and rolls from TBxCL0 to zero, depending on the output mode. An example is shown in Figure 26-12 using TBxCL0 and TBxCL1.

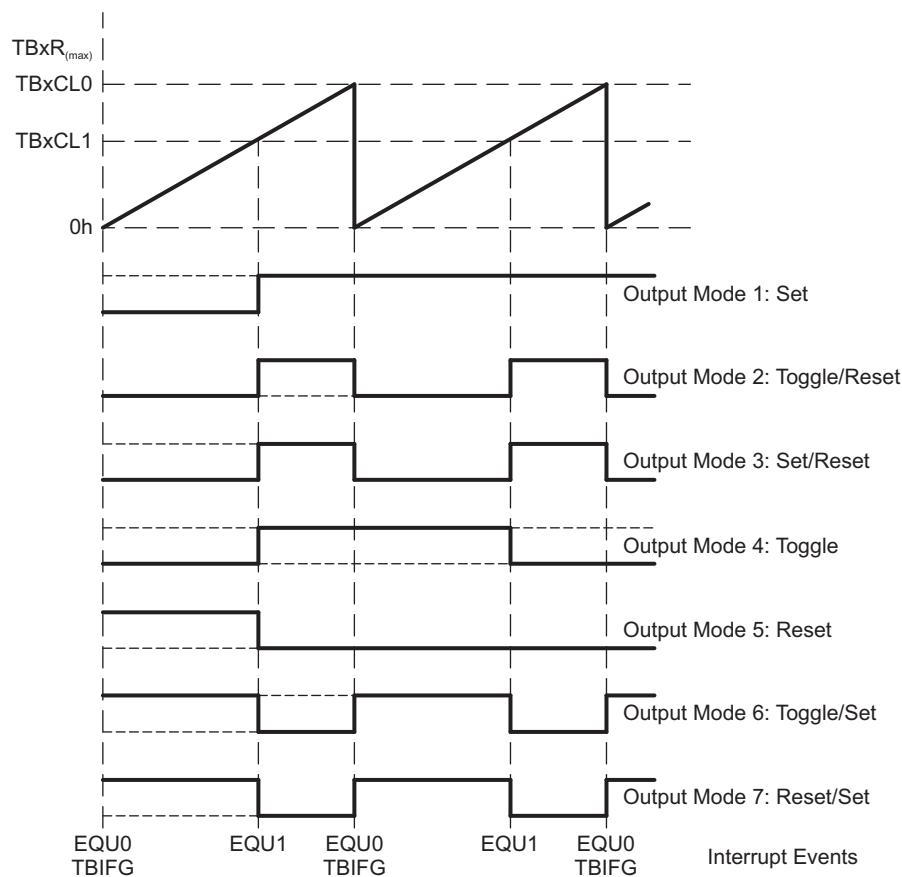
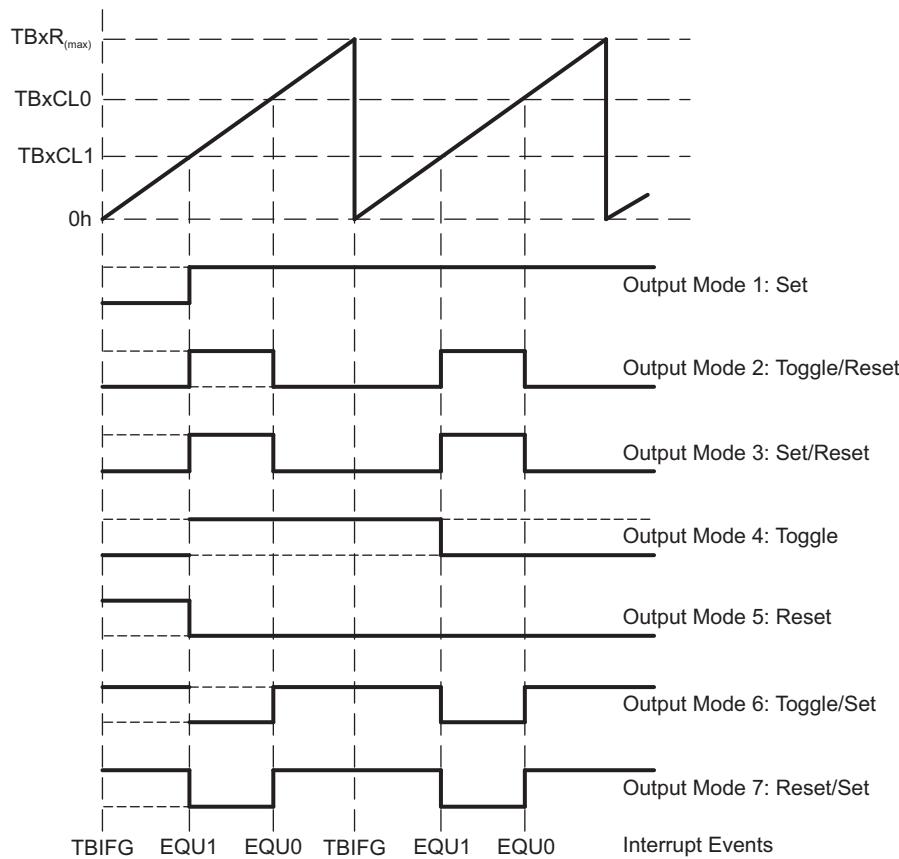


Figure 26-12. Output Example – Timer in Up Mode

### 26.2.5.1.2 Output Example – Timer in Continuous Mode

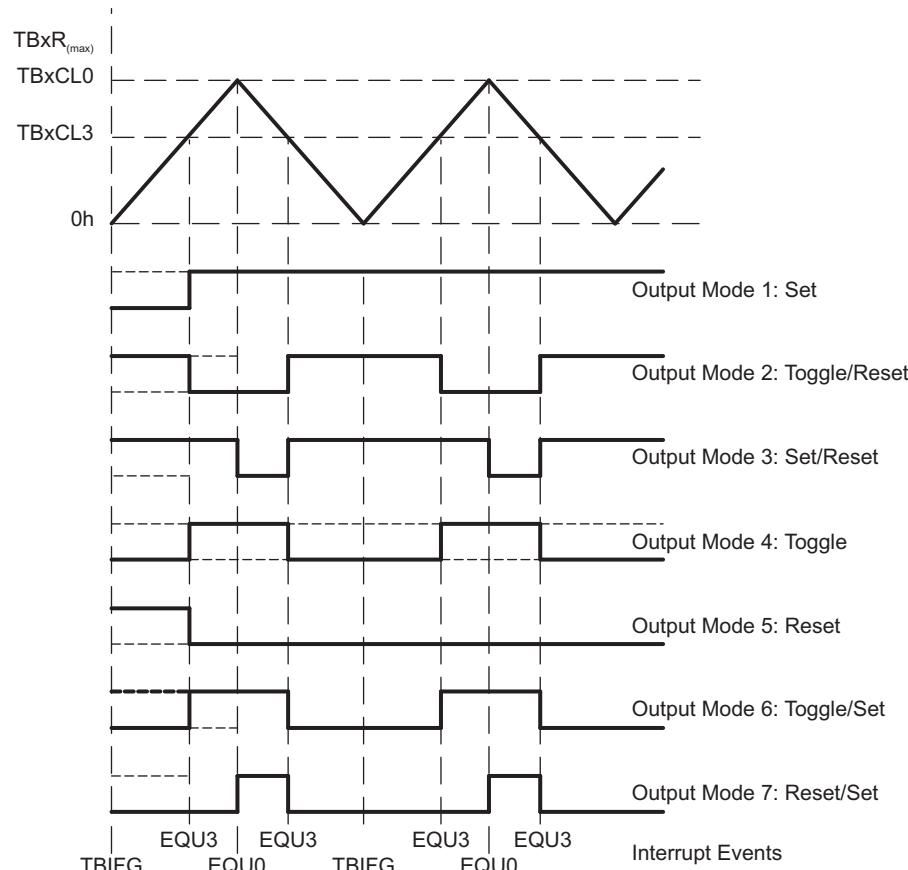
The OUTn signal is changed when the timer reaches the TBxCLn and TBxCL0 values, depending on the output mode. An example is shown in Figure 26-13 using TBxCL0 and TBxCL1.



**Figure 26-13. Output Example – Timer in Continuous Mode**

### 26.2.5.1.3 Output Example – Timer in Up/Down Mode

The OUTn signal changes when the timer equals TBxCLn in either count direction and when the timer equals TBxCL0, depending on the output mode. An example is shown in Figure 26-14 using TBxCL0 and TBxCL3.



**Figure 26-14. Output Example – Timer in Up/Down Mode**

---

**NOTE: Switching between output modes**

When switching between output modes, one of the OUTMOD bits should remain set during the transition, unless switching to mode 0. Otherwise, output glitching can occur because a NOR gate decodes output mode 0. A safe method for switching between output modes is to use output mode 7 as a transition state:

```
BIS #OUTMOD_7,&TBCCTLx ; Set output mode=7
BIC #OUTMOD,&TBCCTLx ; Clear unwanted bits
```

---

## 26.2.6 Timer\_B Interrupts

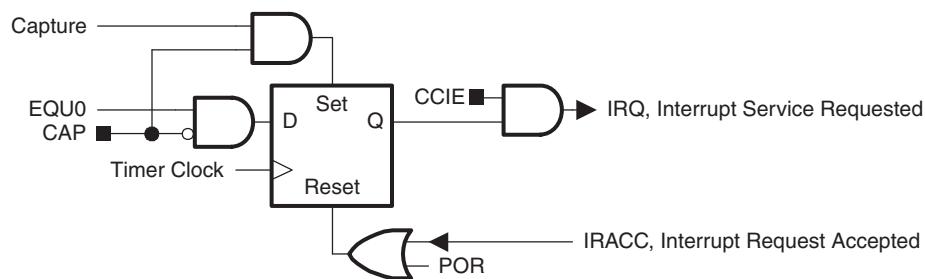
Two interrupt vectors are associated with the 16-bit Timer\_B module:

- TBxCCR0 interrupt vector for TBxCCR0 CCIFG
- TBIV interrupt vector for all other CCIFG flags and TBIFG

In capture mode, any CCIFG flag is set when a timer value is captured in the associated TBxCCRn register. In compare mode, any CCIFG flag is set when TBxR *counts* to the associated TBxCLn value. Software may also set or clear any CCIFG flag. All CCIFG flags request an interrupt when their corresponding CCIE bit and the GIE bit are set.

### 26.2.6.1 TBxCCR0 Interrupt Vector

The TBxCCR0 CCIFG flag has the highest Timer\_B interrupt priority and has a dedicated interrupt vector (see [Figure 26-15](#)). The TBxCCR0 CCIFG flag is automatically reset when the TBxCCR0 interrupt request is serviced.



**Figure 26-15. Capture/Compare TBxCCR0 Interrupt Flag**

### 26.2.6.2 TBxIV, Interrupt Vector Generator

The TBIFG flag and TBxCCRn CCIFG flags (excluding TBxCCR0 CCIFG) are prioritized and combined to source a single interrupt vector. The interrupt vector register TBxIV is used to determine which flag requested an interrupt.

The highest-priority enabled interrupt (excluding TBxCCR0 CCIFG) generates a number in the TBxIV register (see register description). This number can be evaluated or added to the program counter to automatically enter the appropriate software routine. Disabled Timer\_B interrupts do not affect the TBxIV value.

Any access, read or write, of the TBxIV register automatically resets the highest-pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. For example, if the TBxCCR1 and TBxCCR2 CCIFG flags are set when the interrupt service routine accesses the TBxIV register, TBxCCR1 CCIFG is reset automatically. After the RETI instruction of the interrupt service routine is executed, the TBxCCR2 CCIFG flag generates another interrupt.

### 26.2.6.3 TBxIV, Interrupt Handler Examples

The following software example shows the recommended use of TBxIV and the handling overhead. The TBxIV value is added to the PC to automatically jump to the appropriate routine. The example assumes a single instantiation of the largest timer configuration available.

The numbers at the right margin show the necessary CPU clock cycles for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself. The latencies are:

- Capture/compare block CCR0: 11 cycles
- Capture/compare blocks CCR1 to CCR6: 16 cycles
- Timer overflow TBIFG: 14 cycles

The following software example shows the recommended use of TBxIV for Timer\_B3.

|                                                                |                                      | Cycles                                                |
|----------------------------------------------------------------|--------------------------------------|-------------------------------------------------------|
| ; Interrupt handler for TB0CCR0 CCIFG.                         |                                      |                                                       |
| CCIFG_0_HND                                                    |                                      |                                                       |
| ; ...                                                          | ; Start of handler Interrupt latency | 6                                                     |
| RETI                                                           |                                      | 5                                                     |
| ;                                                              |                                      |                                                       |
| ; Interrupt handler for TB0IFG, TB0CCR1 through TB0CCR6 CCIFG. |                                      |                                                       |
| TB0_HND                                                        | ...                                  |                                                       |
| ADD                                                            | &TB0IV, PC                           | ; Interrupt latency 6<br>; Add offset to Jump table 3 |
| RETI                                                           |                                      | ; Vector 0: No interrupt 5                            |
| JMP                                                            | CCIFG_1_HND                          | ; Vector 2: TB0CCR1 2                                 |
| JMP                                                            | CCIFG_2_HND                          | ; Vector 4: TB0CCR2 2                                 |
| JMP                                                            | CCIFG_3_HND                          | ; Vector 6: TB0CCR3 2                                 |
| JMP                                                            | CCIFG_4_HND                          | ; Vector 8: TB0CCR4 2                                 |
| JMP                                                            | CCIFG_5_HND                          | ; Vector 10: TB0CCR5 2                                |
| JMP                                                            | CCIFG_6_HND                          | ; Vector 12: TB0CCR6 2                                |
| TB0IFG_HND                                                     |                                      | ; Vector 14: TB0IFG Flag                              |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      |                                                       |
| CCIFG_6_HND                                                    |                                      |                                                       |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      | ; Back to main program 5                              |
| CCIFG_5_HND                                                    |                                      |                                                       |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      | ; Back to main program 5                              |
| CCIFG_4_HND                                                    |                                      |                                                       |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      | ; Back to main program 5                              |
| CCIFG_3_HND                                                    |                                      |                                                       |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      | ; Back to main program 5                              |
| CCIFG_2_HND                                                    |                                      |                                                       |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      | ; Back to main program 5                              |
| CCIFG_1_HND                                                    |                                      |                                                       |
| ; ...                                                          |                                      | ; Task starts here                                    |
| RETI                                                           |                                      | ; Back to main program 5                              |

## 26.3 Timer\_B Registers

The Timer\_B registers are listed in [Table 26-5](#). The base address can be found in the device-specific data sheet. The address offset is listed in [Table 26-5](#).

**Table 26-5. Timer\_B Registers**

| Offset | Acronym  | Register Name                     | Type       | Access | Reset | Section                        |
|--------|----------|-----------------------------------|------------|--------|-------|--------------------------------|
| 00h    | TBxCTL   | Timer_B Control                   | Read/write | Word   | 0000h | <a href="#">Section 26.3.1</a> |
| 02h    | TBxCCTL0 | Timer_B Capture/Compare Control 0 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 04h    | TBxCCTL1 | Timer_B Capture/Compare Control 1 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 06h    | TBxCCTL2 | Timer_B Capture/Compare Control 2 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 08h    | TBxCCTL3 | Timer_B Capture/Compare Control 3 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 0Ah    | TBxCCTL4 | Timer_B Capture/Compare Control 4 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 0Ch    | TBxCCTL5 | Timer_B Capture/Compare Control 5 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 0Eh    | TBxCCTL6 | Timer_B Capture/Compare Control 6 | Read/write | Word   | 0000h | <a href="#">Section 26.3.3</a> |
| 10h    | TBxR     | Timer_B Counter                   | Read/write | Word   | 0000h | <a href="#">Section 26.3.2</a> |
| 12h    | TBxCCR0  | Timer_B Capture/Compare 0         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 14h    | TBxCCR1  | Timer_B Capture/Compare 1         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 16h    | TBxCCR2  | Timer_B Capture/Compare 2         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 18h    | TBxCCR3  | Timer_B Capture/Compare 3         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 1Ah    | TBxCCR4  | Timer_B Capture/Compare 4         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 1Ch    | TBxCCR5  | Timer_B Capture/Compare 5         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 1Eh    | TBxCCR6  | Timer_B Capture/Compare 6         | Read/write | Word   | 0000h | <a href="#">Section 26.3.4</a> |
| 2Eh    | TBxIV    | Timer_B Interrupt Vector          | Read only  | Word   | 0000h | <a href="#">Section 26.3.5</a> |
| 20h    | TBxEX0   | Timer_B Expansion 0               | Read/write | Word   | 0000h | <a href="#">Section 26.3.6</a> |

### 26.3.1 TBxCTL Register

Timer\_B x Control Register

**Figure 26-16. TBxCTL Register**

| 15       | 14                   | 13     | 12     | 11       | 10       | 9      | 8      |
|----------|----------------------|--------|--------|----------|----------|--------|--------|
| Reserved | TBCLGRP <sub>x</sub> |        |        | CNTL     | Reserved | TBSSEL |        |
| rw-(0)   | rw-(0)               | rw-(0) | rw-(0) | rw-(0)   | rw-(0)   | rw-(0) | rw-(0) |
| 7        | 6                    | 5      | 4      | 3        | 2        | 1      | 0      |
| ID       | MC                   |        |        | Reserved | TBCLR    | TBIE   | TBIFG  |
| rw-(0)   | rw-(0)               | rw-(0) | rw-(0) | rw-(0)   | w-(0)    | rw-(0) | rw-(0) |

**Table 26-6. TBxCTL Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 14-13 | TBCLGRP  | RW   | 0h    | TBxCLn group<br>00b = Each TBxCLn latch loads independently.<br>01b = TBxCL1+TBxCL2 (TBxCCR1 CLLD bits control the update);<br>TBxCL3+TBxCL4 (TBxCCR3 CLLD bits control the update); TBxCL5+TBxCL6 (TBxCCR5 CLLD bits control the update); TBxCL0 independent<br>10b = TBxCL1+TBxCL2+TBxCL3 (TBxCCR1 CLLD bits control the update);<br>TBxCL4+TBxCL5+TBxCL6 (TBxCCR4 CLLD bits control the update); TBxCL0 independent<br>11b = TBxCL0+TBxCL1+TBxCL2+TBxCL3+TBxCL4+TBxCL5+TBxCL6 (TBxCCR1 CLLD bits control the update) |
| 12-11 | CNTL     | RW   | 0h    | Counter length<br>00b = 16-bit, TBxR(max) = 0FFFFh<br>01b = 12-bit, TBxR(max) = 0FFFh<br>10b = 10-bit, TBxR(max) = 03FFh<br>11b = 8-bit, TBxR(max) = 0FFh                                                                                                                                                                                                                                                                                                                                                               |
| 10    | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 9-8   | TBSSEL   | RW   | 0h    | Timer_B clock source select<br>00b = TBxCLK<br>01b = ACLK<br>10b = SMCLK<br>11b = INCLK                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 7-6   | ID       | RW   | 0h    | Input divider. These bits, along with the TBIDEX bits, select the divider for the input clock.<br>00b = /1<br>01b = /2<br>10b = /4<br>11b = /8                                                                                                                                                                                                                                                                                                                                                                          |
| 5-4   | MC       | RW   | 0h    | Mode control. Setting MC = 00h when Timer_B is not in use conserves power.<br>00b = Stop mode: Timer is halted<br>01b = Up mode: Timer counts up to TBxCL0<br>10b = Continuous mode: Timer counts up to the value set by CNTL<br>11b = Up/down mode: Timer counts up to TBxCL0 and down to 0000h                                                                                                                                                                                                                        |
| 3     | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 2     | TBCLR    | RW   | 0h    | Timer_B clear. Setting this bit clears TBR, the clock divider logic (the divider setting remains unchanged), and the count direction. The TBCLR bit is automatically reset and is always read as zero.                                                                                                                                                                                                                                                                                                                  |
| 1     | TBIE     | RW   | 0h    | Timer_B interrupt enable. This bit enables the TBIFG interrupt request.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                                                                                                                                                                                                                            |

**Table 26-6. TBxCTL Register Description (continued)**

| Bit | Field | Type | Reset | Description                                                                   |
|-----|-------|------|-------|-------------------------------------------------------------------------------|
| 0   | TBIFG | RW   | 0h    | Timer_B interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending |

### 26.3.2 TBxR Register

Timer\_B x Counter Register

**Figure 26-17. TBxR Register**

|        |        |        |        |        |        |        |        |
|--------|--------|--------|--------|--------|--------|--------|--------|
| 15     | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
| TBxR   |        |        |        |        |        |        |        |
| rw-(0) |
| TBxR   |        |        |        |        |        |        |        |
| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
| rw-(0) |

**Table 26-7. TBxR Register Description**

| Bit  | Field | Type | Reset | Description                                                  |
|------|-------|------|-------|--------------------------------------------------------------|
| 15-0 | TBxR  | RW   | 0h    | Timer_B register. The TBxR register is the count of Timer_B. |

### 26.3.3 TBxCCTLn Register

Timer\_B x Capture/Compare Control Register n

**Figure 26-18. TBxCCTLn Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|--------|--------|--------|--------|--------|--------|--------|--------|
| CM     |        | CCIS   |        | SCS    |        | CLLD   | CAP    |
| rw-(0) |
| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
|        | OUTMOD |        | CCIE   | CCI    | OUT    | COV    | CCIFG  |
| rw-(0) | rw-(0) | rw-(0) | rw-(0) | r      | rw-(0) | rw-(0) | rw-(0) |

**Table 26-8. TBxCCTLn Register Description**

| Bit   | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                     |
|-------|--------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | CM     | RW   | 0h    | Capture mode<br>00b = No capture<br>01b = Capture on rising edge<br>10b = Capture on falling edge<br>11b = Capture on both rising and falling edges                                                                                                                                                                                             |
| 13-12 | CCIS   | RW   | 0h    | Capture/compare input select. These bits select the TBxCCRn input signal. See the device-specific data sheet for specific signal connections.<br>00b = CC <sub>I</sub> xA<br>01b = CC <sub>I</sub> xB<br>10b = GND<br>11b = VCC                                                                                                                 |
| 11    | SCS    | RW   | 0h    | Synchronize capture source. This bit is used to synchronize the capture input signal with the timer clock.<br>0b = Asynchronous capture<br>1b = Synchronous capture                                                                                                                                                                             |
| 10-9  | CLLD   | RW   | 0h    | Compare latch load. These bits select the compare latch load event.<br>00b = TBxCLn loads on write to TBxCCRn<br>01b = TBxCLn loads when TBxR counts to 0<br>10b = TBxCLn loads when TBxR counts to 0 (up or continuous mode). TBxCLn loads when TBxR counts to TBxCL0 or to 0 (up/down mode).<br>11b = TBxCLn loads when TBxR counts to TBxCLn |
| 8     | CAP    | RW   | 0h    | Capture mode<br>0b = Compare mode<br>1b = Capture mode                                                                                                                                                                                                                                                                                          |
| 7-5   | OUTMOD | RW   | 0h    | Output mode. Modes 2, 3, 6, and 7 are not useful for TBxCL0 because EQUn = EQU0.<br>000b = OUT bit value<br>001b = Set<br>010b = Toggle/reset<br>011b = Set/reset<br>100b = Toggle<br>101b = Reset<br>110b = Toggle/set<br>111b = Reset/set                                                                                                     |
| 4     | CCIE   | RW   | 0h    | Capture/compare interrupt enable. This bit enables the interrupt request of the corresponding CCIFG flag.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                  |
| 3     | CCI    | R    | Undef | Capture/compare input. The selected input signal can be read by this bit.                                                                                                                                                                                                                                                                       |

**Table 26-8. TBxCCTLn Register Description (continued)**

| Bit | Field | Type | Reset | Description                                                                                                                                                               |
|-----|-------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2   | OUT   | RW   | 0h    | Output. For output mode 0, this bit directly controls the state of the output.<br>0b = Output low<br>1b = Output high                                                     |
| 1   | COV   | RW   | 0h    | Capture overflow. This bit indicates a capture overflow occurred. COV must be reset with software.<br>0b = No capture overflow occurred<br>1b = Capture overflow occurred |
| 0   | CCIFG | RW   | 0h    | Capture/compare interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                     |

### **26.3.4 TBxCCRn Register**

Timer\_B x Capture/Compare Register n

**Figure 26-19. TBxCCRn Register**

| 15      | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|---------|--------|--------|--------|--------|--------|--------|--------|
| TBxCCRn |        |        |        |        |        |        |        |
| rw-(0)  | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| TBxCCRn |        |        |        |        |        |        |        |
| 7       | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
| rw-(0)  | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 26-9. TBxCCRn Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                                |
|------|---------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TBxCCRn | RW   | 0h    | Timer_B capture/compare register.<br>Compare mode: TBxCCRn holds the data for the comparison to the timer value in the Timer_B Register, TBR.<br>Capture mode: The Timer_B Register, TBR, is copied into the TBxCCRn register when a capture is performed. |

### 26.3.5 TBxIV Register

Timer\_B x Interrupt Vector Register

**Figure 26-20. TBxIV Register**

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 15    | 14    | 13    | 12    | 11    | 10    | 9     | 8     |
| TBIV  |       |       |       |       |       |       |       |
| r-(0) |
| TBIV  |       |       |       |       |       |       |       |
| r-(0) |

**Table 26-10. TBxIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------|-------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | TBIV  | R    | 0h    | Timer_B interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Capture/compare 1; Interrupt Flag: TBxCCR1 CCIFG; Interrupt Priority: Highest<br>04h = Interrupt Source: Capture/compare 2; Interrupt Flag: TBxCCR2 CCIFG<br>06h = Interrupt Source: Capture/compare 3; Interrupt Flag: TBxCCR3 CCIFG<br>08h = Interrupt Source: Capture/compare 4; Interrupt Flag: TBxCCR4 CCIFG<br>0Ah = Interrupt Source: Capture/compare 5; Interrupt Flag: TBxCCR5 CCIFG<br>0Ch = Interrupt Source: Capture/compare 6; Interrupt Flag: TBxCCR6 CCIFG<br>0Eh = Interrupt Source: Timer overflow; Interrupt Flag: TBxCTL TBIFG; Interrupt Priority: Lowest |

### 26.3.6 TBxEX0 Register

Timer\_B x Expansion Register 0

**Figure 26-21. TBxEX0 Register**

|          |    |    |    |    |        |                       |        |
|----------|----|----|----|----|--------|-----------------------|--------|
| 15       | 14 | 13 | 12 | 11 | 10     | 9                     | 8      |
| Reserved |    |    |    |    |        |                       |        |
| r0       | r0 | r0 | r0 | r0 | r0     | r0                    | r0     |
| 7        | 6  | 5  | 4  | 3  | 2      | 1                     | 0      |
| Reserved |    |    |    |    |        | TBIDEX <sup>(1)</sup> |        |
| r0       | r0 | r0 | r0 | r0 | rw-(0) | rw-(0)                | rw-(0) |

<sup>(1)</sup> After programming TBIDEX bits and configuration of the timer, set TBCLR bit to ensure proper reset of the timer divider logic.

**Table 26-11. TBxEX0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                        |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                       |
| 2-0  | TBIDEX   | RW   | 0h    | Input divider expansion. These bits along with the ID bits select the divider for the input clock.<br>000b = Divide by 1<br>001b = Divide by 2<br>010b = Divide by 3<br>011b = Divide by 4<br>100b = Divide by 5<br>101b = Divide by 6<br>110b = Divide by 7<br>111b = Divide by 8 |

## Real-Time Clock (RTC) Overview

### 27.1 RTC Overview

**Table 27-1. RTC Overview**

| Feature                               | RTC_B<br>LPM3.5, Calendar Mode Only                                  | RTC_C<br>Protection + Improved Calibration and Compensation     |
|---------------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------|
| Calendar Mode                         | Yes                                                                  | Yes                                                             |
| Counter Mode                          | No                                                                   | Optional (device-dependent) <sup>(1)</sup>                      |
| Programmable Alarms                   | Yes                                                                  | Yes                                                             |
| Password Protected Calendar Registers | No                                                                   | Yes                                                             |
| Input Clocks                          | 32-kHz crystal oscillator                                            | 32-kHz crystal oscillator                                       |
| LPM3.5 Support                        | Yes                                                                  | Yes                                                             |
| Offset Calibration Register           | Yes                                                                  | Yes                                                             |
| Temperature Compensation Register     | No                                                                   | Yes                                                             |
| Frequency Adjustment Range            | -2.17 ppm $\times$ 59 ≈ -128 ppm<br>+4.34 ppm $\times$ 59 ≈ +256 ppm | -240 ppm, +240 ppm <sup>(2)</sup>                               |
| Frequency Adjustment Steps            | -2.17 ppm, +4.34 ppm                                                 | -1 ppm, +1 ppm                                                  |
| Temperature Compensation              | With software, manipulating offset calibration value                 | With software using separate temperature compensation register  |
| Calibration and Compensation Period   | 60 min                                                               | 1 min                                                           |
| BCD to Binary Conversion              | Integrated for Calendar Mode plus separate conversion registers      | Integrated for Calendar Mode plus separate conversion registers |
| Event/Tamper Detect with Time Stamp   | No                                                                   | Optional (device-dependent) <sup>(1)</sup>                      |

<sup>(1)</sup> See the device-specific data sheet.

<sup>(2)</sup> Total adjustment range of offset calibration plus temperature compensation. See the RTC\_C chapter for details.

## **Real-Time Clock B (RTC\_B)**

The real-time clock RTC\_B module provides clock counters with calendar mode, a flexible programmable alarm, and calibration. Note that the RTC\_B supports only calendar mode and not counter mode. The RTC\_B also support operation in LPM3.5. See the device-specific data sheet for the supported features. This chapter describes the RTC\_B module.

| Topic                                                | Page       |
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| <b>28.2 RTC_B Operation.....</b>                     | <b>690</b> |
| <b>28.3 RTC_B Registers .....</b>                    | <b>695</b> |

## 28.1 Real-Time Clock RTC\_B Introduction

The RTC\_B module provides configurable clock counters.

RTC\_B features include:

- Real-time clock and calendar mode providing seconds, minutes, hours, day of week, day of month, month, and year (including leap year correction)

Note that only the calendar mode is supported by RTC\_B; the counter mode that is available in some other RTC modules is not supported.

- Interrupt capability
- Selectable BCD or binary format
- Programmable alarms
- Calibration logic for time offset correction
- Operation in LPM3.5

The RTC\_B block diagram for devices supporting LPM3.5 is shown in [Figure 28-1](#).

---

**NOTE: Real-time clock initialization**

Most RTC\_B module registers have no initial condition. These registers must be configured by user software before use.

---

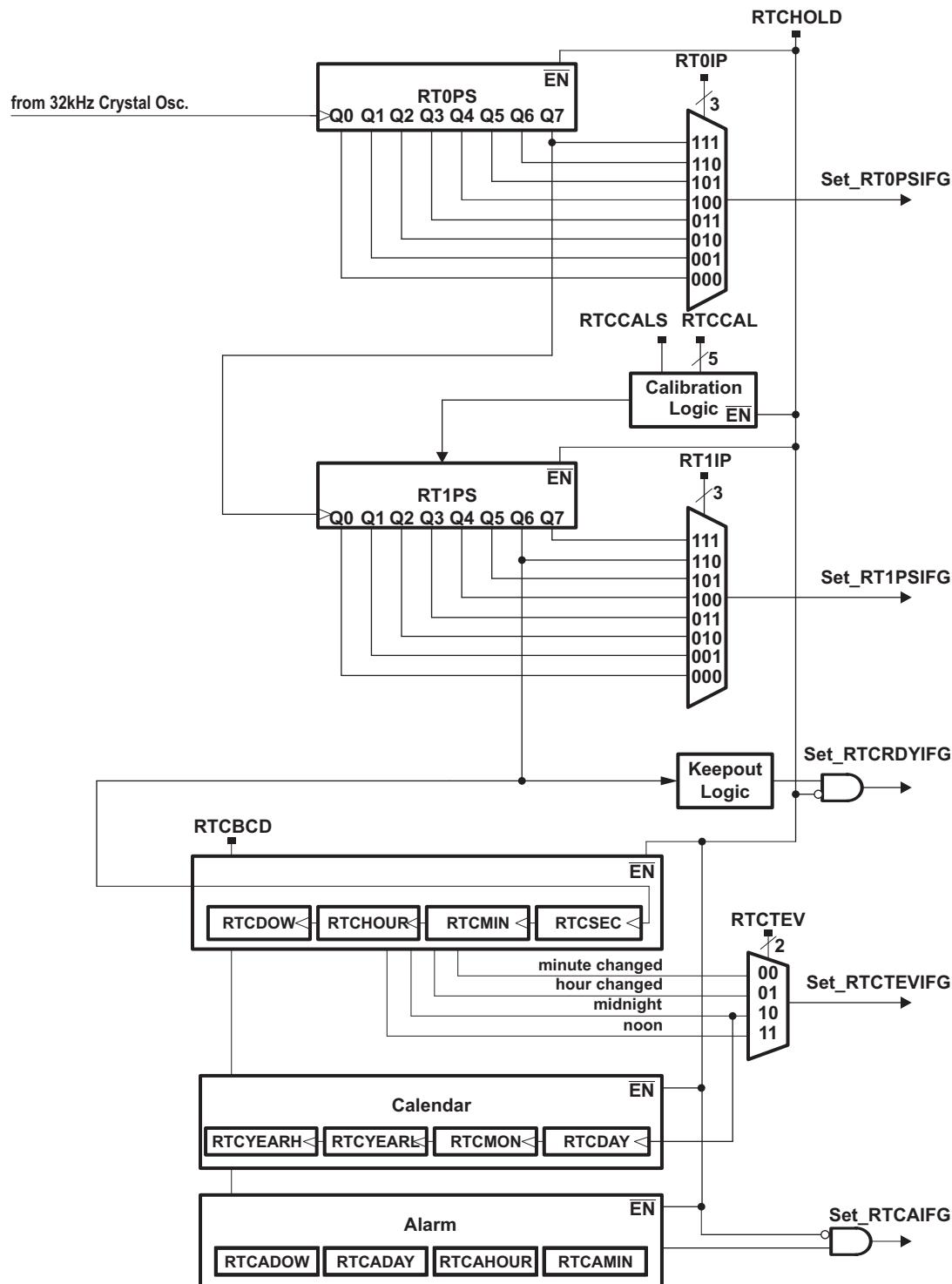


Figure 28-1. RTC\_B Block Diagram

## 28.2 RTC\_B Operation

The RTC\_B module provides seconds, minutes, hours, day of week, day of month, month, and year in selectable BCD or hexadecimal format. The calendar includes a leap-year algorithm that considers all years evenly divisible by four as leap years. This algorithm is accurate from the year 1901 through 2099.

### 28.2.1 Real-Time Clock and Prescale Dividers

The prescale dividers, RT0PS and RT1PS, are automatically configured to provide a 1-s clock interval for the RTC\_B. The low-frequency oscillator must be operated at 32768 Hz (nominal) for proper RTC\_B operation. RT0PS is sourced from the low-frequency oscillator XT1. The output of RT0PS / 256 (Q7) is used to source RT1PS. RT1PS is further divider and the /128 output sources the real-time clock counter registers providing the required 1-second time interval.

When RTCBCD = 1, BCD format is selected for the calendar registers. It is possible to switch between BCD and hexadecimal format while the RTC is counting.

Setting RTCHOLD halts the real-time counters and prescale counters, RT0PS, and RT1PS.

### 28.2.2 Real-Time Clock Alarm Function

The RTC\_B module provides for a flexible alarm system. There is a single user-programmable alarm that can be programmed based on the settings contained in the alarm registers for minutes, hours, day of week, and day of month.

Each alarm register contains an alarm enable (AE) bit that can be used to enable the respective alarm register. By setting AE bits of the various alarm registers, a variety of alarm events can be generated.

- Example 1: A user wishes to set an alarm every hour at 15 minutes past the hour (that is, at 00:15:00, 01:15:00, 02:15:00, etc). This is possible by setting RTCAMIN to 15. By setting the AE bit of the RTCAMIN and clearing all other AE bits of the alarm registers, the alarm is enabled. When enabled, the RTCAIFG is set when the count transitions from 00:14:59 to 00:15:00, 01:14:59 to 01:15:00, 02:14:59 to 02:15:00, and so on.
- Example 2: A user wishes to set an alarm every day at 04:00:00. This is possible by setting RTCAHOUR to 4. By setting the AE bit of the RTCHOUR and clearing all other AE bits of the alarm registers, the alarm is enabled. When enabled, the RTCAIFG is set when the count transitions from 03:59:59 to 04:00:00.
- Example 3: A user wishes to set an alarm for 06:30:00. RTCAHOUR would be set to 6 and RTCAMIN would be set to 30. By setting the AE bits of RTCAHOUR and RTCAMIN, the alarm is enabled. Once enabled, the RTCAIFG is set when the time count transitions from 06:29:59 to 06:30:00. In this case, the alarm event occurs every day at 06:30:00.
- Example 4: A user wishes to set an alarm every Tuesday at 06:30:00. RTCADOW would be set to 2, RTCAHOUR would be set to 6, and RTCAMIN would be set to 30. By setting the AE bits of RTCADOW, RTCAHOUR, and RTCAMIN, the alarm is enabled. Once enabled, the RTCAIFG is set when the time count transitions from 06:29:59 to 06:30:00 and the RTCDOW transitions from 1 to 2.
- Example 5: A user wishes to set an alarm the fifth day of each month at 06:30:00. RTCADAY would be set to 5, RTCAHOUR would be set to 6, and RTCAMIN would be set to 30. By setting the AE bits of RTCADAY, RTCAHOUR, and RTCAMIN, the alarm is enabled. Once enabled, the RTCAIFG is set when the time count transitions from 06:29:59 to 06:30:00 and the RTCDAY equals 5.

---

**NOTE: Setting the alarm**

Before setting an initial alarm, all alarm registers including the AE bits should be cleared.

To prevent potential erroneous alarm conditions from occurring, the alarms should be disabled by clearing the RTCAIE, RTCAIFG, and AE bits before writing initial or new time values to the RTC time registers.

---

---

**NOTE: Invalid alarm settings**

Invalid alarm settings are not checked by hardware. It is the user's responsibility that valid alarm settings are entered.

---

**NOTE: Invalid time and date values**

Writing of invalid date or time information or data values outside the legal ranges specified in the RTCSEC, RTCMIN, RTCHOUR, RTCDAY, RTCDOW, RTCYEAR, RTCAMIN, RTCAHOUR, RTCADAY, and RTCADOW registers can result in unpredictable behavior.

---

### 28.2.3 Reading or Writing Real-Time Clock Registers

Because the system clock may in fact be asynchronous to the RTC\_B clock source, special care must be used when accessing the real-time clock registers.

The real-time clock registers are updated once per second. To prevent reading any real-time clock register at the time of an update, which could result in an invalid time being read, a keep-out window is provided. The keep-out window is centered approximately 128/32768 seconds around the update transition. The read-only RTCRDY bit is reset during the keep-out window period and set outside the keep-out the window period. Any read of the clock registers while RTCRDY is reset is considered to be potentially invalid, and the time read should be ignored.

An easy way to safely read the real-time clock registers is to utilize the RTCRDYIFG interrupt flag. Setting RTCRDYIE enables the RTCRDYIFG interrupt. Once enabled, an interrupt is generated based on the rising edge of the RTCRDY bit, causing the RTCRDYIFG to be set. At this point, the application has nearly a complete second to safely read any or all of the real-time clock registers. This synchronization process prevents reading the time value during transition. The RTCRDYIFG flag is reset automatically when the interrupt is serviced, or it can be reset with software.

---

**NOTE: Reading or writing real-time clock registers**

When the counter clock is asynchronous to the CPU clock, any read from any RTCSEC, RTCMIN, RTCHOUR, RTCDOW, RTCDAY, RTCMON, or RTCYEAR register while the RTCRDY is reset may result in invalid data being read. To safely read the counting registers, either polling of the RTCRDY bit or the synchronization procedure previously described can be used. Alternatively, the counter register can be read multiple times while operating, and a majority vote taken in software to determine the correct reading. Reading the RT0PS and RT1PS can only be handled by reading the registers multiple times and a majority vote taken in software to determine the correct reading.

Any write to any counting register takes effect immediately. However, the clock is stopped during the write. In addition, RT0PS and RT1PS registers are reset. This could result in losing up to 1 second during a write. Writing of data outside the legal ranges or invalid time stamp combinations results in unpredictable behavior.

---

### 28.2.4 Real-Time Clock Interrupts

Six sources for interrupts are available, namely RT0PSIFG, RT1PSIFG, RTCRDYIFG, RTCTEVIFG, RTCAIFG, and RTCOFIFG. These flags are prioritized and combined to source a single interrupt vector. The interrupt vector register (RTCIV) is used to determine which flag requested an interrupt.

The highest-priority enabled interrupt generates a number in the RTCIV register (see register description). This number can be evaluated or added to the program counter (PC) to automatically enter the appropriate software routine. Disabled RTC interrupts do not affect the RTCIV value.

Any access, read or write, of the RTCIV register automatically resets the highest-pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. In addition, all flags can be cleared by software.

The user-programmable alarm event sources the real-time clock interrupt, RTCAIFG. Setting RTCAIE enables the interrupt. In addition to the user-programmable alarm, the RTC\_B module provides for an interval alarm that sources real-time clock interrupt, RTCTEVIFG. The interval alarm can be selected to cause an alarm event when RTCMIN changed or RTCHOUR changed, every day at midnight (00:00:00) or every day at noon (12:00:00). The event is selectable with the RTCTEV bits. Setting the RTCTEVIE bit enables the interrupt.

The RTCRDY bit sources the real-time clock interrupt, RTCRDYIFG, and is useful in synchronizing the read of time registers with the system clock. Setting the RTCRDYIE bit enables the interrupt.

RT0PSIFG can be used to generate interrupt intervals selectable by the RT0IP bits. RT0PS is sourced with low-frequency oscillator clock at 32768 Hz, so intervals of 16384 Hz, 8192 Hz, 4096 Hz, 2048 Hz, 1024 Hz, 512 Hz, 256 Hz, or 128 Hz are possible. Setting the RT0PSIE bit enables the interrupt.

RT1PSIFG can be used to generate interrupt intervals selectable by the RT1IP bits. RT1PS is sourced with the output of RT0PS, which is 128 Hz (32768/256 Hz). Therefore, intervals of 64 Hz, 32 Hz, 16 Hz, 8 Hz, 4 Hz, 2 Hz, 1 Hz, or 0.5 Hz are possible. Setting the RT1PSIE bit enables the interrupt.

---

**NOTE: Changing RT0IP or RT1IP**

Changing the settings of the interrupt interval bits RT0IP or RT1IP while the corresponding prescaler is running or is stopped in a non-zero state can result in setting the corresponding interrupt flags.

---

The RTCOFIGF bit flags a failure of the 32-kHz crystal oscillator. Its main purpose is to wake up the CPU from LPM3.5 if an oscillator failure occurs.

#### 28.2.4.1 RTCIV Software Example

The following software example shows the recommended use of RTCIV and the handling overhead. The RTCIV value is added to the PC to automatically jump to the appropriate routine.

The numbers at the right margin show the necessary CPU cycles for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself.

; Interrupt handler for RTC interrupt flags.

```

RTC_HND          ; Interrupt latency      6
    ADD &RTCIV,PC   ; Add offset to Jump table 3
    RETI           ; Vector 0: No interrupt  5
    JMP RTCRDYIFG_HND ; Vector 2: RTCRDYIFG     2
    JMP RTCTEVIFG_HND ; Vector 4: RTCTEVIFG     2
    JMP RTCAIFG_HND  ; Vector 6: RTCAIFG       5
    JMP RT0PSIFG_HND ; Vector 8: RT0PSIFG       5
    JMP RT1PSIFG_HND ; Vector A: RT1PSIFG       5
    JMP RTCOFIGF_HND ; Vector C: RTCOFIGF       5
    RETI           ; Vector E: Reserved      5

RTCRDYIFG_HND   ; Vector 2: RTCRDYIFG Flag
...
RETI           ; Task starts here
                ; Back to main program      5

RTCTEVIFG_HND   ; Vector 4: RTCTEVIFG Flag
...
RETI           ; Task starts here
                ; Back to main program      5

RTCAIFG_HND     ; Vector 6: RTCAIFG Flag
...
RETI           ; Task starts here
                ; Back to main program      5

RT0PSIFG_HND    ; Vector 8: RT0PSIFG Flag

```

|              |                           |   |
|--------------|---------------------------|---|
| ...          | ; Task starts here        |   |
| RETI         | ; Back to main program    | 5 |
| <br>         |                           |   |
| RT1PSIFG_HND | ; Vector A: RT1PSIFG Flag |   |
| ...          | ; Task starts here        |   |
| RETI         | ; Back to main program    | 5 |
| <br>         |                           |   |
| RTCOFIFG_HND | ; Vector C: RTCOFIFG Flag |   |
| ...          | ; Task starts here        |   |
| RETI         | ; Back to main program    | 5 |

### **28.2.5 Real-Time Clock Calibration**

The RTC\_B module has calibration logic that allows for adjusting the crystal frequency in approximately +4-ppm or -2-ppm steps, allowing for higher time keeping accuracy from standard crystals. The RTCCALx bits are used to adjust the frequency. When RTCCALS is set, each RTCCALx LSB causes a  $\approx$  +4-ppm adjustment. When RTCCALS is cleared, each RTCCALx LSB causes a  $\approx$  -2-ppm adjustment.

Calibration is accomplished by periodically adjusting the RT1PS counter based on the RTCCALS and RTCCALx settings. The RT0PS divides the nominal 37268-Hz low-frequency (LF) crystal clock input by 256. A 60-minute period has  $32768 \text{ cycles/sec} \times 60 \text{ sec/min} \times 60 \text{ min} = 117964800 \text{ cycles}$ . Therefore, a -2-ppm reduction in frequency (down calibration) approximately equates to adding an additional 256 cycles every 117964800 cycles ( $256/117964800 = 2.17 \text{ ppm}$ ). This is accomplished by holding the RT1PS counter for one additional clock of the RT0PS output within a 60-minute period. Similarly, a +4-ppm increase in frequency (up calibration) approximately equates to removing 512 cycles every 117964800 cycle ( $512/117964800 = 4.34 \text{ ppm}$ ). This is accomplished by incrementing the RT1PS counter for two additional clocks of the RT0PS output within a 60-minute period. Each RTCCALx calibration bit causes either 256 LF crystal clock cycles to be added every 60 minutes or 512 LF crystal clock cycles to be subtracted every 60 minutes, giving a frequency adjustment of approximately -2 ppm or +4 ppm, respectively.

To calibrate the frequency, the RTCCLK output signal is available at a pin. RTCCALF bits can be used to select the frequency rate of the output signal, either no signal, 512 Hz, 256 Hz, or 1 Hz.

The basic flow to calibrate the frequency is as follows:

1. Configure the RTCCLK pin.
2. Measure the RTCCLK output signal with an appropriate resolution frequency counter ; that is, within the resolution required.
3. Compute the absolute error in ppm: Absolute error (ppm) =  $|10^6 (f_{\text{MEASURED}} - f_{\text{RTCCLK}})/f_{\text{RTCCLK}}|$ , where  $f_{\text{RTCCLK}}$  is the expected frequency of 512 Hz, 256 Hz, or 1 Hz.
4. Adjust the frequency by performing the following:
  - a. If the frequency is too low, set RTCCALS = 1 and apply the appropriate RTCCALx bits, where  $\text{RTCCALx} = (\text{Absolute Error}) / 4.34$  rounded to the nearest integer
  - b. If the frequency is too high, clear RTCCALS = 0 and apply the appropriate RTCCALx bits, where  $\text{RTCCALx} = (\text{Absolute Error}) / 2.17$  rounded to the nearest integer

For example, assume that RTCCLK is configured to output at a frequency of 512 Hz. The measured RTCCLK is 511.9658 Hz. This frequency error is approximately 66.8 ppm too low. To increase the frequency by 66.8 ppm, RTCCALS would be set, and RTCCALx would be set to 15 ( $66.8 / 4.34$ ). Similarly, assume that the measured RTCCLK is 512.0125 Hz. The frequency error is approximately 24.4 ppm too high. To decrease the frequency by 24.4 ppm, RTCCALS would be cleared, and RTCCAL would be set to 11 ( $24.4 / 2.17$ ).

The calibration corrects only initial offsets and does not adjust for temperature and aging effects. These effects can be handled by periodically measuring temperature and using the crystal's characteristic curve to adjust the ppm based on temperature, as required.

**NOTE: Minimum Possible Calibration**

The minimal calibration possible is -4 ppm or +8 ppm. For example, setting RTCCALS = 0 and RTCCAL = 0h would result in a -4 ppm decrease in frequency. Similarly, setting RTCCALS = 1 and RTCCAL = 0h would result in a +8 ppm increase in frequency.

**NOTE: Calibration output frequency**

The 512-Hz and 256-Hz output frequencies observed at the RTCCLK pin are not affected by changes in the calibration settings, because these output frequencies are generated before the calibration logic. The 1-Hz output frequency is affected by changes in the calibration settings. Because the frequency change is small and infrequent over a very long time interval, it can be difficult to observe.

### **28.2.6 Real-Time Clock Operation in LPM3.5 Low-Power Mode**

The regulator of the Power Management Module (PMM) is disabled upon entering LPM3.5, which causes most of the RTC\_B configuration registers to be lost; only the counters are retained. Table 28-1 lists the retained registers in LPM3.5. Also the configuration of the interrupts is stored so that the configured interrupts can cause a wakeup upon exit from LPM3.5. Interrupt flags that are set before entering LPM3.5 are cleared upon entering LPM3.5 (Note: this can only happen if the corresponding interrupt is not enabled). The interrupt flags RTCTEVIFG, RTCAIFG, RT1PSIFG, and RTCOFIFG can be used as RTC\_B wake-up interrupt sources. After restoring the configuration registers (and clearing LOCKLPM5) the interrupts can be serviced as usual. The detailed flow is as follows:

1. Set all I/Os to general purpose I/Os and configure as needed. Optionally configure input interrupt pins for wake-up. Configure RTC\_B interrupts for wake-up (set RTCTEVIE, RTCAIE, RT1PSIE, or RTCOFIE. If the alarm interrupt is also used as wake-up event, the alarm registers must be configured as needed).
2. Enter LPMx.5 with LPMx.5 entry sequence.

```
MOV #PMMKEY + PMMREGOFF, &PMMCTL0 ; Open PMM registers for write and set PMMREGOFF
;
BIS #LPM4,SR                      ; Enter LPMx.5 when PMMREGOFF is set
```

3. LOCKLPM5 is automatically set by hardware upon entering LPMx.5, the core voltage regulator is disabled, and all clocks are disabled except for the 32-kHz crystal oscillator clock if the RTC is enabled with RTCHOLD = 0.
4. An LPMx.5 wake-up event, such as an edge on a wake-up input pin, or an RTC\_B interrupt event will start the BOR entry sequence together with the core voltage regulator. All peripheral registers are set to their default conditions. The I/O pin state remains locked as well as the interrupt configuration for the RTC\_B.
5. The device can be configured. The I/O configuration and the RTC\_B interrupt configuration that was not retained during LPM3.5 should be restored to the values before entering LPM3.5. Then the LOCKLPM5 bit can be cleared, this releases the I/O pin conditions as well as the RTC\_B interrupt configuration.
6. After enabling I/O and RTC\_B interrupts, the interrupt that caused the wake-up can be serviced.
7. To re-enter LPMx.5, the LOCKLPM5 bit must be cleared before re-entry, otherwise LPMx.5 is not entered.

If the RTC is enabled (RTCHOLD = 0), the 32-kHz oscillator remains active during LPM3.5. The fault detection also remains functional. If a fault occurs during LPM3.5 and the RTCOFIE was set before entering LPM3.5, a wake-up event is issued.

## 28.3 RTC\_B Registers

The RTC\_B module registers are listed in [Table 28-1](#). This table also lists the retention during LPMx.5. Registers that are not retained during LPMx.5 must be restored after exit from LPMx.5. The base address for the RTC\_B module registers can be found in the device-specific data sheet. The address offsets are given in [Table 28-1](#).

---

**NOTE:** Most registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 28-1. RTC\_B Registers**

| Offset | Acronym                    | Register Name                         | Type       | Access | Reset     | LPMx.5 and Backup Operation |
|--------|----------------------------|---------------------------------------|------------|--------|-----------|-----------------------------|
| 00h    | RTCCTL01                   | Real-Time Clock Control 0, 1          | Read/write | Word   | 7000h     | not retained                |
| 00h    | RTCCTL0 or RTCCTL01_L      | Real-Time Clock Control 0             | Read/write | Byte   | 00h       | not retained                |
| 01h    | RTCCTL1 or RTCCTL01_H      | Real-Time Clock Control 1             | Read/write | Byte   | 70h       | not retained                |
| 02h    | RTCCTL23                   | Real-Time Clock Control 2, 3          | Read/write | Word   | 0000h     | retained                    |
| 02h    | RTCCTL2 or RTCCTL23_L      | Real-Time Clock Control 2             | Read/write | Byte   | 00h       | retained                    |
| 03h    | RTCCTL3 or RTCCTL23_H      | Real-Time Clock Control 3             | Read/write | Byte   | 00h       | retained                    |
| 08h    | RTCP0SCTL                  | Real-Time Prescale Timer 0 Control    | Read/write | Word   | 0000h     | not retained                |
| 08h    | RTCP0SCTL_L or RTCP0SCTL_L |                                       | Read/write | Byte   | 00h       | not retained                |
| 09h    | RTCP0SCTLH or RTCP0SCTL_H  |                                       | Read/write | Byte   | 00h       | not retained                |
| 0Ah    | RTCP1SCTL                  | Real-Time Prescale Timer 1 Control    | Read/write | Word   | 0000h     | not retained                |
| 0Ah    | RTCP1SCTL_L or RTCP1SCTL_L |                                       | Read/write | Byte   | 00h       | not retained                |
| 0Bh    | RTCP0SCTLH or RTCP0SCTL_H  |                                       | Read/write | Byte   | 00h       | not retained                |
| 0Ch    | RTCP0S                     | Real-Time Prescale Timer 0, 1 Counter | Read/write | Word   | none      | retained                    |
| 0Ch    | RT0PS or RTCP0S_L          | Real-Time Prescale Timer 0 Counter    | Read/write | Byte   | none      | retained                    |
| 0Dh    | RT1PS or RTCP0S_H          | Real-Time Prescale Timer 1 Counter    | Read/write | Byte   | none      | retained                    |
| 0Eh    | RTCIV                      | Real Time Clock Interrupt Vector      | Read       | Word   | 0000h     | not retained                |
| 10h    | RTCTIM0                    | Real-Time Clock Seconds, Minutes      | Read/write | Word   | undefined | retained                    |
| 10h    | RTCSEC or RTCTIM0_L        | Real-Time Clock Seconds               | Read/write | Byte   | undefined | retained                    |
| 11h    | RTCMIN or RTCTIM0_H        | Real-Time Clock Minutes               | Read/write | Byte   | undefined | retained                    |
| 12h    | RTCTIM1                    | Real-Time Clock Hour, Day of Week     | Read/write | Word   | undefined | retained                    |
| 12h    | RTCHOUR or RTCTIM1_L       | Real-Time Clock Hour                  | Read/write | Byte   | undefined | retained                    |
| 13h    | RTCDOW or RTCTIM1_H        | Real-Time Clock Day of Week           | Read/write | Byte   | undefined | retained                    |

Table 28-1. RTC\_B Registers (continued)

| Offset | Acronym                    | Register Name                                   | Type       | Access | Reset     | LPMx.5 and Backup Operation |
|--------|----------------------------|-------------------------------------------------|------------|--------|-----------|-----------------------------|
| 14h    | RTCDATE                    | Real-Time Clock Date                            | Read/write | Word   | undefined | retained                    |
| 14h    | RTCDAY<br>or RTCDATE_L     | Real-Time Clock Day of Month                    | Read/write | Byte   | undefined | retained                    |
| 15h    | RTCMON<br>or RTCDATE_H     | Real-Time Clock Month                           | Read/write | Byte   | undefined | retained                    |
| 16h    | RTCYEAR                    | Real-Time Clock Year <sup>(1)</sup>             | Read/write | Word   | undefined | retained                    |
| 18h    | RTCAMINHR                  | Real-Time Clock Minutes, Hour Alarm             | Read/write | Word   | undefined | retained                    |
| 18h    | RTCAMIN<br>or RTCAMINHR_L  | Real-Time Clock Minutes Alarm                   | Read/write | Byte   | undefined | retained                    |
| 19h    | RTCAHOUR<br>or RTCAMINHR_H | Real-Time Clock Hours Alarm                     | Read/write | Byte   | undefined | retained                    |
| 1Ah    | RTCADOWDAY                 | Real-Time Clock Day of Week, Day of Month Alarm | Read/write | Word   | undefined | retained                    |
| 1Ah    | RTCADOW<br>or RTCADOWDAY_L | Real-Time Clock Day of Week Alarm               | Read/write | Byte   | undefined | retained                    |
| 1Bh    | RTCADAY<br>or RTCADOWDAY_H | Real-Time Clock Day of Month Alarm              | Read/write | Byte   | undefined | retained                    |
| 1Ch    | BIN2BCD                    | Binary-to-BCD Conversion Register               | Read/write | Word   | 00h       | not retained                |
| 1Eh    | BCD2BIN                    | BCD-to-Binary Conversion Register               | Read/write | Word   | 00h       | not retained                |

<sup>(1)</sup> Do not access the RTCYEAR register in byte mode.

### 28.3.1 RTCCTL0 Register

Real-Time Clock Control 0 Register

**Figure 28-2. RTCCTL0 Register**

| 7                      | 6                       | 5                     | 4        | 3       | 2         | 1       | 0         |
|------------------------|-------------------------|-----------------------|----------|---------|-----------|---------|-----------|
| RTCOFIE <sup>(1)</sup> | RTCTEVIE <sup>(1)</sup> | RTCAIE <sup>(1)</sup> | RTCRDYIE | RTCOFIG | RTCTEVIFG | RTCAIFG | RTCRDYIFG |
| rw-0                   | rw-0                    | rw-0                  | rw-0     | rw-(0)  | rw-(0)    | rw-(0)  | rw-(0)    |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits itself; therefore, reconfiguration after wake-up from LPMx.5 before clearing LOCKLPM5 is required.

**Table 28-2. RTCCTL0 Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                         |
|-----|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | RTCOFIE   | RW   | 0h    | 32-kHz crystal oscillator fault interrupt enable. This interrupt can be used as LPMx.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPMx.5 wake-up enabled)                                                                                              |
| 6   | RTCTEVIE  | RW   | 0h    | Real-time clock time event interrupt enable. In modules supporting LPMx.5 this interrupt can be used as LPMx.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPMx.5 wake-up enabled)                                                                      |
| 5   | RTCAIE    | RW   | 0h    | Real-time clock alarm interrupt enable. In modules supporting LPMx.5 this interrupt can be used as LPMx.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPMx.5 wake-up enabled)                                                                           |
| 4   | RTCRDYIE  | RW   | 0h    | Real-time clock ready interrupt enable.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled                                                                                                                                                                                     |
| 3   | RTCOFIG   | RW   | 0h    | 32-kHz crystal oscillator fault interrupt flag. This interrupt can be used as LPMx.5 wake-up event. It also indicates a clock failure during backup operation.<br>0b = No interrupt pending<br>1b = Interrupt pending. A 32-kHz crystal oscillator fault occurred after last reset. |
| 2   | RTCTEVIFG | RW   | 0h    | Real-time clock time event interrupt flag. In modules supporting LPMx.5 this interrupt can be used as LPMx.5 wake-up event.<br>0b = No time event occurred<br>1b = Time event occurred                                                                                              |
| 1   | RTCAIFG   | RW   | 0h    | Real-time clock alarm interrupt flag. In modules supporting LPMx.5 this interrupt can be used as LPMx.5 wake-up event.<br>0b = No time event occurred<br>1b = Time event occurred                                                                                                   |
| 0   | RTCRDYIFG | RW   | 0h    | Real-time clock ready interrupt flag<br>0b = RTC cannot be read safely<br>1b = RTC can be read safely                                                                                                                                                                               |

### 28.3.2 RTCCTL1 Register

Real-Time Clock Control Register 1

**Figure 28-3. RTCCTL1 Register**

| 7       | 6                      | 5        | 4      | 3        | 2        | 1                      | 0      |
|---------|------------------------|----------|--------|----------|----------|------------------------|--------|
| RTCBBCD | RTCHOLD <sup>(1)</sup> | Reserved | RTCRDY | Reserved | Reserved | RTCTEVx <sup>(1)</sup> |        |
| rw-(0)  | rw-(1)                 | r1       | r-(1)  | r0       | r0       | rw-(0)                 | rw-(0) |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits itself; therefore, reconfiguration after wake-up from LPMx.5 before clearing LOCKLPM5 is required.

**Table 28-3. RTCCTL1 Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                         |
|-----|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | RTCBBCD  | RW   | 0h    | Real-time clock BCD select. Selects BCD counting for real-time clock.<br>0b = Binary-hexadecimal code selected<br>1b = BCD Binary coded decimal (BCD) code selected                 |
| 6   | RTCHOLD  | RW   | 1h    | Real-time clock hold<br>0b = Real-time clock is operational.<br>1b = The calendar is stopped as well as the prescale counters, RT0PS, and RT1PS.                                    |
| 5   | Reserved | R    | 1h    | Reserved. Always read as 1.                                                                                                                                                         |
| 4   | RTCRDY   | RW   | 1h    | Real-time clock ready<br>0b = RTC time values in transition<br>1b = RTC time values safe for reading. This bit indicates when the real-time clock time values are safe for reading. |
| 3-2 | Reserved | R    | 0h    | Reserved. Always read as 0.                                                                                                                                                         |
| 1-0 | RTCTEVx  | RW   | 0h    | Real-time clock time interrupt event<br>00b = Minute changed<br>01b = Hour changed<br>10b = Every day at midnight (00:00)<br>11b = Every day at noon (12:00)                        |

### 28.3.3 RTCCTL2 Register

Real-Time Clock Control 2 Register

**Figure 28-4. RTCCTL2 Register**

| 7       | 6        | 5       | 4      | 3      | 2      | 1      | 0      |
|---------|----------|---------|--------|--------|--------|--------|--------|
| RTCCALS | Reserved | RTCCALX |        |        |        |        |        |
| rw-(0)  | r0       | rw-(0)  | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 28-4. RTCCTL2 Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                            |
|-----|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------|
| 7   | RTCCALS  | RW   | 0h    | Real-time clock calibration sign<br>0b = Frequency adjusted down<br>1b = Frequency adjusted up                                         |
| 6   | Reserved | R    | 0h    | Reserved. Always read as 0.                                                                                                            |
| 5-0 | RTCCALX  | RW   | 0h    | Real-time clock calibration. Each LSB represents approximately +4-ppm (RTCCALS = 1) or a -2-ppm (RTCCALS = 0) adjustment in frequency. |

### 28.3.4 RTCCTL3 Register

Real-Time Clock Control 3 Register

**Figure 28-5. RTCCTL3 Register**

| 7        | 6  | 5  | 4  | 3  | 2  | 1      | 0        |
|----------|----|----|----|----|----|--------|----------|
| Reserved |    |    |    |    |    |        | RTCCALFx |
| r0       | r0 | r0 | r0 | r0 | r0 | rw-(0) | rw-(0)   |

**Table 28-5. RTCCTL3 Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                       |
|-----|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-2 | Reserved | R    | 0h    | Reserved. Always read as 0.                                                                                                                                                                                                                                                       |
| 1-0 | RTCCALFx | RW   | 0h    | Real-time clock calibration frequency. Selects frequency output to RTCCLK pin for calibration measurement. The corresponding port must be configured for the peripheral module function.<br>00b = No frequency output to RTCCLK pin<br>01b = 512 Hz<br>10b = 256 Hz<br>11b = 1 Hz |

### 28.3.5 RTCSEC Register – Hexadecimal Format

Real-Time Clock Seconds Register – Hexadecimal Format

**Figure 28-6. RTCSEC Register**

| 7   | 6   | 5  | 4  | 3  | 2  | 1  | 0       |
|-----|-----|----|----|----|----|----|---------|
| 0   | 0   |    |    |    |    |    | Seconds |
| r-0 | r-0 | rw | rw | rw | rw | rw | rw      |

**Table 28-6. RTCSEC Register Description**

| Bit | Field   | Type | Reset     | Description                        |
|-----|---------|------|-----------|------------------------------------|
| 7-6 | 0       | R    | 0h        | Always reads as 0.                 |
| 5-0 | Seconds | RW   | undefined | Seconds. Valid values are 0 to 59. |

### 28.3.6 RTCSEC Register – BCD Format

Real-Time Clock Seconds Register – BCD Format

**Figure 28-7. RTCSEC Register**

| 7   | 6  | 5                    | 4  | 3  | 2  | 1                   | 0  |
|-----|----|----------------------|----|----|----|---------------------|----|
| 0   |    | Seconds – high digit |    |    |    | Seconds – low digit |    |
| r-0 | rw | rw                   | rw | rw | rw | rw                  | rw |

**Table 28-7. RTCSEC Register Description**

| Bit | Field                | Type | Reset     | Description                                    |
|-----|----------------------|------|-----------|------------------------------------------------|
| 7   | 0                    | R    | 0h        | Always reads as 0.                             |
| 6-4 | Seconds – high digit | RW   | undefined | Seconds – high digit. Valid values are 0 to 5. |
| 3-0 | Seconds – low digit  | RW   | undefined | Seconds – low digit. Valid values are 0 to 9.  |

### **28.3.7 RTCMIN Register – Hexadecimal Format**

Real-Time Clock Minutes Register – Hexadecimal Format

**Figure 28-8. RTCMIN Register**

| 7   | 6   | 5  | 4  | 3  | 2  | 1  | 0       |
|-----|-----|----|----|----|----|----|---------|
| 0   | 0   |    |    |    |    |    | Minutes |
| r-0 | r-0 | rw | rw | rw | rw | rw | rw      |

**Table 28-8. RTCMIN Register Description**

| Bit | Field   | Type | Reset     | Description                        |
|-----|---------|------|-----------|------------------------------------|
| 7-6 | 0       | R    | 0h        | Always reads as 0.                 |
| 5-0 | Minutes | RW   | undefined | Minutes. Valid values are 0 to 59. |

### **28.3.8 RTCMIN Register – BCD Format**

Real-Time Clock Minutes Register – BCD Format

**Figure 28-9. RTCMIN Register**

| 7   | 6  | 5                    | 4  | 3  | 2                   | 1  | 0  |
|-----|----|----------------------|----|----|---------------------|----|----|
| 0   |    | Minutes – high digit |    |    | Minutes – low digit |    |    |
| r-0 | rw | rw                   | rw | rw | rw                  | rw | rw |

**Table 28-9. RTCMIN Register Description**

| Bit | Field                | Type | Reset     | Description                                    |
|-----|----------------------|------|-----------|------------------------------------------------|
| 7   | 0                    | R    | 0h        | Always reads as 0.                             |
| 6-4 | Minutes – high digit | RW   | undefined | Minutes – high digit. Valid values are 0 to 5. |
| 3-0 | Minutes – low digit  | RW   | undefined | Minutes – low digit. Valid values are 0 to 9.  |

### 28.3.9 RTCHOUR Register – Hexadecimal Format

Real-Time Clock Hours Register – Hexadecimal Format

**Figure 28-10. RTCHOUR Register**

| 7   | 6   | 5   | 4  | 3  | 2     | 1  | 0  |
|-----|-----|-----|----|----|-------|----|----|
| 0   | 0   | 0   |    |    | Hours |    |    |
| r-0 | r-0 | r-0 | rw | rw | rw    | rw | rw |

**Table 28-10. RTCHOUR Register Description**

| Bit | Field | Type | Reset     | Description                      |
|-----|-------|------|-----------|----------------------------------|
| 7-5 | 0     | R    | 0h        | Always reads as 0.               |
| 4-0 | Hours | RW   | undefined | Hours. Valid values are 0 to 23. |

### 28.3.10 RTCHOUR Register – BCD Format

Real-Time Clock Hours Register – BCD Format

**Figure 28-11. RTCHOUR Register**

| 7   | 6   | 5                  | 4  | 3                 | 2  | 1  | 0  |
|-----|-----|--------------------|----|-------------------|----|----|----|
| 0   | 0   | Hours – high digit |    | Hours – low digit |    |    |    |
| r-0 | r-0 | rw                 | rw | rw                | rw | rw | rw |

**Table 28-11. RTCHOUR Register Description**

| Bit | Field              | Type | Reset     | Description                                  |
|-----|--------------------|------|-----------|----------------------------------------------|
| 7-6 | 0                  | R    | 0h        | Always reads as 0.                           |
| 5-4 | Hours – high digit | RW   | undefined | Hours – high digit. Valid values are 0 to 2. |
| 3-0 | Hours – low digit  | RW   | undefined | Hours – low digit. Valid values are 0 to 9.  |

### 28.3.11 RTCDOW Register

Real-Time Clock Day of Week Register

**Figure 28-12. RTCDOW Register**

| 7   | 6   | 5   | 4   | 3   | 2  | 1  | 0           |
|-----|-----|-----|-----|-----|----|----|-------------|
| 0   | 0   | 0   | 0   | 0   |    |    | Day of week |
| r-0 | r-0 | r-0 | r-0 | r-0 | rw | rw | rw          |

**Table 28-12. RTCDOW Register Description**

| Bit | Field       | Type | Reset     | Description                           |
|-----|-------------|------|-----------|---------------------------------------|
| 7-3 | 0           | R    | 0h        | Always reads as 0.                    |
| 2-0 | Day of week | RW   | undefined | Day of week. Valid values are 0 to 6. |

### 28.3.12 RTCDAY Register – Hexadecimal Format

Real-Time Clock Day of Month Register – Hexadecimal Format

**Figure 28-13. RTCDAY Register**

| 7   | 6   | 5   | 4  | 3  | 2  | 1  | 0            |
|-----|-----|-----|----|----|----|----|--------------|
| 0   | 0   | 0   |    |    |    |    | Day of month |
| r-0 | r-0 | r-0 | rw | rw | rw | rw | rw           |

**Table 28-13. RTCDAY Register Description**

| Bit | Field        | Type | Reset     | Description                             |
|-----|--------------|------|-----------|-----------------------------------------|
| 7-5 | 0            | R    | 0h        | Always reads as 0.                      |
| 4-0 | Day of month | RW   | undefined | Day of month. Valid values are 1 to 31. |

### 28.3.13 RTCDAY Register – BCD Format

Real-Time Clock Day of Month Register – BCD Format

**Figure 28-14. RTCDAY Register**

| 7   | 6   | 5                         | 4  | 3  | 2                        | 1  | 0  |
|-----|-----|---------------------------|----|----|--------------------------|----|----|
| 0   | 0   | Day of month – high digit |    |    | Day of month – low digit |    |    |
| r-0 | r-0 | rw                        | rw | rw | rw                       | rw | rw |

**Table 28-14. RTCDAY Register Description**

| Bit | Field                     | Type | Reset     | Description                                         |
|-----|---------------------------|------|-----------|-----------------------------------------------------|
| 7-6 | 0                         | R    | 0h        | Always reads as 0.                                  |
| 5-4 | Day of month – high digit | RW   | undefined | Day of month – high digit. Valid values are 0 to 3. |
| 3-0 | Day of month – low digit  | RW   | undefined | Day of month – low digit. Valid values are 0 to 9.  |

### 28.3.14 RTCMON Register – Hexadecimal Format

Real-Time Clock Month Register – Hexadecimal Format

**Figure 28-15. RTCMON Register**

| 7   | 6   | 5   | 4   | 3  | 2  | 1     | 0  |
|-----|-----|-----|-----|----|----|-------|----|
| 0   | 0   | 0   | 0   |    |    | Month |    |
| r-0 | r-0 | r-0 | r-0 | rw | rw | rw    | rw |

**Table 28-15. RTCMON Register Description**

| Bit | Field | Type | Reset     | Description                      |
|-----|-------|------|-----------|----------------------------------|
| 7-4 | 0     | R    | 0h        | Always reads as 0.               |
| 3-0 | Month | RW   | undefined | Month. Valid values are 1 to 12. |

### 28.3.15 RTCMON Register – BCD Format

Real-Time Clock Month Register

**Figure 28-16. RTCMON Register**

| 7   | 6   | 5   | 4                  | 3  | 2  | 1                 | 0  |
|-----|-----|-----|--------------------|----|----|-------------------|----|
| 0   | 0   | 0   | Month – high digit |    |    | Month – low digit |    |
| r-0 | r-0 | r-0 | rw                 | rw | rw | rw                | rw |

**Table 28-16. RTCMON Register Description**

| Bit | Field              | Type | Reset     | Description                                  |
|-----|--------------------|------|-----------|----------------------------------------------|
| 7-5 | 0                  | R    | 0h        | Always reads as 0.                           |
| 4   | Month – high digit | RW   | undefined | Month – high digit. Valid values are 0 or 1. |
| 3-0 | Month – low digit  | RW   | undefined | Month – low digit. Valid values are 0 to 9.  |

### 28.3.16 RTCYEAR Register – Hexadecimal Format

Real-Time Clock Year Register – Hexadecimal Format

**Figure 28-17. RTCYEAR Register**

| 15  | 14  | 13  | 12  | 11 | 10 | 9                | 8  |
|-----|-----|-----|-----|----|----|------------------|----|
| 0   | 0   | 0   | 0   |    |    | Year – high byte |    |
| r-0 | r-0 | r-0 | r-0 | rw | rw | rw               | rw |
| 7   | 6   | 5   | 4   | 3  | 2  | 1                | 0  |
| rw  | rw  | rw  | rw  | rw | rw | rw               | rw |

**Table 28-17. RTCYEAR Register Description**

| Bit   | Field            | Type | Reset     | Description                                           |
|-------|------------------|------|-----------|-------------------------------------------------------|
| 15-12 | 0                | R    | 0h        | Always reads as 0.                                    |
| 11-8  | Year – high byte | RW   | undefined | Year – high byte. Valid values of Year are 0 to 4095. |
| 7-0   | Year – low byte  | RW   | undefined | Year – low byte. Valid values of Year are 0 to 4095.  |

### 28.3.17 RTCYEAR Register – BCD Format

Real-Time Clock Year Register – BCD Format

**Figure 28-18. RTCYEAR Register**

| 15  | 14 | 13                   | 12 | 11 | 10                  | 9  | 8  |
|-----|----|----------------------|----|----|---------------------|----|----|
| 0   |    | Century – high digit |    |    | Century – low digit |    |    |
| r-0 | rw | rw                   | rw | rw | rw                  | rw | rw |
| 7   | 6  | 5                    | 4  | 3  | 2                   | 1  | 0  |
|     |    | Decade               |    |    | Year – lowest digit |    |    |
| rw  | rw | rw                   | rw | rw | rw                  | rw | rw |

**Table 28-18. RTCYEAR Register Description**

| Bit   | Field                | Type | Reset     | Description                                     |
|-------|----------------------|------|-----------|-------------------------------------------------|
| 15    | 0                    | R    | 0h        | Always reads as 0.                              |
| 14-12 | Century – high digit | RW   | undefined | Century – high digit . Valid values are 0 to 4. |
| 11-8  | Century – low digit  | RW   | undefined | Century – low digit. Valid values are 0 to 9.   |
| 7-4   | Decade               | RW   | undefined | Decade. Valid values are 0 to 9.                |
| 3-0   | Year – lowest digit  | RW   | undefined | Year – lowest digit. Valid values are 0 to 9.   |

### 28.3.18 RTCAMIN Register – Hexadecimal Format

Real-Time Clock Minutes Alarm Register – Hexadecimal Format

**Figure 28-19. RTCAMIN Register**

| 7  | 6   | 5  | 4  | 3  | 2  | 1  | 0       |
|----|-----|----|----|----|----|----|---------|
| AE | 0   |    |    |    |    |    | Minutes |
| rw | r-0 | rw | rw | rw | rw | rw | rw      |

**Table 28-19. RTCAMIN Register Description**

| Bit | Field   | Type | Reset     | Description                                                                                 |
|-----|---------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE      | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6   | 0       | R    | 0h        | Always reads as 0.                                                                          |
| 5-0 | Minutes | RW   | undefined | Minutes. Valid values are 0 to 59.                                                          |

### 28.3.19 RTCAMIN Register – BCD Format

Real-Time Clock Minutes Alarm Register – BCD Format

**Figure 28-20. RTCAMIN Register**

| 7  | 6  | 5                    | 4  | 3  | 2  | 1                   | 0  |
|----|----|----------------------|----|----|----|---------------------|----|
| AE |    | Minutes – high digit |    |    |    | Minutes – low digit |    |
| rw | rw | rw                   | rw | rw | rw | rw                  | rw |

**Table 28-20. RTCAMIN Register Description**

| Bit | Field                | Type | Reset     | Description                                                                                 |
|-----|----------------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE                   | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-4 | Minutes – high digit | RW   | undefined | Minutes – high digit. Valid values are 0 to 5.                                              |
| 3-0 | Minutes – low digit  | RW   | undefined | Minutes – low digit. Valid values are 0 to 9.                                               |

### **28.3.20 RTCAHOUR Register – Hexadecimal Format**

Real-Time Clock Hours Alarm Register – Hexadecimal Format

**Figure 28-21. RTCAHOUR Register**

| 7  | 6   | 5   | 4  | 3  | 2     | 1  | 0  |
|----|-----|-----|----|----|-------|----|----|
| AE | 0   | 0   |    |    | Hours |    |    |
| rw | r-0 | r-0 | rw | rw | rw    | rw | rw |

**Table 28-21. RTCAHOUR Register Description**

| Bit | Field | Type | Reset     | Description                                                                                 |
|-----|-------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE    | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-5 | 0     | R    | 0h        | Always reads as 0.                                                                          |
| 4-0 | Hours | RW   | undefined | Hours. Valid values are 0 to 23.                                                            |

### **28.3.21 RTCAHOUR Register – BCD Format**

Real-Time Clock Hours Alarm Register – BCD Format

**Figure 28-22. RTCAHOUR Register**

| 7  | 6   | 5  | 4                  | 3  | 2                 | 1  | 0  |
|----|-----|----|--------------------|----|-------------------|----|----|
| AE | 0   |    | Hours – high digit |    | Hours – low digit |    |    |
| rw | r-0 | rw | rw                 | rw | rw                | rw | rw |

**Table 28-22. RTCAHOUR Register Description**

| Bit | Field              | Type | Reset     | Description                                                                                 |
|-----|--------------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE                 | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6   | 0                  | R    | 0h        | Always reads as 0.                                                                          |
| 5-4 | Hours – high digit | RW   | undefined | Hours – high digit. Valid values are 0 to 2.                                                |
| 3-0 | Hours – low digit  | RW   | undefined | Hours – low digit. Valid values are 0 to 9.                                                 |

### 28.3.22 RTCADOW Register

Real-Time Clock Day of Week Alarm Register

**Figure 28-23. RTCADOW Register**

| 7  | 6   | 5   | 4   | 3   | 2  | 1           | 0  |
|----|-----|-----|-----|-----|----|-------------|----|
| AE | 0   | 0   | 0   | 0   |    | Day of week |    |
| rw | r-0 | r-0 | r-0 | r-0 | rw | rw          | rw |

**Table 28-23. RTCADOW Register Description**

| Bit | Field       | Type | Reset     | Description                                                                                 |
|-----|-------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE          | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-3 | 0           | R    | 0h        | Always reads as 0.                                                                          |
| 2-0 | Day of week | RW   | undefined | Day of week. Valid values are 0 to 6.                                                       |

### 28.3.23 RTCADAY Register – Hexadecimal Format

Real-Time Clock Day of Month Alarm Register – Hexadecimal Format

**Figure 28-24. RTCADAY Register**

| 7  | 6   | 5   | 4  | 3  | 2  | 1            | 0  |
|----|-----|-----|----|----|----|--------------|----|
| AE | 0   | 0   |    |    |    | Day of month |    |
| rw | r-0 | r-0 | rw | rw | rw | rw           | rw |

**Table 28-24. RTCADAY Register Description**

| Bit | Field        | Type | Reset     | Description                                                                                 |
|-----|--------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE           | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-5 | 0            | R    | 0h        | Always reads as 0.                                                                          |
| 4-0 | Day of month | RW   | undefined | Day of month. Valid values are 1 to 31.                                                     |

### 28.3.24 RTCADAY Register – BCD Format

Real-Time Clock Day of Month Alarm Register – BCD Format

**Figure 28-25. RTCADAY Register**

| 7  | 6   | 5                         | 4  | 3  | 2                        | 1  | 0  |
|----|-----|---------------------------|----|----|--------------------------|----|----|
| AE | 0   | Day of month – high digit |    |    | Day of month – low digit |    |    |
| rw | r-0 | rw                        | rw | rw | rw                       | rw | rw |

**Table 28-25. RTCADAY Register Description**

| Bit | Field                     | Type | Reset     | Description                                                                                 |
|-----|---------------------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE                        | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6   | 0                         | R    | 0h        | Always reads as 0.                                                                          |
| 5-4 | Day of month – high digit | RW   | undefined | Day of month – high digit. Valid values are 0 to 3.                                         |
| 3-0 | Day of month – low digit  | RW   | undefined | Day of month – low digit. Valid values are 0 to 9.                                          |

### 28.3.25 RTCPS0CTL Register

Real-Time Clock Prescale Timer 0 Control Register

**Figure 28-26. RTCPS0CTL Register**

|          |    |    |                       |        |        |         |          |
|----------|----|----|-----------------------|--------|--------|---------|----------|
| 15       | 14 | 13 | 12                    | 11     | 10     | 9       | 8        |
| Reserved |    |    |                       |        |        |         |          |
| r0       | r0 | r0 | r0                    | r0     | r0     | r0      | r0       |
| 7        | 6  | 5  | 4                     | 3      | 2      | 1       | 0        |
| Reserved |    |    | RT0IPx <sup>(1)</sup> |        |        | RT0PSIE | RT0PSIFG |
| r0       | r0 | r0 | rw-(0)                | rw-(0) | rw-(0) | rw-0    | rw-(0)   |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits itself; therefore, reconfiguration after wake-up from LPMx.5 before clearing LOCKLPM5 is required.

**Table 28-26. RTCPS0CTL Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-5 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                               |
| 4-2  | RT0IPx   | RW   | 0h    | Prescale timer 0 interrupt interval<br>000b = Divide by 2<br>001b = Divide by 4<br>010b = Divide by 8<br>011b = Divide by 16<br>100b = Divide by 32<br>101b = Divide by 64<br>110b = Divide by 128<br>111b = Divide by 256 |
| 1    | RT0PSIE  | RW   | 0h    | Prescale timer 0 interrupt enable<br>0b = Interrupt not enabled<br>1b = Interrupt enabled                                                                                                                                  |
| 0    | RT0PSIFG | RW   | 0h    | Prescale timer 0 interrupt flag<br>0b = No time event occurred<br>1b = Time event occurred                                                                                                                                 |

### **28.3.26 RTCPS1CTL Register**

Real-Time Clock Prescale Timer 1 Control Register

**Figure 28-27. RTCPS1CTL Register**

|          |    |    |        |                       |        |                        |          |
|----------|----|----|--------|-----------------------|--------|------------------------|----------|
| 15       | 14 | 13 | 12     | 11                    | 10     | 9                      | 8        |
| Reserved |    |    |        |                       |        |                        |          |
| r0       | r0 | r0 | r0     | r0                    | r0     | r0                     | r0       |
| 7        | 6  | 5  | 4      | 3                     | 2      | 1                      | 0        |
| Reserved |    |    |        | RT1IPx <sup>(1)</sup> |        | RT1PSIE <sup>(1)</sup> | RT1PSIFG |
| r0       | r0 | r0 | rw-(0) | rw-(0)                | rw-(0) | rw-0                   | rw-(0)   |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits themselves; therefore, reconfiguration after wake-up from LPMx.5 before clearing LOCKLPM5 is required.

**Table 28-27. RTCPS1CTL Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-5 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                               |
| 4-2  | RT1IPx   | RW   | 0h    | Prescale timer 1 interrupt interval<br>000b = Divide by 2<br>001b = Divide by 4<br>010b = Divide by 8<br>011b = Divide by 16<br>100b = Divide by 32<br>101b = Divide by 64<br>110b = Divide by 128<br>111b = Divide by 256 |
| 1    | RT1PSIE  | RW   | 0h    | Prescale timer 1 interrupt enable<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPMx.5 wake-up enabled)                                                                                                         |
| 0    | RT1PSIFG | RW   | 0h    | Prescale timer 1 interrupt flag. In modules supporting LPMx.5 this interrupt can be used as LPMx.5 wake-up event.<br>0b = No time event occurred<br>1b = Time event occurred                                               |

### 28.3.27 RTCPS0 Register

Real-Time Clock Prescale Timer 0 Counter Register

**Figure 28-28. RTCPS0 Register**

| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|-------|----|----|----|----|----|----|----|
| RT0PS |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

**Table 28-28. RTCPS0 Register Description**

| Bit | Field | Type | Reset     | Description                    |
|-----|-------|------|-----------|--------------------------------|
| 7-0 | RT0PS | RW   | undefined | Prescale timer 0 counter value |

### 28.3.28 RTCPS1 Register

Real-Time Clock Prescale Timer 1 Counter Register

**Figure 28-29. RTCPS1 Register**

| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|-------|----|----|----|----|----|----|----|
| RT1PS |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

**Table 28-29. RTCPS1 Register Description**

| Bit | Field | Type | Reset     | Description                    |
|-----|-------|------|-----------|--------------------------------|
| 7-0 | RT1PS | RW   | undefined | Prescale timer 1 counter value |

### **28.3.29 RTCIV Register**

Real-Time Clock Interrupt Vector Register

**Figure 28-30. RTCIV Register**

|        |    |    |    |       |       |       |    |
|--------|----|----|----|-------|-------|-------|----|
| 15     | 14 | 13 | 12 | 11    | 10    | 9     | 8  |
| RTClVx |    |    |    |       |       |       |    |
| r0     | r0 | r0 | r0 | r0    | r0    | r0    | r0 |
| RTClVx |    |    |    |       |       |       |    |
| r0     | r0 | r0 | r0 | r-(0) | r-(0) | r-(0) | r0 |

**Table 28-30. RTCIV Register Description**

| Bit  | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|--------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | RTClVx | R    | 0h    | Real-time clock interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: RTC ready; Interrupt Flag: RTCDYIFG; Interrupt Priority: Highest<br>04h = Interrupt Source: RTC interval timer; Interrupt Flag: RTCTEVIFG<br>06h = Interrupt Source: RTC user alarm; Interrupt Flag: RTCAIFG<br>08h = Interrupt Source: RTC prescaler 0; Interrupt Flag: RT0PSIFG<br>0Ah = Interrupt Source: RTC prescaler 1; Interrupt Flag: RT1PSIFG<br>0Ch = Interrupt Source: RTC oscillator failure; Interrupt Flag: RTCOIFG<br>0Eh = Reserved; Interrupt Priority: Lowest |

### 28.3.30 BIN2BCD Register

Binary-to-BCD Conversion Register

**Figure 28-31. BIN2BCD Register**

| 15       | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|----------|------|------|------|------|------|------|------|
| BIN2BCDx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| BIN2BCDx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 28-31. BIN2BCD Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                           |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------|
| 15-0 | BIN2BCDx | RW   | 0h    | Read: 16-bit BCD conversion of previously written 12-bit binary number<br>Write: 12-bit binary number to be converted |

### 28.3.31 BCD2BIN Register

BCD-to-Binary Conversion Register

**Figure 28-32. BCD2BIN Register**

| 15       | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|----------|------|------|------|------|------|------|------|
| BCD2BINx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| BCD2BINx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 28-32. BCD2BIN Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                        |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------|
| 15-0 | BCD2BINx | RW   | 0h    | Read: 12-bit binary conversion of previously written 16-bit BCD number<br>Write: 16-bit BCD number to be converted |

## **Real-Time Clock C (RTC\_C)**

The Real-Time Clock C (RTC\_C) module provides clock counters with calendar mode, a flexible programmable alarm, offset calibration, and a provision for temperature compensation. The RTC\_C also supports operation in LPM3.5. This chapter describes the RTC\_C module.

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## 29.1 Real-Time Clock (RTC\_C) Introduction

The RTC\_C module provides configurable clock counters.

RTC\_C features include:

- Real-time clock and calendar mode that provides seconds, minutes, hours, day of week, day of month, month, and year (including leap year correction)
- Protection for real-time clock registers
- Interrupt capability
- Selectable BCD or binary format
- Programmable alarms
- Real-time clock calibration for crystal offset error
- Real-time clock compensation for crystal temperature drift
- Operation in LPM3.5

The RTC\_C module can provide the following device-dependent features. Refer to the device-specific data sheet to determine if these features are available in a particular device.

- General-purpose counter mode (see [Section 29.3.1](#))
- Event and tamper detection with time stamp (see [Section 29.3.2](#))
- Operation from a separate voltage supply

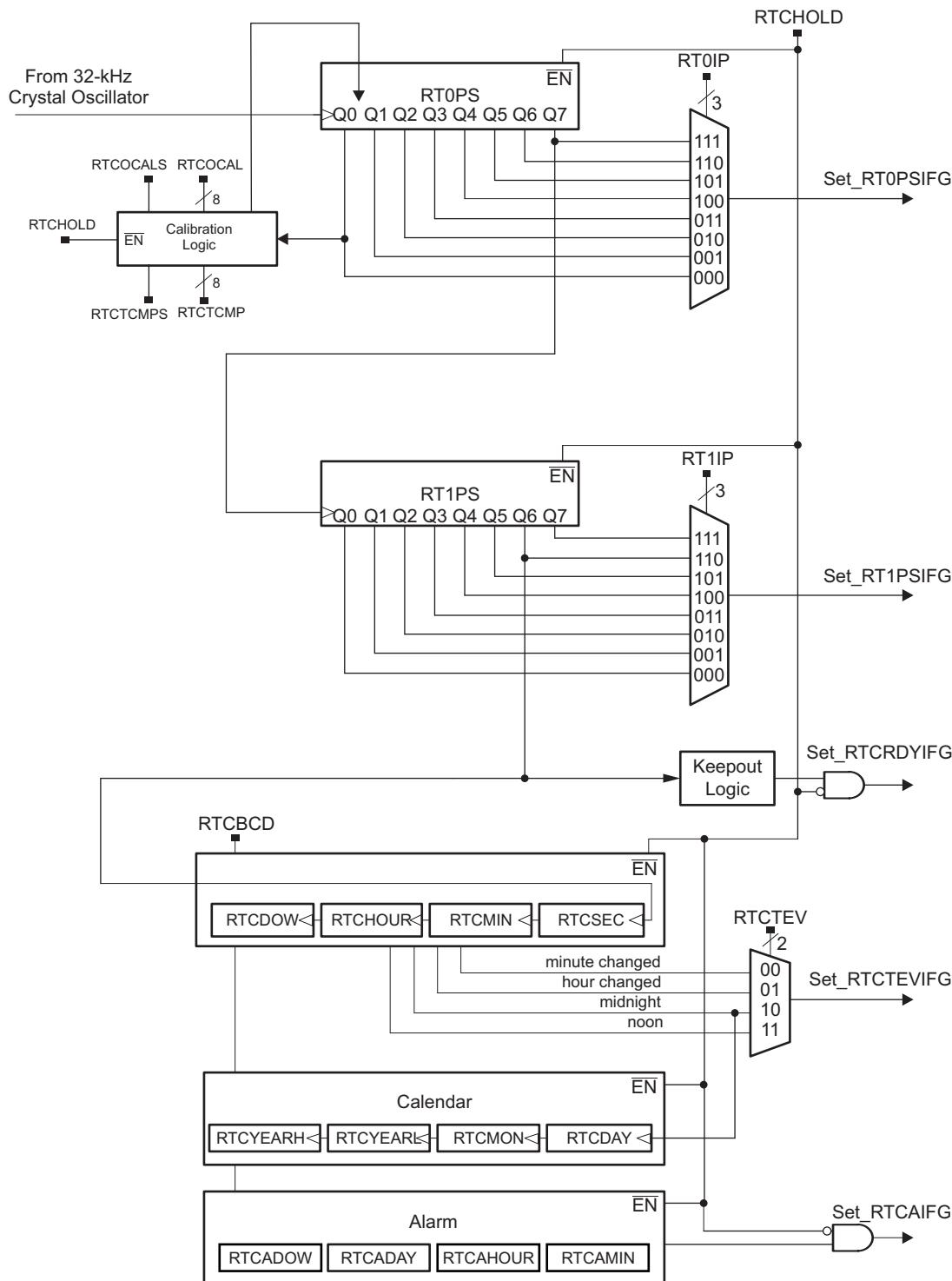
---

**NOTE: Real-time clock initialization**

Most RTC\_C module registers have no initial condition. These registers must be configured by user software before use.

---

[Figure 29-1](#) shows the RTC\_C block diagram.



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**Figure 29-1. RTC\_C Block Diagram (RTCMODE = 1)**

## 29.2 RTC\_C Operation

### 29.2.1 Calendar Mode

Calendar mode is selected when RTCMODE is set. In calendar mode, the RTC\_C module provides seconds, minutes, hours, day of week, day of month, month, and year in selectable BCD or hexadecimal format. The calendar includes a leap-year algorithm that considers all years evenly divisible by four as leap years. This algorithm is accurate from the year 1901 through 2099. Switching from counter mode (if available) to calendar mode **does not** reset the calendar registers (RTCSEC, RTCMIN, RTCHOUR, RTCDAY, RTCDOW, and RTCYEAR) and the prescale counters (RT0PS, RT1PS). These registers must be configured by user software before use.

### 29.2.2 Real-Time Clock and Prescale Dividers

The prescale dividers, RT0PS and RT1PS, are automatically configured to provide a 1-second clock interval for the RTC\_C. The low-frequency oscillator must be operated at 32768 Hz (nominal) for proper RTC\_C operation. RT0PS is sourced from the low-frequency oscillator XT1. The output of RT0PS divided by 256 (Q7) sources RT1PS. RT1PS is further divided by 128 to source the real-time clock counter registers that provide the required 1-second time interval.

When RTCBCD = 1, BCD format is selected for the calendar registers. It is possible to switch between BCD and hexadecimal format while the RTC is counting.

Setting RTCHOLD halts the real-time counters and prescale counters, RT0PS and RT1PS.

---

**NOTE: For reliable update to all Calendar Mode registers**

Set RTCHOLD = 1 before writing into any of the calendar or prescalar registers (RTCPS0, RTCPS1, RTCSEC, RTCMIN, RTCHOUR, RTCDAY, RTCMON, and RTCYEAR).

---

### 29.2.3 Real-Time Clock Alarm Function

The RTC\_C module provides for a flexible alarm system. There is a single user-programmable alarm that can be programmed based on the settings contained in the alarm registers for minutes, hours, day of week, and day of month.

Each alarm register contains an alarm enable (AE) bit that can be used to enable the respective alarm register. By setting AE bits of the various alarm registers, a variety of alarm events can be generated.

- Example 1: A user wishes to set an alarm every hour at 15 minutes past the hour (that is, 00:15:00, 01:15:00, 02:15:00, and so on). This is possible by setting RTCAMIN to 15. By setting the AE bit of the RTCAMIN and clearing all other AE bits of the alarm registers, the alarm is enabled. When enabled, the RTCAIFG is set when the count transitions from 00:14:59 to 00:15:00, 01:14:59 to 01:15:00, 02:14:59 to 02:15:00, and so on.
- Example 2: A user wishes to set an alarm every day at 04:00:00. This is possible by setting RTCAHOUR to 4. By setting the AE bit of the RTCHOUR and clearing all other AE bits of the alarm registers, the alarm is enabled. When enabled, the RTCAIFG is set when the count transitions from 03:59:59 to 04:00:00.
- Example 3: A user wishes to set an alarm for 06:30:00. RTCAHOUR would be set to 6, and RTCAMIN would be set to 30. By setting the AE bits of RTCAHOUR and RTCAMIN, the alarm is enabled. When enabled, the RTCAIFG is set when the time count transitions from 06:29:59 to 06:30:00. In this case, the alarm event occurs every day at 06:30:00.
- Example 4: A user wishes to set an alarm every Tuesday at 06:30:00. RTCADOW would be set to 2, RTCAHOUR would be set to 6, and RTCAMIN would be set to 30. By setting the AE bits of RTCADOW, RTCAHOUR, and RTCAMIN, the alarm is enabled. When enabled, the RTCAIFG is set when the time count transitions from 06:29:59 to 06:30:00 and the RTCDOW transitions from 1 to 2.
- Example 5: A user wishes to set an alarm the fifth day of each month at 06:30:00. RTCADAY would be set to 5, RTCAHOUR would be set to 6, and RTCAMIN would be set to 30. By setting the AE bits of RTCADAY, RTCAHOUR, and RTCAMIN, the alarm is enabled. When enabled, the RTCAIFG is set when the time count transitions from 06:29:59 to 06:30:00 and the RTCDAY equals 5.

**NOTE: Invalid alarm settings**

Invalid alarm settings are not checked by hardware. It is the user's responsibility that valid alarm settings are entered.

**NOTE: Invalid time and date values**

Writing of invalid date or time information or data values outside the legal ranges specified in the RTCSEC, RTCTIM1, RTCHOUR, RTCDAY, RTCDOW, RTCYEARH, RTCYEARL, RTCAMIN, RTCAHOUR, RTCADAY, and RTCADOW registers can result in unpredictable behavior.

**NOTE: Setting the alarm**

Before setting an initial alarm, all alarm registers including the AE bits should be cleared.

To prevent potential erroneous alarm conditions from occurring, the alarms should be disabled by clearing the RTCAIE, RTCAIFG, and AE bits before writing initial or new time values to the RTC time registers.

#### **29.2.4 Real-Time Clock Protection**

RTC\_C registers are key protected to ensure clock integrity and module configuration against software crash or from runaway code. Key protection does not apply for reads from the RTC\_C registers. That is, any RTC\_C register can be read at any time without having to unlock the module. Some predefined registers of RTC\_C are key protected for write access. The control registers, clock registers, calendar register, prescale timer registers, and offset error calibration registers are protected. RTC\_C alarm function registers, prescale timer control registers, interrupt vector register, and temperature compensation registers are not protected. RTC\_C registers that are not protected can be written at any time without unlocking the module. [Table 29-2](#) shows which registers are affected by the protection scheme.

The RTCCTL0\_H register implements key protection and controls the lock or unlock state of the module. When this register is written with correct key, 0A5h, the module is unlocked and unlimited write access possible to RTC\_C registers. After the module is unlocked, it remains unlocked until the user writes any incorrect key or until the module is reset. A read from RTCCTL0\_H register returns value 96h. Write access to any protected registers of RTC\_C is ignored when the module is locked.

##### RTC\_C Key Protection Software Example

```
; Unlock/lock sequence for RTC_C
MOV.B #RTCKEY, &RTCCTL0_H      ; Write correct key to unlock RTC_C
MOV.B #8bit_value, &RTCSEC      ; Write 8 bit value into RTCSEC
MOV.B #8bit_value, &RTCMIN      ; Write 8 bit value into RTCMIN
MOV.W #16bit_value, &RTCTIM1    ; Write 16bit value into RTCTIM1
MOV.W #RTCKEY+8bit_value, &RTCCTL0 ; Write into RTCCTL0 with correct key in word mode
...
MOV.B #00h, &RTCCTL0_H          ; Write incorrect key to lock RTC_C
```

## 29.2.5 Reading or Writing Real-Time Clock Registers

Because the system clock may be asynchronous to the RTC\_C clock source, special care must be used when accessing the real-time clock registers.

The real-time clock registers are updated once per second. To prevent reading any real-time clock register at the time of an update that could result in an invalid time being read, a keep-out window is provided. The keep-out window is centered approximately 128/32768 seconds around the update transition. The read-only RTCRDY bit is reset during the keep-out window period and set outside the keep-out the window period. Any read of the clock registers while RTCRDY is reset is considered to be potentially invalid, and the time read should be ignored.

An easy way to safely read the real-time clock registers is to use the RTCRDYIFG interrupt flag. Setting RTCRDYIE enables the RTCRDYIFG interrupt. When enabled, an interrupt is generated based on the rising edge of the RTCRDY bit, causing the RTCRDYIFG to be set. At this point, the application has nearly a complete second to safely read any or all of the real-time clock registers. This synchronization process prevents reading the time value during transition. The RTCRDYIFG flag is reset automatically when the interrupt is serviced or can be reset with software.

---

**NOTE: Reading or writing real-time clock registers**

When the counter clock is asynchronous to the CPU clock, any read from any RTCSEC, RTCMIN, RTCHOUR, RTCDOW, RTCDAY, RTCMON, RTCYEARL, or RTCYEARH register while the RTCRDY is reset may result in invalid data being read. To safely read the counting registers, either polling of the RTCRDY bit or the synchronization procedure previously described can be used. Alternatively, the counter register can be read multiple times while operating, and a majority vote taken in software to determine the correct reading. Reading the RT0PS and RT1PS can only be handled by reading the registers multiple times and a majority vote taken in software to determine the correct reading.

Any write to any counting register takes effect immediately. However, the clock is stopped during the write. In addition, RT0PS and RT1PS registers are reset. This could result in losing up to 1 second during a write. Writing of data outside the legal ranges or invalid time stamp combinations results in unpredictable behavior.

---

## 29.2.6 Real-Time Clock Interrupts

At least six sources for interrupts are available, namely RT0PSIFG, RT1PSIFG, RTCRDYIFG, RTCTEVIFG, RTCAIFG, and RTCOFIFG. These flags are prioritized and combined to source a single interrupt vector. The interrupt vector register (RTCIV) is used to determine which flag requested an interrupt.

The highest-priority enabled interrupt generates a number in the RTCIV register (see register description). This number can be evaluated or added to the program counter (PC) to automatically enter the appropriate software routine. Disabled RTC interrupts do not affect the RTCIV value.

Writes into RTCIV register clear all pending interrupt conditions. Reads from RTCIV register clear the highest priority pending interrupt condition. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. In addition, all flags can be cleared by software.

The user-programmable alarm event sources the real-time clock interrupt, RTCAIFG. Setting RTCAIE enables the interrupt. In addition to the user-programmable alarm, the RTC\_C module provides for an interval alarm that sources real-time clock interrupt, RTCTEVIFG. The interval alarm can be selected to cause an alarm event when RTCMIN changed or RTCHOUR changed, every day at midnight (00:00:00) or every day at noon (12:00:00). The event is selectable with the RTCTEV bits. Setting the RTCTEVIE bit enables the interrupt.

The RTCRDY bit sources the real-time clock interrupt, RTCRDYIFG, and is useful in synchronizing the read of time registers with the system clock. Setting the RTCRDYIE bit enables the interrupt.

RT0PSIFG can be used to generate interrupt intervals selectable by the RT0IP bits. RT0PS is sourced with low-frequency oscillator clock at 32768 Hz, so intervals of 16384 Hz, 8192 Hz, 4096 Hz, 2048 Hz, 1024 Hz, 512 Hz, 256 Hz, or 128 Hz are possible. Setting the RT0PSIE bit enables the interrupt.

RT1PSIFG can be used to generate interrupt intervals selectable by the RT1IP bits. RT1PS is sourced with the output of RT0PS, which is 128 Hz (32768/256 Hz). Therefore, intervals of 64 Hz, 32 Hz, 16 Hz, 8 Hz, 4 Hz, 2 Hz, 1 Hz, or 0.5 Hz are possible. Setting the RT1PSIE bit enables the interrupt.

---

**NOTE: Changing RT0IP or RT1IP**

Changing the settings of the interrupt interval bits RT0IP or RT1IP while the corresponding prescaler is running or is stopped in a non-zero state can result in setting the corresponding interrupt flags.

---

The RTCOFIG bit flags the failure of the 32-kHz crystal oscillator. Its main purpose is to wake up the CPU from LPM3.5 if an oscillator failure occurs. On devices with separate supply for RTC, this flag also stores a failure event that occurs when the core supply is not available.

#### 29.2.6.1 RTCIV Software Example

The following software example shows the recommended use of RTCIV and the handling overhead. The RTCIV value is added to the PC to automatically jump to the appropriate routine.

The numbers at the right margin show the necessary CPU cycles for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself.

; Interrupt handler for RTC interrupt flags.

|                   |   |                          |   |
|-------------------|---|--------------------------|---|
| RTC_HND           |   |                          |   |
| ADD &RTCIV,PC     | ; | Interrupt latency        | 6 |
| RETI              | ; | Add offset to Jump table | 3 |
| JMP RTCOFIG_HND   | ; | Vector 0: No interrupt   | 5 |
| JMP RTCRDYIFG_HND | ; | Vector 2: RTCOFIG        | 2 |
| JMP RTCTEVIFG_HND | ; | Vector 4: RTCRDYIFG      | 2 |
| JMP RTCAIFG       | ; | Vector 6: RTCTEVIFG      | 2 |
| JMP RT0PSIFG      | ; | Vector 8: RTCAIFG        | 5 |
| JMP RT1PSIFG      | ; | Vector A: RT0PSIFG       | 5 |
| RETI              | ; | Vector C: RT1PSIFG       | 5 |
|                   |   | ;                        |   |
| RTCOFIG_HND       |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Vector E: Reserved       | 5 |
|                   |   | ;                        |   |
| RTCRDYIFG_HND     |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Vector 2: RTCOFIG Flag   | 5 |
|                   |   | ;                        |   |
| RTCTEVIFG_HND     |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Task starts here         | 5 |
|                   |   | ;                        |   |
| RTCAIFG_HND       |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Back to main program     | 5 |
|                   |   | ;                        |   |
| RT0PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Vector 4: RTCRDYIFG Flag | 5 |
|                   |   | ;                        |   |
| RT1PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Task starts here         | 5 |
|                   |   | ;                        |   |
| RT0PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Back to main program     | 5 |
|                   |   | ;                        |   |
| RT1PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Vector 6: RTCTEVIFG      | 5 |
|                   |   | ;                        |   |
| RTCAIFG_HND       |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Task starts here         | 5 |
|                   |   | ;                        |   |
| RT0PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Back to main program     | 5 |
|                   |   | ;                        |   |
| RT1PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Vector 8: RTCAIFG        | 5 |
|                   |   | ;                        |   |
| RT0PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Task starts here         | 5 |
|                   |   | ;                        |   |
| RT1PSIFG_HND      |   | ;                        |   |
| ...               |   | ;                        |   |
| RETI              | ; | Back to main program     | 5 |
|                   |   | ;                        |   |

## 29.2.7 Real-Time Clock Calibration for Crystal Offset Error

The RTC\_C module can be calibrated for crystal manufacturing tolerance or offset error to enable better accuracy of time keeping accuracy. The crystal frequency error of up to  $\pm 240$  ppm can be calibrated smoothly over a period of 60 seconds. RTCOCAL\_L register is used to adjust the frequency. The calibration value is written into RTCOCAL\_L register, and each LSB in this register represent approximately  $\pm 1$ -ppm correction based on RTCOCALS bit in RTCOCAL\_H register. When RTCOCALS bit is set (up calibration), each LSB in RTCOCAL\_L represent +1-ppm adjustment. When RTCOCALS is cleared (down calibration), each LSB in RTCOCAL\_L represent -1-ppm adjustment to frequency. Both RTCOCAL\_L and RTCOCAL\_H registers are protected and require RTC\_C to be unlocked before writing into these registers.

### 29.2.7.1 Calibration Frequency

To calibrate the frequency, the RTCCLK output signal is available at a pin. RTCCALFx bits in RTCCTL3 register can be used to select the frequency rate of the output signal. When RTCCALFx = 00, no signal is output on RTCCLK pin. The other settings of RTCCALFx select one of the three frequencies: 512 Hz, 256 Hz, or 1 Hz. RTCCLK can be measured, and the result of this measurement can be applied to the RTCOCALS and RTCOCALx bits to effectively reduce the initial offset of the clock.

#### 29.2.7.1.1 Calibration Mechanism

RTCOCAL\_L is an 8-bit register. Software can write a value of up to 256 ppm into this register, but the maximum frequency error that can be corrected is only 240 ppm. Software must make sure to write legal values into this register. A read from RTCOCAL always returns the value that was written by software. Real-time clock offset error calibration is inactive when RTC\_C is not enabled (RTCHOLD = 0) or when RTCOCALx bits are zero. RTCOCAL should only be written when RTCHOLD = 1. Writing RTCOCAL resets temperature compensation to zero.

In RTC\_C, the offset error calibration takes place over a period of 60 seconds. To achieve approximately  $\pm 1$ -ppm correction, the 16-kHz clock (Q0 output of RT0PS) is adjusted to add or subtract one clock pulse. For +1-ppm correction, one clock pulse is added to the 16-kHz clock, and for -1-ppm correction, one clock pulse is subtracted from the 16-kHz clock. This correction happens once every quarter second until the programmed ppm error is compensated.

$$f_{\text{ACLK,meas}} < 32768 \text{ Hz} \rightarrow \text{RTCOCALS} = 1, \text{RTCOCALx} = \text{Round}(60 \times 16384 \times (1 - f_{\text{ACLK,meas}}/32768))$$

$$f_{\text{ACLK,meas}} \geq 32768 \text{ Hz} \rightarrow \text{RTCOCALS} = 0, \text{RTCOCALx} = \text{Round}(60 \times 16384 \times (1 - f_{\text{ACLK,meas}}/32768))$$

As an example for up calibration, when the measured frequency is 511.9658 Hz against the reference frequency of 512 Hz, the frequency error is approximately 67 ppm low. To increase the frequency by 67 ppm, RTCOCALS should be set, and RTCOCALx should be set to Round( $60 \times 16384 \times (1 - 511.9658 / 32768)$ ) = 66.

As an example for down calibration, when the measured frequency is 512.0241 Hz against the reference frequency of 512 Hz, the frequency error is approximately 47 ppm high. To decrease the frequency by 47 ppm, RTCOCALS should be cleared, and RTCOCALx should be set to Round( $60 \times 16384 \times (1 - 512.0241 / 32768)$ ) = 46.

