

## Introduction

This reference manual targets application developers. It provides complete information on how to use the STM32F401xB/C and STM32F401xD/E microcontroller memory and peripherals.

STM32F401xB/C and STM32F401xD/E are part of the STM32F401xx family of microcontrollers with different memory sizes, packages and peripherals.

For ordering information, mechanical and electrical device characteristics please refer to the datasheets.

For information on the ARM Cortex™-M4 with FPU core, please refer to the *Cortex™-M4 with FPU Technical Reference Manual*.

## Related documents

Available from STMicroelectronics web site (<http://www.st.com>):

- STM32F401xB/C datasheet
- STM32F401xD/E datasheet
- For information on the ARM Cortex™-M4 core with FPU, refer to the *STM32F3xx/F4xxx Cortex™-M4 programming manual (PM0214)*.

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# 1 Documentation conventions

## 1.1 List of abbreviations for registers

The following abbreviations are used in register descriptions:

read/write (rw)	Software can read and write to these bits.
read-only (r)	Software can only read these bits.
write-only (w)	Software can only write to this bit. Reading the bit returns the reset value.
read/clear (rc_w1)	Software can read as well as clear this bit by writing 1. Writing '0' has no effect on the bit value.
read/clear (rc_w0)	Software can read as well as clear this bit by writing 0. Writing '1' has no effect on the bit value.
read/clear by read (rc_r)	Software can read this bit. Reading this bit automatically clears it to '0'. Writing '0' has no effect on the bit value.
read/set (rs)	Software can read as well as set this bit. Writing '0' has no effect on the bit value.
read-only write trigger (rt_w)	Software can read this bit. Writing '0' or '1' triggers an event but has no effect on the bit value.
toggle (t)	Software can only toggle this bit by writing '1'. Writing '0' has no effect.
Reserved (Res.)	Reserved bit, must be kept at reset value.

## 1.2 Glossary

This section gives a brief definition of acronyms and abbreviations used in this document:

- The CPU core integrates two debug ports:
  - JTAG debug port (JTAG-DP) provides a 5-pin standard interface based on the Joint Test Action Group (JTAG) protocol.
  - SWD debug port (SWD-DP) provides a 2-pin (clock and data) interface based on the Serial Wire Debug (SWD) protocol.  
For both the JTAG and SWD protocols, please refer to the Cortex-M4 with FPU Technical Reference Manual
- Word: data/instruction of 32-bit length.
- Half word: data/instruction of 16-bit length.
- Byte: data of 8-bit length.
- Double word: data of 64-bit length.
- IAP (in-application programming): IAP is the ability to reprogram the Flash memory of a microcontroller while the user program is running.
- ICP (in-circuit programming): ICP is the ability to program the Flash memory of a microcontroller using the JTAG protocol, the SWD protocol or the bootloader while the device is mounted on the user application board.
- I-Code: this bus connects the Instruction bus of the CPU core to the Flash instruction interface. Prefetch is performed on this bus.
- D-Code: this bus connects the D-Code bus (literal load and debug access) of the CPU to the Flash data interface.
- Option bytes: product configuration bits stored in the Flash memory.
- OBL: option byte loader.
- AHB: advanced high-performance bus.
- CPU: refers to the Cortex-M4 with FPU core.

## 1.3 Peripheral availability

For information on the availability and the number of instances of each peripheral in the various STM32F401xx salestypes, please refer to the STM32F401xB/C and STM32F401xD/E datasheets.