All three possible output frequencies (512 Hz, 256 Hz, and 1 Hz) at RTCCLK pin are affected by calibration settings. RT0PS interrupt triggered by RT0PS – Q0 (RT0IPx = 000) is based on the uncalibrated clock, while RT0PS interrupt triggered by RT0PS – Q1 to Q7 (RT0IPx ≠ 000) is based on the calibrated clock. RT1PS interrupt (RT1PSIFG) and RTC counter interrupt (RTCTEVIFG) are also based on the calibrated clock.

## 29.2.8 Real-Time Clock Compensation for Crystal Temperature Drift

The frequency output of the crystal varies considerably due to drift in temperature. It would be necessary to compensate the real-time clock for this temperature drift for higher time keeping accuracy from standard crystals. A hybrid software and hardware approach can be followed to achieve temperature compensation for RTC\_C.

The software can make use of an (on-chip) temperature sensor to measure the temperature at desired intervals (for example, once every few seconds or minutes). The temperature sensor parameters are calibrated at production and stored in the nonvolatile memory. Using the temperature sensor parameters and the measured temperature, software can do parabolic calculations to find out the corresponding frequency error in ppm.

This frequency error can be written into RTCTCMP\_L register for temperature compensation.

RTCTCMP\_L is an 8-bit register that allows correction for a frequency error up to  $\pm 240$  ppm. Each LSB in this register represent  $\pm 1$  ppm based on the RTCTCMPS bit in the RTCTCMP\_H register. When RTCTCMPS bit is set, each LSB in RTCTCMP represents +1-ppm adjustment (up calibration). When RTCTCMPS is cleared, each LSB in RTCTCMP represents -1-ppm adjustment (down calibration). RTCTCMP register is not protected and can be written any time without unlocking RTC\_C.

### 29.2.8.1 Temperature Compensation Scheme

RTCTCMP\_L is an 8-bit register. Software can write up to value of 256 ppm into this register, but the maximum frequency error that can be corrected including the crystal offset error is 240 ppm. Real-time clock temperature compensation is inactive when RTC\_C is not enabled (RTCHOLD = 0) or when RTCTCMPx bits are zero.

When the temperature compensation value is written into RTCTCMP\_L, it is added to the offset error calibration value, and the resulting value is taken into account from next calibration cycle onwards. The ongoing calibration cycle is not affected by writes into the RTCTCMP register. The maximum frequency error that can be corrected to account for both offset error and temperature variation is  $\pm 240$  ppm. This means the sign addition of offset error value and temperature compensation value should not exceed maximum of  $\pm 240$  ppm; otherwise, the excess value above  $\pm 240$  ppm is ignored by hardware. Reading from the RTCTCMP register at any time returns the cumulative value which is the signed addition of RTCOCALx and RTCTCMPx values. (Note that writing RTCOCAL resets the temperature compensation value to zero.)

For example, when RTCOCAL value is +150 ppm, and the value written into RTCTCMP is +200 ppm, the effective value taken in for next calibration cycle is +240 ppm. Software is expected to do temperature measurement at certain regularity, calculate the frequency error, and write into RTCTCMP register to not exceed the maximum limit of  $\pm 240$  ppm.

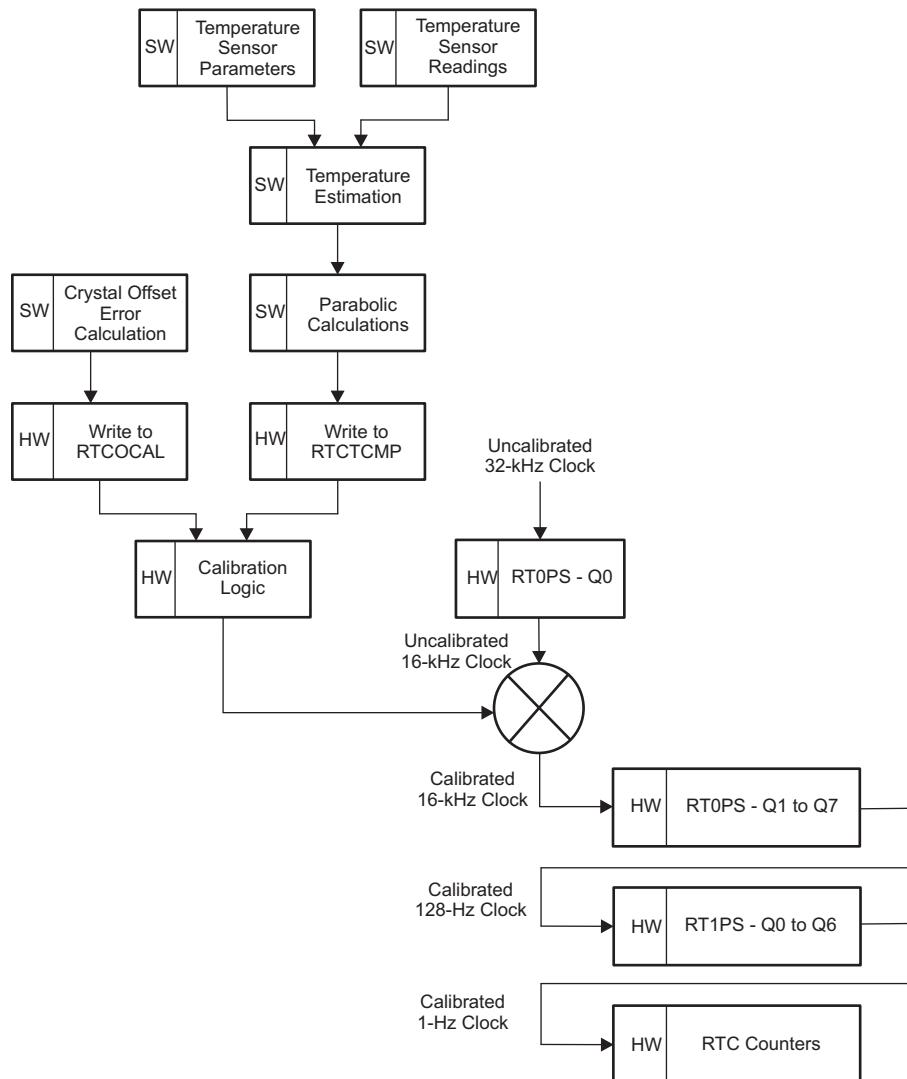
Changing the sign bit by writing to RTCTCMP\_H becomes effective only after also writing RTCTCMP\_L. Thus TI recommends writing the sign bit together with compensation value as a 16-bit value into RTCTCMP.

### 29.2.8.2 Writing to RTCTCMP Register

Because the system clock can be asynchronous to the RTC\_C clock source, the RTCTCRDY bit in the RTCTCMP\_H register should be considered for reliable writing into RTCTCMP register. RTCTCRDY is a read-only bit that is set when the hardware is ready to take in the new temperature compensation value. A write to RTCTCMP should be avoided when RTCTCRDY bit is reset. Writes into RTCTCMP register when RTCTCRDY is reset are ignored.

RTCTCOK is a status bit that indicates if the write to RTCTCMP register is successful or not. RTCTCOK is set if the write to RTCTCMP is successful and reset if the write is unsuccessful. The status remains the same until the next write to the RTCTCMP register. If the write to RTCTCMP is unsuccessful, then the user needs to attempt writing into RTCTCMP again when RTCTCRDY is set.

Figure 29-2 shows the scheme for real-time clock offset error calibration and temperature compensation.



**Figure 29-2. RTC\_C Offset Error Calibration and Temperature Compensation Scheme**

### 29.2.8.3 Temperature Measurement and Updates to RTC\_C

The user may wish to perform temperature measurement once every few seconds or once every minute or once in several minutes. Writing to RTCTCMP register for temperature compensation is effective always once in one minute. This means that if the user performs temperature measurement every minute and updates RTCTCMP register with the frequency error, compensation would immediately work fine. But if software performs temperature measurement more frequently than once per minute (for example once every 5 seconds) then it needs to average the error over one minute and update RTCTCMP register once per minute. If the software performs temperature measurement less frequently than once per minute (for example, once every 5 minutes) then it needs to calculate the frequency error for the measured temperature and write into RTCTCMP register. The value written into RTCTCMP in this case would be effective until it is updated again by software.

## **29.2.9 Real-Time Clock Operation in LPM3.5 Low-Power Mode**

The regulator of the Power Management Module (PMM) is disabled when the device enters LPM3.5, which causes most of the RTC\_C configuration registers to be lost; only the counters and calibration registers are retained. [Table 29-2](#) shows which registers are retained in LPM3.5. Also the configuration of the interrupt enables is stored so that the configured interrupts can cause a wakeup upon exit from LPM3.5. Interrupt flags that are set before entering LPM3.5 are cleared upon entering LPM3.5 (Note: this can only happen if the corresponding interrupt is not enabled). The interrupt flags RTCTEVIFG, RTCAIFG, RT1PSIFG, and RTCOFIFG can be used as RTC\_C wakeup interrupt sources. Any interrupt event that occurs during LPM3.5 is stored in the corresponding flags, but only enabled interrupts can wake up the device. After restoring the configuration registers (and clearing LOCKLPM5), the interrupts can be serviced as usual.

The detailed flow is as follows:

1. Set all I/Os to general-purpose I/Os and configure as needed. Optionally, configure input interrupt pins for wakeup. Configure RTC\_C interrupts for wake-up (set RTCTEVIE, RTCAIE, RT1PSIE, or RTCOFIE. If the alarm interrupt is also used as wake-up event, the alarm registers must be configured as needed).
2. Enter LPM3.5 with LPM3.5 entry sequence:

```
bic #RTCHOLD, &RTCCTL13
bis #PMMKEY + REGOFF, &PMMCTL0
bis #LPM4, SR
```

3. LOCKLPM5 is automatically set by hardware upon entering LPM3.5, the core voltage regulator is disabled, and all clocks are disabled except for the 32-kHz crystal oscillator clock as the RTC\_C is enabled with RTCHOLD = 0.
4. An LPM3.5 wake-up event like an edge on a wake-up input pin or an RTC\_C interrupt event starts the BOR entry sequence and the core voltage regulator. All peripheral registers are set to their default conditions. The I/O pin state and the interrupt configuration for the RTC\_C remain locked.
5. The device can be configured. The I/O configuration and the RTC\_C interrupt configuration that was not retained during LPM3.5 should be restored to the values that they had before entering LPM3.5. Then the LOCKLPM5 bit can be cleared, which releases the I/O pin conditions and the RTC\_C interrupt configuration. Registers that are retained during LPM3.5 should not be altered before LOCKLPM5 is cleared.
6. After enabling I/O and RTC\_C interrupts, the interrupt that caused the wake-up can be serviced.

If the RTC\_C is enabled (RTCHOLD = 0), the 32-kHz oscillator remains active during LPM3.5. The fault detection also remains functional. If a fault occurs during LPM3.5 and the RTCOFIE was set before entering LPM3.5, a wake-up event is issued.

## 29.3 RTC\_C Operation - Device-Dependent Features

### 29.3.1 Counter Mode

**NOTE:** This feature is available only on selected devices. See the device-specific data sheet to determine if this feature is available.

The RTC\_C module can be configured as a real-time clock with calendar function (calendar mode) or as a 32-bit general-purpose counter (counter mode) with the RTCMODE bit.

Counter mode is selected when RTCMODE is reset. In this mode, a 32-bit counter is provided that is directly accessible by software. Figure 29-3 shows the functional block diagram of a RTC\_C module in counter mode (RTCMODE = 0).

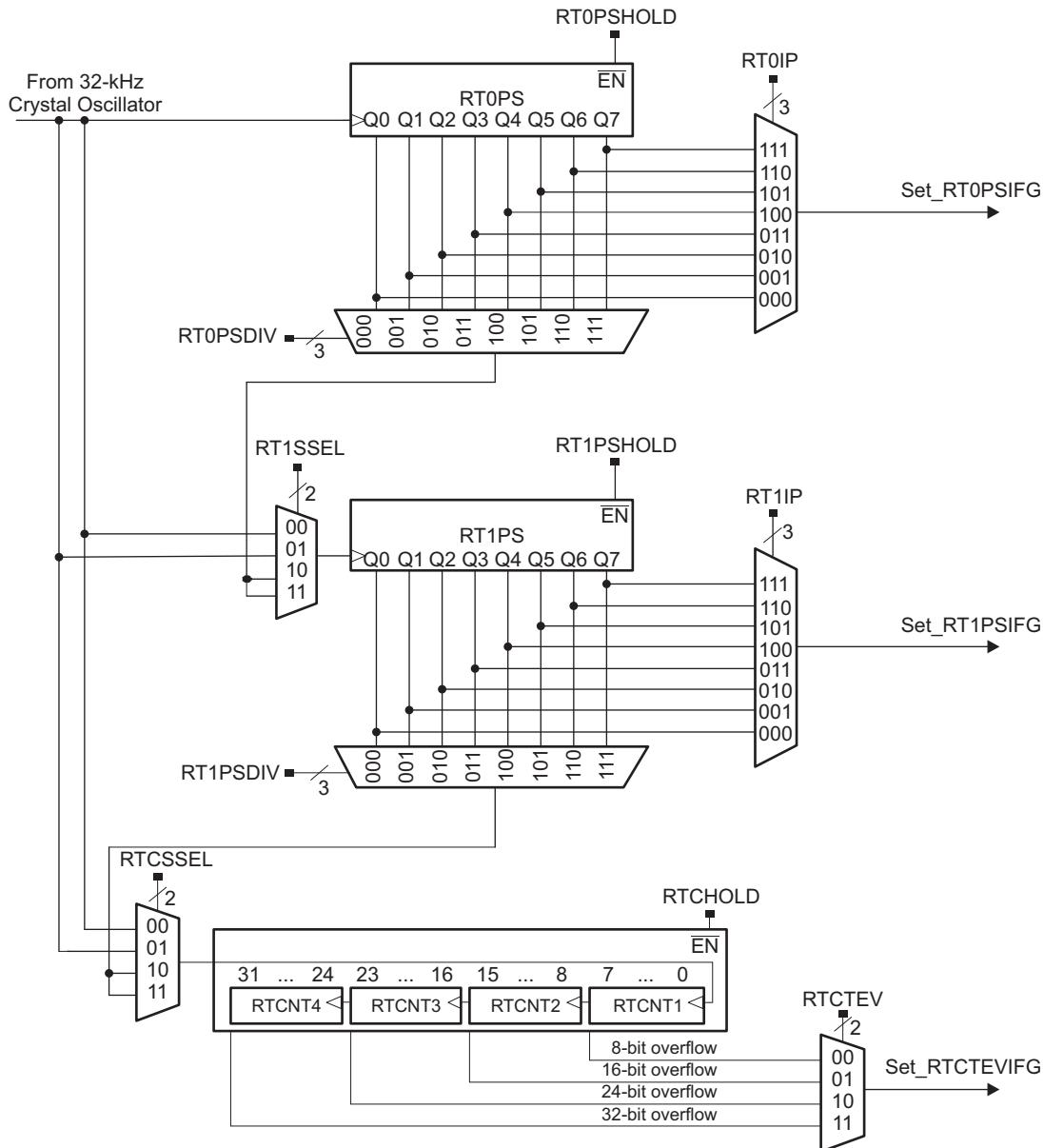


Figure 29-3. RTC\_C Functional Block Diagram in Counter Mode (RTCMODE = 0)

### 29.3.1.1 Switching between Calendar and Counter Mode

To switch from calendar mode to counter mode do the following steps:

1. Stop the RTC with RTCHOLD=1.
2. Clear the RTCMODE bit to enable the counter mode.
3. Initialize the count registers (RTCNT1, RTCNT2, RTCNT3, RTCNT4) and the prescale counters (RT0PS, RT1PS) as needed. (The switch from calendar mode to counter mode **does not** reset the count value (RTCNT1, RTCNT2, RTCNT3, RTCNT4) or the prescale counters (RT0PS, RT1PS). These registers must be configured by user software before use.)
4. Clear the RTCHOLD bit to start the counters.

To switch back from counter mode to calendar mode do the following steps:

1. Stop the counters with RTCHOLD=1.
2. Set RTCMODE=1 to enable the calendar mode.
3. Initialize the clock and calendar registers and the prescale counters (RT0PS, RT1PS) as needed. (The switch from counter mode to calendar mode **does not** reset the clock and calendar registers nor the prescale counters (RT0PS, RT1PS). These registers must be configured by user software before use.)
4. Clear the RTCHOLD bit to start the RTC.

### 29.3.1.2 Counter Mode Operation

The clock that increments the counter can be sourced from the 32-kHz crystal oscillator or from prescaled versions of the 32-kHz crystal oscillator clock. Prescaled versions are sourced from the prescale dividers (RT0PS and RT1PS). RT0PS and RT1PS can output /2, /4, /8, 16, /32, /64, /128, and /256 versions of the 32-kHz clock. The output of RT0PS can be cascaded with RT1PS. The cascaded output can also be used as a clock source input to the 32-bit counter.

Four individual 8-bit counters are cascaded to provide the 32-bit counter. This provides 8-bit, 16-bit, 24-bit, or 32-bit overflow intervals of the counter clock. The RTCTEV bits select the respective trigger event. An RTCTEV event can trigger an interrupt by setting the RTCTEVIE bit. Each counter, RTCNT1 through RTCNT4, is individually accessible and may be written.

RT0PS and RT1PS can be configured as two 8-bit counters or cascaded into a single 16-bit counter. RT0PS and RT1PS can be halted on an individual basis by setting their respective RT0PSHOLD and RT1PSHOLD bits. When RT0PS is cascaded with RT1PS, setting RT0PSHOLD causes both RT0PS and RT1PS to be halted. The 32-bit counter can be halted several ways, depending on the configuration. If the 32-bit counter is sourced directly by the 32-kHz crystal clock, it can be halted by setting RTCHOLD. If it is sourced from the output of RT1PS, it can be halted by setting RT1PSHOLD or RTCHOLD. Finally, if it is sourced from the cascaded outputs of RT0PS and RT1PS, it can be halted by setting RT0PSHOLD, RT1PSHOLD, or RTCHOLD.

---

**NOTE: Accessing the RTCNT1, RTCNT2, RTCNT3, RTCNT4, RT0PS, RT1PS registers**

When the counter clock is asynchronous to the CPU clock, any read from any RTCNT1, RTCNT2, RTCNT3, RTCNT4, RT0PS, or RT1PS register should occur while the counter is not operating. Otherwise, the results may be unpredictable. Alternatively, the counter may be read multiple times while operating, and a majority vote taken in software to determine the correct reading. Any write to these registers takes effect immediately.

---

**NOTE: For reliable update to all Counter Mode registers**

Depending on the cascading of counters, when a write occurs, hold all subsequent counters. For example, if RTPS0 is being updated, set RTCPS1HOLD = 1, and if RTPS1 is being updated, set RTCHOLD = 1.

---

### 29.3.1.3 Real-Time Clock Interrupts in Counter Mode

In counter mode, four interrupt sources are available: RT0PSIFG, RT1PSIFG, RTCTEVIFG, and RTCOFIFG. RTCAIFG and RTCRDYIFG are cleared. RTCRDYIE and RTCAIE are don't care.

RT0PSIFG can be used to generate interrupt intervals selectable by the RT0IP bits. In counter mode, divide ratios of /2, /4, /8, /16, /32, /64, /128, and /256 of the clock source are possible. Setting the RT0PSIE bit enables the interrupt.

RT1PSIFG can be used to generate interrupt intervals selectable by the RT1IP bits. In counter mode, RT1PS is sourced with low-frequency oscillator clock, or the output of RT0PS, so divide ratios of /2, /4, /8, /16, /32, /64, /128, and /256 of the respective clock source are possible. Setting the RT1PSIE bit enables the interrupt.

In Counter Mode, the RTC\_C module provides for an interval timer that sources real-time clock interrupt, RTCTEVIFG. The interval timer can be selected to cause an interrupt event when an 8-bit, 16-bit, 24-bit, or 32-bit overflow occurs within the 32-bit counter. The event is selectable with the RTCTEV bits. Setting the RTCTEVIE bit enables the interrupt.

The RTCOFIFG bit flags a failure of the 32-kHz crystal oscillator. It's main purpose is to wake-up the CPU from LPM3.5 in case an oscillator failure occurred.

## 29.3.2 Real-Time Clock Event/Tamper Detection With Time Stamp

**NOTE:** This feature is available only on selected devices. See the device-specific data sheet to determine if this feature is available.

The RTC\_C module provides an external event or tamper detection and time stamp for up to two external events. The pins RTCCAP0 and RTCCAP1<sup>(1)</sup> can be used as an event or tamper detection input of an external switch (mechanical or electronic). After device power-up, this feature can be enabled by setting the TCEN bit in the RTCTCCTL0 register. Event and tamper detection with time stamp is supported in all MSP430 operating modes, as long as there is a valid RTC power supply.

- When there is an event on RTCCAPx pin and the time capture feature is enabled (TCEN = 1), the corresponding CAPEV bit in RTCCAPxCTL register is set and the corresponding time stamp information (seconds, minutes, hours, day of month, month and year) is stored in the respective backup registers (RTCSECBAKx, RTCMINBAKx, RTCHOURBAKx, RTCDAYBAKx, RTCMONBAKx and RTCYEARBAKx).
- In case of multiple events, **ONLY** the time stamp of the event that occurred first is stored in the respective backup registers. After CAPEV is set by the first event on RTCCAPx, all subsequent events on RTCCAPx are ignored until the CAPEV bit is cleared by the user.
- The CAPES bit in the RTCCAPxCTL register sets the event edge for the corresponding RTCCAPx pin.
  - Bit = 0: CAPEV flag is set with a low-to-high transition.
  - Bit = 1: CAPEV flag is set with a high-to-low transition.

**NOTE: Writing to CAPESx**

Writing to CAPES can result in setting the corresponding interrupt flags.

| CAPESx | RTCCAPx | RTCCAPIFG  |
|--------|---------|------------|
| 0 → 1  | 0       | May be set |
| 0 → 1  | 1       | Unchanged  |
| 1 → 0  | 0       | Unchanged  |
| 1 → 0  | 1       | May be set |

<sup>(1)</sup> These pins are present only on devices that support this feature of RTC\_C. Refer to the device-specific data sheet to determine the availability of this feature.

- The interrupt flag RTCCAPIFG is set when any of the individual CAPEV bits are set. If the RTCIV is read, RTCCAPIFG is cleared but not the status flags (CAPEV bits). They are then read by the CPU and must be cleared by software only.
- By setting the RTCCAPIE bit, an event on RTCCAPx generates an interrupt. This interrupt can be used as LPM3.5 or LPM4.5 wake-up event in modules that support LPM3.5 or LPM4.5.
- When the time capture feature is enabled (TCEN = 1), all of the backup registers (RTCSECBAKx, RTCMINBAKx, RTCHOURBAKx, RTCDAYBAKx, RTCMONBAKx, and RTCYEARBAKx) are read-only to user and can be written only by the RTC hardware. When RTCBCD = 1 and TCEN = 1, BCD format is selected for the backup registers. If the backup registers were written to by the hardware before TCEN was set, then the previous values are retained until there is a time capture event that overrides the values with the time stamp.
- When the time capture feature is disabled (TCEN = 0), all of the backup registers (RTCSECBAKx, RTCMINBAKx, RTCHOURBAKx, RTCDAYBAKx, RTCMONBAKx, and RTCYEARBAKx) can be written only by the CPU. When TCEN = 0, the RTCBCD bit setting is ignored for the backup registers. The data in the backup registers when TCEN = 1 is retained until the user writes new values after TCEN is cleared.
- When TCEN is cleared, all CAPEV bits and RTCCAPIFG are cleared.
- Table 29-1** shows how to use the DIR, REN, and OUT bits in RTCCAPxCTL for proper configuration of RTCCAPx pins.

**Table 29-1. RTCCAPx Pin Configuration**

| <b>DIR</b> | <b>REN</b> | <b>OUT</b> | <b>RTCCAPx Configuration</b> |
|------------|------------|------------|------------------------------|
| 0          | 0          | x          | Input                        |
| 0          | 1          | 0          | Input with pulldown resistor |
| 0          | 1          | 1          | Input with pullup resistor   |
| 1          | x          | x          | Output                       |

### 29.3.2.1 Real-Time Clock Event/Tamper Detection Interrupts

With the event or tamper detection feature, one additional interrupt sources is available, RTCCAPIFG. This flag is prioritized and combined with the other interrupt flags to source a single interrupt vector. The interrupt vector register (RTCIV) is used to determine which flag requested an interrupt.

The RTCCAPIFG bit flags the occurrence of a tamper event. The exact source of the interrupt among multiple tamper events can be found out by reading the CAPEV bit in the respective RTCCAPxCTL registers (one per tamper source). When RTCIV is read, the RTCCAPIFG is cleared but not the status flags (CAPEV bits).

## 29.4 RTC\_C Registers

The RTC\_C module registers are shown in [Table 29-2](#). This table also shows which registers are key protected and which are retained during LPM3.5. The registers that are retained during LPM3.5 and given with a reset value are not reset on POR. Registers that are not retained during LPM3.5 must be restored after exit from LPM3.5.

The high-side SVS must not be disabled by software if the real-time clock feature is needed. When the high-side SVS is disabled, the RTC\_C registers with LPM3.5 retention are not accessible by the CPU.

The base address for the RTC\_C module registers can be found in the device-specific data sheet. The address offsets are shown in [Table 29-2](#).

The additional registers that are available if Event/Tamper Detection is implemented are shown in [Table 29-3](#) together with the corresponding address offsets.

If the counter mode is supported, the register aliases shown in [Table 29-4](#) can be used to access the counter registers.

---

**NOTE:** Most registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 29-2. RTC\_C Registers**

| Offset | Acronym       | Register Name                            | Type       | Access | Reset | Key Protected | LPM3.5 Retention   |
|--------|---------------|------------------------------------------|------------|--------|-------|---------------|--------------------|
| 00h    | RTCCTL0       | Real-Time Clock Control 0                | Read/write | Word   | 9600h | yes           | not retained       |
| 00h    | RTCCTL0_L     | Real-Time Clock Control 0 Low            | Read/write | Byte   | 00h   | yes           | not retained       |
| 01h    | RTCCTL0_H     | Real-Time Clock Control 0 High           | Read/write | Byte   | 96h   | n/a           | not retained       |
| 02h    | RTCCTL13      | Real-Time Clock Control 1, 3             | Read/write | Word   | 0070h | yes           | high byte retained |
| 02h    | RTCCTL1       | Real-Time Clock Control 1                | Read/write | Byte   | 70h   | yes           | not retained       |
|        | or RTCCTL13_L |                                          |            |        |       |               |                    |
| 03h    | RTCCTL3       | Real-Time Clock Control 3                | Read/write | Byte   | 00h   | yes           | retained           |
|        | or RTCCTL13_H |                                          |            |        |       |               |                    |
| 04h    | RTCOCAL       | Real-Time Clock Offset Calibration       | Read/write | Word   | 0000h | yes           | retained           |
| 04h    | RTCOCAL_L     |                                          | Read/write | Byte   | 00h   | yes           | retained           |
| 05h    | RTCOCAL_H     |                                          | Read/write | Byte   | 00h   | yes           | retained           |
| 06h    | RTCTCMP       | Real-Time Clock Temperature Compensation | Read/write | Word   | 4000h | no            | partially retained |
| 06h    | RTCTCMP_L     |                                          | Read/write | Byte   | 00h   | no            | partially retained |
| 07h    | RTCTCMP_H     |                                          | Read/write | Byte   | 40h   | no            | partially retained |
| 08h    | RTCP0S0CTL    | Real-Time Prescale Timer 0 Control       | Read/write | Word   | 0100h | no            | not retained       |
| 08h    | RTCP0S0CTL_L  |                                          | Read/write | Byte   | 00h   | no            | not retained       |
| 09h    | RTCP0S0CTL_H  |                                          | Read/write | Byte   | 01h   | no            | not retained       |
| 0Ah    | RTCP0S1CTL    | Real-Time Prescale Timer 1 Control       | Read/write | Word   | 0100h | no            | not retained       |
| 0Ah    | RTCP0S1CTL_L  |                                          | Read/write | Byte   | 00h   | no            | not retained       |
| 0Bh    | RTCP0S1CTL_H  |                                          | Read/write | Byte   | 01h   | no            | not retained       |
| 0Ch    | RTCP0S        | Real-Time Prescale Timer 0, 1 Counter    | Read/write | Word   | none  | yes           | retained           |
| 0Ch    | RT0PS         | Real-Time Prescale Timer 0 Counter       | Read/write | Byte   | none  | yes           | retained           |

Table 29-2. RTC\_C Registers (continued)

| Offset          | Acronym    | Register Name                                   | Type       | Access | Reset     | Key Protected | LPM3.5 Retention |
|-----------------|------------|-------------------------------------------------|------------|--------|-----------|---------------|------------------|
| or RTCPS_L      |            |                                                 |            |        |           |               |                  |
| 0Dh             | RT1PS      | Real-Time Prescale Timer 1 Counter              | Read/write | Byte   | none      | yes           | retained         |
| or RTCPS_H      |            |                                                 |            |        |           |               |                  |
| 0Eh             | RTCIV      | Real Time Clock Interrupt Vector                | Read       | Word   | 0000h     | no            | not retained     |
| 10h             | RTCTIM0    | Real-Time Clock Seconds, Minutes                | Read/write | Word   | undefined | yes           | retained         |
| 10h             | RTCSEC     | Real-Time Clock Seconds                         | Read/write | Byte   | undefined | yes           | retained         |
| or RTCTIM0_L    |            |                                                 |            |        |           |               |                  |
| 11h             | RTCMIN     | Real-Time Clock Minutes                         | Read/write | Byte   | undefined | yes           | retained         |
| or RTCTIM0_H    |            |                                                 |            |        |           |               |                  |
| 12h             | RTCTIM1    | Real-Time Clock Hour, Day of Week               | Read/write | Word   | undefined | yes           | retained         |
| 12h             | RTCHOUR    | Real-Time Clock Hour                            | Read/write | Byte   | undefined | yes           | retained         |
| or RTCTIM1_L    |            |                                                 |            |        |           |               |                  |
| 13h             | RTCDOW     | Real-Time Clock Day of Week                     | Read/write | Byte   | undefined | yes           | retained         |
| or RTCTIM1_H    |            |                                                 |            |        |           |               |                  |
| 14h             | RTCDATE    | Real-Time Clock Date                            | Read/write | Word   | undefined | yes           | retained         |
| 14h             | RTCDAY     | Real-Time Clock Day of Month                    | Read/write | Byte   | undefined | yes           | retained         |
| or RTCDATE_L    |            |                                                 |            |        |           |               |                  |
| 15h             | RTCMON     | Real-Time Clock Month                           | Read/write | Byte   | undefined | yes           | retained         |
| or RTCDATE_H    |            |                                                 |            |        |           |               |                  |
| 16h             | RTCYEAR    | Real-Time Clock Year <sup>(1)</sup>             | Read/write | Word   | undefined | yes           | retained         |
| 18h             | RTCAMINHR  | Real-Time Clock Minutes, Hour Alarm             | Read/write | Word   | undefined | no            | retained         |
| 18h             | RTCAMIN    | Real-Time Clock Minutes Alarm                   | Read/write | Byte   | undefined | no            | retained         |
| or RTCAMINHR_L  |            |                                                 |            |        |           |               |                  |
| 19h             | RTCAHOUR   | Real-Time Clock Hours Alarm                     | Read/write | Byte   | undefined | no            | retained         |
| or RTCAMINHR_H  |            |                                                 |            |        |           |               |                  |
| 1Ah             | RTCADOWDAY | Real-Time Clock Day of Week, Day of Month Alarm | Read/write | Word   | undefined | no            | retained         |
| 1Ah             | RTCADOW    | Real-Time Clock Day of Week Alarm               | Read/write | Byte   | undefined | no            | retained         |
| or RTCADOWDAY_L |            |                                                 |            |        |           |               |                  |
| 1Bh             | RTCADAY    | Real-Time Clock Day of Month Alarm              | Read/write | Byte   | undefined | no            | retained         |
| or RTCADOWDAY_H |            |                                                 |            |        |           |               |                  |
| 1Ch             | BIN2BCD    | Binary-to-BCD conversion register               | Read/write | Word   | 0000h     | no            | not retained     |
| 1Eh             | BCD2BIN    | BCD-to-binary conversion register               | Read/write | Word   | 0000h     | no            | not retained     |

<sup>(1)</sup> Do not access the year register RTCYEAR in byte mode.

**Table 29-3. RTC\_C Event and Tamper Detection Registers**

| Offset | Acronym     | Register Name                                   | Type       | Access | Reset | Key Protected | LPM3.5 Retention |
|--------|-------------|-------------------------------------------------|------------|--------|-------|---------------|------------------|
| 20h    | RTCTCCTL0   | Real-Time Clock Time Capture Control Register 0 | Read/write | Byte   | 02h   | yes           | retained         |
| 21h    | RTCTCCTL1   | Real-Time Clock Time Capture Control Register 1 | Read/write | Byte   | 00h   | yes           | not retained     |
| 22h    | RTCCAP0CTL  | Tamper Detect Pin 0 Control Register            | Read/write | Byte   | 00h   | yes           | not retained     |
| 23h    | RTCCAP1CTL  | Tamper Detect Pin 1 Control Register            | Read/write | Byte   | 00h   | yes           | not retained     |
| 30h    | RTCSECBK0   | Real-Time Clock Seconds Backup Register 0       | Read/write | Byte   | 00h   | yes           | retained         |
| 31h    | RTCMINBAK0  | Real-Time Clock Minutes Backup Register 0       | Read/write | Byte   | 00h   | yes           | retained         |
| 32h    | RTCHOURBAK0 | Real-Time Clock Hours Backup Register 0         | Read/write | Byte   | 00h   | yes           | retained         |
| 33h    | RTCDAYBAK0  | Real-Time Clock Days Backup Register 0          | Read/write | Byte   | 00h   | yes           | retained         |
| 34h    | RTCMONBAK0  | Real-Time Clock Months Backup Register 0        | Read/write | Byte   | 00h   | yes           | retained         |
| 36h    | RTCYEARBAK0 | Real-Time Clock year Backup Register 0          | Read/write | Word   | 00h   | yes           | retained         |
| 38h    | RTCSECBK1   | Real-Time Clock Seconds Backup Register 1       | Read/write | Byte   | 00h   | yes           | retained         |
| 39h    | RTCMINBAK1  | Real-Time Clock Minutes Backup Register 1       | Read/write | Byte   | 00h   | yes           | retained         |
| 3Ah    | RTCHOURBAK1 | Real-Time Clock Hours Backup Register 1         | Read/write | Byte   | 00h   | yes           | retained         |
| 3Bh    | RTCDAYBAK1  | Real-Time Clock Days Backup Register 1          | Read/write | Byte   | 00h   | yes           | retained         |
| 3Ch    | RTCMONBAK1  | Real-Time Clock Months Backup Register 1        | Read/write | Byte   | 00h   | yes           | retained         |
| 3Eh    | RTCYEARBAK1 | Real-Time Clock Year Backup Register 1          | Read/write | Word   | 00h   | yes           | retained         |

**Table 29-4. RTC\_C Real-Time Clock Counter Mode Aliases**

| Offset | Acronym  | Register Name          | Type       | Access | Reset     | Key Protected | LPM3.5 Retention |
|--------|----------|------------------------|------------|--------|-----------|---------------|------------------|
| 10h    | RTCCNT12 | Real-Time Counter 1, 2 | Read/write | Word   | undefined | yes           | retained         |
| 10h    | RTCCNT1  | Real-Time Counter 1    | Read/write | Byte   | undefined | yes           | retained         |
| 11h    | RTCCNT2  | Real-Time Counter 2    | Read/write | Byte   | undefined | yes           | retained         |
| 12h    | RTCCNT34 | Real-Time Counter 3, 4 | Read/write | Word   | undefined | yes           | retained         |
| 12h    | RTCCNT3  | Real-Time Counter 3    | Read/write | Byte   | undefined | yes           | retained         |
| 13h    | RTCCNT4  | Real-Time Counter 4    | Read/write | Byte   | undefined | yes           | retained         |

### 29.4.1 RTCCTL0\_L Register

Real-Time Clock Control 0 Low Register

**Figure 29-4. RTCCTL0\_L Register**

| 7                      | 6                       | 5                     | 4        | 3       | 2         | 1       | 0         |
|------------------------|-------------------------|-----------------------|----------|---------|-----------|---------|-----------|
| RTCOFIE <sup>(1)</sup> | RTCTEVIE <sup>(1)</sup> | RTCAIE <sup>(1)</sup> | RTCRDYIE | RTCOFIG | RTCTEVIFG | RTCAIFG | RTCRDYIFG |
| rw-0                   | rw-0                    | rw-0                  | rw-0     | rw-(0)  | rw-(0)    | rw-(0)  | rw-(0)    |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits themselves; therefore, reconfiguration is required after wakeup from LPMx.5 before clearing LOCKLPM5.

**Table 29-5. RTCCTL0\_L Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                         |
|-----|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | RTCOFIE   | RW   | 0h    | 32-kHz crystal oscillator fault interrupt enable. This interrupt can be used as LPM3.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPM3.5 wake-up enabled)                                                                                              |
| 6   | RTCTEVIE  | RW   | 0h    | Real-time clock time event interrupt enable. In modules supporting LPM3.5 this interrupt can be used as LPM3.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPM3.5 wake-up enabled)                                                                      |
| 5   | RTCAIE    | RW   | 0h    | Real-time clock alarm interrupt enable. In modules supporting LPM3.5 this interrupt can be used as LPM3.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPM3.5 wake-up enabled)                                                                           |
| 4   | RTCRDYIE  | RW   | 0h    | Real-time clock ready interrupt enable<br>0b = Interrupt not enabled<br>1b = Interrupt enabled                                                                                                                                                                                      |
| 3   | RTCOFIG   | RW   | 0h    | 32-kHz crystal oscillator fault interrupt flag. This interrupt can be used as LPM3.5 wake-up event. It also indicates a clock failure during backup operation.<br>0b = No interrupt pending<br>1b = Interrupt pending. A 32-kHz crystal oscillator fault occurred after last reset. |
| 2   | RTCTEVIFG | RW   | 0h    | Real-time clock time event interrupt flag. In modules supporting LPM3.5 this interrupt can be used as LPM3.5 wake-up event.<br>0b = No time event occurred<br>1b = Time event occurred                                                                                              |
| 1   | RTCAIFG   | RW   | 0h    | Real-time clock alarm interrupt flag. In modules supporting LPM3.5 this interrupt can be used as LPM3.5 wake-up event.<br>0b = No time event occurred<br>1b = Time event occurred                                                                                                   |
| 0   | RTCRDYIFG | RW   | 0h    | Real-time clock ready interrupt flag<br>0b = RTC cannot be read safely<br>1b = RTC can be read safely                                                                                                                                                                               |

### **29.4.2 RTCCTL0\_H Register**

Real-Time Clock Control 0 High Register

**Figure 29-5. RTCCTL0\_H Register**

| 7      | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|--------|------|------|------|------|------|------|------|
| RTCKEY |      |      |      |      |      |      |      |
| rw-1   | rw-0 | rw-0 | rw-1 | rw-0 | rw-1 | rw-1 | rw-0 |

**Table 29-6. RTCCTL0\_H Register Description**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                        |
|-----|--------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-0 | RTCKEY | RW   | 96h   | Real-time clock key. This register should be written with A5h to unlock RTC_C. A write with a value other than A5h locks the module. A read from this register always returns 96h. |

### 29.4.3 RTCCTL1 Register

Real-Time Clock Control Register 1

**Figure 29-6. RTCCTL1 Register**

| 7      | 6                      | 5                      | 4      | 3                       | 2      | 1                      | 0      |
|--------|------------------------|------------------------|--------|-------------------------|--------|------------------------|--------|
| RTCBCD | RTCHOLD <sup>(1)</sup> | RTCMODE <sup>(1)</sup> | RTCRDY | RTCSSELx <sup>(1)</sup> |        | RTCTEVx <sup>(1)</sup> |        |
| rw-(0) | rw-(1)                 | rw-(1)                 | r-(1)  | rw-(0)                  | rw-(0) | rw-(0)                 | rw-(0) |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits themselves; therefore, reconfiguration is required after wakeup from LPMx.5 before clearing LOCKLPM5.

**Table 29-7. RTCCTL1 Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                         |
|-----|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | RTCBCD   | RW   | 0h    | Real-time clock BCD select. Selects BCD counting for real-time clock. Applies to calendar mode (RTCMODE = 1) only; setting is ignored in counter mode.<br>0b = Binary (hexadecimal) code selected<br>1b = Binary coded decimal (BCD) code selected                                                                                                  |
| 6   | RTCHOLD  | RW   | 1h    | Real-time clock hold<br>0b = Real-time clock (32-bit counter or calendar mode) is operational.<br>1b = In counter mode (RTCMODE = 0), only the 32-bit counter is stopped. In calendar mode (RTCMODE = 1), the calendar is stopped as well as the prescale counters, RT0PS and RT1PS. RT0PSHOLD and RT1PSHOLD are don't care.                        |
| 5   | RTCMODE  | RW   | 1h    | Real-time clock mode. In RTC_C modules without counter mode support this bit is read-only and always reads 1.<br>0b = 32-bit counter mode<br>1b = Calendar mode. Switching between counter and calendar mode does not reset the real-time clock counter registers. These registers must be configured by user software before use.                  |
| 4   | RTCRDY   | R    | 1h    | Real-time clock ready<br>0b = RTC time values in transition (calendar mode only)<br>1b = RTC time values safe for reading (calendar mode only). This bit indicates when the real-time clock time values are safe for reading (calendar mode only). In counter mode, RTCRDY remains cleared.                                                         |
| 3-2 | RTCSSELx | RW   | 0h    | Real-time clock source select. In counter mode, selects clock input source to the 32-bit counter. In calendar mode, these bits are don't care. The clock input is automatically set to the output of RT1PS.<br>00b = 32-kHz crystal oscillator clock<br>01b = 32-kHz crystal oscillator clock<br>10b = Output from RT1PS<br>11b = Output from RT1PS |
| 1-0 | RTCTEVx  | RW   | 0h    | Real-time clock time event<br>Calendar Mode (RTCMODE = 1)<br>00b = Minute changed<br>01b = Hour changed<br>10b = Every day at midnight (00:00)<br>11b = Every day at noon (12:00)<br>Counter Mode (RTCMODE = 0)<br>00b = 8-bit overflow<br>01b = 16-bit overflow<br>10b = 24-bit overflow<br>11b = 32-bit overflow                                  |

#### 29.4.4 RTCCTL3 Register

Real-Time Clock Control 3 Register

**Figure 29-7. RTCCTL3 Register**

| 7        | 6  | 5  | 4  | 3  | 2  | 1                       | 0      |
|----------|----|----|----|----|----|-------------------------|--------|
| Reserved |    |    |    |    |    | RTCCALFx <sup>(1)</sup> |        |
| r0       | r0 | r0 | r0 | r0 | r0 | rw-(0)                  | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-8. RTCCTL3 Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                         |
|-----|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-2 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                        |
| 1-0 | RTCCALFx | RW   | 0h    | Real-time clock calibration frequency. Selects frequency output to RTCCLK pin for calibration measurement. The corresponding port must be configured for the peripheral module function. The RTCCLK is not available in counter mode and remains low, and the RTCCALF bits are don't care.<br>00b = No frequency output to RTCCLK pin<br>01b = 512 Hz<br>10b = 256 Hz<br>11b = 1 Hz |

#### 29.4.5 RTCOCAL Register

Real-Time Clock Offset Calibration Register

**Figure 29-8. RTCOCAL Register**

| 15                      | 14     | 13       | 12     | 11     | 10     | 9      | 8      |
|-------------------------|--------|----------|--------|--------|--------|--------|--------|
| RTCOALS <sup>(1)</sup>  |        | Reserved |        |        |        |        |        |
| rw-(0)                  | r0     | r0       | r0     | r0     | r0     | r0     | r0     |
| RTCOCALx <sup>(1)</sup> |        |          |        |        |        | 0      |        |
| rw-(0)                  | rw-(0) | rw-(0)   | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-9. RTCOCAL Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                      |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | RTCOALS  | RW   | 0h    | Real-time clock offset error calibration sign. This bit decides the sign of offset error calibration.<br>0b = Down calibration. Frequency adjusted down.<br>1b = Up calibration. Frequency adjusted up.                                                          |
| 14-8 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                     |
| 7-0  | RTCOCALx | RW   | 0h    | Real-time clock offset error calibration. Each LSB represents approximately +1 ppm (RTCOALS = 1) or -1 ppm (RTCOALS = 0) adjustment in frequency. Maximum effective calibration value is ±240 ppm. Excess values written above ±240 ppm are ignored by hardware. |

## 29.4.6 RTCTCMP Register

Real-Time Clock Temperature Compensation Register

**Figure 29-9. RTCTCMP Register**

| 15                      | 14                      | 13      | 12     | 11     | 10       | 9      | 8      |
|-------------------------|-------------------------|---------|--------|--------|----------|--------|--------|
| RTCTCMPS <sup>(1)</sup> | RTCTCRDY <sup>(1)</sup> | RTCTCOK |        |        | Reserved |        |        |
| rw-(0)                  | r-(1)                   | r-(0)   | r0     | r0     | r0       | r0     | r0     |
| 7                       | 6                       | 5       | 4      | 3      | 2        | 1      | 0      |
| RTCTCMPx <sup>(1)</sup> |                         |         |        |        |          |        |        |
| rw-(0)                  | rw-(0)                  | rw-(0)  | rw-(0) | rw-(0) | rw-(0)   | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-10. RTCTCMP Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                        |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | RTCTCMPS | RW   | 0h    | Real-time clock temperature compensation sign. This bit decides the sign of temperature compensation. <sup>(1)</sup><br>0b = Down calibration. Frequency adjusted down.<br>1b = Up calibration. Frequency adjusted up.                                                                                                                             |
| 14   | RTCTCRDY | R    | 1h    | Real-time clock temperature compensation ready. This is a read only bit that indicates when the RTCTCMPx can be written. Write to RTCTCMPx should be avoided when RTCTCRDY is reset.                                                                                                                                                               |
| 13   | RTCTCOK  | R    | 0h    | Real-time clock temperature compensation write OK. This is a read-only bit that indicates if the write to RTCTCMP is successful or not.<br>0b = Write to RTCTCMPx is unsuccessful<br>1b = Write to RTCTCMPx is successful                                                                                                                          |
| 12-8 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                       |
| 7-0  | RTCTCMPx | RW   | 0h    | Real-time clock temperature compensation. Value written into this register is used for temperature compensation of RTC_C. Each LSB represents approximately +1 ppm (RTCTCMPS = 1) or -1 ppm (RTCTCMPS = 0) adjustment in frequency. Maximum effective calibration value is ±240 ppm. Excess values written above ±240 ppm are ignored by hardware. |

<sup>(1)</sup> Changing the sign-bit by writing to RTCTCMP\_H becomes effective only after also writing RTCTCMP\_L.

### 29.4.7 RTCNT1 Register

Real-Time Clock Counter 1 Register – Counter Mode

**Figure 29-10. RTCNT1 Register**

| 7      | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|--------|----|----|----|----|----|----|----|
| RTCNT1 |    |    |    |    |    |    |    |
| rw     | rw | rw | rw | rw | rw | rw | rw |

**Table 29-11. RTCNT1 Register Description**

| Bit | Field  | Type | Reset     | Description                                |
|-----|--------|------|-----------|--------------------------------------------|
| 7-0 | RTCNT1 | RW   | undefined | The RTCNT1 register is the count of RTCNT1 |

### 29.4.8 RTCNT2 Register

Real-Time Clock Counter 2 Register – Counter Mode

**Figure 29-11. RTCNT2 Register**

| 7      | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|--------|----|----|----|----|----|----|----|
| RTCNT2 |    |    |    |    |    |    |    |
| rw     | rw | rw | rw | rw | rw | rw | rw |

**Table 29-12. RTCNT2 Register Description**

| Bit | Field  | Type | Reset     | Description                                |
|-----|--------|------|-----------|--------------------------------------------|
| 7-0 | RTCNT2 | RW   | undefined | The RTCNT2 register is the count of RTCNT2 |

### 29.4.9 RTCNT3 Register

Real-Time Clock Counter 3 Register – Counter Mode

**Figure 29-12. RTCNT3 Register**

| 7      | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|--------|----|----|----|----|----|----|----|
| RTCNT3 |    |    |    |    |    |    |    |
| rw     | rw | rw | rw | rw | rw | rw | rw |

**Table 29-13. RTCNT3 Register Description**

| Bit | Field  | Type | Reset     | Description                                |
|-----|--------|------|-----------|--------------------------------------------|
| 7-0 | RTCNT3 | RW   | undefined | The RTCNT3 register is the count of RTCNT3 |

### 29.4.10 RTCNT4 Register

Real-Time Clock Counter 4 Register – Counter Mode

**Figure 29-13. RTCNT4 Register**

| 7      | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|--------|----|----|----|----|----|----|----|
| RTCNT4 |    |    |    |    |    |    |    |
| rw     | rw | rw | rw | rw | rw | rw | rw |

**Table 29-14. RTCNT4 Register Description**

| Bit | Field  | Type | Reset     | Description                                 |
|-----|--------|------|-----------|---------------------------------------------|
| 7-0 | RTCNT4 | RW   | undefined | The RTCNT4 register is the count of RTCNT4. |

### 29.4.11 RTCSEC Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Seconds Register – Calendar Mode With Hexadecimal Format

**Figure 29-14. RTCSEC Register**

| 7   | 6       | 5  | 4  | 3  | 2  | 1  | 0  |
|-----|---------|----|----|----|----|----|----|
| 0   | Seconds |    |    |    |    |    |    |
| r-0 | r-0     | rw | rw | rw | rw | rw | rw |

**Table 29-15. RTCSEC Register Description**

| Bit | Field   | Type | Reset     | Description       |
|-----|---------|------|-----------|-------------------|
| 7-6 | 0       | R    | 0h        | Always 0          |
| 5-0 | Seconds | RW   | undefined | Seconds (0 to 59) |

### 29.4.12 RTCSEC Register – Calendar Mode With BCD Format

Real-Time Clock Seconds Register – Calendar Mode With BCD Format

**Figure 29-15. RTCSEC Register**

| 7   | 6                    | 5  | 4  | 3  | 2                   | 1  | 0  |
|-----|----------------------|----|----|----|---------------------|----|----|
| 0   | Seconds – high digit |    |    |    | Seconds – low digit |    |    |
| r-0 | rw                   | rw | rw | rw | rw                  | rw | rw |

**Table 29-16. RTCSEC Register Description**

| Bit | Field                | Type | Reset     | Description                   |
|-----|----------------------|------|-----------|-------------------------------|
| 7   | 0                    | R    | 0h        | Always 0                      |
| 6-4 | Seconds – high digit | RW   | undefined | Seconds – high digit (0 to 5) |
| 3-0 | Seconds – low digit  | RW   | undefined | Seconds – low digit (0 to 9)  |

### **29.4.13 RTCMIN Register – Calendar Mode With Hexadecimal Format**

Real-Time Clock Minutes Register – Calendar Mode With Hexadecimal Format

**Figure 29-16. RTCMIN Register**

| 7   | 6       | 5  | 4  | 3  | 2  | 1  | 0  |
|-----|---------|----|----|----|----|----|----|
| 0   | Minutes |    |    |    |    |    |    |
| r-0 | r-0     | rw | rw | rw | rw | rw | rw |

**Table 29-17. RTCMIN Register Description**

| Bit | Field   | Type | Reset     | Description       |
|-----|---------|------|-----------|-------------------|
| 7-6 | 0       | R    | 0h        | Always 0          |
| 5-0 | Minutes | RW   | undefined | Minutes (0 to 59) |

### **29.4.14 RTCMIN Register – Calendar Mode With BCD Format**

Real-Time Clock Minutes Register – Calendar Mode With BCD Format

**Figure 29-17. RTCMIN Register**

| 7   | 6                    | 5  | 4  | 3  | 2                   | 1  | 0  |
|-----|----------------------|----|----|----|---------------------|----|----|
| 0   | Minutes – high digit |    |    |    | Minutes – low digit |    |    |
| r-0 | rw                   | rw | rw | rw | rw                  | rw | rw |

**Table 29-18. RTCMIN Register Description**

| Bit | Field                | Type | Reset     | Description                   |
|-----|----------------------|------|-----------|-------------------------------|
| 7   | 0                    | R    | 0h        | Always 0                      |
| 6-4 | Minutes – high digit | RW   | undefined | Minutes – high digit (0 to 5) |
| 3-0 | Minutes – low digit  | RW   | undefined | Minutes – low digit (0 to 9)  |

### 29.4.15 RTCHOUR Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Hours Register – Calendar Mode With Hexadecimal Format

**Figure 29-18. RTCHOUR Register**

| 7   | 6   | 5   | 4  | 3     | 2  | 1  | 0  |  |  |  |
|-----|-----|-----|----|-------|----|----|----|--|--|--|
| 0   |     |     |    | Hours |    |    |    |  |  |  |
| r-0 | r-0 | r-0 | rw | rw    | rw | rw | rw |  |  |  |

**Table 29-19. RTCHOUR Register Description**

| Bit | Field | Type | Reset     | Description     |
|-----|-------|------|-----------|-----------------|
| 7-5 | 0     | R    | 0h        | Always 0        |
| 4-0 | Hours | RW   | undefined | Hours (0 to 23) |

### 29.4.16 RTCHOUR Register – Calendar Mode With BCD Format

Real-Time Clock Hours Register – Calendar Mode With BCD Format

**Figure 29-19. RTCHOUR Register**

| 7   | 6   | 5                  | 4  | 3  | 2                 | 1  | 0  |
|-----|-----|--------------------|----|----|-------------------|----|----|
| 0   |     | Hours – high digit |    |    | Hours – low digit |    |    |
| r-0 | r-0 | rw                 | rw | rw | rw                | rw | rw |

**Table 29-20. RTCHOUR Register Description**

| Bit | Field              | Type | Reset     | Description                 |
|-----|--------------------|------|-----------|-----------------------------|
| 7-6 | 0                  | R    | 0h        | Always 0                    |
| 5-4 | Hours – high digit | RW   | undefined | Hours – high digit (0 to 2) |
| 3-0 | Hours – low digit  | RW   | undefined | Hours – low digit (0 to 9)  |

### 29.4.17 RTCDOW Register – Calendar Mode

Real-Time Clock Day of Week Register – Calendar Mode

**Figure 29-20. RTCDOW Register**

| 7   | 6   | 5   | 4   | 3           | 2  | 1  | 0  |  |  |
|-----|-----|-----|-----|-------------|----|----|----|--|--|
|     |     |     | 0   | Day of week |    |    |    |  |  |
| r-0 | r-0 | r-0 | r-0 | r-0         | rw | rw | rw |  |  |

**Table 29-21. RTCDOW Register Description**

| Bit | Field       | Type | Reset     | Description          |
|-----|-------------|------|-----------|----------------------|
| 7-3 | 0           | R    | 0h        | Always 0             |
| 2-0 | Day of week | RW   | undefined | Day of week (0 to 6) |

### 29.4.18 RTCDAY Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Day of Month Register – Calendar Mode With Hexadecimal Format

**Figure 29-21. RTCDAY Register**

| 7   | 6   | 5   | 4  | 3            | 2  | 1  | 0  |  |  |
|-----|-----|-----|----|--------------|----|----|----|--|--|
|     |     |     | 0  | Day of month |    |    |    |  |  |
| r-0 | r-0 | r-0 | rw | rw           | rw | rw | rw |  |  |

**Table 29-22. RTCDAY Register Description**

| Bit | Field        | Type | Reset     | Description                        |
|-----|--------------|------|-----------|------------------------------------|
| 7-5 | 0            | R    | 0h        | Always 0                           |
| 4-0 | Day of month | RW   | undefined | Day of month (1 to 28, 29, 30, 31) |

### 29.4.19 RTCDAY Register – Calendar Mode With BCD Format

Real-Time Clock Day of Month Register – Calendar Mode With BCD Format

**Figure 29-22. RTCDAY Register**

| 7   | 6   | 5  | 4  | 3                         | 2  | 1                        | 0  |
|-----|-----|----|----|---------------------------|----|--------------------------|----|
|     |     |    | 0  | Day of month – high digit |    | Day of month – low digit |    |
| r-0 | r-0 | rw | rw | rw                        | rw | rw                       | rw |

**Table 29-23. RTCDAY Register Description**

| Bit | Field                     | Type | Reset     | Description                        |
|-----|---------------------------|------|-----------|------------------------------------|
| 7-6 | 0                         | R    | 0h        |                                    |
| 5-4 | Day of month – high digit | RW   | undefined | Day of month – high digit (0 to 3) |
| 3-0 | Day of month – low digit  | RW   | undefined | Day of month – low digit (0 to 9)  |

### 29.4.20 RTCMON Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Month Register – Calendar Mode With Hexadecimal Format

**Figure 29-23. RTCMON Register**

| 7   | 6   | 5   | 4   | 3     | 2  | 1  | 0  |  |  |
|-----|-----|-----|-----|-------|----|----|----|--|--|
|     |     |     | 0   | Month |    |    |    |  |  |
| r-0 | r-0 | r-0 | r-0 | rw    | rw | rw | rw |  |  |

**Table 29-24. RTCMON Register Description**

| Bit | Field | Type | Reset     | Description     |
|-----|-------|------|-----------|-----------------|
| 7-4 | 0     | R    | 0h        | Always 0        |
| 3-0 | Month | RW   | undefined | Month (1 to 12) |

### 29.4.21 RTCMON Register – Calendar Mode With BCD Format

Real-Time Clock Month Register – Calendar Mode With BCD Format

**Figure 29-24. RTCMON Register**

| 7   | 6   | 5   | 4  | 3                  | 2  | 1                 | 0  |
|-----|-----|-----|----|--------------------|----|-------------------|----|
|     |     |     | 0  | Month – high digit |    | Month – low digit |    |
| r-0 | r-0 | r-0 | rw | rw                 | rw | rw                | rw |

**Table 29-25. RTCMON Register Description**

| Bit | Field              | Type | Reset     | Description                 |
|-----|--------------------|------|-----------|-----------------------------|
| 7-5 | 0                  | R    | 0h        | Always 0                    |
| 4   | Month – high digit | RW   | undefined | Month – high digit (0 or 1) |
| 3-0 | Month – low digit  | RW   | undefined | Month – low digit (0 to 9)  |

### 29.4.22 RTCYEAR Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Year Low-Byte Register – Calendar Mode With Hexadecimal Format

**Figure 29-25. RTCYEAR Register**

| 15  | 14  | 13  | 12  | 11               | 10 | 9  | 8  |  |  |
|-----|-----|-----|-----|------------------|----|----|----|--|--|
|     |     | 0   |     | Year – high byte |    |    |    |  |  |
| r-0 | r-0 | r-0 | r-0 | rw               | rw | rw | rw |  |  |
| 7   | 6   | 5   | 4   | 3                | 2  | 1  | 0  |  |  |
| rw  | rw  | rw  | rw  | rw               | rw | rw | rw |  |  |

**Table 29-26. RTCYEAR Register Description**

| Bit   | Field            | Type | Reset     | Description                                            |
|-------|------------------|------|-----------|--------------------------------------------------------|
| 15-12 | 0                | R    | 0h        | Always 0                                               |
| 11-8  | Year – high byte | RW   | undefined | Year – high byte. Valid values for Year are 0 to 4095. |
| 7-0   | Year – low byte  | RW   | undefined | Year – low byte. Valid values for Year are 0 to 4095.  |

### 29.4.23 RTCYEAR Register – Calendar Mode With BCD Format

Real-Time Clock Year Low-Byte Register – Calendar Mode With BCD Format

**Figure 29-26. RTCYEAR Register**

| 15     | 14 | 13                   | 12 | 11                  | 10                  | 9  | 8  |
|--------|----|----------------------|----|---------------------|---------------------|----|----|
| 0      |    | Century – high digit |    |                     | Century – low digit |    |    |
| r-0    | rw | rw                   | rw | rw                  | rw                  | rw | rw |
| 7      | 6  | 5                    | 4  | 3                   | 2                   | 1  | 0  |
| Decade |    |                      |    | Year – lowest digit |                     |    |    |
| rw     | rw | rw                   | rw | rw                  | rw                  | rw | rw |

**Table 29-27. RTCYEAR Register Description**

| Bit   | Field                | Type | Reset     | Description                   |
|-------|----------------------|------|-----------|-------------------------------|
| 15    | 0                    | R    | 0h        | Always 0                      |
| 14-10 | Century – high digit | RW   | undefined | Century – high digit (0 to 4) |
| 11-8  | Century – low digit  | RW   | undefined | Century – low digit (0 to 9)  |
| 7-4   | Decade               | RW   | undefined | Decade (0 to 9)               |
| 3-0   | Year – lowest digit  | RW   | undefined | Year – lowest digit (0 to 9)  |

#### 29.4.24 RTCAMIN Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Minutes Alarm Register – Calendar Mode With Hexadecimal Format

**Figure 29-27. RTCAMIN Register**

| 7  | 6   | 5  | 4  | 3  | 2  | 1  | 0       |
|----|-----|----|----|----|----|----|---------|
| AE | 0   |    |    |    |    |    | Minutes |
| rw | r-0 | rw | rw | rw | rw | rw | rw      |

**Table 29-28. RTCAMIN Register Description**

| Bit | Field   | Type | Reset     | Description                                                                                 |
|-----|---------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE      | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6   | 0       | R    | 0h        | Always 0.                                                                                   |
| 5-0 | Minutes | RW   | undefined | Minutes (0 to 59)                                                                           |

#### 29.4.25 RTCAMIN Register – Calendar Mode With BCD Format

Real-Time Clock Minutes Alarm Register – Calendar Mode With BCD Format

**Figure 29-28. RTCAMIN Register**

| 7  | 6  | 5                    | 4  | 3  | 2                   | 1  | 0  |
|----|----|----------------------|----|----|---------------------|----|----|
| AE |    | Minutes – high digit |    |    | Minutes – low digit |    |    |
| rw | rw | rw                   | rw | rw | rw                  | rw | rw |

**Table 29-29. RTCAMIN Register Description**

| Bit | Field                | Type | Reset     | Description                                                                                 |
|-----|----------------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE                   | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-4 | Minutes – high digit | RW   | undefined | Minutes – high digit (0 to 5)                                                               |
| 3-0 | Minutes – low digit  | RW   | undefined | Minutes – low digit (0 to 9)                                                                |

### 29.4.26 RTCAHOUR Register

Real-Time Clock Hours Alarm Register – Calendar Mode With Hexadecimal Format

**Figure 29-29. RTCAHOUR Register**

| 7  | 6   | 5   | 4  | 3  | 2     | 1  | 0  |
|----|-----|-----|----|----|-------|----|----|
| AE | 0   |     |    |    | Hours |    |    |
| rw | r-0 | r-0 | rw | rw | rw    | rw | rw |

**Table 29-30. RTCAHOUR Register Description**

| Bit | Field | Type | Reset     | Description                                                                                 |
|-----|-------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE    | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-5 | 0     | R    | 0h        | Always 0                                                                                    |
| 4-0 | Hours | RW   | undefined | Hours (0 to 23)                                                                             |

### 29.4.27 RTCAHOUR Register – Calendar Mode With BCD Format

Real-Time Clock Hours Alarm Register – Calendar Mode With BCD Format

**Figure 29-30. RTCAHOUR Register**

| 7  | 6   | 5  | 4                  | 3  | 2                 | 1  | 0  |
|----|-----|----|--------------------|----|-------------------|----|----|
| AE | 0   |    | Hours – high digit |    | Hours – low digit |    |    |
| rw | r-0 | rw | rw                 | rw | rw                | rw | rw |

**Table 29-31. RTCAHOUR Register Description**

| Bit | Field              | Type | Reset     | Description                                                                                 |
|-----|--------------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE                 | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6   | 0                  | R    | 0h        | Always 0                                                                                    |
| 5-4 | Hours – high digit | RW   | undefined | Hours – high digit (0 to 2)                                                                 |
| 3-0 | Hours – low digit  | RW   | undefined | Hours – low digit (0 to 9)                                                                  |

### 29.4.28 RTCADOW Register – Calendar Mode

Real-Time Clock Day of Week Alarm Register – Calendar Mode

**Figure 29-31. RTCADOW Register**

| 7  | 6   | 5   | 4   | 3   | 2  | 1           | 0  |
|----|-----|-----|-----|-----|----|-------------|----|
| AE |     | 0   |     |     |    | Day of week |    |
| rw | r-0 | r-0 | r-0 | r-0 | rw | rw          | rw |

**Table 29-32. RTCADOW Register Description**

| Bit | Field       | Type | Reset     | Description                                                                                 |
|-----|-------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE          | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-3 | 0           | R    | 0h        | Always 0                                                                                    |
| 2-0 | Day of week | RW   | undefined | Day of week (0 to 6)                                                                        |

### 29.4.29 RTCADAY Register – Calendar Mode With Hexadecimal Format

Real-Time Clock Day of Month Alarm Register – Calendar Mode With Hexadecimal Format

**Figure 29-32. RTCADAY Register**

| 7  | 6   | 5            | 4  | 3  | 2  | 1  | 0  |
|----|-----|--------------|----|----|----|----|----|
| AE | 0   | Day of month |    |    |    |    |    |
| rw | r-0 | r-0          | rw | rw | rw | rw | rw |

**Table 29-33. RTCADAY Register Description**

| Bit | Field        | Type | Reset     | Description                                                                                 |
|-----|--------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE           | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6-5 | 0            | R    | 0h        | Always 0                                                                                    |
| 4-0 | Day of month | RW   | undefined | Day of month (1 to 28, 29, 30, 31)                                                          |

### 29.4.30 RTCADAY Register – Calendar Mode With BCD Format

Real-Time Clock Day of Month Alarm Register – Calendar Mode With BCD Format

**Figure 29-33. RTCADAY Register**

| 7  | 6   | 5                         | 4  | 3  | 2  | 1                        | 0  |
|----|-----|---------------------------|----|----|----|--------------------------|----|
| AE | 0   | Day of month – high digit |    |    |    | Day of month – low digit |    |
| rw | r-0 | rw                        | rw | rw | rw | rw                       | rw |

**Table 29-34. RTCADAY Register Description**

| Bit | Field                     | Type | Reset     | Description                                                                                 |
|-----|---------------------------|------|-----------|---------------------------------------------------------------------------------------------|
| 7   | AE                        | RW   | undefined | Alarm enable<br>0b = This alarm register is disabled<br>1b = This alarm register is enabled |
| 6   | 0                         | R    | 0h        | Always 0                                                                                    |
| 5-4 | Day of month – high digit | RW   | undefined | Day of month – high digit (0 to 3)                                                          |
| 3-0 | Day of month – low digit  | RW   | undefined | Day of month – low digit (0 to 9)                                                           |

### 29.4.31 RTCPS0CTL Register

Real-Time Clock Prescale Timer 0 Control Register

**Figure 29-34. RTCPS0CTL Register**

| 15       | 14 | 13                      | 12     | 11     | 10     | 9        | 8                        |
|----------|----|-------------------------|--------|--------|--------|----------|--------------------------|
| Reserved |    | RT0PSDIV <sup>(1)</sup> |        |        |        | Reserved | RT0PSHOLD <sup>(1)</sup> |
| r0       | r0 | rw-(0)                  | rw-(0) | rw-(0) | r0     | r0       | rw-(1)                   |
| 7        | 6  | 5                       | 4      | 3      | 2      | 1        | 0                        |
| Reserved |    | RT0IP <sup>(1)</sup>    |        |        |        | RT0PSIE  | RT0PSIFG                 |
| r0       | r0 | r0                      | rw-(0) | rw-(0) | rw-(0) | rw-0     | rw-(0)                   |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits themselves; therefore, reconfiguration is required after wake-up from LPMx.5 before clearing LOCKLPM5.

**Table 29-35. RTCPS0CTL Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 13-11 | RT0PSDIV  | RW   | 0h    | Prescale timer 0 clock divide. These bits control the divide ratio of the RT0PS counter. In real-time clock calendar mode, these bits are don't care for RT0PS and RT1PS. RT0PS clock output is automatically set to /256. RT1PS clock output is automatically set to /128.<br>000b = Divide by 2<br>001b = Divide by 4<br>010b = Divide by 8<br>011b = Divide by 16<br>100b = Divide by 32<br>101b = Divide by 64<br>110b = Divide by 128<br>111b = Divide by 256 |
| 10-9  | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 8     | RT0PSHOLD | RW   | 1h    | Prescale timer 0 hold. In real-time clock calendar mode, this bit is don't care. RT0PS is stopped by the RTCHOLD bit.<br>0b = RT0PS is operational<br>1b = RT0PS is held                                                                                                                                                                                                                                                                                           |
| 7-5   | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 4-2   | RT0IP     | RW   | 0h    | Prescale timer 0 interrupt interval<br>000b = Divide by 2<br>001b = Divide by 4<br>010b = Divide by 8<br>011b = Divide by 16<br>100b = Divide by 32<br>101b = Divide by 64<br>110b = Divide by 128<br>111b = Divide by 256                                                                                                                                                                                                                                         |
| 1     | RT0PSIE   | RW   | 0h    | Prescale timer 0 interrupt enable<br>0b = Interrupt not enabled<br>1b = Interrupt enabled                                                                                                                                                                                                                                                                                                                                                                          |
| 0     | RT0PSIFG  | RW   | 0h    | Prescale timer 0 interrupt flag<br>0b = No time event occurred<br>1b = Time event occurred                                                                                                                                                                                                                                                                                                                                                                         |

### 29.4.32 RTCPS1CTL Register

Real-Time Clock Prescale Timer 1 Control Register

**Figure 29-35. RTCPS1CTL Register**

| 15                      | 14     | 13                       | 12     | 11     | 10     | 9        | 8                        |
|-------------------------|--------|--------------------------|--------|--------|--------|----------|--------------------------|
| RT1SSELx <sup>(1)</sup> |        | RT1PSDIVx <sup>(1)</sup> |        |        |        | Reserved | RT1PSHOLD <sup>(1)</sup> |
| rw-(0)                  | rw-(0) | rw-(0)                   | rw-(0) | rw-(0) | r0     | r0       | rw-(1)                   |
| 7                       | 6      | 5                        | 4      | 3      | 2      | 1        | 0                        |
| Reserved                |        | RT1IPx <sup>(1)</sup>    |        |        |        | RT1PSIE  | RT1PSIFG                 |
| r0                      | r0     | r0                       | rw-(0) | rw-(0) | rw-(0) | rw-0     | rw-(0)                   |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the register bits themselves; therefore, reconfiguration is required after wake-up from LPMx.5 before clearing LOCKLPM5.

**Table 29-36. RTCPS1CTL Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | RT1SSELx  | RW   | 0h    | Prescale timer 1 clock source select. Selects clock input source to the RT1PS counter. In real-time clock calendar mode, these bits are do not care. RT1PS clock input is automatically set to the output of RT0PS.<br>00b = 32-kHz crystal oscillator clock<br>01b = 32-kHz crystal oscillator clock<br>10b = Output from RT0PS<br>11b = Output from RT0PS                                                                                                        |
| 13-11 | RT1PSDIVx | RW   | 0h    | Prescale timer 1 clock divide. These bits control the divide ratio of the RT0PS counter. In real-time clock calendar mode, these bits are don't care for RT0PS and RT1PS. RT0PS clock output is automatically set to /256. RT1PS clock output is automatically set to /128.<br>000b = Divide by 2<br>001b = Divide by 4<br>010b = Divide by 8<br>011b = Divide by 16<br>100b = Divide by 32<br>101b = Divide by 64<br>110b = Divide by 128<br>111b = Divide by 256 |
| 10-9  | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 8     | RT1PSHOLD | RW   | 1h    | Prescale timer 1 hold. In real-time clock calendar mode, this bit is don't care. RT1PS is stopped by the RTCHOLD bit.<br>0b = RT1PS is operational<br>1b = RT1PS is held                                                                                                                                                                                                                                                                                           |
| 7-5   | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 4-2   | RT1IPx    | RW   | 0h    | Prescale timer 1 interrupt interval<br>000b = Divide by 2<br>001b = Divide by 4<br>010b = Divide by 8<br>011b = Divide by 16<br>100b = Divide by 32<br>101b = Divide by 64<br>110b = Divide by 128<br>111b = Divide by 256                                                                                                                                                                                                                                         |
| 1     | RT1PSIE   | RW   | 0h    | Prescale timer 1 interrupt enable<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPMx.5 wake-up enabled)                                                                                                                                                                                                                                                                                                                                                 |

**Table 29-36. RTCPS1CTL Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                     |
|-----|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 0   | RT1PSIFG | RW   | 0h    | Prescale timer 1 interrupt flag. This interrupt can be used as LPMx.5 wake-up event.<br>0b = No time event occurred<br>1b = Time event occurred |

### **29.4.33 RTCPS0 Register**

Real-Time Clock Prescale Timer 0 Counter Register

**Figure 29-36. RTCPS0 Register**

|       |    |    |    |    |    |    |    |
|-------|----|----|----|----|----|----|----|
| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| RT0PS |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

**Table 29-37. RTCPS0 Register Description**

| Bit | Field | Type | Reset     | Description                    |
|-----|-------|------|-----------|--------------------------------|
| 7-0 | RT0PS | RW   | undefined | Prescale timer 0 counter value |

### **29.4.34 RTCPS1 Register**

Real-Time Clock Prescale Timer 1 Counter Register

**Figure 29-37. RTCPS1 Register**

|       |    |    |    |    |    |    |    |
|-------|----|----|----|----|----|----|----|
| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| RT1PS |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

**Table 29-38. RTCPS1 Register Description**

| Bit | Field | Type | Reset     | Description                    |
|-----|-------|------|-----------|--------------------------------|
| 7-0 | RT1PS | RW   | undefined | Prescale timer 1 counter value |

### 29.4.35 RTCIV Register

Real-Time Clock Interrupt Vector Register

**Figure 29-38. RTCIV Register**

|        |    |    |       |       |       |       |    |
|--------|----|----|-------|-------|-------|-------|----|
| 15     | 14 | 13 | 12    | 11    | 10    | 9     | 8  |
| RTClVx |    |    |       |       |       |       |    |
| r0     | r0 | r0 | r0    | r0    | r0    | r0    | r0 |
| RTClVx |    |    |       |       |       |       |    |
| r0     | r0 | r0 | r-(0) | r-(0) | r-(0) | r-(0) | r0 |

**Table 29-39. RTCIV Register Description**

| Bit  | Field  | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------|--------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | RTClVx | R    | 0h    | <p>Real-time clock interrupt vector value</p> <p>Without Event/Tamper Detection implemented:</p> <ul style="list-style-type: none"> <li>00h = No interrupt pending</li> <li>02h = Interrupt Source: RTC oscillator failure; Interrupt Flag: RTCOIFG; Interrupt Priority: Highest</li> <li>04h = Interrupt Source: RTC ready; Interrupt Flag: RTCRDYIFG</li> <li>06h = Interrupt Source: RTC interval timer; Interrupt Flag: RTCTEVIFG</li> <li>08h = Interrupt Source: RTC user alarm; Interrupt Flag: RTCAIFG</li> <li>0Ah = Interrupt Source: RTC prescaler 0; Interrupt Flag: RT0PSIFG</li> <li>0Ch = Interrupt Source: RTC prescaler 1; Interrupt Flag: RT1PSIFG</li> <li>0Eh = Reserved</li> <li>10h = Reserved ; Interrupt Priority: Lowest</li> </ul> <p>With Event/Tamper Detection implemented:</p> <ul style="list-style-type: none"> <li>00h = No interrupt pending</li> <li>02h = Interrupt Source: RTC oscillator failure; Interrupt Flag: RTCOIFG; Interrupt Priority: Highest</li> <li>04h = Interrupt Source: RTC Tamper Event; Interrupt Flag: RTCCAPIFG</li> <li>06h = Interrupt Source: RTC ready; Interrupt Flag: RTCRDYIFG</li> <li>08h = Interrupt Source: RTC interval timer; Interrupt Flag: RTCTEVIFG</li> <li>0Ah = Interrupt Source: RTC user alarm; Interrupt Flag: RTCAIFG</li> <li>0Ch = Interrupt Source: RTC prescaler 0; Interrupt Flag: RT0PSIFG</li> <li>0Eh = Interrupt Source: RTC prescaler 1; Interrupt Flag: RT1PSIFG</li> <li>10h = Reserved ; Interrupt Priority: Lowest</li> </ul> |

### 29.4.36 BIN2BCD Register

Binary-to-BCD Conversion Register

**Figure 29-39. BIN2BCD Register**

| 15       | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|----------|------|------|------|------|------|------|------|
| BIN2BCDx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| BIN2BCDx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 29-40. BIN2BCD Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                             |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------|
| 15-0 | BIN2BCDx | RW   | 0h    | Read: 16-bit BCD conversion of previously written 12-bit binary number.<br>Write: 12-bit binary number to be converted. |

### 29.4.37 BCD2BIN Register

BCD-to-Binary Conversion Register

**Figure 29-40. BCD2BIN Register**

| 15       | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
|----------|------|------|------|------|------|------|------|
| BCD2BINx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| BCD2BINx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 29-41. BCD2BIN Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                          |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------|
| 15-0 | BCD2BINx | RW   | 0h    | Read: 12-bit binary conversion of previously written 16-bit BCD number.<br>Write: 16-bit BCD number to be converted. |

### 29.4.38 RTCSECBAKx Register – Hexadecimal Format

Real-Time Clock Seconds Backup Register – Hexadecimal Format

**Figure 29-41. RTCSECBAKx Register**

| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0                      |
|--------|--------|--------|--------|--------|--------|--------|------------------------|
| 0      | 0      |        |        |        |        |        | Seconds <sup>(1)</sup> |
| rw-(0)                 |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-42. RTCSECBAKx Register Description**

| Bit | Field   | Type | Reset | Description                        |
|-----|---------|------|-------|------------------------------------|
| 7-6 | 0       | RW   | 0h    | Always 0.                          |
| 5-0 | Seconds | RW   | 0h    | Seconds. Valid values are 0 to 59. |

### 29.4.39 RTCSECBAKx Register – BCD Format

Real-Time Clock Seconds Backup Register – BCD Format

**Figure 29-42. RTCSECBAKx Register**

| 7      | 6      | 5                                   | 4      | 3      | 2                                  | 1      | 0      |
|--------|--------|-------------------------------------|--------|--------|------------------------------------|--------|--------|
| 0      |        | Seconds – high digit <sup>(1)</sup> |        |        | Seconds – low digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                              | rw-(0) | rw-(0) | rw-(0)                             | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-43. RTCSECBAKx Register Description**

| Bit | Field                | Type | Reset | Description                                    |
|-----|----------------------|------|-------|------------------------------------------------|
| 7   | 0                    | RW   | 0h    | Always 0.                                      |
| 6-4 | Seconds – high digit | RW   | 0h    | Seconds – high digit. Valid values are 0 to 5. |
| 3-0 | Seconds – low digit  | RW   | 0h    | Seconds – low digit. Valid values are 0 to 9.  |

#### **29.4.40 RTCMINBAKx Register – Hexadecimal Format**

Real-Time Clock Minutes Backup Register – Hexadecimal Format

**Figure 29-43. RTCMINBAKx Register**

| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0                      |
|--------|--------|--------|--------|--------|--------|--------|------------------------|
| 0      | 0      |        |        |        |        |        | Minutes <sup>(1)</sup> |
| rw-(0)                 |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-44. RTCMINBAKx Register Description**

| Bit | Field   | Type | Reset | Description                        |
|-----|---------|------|-------|------------------------------------|
| 7-6 | 0       | RW   | 0h    | Always 0.                          |
| 5-0 | Minutes | RW   | 0h    | Minutes. Valid values are 0 to 59. |

#### **29.4.41 RTCMINBAKx Register – BCD Format**

Real-Time Clock Minutes Backup Register – BCD Format

**Figure 29-44. RTCMINBAKx Register**

| 7      | 6      | 5                                   | 4      | 3      | 2                                  | 1      | 0      |
|--------|--------|-------------------------------------|--------|--------|------------------------------------|--------|--------|
| 0      |        | Minutes – high digit <sup>(1)</sup> |        |        | Minutes – low digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                              | rw-(0) | rw-(0) | rw-(0)                             | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-45. RTCMINBAKx Register Description**

| Bit | Field                | Type | Reset | Description                                    |
|-----|----------------------|------|-------|------------------------------------------------|
| 7   | 0                    | RW   | 0h    | Always 0.                                      |
| 6-4 | Minutes – high digit | RW   | 0h    | Minutes – high digit. Valid values are 0 to 5. |
| 3-0 | Minutes – low digit  | RW   | 0h    | Minutes – low digit. Valid values are 0 to 9.  |

#### 29.4.42 RTCHOURBAKx Register – Hexadecimal Format

Real-Time Clock Hours Backup Register – Hexadecimal Format

**Figure 29-45. RTCHOURBAKx Register**

| 7      | 6      | 5      | 4      | 3      | 2      | 1                    | 0      |
|--------|--------|--------|--------|--------|--------|----------------------|--------|
| 0      | 0      | 0      |        |        |        | Hours <sup>(1)</sup> |        |
| rw-(0)               | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-46. RTCHOURBAKx Register Description**

| Bit | Field | Type | Reset | Description                      |
|-----|-------|------|-------|----------------------------------|
| 7-5 | 0     | RW   | 0h    | Always 0.                        |
| 4-0 | Hours | RW   | 0h    | Hours. Valid values are 0 to 23. |

#### 29.4.43 RTCHOURBAKx Register – BCD Format

Real-Time Clock Hours Backup Register – BCD Format

**Figure 29-46. RTCHOURBAKx Register**

| 7      | 6      | 5                                 | 4      | 3      | 2                                | 1      | 0      |
|--------|--------|-----------------------------------|--------|--------|----------------------------------|--------|--------|
| 0      | 0      | Hours – high digit <sup>(1)</sup> |        |        | Hours – low digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                            | rw-(0) | rw-(0) | rw-(0)                           | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-47. RTCHOURBAKx Register Description**

| Bit | Field              | Type | Reset | Description                                  |
|-----|--------------------|------|-------|----------------------------------------------|
| 7-6 | 0                  | RW   | 0h    | Always 0.                                    |
| 5-4 | Hours – high digit | RW   | 0h    | Hours – high digit. Valid values are 0 to 2. |
| 3-0 | Hours – low digit  | RW   | 0h    | Hours – low digit. Valid values are 0 to 9.  |

#### 29.4.44 RTCDAYBAKx Register – Hexadecimal Format

Real-Time Clock Day of Month Backup Register – Hexadecimal Format

**Figure 29-47. RTCDAYBAKx Register**

| 7      | 6      | 5      | 4      | 3                           | 2      | 1      | 0      |  |  |  |
|--------|--------|--------|--------|-----------------------------|--------|--------|--------|--|--|--|
| 0      | 0      | 0      |        | Day of month <sup>(1)</sup> |        |        |        |  |  |  |
| rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0)                      | rw-(0) | rw-(0) | rw-(0) |  |  |  |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-48. RTCDAYBAKx Register Description**

| Bit | Field        | Type | Reset | Description                             |
|-----|--------------|------|-------|-----------------------------------------|
| 7-5 | 0            | RW   | 0h    | Always 0.                               |
| 4-0 | Day of month | RW   | 0h    | Day of month. Valid values are 1 to 31. |

#### 29.4.45 RTCDAYBAKx Register – BCD Format

Real-Time Clock Day of Month Backup Register – BCD Format

**Figure 29-48. RTCDAYBAKx Register**

| 7      | 6      | 5                                        | 4      | 3      | 2                                       | 1      | 0      |
|--------|--------|------------------------------------------|--------|--------|-----------------------------------------|--------|--------|
| 0      | 0      | Day of month – high digit <sup>(1)</sup> |        |        | Day of month – low digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                                   | rw-(0) | rw-(0) | rw-(0)                                  | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-49. RTCDAYBAKx Register Description**

| Bit | Field                     | Type | Reset | Description                                         |
|-----|---------------------------|------|-------|-----------------------------------------------------|
| 7-6 | 0                         | RW   | 0h    | Always 0.                                           |
| 5-4 | Day of month – high digit | RW   | 0h    | Day of month – high digit. Valid values are 0 to 3. |
| 3-0 | Day of month – low digit  | RW   | 0h    | Day of month – low digit. Valid values are 0 to 9.  |

#### 29.4.46 RTCMONBAKx Register – Hexadecimal Format

Real-Time Clock Month Backup Register – Hexadecimal Format

**Figure 29-49. RTCMONBAKx Register**

| 7      | 6      | 5      | 4      | 3      | 2      | 1                    | 0      |
|--------|--------|--------|--------|--------|--------|----------------------|--------|
| 0      | 0      | 0      | 0      |        |        | Month <sup>(1)</sup> |        |
| rw-(0)               | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-50. RTCMONBAKx Register Description**

| Bit | Field | Type | Reset | Description                      |
|-----|-------|------|-------|----------------------------------|
| 7-4 | 0     | RW   | 0h    | Always 0.                        |
| 3-0 | Month | RW   | 0h    | Month. Valid values are 1 to 12. |

#### 29.4.47 RTCMONBAKx Register – BCD Format

Real-Time Clock Month Backup Register – BCD Format

**Figure 29-50. RTCMONBAKx Register**

| 7      | 6      | 5                                 | 4      | 3      | 2                                | 1      | 0      |
|--------|--------|-----------------------------------|--------|--------|----------------------------------|--------|--------|
| 0      | 0      | Month – high digit <sup>(1)</sup> |        |        | Month – low digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                            | rw-(0) | rw-(0) | rw-(0)                           | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-51. RTCMONBAKx Register Description**

| Bit | Field              | Type | Reset | Description                                  |
|-----|--------------------|------|-------|----------------------------------------------|
| 7-6 | 0                  | RW   | 0h    | Always 0.                                    |
| 5-4 | Month – high digit | RW   | 0h    | Month – high digit. Valid values are 0 to 3. |
| 3-0 | Month – low digit  | RW   | 0h    | Month – low digit. Valid values are 0 to 9.  |

#### 29.4.48 RTCYEARBAKx Register – Hexadecimal Format

Real-Time Clock Year Low-Byte Backup Register – Hexadecimal Format

**Figure 29-51. RTCYEARBAKx Register**

| 15     | 14     | 13     | 12     | 11     | 10                              | 9      | 8      |
|--------|--------|--------|--------|--------|---------------------------------|--------|--------|
| 0      | 0      | 0      | 0      |        | Year – high byte <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0)                          | rw-(0) | rw-(0) |
| 7      | 6      | 5      | 4      | 3      | 2                               | 1      | 0      |
| rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0)                          | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-52. RTCYEARBAKx Register Description**

| Bit   | Field            | Type | Reset | Description                                           |
|-------|------------------|------|-------|-------------------------------------------------------|
| 15-12 | 0                | RW   | 0h    | Always 0.                                             |
| 11-8  | Year – high byte | RW   | 0h    | Year – high byte. Valid values of Year are 0 to 4095. |
| 7-0   | Year – low byte  | RW   | 0h    | Year – low byte. Valid values of Year are 0 to 4095.  |

#### 29.4.49 RTCYEARBAKx Register – BCD Format

Real-Time Clock Year Low-Byte Backup Register – BCD Format

**Figure 29-52. RTCYEARBAKx Register**

| 15     | 14     | 13                                  | 12     | 11     | 10                                 | 9      | 8      |
|--------|--------|-------------------------------------|--------|--------|------------------------------------|--------|--------|
| 0      |        | Century – high digit <sup>(1)</sup> |        |        | Century – low digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                              | rw-(0) | rw-(0) | rw-(0)                             | rw-(0) | rw-(0) |
| 7      | 6      | 5                                   | 4      | 3      | 2                                  | 1      | 0      |
|        |        | Decade <sup>(1)</sup>               |        |        | Year – lowest digit <sup>(1)</sup> |        |        |
| rw-(0) | rw-(0) | rw-(0)                              | rw-(0) | rw-(0) | rw-(0)                             | rw-(0) | rw-(0) |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-53. RTCYEARBAKx Register Description**

| Bit   | Field                | Type | Reset | Description                                    |
|-------|----------------------|------|-------|------------------------------------------------|
| 15    | 0                    | RW   | 0h    | Always 0.                                      |
| 14-12 | Century – high digit | RW   | 0h    | Century – high digit. Valid values are 0 to 4. |
| 11-8  | Century – low digit  | RW   | 0h    | Century – low digit. Valid values are 0 to 9.  |
| 7-4   | Decade               | RW   | 0h    | Decade. Valid values are 0 to 9.               |
| 3-0   | Year – lowest digit  | RW   | 0h    | Year – lowest digit. Valid values are 0 to 9.  |

### 29.4.50 RTCTCCTL0 Register

Real-Time Clock Time Capture Control Register 0

**Figure 29-53. RTCTCCTL0 Register**

| 7        | 6   | 5   | 4   | 3   | 2   | 1                      | 0                   |
|----------|-----|-----|-----|-----|-----|------------------------|---------------------|
| Reserved |     |     |     |     |     | AUX3RST <sup>(1)</sup> | TCEN <sup>(1)</sup> |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-(1)                 | rw-(0)              |

<sup>(1)</sup> These bits are not reset on POR.

**Table 29-54. RTCTCCTL0 Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                               |
|-----|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-2 | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                              |
| 1   | AUX3RST  | RW   | 1h    | Indication of power cycle on AUXVCC3<br>0b = No power cycle on AUXVCC3 since the last clear by the User<br>1b = Indication of AUXVCC3 power cycle. Needs to be cleared by User to observe the next power cycle on AUXVCC3 |
| 0   | TCEN     | RW   | 0h    | Enable for RTC tamper detection with time stamp<br>0b = Tamper detection with time stamp disabled<br>1b = Tamper detection with time stamp enabled                                                                        |

### 29.4.51 RTCTCCTL1 Register

Real-Time Clock Time Capture Control Register 1

**Figure 29-54. RTCTCCTL1 Register**

| 7        | 6   | 5   | 4   | 3   | 2   | 1        | 0         |
|----------|-----|-----|-----|-----|-----|----------|-----------|
| Reserved |     |     |     |     |     | RTCCAPIE | RTCCAPIFG |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-(0)   | rw-(0)    |

**Table 29-55. RTCTCCTL1 Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                           |
|-----|-----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-2 | Reserved  | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                          |
| 1   | RTCCAPIE  | RW   | 0h    | Tamper event interrupt enable. In modules that support LPM3.5 or LPM4.5, this interrupt can be used as LPM3.5 or LPM4.5 wake-up event.<br>0b = Interrupt not enabled<br>1b = Interrupt enabled (LPM3.5 and LPM4.5 wake-up enabled)                                                                                    |
| 0   | RTCCAPIFG | RW   | 0h    | Common interrupt flag for all tamper events. In modules that support LPM3.5 or LPM4.5, this interrupt can be used as LPM3.5 or LPM4.5 wake-up event.<br>0b = Tamper event did not occur<br>1b = At least one tamper event occurred. Status of individual tamper events can be found from the CAPEV bit in RTCCAPxCTL. |

### 29.4.52 RTCCAPxCTL Register

Tamper Detect Pin Control Register

**Figure 29-55. RTCCAPxCTL Register**

| 7        | 6                  | 5                  | 4                 | 3                  | 2                    | 1        | 0                    |
|----------|--------------------|--------------------|-------------------|--------------------|----------------------|----------|----------------------|
| Reserved | OUT <sup>(1)</sup> | DIR <sup>(1)</sup> | IN <sup>(1)</sup> | REN <sup>(1)</sup> | CAPES <sup>(1)</sup> | Reserved | CAPEV <sup>(1)</sup> |
| r-0      | rw-(0)             | rw-(0)             | r                 | rw-(0)             | rw-(0)               | r-0      | r/w0                 |

<sup>(1)</sup> The configuration of these bits is retained during LPMx.5 until LOCKLPM5 is cleared, but not the bits themselves; therefore, reconfiguration is required after wakeup from LPMx.5 before clearing LOCKLPM5.

**Table 29-56. RTCCAPxCTL Register Description**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                           |
|-----|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                          |
| 6   | OUT      | RW   | 0h    | RTCCAPx output<br>0b = Output low<br>1b = Output high                                                                                                                                                                                                 |
| 5   | DIR      | RW   | 0h    | RTCCAPx pin direction<br>0b = RTCCAPx pin configured as input<br>1b = RTCCAPx pin configured as output                                                                                                                                                |
| 4   | IN       | R    | 0h    | RTCCAPx input. The external input on RTCCAPx pin can be read by this bit.<br>0b = Input is low<br>1b = Input is high                                                                                                                                  |
| 3   | REN      | RW   | 0h    | RTCCAPx pin pullup or pulldown resistor enable. When respective pin is configured as input, setting this bit enables the pullup or pulldown (see <a href="#">Table 29-1</a> ).<br>0b = Pullup or pulldown disabled<br>1b = Pullup or pulldown enabled |
| 2   | CAPES    | RW   | 0h    | Event edge selection<br>0b = Event on a low-to-high transition<br>1b = Event on a high-to-low transition                                                                                                                                              |
| 1   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                          |
| 0   | CAPEV    | RW   | 0h    | Tamper event status flag. All subsequent events on RTCCAPx after CAPEV is set are ignored until CAPEV is cleared by the user. Can only be written as 0.<br>0b = Tamper event did not occur<br>1b = Tamper event occurred                              |

## ***Enhanced Universal Serial Communication Interface (eUSCI) – UART Mode***

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The enhanced universal serial communication interface A (eUSCI\_A) supports multiple serial communication modes with one hardware module. This chapter discusses the operation of the asynchronous UART mode.

| Topic                                                                             | Page |
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## 30.1 Enhanced Universal Serial Communication Interface A (eUSCI\_A) Overview

The eUSCI\_A module supports two serial communication modes:

- UART mode
- SPI mode

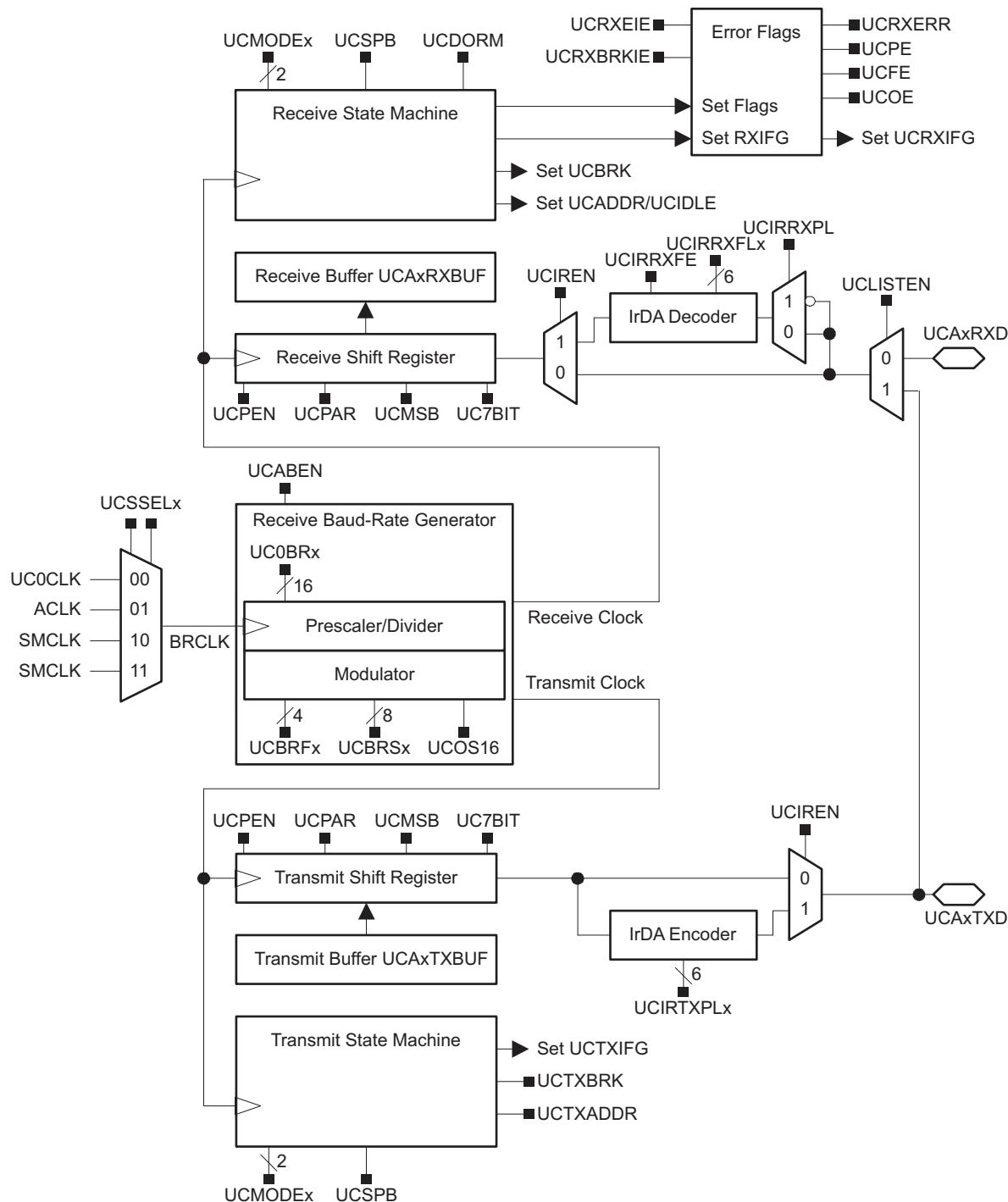
## 30.2 eUSCI\_A Introduction – UART Mode

In asynchronous mode, the eUSCI\_Ax modules connect the device to an external system through two external pins, UCAXRXD and UCAXTXD. UART mode is selected when the UCSYNC bit is cleared.

UART mode features include:

- 7-bit or 8-bit data with odd, even, or no parity
- Independent transmit and receive shift registers
- Separate transmit and receive buffer registers
- LSB-first or MSB-first data transmit and receive
- Built-in idle-line and address-bit communication protocols for multiprocessor systems
- Receiver start edge detection for automatic wake from LPMx modes (wake from LPMx.5 is not supported)
- Programmable baud rate with modulation for fractional baud-rate support
- Status flags for error detection and suppression
- Status flags for address detection
- Independent interrupt capability for receive, transmit, start bit received, and transmit complete

Figure 30-1 shows the eUSCI\_Ax when configured for UART mode.



**Figure 30-1. eUSCI\_Ax Block Diagram – UART Mode (UCSYNC = 0)**

### 30.3 eUSCI\_A Operation – UART Mode

In UART mode, the eUSCI\_A transmits and receives characters at a bit rate asynchronous to another device. Timing for each character is based on the selected baud rate of the eUSCI\_A. The transmit and receive functions use the same baud-rate frequency.

#### 30.3.1 eUSCI\_A Initialization and Reset

The eUSCI\_A is reset by a PUC or by setting the UCSWRST bit. After a PUC, the UCSWRST bit is automatically set, keeping the eUSCI\_A in a reset condition. When set, the UCSWRST bit sets the UCTXIFG bit and resets the UCRXIE, UCTXIE, UCRXIFG, UCRXERR, UCBRK, UCPE, UCOE, UCFE, UCSTOE, and UCBTOE bits. Clearing UCSWRST releases the eUSCI\_A for operation.

Configuring and reconfiguring the eUSCI\_A module should be done when UCSWRST is set to avoid unpredictable behavior.

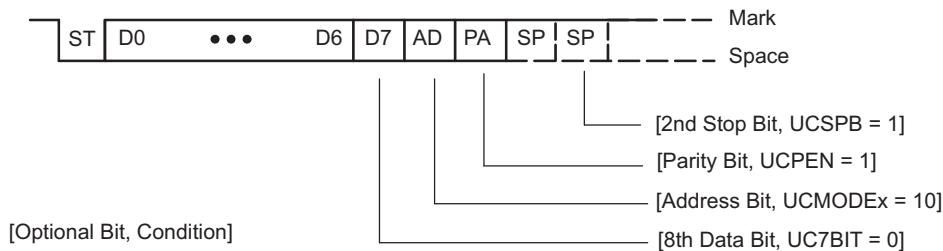
**NOTE: Initializing or reconfiguring the eUSCI\_A module**

The recommended eUSCI\_A initialization/reconfiguration process is:

1. Set UCSWRST (**BIS.B**  
#UCSWRST, &UCAxCTL1).
2. Initialize all eUSCI\_A registers with UCSWRST = 1 (including UCAxCTL1).
3. Configure ports.
4. Clear UCSWRST through software (**BIC.B**  
#UCSWRST, &UCAxCTL1).
5. Enable interrupts (optional) through UCRXIE or UCTXIE.

#### 30.3.2 Character Format

The UART character format (see [Figure 30-2](#)) consists of a start bit, seven or eight data bits, an even/odd/no parity bit, an address bit (address-bit mode), and one or two stop bits. The UCMSB bit controls the direction of the transfer and selects LSB or MSB first. LSB first is typically required for UART communication.



**Figure 30-2. Character Format**

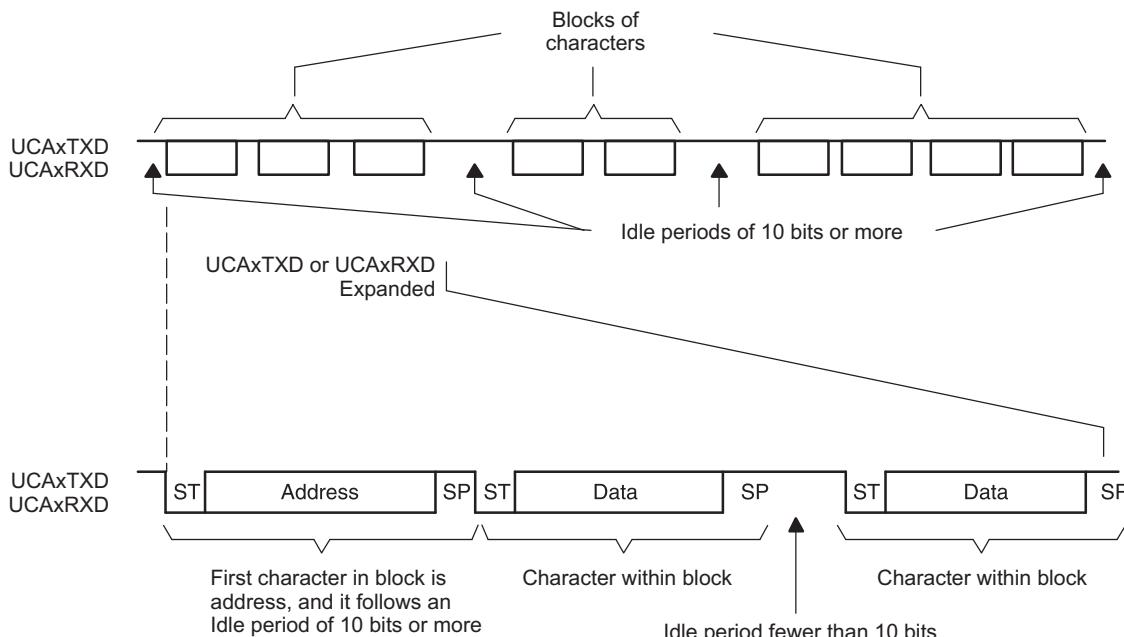
#### 30.3.3 Asynchronous Communication Format

When two devices communicate asynchronously, no multiprocessor format is required for the protocol. When three or more devices communicate, the eUSCI\_A supports the idle-line and address-bit multiprocessor communication formats.

##### 30.3.3.1 Idle-Line Multiprocessor Format

When UCMODEx = 01, the idle-line multiprocessor format is selected. Blocks of data are separated by an idle time on the transmit or receive lines (see [Figure 30-3](#)). An idle receive line is detected when ten or more continuous ones (marks) are received after the one or two stop bits of a character. The baud-rate generator is switched off after reception of an idle line until the next start edge is detected. When an idle line is detected, the UCIDLE bit is set.

The first character received after an idle period is an address character. The UCIDLE bit is used as an address tag for each block of characters. In idle-line multiprocessor format, this bit is set when a received character is an address.



**Figure 30-3. Idle-Line Format**

The UCDORM bit is used to control data reception in the idle-line multiprocessor format. When UCDORM = 1, all non-address characters are assembled but not transferred into the UCAxRXBUF, and interrupts are not generated. When an address character is received, the character is transferred into UCAxRXBUF, UCRXIFG is set, and any applicable error flag is set when UCRXEIE = 1. When UCRXEIE = 0 and an address character is received but has a framing error or parity error, the character is not transferred into UCAxRXBUF and UCRXIFG is not set.

If an address is received, user software can validate the address and must reset UCDORM to continue receiving data. If UCDORM remains set, only address characters are received. When UCDORM is cleared during the reception of a character, the receive interrupt flag is set after the reception completed. The UCDORM bit is not modified automatically by the eUSCI\_A hardware.

For address transmission in idle-line multiprocessor format, a precise idle period can be generated by the eUSCI\_A to generate address character identifiers on UCAxTXD. The double-buffered UCTXADDR flag indicates if the next character loaded into UCAxTXBUF is preceded by an idle line of 11 bits. UCTXADDR is automatically cleared when the start bit is generated.

### 30.3.3.1.1 Transmitting an Idle Frame

The following procedure sends out an idle frame to indicate an address character followed by associated data:

1. Set UCTXADDR, then write the address character to UCAxTXBUF. UCAxTXBUF must be ready for new data (UCTXIFG = 1).

This generates an idle period of exactly 11 bits followed by the address character. UCTXADDR is reset automatically when the address character is transferred from UCAxTXBUF into the shift register.

2. Write desired data characters to UCAxTXBUF. UCAxTXBUF must be ready for new data (UCTXIFG = 1).

The data written to UCAxTXBUF is transferred to the shift register and transmitted as soon as the shift register is ready for new data.

The idle-line time must not be exceeded between address and data transmission or between data transmissions. Otherwise, the transmitted data is misinterpreted as an address.

### 30.3.3.2 Address-Bit Multiprocessor Format

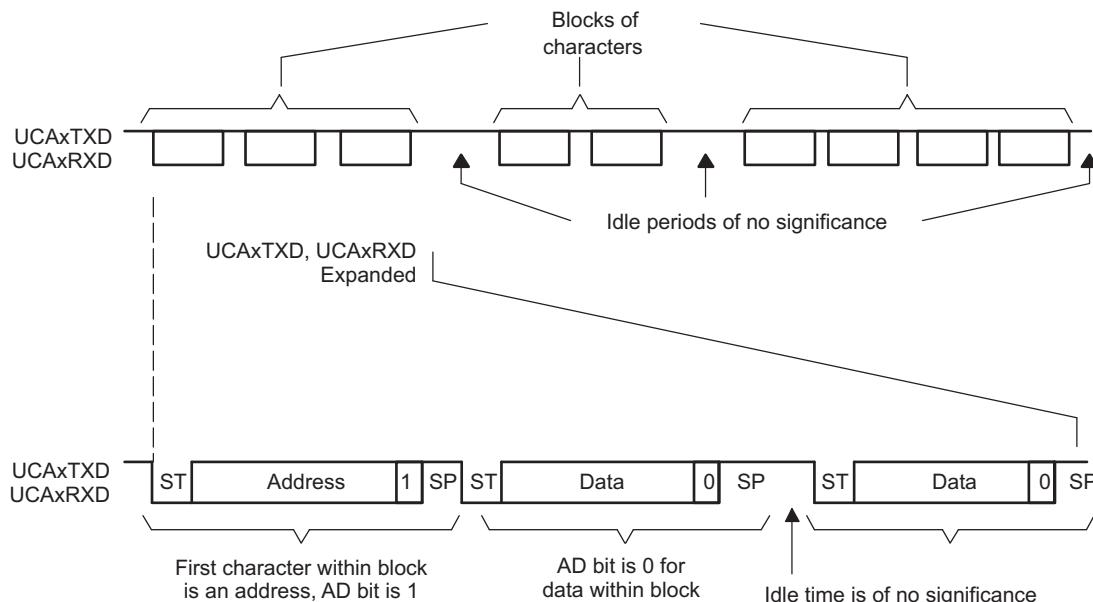
When UCMODEx = 10, the address-bit multiprocessor format is selected. Each processed character contains an extra bit used as an address indicator (see Figure 30-4). The first character in a block of characters carries a set address bit that indicates that the character is an address. The eUSCI\_A UCADDR bit is set when a received character has its address bit set and is transferred to UCAXRXBUF.

The UCDORM bit is used to control data reception in the address-bit multiprocessor format. When UCDORM is set, data characters with address bit = 0 are assembled by the receiver but are not transferred to UCAXRXBUF and no interrupts are generated. When a character containing a set address bit is received, the character is transferred into UCAXRXBUF, UCRXIFG is set, and any applicable error flag is set when UCRXEIE = 1. When UCRXEIE = 0 and a character containing a set address bit is received but has a framing error or parity error, the character is not transferred into UCAXRXBUF and UCRXIFG is not set.

If an address is received, user software can validate the address and must reset UCDORM to continue receiving data. If UCDORM remains set, only address characters with address bit = 1 are received. The UCDORM bit is not modified by the eUSCI\_A hardware automatically.

When UCDORM = 0, all received characters set the receive interrupt flag UCRXIFG. If UCDORM is cleared during the reception of a character, the receive interrupt flag is set after the reception is completed.

For address transmission in address-bit multiprocessor mode, the address bit of a character is controlled by the UCTXADDR bit. The value of the UCTXADDR bit is loaded into the address bit of the character transferred from UCAXTXBUF to the transmit shift register. UCTXADDR is automatically cleared when the start bit is generated.



**Figure 30-4. Address-Bit Multiprocessor Format**

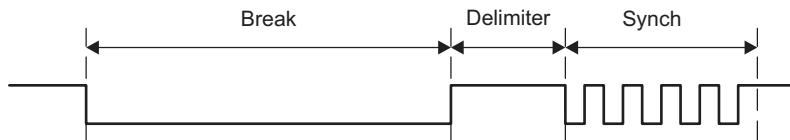
#### 30.3.3.2.1 Break Reception and Generation

When UCMODEx = 00, 01, or 10, the receiver detects a break when all data, parity, and stop bits are low, regardless of the parity, address mode, or other character settings. When a break is detected, the UCBRK bit is set. If the break interrupt enable bit (UCBRKIE) is set, the receive interrupt flag UCRXIFG is also set. In this case, the value in UCAXRXBUF is 0h, because all data bits were zero.

To transmit a break, set the UCTXBRK bit, then write 0h to UCAXTXBUF. UCAXTXBUF must be ready for new data (UCTXIFG = 1). This generates a break with all bits low. UCTXBRK is automatically cleared when the start bit is generated.

### 30.3.4 Automatic Baud-Rate Detection

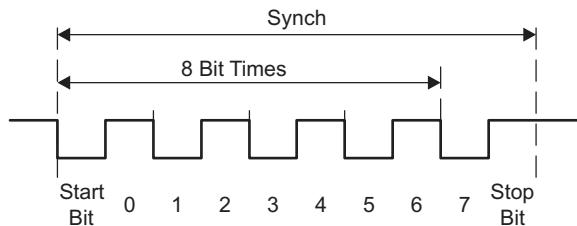
When UCMODE<sub>x</sub> = 11, UART mode with automatic baud-rate detection is selected. For automatic baud-rate detection, a data frame is preceded by a synchronization sequence that consists of a break and a synch field. A break is detected when 11 or more continuous zeros (spaces) are received. If the length of the break exceeds 21 bit times, the break timeout error flag UCBTOE is set. The eUSCI\_A cannot transmit data while receiving the break/sync field. The synch field follows the break as shown in [Figure 30-5](#).



**Figure 30-5. Auto Baud-Rate Detection – Break/Synch Sequence**

For LIN conformance, the character format should be set to eight data bits, LSB first, no parity, and one stop bit. No address bit is available.

The synch field consists of the data 055h inside a byte field (see [Figure 30-6](#)). The synchronization is based on the time measurement between the first falling edge and the last falling edge of the pattern. The transmit baud-rate generator is used for the measurement if automatic baud-rate detection is enabled by setting UCABDEN. Otherwise, the pattern is received but not measured. The result of the measurement is transferred into the baud-rate control registers (UCAxBRW and UCAxMCTLW). If the length of the synch field exceeds the measurable time, the synch timeout error flag UCSTOE is set. The result can be read after the receive interrupt flag UCRXIFG is set.



**Figure 30-6. Auto Baud-Rate Detection – Synch Field**

The UCDORM bit is used to control data reception in this mode. When UCDORM is set, all characters are received but not transferred into the UCAxRXBUF, and interrupts are not generated. When a break/synch field is detected, the UCBRK flag is set. The character following the break/synch field is transferred into UCAxRXBUF and the UCRXIFG interrupt flag is set. Any applicable error flag is also set. If the UCBRKIE bit is set, reception of the break/synch sets the UCRXIFG. The UCBRK bit is reset by user software or by reading the receive buffer UCAxRXBUF.

When a break/synch field is received, user software must reset UCDORM to continue receiving data. If UCDORM remains set, only the character after the next reception of a break/synch field is received. The UCDORM bit is not modified by the eUSCI\_A hardware automatically.

When UCDORM = 0, all received characters set the receive interrupt flag UCRXIFG. If UCDORM is cleared during the reception of a character, the receive interrupt flag is set after the reception is complete.

The counter used to detect the baud rate is limited to 0FFFFh ( $2^{16}$ ) counts. This means the minimum baud rate detectable is 244 baud in oversampling mode and 15 baud in low-frequency mode. The highest detectable baud rate is 1 Mbaud.

The automatic baud-rate detection mode can be used in a full-duplex communication system with some restrictions. The eUSCI\_A cannot transmit data while receiving the break/sync field and, if a 0h byte with framing error is received, any data transmitted during this time is corrupted. The latter case can be discovered by checking the received data and the UCFE bit.

### 30.3.4.1 Transmitting a Break/Synch Field

The following procedure transmits a break/synch field:

1. Set UCTXBRK with UMODEx = 11.
2. Write 055h to UCAXTXBUF. UCAXTXBUF must be ready for new data (UCTXIFG = 1).

This generates a break field of 13 bits followed by a break delimiter and the synch character. The length of the break delimiter is controlled with the UCDELIMx bits. UCTXBRK is reset automatically when the synch character is transferred from UCAXTXBUF into the shift register.

3. Write desired data characters to UCAXTXBUF. UCAXTXBUF must be ready for new data (UCTXIFG = 1).

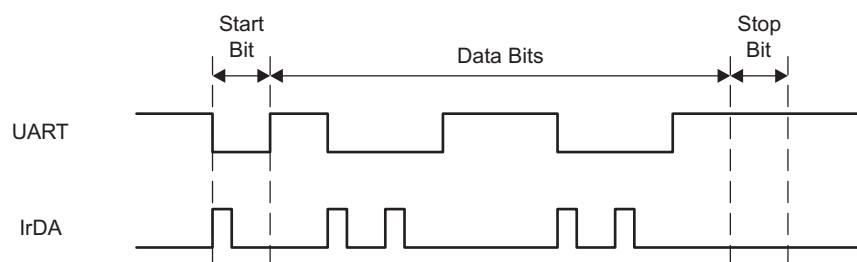
The data written to UCAXTXBUF is transferred to the shift register and transmitted as soon as the shift register is ready for new data.

### 30.3.5 IrDA Encoding and Decoding

When UCIREN is set, the IrDA encoder and decoder are enabled and provide hardware bit shaping for IrDA communication.

#### 30.3.5.1 IrDA Encoding

The encoder sends a pulse for every zero bit in the transmit bitstream coming from the UART (see [Figure 30-7](#)). The pulse duration is defined by UCIRTXPLx bits specifying the number of one-half clock periods of the clock selected by UCIRTXCLK.



**Figure 30-7. UART vs IrDA Data Format**

To set the pulse time of 3/16 bit period required by the IrDA standard, the BITCLK16 clock is selected with UCIRTXCLK = 1, and the pulse length is set to six one-half clock cycles with UCIRTXPLx = 6 – 1 = 5.

When UCIRTXCLK = 0, the pulse length  $t_{PULSE}$  is based on BRCLK and is calculated as:

$$\text{UCIRTXPLx} = t_{PULSE} \times 2 \times f_{BRCLK} - 1$$

When UCIRTXCLK = 0, the prescaler UCBRx must be set to a value greater or equal to 5.

#### 30.3.5.2 IrDA Decoding

The decoder detects high pulses when UCIRRXPL = 0. Otherwise, it detects low pulses. In addition to the analog deglitch filter, an additional programmable digital filter stage can be enabled by setting UCIRRXFE. When UCIRRXFE is set, only pulses longer than the programmed filter length are passed. Shorter pulses are discarded. The equation to program the filter length UCIRRXFLx is:

$$\text{UCIRRXFLx} = (t_{PULSE} - t_{WAKE}) \times 2 \times f_{BRCLK} - 4$$

Where:

$t_{PULSE}$  = Minimum receive pulse width

$t_{WAKE}$  = Wake time from any low-power mode. Zero when the device is in active mode.

### 30.3.6 Automatic Error Detection

Glitch suppression prevents the eUSCI\_A from being accidentally started. Any pulse on UC $A_x$ RXD shorter than the deglitch time  $t_g$  (selected by UCGLITx) is ignored (see the device-specific data sheet for parameters).

When a low period on UC $A_x$ RXD exceeds  $t_g$ , a majority vote is taken for the start bit. If the majority vote fails to detect a valid start bit, the eUSCI\_A halts character reception and waits for the next low period on UC $A_x$ RXD. The majority vote is also used for each bit in a character to prevent bit errors.

The eUSCI\_A module automatically detects framing errors, parity errors, overrun errors, and break conditions when receiving characters. The bits UCFE, UCPE, UCOE, and UCBRK are set when their respective condition is detected. When the error flags UCFE, UCPE, or UCOE are set, UCRXERR is also set. The error conditions are described in [Table 30-1](#).

**Table 30-1. Receive Error Conditions**

| Error Condition | Error Flag | Description                                                                                                                                                                                                                                                                           |
|-----------------|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Framing error   | UCFE       | A framing error occurs when a low stop bit is detected. When two stop bits are used, both stop bits are checked for framing error. When a framing error is detected, the UCFE bit is set.                                                                                             |
| Parity error    | UCPE       | A parity error is a mismatch between the number of 1s in a character and the value of the parity bit. When an address bit is included in the character, it is included in the parity calculation. When a parity error is detected, the UCPE bit is set.                               |
| Receive overrun | UCOE       | An overrun error occurs when a character is loaded into UC $A_x$ RXB $U$ before the prior character has been read. When an overrun occurs, the UCOE bit is set.                                                                                                                       |
| Break condition | UCBRK      | When not using automatic baud-rate detection, a break is detected when all data, parity, and stop bits are low. When a break condition is detected, the UCBRK bit is set. A break condition can also set the interrupt flag UCRXIFG if the break interrupt enable UCBRKIE bit is set. |

When UCRXEIE = 0 and a framing error or parity error is detected, no character is received into UC $A_x$ RXB $U$ . When UCRXEIE = 1, characters are received into UC $A_x$ RXB $U$  and any applicable error bit is set.

When any of the UCFE, UCPE, UCOE, UCBRK, or UCRXERR bit is set, the bit remains set until user software resets it or UC $A_x$ RXB $U$  is read. UCOE must be reset by reading UC $A_x$ RXB $U$ . Otherwise, it does not function properly. To detect overflows reliably, TI recommends the following flow. After a character is received and UC $A_x$ RXIFG is set, first read UC $A_x$ STATW to check the error flags including the overflow flag UCOE. Read UC $A_x$ RXB $U$  next. This clears all error flags except UCOE, if UC $A_x$ RXB $U$  was overwritten between the read access to UC $A_x$ STATW and to UC $A_x$ RXB $U$ . Therefore, the UCOE flag should be checked after reading UC $A_x$ RXB $U$  to detect this condition. Note that, in this case, the UCRXERR flag is not set.

### 30.3.7 eUSCI\_A Receive Enable

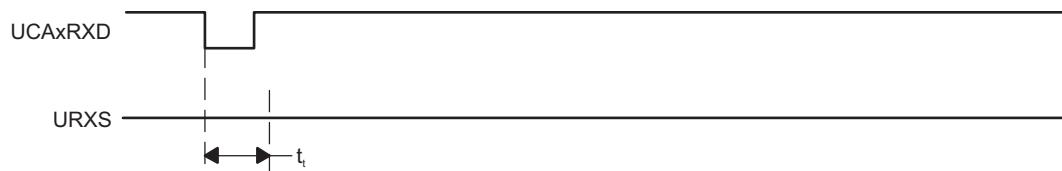
The eUSCI\_A module is enabled by clearing the UCSWRST bit and the receiver is ready and in an idle state. The receive baud rate generator is in a ready state but is not clocked nor producing any clocks.

The falling edge of the start bit enables the baud rate generator and the UART state machine checks for a valid start bit. If no valid start bit is detected the UART state machine returns to its idle state and the baud rate generator is turned off again. If a valid start bit is detected, a character is received.

When the idle-line multiprocessor mode is selected with UCMODEx = 01, the UART state machine checks for an idle line after receiving a character. If a start bit is detected, another character is received. Otherwise, the UCIDLE flag is set after 10 ones are received, the UART state machine returns to its idle state, and the baud rate generator is turned off.

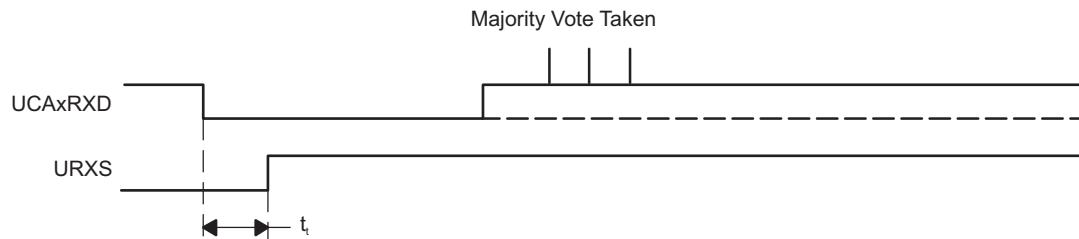
#### 30.3.7.1 Receive Data Glitch Suppression

Glitch suppression prevents the eUSCI\_A from being accidentally started. Any glitch on UCAXRXD shorter than the deglitch time  $t_g$  is ignored by the eUSCI\_A, and further action is initiated as shown in [Figure 30-8](#) (see the device-specific data sheet for parameters). The deglitch time  $t_g$  can be set to four different values using the UCGLITx bits.



**Figure 30-8. Glitch Suppression, eUSCI\_A Receive Not Started**

When a glitch is longer than  $t_g$ , or a valid start bit occurs on UCAXRXD, the eUSCI\_A receive operation is started and a majority vote is taken (see [Figure 30-9](#)). If the majority vote fails to detect a start bit, the eUSCI\_A halts character reception.



**Figure 30-9. Glitch Suppression, eUSCI\_A Activated**

### 30.3.8 eUSCI\_A Transmit Enable

The eUSCI\_A module is enabled by clearing the UCSWRST bit and the transmitter is ready and in an idle state. The transmit baud-rate generator is ready but is not clocked nor producing any clocks.

A transmission is initiated by writing data to UCAXTXBUF. When this occurs, the baud-rate generator is enabled, and the data in UCAXTXBUF is moved to the transmit shift register on the next BITCLK after the transmit shift register is empty. UCTXIFG is set when new data can be written into UCAXTXBUF.

Transmission continues as long as new data is available in UCAXTXBUF at the end of the previous byte transmission. If new data is not in UCAXTXBUF when the previous byte has transmitted, the transmitter returns to its idle state and the baud-rate generator is turned off.

### 30.3.9 UART Baud-Rate Generation

The eUSCI\_A baud-rate generator is capable of producing standard baud rates from nonstandard source frequencies. It provides two modes of operation selected by the UCOS16 bit.

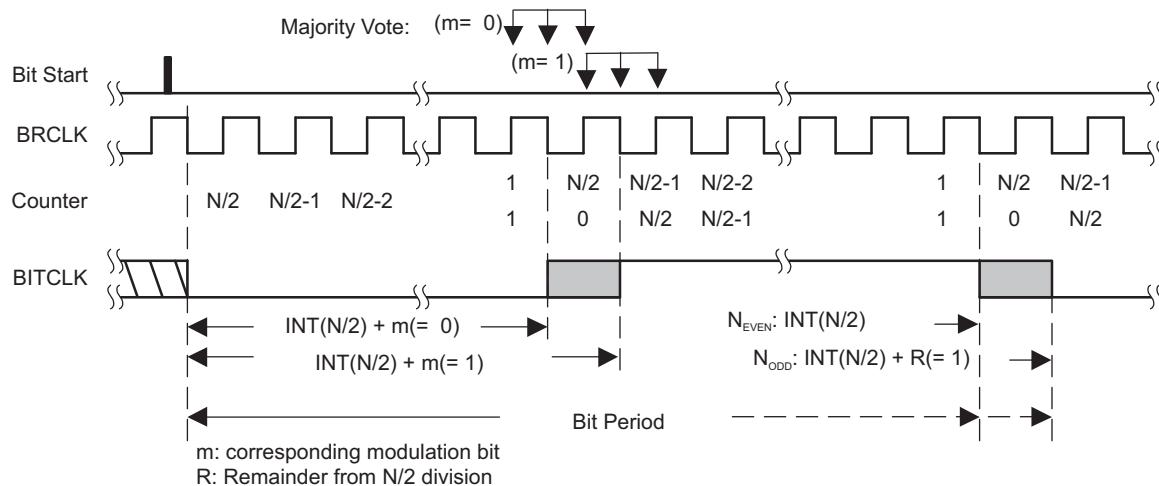
A quick setup for finding the correct baud rate settings for the eUSCI\_A can be found in [Section 30.3.10](#).

#### 30.3.9.1 Low-Frequency Baud-Rate Generation

The low-frequency mode is selected when UCOS16 = 0. This mode allows generation of baud rates from low-frequency clock sources (for example, 9600 baud from a 32768-Hz crystal). By using a lower input frequency, the power consumption of the module is reduced. Using this mode with higher frequencies and higher prescaler settings causes the majority votes to be taken in an increasingly smaller window and, thus, decrease the benefit of the majority vote.

In low-frequency mode, the baud-rate generator uses one prescaler and one modulator to generate bit clock timing. This combination supports fractional divisors for baud-rate generation. In this mode, the maximum eUSCI\_A baud rate is one-third the UART source clock frequency BRCLK.

Timing for each bit is shown in [Figure 30-10](#). For each bit received, a majority vote is taken to determine the bit value. These samples occur at the  $N/2 - 1/2$ ,  $N/2$ , and  $N/2 + 1/2$  BRCLK periods, where N is the number of BRCLKs per BITCLK.



**Figure 30-10. BITCLK Baud-Rate Timing With UCOS16 = 0**

Modulation is based on the UCBRSx setting as shown in [Table 30-2](#). A 1 in the table indicates that  $m = 1$  and the corresponding BITCLK period is one BRCLK period longer than a BITCLK period with  $m = 0$ . The modulation wraps around after 8 bits but restarts with each new start bit.

**Table 30-2. Modulation Pattern Examples**

| UCBRSx | Bit 0<br>(Start Bit) | Bit 1 | Bit 2 | Bit 3 | Bit 4 | Bit 5 | Bit 6 | Bit 7 |
|--------|----------------------|-------|-------|-------|-------|-------|-------|-------|
| 0x00   | 0                    | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| 0x01   | 0                    | 0     | 0     | 0     | 0     | 0     | 0     | 1     |
|        |                      |       |       |       |       |       |       |       |
| ⋮      |                      |       |       |       |       |       |       |       |
| 0x35   | 0                    | 0     | 1     | 1     | 0     | 1     | 0     | 1     |
| 0x36   | 0                    | 0     | 1     | 1     | 0     | 1     | 1     | 0     |
| 0x37   | 0                    | 0     | 1     | 1     | 0     | 1     | 1     | 1     |
|        |                      |       |       |       |       |       |       |       |
| ⋮      |                      |       |       |       |       |       |       |       |
| 0xff   | 1                    | 1     | 1     | 1     | 1     | 1     | 1     | 1     |

The correct setting of UCBRSx can be found as described in [Section 30.3.10](#).

### 30.3.9.2 Oversampling Baud-Rate Generation

The oversampling mode is selected when UCOS16 = 1. This mode supports sampling a UART bitstream with higher input clock frequencies. This results in majority votes that are always 1/16 of a bit clock period apart. This mode also easily supports IrDA pulses with a 3/16 bit time when the IrDA encoder and decoder are enabled.

This mode uses one prescaler and one modulator to generate the BITCLK16 clock that is 16 times faster than the BITCLK. An additional divider by 16 and modulator stage generates BITCLK from BITCLK16.

This combination supports fractional divisions of both BITCLK16 and BITCLK for baud-rate generation. In this mode, the maximum eUSCI\_A baud rate is 1/16 the UART source clock frequency BRCLK.

Modulation for BITCLK16 is based on the UCBRFx setting (see [Table 30-3](#)). A 1 in the table indicates that the corresponding BITCLK16 period is one BRCLK period longer than the periods  $m = 0$ . The modulation restarts with each new bit timing.

Modulation for BITCLK is based on the UCBRSp setting as previously described.

**Table 30-3. BITCLK16 Modulation Pattern**

| UCBRFx | Number of BITCLK16 Clocks After Last Falling BITCLK Edge |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |
|--------|----------------------------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
|        | 0                                                        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 00h    | 0                                                        | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 0  | 0  |
| 01h    | 0                                                        | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 0  | 0  |
| 02h    | 0                                                        | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 0  | 1  |
| 03h    | 0                                                        | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 0  | 1  |
| 04h    | 0                                                        | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 1  | 1  |
| 05h    | 0                                                        | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 1  | 1  |
| 06h    | 0                                                        | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 1  | 1  | 1  |
| 07h    | 0                                                        | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 0  | 1  | 1  | 1  |
| 08h    | 0                                                        | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0  | 0  | 1  | 1  | 1  | 1  |
| 09h    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0  | 0  | 1  | 1  | 1  | 1  |
| 0Ah    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0  | 1  | 1  | 1  | 1  | 1  |
| 0Bh    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0  | 1  | 1  | 1  | 1  | 1  |
| 0Ch    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1  | 1  | 1  | 1  | 1  | 1  |
| 0Dh    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1  | 1  | 1  | 1  | 1  | 1  |
| 0Eh    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 1  | 1  |
| 0Fh    | 0                                                        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  |

### 30.3.10 Setting a Baud Rate

For a given BRCLK clock source, the baud rate used determines the required division factor N:

$$N = f_{\text{BRCLK}} / \text{baud rate}$$

The division factor N is often a noninteger value, thus, at least one divider and one modulator stage is used to meet the factor as closely as possible.

If N is equal or greater than 16, TI recommends using the oversampling baud-rate generation mode by setting UCOS16.

**NOTE: Baud-rate settings quick set up**

To calculate the correct settings for the baud-rate generation, perform these steps:

1. Calculate  $N = f_{\text{BRCLK}} / \text{baud rate}$  [if  $N > 16$  continue with step 3, otherwise with step 2]
2.  $\text{OS16} = 0$ ,  $\text{UCBRx} = \text{INT}(N)$  [continue with step 4]
3.  $\text{OS16} = 1$ ,  $\text{UCBRx} = \text{INT}(N/16)$ ,  $\text{UCBRFx} = \text{INT}([(N/16) - \text{INT}(N/16)] \times 16)$
4. UCBRSx can be found by looking up the fractional part of N ( $= N - \text{INT}(N)$ ) in table [Table 30-4](#)
5. If  $\text{OS16} = 0$  was chosen, TI recommends performing a detailed error calculation.

[Table 30-4](#) can be used as a lookup table for finding the correct UCBRSx modulation pattern for the corresponding fractional part of N. The values there are optimized for transmitting.

**Table 30-4. UCBRSx Settings for Fractional Portion of  $N = f_{\text{BRCLK}} / \text{Baud Rate}$**

| Fractional Portion of N | UCBRSx <sup>(1)</sup> | Fractional Portion of N | UCBRSx <sup>(1)</sup> |
|-------------------------|-----------------------|-------------------------|-----------------------|
| 0.0000                  | 0x00                  | 0.5002                  | 0xAA                  |
| 0.0529                  | 0x01                  | 0.5715                  | 0x6B                  |
| 0.0715                  | 0x02                  | 0.6003                  | 0xAD                  |
| 0.0835                  | 0x04                  | 0.6254                  | 0xB5                  |
| 0.1001                  | 0x08                  | 0.6432                  | 0xB6                  |
| 0.1252                  | 0x10                  | 0.6667                  | 0xD6                  |
| 0.1430                  | 0x20                  | 0.7001                  | 0xB7                  |
| 0.1670                  | 0x11                  | 0.7147                  | 0xBB                  |
| 0.2147                  | 0x21                  | 0.7503                  | 0xDD                  |
| 0.2224                  | 0x22                  | 0.7861                  | 0xED                  |
| 0.2503                  | 0x44                  | 0.8004                  | 0xEE                  |
| 0.3000                  | 0x25                  | 0.8333                  | 0xBF                  |
| 0.3335                  | 0x49                  | 0.8464                  | 0xDF                  |
| 0.3575                  | 0x4A                  | 0.8572                  | 0xEF                  |
| 0.3753                  | 0x52                  | 0.8751                  | 0xF7                  |
| 0.4003                  | 0x92                  | 0.9004                  | 0xFB                  |
| 0.4286                  | 0x53                  | 0.9170                  | 0xFD                  |
| 0.4378                  | 0x55                  | 0.9288                  | 0xFE                  |

<sup>(1)</sup> The UCBRSx setting in one row is valid from the fractional portion given in that row until the one in the next row

#### 30.3.10.1 Low-Frequency Baud-Rate Mode Setting

In low-frequency mode, the integer portion of the divisor is realized by the prescaler:

$$\text{UCBRx} = \text{INT}(N)$$

The fractional portion is realized by the modulator with its UCBRSx setting. The recommended way of determining the correct UCBRSx is performing a detailed error calculation as explained in the following sections. However it is also possible to look up the correct settings in table with typical crystals (see [Table 30-5](#)).

### 30.3.10.2 Oversampling Baud-Rate Mode Setting

In the oversampling mode, the prescaler is set to:

$$\text{UCBRx} = \text{INT}(N/16)$$

and the first stage modulator is set to:

$$\text{UCBRFx} = \text{INT}([(N/16) - \text{INT}(N/16)] \times 16)$$

The second modulation stage setting (UCBRSx) can be found by performing a detailed error calculation or by using [Table 30-4](#) and the fractional part of  $N = f_{\text{BRCLK}}/\text{baud rate}$ .

### 30.3.11 Transmit Bit Timing - Error calculation

The timing for each character is the sum of the individual bit timings. Using the modulation features of the baud-rate generator reduces the cumulative bit error. The individual bit error can be calculated using the following steps.

#### 30.3.11.1 Low-Frequency Baud-Rate Mode Bit Timing

In low-frequency mode, calculation of the length of bit  $i T_{\text{bit,TX}}[i]$  is based on the UCBRx and UCBRSx settings:

$$T_{\text{bit,TX}}[i] = (1/f_{\text{BRCLK}})(\text{UCBRx} + m_{\text{UCBRSx}}[i])$$

Where:

$m_{\text{UCBRSx}}[i]$  = Modulation of bit  $i$  of UCBRSx

#### 30.3.11.2 Oversampling Baud-Rate Mode Bit Timing

In oversampling baud-rate mode, calculation of the length of bit  $i T_{\text{bit,TX}}[i]$  is based on the baud-rate generator UCBRx, UCBRFx and UCBRSx settings:

$$t_{\text{bit,TX}}[i] = \frac{1}{f_{\text{BRCLK}}} \left( (16 \times \text{UCBRx}) + \sum_{j=0}^{15} m_{\text{UCBRFx}}[j] + m_{\text{UCBRSx}}[i] \right)$$

Where:

$\sum_{j=0}^{15} m_{\text{UCBRFx}}[j]$  = Sum of ones from the corresponding row in [Table 30-3](#)

$m_{\text{UCBRSx}}[i]$  = Modulation of bit  $i$  of UCBRSx

This results in an end-of-bit time  $t_{\text{bit,TX}}[i]$  equal to the sum of all previous and the current bit times:

$$t_{\text{bit,TX}}[i] = \sum_{j=0}^i t_{\text{bit,TX}}[j]$$

To calculate bit error, this time is compared to the ideal bit time  $t_{\text{bit,ideal,TX}}[i]$ :

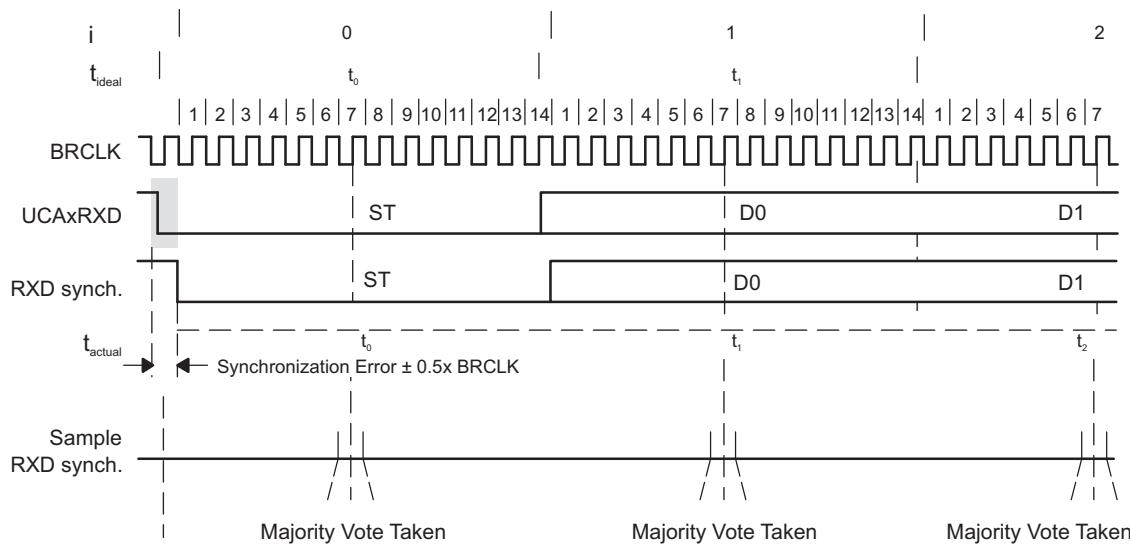
$$t_{\text{bit,ideal,TX}}[i] = (1/\text{baud rate})(i + 1)$$

This results in an error normalized to one ideal bit time ( $1/\text{baud rate}$ ):

$$\text{Error}_{\text{TX}}[i] = (t_{\text{bit,TX}}[i] - t_{\text{bit,ideal,TX}}[i]) \times \text{baud rate} \times 100\%$$

### 30.3.12 Receive Bit Timing – Error Calculation

Receive timing error consists of two error sources. The first is the bit-to-bit timing error similar to the transmit bit timing error. The second is the error between a start edge occurring and the start edge being accepted by the eUSCI\_A module. [Figure 30-11](#) shows the asynchronous timing errors between data on the UCAXRXD pin and the internal baud-rate clock. This results in an additional synchronization error. The synchronization error  $t_{\text{SYNC}}$  is between  $-0.5$  BRCLKs and  $+0.5$  RCLKs, independent of the selected baud-rate generation mode.



**Figure 30-11. Receive Error**

The ideal sampling time  $t_{\text{bit,ideal,RX}}[i]$  is in the middle of a bit period:

$$t_{\text{bit,ideal,RX}}[i] = (1/\text{baud rate})(i + 0.5)$$

The real sampling time,  $t_{\text{bit,RX}}[i]$ , is equal to the sum of all previous bits according to the formulas shown in the transmit timing section, plus one-half BITCLK for the current bit  $i$ , plus the synchronization error  $t_{\text{SYNC}}$ .

This results in the following  $t_{\text{bit,RX}}[i]$  for the low-frequency baud-rate mode:

$$t_{\text{bit,RX}}[i] = t_{\text{SYNC}} + \sum_{j=0}^{i-1} T_{\text{bit,RX}}[j] + \frac{1}{f_{\text{BRCLK}}} \left( \text{INT}(1/2 \text{UCBRx}) + m_{\text{UCBRSx}}[i] \right)$$

Where:

$$T_{\text{bit,RX}}[i] = (1/f_{\text{BRCLK}})(\text{UCBRx} + m_{\text{UCBRSx}}[i])$$

$m_{\text{UCBRSx}}[i]$  = Modulation of bit  $i$  of UCBRSx

For the oversampling baud-rate mode, the sampling time  $t_{\text{bit,RX}}[i]$  of bit  $i$  is calculated by:

$$t_{\text{bit,RX}}[i] = t_{\text{SYNC}} + \sum_{j=0}^{i-1} T_{\text{bit,RX}}[j] + \frac{1}{f_{\text{BRCLK}}} \left( (8 * \text{UCBRx}) + \sum_{j=0}^7 m_{\text{UCBFRx}}[j] + m_{\text{UCBRSx}}[i] \right)$$

Where:

$$T_{\text{bit,RX}}[i] = \frac{1}{f_{\text{BRCLK}}} \left( (16 * \text{UCBRx}) + \sum_{j=0}^{15} m_{\text{UCBFRx}}[j] + m_{\text{UCBRSx}}[i] \right)$$

$$\sum_{j=0}^{7+m_{\text{UCBRSx}}[i]} m_{\text{UCBFRx}}[j]$$

= Sum of ones from columns 0 to  $(7 + m_{\text{UCBRSx}}[i])$  from the corresponding row in

**Table 30-3.**

$m_{\text{UCBRSx}}[i]$  = Modulation of bit  $i$  of UCBRSx

This results in an error normalized to one ideal bit time ( $1/\text{baud rate}$ ) according to the following formula:

$$\text{Error}_{\text{RX}}[i] = (t_{\text{bit,RX}}[i] - t_{\text{bit,ideal,RX}}[i]) \times \text{baud rate} \times 100\%$$

### 30.3.13 Typical Baud Rates and Errors

Standard baud-rate data for UCBRx, UCBRSx, and UCBFRx are listed in [Table 30-5](#) for a 32768-Hz crystal sourcing ACLK and typical SMCLK frequencies. Make sure that the selected BRCLK frequency does not exceed the device specific maximum eUSCI\_A input frequency (see the device-specific data sheet).

The receive error is the accumulated time versus the ideal scanning time in the middle of each bit. The worst-case error is given for the reception of an 8-bit character with parity and one stop bit including synchronization error.

The transmit error is the accumulated timing error versus the ideal time of the bit period. The worst-case error is given for the transmission of an 8-bit character with parity and stop bit.

**Table 30-5. Recommended Settings for Typical Crystals and Baud Rates<sup>(1)</sup>**

| BRCLK   | Baud Rate | UCOS16 | UCBRx | UCBRFx | UCBRSp <sup>(2)</sup> | TX Error <sup>(2)</sup> (%) |       | RX Error <sup>(2)</sup> (%) |       |
|---------|-----------|--------|-------|--------|-----------------------|-----------------------------|-------|-----------------------------|-------|
|         |           |        |       |        |                       | neg                         | pos   | neg                         | pos   |
| 32768   | 1200      | 1      | 1     | 11     | 0x25                  | -2.29                       | 2.25  | -2.56                       | 5.35  |
| 32768   | 2400      | 0      | 13    | -      | 0xB6                  | -3.12                       | 3.91  | -5.52                       | 8.84  |
| 32768   | 4800      | 0      | 6     | -      | 0xEE                  | -7.62                       | 8.98  | -21                         | 10.25 |
| 32768   | 9600      | 0      | 3     | -      | 0x92                  | -17.19                      | 16.02 | -23.24                      | 37.3  |
| 1000000 | 9600      | 1      | 6     | 8      | 0x20                  | -0.48                       | 0.64  | -1.04                       | 1.04  |
| 1000000 | 19200     | 1      | 3     | 4      | 0x2                   | -0.8                        | 0.96  | -1.84                       | 1.84  |
| 1000000 | 38400     | 1      | 1     | 10     | 0x0                   | 0                           | 1.76  | 0                           | 3.44  |
| 1000000 | 57600     | 0      | 17    | -      | 0x4A                  | -2.72                       | 2.56  | -3.76                       | 7.28  |
| 1000000 | 115200    | 0      | 8     | -      | 0xD6                  | -7.36                       | 5.6   | -17.04                      | 6.96  |
| 1048576 | 9600      | 1      | 6     | 13     | 0x22                  | -0.46                       | 0.42  | -0.48                       | 1.23  |
| 1048576 | 19200     | 1      | 3     | 6      | 0xAD                  | -0.88                       | 0.83  | -2.36                       | 1.18  |
| 1048576 | 38400     | 1      | 1     | 11     | 0x25                  | -2.29                       | 2.25  | -2.56                       | 5.35  |
| 1048576 | 57600     | 0      | 18    | -      | 0x11                  | -2                          | 3.37  | -5.31                       | 5.55  |
| 1048576 | 115200    | 0      | 9     | -      | 0x08                  | -5.37                       | 4.49  | -5.93                       | 14.92 |
| 4000000 | 9600      | 1      | 26    | 0      | 0xB6                  | -0.08                       | 0.16  | -0.28                       | 0.2   |
| 4000000 | 19200     | 1      | 13    | 0      | 0x84                  | -0.32                       | 0.32  | -0.64                       | 0.48  |
| 4000000 | 38400     | 1      | 6     | 8      | 0x20                  | -0.48                       | 0.64  | -1.04                       | 1.04  |
| 4000000 | 57600     | 1      | 4     | 5      | 0x55                  | -0.8                        | 0.64  | -1.12                       | 1.76  |
| 4000000 | 115200    | 1      | 2     | 2      | 0xBB                  | -1.44                       | 1.28  | -3.92                       | 1.68  |
| 4000000 | 230400    | 0      | 17    | -      | 0x4A                  | -2.72                       | 2.56  | -3.76                       | 7.28  |
| 4194304 | 9600      | 1      | 27    | 4      | 0xFB                  | -0.11                       | 0.1   | -0.33                       | 0     |
| 4194304 | 19200     | 1      | 13    | 10     | 0x55                  | -0.21                       | 0.21  | -0.55                       | 0.33  |
| 4194304 | 38400     | 1      | 6     | 13     | 0x22                  | -0.46                       | 0.42  | -0.48                       | 1.23  |
| 4194304 | 57600     | 1      | 4     | 8      | 0xEE                  | -0.75                       | 0.74  | -2                          | 0.87  |
| 4194304 | 115200    | 1      | 2     | 4      | 0x92                  | -1.62                       | 1.37  | -3.56                       | 2.06  |
| 4194304 | 230400    | 0      | 18    | -      | 0x11                  | -2                          | 3.37  | -5.31                       | 5.55  |
| 8000000 | 9600      | 1      | 52    | 1      | 0x49                  | -0.08                       | 0.04  | -0.1                        | 0.14  |
| 8000000 | 19200     | 1      | 26    | 0      | 0xB6                  | -0.08                       | 0.16  | -0.28                       | 0.2   |
| 8000000 | 38400     | 1      | 13    | 0      | 0x84                  | -0.32                       | 0.32  | -0.64                       | 0.48  |
| 8000000 | 57600     | 1      | 8     | 10     | 0xF7                  | -0.32                       | 0.32  | -1                          | 0.36  |
| 8000000 | 115200    | 1      | 4     | 5      | 0x55                  | -0.8                        | 0.64  | -1.12                       | 1.76  |
| 8000000 | 230400    | 1      | 2     | 2      | 0xBB                  | -1.44                       | 1.28  | -3.92                       | 1.68  |
| 8000000 | 460800    | 0      | 17    | -      | 0x4A                  | -2.72                       | 2.56  | -3.76                       | 7.28  |
| 8388608 | 9600      | 1      | 54    | 9      | 0xEE                  | -0.06                       | 0.06  | -0.11                       | 0.13  |
| 8388608 | 19200     | 1      | 27    | 4      | 0xFB                  | -0.11                       | 0.1   | -0.33                       | 0     |
| 8388608 | 38400     | 1      | 13    | 10     | 0x55                  | -0.21                       | 0.21  | -0.55                       | 0.33  |
| 8388608 | 57600     | 1      | 9     | 1      | 0xB5                  | -0.31                       | 0.31  | -0.53                       | 0.78  |
| 8388608 | 115200    | 1      | 4     | 8      | 0xEE                  | -0.75                       | 0.74  | -2                          | 0.87  |

<sup>(1)</sup> The listed UCBRSx settings are determined by a search algorithm for the lowest error. Other settings for UCBRSx might result in similar or same errors.

<sup>(2)</sup> Assumes a stable clock source for BRCLK with negligible jitter (for example, from a crystal oscillator). Any frequency variation or jitter of the clock source will make the errors worse.

**Table 30-5. Recommended Settings for Typical Crystals and Baud Rates<sup>(1)</sup> (continued)**

| BRCLK    | Baud Rate | UCOS16 | UCBRx | UCBRFx | UCBRSx <sup>(2)</sup> | TX Error <sup>(2)</sup> (%) |      | RX Error <sup>(2)</sup> (%) |      |
|----------|-----------|--------|-------|--------|-----------------------|-----------------------------|------|-----------------------------|------|
|          |           |        |       |        |                       | neg                         | pos  | neg                         | pos  |
| 8388608  | 230400    | 1      | 2     | 4      | 0x92                  | -1.62                       | 1.37 | -3.56                       | 2.06 |
| 8388608  | 460800    | 0      | 18    | -      | 0x11                  | -2                          | 3.37 | -5.31                       | 5.55 |
| 12000000 | 9600      | 1      | 78    | 2      | 0x0                   | 0                           | 0    | 0                           | 0.04 |
| 12000000 | 19200     | 1      | 39    | 1      | 0x0                   | 0                           | 0    | 0                           | 0.16 |
| 12000000 | 38400     | 1      | 19    | 8      | 0x65                  | -0.16                       | 0.16 | -0.4                        | 0.24 |
| 12000000 | 57600     | 1      | 13    | 0      | 0x25                  | -0.16                       | 0.32 | -0.48                       | 0.48 |
| 12000000 | 115200    | 1      | 6     | 8      | 0x20                  | -0.48                       | 0.64 | -1.04                       | 1.04 |
| 12000000 | 230400    | 1      | 3     | 4      | 0x2                   | -0.8                        | 0.96 | -1.84                       | 1.84 |
| 12000000 | 460800    | 1      | 1     | 10     | 0x0                   | 0                           | 1.76 | 0                           | 3.44 |
| 16000000 | 9600      | 1      | 104   | 2      | 0xD6                  | -0.04                       | 0.02 | -0.09                       | 0.03 |
| 16000000 | 19200     | 1      | 52    | 1      | 0x49                  | -0.08                       | 0.04 | -0.1                        | 0.14 |
| 16000000 | 38400     | 1      | 26    | 0      | 0xB6                  | -0.08                       | 0.16 | -0.28                       | 0.2  |
| 16000000 | 57600     | 1      | 17    | 5      | 0xDD                  | -0.16                       | 0.2  | -0.3                        | 0.38 |
| 16000000 | 115200    | 1      | 8     | 10     | 0xF7                  | -0.32                       | 0.32 | -1                          | 0.36 |
| 16000000 | 230400    | 1      | 4     | 5      | 0x55                  | -0.8                        | 0.64 | -1.12                       | 1.76 |
| 16000000 | 460800    | 1      | 2     | 2      | 0xBB                  | -1.44                       | 1.28 | -3.92                       | 1.68 |
| 16777216 | 9600      | 1      | 109   | 3      | 0xB5                  | -0.03                       | 0.02 | -0.05                       | 0.06 |
| 16777216 | 19200     | 1      | 54    | 9      | 0xEE                  | -0.06                       | 0.06 | -0.11                       | 0.13 |
| 16777216 | 38400     | 1      | 27    | 4      | 0xFB                  | -0.11                       | 0.1  | -0.33                       | 0    |
| 16777216 | 57600     | 1      | 18    | 3      | 0x44                  | -0.16                       | 0.15 | -0.2                        | 0.45 |
| 16777216 | 115200    | 1      | 9     | 1      | 0xB5                  | -0.31                       | 0.31 | -0.53                       | 0.78 |
| 16777216 | 230400    | 1      | 4     | 8      | 0xEE                  | -0.75                       | 0.74 | -2                          | 0.87 |
| 16777216 | 460800    | 1      | 2     | 4      | 0x92                  | -1.62                       | 1.37 | -3.56                       | 2.06 |
| 20000000 | 9600      | 1      | 130   | 3      | 0x25                  | -0.02                       | 0.03 | 0                           | 0.07 |
| 20000000 | 19200     | 1      | 65    | 1      | 0xD6                  | -0.06                       | 0.03 | -0.1                        | 0.1  |
| 20000000 | 38400     | 1      | 32    | 8      | 0xEE                  | -0.1                        | 0.13 | -0.27                       | 0.14 |
| 20000000 | 57600     | 1      | 21    | 11     | 0x22                  | -0.16                       | 0.13 | -0.16                       | 0.38 |
| 20000000 | 115200    | 1      | 10    | 13     | 0xAD                  | -0.29                       | 0.26 | -0.46                       | 0.66 |
| 20000000 | 230400    | 1      | 5     | 6      | 0xEE                  | -0.67                       | 0.51 | -1.71                       | 0.62 |
| 20000000 | 460800    | 1      | 2     | 11     | 0x92                  | -1.38                       | 0.99 | -1.84                       | 2.8  |

### 30.3.14 Using the eUSCI\_A Module in UART Mode With Low-Power Modes

The eUSCI\_A module provides automatic clock activation for use with low-power modes. When the eUSCI\_A clock source is inactive because the device is in a low-power mode, the eUSCI\_A module automatically activates it when needed, regardless of the control-bit settings for the clock source. The clock remains active until the eUSCI\_A module returns to its idle condition. After the eUSCI\_A module returns to the idle condition, control of the clock source reverts to the settings of its control bits.

#### NOTE: Clock Activation Time

If the clock source is not already active when the eUSCI\_A module requests it then the clock must be activated. This takes time. This clock activation time depending on the selected clock source and the selected low power mode. If the DCO is used as clock source the activation time is approximately the wake-up time as specified in the device-specific data sheet.

### 30.3.15 eUSCI\_A Interrupts in UART Mode

The eUSCI\_A has only one interrupt vector that is shared for transmission and for reception.

#### 30.3.15.1 UART Transmit Interrupt Operation

The UCTXIFG interrupt flag is set by the transmitter to indicate that UCAXTXBUF is ready to accept another character. An interrupt request is generated if UCTXIE and GIE are also set. UCTXIFG is automatically reset if a character is written to UCAXTXBUF.

UCTXIFG is set after a PUC or when UCSWRST = 1. UCTXIE is reset after a PUC or when UCSWRST = 1.

#### 30.3.15.2 UART Receive Interrupt Operation

The UCRXIFG interrupt flag is set each time a character is received and loaded into UCAXRXBUF. An interrupt request is generated if UCRXIE and GIE are also set. UCRXIFG and UCRXIE are reset by a system reset PUC signal or when UCSWRST = 1. UCRXIFG is automatically reset when UCAXRXBUF is read.

Additional interrupt control features include:

- When UCAXRXEIE = 0, erroneous characters do not set UCRXIFG.
- When UCDORM = 1, nonaddress characters do not set UCRXIFG in multiprocessor modes. In plain UART mode, no characters are set UCRXIFG.
- When UCBRKIE = 1, a break condition sets the UCBRK bit and the UCRXIFG flag.

#### 30.3.15.3 UART State Change Interrupt Operation

[Table 30-6](#) describes the UART state change interrupt flags.

**Table 30-6. UART State Change Interrupt Flags**

| Interrupt Flag | Interrupt Condition                                                                                                                                                                       |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| UCSTTIFG       | START byte received interrupt. This flag is set when the UART module receives a START byte. This flag can be cleared by writing 0 to it.                                                  |
| UCTXCPTIFG     | Transmit complete interrupt. This flag is set after the complete UART byte in the internal shift register including STOP bit is shifted out. This flag can be cleared by writing 0 to it. |

#### 30.3.15.4 UCAXIV, Interrupt Vector Generator

The eUSCI\_A interrupt flags are prioritized and combined to source a single interrupt vector. The interrupt vector register UCAXIV is used to determine which flag requested an interrupt. The highest-priority enabled interrupt generates a number in the UCAXIV register that can be evaluated or added to the program counter to automatically enter the appropriate software routine. Disabled interrupts do not affect the UCAXIV value.

Read access of the UCAXIV register automatically resets the highest-pending Interrupt condition and flag. Write access of the UCAXIV register clears all pending Interrupt conditions and flags. If another interrupt flag is set, another interrupt is generated immediately after servicing the initial interrupt.

[Example 30-1](#) shows the recommended use of UCAXIV. The UCAXIV value is added to the PC to automatically jump to the appropriate routine. The following example is given for eUSCI\_A0.

**Example 30-1. UCAxIV Software Example**

```
#pragma vector = USCI_A0_VECTOR __interrupt void USCI_A0_ISR(void) {
    switch(__even_in_range(UCA0IV,18)) {
        case 0x00:          // Vector 0: No interrupts
            break;
        case 0x02: ...      // Vector 2: UCRXIFG
            break;
        case 0x04: ...      // Vector 4: UCTXIFG
            break;
        case 0x06: ...      // Vector 6: UCSTTIFG
            break;
        case 0x08: ...      // Vector 8: UCTXCPTIFG
            break;
        default: break;
    }
}
```

**30.3.16 DMA Operation**

In devices with a DMA controller, the eUSCI module can trigger DMA transfers when the transmit buffer UCAxTXBUF is empty or when data was received in the UCAxRXBUF buffer. The DMA trigger signals correspond to the UCTXIFG transmit interrupt flag and the UCRXIFG receive interrupt flag, respectively. The interrupt functionality must be disabled for the selected DMA triggers with UCTXIE = 0 and UCRXIE = 0.

A DMA read access to UCAxRXBUF has the same effects as a CPU (software) read: all error flags (UCRXERR, UCFE, UCPE, UCOE, and UCBRK) are cleared after the read. Thus these errors might go unnoticed.

### 30.4 eUSCI\_A UART Registers

The eUSCI\_A registers applicable in UART mode and their address offsets are listed in [Table 30-7](#). The base address can be found in the device-specific data sheet.

**Table 30-7. eUSCI\_A UART Registers**

| Offset | Acronym                 | Register Name                    | Type       | Access | Reset | Section                         |
|--------|-------------------------|----------------------------------|------------|--------|-------|---------------------------------|
| 00h    | UCAxCTLW0               | eUSCI_Ax Control Word 0          | Read/write | Word   | 0001h | <a href="#">Section 30.4.1</a>  |
| 01h    | UCAxCTL0 <sup>(1)</sup> | eUSCI_Ax Control 0               | Read/write | Byte   | 00h   |                                 |
| 00h    | UCAxCTL1                | eUSCI_Ax Control 1               | Read/write | Byte   | 01h   |                                 |
| 02h    | UCAxCTLW1               | eUSCI_Ax Control Word 1          | Read/write | Word   | 0003h | <a href="#">Section 30.4.2</a>  |
| 06h    | UCAxBRW                 | eUSCI_Ax Baud Rate Control Word  | Read/write | Word   | 0000h | <a href="#">Section 30.4.3</a>  |
| 06h    | UCAxBR0 <sup>(1)</sup>  | eUSCI_Ax Baud Rate Control 0     | Read/write | Byte   | 00h   |                                 |
| 07h    | UCAxBR1                 | eUSCI_Ax Baud Rate Control 1     | Read/write | Byte   | 00h   |                                 |
| 08h    | UCAxMCTLW               | eUSCI_Ax Modulation Control Word | Read/write | Word   | 00h   | <a href="#">Section 30.4.4</a>  |
| 0Ah    | UCAxSTATW               | eUSCI_Ax Status                  | Read/write | Word   | 00h   | <a href="#">Section 30.4.5</a>  |
| 0Ch    | UCAxRXBUF               | eUSCI_Ax Receive Buffer          | Read/write | Word   | 00h   | <a href="#">Section 30.4.6</a>  |
| 0Eh    | UCAxTXBUF               | eUSCI_Ax Transmit Buffer         | Read/write | Word   | 00h   | <a href="#">Section 30.4.7</a>  |
| 10h    | UCAxABCTL               | eUSCI_Ax Auto Baud Rate Control  | Read/write | Word   | 00h   | <a href="#">Section 30.4.8</a>  |
| 12h    | UCAxIRCTL               | eUSCI_Ax IrDA Control            | Read/write | Word   | 0000h | <a href="#">Section 30.4.9</a>  |
| 12h    | UCAxIRCTL               | eUSCI_Ax IrDA Transmit Control   | Read/write | Byte   | 00h   |                                 |
| 13h    | UCAxIRRCTL              | eUSCI_Ax IrDA Receive Control    | Read/write | Byte   | 00h   |                                 |
| 1Ah    | UCAxIE                  | eUSCI_Ax Interrupt Enable        | Read/write | Word   | 00h   | <a href="#">Section 30.4.10</a> |
| 1Ch    | UCAxIFG                 | eUSCI_Ax Interrupt Flag          | Read/write | Word   | 02h   | <a href="#">Section 30.4.11</a> |
| 1Eh    | UCAxIV                  | eUSCI_Ax Interrupt Vector        | Read       | Word   | 0000h | <a href="#">Section 30.4.12</a> |

<sup>(1)</sup> It is recommended to access these registers using 16-bit access. If 8-bit access is used, the corresponding bit names must be followed by "\_H".

### 30.4.1 UCAXCTLW0 Register

eUSCI\_Ax Control Word Register 0

**Figure 30-12. UCAXCTLW0 Register**

| 15     | 14     | 13      | 12     | 11       | 10      | 9       | 8    |
|--------|--------|---------|--------|----------|---------|---------|------|
| UCPEN  | UCPAR  | UCMSB   | UC7BIT | UCSPB    | UCMODEx | UCSYNC  |      |
| rw-0   | rw-0   | rw-0    | rw-0   | rw-0     | rw-0    | rw-0    | rw-0 |
| 7      | 6      | 5       | 4      | 3        | 2       | 1       | 0    |
| UCSELx | UCRXIE | UCBRKIE | UCDORM | UCTXADDR | UCTXBRK | UCSWRST |      |
| rw-0   | rw-0   | rw-0    | rw-0   | rw-0     | rw-0    | rw-0    | rw-1 |

Can be modified only when UCSWRST = 1.

**Table 30-8. UCAXCTLW0 Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                           |
|------|---------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | UCPEN   | RW   | 0h    | Parity enable<br>0b = Parity disabled<br>1b = Parity enabled. Parity bit is generated (UCAxTXD) and expected (UCAxRXD). In address-bit multiprocessor mode, the address bit is included in the parity calculation.                    |
| 14   | UCPAR   | RW   | 0h    | Parity select. UCPAR is not used when parity is disabled.<br>0b = Odd parity<br>1b = Even parity                                                                                                                                      |
| 13   | UCMSB   | RW   | 0h    | MSB first select. Controls the direction of the receive and transmit shift register.<br>0b = LSB first<br>1b = MSB first                                                                                                              |
| 12   | UC7BIT  | RW   | 0h    | Character length. Selects 7-bit or 8-bit character length.<br>0b = 8-bit data<br>1b = 7-bit data                                                                                                                                      |
| 11   | UCSPB   | RW   | 0h    | Stop bit select. Number of stop bits.<br>0b = One stop bit<br>1b = Two stop bits                                                                                                                                                      |
| 10-9 | UCMODEx | RW   | 0h    | eUSCI_A mode. The UCMODEx bits select the asynchronous mode when UCSYNC = 0.<br>00b = UART mode<br>01b = Idle-line multiprocessor mode<br>10b = Address-bit multiprocessor mode<br>11b = UART mode with automatic baud-rate detection |
| 8    | UCSYNC  | RW   | 0h    | Synchronous mode enable<br>0b = Asynchronous mode<br>1b = Synchronous mode                                                                                                                                                            |
| 7-6  | UCSELx  | RW   | 0h    | eUSCI_A clock source select. These bits select the BRCLK source clock.<br>00b = UCLK<br>01b = ACLK<br>10b = SMCLK<br>11b = SMCLK                                                                                                      |
| 5    | UCRXIE  | RW   | 0h    | Receive erroneous-character interrupt enable<br>0b = Erroneous characters rejected and UCRXIFG is not set.<br>1b = Erroneous characters received set UCRXIFG.                                                                         |
| 4    | UCBRKIE | RW   | 0h    | Receive break character interrupt enable<br>0b = Received break characters do not set UCRXIFG.<br>1b = Received break characters set UCRXIFG.                                                                                         |

**Table 30-8. UCAXCTLW0 Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                        |
|-----|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | UCDORM   | RW   | 0h    | Dormant. Puts eUSCI_A into sleep mode.<br>0b = Not dormant. All received characters set UCRXIFG.<br>1b = Dormant. Only characters that are preceded by an idle-line or with address bit set UCRXIFG. In UART mode with automatic baud-rate detection, only the combination of a break and synch field sets UCRXIFG.                                                                |
| 2   | UCTXADDR | RW   | 0h    | Transmit address. Next frame to be transmitted is marked as address, depending on the selected multiprocessor mode.<br>0b = Next frame transmitted is data.<br>1b = Next frame transmitted is an address.                                                                                                                                                                          |
| 1   | UCTXBRK  | RW   | 0h    | Transmit break. Transmits a break with the next write to the transmit buffer. In UART mode with automatic baud-rate detection, 055h must be written into UCAXTXBUF to generate the required break/synch fields. Otherwise, 0h must be written into the transmit buffer.<br>0b = Next frame transmitted is not a break.<br>1b = Next frame transmitted is a break or a break/synch. |
| 0   | UCSWRST  | RW   | 1h    | Software reset enable<br>0b = Disabled. eUSCI_A reset released for operation.<br>1b = Enabled. eUSCI_A logic held in reset state.                                                                                                                                                                                                                                                  |

### 30.4.2 UCAXCTLW1 Register

eUSCI\_Ax Control Word Register 1

**Figure 30-13. UCAXCTLW1 Register**

|          |     |     |     |     |     |      |      |
|----------|-----|-----|-----|-----|-----|------|------|
| 15       | 14  | 13  | 12  | 11  | 10  | 9    | 8    |
| Reserved |     |     |     |     |     |      |      |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0  | r-0  |
| Reserved |     |     |     |     |     |      |      |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-1 | rw-1 |

**Table 30-9. UCAXCTLW1 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                        |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------|
| 15-2 | Reserved | R    | 0h    | Reserved                                                                                                                           |
| 1-0  | UCGLITx  | RW   | 3h    | Deglitch time<br>00b = Approximately 2 ns<br>01b = Approximately 50 ns<br>10b = Approximately 100 ns<br>11b = Approximately 200 ns |

### 30.4.3 UCAXBRW Register

eUSCI\_Ax Baud Rate Control Word Register

**Figure 30-14. UCAXBRW Register**

|       |    |    |    |    |    |    |    |
|-------|----|----|----|----|----|----|----|
| 15    | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |
| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

Can be modified only when UCSWRST = 1.

**Table 30-10. UCAXBRW Register Description**

| Bit  | Field | Type | Reset | Description                                        |
|------|-------|------|-------|----------------------------------------------------|
| 15-0 | UCBRx | RW   | 0h    | Clock prescaler setting of the Baud rate generator |

### 30.4.4 UCAXMCTLW Register

eUSCI\_Ax Modulation Control Word Register

**Figure 30-15. UCAXMCTLW Register**

|        |      |      |      |          |      |        |      |
|--------|------|------|------|----------|------|--------|------|
| 15     | 14   | 13   | 12   | 11       | 10   | 9      | 8    |
| UCBRSx |      |      |      |          |      |        |      |
| rw-0   | rw-0 | rw-0 | rw-0 | rw-0     | rw-0 | rw-0   | rw-0 |
| 7      | 6    | 5    | 4    | 3        | 2    | 1      | 0    |
| UCBRFx |      |      |      | Reserved |      | UCOS16 |      |
| rw-0   | rw-0 | rw-0 | rw-0 | r0       | r0   | r0     | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 30-11. UCAXMCTLW Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                     |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | UCBRSx   | RW   | 0h    | Second modulation stage select. These bits hold a free modulation pattern for BITCLK.                                                                                                                           |
| 7-4  | UCBRFx   | RW   | 0h    | First modulation stage select. These bits determine the modulation pattern for BITCLK16 when UCOS16 = 1. Ignored with UCOS16 = 0. The "Oversampling Baud-Rate Generation" section shows the modulation pattern. |
| 3-1  | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                        |
| 0    | UCOS16   | RW   | 0h    | Oversampling mode enabled<br>0b = Disabled<br>1b = Enabled                                                                                                                                                      |

### 30.4.5 UCAXSTATW Register

eUSCI\_Ax Status Register

**Figure 30-16. UCAXSTATW Register**

|          |      |      |      |       |         |                  |        |
|----------|------|------|------|-------|---------|------------------|--------|
| 15       | 14   | 13   | 12   | 11    | 10      | 9                | 8      |
| Reserved |      |      |      |       |         |                  |        |
| r0       | r0   | r0   | r0   | r0    | r0      | r0               | r0     |
| 7        | 6    | 5    | 4    | 3     | 2       | 1                | 0      |
| UCLISTEN | UCFE | UCOE | UCPE | UCBRK | UCRXERR | UCADDR<br>UCIDLE | UCBUSY |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0  | rw-0    | rw-0             | r-0    |

Can be modified only when UCSWRST = 1.

**Table 30-12. UCAXSTATW Register Description**

| Bit  | Field         | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                             |
|------|---------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved      | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                |
| 7    | UCLISTEN      | RW   | 0h    | Listen enable. The UCLISTEN bit selects loopback mode.<br>0b = Disabled<br>1b = Enabled. UCAXTXD is internally fed back to the receiver.                                                                                                                                                                                                                                |
| 6    | UCFE          | RW   | 0h    | Framing error flag. UCFE is cleared when UCAXRXBUF is read.<br>0b = No error<br>1b = Character received with low stop bit                                                                                                                                                                                                                                               |
| 5    | UCOE          | RW   | 0h    | Overrun error flag. This bit is set when a character is transferred into UCAXRXBUF before the previous character was read. UCOE is cleared automatically when UCxRXBUF is read, and must not be cleared by software. Otherwise, it does not function correctly.<br>0b = No error<br>1b = Overrun error occurred.                                                        |
| 4    | UCPE          | RW   | 0h    | Parity error flag. When UCPE = 0, UCPE is read as 0. UCPE is cleared when UCAXRXBUF is read.<br>0b = No error<br>1b = Character received with parity error                                                                                                                                                                                                              |
| 3    | UCBRK         | RW   | 0h    | Break detect flag. UCBRK is cleared when UCAXRXBUF is read.<br>0b = No break condition<br>1b = Break condition occurred.                                                                                                                                                                                                                                                |
| 2    | UCRXERR       | RW   | 0h    | Receive error flag. This bit indicates a character was received with one or more errors. When UCRXERR = 1, one or more error flags, UCFE, UCPE, or UCOE is also set. UCRXERR is cleared when UCAXRXBUF is read.<br>0b = No receive errors detected<br>1b = Receive error detected                                                                                       |
| 1    | UCADDR UCIDLE | RW   | 0h    | UCADDR: Address received in address-bit multiprocessor mode. UCADDR is cleared when UCAXRXBUF is read.<br>UCIDLE: Idle line detected in idle-line multiprocessor mode. UCIDLE is cleared when UCAXRXBUF is read.<br>0b = UCADDR: Received character is data. UCIDLE: No idle line detected<br>1b = UCADDR: Received character is an address. UCIDLE: Idle line detected |
| 0    | UCBUSY        | R    | 0h    | eUSCI_A busy. This bit indicates if a transmit or receive operation is in progress.<br>0b = eUSCI_A inactive<br>1b = eUSCI_A transmitting or receiving                                                                                                                                                                                                                  |

### 30.4.6 UCAXRXBUF Register

eUSCI\_Ax Receive Buffer Register

**Figure 30-17. UCAXRXBUF Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| Reserved |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| UCRXBUFx |     |     |     |     |     |     |     |
| r        | r   | r   | r   | r   | r   | r   | r   |

**Table 30-13. UCAXRXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                              |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                 |
| 7-0  | UCRXBUFx | R    | 0h    | The receive-data buffer is user accessible and contains the last received character from the receive shift register. Reading UCAXRXBUF resets the receive-error bits, the UCADDR or UCIDLE bit, and UCRXIFG. In 7-bit data mode, UCAXRXBUF is LSB justified and the MSB is always reset. |

### 30.4.7 UCAXTXBUF Register

eUSCI\_Ax Transmit Buffer Register

**Figure 30-18. UCAXTXBUF Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| Reserved |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| UCTXBUFx |     |     |     |     |     |     |     |
| rw       | rw  | rw  | rw  | rw  | rw  | rw  | rw  |

**Table 30-14. UCAXTXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                       |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                          |
| 7-0  | UCTXBUFx | RW   | 0h    | The transmit data buffer is user accessible and holds the data waiting to be moved into the transmit shift register and transmitted on UCAXTXD. Writing to the transmit data buffer clears UCTXIFG. The MSB of UCAXTXBUF is not used for 7-bit data and is reset. |

### 30.4.8 UCAXABCTL Register

eUSCI\_Ax Auto Baud Rate Control Register

**Figure 30-19. UCAXABCTL Register**

|                                                                           |     |      |      |      |      |     |      |
|---------------------------------------------------------------------------|-----|------|------|------|------|-----|------|
| 15                                                                        | 14  | 13   | 12   | 11   | 10   | 9   | 8    |
| Reserved                                                                  |     |      |      |      |      |     |      |
| r-0                                                                       | r-0 | r-0  | r-0  | r-0  | r-0  | r-0 | r-0  |
| 7                                                                         | 6   | 5    | 4    | 3    | 2    | 1   | 0    |
| Reserved      UCDELIMx      UCSTOE      UCBTOE      Reserved      UCABDEN |     |      |      |      |      |     |      |
| r-0                                                                       | r-0 | rw-0 | rw-0 | rw-0 | rw-0 | r-0 | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 30-15. UCAXABCTL Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                               |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-6 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                  |
| 5-4  | UCDELIMx | RW   | 0h    | Break/synch delimiter length<br>00b = 1 bit time<br>01b = 2 bit times<br>10b = 3 bit times<br>11b = 4 bit times                                                                                                                                           |
| 3    | UCSTOE   | RW   | 0h    | Synch field time out error<br>0b = No error<br>1b = Length of synch field exceeded measurable time.                                                                                                                                                       |
| 2    | UCBTOE   | RW   | 0h    | Break time out error<br>0b = No error<br>1b = Length of break field exceeded 22 bit times.                                                                                                                                                                |
| 1    | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                  |
| 0    | UCABDEN  | RW   | 0h    | Automatic baud-rate detect enable<br>0b = Baud-rate detection disabled. Length of break and synch field is not measured.<br>1b = Baud-rate detection enabled. Length of break and synch field is measured and baud-rate settings are changed accordingly. |

### 30.4.9 UCAXIRCTL Register

eUSCI\_Ax IrDA Control Word Register

**Figure 30-20. UCAXIRCTL Register**

| 15        | 14   | 13   | 12   | 11        | 10   | 9        | 8    |
|-----------|------|------|------|-----------|------|----------|------|
| UCIRRXFLx |      |      |      | UCIRRXPL  |      | UCIRRXFE |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0      | rw-0 | rw-0     | rw-0 |
| 7         | 6    | 5    | 4    | 3         | 2    | 1        | 0    |
| UCIRTXPLx |      |      |      | UCIRTXCLK |      | UCIREN   |      |
| rw-0      | rw-0 | rw-0 | rw-0 | rw-0      | rw-0 | rw-0     | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 30-16. UCAXIRCTL Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                              |
|-------|-----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | UCIRRXFLx | RW   | 0h    | Receive filter length. The minimum pulse length for receive is given by:<br>$t_{MIN} = (UCIRRXFLx + 4) / [2 \times f_{IRTXCLK}]$                                                         |
| 9     | UCIRRXPL  | RW   | 0h    | IrDA receive input UCAXRXD polarity<br>0b = IrDA transceiver delivers a high pulse when a light pulse is seen.<br>1b = IrDA transceiver delivers a low pulse when a light pulse is seen. |
| 8     | UCIRRXFE  | RW   | 0h    | IrDA receive filter enabled<br>0b = Receive filter disabled<br>1b = Receive filter enabled                                                                                               |
| 7-2   | UCIRTXPLx | RW   | 0h    | Transmit pulse length.<br>Pulse length $t_{PULSE} = (UCIRTXPLx + 1) / [2 \times f_{IRTXCLK}]$                                                                                            |
| 1     | UCIRTXCLK | RW   | 0h    | IrDA transmit pulse clock select<br>0b = BRCLK<br>1b = BITCLK16 when UCOS16 = 1. Otherwise, BRCLK.                                                                                       |
| 0     | UCIREN    | RW   | 0h    | IrDA encoder/decoder enable<br>0b = IrDA encoder/decoder disabled<br>1b = IrDA encoder/decoder enabled                                                                                   |

### 30.4.10 UCAXIE Register

eUSCI\_Ax Interrupt Enable Register

**Figure 30-21. UCAXIE Register**

|          |     |     |     |           |         |        |        |
|----------|-----|-----|-----|-----------|---------|--------|--------|
| 15       | 14  | 13  | 12  | 11        | 10      | 9      | 8      |
| Reserved |     |     |     |           |         |        |        |
| r-0      | r-0 | r-0 | r-0 | r-0       | r-0     | r-0    | r-0    |
| 7        | 6   | 5   | 4   | 3         | 2       | 1      | 0      |
| Reserved |     |     |     | UCTXCPTIE | UCSTTIE | UCTXIE | UCRXIE |
| r-0      | r-0 | r-0 | r-0 | rw-0      | rw-0    | rw-0   | rw-0   |

**Table 30-17. UCAXIE Register Description**

| Bit  | Field     | Type | Reset | Description                                                                             |
|------|-----------|------|-------|-----------------------------------------------------------------------------------------|
| 15-4 | Reserved  | R    | 0h    | Reserved                                                                                |
| 3    | UCTXCPTIE | RW   | 0h    | Transmit complete interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 2    | UCSTTIE   | RW   | 0h    | Start bit interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled         |
| 1    | UCTXIE    | RW   | 0h    | Transmit interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled          |
| 0    | UCRXIE    | RW   | 0h    | Receive interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled           |

### 30.4.11 UCAXIFG Register

eUSCI\_Ax Interrupt Flag Register

**Figure 30-22. UCAXIFG Register**

| 15       | 14  | 13  | 12  | 11         | 10       | 9       | 8       |
|----------|-----|-----|-----|------------|----------|---------|---------|
| Reserved |     |     |     |            |          |         |         |
| r-0      | r-0 | r-0 | r-0 | r-0        | r-0      | r-0     | r-0     |
| 7        | 6   | 5   | 4   | 3          | 2        | 1       | 0       |
| Reserved |     |     |     | UCTXCPTIFG | UCSTTIFG | UCTXIFG | UCRXIFG |
| r-0      | r-0 | r-0 | r-0 | rw-0       | rw-0     | rw-1    | rw-0    |

**Table 30-18. UCAXIFG Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                            |
|------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-4 | Reserved   | R    | 0h    | Reserved                                                                                                                                                                                               |
| 3    | UCTXCPTIFG | RW   | 0h    | Transmit complete interrupt flag. UCTXCPTIFG is set when the entire byte in the internal shift register got shifted out and UCAXTXBUF is empty.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 2    | UCSTTIFG   | RW   | 0h    | Start bit interrupt flag. UCSTTIFG is set after a Start bit was received<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                        |
| 1    | UCTXIFG    | RW   | 1h    | Transmit interrupt flag. UCTXIFG is set when UCAXTXBUF empty.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                   |
| 0    | UCRXIFG    | RW   | 0h    | Receive interrupt flag. UCRXIFG is set when UCAXRXBUF has received a complete character.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                        |

### 30.4.12 UCAXIV Register

eUSCI\_Ax Interrupt Vector Register

**Figure 30-23. UCAXIV Register**

|       |    |    |    |       |       |       |    |
|-------|----|----|----|-------|-------|-------|----|
| 15    | 14 | 13 | 12 | 11    | 10    | 9     | 8  |
| UCIVx |    |    |    |       |       |       |    |
| r0    | r0 | r0 | r0 | r0    | r0    | r0    | r0 |
| UCIVx |    |    |    |       |       |       |    |
| r0    | r0 | r0 | r0 | r-(0) | r-(0) | r-(0) | r0 |

**Table 30-19. UCAXIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                              |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | UCIVx | R    | 0h    | eUSCI_A interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: Receive buffer full; Interrupt Flag: UCRXIFG; Interrupt Priority: Highest<br>04h = Interrupt Source: Transmit buffer empty; Interrupt Flag: UCTXIFG<br>06h = Interrupt Source: Start bit received; Interrupt Flag: UCSTTIFG<br>08h = Interrupt Source: Transmit complete; Interrupt Flag: UCTXCPTIFG; Interrupt Priority: Lowest |

## ***Enhanced Universal Serial Communication Interface (eUSCI) – SPI Mode***

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The enhanced universal serial communication interfaces, eUSCI\_A and eUSCI\_B, support multiple serial communication modes with one hardware module. This chapter discusses the operation of the synchronous peripheral interface (SPI) mode.

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### 31.1 Enhanced Universal Serial Communication Interfaces (eUSCI\_A, eUSCI\_B) Overview

Both the eUSCI\_A and the eUSCI\_B support serial communication in SPI mode.

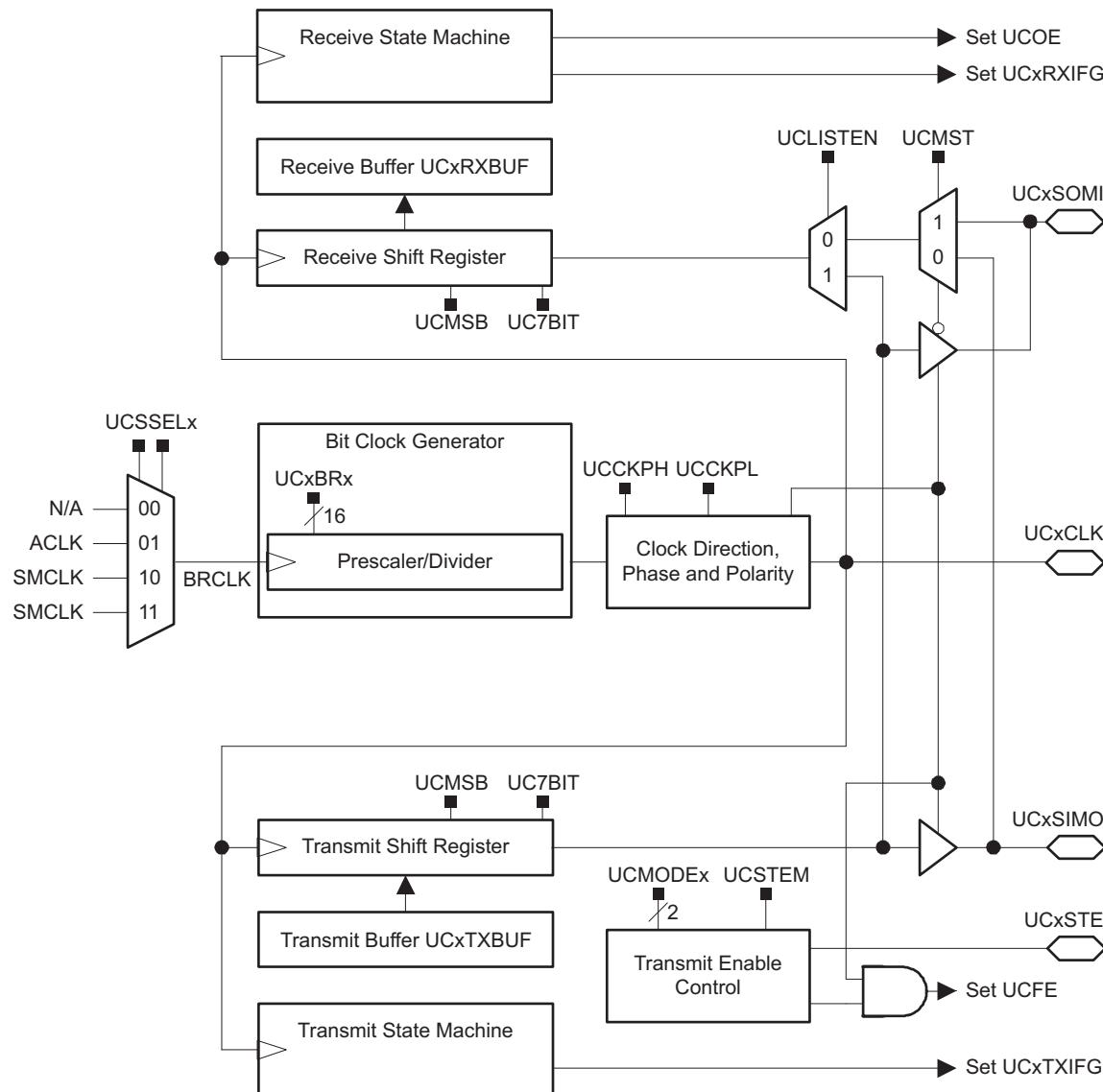
### 31.2 eUSCI Introduction – SPI Mode

In synchronous mode, the eUSCI connects the device to an external system through three or four pins: UCxSIMO, UCxSOMI, UCxCLK, and UCxSTE. SPI mode is selected when the UCSYNC bit is set, and SPI mode (3-pin or 4-pin) is selected with the UCMODEEx bits.

SPI mode features include:

- 7-bit or 8-bit data length
- LSB-first or MSB-first data transmit and receive
- 3-pin and 4-pin SPI operation
- Master or slave modes
- Independent transmit and receive shift registers
- Separate transmit and receive buffer registers
- Continuous transmit and receive operation
- Selectable clock polarity and phase control
- Programmable clock frequency in master mode
- Independent interrupt capability for receive and transmit
- Slave operation in LPM4

[Figure 31-1](#) shows the eUSCI when configured for SPI mode.



**Figure 31-1. eUSCI Block Diagram – SPI Mode**

### 31.3 eUSCI Operation – SPI Mode

In SPI mode, serial data is transmitted and received by multiple devices using a shared clock provided by the master. An additional pin controlled by the master, UCxSTE, is provided to enable a device to receive and transmit data.

Three or four signals are used for SPI data exchange:

- UCxSIMO – slave in, master out  
Master mode: UCxSIMO is the data output line.  
Slave mode: UCxSIMO is the data input line.
- UCxSOMI – slave out, master in  
Master mode: UCxSOMI is the data input line.  
Slave mode: UCxSOMI is the data output line.
- UCxCLK – eUSCI SPI clock  
Master mode: UCxCLK is an output.  
Slave mode: UCxCLK is an input.
- UCxSTE – slave transmit enable.

Used in 4-pin mode to allow multiple masters on a single bus. Not used in 3-pin mode. [Table 31-1](#) describes the UCxSTE operation.

**Table 31-1. UCxSTE Operation**

| UCMODEx | UCxSTE Active State | UCxSTE | Slave    | Master   |
|---------|---------------------|--------|----------|----------|
| 01      | High                | 0      | Inactive | Active   |
|         |                     | 1      | Active   | Inactive |
| 10      | Low                 | 0      | Active   | Inactive |
|         |                     | 1      | Inactive | Active   |

#### 31.3.1 eUSCI Initialization and Reset

The eUSCI is reset by a PUC or by the UCSWRST bit. After a PUC, the UCSWRST bit is automatically set, keeping the eUSCI in a reset condition. When set, the UCSWRST bit resets the UCRXIE, UCTXIE, UCRXIFG, UCOE, and UCFE bits, and sets the UCTXIFG flag. Clearing UCSWRST releases the eUSCI for operation.

Configuring and reconfiguring the eUSCI module should be done when UCSWRST is set to avoid unpredictable behavior.

---

**NOTE: Initializing or reconfiguring the eUSCI module**

The recommended eUSCI initialization or reconfiguration process is:

1. Set UCSWRST.  
`BIS.B #UCSWRST,&UCxCTL1`
  2. Initialize all eUSCI registers with UCSWRST = 1 (including UCxCTL1).
  3. Configure ports.
  4. Ensure that any input signals into the SPI module such as UCxSOMI (in master mode) or UCxSIMO and UCxCLK (in slave mode) have settled to their final voltage levels before clearing UCSWRST and avoid any unwanted transitions during operation.
  5. Clear UCSWRST.  
`BIC.B #UCSWRST,&UCxCTL1`
  6. Enable interrupts (optional) with UCRXIE or UCTXIE.
-

### 31.3.2 Character Format

The eUSCI module in SPI mode supports 7-bit and 8-bit character lengths selected by the UC7BIT bit. In 7-bit data mode, UCxRXBUF is LSB justified and the MSB is always reset. The UCMSB bit controls the direction of the transfer and selects LSB or MSB first.

**NOTE: Default character format**

The default SPI character transmission is LSB first. For communication with other SPI interfaces, MSB-first mode may be required.

**NOTE: Character format for figures**

Figures throughout this chapter use MSB-first format.

### 31.3.3 Master Mode

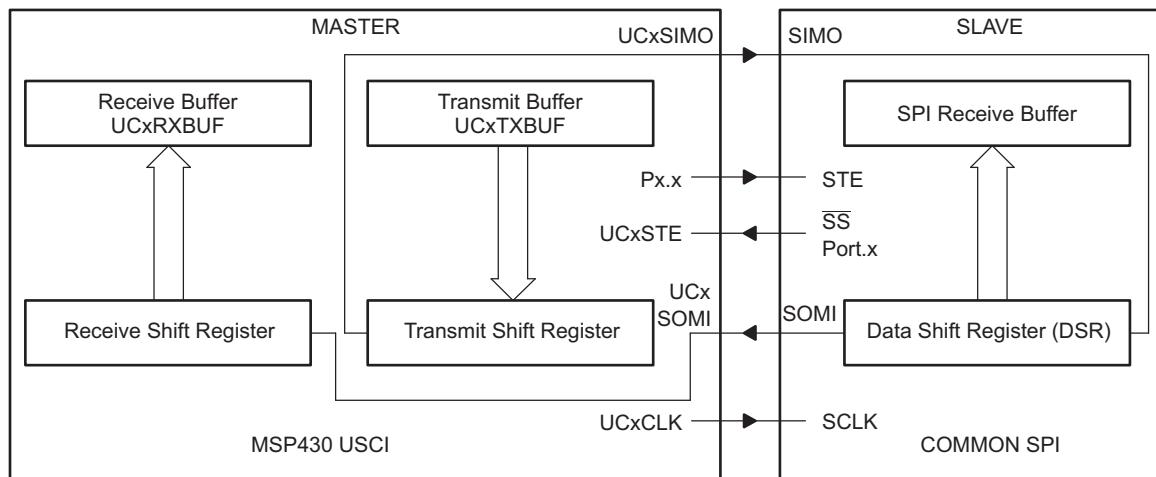


Figure 31-2. eUSCI Master and External Slave (UCSTEM = 0)

Figure 31-2 shows the eUSCI as a master in both 3-pin and 4-pin configurations. The eUSCI initiates data transfer when data is moved to the transmit data buffer UCxTXBUF. The UCxTXBUF data is moved to the transmit (TX) shift register when the TX shift register is empty, initiating data transfer on UCxSIMO starting with either the MSB or LSB, depending on the UCMSB setting. Data on UCxSOMI is shifted into the receive shift register on the opposite clock edge. When the character is received, the receive data is moved from the receive (RX) shift register to the received data buffer UCxRXBUF and the receive interrupt flag UCRXIFG is set, indicating the RX/TX operation is complete.

A set transmit interrupt flag, UCTXIFG, indicates that data has moved from UCxTXBUF to the TX shift register and UCxTXBUF is ready for new data. It does not indicate RX/TX completion.

To receive data into the eUSCI in master mode, data must be written to UCxTXBUF, because receive and transmit operations operate concurrently.

There are two different options for configuring the eUSCI as a 4-pin master, which are described in the next sections:

- The fourth pin is used as input to prevent conflicts with other masters (UCSTEM = 0).
- The fourth pin is used as output to generate a slave enable signal (UCSTEM = 1).

The bit UCSTEM is used to select the corresponding mode.

### 31.3.3.1 4-Pin SPI Master Mode (UCSTEM = 0)

In 4-pin master mode with UCSTEM = 0, UCxSTE is a digital input that can be used to prevent conflicts with another master and controls the master as described in [Table 31-1](#). When UCxSTE is in the master-inactive state and UCSTEM = 0:

- UCxSIMO and UCxCLK are set to inputs and no longer drive the bus.
- The error bit UCFE is set, indicating a communication integrity violation to be handled by the user.
- The internal state machines are reset and the shift operation is aborted.

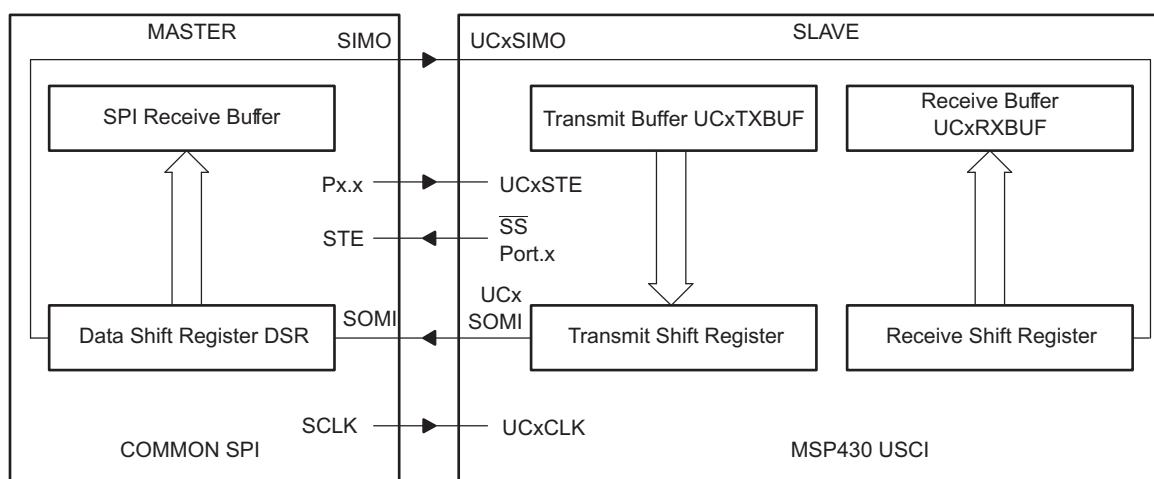
If data is written into UCxTXBUF while the master is held inactive by UCxSTE, it is transmit as soon as UCxSTE transitions to the master-active state. If an active transfer is aborted by UCxSTE transitioning to the master-inactive state, the data must be rewritten into UCxTXBUF to be transferred when UCxSTE transitions back to the master-active state. The UCxSTE input signal is not used in 3-pin master mode.

### 31.3.3.2 4-Pin SPI Master Mode (UCSTEM = 1)

If UCSTEM = 1 in 4-pin master mode, UCxSTE is a digital output. In this mode the slave enable signal for a single slave is automatically generated on UCxSTE. The corresponding behavior can be seen in [Figure 31-4](#).

If multiple slaves are desired, this feature is not applicable and the software needs to use general purpose I/O pins instead to generate STE signals for each slave individually.

### 31.3.4 Slave Mode



**Figure 31-3. eUSCI Slave and External Master**

[Figure 31-3](#) shows the eUSCI as a slave in both 3-pin and 4-pin configurations. UCxCLK is used as the input for the SPI clock and must be supplied by the external master. The data-transfer rate is determined by this clock and not by the internal bit clock generator. Data written to UCxTXBUF and moved to the TX shift register before the start of UCxCLK is transmitted on UCxSOMI. Data on UCxSIMO is shifted into the receive shift register on the opposite edge of UCxCLK and moved to UCxRXBUF when the set number of bits are received. When data is moved from the RX shift register to UCxRXBUF, the UCRXIFG interrupt flag is set, indicating that data has been received. The overrun error bit UCOE is set when the previously received data is not read from UCxRXBUF before new data is moved to UCxRXBUF.

### 31.3.4.1 4-Pin SPI Slave Mode

In 4-pin slave mode, UCxSTE is a digital input used by the slave to enable the transmit and receive operations and is driven by the SPI master. When UCxSTE is in the slave-active state, the slave operates normally. When UCxSTE is in the slave-inactive state:

- Any receive operation in progress on UCxSIMO is halted.
- UCxSOMI is set to the input direction.
- The shift operation is halted until the UCxSTE line transitions into the slave transmit active state.

The UCxSTE input signal is not used in 3-pin slave mode.

### 31.3.5 SPI Enable

When the eUSCI module is enabled by clearing the UCSWRST bit, it is ready to receive and transmit. In master mode, the bit clock generator is ready, but is not clocked nor producing any clocks. In slave mode, the bit clock generator is disabled and the clock is provided by the master.

A transmit or receive operation is indicated by UCBUSY = 1.

A PUC or set UCSWRST bit disables the eUSCI immediately and any active transfer is terminated.

#### 31.3.5.1 Transmit Enable

In master mode, writing to UCxTXBUF activates the bit clock generator, and the data begins to transmit.

In slave mode, transmission begins when a master provides a clock and, in 4-pin mode, when the UCxSTE is in the slave-active state.

#### 31.3.5.2 Receive Enable

The SPI receives data when a transmission is active. Receive and transmit operations operate concurrently.

### 31.3.6 Serial Clock Control

UCxCLK is provided by the master on the SPI bus. When UCMST = 1, the bit clock is provided by the eUSCI bit clock generator on the UCxCLK pin. The clock used to generate the bit clock is selected with the UCSSELx bits. When UCMST = 0, the eUSCI clock is provided on the UCxCLK pin by the master, the bit clock generator is not used, but the UCSSELx bits must be set to 0. The SPI receiver and transmitter operate in parallel and use the same clock source for data transfer.

The 16-bit value of UCBRx in the bit rate control registers UCxxBRW is the division factor of the eUSCI clock source, BRCLK. With UCBRx = 0 the maximum bit clock that can be generated in master mode is BRCLK. Modulation is not used in SPI mode, and UCAxMCTL should be cleared when using SPI mode for eUSCI\_A.

The UCAxCLK or UCBxCLK frequency is given by:

$$f_{\text{BitClock}} = f_{\text{BRCLK}} / \text{UCBRx}$$

If  $\text{UCBRx} = 0$ ,  $f_{\text{BitClock}} = f_{\text{BRCLK}}$

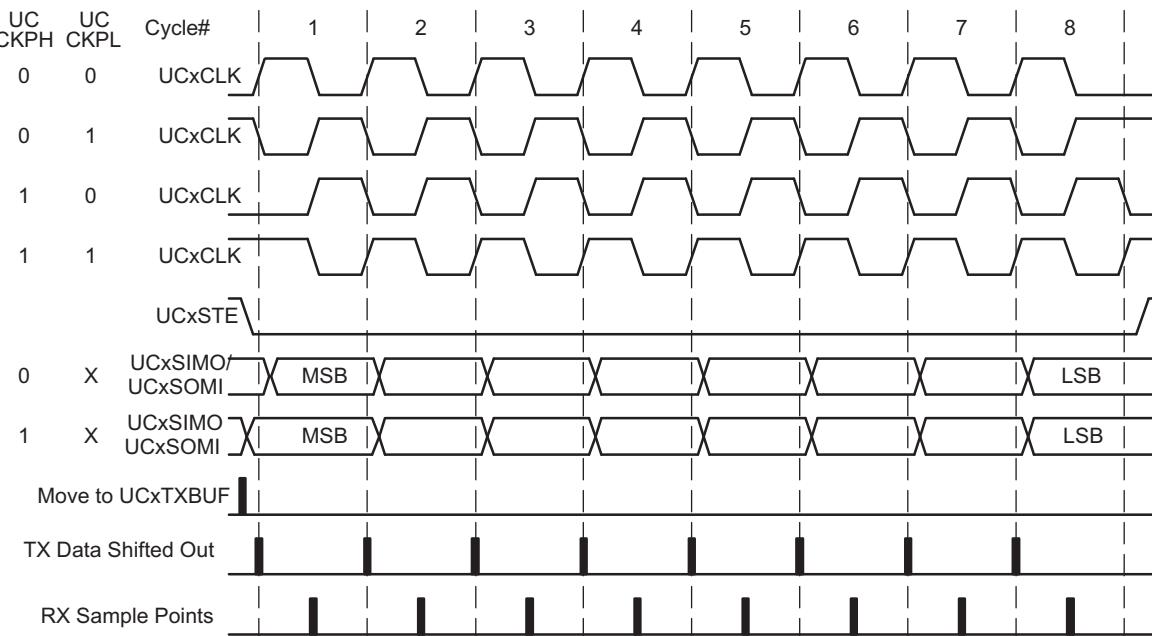
Even UCBRx settings result in even divisions and, thus, generate a bit clock with a 50/50 duty cycle.

Odd UCBRx settings result in odd divisions. In this case, the high phase of the bit clock is one BRCLK cycle longer than the low phase.

When UCBRx = 0, no division is applied to BRCLK, and the bit clock equals BRCLK.

#### 31.3.6.1 Serial Clock Polarity and Phase

The polarity and phase of UCxCLK are independently configured through the UCCKPL and UCCKPH control bits of the eUSCI. Timing for each case is shown in [Figure 31-4](#).



**Figure 31-4. eUSCI SPI Timing With UCMSB = 1**

### 31.3.7 Using the SPI Mode With Low-Power Modes

The eUSCI module provides automatic clock activation for use with low-power modes. When the eUSCI clock source is inactive because the device is in a low-power mode, the eUSCI module automatically activates it when needed, regardless of the control-bit settings for the clock source. The clock remains active until the eUSCI module returns to its idle condition. After the eUSCI module returns to the idle condition, control of the clock source reverts to the settings of its control bits.

In SPI slave mode, no internal clock source is required because the clock is provided by the external master. It is possible to operate the eUSCI in SPI slave mode while the device is in LPM4 and all clock sources are disabled. The receive or transmit interrupt can wake up the CPU from any low-power mode.

### 31.3.8 eUSCI Interrupts in SPI Mode

The eUSCI has only one interrupt vector that is shared for transmission and for reception. eUSCI\_Ax and eUSCI\_Bx do not share the same interrupt vector.

#### 31.3.8.1 SPI Transmit Interrupt Operation

The UCTXIFG interrupt flag is set by the transmitter to indicate that UCxTXBUF is ready to accept another character. An interrupt request is generated if UCTXIE and GIE are also set. UCTXIFG is automatically reset if a character is written to UCxTXBUF. UCTXIFG is set after a PUC or when UCSWRST = 1. UCTXIE is reset after a PUC or when UCSWRST = 1.

**NOTE: Writing to UCxTXBUF in SPI mode**

Data written to UCxTXBUF when UCTXIFG = 0 may result in erroneous data transmission.

#### 31.3.8.2 SPI Receive Interrupt Operation

The UCRXIFG interrupt flag is set each time a character is received and loaded into UCxRXBUF. An interrupt request is generated if UCRXIE and GIE are also set. UCRXIFG and UCRXIE are reset by a system reset PUC signal or when UCSWRST = 1. UCRXIFG is automatically reset when UCxRXBUF is read.

### 31.3.8.3 UCxIV, Interrupt Vector Generator

The eUSCI interrupt flags are prioritized and combined to source a single interrupt vector. The interrupt vector register UCxIV is used to determine which flag requested an interrupt. The highest-priority enabled interrupt generates a number in the UCxIV register that can be evaluated or added to the program counter (PC) to automatically enter the appropriate software routine. Disabled interrupts do not affect the UCxIV value.

Any access, read or write, of the UCxIV register automatically resets the highest-pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt.

#### 31.3.8.3.1 UCxIV Software Example

The following software example shows the recommended use of UCxIV. The UCxIV value is added to the PC to automatically jump to the appropriate routine. The following example is given for eUSCI\_B0.

```
USCI_SPI_ISR
    ADD      &UCB0IV, PC ; Add offset to jump table
    RETI
    JMP      RXIFG_ISR  ; Vector 0: No interrupt
    ...
    TXIFG_ISR
    ...
    RETI
    RXIFG_ISR
    ...
    RETI
```

### 31.4 eUSCI\_A SPI Registers

The eUSCI\_A registers applicable in SPI mode and their address offsets are listed in [Table 31-2](#). The base addresses can be found in the device-specific data sheet.

**Table 31-2. eUSCI\_A SPI Registers**

| Offset | Acronym   | Register Name                  | Type       | Access | Reset | Section                        |
|--------|-----------|--------------------------------|------------|--------|-------|--------------------------------|
| 00h    | UCAxCTLW0 | eUSCI_Ax Control Word 0        | Read/write | Word   | 0001h | <a href="#">Section 31.4.1</a> |
| 00h    | UCAxCTL1  | eUSCI_Ax Control 1             | Read/write | Byte   | 01h   |                                |
| 01h    | UCAxCTL0  | eUSCI_Ax Control 0             | Read/write | Byte   | 00h   |                                |
| 06h    | UCAxBRW   | eUSCI_Ax Bit Rate Control Word | Read/write | Word   | 0000h | <a href="#">Section 31.4.2</a> |
| 06h    | UCAxBR0   | eUSCI_Ax Bit Rate Control 0    | Read/write | Byte   | 00h   |                                |
| 07h    | UCAxBR1   | eUSCI_Ax Bit Rate Control 1    | Read/write | Byte   | 00h   |                                |
| 0Ah    | UCAxSTATW | eUSCI_Ax Status                | Read/write | Word   | 00h   | <a href="#">Section 31.4.3</a> |
| 0Ch    | UCAxRXBUF | eUSCI_Ax Receive Buffer        | Read/write | Word   | 00h   | <a href="#">Section 31.4.4</a> |
| 0Eh    | UCAxTXBUF | eUSCI_Ax Transmit Buffer       | Read/write | Word   | 00h   | <a href="#">Section 31.4.5</a> |
| 1Ah    | UCAxIE    | eUSCI_Ax Interrupt Enable      | Read/write | Word   | 00h   | <a href="#">Section 31.4.6</a> |
| 1Ch    | UCAxIFG   | eUSCI_Ax Interrupt Flag        | Read/write | Word   | 02h   | <a href="#">Section 31.4.7</a> |
| 1Eh    | UCAxIV    | eUSCI_Ax Interrupt Vector      | Read       | Word   | 0000h | <a href="#">Section 31.4.8</a> |

### 31.4.1 UCAXCTLW0 Register

eUSCI\_Ax Control Register 0

**Figure 31-5. UCAXCTLW0 Register**

| 15      | 14     | 13       | 12     | 11    | 10      | 9       | 8    |
|---------|--------|----------|--------|-------|---------|---------|------|
| UCCKPH  | UCCKPL | UCMSB    | UC7BIT | UCMST | UCMODEx | UCSYNC  |      |
| rw-0    | rw-0   | rw-0     | rw-0   | rw-0  | rw-0    | rw-0    | rw-0 |
| 7       | 6      | 5        | 4      | 3     | 2       | 1       | 0    |
| UCSSELx |        | Reserved |        |       | UCSTEM  | UCSWRST |      |
| rw-0    | rw-0   | rw-0     | rw-0   | rw-0  | rw-0    | rw-0    | rw-1 |

Can be modified only when UCSWRST = 1.

**Table 31-3. UCAXCTLW0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                              |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | UCCKPH   | RW   | 0h    | Clock phase select<br>0b = Data is changed on the first UCLK edge and captured on the following edge.<br>1b = Data is captured on the first UCLK edge and changed on the following edge.                                                                                                                 |
| 14   | UCCKPL   | RW   | 0h    | Clock polarity select<br>0b = The inactive state is low.<br>1b = The inactive state is high.                                                                                                                                                                                                             |
| 13   | UCMSB    | RW   | 0h    | MSB first select. Controls the direction of the receive and transmit shift register.<br>0b = LSB first<br>1b = MSB first                                                                                                                                                                                 |
| 12   | UC7BIT   | RW   | 0h    | Character length. Selects 7-bit or 8-bit character length.<br>0b = 8-bit data<br>1b = 7-bit data                                                                                                                                                                                                         |
| 11   | UCMST    | RW   | 0h    | Master mode select<br>0b = Slave mode<br>1b = Master mode                                                                                                                                                                                                                                                |
| 10-9 | UCMODEx  | RW   | 0h    | eUSCI mode. The UCMODEx bits select the synchronous mode when UCSYNC = 1.<br>00b = 3-pin SPI<br>01b = 4-pin SPI with UCxSTE active high: Slave enabled when UCxSTE = 1<br>10b = 4-pin SPI with UCxSTE active low: Slave enabled when UCxSTE = 0<br>11b = Reserved                                        |
| 8    | UCSYNC   | RW   | 0h    | Synchronous mode enable<br>0b = Asynchronous mode<br>1b = Synchronous mode                                                                                                                                                                                                                               |
| 7-6  | UCSSELx  | RW   | 0h    | eUSCI clock source select. These bits select the BRCLK source clock.<br>00b = UCxCLK in slave mode. Do not use in master mode.<br>01b = ACLK in master mode. Do not use in slave mode.<br>10b = SMCLK in master mode. Do not use in slave mode.<br>11b = SMCLK in master mode. Do not use in slave mode. |
| 5-2  | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                 |
| 1    | UCSTEM   | RW   | 0h    | STE mode select in master mode. This byte is ignored in slave or 3-wire mode.<br>0b = STE pin is used to prevent conflicts with other masters<br>1b = STE pin is used to generate the enable signal for a 4-wire slave                                                                                   |
| 0    | UCSWRST  | RW   | 1h    | Software reset enable<br>0b = Disabled. eUSCI reset released for operation.<br>1b = Enabled. eUSCI logic held in reset state.                                                                                                                                                                            |

### 31.4.2 UCAXBRW Register

eUSCI\_Ax Bit Rate Control Register 1

**Figure 31-6. UCAXBRW Register**

|       |    |    |    |    |    |    |    |
|-------|----|----|----|----|----|----|----|
| 15    | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |
| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

Can be modified only when UCSWRST = 1.

**Table 31-4. UCAXBRW Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                    |
|------|-------|------|-------|----------------------------------------------------------------------------------------------------------------|
| 15-0 | UCBRx | RW   | 0h    | Bit clock prescaler setting.<br>$f_{BitClock} = f_{BRCLK} / UCBRx$<br>If UCBRx = 0, $f_{BitClock} = f_{BRCLK}$ |

### 31.4.3 UCAXSTATW Register

eUSCI\_Ax Status Register

**Figure 31-7. UCAXSTATW Register**

|          |      |      |      |          |      |      |        |
|----------|------|------|------|----------|------|------|--------|
| 15       | 14   | 13   | 12   | 11       | 10   | 9    | 8      |
| Reserved |      |      |      |          |      |      |        |
| r0       | r0   | r0   | r0   | r0       | r0   | r0   | r0     |
| 7        | 6    | 5    | 4    | 3        | 2    | 1    | 0      |
| UCLISTEN | UCFE | UCOE |      | Reserved |      |      | UCBUSY |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0     | rw-0 | rw-0 | r-0    |

Can be modified only when UCSWRST = 1.

**Table 31-5. UCAXSTATW Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                    |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                       |
| 7    | UCLISTEN | RW   | 0h    | Listen enable. The UCLISTEN bit selects loopback mode.<br>0b = Disabled<br>1b = Enabled. The transmitter output is internally fed back to the receiver.                                                                                                                                                        |
| 6    | UCFE     | RW   | 0h    | Framing error flag. This bit indicates a bus conflict in 4-wire master mode. UCFE is not used in 3-wire master or any slave mode.<br>0b = No error<br>1b = Bus conflict occurred                                                                                                                               |
| 5    | UCOE     | RW   | 0h    | Overrun error flag. This bit is set when a character is transferred into UCxRXBUF before the previous character was read. UCOE is cleared automatically when UCxRXBUF is read, and must not be cleared by software. Otherwise, it does not function correctly.<br>0b = No error<br>1b = Overrun error occurred |
| 4-1  | Reserved | RW   | 0h    | Reserved                                                                                                                                                                                                                                                                                                       |
| 0    | UCBUSY   | R    | 0h    | eUSCI busy. This bit indicates if a transmit or receive operation is in progress.<br>0b = eUSCI inactive<br>1b = eUSCI transmitting or receiving                                                                                                                                                               |

### **31.4.4 UCAXRXBUF Register**

eUSCI\_Ax Receive Buffer Register

**Figure 31-8. UCAXRXBUF Register**

|          |    |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|----|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Reserved |    |    |    |    |    |    |    |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| UCRXBUFx |    |    |    |    |    |    |    |
| rw       | rw | rw | rw | rw | rw | rw | rw |

**Table 31-6. UCAXRXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                 |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                    |
| 7-0  | UCRXBUFx | R    | 0h    | The receive-data buffer is user accessible and contains the last received character from the receive shift register. Reading UCxRXBUF resets the receive-error bits and UCRXIFG. In 7-bit data mode, UCxRXBUF is LSB justified and the MSB is always reset. |

### 31.4.5 UCAXTXBUF Register

eUSCI\_Ax Transmit Buffer Register

**Figure 31-9. UCAXTXBUF Register**

|          |    |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|----|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Reserved |    |    |    |    |    |    |    |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| 7        | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| UCTXBUFx |    |    |    |    |    |    |    |
| rw       | rw | rw | rw | rw | rw | rw | rw |

**Table 31-7. UCAXTXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                           |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                              |
| 7-0  | UCTXBUFx | RW   | 0h    | The transmit data buffer is user accessible and holds the data waiting to be moved into the transmit shift register and transmitted. Writing to the transmit data buffer clears UCTXIFG. The MSB of UCxTXBUF is not used for 7-bit data and is reset. |

### **31.4.6 UCAXIE Register**

eUSCI\_Ax Interrupt Enable Register

**Figure 31-10. UCAXIE Register**

|          |     |     |     |     |     |      |      |
|----------|-----|-----|-----|-----|-----|------|------|
| 15       | 14  | 13  | 12  | 11  | 10  | 9    | 8    |
| Reserved |     |     |     |     |     |      |      |
| r0       | r0  | r0  | r0  | r0  | r0  | r0   | r0   |
| 7        | 6   | 5   | 4   | 3   | 2   | 1    | 0    |
| Reserved |     |     |     |     |     |      |      |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-0 | rw-0 |

**Table 31-8. UCAXIE Register Description**

| Bit  | Field    | Type | Reset | Description                                                                    |
|------|----------|------|-------|--------------------------------------------------------------------------------|
| 15-2 | Reserved | R    | 0h    | Reserved                                                                       |
| 1    | UCTXIE   | RW   | 0h    | Transmit interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 0    | UCRXIE   | RW   | 0h    | Receive interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |

### 31.4.7 UCAXIFG Register

eUSCI\_Ax Interrupt Flag Register

**Figure 31-11. UCAXIFG Register**

|          |     |     |     |     |     |      |      |
|----------|-----|-----|-----|-----|-----|------|------|
| 15       | 14  | 13  | 12  | 11  | 10  | 9    | 8    |
| Reserved |     |     |     |     |     |      |      |
| r0       | r0  | r0  | r0  | r0  | r0  | r0   | r0   |
| 7        | 6   | 5   | 4   | 3   | 2   | 1    | 0    |
| Reserved |     |     |     |     |     |      |      |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-1 | rw-0 |

**Table 31-9. UCAXIFG Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                     |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-2 | Reserved | R    | 0h    | Reserved                                                                                                                                        |
| 1    | UCTXIFG  | RW   | 1h    | Transmit interrupt flag. UCTXIFG is set when UCxxTXBUF empty.<br>0b = No interrupt pending<br>1b = Interrupt pending                            |
| 0    | UCRXIFG  | RW   | 0h    | Receive interrupt flag. UCRXIFG is set when UCxxRXBUF has received a complete character.<br>0b = No interrupt pending<br>1b = Interrupt pending |

### **31.4.8 UCAXIV Register**

eUSCI\_Ax Interrupt Vector Register

**Figure 31-12. UCAXIV Register**

|       |    |    |     |     |     |     |    |
|-------|----|----|-----|-----|-----|-----|----|
| 15    | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| UCIVx |    |    |     |     |     |     |    |
| r0    | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| UCIVx |    |    |     |     |     |     |    |
| r0    | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 31-10. UCAXIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                        |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | UCIVx | R    | 0h    | eUSCI interrupt vector value<br>000h = No interrupt pending<br>002h = Interrupt Source: Data received; Interrupt Flag: UCRXIFG; Interrupt Priority: Highest<br>004h = Interrupt Source: Transmit buffer empty; Interrupt Flag: UCTXIFG; Interrupt Priority: Lowest |

### 31.5 eUSCI\_B SPI Registers

The eUSCI\_B registers applicable in SPI mode and their address offsets are listed in [Table 31-11](#). The base addresses can be found in the device-specific data sheet.

**Table 31-11. eUSCI\_B SPI Registers**

| Offset | Acronym   | Register Name                  | Type       | Access | Reset | Section                        |
|--------|-----------|--------------------------------|------------|--------|-------|--------------------------------|
| 00h    | UCBxCTLW0 | eUSCI_Bx Control Word 0        | Read/write | Word   | 01C1h | <a href="#">Section 31.5.1</a> |
| 00h    | UCBxCTL1  | eUSCI_Bx Control 1             | Read/write | Byte   | C1h   |                                |
| 01h    | UCBxCTL0  | eUSCI_Bx Control 0             | Read/write | Byte   | 01h   |                                |
| 06h    | UCBxBRW   | eUSCI_Bx Bit Rate Control Word | Read/write | Word   | 0000h | <a href="#">Section 31.5.2</a> |
| 06h    | UCBxBR0   | eUSCI_Bx Bit Rate Control 0    | Read/write | Byte   | 00h   |                                |
| 07h    | UCBxBR1   | eUSCI_Bx Bit Rate Control 1    | Read/write | Byte   | 00h   |                                |
| 08h    | UCBxSTATW | eUSCI_Bx Status                | Read/write | Word   | 00h   | <a href="#">Section 31.5.3</a> |
| 0Ch    | UCBxRXBUF | eUSCI_Bx Receive Buffer        | Read/write | Word   | 00h   | <a href="#">Section 31.5.4</a> |
| 0Eh    | UCBxTXBUF | eUSCI_Bx Transmit Buffer       | Read/write | Word   | 00h   | <a href="#">Section 31.5.5</a> |
| 2Ah    | UCBxIE    | eUSCI_Bx Interrupt Enable      | Read/write | Word   | 00h   | <a href="#">Section 31.5.6</a> |
| 2Ch    | UCBxIFG   | eUSCI_Bx Interrupt Flag        | Read/write | Word   | 02h   | <a href="#">Section 31.5.7</a> |
| 2Eh    | UCBxIV    | eUSCI_Bx Interrupt Vector      | Read       | Word   | 0000h | <a href="#">Section 31.5.8</a> |

### 31.5.1 UCBxCTLW0 Register

eUSCI\_Bx Control Register 0

**Figure 31-13. UCBxCTLW0 Register**

| 15      | 14     | 13       | 12     | 11    | 10      | 9       | 8    |
|---------|--------|----------|--------|-------|---------|---------|------|
| UCCKPH  | UCCKPL | UCMSB    | UC7BIT | UCMST | UCMODEx | UCSYNC  |      |
| rw-0    | rw-0   | rw-0     | rw-0   | rw-0  | rw-0    | rw-0    | rw-1 |
| 7       | 6      | 5        | 4      | 3     | 2       | 1       | 0    |
| UCSSELx |        | Reserved |        |       | UCSTEM  | UCSWRST |      |
| rw-1    | rw-1   | r0       | rw-0   | rw-0  | rw-0    | rw-0    | rw-1 |

Can be modified only when UCSWRST = 1.