## 2 Memory and bus architecture

### 2.1 System architecture

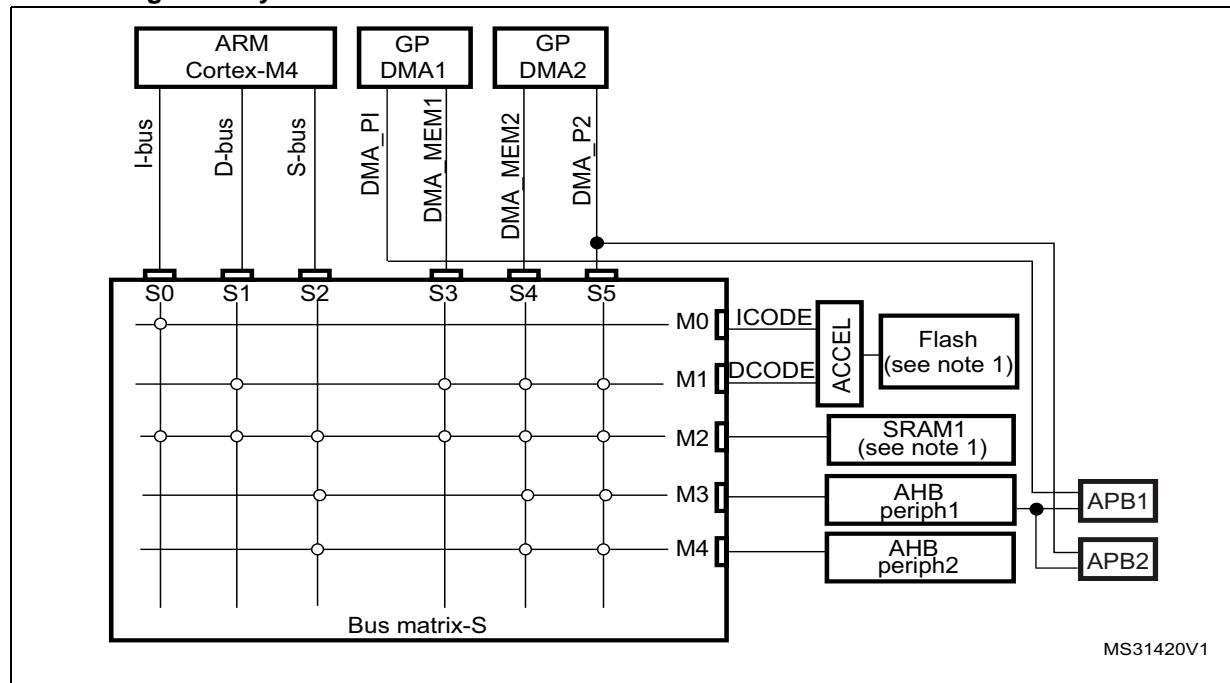
In STM32F401xB/C and STM32F401xD/E, the main system consists of 32-bit multilayer AHB bus matrix that interconnects:

The main system consists of 32-bit multilayer AHB bus matrix that interconnects:

- Six masters:
  - Cortex™-M4 with FPU core I-bus, D-bus and S-bus
  - DMA1 memory bus
  - DMA2 memory bus
  - DMA2 peripheral bus
- Five slaves:
  - Internal Flash memory ICode bus
  - Internal Flash memory DCode bus
  - Main internal SRAM1
  - AHB1 peripherals including AHB to APB bridges and APB peripherals
  - AHB2 peripherals

The bus matrix provides access from a master to a slave, enabling concurrent access and efficient operation even when several high-speed peripherals work simultaneously. This architecture is shown in [Figure 1](#).

**Figure 1. System architecture for STM32F401xB/C and STM32F401xD/E devices**



1. STM32F401xB/C: 128 KBytes / 256 KBytes Flash with 64 KBytes SRAM  
STM32F401xD/E: 384 KBytes / 512KBytes Flash with 96 KBytes SRAM

## 2.1.1 I-bus

This bus connects the Instruction bus of the Cortex™-M4 with FPU core to the BusMatrix. This bus is used by the core to fetch instructions. The target of this bus is a memory containing code (internal Flash memory/SRAM).

## 2.1.2 D-bus

This bus connects the databus of the Cortex™-M4 with FPU to the BusMatrix. This bus is used by the core for literal load and debug access. The target of this bus is a memory containing code or data (internal Flash memory/SRAM).