**Table 31-12. UCBxCTLW0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                          |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | UCCKPH   | RW   | 0h    | Clock phase select<br>0b = Data is changed on the first UCLK edge and captured on the following edge.<br>1b = Data is captured on the first UCLK edge and changed on the following edge.                                                                                                             |
| 14   | UCCKPL   | RW   | 0h    | Clock polarity select<br>0b = The inactive state is low.<br>1b = The inactive state is high.                                                                                                                                                                                                         |
| 13   | UCMSB    | RW   | 0h    | MSB first select. Controls the direction of the receive and transmit shift register.<br>0b = LSB first<br>1b = MSB first                                                                                                                                                                             |
| 12   | UC7BIT   | RW   | 0h    | Character length. Selects 7-bit or 8-bit character length.<br>0b = 8-bit data<br>1b = 7-bit data                                                                                                                                                                                                     |
| 11   | UCMST    | RW   | 0h    | Master mode select<br>0b = Slave mode<br>1b = Master mode                                                                                                                                                                                                                                            |
| 10-9 | UCMODEx  | RW   | 0h    | eUSCI mode. The UCMODEx bits select the synchronous mode when UCSYNC = 1.<br>00b = 3-pin SPI<br>01b = 4-pin SPI with UCxSTE active high: Slave enabled when UCxSTE = 1<br>10b = 4-pin SPI with UCxSTE active low: Slave enabled when UCxSTE = 0<br>11b = I2C mode                                    |
| 8    | UCSYNC   | RW   | 1h    | Synchronous mode enable<br>0b = Asynchronous mode<br>1b = Synchronous mode                                                                                                                                                                                                                           |
| 7-6  | UCSSELx  | RW   | 3h    | eUSCI clock source select. These bits select the BRCLK source clock.<br>00b = UCxCLK in slave mode. Don't use in master mode.<br>01b = ACLK in master mode. Don't use in slave mode.<br>10b = SMCLK in master mode. Don't use in slave mode.<br>11b = SMCLK in master mode. Don't use in slave mode. |
| 5-2  | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                             |
| 1    | UCSTEM   | RW   | 0h    | STE mode select in master mode. This byte is ignored in slave or 3-wire mode.<br>0b = STE pin is used to prevent conflicts with other masters<br>1b = STE pin is used to generate the enable signal for a 4-wire slave                                                                               |
| 0    | UCSWRST  | RW   | 1h    | Software reset enable<br>0b = Disabled. eUSCI reset released for operation.<br>1b = Enabled. eUSCI logic held in reset state.                                                                                                                                                                        |

### 31.5.2 UCBxBRW Register

eUSCI\_Bx Bit Rate Control Register 1

**Figure 31-14. UCBxBRW Register**

|       |    |    |    |    |    |    |    |
|-------|----|----|----|----|----|----|----|
| 15    | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |
| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

Can be modified only when UCSWRST = 1.

**Table 31-13. UCBxBRW Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                |
|------|-------|------|-------|----------------------------------------------------------------------------------------------------------------------------|
| 15-0 | UCBRx | RW   | 0h    | Bit clock prescaler setting.<br>$f_{BitClock} = f_{BRCLK} / UCBRx$<br>If UCBR <sub>X</sub> = 0, $f_{BitClock} = f_{BRCLK}$ |

### 31.5.3 UCBxSTATW Register

eUSCI\_Bx Status Register

**Figure 31-15. UCBxSTATW Register**

|          |      |      |    |          |    |    |        |
|----------|------|------|----|----------|----|----|--------|
| 15       | 14   | 13   | 12 | 11       | 10 | 9  | 8      |
| Reserved |      |      |    |          |    |    |        |
| r0       | r0   | r0   | r0 | r0       | r0 | r0 | r0     |
| 7        | 6    | 5    | 4  | 3        | 2  | 1  | 0      |
| UCLISTEN | UCFE | UCOE |    | Reserved |    |    | UCBUSY |
| rw-0     | rw-0 | rw-0 | r0 | r0       | r0 | r0 | r-0    |

Can be modified only when UCSWRST = 1.

**Table 31-14. UCBxSTATW Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                    |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                       |
| 7    | UCLISTEN | RW   | 0h    | Listen enable. The UCLISTEN bit selects loopback mode.<br>0b = Disabled<br>1b = Enabled. The transmitter output is internally fed back to the receiver.                                                                                                                                                        |
| 6    | UCFE     | RW   | 0h    | Framing error flag. This bit indicates a bus conflict in 4-wire master mode. UCFE is not used in 3-wire master or any slave mode.<br>0b = No error<br>1b = Bus conflict occurred                                                                                                                               |
| 5    | UCOE     | RW   | 0h    | Overrun error flag. This bit is set when a character is transferred into UCxRXBUF before the previous character was read. UCOE is cleared automatically when UCxRXBUF is read, and must not be cleared by software. Otherwise, it does not function correctly.<br>0b = No error<br>1b = Overrun error occurred |
| 4-1  | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                       |
| 0    | UCBUSY   | R    | 0h    | eUSCI busy. This bit indicates if a transmit or receive operation is in progress.<br>0b = eUSCI inactive<br>1b = eUSCI transmitting or receiving                                                                                                                                                               |

### 31.5.4 UCBxRXBUF Register

eUSCI\_Bx Receive Buffer Register

**Figure 31-16. UCBxRXBUF Register**

|          |    |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|----|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Reserved |    |    |    |    |    |    |    |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| UCRXBUFx |    |    |    |    |    |    |    |
| rw       | rw | rw | rw | rw | rw | rw | rw |

**Table 31-15. UCBxRXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                 |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                    |
| 7-0  | UCRXBUFx | R    | 0h    | The receive-data buffer is user accessible and contains the last received character from the receive shift register. Reading UCxRXBUF resets the receive-error bits and UCRXIFG. In 7-bit data mode, UCxRXBUF is LSB justified and the MSB is always reset. |

### 31.5.5 UCBxTXBUF Register

eUSCI\_Bx Transmit Buffer Register

**Figure 31-17. UCBxTXBUF Register**

|          |    |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|----|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Reserved |    |    |    |    |    |    |    |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| UCTXBUFx |    |    |    |    |    |    |    |
| rw       | rw | rw | rw | rw | rw | rw | rw |

**Table 31-16. UCBxTXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                           |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                              |
| 7-0  | UCTXBUFx | RW   | 0h    | The transmit data buffer is user accessible and holds the data waiting to be moved into the transmit shift register and transmitted. Writing to the transmit data buffer clears UCTXIFG. The MSB of UCxTXBUF is not used for 7-bit data and is reset. |

### 31.5.6 UCBxIE Register

eUSCI\_Bx Interrupt Enable Register

**Figure 31-18. UCBxIE Register**

|          |     |     |     |     |     |        |        |
|----------|-----|-----|-----|-----|-----|--------|--------|
| 15       | 14  | 13  | 12  | 11  | 10  | 9      | 8      |
| Reserved |     |     |     |     |     |        |        |
| r0       | r0  | r0  | r0  | r0  | r0  | r0     | r0     |
| 7        | 6   | 5   | 4   | 3   | 2   | 1      | 0      |
| Reserved |     |     |     |     |     | UCTXIE | UCRXIE |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-0   | rw-0   |

**Table 31-17. UCBxIE Register Description**

| Bit  | Field    | Type | Reset | Description                                                                    |
|------|----------|------|-------|--------------------------------------------------------------------------------|
| 15-2 | Reserved | R    | 0h    | Reserved                                                                       |
| 1    | UCTXIE   | RW   | 0h    | Transmit interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 0    | UCRXIE   | RW   | 0h    | Receive interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |

### 31.5.7 UCBxIFG Register

eUSCI\_Bx Interrupt Flag Register

**Figure 31-19. UCBxIFG Register**

|          |     |     |     |     |     |         |         |
|----------|-----|-----|-----|-----|-----|---------|---------|
| 15       | 14  | 13  | 12  | 11  | 10  | 9       | 8       |
| Reserved |     |     |     |     |     |         |         |
| r0       | r0  | r0  | r0  | r0  | r0  | r0      | r0      |
| 7        | 6   | 5   | 4   | 3   | 2   | 1       | 0       |
| Reserved |     |     |     |     |     | UCTXIFG | UCRXIFG |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | rw-1    | rw-0    |

**Table 31-18. UCBxIFG Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                     |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-2 | Reserved | R    | 0h    | Reserved                                                                                                                                        |
| 1    | UCTXIFG  | RW   | 1h    | Transmit interrupt flag. UCTXIFG is set when UCxxTXBUF empty.<br>0b = No interrupt pending<br>1b = Interrupt pending                            |
| 0    | UCRXIFG  | RW   | 0h    | Receive interrupt flag. UCRXIFG is set when UCxxRXBUF has received a complete character.<br>0b = No interrupt pending<br>1b = Interrupt pending |

### **31.5.8 UCBxIV Register**

eUSCI\_Bx Interrupt Vector Register

**Figure 31-20. UCBxIV Register**

|       |    |    |     |     |     |     |    |
|-------|----|----|-----|-----|-----|-----|----|
| 15    | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| UCIVx |    |    |     |     |     |     |    |
| r0    | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| UCIVx |    |    |     |     |     |     |    |
| r0    | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 31-19. UCBxIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                           |
|------|-------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | UCIVx | R    | 0h    | eUSCI interrupt vector value<br>0000h = No interrupt pending<br>0002h = Interrupt Source: Data received; Interrupt Flag: UCRXIFG; Interrupt Priority: Highest<br>0004h = Interrupt Source: Transmit buffer empty; Interrupt Flag: UCTXIFG; Interrupt Priority: Lowest |

## ***Enhanced Universal Serial Communication Interface (eUSCI) – I<sup>2</sup>C Mode***

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The enhanced universal serial communication interface B (eUSCI\_B) supports multiple serial communication modes with one hardware module. This chapter discusses the operation of the I<sup>2</sup>C mode.

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## 32.1 Enhanced Universal Serial Communication Interface B (eUSCI\_B) Overview

The eUSCI\_B module supports two serial communication modes:

- I<sup>2</sup>C mode
- SPI mode

If more than one eUSCI\_B module is implemented on one device, those modules are named with incrementing numbers. For example, if one device has two eUSCI\_B modules, they are named eUSCI0\_B and eUSCI1\_B.

## 32.2 eUSCI\_B Introduction – I<sup>2</sup>C Mode

In I<sup>2</sup>C mode, the eUSCI\_B module provides an interface between the device and I<sup>2</sup>C-compatible devices connected by the two-wire I<sup>2</sup>C serial bus. External components attached to the I<sup>2</sup>C bus serially transmit or receive serial data to or from the eUSCI\_B module through the 2-wire I<sup>2</sup>C interface.

The eUSCI\_B I<sup>2</sup>C mode features include:

- 7-bit and 10-bit device addressing modes
- General call
- START, RESTART, STOP
- Multi-master transmitter or receiver mode
- Slave receiver or transmitter mode
- Standard mode up to 100 kbps and fast mode up to 400 kbps support
- Programmable UCxCLK frequency in master mode
- Designed for low power
- 8-bit byte counter with interrupt capability and automatic STOP assertion
- Up to four hardware slave addresses, each having its own interrupt and DMA trigger
- Mask register for slave address and address received interrupt
- Clock low time-out interrupt to avoid bus stalls
- Slave operation in LPM4
- Slave receiver START detection for auto wake-up from LPMx modes (not LPM3.5 and LPM4.5)

Figure 32-1 shows the eUSCI\_B when configured in I<sup>2</sup>C mode.

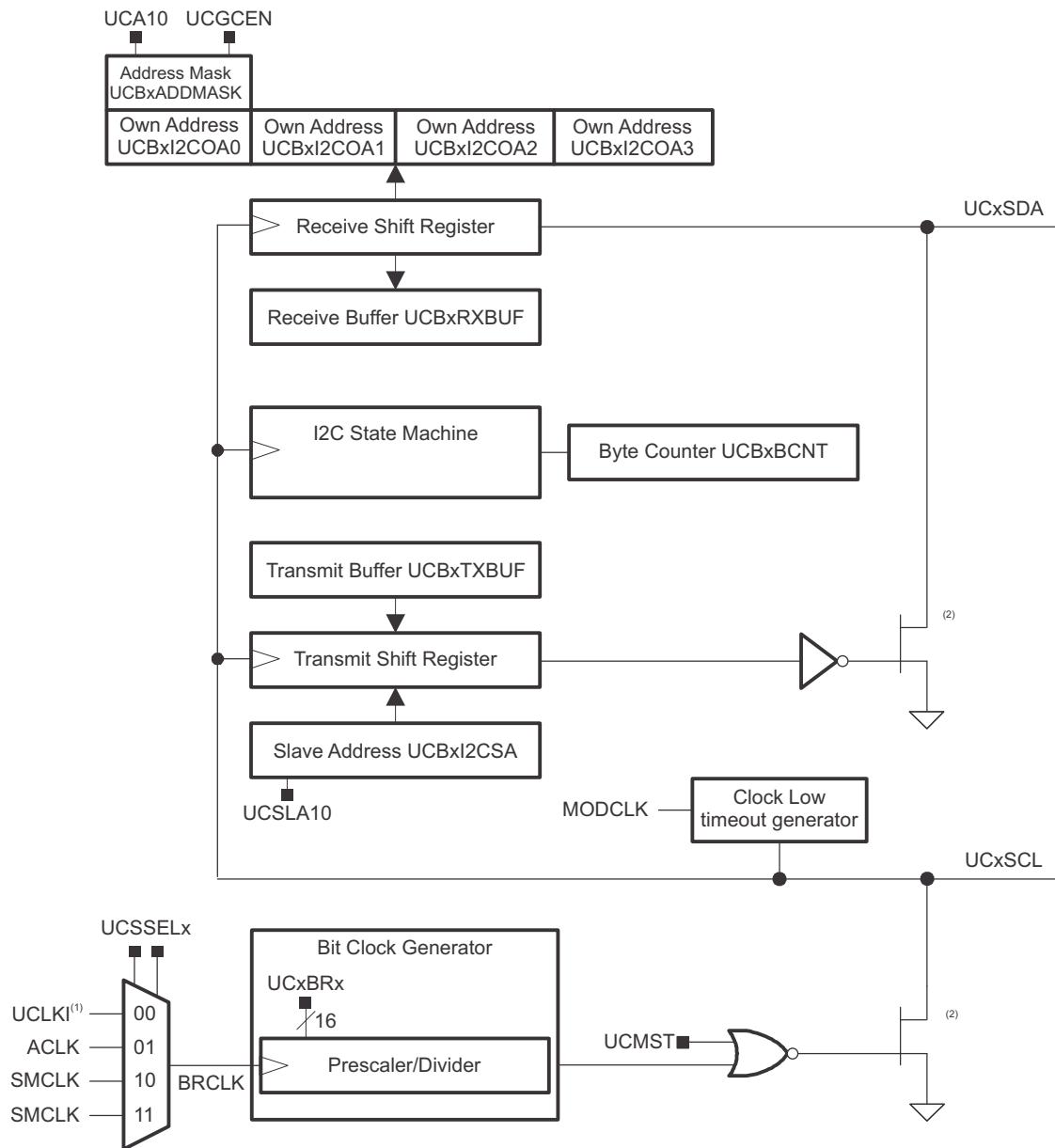
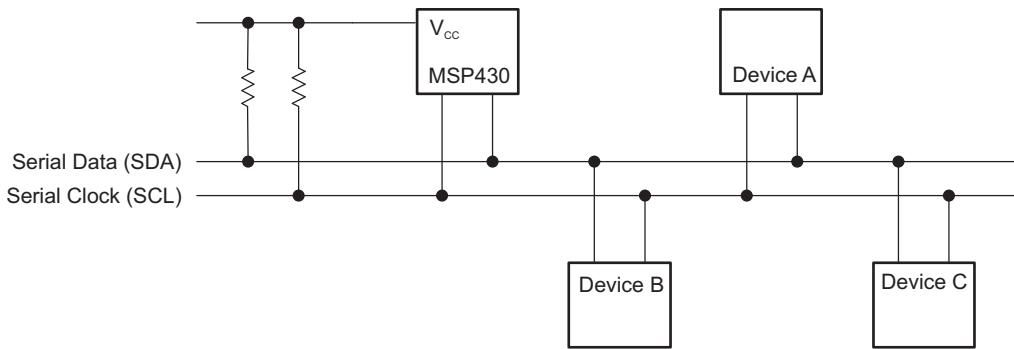


Figure 32-1. eUSCI\_B Block Diagram – I<sup>2</sup>C Mode

### 32.3 eUSCI\_B Operation – I<sup>2</sup>C Mode

The I<sup>2</sup>C mode supports any slave or master I<sup>2</sup>C-compatible device. Figure 32-2 shows an example of an I<sup>2</sup>C bus. Each I<sup>2</sup>C device is recognized by a unique address and can operate as either a transmitter or a receiver. A device connected to the I<sup>2</sup>C bus can be considered as the master or the slave when performing data transfers. A master initiates a data transfer and generates the clock signal SCL. Any device addressed by a master is considered a slave.

I<sup>2</sup>C data is communicated using the serial data (SDA) pin and the serial clock (SCL) pin. Both SDA and SCL are bidirectional and must be connected to a positive supply voltage using a pullup resistor.



**Figure 32-2. I<sup>2</sup>C Bus Connection Diagram**

---

**NOTE: SDA and SCL levels**

The SDA and SCL pins must not be pulled up above the device V<sub>cc</sub> level.

---

### 32.3.1 eUSCI\_B Initialization and Reset

The eUSCI\_B is reset by a PUC or by setting the UCSWRST bit. After a PUC, the UCSWRST bit is automatically set, keeping the eUSCI\_B in a reset condition. To select I<sup>2</sup>C operation, the UCMODEEx bits must be set to 11b. After module initialization, it is ready for transmit or receive operation. Clear UCSWRST to release the eUSCI\_B for operation.

To avoid unpredictable behavior, configure or reconfigure the eUSCI\_B module only when UCSWRST is set. Setting UCSWRST in I<sup>2</sup>C mode has the following effects:

- I<sup>2</sup>C communication stops.
- SDA and SCL are high impedance.
- UCBxSTAT, bits 15-8 and 6-4 are cleared.
- Registers UCBxIE and UCBxIFG are cleared.
- All other bits and registers remain unchanged.

---

**NOTE: Initializing or reconfiguring the eUSCI\_B module**

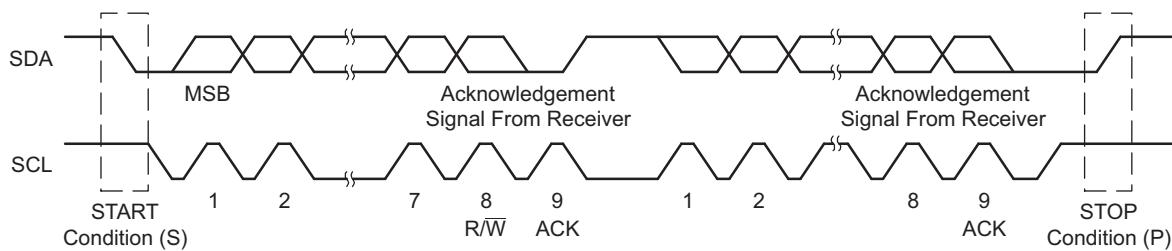
The recommended eUSCI\_B initialization/reconfiguration process is:

1. Set UCSWRST (`BIS.B #UCSWRST, &UCxCTL1`).
  2. Initialize all eUSCI\_B registers with UCSWRST = 1 (including UCxCTL1).
  3. Configure ports.
  4. Clear UCSWRST through software (`BIC.B #UCSWRST, &UCxCTL1`).
  5. Enable interrupts (optional).
- 

### 32.3.2 I<sup>2</sup>C Serial Data

One clock pulse is generated by the master device for each data bit transferred. The I<sup>2</sup>C mode operates with byte data. Data is transferred MSB first as shown in Figure 32-3.

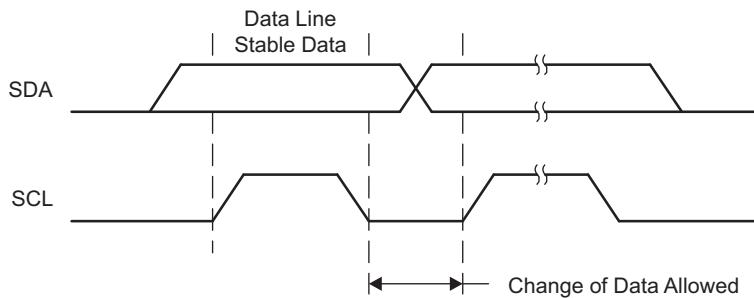
The first byte after a START condition consists of a 7-bit slave address and the R/W bit. When R/W = 0, the master transmits data to a slave. When R/W = 1, the master receives data from a slave. The ACK bit is sent from the receiver after each byte on the ninth SCL clock.



**Figure 32-3. I<sup>C</sup> Module Data Transfer**

START and STOP conditions are generated by the master and are shown in [Figure 32-3](#). A START condition is a high-to-low transition on the SDA line while SCL is high. A STOP condition is a low-to-high transition on the SDA line while SCL is high. The bus busy bit, UCBBUSY, is set after a START and cleared after a STOP.

Data on SDA must be stable during the high period of SCL (see [Figure 32-4](#)). The high and low state of SDA can change only when SCL is low, otherwise START or STOP conditions are generated.



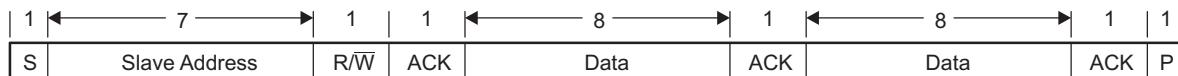
**Figure 32-4. Bit Transfer on I<sup>C</sup> Bus**

### 32.3.3 I<sup>C</sup> Addressing Modes

The I<sup>C</sup> mode supports 7-bit and 10-bit addressing modes.

#### 32.3.3.1 7-Bit Addressing

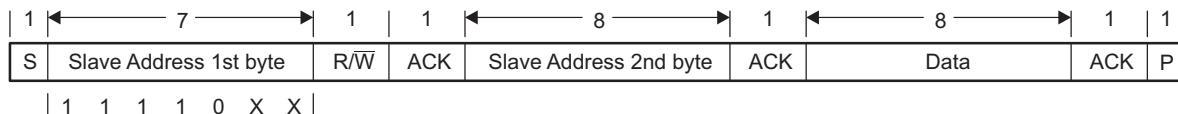
In the 7-bit addressing format (see [Figure 32-5](#)), the first byte is the 7-bit slave address and the R/W bit. The ACK bit is sent from the receiver after each byte.



**Figure 32-5. I<sup>C</sup> Module 7-Bit Addressing Format**

#### 32.3.3.2 10-Bit Addressing

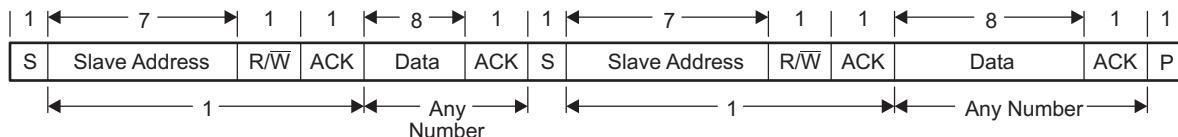
In the 10-bit addressing format (see [Figure 32-6](#)), the first byte is made up of 11110b plus the two MSBs of the 10-bit slave address and the R/W bit. The ACK bit is sent from the receiver after each byte. The next byte is the remaining eight bits of the 10-bit slave address, followed by the ACK bit and the 8-bit data. See [I2C Slave 10-bit Addressing Mode](#) and [I2C Master 10-bit Addressing Mode](#) for details how to use the 10-bit addressing mode with the eUSCI\_B module.



**Figure 32-6. I<sup>2</sup>C Module 10-Bit Addressing Format**

### 32.3.3.3 Repeated Start Conditions

The direction of data flow on SDA can be changed by the master, without first stopping a transfer, by issuing a repeated START condition. This is called a RESTART. After a RESTART is issued, the slave address is again sent out with the new data direction specified by the R/W bit. The RESTART condition is shown in Figure 32-7.



**Figure 32-7. I<sup>2</sup>C Module Addressing Format With Repeated START Condition**

### 32.3.4 I<sup>2</sup>C Quick Setup

This section gives a quick introduction into the operation of the eUSCI\_B in I<sup>2</sup>C mode. The basic steps to start communication are described and shown as a software example. More detailed information about the possible configurations and details can be found in [Section 32.3.5](#).

The latest code examples can be found on the MSP430 web under "Code Examples".

To set up the eUSCI\_B as a master transmitter that transmits to a slave with the address 0x12h, only a few steps are needed (see [Example 32-1](#)).

#### Example 32-1. Master TX With 7-Bit Address

```

UCBxCTL1 |= UCSWRST;           // put eUSCI_B in reset state
UCBxCTLW0 |= UCMODE_3 + UCMST; // I2C master mode
UCBxBRW = 0x0008;              // baud rate = SMCLK / 8
UCBxCTLW1 = UCASTP_2;         // automatic STOP assertion
UCBxTBCNT = 0x07;              // TX 7 bytes of data
UCBxI2CSA = 0x0012;            // address slave is 12hex
P2SEL |= 0x03;                 // configure I2C pins (device specific)
UCBxCTL1 &= ^UCSWRST;          // eUSCI_B in operational state
UCBxIE |= UCTXIE;              // enable TX-interrupt
GIE;                           // general interrupt enable
...
// inside the eUSCI_B TX interrupt service routine
UCBxTXBUF = 0x77;              // fill TX buffer

```

As shown in the code example, all configurations must be done while UCSWRST is set. To select the I<sup>2</sup>C operation of the eUSCI\_B, UCMODE must be set accordingly. The baud rate of the transmission is set by writing the correct divider in the UCBxBRW register. The default clock selected is SMCLK. How many bytes are transmitted in one frame is controlled by the byte counter threshold register UCBxTBCNT together with the UCASPx bits.

The slave address to send to is specified in the UCBxI2CSA register. Finally, the ports must be configured. This step is device dependent; see the data sheet for the pins that must be used.

Each byte that is to be transmitted must be written to the UCBxTXBUF inside the interrupt service routine. The recommended structure of the interrupt service routine can be found in [Example 32-3](#).

[Example 32-2](#) shows the steps needed to set up the eUSCI\_B as a slave with the address 0x12h that is able to receive and transmit data to the master.

#### Example 32-2. Slave RX With 7-Bit Address

```

UCBxCTL1 |= UCSWRST;           // eUSCI_B in reset state
UCBxCTLW0 |= UCMODE_3;         // I2C slave mode
UCBxI2COA0 = 0x0412;          // own address is 12hex
P2SEL |= 0x03;                // configure I2C pins (device specific)
UCBxCTL1 &= ^UCSWRST;         // eUSCI_B in operational state
UCBxIE |= UCTXIE + UCRXIE;   // enable TX&RX-interrupt
GIE;                          // general interrupt enable
...
// inside the eUSCI_B TX interrupt service routine
UCBxTXBUF = 0x77;             // send 077h
...
// inside the eUSCI_B RX interrupt service routine
data = UCBxRXBUF;             // data is the internal variable

```

As shown in [Example 32-2](#), all configurations must be done while UCSWRST is set. For the slave, I<sup>2</sup>C operation is selected by setting UCMODE. The slave address is specified in the UCBxI2COA0 register. To enable the interrupts for receive and transmit requests, the according bits in UCBxIE and, at the end, GIE need to be set. Finally the ports must be configured. This step is device dependent; see the data sheet for the pins that are used.

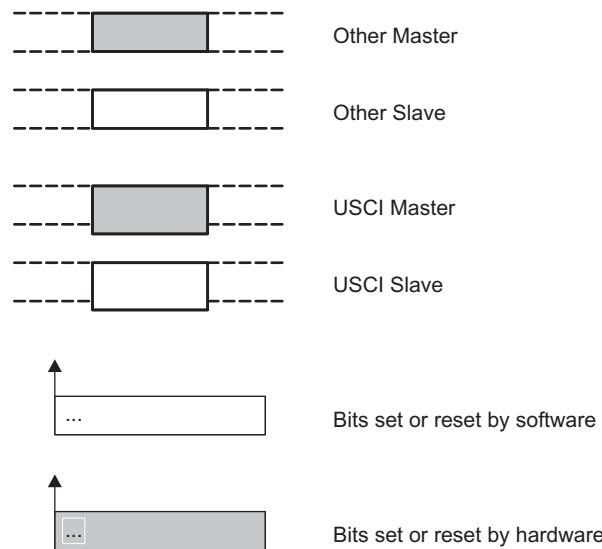
The RX interrupt service routine is called for every byte received by a master device. The TX interrupt service routine is executed each time the master requests a byte. The recommended structure of the interrupt service routine can be found in [Example 32-3](#).

#### 32.3.5 I<sup>2</sup>C Module Operating Modes

In I<sup>2</sup>C mode, the eUSCI\_B module can operate in master transmitter, master receiver, slave transmitter, or slave receiver mode. The modes are discussed in the following sections. Time lines are used to illustrate the modes.

[Figure 32-8](#) shows how to interpret the time-line figures. Data transmitted by the master is represented by grey rectangles; data transmitted by the slave is represented by white rectangles. Data transmitted by the eUSCI\_B module, either as master or slave, is shown by rectangles that are taller than the others.

Actions taken by the eUSCI\_B module are shown in grey rectangles with an arrow indicating where in the data stream the action occurs. Actions that must be handled with software are indicated with white rectangles with an arrow pointing to where in the data stream the action must take place.



**Figure 32-8. I<sup>2</sup>C Time-Line Legend**

### 32.3.5.1 Slave Mode

The eUSCI\_B module is configured as an I<sup>2</sup>C slave by selecting the I<sup>2</sup>C mode with UCMODEEx = 11 and UCSYNC = 1 and clearing the UCMST bit.

Initially, the eUSCI\_B module must be configured in receiver mode by clearing the UCTR bit to receive the I<sup>2</sup>C address. Afterwards, transmit and receive operations are controlled automatically, depending on the R/W bit received together with the slave address.

The eUSCI\_B slave address is programmed with the UCBxI2COA0 register. Support for multiple slave addresses is explained in [Section 32.3.9](#). When UCA10 = 0, 7-bit addressing is selected. When UCA10 = 1, 10-bit addressing is selected. The UCGCEN bit selects if the slave responds to a general call.

When a START condition is detected on the bus, the eUSCI\_B module receives the transmitted address and compares it against its own address stored in UCBxI2COA0. The UCSTTIFG flag is set when address received matches the eUSCI\_B slave address.

#### 32.3.5.1.1 I<sup>2</sup>C Slave Transmitter Mode

Slave transmitter mode is entered when the slave address transmitted by the master is identical to its own address with a set R/W bit. The slave transmitter shifts the serial data out on SDA with the clock pulses that are generated by the master device. The slave device does not generate the clock, but it does hold SCL low while intervention of the CPU is required after a byte has been transmitted.

If the master requests data from the slave, the eUSCI\_B module is automatically configured as a transmitter and UCTR and UCTXIFG0 become set. The SCL line is held low until the first data to be sent is written into the transmit buffer UCBxTXBUF. Then the address is acknowledged and the data is transmitted. As soon as the data is transferred into the shift register, the UCTXIFG0 is set again. After the data is acknowledged by the master, the next data byte written into UCBxTXBUF is transmitted or, if the buffer is empty, the bus is stalled during the acknowledge cycle by holding SCL low until new data is written into UCBxTXBUF. If the master sends a NACK followed by a STOP condition, the UCSTPIFG flag is set. If the NACK is followed by a repeated START condition, the eUSCI\_B I<sup>2</sup>C state machine returns to its address-reception state.

[Figure 32-9](#) shows the slave transmitter operation.

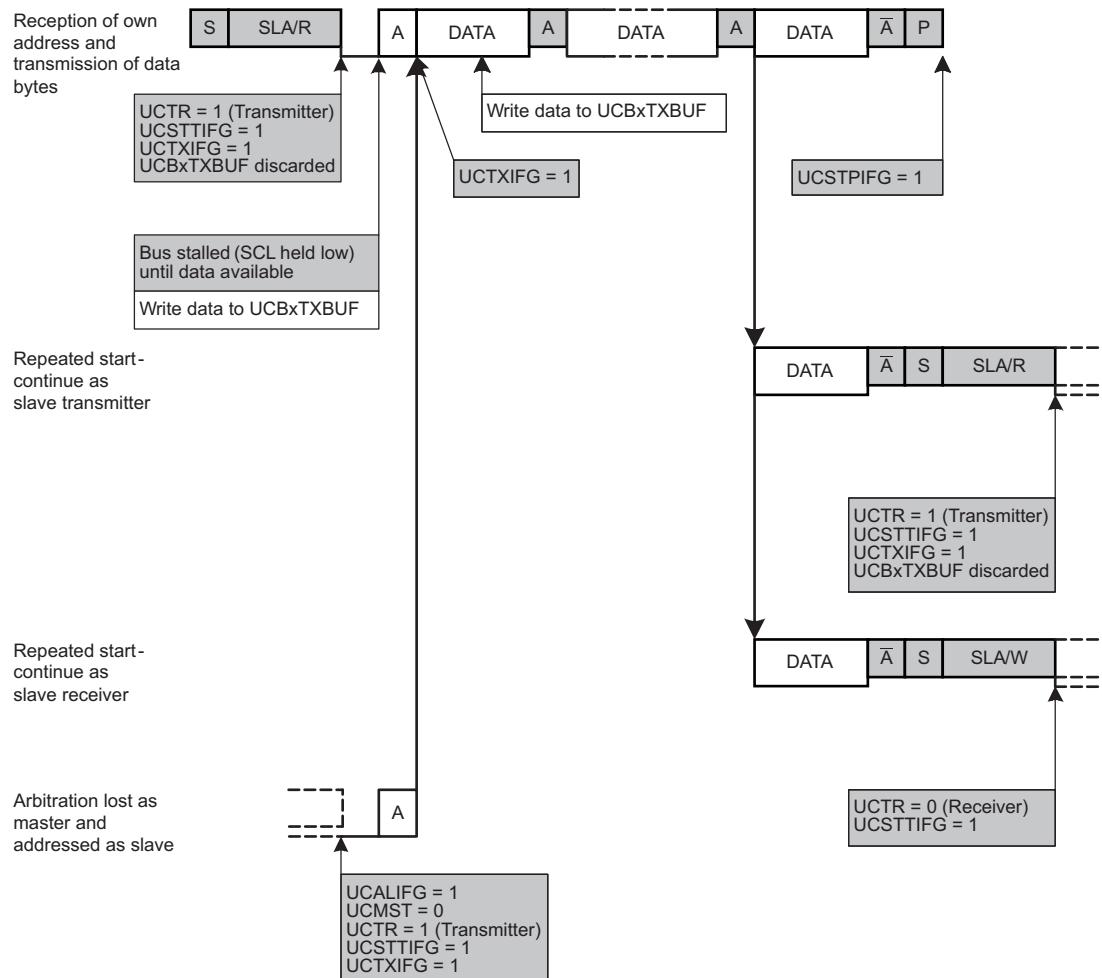


Figure 32-9. I<sup>C</sup> Slave Transmitter Mode

### 32.3.5.1.2 I<sup>C</sup> Slave Receiver Mode

Slave receiver mode is entered when the slave address transmitted by the master is identical to its own address and a cleared R/W bit is received. In slave receiver mode, serial data bits received on SDA are shifted in with the clock pulses that are generated by the master device. The slave device does not generate the clock, but it can hold SCL low if intervention of the CPU is required after a byte has been received.

If the slave receives data from the master, the eUSCI\_B module is automatically configured as a receiver and UCTR is cleared. After the first data byte is received, the receive interrupt flag UCRXIFG0 is set. The eUSCI\_B module automatically acknowledges the received data and can receive the next data byte.

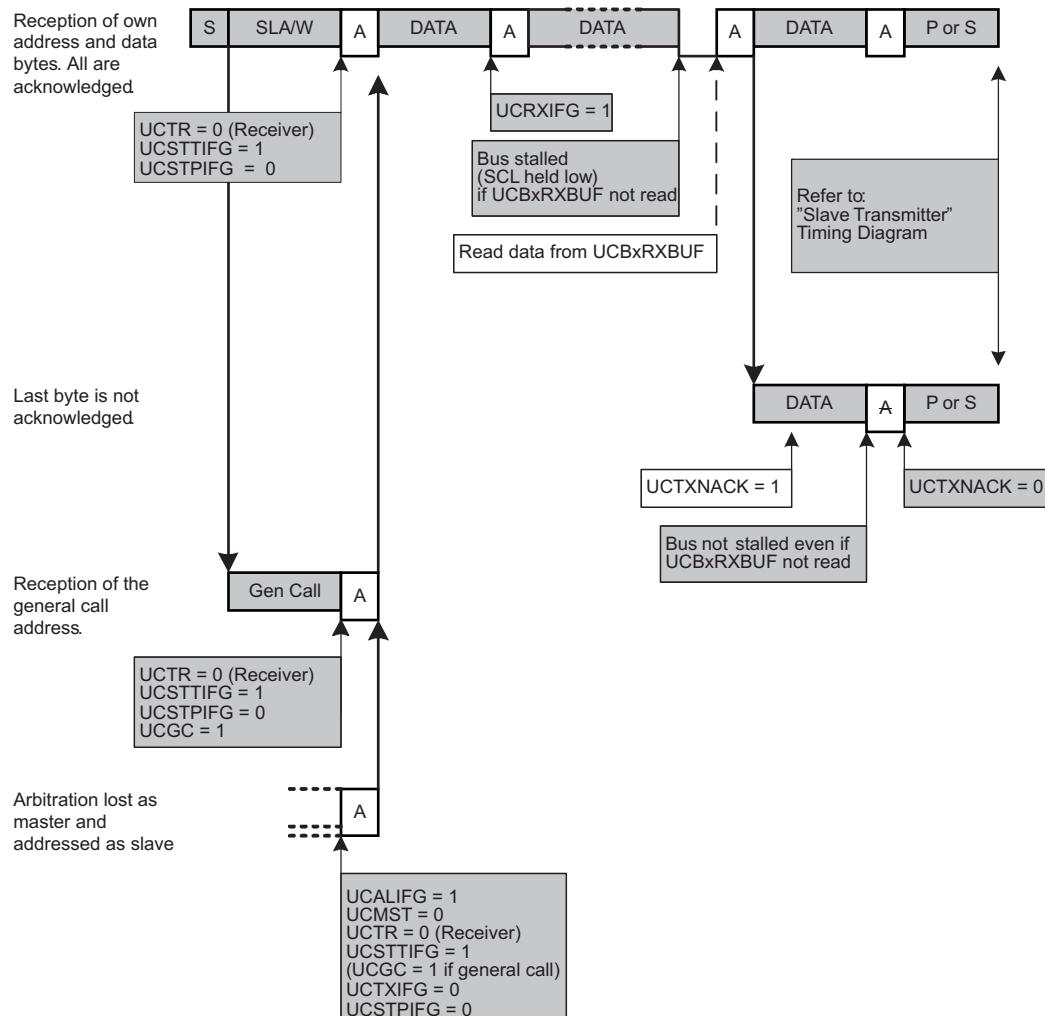
If the previous data was not read from the receive buffer UCBxRXBUF at the end of a reception, the bus is stalled by holding SCL low. As soon as UCBxRXBUF is read, the new data is transferred into UCBxRXBUF, an acknowledge is sent to the master, and the next data can be received.

Setting the UCTXNACK bit causes a NACK to be transmitted to the master during the next acknowledgment cycle. A NACK is sent even if UCBxRXBUF is not ready to receive the latest data. If the UCTXNACK bit is set while SCL is held low, the bus is released, a NACK is transmitted immediately, and UCBxRXBUF is loaded with the last received data. Because the previous data was not read, that data is lost. To avoid loss of data, the UCBxRXBUF must be read before UCTXNACK is set.

When the master generates a STOP condition, the UCSTPIFG flag is set.

If the master generates a repeated START condition, the eUSCI\_B I<sup>2</sup>C state machine returns to its address-reception state.

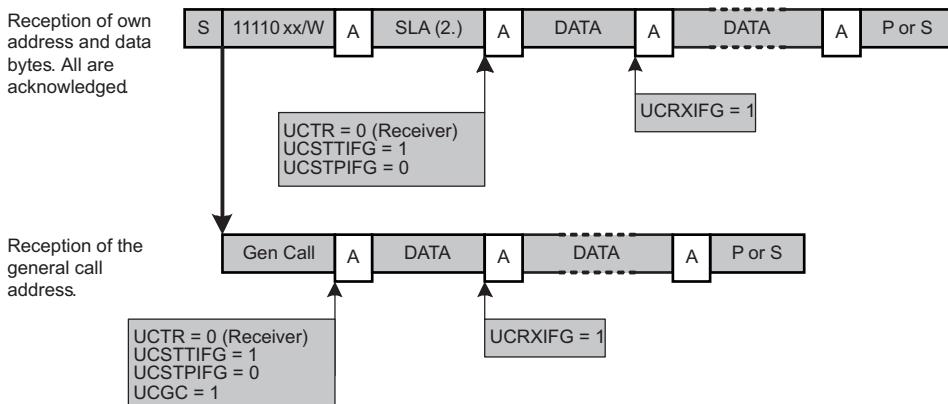
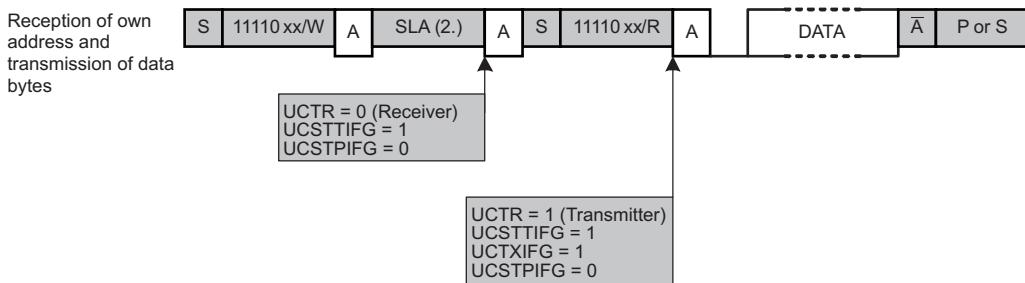
[Figure 32-10](#) shows the I<sup>2</sup>C slave receiver operation.



**Figure 32-10. I<sup>2</sup>C Slave Receiver Mode**

### 32.3.5.1.3 I<sup>2</sup>C Slave 10-Bit Addressing Mode

The 10-bit addressing mode is selected when UCA10 = 1 and is shown in [Figure 32-11](#). In 10-bit addressing mode, the slave is in receive mode after the full address is received. The eUSCI\_B module indicates this by setting the UCSTTIFG flag while the UCTR bit is cleared. To switch the slave into transmitter mode, the master sends a repeated START condition together with the first byte of the address but with the R/W bit set. This sets the UCSTTIFG flag if it was previously cleared by software, and the eUSCI\_B module switches to transmitter mode with UCTR = 1.

**Slave Receiver****Slave Transmitter****Figure 32-11. I<sup>2</sup>C Slave 10-Bit Addressing Mode****32.3.5.2 Master Mode**

The eUSCI\_B module is configured as an I<sup>2</sup>C master by selecting the I<sup>2</sup>C mode with UCMODEEx = 11 and UCSYNC = 1 and setting the UCMST bit. When the master is part of a multi-master system, UCMM must be set and its own address must be programmed into the UCBxI2COA0 register. Support for multiple slave addresses is explained in [Section 32.3.9](#). When UCA10 = 0, 7-bit addressing is selected. When UCA10 = 1, 10-bit addressing is selected. The UCGCEN bit selects if the eUSCI\_B module responds to a general call.

**NOTE: Addresses and multi-master systems**

In master mode with own-address detection enabled (UCOAE = 1)—especially in multi-master systems—it is not allowed to specify the same address in the own address and slave address register (UCBxI2CSA = UCBxI2COAx). This would mean that the eUSCI\_B addresses itself.

The user software must ensure that this situation does not occur. There is no hardware detection for this case, and the consequence is unpredictable behavior of the eUSCI\_B.

### 32.3.5.2.1 I<sup>2</sup>C Master Transmitter Mode

After initialization, master transmitter mode is initiated by writing the desired slave address to the UCBxI2CSA register, selecting the size of the slave address with the UCSLA10 bit, setting UCTR for transmitter mode, and setting UCTXSTT to generate a START condition.

The eUSCI\_B module waits until the bus is available, then generates the START condition, and transmits the slave address. The UCTXIFG0 bit is set when the START condition is generated and the first data to be transmitted can be written into UCBxTXBUF. **The UCTXSTT flag is cleared as soon as the complete address is sent.**

The data written into UCBxTXBUF is transmitted if arbitration is not lost during transmission of the slave address. UCTXIFG0 is set again as soon as the data is transferred from the buffer into the shift register. If there is no data loaded to UCBxTXBUF before the acknowledge cycle, the bus is held during the acknowledge cycle with SCL low until data is written into UCBxTXBUF. Data is transmitted or the bus is held, as long as:

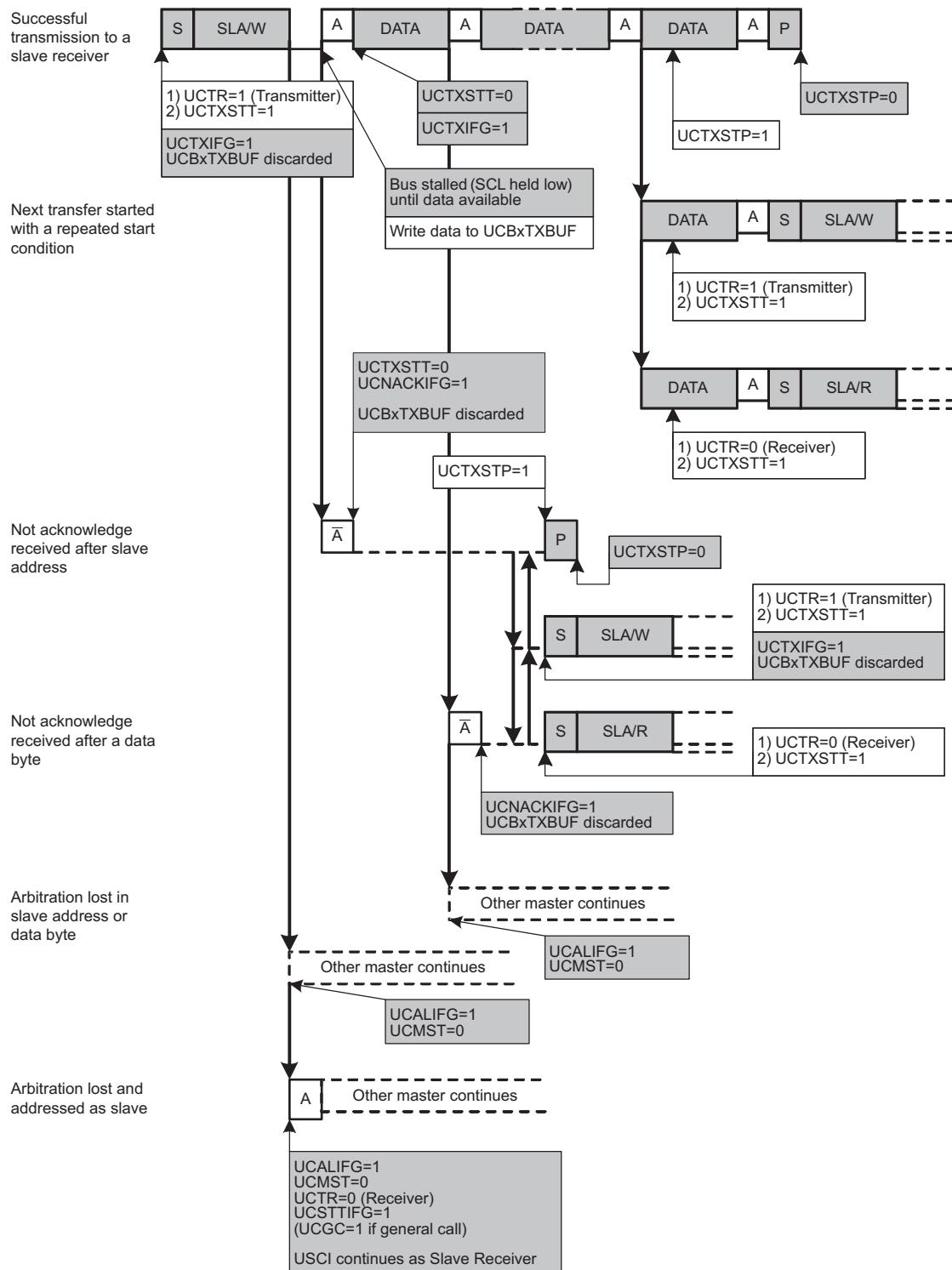
- No automatic STOP is generated
- The UCTXSTP bit is not set
- The UCTXSTT bit is not set

Setting UCTXSTP generates a STOP condition after the next acknowledge from the slave. If UCTXSTP is set during the transmission of the slave address or while the eUSCI\_B module waits for data to be written into UCBxTXBUF, a STOP condition is generated, even if no data was transmitted to the slave. **In this case, the UCSTPIFG is set.** When transmitting a single byte of data, the UCTXSTP bit must be set while the byte is being transmitted or any time after transmission begins, without writing new data into UCBxTXBUF. Otherwise, only the address is transmitted. When the data is transferred from the buffer to the shift register, UCTXIFG0 is set, indicating data transmission has begun, and the UCTXSTP bit may be set. When UCASTPx = 10 is set, the byte counter is used for STOP generation and the user does not need to set the UCTXSTP. **This is recommended when transmitting only one byte.**

Setting UCTXSTT generates a repeated START condition. In this case, UCTR may be set or cleared to configure transmitter or receiver, and a different slave address may be written into UCBxI2CSA, if desired.

If the slave does not acknowledge the transmitted data, the not-acknowledge interrupt flag UCNACKIFG is set. The master must react with either a STOP condition or a repeated START condition. If data was already written into UCBxTXBUF, it is discarded. If this data should be transmitted after a repeated START, it must be written into UCBxTXBUF again. Any set UCTXSTT or UCTXSTP is also discarded.

Figure 32-12 shows the I<sup>2</sup>C master transmitter operation.


**Figure 32-12. I<sup>C</sup> Master Transmitter Mode**

### 32.3.5.2.2 I<sup>2</sup>C Master Receiver Mode

After initialization, master receiver mode is initiated by writing the desired slave address to the UCBxI2CSA register, selecting the size of the slave address with the UCSLA10 bit, clearing UCTR for receiver mode, and setting UCTXSTT to generate a START condition.

The eUSCI\_B module checks if the bus is available, generates the START condition, and transmits the slave address. The UCTXSTT flag is cleared as soon as the complete address is sent.

After the acknowledge of the address from the slave, the first data byte from the slave is received and acknowledged and the UCRXIFG flag is set. Data is received from the slave, as long as:

- No automatic STOP is generated
- The UCTXSTP bit is not set
- The UCTXSTT bit is not set

If a STOP condition was generated by the eUSCI\_B module, the UCSTPIFG is set. If UCBxRXBUF is not read, the master holds the bus during reception of the last data bit and until the UCBxRXBUF is read.

If the slave does not acknowledge the transmitted address, the not-acknowledge interrupt flag UCNACKIFG is set. The master must react with either a STOP condition or a repeated START condition.

A STOP condition is either generated by the automatic STOP generation or by setting the UCTXSTP bit. The next byte received from the slave is followed by a NACK and a STOP condition. This NACK occurs immediately if the eUSCI\_B module is currently waiting for UCBxRXBUF to be read.

If a RESTART is sent, UCTR may be set or cleared to configure transmitter or receiver, and a different slave address may be written into UCBxI2CSA if desired.

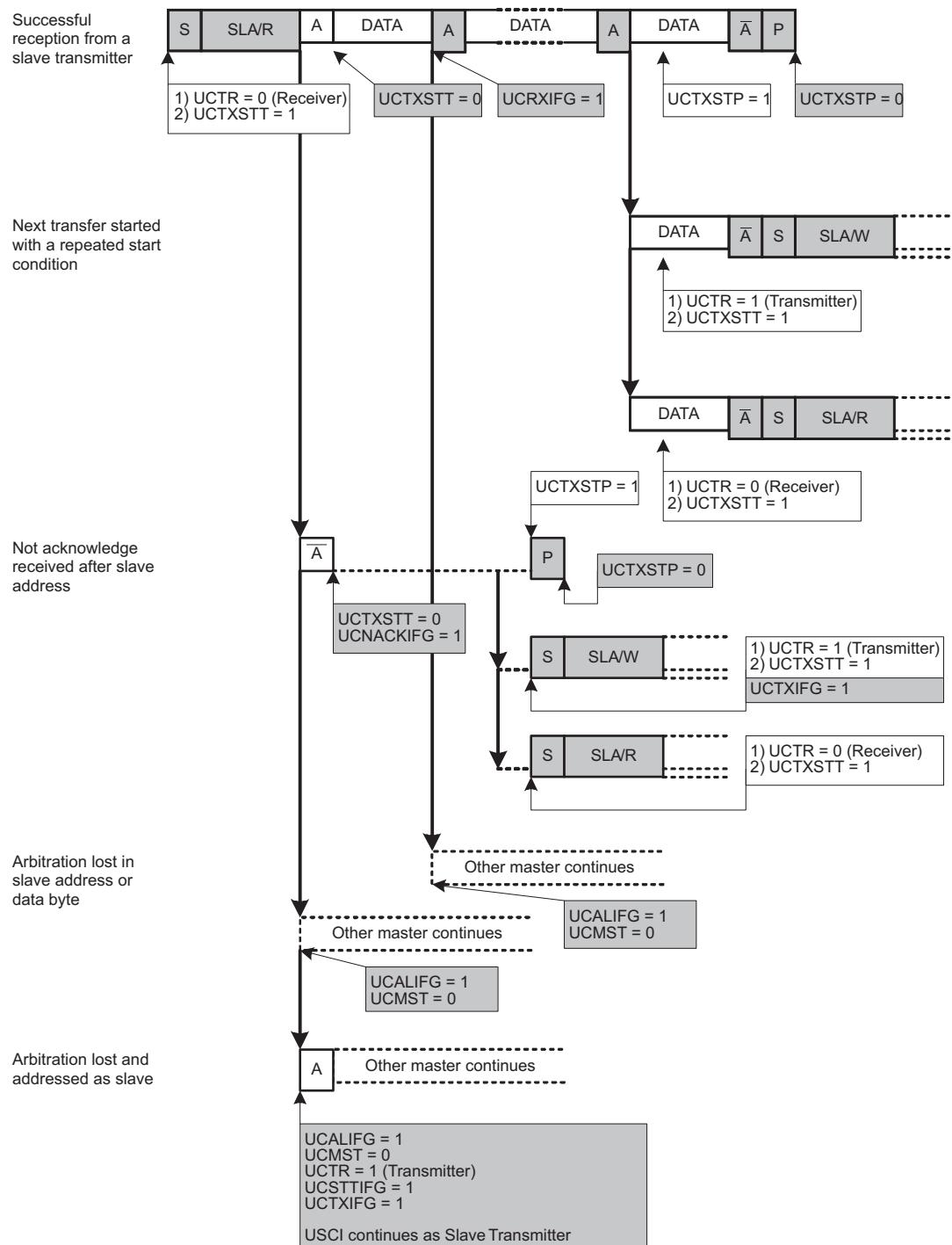
Figure 32-13 shows the I<sup>2</sup>C master receiver operation.

---

**NOTE: Consecutive master transactions without repeated START**

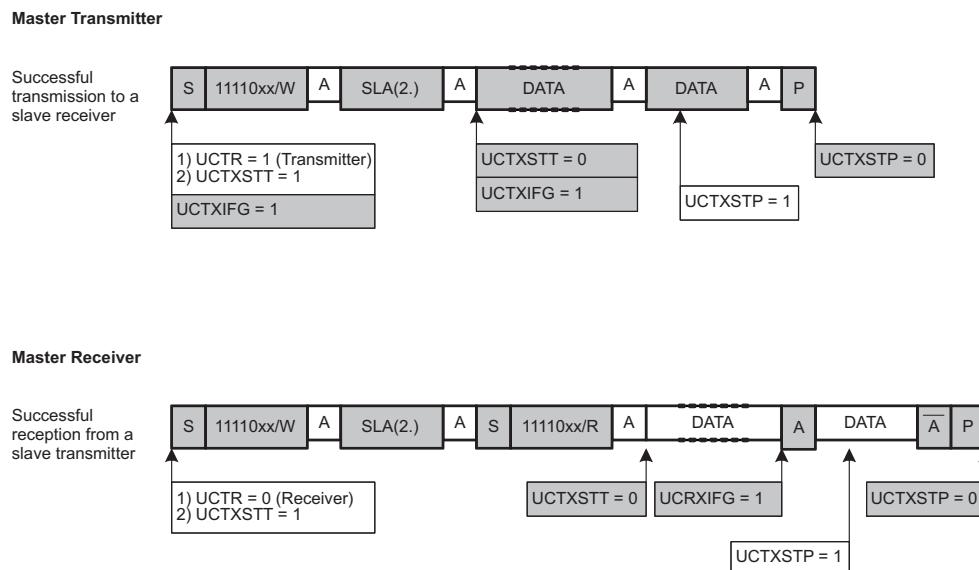
When performing multiple consecutive I<sup>2</sup>C master transactions without the repeated START feature, the current transaction must be completed before the next one is initiated. This can be done by ensuring that the transmit STOP condition flag UCTXSTP is cleared before the next I<sup>2</sup>C transaction is initiated with setting UCTXSTT = 1. Otherwise, the current transaction might be affected.

---

Figure 32-13. I<sup>2</sup>C Master Receiver Mode

### 32.3.5.2.3 I<sup>2</sup>C Master 10-Bit Addressing Mode

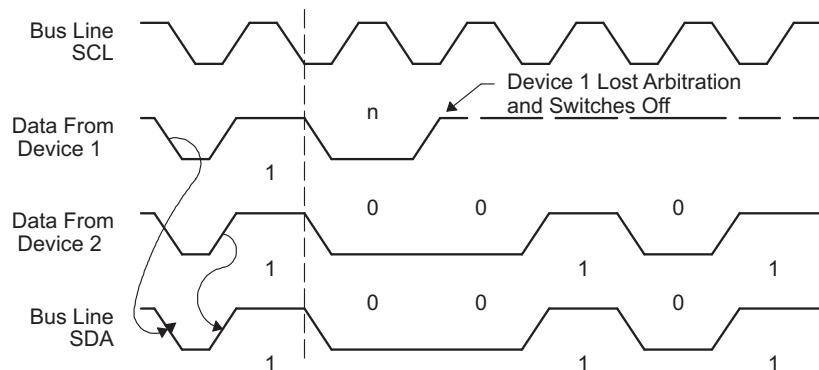
The 10-bit addressing mode is selected when UCSLA10 = 1 and is shown in [Figure 32-14](#).



**Figure 32-14. I<sup>2</sup>C Master 10-Bit Addressing Mode**

### 32.3.5.3 Arbitration

If two or more master transmitters simultaneously start a transmission on the bus, an arbitration procedure is invoked. [Figure 32-15](#) shows the arbitration procedure between two devices. The arbitration procedure uses the data presented on SDA by the competing transmitters. The first master transmitter that generates a logic high is overruled by the opposing master generating a logic low. The arbitration procedure gives priority to the device that transmits the serial data stream with the lowest binary value. The master transmitter that lost arbitration switches to the slave receiver mode and sets the arbitration lost flag UCALIFG. If two or more devices send identical first bytes, arbitration continues on the subsequent bytes.



**Figure 32-15. Arbitration Procedure Between Two Master Transmitters**

There is an undefined condition if the arbitration procedure is still in progress when one master sends a repeated START or a STOP condition while the other master is still sending data. In other words, the following combinations result in an undefined condition:

- Master 1 sends a repeated START condition and master 2 sends a data bit.
- Master 1 sends a STOP condition and master 2 sends a data bit.
- Master 1 sends a repeated START condition and master 2 sends a STOP condition.

### 32.3.6 Glitch Filtering

According to the I<sup>2</sup>C standard, both the SDA and the SCL line need to be glitch filtered. The eUSCI\_B module provides the UCGLITx bits to configure the length of this glitch filter:

**Table 32-1. Glitch Filter Length Selection Bits**

| UCGLITx | Corresponding Glitch Filter Length on SDA and SCL | According to I <sup>2</sup> C Standard |
|---------|---------------------------------------------------|----------------------------------------|
| 00      | Pulses of max 50-ns length are filtered           | yes                                    |
| 01      | Pulses of max 25-ns length are filtered.          | no                                     |
| 10      | Pulses of max 12.5-ns length are filtered.        | no                                     |
| 11      | Pulses of max 6.25-ns length are filtered.        | no                                     |

### 32.3.7 I<sup>2</sup>C Clock Generation and Synchronization

The I<sup>2</sup>C clock SCL is provided by the master on the I<sup>2</sup>C bus. When the eUSCI\_B is in master mode, BITCLK is provided by the eUSCI\_B bit clock generator and the clock source is selected with the UCSSELx bits. In slave mode, the bit clock generator is not used and the UCSSELx bits are don't care.

The 16-bit value of UCBRx in register UCBxBRW is the division factor of the eUSCI\_B clock source, BRCLK. The maximum bit clock that can be used in single master mode is  $f_{BRCLK}/4$ . In multi-master mode, the maximum bit clock is  $f_{BRCLK}/8$ . The BITCLK frequency is given by:

$$f_{BitClock} = f_{BRCLK}/UCBRx$$

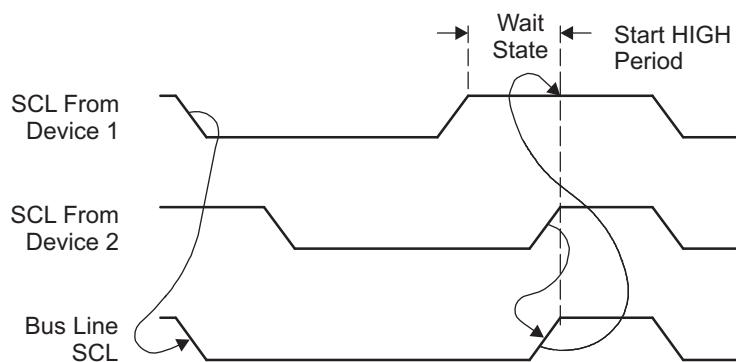
The minimum high and low periods of the generated SCL are:

$$t_{LOW,MIN} = t_{HIGH,MIN} = (UCBRx/2)/f_{BRCLK} \text{ when UCBRx is even}$$

$$t_{LOW,MIN} = t_{HIGH,MIN} = ((UCBRx - 1)/2)/f_{BRCLK} \text{ when UCBRx is odd}$$

The eUSCI\_B clock source frequency and the prescaler setting UCBRx must to be chosen such that the minimum low and high period times of the I<sup>2</sup>C specification are met.

During the arbitration procedure the clocks from the different masters must be synchronized. A device that first generates a low period on SCL overrules the other devices, forcing them to start their own low periods. SCL is then held low by the device with the longest low period. The other devices must wait for SCL to be released before starting their high periods. **Figure 32-16** shows the clock synchronization. This allows a slow slave to slow down a fast master.



**Figure 32-16. Synchronization of Two I<sup>2</sup>C Clock Generators During Arbitration**

#### 32.3.7.1 Clock Stretching

The eUSCI\_B module supports clock stretching and also makes use of this feature as described in the Operation Mode sections.

The UCSCLLOW bit can be used to observe if another device pulls SCL low while the eUSCI\_B module already released SCL due to the following conditions:

- eUSCI\_B is acting as master and a connected slave drives SCL low.

- eUSCI\_B is acting as master and another master drives SCL low during arbitration.

The UCSCLLOW bit is also active if the eUSCI\_B holds SCL low because it is waiting as transmitter for data being written into UCBxTXBUF or as receiver for the data being read from UCBxRXBUF. The UCSCLLOW bit might be set for a short time with each rising SCL edge because the logic observes the external SCL and compares it to the internally generated SCL.

### 32.3.7.2 Avoiding Clock Stretching

Even though clock stretching is part of the I<sup>2</sup>C specification, there are applications in which clock stretching should be avoided.

The clock is stretched by the eUSCI\_B under the following conditions:

- The internal shift register is expecting data, but the TXIFG is still pending
- The internal shift register is full, but the RXIFG is still pending
- The arbitration lost interrupt is pending
- UCSWACK is selected and UCBxI2COA0 did cause a match

To avoid clock stretching, all of these situations for clock stretch either need to be avoided or the corresponding interrupt flags need to be processed before the actual clock stretch can occur.

Using the DMA (on devices that contain a DMA) is the most secure way to avoid clock stretching. If no DMA is available, the software must ensure that the corresponding interrupts are serviced in time before the clock is stretched.

In slave transmitter mode, the TXIFG is set only after the reception of the direction bit; therefore, there is only a short amount of time for the software to write the TXBUF before a clock stretch occurs. This situation can be remedied by using the early Transmit Interrupt (see [Section 32.3.11.2](#)).

### 32.3.7.3 Clock Low Time-out

The UCCLTOIFG interrupt allows the software to react if the clock is low longer than a defined time. It is possible to detect the situation, when a clock is stretched by a master or slave for a too long time. The user can then, for example, reset the eUSCI\_B module by using the UCSWRST bit.

The clock low time-out feature is enabled using the UCCLTO bits. It is possible to select one of three predefined times for the clock low time-out. If the clock has been low longer than the time defined with the UCCLTO bits and the eUSCI\_B was actively receiving or transmitting, the UCCLTOIFG is set and an interrupt request is generated if UCCLTOIE and GIE are set as well. The UCCLTOIFG is set only once, even if the clock is stretched a multiple of the time defined in UCCLTO.

### **32.3.8 Byte Counter**

The eUSCI\_B module supports hardware counting of the bytes received or transmitted. The counter is automatically active and counts up for each byte seen on the bus in both master and slave mode.

The byte counter is incremented at the second bit position of each byte independently of the following ACK or NACK. A START or RESTART condition resets the counter value to zero. Address bytes do not increment the counter. The byte counter is also incremented at the second bit position, if an arbitration lost occurs during the first bit of data.

#### **32.3.8.1 Byte Counter Interrupt**

If UCASTPx = 01 or 10 the UCBCNTIFG is set when the byte counter threshold value UCBxTBCNT is reached in both master- and slave-mode. Writing zero to UCBxTBCNT does not generate an interrupt.

Because the UCBCNTIFG has a lower interrupt priority than the UCBTXIFG and UCBRXIFG, TI recommends using it only for protocol control together with the DMA handling the received and transmitted bytes. Otherwise, the application must have enough processor bandwidth to ensure that the UCBCNT interrupt routine is executed in time to generate for example a RESTART.

#### **32.3.8.2 Automatic STOP Generation**

When the eUSCI\_B module is configured as a master, the byte counter can be used for automatic STOP generation by setting the UCASTPx = 10. Before starting the transmission using UCTXSTT, the byte counter threshold UCBxTBCNT must be set to the number of bytes that are to be transmitted or received. After the number of bytes that are configured in UCBxTBCNT have been transmitted, the eUSCI\_B automatically generates a STOP condition.

UCBxTBCNT cannot be used if the user wants to transmit the slave address only without any data. In this case, TI recommends setting UCTXSTT and UCTXSTP at the same time.

### **32.3.9 Multiple Slave Addresses**

The eUSCI\_B module supports two different ways of implementing multiple slave addresses at the same time:

- Hardware support for up to 4 different slave addresses, each with its own interrupt flag and DMA trigger
- Software support for up to  $2^{10}$  different slave addresses all sharing one interrupt

### 32.3.9.1 Multiple Slave Address Registers

The registers UCBxI2COA0, UCBxI2COA1, UCBxI2COA2, and UCBxI2COA3 contain four slave addresses. Up to four address registers are compared against a received 7- or 10-bit address. Each slave address must be activated by setting the UCAOEN bit in the corresponding UCBxI2COAx register. Register UCBxI2COA3 has the highest priority if the address received on the bus matches more than one of the slave address registers. The priority decreases with the index number of the address register, so that UCBxI2COA0 in combination with the address mask has the lowest priority.

When one of the slave registers matches the 7- or 10-bit address seen on the bus, the address is acknowledged. In the following the corresponding receive- or transmit-interrupt flag (UCTXIFGx or UCRXIFGx) to the received address is updated. The state change interrupt flags are independent of the address comparison result. They are updated according to the bus condition.

### 32.3.9.2 Address Mask Register

The address mask register can be used when the eUSCI\_B is configured in slave or in multiple-master mode. To activate this feature, at least one bit of the address mask in register UCBxADDMASK must be cleared.

If the received address matches the own address in UCBxI2COA0 on all bit positions that are not masked by UCBxADDMASK, the eUSCI\_B module considers the received address as its own address. If UCSWACK = 0, the module sends an acknowledge automatically. If UCSWACK = 1, the user software must evaluate the received address in register UCBxADDRX after the UCSTTIFG is set. To acknowledge the received address, the software must set UCTXACK to 1.

The eUSCI\_B module also automatically acknowledges a slave address that is seen on the bus if the address matches any of the enabled slave addresses defined in UCBxI2COA1 to UCBxI2COA3.

---

**NOTE: UCSWACK and slave-transmitter**

If the user selects manual acknowledge of slave addresses, TXIFG is set if the slave is addressed as a transmitter. If the software decides not to acknowledge the address, TXIFG0 must be reset.

---

### 32.3.10 Using the eUSCI\_B Module in I<sup>C</sup> Mode With Low-Power Modes

The eUSCI\_B module provides automatic clock activation for use with low-power modes. When the eUSCI\_B clock source is inactive because the device is in a low-power mode, the eUSCI\_B module automatically activates it when needed, regardless of the control-bit settings for the clock source. The clock remains active until the eUSCI\_B module returns to its idle condition. After the eUSCI\_B module returns to the idle condition, control of the clock source reverts to the settings of its control bits.

In I<sup>C</sup> slave mode, no internal clock source is required because the clock is provided by the external master. It is possible to operate the eUSCI\_B in I<sup>C</sup> slave mode while the device is in LPM4 and all internal clock sources are disabled. The receive or transmit interrupts can wake up the CPU from any low-power mode.

### 32.3.11 eUSCI\_B Interrupts in I<sup>C</sup> Mode

The eUSCI\_B has only one interrupt vector that is shared for transmission, reception, and the state change.

Each interrupt flag has its own interrupt enable bit. When an interrupt is enabled and the GIE bit is set, the interrupt flag generates an interrupt request. DMA transfers are controlled by the UCTXIFGx and UCRXIFGx flags on devices with a DMA controller. It is possible to react on each slave address with an individual DMA channel.

All interrupt flags are not cleared automatically, but they need to be cleared together by user interactions (for example, reading the UCRXBUFF clears UCRXIFGx). If the user wants to use an interrupt flag he needs to ensure that the flag has the correct state before the corresponding interrupt is enabled.

### 32.3.11.1 I<sup>2</sup>C Transmit Interrupt Operation

The UCTXIFG0 interrupt flag is set whenever the transmitter is able to accept a new byte. When operating as a slave with multiple slave addresses, the UCTXIFGx flags are set corresponding to which address was received before. If, for example, the slave address specified in register UCBxI2COA3 did match the address seen on the bus, the UCTXIFG3 indicates that the UCBxTXBUF is ready to accept a new byte.

When operating in master mode with automatic STOP generation (UCASTPx = 10), the UCTXIFG0 is set as many times as defined in UCBxTBCNT.

An interrupt request is generated if UCTXIE and GIE are also set. UCTXIFGx is automatically reset if a write to UCBxTXBUF occurs or if the UCALIFG is cleared. UCTXIFGx is set when:

- Master mode: UCTXSTT was set by the user
- Slave mode: own address was received (UCETXINT = 0) or START was received (UCETXINT = 1)

UCTXIE is reset after a PUC or when UCSWRST = 1.

### 32.3.11.2 Early I<sup>2</sup>C Transmit Interrupt

Setting the UCETXINT causes UCTXIFG0 to be sent out automatically when a START condition is sent and the eUSCI\_B is configured as slave. In this case, it is not allowed to enable the other slave addresses UCBxI2COA1-UCBxI2COA3. This allows the software more time to handle the UCTXIFG0 compared to the normal situation, when UCTXIFG0 is sent out after the slave address match was detected. Situations where the UCTXIFG0 was set and afterward no slave address match occurred need to be handled in software. TI recommends using the byte counter to handle this.

### 32.3.11.3 I<sup>2</sup>C Receive Interrupt Operation

The UCRXIFG0 interrupt flag is set when a character is received and loaded into UCBxRXBUF. When operating as a slave with multiple slave addresses, the UCRXIFGx flag is set corresponding to which address was received before.

An interrupt request is generated if UCRXIE and GIE are also set. UCRXIFGx and UCRXIE are reset after a PUC signal or when UCSWRST = 1. UCRXIFGx is automatically reset when UCxRXBUF is read.

### 32.3.11.4 I<sup>2</sup>C State Change Interrupt Operation

[Table 32-2](#) describes the I<sup>2</sup>C state change interrupt flags.

**Table 32-2. I<sup>2</sup>C State Change Interrupt Flags**

| Interrupt Flag | Interrupt Condition                                                                                                                                                                                                                                                                                                                                                             |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| UCALIFG        | Arbitration lost interrupt. Arbitration can be lost when two or more transmitters start a transmission simultaneously, or when the eUSCI_B operates as master but is addressed as a slave by another master in the system. The UCALIFG flag is set when arbitration is lost. When UCALIFG is set, the UCMST bit is cleared and the I <sup>2</sup> C controller becomes a slave. |
| UCNACKIFG      | Not acknowledge interrupt. This flag is set when an acknowledge is expected but is not received. UCNACKIFG is used in master mode only.                                                                                                                                                                                                                                         |
| UCCLTOIFG      | Clock low time-out. This interrupt flag is set, if the clock is held low longer than defined by the UCCLTO bits.                                                                                                                                                                                                                                                                |
| UCBIT9IFG      | This interrupt flag is generated each time the eUSCI_B is transferring the ninth clock cycle of a byte of data. This gives the user the ability to follow the I <sup>2</sup> C communication in software if wanted. UCBIT9IFG is not set for address information.                                                                                                               |
| UCBCNTIFG      | Byte counter interrupt. This flag is set when the byte counter value reaches the value defined in UCBxTBCNT and UCASTPx = 01 or 10. This bit allows to organize following communications, especially if a RESTART will be issued.                                                                                                                                               |
| UCSTTIIFG      | START condition detected interrupt. This flag is set when the I <sup>2</sup> C module detects a START condition together with its own address <sup>(1)</sup> . UCSTTIIFG is used in slave mode only.                                                                                                                                                                            |
| UCSTPIFG       | STOP condition detected interrupt. This flag is set when the I <sup>2</sup> C module detects a STOP condition on the bus. UCSTPIFG is used in slave and master mode.                                                                                                                                                                                                            |

<sup>(1)</sup> The address evaluation includes the address mask register if it is used.

### 32.3.11.5 UCBxIV, Interrupt Vector Generator

The eUSCI\_B interrupt flags are prioritized and combined to source a single interrupt vector. The interrupt vector register UCBxIV is used to determine which flag requested an interrupt. The highest-priority enabled interrupt generates a number in the UCBxIV register that can be evaluated or added to the PC to automatically enter the appropriate software routine. Disabled interrupts do not affect the UCBxIV value.

Read access of the UCBxIV register automatically resets the highest-pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt.

Write access of the UCBxIV register clears all pending Interrupt conditions and flags.

Example 32-3 shows the recommended use of UCBxIV. The UCBxIV value is added to the PC to automatically jump to the appropriate routine. The example is given for eUSCI0\_B.

**Example 32-3. UCBxIV Software Example**

```
#pragma vector = USCI_B0_VECTOR __interrupt void USCI_B0_ISR(void) {
    switch(__even_in_range(UCB0IV,0x1e)) {
        case 0x00:      // Vector 0: No interrupts
            break;
        case 0x02: ... // Vector 2: ALIFG
            break;
        case 0x04: ... // Vector 4: NACKIFG
            break;
        case 0x06: ... // Vector 6: STTIFG
            break;
        case 0x08: ... // Vector 8: STPIFG
            break;
        case 0x0a: ... // Vector 10: RXIFG3
            break;
        case 0x0c: ... // Vector 12: TXIFG3
            break;
        case 0x0e: ... // Vector 14: RXIFG2
            break;
        case 0x10: ... // Vector 16: TXIFG2
            break;
        case 0x12: ... // Vector 18: RXIFG1
            break;
        case 0x14: ... // Vector 20: TXIFG1
            break;
        case 0x16: ... // Vector 22: RXIFG0
            break;
        case 0x18: ... // Vector 24: TXIFG0
            break;
        case 0x1a: ... // Vector 26: BCNTIFG
            break;
        case 0x1c: ... // Vector 28: clock low time-out
            break;
        case 0x1e: ... // Vector 30: 9th bit
            break;
        default: break;
    }
}
```

### 32.4 eUSCI\_B I2C Registers

The eUSCI\_B registers applicable in I<sup>2</sup>C mode and their address offsets are listed in [Table 32-3](#). The base address can be found in the device-specific data sheet.

**Table 32-3. eUSCI\_B Registers**

| Offset | Acronym     | Register Name                            | Type       | Access | Reset | Section                         |
|--------|-------------|------------------------------------------|------------|--------|-------|---------------------------------|
| 00h    | UCBxCTLW0   | eUSCI_Bx Control Word 0                  | Read/write | Word   | 01C1h | <a href="#">Section 32.4.1</a>  |
| 00h    | UCBxCTL1    | eUSCI_Bx Control 1                       | Read/write | Byte   | C1h   |                                 |
| 01h    | UCBxCTL0    | eUSCI_Bx Control 0                       | Read/write | Byte   | 01h   |                                 |
| 02h    | UCBxCTLW1   | eUSCI_Bx Control Word 1                  | Read/write | Word   | 0000h | <a href="#">Section 32.4.2</a>  |
| 06h    | UCBxBRW     | eUSCI_Bx Bit Rate Control Word           | Read/write | Word   | 0000h | <a href="#">Section 32.4.3</a>  |
| 06h    | UCBxBR0     | eUSCI_Bx Bit Rate Control 0              | Read/write | Byte   | 00h   |                                 |
| 07h    | UCBxBR1     | eUSCI_Bx Bit Rate Control 1              | Read/write | Byte   | 00h   |                                 |
| 08h    | UCBxSTATW   | eUSCI_Bx Status Word                     | Read       | Word   | 0000h | <a href="#">Section 32.4.4</a>  |
| 08h    | UCBxSTAT    | eUSCI_Bx Status                          | Read       | Byte   | 00h   |                                 |
| 09h    | UCBxBCNT    | eUSCI_Bx Byte Counter Register           | Read       | Byte   | 00h   |                                 |
| 0Ah    | UCBxTBCNT   | eUSCI_Bx Byte Counter Threshold Register | Read/Write | Word   | 00h   | <a href="#">Section 32.4.5</a>  |
| 0Ch    | UCBxRXBUF   | eUSCI_Bx Receive Buffer                  | Read/write | Word   | 00h   | <a href="#">Section 32.4.6</a>  |
| 0Eh    | UCBxTXBUF   | eUSCI_Bx Transmit Buffer                 | Read/write | Word   | 00h   | <a href="#">Section 32.4.7</a>  |
| 14h    | UCBxI2COA0  | eUSCI_Bx I2C Own Address 0               | Read/write | Word   | 0000h | <a href="#">Section 32.4.8</a>  |
| 16h    | UCBxI2COA1  | eUSCI_Bx I2C Own Address 1               | Read/write | Word   | 0000h | <a href="#">Section 32.4.9</a>  |
| 18h    | UCBxI2COA2  | eUSCI_Bx I2C Own Address 2               | Read/write | Word   | 0000h | <a href="#">Section 32.4.10</a> |
| 1Ah    | UCBxI2COA3  | eUSCI_Bx I2C Own Address 3               | Read/write | Word   | 0000h | <a href="#">Section 32.4.11</a> |
| 1Ch    | UCBxADDRX   | eUSCI_Bx Received Address Register       | Read       | Word   |       | <a href="#">Section 32.4.12</a> |
| 1Eh    | UCBxADDMASK | eUSCI_Bx Address Mask Register           | Read/write | Word   | 03FFh | <a href="#">Section 32.4.13</a> |
| 20h    | UCBxI2CSA   | eUSCI_Bx I2C Slave Address               | Read/write | Word   | 0000h | <a href="#">Section 32.4.14</a> |
| 2Ah    | UCBxIE      | eUSCI_Bx Interrupt Enable                | Read/write | Word   | 0000h | <a href="#">Section 32.4.15</a> |
| 2Ch    | UCBxIFG     | eUSCI_Bx Interrupt Flag                  | Read/write | Word   | 0002h | <a href="#">Section 32.4.16</a> |
| 2Eh    | UCBxIV      | eUSCI_Bx Interrupt Vector                | Read       | Word   | 0000h | <a href="#">Section 32.4.17</a> |

### 32.4.1 UCBxCTLW0 Register

eUSCI\_Bx Control Word Register 0

**Figure 32-17. UCBxCTLW0 Register**

| 15     | 14      | 13   | 12       | 11      | 10      | 9       | 8    |
|--------|---------|------|----------|---------|---------|---------|------|
| UCA10  | UCSLA10 | UCMM | Reserved | UCMST   | UCMODEx | UCSYNC  |      |
| rw-0   | rw-0    | rw-0 | r0       | rw-0    | rw-0    | rw-0    | r1   |
| 7      | 6       | 5    | 4        | 3       | 2       | 1       | 0    |
| UCSELx | UCTXACK | UCTR | UCTXNACK | UCTXSTP | UCTXSTT | UCSWRST |      |
| rw-1   | rw-1    | rw-0 | rw-0     | rw-0    | rw-0    | rw-0    | rw-1 |

Can be modified only when UCSWRST = 1.

**Table 32-4. UCBxCTLW0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | UCA10    | RW   | 0h    | Own addressing mode select.<br>Modify only when UCSWRST = 1.<br>0b = Own address is a 7-bit address.<br>1b = Own address is a 10-bit address.                                                                                                                                                                                                                                                                       |
| 14   | UCSLA10  | RW   | 0h    | Slave addressing mode select<br>0b = Address slave with 7-bit address<br>1b = Address slave with 10-bit address                                                                                                                                                                                                                                                                                                     |
| 13   | UCMM     | RW   | 0h    | Multi-master environment select.<br>Modify only when UCSWRST = 1.<br>0b = Single master environment. There is no other master in the system. The address compare unit is disabled.<br>1b = Multi-master environment                                                                                                                                                                                                 |
| 12   | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                            |
| 11   | UCMST    | RW   | 0h    | Master mode select. When a master loses arbitration in a multi-master environment (UCMM = 1), the UCMST bit is automatically cleared and the module acts as slave.<br>0b = Slave mode<br>1b = Master mode                                                                                                                                                                                                           |
| 10-9 | UCMODEx  | RW   | 0h    | eUSCI_B mode. The UCMODEx bits select the synchronous mode when UCSYNC = 1.<br>Modify only when UCSWRST = 1.<br>00b = 3-pin SPI<br>01b = 4-pin SPI (master or slave enabled if STE = 1)<br>10b = 4-pin SPI (master or slave enabled if STE = 0)<br>11b = I2C mode                                                                                                                                                   |
| 8    | UCSYNC   | RW   | 1h    | Synchronous mode enable. For eUSCI_B always read and write as 1.                                                                                                                                                                                                                                                                                                                                                    |
| 7-6  | UCSELx   | RW   | 3h    | eUSCI_B clock source select. These bits select the BRCLK source clock. These bits are ignored in slave mode.<br>Modify only when UCSWRST = 1.<br>00b = UCLKI<br>01b = ACLK<br>10b = SMCLK<br>11b = SMCLK                                                                                                                                                                                                            |
| 5    | UCTXACK  | RW   | 0h    | Transmit ACK condition in slave mode with enabled address mask register. After the UCSTTIFG has been set, the user needs to set or reset the UCTXACK flag to continue with the I2C protocol. The clock is stretched until the UCBxCTL1 register has been written. This bit is cleared automatically after the ACK has been send.<br>0b = Do not acknowledge the slave address<br>1b = Acknowledge the slave address |

**Table 32-4. UCBxCTLW0 Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                                                                                                                                                                                        |
|------------|--------------|-------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4          | UCTR         | RW          | 0h           | Transmitter/receiver<br>0b = Receiver<br>1b = Transmitter                                                                                                                                                                                                                                                                                 |
| 3          | UCTXNACK     | RW          | 0h           | Transmit a NACK. UCTXNACK is automatically cleared after a NACK is transmitted. Only for slave receiver mode.<br>0b = Acknowledge normally<br>1b = Generate NACK                                                                                                                                                                          |
| 2          | UCTXSTP      | RW          | 0h           | Transmit STOP condition in master mode. Ignored in slave mode. In master receiver mode, the STOP condition is preceded by a NACK. UCTXSTP is automatically cleared after STOP is generated. This bit is a don't care, if automatic UCASPx is different from 01 or 10.<br>0b = No STOP generated<br>1b = Generate STOP                     |
| 1          | UCTXSTT      | RW          | 0h           | Transmit START condition in master mode. Ignored in slave mode. In master receiver mode, a repeated START condition is preceded by a NACK. UCTXSTT is automatically cleared after START condition and address information is transmitted. Ignored in slave mode.<br>0b = Do not generate START condition<br>1b = Generate START condition |
| 0          | UCSWRST      | RW          | 1h           | Software reset enable.<br>0b = Disabled. eUSCI_B released for operation.<br>1b = Enabled. eUSCI_B logic held in reset state.                                                                                                                                                                                                              |

### 32.4.2 UCBxCTLW1 Register

eUSCI\_Bx Control Word Register 1

**Figure 32-18. UCBxCTLW1 Register**

|          |      |           |         |         |      |      |          |
|----------|------|-----------|---------|---------|------|------|----------|
| 15       | 14   | 13        | 12      | 11      | 10   | 9    | 8        |
| Reserved |      |           |         |         |      |      | UCETXINT |
| r0       | r0   | r0        | r0      | r0      | r0   | r0   | rw-0     |
| 7        | 6    | 5         | 4       | 3       | 2    | 1    | 0        |
| UCCLTO   |      | UCSTPNACK | UCSWACK | UCASTPx |      |      | UCGLITx  |
| rw-0     | rw-0 | rw-0      | rw-0    | rw-0    | rw-0 | rw-0 | rw-0     |

Can be modified only when UCSWRST = 1.

**Table 32-5. UCBxCTLW1 Register Description**

| Bit  | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-9 | Reserved  | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 8    | UCETXINT  | RW   | 0h    | Early UCTXIFG0. Only in slave mode. When this bit is set, the slave addresses defined in UCxI2COA1 to UCxI2COA3 must be disabled.<br>Modify only when UCSWRST = 1.<br>0b = UCTXIFGx is set after an address match with UCxI2COAx and the direction bit indicating slave transmit<br>1b = UCTXIFG0 is set for each START condition                                                                                                                                                                                                                                  |
| 7-6  | UCCLTO    | RW   | 0h    | Clock low time-out select.<br>Modify only when UCSWRST = 1.<br>00b = Disable clock low time-out counter<br>01b = 135000 MODCLK cycles (approximately 28 ms)<br>10b = 150000 MODCLK cycles (approximately 31 ms)<br>11b = 165000 MODCLK cycles (approximately 34 ms)                                                                                                                                                                                                                                                                                                |
| 5    | UCSTPNACK | RW   | 0h    | The UCSTPNACK bit allows to make the eUSCI_B master acknowledge the last byte in master receiver mode as well. This does not conform to the I2C specification and should only be used for slaves that automatically release the SDA after a fixed packet length.<br>Modify only when UCSWRST = 1.<br>0b = Send a not acknowledge before the STOP condition as a master receiver (conform to I2C standard)<br>1b = All bytes are acknowledged by the eUSCI_B when configured as master receiver                                                                     |
| 4    | UCSWACK   | RW   | 0h    | This bit selects whether sending an ACK of the address is triggered by the eUSCI_B module or is controlled by software.<br>0b = The address acknowledge of the slave is controlled by the eUSCI_B module<br>1b = The user needs to trigger the sending of the address ACK by issuing UCTXACK                                                                                                                                                                                                                                                                       |
| 3-2  | UCASTPx   | RW   | 0h    | Automatic STOP condition generation. In slave mode, only settings 00b and 01b are available.<br>Modify only when UCSWRST = 1.<br>00b = No automatic STOP generation. The STOP condition is generated after the user sets the UCTXSTP bit. The value in UCBxTBCNT is a don't care.<br>01b = UCBCNTIFG is set with the byte counter reaches the threshold defined in UCBxTBCNT<br>10b = A STOP condition is generated automatically after the byte counter value reached UCBxTBCNT. UCBCNTIFG is set with the byte counter reaching the threshold.<br>11b = Reserved |

**Table 32-5. UCBxCTLW1 Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                            |
|------------|--------------|-------------|--------------|-------------------------------------------------------------------------------|
| 1-0        | UCGLITx      | RW          | 0h           | Deglitch time<br>00b = 50 ns<br>01b = 25 ns<br>10b = 12.5 ns<br>11b = 6.25 ns |

### 32.4.3 UCBxBRW Register

eUSCI\_Bx Bit Rate Control Word Register

**Figure 32-19. UCBxBRW Register**

|       |    |    |    |    |    |    |    |
|-------|----|----|----|----|----|----|----|
| 15    | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |
| 7     | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| UCBRx |    |    |    |    |    |    |    |
| rw    | rw | rw | rw | rw | rw | rw | rw |

Can be modified only when UCSWRST = 1.

**Table 32-6. UCBxBRW Register Description**

| Bit  | Field | Type | Reset | Description                                           |
|------|-------|------|-------|-------------------------------------------------------|
| 15-0 | UCBRx | RW   | 0h    | Bit clock prescaler.<br>Modify only when UCSWRST = 1. |

### 32.4.4 UCBxSTATW

eUSCI\_Bx Status Word Register

**Figure 32-20. UCBxSTATW Register**

|          |          |      |         |          |     |     |     |
|----------|----------|------|---------|----------|-----|-----|-----|
| 15       | 14       | 13   | 12      | 11       | 10  | 9   | 8   |
| UCBCNTx  |          |      |         |          |     |     |     |
| r-0      | r-0      | r-0  | r-0     | r-0      | r-0 | r-0 | r-0 |
| 7        | 6        | 5    | 4       | 3        | 2   | 1   | 0   |
| Reserved | UCSCLLOW | UCGC | UCBBUSY | Reserved |     |     |     |
| r0       | r-0      | r-0  | r-0     | r-0      | r0  | r0  | r0  |

**Table 32-7. UCBxSTATW Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                  |
|------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | UCBCNTx  | R    | 0h    | Hardware byte counter value. Reading this register returns the number of bytes received or transmitted on the I2C-Bus since the last START or RESTART. There is no synchronization of this register done. When reading UCBxBCNT during the first bit position, a faulty read back can occur. |
| 7    | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                     |
| 6    | UCSCLLOW | R    | 0h    | SCL low<br>0b = SCL is not held low<br>1b = SCL is held low                                                                                                                                                                                                                                  |
| 5    | UCGC     | R    | 0h    | General call address received. UCGC is automatically cleared when a START condition is received.<br>0b = No general call address received<br>1b = General call address received                                                                                                              |
| 4    | UCBBUSY  | R    | 0h    | Bus busy<br>0b = Bus inactive<br>1b = Bus busy                                                                                                                                                                                                                                               |
| 3-0  | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                     |

### 32.4.5 UCBxTBCNT Register

eUSCI\_Bx Byte Counter Threshold Register

**Figure 32-21. UCBxTBCNT Register**

|          |      |      |      |      |      |      |      |
|----------|------|------|------|------|------|------|------|
| 15       | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| Reserved |      |      |      |      |      |      |      |
| r0       | r0   | r0   | r0   | r0   | r0   | r0   | r0   |
| 7        | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
| UCTBCNTx |      |      |      |      |      |      |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 32-8. UCBxTBCNT Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                              |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                 |
| 7-0  | UCTBCNTx | RW   | 0h    | The byte counter threshold value is used to set the number of I2C data bytes after which the automatic STOP or the UCSTPIFG should occur. This value is evaluated only if UCASTPx is different from 00.<br>Modify only when UCSWRST = 1. |

### 32.4.6 UCBxRXBUF Register

eUSCI\_Bx Receive Buffer Register

**Figure 32-22. UCBxRXBUF Register**

|          |    |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|----|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Reserved |    |    |    |    |    |    |    |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| UCRXBUFx |    |    |    |    |    |    |    |
| r        | r  | r  | r  | r  | r  | r  | r  |

**Table 32-9. UCBxRXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                       |
|------|----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                          |
| 7-0  | UCRXBUFx | R    | 0h    | The receive-data buffer is user accessible and contains the last received character from the receive shift register. Reading UCBxRXBUF resets the UCRXIFGx flags. |

### 32.4.7 UCBxTXBUF

eUSCI\_Bx Transmit Buffer Register

**Figure 32-23. UCBxTXBUF Register**

|          |    |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|----|
| 15       | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Reserved |    |    |    |    |    |    |    |
| r0       | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| UCTXBUFx |    |    |    |    |    |    |    |
| rw       | rw | rw | rw | rw | rw | rw | rw |

**Table 32-10. UCBxTXBUF Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                            |
| 7-0  | UCTXBUFx | RW   | 0h    | The transmit data buffer is user accessible and holds the data waiting to be moved into the transmit shift register and transmitted. Writing to the transmit data buffer clears the UCTXIFGx flags. |

### 32.4.8 UCBxI2COA0 Register

eUSCI\_Bx I2C Own Address 0 Register

**Figure 32-24. UCBxI2COA0 Register**

| 15     | 14       | 13   | 12   | 11   | 10     | 9      | 8    |
|--------|----------|------|------|------|--------|--------|------|
| UCGCEN | Reserved |      |      |      | UCOAEN | I2COA0 |      |
| rw-0   | r0       | r0   | r0   | r0   | rw-0   | rw-0   | rw-0 |
| 7      | 6        | 5    | 4    | 3    | 2      | 1      | 0    |
| I2COA0 |          |      |      |      |        |        |      |
| rw-0   | rw-0     | rw-0 | rw-0 | rw-0 | rw-0   | rw-0   | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 32-11. UCBxI2COA0 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                          |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | UCGCEN   | RW   | 0h    | General call response enable. This bit is only available in UCBxI2COA0.<br>Modify only when UCSWRST = 1.<br>0b = Do not respond to a general call<br>1b = Respond to a general call                                                                                                                  |
| 14-11 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                             |
| 10    | UCOAEN   | RW   | 0h    | Own Address enable register. With this register it can be selected if the I2C slave-address related to this register UCBxI2COA0 is evaluated or not.<br>Modify only when UCSWRST = 1.<br>0b = The slave address defined in I2COA0 is disabled<br>1b = The slave address defined in I2COA0 is enabled |
| 9-0   | I2COAx   | RW   | 0h    | I2C own address. The I2COA0 bits contain the local address of the eUSCIx_B I2C controller. The address is right justified. In 7-bit addressing mode, bit 6 is the MSB and bits 9-7 are ignored. In 10-bit addressing mode, bit 9 is the MSB.<br>Modify only when UCSWRST = 1.                        |

### 32.4.9 UCBxI2COA1 Register

eUSCI\_Bx I2C Own Address 1 Register

**Figure 32-25. UCBxI2COA1 Register**

| 15       | 14   | 13   | 12   | 11     | 10   | 9      | 8    |
|----------|------|------|------|--------|------|--------|------|
| Reserved |      |      |      | UCOAEN |      | I2COA1 |      |
| rw-0     | r0   | r0   | r0   | r0     | rw-0 | rw-0   | rw-0 |
| 7        | 6    | 5    | 4    | 3      | 2    | 1      | 0    |
| I2COA1   |      |      |      |        |      |        |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0   | rw-0 | rw-0   | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 32-12. UCBxI2COA1 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                          |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                             |
| 10    | UCOAEN   | RW   | 0h    | Own Address enable register. With this register it can be selected if the I2C slave-address related to this register UCBxI2COA1 is evaluated or not.<br>Modify only when UCSWRST = 1.<br>0b = The slave address defined in I2COA1 is disabled<br>1b = The slave address defined in I2COA1 is enabled |
| 9-0   | I2COA1   | RW   | 0h    | I2C own address. The I2COAx bits contain the local address of the eUSCIx_B I2C controller. The address is right justified. In 7-bit addressing mode, bit 6 is the MSB and bits 9-7 are ignored. In 10-bit addressing mode, bit 9 is the MSB.<br>Modify only when UCSWRST = 1.                        |

### 32.4.10 UCBxI2COA2 Register

eUSCI\_Bx I2C Own Address 2 Register

**Figure 32-26. UCBxI2COA2 Register**

| 15       | 14   | 13   | 12   | 11     | 10   | 9      | 8    |
|----------|------|------|------|--------|------|--------|------|
| Reserved |      |      |      | UCOAEN |      | I2COA2 |      |
| rw-0     | r0   | r0   | r0   | r0     | rw-0 | rw-0   | rw-0 |
| 7        | 6    | 5    | 4    | 3      | 2    | 1      | 0    |
| I2COA2   |      |      |      |        |      |        |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0   | rw-0 | rw-0   | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 32-13. UCBxI2COA2 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                          |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                             |
| 10    | UCOAEN   | RW   | 0h    | Own Address enable register. With this register it can be selected if the I2C slave-address related to this register UCBxI2COA2 is evaluated or not.<br>Modify only when UCSWRST = 1.<br>0b = The slave address defined in I2COA2 is disabled<br>1b = The slave address defined in I2COA2 is enabled |
| 9-0   | I2COA2   | RW   | 0h    | I2C own address. The I2COAx bits contain the local address of the eUSCIx_B I2C controller. The address is right justified. In 7-bit addressing mode, bit 6 is the MSB and bits 9-7 are ignored. In 10-bit addressing mode, bit 9 is the MSB.<br>Modify only when UCSWRST = 1.                        |

### 32.4.11 UCBxI2COA3 Register

eUSCI\_Bx I2C Own Address 3 Register

**Figure 32-27. UCBxI2COA3 Register**

| 15       | 14   | 13   | 12   | 11    | 10   | 9      | 8    |
|----------|------|------|------|-------|------|--------|------|
| Reserved |      |      |      | UCOEN |      | I2COA3 |      |
| rw-0     | r0   | r0   | r0   | r0    | rw-0 | rw-0   | rw-0 |
| 7        | 6    | 5    | 4    | 3     | 2    | 1      | 0    |
| I2COA3   |      |      |      |       |      |        |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0  | rw-0 | rw-0   | rw-0 |

Can be modified only when UCSWRST = 1.

**Table 32-14. UCBxI2COA3 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                          |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                             |
| 10    | UCOEN    | RW   | 0h    | Own Address enable register. With this register it can be selected if the I2C slave-address related to this register UCBxI2COA3 is evaluated or not.<br>Modify only when UCSWRST = 1.<br>0b = The slave address defined in I2COA3 is disabled<br>1b = The slave address defined in I2COA3 is enabled |
| 9-0   | I2COA3   | RW   | 0h    | I2C own address. The I2COA3 bits contain the local address of the eUSCI_B I2C controller. The address is right justified. In 7-bit addressing mode, bit 6 is the MSB and bits 9-7 are ignored. In 10-bit addressing mode, bit 9 is the MSB.<br>Modify only when UCSWRST = 1.                         |

### 32.4.12 UCBxADDRX Register

eUSCI\_Bx I2C Received Address Register

**Figure 32-28. UCBxADDRX Register**

| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8      |
|----------|-----|-----|-----|-----|-----|-----|--------|
| Reserved |     |     |     |     |     |     | ADDRXX |
| r-0      | r0  | r0  | r0  | r0  | r0  | r-0 | r-0    |
| 7        | 6   | 5   | 4   | 3   | 2   | 1   | 0      |
| ADDRXX   |     |     |     |     |     |     |        |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0    |

**Table 32-15. UCBxADDRX Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                      |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                         |
| 9-0   | ADDRXX   | R    | 0h    | Received Address Register. This register contains the last received slave address on the bus. Using this register and the address mask register it is possible to react on more than one slave address using one eUSCI_B module. |

### 32.4.13 UCBxADDMASK Register

eUSCI\_Bx I2C Address Mask Register

**Figure 32-29. UCBxADDMASK Register**

|          |      |      |      |      |      |          |      |
|----------|------|------|------|------|------|----------|------|
| 15       | 14   | 13   | 12   | 11   | 10   | 9        | 8    |
| Reserved |      |      |      |      |      | ADDMASKx |      |
| r-0      | r0   | r0   | r0   | r0   | r0   | rw-1     | rw-1 |
| 7        | 6    | 5    | 4    | 3    | 2    | 1        | 0    |
| ADDMASKx |      |      |      |      |      |          |      |
| rw-1     | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1     | rw-1 |

Can be modified only when UCSWRST = 1.

**Table 32-16. UCBxADDMASK Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                        |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                           |
| 9-0   | ADDMASKx | RW   | 3FFh  | <p>Address Mask Register. By clearing the corresponding bit of the own address, this bit is a don't care when comparing the address on the bus to the own address. Using this method, it is possible to react on more than one slave address. When all bits of ADDMASKx are set, the address mask feature is deactivated.</p> <p>Modify only when UCSWRST = 1.</p> |

### 32.4.14 UCBxI2CSA Register

eUSCI\_Bx I2C Slave Address Register

**Figure 32-30. UCBxI2CSA Register**

|          |      |      |      |      |      |        |      |
|----------|------|------|------|------|------|--------|------|
| 15       | 14   | 13   | 12   | 11   | 10   | 9      | 8    |
| Reserved |      |      |      |      |      | I2CSAx |      |
| r-0      | r0   | r0   | r0   | r0   | r0   | rw-0   | rw-0 |
| 7        | 6    | 5    | 4    | 3    | 2    | 1      | 0    |
| I2CSAx   |      |      |      |      |      |        |      |
| rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0   | rw-0 |

**Table 32-17. UCBxI2CSA Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                     |
|-------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-10 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                        |
| 9-0   | I2CSAx   | RW   | 0h    | <p>I2C slave address. The I2CSAx bits contain the slave address of the external device to be addressed by the eUSCI_B module. It is only used in master mode. The address is right justified. In 7-bit slave addressing mode, bit 6 is the MSB and bits 9-7 are ignored. In 10-bit slave addressing mode, bit 9 is the MSB.</p> |

### 32.4.15 UCBxIE Register

eUSCI\_Bx I2C Interrupt Enable Register

**Figure 32-31. UCBxIE Register**

| 15       |  | 14       |  | 13       |  | 12      |  | 11      |  | 10      |  | 9       |  | 8       |  |
|----------|--|----------|--|----------|--|---------|--|---------|--|---------|--|---------|--|---------|--|
| Reserved |  | UCBIT9IE |  | UCTXIE3  |  | UCRXIE3 |  | UCTXIE2 |  | UCRXIE2 |  | UCTXIE1 |  | UCRXIE1 |  |
| r0       |  | rw-0     |  | rw-0     |  | rw-0    |  | rw-0    |  | rw-0    |  | rw-0    |  | rw-0    |  |
| 7        |  | 6        |  | 5        |  | 4       |  | 3       |  | 2       |  | 1       |  | 0       |  |
| UCCLTOIE |  | UCBCNTIE |  | UCNACKIE |  | UCALIE  |  | UCSTPIE |  | UCSTTIE |  | UCTXIE0 |  | UCRXIE0 |  |
| rw-0     |  | rw-0     |  | rw-0     |  | rw-0    |  | rw-0    |  | rw-0    |  | rw-0    |  | rw-0    |  |

**Table 32-18. UCBxIE Register Description**

| Bit | Field    | Type | Reset | Description                                                                               |
|-----|----------|------|-------|-------------------------------------------------------------------------------------------|
| 15  | Reserved | R    | 0h    | Reserved                                                                                  |
| 14  | UCBIT9IE | RW   | 0h    | Bit position 9 interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled      |
| 13  | UCTXIE3  | RW   | 0h    | Transmit interrupt enable 3<br>0b = Interrupt disabled<br>1b = Interrupt enabled          |
| 12  | UCRXIE3  | RW   | 0h    | Receive interrupt enable 3<br>0b = Interrupt disabled<br>1b = Interrupt enabled           |
| 11  | UCTXIE2  | RW   | 0h    | Transmit interrupt enable 2<br>0b = Interrupt disabled<br>1b = Interrupt enabled          |
| 10  | UCRXIE2  | RW   | 0h    | Receive interrupt enable 2<br>0b = Interrupt disabled<br>1b = Interrupt enabled           |
| 9   | UCTXIE1  | RW   | 0h    | Transmit interrupt enable 1<br>0b = Interrupt disabled<br>1b = Interrupt enabled          |
| 8   | UCRXIE1  | RW   | 0h    | Receive interrupt enable 1<br>0b = Interrupt disabled<br>1b = Interrupt enabled           |
| 7   | UCCLTOIE | RW   | 0h    | Clock low time-out interrupt enable.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 6   | UCBCNTIE | RW   | 0h    | Byte counter interrupt enable.<br>0b = Interrupt disabled<br>1b = Interrupt enabled       |
| 5   | UCNACKIE | RW   | 0h    | Not-acknowledge interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled     |
| 4   | UCALIE   | RW   | 0h    | Arbitration lost interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled    |
| 3   | UCSTPIE  | RW   | 0h    | STOP condition interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled      |

**Table 32-18. UCBxE Register Description (continued)**

| Bit | Field   | Type | Reset | Description                                                                           |
|-----|---------|------|-------|---------------------------------------------------------------------------------------|
| 2   | UCSTTIE | RW   | 0h    | START condition interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 1   | UCTXIE0 | RW   | 0h    | Transmit interrupt enable 0<br>0b = Interrupt disabled<br>1b = Interrupt enabled      |
| 0   | UCRXIE0 | RW   | 0h    | Receive interrupt enable 0<br>0b = Interrupt disabled<br>1b = Interrupt enabled       |

### 32.4.16 UCBxIFG Register

eUSCI\_Bx I2C Interrupt Flag Register

**Figure 32-32. UCBxIFG Register**

| 15        | 14        | 13        | 12       | 11       | 10       | 9        | 8        |
|-----------|-----------|-----------|----------|----------|----------|----------|----------|
| Reserved  | UCBIT9IFG | UCTXIFG3  | UCRXIFG3 | UCTXIFG2 | UCRXIFG2 | UCTXIFG1 | UCRXIFG1 |
| r0        | rw-0      | rw-0      | rw-0     | rw-0     | rw-0     | rw-0     | rw-0     |
| 7         | 6         | 5         | 4        | 3        | 2        | 1        | 0        |
| UCCLTOIFG | UCBCNTIFG | UCNACKIFG | UCALIFG  | UCSTPIFG | UCSTTIFG | UCTXIFG0 | UCRXIFG0 |
| rw-0      | rw-0      | rw-0      | rw-0     | rw-0     | rw-0     | rw-1     | rw-0     |

**Table 32-19. UCBxIFG Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                 |
|-----|-----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15  | Reserved  | R    | 0h    | Reserved                                                                                                                                                                                                                                    |
| 14  | UCBIT9IFG | RW   | 0h    | Bit position 9 interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                                                        |
| 13  | UCTXIFG3  | RW   | 0h    | eUSCI_B transmit interrupt flag 3. UCTXIFG3 is set when UCBxTXBUF is empty in slave mode, if the slave address defined in UCBxI2COA3 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending               |
| 12  | UCRXIFG3  | RW   | 0h    | Receive interrupt flag 3. UCRXIFG3 is set when UCBxRXBUF has received a complete byte in slave mode and if the slave address defined in UCBxI2COA3 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 11  | UCTXIFG2  | RW   | 0h    | eUSCI_B transmit interrupt flag 2. UCTXIFG2 is set when UCBxTXBUF is empty in slave mode, if the slave address defined in UCBxI2COA2 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending               |
| 10  | UCRXIFG2  | RW   | 0h    | Receive interrupt flag 2. UCRXIFG2 is set when UCBxRXBUF has received a complete byte in slave mode and if the slave address defined in UCBxI2COA2 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 9   | UCTXIFG1  | RW   | 0h    | eUSCI_B transmit interrupt flag 1. UCTXIFG1 is set when UCBxTXBUF is empty in slave mode, if the slave address defined in UCBxI2COA1 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending               |
| 8   | UCRXIFG1  | RW   | 0h    | Receive interrupt flag 1. UCRXIFG1 is set when UCBxRXBUF has received a complete byte in slave mode and if the slave address defined in UCBxI2COA1 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 7   | UCCLTOIFG | RW   | 0h    | Clock low time-out interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                                                    |
| 6   | UCBCNTIFG | RW   | 0h    | Byte counter interrupt flag. When using this interrupt the user needs to ensure enough processing bandwidth (see the Byte Counter Interrupt section).<br>0b = No interrupt pending<br>1b = Interrupt pending                                |

**Table 32-19. UCBxIFG Register Description (continued)**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                                             |
|-----|-----------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5   | UCNACKIFG | RW   | 0h    | Not-acknowledge received interrupt flag. This flag only is updated when operating in master mode.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                |
| 4   | UCALIFG   | RW   | 0h    | Arbitration lost interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                                                                                  |
| 3   | UCSTPIFG  | RW   | 0h    | STOP condition interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                                                                                    |
| 2   | UCSTTIFG  | RW   | 0h    | START condition interrupt flag<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                                                                                                   |
| 1   | UCTXIFG0  | RW   | 0h    | eUSCI_B transmit interrupt flag 0. UCTXIFG0 is set when UCBxTXBUF is empty in master mode or in slave mode, if the slave address defined in UCBxI2COA0 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending                         |
| 0   | UCRXIFG0  | RW   | 0h    | eUSCI_B receive interrupt flag 0. UCRXIFG0 is set when UCBxRXBUF has received a complete character in master mode or in slave mode, if the slave address defined in UCBxI2COA0 was on the bus in the same frame.<br>0b = No interrupt pending<br>1b = Interrupt pending |

### 32.4.17 UCBxIV Register

eUSCI\_Bx Interrupt Vector Register

**Figure 32-33. UCBxIV Register**

|       |    |    |    |     |     |     |    |
|-------|----|----|----|-----|-----|-----|----|
| 15    | 14 | 13 | 12 | 11  | 10  | 9   | 8  |
| UCIVx |    |    |    |     |     |     |    |
| r0    | r0 | r0 | r0 | r0  | r0  | r0  | r0 |
| UCIVx |    |    |    |     |     |     |    |
| r0    | r0 | r0 | r0 | r-0 | r-0 | r-0 | r0 |

**Table 32-20. UCBxIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|-------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | UCIVx | R    | 0h    | <p>eUSCI_B interrupt vector value. It generates an value that can be used as address offset for fast interrupt service routine handling. Writing to this register clears all pending interrupt flags.</p> <p>00h = No interrupt pending</p> <p>02h = Interrupt Source: Arbitration lost; Interrupt Flag: UCALIFG; Interrupt Priority: Highest</p> <p>04h = Interrupt Source: Not acknowledgment; Interrupt Flag: UCNACKIFG</p> <p>06h = Interrupt Source: Start condition received; Interrupt Flag: UCSTTIFG</p> <p>08h = Interrupt Source: Stop condition received; Interrupt Flag: UCSTPIFG</p> <p>0Ah = Interrupt Source: Slave 3 Data received; Interrupt Flag: UCRXIFG3</p> <p>0Ch = Interrupt Source: Slave 3 Transmit buffer empty; Interrupt Flag: UCTXIFG3</p> <p>0Eh = Interrupt Source: Slave 2 Data received; Interrupt Flag: UCRXIFG2</p> <p>10h = Interrupt Source: Slave 2 Transmit buffer empty; Interrupt Flag: UCTXIFG2</p> <p>12h = Interrupt Source: Slave 1 Data received; Interrupt Flag: UCRXIFG1</p> <p>14h = Interrupt Source: Slave 1 Transmit buffer empty; Interrupt Flag: UCTXIFG1</p> <p>16h = Interrupt Source: Data received; Interrupt Flag: UCRXIFG0</p> <p>18h = Interrupt Source: Transmit buffer empty; Interrupt Flag: UCTXIFG0</p> <p>1Ah = Interrupt Source: Byte counter zero; Interrupt Flag: UCBCNTIFG</p> <p>1Ch = Interrupt Source: Clock low time-out; Interrupt Flag: UCCLTOIFG</p> <p>1Eh = Interrupt Source: 9th bit position; Interrupt Flag: UCBIT9IFG; Priority: Lowest</p> |

**REF\_A**

The REF\_A module is a general-purpose reference system that generates the voltage references required for other subsystems such as digital-to-analog converters, analog-to-digital converters, or comparators. This chapter describes the REF\_A module.

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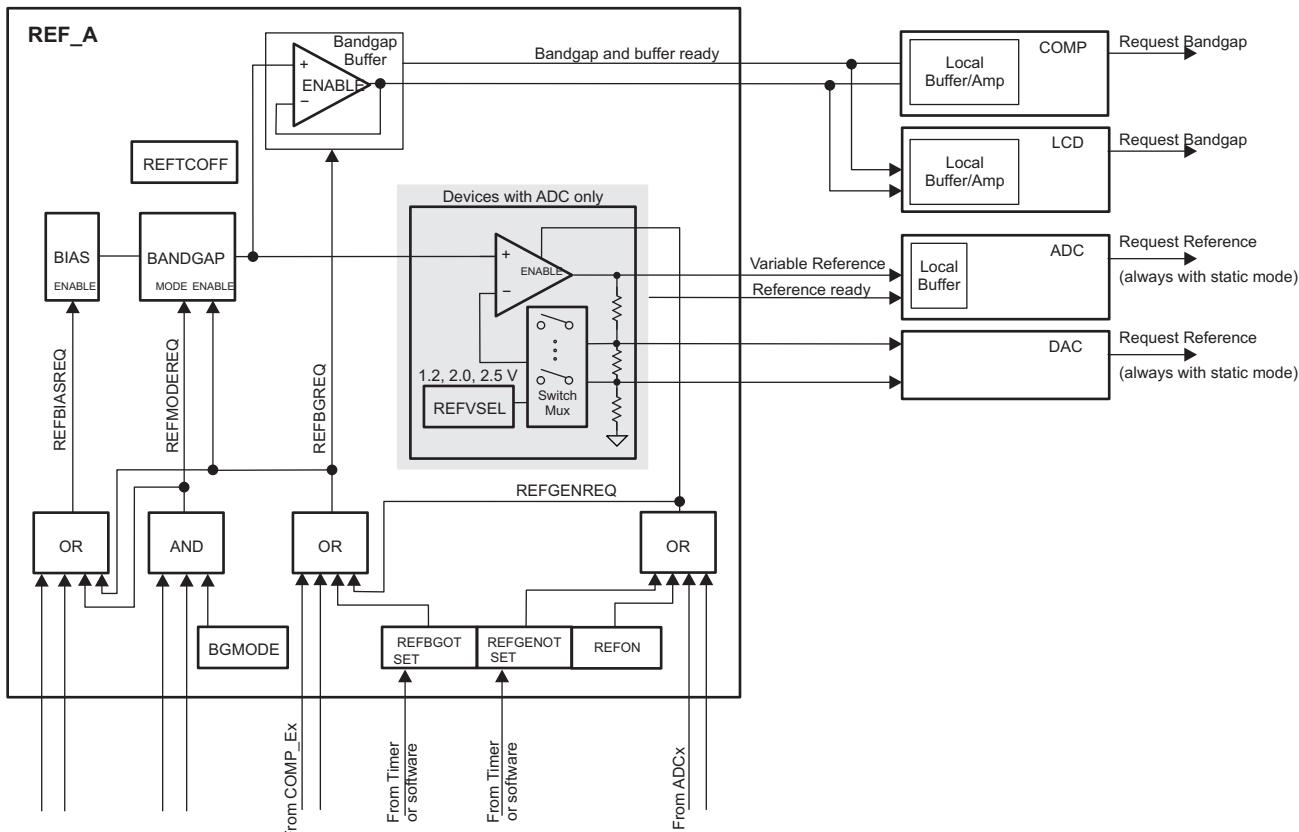
### 33.1 REF\_A Introduction

The reference module (REF) is responsible for generation of all critical reference voltages that can be used by various analog peripherals in a given device. The heart of the reference system is the bandgap from which all other references are derived by unity or noninverting gain stages. The REFGEN subsystem consists of the bandgap, the bandgap bias, and the noninverting buffer stage, which generates the three primary voltage reference available in the system (1.2 V, 2.0 V, and 2.5 V). In addition, when enabled, a buffered bandgap voltage is available.

Features of the REF\_A include:

- Centralized factory-trimmed bandgap with excellent PSRR, temperature coefficient, and accuracy
- 1.2-V, 2.0-V, or 2.5-V user-selectable internal references
- Buffered bandgap voltage available to rest of system
- Power saving features
- Hardware reference request and reference ready signals for bandgap and variable reference voltages for safe operation

[Figure 33-1](#) shows an example block diagram of the REF\_A module. The example shown here is for a device with an ADC, a DAC, an LCD, and two Comparators.



**Figure 33-1. REF\_A Block Diagram**

### 33.2 Principle of Operation

The REF\_A module provides all of the necessary voltage references for use by various peripheral modules throughout the system.

The REFGEN subsystem contains a high-performance bandgap. This bandgap has very good accuracy (factory trimmed), low temperature coefficient, and high PSRR even while operating at low power. The bandgap voltage is used to generate three voltages (1.2 V, 2.0 V, and 2.5 V) through a noninverting amplifier stage. One voltage can be selected at a time. One output of the REFGEN subsystem is the variable reference line. The variable reference line provides either 1.2 V, 2.0 V, or 2.5 V to the rest of the system. The second output of the REFGEN subsystem is the buffered bandgap reference line. Additionally, the REFGEN supports the voltage references that are required for a DAC module, if available. Lastly, the REFGEN subsystem also includes the temperature sensor circuitry, which is derived from the bandgap. The temperature sensor is used by an ADC to measure a voltage proportional to temperature.

#### 33.2.1 Low-Power Operation

The REF\_A module can support low-power applications such as LCD generation. Many of these applications do not require a very accurate reference, compared to data conversion, yet power is of prime concern. To support these kinds of applications, the bandgap can be used in a sampled mode. In sampled mode, the bandgap circuitry is clocked by the VLO at an appropriate duty cycle. This reduces the average power of the bandgap circuitry significantly, at the cost of accuracy. When not in sampled mode, the bandgap is in static mode. Its power is at its highest, but so is its accuracy.

Modules can request static mode or sampled mode through their own individual request lines. In this way, the particular module determines which mode is appropriate for its proper operation and performance. Any one active module that requests static mode causes all other modules to use static mode, even if another module requests sampled mode. For example, any module using the gray box in the [block diagram](#) requests static mode and causes all other modules to use static mode. In other words, static mode always has higher priority than sampled mode.

#### 33.2.2 Reference System Requests

There are three basic reference system requests that are used by the reference system. Each module can use these requests to obtain the proper response from the reference system. The three basic requests are REFGENREQ, REFBGREQ, and REFMODEREQ. No interaction is required by the user code. The modules automatically select the proper request.

A reference request signal, REFGENREQ, is available as an input into the REFGEN subsystem. This signal represents a logical OR of individual requests coming from the various modules in the system that require a voltage reference to be available on the variable reference line. When a module requires a voltage reference, it asserts its corresponding REFGENREQ signal. When the REFGENREQ is asserted, the REFGEN subsystem is enabled. After the specified settling time, the variable reference line voltage is stable and ready for use. The REFVSEL settings determine which voltage is generated on the variable reference line.

After the specified settling time of the REFGEN subsystem, the REF\_A module sets the REFGENDRDY signal. This signal can be used by each module to wait, for example, before a conversion is started after a REFGENREQ was set. The generation of the reference voltage can be triggered by a timer or by software to make sure that the reference voltage is ready when a module requires it.

In addition to the REFGENREQ, a second reference request signal, REFBGREQ, is available. The REFBGREQ signal represents a logical OR of requests coming from the various modules that require the bandgap reference line. When the REFBGREQ is asserted, the bandgap and its bias circuitry and local buffer are enabled, if not already enabled by a prior request.

After the specified settling time of the REFBGREQ subsystem, the REF\_A module sets the REFBGRDY signal. This signal can be used by each module to delay operation while the bandgap reference voltage is settling. The generation of the buffered bandgap voltage can be triggered by a timer or by software to make sure that the reference voltage is ready when a module requires it.

The REFMODEREQ request signal configures the bandgap and its bias circuitry to operate in either sampled or static mode of operation. The REFMODEREQ signal represents a logical AND of individual requests coming from the various analog modules. A REFMODEREQ occurs only if a REFGENREQ or REFBGQ is also asserted by a module, otherwise it is a don't care. When REFMODEREQ = 1, the bandgap operates in sampled mode. When a module asserts its corresponding REFMODEREQ signal, it is requesting that the bandgap operate in sampled mode. Because REMODEREQ is a logical AND of all individual requests, any modules that request static mode cause the bandgap to operate in static mode. The BGMODE bit can be read for use as an indicator of static or sampled mode of operation.

### 33.2.2.1 REFBGACT, REFGENACT, REFGENBUSY

Any module that is using the variable reference line causes REFGENACT to be set inside the REFCTL register. This bit is read only and indicates to the user whether the REFGEN is active or off. Similarly, the REFBGACT is active any time one or more modules are actively using the bandgap reference line and, therefore, indicates to the user whether the REFBG is active or off.

The REFGENBUSY signal, when asserted, indicates that a module is using the reference and that no changes should be made to the reference settings. For example, during an active ADC12\_B conversion, the reference voltage level should not be changed. REFGENBUSY is asserted when there is an active ADC12\_B conversion (ADC12BUSY = 1). REFGENBUSY when asserted, write protects the REFCTL register. This prevents the reference from being disabled or its level changed during any active conversion.

### 33.2.2.2 ADC12\_B

For devices that contain an ADC12\_B module, there are two buffers. The larger buffer can be used to drive the reference voltage, which is present on the variable reference line. This buffer has larger power consumption to drive larger DC loads that may be present outside the device. The large buffer is enabled continuously when REFON = 1 and REFOUT = 1. In addition, when REFON = 1 and REFOUT = 1, the second smaller buffer is automatically disabled. In this case, the output of the large buffer is connected to the capacitor array through an internal analog switch. This makes sure that the same reference is used throughout the system. If REFON = 1 and REFOUT = 0, the internal buffer is used for ADC conversion, and the large buffer remains disabled.

### 33.2.2.3 LCD Modules

On devices that contain an LCD module, this module requires a reference to generate the proper LCD voltages. The bandgap reference line from the REFGEN subsystem is used for this purpose. Enabling the LCD module in a mode that requires a reference voltage causes a REFBGREQ from the LCD module to be asserted. The buffered bandgap is made available on the bandgap reference line for use inside the LCD module.

### 33.3 REF\_A Registers

The REF\_A registers are listed in [Table 33-1](#). The base address can be found in the device specific datasheet. The address offset is listed in [Table 33-1](#).

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 33-1. REF\_A Registers**

| Offset | Acronym   | Register Name | Type       | Access | Reset | Section                        |
|--------|-----------|---------------|------------|--------|-------|--------------------------------|
| 00h    | REFCTL0   | REFCTL0       | Read/write | Word   | 0000h | <a href="#">Section 33.3.1</a> |
| 00h    | REFCTL0_L |               | Read/write | Byte   | 00h   |                                |
| 01h    | REFCTL0_H |               | Read/write | Byte   | 00h   |                                |

### 33.3.1 REFCTL0 Register (offset = 00h) [reset = 0000h]

REF\_A Control Register 0

**Figure 33-2. REFCTL0 Register**

| 15                                        | 14       | 13       | 12        | 11       | 10         | 9       | 8         |
|-------------------------------------------|----------|----------|-----------|----------|------------|---------|-----------|
| Reserved                                  |          | REFBGRDY | REFGENRDY | BGMODE   | REFGENBUSY | REFBACT | REFGENACT |
| r0                                        | r0       | r-(0)    | r-(0)     | r-(0)    | r-(0)      | r-(0)   | r-(0)     |
| 7                                         | 6        | 5        | 4         | 3        | 2          | 1       | 0         |
| REFBGOT                                   | REFGENOT | REFVSEL  | REFTCOFF  | Reserved | REFOUT     | REFON   |           |
| rw-0                                      | rw-0     | rw-(0)   | rw-(0)    | rw-(0)   | r0         | rw-(0)  | rw-(0)    |
| Can be modified only when REFGENBUSY = 0. |          |          |           |          |            |         |           |

**Table 33-2. REFCTL0 Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                            |
|-------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                           |
| 13    | REFBGRDY   | R    | 0h    | Buffered bandgap voltage is ready to be used. Both the bandgap and the bandgap buffer are active, and the reference voltage is settled for use by the comparator and the LCD.<br>0b = Buffered bandgap voltage is not ready to be used<br>1b = Buffered bandgap voltage is ready to be used                                                            |
| 12    | REFGENRDY  | R    | 0h    | Variable reference voltage ready status. Variable reference voltage is ready to be used. Both the bandgap and the reference voltage amplifier are active and the variable reference voltage is settled; for example, for use by the ADC.<br>0b = Reference voltage output is not ready to be used<br>1b = Reference voltage output is ready to be used |
| 11    | BGMODE     | R    | 0h    | Bandgap mode. Read only.<br>0b = Static mode<br>1b = Sampled mode                                                                                                                                                                                                                                                                                      |
| 10    | REFGENBUSY | R    | 0h    | Reference generator busy. Read only.<br>0b = Reference generator not busy<br>1b = Reference generator busy                                                                                                                                                                                                                                             |
| 9     | REFBACT    | R    | 0h    | Reference bandgap active. Read only.<br>0b = Reference bandgap buffer not active<br>1b = Reference bandgap buffer active                                                                                                                                                                                                                               |
| 8     | REFGENACT  | R    | 0h    | Reference generator active. Read only.<br>0b = Reference generator not active<br>1b = Reference generator active                                                                                                                                                                                                                                       |
| 7     | REFBGOT    | RW   | 0h    | Bandgap and bandgap buffer one-time trigger. If written with a 1, the generation of the buffered bandgap voltage is started. When the bandgap buffer voltage request is set, this bit is cleared by hardware.<br>0b = No trigger<br>1b = Generation of the bandgap voltage is started by writing 1 or by a hardware trigger                            |
| 6     | REFGENOT   | RW   | 0h    | Reference generator one-time trigger. If written with a 1, the generation of the variable reference voltage is started. When the reference voltage request is set, this bit is cleared by hardware.<br>0b = No trigger<br>1b = Generation of the reference voltage is started by writing 1 or by a hardware trigger                                    |
| 5-4   | REFVSEL    | RW   | 0h    | Reference voltage level select.<br>Can be modified only when REFGENBUSY = 0.<br>00b = 1.2 V available when reference requested or REFON = 1<br>01b = 2.0 V available when reference requested or REFON = 1<br>10b = 2.5 V available when reference requested or REFON = 1<br>11b = 2.5 V available when reference requested or REFON = 1               |

**Table 33-2. REFCTL0 Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                               |
|-----|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | REFTCOFF | RW   | 0h    | Temperature sensor disable. The temperature sensor is disabled if the ADC on the device is not enabled independent of this control bit.<br>Can be modified only when REFGENBUSY = 0.<br>0b = Temperature sensor enabled<br>1b = Temperature sensor disabled to save power |
| 2   | Reserved | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                              |
| 1   | REFOUT   | RW   | 0h    | Reference output buffer. On devices with an ADC10_A, this bit must be written with 0.<br>Can be modified only when REFGENBUSY = 0.<br>0b = Reference output not available externally<br>1b = Reference output available externally                                        |
| 0   | REFON    | RW   | 0h    | Reference enable.<br>Can be modified only when REFGENBUSY = 0.<br>0b = Disables reference if no other reference requests are pending<br>1b = Enables reference                                                                                                            |

**ADC12\_B**

The ADC12\_B module is a high-performance 12-bit analog-to-digital converter (ADC). This chapter describes the operation of the ADC12\_B module.

| Topic                          | Page |
|--------------------------------|------|
| 34.1 ADC12_B Introduction..... | 866  |
| 34.2 ADC12_B Operation.....    | 868  |
| 34.3 ADC12_B Registers .....   | 884  |

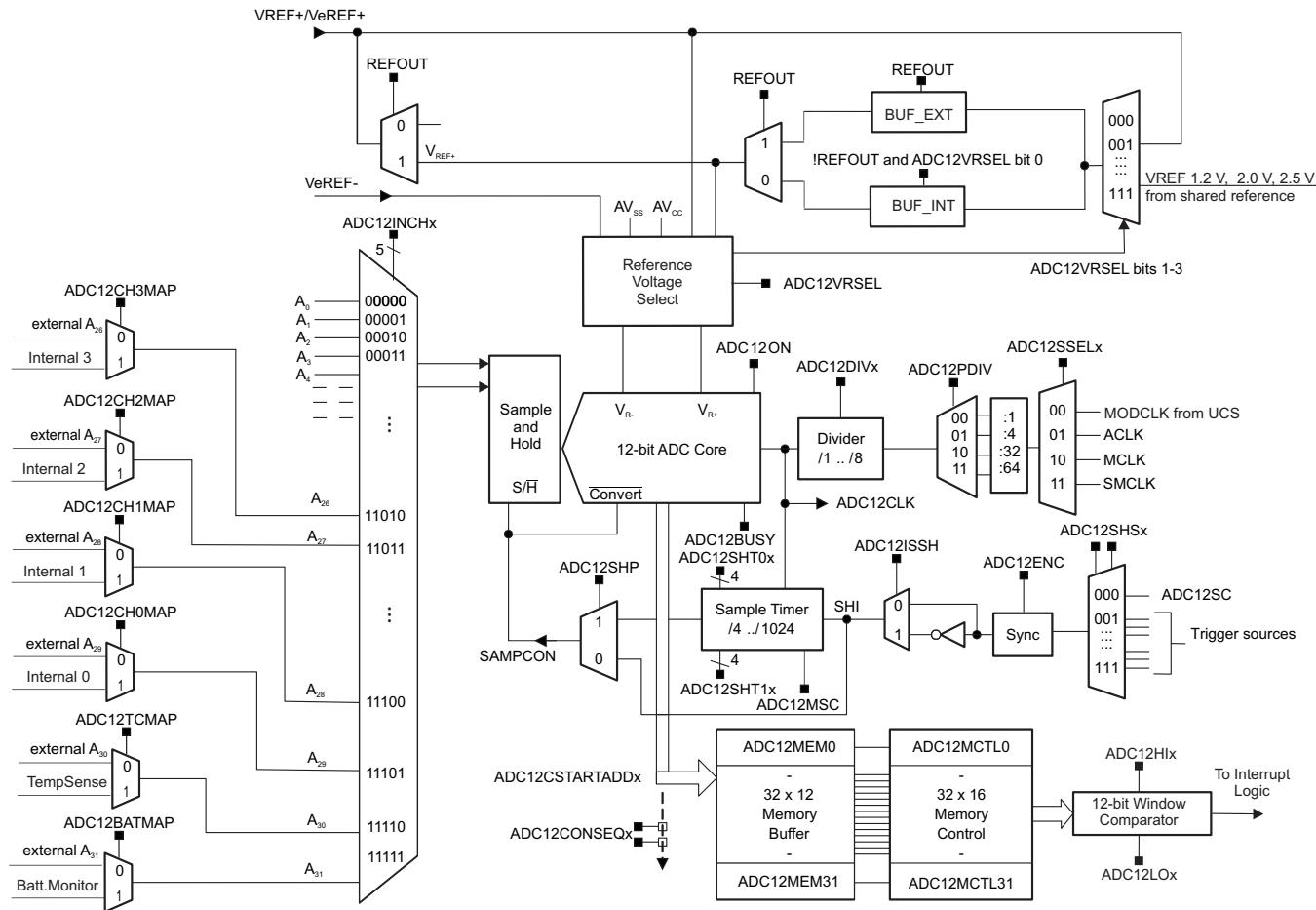
### 34.1 ADC12\_B Introduction

The ADC12\_B module supports fast 12-bit analog-to-digital conversions. The module implements a 12-bit SAR core, sample select control, and up to 32 independent conversion-and-control buffers. The conversion-and-control buffer allows up to 32 independent analog-to-digital converter (ADC) samples to be converted and stored without any CPU intervention.

ADC12\_B features include:

- 200-ksps maximum conversion rate at maximum resolution of 12 bits
- Monotonic 12-bit converter with no missing codes
- Sample-and-hold with programmable sampling periods controlled by software or timers
- Conversion initiation by software or timers
- Software-selectable on-chip reference voltage generation (1.2 V, 2.0 V, or 2.5 V) with option to make available externally
- Software-selectable internal or external reference
- Up to 32 individually configurable external input channels with single-ended or differential input selection available
- Internal conversion channels for internal temperature sensor and  $1/2 \times AV_{CC}$  and four more internal channels available on select devices (see the device-specific data sheet for availability and function)
- Independent channel-selectable reference sources for both positive and negative references
- Selectable conversion clock source
- Single-channel, repeat-single-channel, sequence (autoscan), and repeat-sequence (repeated autoscan) conversion modes
- Interrupt vector register for fast decoding of 38 ADC interrupts
- 32 conversion-result storage registers
- Window comparator for low-power monitoring of input signals of conversion-result registers

Figure 34-1 shows the block diagram of ADC12\_B. The reference generation is located in the reference module (REF) (see the device-specific data sheet).



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- A The MODCLK is part of the UCS. See the UCS chapter for more information.
- B See the device-specific data sheet for timer sources available.
- C See the device-specific data sheet for Internal Channel 0-3 availability and function.
- D REFOUT bit is part of the Reference module registers.

**Figure 34-1. ADC12\_B Block Diagram**

## 34.2 ADC12\_B Operation

The ADC12\_B module is configured with user software. The following sections describe the setup and operation of the ADC12\_B.

### 34.2.1 12-Bit ADC Core

The ADC core converts an analog input to its 12-bit digital representation. The core uses two programmable and selectable voltage levels ( $V_{R+}$  and  $V_{R-}$ ) to define the upper and lower limits of the conversion. The digital output ( $N_{ADC}$ ) is full scale (0FFFh) when the input signal is equal to or higher than  $V_{R+}$ , and is zero when the input signal is equal to or lower than  $V_{R-}$ . The input channel and the reference voltage levels ( $V_{R+}$  and  $V_{R-}$ ) are defined in the conversion-control memory.

[Equation 13](#) shows the conversion formula for the ADC result  $N_{ADC}$  for single-ended mode.

$$N_{ADC} = 4096 \times \frac{(V_{in+} + \frac{1}{2} LSB) - V_{R-}}{V_{R+} - V_{R-}} \quad \text{Where, } 1 \text{ LSB} = \frac{V_{R+} - V_{R-}}{4096} \quad (13)$$

[Equation 14](#) shows the conversion formula for the ADC result  $N_{ADC}$  for differential mode.

$$N_{ADC} = \left( 2048 \times \frac{V_{in+} - V_{in-} + \frac{1}{2} LSB}{V_{R+} - V_{R-}} \right) + 2048 \quad \text{Where, } 1 \text{ LSB} = \frac{V_{R+} - V_{R-}}{2048} \quad (14)$$

[Equation 15](#) describes the input voltage at which the ADC output saturates for singled-ended mode.

$$V_{in+} = V_{R+} - V_{R-} - 1.5 \text{ LSB} \quad (15)$$

[Equation 16](#) describes the input voltage at which the ADC output saturates for differential mode.

$$V_{in+} - V_{in-} = V_{R+} - V_{R-} - 1.5 \text{ LSB}$$

where

- $V_{R-} < V_{in+} < V_{R+}$
  - $V_{R-} < V_{in-} < V_{R+}$
- (16)

Four control registers configure the ADC12\_B core: ADC12CTL0, ADC12CTL1, ADC12CTL2, and ADC12CTL3. The ADC12ON bit enables or disables the core. The ADC12\_B can be turned off when it is not in use to save power. If the ADC12ON bit is set to 0 during a conversion, the conversion is abruptly exited and the module is powered down. With few exceptions, an application can modify the ADC12\_B control bits only when ADC12ENC = 0. ADC12ENC must be set to 1 before any conversion can take place.

The conversion results are always stored in binary unsigned format. For differential input, this means that an offset of 2048 is added to the result to make the number positive. The data format bit ADC12DF in ADC12CTL2 allows the user to read the conversion results as binary unsigned or signed binary (2s complement).

#### 34.2.1.1 Conversion Clock Selection

The ADC12CLK operates as the conversion clock and also generates the sampling period when the pulse sampling mode is selected. The ADC12SSELx bit selects the ADC12\_B source clock. SMCLK, MCLK, ACLK, and the MODCLK are the possible ADC12CLK sources. The ADC12PDIV bits set the initial divider on the input clock (1, 4, 32, or 64), and then ADC12DIV bits set an additional divider of 1 to 8.

The user must ensure that the clock that is used for ADC12CLK remains active until the end of a conversion. If the clock is removed during a conversion, the operation does not complete and any result is invalid.

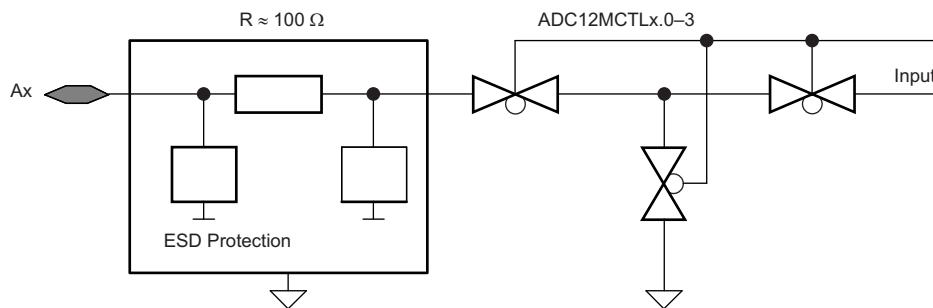
### 34.2.2 ADC12\_B Inputs and Multiplexer

Up to 32 external and up to 6 internal analog signals are selected as the channel for conversion by the analog input multiplexer based on the ADC12INCHx bit and for A<sub>26</sub>-A<sub>31</sub> the ADC12CTL3 register. The number of channels that are available as well as internal channel 0-3 is device specific and is shown in the device-specific data sheet. The input multiplexer is a break-before-make type to reduce input-to-input noise injection that can result from channel switching (see Figure 34-2). The input multiplexer is also a T-switch to minimize the coupling between channels. Channels that are not selected are isolated from the ADC, and the intermediate node is connected to analog ground (AVSS), so that the stray capacitance is grounded to eliminate crosstalk.

The ADC12\_B supports single-ended input or differential inputs configurable for each conversion memory with the ADC12DIF bit in the ADC12\_B Conversion Memory Control x Register (ADC12MCTLx).

Differential input mode should be selected for differential input signals and can also be used for single-ended signals by tying the negative input to AVSS. The advantage of using differential mode is increased common mode noise rejection at the cost of a small increase in current consumption.

The ADC12\_B uses the charge redistribution method. When the inputs are internally switched, the switching action may cause transients on the input signal. These transients decay and settle before causing errant conversion.



**Figure 34-2. Analog Multiplexer T-Switch**

#### 34.2.2.1 Analog Port Selection

The ADC12\_B inputs are multiplexed with digital port pins. When analog signals are applied to digital gates, parasitic current can flow from V<sub>CC</sub> to GND. This parasitic current occurs if the input voltage is near the transition level of the gate. Disabling the digital part of the port pin eliminates the parasitic current flow and, therefore, reduces overall current consumption. The PySELx bits can disable the port pin input and output buffers. Refer to the device specific port x input/output schematic and table for the ADC12\_B input pin for PySELx details.

#### 34.2.3 Voltage References

The ADC12\_B module may use an on-chip shared reference module that supplies three selectable voltage levels of 1.2 V, 2.0 V, and 2.5 V (see the reference module for proper configuration details) to supply V<sub>R+</sub> and V<sub>R-</sub>. These reference voltages may be used internally and externally on pin VREF+ if REFOUT=1. Alternatively, external references may be supplied for V<sub>R+</sub> and V<sub>R-</sub> through pins VREF+/VeREF+ and VeREF-. The ADC12\_B module reference selection is through the ADC12VRSEL bits. For pin flexibility VR+ and VR- are not restricted to VeREF+ and VeREF- respectively. Care must be taken that ADC12VRSEL does not conflict with REFOUT bit settings as only one buffer is available for internal reference with REFOUT=1 or ADC12\_B module reference when external reference with internal buffer is selected. So if REFOUT=1, VeREF+ buffered should not be selected with ADC12VRSEL = 0x3, 0x5, or 0xF.

### 34.2.4 Auto Power Down

The ADC12\_B is designed for low-power applications. When the ADC12\_B is not actively converting, the core is automatically disabled and automatically reenabled when needed. The MODOSC that sources MODCLK is also automatically enabled when needed and disabled when not needed, if the ADC12VRSEL selects the internal reference for the ADC.

If REFON=1, the internal reference is on continually; otherwise, it is only requested when an ADC conversion is triggered. The REF buffer is powered down between conversions to save power unless REFOUT=1, or pulse sample mode is used with ADC12MSC=1, or a conversion mode other than single-channel single conversion is used. When the REF buffer is powered down in pulse sample mode, the ADC sample time does not start until the REF buffer is ready (ADC12RDYIFFG=1), so the user does not need to do anything. When the REF buffer is powered down in extended sample mode, the user must account for the REF buffer settle/ready time by using the ADC12RDYIFFG=1 in calculating the time the trigger should be asserted to make sure that the application meets the required sample time or ADC12\_B minimum sample time.

### 34.2.5 Sample Frequency Mode Selection

The ADC12PWRMD bit optimizes the ADC12\_B power consumption at two ADC12CLK ranges. Select the lowest ADC12CLK frequency that meets or exceeds the application requirements. If ADC12CLK is 1/4 or less of data sheet specified maximum for ADC12PWRMD=0, ADC12PWRMD=1 may be set to save power.

### 34.2.6 Sample and Conversion Timing

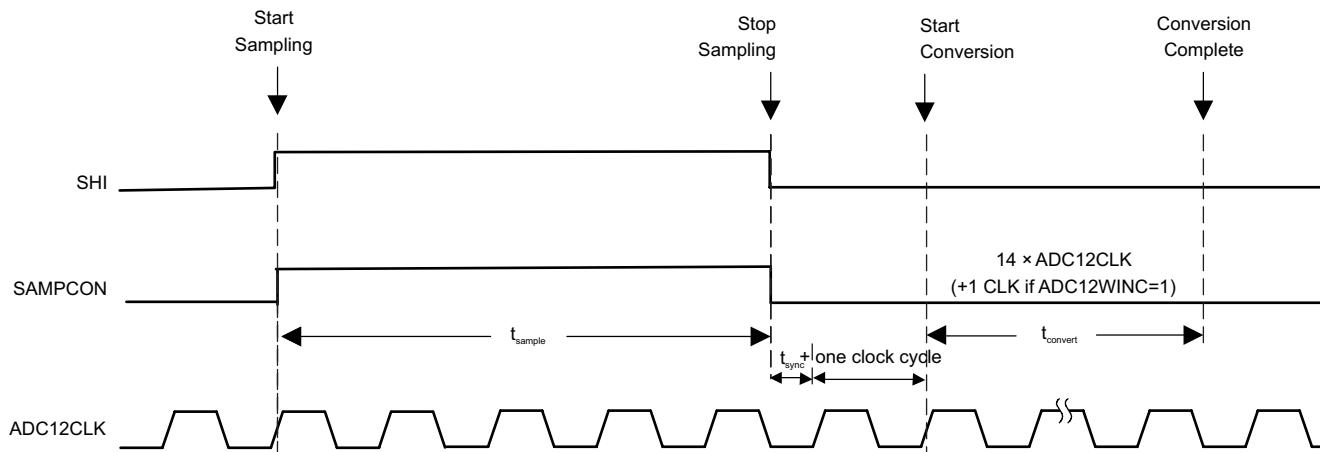
A rising edge of the sample input signal (SHI) initiates an analog-to-digital conversion. The sample input signal can be inverted with the ADC12ISSH bit. The SHSx bits select the source for SHI and include the following:

- ADC12SC bit
- Up to seven other sources that may include timer output (see to the device-specific data sheet for available sources).

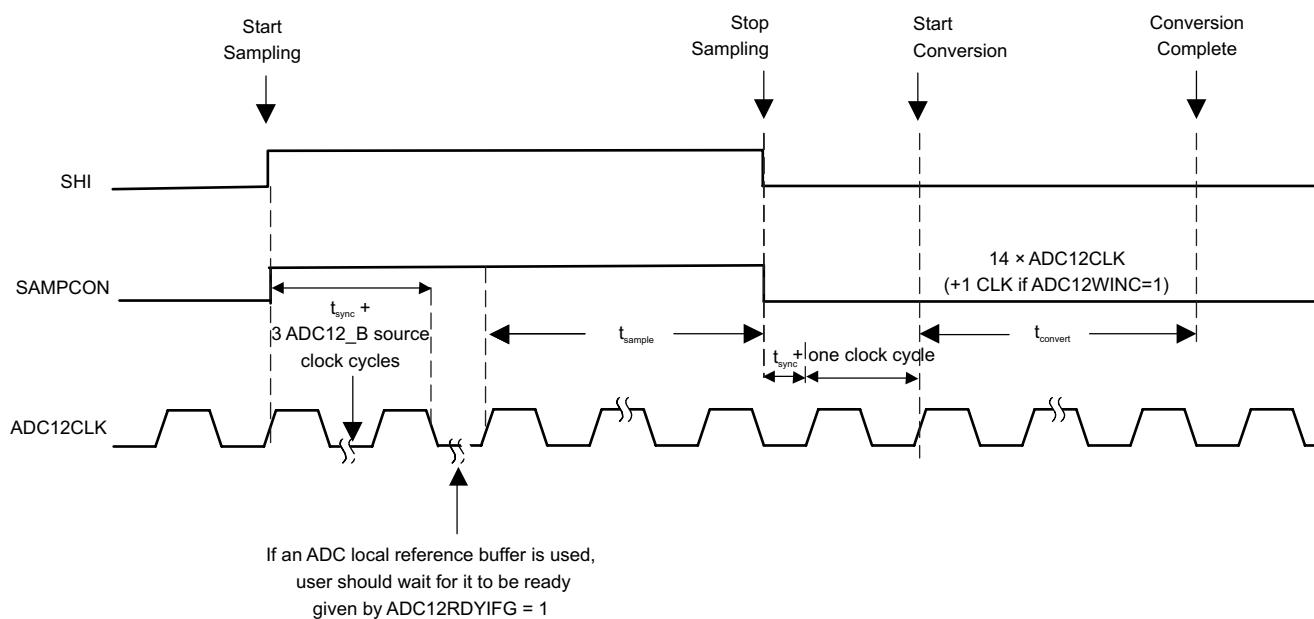
The ADC12\_B supports 8-bit, 10-bit, and 12-bit resolution modes, and the ADC12RES bits select the current mode. The analog-to-digital conversion requires 10, 12, and 14 ADC12CLK cycles, respectively. The ADC12ISSH bit can invert the polarity of the SHI signal source. The SAMPCON signal controls the sample period and start of conversion. When SAMPCON is high, sampling is active. The high-to-low SAMPCON transition starts the analog-to-digital conversion after one clock cycle for pulse sample mode and after one clock cycle plus a clock sync in extended sample mode. Control bit ADC12SHP defines the sample-timing method, either extended sample mode or pulse mode. See the device-specific data sheet for timers that are available for SHI sources.

#### 34.2.6.1 Extended Sample Mode

ADC12SHP = 0 selects the extended sample mode. The SHI signal directly controls SAMPCON and defines the length of the sample period  $t_{sample}$ . If an ADC local reference buffer is used, the user should assert the sample trigger, wait for the ADC12RDYIFG flag to be set (which indicates that the ADC12\_B local reference buffer is settled, and the flag does not occur if the sample trigger has not been asserted), and then keep the sample trigger asserted for the desired sample period before de-asserting. Alternately, if a local reference buffer is used, the user may assert the sample trigger for the desired sample time plus the maximum time for the reference and buffers to settle (reference and buffer settling times are provided in the device-specific data sheet). An ADC local reference buffer is used when ADC12VRSEL= 0001, 0011, 0101, 0111, 1001, 1011, 1101, or 1111. When SAMPCON is high, sampling is active. The high-to-low SAMPCON transition starts the conversion after synchronization with ADC12CLK plus one clock cycle (see [Figure 34-3](#) and [Figure 34-4](#)).



**Figure 34-3. Extended Sample Mode Without Internal Reference in 12-Bit Mode**

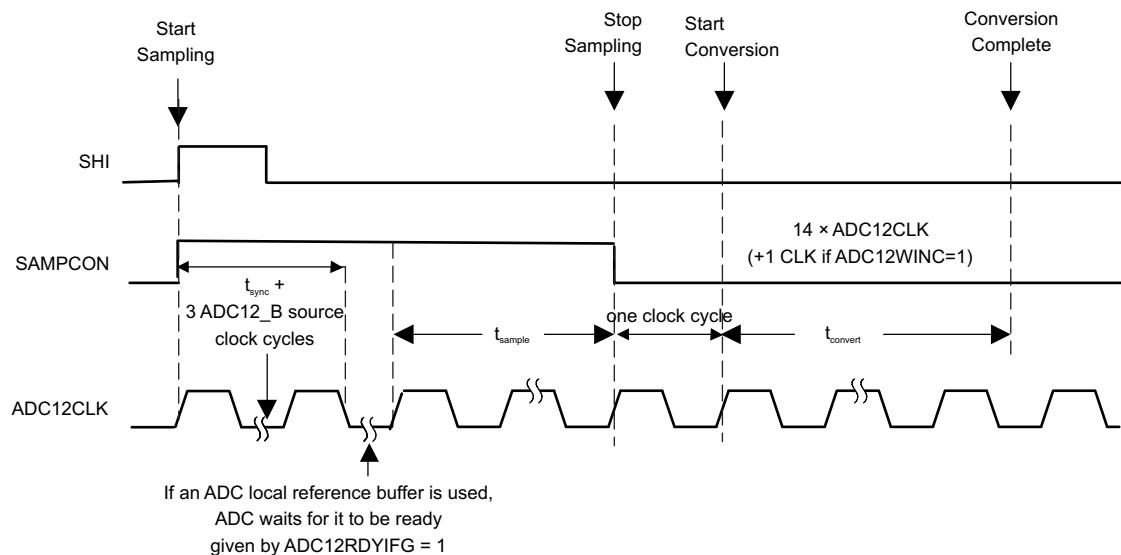


**Figure 34-4. Extended Sample Mode With Internal Reference in 12-Bit Mode**

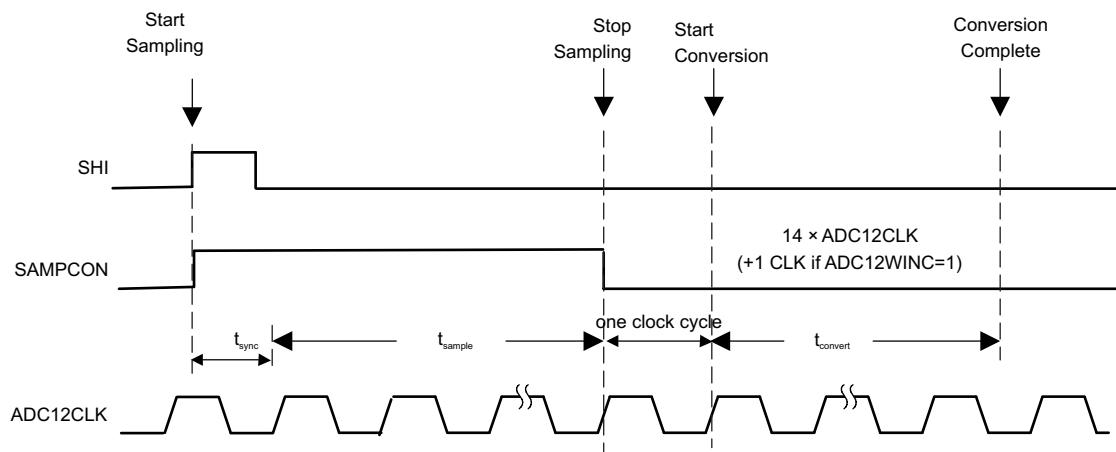
#### 34.2.6.2 Pulse Sample Mode

$\text{ADC12SHP} = 1$  selects the pulse sample mode. The SHI signal triggers the sampling timer. The  $\text{ADC12SHT0x}$  and  $\text{ADC12SHT1x}$  bits in  $\text{ADC12CTL0}$  control the interval of the sampling timer that defines the SAMPCon sample period  $t_{\text{sample}}$ . The sampling timer keeps SAMPCon high while waiting for reference and ADC local reference buffer to settle (if the internal reference is used), synchronization with AD12CLK, and for the programmed interval  $t_{\text{sample}}$ . The exception is for the first conversion or where  $\text{ADC12MSC}=0$  where an extra 3 ADC12\_B source clock cycles is required when SAMPCon goes high. (see [Figure 34-5](#) and [Figure 34-6](#)).

The  $\text{ADC12SHTx}$  bits select the sampling time in 4x multiples of  $\text{ADC12CLK}$ .  $\text{ADC12SHT1x}$  selects the sampling time for  $\text{ADC12MEM8}$  to  $\text{ADC12MEM23}$ , and  $\text{ADC12SHT0x}$  selects the sampling time for  $\text{ADC12MEM0}$  to  $\text{ADC12MEM7}$  and  $\text{ADC12MEM24}$  to  $\text{ADC12MEM31}$ .



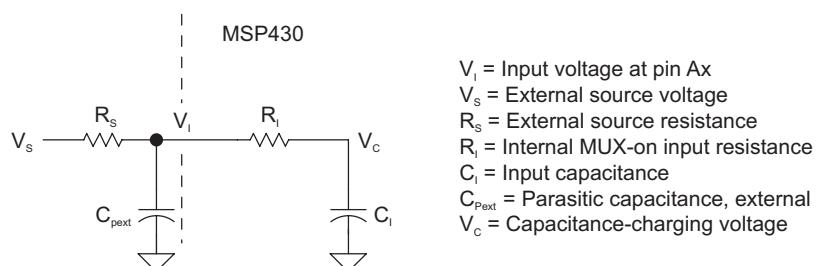
**Figure 34-5. Pulse Sample Mode First Conversion or Where  $\text{ADC12MSC} = 0$  in 12-Bit Mode**



**Figure 34-6. Pulse Sample Mode Subsequent Conversions in 12-Bit Mode**

### 34.2.6.3 Sample Timing Considerations

When  $\text{SAMPCON} = 0$ , all  $A_x$  inputs are high impedance. When  $\text{SAMPCON} = 1$ , the selected  $A_x$  input can be modeled as an RC low-pass filter during the sampling time  $t_{sample}$  (see Figure 34-7). An internal MUX-on input resistance  $R_i$  (see the device-specific data sheet) in series with capacitor  $C_i$  (see the device-specific data sheet) is seen by the source. The capacitor  $C_i$  voltage ( $V_c$ ) must be charged to within one-half LSB of the source voltage ( $V_s$ ) for an accurate n-bit conversion, where n is the bits of resolution required.



**Figure 34-7. Analog Input Equivalent Circuit**

The resistance of the source  $R_S$  and  $R_I$  affect  $t_{\text{sample}}$ . Use [Equation 17](#) to calculate the minimum sampling time  $t_{\text{sample}}$  for a n-bit conversion, where n equals the bits of resolution.

$$t_{\text{sample}} \geq (R_S + R_I) \times \ln(2^{n+2}) \times (C_I + C_{\text{pext}}), R_S < 10 \text{ k}\Omega \quad (17)$$

See the device-specific data sheet for  $R_I$  and  $C_I$  values.

### 34.2.7 Conversion Memory

32 ADC12MEMx conversion memory registers store the conversion results. Each ADC12MEMx is configured with an associated ADC12MCTLx control register. The ADC12VRSEL bits define the voltage reference, and the ADC12INCHx and ADC12DIF bits select the input channels. The ADC12EOS bit defines the end of sequence when a sequential conversion mode is used. A sequence rolls over from ADC12MEM31 to ADC12MEM0 when the ADC12EOS bit in ADC12MCTL31 is not set.

The CSTARTADDx bits define the first ADC12MCTLx used for any conversion. If the conversion mode is single-channel or repeat-single-channel, the CSTARTADDx points to the single ADC12MCTLx to be used.

If the conversion mode selected is either sequence-of-channels or repeat-sequence-of-channels, CSTARTADDx points to the first ADC12MCTLx location to be used in a sequence. A pointer, not visible to software, is incremented automatically to the next ADC12MCTLx in sequence when each conversion completes. The sequence continues until an ADC12EOS bit in ADC12MCTLx is processed; this is, the last control byte processed.

When conversion results are written to a selected ADC12MEMx, the corresponding flag in the ADC12IFGRx register is set.

There are two formats available to read the conversion result from ADC12MEMx. When ADC12DF = 0, the conversion is right justified and unsigned. For ADC12DF = 0 with ADC12DIF = 0 and 8-bit, 10-bit, and 12-bit resolutions, the upper 8, 6, and 4 bits, respectively, of an ADC12MEMx read are always zeros. To convert a ADC12DIF = 1 to binary unsigned, the maximum negative value is added to the conversion. Therefore, 128 is added for 8-bit conversions, 512 is added for 10-bit conversions, and 2048 is added for 12-bit conversions.

When ADC12DF = 1, the conversion result is left justified and two's complement. For 8-bit, 10-bit, and 12-bit resolutions, the lower 8, 6, and 4 bits, respectively, of a ADC12MEMx read are always zeros.

[Table 34-1](#) summarizes the output data formats.

**Table 34-1. ADC12\_B Conversion Result Formats**

| Analog Input Voltage Range                    | ADC12DIF | ADC12DF | ADC12RES | Ideal Conversion Results (With Offset Added When ADC12DIF = 1) | ADC12MEMx Read Value |
|-----------------------------------------------|----------|---------|----------|----------------------------------------------------------------|----------------------|
| Vin to $V_{R^-}$ :<br>$V_{R^-}$ to $+V_{R^+}$ | 0        | 0       | 00       | 0 to 255                                                       | 0000h to 00FFh       |
|                                               | 0        | 0       | 01       | 0 to 1023                                                      | 0000h to 03FFh       |
|                                               | 0        | 0       | 10       | 0 to 4095                                                      | 0000h to 0FFFh       |
|                                               | 0        | 1       | 00       | -128 to 127                                                    | 8000h to 7F00h       |
|                                               | 0        | 1       | 01       | -512 to 511                                                    | 8000h to 7FC0h       |
|                                               | 0        | 1       | 10       | -2048 to 2047                                                  | 8000h to 7FF0h       |
| Vin+ to Vin-:<br>$V_{R^-}$ to $+V_{R^+}$      | 1        | 0       | 00       | -128 to 127<br>(0 to 255)                                      | 0000h to 00FFh       |
|                                               | 1        | 0       | 01       | -512 to 511<br>(0 to 1023)                                     | 0000h to 03FFh       |
|                                               | 1        | 0       | 10       | -2048 to 2047<br>(0 to 4095)                                   | 0000h to 0FFFh       |
|                                               | 1        | 1       | 00       | -128 to 127                                                    | 8000h to 7F00h       |
|                                               | 1        | 1       | 01       | -512 to 511                                                    | 8000h to 7FC0h       |
|                                               | 1        | 1       | 10       | -2048 to 2047                                                  | 8000h to 7FF0h       |

### 34.2.8 ADC12\_B Conversion Modes

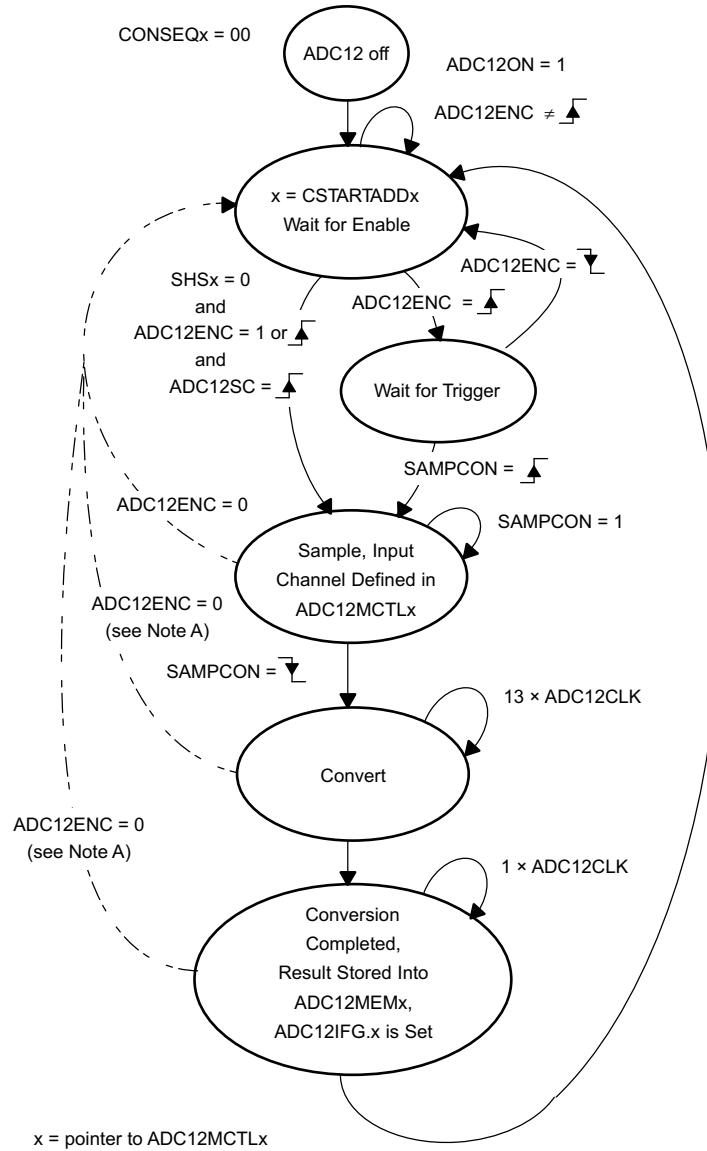
Table 34-2 shows the four operating modes that are selected by the CONSEQx bits. All state diagrams assume a 12-bit resolution setting.

**Table 34-2. Conversion Mode Summary**

| ADC12CONSEQx | Mode                                            | Operation                                       |
|--------------|-------------------------------------------------|-------------------------------------------------|
| 00           | Single-channel single-conversion                | A single channel is converted once.             |
| 01           | Sequence-of-channels (autoscan)                 | A sequence of channels is converted once.       |
| 10           | Repeat-single-channel                           | A single channel is converted repeatedly.       |
| 11           | Repeat-sequence-of-channels (repeated autoscan) | A sequence of channels is converted repeatedly. |

### 34.2.8.1 Single-Channel Single-Conversion Mode

A single channel is sampled and converted once. The ADC result is written to the ADC12MEMx that is defined by the CSTARTADDx bits. Figure 34-8 shows the flow of the single-channel single-conversion mode when RES = 0x2 for 12-bit mode. When ADC12SC triggers a conversion, the ADC12SC bit can trigger successive conversions. When any other trigger source is used, ADC12ENC must be toggled between each conversion. When there are multiple triggers then ADC12ENC bit must be toggled after the additional trigger(s) for lowest power (otherwise clocks are still requested even after conversion is complete).



A Conversion result is unpredictable.

**Figure 34-8. Single-Channel Single-Conversion Mode, ADC12ISSH = 0**

### 34.2.8.2 Sequence-of-Channels Mode (Autoscan Mode)

In sequence-of-channels mode, also called autoscan mode, a sequence of channels is sampled and converted once. The ADC results are written to the conversion memories starting with the ADC12MEMx that is defined by the CSTARTADDx bits. The sequence stops after the measurement of the channel with a set ADC12EOS bit. Figure 34-9 shows the sequence-of-channels mode when RES = 0x02 for 12-bit mode. When ADC12SC triggers a sequence, the ADC12SC bit can trigger successive sequences. When any other trigger source is used, ADC12ENC must be toggled between each sequence. When there are multiple triggers then ADC12ENC bit must be toggled after the additional trigger(s) for lowest power (otherwise clocks are still requested even after conversion sequence is complete).

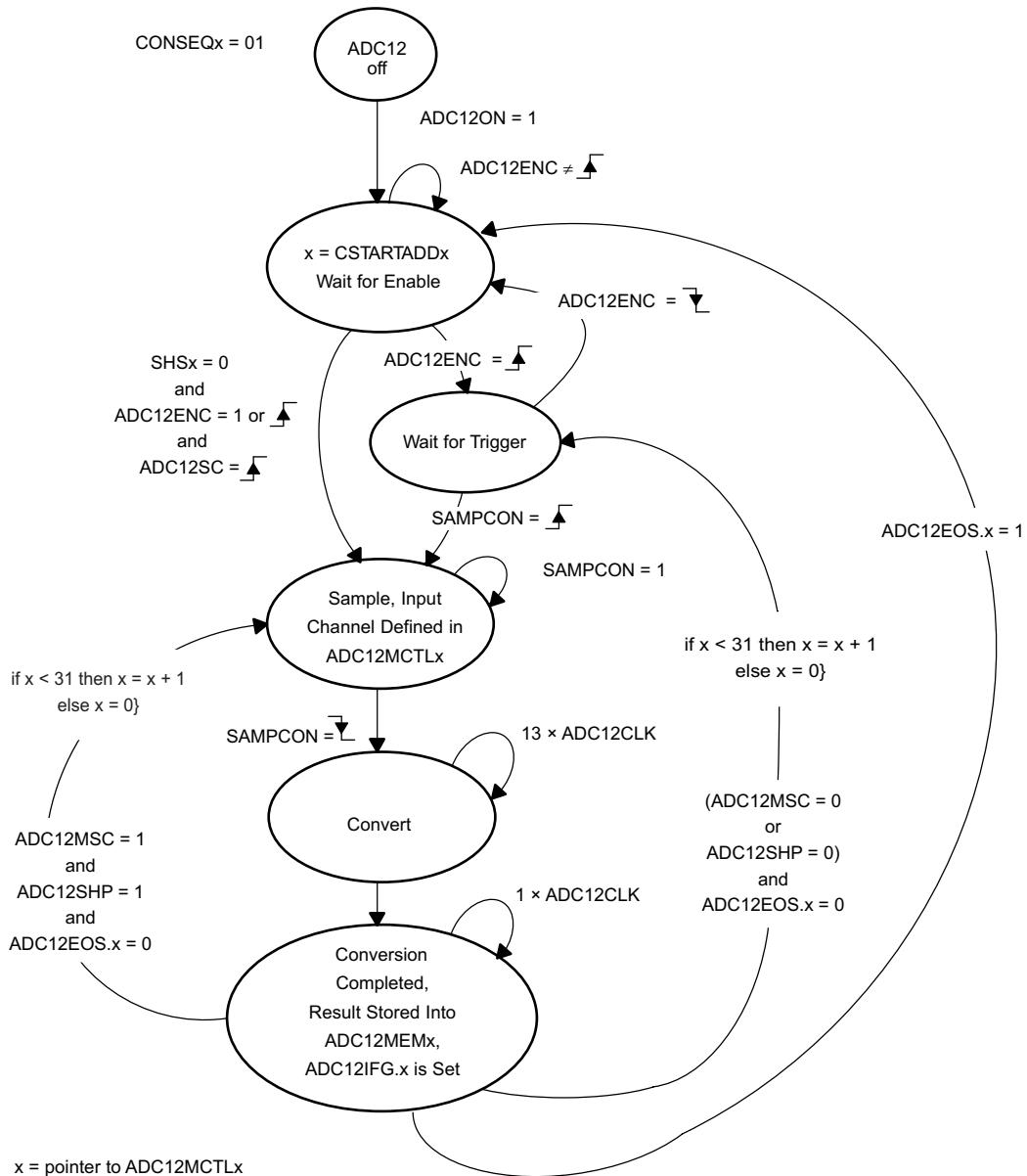
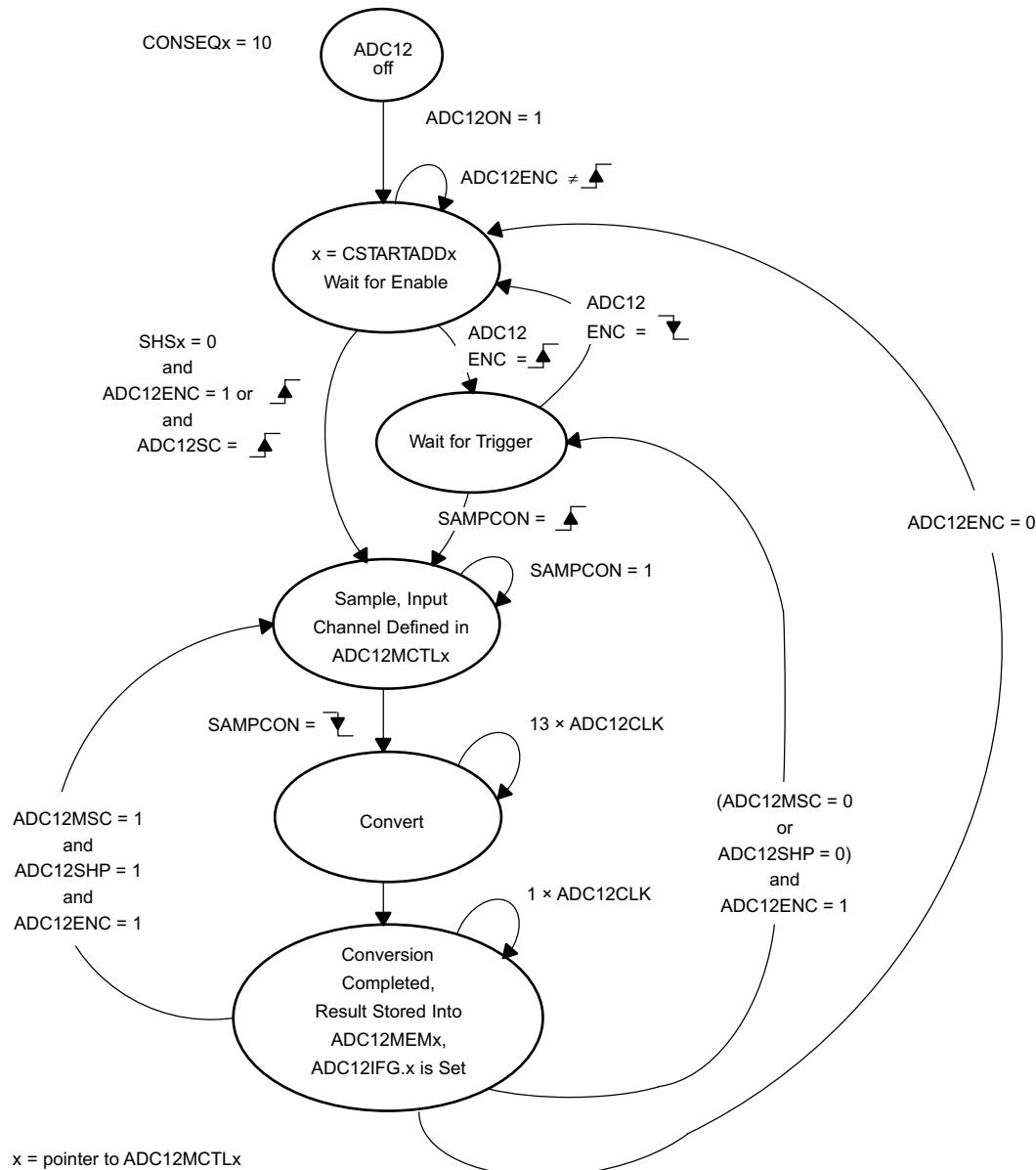


Figure 34-9. Sequence-of-Channels Mode,  $\text{ADC12ISSH} = 0$

### 34.2.8.3 Repeat-Single-Channel Mode

In repeat-single-channel mode, a single channel is sampled and converted continuously. The ADC results are written to the ADC12MEMx defined by the CSTARTADDx bits. It is necessary to read the result after the completed conversion, because only one ADC12MEMx memory is used and is overwritten by the next conversion. [Figure 34-10](#) shows the repeat-single-channel mode when RES = 0x2 for 12-bit mode.



**Figure 34-10. Repeat-Single-Channel Mode, ADC12ISSH = 0**

### 34.2.8.4 Repeat-Sequence-of-Channels Mode (Repeated Autoscan Mode)

In repeat-sequence-of-channels mode, a sequence of channels is sampled and converted repeatedly. This mode is also called repeated autoscan mode. The ADC results are written to the conversion memories starting with the ADC12MEMx that is defined by the CSTARTADDx bits. The sequence ends after the measurement of the channel with a set ADC12EOS bit, and the next trigger signal restarts the sequence. Figure 34-11 shows the repeat-sequence-of-channels mode.

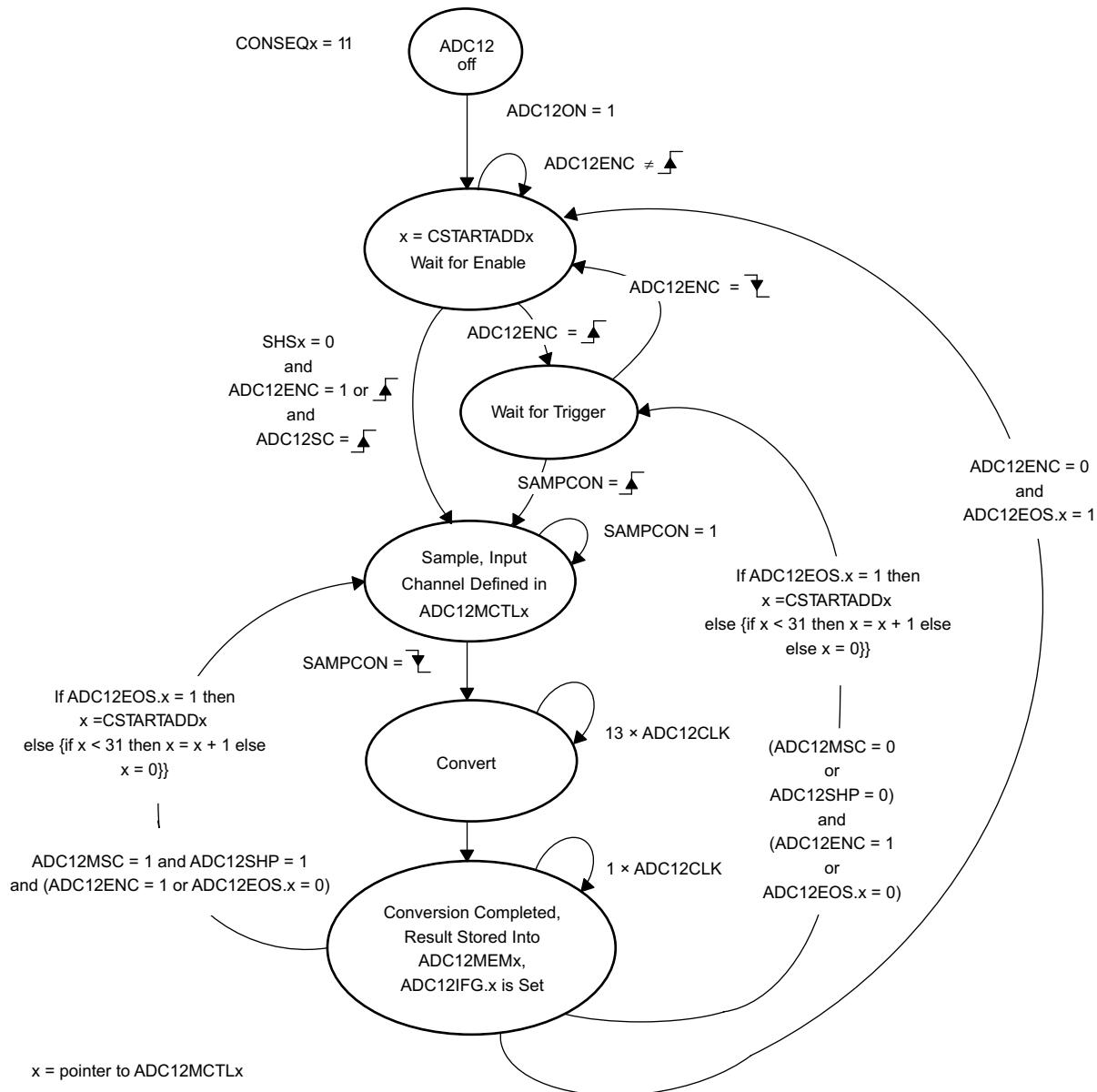


Figure 34-11. Repeat-Sequence-of-Channels Mode, ADC12ISSH = 0

### 34.2.8.5 Using the Multiple Sample and Convert (ADC12MSC) Bit

To configure the converter to perform successive conversions automatically and as quickly as possible, a multiple sample and convert function is available. When ADC12MSC = 1, CONSEQx > 0, and the sample timer is used (pulse sample mode, ADC12SHP = 1), the first rising edge of SHI signal triggers the first conversion. Successive conversions are triggered automatically as soon as the prior conversion is completed (if the ADC local reference buffer is used, ADC12VRSEL= 0001, 0011, 0101, 0111, 1001, 1011, 1101, or 1111, there is one clock cycle before the successive conversion is triggered). Additional SHI triggers are ignored until the sequence is completed in the single-sequence mode, or until the ADC12ENC bit is toggled in repeat-single-channel or repeated-sequence modes. The function of the ADC12ENC bit is unchanged when using the ADC12MSC bit.

### 34.2.8.6 Stopping Conversions

Stopping ADC12\_B activity depends on the mode of operation. The recommended ways to stop an active conversion or conversion sequence are:

- Reset ADC12ENC in single-channel single-conversion mode to stop a conversion immediately. The results are unreliable. For correct results, poll the busy bit until it is reset before clearing ADC12ENC.
- Reset ADC12ENC during repeat-single-channel operation to stop the converter at the end of the current conversion.
- Reset ADC12ENC during a sequence or repeat-sequence mode to stop the converter at the end of the current conversion.
- Stop any conversion mode immediately by setting the CONSEQx = 0 and resetting the ADC12ENC and ADC12ON bit. Conversion data are unreliable.

---

**NOTE: No ADC12EOS bit set for sequence**

If no ADC12EOS bit is set and a sequence mode is selected, resetting the ADC12ENC bit does not stop the sequence. To stop the sequence, first select a single-channel mode and then reset ADC12ENC.

---

### 34.2.9 Operation in LPM3 and LPM4

The ADC remains active in LPM3 if the following are all true:

- ADC is on (ADC12ON = 1).
- Conversion is enabled (ADC12ENC = 1).
- External triggers are selected (ADC12SHSx ≠ 0) OR ACLK is ADC12B source clock (ADC12SSELx = 01b).

The ADC remains active in LPM4 if the following are all true:

- ADC is on (ADC12ON = 1).
- Conversion is enabled (ADC12ENC = 1).
- External triggers are selected (ADC12SHSx ≠ 0).

### 34.2.10 Window Comparator

The window comparator allows to monitor analog signals without any CPU interaction. It is enabled for the desired ADC12MEMx conversion with the ADC12WINC bit in the ADC12MCTLx register. In the following the window comparator interrupts are listed:

- The ADC12LO interrupt flag (ADC12LOIFG) is set if the current result of the ADC12\_B conversion is below the low threshold defined in register ADC12LO.
- The ADC12HI interrupt flag (ADC12HIIFG) is set if the current result of the ADC12\_B conversion is greater than the high threshold defined in the register ADC12HI.
- The ADC12IN interrupt flag (ADC12INIFG) is set if the current result of the ADC12\_B conversion is greater than the low threshold defined in register ADC12LO and less than the high threshold defined in ADC12HI.

These interrupts are generated independently of the conversion mode selected by the user. The update of the window comparator interrupt flags happen after the ADC12IFGx.

The lower and higher threshold in the ADC12LO and ADC12HI registers have to be given in the correct data format. If the binary unsigned data format is selected by ADC12DF = 0, then the thresholds in the registers ADC12LO and ADC12HI must be written as binary unsigned values. If the signed binary (2s complement) data format is selected by ADC12DF = 1, then the thresholds in the registers ADC12LO and ADC12HI must be written as signed binary (2s complement). Altering the ADC12DF register or the ADC12RES register resets the threshold registers.

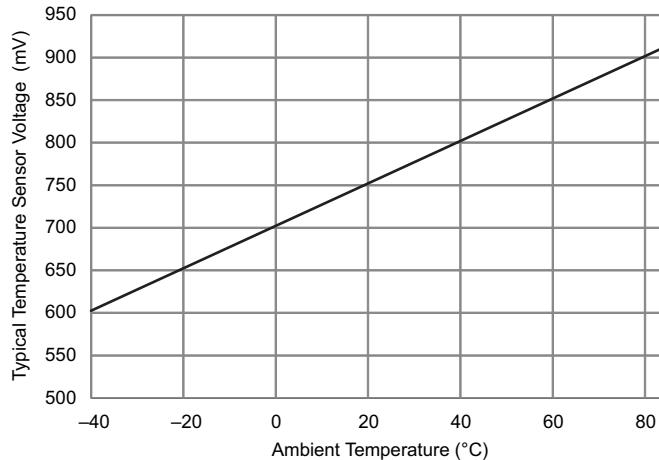
The interrupt flags are reset by the user software. The ADC12\_B sets the interrupt flags each time a new conversion result is available in the ADC12MEMx register if applicable. Interrupt flags are not cleared by hardware. The user software resets the window comparator interrupt flags per the application needs.

#### 34.2.11 Using the Integrated Temperature Sensor

To use the on-chip temperature sensor, the user must enable the temperature sensor input channel by setting the ADC12TCMAP bit equal to 1 in the ADC12CTL3 register. The user must then select the analog input channel ADC12INCHx = 0x1E for the temperature sensor. Any other configuration is done as if an external channel were selected, including reference selection, conversion-memory selection, and so on. The temperature sensor is in the REF module.

A typical temperature sensor transfer function is shown in [Figure 34-12](#). The transfer function shown is only an example. Calibration is required to determine the corresponding voltages for a specific device. When using the temperature sensor, the sample period must be greater than 30  $\mu$ s. The temperature sensor offset error can be large and may need to be calibrated for most applications. Temperature calibration values are available for use in the TLV descriptors (see the device-specific data sheet for locations). Some MSP430 devices include calibration data that can be used to compute temperature more accurately. For more information, refer to [Section 1.14.3.3](#).

Selecting the temperature sensor automatically turns on the on-chip reference generator as a voltage source for the temperature sensor. However, it does not enable the VREF+ output or affect the reference selections for the conversion. The reference choices for converting the temperature sensor are the same as with any other channel.



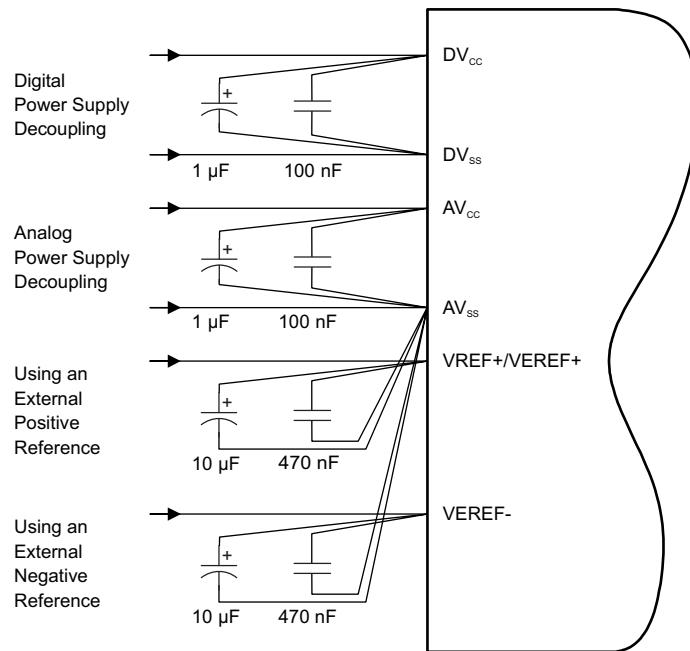
**Figure 34-12. Typical Temperature Sensor Transfer Function**

### **34.2.12 ADC12\_B Grounding and Noise Considerations**

As with any high-resolution ADC, appropriate printed-circuit-board layout and grounding techniques should be followed to eliminate ground loops, unwanted parasitic effects, and noise.

Ground loops are formed when return current from the ADC flows through paths that are common with other analog or digital circuitry. If care is not taken, this current can generate small unwanted offset voltages that can add to or subtract from the reference or input voltages of the ADC. The connections shown in Figure 34-13 prevent this.

In addition to grounding, ripple and noise spikes on the power-supply lines due to digital switching or switching power supplies can corrupt the conversion result. A noise-free design using separate analog and digital ground planes with a single-point connection is recommended to achieve high accuracy.



**Figure 34-13. ADC12\_B Grounding and Noise Considerations**

### 34.2.13 ADC12\_B Calibration

The device TLV structure contains calibration values that can be used to improve the measurement capability of the ADC12\_B. Refer to [Section 1.14](#) of the *System Resets, Interrupts, and Operating Modes, System Control Module (SYS)* chapter for more details.

### 34.2.14 ADC12\_B Interrupts

The ADC12\_B has 38 interrupt sources:

- ADC12IFG0 to ADC12IFG31
- ADC12OVIFG: ADC12MEMx overflow
- ADC12TOVIFG: ADC12\_B conversion time overflow
- ADC12LOIFG, ADC12INIFG, and ADC12HIIIFG for ADC12MEMx
- ADC12RDYIFG: ADC12\_B local reference buffer ready

The ADC12IFGx bits are set when their corresponding ADC12MEMx memory register is loaded with a conversion result. An interrupt request is generated if the corresponding ADC12IEx bit and the GIE bit are set. The conversion result written into ADC12MEMx result register also sets the ADC12LOIFG, ADC12INIFG or ADC12HIIIFG if applicable. The ADC12OVIFG condition occurs when a conversion result is written to any ADC12MEMx before its previous conversion result was read. The ADC12TOVIFG condition is generated when another sample-and-conversion is requested before the current conversion is completed. The DMA is triggered after the conversion in single-channel conversion mode or after the completion of a sequence of channel conversions in sequence-of-channels conversion mode. See [Section 11.2.11](#) for additional details. The ADC12RDYIFG is set after the sample trigger is asserted when the ADC12\_B local reference buffer is ready. Note the ADC12RDYIFG will be set even when the ADC12B does not select the buffered reference. It can be used during extended sample mode instead of adding the max ADC12\_B local reference buffer settle time to the sample signal time.

#### 34.2.14.1 ADC12IV, Interrupt Vector Generator

All ADC12\_B interrupt sources are prioritized and combined to source a single interrupt vector. The interrupt vector register ADC12IV is used to determine which ADC12\_B interrupt source requested an interrupt.

The highest-priority enabled ADC12\_B interrupt generates a number in the ADC12IV register (see [Section 34.3.15](#)). This number can be evaluated or added to the program counter (PC) to automatically enter the appropriate software routine. ADC12\_B interrupts that are disabled do not affect the ADC12IV value.

Read access of the ADC12IV register automatically resets the highest pending interrupt condition and flag except the ADC12IFGx flags. ADC12IFGx bits are reset automatically by accessing their associated ADC12MEMx register or may be reset with software.

Write access of the ADC12IV register clears all pending interrupt conditions and flags.

If another interrupt is pending after servicing of an interrupt, another interrupt is generated. For example, if the ADC12OV and ADC12IFG3 interrupts are pending when the interrupt service routine accesses the ADC12IV register, the ADC12OV interrupt condition is reset automatically. After the RETI instruction of the interrupt service routine is executed, the ADC12IFG3 generates another interrupt.

### **34.2.14.2 ADC12\_B Interrupt Handling Software Example**

The following software example shows the recommended use of the ADC12IV and handling overhead. The ADC12IV value is added to the PC to automatically jump to the appropriate routine.

The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself, are:

- ADC12IFG0 through ADC12IFG30, ADC12TOV, ADC12OV, ADC12LO, ADC12HI, ADC12IN, ADC12RDY: 16 cycles
- ADC12IFG31: 14 cycles

The interrupt handler for ADC12IFG31 shows a way to check immediately if a higher-prioritized interrupt occurred during the processing of ADC12IFG31. This saves nine cycles if another ADC12\_B interrupt is pending.

```
; Interrupt handler for ADC12.
INT_ADC12          ; Enter Interrupt Service Routine
    ADD    &ADC12IV,PC ; Add offset to PC
    RETI               ; Vector 0: No interrupt
    JMP    ADOV        ; Vector 2: ADC overflow
    JMP    ADTOV       ; Vector 4: ADC timing overflow
    JMP    ADHI        ; Vector 6: ADC12HIIFG
    JMP    ADLO        ; Vector 8: ADC12LOIFG
    JMP    ADIN        ; Vector A: ADC12INIFG
    JMP    ADM0        ; Vector C: ADC12IFG0
    ...
    JMP    ADM30       ; Vectors E-70
    ...
    JMP    ADRDY       ; Vector 72: ADC12IFG30
;
; Handler for ADC12IFG31 starts here. No JMP required.
;
;
ADM31   MOV    &ADC12MEM31,xxx      ; Move result, flag is reset
        ...
        JMP    INT_ADC12      ; Other instruction needed?
;
; ADC12IFG30-ADC12IFG1 handlers go here
;
ADM0    MOV    &ADC12MEM0,xxx      ; Move result, flag is reset
        ...
        RETI               ; Other instruction needed?
        ;
ADTOV  ...                  ; Return;
        RETI               ; Handle Conv. time overflow
        ;
ADOV   ...                  ; Return;
        RETI               ; Handle ADC12MEMx overflow
        ;
ADHI   ...                  ; Return;
        RETI               ; Handle window comparator high Interrupt
        ;
ADLO   ...                  ; Return;
        RETI               ; Handle window comparator low Interrupt
        ;
ADIN   ...                  ; Return;
        RETI               ; Handle window comparator in window Interrupt
        ;
ADRDY  ...                  ; Return;
        RETI               ; Handle window comparator in window Interrupt
```

### 34.3 ADC12\_B Registers

[Table 34-3](#) lists the memory-mapped registers for the ADC12\_B. See the device-specific data sheet for the base memory address of these registers. All other register offset addresses not listed in [Table 34-3](#) should be considered as reserved locations, and the register contents should not be modified.

---

**NOTE:** All registers have word or byte register access. For a generic register ANYREG, the suffix "\_L" (ANYREG\_L) refers to the lower byte of the register (bits 0 through 7). The suffix "\_H" (ANYREG\_H) refers to the upper byte of the register (bits 8 through 15).

---

**Table 34-3. ADC12\_B Registers**

| Offset | Acronym      | Register Name                                     | Type       | Access | Reset | Section                         |
|--------|--------------|---------------------------------------------------|------------|--------|-------|---------------------------------|
| 00h    | ADC12CTL0    | ADC12_B Control 0                                 | Read/write | Word   | 0000h | <a href="#">Section 34.3.1</a>  |
| 00h    | ADC12CTL0_L  |                                                   | Read/write | Byte   | 00h   |                                 |
| 01h    | ADC12CTL0_H  |                                                   | Read/write | Byte   | 00h   |                                 |
| 02h    | ADC12CTL1    | ADC12_B Control 1                                 | Read/write | Word   | 0000h | <a href="#">Section 34.3.2</a>  |
| 02h    | ADC12CTL1_L  |                                                   | Read/write | Byte   | 00h   |                                 |
| 03h    | ADC12CTL1_H  |                                                   | Read/write | Byte   | 00h   |                                 |
| 04h    | ADC12CTL2    | ADC12_B Control 2                                 | Read/write | Word   | 0020h | <a href="#">Section 34.3.3</a>  |
| 04h    | ADC12CTL2_L  |                                                   | Read/write | Byte   | 20h   |                                 |
| 05h    | ADC12CTL2_H  |                                                   | Read/write | Byte   | 00h   |                                 |
| 06h    | ADC12CTL3    | ADC12_B Control 3                                 | Read/write | Byte   | 0000h | <a href="#">Section 34.3.4</a>  |
| 06h    | ADC12CTL3_L  |                                                   | Read/write | Byte   | 00h   |                                 |
| 07h    | ADC12CTL3_H  |                                                   | Read/write |        | 00h   |                                 |
| 08h    | ADC12LO      | ADC12_B Window Comparator Low Threshold Register  | Read/write | Word   | 0000h | <a href="#">Section 34.3.8</a>  |
| 08h    | ADC12LO_L    |                                                   | Read/write | Byte   | 00h   |                                 |
| 09h    | ADC12LO_H    |                                                   | Read/write | Byte   | 00h   |                                 |
| 0Ah    | ADC12HI      | ADC12_B Window Comparator High Threshold Register | Read/write | Word   | 0FFFh | <a href="#">Section 34.3.7</a>  |
| 0Ah    | ADC12HI_L    |                                                   | Read/write | Byte   | FFh   |                                 |
| 0Bh    | ADC12HI_H    |                                                   | Read/write | Byte   | 0Fh   |                                 |
| 0Ch    | ADC12IFGR0   | ADC12_B Interrupt Flag 0                          | Read/write | Word   | 0000h | <a href="#">Section 34.3.12</a> |
| 0Ch    | ADC12IFGR0_L |                                                   | Read/write | Byte   | 00h   |                                 |
| 0Dh    | ADC12IFGR0_H |                                                   | Read/write | Byte   | 00h   |                                 |
| 0Eh    | ADC12IFGR1   | ADC12_B Interrupt Flag 1                          | Read/write | Word   | 0000h | <a href="#">Section 34.3.13</a> |
| 0Eh    | ADC12IFGR1_L |                                                   | Read/write | Byte   | 00h   |                                 |
| 0Fh    | ADC12IFGR1_H |                                                   | Read/write | Byte   | 00h   |                                 |
| 10h    | ADC12IFGR2   | ADC12_B Interrupt Flag 2                          | Read/write | Word   | 0000h | <a href="#">Section 34.3.14</a> |
| 10h    | ADC12IFGR2_L |                                                   | Read/write | Byte   | 00h   |                                 |
| 11h    | ADC12IFGR2_H |                                                   | Read/write | Byte   | 00h   |                                 |
| 12h    | ADC12IER0    | ADC12_B Interrupt Enable 0                        | Read/write | Word   | 0000h | <a href="#">Section 34.3.9</a>  |
| 12h    | ADC12IER0_L  |                                                   | Read/write | Byte   | 00h   |                                 |
| 13h    | ADC12IER0_H  |                                                   | Read/write | Byte   | 00h   |                                 |
| 14h    | ADC12IER1    | ADC12_B Interrupt Enable 1                        | Read/write | Word   | 0000h | <a href="#">Section 34.3.10</a> |
| 14h    | ADC12IER1_L  |                                                   | Read/write | Byte   | 00h   |                                 |
| 15h    | ADC12IER1_H  |                                                   | Read/write | Byte   | 00h   |                                 |
| 16h    | ADC12IER2    | ADC12_B Interrupt Enable 2                        | Read/write | Word   | 0000h | <a href="#">Section 34.3.11</a> |
| 16h    | ADC12IER2_L  |                                                   | Read/write | Byte   | 00h   |                                 |
| 17h    | ADC12IER2_H  |                                                   | Read/write | Byte   | 00h   |                                 |

**Table 34-3. ADC12\_B Registers (continued)**

| Offset | Acronym       | Register Name             | Type       | Access | Reset | Section                         |
|--------|---------------|---------------------------|------------|--------|-------|---------------------------------|
| 18h    | ADC12IV       | ADC12_B Interrupt Vector  | Read/write | Word   | 0000h | <a href="#">Section 34.3.15</a> |
| 18h    | ADC12IV_L     |                           | Read/write | Byte   | 00h   |                                 |
| 19h    | ADC12IV_H     |                           | Read       | Byte   | 00h   |                                 |
| 20h    | ADC12MCTL0    | ADC12_B Memory Control 0  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 20h    | ADC12MCTL0_L  |                           | Read/write | Byte   | 00h   |                                 |
| 21h    | ADC12MCTL0_H  |                           | Read/write | Byte   | 00h   |                                 |
| 22h    | ADC12MCTL1    | ADC12_B Memory Control 1  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 22h    | ADC12MCTL1_L  |                           | Read/write | Byte   | 00h   |                                 |
| 23h    | ADC12MCTL1_H  |                           | Read/write | Byte   | 00h   |                                 |
| 24h    | ADC12MCTL2    | ADC12_B Memory Control 2  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 24h    | ADC12MCTL2_L  |                           | Read/write | Byte   | 00h   |                                 |
| 25h    | ADC12MCTL2_H  |                           | Read/write | Byte   | 00h   |                                 |
| 26h    | ADC12MCTL3    | ADC12_B Memory Control 3  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 26h    | ADC12MCTL3_L  |                           | Read/write | Byte   | 00h   |                                 |
| 27h    | ADC12MCTL3_H  |                           | Read/write | Byte   | 00h   |                                 |
| 28h    | ADC12MCTL4    | ADC12_B Memory Control 4  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 28h    | ADC12MCTL4_L  |                           | Read/write | Byte   | 00h   |                                 |
| 29h    | ADC12MCTL4_H  |                           | Read/write | Byte   | 00h   |                                 |
| 2Ah    | ADC12MCTL5    | ADC12_B Memory Control 5  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 2Ah    | ADC12MCTL5_L  |                           | Read/write | Byte   | 00h   |                                 |
| 2Bh    | ADC12MCTL5_H  |                           | Read/write | Byte   | 00h   |                                 |
| 2Ch    | ADC12MCTL6    | ADC12_B Memory Control 6  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 2Ch    | ADC12MCTL6_L  |                           | Read/write | Byte   | 00h   |                                 |
| 2Dh    | ADC12MCTL6_H  |                           | Read/write | Byte   | 00h   |                                 |
| 2Eh    | ADC12MCTL7    | ADC12_B Memory Control 7  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 2Eh    | ADC12MCTL7_L  |                           | Read/write | Byte   | 00h   |                                 |
| 2Fh    | ADC12MCTL7_H  |                           | Read/write | Byte   | 00h   |                                 |
| 30h    | ADC12MCTL8    | ADC12_B Memory Control 8  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 30h    | ADC12MCTL8_L  |                           | Read/write | Byte   | 00h   |                                 |
| 31h    | ADC12MCTL8_H  |                           | Read/write | Byte   | 00h   |                                 |
| 32h    | ADC12MCTL9    | ADC12_B Memory Control 9  | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 32h    | ADC12MCTL9_L  |                           | Read/write | Byte   | 00h   |                                 |
| 33h    | ADC12MCTL9_H  |                           | Read/write | Byte   | 00h   |                                 |
| 34h    | ADC12MCTL10   | ADC12_B Memory Control 10 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 34h    | ADC12MCTL10_L |                           | Read/write | Byte   | 00h   |                                 |
| 35h    | ADC12MCTL10_H |                           | Read/write | Byte   | 00h   |                                 |
| 36h    | ADC12MCTL11   | ADC12_B Memory Control 11 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 36h    | ADC12MCTL11_L |                           | Read/write | Byte   | 00h   |                                 |
| 37h    | ADC12MCTL11_H |                           | Read/write | Byte   | 00h   |                                 |
| 38h    | ADC12MCTL12   | ADC12_B Memory Control 12 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 38h    | ADC12MCTL12_L |                           | Read/write | Byte   | 00h   |                                 |
| 39h    | ADC12MCTL12_H |                           | Read/write | Byte   | 00h   |                                 |
| 3Ah    | ADC12MCTL13   | ADC12_B Memory Control 13 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a>  |
| 3Ah    | ADC12MCTL13_L |                           | Read/write | Byte   | 00h   |                                 |
| 3Bh    | ADC12MCTL13_H |                           | Read/write | Byte   | 00h   |                                 |

**Table 34-3. ADC12\_B Registers (continued)**

| Offset | Acronym       | Register Name             | Type       | Access | Reset | Section                        |
|--------|---------------|---------------------------|------------|--------|-------|--------------------------------|
| 3Ch    | ADC12MCTL14   | ADC12_B Memory Control 14 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 3Ch    | ADC12MCTL14_L |                           | Read/write | Byte   | 00h   |                                |
| 3Dh    | ADC12MCTL14_H |                           | Read/write | Byte   | 00h   |                                |
| 3Eh    | ADC12MCTL15   | ADC12_B Memory Control 15 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 3Eh    | ADC12MCTL15_L |                           | Read/write | Byte   | 00h   |                                |
| 3Fh    | ADC12MCTL15_H |                           | Read/write | Byte   | 00h   |                                |
| 40h    | ADC12MCTL16   | ADC12_B Memory Control 16 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 40h    | ADC12MCTL16_L |                           | Read/write | Byte   | 00h   |                                |
| 41h    | ADC12MCTL16_H |                           | Read/write | Byte   | 00h   |                                |
| 42h    | ADC12MCTL17   | ADC12_B Memory Control 17 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 42h    | ADC12MCTL17_L |                           | Read/write | Byte   | 00h   |                                |
| 43h    | ADC12MCTL17_H |                           | Read/write | Byte   | 00h   |                                |
| 44h    | ADC12MCTL18   | ADC12_B Memory Control 18 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 44h    | ADC12MCTL18_L |                           | Read/write | Byte   | 00h   |                                |
| 45h    | ADC12MCTL18_H |                           | Read/write | Byte   | 00h   |                                |
| 46h    | ADC12MCTL19   | ADC12_B Memory Control 19 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 46h    | ADC12MCTL19_L |                           | Read/write | Byte   | 00h   |                                |
| 47h    | ADC12MCTL19_H |                           | Read/write | Byte   | 00h   |                                |
| 48h    | ADC12MCTL20   | ADC12_B Memory Control 20 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 48h    | ADC12MCTL20_L |                           | Read/write | Byte   | 00h   |                                |
| 49h    | ADC12MCTL20_H |                           | Read/write | Byte   | 00h   |                                |
| 4Ah    | ADC12MCTL21   | ADC12_B Memory Control 21 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 4Ah    | ADC12MCTL21_L |                           | Read/write | Byte   | 00h   |                                |
| 4Bh    | ADC12MCTL21_H |                           | Read/write | Byte   | 00h   |                                |
| 4Ch    | ADC12MCTL22   | ADC12_B Memory Control 22 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 4Ch    | ADC12MCTL22_L |                           | Read/write | Byte   | 00h   |                                |
| 4Dh    | ADC12MCTL22_H |                           | Read/write | Byte   | 00h   |                                |
| 4Eh    | ADC12MCTL23   | ADC12_B Memory Control 23 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 4Eh    | ADC12MCTL23_L |                           | Read/write | Byte   | 00h   |                                |
| 4Fh    | ADC12MCTL23_H |                           | Read/write | Byte   | 00h   |                                |
| 50h    | ADC12MCTL24   | ADC12_B Memory Control 24 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 50h    | ADC12MCTL24_L |                           | Read/write | Byte   | 00h   |                                |
| 51h    | ADC12MCTL24_H |                           | Read/write | Byte   | 00h   |                                |
| 52h    | ADC12MCTL25   | ADC12_B Memory Control 25 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 52h    | ADC12MCTL25_L |                           | Read/write | Byte   | 00h   |                                |
| 53h    | ADC12MCTL25_H |                           | Read/write | Byte   | 00h   |                                |
| 54h    | ADC12MCTL26   | ADC12_B Memory Control 26 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 54h    | ADC12MCTL26_L |                           | Read/write | Byte   | 00h   |                                |
| 55h    | ADC12MCTL26_H |                           | Read/write | Byte   | 00h   |                                |
| 56h    | ADC12MCTL27   | ADC12_B Memory Control 27 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 56h    | ADC12MCTL27_L |                           | Read/write | Byte   | 00h   |                                |
| 57h    | ADC12MCTL27_H |                           | Read/write | Byte   | 00h   |                                |
| 58h    | ADC12MCTL28   | ADC12_B Memory Control 28 | Read/write | Word   | 0000h | <a href="#">Section 34.3.6</a> |
| 58h    | ADC12MCTL28_L |                           | Read/write | Byte   | 00h   |                                |
| 59h    | ADC12MCTL28_H |                           | Read/write | Byte   | 00h   |                                |

**Table 34-3. ADC12\_B Registers (continued)**

| Offset | Acronym       | Register Name             | Type       | Access | Reset     | Section                        |
|--------|---------------|---------------------------|------------|--------|-----------|--------------------------------|
| 5Ah    | ADC12MCTL29   | ADC12_B Memory Control 29 | Read/write | Word   | 0000h     | <a href="#">Section 34.3.6</a> |
| 5Ah    | ADC12MCTL29_L |                           | Read/write | Byte   | 00h       |                                |
| 5Bh    | ADC12MCTL29_H |                           | Read/write | Byte   | 00h       |                                |
| 5Ch    | ADC12MCTL30   | ADC12_B Memory Control 30 | Read/write | Word   | 0000h     | <a href="#">Section 34.3.6</a> |
| 5Ch    | ADC12MCTL30_L |                           | Read/write | Byte   | 00h       |                                |
| 5Dh    | ADC12MCTL30_H |                           | Read/write | Byte   | 00h       |                                |
| 5Eh    | ADC12MCTL31   | ADC12_B Memory Control 31 | Read/write | Word   | 0000h     | <a href="#">Section 34.3.6</a> |
| 5Eh    | ADC12MCTL31_L |                           | Read/write | Byte   | 00h       |                                |
| 5Fh    | ADC12MCTL31_H |                           | Read/write | Byte   | 00h       |                                |
| 60h    | ADC12MEM0     | ADC12_B Memory 0          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 60h    | ADC12MEM0_L   |                           | Read/write | Byte   | undefined |                                |
| 61h    | ADC12MEM0_H   |                           | Read/write | Byte   | undefined |                                |
| 62h    | ADC12MEM1     | ADC12_B Memory 1          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 62h    | ADC12MEM1_L   |                           | Read/write | Byte   | undefined |                                |
| 63h    | ADC12MEM1_H   |                           | Read/write | Byte   | undefined |                                |
| 64h    | ADC12MEM2     | ADC12_B Memory 2          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 64h    | ADC12MEM2_L   |                           | Read/write | Byte   | undefined |                                |
| 65h    | ADC12MEM2_H   |                           | Read/write | Byte   | undefined |                                |
| 66h    | ADC12MEM3     | ADC12_B Memory 3          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 66h    | ADC12MEM3_L   |                           | Read/write | Byte   | undefined |                                |
| 67h    | ADC12MEM3_H   |                           | Read/write | Byte   | undefined |                                |
| 68h    | ADC12MEM4     | ADC12_B Memory 4          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 68h    | ADC12MEM4_L   |                           | Read/write | Byte   | undefined |                                |
| 69h    | ADC12MEM4_H   |                           | Read/write | Byte   | undefined |                                |
| 6Ah    | ADC12MEM5     | ADC12_B Memory 5          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 6Ah    | ADC12MEM5_L   |                           | Read/write | Byte   | undefined |                                |
| 6Bh    | ADC12MEM5_H   |                           | Read/write | Byte   | undefined |                                |
| 6Ch    | ADC12MEM6     | ADC12_B Memory 6          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 6Ch    | ADC12MEM6_L   |                           | Read/write | Byte   | undefined |                                |
| 6Dh    | ADC12MEM6_H   |                           | Read/write | Byte   | undefined |                                |
| 6Eh    | ADC12MEM7     | ADC12_B Memory 7          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 6Eh    | ADC12MEM7_L   |                           | Read/write | Byte   | undefined |                                |
| 6Fh    | ADC12MEM7_H   |                           | Read/write | Byte   | undefined |                                |
| 70h    | ADC12MEM8     | ADC12_B Memory 8          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 70h    | ADC12MEM8_L   |                           | Read/write | Byte   | undefined |                                |
| 71h    | ADC12MEM8_H   |                           | Read/write | Byte   | undefined |                                |
| 72h    | ADC12MEM9     | ADC12_B Memory 9          | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 72h    | ADC12MEM9_L   |                           | Read/write | Byte   | undefined |                                |
| 73h    | ADC12MEM9_H   |                           | Read/write | Byte   | undefined |                                |
| 74h    | ADC12MEM10    | ADC12_B Memory 10         | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 74h    | ADC12MEM10_L  |                           | Read/write | Byte   | undefined |                                |
| 75h    | ADC12MEM10_H  |                           | Read/write | Byte   | undefined |                                |
| 76h    | ADC12MEM11    | ADC12_B Memory 11         | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 76h    | ADC12MEM11_L  |                           | Read/write | Byte   | undefined |                                |
| 77h    | ADC12MEM11_H  |                           | Read/write | Byte   | undefined |                                |

**Table 34-3. ADC12\_B Registers (continued)**

| Offset | Acronym      | Register Name     | Type       | Access | Reset     | Section                        |
|--------|--------------|-------------------|------------|--------|-----------|--------------------------------|
| 78h    | ADC12MEM12   | ADC12_B Memory 12 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 78h    | ADC12MEM12_L |                   | Read/write | Byte   | undefined |                                |
| 79h    | ADC12MEM12_H |                   | Read/write | Byte   | undefined |                                |
| 7Ah    | ADC12MEM13   | ADC12_B Memory 13 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 7Ah    | ADC12MEM13_L |                   | Read/write | Byte   | undefined |                                |
| 7Bh    | ADC12MEM13_H |                   | Read/write | Byte   | undefined |                                |
| 7Ch    | ADC12MEM14   | ADC12_B Memory 14 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 7Ch    | ADC12MEM14_L |                   | Read/write | Byte   | undefined |                                |
| 7Dh    | ADC12MEM14_H |                   | Read/write | Byte   | undefined |                                |
| 7Eh    | ADC12MEM15   | ADC12_B Memory 15 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 7Eh    | ADC12MEM15_L |                   | Read/write | Byte   | undefined |                                |
| 7Fh    | ADC12MEM15_H |                   | Read/write | Byte   | undefined |                                |
| 80h    | ADC12MEM16   | ADC12_B Memory 16 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 80h    | ADC12MEM16_L |                   | Read/write | Byte   | undefined |                                |
| 81h    | ADC12MEM16_H |                   | Read/write | Byte   | undefined |                                |
| 82h    | ADC12MEM17   | ADC12_B Memory 17 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 82h    | ADC12MEM17_L |                   | Read/write | Byte   | undefined |                                |
| 83h    | ADC12MEM17_H |                   | Read/write | Byte   | undefined |                                |
| 84h    | ADC12MEM18   | ADC12_B Memory 18 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 84h    | ADC12MEM18_L |                   | Read/write | Byte   | undefined |                                |
| 85h    | ADC12MEM18_H |                   | Read/write | Byte   | undefined |                                |
| 86h    | ADC12MEM19   | ADC12_B Memory 19 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 86h    | ADC12MEM19_L |                   | Read/write | Byte   | undefined |                                |
| 87h    | ADC12MEM19_H |                   | Read/write | Byte   | undefined |                                |
| 88h    | ADC12MEM20   | ADC12_B Memory 20 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 88h    | ADC12MEM20_L |                   | Read/write | Byte   | undefined |                                |
| 89h    | ADC12MEM20_H |                   | Read/write | Byte   | undefined |                                |
| 8Ah    | ADC12MEM21   | ADC12_B Memory 21 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 8Ah    | ADC12MEM21_L |                   | Read/write | Byte   | undefined |                                |
| 8Bh    | ADC12MEM21_H |                   | Read/write | Byte   | undefined |                                |
| 8Ch    | ADC12MEM22   | ADC12_B Memory 22 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 8Ch    | ADC12MEM22_L |                   | Read/write | Byte   | undefined |                                |
| 8Dh    | ADC12MEM22_H |                   | Read/write | Byte   | undefined |                                |
| 8Eh    | ADC12MEM23   | ADC12_B Memory 23 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 8Eh    | ADC12MEM23_L |                   | Read/write | Byte   | undefined |                                |
| 8Fh    | ADC12MEM23_H |                   | Read/write | Byte   | undefined |                                |
| 90h    | ADC12MEM24   | ADC12_B Memory 24 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 90h    | ADC12MEM24_L |                   | Read/write | Byte   | undefined |                                |
| 91h    | ADC12MEM24_H |                   | Read/write | Byte   | undefined |                                |
| 92h    | ADC12MEM25   | ADC12_B Memory 25 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 92h    | ADC12MEM25_L |                   | Read/write | Byte   | undefined |                                |
| 93h    | ADC12MEM25_H |                   | Read/write | Byte   | undefined |                                |
| 94h    | ADC12MEM26   | ADC12_B Memory 26 | Read/write | Word   | undefined | <a href="#">Section 34.3.5</a> |
| 94h    | ADC12MEM26_L |                   | Read/write | Byte   | undefined |                                |
| 95h    | ADC12MEM26_H |                   | Read/write | Byte   | undefined |                                |

**Table 34-3. ADC12\_B Registers (continued)**

| <b>Offset</b> | <b>Acronym</b> | <b>Register Name</b> | <b>Type</b> | <b>Access</b> | <b>Reset</b> | <b>Section</b>                 |
|---------------|----------------|----------------------|-------------|---------------|--------------|--------------------------------|
| 96h           | ADC12MEM27     | ADC12_B Memory 27    | Read/write  | Word          | undefined    | <a href="#">Section 34.3.5</a> |
| 96h           | ADC12MEM27_L   |                      | Read/write  | Byte          | undefined    |                                |
| 97h           | ADC12MEM27_H   |                      | Read/write  | Byte          | undefined    |                                |
| 98h           | ADC12MEM28     | ADC12_B Memory 28    | Read/write  | Word          | undefined    | <a href="#">Section 34.3.5</a> |
| 98h           | ADC12MEM28_L   |                      | Read/write  | Byte          | undefined    |                                |
| 99h           | ADC12MEM28_H   |                      | Read/write  | Byte          | undefined    |                                |
| 9Ah           | ADC12MEM29     | ADC12_B Memory 29    | Read/write  | Word          | undefined    | <a href="#">Section 34.3.5</a> |
| 9Ah           | ADC12MEM29_L   |                      | Read/write  | Byte          | undefined    |                                |
| 9Bh           | ADC12MEM29_H   |                      | Read/write  | Byte          | undefined    |                                |
| 9Ch           | ADC12MEM30     | ADC12_B Memory 30    | Read/write  | Word          | undefined    | <a href="#">Section 34.3.5</a> |
| 9Ch           | ADC12MEM30_L   |                      | Read/write  | Byte          | undefined    |                                |
| 9Dh           | ADC12MEM30_H   |                      | Read/write  | Byte          | undefined    |                                |
| 9Eh           | ADC12MEM31     | ADC12_B Memory 31    | Read/write  | Word          | undefined    | <a href="#">Section 34.3.5</a> |
| 9Eh           | ADC12MEM31_L   |                      | Read/write  | Byte          | undefined    |                                |
| 9Fh           | ADC12MEM31_H   |                      | Read/write  | Byte          | undefined    |                                |

### 34.3.1 ADC12CTL0 Register (offset = 00h) [reset = 0000h]

ADC12\_B Control 0 Register

**Figure 34-14. ADC12CTL0 Register**

|                                         |          |        |         |            |        |          |         |
|-----------------------------------------|----------|--------|---------|------------|--------|----------|---------|
| 15                                      | 14       | 13     | 12      | 11         | 10     | 9        | 8       |
| ADC12SHT1x                              |          |        |         | ADC12SHT0x |        |          |         |
| rw-(0)                                  | rw-(0)   | rw-(0) | rw-(0)  | rw-(0)     | rw-(0) | rw-(0)   | rw-(0)  |
| 7                                       | 6        | 5      | 4       | 3          | 2      | 1        | 0       |
| ADC12MSC                                | Reserved |        | ADC12ON | Reserved   |        | ADC12ENC | ADC12SC |
| rw-(0)                                  | r-0      | r-0    | rw-(0)  | r-0        | r-0    | rw-(0)   | rw-(0)  |
| Can be modified only when ADC12ENC = 0. |          |        |         |            |        |          |         |

**Table 34-4. ADC12CTL0 Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------|------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | ADC12SHT1x | RW   | 0     | ADC12_B sample-and-hold time. These bits define the number of ADC12CLK cycles in the sampling period for registers ADC12MEM8 to ADC12MEM23. Can be modified only when ADC12ENC = 0.<br>0000b = 4 ADC12CLK cycles<br>0001b = 8 ADC12CLK cycles<br>0010b = 16 ADC12CLK cycles<br>0011b = 32 ADC12CLK cycles<br>0100b = 64 ADC12CLK cycles<br>0101b = 96 ADC12CLK cycles<br>0110b = 128 ADC12CLK cycles<br>0111b = 192 ADC12CLK cycles<br>1000b = 256 ADC12CLK cycles<br>1001b = 384 ADC12CLK cycles<br>1010b = 512 ADC12CLK cycles<br>1011b = Reserved<br>1100b = Reserved<br>1101b = Reserved<br>1110b = Reserved<br>1111b = Reserved                             |
| 11-8  | ADC12SHT0x | RW   | 0     | ADC12_B sample-and-hold time. These bits define the number of ADC12CLK cycles in the sampling period for registers ADC12MEM0 to ADC12MEM7 and ADC12MEM24 to ADC12MEM31. Can be modified only when ADC12ENC = 0.<br>0000b = 4 ADC12CLK cycles<br>0001b = 8 ADC12CLK cycles<br>0010b = 16 ADC12CLK cycles<br>0011b = 32 ADC12CLK cycles<br>0100b = 64 ADC12CLK cycles<br>0101b = 96 ADC12CLK cycles<br>0110b = 128 ADC12CLK cycles<br>0111b = 192 ADC12CLK cycles<br>1000b = 256 ADC12CLK cycles<br>1001b = 384 ADC12CLK cycles<br>1010b = 512 ADC12CLK cycles<br>1011b = Reserved<br>1100b = Reserved<br>1101b = Reserved<br>1110b = Reserved<br>1111b = Reserved |

**Table 34-4. ADC12CTL0 Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | ADC12MSC | RW   | 0     | ADC12_B multiple sample and conversion. Valid only for sequence or repeated modes. Can be modified only when ADC12ENC = 0.<br>0b = The sampling timer requires a rising edge of the SHI signal to trigger each sample-and-convert.<br>1b = The incidence of the first rising edge of the SHI signal triggers the sampling timer, but further sample-and-conversions are performed automatically as soon as the prior conversion is completed. |
| 6-5 | Reserved | R    | 0     | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 4   | ADC12ON  | RW   | 0     | ADC12_B on. Can be modified only when ADC12ENC = 0.<br>0b = ADC12_B off<br>1b = ADC12_B on                                                                                                                                                                                                                                                                                                                                                    |
| 3-2 | Reserved | R    | 0     | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 1   | ADC12ENC | RW   | 0     | ADC12_B enable conversion.<br>0b = ADC12_B disabled<br>1b = ADC12_B enabled                                                                                                                                                                                                                                                                                                                                                                   |
| 0   | ADC12SC  | RW   | 0     | ADC12_B start conversion. Software-controlled sample-and-conversion start. ADC12SC and ADC12ENC may be set together with one instruction. ADC12SC is reset automatically.<br>0b = No sample-and-conversion-start<br>1b = Start sample-and-conversion                                                                                                                                                                                          |

### 34.3.2 ADC12CTL1 Register (offset = 02h) [reset = 0000h]

ADC12\_B Control 1 Register

**Figure 34-15. ADC12CTL1 Register**

| 15                                      | 14        | 13     | 12         | 11     | 10           | 9         | 8      |
|-----------------------------------------|-----------|--------|------------|--------|--------------|-----------|--------|
| Reserved                                | ADC12PDIV |        | ADC12SHSx  |        | ADC12SHP     | ADC12ISSH |        |
| r-0                                     | rw-(0)    | rw-(0) | rw-(0)     | rw-(0) | rw-(0)       | rw-(0)    | rw-(0) |
| 7                                       | 6         | 5      | 4          | 3      | 2            | 1         | 0      |
|                                         | ADC12DIVx |        | ADC12SSELx |        | ADC12CONSEQx | ADC12BUSY |        |
| rw-(0)                                  | rw-(0)    | rw-(0) | rw-(0)     | rw-(0) | rw-(0)       | rw-(0)    | r-(0)  |
| Can be modified only when ADC12ENC = 0. |           |        |            |        |              |           |        |