## 2.1.3 S-bus

This bus connects the system bus of the Cortex™-M4 with FPU core to a BusMatrix. This bus is used to access data located in a peripheral or in SRAM. Instructions may also be fetched on this bus (less efficient than ICode). The targets of this bus are the internal SRAM, the AHB1 peripherals including the APB peripherals and the AHB2 peripherals.

## 2.1.4 DMA memory bus

This bus connects the DMA memory bus master interface to the BusMatrix. It is used by the DMA to perform transfer to/from memories. The targets of this bus are data memories: internal Flash memory, internal SRAM and additionally for S4 the AHB1/AHB2 peripherals including the APB peripherals.

## 2.1.5 DMA peripheral bus

This bus connects the DMA peripheral master bus interface to the BusMatrix. This bus is used by the DMA to access AHB peripherals or to perform memory-to-memory transfers. The targets of this bus are the AHB and APB peripherals plus data memories: Flash memory and internal SRAM.

## 2.1.6 BusMatrix

The BusMatrix manages the access arbitration between masters. The arbitration uses a round-robin algorithm.

## 2.1.7 AHB/APB bridges (APB)

The two AHB/APB bridges, APB1 and APB2, provide full synchronous connections between the AHB and the two APB buses, allowing flexible selection of the peripheral frequency.

Refer to the device datasheets for more details on APB1 and APB2 maximum frequencies, and to [Table 1](#) for the address mapping of AHB and APB peripherals.

After each device reset, all peripheral clocks are disabled (except for the SRAM and Flash memory interface). Before using a peripheral you have to enable its clock in the RCC\_AHBxENR or RCC\_APBxENR register.

*Note:* When a 16- or an 8-bit access is performed on an APB register, the access is transformed into a 32-bit access: the bridge duplicates the 16- or 8-bit data to feed the 32-bit vector.

## 2.2 Memory organization

Program memory, data memory, registers and I/O ports are organized within the same linear 4 Gbyte address space.

The bytes are coded in memory in little endian format. The lowest numbered byte in a word is considered the word's least significant byte and the highest numbered byte, the word's most significant.

For the detailed mapping of peripheral registers, please refer to the related chapters.

The addressable memory space is divided into 8 main blocks, each of 512 MB.

All the memory areas that are not allocated to on-chip memories and peripherals are considered “Reserved”). Refer to the memory map figure in the product datasheet.

## 2.3 Memory map

See the datasheet corresponding to your device for a comprehensive diagram of the memory map. *Table 1* gives the boundary addresses of the peripherals available in STM32F401xB/C and STM32F401xD/E devices.

**Table 1. STM32F401xB/C and STM32F401xD/E register boundary addresses**

Boundary address	Peripheral	Bus	Register map
0x5000 0000 - 0x5003 FFFF	USB OTG FS	AHB2	<a href="#">Section 22.16.6: OTG_FS register map on page 742</a>
0x4002 6400 - 0x4002 67FF	DMA2	AHB1	<a href="#">Section 9.5.11: DMA register map on page 192</a>
0x4002 6000 - 0x4002 63FF	DMA1		<a href="#">Section 3.8: Flash interface registers on page 59</a>
0x4002 3C00 - 0x4002 3FFF	Flash interface register		<a href="#">Section 6.3.22: RCC register map on page 132</a>
0x4002 3800 - 0x4002 3BFF	RCC		<a href="#">Section 4.4.4: CRC register map on page 69</a>
0x4002 3000 - 0x4002 33FF	CRC		
0x4002 1C00 - 0x4002 1FFF	GPIOH		
0x4002 1000 - 0x4002 13FF	GPIOE		
0x4002 0C00 - 0x4002 0FFF	GPIOD		
0x4002 0800 - 0x4002 0BFF	GPIOC		
0x4002 0400 - 0x4002 07FF	GPIOB		
0x4002 0000 - 0x4002 03FF	GPIOA		

**Table 1. STM32F401xB/C and STM32F401xD/E register boundary addresses (continued)**

Boundary address	Peripheral	Bus	Register map
0x4001 4800 - 0x4001 4BFF	TIM11	APB2	<a href="#">Section 14.5.10: TIM10/11 register map on page 404</a>
0x4001 4400 - 0x4001 47FF	TIM10		<a href="#">Section 14.4.13: TIM9/11 register map on page 395</a>
0x4001 4000 - 0x4001 43FF	TIM9		<a href="#">Section 10.3.7: EXTI register map on page 206</a>
0x4001 3C00 - 0x4001 3FFF	EXTI		<a href="#">Section 7.2.8: SYSCFG register map</a>
0x4001 3800 - 0x4001 3BFF	SYSCFG		<a href="#">Section 20.5.10: SPI register map on page 600</a>
0x4001 3400 - 0x4001 37FF	SPI4		<a href="#">Section 21.9.16: SDIO register map on page 655</a>
0x4001 3000 - 0x4001 33FF	SPI1		<a href="#">Section 11.12.16: ADC register map on page 233</a>
0x4001 2C00 - 0x4001 2FFF	SDIO		<a href="#">Section 19.6.8: USART register map on page 545</a>
0x4001 2000 - 0x4001 23FF	ADC1		<a href="#">Section 12.4.21: TIM1 register map on page 302</a>
0x4001 1400 - 0x4001 17FF	USART6		<a href="#">Section 5.5: PWR register map on page 87</a>
0x4001 1000 - 0x4001 13FF	USART1	APB1	<a href="#">Section 18.6.11: I2C register map on page 493</a>
0x4001 0000 - 0x4001 03FF	TIM1		<a href="#">Section 19.6.8: USART register map on page 545</a>
0x4000 7000 - 0x4000 73FF	PWR		<a href="#">Section 20.5.10: SPI register map on page 600</a>
0x4000 5C00 - 0x4000 5FFF	I2C3		<a href="#">Section 15.4.5: IWDG register map on page 411</a>
0x4000 5800 - 0x4000 5BFF	I2C2		<a href="#">Section 16.6.4: WWDG register map on page 418</a>
0x4000 5400 - 0x4000 57FF	I2C1		<a href="#">Section 17.6.21: RTC register map on page 456</a>
0x4000 4400 - 0x4000 47FF	USART2		<a href="#">Section 13.4.21: TIMx register map on page 362</a>
0x4000 4000 - 0x4000 43FF	I2S3ext		
0x4000 3C00 - 0x4000 3FFF	SPI3 / I2S3		
0x4000 3800 - 0x4000 3BFF	SPI2 / I2S2		
0x4000 3400 - 0x4000 37FF	I2S2ext		
0x4000 3000 - 0x4000 33FF	IWDG		
0x4000 2C00 - 0x4000 2FFF	WWDG		
0x4000 2800 - 0x4000 2BFF	RTC & BKP Registers		
0x4000 0C00 - 0x4000 0FFF	TIM5		
0x4000 0800 - 0x4000 0BFF	TIM4		
0x4000 0400 - 0x4000 07FF	TIM3		
0x4000 0000 - 0x4000 03FF	TIM2		

### 2.3.1 Embedded SRAM

STM32F401xB/C devices feature 64 Kbytes and STM32F401xD/E devices feature 96 Kbytes of system SRAM.

The embedded SRAM can be accessed as bytes, half-words (16 bits) or full words (32 bits). Read and write operations are performed at CPU speed with 0 wait state.

The CPU can access the embedded SRAM through the System Bus or through the I-Code/D-Code buses when boot from SRAM is selected or when physical remap is selected ([Section 7.2.1: SYSCFG memory remap register \(SYSCFG\\_MEMRMP\)](#)) in the SYSCFG controller). To get the max performance on SRAM execution, physical remap should be selected (boot or software selection).