**Table 34-5. ADC12CTL1 Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 14-13 | ADC12PDIV  | RW   | 0h    | ADC12_B predivider. This bit predivides the selected ADC12_B clock source.<br>00b = Predivide by 1<br>01b = Predivide by 4<br>10b = Predivide by 32<br>11b = Predivide by 64                                                                                                                                                                                                                                                                                        |
| 12-10 | ADC12SHSx  | RW   | 0h    | ADC12_B sample-and-hold source select<br>000b = ADC12SC bit<br>001b = see the device-specific data sheet for source<br>010b = see the device-specific data sheet for source<br>011b = see the device-specific data sheet for source<br>100b = see the device-specific data sheet for source<br>101b = see the device-specific data sheet for source<br>110b = see the device-specific data sheet for source<br>111b = see the device-specific data sheet for source |
| 9     | ADC12SHP   | RW   | 0h    | ADC12_B sample-and-hold pulse-mode select. This bit selects the source of the sampling signal (SAMPCON) to be either the output of the sampling timer or the sample-input signal directly.<br>0b = SAMPCON signal is sourced from the sample-input signal.<br>1b = SAMPCON signal is sourced from the sampling timer.                                                                                                                                               |
| 8     | ADC12ISSH  | RW   | 0h    | ADC12_B invert signal sample-and-hold.<br>0b = The sample-input signal is not inverted.<br>1b = The sample-input signal is inverted.                                                                                                                                                                                                                                                                                                                                |
| 7-5   | ADC12DIVx  | RW   | 0h    | ADC12_B clock divider<br>000b = /1<br>001b = /2<br>010b = /3<br>011b = /4<br>100b = /5<br>101b = /6<br>110b = /7<br>111b = /8                                                                                                                                                                                                                                                                                                                                       |
| 4-3   | ADC12SSELx | RW   | 0h    | ADC12_B clock source select<br>00b = ADC12OSC (MODOSC)<br>01b = ACLK<br>10b = MCLK<br>11b = SMCLK                                                                                                                                                                                                                                                                                                                                                                   |

**Table 34-5. ADC12CTL1 Register Description (continued)**

| Bit | Field        | Type | Reset | Description                                                                                                                                                                                                                                                                                                                      |
|-----|--------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2-1 | ADC12CONSEQx | RW   | 0h    | ADC12_B conversion sequence mode select. This bit should only be modified when ADC12ENC = 0 except to stop a conversion immediately by setting ADC12CONSEQx = 00 when ADC12ENC = 1.<br>00b = Single-channel, single-conversion<br>01b = Sequence-of-channels<br>10b = Repeat-single-channel<br>11b = Repeat-sequence-of-channels |
| 0   | ADC12BUSY    | R    | 0h    | ADC12_B busy. This bit indicates an active sample or conversion operation.<br>0b = No operation is active.<br>1b = A sequence, sample, or conversion is active.                                                                                                                                                                  |

**34.3.3 ADC12CTL2 Register (offset = 04h) [reset = 0020h]**

ADC12\_B Control 2 Register

**Figure 34-16. ADC12CTL2 Register**

|          |    |        |        |        |    |    |        |
|----------|----|--------|--------|--------|----|----|--------|
| 15       | 14 | 13     | 12     | 11     | 10 | 9  | 8      |
| Reserved |    |        |        |        |    |    |        |
| r0       | r0 | r0     | r0     | r0     | r0 | r0 | r0     |
| 7        | 6  | 5      | 4      | 3      | 2  | 1  | 0      |
| Reserved |    |        |        |        |    |    |        |
| r0       | r0 | rw-(1) | rw-(0) | rw-(0) | r0 | r0 | rw-(0) |

**Table 34-6. ADC12CTL2 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------|------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-6 | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 5-4  | ADC12RES   | RW   | 2h    | ADC12_B resolution. This bit defines the conversion result resolution. This bit should only be modified when ADC12ENC=0.<br>00b = 8 bit (10 clock cycle conversion time)<br>01b = 10 bit (12 clock cycle conversion time)<br>10b = 12 bit (14 clock cycle conversion time)<br>11b = Reserved                                                                                                                                                                              |
| 3    | ADC12DF    | RW   | 0h    | ADC12_B data read-back format. Data is always stored in the binary unsigned format.<br>0b = Binary unsigned. Theoretically for ADC12DIF = 0 and 12-bit mode the analog input voltage – VREF results in 0000h, the analog input voltage + VREF results in 0FFFh.<br>1b = Signed binary (2s complement), left aligned. Theoretically, for ADC12DIF = 0 and 12-bit mode, the analog input voltage – VREF results in 8000h, the analog input voltage + VREF results in 7FF0h. |
| 2-1  | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 0    | ADC12PWRMD | RW   | 0h    | Enables ADC low-power mode for ADC12CLK with 1/4 the specified maximum for ADC12PWRMD = 0. This bit should only be modified when ADC12ENC = 0.<br>0b = Regular power mode where sample rate is not restricted<br>1b = Low power mode enable, ADC12CLK can not be greater than 1/4 the device-specific data sheet specified maximum for ADC12PWRMD = 0                                                                                                                     |

### 34.3.4 ADC12CTL3 Register (offset = 06h) [reset = 0000h]

ADC12\_B Control 3 Register

**Figure 34-17. ADC12CTL3 Register**

| 15         | 14                                      | 13       | 12              | 11           | 10           | 9            | 8            |
|------------|-----------------------------------------|----------|-----------------|--------------|--------------|--------------|--------------|
| Reserved   |                                         |          |                 | ADC12ICH3MAP | ADC12ICH2MAP | ADC12ICH1MAP | ADC12ICH0MAP |
| r0         | r0                                      | r0       | r0              | rw-(0)       | rw-(0)       | rw-(0)       | rw-(0)       |
| 7          | 6                                       | 5        | 4               | 3            | 2            | 1            | 0            |
| ADC12TCMAP | ADC12BATMAP                             | Reserved | ADC12CSTARTADDx |              |              |              |              |
| rw-(0)     | rw-(0)                                  | r0       | rw-(0)          | rw-(0)       | rw-(0)       | rw-(0)       | rw-(0)       |
|            | Can be modified only when ADC12ENC = 0. |          |                 |              |              |              |              |

**Table 34-7. ADC12CTL3 Register Description**

| Bit   | Field           | Type | Reset | Description                                                                                                                                                                                                                                                                                     |
|-------|-----------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | Reserved        | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                    |
| 11    | ADC12ICH3MAP    | RW   | 0h    | Controls internal channel 3 selection to ADC input channel A26. Can be modified only when ADC12ENC = 0.<br>0b = external pin is selected for ADC input channel A26<br>1b = ADC input channel internal 3 is selected for ADC input channel A26, see device-specific data sheet for availability  |
| 10    | ADC12ICH2MAP    | RW   | 0h    | Controls internal channel 2 selection to ADC input channel A27. Can be modified only when ADC12ENC = 0.<br>0b = external pin is selected for ADC input channel A27<br>1b = ADC input channel internal 2 is selected for ADC input channel A27, see device-specific data sheet for availability  |
| 9     | ADC12ICH1MAP    | RW   | 0h    | Controls internal channel 1 selection to ADC input channel A28. Can be modified only when ADC12ENC = 0.<br>0b = external pin is selected for ADC input channel A28<br>1b = ADC input channel internal 1 is selected for ADC input channel A28, see device-specific data sheet for availability  |
| 8     | ADC12ICH0MAP    | RW   | 0h    | Controls internal channel 0 selection to ADC input channel A29. Can be modified only when ADC12ENC = 0.<br>0b = external pin is selected for ADC input channel A29<br>1b = ADC input channel internal 0 is selected for ADC input channel A29, see device-specific data sheet for availability  |
| 7     | ADC12TCMAP      | RW   | 0h    | Controls temperature sensor ADC input channel selection. Can be modified only when ADC12ENC = 0.<br>0b = external pin is selected for ADC input channel A30<br>1b = ADC internal temperature sensor channel is selected for ADC input channel A30                                               |
| 6     | ADC12BATMAP     | RW   | 0h    | Controls 1/2 AVCC ADC input channel selection. Can be modified only when ADC12ENC = 0.<br>0b = external pin is selected for ADC input channel A31<br>1b = ADC internal 1/2 x AVCC channel is selected for ADC input channel A31                                                                 |
| 5     | Reserved        | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                    |
| 4-0   | ADC12CSTARTADDx | RW   | 0h    | ADC12_B conversion start address. These bits select which ADC12_B conversion memory register is used for a single conversion or for the first conversion in a sequence. The value of CSTARTADDx is 0h to 1Fh, corresponding to ADC12MEM0 to ADC12MEM31. Can be modified only when ADC12ENC = 0. |

### 34.3.5 ADC12MEMx Register ( $x = 0$ to 31)

ADC12\_B Conversion Memory x Register ( $x = 0$  to 31)

**Figure 34-18. ADC12MEMx Register**

|                    |    |    |    |    |    |    |    |
|--------------------|----|----|----|----|----|----|----|
| 15                 | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
| Conversion Results |    |    |    |    |    |    |    |
| rw                 | rw | rw | rw | rw | rw | rw | rw |
| 7                  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| Conversion Results |    |    |    |    |    |    |    |
| rw                 | rw | rw | rw | rw | rw | rw | rw |

**Table 34-8. ADC12MEMx Register Description**

| Bit  | Field              | Type | Reset     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------|--------------------|------|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | Conversion Results | RW   | undefined | If ADC12DF = 0: The 12-bit conversion results are right justified. Bit 11 is the MSB. Bits 15-12 are 0 in 12-bit mode, bits 15-10 are 0 in 10-bit mode, and bits 15-8 are 0 in 8-bit mode. If the user writes to the conversion memory registers, the results are corrupted.<br>If ADC12DF = 1: The 12-bit conversion results are left-justified 2s-complement format. Bit 15 is the MSB. Bits 3-0 are 0 in 12-bit mode, bits 5-0 are 0 in 10-bit mode, and bits 7-0 are 0 in 8-bit mode. The data is stored in the right-justified format and is converted to the left-justified 2s-complement format during read back. If the user writes to the conversion memory registers, the results are corrupted. |

### 34.3.6 ADC12MCTLx Register (x = 0 to 31)

ADC12\_B Conversion Memory Control x Register (x = 0 to 31)

**Figure 34-19. ADC12MCTLx Register**

| 15       | 14                                      | 13       | 12         | 11         | 10     | 9      | 8      |
|----------|-----------------------------------------|----------|------------|------------|--------|--------|--------|
| Reserved | ADC12WINC                               | ADC12DIF | Reserved   | ADC12VRSEL |        |        |        |
| r0       | rw-(0)                                  | rw-(0)   | r0         | rw-(0)     | rw-(0) | rw-(0) | rw-(0) |
| 7        | 6                                       | 5        | 4          | 3          | 2      | 1      | 0      |
| ADC12EOS | Reserved                                |          | ADC12INCHx |            |        |        |        |
| rw-(0)   | r0                                      | r0       | rw-(0)     | rw-(0)     | rw-(0) | rw-(0) | rw-(0) |
|          | Can be modified only when ADC12ENC = 0. |          |            |            |        |        |        |

**Table 34-9. ADC12MCTLx Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------|------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 14   | ADC12WINC  | RW   | 0h    | Comparator window enable. Can be modified only when ADC12ENC = 0.<br>0b = Comparator window disabled<br>1b = Comparator window enabled                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 13   | ADC12DIF   | RW   | 0h    | Differential mode. Can be modified only when ADC12ENC = 0.<br>0b = Single-ended mode enabled<br>1b = Differential mode enabled                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 12   | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 11-8 | ADC12VRSEL | RW   | 0h    | Selects combinations of VR+ and VR- sources as well as the buffer selection.<br>Note: there is only one buffer so it can be used for either VR+ or VR-, but not both. Can be modified only when ADC12ENC = 0.<br>0000b = VR+ = AVCC, VR- = AVSS<br>0001b = VR+ = VREF buffered, VR- = AVSS<br>0010b = VR+ = VeREF-, VR- = AVSS<br>0011b = VR+ = VeREF+ buffered, VR- = AVSS<br>0100b = VR+ = VeREF+, VR- = AVSS<br>0101b = VR+ = AVCC, VR- = VeREF+ buffered<br>0110b = VR+ = AVCC, VR- = VeREF+<br>0111b = VR+ = VREF buffered, VR- = VeREF+<br>1000b = Reserved<br>1001b = VR+ = AVCC, VR- = VREF buffered<br>1010b = Reserved<br>1011b = VR+ = VeREF+, VR- = VREF buffered<br>1100b = VR+ = AVCC, VR- = VeREF-<br>1101b = VR+ = VREF buffered, VR- = VeREF-<br>1110b = VR+ = VeREF+, VR- = VeREF-<br>1111b = VR+ = VREF+ buffered, VR- = VeREF- |
| 7    | ADC12EOS   | RW   | 0h    | End of sequence. Indicates the last conversion in a sequence. Can be modified only when ADC12ENC = 0.<br>0b = Not end of sequence<br>1b = End of sequence                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 6-5  | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

**Table 34-9. ADC12MCTLx Register Description (continued)**

| Bit | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----|------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4-0 | ADC12INCHx | RW   | 0h    | <p>Input channel select. If even channels are set as differential, then odd channel configuration is ignored. Can be modified only when ADC12ENC = 0.</p> <p>00000b = If ADC12DIF = 0: A0; If ADC12DIF = 1: Ain+ = A0, Ain- = A1</p> <p>00001b = If ADC12DIF = 0: A1; If ADC12DIF = 1: Ain+ = A0, Ain- = A1</p> <p>00010b = If ADC12DIF = 0: A2; If ADC12DIF = 1: Ain+ = A2, Ain- = A3</p> <p>00011b = If ADC12DIF = 0: A3; If ADC12DIF = 1: Ain+ = A2, Ain- = A3</p> <p>00100b = If ADC12DIF = 0: A4; If ADC12DIF = 1: Ain+ = A4, Ain- = A5</p> <p>00101b = If ADC12DIF = 0: A5; If ADC12DIF = 1: Ain+ = A4, Ain- = A5</p> <p>00110b = If ADC12DIF = 0: A6; If ADC12DIF = 1: Ain+ = A6, Ain- = A7</p> <p>00111b = If ADC12DIF = 0: A7; If ADC12DIF = 1: Ain+ = A6, Ain- = A7</p> <p>01000b = If ADC12DIF = 0: A8; If ADC12DIF = 1: Ain+ = A8, Ain- = A9</p> <p>01001b = If ADC12DIF = 0: A9; If ADC12DIF = 1: Ain+ = A8, Ain- = A9</p> <p>01010b = If ADC12DIF = 0: A10; If ADC12DIF = 1: Ain+ = A10, Ain- = A11</p> <p>01011b = If ADC12DIF = 0: A11; If ADC12DIF = 1: Ain+ = A10, Ain- = A11</p> <p>01100b = If ADC12DIF = 0: A12; If ADC12DIF = 1: Ain+ = A12, Ain- = A13</p> <p>01101b = If ADC12DIF = 0: A13; If ADC12DIF = 1: Ain+ = A12, Ain- = A13</p> <p>01110b = If ADC12DIF = 0: A14; If ADC12DIF = 1: Ain+ = A14, Ain- = A15</p> <p>01111b = If ADC12DIF = 0: A15; If ADC12DIF = 1: Ain+ = A14, Ain- = A15</p> <p>10000b = If ADC12DIF = 0: A16; If ADC12DIF = 1: Ain+ = A16, Ain- = A17</p> <p>10001b = If ADC12DIF = 0: A17; If ADC12DIF = 1: Ain+ = A16, Ain- = A17</p> <p>10010b = If ADC12DIF = 0: A18; If ADC12DIF = 1: Ain+ = A18, Ain- = A19</p> <p>10011b = If ADC12DIF = 0: A19; If ADC12DIF = 1: Ain+ = A18, Ain- = A19</p> <p>10100b = If ADC12DIF = 0: A20; If ADC12DIF = 1: Ain+ = A20, Ain- = A21</p> <p>10101b = If ADC12DIF = 0: A21; If ADC12DIF = 1: Ain+ = A20, Ain- = A21</p> <p>10110b = If ADC12DIF = 0: A22; If ADC12DIF = 1: Ain+ = A22, Ain- = A23</p> <p>10111b = If ADC12DIF = 0: A23; If ADC12DIF = 1: Ain+ = A22, Ain- = A23</p> <p>11000b = If ADC12DIF = 0: A24; If ADC12DIF = 1: Ain+ = A24, Ain- = A25</p> <p>11001b = If ADC12DIF = 0: A25; If ADC12DIF = 1: Ain+ = A24, Ain- = A25</p> <p>11010b = If ADC12DIF = 0: A26; If ADC12DIF = 1: Ain+ = A26, Ain- = A27</p> <p>11011b = If ADC12DIF = 0: A27; If ADC12DIF = 1: Ain+ = A26, Ain- = A27</p> <p>11100b = If ADC12DIF = 0: A28; If ADC12DIF = 1: Ain+ = A28, Ain- = A29</p> <p>11101b = If ADC12DIF = 0: A29; If ADC12DIF = 1: Ain+ = A28, Ain- = A29</p> <p>11110b = If ADC12DIF = 0: A30; If ADC12DIF = 1: Ain+ = A30, Ain- = A31</p> <p>11111b = If ADC12DIF = 0: A31; If ADC12DIF = 1: Ain+ = A30, Ain- = A31</p> |

### 34.3.7 ADC12HI Register (offset = 0Ah) [reset = 0FFFh]

ADC12\_B Window Comparator High Threshold Register

**Figure 34-20. ADC12HI Register**

| 15             | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|----------------|--------|--------|--------|--------|--------|--------|--------|
| High Threshold |        |        |        |        |        |        |        |
| rw-(0)         | rw-(0) | rw-(0) | rw-(0) | rw-(1) | rw-(1) | rw-(1) | rw-(1) |
| High Threshold |        |        |        |        |        |        |        |
| rw-(1)         | rw-(1) | rw-(1) | rw-(1) | rw-(1) | rw-(1) | rw-(1) | rw-(1) |

**Table 34-10. ADC12HI Register Description**

| Bit  | Field          | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------|----------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | High Threshold | RW   | 0FFFh | Window comparator high threshold should only be modified when ADC12ENC=0. If ADC12DF = 0: The 12-bit threshold value is right justified when ADC12DF = 0. Bits 15-12 are 0. Bit 11 is the MSB. Bits 11-10 are 0 in 10-bit mode, and bits 11-8 are 0 in 8-bit mode.<br>If ADC12DF = 1: The 12-bit threshold value is left justified when ADC12DF = 1, 2s-complement format. Bit 15 is the MSB. Bits 3-0 are 0 in 12-bit mode, bits 5-0 are 0 in 10-bit mode, and bits 7-0 are 0 in 8-bit mode. |

### 34.3.8 ADC12LO Register (offset = 08h) [reset = 0000h]

ADC12\_B Window Comparator Low Threshold Register

**Figure 34-21. ADC12LO Register**

| 15            | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|---------------|--------|--------|--------|--------|--------|--------|--------|
| Low Threshold |        |        |        |        |        |        |        |
| rw-(0)        | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |
| Low Threshold |        |        |        |        |        |        |        |
| rw-(0)        | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) |

**Table 34-11. ADC12LO Register Description**

| Bit  | Field         | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|---------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | Low Threshold | RW   | 0h    | Window comparator low threshold should only be modified when ADC12ENC=0. If ADC12DF = 0: The 12-bit threshold value is right justified when ADC12DF = 0. Bits 15-12 are 0. Bit 11 is the MSB. Bits 11-10 are 0 in 10-bit mode, and bits 11-8 are 0 in 8-bit mode.<br>If ADC12DF = 1: The 12-bit threshold value is left justified when ADC12DF = 1, 2s-complement format. Bit 15 is the MSB. Bits 3-0 are 0 in 12-bit mode, bits 5-0 are 0 in 10-bit mode, and bits 7-0 are 0 in 8-bit mode. |

### 34.3.9 ADC12IER0 Register (offset = 12h) [reset = 0000h]

ADC12\_B Interrupt Enable 0 Register

**Figure 34-22. ADC12IER0 Register**

| 15        | 14        | 13        | 12        | 11        | 10        | 9        | 8        |
|-----------|-----------|-----------|-----------|-----------|-----------|----------|----------|
| ADC12IE15 | ADC12IE14 | ADC12IE13 | ADC12IE12 | ADC12IE11 | ADC12IE10 | ADC12IE9 | ADC12IE8 |
| rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)   | rw-(0)   |
| 7         | 6         | 5         | 4         | 3         | 2         | 1        | 0        |
| ADC12IE7  | ADC12IE6  | ADC12IE5  | ADC12IE4  | ADC12IE3  | ADC12IE2  | ADC12IE1 | ADC12IE0 |
| rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)    | rw-(0)   | rw-(0)   |

**Table 34-12. ADC12IER0 Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                          |
|-----|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------|
| 15  | ADC12IE15 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG15 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 14  | ADC12IE14 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG14 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 13  | ADC12IE13 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG13 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 12  | ADC12IE12 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG12 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 11  | ADC12IE11 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG11 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 10  | ADC12IE10 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG10 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 9   | ADC12IE9  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG9 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |
| 8   | ADC12IE8  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG8 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |
| 7   | ADC12IE7  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG7 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |
| 6   | ADC12IE6  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG6 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |
| 5   | ADC12IE5  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG5 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |
| 4   | ADC12IE4  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG4 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |
| 3   | ADC12IE3  | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG3 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled  |

**Table 34-12. ADC12IER0 Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                  |
|------------|--------------|-------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------|
| 2          | ADC12IE2     | RW          | 0h           | Interrupt enable. Enables or disables the interrupt request for ADC12IFG2 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 1          | ADC12IE1     | RW          | 0h           | Interrupt enable. Enables or disables the interrupt request for ADC12IFG1 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 0          | ADC12IE0     | RW          | 0h           | Interrupt enable. Enables or disables the interrupt request for ADC12IFG0 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |

**34.3.10 ADC12IER1 Register (offset = 14h) [reset = 0000h]**

ADC12\_B Interrupt Enable 1 Register

**Figure 34-23. ADC12IER1 Register**

| 15        | 14        | 13        | 12        | 11        | 10        | 9         | 8         |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| ADC12IE31 | ADC12IE30 | ADC12IE29 | ADC12IE28 | ADC12IE27 | ADC12IE26 | ADC12IE25 | ADC12IE24 |
| rw-(0)    |
| 7         | 6         | 5         | 4         | 3         | 2         | 1         | 0         |
| ADC12IE23 | ADC12IE22 | ADC12IE21 | ADC12IE20 | ADC12IE19 | ADC12IE18 | ADC12IE17 | ADC12IE16 |
| rw-(0)    |

**Table 34-13. ADC12IER1 Register Description**

| Bit | Field     | Type | Reset | Description                                                                                                                          |
|-----|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------|
| 15  | ADC12IE31 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG31 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 14  | ADC12IE30 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG30 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 13  | ADC12IE29 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG29 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 12  | ADC12IE28 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG28 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 11  | ADC12IE27 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG27 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 10  | ADC12IE26 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG26 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 9   | ADC12IE25 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG25 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 8   | ADC12IE24 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG24 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 7   | ADC12IE23 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG23 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 6   | ADC12IE22 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG22 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 5   | ADC12IE21 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG21 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 4   | ADC12IE20 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG20 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 3   | ADC12IE19 | RW   | 0h    | Interrupt enable. Enables or disables the interrupt request for ADC12IFG19 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |

**Table 34-13. ADC12IER1 Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                   |
|------------|--------------|-------------|--------------|--------------------------------------------------------------------------------------------------------------------------------------|
| 2          | ADC12IE18    | RW          | 0h           | Interrupt enable. Enables or disables the interrupt request for ADC12IFG18 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 1          | ADC12IE17    | RW          | 0h           | Interrupt enable. Enables or disables the interrupt request for ADC12IFG17 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 0          | ADC12IE16    | RW          | 0h           | Interrupt enable. Enables or disables the interrupt request for ADC12IFG16 bit.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |

**34.3.11 ADC12IER2 Register (offset = 16h) [reset = 0000h]**

ADC12\_B Interrupt Enable 2 Register

**Figure 34-24. ADC12IER2 Register**

| 15       | 14         | 13         | 12        | 11         | 10        | 9         | 8        |
|----------|------------|------------|-----------|------------|-----------|-----------|----------|
| Reserved |            |            |           |            |           |           |          |
| r0       | r0         | r0         | r0        | r0         | r0        | r0        | r0       |
| 7        | 6          | 5          | 4         | 3          | 2         | 1         | 0        |
| Reserved | ADC12RDYIE | ADC12TOVIE | ADC12OVIE | ADC12HIIIE | ADC12LOIE | ADC12INIE | Reserved |
| r0       | rw-(0)     | rw-(0)     | rw-(0)    | rw-(0)     | rw-(0)    | rw-(0)    | r0       |

**Table 34-14. ADC12IER2 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                |
|------|------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-7 | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                               |
| 6    | ADC12RDYIE | RW   | 0h    | ADC12_B local reference buffer ready interrupt enable. The GIE bit must also be set to enable the interrupt.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                          |
| 5    | ADC12TOVIE | RW   | 0h    | ADC12_B conversion-time-overflow interrupt enable. The GIE bit must also be set to enable the interrupt.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                              |
| 4    | ADC12OVIE  | RW   | 0h    | ADC12MEMx overflow-interrupt enable. The GIE bit must also be set to enable the interrupt.<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                            |
| 3    | ADC12HIIIE | RW   | 0h    | Interrupt enable for the exceeding the upper limit interrupt of the window comparator for ADC12MEMx result register. The GIE bit must also be set to enable the interrupt.<br>0b = Interrupt disabled<br>1b = Interrupt enabled            |
| 2    | ADC12LOIE  | RW   | 0h    | Interrupt enable for the falling short of the lower limit interrupt of the window comparator for the ADC12MEMx result register. The GIE bit must also be set to enable the interrupt.<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 1    | ADC12INIE  | RW   | 0h    | Interrupt enable for the ADC12MEMx result register being greater than the ADC12LO threshold and below the ADC12HI threshold. The GIE bit must also be set to enable the interrupt.<br>0b = Interrupt disabled<br>1b = Interrupt enabled    |
| 0    | Reserved   | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                                                               |

**34.3.12 ADC12IFGR0 Register (offset = 0Ch) [reset = 0000h]**

ADC12\_B Interrupt Flag 0 Register

**Figure 34-25. ADC12IFGR0 Register**

| 15         | 14         | 13         | 12         | 11         | 10         | 9         | 8         |
|------------|------------|------------|------------|------------|------------|-----------|-----------|
| ADC12IFG15 | ADC12IFG14 | ADC12IFG13 | ADC12IFG12 | ADC12IFG11 | ADC12IFG10 | ADC12IFG9 | ADC12IFG8 |
| rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)    | rw-(0)    |
| 7          | 6          | 5          | 4          | 3          | 2          | 1         | 0         |
| ADC12IFG7  | ADC12IFG6  | ADC12IFG5  | ADC12IFG4  | ADC12IFG3  | ADC12IFG2  | ADC12IFG1 | ADC12IFG0 |
| rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)     | rw-(0)    | rw-(0)    |

**Table 34-15. ADC12IFGR0 Register Description**

| Bit | Field      | Type | Reset | Description                                                                                                                                                                                                                                    |
|-----|------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15  | ADC12IFG15 | RW   | 0h    | ADC12MEM15 interrupt flag. This bit is set when ADC12MEM15 is loaded with a conversion result. The ADC12IFG15 bit is reset if ADC12MEM15 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 14  | ADC12IFG14 | RW   | 0h    | ADC12MEM14 interrupt flag. This bit is set when ADC12MEM14 is loaded with a conversion result. The ADC12IFG14 bit is reset if ADC12MEM14 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 13  | ADC12IFG13 | RW   | 0h    | ADC12MEM13 interrupt flag. This bit is set when ADC12MEM13 is loaded with a conversion result. The ADC12IFG13 bit is reset if ADC12MEM13 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 12  | ADC12IFG12 | RW   | 0h    | ADC12MEM12 interrupt flag. This bit is set when ADC12MEM12 is loaded with a conversion result. The ADC12IFG12 bit is reset if ADC12MEM12 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 11  | ADC12IFG11 | RW   | 0h    | ADC12MEM11 interrupt flag. This bit is set when ADC12MEM11 is loaded with a conversion result. The ADC12IFG11 bit is reset if ADC12MEM11 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 10  | ADC12IFG10 | RW   | 0h    | ADC12MEM10 interrupt flag. This bit is set when ADC12MEM10 is loaded with a conversion result. The ADC12IFG10 bit is reset if ADC12MEM10 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 9   | ADC12IFG9  | RW   | 0h    | ADC12MEM9 interrupt flag. This bit is set when ADC12MEM9 is loaded with a conversion result. The ADC12IFG9 bit is reset if ADC12MEM9 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending     |
| 8   | ADC12IFG8  | RW   | 0h    | ADC12MEM8 interrupt flag. This bit is set when ADC12MEM8 is loaded with a conversion result. The ADC12IFG8 bit is reset if ADC12MEM8 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending     |

**Table 34-15. ADC12IFGR0 Register Description (continued)**

| Bit | Field     | Type | Reset | Description                                                                                                                                                                                                                                |
|-----|-----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | ADC12IFG7 | RW   | 0h    | ADC12MEM7 interrupt flag. This bit is set when ADC12MEM7 is loaded with a conversion result. The ADC12IFG7 bit is reset if ADC12MEM7 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 6   | ADC12IFG6 | RW   | 0h    | ADC12MEM6 interrupt flag. This bit is set when ADC12MEM6 is loaded with a conversion result. The ADC12IFG6 bit is reset if ADC12MEM6 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 5   | ADC12IFG5 | RW   | 0h    | ADC12MEM5 interrupt flag. This bit is set when ADC12MEM5 is loaded with a conversion result. The ADC12IFG5 bit is reset if ADC12MEM5 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 4   | ADC12IFG4 | RW   | 0h    | ADC12MEM4 interrupt flag. This bit is set when ADC12MEM4 is loaded with a conversion result. The ADC12IFG4 bit is reset if ADC12MEM4 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 3   | ADC12IFG3 | RW   | 0h    | ADC12MEM3 interrupt flag. This bit is set when ADC12MEM3 is loaded with a conversion result. The ADC12IFG3 bit is reset if ADC12MEM3 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 2   | ADC12IFG2 | RW   | 0h    | ADC12MEM2 interrupt flag. This bit is set when ADC12MEM2 is loaded with a conversion result. The ADC12IFG2 bit is reset if ADC12MEM2 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 1   | ADC12IFG1 | RW   | 0h    | ADC12MEM1 interrupt flag. This bit is set when ADC12MEM1 is loaded with a conversion result. The ADC12IFG1 bit is reset if ADC12MEM1 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 0   | ADC12IFG0 | RW   | 0h    | ADC12MEM0 interrupt flag. This bit is set when ADC12MEM0 is loaded with a conversion result. The ADC12IFG0 bit is reset if ADC12MEM0 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |

**34.3.13 ADC12IFGR1 Register (offset = 0Eh) [reset = 0000h]**

ADC12\_B Interrupt Flag 1 Register

**Figure 34-26. ADC12IFGR1 Register**

| 15         | 14         | 13         | 12         | 11         | 10         | 9          | 8          |
|------------|------------|------------|------------|------------|------------|------------|------------|
| ADC12IFG31 | ADC12IFG30 | ADC12IFG29 | ADC12IFG28 | ADC12IFG27 | ADC12IFG26 | ADC12IFG25 | ADC12IFG24 |
| rw-(0)     |
| 7          | 6          | 5          | 4          | 3          | 2          | 1          | 0          |
| ADC12IFG23 | ADC12IFG22 | ADC12IFG21 | ADC12IFG20 | ADC12IFG19 | ADC12IFG18 | ADC12IFG17 | ADC12IFG16 |
| rw-(0)     |

**Table 34-16. ADC12IFGR1 Register Description**

| Bit | Field      | Type | Reset | Description                                                                                                                                                                                                                                    |
|-----|------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15  | ADC12IFG31 | RW   | 0h    | ADC12MEM31 interrupt flag. This bit is set when ADC12MEM31 is loaded with a conversion result. The ADC12IFG31 bit is reset if ADC12MEM31 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 14  | ADC12IFG30 | RW   | 0h    | ADC12MEM30 interrupt flag. This bit is set when ADC12MEM30 is loaded with a conversion result. The ADC12IFG30 bit is reset if ADC12MEM30 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 13  | ADC12IFG29 | RW   | 0h    | ADC12MEM29 interrupt flag. This bit is set when ADC12MEM29 is loaded with a conversion result. The ADC12IFG29 bit is reset if ADC12MEM29 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 12  | ADC12IFG28 | RW   | 0h    | ADC12MEM28 interrupt flag. This bit is set when ADC12MEM28 is loaded with a conversion result. The ADC12IFG28 bit is reset if ADC12MEM28 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 11  | ADC12IFG27 | RW   | 0h    | ADC12MEM27 interrupt flag. This bit is set when ADC12MEM27 is loaded with a conversion result. The ADC12IFG27 bit is reset if ADC12MEM27 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 10  | ADC12IFG26 | RW   | 0h    | ADC12MEM26 interrupt flag. This bit is set when ADC12MEM26 is loaded with a conversion result. The ADC12IFG26 bit is reset if ADC12MEM26 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 9   | ADC12IFG25 | RW   | 0h    | ADC12MEM25 interrupt flag. This bit is set when ADC12MEM25 is loaded with a conversion result. The ADC12IFG25 bit is reset if ADC12MEM25 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 8   | ADC12IFG24 | RW   | 0h    | ADC12MEM24 interrupt flag. This bit is set when ADC12MEM24 is loaded with a conversion result. The ADC12IFG24 bit is reset if ADC12MEM24 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |

**Table 34-16. ADC12IFGR1 Register Description (continued)**

| Bit | Field      | Type | Reset | Description                                                                                                                                                                                                                                    |
|-----|------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | ADC12IFG23 | RW   | 0h    | ADC12MEM23 interrupt flag. This bit is set when ADC12MEM23 is loaded with a conversion result. The ADC12IFG23 bit is reset if ADC12MEM23 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 6   | ADC12IFG22 | RW   | 0h    | ADC12MEM22 interrupt flag. This bit is set when ADC12MEM22 is loaded with a conversion result. The ADC12IFG22 bit is reset if ADC12MEM22 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 5   | ADC12IFG21 | RW   | 0h    | ADC12MEM21 interrupt flag. This bit is set when ADC12MEM21 is loaded with a conversion result. The ADC12IFG21 bit is reset if ADC12MEM21 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 4   | ADC12IFG20 | RW   | 0h    | ADC12MEM20 interrupt flag. This bit is set when ADC12MEM20 is loaded with a conversion result. The ADC12IFG20 bit is reset if ADC12MEM20 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 3   | ADC12IFG19 | RW   | 0h    | ADC12MEM19 interrupt flag. This bit is set when ADC12MEM19 is loaded with a conversion result. The ADC12IFG19 bit is reset if ADC12MEM19 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 2   | ADC12IFG18 | RW   | 0h    | ADC12MEM18 interrupt flag. This bit is set when ADC12MEM18 is loaded with a conversion result. The ADC12IFG18 bit is reset if ADC12MEM18 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 1   | ADC12IFG17 | RW   | 0h    | ADC12MEM17 interrupt flag. This bit is set when ADC12MEM17 is loaded with a conversion result. The ADC12IFG17 bit is reset if ADC12MEM17 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 0   | ADC12IFG16 | RW   | 0h    | ADC12MEM16 interrupt flag. This bit is set when ADC12MEM16 is loaded with a conversion result. The ADC12IFG16 bit is reset if ADC12MEM16 is accessed, or it can be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |

### 34.3.14 ADC12IFGR2 Register (offset = 10h) [reset = 0000h]

ADC12\_B Interrupt Flag 2 Register

**Figure 34-27. ADC12IFGR2 Register**

| 15       | 14          | 13          | 12         | 11          | 10         | 9          | 8        |
|----------|-------------|-------------|------------|-------------|------------|------------|----------|
| Reserved |             |             |            |             |            |            |          |
| r0       | r0          | r0          | r0         | r0          | r0         | r0         | r0       |
| 1        |             |             |            |             |            |            |          |
| 7        | 6           | 5           | 4          | 3           | 2          | 1          | 0        |
| Reserved | ADC12RDYIFG | ADC12TOVIFG | ADC12OVIFG | ADC12HIIIFG | ADC12LOIFG | ADC12INIFG | Reserved |
| r0       | rw-(0)      | rw-(0)      | rw-(0)     | rw-(0)      | rw-(0)     | rw-(0)     | r0       |

**Table 34-17. ADC12IFGR2 Register Description**

| Bit  | Field       | Type | Reset | Description                                                                                                                                                                                 |
|------|-------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-7 | Reserved    | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                |
| 6    | ADC12RDYIFG | RW   | 0h    | ADC12_B local reference buffer ready interrupt flag. The flag does not occur if the sample trigger has not been asserted.<br>0b = No interrupt pending<br>1b = Interrupt pending            |
| 5    | ADC12TOVIFG | RW   | 0h    | ADC12_B conversion-time-overflow interrupt flag.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                     |
| 4    | ADC12OVIFG  | RW   | 0h    | ADC12MEMx overflow-interrupt flag.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                   |
| 3    | ADC12HIIIFG | RW   | 0h    | Interrupt flag for exceeding the upper limit interrupt of the window comparator for ADC12MEMx result register.<br>0b = No interrupt pending<br>1b = Interrupt pending                       |
| 2    | ADC12LOIFG  | RW   | 0h    | Interrupt flag for falling short of the lower limit interrupt of the window comparator for the ADC12MEMx result register.<br>0b = No interrupt pending<br>1b = Interrupt pending            |
| 1    | ADC12INIFG  | RW   | 0h    | Interrupt flag for the ADC12MEMx result register being greater than the ADC12LO threshold and below the ADC12HI threshold interrupt.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 0    | Reserved    | R    | 0h    | Reserved. Always reads as 0.                                                                                                                                                                |

**34.3.15 ADC12IV Register (offset = 18h) [reset = 0000h]**

ADC12\_B Interrupt Vector

**Figure 34-28. ADC12IV Register**

|          |        |        |        |        |        |        |    |
|----------|--------|--------|--------|--------|--------|--------|----|
| 15       | 14     | 13     | 12     | 11     | 10     | 9      | 8  |
| ADC12IVx |        |        |        |        |        |        |    |
| r0       | r0     | r0     | r0     | r0     | r0     | r0     | r0 |
| ADC12IVx |        |        |        |        |        |        |    |
| r0       | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | rw-(0) | r0 |

**Table 34-18. ADC12IV Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | ADC12IVx | RW   | 0h    | <p>ADC12_B interrupt vector value. Writing to this register clears all pending interrupt flags.</p> <p>000h = Interrupt Source: No interrupt pending, Interrupt Flag: None</p> <p>002h = Interrupt Source: ADC12MEMx overflow, Interrupt Flag: ADC12OVIFG, Interrupt Priority: Highest</p> <p>004h = Interrupt Source: Conversion time overflow, Interrupt Flag: ADC12TOVIFG</p> <p>006h = Interrupt Source: ADC12 window high interrupt flag, Interrupt Flag: ADC12HIIFG</p> <p>008h = Interrupt Source: ADC12 window low interrupt flag, Interrupt Flag: ADC12LOIFG</p> <p>00Ah = Interrupt Source: ADC12 in-window interrupt flag, Interrupt Flag: ADC12INIIFG</p> <p>00Ch = Interrupt Source: ADC12MEM0 interrupt flag, Interrupt Flag: ADC12IFG0</p> <p>00Eh = Interrupt Source: ADC12MEM1 interrupt flag, Interrupt Flag: ADC12IFG1</p> <p>010h = Interrupt Source: ADC12MEM2 interrupt flag, Interrupt Flag: ADC12IFG2</p> <p>012h = Interrupt Source: ADC12MEM3 interrupt flag, Interrupt Flag: ADC12IFG3</p> <p>014h = Interrupt Source: ADC12MEM4 interrupt flag, Interrupt Flag: ADC12IFG4</p> <p>016h = Interrupt Source: ADC12MEM5 interrupt flag, Interrupt Flag: ADC12IFG5</p> <p>018h = Interrupt Source: ADC12MEM6 interrupt flag, Interrupt Flag: ADC12IFG6</p> <p>01Ah = Interrupt Source: ADC12MEM7 interrupt flag, Interrupt Flag: ADC12IFG7</p> <p>01Ch = Interrupt Source: ADC12MEM8 interrupt flag, Interrupt Flag: ADC12IFG8</p> <p>01Eh = Interrupt Source: ADC12MEM9 interrupt flag, Interrupt Flag: ADC12IFG9</p> <p>020h = Interrupt Source: ADC12MEM10 interrupt flag, Interrupt Flag: ADC12IFG10</p> <p>022h = Interrupt Source: ADC12MEM11 interrupt flag, Interrupt Flag: ADC12IFG11</p> <p>024h = Interrupt Source: ADC12MEM12 interrupt flag, Interrupt Flag: ADC12IFG12</p> <p>026h = Interrupt Source: ADC12MEM13 interrupt flag, Interrupt Flag: ADC12IFG13</p> <p>028h = Interrupt Source: ADC12MEM14 interrupt flag, Interrupt Flag: ADC12IFG14</p> <p>02Ah = Interrupt Source: ADC12MEM15 interrupt flag, Interrupt Flag: ADC12IFG15</p> <p>02Ch = Interrupt Source: ADC12MEM16 interrupt flag, Interrupt Flag: ADC12IFG16</p> <p>02Eh = Interrupt Source: ADC12MEM17 interrupt flag, Interrupt Flag: ADC12IFG17</p> <p>030h = Interrupt Source: ADC12MEM18 interrupt flag, Interrupt Flag: ADC12IFG18</p> |

**Table 34-18. ADC12IV Register Description (continued)**

| Bit | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-----|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     |       |      |       | 032h = Interrupt Source: ADC12MEM19 interrupt flag, Interrupt Flag: ADC12IFG19<br>034h = Interrupt Source: ADC12MEM20 interrupt flag, Interrupt Flag: ADC12IFG20<br>036h = Interrupt Source: ADC12MEM21 interrupt flag, Interrupt Flag: ADC12IFG21<br>038h = Interrupt Source: ADC12MEM22 interrupt flag, Interrupt Flag: ADC12IFG22<br>03Ah = Interrupt Source: ADC12MEM23 interrupt flag, Interrupt Flag: ADC12IFG23<br>03Ch = Interrupt Source: ADC12MEM24 interrupt flag, Interrupt Flag: ADC12IFG24<br>03Eh = Interrupt Source: ADC12MEM25 interrupt flag, Interrupt Flag: ADC12IFG25<br>040h = Interrupt Source: ADC12MEM26 interrupt flag, Interrupt Flag: ADC12IFG26<br>042h = Interrupt Source: ADC12MEM27 interrupt flag, Interrupt Flag: ADC12IFG27<br>044h = Interrupt Source: ADC12MEM28 interrupt flag, Interrupt Flag: ADC12IFG28<br>046h = Interrupt Source: ADC12MEM29 interrupt flag, Interrupt Flag: ADC12IFG29<br>048h = Interrupt Source: ADC12MEM30 interrupt flag, Interrupt Flag: ADC12IFG30<br>04Ah = Interrupt Source: ADC12MEM31 interrupt flag, Interrupt Flag: ADC12IFG31<br>04Ch = Interrupt Source: ADC12RDYIFG interrupt flag, Interrupt Flag: ADC12RDYIFG |

## **Comparator E (COMP\_E) Module**

Comparator\_E is an analog voltage comparator. This chapter describes the Comparator\_E. Comparator\_E supports general comparator functionality for up to 16 channels.

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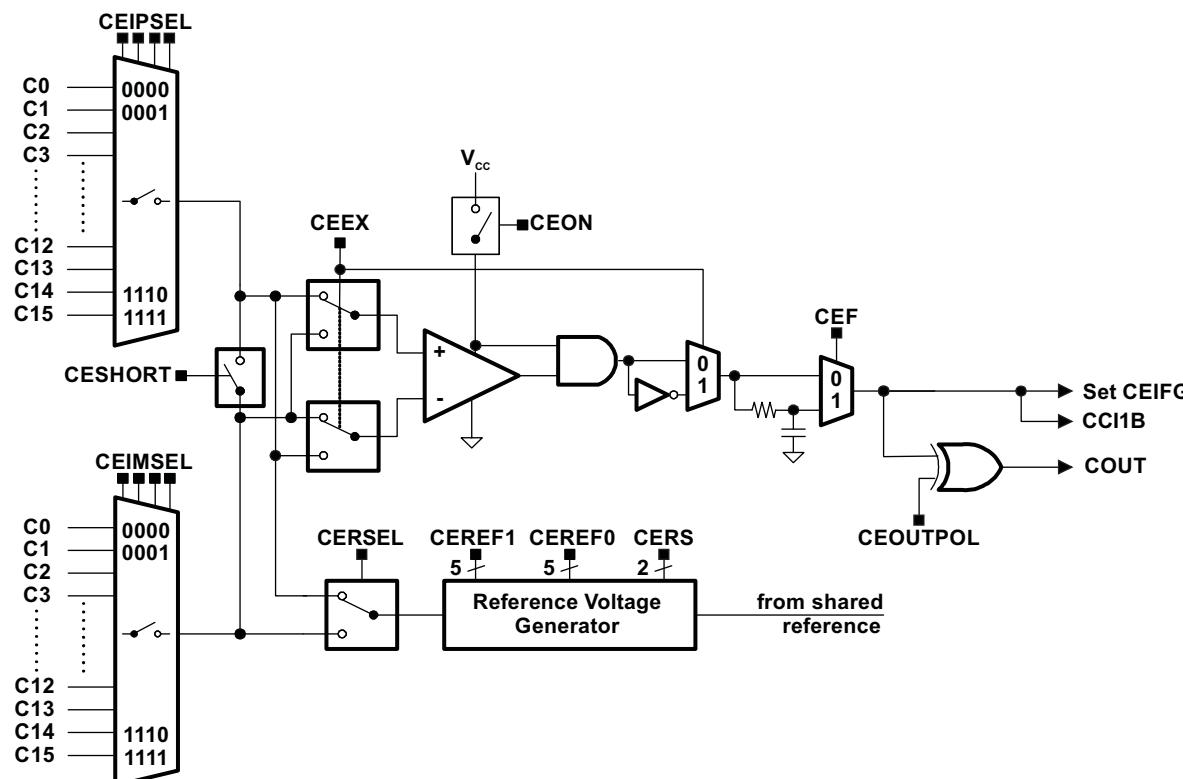
### 35.1 COMP\_E Introduction

The COMP\_E module supports precision slope analog-to-digital conversions, supply voltage supervision, and monitoring of external analog signals.

Features of COMP\_E include:

- Inverting and noninverting terminal input multiplexer
- Software-selectable RC filter for the comparator output
- Output provided to Timer\_A capture input
- Software control of the port input buffer
- Interrupt capability
- Selectable reference voltage generator and voltage hysteresis generator
- Reference voltage input from shared reference
- Ultra-low-power comparator mode
- Interrupt driven measurement system for low-power operation support

Figure 35-1 shows the Comparator\_E block diagram.



**Figure 35-1. Comparator\_E Block Diagram**

## 35.2 COMP\_E Operation

The COMP\_E module is configured by user software. The setup and operation of COMP\_E is discussed in the following sections.

### 35.2.1 Comparator

The comparator compares the analog voltages at the positive (+) and negative (–) input terminals. If the + terminal is more positive than the – terminal, the comparator output CEOUT is high. The comparator can be switched on or off using control bit CEON. The comparator should be switched off when not in use to reduce current consumption. When the comparator is off, CEOUT is low when CEOUTPOL bit is set to 0, and CEOUT is high when CEOUTPOL bit is set to 1.

To optimize current consumption for the application, the lowest power mode that meets the comparator speed requirements (see the device-specific data sheet for the comparator propagation delay and response time) should be selected with the CEPWRMD bits. The CEPWRMD bits default to 0x0, which is the highest power and fastest speed. CEPWRMD = 0x2 is the lowest power and slowest speed option.

### 35.2.2 Analog Input Switches

The analog input switches connect or disconnect the two comparator input terminals to associated port pins using the CEIPSELx and CEIMSELx bits. The comparator terminal inputs can be controlled individually. The CEIPSELx and CEIMSELx bits allow:

- Application of an external signal to the V+ and V– terminals of the comparator
- Application of an external current source (for example, a resistor) to the V+ or V– terminal of the comparator
- Mapping of both terminals of the internal multiplexer to the outside

Internally, the input switch is constructed as a T-switch to suppress distortion in the signal path.

**NOTE: Comparator Input Connection**

When the comparator is on, the input terminals must be connected to a signal, power, or ground. Otherwise, floating levels may cause unexpected interrupts and increased current consumption.

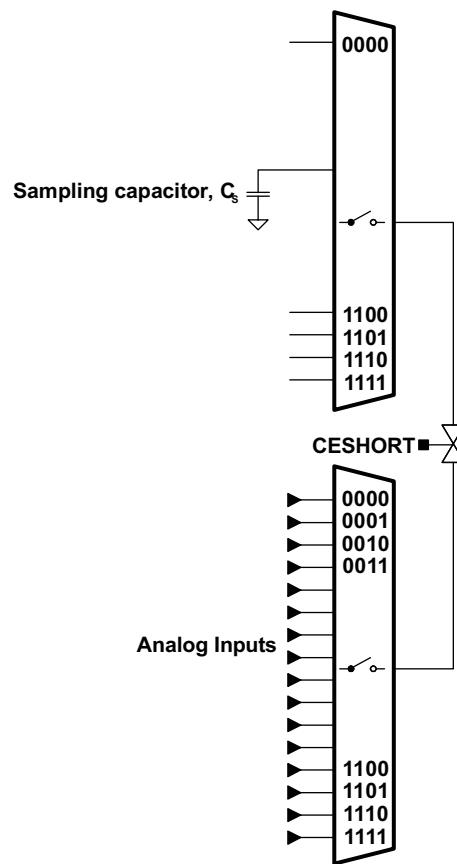
The CEEX bit controls the input multiplexer, permuting the input signals of the comparator's V+ and V– terminals. Additionally, when the comparator terminals are permuted, the output signal from the comparator is also inverted. This allows the user to determine or compensate for the comparator input offset voltage.

### 35.2.3 Port Logic

The Px.y pins that are associated with a comparator channel are enabled by the CEIPSELx or CEIMSELx bits to disable the digital components while the terminals are used as comparator inputs. Only one of the comparator input pins is selected as input to the comparator by the input multiplexer at a time.

### 35.2.4 Input Short Switch

The CESHORT bit shorts the Comparator\_E inputs. This can be used to build a simple sample-and-hold for the comparator as shown in [Figure 35-2](#).



**Figure 35-2. Comparator\_E Sample-And-Hold**

The required sampling time is proportional to the size of the sampling capacitor  $R_s$ , the resistance of the input switches in series with the short switch ( $R_i$ ), and the resistance of the external source ( $R_s$ ). The sampling capacitor  $C_s$  should be greater than 100 pF. The time constant, Tau, to charge the sampling capacitor  $C_s$  can be calculated with the following equation:

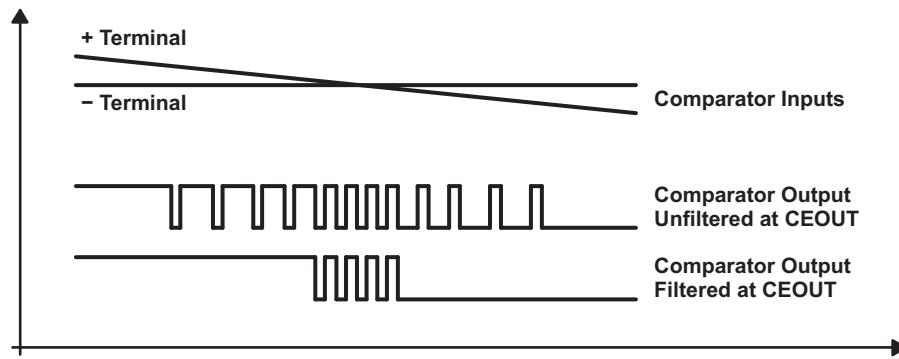
$$\text{Tau} = (R_i + R_s) \times C_s$$

Depending on the required accuracy, 3 to 10 Tau should be used as a sampling time. With 3 Tau, the sampling capacitor is charged to approximately 95% of the input signal's voltage level; with 5 Tau, it is charged to more than 99%; and with 10 Tau, the sampled voltage is sufficient for 12-bit accuracy.

### 35.2.5 Output Filter

The output of the comparator can be used with or without internal filtering. When control bit CEF is set, the output is filtered with an on-chip RC filter. The delay of the filter can be adjusted in four steps with the CEFDLY bit.

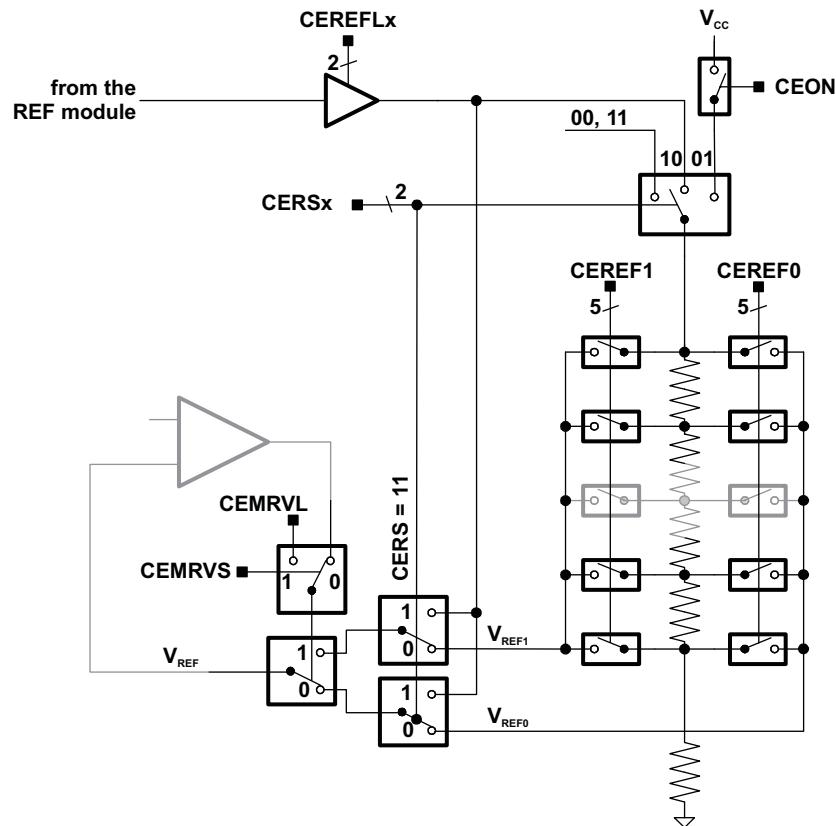
All comparator outputs oscillate if the voltage difference across the input terminals is small (see [Figure 35-3](#)). Internal and external parasitic effects and cross coupling on and between signal lines, power supply lines, and other parts of the system are responsible for this behavior. The comparator output oscillation reduces the accuracy and resolution of the comparison result. Enable the output filter to reduce errors associated with comparator oscillation.



**Figure 35-3. RC-Filter Response at the Output of the Comparator**

### 35.2.6 Reference Voltage Generator

Figure 35-4 shows the Comparator\_E reference generator block diagram.



**Figure 35-4. Reference Generator Block Diagram**

The interrupt flags of the comparator and the comparator output are unchanged while the reference voltage from the shared reference is settling. If CEREFLx is changed from a nonzero value to another nonzero value, the interrupt flags may show unpredictable behavior. TI recommends setting CEREFLx = 00 before changing the CEREFLx settings.

The voltage reference generator is used to generate VREF, which can be applied to either comparator input terminal. The CEREF1x (VREF1) and CEREF0x (VREF0) bits control the output of the voltage generator. The CERSEL bit selects the comparator terminal to which VREF is applied. If external signals are applied to both comparator input terminals, the internal reference generator should be turned off to reduce current consumption. The voltage reference generator can generate a fraction of the device  $V_{CC}$  or of the voltage reference of the integrated precision voltage reference source. Vref1 is used while CEOUT is 1, and Vref0 is used while CEOUT is 0. This allows the generation of a hysteresis without using external components.

### 35.2.7 Port Disable Register (CEPD)

The comparator input and output functions are multiplexed with I/O port pins, which are digital CMOS gates. When analog signals are applied to digital CMOS gates, parasitic current can flow from  $V_{CC}$  to GND. This parasitic current occurs if the input voltage is near the transition level of the gate. Disabling the port pin buffer eliminates the parasitic current flow and therefore reduces overall current consumption.

The CEPDx bits, when set, disable the corresponding Px.y input buffer (see Figure 35-5). When current consumption is critical, any Px.y pin connected to analog signals should be disabled with the associated CEPDx bits.

Selecting an input pin to the comparator multiplexer with the CEIPSEL or CEIMSEL bits automatically disables the input buffer for that pin, regardless of the state of the associated CEPDx bit.

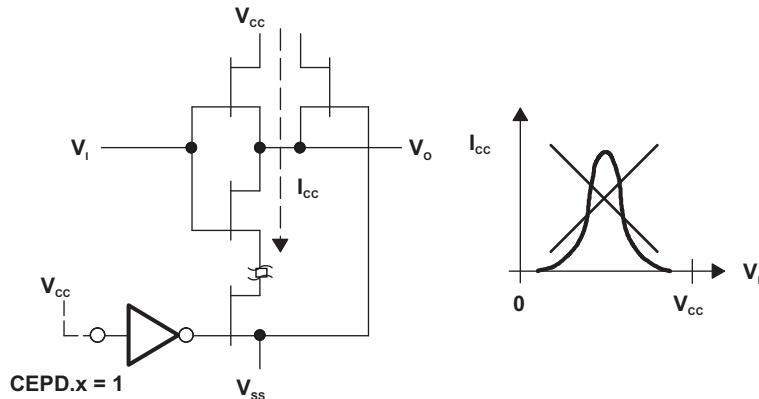


Figure 35-5. Transfer Characteristic and Power Dissipation in a CMOS Inverter and Buffer

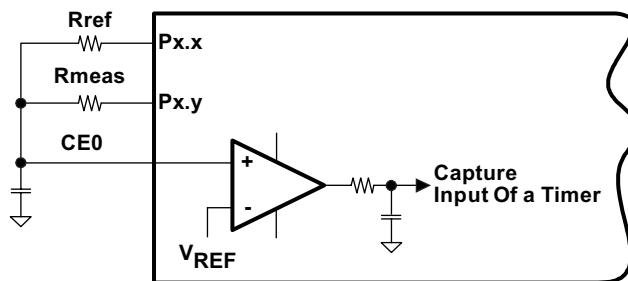
### 35.2.8 Comparator\_E Interrupts

One interrupt flag and one interrupt vector are associated with the Comparator\_E.

The interrupt flag CEIFG is set on either the rising or falling edge of the comparator output, selected by the CEIES bit. If both the CEIE and the GIE bits are set, then the CEIFG interrupt flag generates an interrupt request.

### 35.2.9 Comparator\_E Used to Measure Resistive Elements

The Comparator\_E can be optimized to precisely measure resistive elements using single slope analog-to-digital conversion. For example, temperature can be converted into digital data using a thermistor, by comparing the thermistor's capacitor discharge time to that of a reference resistor as shown in Figure 35-6. A reference resistor Rref is compared to Rmeas.



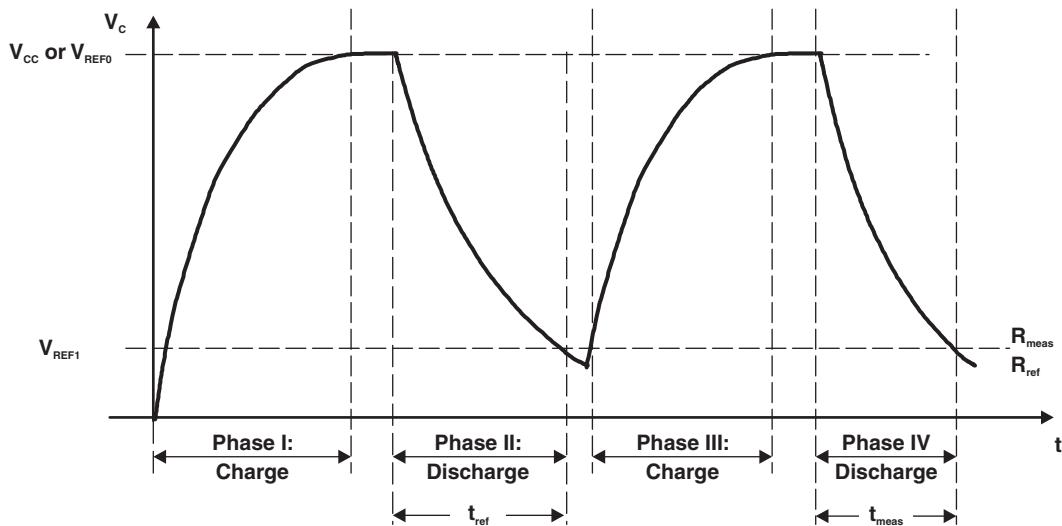
**Figure 35-6. Temperature Measurement System**

The resources used to calculate the temperature sensed by  $R_{meas}$  are:

- Two digital I/O pins charge and discharge the capacitor.
- I/O is set to output high ( $V_{cc}$ ) to charge capacitor, reset to discharge.
- I/O is switched to high-impedance input with  $CEPDx$  set when not in use.
- One output charges and discharges the capacitor through  $R_{ref}$ .
- One output discharges capacitor through  $R_{meas}$ .
- The + terminal is connected to the positive terminal of the capacitor.
- The - terminal is connected to a reference level, for example  $0.25 \times V_{cc}$ .
- The output filter should be used to minimize switching noise.
- $CEOUT$  is used to gate a timer capturing capacitor discharge time.

More than one resistive element can be measured. Additional elements are connected to  $CE0$  with available I/O pins and switched to high impedance when not being measured.

The thermistor measurement is based on a ratiometric conversion principle. The ratio of two capacitor discharge times is calculated as shown in [Figure 35-7](#).



**Figure 35-7. Timing for Temperature Measurement Systems**

The  $V_{cc}$  voltage and the capacitor value should remain constant during the conversion but are not critical, because they cancel in the ratio:

$$\frac{N_{\text{meas}}}{N_{\text{ref}}} = \frac{-R_{\text{meas}} \times C \times \ln \frac{V_{\text{ref1}}}{V_{\text{cc}}}}{-R_{\text{ref}} \times C \times \ln \frac{V_{\text{ref1}}}{V_{\text{cc}}}}$$

$$\frac{N_{\text{meas}}}{N_{\text{ref}}} = \frac{R_{\text{meas}}}{R_{\text{ref}}}$$

$$R_{\text{meas}} = R_{\text{ref}} \times \frac{N_{\text{meas}}}{N_{\text{ref}}}$$

### 35.3 COMP\_E Registers

The Comparator\_E registers are listed in [Table 35-1](#). The base address of the Comparator\_E module can be found in each device-specific data sheet.

**Table 35-1. COMP\_E Registers**

| Offset | Acronym | Register Name                      | Type       | Access | Reset | Section                        |
|--------|---------|------------------------------------|------------|--------|-------|--------------------------------|
| 00h    | CECTL0  | Comparator_E control register 0    | Read/write | Word   | 0000h | <a href="#">Section 35.3.1</a> |
| 02h    | CECTL1  | Comparator_E control register 1    | Read/write | Word   | 0000h | <a href="#">Section 35.3.2</a> |
| 04h    | CECTL2  | Comparator_E control register 2    | Read/write | Word   | 0000h | <a href="#">Section 35.3.3</a> |
| 06h    | CECTL3  | Comparator_E control register 3    | Read/write | Word   | 0000h | <a href="#">Section 35.3.4</a> |
| 0Ch    | CEINT   | Comparator_E interrupt register    | Read/write | Word   | 0000h | <a href="#">Section 35.3.5</a> |
| 0Eh    | CEIV    | Comparator_E interrupt vector word | Read       | Word   | 0000h | <a href="#">Section 35.3.6</a> |

### 35.3.1 CECTL0 Register (offset = 00h) [reset = 0000h]

Comparator\_E Control Register 0

**Figure 35-8. CECTL0 Register**

| 15     | 14       | 13  | 12  | 11   | 10      | 9    | 8    |
|--------|----------|-----|-----|------|---------|------|------|
| CEIMEN | Reserved |     |     |      | CEIMSEL |      |      |
| rw-0   | r-0      | r-0 | r-0 | rw-0 | rw-0    | rw-0 | rw-0 |
| 7      | 6        | 5   | 4   | 3    | 2       | 1    | 0    |
| CEIPEN | Reserved |     |     |      | CEIPSEL |      |      |
| rw-0   | r-0      | r-0 | r-0 | rw-0 | rw-0    | rw-0 | rw-0 |

**Table 35-2. CECTL0 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                   |
|-------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | CEIMEN   | RW   | 0h    | Channel input enable for the – terminal of the comparator.<br>0b = Selected analog input channel for V– terminal is disabled.<br>1b = Selected analog input channel for V– terminal is enabled. The internal reference voltage is disabled for this channel.  |
| 14-12 | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                         |
| 11-8  | CEIMSEL  | RW   | 0h    | Channel input selected for the – terminal of the comparator if CEIMEN is set to 1.                                                                                                                                                                            |
| 7     | CEIPEN   | RW   | 0h    | Channel input enable for the V+ terminal of the comparator.<br>0b = Selected analog input channel for V+ terminal is disabled.<br>1b = Selected analog input channel for V+ terminal is enabled. The internal reference voltage is disabled for this channel. |
| 6-4   | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                         |
| 3-0   | CEIPSEL  | RW   | 0h    | Channel input selected for the V+ terminal of the comparator if CEIPEN is set to 1.                                                                                                                                                                           |

### 35.3.2 CECTL1 Register (offset = 02h) [reset = 0000h]

Comparator\_E Control Register 1

**Figure 35-9. CECTL1 Register**

| 15       | 14   | 13   | 12      | 11     | 10   | 9        | 8     |
|----------|------|------|---------|--------|------|----------|-------|
| Reserved |      |      | CEMRVS  | CEMRLV | CEON | CEPWRMD  |       |
| r-0      | r-0  | r-0  | rw-0    | rw-0   | rw-0 | rw-0     | rw-0  |
| 7        | 6    | 5    | 4       | 3      | 2    | 1        | 0     |
| CEFDLY   |      | CEEX | CESHORT | CEIES  | CEF  | CEOUTPOL | CEOUT |
| rw-0     | rw-0 | rw-0 | rw-0    | rw-0   | rw-0 | rw-0     | r-0   |

**Table 35-3. CECTL1 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                             |
|-------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                                                                                                   |
| 12    | CEMRVS   | RW   | 0h    | This bit defines if the comparator output selects between VREF0 or VREF1 if CERS = 00, 01, or 10.<br>0b = Comparator output state selects between VREF0 or VREF1.<br>1b = CEMRVL selects between VREF0 or VREF1.                                                                                                                        |
| 11    | CEMRLV   | RW   | 0h    | This bit is valid of CEMRVS is set to 1.<br>0b = VREF0 is selected if CERS = 00, 01, or 10<br>1b = VREF1 is selected if CERS = 00, 01, or 10                                                                                                                                                                                            |
| 10    | CEON     | RW   | 0h    | On. This bit turns the comparator on. When the comparator is turned off the Comparator_E consumes no power.<br>0b = Off<br>1b = On                                                                                                                                                                                                      |
| 9-8   | CEPWRMD  | RW   | 0h    | Power mode<br>00b = High-speed mode<br>01b = Normal mode<br>10b = Ultra-low power mode<br>11b = Reserved                                                                                                                                                                                                                                |
| 7-6   | CEFDLY   | RW   | 0h    | Filter delay. The filter delay can be selected in four steps. See the device-specific data sheet for details.<br>00b = Typical filter delay of approximately 450 ns<br>01b = Typical filter delay of approximately 900 ns<br>10b = Typical filter delay of approximately 1800 ns<br>11b = Typical filter delay of approximately 3600 ns |
| 5     | CEEX     | RW   | 0h    | Exchange. This bit permutes the comparator 0 inputs and inverts the comparator 0 output.<br>0b = Exchange off<br>1b = Exchange on                                                                                                                                                                                                       |
| 4     | CESHORT  | RW   | 0h    | Input short. This bit shorts the + and – input terminals.<br>0b = Inputs not shorted<br>1b = Inputs shorted                                                                                                                                                                                                                             |
| 3     | CEIES    | RW   | 0h    | Interrupt edge select for CEIIFG and CEIFG. Changing CEIES might set CEIFG.<br>0b = Rising edge for CEIFG, falling edge for CEIIFG<br>1b = Falling edge for CEIFG, rising edge for CEIIFG                                                                                                                                               |
| 2     | CEF      | RW   | 0h    | Output filter. Available if CEPWRMD = 00 or 01.<br>0b = Comparator_E output is not filtered<br>1b = Comparator_E output is filtered                                                                                                                                                                                                     |
| 1     | CEOUTPOL | RW   | 0h    | Output polarity. This bit defines the CEOUT polarity.<br>0b = Noninverted<br>1b = Inverted                                                                                                                                                                                                                                              |
| 0     | CEOUT    | R    | 0h    | Output value. This bit reflects the value of the Comparator_E output. Writing this bit has no effect on the comparator output.                                                                                                                                                                                                          |

### 35.3.3 CECTL2 Register (offset = 04h) [reset = 0000h]

Comparator\_E Control Register 2

**Figure 35-10. CECTL2 Register**

| 15       | 14     | 13   | 12      | 11   | 10   | 9    | 8    |
|----------|--------|------|---------|------|------|------|------|
| CEREFACC | CEREFL |      | CEREF1  |      |      |      |      |
| rw-0     | rw-0   | rw-0 | rw-0    | rw-0 | rw-0 | rw-0 | rw-0 |
| 7        | 6      | 5    | 4       | 3    | 2    | 1    | 0    |
| CERS     | CERSEL |      | CEREOF0 |      |      |      |      |
| rw-0     | rw-0   | rw-0 | rw-0    | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 35-4. CECTL2 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                               |
|-------|----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | CEREFACC | RW   | 0h    | Reference accuracy. A reference voltage is requested only if CEREFL > 0.<br>0b = Static mode<br>1b = Clocked (low power, low accuracy) mode                                                                                                                                                                                                                               |
| 14-13 | CEREFL   | RW   | 0h    | Reference voltage level<br>00b = Reference amplifier is disabled. No reference voltage is requested.<br>01b = 1.2 V is selected as shared reference voltage input<br>10b = 2.0 V is selected as shared reference voltage input<br>11b = 2.5 V is selected as shared reference voltage input                                                                               |
| 12-8  | CEREF1   | RW   | 0h    | Reference resistor tap 1. This register defines the tap of the resistor string while CEOUT = 1.                                                                                                                                                                                                                                                                           |
| 7-6   | CERS     | RW   | 0h    | Reference source. This bit define if the reference voltage is derived from VCC or from the precise shared reference.<br>00b = No current is drawn by the reference circuitry.<br>01b = VCC applied to the resistor ladder<br>10b = Shared reference voltage applied to the resistor ladder.<br>11b = Shared reference voltage supplied to VCCREF. Resistor ladder is off. |
| 5     | CERSEL   | RW   | 0h    | Reference select. This bit selects to which terminal the VCCREF is applied.<br>When CEEX = 0:<br>0b = When CEEX = 0: VREF is applied to the V+ terminal; When CEEX = 1: VREF is applied to the V- terminal<br>1b = When CEEX = 0: VREF is applied to the V- terminal; When CEEX = 1: VREF is applied to the V+ terminal                                                   |
| 4-0   | CEREOF0  | RW   | 0h    | Reference resistor tap 0. This register defines the tap of the resistor string while CEOUT = 0.                                                                                                                                                                                                                                                                           |

### 35.3.4 CECTL3 Register (offset = 06h) [reset = 0000h]

Comparator\_E Control Register 3

**Figure 35-11. CECTL3 Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|--------|--------|--------|--------|--------|--------|--------|--------|
| CEPD15 | CEPD14 | CEPD13 | CEPD12 | CEPD11 | CEPD10 | CEPD9  | CEPD8  |
| rw-(0) |
| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
| CEPD7  | CEPD6  | CEPD5  | CEPD4  | CEPD3  | CEPD2  | CEPD1  | CEPD0  |
| rw-(0) |

**Table 35-5. CECTL3 Register Description**

| Bit | Field  | Type | Reset | Description                                                                                                                                                                                                                                                     |
|-----|--------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15  | CEPD15 | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD15 disables the port of the comparator channel 15.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 14  | CEPD14 | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD14 disables the port of the comparator channel 14.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 13  | CEPD13 | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD13 disables the port of the comparator channel 13.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 12  | CEPD12 | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD12 disables the port of the comparator channel 12.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 11  | CEPD11 | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD11 disables the port of the comparator channel 11.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 10  | CEPD10 | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD10 disables the port of the comparator channel 10.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 9   | CEPD9  | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD9 disables the port of the comparator channel 9.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled.   |
| 8   | CEPD8  | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD8 disables the port of the comparator channel 8.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled.   |
| 7   | CEPD7  | RW   | 0h    | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD7 disables the port of the comparator channel 7.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled.   |

**Table 35-5. CECTL3 Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                                                                                                            |
|------------|--------------|-------------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6          | CEPD6        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD6 disables the port of the comparator channel 6.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 5          | CEPD5        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD5 disables the port of the comparator channel 5.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 4          | CEPD4        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD4 disables the port of the comparator channel 4.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 3          | CEPD3        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD3 disables the port of the comparator channel 3.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 2          | CEPD2        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD2 disables the port of the comparator channel 2.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 1          | CEPD1        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD1 disables the port of the comparator channel 1.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |
| 0          | CEPD0        | RW          | 0h           | Port disable. These bits individually disable the input buffer for the pins of the port associated with Comparator_E. The bit CEPD0 disables the port of the comparator channel 0.<br>0b = The input buffer is enabled.<br>1b = The input buffer is disabled. |

### 35.3.5 CEINT Register (offset = 0Ch) [reset = 0000h]

Comparator\_E Interrupt Control Register

**Figure 35-12. CEINT Register**

| 15  | 14  | 13       | 12       | 11  | 10       | 9      | 8     |
|-----|-----|----------|----------|-----|----------|--------|-------|
|     |     | Reserved | CERDYIE  |     | Reserved | CEIIE  | CEIE  |
| r-0 | r-0 | r-0      | rw-0     | r-0 | r-0      | rw-0   | rw-0  |
| 7   | 6   | 5        | 4        | 3   | 2        | 1      | 0     |
|     |     | Reserved | CERDYIFG |     | Reserved | CEIIFG | CEIFG |
| r-0 | r-0 | r-0      | rw-0     | r-0 | r-0      | rw-0   | rw-0  |

**Table 35-6. CEINT Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                              |
|-------|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                    |
| 12    | CERDYIE  | RW   | 0h    | Comparator_E ready interrupt enable.<br>0b = Interrupt is disabled<br>1b = Interrupt is enabled                                                                                                                                                          |
| 11-10 | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                    |
| 9     | CEIIE    | RW   | 0h    | Comparator_E output interrupt enable inverted polarity<br>0b = Interrupt is disabled<br>1b = Interrupt is enabled                                                                                                                                        |
| 8     | CEIE     | RW   | 0h    | Comparator_E output interrupt enable<br>0b = Interrupt is disabled<br>1b = Interrupt is enabled                                                                                                                                                          |
| 7-5   | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                    |
| 4     | CERDYIFG | RW   | 0h    | Comparator_E ready interrupt flag. This bit is set if the Comparator_E reference sources are settled and the Comparator_E module is operational. This bit has to be cleared by software.<br>0b = No interrupt pending.<br>1b = Output interrupt pending. |
| 3-2   | Reserved | R    | 0h    | Reserved. Reads as 0.                                                                                                                                                                                                                                    |
| 1     | CEIIFG   | RW   | 0h    | Comparator_E output inverted interrupt flag. The bit CEIES defines the transition of the output setting this bit.<br>0b = No interrupt pending.<br>1b = Output interrupt pending.                                                                        |
| 0     | CEIFG    | RW   | 0h    | Comparator_E output interrupt flag. The bit CEIES defines the transition of the output setting this bit.<br>0b = No interrupt pending.<br>1b = Output interrupt pending.                                                                                 |

### **35.3.6 CEIV Register (offset = 0Eh) [reset = 0000h]**

Comparator\_E Interrupt Vector Word Register

**Figure 35-13. CEIV Register**

|      |    |    |    |    |     |     |    |
|------|----|----|----|----|-----|-----|----|
| 15   | 14 | 13 | 12 | 11 | 10  | 9   | 8  |
| CEIV |    |    |    |    |     |     |    |
| r0   | r0 | r0 | r0 | r0 | r0  | r0  | r0 |
| CEIV |    |    |    |    |     |     |    |
| r0   | r0 | r0 | r0 | r0 | r-0 | r-0 | r0 |

**Table 35-7. CEIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|-------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | CEIV  | R    | 0h    | <p>Comparator_E interrupt vector word register. The interrupt vector register reflects only interrupt flags whose interrupt enable bit are set. Reading the CEIV register clears the pending interrupt flag with the highest priority.</p> <p>00h = No interrupt pending<br/>           02h = Interrupt Source: CEOUT interrupt; Interrupt Flag: CEIFG; Interrupt Priority: Highest<br/>           04h = Interrupt Source: CEOUT interrupt inverted polarity; Interrupt Flag: CEIIFG<br/>           06h = Reserved<br/>           08h = Reserved<br/>           0Ah = Interrupt Source: Comparator ready interrupt; Interrupt Flag: CERDYIFG; Interrupt Priority: Lowest</p> |

## ***LCD\_C Controller***

The LCD\_C controller drives static and 2-mux to 8-mux LCDs. This chapter describes the LCD\_C controller. The differences between LCD\_B and LCD\_C are listed in [Table 36-1](#).

| Topic                                | Page       |
|--------------------------------------|------------|
| <b>36.1 LCD_C Introduction .....</b> | <b>929</b> |
| <b>36.2 LCD_C Operation.....</b>     | <b>931</b> |
| <b>36.3 LCD_C Registers .....</b>    | <b>947</b> |

### **36.1 LCD\_C Introduction**

The LCD\_C controller directly drives LCD displays by automatically creating the ac segment and common voltage signals. The LCD\_C controller can support static and 2-mux to 8-mux LCD glasses.

The LCD\_C controller features are:

- Display memory
- Automatic signal generation
- Configurable frame frequency
- Blinking of individual segments with separate blinking memory for static, and 2- to 4-mux LCDs
- Blinking of complete display for 5- to 8-mux LCDs
- Regulated charge pump up to 3.44 V (typical)
- Contrast control by software
- Support for the following types of LCDs
  - Static
  - 2-mux, 1/2 bias or 1/3 bias
  - 3-mux, 1/2 bias or 1/3 bias
  - 4-mux, 1/2 bias or 1/3 bias
  - 5-mux, 1/3 bias
  - 6-mux, 1/3 bias
  - 7-mux, 1/3 bias
  - 8-mux, 1/3 bias

The differences between LCD\_B and LCD\_C are listed in [Table 36-1](#).

**Table 36-1. Differences Between LCD\_B and LCD\_C**

| Feature                                      | LCD_B                     | LCD_C                                |
|----------------------------------------------|---------------------------|--------------------------------------|
| Supported types of LCDs                      | Static, 2-, 3-, 4-mux     | Static, 2-, 3-, 4-, 5-, 6-, 7, 8-mux |
| Maximum VLCDx settings                       | 001111b                   | 001111b                              |
| Maximum LCD voltage ( $V_{LCD,typ}$ )        | 3.44 V                    | 3.44 V                               |
| Supported biasing schemes for 5-mux to 8-mux | 5- to 8-mux not supported | 1/3 biasing                          |

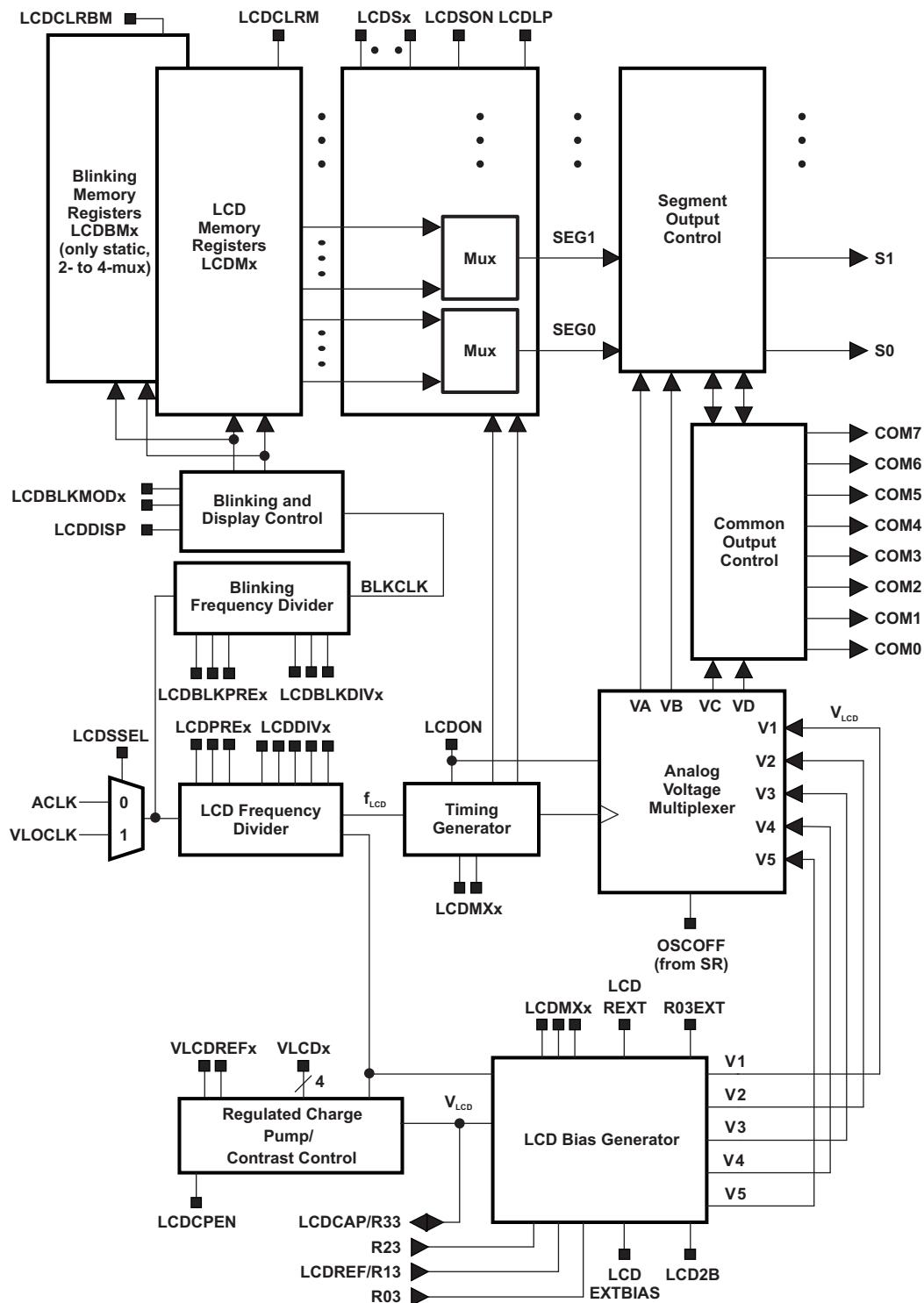
[Figure 36-1](#) shows the LCD controller block diagram.

---

**NOTE: Maximum LCD Segment Control**

The maximum number of segment lines and memory registers available differs with device. See the device-specific data sheet for available segment pins and the maximum number of segments supported.

---



**Figure 36-1. LCD Controller Block Diagram**

## 36.2 LCD\_C Operation

The LCD controller is configured with user software. The setup and operation of the LCD controller is discussed in the following sections.

### **36.2.1 LCD Memory**

The LCD memory organization differs slightly depending on the mode.

Each memory bit corresponds to one LCD segment or is not used, depending on the mode. To turn on an LCD segment, its corresponding memory bit is set.

The memory can also be accessed word-wise using the even addresses starting at LCDM1, LCDM3, ...

Setting the bit LCDCLRM clears all LCD memory registers at the next frame boundary. It is reset automatically after the registers are cleared.

### 36.2.1.1 Static and 2-Mux to 4-Mux Mode

For static and 2-mux to 4-mux modes, one byte of the LCD memory contains the information for two segment lines. Figure 36-2 shows an example LCD memory map for these modes with 160 segments.

**Figure 36-2. LCD Memory for Static and 2-Mux to 4-Mux Mode - Example for 160 Segments**

### 36.2.1.2 5-Mux to 8-Mux Mode

For 5-mux to 8-mux modes, one byte of the LCD memory contains the information for one segment line. Figure 36-3 shows an example LCD memory map for these modes with 160 segments.

| Associated Common Pins | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | Associated Segment Pins |
|------------------------|----|----|----|----|----|----|----|----|-------------------------|
| Register               | 7  |    |    |    | 0  | n  |    |    |                         |
| LCDM20                 | -- | -- | -- | -- | -- | -- | -- | -- | 19 19                   |
| LCDM19                 | -- | -- | -- | -- | -- | -- | -- | -- | 18 18                   |
| LCDM18                 | -- | -- | -- | -- | -- | -- | -- | -- | 17 17                   |
| LCDM17                 | -- | -- | -- | -- | -- | -- | -- | -- | 16 16                   |
| LCDM16                 | -- | -- | -- | -- | -- | -- | -- | -- | 15 15                   |
| LCDM15                 | -- | -- | -- | -- | -- | -- | -- | -- | 14 14                   |
| LCDM14                 | -- | -- | -- | -- | -- | -- | -- | -- | 13 13                   |
| LCDM13                 | -- | -- | -- | -- | -- | -- | -- | -- | 12 12                   |
| LCDM12                 | -- | -- | -- | -- | -- | -- | -- | -- | 11 11                   |
| LCDM11                 | -- | -- | -- | -- | -- | -- | -- | -- | 10 10                   |
| LCDM10                 | -- | -- | -- | -- | -- | -- | -- | -- | 9 9                     |
| LCDM9                  | -- | -- | -- | -- | -- | -- | -- | -- | 8 8                     |
| LCDM8                  | -- | -- | -- | -- | -- | -- | -- | -- | 7 7                     |
| LCDM7                  | -- | -- | -- | -- | -- | -- | -- | -- | 6 6                     |
| LCDM6                  | -- | -- | -- | -- | -- | -- | -- | -- | 5 5                     |
| LCDM5                  | -- | -- | -- | -- | -- | -- | -- | -- | 4 4                     |
| LCDM4                  | -- | -- | -- | -- | -- | -- | -- | -- | 3 3                     |
| LCDM3                  | -- | -- | -- | -- | -- | -- | -- | -- | 2 2                     |
| LCDM2                  | -- | -- | -- | -- | -- | -- | -- | -- | 1 1                     |
| LCDM1                  | -- | -- | -- | -- | -- | -- | -- | -- | 0 0                     |

Figure 36-3. LCD Memory for 5-Mux to 8-Mux Mode - Example for 160 Segments

### 36.2.2 LCD Timing Generation

The LCD\_C controller uses the  $f_{LCD}$  signal from the integrated clock divider to generate the timing for common and segment lines. With the LCDSSEL bit, ACLK with a frequency between 30 kHz and 40 kHz or VLOCLK can be selected as clock source into the divider. The  $f_{LCD}$  frequency is selected with the LCDPREx and LCDDIVx bits. The resulting  $f_{LCD}$  frequency is calculated by:

$$f_{LCD} = \frac{f_{ACLK/VLOCLK}}{(LCDDIVx + 1) \times 2^{LCDPRE}}$$

The proper  $f_{LCD}$  frequency depends on the LCD's requirement for framing frequency and the LCD multiplex rate. It is calculated by:

$$f_{LCD} = 2 \times \text{mux} \times f_{Frame}$$

For example, to calculate  $f_{LCD}$  for a 3-mux LCD with a frame frequency of 30 Hz to 100 Hz:

$$f_{Frame} \text{ (from LCD data sheet)} = 30 \text{ Hz to } 100 \text{ Hz}$$

$$f_{LCD} = 2 \times 3 \times f_{Frame}$$

$$f_{LCD}(\min) = 180 \text{ Hz}$$

$$f_{LCD}(\max) = 600 \text{ Hz}$$

With  $f_{ACLK/VLOCLK} = 32768 \text{ Hz}$ ,  $\text{LCDPRE} = 011$ , and  $\text{LCDDIVx} = 10101$ :

$$f_{LCD} = 32768 \text{ Hz} / ((21+1) \times 2^3) = 32768 \text{ Hz} / 176 = 186 \text{ Hz}$$

With LCDPREx = 001 and LCDDIVx = 11011:

$$f_{LCD} = 32768 \text{ Hz} / ((27+1) \times 2^1) = 32768 \text{ Hz} / 56 = 585 \text{ Hz}$$

The lowest frequency has the lowest current consumption. The highest frequency has the least flicker.

### **36.2.3 Blanking the LCD**

The LCD controller allows blanking the complete LCD. The LCDSON bit is combined with a logical AND with each segment's memory bit. When LCDSON = 1, each segment is on or off according to its bit value. When LCDSON = 0, each LCD segment is off.

### **36.2.4 LCD Blinking**

The LCD controller also supports blinking. In static and 2-mux to 4-mux mode, the blinking mode LCDBLKMODx = 01 allows blinking of individual segments; with LCDBLKMODx = 10 all segments are blinking; and with LCDBLKMODx = 00 blinking is disabled. In 5-mux mode and above, only blinking mode LCDBLKMODx = 10 that allows blinking of all segments is available; if another mode is selected, blinking is disabled.

#### **36.2.4.1 Blinking Memory**

In static and 2-mux to 4-mux mode, a separate blinking memory is implemented to select the blinking segments. To enable individual segments for blinking, the corresponding bit in the blinking memory LCDBMx registers must be set. The memory uses the same structure as the LCD memory (see [Figure 36-2](#)). Each memory bit corresponds to one LCD segment or is not used, depending on the multiplexing mode LCDMXx. To enable blinking for a LCD segment, its corresponding memory bit is set.

The blinking memory can also be accessed word-wise using the even addresses starting at LCDBM1, LCDBM3, ...

Setting the bit LCDCLRBM clears all blinking memory registers at the next frame boundary. It is automatically reset after the registers are cleared.

#### **36.2.4.2 Blinking Frequency**

The blinking frequency  $f_{BLINK}$  is selected with the LCDBLKPREx and LCDBLKDIVx bits. The same clock is used as selected for the LCD frequency  $f_{LCD}$ . The resulting  $f_{BLINK}$  frequency is calculated by:

$$f_{Blink} = \frac{f_{ACLKVLO}}{(LCDBLKDIVx + 1) \times 2^{9+LCDBLKPREx}}$$

The divider generating the blinking frequency  $f_{BLINK}$  is reset when LCDBLKMODx = 00. After a blinking mode LCDBLKMODx = 01 or 10 is selected, the enabled segments or all segments go blank at the next frame boundary and stay off for half of a BLKCLK period. Then they go active at the next frame boundary and stay on for another half BLKCLK period before they go blank again at a frame boundary.

---

#### **NOTE: Blinking Frequency Restrictions**

The blinking frequency must be smaller than the frame frequency  $f_{Frame}$ .

The blinking frequency should only be changed when LCDBLKMODx = 00.

---

#### **36.2.4.3 Dual Display Memory**

In static and 2-mux to 4-mux mode, the blinking memory can also be used as a secondary display memory when no blinking mode LCDBLKMODx = 01 or 10 is selected. The memory to be displayed can be selected either manually using the LCDDISP bit or automatically with LCDBLKMODx = 11.

With LCDDISP = 0, the LCD memory is selected, and with LCDDISP = 1 the blinking memory is selected as display memory. Switching between the memories is synchronized to the frame boundaries.

With  $\text{LCDBLKMODx} = 11$  the LCD controller switches automatically between the memories using the divider to generate the blinking frequency. After  $\text{LCDBLKMODx} = 11$  is selected, the memory to be displayed for the first half a BLKCLK period is the LCD memory. In the second half, the blinking memory is used as display memory. Switching between the memories is synchronized to the frame boundaries.

### 36.2.5 LCD Voltage And Bias Generation

The LCD\_C module allows selectable sources for the peak output waveform voltage,  $V_1$ , as well as the fractional LCD biasing voltages  $V_2$  to  $V_5$ .  $V_{\text{LCD}}$  may be sourced from  $V_{\text{CC}}$ , an internal charge pump, or externally.

All internal voltage generation is disabled if the selected clock source (ACLK or VLOCLK) is turned off ( $\text{OSCOFF} = 1$ ) or the LCD\_C module is disabled ( $\text{LCDON} = 0$ ).

#### 36.2.5.1 LCD Voltage Selection

$V_{\text{LCD}}$  is sourced from  $V_{\text{CC}}$  when  $\text{VLCDEXT} = 0$ ,  $\text{VLCDx} = 0$ , and  $\text{VREFx} = 0$ .  $V_{\text{LCD}}$  is sourced from the internal charge pump when  $\text{VLCDEXT} = 0$ ,  $\text{VLDCPEN} = 1$ , and  $\text{VLCDx} > 0$ . The charge pump is always sourced from  $DV_{\text{CC}}$ . The VLCDx bits provide a software selectable LCD voltage from 2.6 V to 3.44 V (typical) independent of  $DV_{\text{CC}}$ . See the device-specific data sheet for specifications.

When the internal charge pump is used, a 4.7- $\mu\text{F}$  or larger capacitor must be connected between the  $\text{LCDCAP}$  pin and ground. If no capacitor is connected and the charge pump is enabled, the  $\text{LCDNOCAPIFG}$  interrupt flag is set, and the charge pump is disabled to prevent damage to the device.

To reduce system noise the charge pump can be temporarily disabled. It is disabled when  $\text{LCDCPEN} = 0$  and re-enabled when  $\text{LCDCPEN}$  is changed back to 1. If the charge pump is temporarily disabled the voltage stored on the external capacitor is used for the LCD voltages until the charge pump is re-enabled.

Some devices can also automatically disable the charge pump during certain periods of time (for example during an ADC conversion). To enable this feature set the corresponding  $\text{LCDCPDISx}$  bits in the  $\text{LCDBCPCTL}$  register. For details see the device-specific data sheet (if the feature is not listed in the data sheet it is not supported by the respective device).

---

**NOTE: Capacitor Required For Internal Charge Pump**

A 4.7- $\mu\text{F}$  or larger capacitor must be connected from the  $\text{LCDCAP}$  pin to ground when the internal charge pump is enabled. If no capacitor is connected, the  $\text{LCDNOCAPIFG}$  interrupt flag is set and the charge pump is disabled.

---

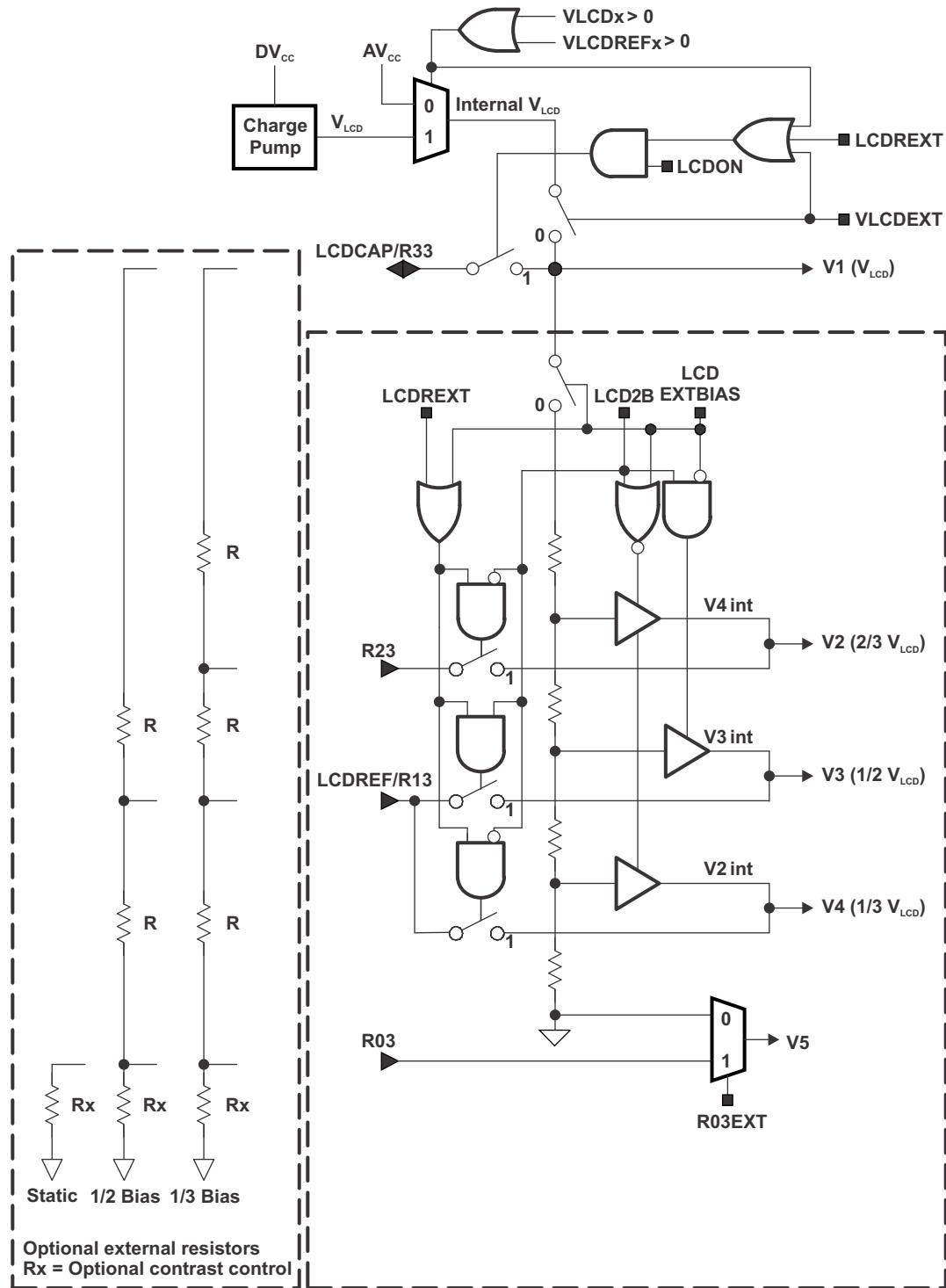
The internal charge pump may use an external reference voltage when  $\text{VLCDREFx} = 01$  (and  $\text{LCDREXT} = 0$  and  $\text{LCDEXTBIAS} = 0$ ). In this case, the charge pump voltage is set to a multiply of the external reference voltage according to the VLCDx bits setting.

When  $\text{VLCDEXT} = 1$ ,  $V_{\text{LCD}}$  is sourced externally from the  $\text{LCDCAP}$  pin and the internal charge pump is disabled.

### 36.2.5.2 LCD Bias Generation

The fractional LCD biasing voltages, V2 to V5 can be generated internally or externally, independent of the source for  $V_{LCD}$ .

The bias generation block diagram for LCD\_C static and 2-mux to 8-mux modes is shown in [Figure 36-4](#).



**Figure 36-4. Bias Generation**

The internally generated bias voltages V2 to V4 are switched to external pins with  $LCDREXT = 1$ .

To source the bias voltages V2 to V4 externally, LCDEXTBIAS is set. This also disables the internal bias generation. Typically, an equally weighted resistor divider is used with resistors ranging from a few  $k\Omega$  to  $1 M\Omega$ , depending on the size of the display. When using an external resistor divider, the  $V_{LCD}$  voltage may be sourced from the internal charge pump when VLCDEXT = 0 taking the maximum charge pump load current into account. V5 can also be sourced externally when R03EXT = 1. In static mode and all mux modes using 1/2 biasing or 1/3 biasing, when R03EXT = 1 V5 can control the contrast of the connected display by changing the voltage at the low end of the external resistor divider Rx as shown in the left part of [Figure 36-4](#).

When using an external resistor divider, R33 may serve as a switched  $V_{LCD}$  output when VLCDEXT = 0. This allows the power to the resistor ladder to be turned off, which eliminates current consumption when the LCD is not used. When VLCDEXT = 1, R33 serves as a  $V_{LCD}$  input.

The bias generator supports 1/2 biasing when LCD2B = 1 and 1/3 biasing when LCD2B = 0. In static mode, the internal divider is disabled.

**Table 36-2. Bias Voltages and external Pins**

| Mode                | Bias Configuration | LCD2B | Voltage Level | Pin | Condition                        |
|---------------------|--------------------|-------|---------------|-----|----------------------------------|
| Static              | Static             | X     | V1 ("1")      | R33 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V5 ("0")      | R03 | if R03EXT = 1                    |
| 2-mux, 3-mux, 4-mux | 1/2                | 1     | V1 ("1")      | R33 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V3 ("1/2")    | R13 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V5 ("0")      | R03 | if R03EXT = 1                    |
| 2-mux, 3-mux, 4-mux | 1/3                | 0     | V1 ("1")      | R33 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V2 ("2/3")    | R23 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V4 ("1/3")    | R13 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V5 ("0")      | R03 | if R03EXT = 1                    |
| 5-mux to 8-mux      | 1/3                | 0     | V1 ("1")      | R33 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V2 ("2/3")    | R23 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V4 ("1/3")    | R13 | if LCDREXT = 1 or LCDEXTBIAS = 1 |
|                     |                    |       | V5 ("0")      | R03 | if R03EXT = 1                    |

### 36.2.5.3 LCD Contrast Control

The peak voltage of the output waveforms together with the selected mode and biasing determine the contrast and the contrast ratio of the LCD. The LCD contrast can be controlled in software by adjusting the LCD voltage generated by the integrated charge pump using the VLCDx settings.

The contrast ratio depends on the used LCD display and the selected biasing scheme. [Table 36-3](#) shows the biasing configurations that apply to the different modes together with the RMS voltages for the segments turned on ( $V_{RMS,ON}$ ) and turned off ( $V_{RMS,OFF}$ ) as functions of  $V_{LCD}$ . It also shows the resulting contrast ratios between the on and off states.

**Table 36-3. LCD Voltage and Biasing Characteristics**

| Mode   | Bias Config        | LCDMx | LCD2B | COM Lines | Voltage Levels       | $V_{RMS,OFF}/V_{LCD}$ | $V_{RMS,ON}/V_{LCD}$ | Contrast Ratio $V_{RMS,ON}/V_{RMS,OFF}$ |
|--------|--------------------|-------|-------|-----------|----------------------|-----------------------|----------------------|-----------------------------------------|
| Static | Static             | 0000  | X     | 1         | $V_1, V_5$           | 0                     | 1                    | 1/0                                     |
| 2-mux  | 1/2 <sup>(1)</sup> | 0001  | 1     | 2         | $V_1, V_3, V_5$      | 0.354                 | 0.791                | 2.236                                   |
|        | 1/3                | 0001  | 0     | 2         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.745                | 2.236                                   |
| 3-mux  | 1/2                | 0010  | 1     | 3         | $V_1, V_3, V_5$      | 0.408                 | 0.707                | 1.732                                   |
|        | 1/3 <sup>(1)</sup> | 0010  | 0     | 3         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.638                | 1.915                                   |
| 4-mux  | 1/2                | 0011  | 1     | 4         | $V_1, V_3, V_5$      | 0.433                 | 0.661                | 1.528                                   |
|        | 1/3 <sup>(1)</sup> | 0011  | 0     | 4         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.577                | 1.732                                   |
| 5-mux  | 1/3 <sup>(1)</sup> | 0100  | 0     | 5         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.537                | 1.612                                   |
| 6-mux  | 1/3 <sup>(1)</sup> | 0101  | 0     | 6         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.509                | 1.528                                   |
| 7-mux  | 1/3 <sup>(1)</sup> | 0110  | 0     | 7         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.488                | 1.464                                   |
| 8-mux  | 1/3 <sup>(1)</sup> | 0111  | 0     | 8         | $V_1, V_2, V_4, V_5$ | 0.333                 | 0.471                | 1.414                                   |

<sup>(1)</sup> Recommended setting to achieve best contrast

A typical approach to determine the required  $V_{LCD}$  is by equating  $V_{RMS,OFF}$  with a LCD threshold voltage provided by the LCD manufacturer, for example when the LCD exhibits approximately 10% contrast ( $V_{th,10\%}$ ):  $V_{RMS,OFF} = V_{th,10\%}$ . Using the values for  $V_{RMS,OFF}/V_{LCD}$  provided in the table results in  $V_{LCD} = V_{th,10\%}/(V_{RMS,OFF}/V_{LCD})$ . In the static mode, a suitable choice is  $V_{LCD}$  greater than or equal to three times  $V_{th,10\%}$ .

In 3-mux and 4-mux mode, a 1/3 biasing is typically used, but a 1/2 biasing scheme is also possible. The 1/2 bias reduces the contrast ratio, but the advantage is a reduction of the required full-scale LCD voltage  $V_{LCD}$ .

### 36.2.6 LCD Outputs

Some LCD segment, common, and Rxx functions are multiplexed with digital I/O functions. These pins can function either as digital I/O or as LCD functions.

The LCD segment functions, when multiplexed with digital I/O, are selected using the LCDSx bits in the LCDCPCTLx registers. The LCDSx bits select the LCD function for each segment line. When LCDSx = 0, a multiplexed pin is set to digital I/O function. When LCDSx = 1, a multiplexed pin is selected as LCD function.

The pin functions for COMx and Rxx, when multiplexed with digital I/O, are selected as described in the port schematic section of the device-specific data sheet. An some devices the COM1 to COM7 pins are shared with segment lines, refer to the device-specific data sheet. If these pins are required as COM pins due to the selected LCD multiplexing mode, the COM functionality takes precedence over the segment function that can be selected for those pins with the LCDSx bits as for all other segment pins.

See the port schematic section of the device-specific data sheet for details on controlling the pin functionality.

**NOTE: LCDS<sub>x</sub> Bits Do Not Affect Dedicated LCD Segment Pins**

The LCDS<sub>x</sub> bits only affect pins with multiplexed LCD segment functions and digital I/O functions. Dedicated LCD segment pins are not affected by the LCDS<sub>x</sub> bits.

### 36.2.7 LCD Interrupts

The LCD\_C module has four interrupt sources available, each with independent enables and flags.

The four interrupt flags, namely LCDFRMIFG, LCDBLKOFFIFG, LCDBLKONIFG, and LCDNOCAPIFG, are prioritized and combined to source a single interrupt vector. The interrupt vector register LCDCIV is used to determine which flag requested an interrupt.

The highest priority enabled interrupt generates a number in the LCDCIV register (see register description). This number can be evaluated or added to the program counter to automatically enter the appropriate software routine. Disabled LCD interrupts do not affect the LCDCIV value.

Any read access of the LCDCIV register automatically resets the highest pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. A write access to the LCDCIV register automatically resets all pending interrupt flags. In addition, all flags can be cleared by software.

The LCDNOCAPIFG indicates that no capacitor is present at the LCDCAP pin when the charge pump is enabled. Setting the LCDNOCAPIE bit enables the interrupt.

The LCDBLKONIFG is set at the BLKCLK edge synchronized to the frame boundaries that turns on the segments when blinking is enabled with LCDBLKMOD<sub>x</sub> = 01 or 10. It is also set at the BLKCLK edge synchronized to the frame boundaries that selects the blinking memory as display memory when LCDBLKMOD<sub>x</sub> = 11. It is automatically cleared when a LCD or blinking memory register is written. Setting the LCDBLKONIE bit enables the interrupt.

The LCDBLKOFFIFG is set at the BLKCLK edge synchronized to the frame boundaries that blanks the segments when blinking is enabled with LCDBLKMOD<sub>x</sub> = 01 or 10. It is also set at the BLKCLK edge synchronized to the frame boundaries that selects the LCD memory as display memory when LCDBLKMOD<sub>x</sub> = 11. It is automatically cleared when a LCD or blinking memory register is written. Setting the LCDBLKOFFIE bit enables the interrupt.

The LCDFRMIFG is set at a frame boundary. It is automatically cleared when a LCD or blinking memory register is written. Setting the LCDFRMIFGIE bit enables the interrupt.

### 36.2.7.1 LCDCIV Software Example

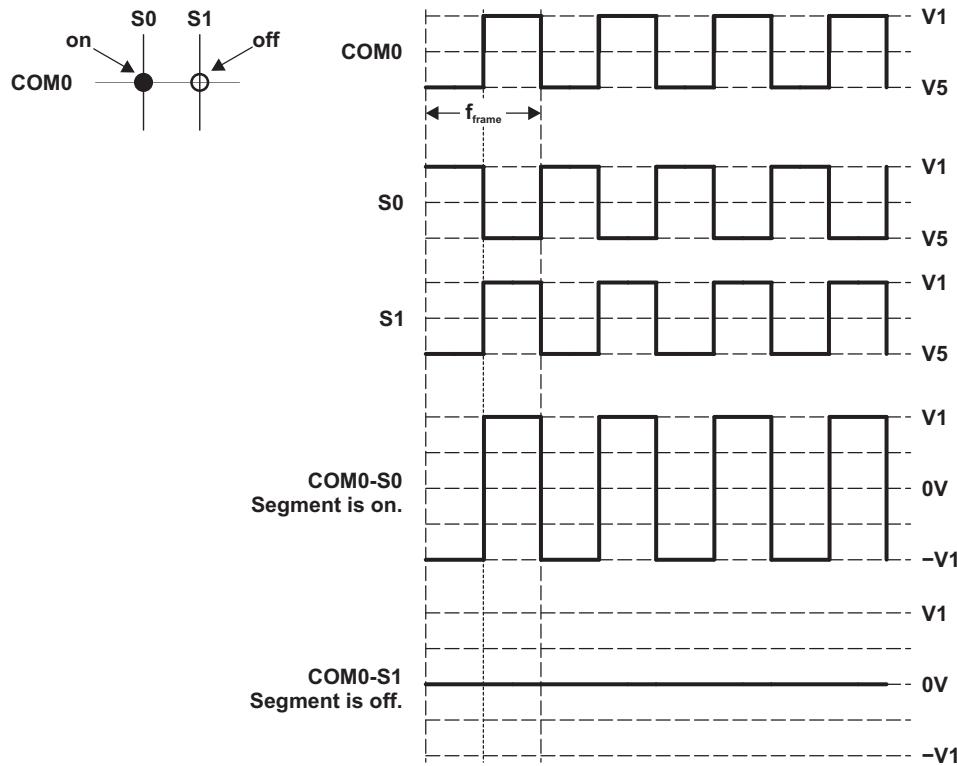
The following software example shows the recommended use of LCDCIV and the handling overhead. The LCDCIV value is added to the PC to automatically jump to the appropriate routine.