### 2.3.2 Flash memory overview

The Flash memory interface manages CPU AHB I-Code and D-Code accesses to the Flash memory. It implements the erase and program Flash memory operations and the read and write protection mechanisms. It accelerates code execution with a system of instruction prefetch and cache lines.

The Flash memory is organized as follows:

- A main memory block divided into sectors.
- System memory from which the device boots in System memory boot mode
- 512 OTP (one-time programmable) bytes for user data.
- Option bytes to configure read and write protection, BOR level, watchdog software/hardware and reset when the device is in Standby or Stop mode.

Refer to [Section 3: Embedded Flash memory interface](#) for more details.

### 2.3.3 Bit banding

The Cortex™-M4 with FPU memory map includes two bit-band regions. These regions map each word in an alias region of memory to a bit in a bit-band region of memory. Writing to a word in the alias region has the same effect as a read-modify-write operation on the targeted bit in the bit-band region.

In the STM32F4xx devices both the peripheral registers and the SRAM are mapped to a bit-band region, so that single bit-band write and read operations are allowed. The operations are only available for Cortex™-M4 with FPU accesses, and not from other bus masters (e.g. DMA).

A mapping formula shows how to reference each word in the alias region to a corresponding bit in the bit-band region. The mapping formula is:

$$\text{bit\_word\_addr} = \text{bit\_band\_base} + (\text{byte\_offset} \times 32) + (\text{bit\_number} \times 4)$$

where:

- *bit\_word\_addr* is the address of the word in the alias memory region that maps to the targeted bit
- *bit\_band\_base* is the starting address of the alias region
- *byte\_offset* is the number of the byte in the bit-band region that contains the targeted bit
- *bit\_number* is the bit position (0-7) of the targeted bit

#### Example

The following example shows how to map bit 2 of the byte located at SRAM address 0x20000300 to the alias region:

$$0x22006008 = 0x22000000 + (0x300*32) + (2*4)$$

Writing to address 0x22006008 has the same effect as a read-modify-write operation on bit 2 of the byte at SRAM address 0x20000300.

Reading address 0x22006008 returns the value (0x01 or 0x00) of bit 2 of the byte at SRAM address 0x20000300 (0x01: bit set; 0x00: bit reset).

For more information on bit-banding, please refer to the *Cortex™-M4 with FPU programming manual* (see [Related documents on page 1](#)).

## 2.4 Boot configuration

Due to its fixed memory map, the code area starts from address 0x0000 0000 (accessed through the ICode/DCode buses) while the data area (SRAM) starts from address 0x2000 0000 (accessed through the system bus). The Cortex™-M4 with FPU CPU always fetches the reset vector on the ICode bus, which implies to have the boot space available only in the code area (typically, Flash memory). STM32F4xx microcontrollers implement a special mechanism to be able to boot from other memories (like the internal SRAM).

In the STM32F4xx, three different boot modes can be selected through the BOOT[1:0] pins as shown in [Table 2](#).

**Table 2. Boot modes**

Boot mode selection pins		Boot mode	Aliasing
BOOT1	BOOT0		
x	0	Main Flash memory	Main Flash memory is selected as the boot space
0	1	System memory	System memory is selected as the boot space
1	1	Embedded SRAM	Embedded SRAM is selected as the boot space

The values on the BOOT pins are latched on the 4th rising edge of SYSCLK after a reset. It is up to the user to set the BOOT1 and BOOT0 pins after reset to select the required boot mode.

BOOT0 is a dedicated pin while BOOT1 is shared with a GPIO pin. Once BOOT1 has been sampled, the corresponding GPIO pin is free and can be used for other purposes.