The numbers at the right margin show the necessary CPU cycles for each instruction. The software overhead for different interrupt sources includes interrupt latency and return-from-interrupt cycles, but not the task handling itself.

```
; Interrupt handler for LCD_B interrupt flags.
LCDB_HND           ; Interrupt latency      6
    ADD &LCDBIV,PC ; Add offset to Jump table   3
    RETI             ; Vector 0: No interrupt     5
    JMP LCDNOCAP_HND ; Vector 2: LCDNOCAPIFG    2
    JMP LCDBLKON_HND ; Vector 4: LCDBLKONIFG    2
    JMP LCDBLKOFF_HND; Vector 6: LCDBLKOFFIFG   2
    LCDFRM_HND       ; Vector 8: LCDFRMIFG     2
    ...              ; Task starts here          5
    RETI
LCDNOCAP_HND ; Vector 2: LCDNOCAPIFG
    ... ; Task starts here          5
    RETI
LCDBLKON_HND ; Vector 4: LCDBLKONIFG
    ... ; Task starts here          5
    RETI ; Back to main program
LCDBLKOFF_HND ; Vector 6: LCDBLKOFFIFG
    ... ; Task starts here          5
    RETI ; Back to main program
```

### 36.2.8 Static Mode

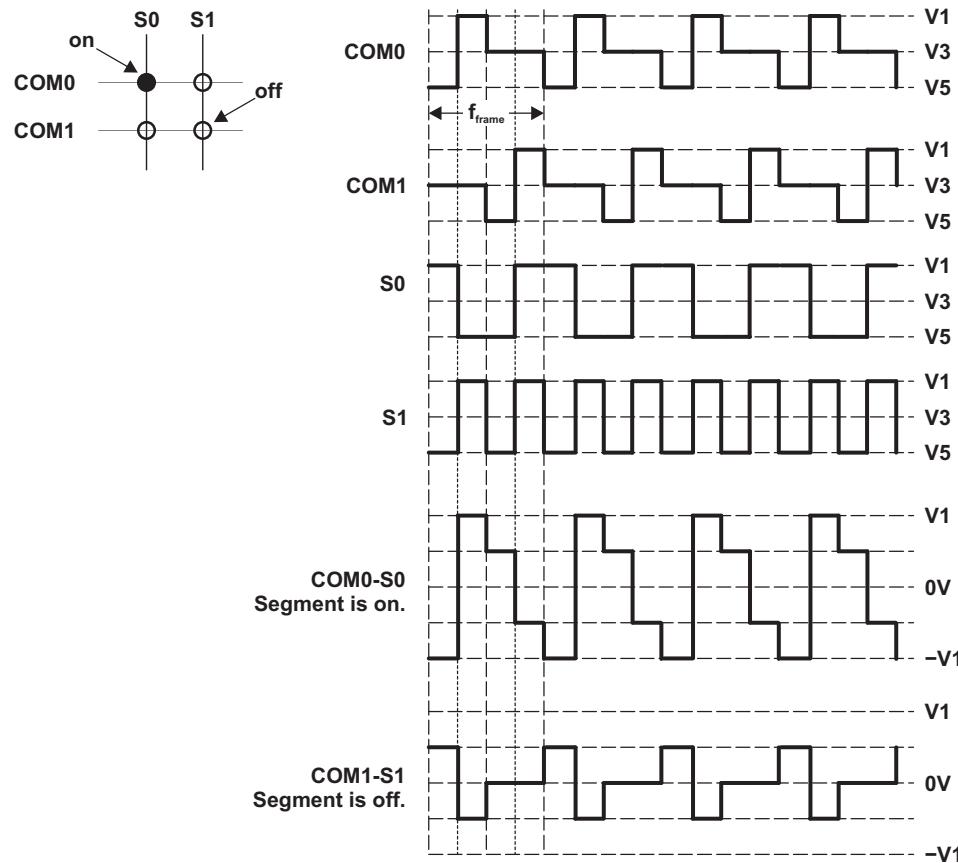
In static mode, each MSP430 segment pin drives one LCD segment, and one common line (COM0) is used. [Figure 36-5](#) shows some example static waveforms.



**Figure 36-5. Example Static Waveforms**

### 36.2.9 2-Mux Mode

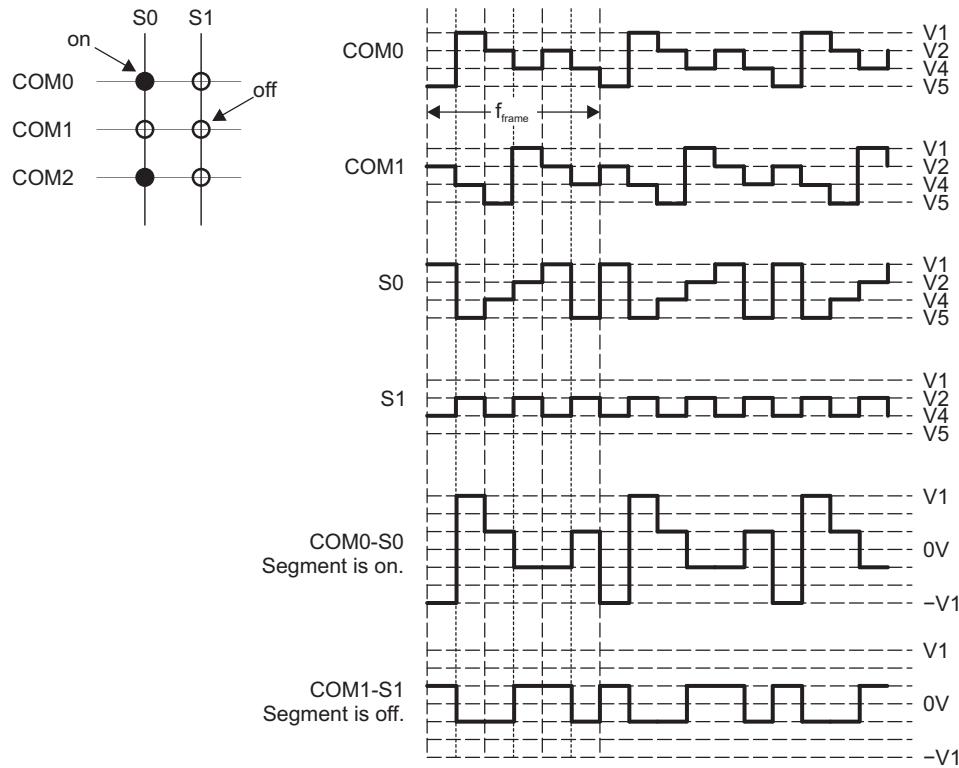
In 2-mux mode, each MSP430 segment pin drives two LCD segments, and two common lines (COM0 and COM1) are used. [Figure 36-6](#) shows some example 2-mux 1/2-bias waveforms.



**Figure 36-6. Example 2-Mux Waveforms**

### 36.2.10 3-Mux Mode

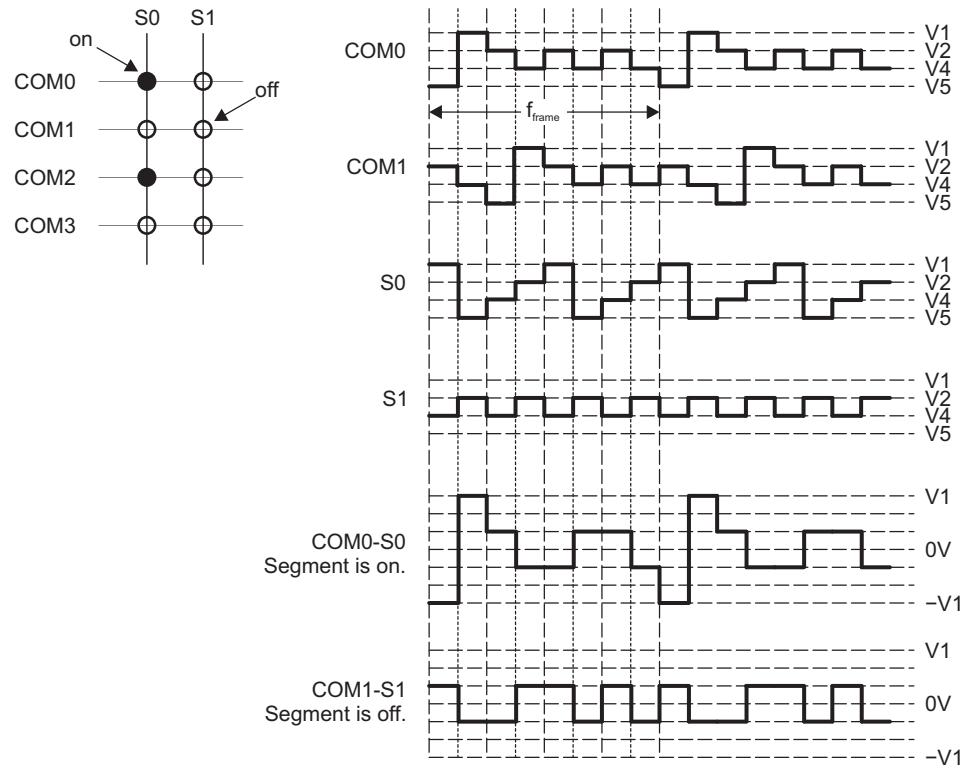
In 3-mux mode, each MSP430 segment pin drives three LCD segments, and three common lines (COM0, COM1, and COM2) are used. [Figure 36-7](#) shows some example 3-mux 1/3-bias waveforms.



**Figure 36-7. Example 3-Mux Waveforms**

### 36.2.11 4-Mux Mode

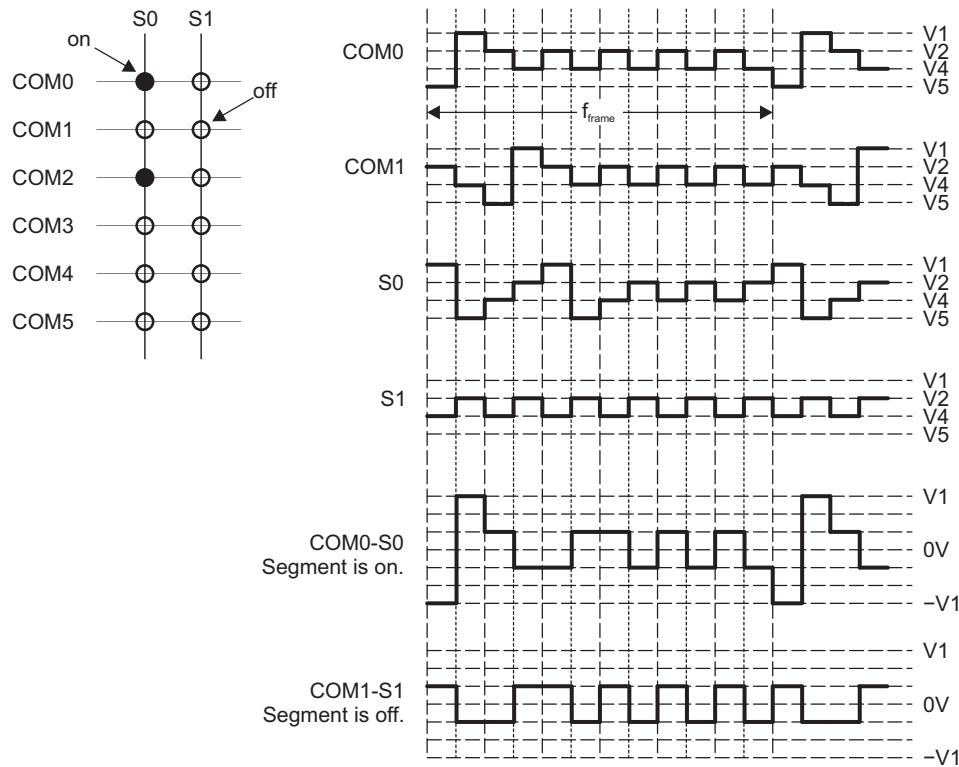
In 4-mux mode, each MSP430 segment pin drives four LCD segments and four common lines (COM0, COM1, COM2, and COM3) are used. [Figure 36-8](#) shows some example 4-mux 1/3-bias waveforms.



**Figure 36-8. Example 4-Mux Waveforms**

### 36.2.12 6-Mux Mode

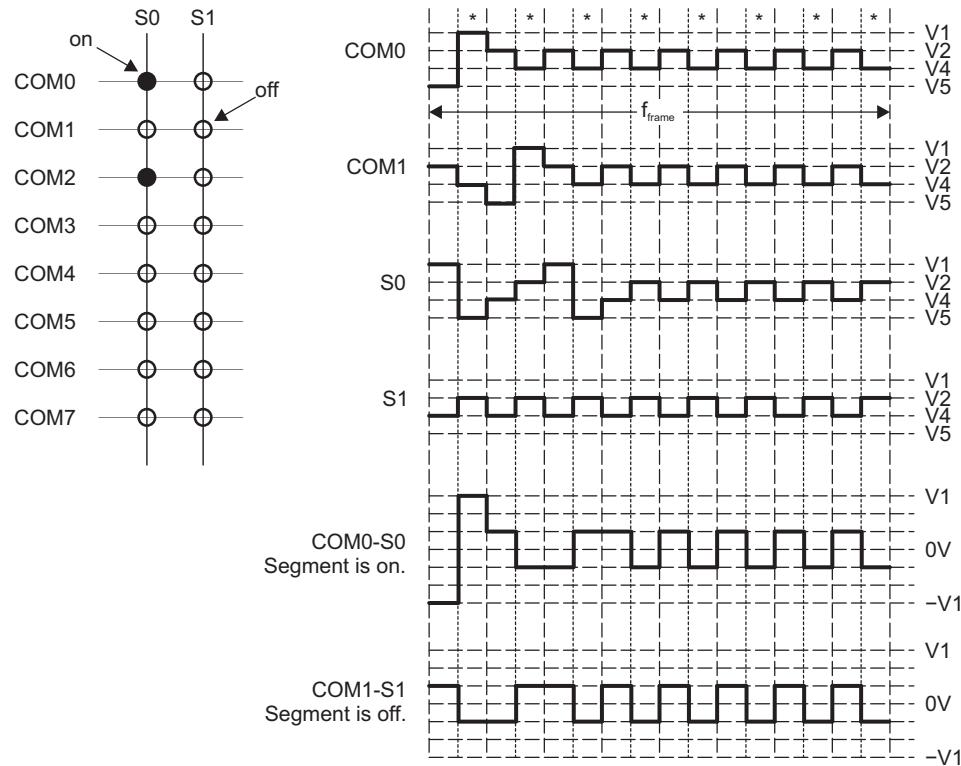
In 6-mux mode, each MSP430 segment pin drives six LCD segments, and six common lines (COM0, COM1, COM2, COM3, COM4, and COM5) are used. [Figure 36-9](#) shows some example 6-mux 1/3-bias waveforms.



**Figure 36-9. Example 6-Mux Waveforms**

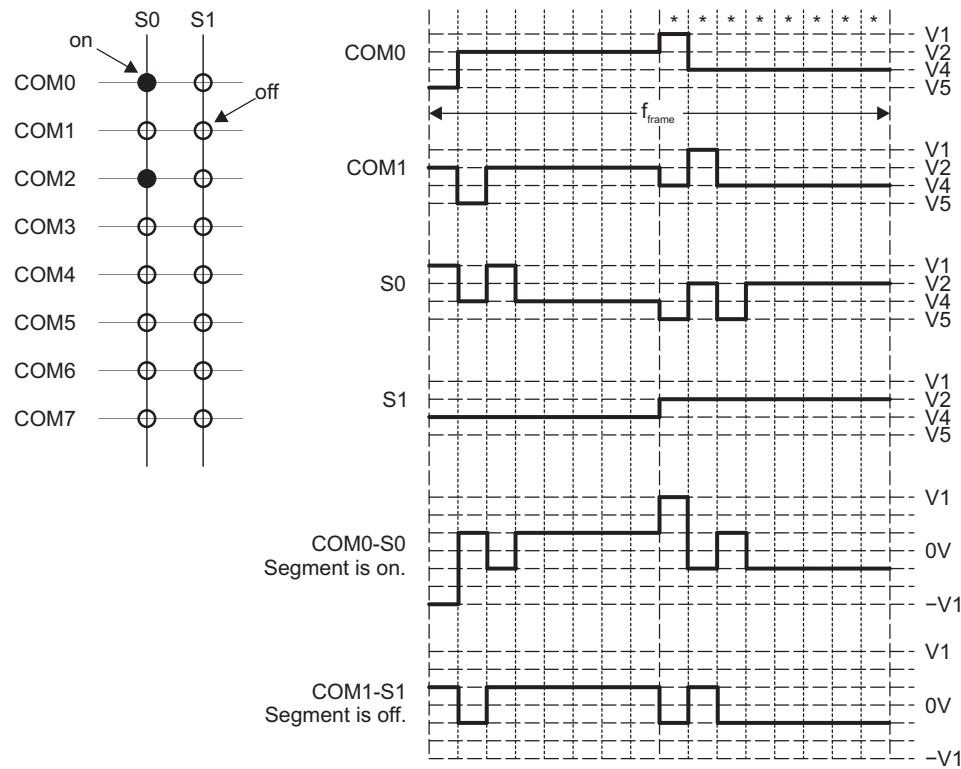
### 36.2.13 8-Mux Mode

In 8-mux mode, each MSP430 segment pin drives eight LCD segments, and eight common lines (COM0 through COM7) are used. [Figure 36-10](#) shows some example 8-mux 1/3-bias waveforms.



**Figure 36-10. Example 8-Mux, 1/3 Bias Waveforms (LCDLP = 0)**

Figure 36-11 shows some example 8-mux 1/3-bias waveforms with LCDLP = 1. With LCDLP = 1, the voltage sequence compared to the non-low power waveform is reshuffled; that is, all of the timeslots marked with "\*" in Figure 36-10 are grouped together. The same principle applies to all mux modes.



**Figure 36-11. Example 8-Mux, 1/3 Bias Low-Power Waveforms (LCDLP = 1)**

### **36.3 LCD\_C Registers**

The LCD\_C registers are listed in [Table 36-4](#) to [Table 36-7](#). The LCD memory and blinking memory registers can also be accessed as word.

The number of available memory registers on a given device depends on the number of available segment pins; see the device-specific data sheet.

**Table 36-4. LCD\_C Control Registers**

| Offset | Acronym    | Register Name                               | Type       | Reset | Section                         |
|--------|------------|---------------------------------------------|------------|-------|---------------------------------|
| 000h   | LCDCCTL0   | LCD_C control 0                             | Read/write | 0000h | <a href="#">Section 36.3.1</a>  |
| 002h   | LCDCCTL1   | LCD_C control 1                             | Read/write | 0000h | <a href="#">Section 36.3.2</a>  |
| 004h   | LCDCBLKCTL | LCD_C blinking control                      | Read/write | 0000h | <a href="#">Section 36.3.3</a>  |
| 006h   | LCDCMEMCTL | LCD_C memory control                        | Read/write | 0000h | <a href="#">Section 36.3.4</a>  |
| 008h   | LCDCVCTL   | LCD_C voltage control                       | Read/write | 0000h | <a href="#">Section 36.3.5</a>  |
| 00Ah   | LCDCPCTL0  | LCD_C port control 0                        | Read/write | 0000h | <a href="#">Section 36.3.6</a>  |
| 00Ch   | LCDCPCTL1  | LCD_C port control 1                        | Read/write | 0000h | <a href="#">Section 36.3.7</a>  |
| 00Eh   | LCDCPCTL2  | LCD_C port control 2 ( $\geq 256$ segments) | Read/write | 0000h | <a href="#">Section 36.3.8</a>  |
| 010h   | LCDCPCTL3  | LCD_C port control 3 (384 segments)         | Read/write | 0000h | <a href="#">Section 36.3.9</a>  |
| 012h   | LCDCCPCTL  | LCD_C charge pump control                   | Read/write | 0000h | <a href="#">Section 36.3.10</a> |
| 014h   |            | Reserved                                    |            |       |                                 |
| 016h   |            | Reserved                                    |            |       |                                 |
| 018h   |            | Reserved                                    |            |       |                                 |
| 01Ah   |            | Reserved                                    |            |       |                                 |
| 01Ch   |            | Reserved                                    |            |       |                                 |
| 01Eh   | LCDCIV     | LCD_C interrupt vector                      | Read/write | 0000h | <a href="#">Section 36.3.11</a> |

**Table 36-5. LCD\_C Memory Registers for Static and 2-Mux to 4-Mux Modes<sup>(1)(2)</sup>**

| Offset | Acronym | Register Name           | Type       | Reset     |
|--------|---------|-------------------------|------------|-----------|
| 020h   | LCDM1   | LCD memory 1 (S1/S0)    | Read/write | Unchanged |
| 021h   | LCDM2   | LCD memory 2 (S3/S2)    | Read/write | Unchanged |
| 022h   | LCDM3   | LCD memory 3 (S5/S4)    | Read/write | Unchanged |
| 023h   | LCDM4   | LCD memory 4 (S7/S6)    | Read/write | Unchanged |
| 024h   | LCDM5   | LCD memory 5 (S9/S8)    | Read/write | Unchanged |
| 025h   | LCDM6   | LCD memory 6 (S11/S10)  | Read/write | Unchanged |
| 026h   | LCDM7   | LCD memory 7 (S13/S12)  | Read/write | Unchanged |
| 027h   | LCDM8   | LCD memory 8 (S15/S14)  | Read/write | Unchanged |
| 028h   | LCDM9   | LCD memory 9 (S17/S16)  | Read/write | Unchanged |
| 029h   | LCDM10  | LCD memory 10 (S19/S18) | Read/write | Unchanged |
| 02Ah   | LCDM11  | LCD memory 11 (S21/S20) | Read/write | Unchanged |
| 02Bh   | LCDM12  | LCD memory 12 (S23/S22) | Read/write | Unchanged |
| 02Ch   | LCDM13  | LCD memory 13 (S25/S24) | Read/write | Unchanged |
| 02Dh   | LCDM14  | LCD memory 14 (S27/S26) | Read/write | Unchanged |
| 02Eh   | LCDM15  | LCD memory 15 (S29/S28) | Read/write | Unchanged |
| 02Fh   | LCDM16  | LCD memory 16 (S31/S30) | Read/write | Unchanged |
| 030h   | LCDM17  | LCD memory 17 (S33/S32) | Read/write | Unchanged |
| 031h   | LCDM18  | LCD memory 18 (S35/S34) | Read/write | Unchanged |
| 032h   | LCDM19  | LCD memory 19 (S37/S36) | Read/write | Unchanged |
| 033h   | LCDM20  | LCD memory 20 (S39/S38) | Read/write | Unchanged |
| 034h   | LCDM21  | LCD memory 21 (S41/S40) | Read/write | Unchanged |
| 035h   | LCDM22  | LCD memory 22 (S43/S42) | Read/write | Unchanged |
| 036h   | LCDM23  | LCD memory 23 (S45/S44) | Read/write | Unchanged |
| 037h   | LCDM24  | LCD memory 24 (S47/S46) | Read/write | Unchanged |
| 038h   | LCDM25  | LCD memory 25 (S49/S48) | Read/write | Unchanged |
| 039h   | LCDM26  | LCD memory 26 (S51/S50) | Read/write | Unchanged |
| 03Ah   | LCDM27  | LCD memory 27 (S53/S52) | Read/write | Unchanged |
| 03Bh   | LCDM28  | LCD memory 28 (S54)     | Read/write | Unchanged |
| 03Ch   |         | Reserved                |            |           |
| 03Dh   |         | Reserved                |            |           |
| 03Eh   |         | Reserved                |            |           |
| 03Fh   |         | Reserved                |            |           |

<sup>(1)</sup> The LCD memory registers can also be accessed as word.

<sup>(2)</sup> The number of available memory registers on a given device depends on the number of available segment pins; see the device-specific data sheet.

**Table 36-6. LCD Blinking Memory Registers for Static and 2-Mux to 4-Mux Modes<sup>(1)(2)</sup>**

| <b>Offset</b> | <b>Acronym</b> | <b>Register Name</b>   | <b>Type</b> | <b>Reset</b> |
|---------------|----------------|------------------------|-------------|--------------|
| 040h          | LCDBM1         | LCD blinking memory 1  | Read/write  | Unchanged    |
| 041h          | LCDBM2         | LCD blinking memory 2  | Read/write  | Unchanged    |
| 042h          | LCDBM3         | LCD blinking memory 3  | Read/write  | Unchanged    |
| 043h          | LCDBM4         | LCD blinking memory 4  | Read/write  | Unchanged    |
| 044h          | LCDBM5         | LCD blinking memory 5  | Read/write  | Unchanged    |
| 045h          | LCDBM6         | LCD blinking memory 6  | Read/write  | Unchanged    |
| 046h          | LCDBM7         | LCD blinking memory 7  | Read/write  | Unchanged    |
| 047h          | LCDBM8         | LCD blinking memory 8  | Read/write  | Unchanged    |
| 048h          | LCDBM9         | LCD blinking memory 9  | Read/write  | Unchanged    |
| 049h          | LCDBM10        | LCD blinking memory 10 | Read/write  | Unchanged    |
| 04Ah          | LCDBM11        | LCD blinking memory 11 | Read/write  | Unchanged    |
| 04Bh          | LCDBM12        | LCD blinking memory 12 | Read/write  | Unchanged    |
| 04Ch          | LCDBM13        | LCD blinking memory 13 | Read/write  | Unchanged    |
| 04Dh          | LCDBM14        | LCD blinking memory 14 | Read/write  | Unchanged    |
| 04Eh          | LCDBM15        | LCD blinking memory 15 | Read/write  | Unchanged    |
| 04Fh          | LCDBM16        | LCD blinking memory 16 | Read/write  | Unchanged    |
| 050h          | LCDBM17        | LCD blinking memory 17 | Read/write  | Unchanged    |
| 051h          | LCDBM18        | LCD blinking memory 18 | Read/write  | Unchanged    |
| 052h          | LCDBM19        | LCD blinking memory 19 | Read/write  | Unchanged    |
| 053h          | LCDBM20        | LCD blinking memory 20 | Read/write  | Unchanged    |
| 054h          | LCDBM21        | LCD blinking memory 21 | Read/write  | Unchanged    |
| 055h          | LCDBM22        | LCD blinking memory 22 | Read/write  | Unchanged    |
| 056h          | LCDBM23        | LCD blinking memory 23 | Read/write  | Unchanged    |
| 057h          | LCDBM24        | LCD blinking memory 24 | Read/write  | Unchanged    |
| 058h          | LCDBM25        | LCD blinking memory 25 | Read/write  | Unchanged    |
| 059h          | LCDBM26        | LCD blinking memory 26 | Read/write  | Unchanged    |
| 05Ah          | LCDBM27        | LCD blinking memory 27 | Read/write  | Unchanged    |
| 05Bh          | LCDBM28        | LCD blinking memory 28 | Read/write  | Unchanged    |
| 05Ch          |                | Reserved               |             |              |
| 05Dh          |                | Reserved               |             |              |
| 05Eh          |                | Reserved               |             |              |
| 05Fh          |                | Reserved               |             |              |

<sup>(1)</sup> The LCD blinking memory registers can also be accessed as word.

<sup>(2)</sup> The number of available memory registers on a given device depends on the number of available segment pins; see the device-specific data sheet.

**Table 36-7. LCD Memory Registers for 5-Mux to 8-Mux<sup>(1)(2)</sup>**

| <b>Offset</b> | <b>Acronym</b> | <b>Register Name</b> | <b>Type</b> | <b>Reset</b> |
|---------------|----------------|----------------------|-------------|--------------|
| 020h          | LCDM1          | LCD memory 1 (S0)    | Read/write  | Unchanged    |
| 021h          | LCDM2          | LCD memory 2 (S1)    | Read/write  | Unchanged    |
| 022h          | LCDM3          | LCD memory 3 (S2)    | Read/write  | Unchanged    |
| 023h          | LCDM4          | LCD memory 4 (S3)    | Read/write  | Unchanged    |
| 024h          | LCDM5          | LCD memory 5 (S4)    | Read/write  | Unchanged    |
| 025h          | LCDM6          | LCD memory 6 (S5)    | Read/write  | Unchanged    |
| 026h          | LCDM7          | LCD memory 7 (S6)    | Read/write  | Unchanged    |
| 027h          | LCDM8          | LCD memory 8 (S7)    | Read/write  | Unchanged    |
| 028h          | LCDM9          | LCD memory 9 (S8)    | Read/write  | Unchanged    |
| 029h          | LCDM10         | LCD memory 10 (S9)   | Read/write  | Unchanged    |
| 02Ah          | LCDM11         | LCD memory 11 (S10)  | Read/write  | Unchanged    |
| 02Bh          | LCDM12         | LCD memory 12 (S11)  | Read/write  | Unchanged    |
| 02Ch          | LCDM13         | LCD memory 13 (S12)  | Read/write  | Unchanged    |
| 02Dh          | LCDM14         | LCD memory 14 (S13)  | Read/write  | Unchanged    |
| 02Eh          | LCDM15         | LCD memory 15 (S14)  | Read/write  | Unchanged    |
| 02Fh          | LCDM16         | LCD memory 16 (S15)  | Read/write  | Unchanged    |
| 030h          | LCDM17         | LCD memory 17 (S16)  | Read/write  | Unchanged    |
| 031h          | LCDM18         | LCD memory 18 (S17)  | Read/write  | Unchanged    |
| 032h          | LCDM19         | LCD memory 19 (S18)  | Read/write  | Unchanged    |
| 033h          | LCDM20         | LCD memory 20 (S19)  | Read/write  | Unchanged    |
| 034h          | LCDM21         | LCD memory 21 (S20)  | Read/write  | Unchanged    |
| 035h          | LCDM22         | LCD memory 22 (S21)  | Read/write  | Unchanged    |
| 036h          | LCDM23         | LCD memory 23 (S22)  | Read/write  | Unchanged    |
| 037h          | LCDM24         | LCD memory 24 (S23)  | Read/write  | Unchanged    |
| 038h          | LCDM25         | LCD memory 25 (S24)  | Read/write  | Unchanged    |
| 039h          | LCDM26         | LCD memory 26 (S25)  | Read/write  | Unchanged    |
| 03Ah          | LCDM27         | LCD memory 27 (S26)  | Read/write  | Unchanged    |
| 03Bh          | LCDM28         | LCD memory 28 (S27)  | Read/write  | Unchanged    |
| 03Ch          | LCDM29         | LCD memory 29 (S28)  | Read/write  | Unchanged    |
| 03Dh          | LCDM30         | LCD memory 30 (S29)  | Read/write  | Unchanged    |
| 03Eh          | LCDM31         | LCD memory 31 (S30)  | Read/write  | Unchanged    |
| 03Fh          | LCDM32         | LCD memory 32 (S31)  | Read/write  | Unchanged    |
| 040h          | LCDM33         | LCD memory 33 (S32)  | Read/write  | Unchanged    |
| 041h          | LCDM34         | LCD memory 34 (S33)  | Read/write  | Unchanged    |
| 042h          | LCDM35         | LCD memory 35 (S34)  | Read/write  | Unchanged    |
| 043h          | LCDM36         | LCD memory 36 (S35)  | Read/write  | Unchanged    |
| 044h          | LCDM37         | LCD memory 37 (S36)  | Read/write  | Unchanged    |
| 045h          | LCDM38         | LCD memory 38 (S37)  | Read/write  | Unchanged    |
| 046h          | LCDM39         | LCD memory 39 (S38)  | Read/write  | Unchanged    |
| 047h          | LCDM40         | LCD memory 40 (S39)  | Read/write  | Unchanged    |
| 048h          | LCDM41         | LCD memory 41 (S40)  | Read/write  | Unchanged    |
| 049h          | LCDM42         | LCD memory 42 (S41)  | Read/write  | Unchanged    |
| 04Ah          | LCDM43         | LCD memory 43 (S42)  | Read/write  | Unchanged    |
| 04Bh          | LCDM44         | LCD memory 44 (S43)  | Read/write  | Unchanged    |
| 04Ch          | LCDM45         | LCD memory 45 (S44)  | Read/write  | Unchanged    |

<sup>(1)</sup> The LCD memory registers can also be accessed as word.<sup>(2)</sup> The number of available memory registers on a given device depends on the number of available segment pins; see the device-specific data sheet.

**Table 36-7. LCD Memory Registers for 5-Mux to 8-Mux<sup>(1)(2)</sup> (continued)**

| <b>Offset</b> | <b>Acronym</b> | <b>Register Name</b> | <b>Type</b> | <b>Reset</b> |
|---------------|----------------|----------------------|-------------|--------------|
| 04Dh          | LCDM46         | LCD memory 46 (S45)  | Read/write  | Unchanged    |
| 04Eh          | LCDM47         | LCD memory 47 (S46)  | Read/write  | Unchanged    |
| 04Fh          | LCDM48         | LCD memory 48 (S47)  | Read/write  | Unchanged    |
| 050h          | LCDM49         | LCD memory 49 (S48)  | Read/write  | Unchanged    |
| 051h          | LCDM50         | LCD memory 50 (S49)  | Read/write  | Unchanged    |
| 052h          | LCDM51         | LCD memory 51 (S50)  | Read/write  | Unchanged    |
| 053h          | LCDM52         | LCD memory 52 (S51)  | Read/write  | Unchanged    |
| 054h          |                | Reserved             |             |              |
| 055h          |                | Reserved             |             |              |
| 056h          |                | Reserved             |             |              |
| 057h          |                | Reserved             |             |              |
| 058h          |                | Reserved             |             |              |
| 059h          |                | Reserved             |             |              |
| 05Ah          |                | Reserved             |             |              |
| 05Bh          |                | Reserved             |             |              |
| 05Ch          |                | Reserved             |             |              |
| 05Dh          |                | Reserved             |             |              |
| 05Eh          |                | Reserved             |             |              |
| 05Fh          |                | Reserved             |             |              |

### 36.3.1 LCDCCTL0 Register

LCD\_C Control Register 0

NOTE: Settings for LCDDIVx, LCDPREx, LCDSSEL, LCDLP and LCDMXx should be changed only while LCDON = 0.

**Figure 36-12. LCDCCTL0 Register**

| 15      | 14       | 13     | 12   | 11      | 10     | 9     | 8     |
|---------|----------|--------|------|---------|--------|-------|-------|
| LCDDIVx |          |        |      | LCDPREx |        |       |       |
| rw-0    | rw-0     | rw-0   | rw-0 | rw-0    | rw-0   | rw-0  | rw-0  |
| 7       | 6        | 5      | 4    | 3       | 2      | 1     | 0     |
| LCDSEL  | Reserved | LCDMXx |      |         | LCDSON | LCDLP | LCDON |
| rw-0    | r0       | rw-0   | rw-0 | rw-0    | rw-0   | rw-0  | rw-0  |

**Table 36-8. LCDCCTL0 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                    |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | LCDDIVx  | RW   | 0h    | LCD frequency divider. Together with LCDPREx the LCD frequency $f_{LCD}$ is calculated as $f_{LCD} = f_{ACLK/VLO} / ((LCDDIVx + 1) \times 2^{LCDPREx})$ .<br>00000b = Divide by 1<br>00001b = Divide by 2<br>⋮<br>11110b = Divide by 31<br>11111b = Divide by 32                                                                                                                               |
| 10-8  | LCDPREx  | RW   | 0h    | LCD frequency pre-scaler. Together with LCDDIVx the LCD frequency $f_{LCD}$ is calculated as $f_{LCD} = f_{ACLK/VLO} / ((LCDDIVx + 1) \times 2^{LCDPREx})$ .<br>000b = Divide by 1<br>001b = Divide by 2<br>010b = Divide by 4<br>011b = Divide by 8<br>100b = Divide by 16<br>101b = Divide by 32<br>110b = Reserved (defaults to divide by 32)<br>111b = Reserved (defaults to divide by 32) |
| 7     | LCDSEL   | RW   | 0h    | Clock source select for LCD and blinking frequency<br>0b = ACLK (30 kHz to 40 kHz)<br>1b = VLOCLK                                                                                                                                                                                                                                                                                              |
| 6     | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                       |
| 5-3   | LCDMXx   | RW   | 0h    | LCD mux rate. These bits select the LCD mode.<br>000b = Static<br>001b = 2-mux<br>010b = 3-mux<br>011b = 4-mux<br>100b = 5-mux<br>101b = 6-mux<br>110b = 7-mux<br>111b = 8-mux                                                                                                                                                                                                                 |
| 2     | LCDSON   | RW   | 0h    | LCD segments on. This bit supports flashing LCD applications by turning off all segment lines, while leaving the LCD timing generator and R33 enabled.<br>0b = All LCD segments are off<br>1b = All LCD segments are enabled and on or off according to their corresponding memory location                                                                                                    |
| 1     | LCDLP    | RW   | 0h    | LCD low-power waveform<br>0b = Standard LCD waveforms on segment and common lines selected<br>1b = Low-power LCD waveforms on segment and common lines selected                                                                                                                                                                                                                                |

**Table 36-8. LCDCCTL0 Register Description (continued)**

| Bit | Field | Type | Reset | Description                                                                                         |
|-----|-------|------|-------|-----------------------------------------------------------------------------------------------------|
| 0   | LCDON | RW   | 0h    | LCD on. This bit turns the LCD_C module on or off.<br>0b = LCD_C module off<br>1b = LCD_C module on |

### 36.3.2 LCDCCTL1 Register

LCD\_C Control Register 1

**Figure 36-13. LCDCCTL1 Register**

| 15 | 14 | 13       | 12 | 11          | 10         | 9           | 8        |
|----|----|----------|----|-------------|------------|-------------|----------|
|    |    | Reserved |    | LCDNOCAPIE  | LDBLKONIE  | LDBLKOFFIE  | LDFRMIE  |
| r0 | r0 | r0       | r0 | rw-0        | rw-0       | rw-0        | rw-0     |
| 7  | 6  | 5        | 4  | 3           | 2          | 1           | 0        |
|    |    | Reserved |    | LCDNOCAPIFG | LDBLKONIFG | LDBLKOFFIFG | LDFRMIFG |
| r0 | r0 | r0       | r0 | rw-0        | rw-0       | rw-0        | rw-0     |

**Table 36-9. LCDCCTL1 Register Description**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                    |
|-------|-------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | Reserved    | R    | 0h    | Reserved                                                                                                                                                                       |
| 11    | LCDNOCAPIE  | RW   | 0h    | No capacitance connected interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                 |
| 10    | LDBLKONIE   | RW   | 0h    | LCD blinking interrupt enable, segments switched on<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                       |
| 9     | LDBLKOFFIE  | RW   | 0h    | LCD blinking interrupt enable, segments switched off<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                      |
| 8     | LDFRMIE     | RW   | 0h    | LCD frame interrupt enable<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                |
| 7-4   | Reserved    | R    | 0h    | Reserved                                                                                                                                                                       |
| 3     | LCDNOCAPIFG | RW   | 0h    | No capacitance connected interrupt flag. Set when charge pump is enabled but no capacitance is connected to LCDCAP pin.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 2     | LDBLKONIFG  | RW   | 0h    | LCD blinking interrupt flag, segments switched on. Automatically cleared when data is written into a memory register.<br>0b = No interrupt pending<br>1b = Interrupt pending   |
| 1     | LDBLKOFFIFG | RW   | 0h    | LCD blinking interrupt flag, segments switched off. Automatically cleared when data is written into a memory register.<br>0b = No interrupt pending<br>1b = Interrupt pending  |
| 0     | LDFRMIFG    | RW   | 0h    | LCD frame interrupt flag. Automatically cleared when data is written into a memory register.<br>0b = No interrupt pending<br>1b = Interrupt pending                            |

### 36.3.3 LCDCBLKCTL Register

LCD\_C Blink Control Register

NOTE: Settings for LCDBLKDIVx and LCDBLKPReX should only be changed while LCDBLKMODx = 00.

**Figure 36-14. LCDCBLKCTL Register**

| 15         | 14   | 13   | 12         | 11   | 10   | 9          | 8    |
|------------|------|------|------------|------|------|------------|------|
| Reserved   |      |      |            |      |      |            |      |
| r0         | r0   | r0   | r0         | r0   | r0   | r0         | r0   |
| 7          | 6    | 5    | 4          | 3    | 2    | 1          | 0    |
| LCDBLKDIVx |      |      | LCDBLKPReX |      |      | LCDBLKMODx |      |
| rw-0       | rw-0 | rw-0 | rw-0       | rw-0 | rw-0 | rw-0       | rw-0 |

**Table 36-10. LCDCBLKCTL Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-8 | Reserved   | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 7-5  | LCDBLKDIVx | RW   | 0h    | <p>Clock divider for blinking frequency. Together with LCDBLKPReX, the blinking frequency <math>f_{BLINK}</math> is calculated as <math>f_{BLINK} = f_{ACLK/VLO} / ((LCDBLKDIVx + 1) \times 2^{9+LCDBLKPReX})</math>.</p> <p>NOTE: Should only be changed while LCDBLKMODx = 00.</p> <p>000b = Divide by 1<br/>     001b = Divide by 2<br/>     010b = Divide by 3<br/>     011b = Divide by 4<br/>     100b = Divide by 5<br/>     101b = Divide by 6<br/>     110b = Divide by 7<br/>     111b = Divide by 8</p>                              |
| 4-2  | LCDBLKPReX | RW   | 0h    | <p>Clock pre-scaler for blinking frequency. Together with LCDBLKDIVx, the blinking frequency <math>f_{BLINK}</math> is calculated as <math>f_{BLINK} = f_{ACLK/VLO} / ((LCDBLKDIVx + 1) \times 2^{9+LCDBLKPReX})</math>.</p> <p>NOTE: Should only be changed while LCDBLKMODx = 00.</p> <p>000b = Divide by 512<br/>     001b = Divide by 1024<br/>     010b = Divide by 2048<br/>     011b = Divide by 4096<br/>     100b = Divide by 8162<br/>     101b = Divide by 16384<br/>     110b = Divide by 32768<br/>     111b = Divide by 65536</p> |
| 1-0  | LCDBLKMODx | RW   | 0h    | <p>Blinking mode</p> <p>00b = Blinking disabled<br/>     01b = Blinking of individual segments as enabled in blinking memory register LCDBMx. In mux mode &gt;5 blinking is disabled.<br/>     10b = Blinking of all segments<br/>     11b = Switching between display contents as stored in LCDMx and LCDBMx memory registers. In mux mode &gt;5 blinking is disabled.</p>                                                                                                                                                                     |

### 36.3.4 LCDMEMCTL Register

LCD\_C Memory Control Register

**Figure 36-15. LCDMEMCTL Register**

|          |    |    |    |    |                      |         |         |
|----------|----|----|----|----|----------------------|---------|---------|
| 15       | 14 | 13 | 12 | 11 | 10                   | 9       | 8       |
| Reserved |    |    |    |    |                      |         |         |
| r0       | r0 | r0 | r0 | r0 | r0                   | r0      | r0      |
| 7        | 6  | 5  | 4  | 3  | 2                    | 1       | 0       |
| Reserved |    |    |    |    | LCDCLRB <sub>M</sub> | LCDCLRM | LCDDISP |
| r0       | r0 | r0 | r0 | r0 | rw-0                 | rw-0    | rw-0    |

**Table 36-11. LCDMEMCTL Register Description**

| Bit  | Field                | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------|----------------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-3 | Reserved             | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 2    | LCDCLRB <sub>M</sub> | RW   | 0h    | <p>Clear LCD blinking memory<br/>           Clears all blinking memory registers LCDBM<sub>x</sub>. The bit is automatically reset when the blinking memory is cleared.<br/>           Setting this bit has in 5-mux mode and above has no effect. It's immediately reset again.<br/>           0b = Contents of blinking memory registers LCDBM<sub>x</sub> remain unchanged<br/>           1b = Clear content of all blinking memory registers LCDBM<sub>x</sub></p>                                                                                                                                     |
| 1    | LCDCLRM              | RW   | 0h    | <p>Clear LCD memory<br/>           Clears all LCD memory registers LCDM<sub>x</sub>. The bit is automatically reset when the LCD memory is cleared.<br/>           0b = Contents of LCD memory registers LCDM<sub>x</sub> remain unchanged<br/>           1b = Clear content of all LCD memory registers LCDM<sub>x</sub></p>                                                                                                                                                                                                                                                                              |
| 0    | LCDDISP              | RW   | 0h    | <p>Select LCD memory registers for display<br/>           The bit is cleared in LCDBLKMOD<sub>x</sub> = 01 and LCDBLKMOD<sub>x</sub> = 10 or if a mux mode <math>\geq 5</math> is selected and cannot be changed by software.<br/>           When LCDBLKMOD<sub>x</sub> = 11, this bit reflects the currently displayed memory but cannot be changed by software. When returning to LCDBLKMOD<sub>x</sub> = 00 the bit is cleared.<br/>           0b = Display content of LCD memory registers LCDM<sub>x</sub><br/>           1b = Display content of LCD blinking memory registers LCDBM<sub>x</sub></p> |

### 36.3.5 LCDCVCTL Register

LCD\_C Voltage Control Register

NOTE: Settings for LCDREXT, R03EXT, LCDEXTBIAS, VLCDEXT, VLCDREFx, and LCD2B should be changed only while LCDON = 0.

**Figure 36-16. LCDCVCTL Register**

| 15       | 14     | 13         | 12      | 11      | 10       | 9        | 8    |
|----------|--------|------------|---------|---------|----------|----------|------|
| Reserved |        | VLCDx      |         |         |          | Reserved |      |
| r0       | rw-0   | rw-0       | rw-0    | rw-0    | rw-0     | rw-0     | r0   |
| 7        | 6      | 5          | 4       | 3       | 2        | 1        | 0    |
| LCDREXT  | R03EXT | LCDEXTBIAS | VLCDEXT | LCDCPEN | VLCDREFx | LCD2B    |      |
| rw-0     | rw-0   | rw-0       | rw-0    | rw-0    | rw-0     | rw-0     | rw-0 |

**Table 36-12. LCDCVCTL Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------|------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | Reserved   | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 12-9  | VLCDx      | RW   | 0h    | Charge pump voltage select. LCDCPEN must be 1 for the charge pump to be enabled. VCC is used for $V_{LCD}$ when VLCDx = 0000 and VLCDREFx = 00 and VLCDEXT = 0.<br>0000b = Charge pump disabled<br>0001b =<br>If VLCDREFx = 00 or 10: $V_{LCD} = 2.60 \text{ V}$ ;<br>If VLCDREFx = 01 or 11: $V_{LCD} = 2.17 \times V_{REF}$<br>0010b to 1110b =<br>If VLCDREFx = 00 or 10: $V_{LCD} = 2.60 \text{ V} + (\text{VLCDx} - 1) \times 0.06 \text{ V}$ ;<br>If VLCDREFx = 01 or 11: $V_{LCD} = 2.17 \times V_{REF} + (\text{VLCDx} - 1) \times 0.05 \times V_{REF}$<br>1111b =<br>If VLCDREFx = 00 or 10: $V_{LCD} = 2.60 \text{ V} + (15 - 1) \times 0.06 \text{ V} = 3.44 \text{ V}$ ;<br>If VLCDREFx = 01 or 11: $V_{LCD} = 2.17 \times V_{REF} + (15 - 1) \times 0.05 \times V_{REF} = 2.87 \times V_{REF}$ |
| 8     | Reserved   | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 7     | LCDREXT    | RW   | 0h    | V2 to V4 voltage on external Rx3 pins. This bit selects the external connections for voltages V2 to V4 with internal bias generation (LCDEXTBIAS = 0). The bit is don't care if external biasing is selected (LCDEXTBIAS = 1).<br>NOTE: Should be changed only while LCDON = 0.<br>0b = Internally generated V2 to V4 are not switched to pins (LCDEXTBIAS = 0)<br>1b = Internally generated V2 to V4 are switched to pins (LCDEXTBIAS = 0)                                                                                                                                                                                                                                                                                                                                                                 |
| 6     | R03EXT     | RW   | 0h    | V5 voltage select. This bit selects the external connection for the lowest LCD voltage. R03EXT is ignored if there is no R03 pin available.<br>NOTE: Should be changed only while LCDON = 0.<br>0b = V5 is VSS<br>1b = V5 is sourced from the R03 pin                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 5     | LCDEXTBIAS | RW   | 0h    | V2 to V4 voltage select. This bit selects the generation for voltages V2 to V4.<br>NOTE: Should be changed only while LCDON = 0.<br>0b = V2 to V4 are generated internally<br>1b = V2 to V4 are sourced externally and the internal bias generator is switched off                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 4     | VLCDEXT    | RW   | 0h    | $V_{LCD}$ source select<br>NOTE: Should be changed only while LCDON = 0.<br>0b = $V_{LCD}$ is generated internally<br>1b = $V_{LCD}$ is sourced externally                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

**Table 36-12. LCDCVCTL Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | LCDCPEN  | RW   | 0h    | Charge pump enable<br>0b = Charge pump disabled<br>1b = Charge pump enabled when $V_{LCD}$ is generated internally ( $VLCDEXT = 0$ ) and $VLCDx > 0$ or $VLCDREFx > 0$                                                                                                                                                                                                                                                         |
| 2-1 | VLCDREFx | RW   | 0h    | Charge pump reference select. If $LCDEXTBIAS = 1$ or $LCDREXT = 1$ , settings 01, 10, and 11 are not supported; the internal reference voltage is used instead.<br>NOTE: Should be changed only while $LCDON = 0$ .<br>00b = Internal reference voltage<br>01b = External reference voltage<br>10b = Internal reference voltage switched to external pin LCDREF/R13<br>11b = Reserved (defaults to external reference voltage) |
| 0   | LCD2B    | RW   | 0h    | Bias select. LCD2B is ignored in static mode or mux modes $\geq 5$ .<br>NOTE: Should be changed only while $LCDON = 0$ .<br>0b = 1/3 bias<br>1b = 1/2 bias                                                                                                                                                                                                                                                                     |

### 36.3.6 LCDCPCTL0 Register

LCD\_C Port Control Register 0

NOTE: Settings for LCDSx should be changed only while LCDON = 0.

**Figure 36-17. LCDCPCTL0 Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9     | 8     |
|--------|--------|--------|--------|--------|--------|-------|-------|
| LCDS15 | LCDS14 | LCDS13 | LCDS12 | LCDS11 | LCDS10 | LCDS9 | LCDS8 |
| rw-0   | rw-0   | rw-0   | rw-0   | rw-0   | rw-0   | rw-0  | rw-0  |
| 7      | 6      | 5      | 4      | 3      | 2      | 1     | 0     |
| LCDS7  | LCDS6  | LCDS5  | LCDS4  | LCDS3  | LCDS2  | LCDS1 | LCDS0 |
| rw-0   | rw-0   | rw-0   | rw-0   | rw-0   | rw-0   | rw-0  | rw-0  |

**Table 36-13. LCDCPCTL0 Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                  |
|------|-------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | LCDSx | RW   | 0h    | <p>LCD segment line x enable. This bit affects only pins with multiplexed functions. Dedicated LCD pins are always LCD function.</p> <p>NOTE: Settings for LCDSx should be changed only while LCDON = 0.</p> <p>0b = Multiplexed pins are port functions<br/>1b = Pins are LCD functions</p> |

### 36.3.7 LCDCPCTL1 Register

LCD\_C Port Control Register 1

NOTE: Settings for LCDSx should be changed only while LCDON = 0.

**Figure 36-18. LCDCPCTL1 Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|--------|--------|--------|--------|--------|--------|--------|--------|
| LCDS31 | LCDS30 | LCDS29 | LCDS28 | LCDS27 | LCDS26 | LCDS25 | LCDS24 |
| rw-0   |
| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
| LCDS23 | LCDS22 | LCDS21 | LCDS20 | LCDS19 | LCDS18 | LCDS17 | LCDS16 |
| rw-0   |

**Table 36-14. LCDCPCTL1 Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------|-------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | LCDSx | RW   | 0h    | <p>LCD segment line x enable.</p> <p>On devices supporting a maximum of 192 segments LCDS31 is reserved, if COM7 to COM1 are shared with segments. If COM7 to COM1 are not shared with segments LCDS24 to LCDS31 are reserved.</p> <p>This bit affects only pins with multiplexed functions. Dedicated LCD pins are always LCD function.</p> <p>NOTE: Settings for LCDSx should be changed only while LCDON = 0.</p> <p>0b = Multiplexed pins are port functions<br/>1b = Pins are LCD functions</p> |

### 36.3.8 LCDCPCTL2 Register

LCD\_C Port Control Register 2 ( $\geq 256$  Segments)

NOTE: Settings for LCDSx should be changed only while LCDON = 0.

**Figure 36-19. LCDCPCTL2 Register**

| 15     | 14     | 13     | 12     | 11     | 10     | 9      | 8      |
|--------|--------|--------|--------|--------|--------|--------|--------|
| LCDS47 | LCDS46 | LCDS45 | LCDS44 | LCDS43 | LCDS42 | LCDS41 | LCDS40 |
| rw-0   |
| 7      | 6      | 5      | 4      | 3      | 2      | 1      | 0      |
| LCDS39 | LCDS38 | LCDS37 | LCDS36 | LCDS35 | LCDS34 | LCDS33 | LCDS32 |
| rw-0   |

**Table 36-15. LCDCPCTL2 Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------|-------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | LCDSx | RW   | 0h    | <p>LCD segment line x enable.</p> <p>On devices supporting a maximum of 256 segments LCDS39 to LCDS47 are reserved, if COM7 to COM1 are shared with segments. If COM7 to COM1 are not shared with segments the complete register LCDCPCTL2 is not available.</p> <p>On devices supporting a maximum of 320 segments, LCDS47 is reserved if COM7 to COM1 are shared with segments. If COM7 to COM1 are not shared with segments, LCDS40 to LCDS47 are reserved.</p> <p>This bit affects only pins with multiplexed functions. Dedicated LCD pins are always LCD function.</p> <p>NOTE: Settings for LCDSx should be changed only while LCDON = 0.</p> <p>0b = Multiplexed pins are port functions<br/>1b = Pins are LCD functions</p> |

### 36.3.9 LCDCPCTL3 Register

LCD\_C Port Control Register 2 (384 Segments, COMs Shared With Segments)

NOTE: Settings for LCDSx should be changed only while LCDON = 0.

**Figure 36-20. LCDCPCTL3 Register**

| 15       | 14     | 13     | 12     | 11     | 10     | 9      | 8    |
|----------|--------|--------|--------|--------|--------|--------|------|
| Reserved |        |        |        |        |        |        |      |
| r0       | r0     | r0     | r0     | r0     | r0     | r0     | r0   |
| 7        | 6      | 5      | 4      | 3      | 2      | 1      | 0    |
| Reserved | LCDS53 | LCDS52 | LCDS51 | LCDS50 | LCDS49 | LCDS48 |      |
| r0       | r0     | rw-0   | rw-0   | rw-0   | rw-0   | rw-0   | rw-0 |

**Table 36-16. LCDCPCTL3 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                         |
|------|----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-6 | Reserved | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                            |
| 5-0  | LCDSx    | RW   | 0h    | <p>LCD segment line x enable.</p> <p>This bit affects only pins with multiplexed functions. Dedicated LCD pins are always LCD function.</p> <p>NOTE: Settings for LCDSx should be changed only while LCDON = 0.</p> <p>0b = Multiplexed pins are port functions<br/>1b = Pins are LCD functions</p> |

### 36.3.10 LCDCCPCTL Register

LCD\_C Charge Pump Control Register

**Figure 36-21. LCDCCPCTL Register**

| 15               | 14       | 13   | 12   | 11   | 10   | 9    | 8    |
|------------------|----------|------|------|------|------|------|------|
| LCDCPCLK<br>SYNC | Reserved |      |      |      |      |      |      |
| rw-0             | r0       | r0   | r0   | r0   | r0   | r0   | r0   |
| 7                | 6        | 5    | 4    | 3    | 2    | 1    | 0    |
| LCDCPDISx        |          |      |      |      |      |      |      |
| rw-0             | rw-0     | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 36-17. LCDCCPCTL Register Description**

| Bit  | Field        | Type | Reset | Description                                                                                                                                                                                                                                                                                                                     |
|------|--------------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | LCDCPCLKSYNC | RW   | 0h    | LCD charge pump clock synchronization (device specific).<br>The charge pump clock is synchronized to a device specific clock (device-specific) when the respective clock source is enabled and does not indicate a fault with its fault signal - if available.<br>0b = Synchronization disabled<br>1b = Synchronization enabled |
| 14-8 | Reserved     | R    | 0h    | Reserved                                                                                                                                                                                                                                                                                                                        |
| 7-0  | LCDCPDISx    | RW   | 0h    | LCD charge pump disable (number of implemented bits and connected function is device-specific)<br>0b = Connected function cannot disable charge pump<br>1b = Connected function can disable charge pump                                                                                                                         |

### 36.3.11 LCDCIV Register

LCD\_C Interrupt Vector Register

**Figure 36-22. LCDCIV Register**

| 15      | 14 | 13 | 12 | 11 | 10 | 9  | 8  |
|---------|----|----|----|----|----|----|----|
| LCDCIVx |    |    |    |    |    |    |    |
| r0      | r0 | r0 | r0 | r0 | r0 | r0 | r0 |
| 7       | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
| LCDCIVx |    |    |    |    |    |    |    |
| r0      | r0 | r0 | r0 | r0 | r0 | r0 | r0 |

**Table 36-18. LCDCIV Register Description**

| Bit  | Field   | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                      |
|------|---------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | LCDCIVx | R    | 0h    | LCD_C interrupt vector value<br>00h = No interrupt pending<br>02h = Interrupt Source: No capacitor connected; Interrupt Flag: LCDNOCAPIFG; Interrupt Priority: Highest<br>04h = Interrupt Source: Blink, segments off; Interrupt Flag: LCDBLKOFFIFG<br>06h = Interrupt Source: Blink, segments on; Interrupt Flag: LCDBLKONIFG<br>08h = Interrupt Source: Frame interrupt; Interrupt Flag: LCDFRMIFG; Interrupt Priority: Lowest |

## ***Extended Scan Interface (ESI)***

The Extended Scan Interface (ESI) peripheral automatically scans sensors and measures linear or rotational motion. This document describes the Extended Scan interface.

| Topic                       | Page |
|-----------------------------|------|
| 37.1 ESI Introduction ..... | 963  |
| 37.2 ESI Operation.....     | 964  |
| 37.3 ESI Registers .....    | 990  |

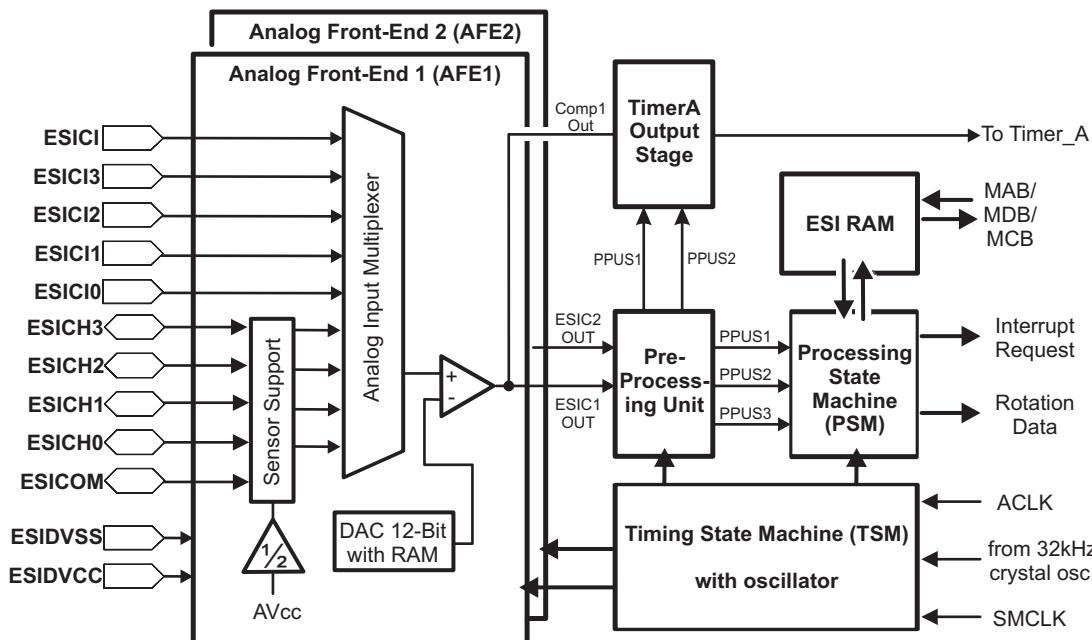
### 37.1 ESI Introduction

The ESI module is used to automatically measure linear or rotational motion with the lowest possible power consumption. The ESI consists of following blocks: the analog front end (AFE1 and AFE2), the preprocessing unit (PPU), the processing state machine (PSM) with its associated RAM, the timing state machine (TSM), and the Timer\_A Output Stage. The analog front end stimulates the sensors, senses the signal levels, and converts them into their digital representation. The digital representations of a measurement sequence are stored in the preprocessing unit. The stored digital signals are passed into the processing state machine. The processing state machine is used to analyze and count rotation or motion. The timing state machine controls the analog front end, the preprocessing unit, and the processing state machine. The Timer\_A Output Stage generates signals that are fed into Timer\_A capture inputs; this allows for time measurements (for example, LC-sensor envelope test).

The ESI features include:

- Support for different types of sensors
  - LC sensors
  - Resistive sensors such as Hall-effect or giant magnetoresistive (GMR) sensors
  - Optical sensors
  - And more
- Measurement of sensor signal envelope
- Measurement of sensor signal oscillation amplitude
- Direct analog input for analog-to-digital conversion
- Direct digital input for digital sensors such as optical decoders
- Support for quadrature decoding

[Figure 37-1](#) shows the ESI module block diagram.



**Figure 37-1. ESI Block Diagram**

## 37.2 ESI Operation

The ESI is configured with user software. The setup and operation of the ESI is described in the following sections.

### 37.2.1 ESI Analog Front End

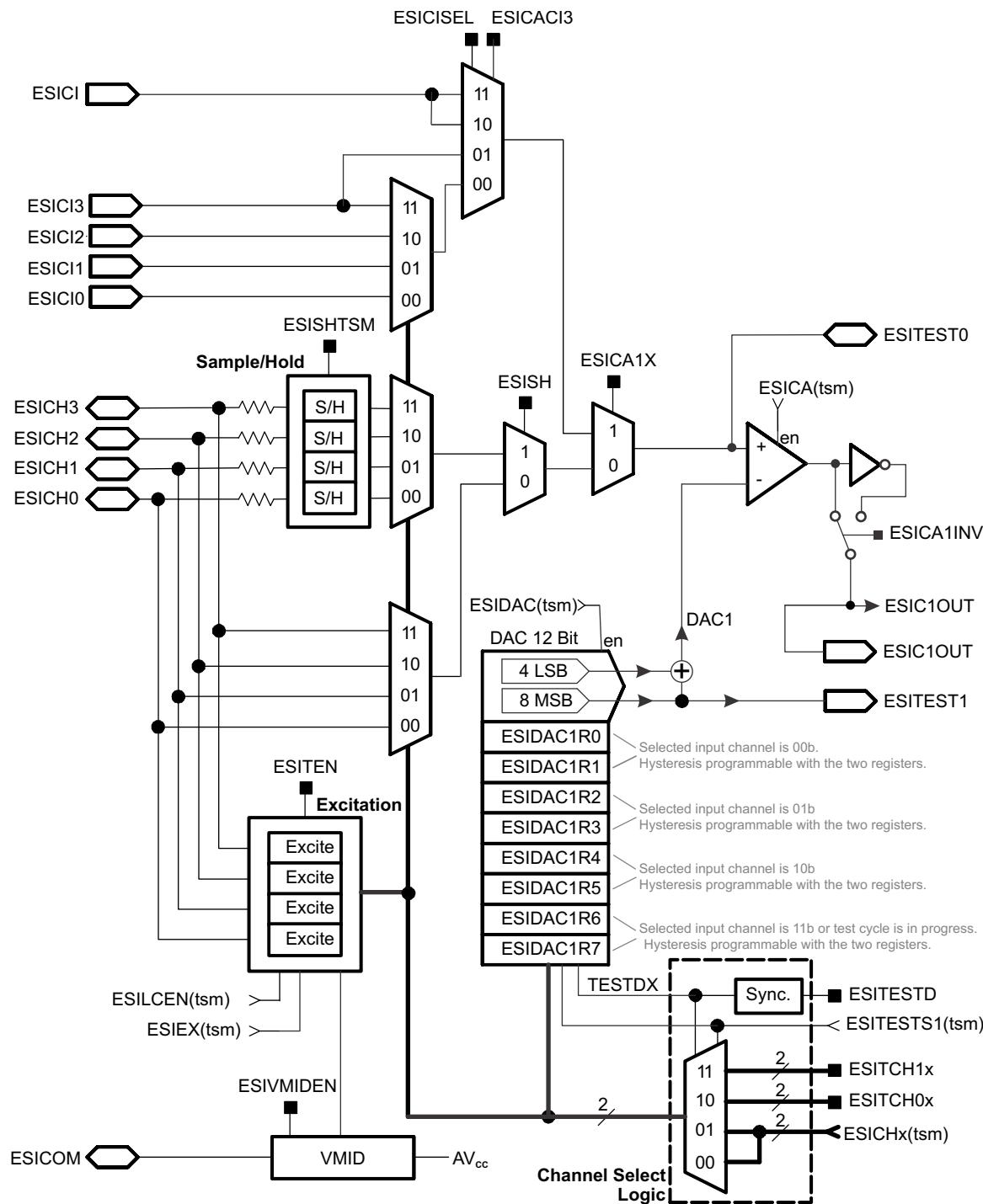
There are two analog front ends available in the ESI. The analog front end AFE1 provides sensor excitation and sample-and-hold circuit for measurements. The analog front end is automatically controlled by the timing state machine (TSM) according to the information in the timing state machine table. [Figure 37-2](#) shows the analog front end block diagram.

---

**NOTE: Timing State Machine Signals**

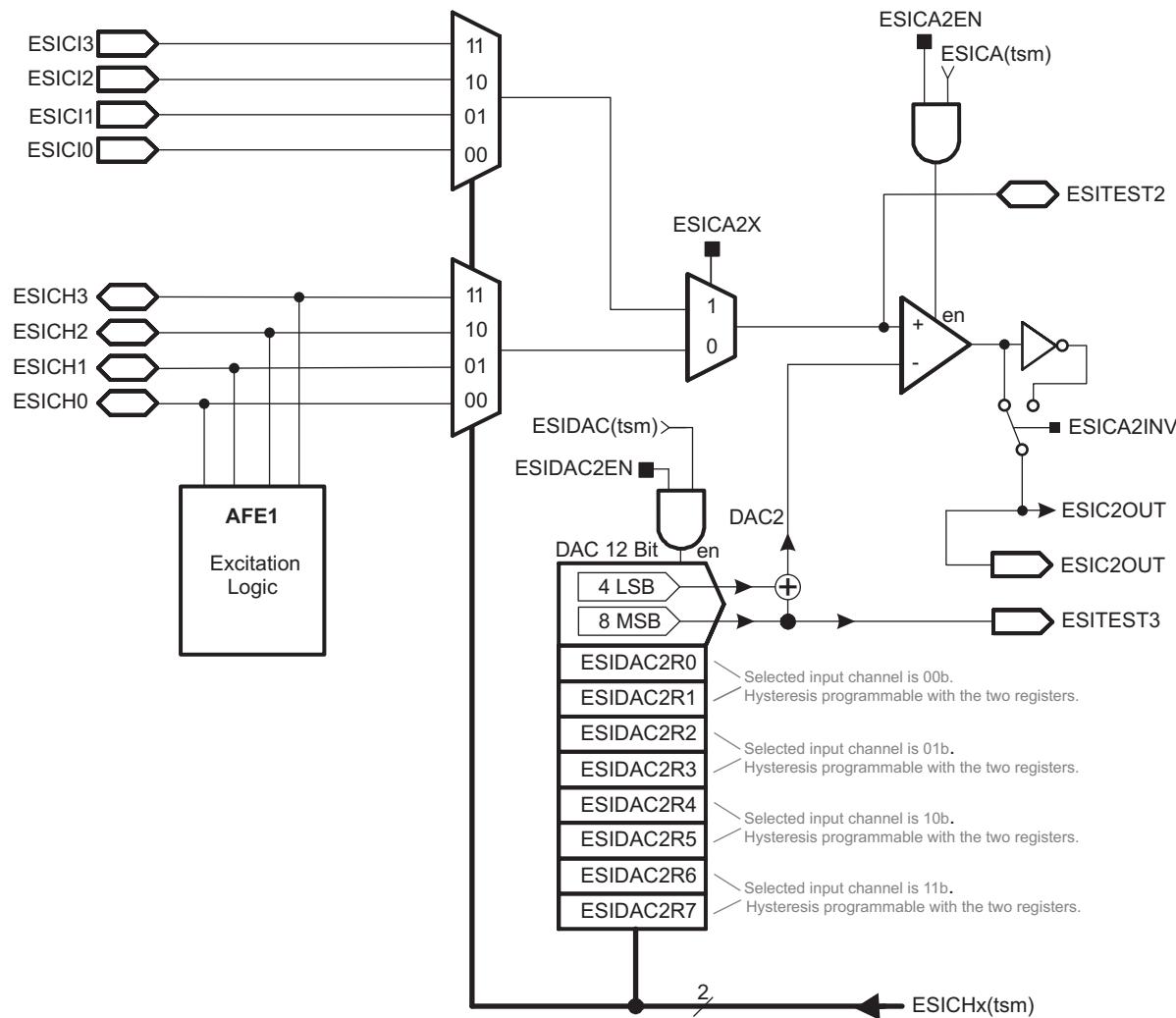
Throughout this chapter, signals from the ESITSM $x$  registers ( $x = 0$  to 31) are noted in the signal name with (tsm). For example, the signal ESIEX(tsm) comes from the actual active ESITSM $x$  register.

---



**Figure 37-2. ESI Analog Front End AFE1 Block Diagram**

The AFE2 is disabled after reset. AFE2 can be enabled by setting the ESICA2EN and ESIDAC2EN bits. If the AFE2 is disabled (ESICA2EN = 0 and ESIDAC2EN = 0), the AFE2 comparator output is always low (0 level).



**Figure 37-3. ESI Analog Front End AFE2 Block Diagram**

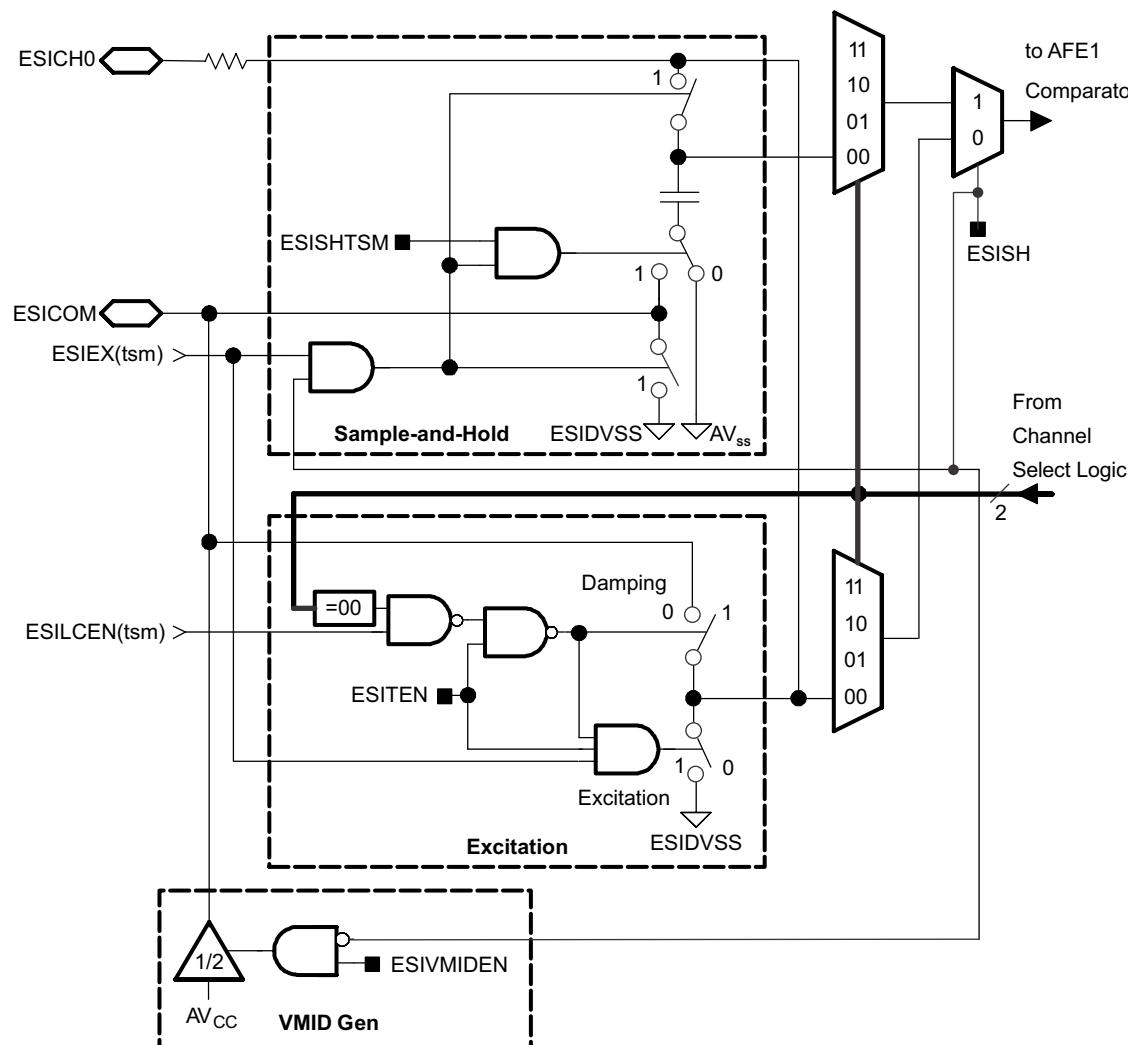
### 37.2.1.1 Excitation

The excitation circuitry is used to excite the LC sensors or to power the resistor dividers. The excitation circuitry is shown in [Figure 37-4](#) for one LC sensor connected. When the ESITEN bit is set and the ESISH bit is cleared, the excitation circuitry is enabled and the sample-and-hold circuitry is disabled.

When the ESIEX(tsm) signal from the timing state machine is high, the ESICHx input of the selected channel is connected to ground (ESIDVSS pin) and the ESICOM input is connected to the mid-voltage generator to excite the sensor. The ESILCEN(tsm) signal must be high for excitation. While one channel is excited and measured, all other channels are automatically disabled. Only the selected channel is excited and measured.

The excitation period should be long enough to overload the LC sensor slightly. After excitation the ESICHx input is released from ground when ESIEX(tsm) = 0, and the LC sensor can oscillate freely. The oscillations swing above the positive supply but are clipped by the protection diode to the positive supply voltage plus one diode drop. This gives consistent maximum oscillation amplitude.

At the end of the measurement, the sensor should be damped by setting ESILCEN(tsm) = 0 to remove any residual energy before the next measurement.



**Figure 37-4. Excitation and Sample-And-Hold Circuitry**

### 37.2.1.2 Mid-Voltage Generator

The mid-voltage generator is on when ESIVMIDEN = 1 and allows the LC sensors to oscillate freely. The mid-voltage generator requires a maximum of 6 ms to settle and requires ACLK to be active and operating at 32768 Hz.

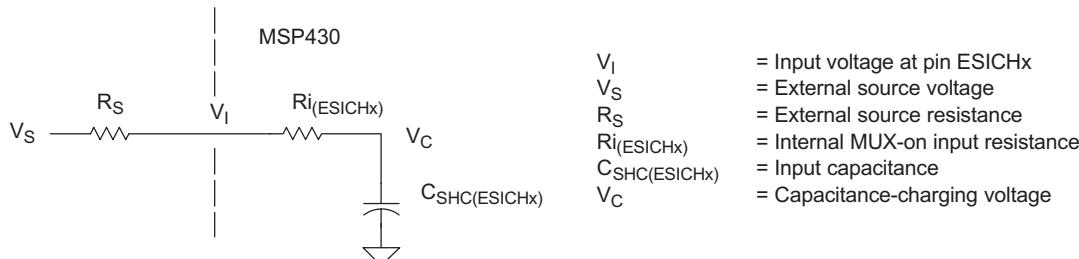
### 37.2.1.3 Sample-And-Hold

Note that the sample-and-hold circuit is only available in the analog front-end AFE1.

The sample-and-hold is used to sample the sensor voltage to be measured. [Figure 37-4](#) shows the sample-and-hold circuitry. When ESISH = 1 and ESITEN = 0, the sample-and-hold circuitry is enabled and the excitation circuitry and mid-voltage generator are disabled. The sample-and-hold is used for resistive dividers or for other analog signals that should be sampled.

Up to four resistor dividers can be connected to ESICHx and ESICOM. AVCC and ESICOM are the common positive and negative potentials for all connected resistor dividers. When ESIEX(tsm) = 1, ESICOM is connected to ESIDVSS and allows current to flow through the dividers. This charges the capacitors of each sample-and-hold circuit to the divider voltages. All resistor divider channels are sampled simultaneously. When ESIEX(tsm) = 0, the sample-and-hold capacitor is disconnected from the resistor divider, and ESICOM is disconnected from ESIDVSS. After sampling, each channel can be measured sequentially using the channel select logic, the comparator, and the DAC.

The selected ESICHx input can be modeled as an RC low-pass filter during the sampling time,  $t_{\text{sample}}$ , as shown in [Figure 37-5](#). An internal MUX-on input resistance  $R_{i(\text{ESICHx})}$  (3 k $\Omega$  maximum) in series with capacitor  $C_{\text{SHC}(\text{ESICHx})}$  (9 pF maximum) is seen by the resistor-divider. The capacitor voltage  $V_C$  must be charged to within one-half LSB of the resistor divider voltage for an accurate 12-bit conversion. See the device-specific data sheet for parameters.



**Figure 37-5. Analog Input Equivalent Circuit**

The resistance of the source  $R_S$  and  $R_{i(\text{ESICHx})}$  affect  $t_{\text{sample}}$ . [Equation 18](#) can be used to calculate the minimum sampling time  $t_{\text{sample}}$  for a 12-bit conversion:

$$t_{\text{sample}} > (R_S + R_{i(\text{ESICHx})}) \times \ln(2^{13}) \times C_{\text{SHC}(\text{ESICHx})} \quad (18)$$

Substituting the values for  $R_{i(\text{ESICHx})}$  and  $C_{\text{SHC}(\text{ESICHx})}$  given above, the equation becomes:

$$t_{\text{sample}} > (R_S + 3k) \times 9.011 \times 9 \text{ pF} \quad (19)$$

For example, if  $R_S$  is 10 k $\Omega$ ,  $t_{\text{sample}}$  must be greater than 1054 ns.

### 37.2.1.4 Direct Analog And Digital Inputs

By setting the ESICA1X or ESICA2X bit, external analog or digital signals can be connected directly to the particular comparator through the ESIClx inputs. This allows measurement capabilities for optical encoders and other sensors.

Both analog front-ends have own control bits to select either the sensor input (ESICHx) or the direct input (ESIClx). This allows to use different input settings (selection of ESIClx or ESICHx) for AFE1 and AFE2.

### 37.2.1.5 Comparator Input Selection And Output Bit Selection

The ESICA1X and ESISH bits within AFE1 select between the ESIClx channels and the ESICHx channels for the comparator input as described in [Table 37-1](#).

The AFE2's ESICA2X bit selects either ESIClx channels (ESICA2X = 1) or the ESICHx channels (ESICA2X = 0) for the analog front-end AFE2.

**Table 37-1. ESICAX and ESISH Input Selection**

| ESICA1X | ESISH | Operation                                                    |
|---------|-------|--------------------------------------------------------------|
| 0       | 0     | ESICHx and excitation circuitry is selected within AFE1      |
| 0       | 1     | ESICHx and sample-and-hold circuitry is selected within AFE1 |
| 1       | X     | ESIClx inputs are selected within AFE1                       |

Note that the test insertion feature is only available for AFE1. The TESTDX signal and ESITESTS1(tsm) signal select between the ESIOUTx output bits and the ESITCHOUTx output bits for the comparator output as described in [Table 37-2](#). TESTDX is controlled by the ESITESTD bit.

**Table 37-2. Selected Output Bits**

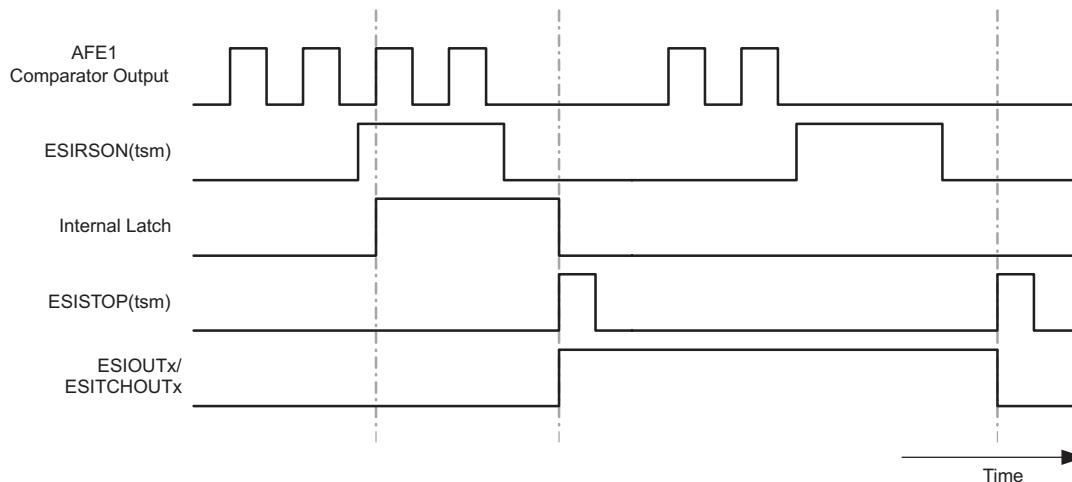
| TESTDX | ESICHx(tsm) | ESITEST1(tsm) | Selected Output Bit |
|--------|-------------|---------------|---------------------|
| 0      | 00          | X             | ESIOUT0 and ESIOUT4 |
| 0      | 01          | X             | ESIOUT1 and ESIOUT5 |
| 0      | 10          | X             | ESIOUT2 and ESIOUT6 |
| 0      | 11          | X             | ESIOUT3 and ESIOUT7 |
| 1      | X           | 0             | ESITCHOUT0          |
| 1      | X           | 1             | ESITCHOUT1          |

When TESTDX = 0, the ESICHx(tsm) signals select which ESICI<sub>x</sub> or ESICHx channel is excited and connected to the comparator. The ESICHx(tsm) signals also select the corresponding output bit for the comparator result.

When TESTDX = 1, channel selection depends on the ESITESTS1(tsm) signal. When TESTDX = 1 and ESITESTS1(tsm) = 0, input channel selection is controlled with the ESITCH0<sub>x</sub> bits and the output bit is ESITCHOUT0. When TESTDX = 1 and ESITESTS1(tsm) = 1, input channel selection is controlled with the ESITCH1<sub>x</sub> bits and the output bit is ESITCHOUT1.

When AFE1's ESICA1X = 1, the ESICSEL and ESICI3 bits select between the ESICI<sub>x</sub> channels and the ESICI input, allowing storage of the comparator output for one input signal into the four output bits ESIOUT0 to ESIOUT3. This can be used to observe the envelope function of sensors.

The output logic is enabled by the ESIRSON(tsm) signal. When a comparator output is high while ESIRSON = 1, an internal latch is set. Otherwise the latch is reset. The latch output is written into the selected output bit with the rising edge of the ESISTOP(tsm) signal as shown in [Figure 37-6](#).


**Figure 37-6. Analog Front-End Output Timing**

### 37.2.1.6 Comparator and DAC

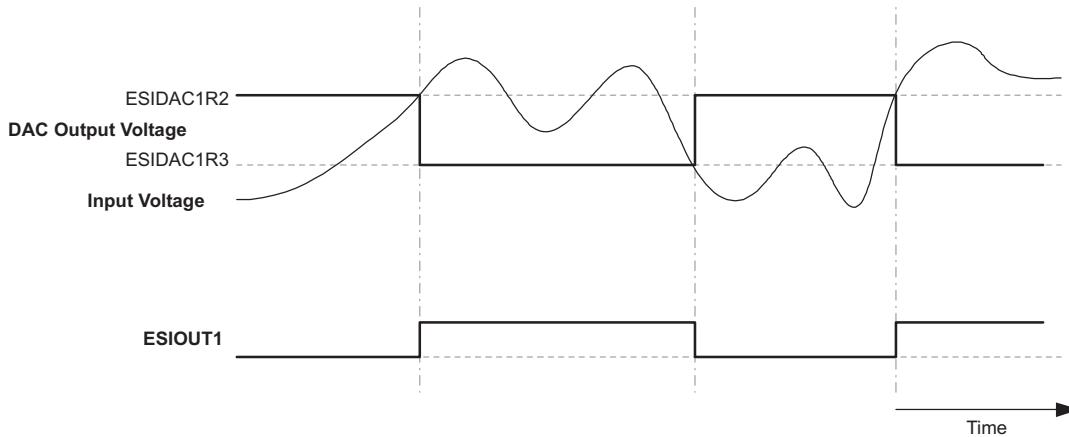
The analog input signals are converted into digital signals by the comparator and the programmable 12-bit DAC. The comparator compares the selected analog signal to a reference voltage generated by the DAC. If the voltage is above the reference, the comparator output is high. Otherwise, it is low. The comparator outputs of both analog front-ends can be individually inverted by setting ESICA1INV for AFE1 or ESICA2INV for AFE2. The comparator output is stored in the selected output bit and processed by the processing state machine to detect motion and direction.

The comparator and the DAC in both analog front-ends AFE1 and AFE2 are turned on and off by ESICA(tsm) signal and the ESIDAC(tsm) signal. In case, the AFE1's comparator or DAC are not needed they can be disabled by clearing the ESICA(tsm) and ESIDAC(tsm) control bits within ESITSM0 register. AFE2 is disabled when its comparator and DAC are disabled. This can be done by clearing the ESICA2EN and ESIDAC2EN bits. In case these bits are set the AFE2's comparator and DAC will be controlled by the ESICA(tsm) and ESIDAC(tsm) control bits.

For each input there are two DAC registers to set the reference level as listed in [Table 37-3](#). Together with the last stored output of the comparator, ESIOUTx, the two levels can be used as an analog hysteresis as shown in [Figure 37-7](#). The individual settings for the four inputs can be used to compensate for mismatches between the sensors.

**Table 37-3. Selected DAC Registers**

| Analog Front-End | Selected Output Bit, ESIOUTx | Last Value of ESIOUTx | DAC Register Used |
|------------------|------------------------------|-----------------------|-------------------|
| AFE1             | ESIOUT0                      | 0                     | ESIDAC1R0         |
|                  |                              | 1                     | ESIDAC1R1         |
|                  | ESIOUT1                      | 0                     | ESIDAC1R2         |
|                  |                              | 1                     | ESIDAC1R3         |
|                  | ESIOUT2                      | 0                     | ESIDAC1R4         |
|                  |                              | 1                     | ESIDAC1R5         |
|                  | ESIOUT3                      | 0                     | ESIDAC1R6         |
|                  |                              | 1                     | ESIDAC1R7         |
| AFE2             | ESIOUT4                      | 0                     | ESIDAC2R0         |
|                  |                              | 1                     | ESIDAC2R1         |
|                  | ESIOUT5                      | 0                     | ESIDAC2R2         |
|                  |                              | 1                     | ESIDAC2R3         |
|                  | ESIOUT6                      | 0                     | ESIDAC2R4         |
|                  |                              | 1                     | ESIDAC2R5         |
|                  | ESIOUT7                      | 0                     | ESIDAC2R6         |
|                  |                              | 1                     | ESIDAC2R7         |



**Figure 37-7. Analog Hysteresis With DAC Registers**

When TESTDX = 1, the ESIDAC1R6 and ESIDAC1R7 registers are used as the comparator reference as described in [Table 37-4](#). Note that this feature is only available in AFE1.

**Table 37-4. DAC Register Select When TESTDX=1**

| ESITESTS1(tsm) | DAC Register Used |
|----------------|-------------------|
| 0              | ESIDAC1R6         |
| 1              | ESIDAC1R7         |

### 37.2.1.7 Optional Comparator Offset Cancellation

The ESI's comparator has an offset that drifts over temperature and supply voltage. For some applications the specified offset error and offset drift may be acceptable - see device-specific data sheet. If the offset error is not acceptable, adding a comparator autozero cycle within the TSM sequence can minimize the offset error. After the inserted autozero TSM cycle, the comparator operates effectively with a zeroed offset.

Adding an ESITSMx state within the TSM sequence, which has the ESICAAZ bit selected (ESITSM.ESICLKAZSEL=1) and set, performs the comparator autozeroing. As long as the ESICAAZ bit is set the autozeroing is performed. This means, the length of the appropriate ESITSMx state defines the length of autozeroing. The following code excerpt shows how to include an autozeroing cycle within a TSM sequence. The example focus on ESICA and ESICAAZ control bits:

```
...
ESITSM5 = TSM_State5;    // TSM_State5 is a placeholder for any setting;
                           // Comparator is
disabled (ESICA=0, ESICAAZ=0)
ESITSM6 = ESICA + ESICAAZ + Length + TSM_State6;
           // comparator is switched on and at the same time the autozeroing is
           // performed. Length is defined by ESCLK and ESIREPEATx bits -
           // appropriate setting needed to meet autozeroing timing requirements;
           // see device-specific data sheet (ESICA=1, ESICAAZ=1)
ESITSM7 = ESICA + TSM_State7;
           // normal comparator operation: settle comparator
           // (ESICA=1, ESICAAZ=0)
ESITSM8 = ESICA + TSM_State8;
           // normal comparator operation: processing of comparator output signal
           // (ESICA=1, ESICAAZ=0)
...

```

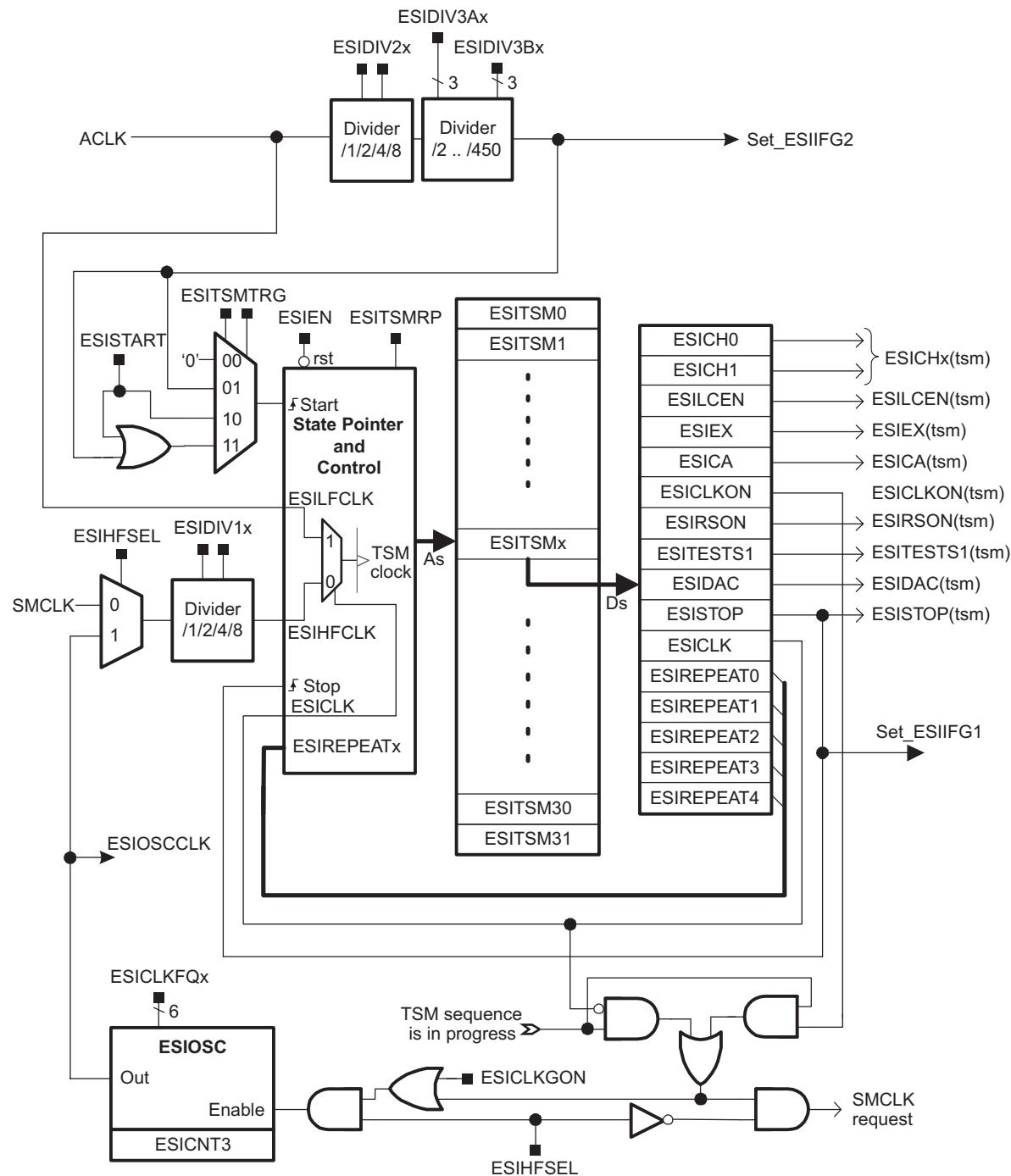
### 37.2.2 ESI Timing State Machine

The TSM is a sequential state machine that cycles through the ESITSMx registers and controls the analog front end and sensor excitation automatically with no CPU intervention. The states are defined within a 32 x 16-bit memory, ESITSM0 to ESITSM31. The ESIEN bit enables the TSM. The ESI uses ACLK as its source for the low frequency clock signal ESILFCLK. When ESIEN = 0, the ACLK input divider, the TSM start flip-flop, and the TSM outputs are reset and the internal oscillator is stopped. The TSM block diagram is shown in [Figure 37-8](#).

A TSM sequence begins at ESITSM0 and ends when the TSM encounters a ESITSMx state with a set ESITSTOP bit. When a state with a set ESITSTOP bit is reached, the state counter is reset to zero and state processing stops. State processing re-starts at ESITSM0 with a software trigger (setting the ESISTART control bit), the next start condition when ESITSMRP = 0, or immediately when ESITSMRP = 1

After generation of the ESITSTOP(tsm) pulse, the timing state machine will load and maintain the conditions defined in ESITSM0. For the case an LC sensor is used the ESILCEN(tsm) bit should be reset in ESITSM0 to ensure that all LC oscillators are shorted (damped) while no measurement sequence is in progress.

In case a TSM sequence is started with a software trigger, the ESISTART control bit is automatically cleared as soon as a TSM sequence is completed and the system is again in idle mode (ESITSM0 settings are used in idle mode).



**Figure 37-8. Timing State Machine Block Diagram**

### 37.2.2.1 TSM Operation

Starting of a TSM sequence depends on the selected trigger. Possible triggers are the control bit ESISTART, the divided ACLK and an or combination of these two triggers (ESISTART or divided ACLK).

If the divided ACLK is chosen, the TSM automatically starts and re-starts periodically based on a divided ACLK start signal selected with the ESIDIV2x bits, the ESIDIV3Ax and ESIDIV3Bx bits when ESITSMRP = 0. For example, if ESIDIV2x, ESIDIV3Ax, and ESIDIV3Bx are configured to 270 ACLK cycles, then the TSM automatically starts every 270 ACLK cycles. When ESITSMRP = 1 the TSM restarts immediately with the ESITSM0 state at the end of the previous sequence i.e. with the next ACLK cycle after encountering a state with ESISTOP = 1. The ESIIFG2 interrupt flag is set when the TSM starts.

The ESIDIV2x, ESIDIV3Ax, and ESIDIV3Bx bits may be updated anytime during operation. When updated, the current TSM sequence will continue with the old settings until the last state of the sequence completes. The new settings will take affect at the start of the next sequence.

Setting ESISTART bit is another trigger for starting a TSM sequence. The ESISTART bit is set as long as the actual TSM sequence is in progress. As soon as the TSM sequence is completed and ESITSM0 register is again active for idle state configuration the ESISTART bit is automatically cleared. In case ESISTART is the only source for a start trigger (ESITSMTRG = 01) an ACLK synchronization sequence is performed, which may take up to 2.5 ACLK cycles. For all other cases no special synchronization is needed and TSM starts with the appropriate positive ACLK edge.

---

**NOTE:** It is important to set the ESISTOP(tsm) bit at least once the control registers ESITSM2 to ESITSM31. The ESISTOP(tsm) control bit ensures that a user-defined TSM sequence is terminated and the TSM progressing is switching into idle mode awaiting the next start trigger.

---

### 37.2.2.2 TSM Idle Condition Selectable With ESITSM0

ESITSM0 register is used for two different tasks. First, by definition ESITSM0 register is always the first ESITSMx register within a TSM sequence. The second purpose of ESITSM0 is to define the settings of the analog front ends during idle time; idle time means no TSM sequence is in progress.

When ESITSM0 defines the AFE1 and AFE2 settings in idle time only some of the ESITSMx control bits are functional. These functional bits are ESICLKON, ESIRSON, ESIEX, ESILCEN, and ESICHx. Some bits do not have any effect in idle mode, like ESIDAC, ESICA, ESIREPEATx bits and ESICLK bit; the ESIREPEATx bits and ESICLK bit are only utilized when ESITSM0 is used within a TSM sequence. ESIDAC and ESICA bits should be '0' in ESITSM0 state for reduced current consumption.

Note that changing ESITSM0 register gets effective not before the next TSM sequence is started. This has to be considered especially after powering up the device and doing the first initialization of the ESI.

### 37.2.2.3 TSM Control of the AFE

The TSM controls the AFE with the ESICHx, ESILCEN, ESIEX, ESICA, ESICLKON, ESIRSON, ESITESTS1, ESIDAC, ESISTOP, and ESICLK bits. When any of these bits are set, their corresponding signal(s), ESICHx(tsm), ESILCEN(tsm), ESIEX(tsm), ESICA(tsm), ESICLKON(tsm), ESIRSON(tsm), ESITESTS1(tsm), ESIDAC(tsm), ESISTOP(tsm), and ESICLK(tsm) are high for the duration of the state. Otherwise, the corresponding signal(s) are low.

### 37.2.2.4 TSM State Duration

The duration of each state is individually configurable with the ESIREPEATx bits. The duration of each state is ESIREPEATx + 1 times the selected clock source. For example, if a state were defined with ESIREPEATx = 3 and ESICLK = 1, the duration of that state would be 4 x ACLK cycles. Because of clock synchronization, the duration of each state is affected by the clock source for the previous state, as shown in [Table 37-5](#).

**Table 37-5. TSM State Duration**

| ESICLK             |                   |                                                                                                                        |
|--------------------|-------------------|------------------------------------------------------------------------------------------------------------------------|
| For Previous State | For Current State | State Duration, T                                                                                                      |
| 0                  | 0                 | $T = (\text{ESIREPEATx} + 1) \times 1/f_{\text{ESIHFCCLK}}$                                                            |
| 0                  | 1                 | $(\text{ESIREPEATx}) \times 1/f_{\text{ACLK}} < T \leq (\text{ESIREPEATx} + 1) \times 1/f_{\text{ACLK}}$               |
| 1                  | 0                 | $(\text{ESIREPEATx} + 1) \times 1/f_{\text{ESIHFCCLK}} \leq T < (\text{ESIREPEATx} + 3) \times 1/f_{\text{ESIHFCCLK}}$ |
| 1                  | 1                 | $T = (\text{ESIREPEATx} + 1) \times 1/f_{\text{ACLK}}$                                                                 |

### 37.2.2.5 TSM State Clock Source Select

The TSM clock source is individually configurable for each state. The TSM can be clocked from ACLK or a high frequency clock selected with the ESICLK bit. When ESICLK = 1, ACLK is used for the state, and when ESICLK = 0, the high frequency clock is used. The high frequency clock can be sourced from SMCLK or the TSM internal oscillator, selected by the ESIHFSEL bit. The high-frequency clock can be divided by 1, 2, 4, or 8 with ESIDIV1x bits.

A set ESICLKON bit is used to turn on the selected high frequency clock source for the duration of the state, when it is not used for the state. If the DCO is selected as the high frequency clock source, it is automatically turned on, regardless of the low-power mode settings of the MSP430.

The TSM internal oscillator should be adjusted to the nominal frequency of 4.8 MHz. To realize this it can be tuned in nominal 3% steps from around 1 MHz to around 8MHz with the ESICLKFX. The frequency and the steps differ from unit to unit. See the device-specific data sheet for parameters.

The TSM internal oscillator frequency can be measured with ACLK. When ESIHFSEL = 1 and ESICLKGON = 1 ESICNT3 is reset, and beginning with the next rising edge of ACLK, ESICNT3 counts the clock cycles of the internal oscillator. ESICNT3 counts the internal oscillator cycles for one ACLK period. Reading ESICNT3 while it is counting will result in reading 01h.

The ACLK is automatically turned on for the following cases, regardless of the low-power mode settings of the MSP430:

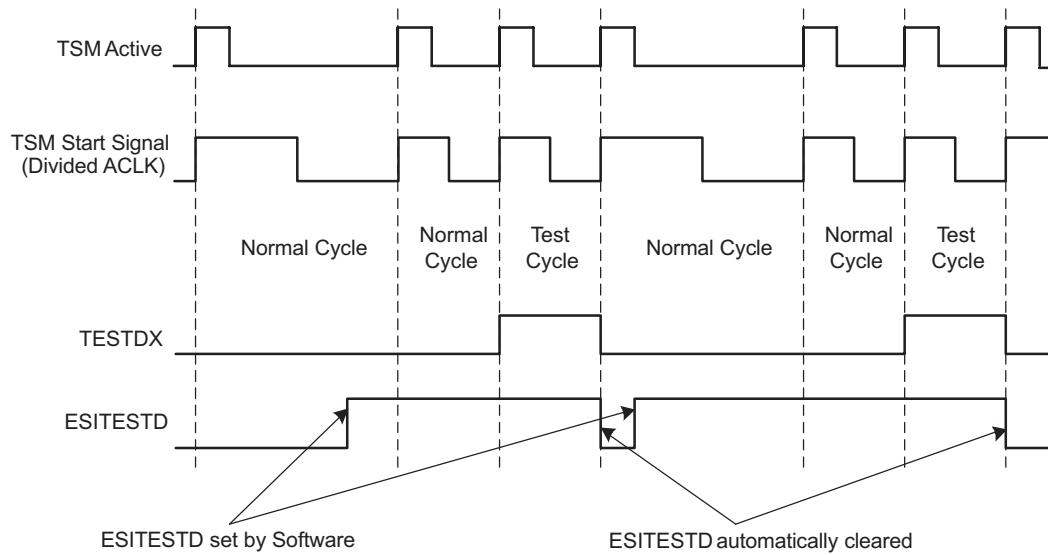
- ACLK is automatically turned on all the time when the divided ACLK signal (ESIDIV2x, ESIDIV3Ax, and ESIDIV3Bx dividers) is selected as trigger for starting a TSM sequence.
- While a TSM sequence is in progress the ACLK is automatically turned on.

### 37.2.2.6 TSM Stop Condition

A TSM sequence always starts with ESITSM0, uses some ESITSMx states to do a measurement, and ends at the subsequent ESITSMx state with a set ESISTOP bit (stop state). The duration of this last state (stop state) is always one ESIHFCLK cycle regardless of the ESICLK or ESIREPEATx settings. The ESIIFG1 interrupt flag is set at when the TSM encounters a state with a set ESISTOP bit.

### 37.2.2.7 TSM Test Cycles

For calibration purposes, to detect sensor drift, or to measure signals other than the sensor signals, a test cycle may be inserted between TSM cycles by setting the ESITESTD bit. The time between the TSM cycles is not altered by the test cycle insertion as shown in [Figure 37-9](#). At the end of the test cycle the ESITESTD bit is automatically cleared. The TESTDX signal is active during the test cycle to control input and output channel selection. TESTDX is generated after the ESITESTD bit is set and the next TSM sequence completes.


**Figure 37-9. Test Cycle Insertion**

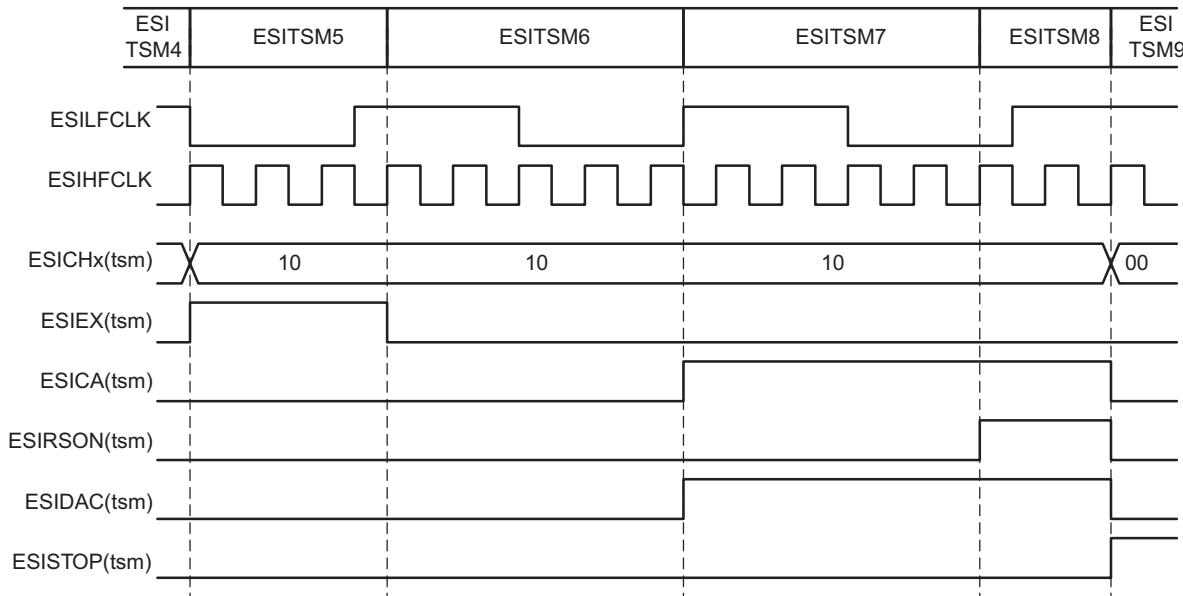
#### 37.2.2.8 TSM Example

Figure 37-10 shows an example for a TSM sequence. The TSMx register values for the example are shown in Table 37-6. ACLK and ESIHFCLK are not drawn to scale. The TSM sequence starts with ESITSM0 and ends with a set ESISTOP bit in ESITSM9. Only the ESITSM5 to ESITSM9 states are shown.

**Table 37-6. TSM Example Register Values**

| TSMx Register | TSMx Register Contents |
|---------------|------------------------|
| ESITSM5       | 0100Ah                 |
| ESITSM6       | 00402h                 |
| ESITSM7       | 01912h                 |
| ESITSM8       | 00952h                 |
| ESITSM9       | 00200h                 |

The example also shows the affects of the clock synchronization when switching between ESIHFCLK and ACLK. In state ESITSM6, ESICLK is set, whereas in the previous state and the successive state, ESICLK is cleared. The waveform shows the duration of ESITSM6 is less than one ACLK cycle and the duration of state ESITSM7 is up to one ESIHFCLK period longer than configured by the ESIREPEATx bits.



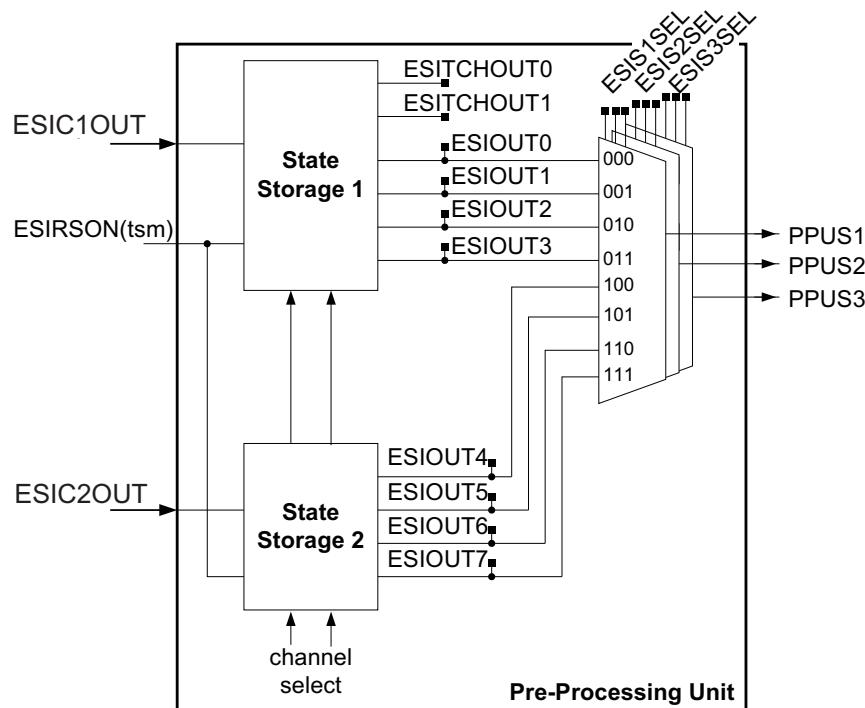
**Figure 37-10. Timing State Machine Example**

### 37.2.3 ESI Pre-Processing and State Storage

The Pre-Processing Unit (PPU) stores the measurement results of a TSM sequence. Beside this it also allows to select up to three signals that are processed by the Processing State Machine (PSM).

Up to four regular measurements and two test insertion measurements could sequentially be done within one TSM sequence. When ESIRSON(tsm) is high the comparator output signal is latched in the PPU's State Storage block. The State Storage consist of several latches. The output of these latches can be read from the ESIOUTx and ESITCHOUTx bits located in ESIPPU control register. Each input channel has its own latch. The ESICHx(tsm), ESITCH0x, or ESITCH1x bits define which of the latches is used.

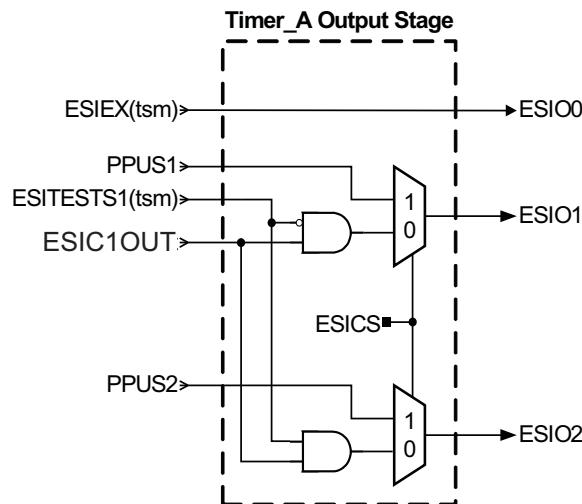
The block diagram of the Pre-Processing Unit is shown in [Figure 37-11](#).



**Figure 37-11. Pre-Processing Unit**

#### 37.2.4 TimerA Output Stage

The comparator output of the analog front end AFE1, the ESIEX(tsm) signal, and two preprocessing unit outputs PPUS1 and PPUS2 are connected to a Timer\_A's capture inputs through the ESI's Timer\_A output stage, shown in [Figure 37-12](#). There are two different modes that are selected by the ESICS bit. The Timer\_A Output Stage provides the ESIOx signals to one of the device's Timer\_A module. See the device-specific data sheet for connection of these signals.



**Figure 37-12. Timer\_A Output Stage of the Analog Front End**

When ESICS = 0, the ESIEX(tsm) signal and the comparator output can be selected as inputs to different Timer\_A capture/compare registers. This can be used to measure the time between excitation of a sensor and the last oscillation that passes through the comparator or to perform a slope A/D conversion.

When ESICS = 1, the ESIEX(tsm) signal and the output bits PPUS1 and PPUS2 from the PPU can be selected as inputs to Timer\_A. This can be used to measure the duty cycle of PPUS1 or PPUS2.

### 37.2.5 ESI Processing State Machine

The PSM is a programmable state machine used to determine rotation and direction with its state table stored within the ESI memory (ESI RAM). The processing state machine measures rotation and controls interrupt generation based on the inputs from the timing state machine and the analog front-end. The PSM block diagram is shown in Figure 37-13.

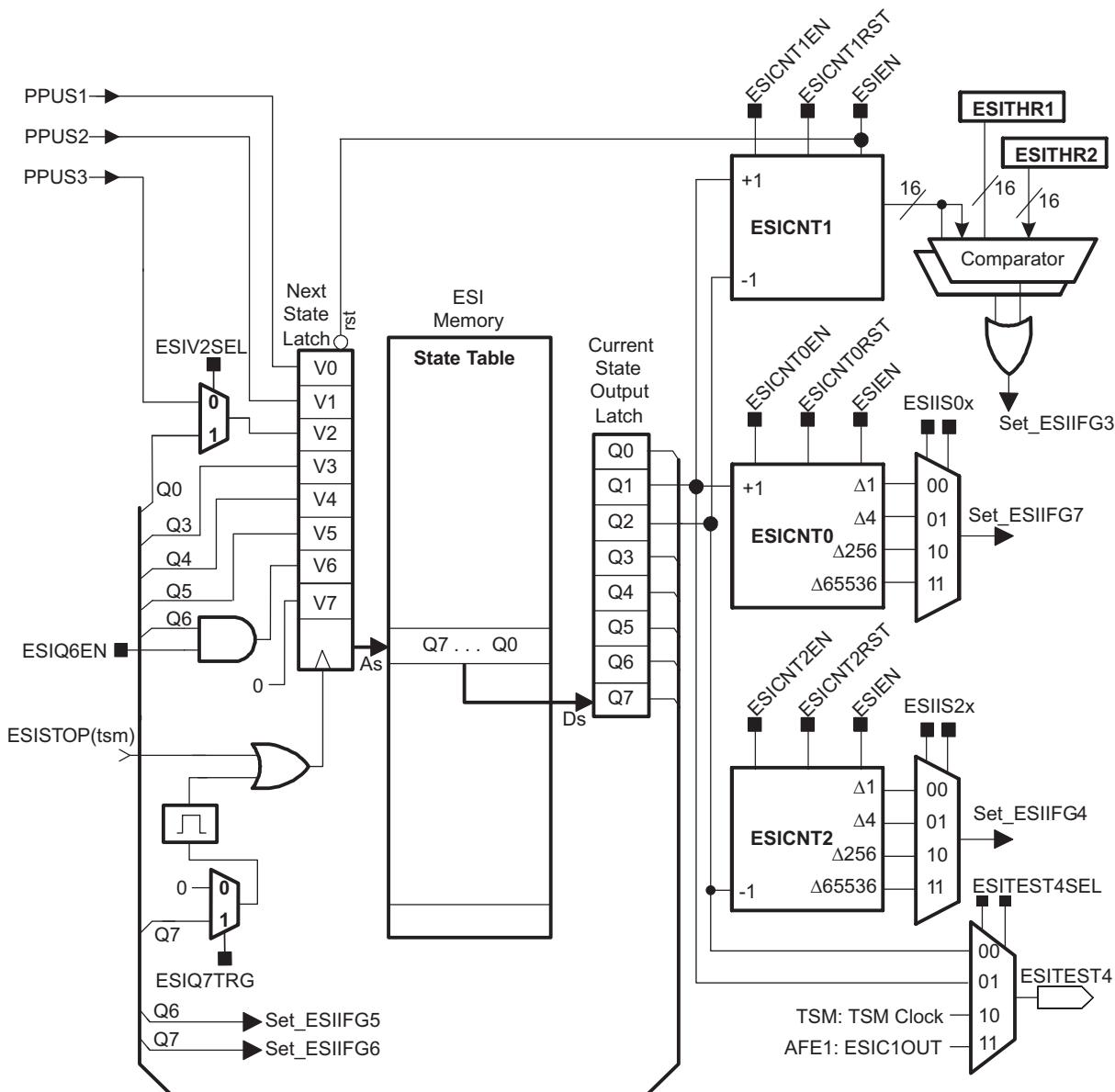


Figure 37-13. ESI Processing State Machine Block Diagram

#### 37.2.5.1 PSM Operation

The PSM is triggered at any rising edge of ESISTOP(tsm) signal during a normal cycle. Note that a test cycle insertion does not trigger the PSM. Triggering the PSM means, the PSM starts a sequence moving the current-state byte (Q0...Q7) from the PSM state table located in ESI RAM to the PSM next state latch (V2...V6 or V3...V6). All accesses to the PSM state table are done automatically with no CPU intervention.

The current-state and next-state logic are reset while the ESI is disabled. The ESI allow selecting either two signals or three signals for the processing. When the ESI is enabled following scenarios do exist for first processing:

- Two input signals are chosen (ESIV2SEL = 1):  
The byte stored at addresses 0 within PSM State Table (ESI RAM) will be loaded first when the ESI is enabled.
- Three input signals are chosen (ESIV2SEL = 0):  
The byte stored at addresses 0 within PSM State Table (ESI RAM) will be loaded first when the ESI is enabled.

Signals PPUS1 and PPUS2 form a 2-bit offset (ESIV2SEL = 1) and signals PPUS1, PPUS2, and PPUS3 form a 3-bit offset (ESIV2SEL = 0) added to the base address of the PSM State Table to determine the byte loaded to the PSM current-state output latch. For example, when two input signals are chosen (ESIV2SEL = 1) and PPUS2 = 1, and PPUS1 = 0, the byte loaded by the PSM will be at the address <current address of PSM State Table> + 2. The next byte and further subsequent bytes are determined by the next state calculations and are calculated by the PSM based on the state table contents and the values of signals PPUS1 and PPUS2.

The PSM needs two TSM clock cycles to complete the processing of the measurement results from a single TSM sequence.

### 37.2.5.2 ESI RAM

The purpose of the ESI RAM is to store the user-defined PSM table. The ESI RAM can be accessed by PSM or CPU. CPU write and read access to ESI RAM is only possible when ESI is disabled (ESIEN = 0). Any CPU write access to ESI RAM is ignored while ESI is active (ESIEN = 1). A CPU read access to ESI RAM is not possible while ESI is active; in this case the CPU would read a 0x00 (byte access) or 0x0000 (word access).

---

**NOTE:** The ESI RAM does not support stack usage. This means, stack pointer should not point to ESI RAM addresses.

The ESI RAM start address (base address) can be found in the device-specific data sheet (see *Peripheral File Map* section).

---

### 37.2.5.3 Next State Calculation

Either bit 0 (Q0) or signal PPUS3, and bits 3-5 (Q3, Q4, Q5), and, if enabled by ESIQ6EN, bit 6 (Q6) are used together with the signals PPUS1, PPUS2, and optional PPUS3 to calculate the next state. When ESIQ6EN = 1, Q6 is used in the next-state calculation. The next state is:

| 0  | Q6 | Q5 | Q4 | Q3 | Q0 or PPUS3 | PPUS2 | PPUS1 |
|----|----|----|----|----|-------------|-------|-------|
| ↓  | ↓  | ↓  | ↓  | ↓  | ↓           | ↓     | ↓     |
| V7 | V6 | V5 | V4 | V3 | V2          | V1    | V0    |

If ESIQ7TRG = 0, the Q7 bit can be used to generate an interrupt (ESIIFG7).

Enabling Q7 as trigger (ESIQ7TRG = 1) causes the following functionality: When Q7 = 0, the PSM state is updated by the falling edge of the ESISTOP(tsm) at the end of a TSM sequence. After updating the current state the PSM moves the corresponding state table entry to the output latch. When Q7 = 1, the next state is calculated immediately without waiting for the next falling edge of ESISTOP(tsm). The state is then updated with the next ESIOSC cycle. The worst-case time between state transitions in this case is 6 ESIOSC cycles.

### 37.2.5.4 PSM Counters

The PSM has three 16-bit counters ESICNT0, ESICNT1, and ESICNT2. ESICNT0 is updated with Q1, ESICNT1 is updated with Q1 and Q2, and ESICNT2 is updated with Q2. The counters can be read from the ESICNT0, ESICNT1, and ESICNT2 registers. The different counters can individually be reset by setting the ESICNTxRST control bits. When ESIEN = 0, all counters are held in reset.

ESICNT0 increments based on Q1. When ESICNT0EN = 1, ESICNT0 increments on a transition to a state where bit Q1 is set.

ESICNT1 can increment or decrement based on Q1 and Q2. When ESICNT1EN = 1, ESICNT1 decrements on a transition to a state where bit Q2 is set and it increments on a transition to a state where bit Q1 is set. In case both bits Q1 and Q2 are set on a state transition, ESICNT1 does not increment or decrement.

ESICNT2 decrements based on Q2. When ESICNT2EN = 1, ESICNT2 decrements on a transition to a state where bit Q2 is set. On the first count after a reset ESICNT2 will roll over from zero to 65535 (0FFFFh).

When the next state is calculated to be the same state as the current state, the counters ESICNT0, ESICNT1, and ESICNT2 are incremented or decremented according to Q1 and Q2 at the state transition. For example, if the current state is 05h and Q2 is set, and if the next state is calculated to be 05h, the transition from state 05h to 05h will decrement ESICNT2 if ESICNT2EN = 1.

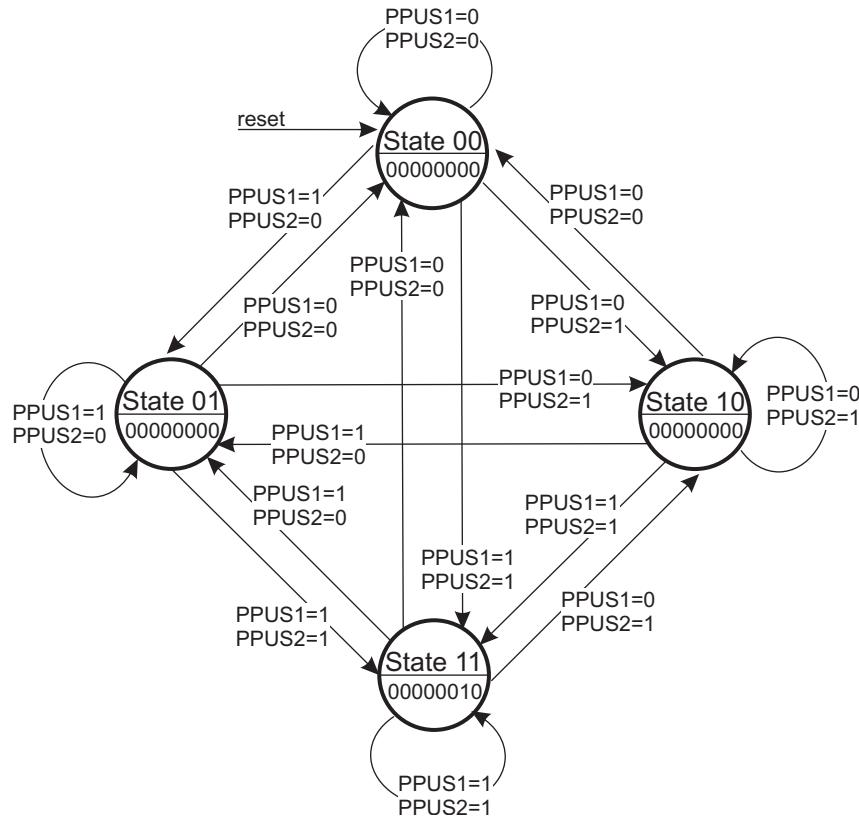
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**NOTE:** A read from any ESICNTx register should occur while PSM counters are not triggered. This can be realized by reading the ESI counters in the ESIIIFG1 interrupt service routine and choosing appropriate timing of TSM sequences. Alternatively, the ESI counters may be read multiple times, and a majority vote taken in software to determine the correct reading.

---

### 37.2.5.5 Simplest State Machine

Figure 37-14 shows the simplest state machine that can be realized with the PSM. The following code shows the corresponding state table.



**Figure 37-14. Simplest PSM State Diagram (ESIV2SEL=1)**

```

; Simplest State Machine Example
SIMPLEST_PSM db 000h ; State 00 (State Table Index 0)
db 000h ; State 01 (State Table Index 1)
db 000h ; State 10 (State Table Index 2)
db 002h ; State 11 (State Table Index 3)
  
```

If the PSM is in state 01 of the simplest state machine and the PSM has loaded the corresponding byte at index 01h of the state table:

| Q7 | Q6 | Q5 | Q4 | Q3 | Q2 | Q1 | Q0 |
|----|----|----|----|----|----|----|----|
| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

For this example, PPUS1 and PPUS2 are set at the end of the next TSM sequence. To calculate the next state the bits Q5 - Q3 and Q0 of the state 01 table entry, together with the PPUS1 and PPUS2 signals are combined to form the next state:

| V7 | V6 (Q6) | V5 (Q5) | V4 (Q4) | V3 (Q3) | V2 (Q0) | V1 (PPUS2) | V0 (PPUS1) |
|----|---------|---------|---------|---------|---------|------------|------------|
| 0  | 0       | 0       | 0       | 0       | 0       | 1          | 1          |

The state table entry for state 11 is loaded at the next state transition:

| V7 | V6 (Q6) | V5 (Q5) | V4 (Q4) | V3 (Q3) | V2 (Q0) | V1 (PPUS2) | V0 (PPUS1) |
|----|---------|---------|---------|---------|---------|------------|------------|
| 0  | 0       | 0       | 0       | 0       | 0       | 1          | 0          |

Q1 is set in state 11, so ESICNT1 will be incremented.

More complex state machines can be built by combining simple state machines to meet the requirements of specific applications.

### 37.2.6 ESI Debug Register

The Scan IF peripheral has several ESIDEBUGx registers for debugging and development.

- Reading ESIDEBUG1 shows the last address read by the PSM.
- Reading ESIDEBUG2 shows the index of the TSM and the PSM bits Q7 to Q0.
- Reading ESIDEBUG3 shows the TSM output.
- Reading ESIDEBUG4 shows which DAC1 register is selected and its contents.
- Reading ESIDEBUG5 shows which DAC2 register is selected and its contents.

### 37.2.7 ESI Interrupts

The Extended Scan IF has one interrupt vector for nine interrupt flags listed in [Table 37-7](#). Each interrupt flag has its own interrupt enable bit. When an interrupt is enabled, and the GIE bit is set, the interrupt flag will generate an interrupt. The interrupt flags are not automatically cleared. They must be cleared with software. The interrupt vector register ESIV is used to determine which interrupt flags requested an interrupt.

**Table 37-7. ESI Interrupts**

| Interrupt Flag | Interrupt Condition                                                                                                  |
|----------------|----------------------------------------------------------------------------------------------------------------------|
| ESIIFG0        | ESIIFG0 is set by one of the ESIOUT0 to ESIOUT3 outputs selected with the ESIIFGSET1x bits.                          |
| ESIIFG1        | ESIIFG1 is set by the rising edge of the ESISTOP(tsm) signal.                                                        |
| ESIIFG2        | ESIIFG2 is set at the start of a TSM sequence.                                                                       |
| ESIIFG3        | ESIIFG3 is set at different count intervals of the ESICNT1 counter, selected with the ESITHR1 and ESITHR2 registers. |
| ESIIFG4        | ESIIFG4 is set at different count intervals of the ESICNT2 counter, selected with the ESIIS2x bits.                  |
| ESIIFG5        | ESIIFG5 is set when the PSM transitions to a state with Q6 set.                                                      |
| ESIIFG6        | ESIIFG6 is set when the PSM transitions to a state with Q7 set.                                                      |
| ESIIFG7        | ESIIFG7 is set at different count intervals of the ESICNT0 counter, selected with the ESIIS0x bits.                  |
| ESIIFG8        | ESIIFG8 is set by one of the ESIOUT4 to ESIOUT7 outputs selected with the ESIIFGSET2x bits.                          |

#### 37.2.7.1 PSM Counter ESICNT0 and ESICNT2 Interrupt Handling

The interrupt logic of the PSM counters ESICNT0 and ESICNT2 is generating an interrupt using either the counter input directly or one out of three defined counter outputs. This means, there are four different settings possible: generating an interrupt on 1, 4, 256, or 65536 count steps.

#### 37.2.7.2 PSM Counter ESICNT1 Interrupt Handling

The PSM ESICNT1 counter interrupt logic generates an interrupt as soon as its counter value is equal to the content of the control registers ESITHR1 or ESITHR2. These two threshold registers can be defined by user; the registers contain a 16-bit value that is compared with the 16-bit ESICNT1 register. The interrupt ESIIFG3 is set as soon as the content of ESICNT1 counter is equal to the content of ESITHR1 or ESITHR2.

### 37.2.7.3 ESIIIV, Interrupt Vector Generator

The ESIIIFGx interrupt flags are prioritized and combined to source a single interrupt vector. The interrupt vector register ESIIIV is used to determine which flag requested an interrupt.

The highest-priority enabled interrupt generates a number in the ESIIIV register (see register description). This number can be evaluated or added to the program counter to automatically enter the appropriate software routine. Disabled ESI interrupt do not affect the ESIIIV value.

A read access of the ESIIIV register automatically resets the highest-pending interrupt flag. If another interrupt flag is set, another interrupt is immediately generated after servicing the initial interrupt. For example, if the ESICNT1 (ESIIIFG3) and ESICNT2 (ESIIIFG4) interrupt flags are set when the interrupt service routine accesses the ESIIIV register, ESIIIFG3 is reset automatically. After the RETI instruction of the interrupt service routine is executed, the ESIIIFG4 interrupt flag generates another interrupt.

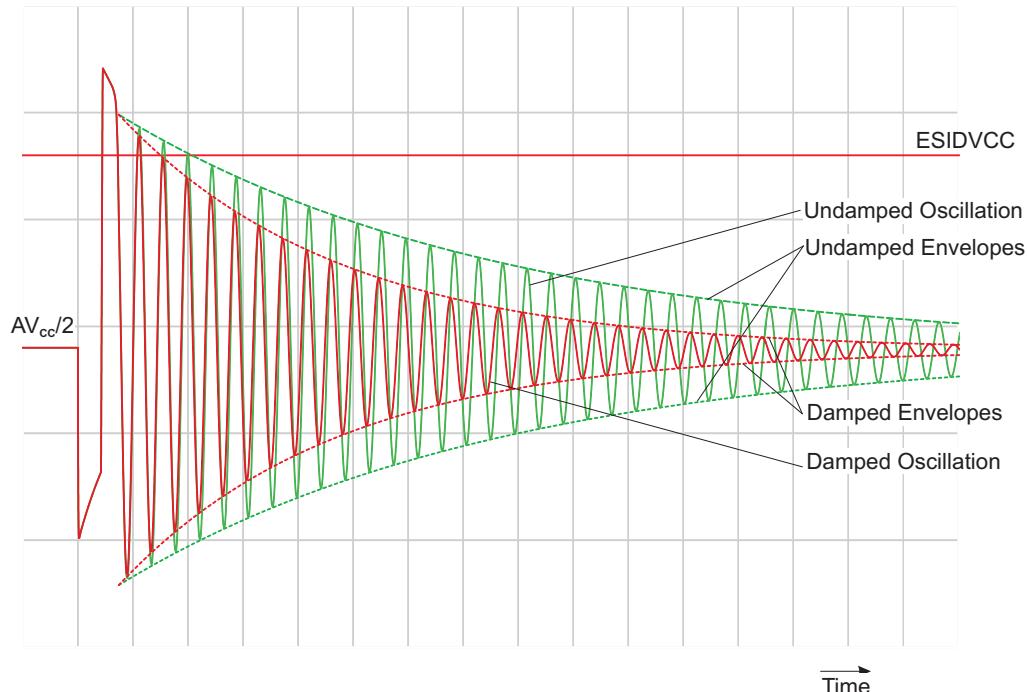
A write access to the ESIIIV register clears all pending ESI interrupt flags.

### 37.2.8 Overview of ESI Applications

The ESI supports different types of sensors. This chapter introduces only a few of the existing solutions of how to use the ESI.

#### 37.2.8.1 Using the ESI with LC Sensors

Systems with LC sensors use a disk that is partially covered with a damping material to measure rotation. Rotation is measured with LC sensors by exciting the sensors and observing the resulting oscillation. The oscillation is either damped or un-damped by the rotating disk. The oscillation is always decaying because of energy losses but it decays faster when the damping material on the disk is within the field of the LC sensor, as shown in [Figure 37-15](#). The LC oscillations can be measured with the oscillation test or the envelope test.

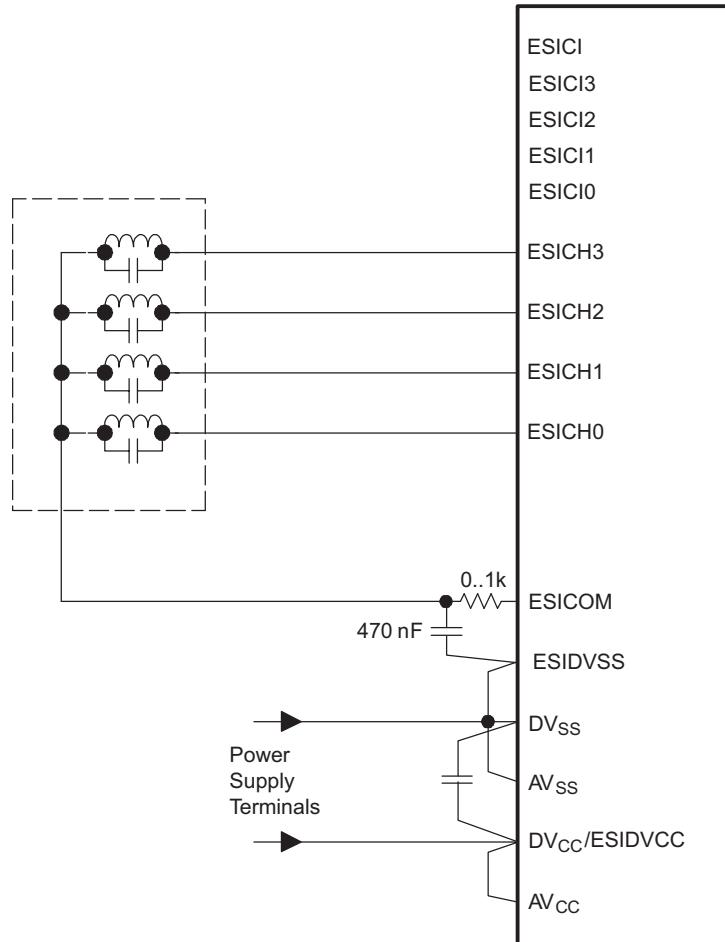


**Figure 37-15. LC Sensor Oscillations**

### 37.2.8.1.1 LC-Sensor Oscillation Test

The oscillation test tests if the amplitude of the oscillation after sensor excitation is above a reference level. The DAC is used to set the reference level for the comparator, and the comparator detects if the LC sensor oscillations are above or below the reference level. If the oscillations are above the reference level, the comparator will output a pulse train corresponding to the oscillations and the selected AFE output bit will 1. The measurement timing and reference level depend on the sensors and the system and should be chosen such that the difference between the damped and the undamped amplitude is maximized.

[Figure 37-16](#) shows the connections for the oscillation test.

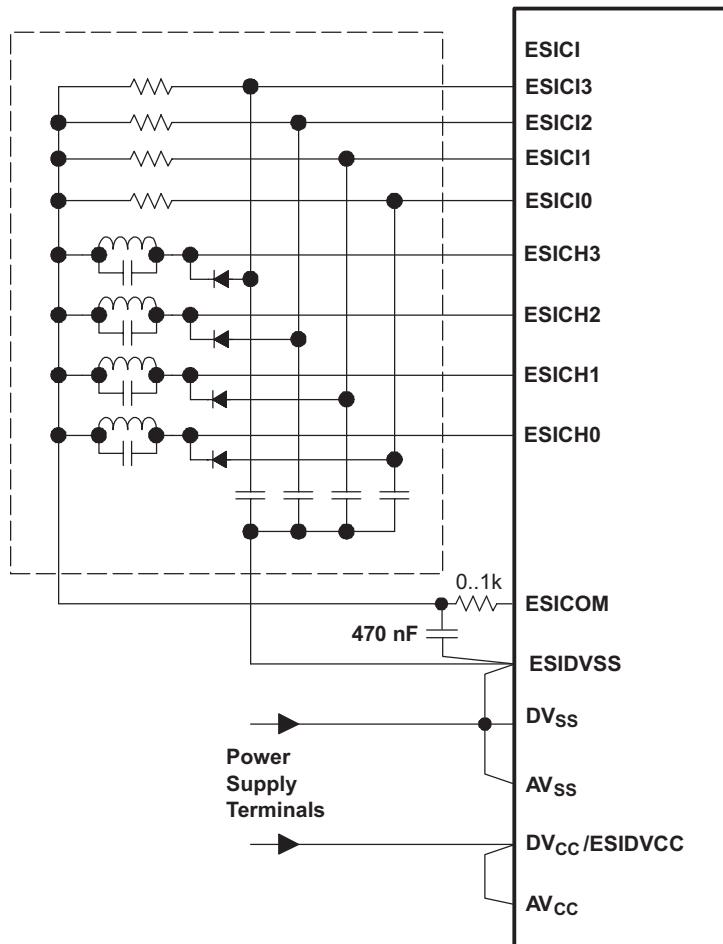


**Figure 37-16. Sensor Connections For The Oscillation Test**

### 37.2.8.1.2 LC-Sensor Envelope Test

The envelop test measures the decay time of the oscillations after sensor excitation. The oscillation envelope is created by the diodes and RC filters. The DAC is used to set the reference level for the comparator, and the comparator detects if the oscillation envelop is above or below the reference level. The comparator and AFE outputs are connected to Timer\_A and the capture/compare registers for Timer\_A are used to time the decay of the oscillation envelope. The PSM is not used for the envelope test.

When the sensors are connected to the individual ESICIx inputs as shown in [Figure 37-17](#), the comparator reference level can be adjusted for each sensor individually. When all sensors are connected to the ESICI input as shown in [Figure 37-18](#), only one comparator reference level is set for all sensors.



**Figure 37-17. LC Sensor Connections For The Envelope Test**

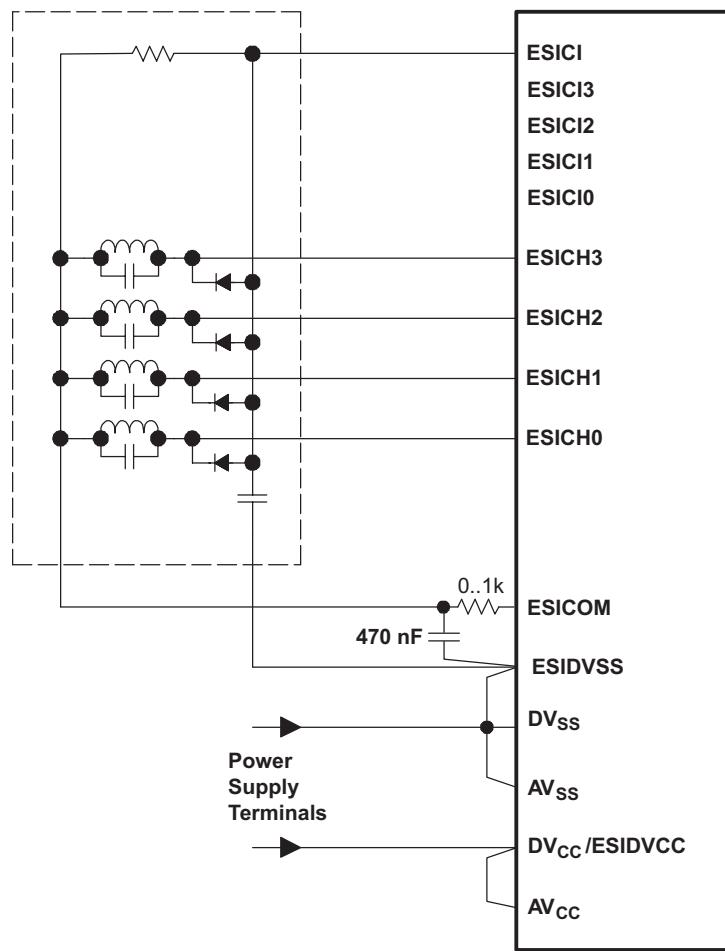
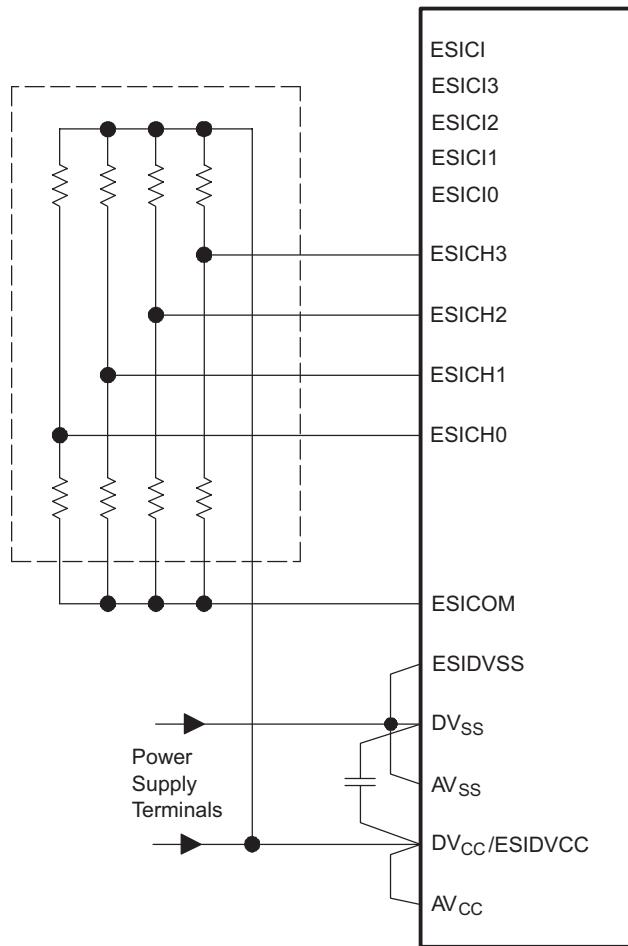


Figure 37-18. LC Sensor Connections For the Envelope Test

### 37.2.8.2 Using the ESI With Resistive Sensors

Systems with GMRs use magnets on an impeller to measure rotation. The damping material and magnets modify the electrical behavior of the sensor so that rotation and direction can be detected.

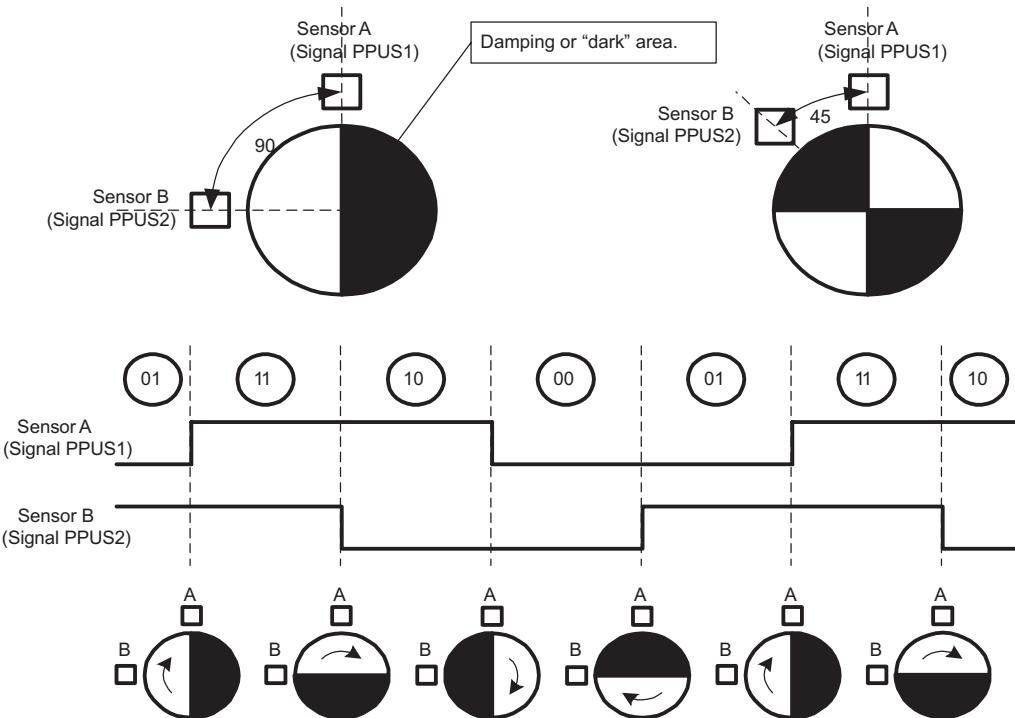
Rotation is measured with resistive sensors by connecting the resistor dividers to ground for a short time allowing current flow through the dividers. The resistors are affected by the rotating disc creating different divider voltages. The divider voltages are sampled with the sample-and-hold circuits. After the signals have settled the dividers may be switched off to prevent current flow and reduce power consumption. The DAC is used to set the reference level for the comparator, and the comparator detects if the sampled voltage is above or below the reference level. If the sampled voltage is above the reference level the comparator output is high. [Figure 37-19](#) shows the connection for resistive sensors.



**Figure 37-19. Resistive Sensor Connections**

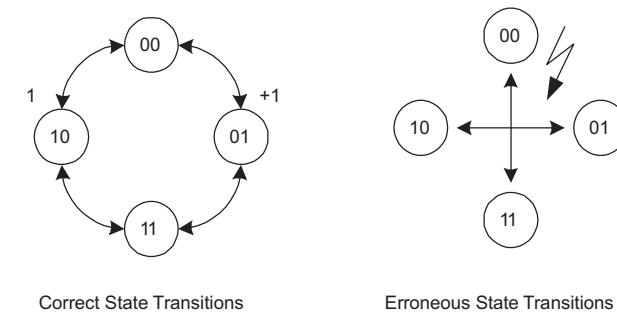
### 37.2.8.3 Quadrature Decoding

The ESI can be used to decode quadrature-encoded signals. Signals that are  $90^\circ$  out of phase with each other are said to be in quadrature. To Create the signals, two sensors are positioned depending on the slotting, or coating of the encoder disk. Figure 37-20 shows two examples for the sensor positions and a quadrature-encoded signal waveform.



**Figure 37-20. Sensor Position and Quadrature Signals (S1=PPUS1, S2=PPUS2)**

Quadrature decoding requires knowing the previous quadrature pair S1 (PPUS1) and S2 (PPUS2), as well as the current pair. Comparing these two pairs will tell the direction of the rotation. For example, if the current pair is 00 it can change to 01 or 10, depending on direction. Any other change in the signal pair would represent an error as shown in Figure 37-21.



**Figure 37-21. Quadrature Decoding State Diagram**

To transfer the state encoding into counts it is necessary to decide what fraction of the rotation should be counted and on what state transitions. In this example only full rotations will be counted on the transition from state 00 to 01 or 10 using a  $180^\circ$  disk with the sensors  $90^\circ$  apart. All the possible state transitions can be put into a table and this table can be translated into the corresponding state table entries for the processing state machine as shown in Table 37-8.

**Table 37-8. Quadrature Decoding PSM Table**

| Previous Quadrature Pair | Current Quadrature Pair | Movement        | State Table Entry |    |    |                         |    | Byte Code |
|--------------------------|-------------------------|-----------------|-------------------|----|----|-------------------------|----|-----------|
|                          |                         |                 | Q6                | Q2 | Q1 | Q3                      | Q0 |           |
|                          |                         |                 | Error             | -1 | +1 | Current Quadrature Pair |    |           |
| 00                       | 00                      | No Rotation     | 0                 | 0  | 0  | 0                       | 0  | 000h      |
| 00                       | 01                      | Turns right, +1 | 0                 | 0  | 1  | 0                       | 1  | 003h      |
| 00                       | 10                      | Turns left, -1  | 0                 | 1  | 0  | 1                       | 0  | 00Ch      |
| 00                       | 11                      | Error           | 1                 | 0  | 0  | 1                       | 1  | 049h      |
| 01                       | 00                      | Turns left      | 0                 | 0  | 0  | 0                       | 0  | 000h      |
| 01                       | 01                      | No rotation     | 0                 | 0  | 0  | 0                       | 1  | 001h      |
| 01                       | 10                      | Error           | 1                 | 0  | 0  | 1                       | 0  | 048h      |
| 01                       | 11                      | Turns right     | 0                 | 0  | 0  | 1                       | 1  | 009h      |
| 10                       | 00                      | Turns right     | 0                 | 0  | 0  | 0                       | 0  | 000h      |
| 10                       | 01                      | Error           | 1                 | 0  | 0  | 0                       | 1  | 041h      |
| 10                       | 10                      | No rotation     | 0                 | 0  | 0  | 1                       | 0  | 008h      |
| 10                       | 11                      | Turns left      | 0                 | 0  | 0  | 1                       | 1  | 009h      |
| 11                       | 00                      | Error           | 1                 | 0  | 0  | 0                       | 0  | 040h      |
| 11                       | 01                      | Turns left      | 0                 | 0  | 0  | 0                       | 1  | 001h      |
| 11                       | 10                      | Turns right     | 0                 | 0  | 0  | 1                       | 0  | 008h      |
| 11                       | 11                      | No rotation     | 0                 | 0  | 0  | 1                       | 1  | 009h      |

### 37.3 ESI Registers

The Extended Scan Interface registers are listed in [Table 37-9](#).

---

**NOTE:** The ESI RAM start address (base address) can be found in the *Peripheral File Map* section of the device-specific data sheet.

---

**Table 37-9. ESI Registers**

| Offset     | Acronym                | Register Name                              | Type       | Access | Reset          |
|------------|------------------------|--------------------------------------------|------------|--------|----------------|
| 0h         | ESIDEBUG1              | ESI debug register 1                       | Read       | Word   | Reset with PUC |
| 02h        | ESIDEBUG2              | ESI debug register 2                       | Read       | Word   | Reset with PUC |
| 04h        | ESIDEBUG3              | ESI debug register 3                       | Read       | Word   | Reset with PUC |
| 06h        | ESIDEBUG4              | ESI debug register 4                       | Read       | Word   | Reset with PUC |
| 08h        | ESIDEBUG5              | ESI debug register 5                       | Read       | Word   | Reset with PUC |
| 0Ah        | Reserved               |                                            |            |        |                |
| 0Ch        | Reserved               |                                            |            |        |                |
| 0Eh        | Reserved               |                                            |            |        |                |
| 10h        | ESICNT0                | ESI PSM counter 0                          | Read       | Word   | Reset with PUC |
| 12h        | ESICNT1                | ESI PSM counter 1                          | Read       | Word   | Reset with PUC |
| 14h        | ESICNT2                | ESI PSM counter 2                          | Read       | Word   | Reset with PUC |
| 16h        | ESICNT3                | ESI oscillator counter register            | Read       | Word   | Reset with PUC |
| 18h        | Reserved               |                                            |            |        |                |
| 1Ah        | ESIIV                  | ESI interrupt vector                       | Read       | Word   | Reset with PUC |
| 1Ch        | ESIINT1                | ESI interrupt register 1                   | Read/Write | Word   | Reset with PUC |
| 1Eh        | ESIINT2                | ESI interrupt register 2                   | Read/Write | Word   | Reset with PUC |
| 20h        | ESIAFE                 | ESI AFE control register                   | Read/Write | Word   | Reset with PUC |
| 22h        | ESIPPU                 | ESI PPU control register                   | Read/Write | Word   | Reset with PUC |
| 24h        | ESITSM                 | ESI TSM control register                   | Read/Write | Word   | Reset with PUC |
| 26h        | ESIPSM                 | ESI PSM control register                   | Read/Write | Word   | Reset with PUC |
| 28h        | ESIOSC                 | ESI oscillator control register            | Read/Write | Word   | Reset with PUC |
| 28h        | ESIOSC_L               |                                            | Read/Write | Byte   | Reset with PUC |
| 29h        | ESIOSC_H               |                                            | Read/Write | Byte   | Reset with PUC |
| 2Ah        | ESICTL                 | ESI control register                       | Read/Write | Word   | Reset with PUC |
| 2Ch        | ESITHR1                | ESI PSM Counter Threshold 1 register       | Read/Write | Word   | Reset with PUC |
| 2Eh        | ESITHR2                | ESI PSM Counter Threshold 2 register       | Read/Write | Word   | Reset with PUC |
| 30h        | Reserved               |                                            |            |        |                |
| 32h        | Reserved               |                                            |            |        |                |
| 34h        | Reserved               |                                            |            |        |                |
| 36h        | Reserved               |                                            |            |        |                |
| 38h        | Reserved               |                                            |            |        |                |
| 3Ah        | Reserved               |                                            |            |        |                |
| 3Ch        | Reserved               |                                            |            |        |                |
| 3Eh        | Reserved               |                                            |            |        |                |
| 40h to 4Eh | ESIDAC1R0 to ESIDAC1R7 | ESI DAC1 register 0 to ESI DAC1 register 7 | Read/Write | Word   | Unchanged      |
| 50h to 5Eh | ESIDAC2R0 to ESIDAC2R7 | ESI DAC2 register 0 to ESI DAC2 register 7 | Read/Write | Word   | Unchanged      |
| 60h to 9Eh | ESITSM0 to ESITSMS1    | ESI TSM 0 to ESI TSM 31                    | Read/Write | Word   | Unchanged      |

### 37.3.1 ESIDEBUG1 Register

Extended Scan Interface Debug Register 1

**Figure 37-22. ESIDEBUG1 Register**

|        |    |    |    |    |    |   |   |
|--------|----|----|----|----|----|---|---|
| 15     | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Unused |    |    |    |    |    |   |   |
| r      | r  | r  | r  | r  | r  | r | r |
| 7      | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| Unused |    |    |    |    |    |   |   |
| r      | r  | r  | r  | r  | r  | r | r |

**Table 37-10. ESIDEBUG1 Register Description**

| Bit  | Field            | Type | Reset | Description                                       |
|------|------------------|------|-------|---------------------------------------------------|
| 15-7 | Unused           | R    | 0h    | Unused. These bits are always read as zero.       |
| 6-0  | Last_PSM_Address | R    | 0h    | ESIDEBUG1 shows the last address read by the PSM. |

### 37.3.2 ESIDEBUG2 Register

Extended Scan Interface Debug Register 2

**Figure 37-23. ESIDEBUG2 Register**

|          |    |    |    |    |    |   |   |
|----------|----|----|----|----|----|---|---|
| 15       | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Unused   |    |    |    |    |    |   |   |
| r        | r  | r  | r  | r  | r  | r | r |
| 7        | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| PSM_Bits |    |    |    |    |    |   |   |
| r        | r  | r  | r  | r  | r  | r | r |

**Table 37-11. ESIDEBUG2 Register Description**

| Bit   | Field     | Type | Reset | Description                                     |
|-------|-----------|------|-------|-------------------------------------------------|
| 15-13 | Unused    | R    | 0h    | Unused. These bits are always read as zero.     |
| 12-8  | TSM_Index | R    | 0h    | These bits show the TSM register pointer index. |
| 7-0   | PSM_Bits  | R    | 0h    | These bits show the PSM bits Q7 to Q0.          |

### 37.3.3 ESIDEBUG3 Register

Extended Scan Interface Debug Register 3

**Figure 37-24. ESIDEBUG3 Register**

|                  |    |    |    |    |    |   |   |
|------------------|----|----|----|----|----|---|---|
| 15               | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Register_Content |    |    |    |    |    |   |   |
| r                | r  | r  | r  | r  | r  | r | r |
| 7                | 6  | 5  | 4  | 3  | 2  | 1 | 0 |
| Register_Content |    |    |    |    |    |   |   |
| r                | r  | r  | r  | r  | r  | r | r |

**Table 37-12. ESIDEBUG3 Register Description**

| Bit  | Field            | Type | Reset | Description                                                       |
|------|------------------|------|-------|-------------------------------------------------------------------|
| 15-0 | Register_Content | R    | 0h    | Current ESITSMx register content. These bits show the TSM output. |

### 37.3.4 ESIDEBUG4 Register

Extended Scan Interface Debug Register 4

**Figure 37-25. ESIDEBUG4 Register**

| 15        | 14            | 13 | 12 | 11 | 10        | 9 | 8 |
|-----------|---------------|----|----|----|-----------|---|---|
| Unused    | DAC1_Register |    |    |    | DAC1_Data |   |   |
| r         | r             | r  | r  | r  | r         | r | r |
| 7         | 6             | 5  | 4  | 3  | 2         | 1 | 0 |
| DAC1_Data |               |    |    |    |           |   |   |
| r         | r             | r  | r  | r  | r         | r | r |

**Table 37-13. ESIDEBUG4 Register Description**

| Bit   | Field         | Type | Reset | Description                                                                    |
|-------|---------------|------|-------|--------------------------------------------------------------------------------|
| 15    | Unused        | R    | 0h    | Unused. This bit is always read as zero.                                       |
| 14-12 | DAC1_Register | R    | 0h    | These bits show which DAC1 register is currently selected to control the DAC1. |
| 11-0  | DAC1_Data     | R    | 0h    | These bits show value of the currently selected DAC1 register.                 |

### 37.3.5 ESIDEBUG5 Register

Extended Scan Interface Debug Register 5

**Figure 37-26. ESIDEBUG5 Register**

| 15        | 14            | 13 | 12 | 11 | 10        | 9 | 8 |
|-----------|---------------|----|----|----|-----------|---|---|
| Unused    | DAC2_Register |    |    |    | DAC2_Data |   |   |
| r         | r             | r  | r  | r  | r         | r | r |
| 7         | 6             | 5  | 4  | 3  | 2         | 1 | 0 |
| DAC2_Data |               |    |    |    |           |   |   |
| r         | r             | r  | r  | r  | r         | r | r |

**Table 37-14. ESIDEBUG5 Register Description**

| Bit   | Field         | Type | Reset | Description                                                                    |
|-------|---------------|------|-------|--------------------------------------------------------------------------------|
| 15    | Unused        | R    | 0h    | Unused. This bit is always read as zero.                                       |
| 14-12 | DAC2_Register | R    | 0h    | These bits show which DAC2 register is currently selected to control the DAC2. |
| 11-0  | DAC2_Data     | R    | 0h    | These bits show value of the currently selected DAC2 register.                 |

### 37.3.6 ESICNT0 Register

Extended Scan Interface Counter 0 Register

**Figure 37-27. ESICNT0 Register**

| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
|----------|-----|-----|-----|-----|-----|-----|-----|
| ESICNT0x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| ESICNT0x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |

**Table 37-15. ESICNT0 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                          |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------|
| 15-0 | ESICNT0x | R    | 0h    | ESICNT0. These bits are the ESICNT0 counter. ESICNT0 is reset when ESIEN = 0 or when ESICNT0RST = 1. |

### 37.3.7 ESICNT1 Register

Extended Scan Interface Counter 1 Register

**Figure 37-28. ESICNT1 Register**

| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
|----------|-----|-----|-----|-----|-----|-----|-----|
| ESICNT1x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| ESICNT1x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |

**Table 37-16. ESICNT1 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                          |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------|
| 15-0 | ESICNT1x | R    | 0h    | ESICNT1. These bits are the ESICNT1 counter. ESICNT1 is reset when ESIEN = 0 or when ESICNT1RST = 1. |

### 37.3.8 ESICNT2 Register

Extended Scan Interface Counter 2 Register

**Figure 37-29. ESICNT2 Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| ESICNT2x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| ESICNT2x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |

**Table 37-17. ESICNT2 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                          |
|------|----------|------|-------|------------------------------------------------------------------------------------------------------|
| 15-0 | ESICNT2x | R    | 0h    | ESICNT2. These bits are the ESICNT2 counter. ESICNT2 is reset when ESIEN = 0 or when ESICNT2RST = 1. |

### 37.3.9 ESICNT3 Register

Extended Scan Interface Oscillator Counter Register

**Figure 37-30. ESICNT3 Register**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| 15       | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| ESICNT3x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |
| ESICNT3x |     |     |     |     |     |     |     |
| r-0      | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 | r-0 |

**Table 37-18. ESICNT3 Register Description**

| Bit  | Field    | Type | Reset | Description                                                                                                                                                                                                              |
|------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | ESICNT3x | R    | 0h    | Internal oscillator counter. ESICNT3 counts internal oscillator clock cycles during one ACLK period after ESICLKON and ESIHFSEL are both set. Setting the control bits ESIHFSEL and ESICLKON resets the ESICNT3 counter. |

### 37.3.10 ESIIV Register

Extended Scan Interface Interrupt Vector Register

**Figure 37-31. ESIIV Register**

|       |    |    |     |     |     |     |    |
|-------|----|----|-----|-----|-----|-----|----|
| 15    | 14 | 13 | 12  | 11  | 10  | 9   | 8  |
| ESIIV |    |    |     |     |     |     |    |
| r0    | r0 | r0 | r0  | r0  | r0  | r0  | r0 |
| ESIIV |    |    |     |     |     |     |    |
| r0    | r0 | r0 | r-0 | r-0 | r-0 | r-0 | r0 |

**Table 37-19. ESIIV Register Description**

| Bit  | Field | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------|-------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | ESIIV | R    | 0h    | <p>Extended Scan Interface interrupt vector value. The ESIIV register helps to easily find out the source of an Extended Scan Interface interrupt. By adding the ESIIV register content to the program counter (PC) the code execution is continued on one of the following instructions. This allows to realize a jump table that optimizes the detection of interrupt source. Writing to this register clears all pending Extended Scan Interface interrupt flags.</p> <p>00h = No interrupt pending</p> <p>02h = Interrupt Source: Rising edge of the ESISTOP(tsm) signal; Interrupt Flag: ESIIIFG1; Interrupt Priority: Highest</p> <p>04h = Interrupt Source: ESIOUT0 to ESIOUT3 conditions selected by ESIIFGSETx bits; Interrupt Flag: ESIIIFG0</p> <p>06h = Interrupt Source: ESIOUT4 to ESIOUT7 conditions selected by ESIIFGSET2x bits; Interrupt Flag: ESIIIFG8</p> <p>08h = Interrupt Source: ESICNT1 counter conditions selected with the ESITHR1 and ESITHR2 registers; Interrupt Flag: ESIIIFG3</p> <p>0Ah = Interrupt Source: PSM transitions to a state with a set Q7 bit; Interrupt Flag: ESIIIFG6</p> <p>0Ch = Interrupt Source: PSM transitions to a state with a set Q6 bit; Interrupt Flag: ESIIIFG5</p> <p>0Eh = Interrupt Source: ESICNT2 counter conditions selected with the ESIS2x bits; Interrupt Flag: ESIIIFG4</p> <p>10h = Interrupt Source: ESICNT0 counter conditions selected with the ESIS0x bits; Interrupt Flag: ESIIIFG7</p> <p>12h = Interrupt Source: Start of a TSM sequence; Interrupt Flag: ESIIIFG2; Interrupt Priority: Lowest</p> |

### 37.3.11 ESIINT1 Register

Extended Scan Interface Interrupt Register 1

**Figure 37-32. ESIINT1 Register**

| 15          | 14      | 13      | 12      | 11          | 10      | 9        | 8       |
|-------------|---------|---------|---------|-------------|---------|----------|---------|
| ESIIFGSET2x |         |         |         | ESIIFGSET1x |         | Reserved | ESIIIE8 |
| rw-0        | rw-0    | rw-0    | rw-0    | rw-0        | rw-0    | r0       | rw-0    |
| 7           | 6       | 5       | 4       | 3           | 2       | 1        | 0       |
| ESIIIE7     | ESIIIE6 | ESIIIE5 | ESIIIE4 | ESIIIE3     | ESIIIE2 | ESIIIE1  | ESIIIE0 |
| rw-0        | rw-0    | rw-0    | rw-0    | rw-0        | rw-0    | rw-0     | rw-0    |

**Table 37-20. ESIINT1 Register Description**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------|-------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | ESIIFGSET2x | RW   | 0h    | ESIIFG8 interrupt flag source. These bits select when the ESIIFG8 flag is set.<br>000b = ESIIFG8 is set when ESIOUT4 is set.<br>001b = ESIIFG8 is set when ESIOUT4 is reset.<br>010b = ESIIFG8 is set when ESIOUT5 is set.<br>011b = ESIIFG8 is set when ESIOUT5 is reset.<br>100b = ESIIFG8 is set when ESIOUT6 is set.<br>101b = ESIIFG8 is set when ESIOUT6 is reset.<br>110b = ESIIFG8 is set when ESIOUT7 is set.<br>111b = ESIIFG8 is set when ESIOUT7 is reset. |
| 12-10 | ESIIFGSET1x | RW   | 0h    | ESIIFG0 interrupt flag source. These bits select when the ESIIFG0 flag is set.<br>000b = ESIIFG0 is set when ESIOUT0 is set.<br>001b = ESIIFG0 is set when ESIOUT0 is reset.<br>010b = ESIIFG0 is set when ESIOUT1 is set.<br>011b = ESIIFG0 is set when ESIOUT1 is reset.<br>100b = ESIIFG0 is set when ESIOUT2 is set.<br>101b = ESIIFG0 is set when ESIOUT2 is reset.<br>110b = ESIIFG0 is set when ESIOUT3 is set.<br>111b = ESIIFG0 is set when ESIOUT3 is reset. |
| 9     | Reserved    | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                                                                                                                                                                                                                          |
| 8     | ESIIIE8     | RW   | 0h    | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG8 bit. Details about the interrupt functionality can be found in the ESIIFG8 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                                  |
| 7     | ESIIIE7     | RW   | 0h    | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG7 bit. Details about the interrupt functionality can be found in the ESIIFG7 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                                  |
| 6     | ESIIIE6     | RW   | 0h    | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG6 bit. Details about the interrupt functionality can be found in the ESIIFG6 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                                  |
| 5     | ESIIIE5     | RW   | 0h    | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG5 bit. Details about the interrupt functionality can be found in the ESIIFG5 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled                                                                                                                                                                                                  |

**Table 37-20. ESIINT1 Register Description (continued)**

| <b>Bit</b> | <b>Field</b> | <b>Type</b> | <b>Reset</b> | <b>Description</b>                                                                                                                                                                                                                                                    |
|------------|--------------|-------------|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4          | ESIIE4       | RW          | 0h           | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG4 bit. Details about the interrupt functionality can be found in the ESIIFG4 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 3          | ESIIE3       | RW          | 0h           | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG3 bit. Details about the interrupt functionality can be found in the ESIIFG3 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 2          | ESIIE2       | RW          | 0h           | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG2 bit. Details about the interrupt functionality can be found in the ESIIFG2 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 1          | ESIIE1       | RW          | 0h           | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG1 bit. Details about the interrupt functionality can be found in the ESIIFG1 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled |
| 0          | ESIIE0       | RW          | 0h           | Interrupt enable. These bits enable or disable the interrupt request for the ESIIFG0 bit. Details about the interrupt functionality can be found in the ESIIFG0 bit descriptions (see control register ESIINT2).<br>0b = Interrupt disabled<br>1b = Interrupt enabled |

### 37.3.12 ESIINT2 Register

Extended Scan Interface Interrupt Register 2

**Figure 37-33. ESIINT2 Register**

| 15       | 14      | 13      | 12       | 11      | 10      | 9        | 8       |
|----------|---------|---------|----------|---------|---------|----------|---------|
| Reserved | ESIIS2x |         | Reserved | ESIIS0x |         | Reserved | ESIIFG8 |
| r0       | rw-0    | rw-0    | r0       | rw-0    | rw-0    | r0       | rw-0    |
| 7        | 6       | 5       | 4        | 3       | 2       | 1        | 0       |
| ESIIFG7  | ESIIFG6 | ESIIFG5 | ESIIFG4  | ESIIFG3 | ESIIFG2 | ESIIFG1  | ESIIFG0 |
| rw-0     | rw-0    | rw-0    | rw-0     | rw-0    | rw-0    | rw-0     | rw-0    |

**Table 37-21. ESIINT2 Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                                                                                                                                                                                  |
|-------|----------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | Reserved | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                |
| 14-13 | ESIIS2x  | RW   | 0h    | ESIIFG4 interrupt flag source<br>00b = ESIIFG4 is set with each count of ESICNT2.<br>01b = ESIIFG4 is set if (ESICNT2 modulo 4) = 0.<br>10b = ESIIFG4 is set if (ESICNT2 modulo 256) = 0.<br>11b = ESIIFG4 is set when ESICNT2 decrements from 01h to 00h.   |
| 12    | Reserved | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                |
| 11-10 | ESIIS0x  | RW   | 0h    | ESIIFG7 interrupt flag source<br>00b = ESIIFG7 is set with each count of ESICNT0.<br>01b = ESIIFG7 is set if (ESICNT0 modulo 4) = 0.<br>10b = ESIIFG7 is set if (ESICNT0 modulo 256) = 0.<br>11b = ESIIFG7 is set when ESICNT0 increments from FFFFh to 00h. |
| 9     | Reserved | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                |
| 8     | ESIIFG8  | RW   | 0h    | ESIIFG8 is set by one of the AFE2's ESIOUTx outputs selected with the ESIIFGSET2x bits.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                                                               |
| 7     | ESIIFG7  | RW   | 0h    | ESI interrupt flag 7. ESIIFG7 is set at different count intervals of the ESICNT0 counter, selected with the ESIIS0x bits. ESIIFG6 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                        |
| 6     | ESIIFG6  | RW   | 0h    | ESI interrupt flag 6. This bit is set when the PSM transitions to a state with a set Q7 bit. ESIIFG6 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                     |
| 5     | ESIIFG5  | RW   | 0h    | ESI interrupt flag 5. This bit is set when the PSM transitions to a state with a set Q6 bit. ESIIFG5 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                     |
| 4     | ESIIFG4  | RW   | 0h    | ESI interrupt flag 4. This bit is set by the ESICNT2 counter conditions selected with the ESIIS2x bits. ESIIFG4 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                          |
| 3     | ESIIFG3  | RW   | 0h    | ESI interrupt flag 3. This bit is set by the ESICNT1 counter conditions selected with the ESITHR1 and ESITHR2 registers. ESIIFG3 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                         |

**Table 37-21. ESIINT2 Register Description (continued)**

| Bit | Field   | Type | Reset | Description                                                                                                                                                                                                                                                    |
|-----|---------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2   | ESIIFG2 | RW   | 0h    | ESI interrupt flag 2. This bit is set at the start of a TSM sequence generated by the divided ACLK. A TSM sequence started with ESISTART bit does not set ESIIFG2. ESIIFG2 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending |
| 1   | ESIIFG1 | RW   | 0h    | ESI interrupt flag 1. This bit is set by the rising edge of the ESISTOP(tsm) signal. ESIIFG1 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                                               |
| 0   | ESIIFG0 | RW   | 0h    | ESI interrupt flag 0. This bit is set by the AFE1's ESIOUTx conditions selected by the ESIIFGSET1x bits. ESIIFG0 must be reset with software.<br>0b = No interrupt pending<br>1b = Interrupt pending                                                           |

### 37.3.13 ESIAFE Register

Extended Scan Interface Analog Front-End Control Register

**Figure 37-34. ESIAFE Register**

| 15       | 14       | 13       | 12       | 11                      | 10                       | 9         | 8         |
|----------|----------|----------|----------|-------------------------|--------------------------|-----------|-----------|
| Reserved | Reserved | Reserved | Reserved | ESIDAC2EN               | ESICA2EN                 | ESICA2INV | ESICA1INV |
| rw-0     | rw-0     | rw-0     | rw-0     | rw-0                    | rw-0                     | rw-0      | rw-0      |
| 7        | 6        | 5        | 4        | 3                       | 2                        | 1         | 0         |
| ESICA2X  | ESICA1X  | ESICISEL | ESICACI3 | ESISHTSM <sup>(1)</sup> | ESIVMIDEN <sup>(2)</sup> | ESISH     | ESITEN    |
| rw-0     | rw-0     | rw-0     | rw-0     | rw-0                    | rw-0                     | rw-0      | rw-0      |

<sup>(1)</sup> The control bit ESIVSS was renamed to ESISHTSM to avoid confusion with supply pin naming.

<sup>(2)</sup> The control bit ESIVCC2 was renamed to ESIVMIDEN to avoid confusion with supply pin naming.

**Table 37-22. ESIAFE Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                   |
|-------|-----------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-12 | Reserved  | RW   | 0h    | Reserved for test purposes. It is strongly recommended to always write these bits as 0.                                                                                                                                                                                                                                                       |
| 11    | ESIDAC2EN | RW   | 0h    | Enable ESIDAC(tsm) control for DAC in AFE2.<br>0b = AFE2's DAC is always disabled, independently from ESIDAC(tsm) setting.<br>1b = AFE2's DAC is controlled by ESIDAC(tsm) bit.                                                                                                                                                               |
| 10    | ESICA2EN  | RW   | 0h    | Enable ESICA(tsm) control for comparator in AFE2.<br>0b = AFE2's comparator is always disabled, independently from ESICA(tsm) setting.<br>1b = AFE2's comparator is controlled by ESICA(tsm) bit.                                                                                                                                             |
| 9     | ESICA2INV | RW   | 0h    | Invert AFE2's comparator output<br>0b = Comparator output in AFE2 is not inverted<br>1b = Comparator output in AFE2 is inverted                                                                                                                                                                                                               |
| 8     | ESICA1INV | RW   | 0h    | Invert AFE1's comparator output<br>0b = Comparator output in AFE1 is not inverted<br>1b = Comparator output in AFE1 is inverted                                                                                                                                                                                                               |
| 7     | ESICA2X   | RW   | 0h    | AFE2's comparator input select. This bit selects groups of signals for the comparator input.<br>0b = AFE2's comparator input is one of the ESICHx channels, selected with the channel select logic.<br>1b = AFE2's comparator input is one of the ESIClx channels, selected with the channel select logic and the ESICISEL and ESICACI3 bits. |
| 6     | ESICA1X   | RW   | 0h    | AFE1's comparator input select. This bit selects groups of signals for the comparator input.<br>0b = AFE1's comparator input is one of the ESICHx channels, selected with the channel select logic.<br>1b = AFE1's comparator input is one of the ESIClx channels, selected with the channel select logic and the ESICISEL and ESICACI3 bits. |
| 5     | ESICISEL  | RW   | 0h    | Comparator input select for AFE1 only. This bit is used with the ESICACI3 bit to select the comparator input when ESICAX = 1.<br>0b = Comparator input is one of the ESIClx channels, selected with the channel select logic and ESICACI3 bit.<br>1b = Comparator input is the ESICI channel                                                  |
| 4     | ESICACI3  | RW   | 0h    | Comparator input select for AFE1 only. This bit is selected the comparator input when ESICISEL = 0 and ESICAX = 1.<br>0b = Comparator input is selected with the channel select logic.<br>1b = Comparator input is ESICl3.                                                                                                                    |

**Table 37-22. ESIAFE Register Description (continued)**

| Bit | Field                    | Type | Reset | Description                                                                                                                                                                                                                  |
|-----|--------------------------|------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | ESISHTSM <sup>(1)</sup>  | RW   | 0h    | Sample-and-hold ESIDVSS select.<br>0b = The ground connection of the sample capacitor is connected to ESIDVSS, regardless of the TSM control.<br>1b = The ground connection of the sample capacitor is controlled by the TSM |
| 2   | ESIVMIDEN <sup>(2)</sup> | RW   | 0h    | Mid-voltage generator<br>0b = AVCC/2 generator is off<br>1b = AVCC/2 generator is on if ESISH = 0                                                                                                                            |
| 1   | ESISH                    | RW   | 0h    | Sample-and-hold enable<br>0b = Sample-and-hold is disabled<br>1b = Sample-and-hold is enabled                                                                                                                                |
| 0   | ESITEN                   | RW   | 0h    | Excitation enable<br>0b = Excitation circuitry is disabled<br>1b = Excitation circuitry is enabled                                                                                                                           |

<sup>(1)</sup> The control bit ESIVSS was renamed to ESISHTSM to avoid confusion with supply pin naming.

<sup>(2)</sup> The control bit ESIVCC2 was renamed to ESIVMIDEN to avoid confusion with supply pin naming.

### 37.3.14 ESIPPU Register

Extended Scan Interface Pre-Processing Unit Control Register

**Figure 37-35. ESIPPU Register**

| 15       | 14      | 13      | 12      | 11      | 10      | 9          | 8          |
|----------|---------|---------|---------|---------|---------|------------|------------|
| Reserved |         |         |         |         |         | ESITCHOUT1 | ESITCHOUT0 |
| r0       | r0      | r0      | r0      | r0      | r0      | r-(0)      | r-(0)      |
| 7        | 6       | 5       | 4       | 3       | 2       | 1          | 0          |
| ESIOUT7  | ESIOUT6 | ESIOUT5 | ESIOUT4 | ESIOUT3 | ESIOUT2 | ESIOUT1    | ESIOUT0    |
| r-(0)    | r-(0)   | r-(0)   | r-(0)   | r-(0)   | r-(0)   | r-(0)      | r-(0)      |

**Table 37-23. ESIPPU Register Description**

| Bit   | Field      | Type | Reset | Description                                                                                    |
|-------|------------|------|-------|------------------------------------------------------------------------------------------------|
| 15-10 | Reserved   | R    | 0h    | Reserved. These bits are always read as zero and, when written, do not affect the bit setting. |
| 9     | ESITCHOUT1 | R    | 0h    | Latched AFE1 comparator output for test channel 1                                              |
| 8     | ESITCHOUT0 | R    | 0h    | Latched AFE1 comparator output for test channel 0                                              |
| 7     | ESIOUT7    | R    | 0h    | Latched AFE2 comparator output when ESICH3 input is selected                                   |
| 6     | ESIOUT6    | R    | 0h    | Latched AFE2 comparator output when ESICH2 input is selected                                   |
| 5     | ESIOUT5    | R    | 0h    | Latched AFE2 comparator output when ESICH1 input is selected                                   |
| 4     | ESIOUT4    | R    | 0h    | Latched AFE2 comparator output when ESICH0 input is selected                                   |
| 3     | ESIOUT3    | R    | 0h    | Latched AFE1 comparator output when ESICH3 input is selected                                   |
| 2     | ESIOUT2    | R    | 0h    | Latched AFE1 comparator output when ESICH2 input is selected                                   |
| 1     | ESIOUT1    | R    | 0h    | Latched AFE1 comparator output when ESICH1 input is selected                                   |
| 0     | ESIOUT0    | R    | 0h    | Latched AFE1 comparator output when ESICH0 input is selected                                   |

### 37.3.15 ESITSM Register

Extended Scan Interface Timing State Machine Control Register

**Figure 37-36. ESITSM Register**

| 15        | 14          | 13         | 12   | 11       | 10       | 9         | 8    |
|-----------|-------------|------------|------|----------|----------|-----------|------|
| Reserved  | ESICLKAZSEL | ESITSMTRGx |      | ESISTART | ESITSMRP | ESIDIV3Bx |      |
| r0        | rw-0        | rw-0       | rw-0 | rw-0     | rw-0     | rw-0      | rw-0 |
| 7         | 6           | 5          | 4    | 3        | 2        | 1         | 0    |
| ESIDIV3Bx |             | ESIDIV3Ax  |      | ESIDIV2x |          | ESIDIV1x  |      |
| rw-0      | rw-0        | rw-0       | rw-0 | rw-0     | rw-0     | rw-0      | rw-0 |

**Table 37-24. ESITSM Register Description**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------|-------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | Reserved    | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 14    | ESICLKAZSEL | RW   | 0h    | Control bit functionality selection. This bit allows to define the functionality of bit 5 in register ESITSMx.<br>0b = ESITSMx.5 bit is used as ESICLKON. See ESITSMx control register for further description.<br>1b = ESITSMx.5 bit is used as ESICAAZ. See ESITSMx control register for further description.                                                                                                                                                                                                                                                                                                            |
| 13-12 | ESITSMTRGx  | RW   | 0h    | TSM start trigger selection. These bits allow to chose the source for the TSM start trigger.<br>00b = Halt mode. This setting allows to stop the TSM.<br>01b = TSM start trigger ACLK divider is used. ESIDIV3Ax and ESIDIV3Bx bits select the division rate for the TSM start trigger.<br>10b = Software trigger for TSM. When ESISTART bit is set by software a TSM start trigger is generated. Note that for this setting an ACLK synchronization sequence is performed that takes up to 2.5 ACLK cycles.<br>11b = Either the ACLK divider (ESIDIV3Ax and ESIDIV3Bx) or the ESISTART bit is used for TSM start trigger. |
| 11    | ESISTART    | RW   | 0h    | TSM software start trigger. In case the ESISTART bit is selected for TSM trigger generation this bit allows to generate a TSM start trigger by software.<br>0b = Idle state<br>1b = A TSM sequence is started. ESISTART is automatically cleared as soon as the TSM sequence starts.                                                                                                                                                                                                                                                                                                                                       |
| 10    | ESITSMRP    | RW   | 0h    | TSM repeat mode<br>0b = Each TSM sequence is triggered by the ACLK divider controlled with the ESIDIV3Ax and ESIDIV3Bx bits or ESISTART control bit depending on ESITSMTRGx setting.<br>1b = Each TSM sequence is immediately started at the end of the previous sequence.                                                                                                                                                                                                                                                                                                                                                 |
| 9-7   | ESIDIV3Bx   | RW   | 0h    | TSM start trigger ACLK divider. These bits together with the ESIDIV3Ax bits select the division rate for the TSM start trigger.<br>The division rate is shown in <a href="#">Table 37-25</a> .<br>The division rate can be calculated as: $((ESIDIV3A + 1) \times 2 - 1) \times ((ESIDIV3B + 1) \times 2 - 1) \times 2$                                                                                                                                                                                                                                                                                                    |
| 6-4   | ESIDIV3Ax   | RW   | 0h    | TSM start trigger ACLK divider. These bits together with the ESIDIV3Bx bits select the division rate for the TSM start trigger.<br>The division rate is shown in <a href="#">Table 37-25</a> .<br>The division rate can be calculated as: $((ESIDIV3A + 1) \times 2 - 1) \times ((ESIDIV3B + 1) \times 2 - 1) \times 2$                                                                                                                                                                                                                                                                                                    |
| 3-2   | ESIDIV2x    | RW   | 0h    | ACLK divider. These bits select the ACLK division.<br>00b = /1<br>01b = /2<br>10b = /4<br>11b = /8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

**Table 37-24. ESITSM Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                          |
|-----|----------|------|-------|----------------------------------------------------------------------------------------------------------------------|
| 1-0 | ESIDIV1x | RW   | 0h    | TSM SMCLK divider. These bits select the SMCLK division for the TSM.<br>00b = /1<br>01b = /2<br>10b = /4<br>11b = /8 |

**Table 37-25. TSM Start Trigger ACLK Divider**

| ACLK Divider | ESIDIV3Bx | ESIDIV3Ax |  | ACLK Divider | ESIDIV3Bx | ESIDIV3Ax |
|--------------|-----------|-----------|--|--------------|-----------|-----------|
| 2            | 000       | 000       |  | 126          | 011       | 100       |
| 6            | 000       | 001       |  | 130          | 010       | 110       |
| 10           | 000       | 010       |  | 150          | 010       | 111       |
| 14           | 000       | 011       |  | 154          | 011       | 101       |
| 18           | 000       | 100       |  | 162          | 100       | 100       |
| 22           | 000       | 101       |  | 182          | 011       | 110       |
| 26           | 000       | 110       |  | 198          | 100       | 101       |
| 30           | 000       | 111       |  | 210          | 011       | 111       |
| 42           | 001       | 011       |  | 234          | 100       | 110       |
| 50           | 010       | 010       |  | 242          | 101       | 101       |
| 54           | 001       | 100       |  | 270          | 100       | 111       |
| 66           | 001       | 101       |  | 286          | 101       | 110       |
| 70           | 010       | 011       |  | 330          | 101       | 111       |
| 78           | 001       | 110       |  | 338          | 110       | 110       |
| 90           | 001       | 111       |  | 390          | 110       | 111       |
| 98           | 011       | 011       |  | 450          | 111       | 111       |
| 110          | 010       | 101       |  |              |           |           |

### 37.3.16 ESIPSM Register

Extended Scan Interface Processing State Machine Control Register

**Figure 37-37. ESIPSM Register**

| 15         | 14         | 13         | 12        | 11        | 10       | 9           | 8       |
|------------|------------|------------|-----------|-----------|----------|-------------|---------|
| ESICNT2RST | ESICNT1RST | ESICNT0RST |           | Reserved  |          | ESITEST4SEL |         |
| rw-0       | rw-0       | rw-0       | r0        | r0        | r0       | rw-0        | rw-0    |
| 7          | 6          | 5          | 4         | 3         | 2        | 1           | 0       |
| ESIV2SEL   | Reserved   | ESICNT2EN  | ESICNT1EN | ESICNT0EN | ESIQ7TRG | Reserved    | ESIQ6EN |
| rw-1       | r0         | rw-0       | rw-0      | rw-0      | rw-0     | r0          | rw-0    |

**Table 37-26. ESIPSM Register Description**

| Bit   | Field       | Type | Reset | Description                                                                                                                                                                                                                                                                                                     |
|-------|-------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15    | ESICNT2RST  | RW   | 0h    | ESI Counter 2 reset. Setting this bit resets ESICNT2 register. After ESICNT2 register is cleared, the ESICNT2RST bit is automatically reset. This bit is always read as zero.                                                                                                                                   |
| 14    | ESICNT1RST  | RW   | 0h    | ESI Counter 1 reset. Setting this bit resets ESICNT1 register. After ESICNT1 register is cleared, the ESICNT1RST bit is automatically reset. This bit is always read as zero.                                                                                                                                   |
| 13    | ESICNT0RST  | RW   | 0h    | ESI Counter 0 reset. Setting this bit resets ESICNT0 register. After ESICNT0 register is cleared, the ESICNT0RST bit is automatically reset. This bit is always read as zero.                                                                                                                                   |
| 12-10 | Reserved    | R    | 0h    | Reserved. These bits are always read as zero and, when written, do not affect the bit setting.                                                                                                                                                                                                                  |
| 9-8   | ESITEST4SEL | RW   | 0h    | Output signal selection for ESITEST4 pin.<br>00b = Q2 signal from PSM table<br>01b = Q1 signal from PSM table<br>10b = TSM clock signal from Timing State Machine<br>11b = AFE1's comparator output signal ESIC1OUT                                                                                             |
| 7     | ESIV2SEL    | RW   | 1h    | Source Selection for V2 bit of Next State Latch<br>0b = PPUS3 signal is used for V2 bit<br>1b = Q0 is used for V2 bit                                                                                                                                                                                           |
| 6     | Reserved    | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                                                                   |
| 5     | ESICNT2EN   | RW   | 0h    | ESICNT2 enable (down counter)<br>0b = ESICNT2 is disabled<br>1b = ESICNT2 is enabled                                                                                                                                                                                                                            |
| 4     | ESICNT1EN   | RW   | 0h    | ESICNT1 enable (up/down counter)<br>0b = ESICNT1 is disabled<br>1b = ESICNT1 is enabled                                                                                                                                                                                                                         |
| 3     | ESICNT0EN   | RW   | 0h    | ESICNT0 enable (up counter)<br>0b = ESICNT0 is disabled<br>1b = ESICNT0 is enabled                                                                                                                                                                                                                              |
| 2     | ESIQ7TRG    | RW   | 0h    | Enabling to use Q7 as trigger for a PSM sequence.<br>0b = Only ESISTOP(tsm) is used as PSM trigger.<br>1b = ESISTOP(tsm) and Q7 are used as PSM triggers. As soon as a PSM state is reached with Q7 bit set the next state is calculated immediately without waiting for the next falling edge of ESISTOP(tsm). |
| 1     | Reserved    | R    | 0h    | Reserved. This bit is always read as zero and, when written, does not affect the bit setting.                                                                                                                                                                                                                   |
| 0     | ESIQ6EN     | RW   | 0h    | Q6 enable. This bit enables Q6 for the next PSM state calculation.<br>0b = Q6 is not used to determine the next PSM state<br>1b = Q6 is used to determine the next PSM state                                                                                                                                    |

### 37.3.17 ESIOSC Register

Extended Scan Interface Oscillator Control Register

**Figure 37-38. ESIOSC Register**

| 15       | 14 | 13        | 12   | 11   | 10   | 9         | 8        |
|----------|----|-----------|------|------|------|-----------|----------|
| Reserved |    | ESICLKFXQ |      |      |      |           |          |
| r0       | r0 | rw-1      | rw-0 | rw-0 | rw-0 | rw-0      | rw-0     |
| 7        | 6  | 5         | 4    | 3    | 2    | 1         | 0        |
|          |    | Reserved  |      |      |      | ESICLKGON | ESIHFSEL |
| r0       | r0 | r0        | r0   | r0   | r0   | rw-0      | rw-0     |

**Table 37-27. ESIOSC Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                 |
|-------|-----------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-14 | Reserved  | R    | 0h    | Reserved. These bits are always read as zero and, when written, do not affect the bit setting.                                                                                                                                                                                                                                              |
| 13-8  | ESICLKFXQ | RW   | 20h   | Internal oscillator frequency adjust. These bits are used to adjust the internal oscillator frequency. Each increase or decrease of the ESICLKFXQ bits increases or decreases the internal oscillator frequency by approximately 3%.<br>000000b = Minimum frequency<br>⋮<br>100000b = Nominal frequency<br>⋮<br>111111b = Maximum frequency |
| 7-2   | Reserved  | R    | 0h    | Reserved. These bits are always read as zero and, when written, do not affect the bit setting.                                                                                                                                                                                                                                              |
| 1     | ESICLKGON | RW   | 0h    | Internal oscillator control. When ESICLKGON = 1 and ESIHFSEL = 1, the internal oscillator calibration is started. ESICLKGON is not used when ESIHFSEL = 0.<br>0b = No internal oscillator calibration is started.<br>1b = The internal oscillator calibration is started when ESIHFSEL = 1.                                                 |
| 0     | ESIHFSEL  | RW   | 0h    | Internal oscillator enable. This bit selects the high frequency clock source for the TSM.<br>0b = TSM high frequency clock source is SMCLK.<br>1b = TSM high frequency clock source is the Extended Scan IF internal oscillator.                                                                                                            |

### 37.3.18 ESICTL Register

Extended Scan Interface General Control Register

**Figure 37-39. ESICTL Register**

|           |          |      |           |          |      |       |           |
|-----------|----------|------|-----------|----------|------|-------|-----------|
| 15        | 14       | 13   | 12        | 11       | 10   | 9     | 8         |
| ESIS3SELx |          |      | ESIS2SELx |          |      |       | ESIS1SELx |
| rw-0      | rw-0     | rw-0 | rw-0      | rw-0     | rw-0 | rw-0  | rw-0      |
| 7         |          |      |           | 6        | 5    | 4     | 3         |
| ESIS1SELx | ESITCH1x |      |           | ESITCH0x |      | ESICS | ESITESTD  |
| rw-0      | rw-0     | rw-0 | rw-0      | rw-0     | rw-0 | rw-0  | rw-0      |

**Table 37-28. ESICTL Register Description**

| Bit   | Field     | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------|-----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-13 | ESIS3SELx | RW   | 0h    | PPUS3 source select. These bits select the PPUS3 source for the PSM.<br>000b = ESIOUT0 is the PPUS3 source<br>001b = ESIOUT1 is the PPUS3 source<br>010b = ESIOUT2 is the PPUS3 source<br>011b = ESIOUT3 is the PPUS3 source<br>100b = ESIOUT4 is the PPUS3 source<br>101b = ESIOUT5 is the PPUS3 source<br>110b = ESIOUT6 is the PPUS3 source<br>111b = ESIOUT7 is the PPUS3 source                                                                           |
| 12-10 | ESIS2SELx | RW   | 0h    | PPUS2 source select. These bits select the PPUS2 source for the PSM.<br>000b = ESIOUT0 is the PPUS2 source<br>001b = ESIOUT1 is the PPUS2 source<br>010b = ESIOUT2 is the PPUS2 source<br>011b = ESIOUT3 is the PPUS2 source<br>100b = ESIOUT4 is the PPUS2 source<br>101b = ESIOUT5 is the PPUS2 source<br>110b = ESIOUT6 is the PPUS2 source<br>111b = ESIOUT7 is the PPUS2 source                                                                           |
| 9-7   | ESIS1SELx | RW   | 0h    | PPUS1 source select. These bits select the PPUS1 source for the PSM.<br>000b = ESIOUT0 is the PPUS1 source<br>001b = ESIOUT1 is the PPUS1 source<br>010b = ESIOUT2 is the PPUS1 source<br>011b = ESIOUT3 is the PPUS1 source<br>100b = ESIOUT4 is the PPUS1 source<br>101b = ESIOUT5 is the PPUS1 source<br>110b = ESIOUT6 is the PPUS1 source<br>111b = ESIOUT7 is the PPUS1 source                                                                           |
| 6-5   | ESITCH1x  | RW   | 0h    | These bits select the comparator input for test channel 1.<br>00b = Comparator input is ESICH0 when ESICAX = 0; Comparator input is ESIC10 when ESICAX = 1.<br>01b = Comparator input is ESICH1 when ESICAX = 0; Comparator input is ESIC11 when ESICAX = 1.<br>10b = Comparator input is ESICH2 when ESICAX = 0; Comparator input is ESIC12 when ESICAX = 1.<br>11b = Comparator input is ESICH3 when ESICAX = 0; Comparator input is ESIC13 when ESICAX = 1. |

**Table 37-28. ESICCTL Register Description (continued)**

| Bit | Field    | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----|----------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4-3 | ESITCH0  | RW   | 0h    | These bits select the comparator input for test channel 0.<br>00b = Comparator input is ESICH0 when ESICAX = 0; Comparator input is ESICIO when ESICAX = 1.<br>01b = Comparator input is ESICH1 when ESICAX = 0; Comparator input is ESICI1 when ESICAX = 1.<br>10b = Comparator input is ESICH2 when ESICAX = 0; Comparator input is ESICI2 when ESICAX = 1.<br>11b = Comparator input is ESICH3 when ESICAX = 0; Comparator input is ESICI3 when ESICAX = 1. |
| 2   | ESICS    | RW   | 0h    | Comparator output ir Timer_A input selection<br>0b = The ESIEX(tsm) signal and the comparator output are connected to the TACCRx inputs.<br>1b = The ESIEX(tsm) signal and the ESIOUTx outputs are connected to the TACCRx inputs selected with the ESIS1SELx and ESIS2SELx bits (PPUS1 and PPUS2 signals).                                                                                                                                                    |
| 1   | ESITESTD | RW   | 0h    | Test cycle insertion. Setting this bit inserts a test cycle between TSM cycles. ESITESTD is automatically reset at the end of the test cycle. Note that a test cycle insertion should only be done when divided ACLK is used as start trigger for TSM sequences (ESITSMTRGx = 01 and ESITSMRP=0).<br>0b = No test cycle inserted<br>1b = Test cycle inserted between TSM cycles.                                                                               |
| 0   | ESIEN    | RW   | 0h    | Extended Scan interface enable. Setting this bit enables the Extended Scan Interface and its components.<br>0b = Extended Scan Interface disabled<br>1b = Extended Scan Interface enabled                                                                                                                                                                                                                                                                      |

### **37.3.19 ESITHR1 Register**

ESI PSM Counter Threshold 1 Register

**Figure 37-40. ESITHR1 Register**

|            |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|
| 15         | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| Threshold1 |      |      |      |      |      |      |      |
| rw-0       | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |
| Threshold1 |      |      |      |      |      |      |      |
| rw-0       | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 | rw-0 |

**Table 37-29. ESITHR1 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                 |
|------|------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | Threshold1 | RW   | 0h    | Threshold for ESICNT1 counter. The interrupt flag ESIIFG3 is set when ESICNT1 content and Threshold 1 is equal. (for example, used to detect a certain increase of ESICNT1) |

### **37.3.20 ESITHR2 Register**

ESI PSM Counter Threshold 2 Register

**Figure 37-41. ESITHR2 Register**

|            |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|
| 15         | 14   | 13   | 12   | 11   | 10   | 9    | 8    |
| Threshold2 |      |      |      |      |      |      |      |
| rw-1       | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |
| Threshold2 |      |      |      |      |      |      |      |
| rw-1       | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 | rw-1 |

**Table 37-30. ESITHR2 Register Description**

| Bit  | Field      | Type | Reset | Description                                                                                                                                                                 |
|------|------------|------|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-0 | Threshold2 | RW   | FFFFh | Threshold for ESICNT1 counter. The interrupt flag ESIIFG3 is set when ESICNT1 content and Threshold 2 is equal. (for example, used to detect a certain decrease of ESICNT1) |

### 37.3.21 ESIDAC1Rx Register ( $x = 0$ to 7)

Extended Scan Interface Digital-To-Analog Converter 1 Register  $x$  ( $x = 0$  to 7)

**Figure 37-42. ESIDAC1Rx Register**

| 15       | 14 | 13 | 12 | 11       | 10 | 9  | 8  |
|----------|----|----|----|----------|----|----|----|
| Reserved |    |    |    | DAC_Data |    |    |    |
| r0       | r0 | r0 | r0 | rw       | rw | rw | rw |
| 7        | 6  | 5  | 4  | 3        | 2  | 1  | 0  |
| DAC_Data |    |    |    |          |    |    |    |
| rw       | rw | rw | rw | rw       | rw | rw | rw |

**Table 37-31. ESIDAC1Rx Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                    |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------|
| 15-12 | Reserved | R    | 0h    | Reserved. These bits are always read as zero and, when written, do not affect the bit setting. |
| 11-0  | DAC_Data | RW   | 0h    | 12-bit DAC data                                                                                |

### 37.3.22 ESIDAC2Rx Register ( $x = 0$ to 7)

Extended Scan Interface Digital-To-Analog Converter 2 Register  $x$  ( $x = 0$  to 7)

**Figure 37-43. ESIDAC2Rx Register**

| 15       | 14 | 13 | 12 | 11       | 10 | 9  | 8  |
|----------|----|----|----|----------|----|----|----|
| Reserved |    |    |    | DAC_Data |    |    |    |
| r0       | r0 | r0 | r0 | rw       | rw | rw | rw |
| 7        | 6  | 5  | 4  | 3        | 2  | 1  | 0  |
| DAC_Data |    |    |    |          |    |    |    |
| rw       | rw | rw | rw | rw       | rw | rw | rw |

**Table 37-32. ESIDAC2Rx Register Description**

| Bit   | Field    | Type | Reset | Description                                                                                    |
|-------|----------|------|-------|------------------------------------------------------------------------------------------------|
| 15-12 | Reserved | R    | 0h    | Reserved. These bits are always read as zero and, when written, do not affect the bit setting. |
| 11-0  | DAC_Data | RW   | 0h    | 12-bit DAC data                                                                                |

### 37.3.23 ESITSM $x$ Register ( $x = 0$ to 31)

Extended Scan Interface Timing State Machine Register

**NOTE:**

A TSM sequence should at least consist of three ESITSM $x$  registers. For example, using ESITSM0 for idle state, ESITSM1 for measurement, and ESITSM2 as stop state; note that usually several ESITSM $x$  registers are needed to perform a measurement.

While a TSM sequence is in progress the access to the ESITSM $x$  registers is blocked. Reading the ESITSM $x$  registers while a TSM sequence is in progress returns always a 0x0000.

**Figure 37-44. ESITSM $x$  Register**

| 15            | 14      | 13                  | 12    | 11    | 10      | 9         | 8  |
|---------------|---------|---------------------|-------|-------|---------|-----------|----|
| ESIREPEAT $x$ |         |                     |       |       |         |           |    |
| rw            | rw      | rw                  | rw    | rw    | rw      | rw        | rw |
| 7             | 6       | 5                   | 4     | 3     | 2       | 1         | 0  |
| ESITESTS1     | ESIRSON | ESICLKON<br>ESICAAZ | ESICA | ESIEX | ESILCEN | ESICH $x$ |    |
| rw            | rw      | rw                  | rw    | rw    | rw      | rw        | rw |

**Table 37-33. ESITSM $x$  Register Description**

| Bit   | Field         | Type | Reset | Description                                                                                                                                                                                                                                                                                                                            |
|-------|---------------|------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15-11 | ESIREPEAT $x$ | RW   | 0h    | These bits together with the ESICLK bit configure the duration of this state. ESIREPEAT $x$ selects the number of clock cycles for this state. The number of clock cycles = ESIREPEAT $x$ + 1. Note that all ESIREPEAT $x$ bits should be cleared within the ESITSM $x$ state that generates the end of sequence (ESISTOP bit is set). |
| 10    | ESICLK        | RW   | 0h    | This bit selects the clock source for the TSM.<br>0b = The TSM clock source is the high frequency source selected by the ESIHFSEL bit.<br>1b = The TSM clock source is ACLK                                                                                                                                                            |
| 9     | ESISTOP       | RW   | 0h    | This bit indicates the end of the TSM sequence. The duration of this state is always one high-frequency clock period, regardless of the ESICLK and ESIREPEAT $x$ settings.<br>0b = TSM sequence continues with next state<br>1b = End of TSM sequence                                                                                  |
| 8     | ESIDAC        | RW   | 0h    | TSM DAC on. This bit turns the AFE1 DAC and optionally also AFE2 DAC on.<br>0b = AFE1 DAC and AFE2 DAC are off during this state.<br>1b = AFE1 DAC is on during this state. AFE2 DAC is only on when ESIDAC2EN in ESIAFE control register is set.                                                                                      |
| 7     | ESITESTS1     | RW   | 0h    | TSM test cycle control. This bit selects for this state which channel-control bits and which DAC registers are used for a test cycle.<br>0b = The ESITCH0x bits select the channel and ESIDACR6 is used for the DAC<br>1b = The ESITCH1x bits select the channel and ESIDACR7 is used for the DAC                                      |
| 6     | ESIRSON       | RW   | 0h    | Internal output latches enabled. This bit enables the internal latches of the AFE output stage.<br>0b = Output latches disabled<br>1b = Output latches enabled                                                                                                                                                                         |

**Table 37-33. ESITSMx Register Description (continued)**

| Bit | Field            | Type | Reset | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----|------------------|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5   | ESICLKON ESICAAZ | RW   | 0h    | <p>This control bit in the ESITSMx control register can either be used as ESICLKON bit or ESICAAZ bit. Its functionality is selectable by the control bit CLKCAAZSEL in register TSM.</p> <p>ESITSM.ESICLKAZSEL=0 → ESICLKON:<br/>           High-frequency clock on. Setting this bit turns the high-frequency clock source on for this state when ESICLK = 1, even though the high frequency clock is not used for the TSM. When the . high-frequency clock is sourced from the DCO, the DCO is forced on for this state, regardless of the MSP430 low-power mode.<br/>           0b = High-frequency clock is off for this state when ESICLK = 1<br/>           1b = High-frequency clock is on for this state when ESICLK = 1</p> <p>ESITSM.ESICLKAZSEL=1 → ESICAAZ:<br/>           Comparator Offset cancellation by doing an autozero cycle.<br/>           0b = "AZ-compensation Compare phase", Comparator compares (this phase must be preceded by the "AZ-compensation Auto Zero Phase" for each compare).<br/>           1b = "AZ-compensation Auto Zero phase", Comparator Offset cancellation sequence is active (autozero). The length for autozero is adjusted by the selected clock (ESICLK) and the programmed repeat cycles (ESIREPEATx). See device-specific data sheet for appropriate timing requirements.</p> |
| 4   | ESICA            | RW   | 0h    | <p>TSM comparator on. Setting this bit turns the AFE1 comparator and optionally the AFE2 comparator on for this state.<br/>           0b = AFE1 comparator and AFE2 comparator are off during this state<br/>           1b = AFE1 comparator is on during this state. AFE2 comparator is only on when ESICA2EN in ESIAFE control register is set.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 3   | ESIEX            | RW   | 0h    | <p>Excitation and sample-and-hold. This bit, together with the ESISH and ESITEN bits, enables the excitation transistor or samples the input voltage during this state. ESILCEN must be set to 1 when ESIEX = 1.<br/>           0b = Excitation transistor disabled when ESISH = 0 and ESITEN = 1. Sampling disabled when ESISH = 1 and ESITEN = 0.<br/>           1b = Excitation transistor enabled when ESISH = 0 and ESITEN = 1. Sampling enabled when ESISH = 1 and ESITEN = 0.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 2   | ESILCEN          | RW   | 0h    | <p>LC enable. Setting this bit turns the damping transistor off, enabling the LC oscillations during this state when ESITEN = 1.<br/>           0b = All ESICHx channels are internally damped. No LC oscillations.<br/>           1b = The selected ESICHx channel is not internally damped; the LC oscillates. All other unselected ESICHx channels are internally damped (no LC oscillations).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 1-0 | ESICHx           | RW   | 0h    | <p>Input channel select. These bits select the input channel to be measured or excited during this state.<br/>           00b = ESICH0<br/>           01b = ESICH1<br/>           10b = ESICH2<br/>           11b = ESICH3</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

### 37.3.24 Extended Scan Interface Processing State Machine Table Entry (ESI Memory)

Extended Scan Interface Processing State Machine Table Entry (ESI Memory)

**Figure 37-45. Extended Scan Interface Processing State Machine Table Entry Register**

| 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|----|----|----|----|----|----|----|----|
| Q7 | Q6 | Q5 | Q4 | Q3 | Q2 | Q1 | Q0 |

**Table 37-34. Extended Scan Interface Processing State Machine Table Entry Description**

| Bit | Field | Type | Reset | Description                                                                                                                                                                                                         |
|-----|-------|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | Q7    |      |       | When Q7 = 1, ESIIIFG6 will be set. When ESIQ6EN = 1 and ESIQ7EN = 1 and Q7 = 1, the PSM proceeds to the next state immediately, regardless of the ESISTOP(tsm) signal and Q7 is used in the next-state calculation. |
| 6   | Q6    |      |       | When Q6 = 1, ESIIIFG5 will be set. When ESIQ6EN = 1, Q6 will be used in the next-state calculation.                                                                                                                 |
| 5   | Q5    |      |       | Bit 5 of the next state                                                                                                                                                                                             |
| 4   | Q4    |      |       | Bit 4 of the next state                                                                                                                                                                                             |
| 3   | Q3    |      |       | Bit 3 of the next state                                                                                                                                                                                             |
| 2   | Q2    |      |       | When Q2 = 1, ESICNT1 decrements if ESICNT1EN = 1 and ESICNT2 decrements if ESICNT2EN = 1.                                                                                                                           |
| 1   | Q1    |      |       | When Q1 = 1, ESICNT1 increments if ESICNT1EN = 1 and ESICNT0 increments if ESICNT0EN = 1.                                                                                                                           |
| 0   | Q0    |      |       | When ESIV2SEL=0 the PPUS3 signal is used as bit 2 (V2) for the next state. For the case ESIV2SEL=1 the Q0 bit is used.                                                                                              |

## ***Embedded Emulation Module (EEM)***

This chapter describes the embedded emulation module (EEM) that is implemented in all devices.

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| 38.2 EEM Building Blocks .....                          | 1017 |
| 38.3 EEM Configurations .....                           | 1018 |

### 38.1 Embedded Emulation Module (EEM) Introduction

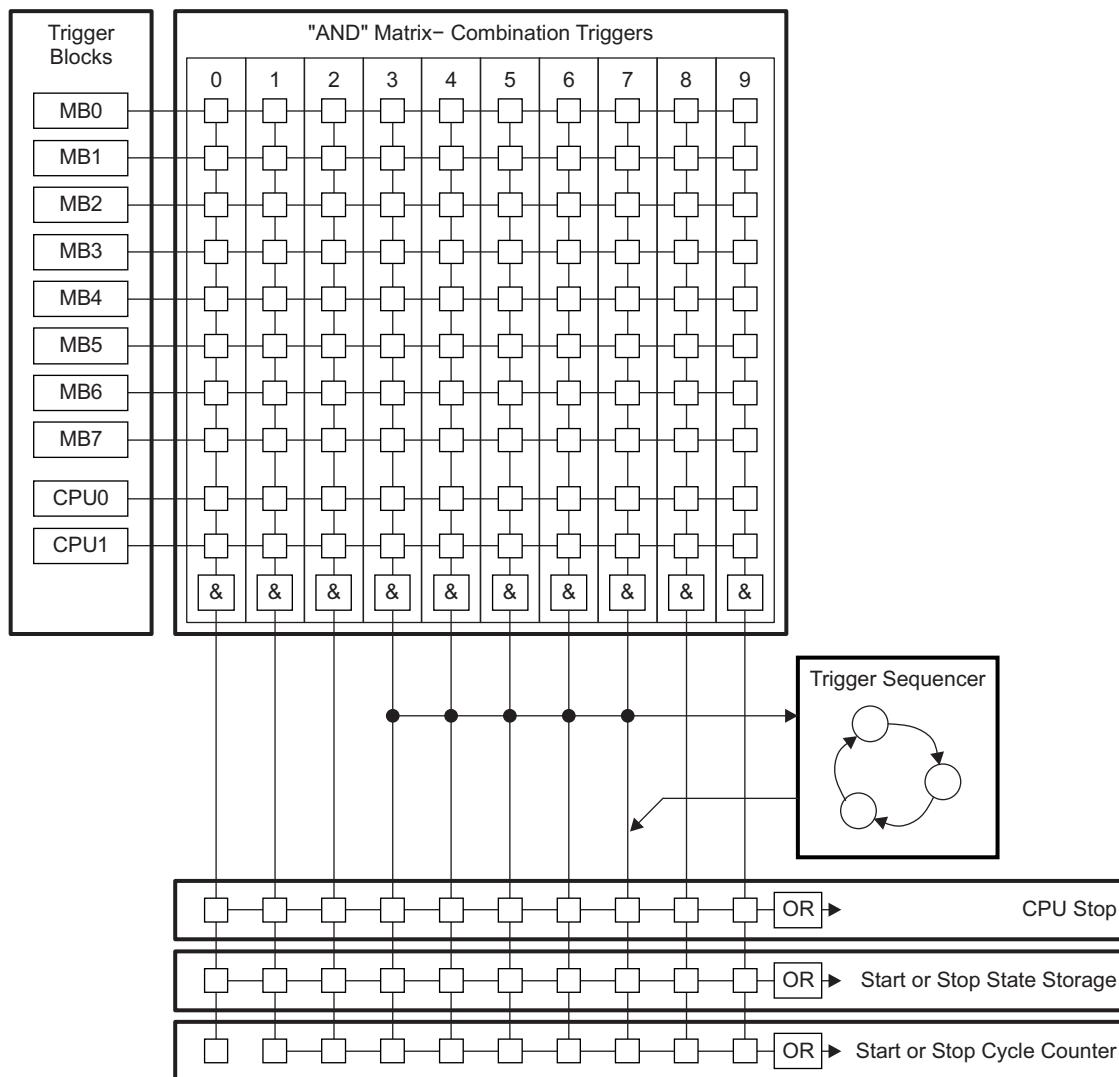
Every MSP430 microcontroller implements an EEM. It is accessed and controlled through either 4-wire JTAG mode or Spy-Bi-Wire mode. Each implementation is device-dependent and is described in [Section 38.3](#), the EEM Configurations section, and the device-specific data sheet.

In general, the following features are available:

- Nonintrusive code execution with real-time breakpoint control
- Single-step, step-into, and step-over functionality
- Full support of all low-power modes
- Support for all system frequencies, for all clock sources
- Up to eight (device-dependent) hardware triggers or breakpoints on memory address bus (MAB) or memory data bus (MDB)
- Up to two (device-dependent) hardware triggers or breakpoints on CPU register write accesses
- MAB, MDB, and CPU register access triggers can be combined to form up to ten (device-dependent) complex triggers or breakpoints
- Up to two (device-dependent) cycle counters
- Trigger sequencing (device-dependent)
- Storage of internal bus and control signals using an integrated trace buffer (device-dependent)
- Clock control for timers, communication peripherals, and other modules on a global device level or on a per-module basis during an emulation stop
- EnergyTrace++™ Technology

[Figure 38-1](#) shows a simplified block diagram of the largest currently-available EEM implementation.

For more details on how the features of the EEM can be used together with the IAR Embedded Workbench™ debugger or with Code Composer Studio (CCS), see *Advanced Debugging Using the Enhanced Emulation Module (SLAA393)* at [www.msp430.com](http://www.msp430.com). Most other debuggers supporting the MSP430 devices have the same or a similar feature set. For details, see the user's guide of the applicable debugger.



**Figure 38-1. Large Implementation of EEM**

## 38.2 EEM Building Blocks

### 38.2.1 Triggers

The event control in the EEM of the MSP430 system consists of triggers, which are internal signals indicating that a certain event has happened. These triggers may be used as simple breakpoints, but it is also possible to combine two or more triggers to allow detection of complex events and cause various reactions other than stopping the CPU.

In general, the triggers can be used to control the following functional blocks of the EEM:

- Breakpoints (CPU stop)
- State storage
- Sequencer
- Cycle counter

There are two different types of triggers – the memory trigger and the CPU register write trigger.

Each memory trigger block can be independently selected to compare either the MAB or the MDB with a given value. Depending on the implemented EEM, the comparison can be  $=$ ,  $\neq$ ,  $\geq$ , or  $\leq$ . The comparison can also be limited to certain bits with the use of a mask. The mask is either bit-wise or byte-wise, depending upon the device. In addition to selecting the bus and the comparison, the condition under which the trigger is active can be selected. The conditions include read access, write access, DMA access, and instruction fetch.

Each CPU register write trigger block can be independently selected to compare what is written into a selected register with a given value. The observed register can be selected for each trigger independently. The comparison can be  $=$ ,  $\neq$ ,  $\geq$ , or  $\leq$ . The comparison can also be limited to certain bits with the use of a bit mask.

Both types of triggers can be combined to form more complex triggers. For example, a complex trigger can signal when a particular value is written into a user-specified address.

### 38.2.2 Trigger Sequencer

The trigger sequencer allows the definition of a certain sequence of trigger signals before an event is accepted for a break or state storage event. Within the trigger sequencer, it is possible to use the following features:

- Four states (State 0 to State 3)
- Two transitions per state to any other state
- Reset trigger that resets the sequencer to State 0.

The trigger sequencer always starts at State 0 and must execute to State 3 to generate an action. If State 1 or State 2 are not required, they can be bypassed.

### 38.2.3 State Storage (*Internal Trace Buffer*)

The state storage function uses a built-in buffer to store MAB, MDB, and CPU control signal information (that is, read, write, or instruction fetch) in a nonintrusive manner. The built-in buffer can hold up to eight entries. The flexible configuration allows the user to record the information of interest very efficiently.

### 38.2.4 Cycle Counter

The cycle counter provides one or two 40-bit counters to measure the cycles used by the CPU to execute certain tasks. On some devices, the cycle counter operation can be controlled using triggers. This allows, for example, conditional profiling, such as profiling a specific section of code.

### 38.2.5 EnergyTrace++™ Technology

The EEM implements circuitry to support EnergyTrace++ technology. The EnergyTrace++ technology allows you to observe information about the internal states of the microcontroller. These states include the CPU Program Counter (PC), the ON or OFF status of the peripherals and the system clocks (regardless of the clock source), and the low-power mode currently in use. These states can always be read by a debug tool, even when the microcontroller sleeps in LPMx.5 modes. See *Code Composer Studio for MSP430 User's Guide (SLAU157)* for more information about integration into the IDE. See *MSP430™ Advanced Power Optimizations: ULP Advisor™ and EnergyTrace++ Technology (SLAA603)* for examples of use.

### 38.2.6 Clock Control

The EEM provides device-dependent flexible clock control. This is useful in applications where a running clock is needed for peripherals after the CPU is stopped (for example, to allow a UART module to complete its transfer of a character or to allow a timer to continue generating a PWM signal).

The clock control is flexible and supports both modules that need a running clock and modules that must be stopped when the CPU is stopped due to a breakpoint.

### 38.2.7 Debug Modes

The TEST/SBWTCK pin is used to enable the connection of external development tools with the EEM through Spy-Bi-Wire or JTAG debug protocols. The connection is usually enabled when the TEST/SBWTCK is high. When the connection is enabled, the device enters a debug mode. In the debug mode, the entry and wakeup times to and from low-power modes may be different compared to normal operation (application mode).

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**NOTE:** Pay careful attention to the real-time behavior when using low-power modes with the device connected to a development tool.

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There are two different debug modes available: the default debug mode and a ultra-low power debug mode. See *Code Composer Studio for MSP430 User's Guide (SLAU157)* for more information how to select the mode in the IDE.

Features and restrictions of the default debug mode are:

- It is possible to change breakpoint settings while the program is executed
- LPMx.5 is not supported
- Wakeup from low-power modes are faster than in application mode
- FRAM is forced on. It cannot be switched off using the FRAM Power Control bits

Features and restrictions of the ultra-low power debug mode are:

- It is not possible to change breakpoint settings while the program is executed
- LPMx.5 is supported
- Entry and wakeup times to and from low power modes may be longer than in application mode (for details see below)
- FRAM can be switched off using the FRAM Power Control bits.

In ultra-low power debug mode, the LPM entry and exit may be delayed. Low-power mode entry and wakeup from low-power modes is only possible while the debug protocol is in a certain state. Thus, the delay depends on the speed of the selected debug protocol. With Spy-Bi-Wire the delay is longer than when using JTAG. Also, the reaction on a DMA trigger or on a SMCLK or MCLK request may be delayed.

## 38.3 EEM Configurations

[Table 38-1](#) gives an overview of the EEM configurations. The implemented configuration is device-dependent, and details can be found in the device-specific data sheet and these documents:

*Advanced Debugging Using the Enhanced Emulation Module (EEM) With CCS (SLAA393)*

*IAR Embedded Workbench Version 3+ for MSP430 User's Guide (SLAU138)*

*Code Composer Studio for MSP430 User's Guide (SLAU157)*

**Table 38-1. EEM Configurations**

| Feature                     | XS                                                     | S                                                      | M                                                      | L                                        |
|-----------------------------|--------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------|------------------------------------------|
| Memory bus triggers         | 2<br>(=, ≠ only)                                       | 3                                                      | 5                                                      | 8                                        |
| Memory bus trigger mask for | 1) Low byte<br>2) High byte<br>3) Four upper addr bits | 1) Low byte<br>2) High byte<br>3) Four upper addr bits | 1) Low byte<br>2) High byte<br>3) Four upper addr bits | All 16 or 20 bits                        |
| CPU register write triggers | 0                                                      | 1                                                      | 1                                                      | 2                                        |
| Combination triggers        | 2                                                      | 4                                                      | 6                                                      | 10                                       |
| Sequencer                   | No                                                     | No                                                     | Yes                                                    | Yes                                      |
| State storage               | No                                                     | No                                                     | No                                                     | Yes                                      |
| Cycle counter               | 1                                                      | 1                                                      | 1                                                      | 2<br>(including triggered start or stop) |

In general, the following features can be found on any device:

- At least two MAB or MDB triggers supporting:
  - Distinction between CPU, DMA, read, and write accesses
  - =, ≠, ≥, or ≤ comparison (in XS, only =, ≠)
- At least two trigger combination registers
- Hardware breakpoints using the CPU stop reaction
- At least one 40-bit cycle counter
- Enhanced clock control with individual control of module clocks
- EnergyTrace++™ Technology

## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from June 2, 2017 to December 15, 2017                                                                                                                                | Page |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| • Added "The CPU must execute from RAM to clear the FRPWR bit for turning off power to FRAM" in the second paragraph of <a href="#">Section 7.8, FRAM Power Control</a> ..... | 289  |
| • Added USS_A and related description to <a href="#">Chapter 18, Ultrasonic Sensing Solution (USS, USS_A)</a> .....                                                           | 447  |
| • Updated <a href="#">Figure 20-1, USS or USS_A Block Diagram</a> , to add USS_A-specific information.....                                                                    | 476  |
| • Added SAPH_A and related description in <a href="#">Chapter 21, Sequencer for Acquisition, Programmable Pulse Generator, and Physical Interface (SAPH, SAPH_A)</a> .....    | 492  |

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