The BOOT pins are also resampled when the device exits the Standby mode. Consequently, they must be kept in the required Boot mode configuration when the device is in the Standby mode. After this startup delay is over, the CPU fetches the top-of-stack value from address 0x0000 0000, then starts code execution from the boot memory starting from 0x0000 0004.

**Note:** *When the device boots from SRAM, in the application initialization code, you have to relocate the vector table in SRAM using the NVIC exception table and the offset register.*

## Embedded bootloader

The embedded bootloader mode is used to reprogram the Flash memory using one of the following serial interfaces:

- USART1 (PA9/PA10)
- USART2 (PD5/PD6)
- I2C1 (PB6/PB7)
- I2C2 (PB10/PB3)
- I2C3 (PA8/PB4)
- SPI1 (PA4/PA5/PA6/PA7)
- SPI2 (PB12/PB13/PB14/PB15)
- SPI3 (PA15/PC10/PC11/PC12)
- USB OTG FS (PA11/12) in Device mode (DFU: device firmware upgrade).

The USART peripherals operate at the internal 16 MHz oscillator (HSI) frequency, while the USB OTG FS require an external clock (HSE) multiple of 1 MHz (ranging from 4 to 26 MHz).

The embedded bootloader code is located in system memory. It is programmed by ST during production. For additional information, refer to application note AN2606.

## Physical remap in STM32F401xB/C and STM32F401xD/E

Once the boot pins are selected, the application software can modify the memory accessible in the code area (in this way the code can be executed through the ICode bus in place of the System bus). This modification is performed by programming the [Section 7.2.1: SYSCFG memory remap register \(SYSCFG\\_MEMRMP\)](#) in the SYSCFG controller.

The following memories can thus be remapped:

- Main Flash memory
- System memory
- Embedded SRAM1

**Table 3. Memory mapping vs. Boot mode/physical remap in STM32F401xB/C**

Addresses	Boot/Remap in main Flash memory	Boot/Remap in embedded SRAM	Boot/Remap in System memory
0x2000 0000 - 0x2000 FFFF	SRAM1 (64 KB)	SRAM1 (64 KB)	SRAM1 (64 KB)
0x1FFF 0000 - 0x1FFF 77FF	System memory	System memory	System memory
0x0804 0000 - 0x1FFE FFFF	Reserved	Reserved	Reserved
0x0800 0000 - 0x0803 FFFF	Flash memory	Flash memory	Flash memory
0x0400 000 - 0x07FF FFFF	Reserved	Reserved	Reserved
0x0000 0000 - 0x0003 FFFF <sup>(1)</sup>	Flash (256 KB) Aliased	SRAM1 (64 KB) Aliased	System memory (30 KB) Aliased

1. Even when aliased in the boot memory space, the related memory is still accessible at its original memory space.

**Table 4. Memory mapping vs. Boot mode/physical remap in STM32F401xD/E**

Addresses	Boot/Remap in main Flash memory	Boot/Remap in embedded SRAM	Boot/Remap in System memory
0x2000 0000 - 0x2000 FFFF	SRAM1 (96 KB)	SRAM1 (96KB)	SRAM1 (96KB)
0x1FFF 0000 - 0x1FFF 77FF	System memory	System memory	System memory
0x0804 0000 - 0x1FFE FFFF	Reserved	Reserved	Reserved
0x0800 0000 - 0x0807 FFFF	Flash memory	Flash memory	Flash memory
0x0400 000 - 0x07FF FFFF	Reserved	Reserved	Reserved
0x0000 0000 - 0x0007 FFFF <sup>(1)</sup>	Flash (512 KB) Aliased	SRAM1 (96 KB) Aliased	System memory (30 KB) Aliased

1. Even when aliased in the boot memory space, the related memory is still accessible at its original memory space.

## 3 Embedded Flash memory interface

### 3.1 Introduction

The Flash memory interface manages CPU AHB I-Code and D-Code accesses to the Flash memory. It implements the erase and program Flash memory operations and the read and write protection mechanisms.

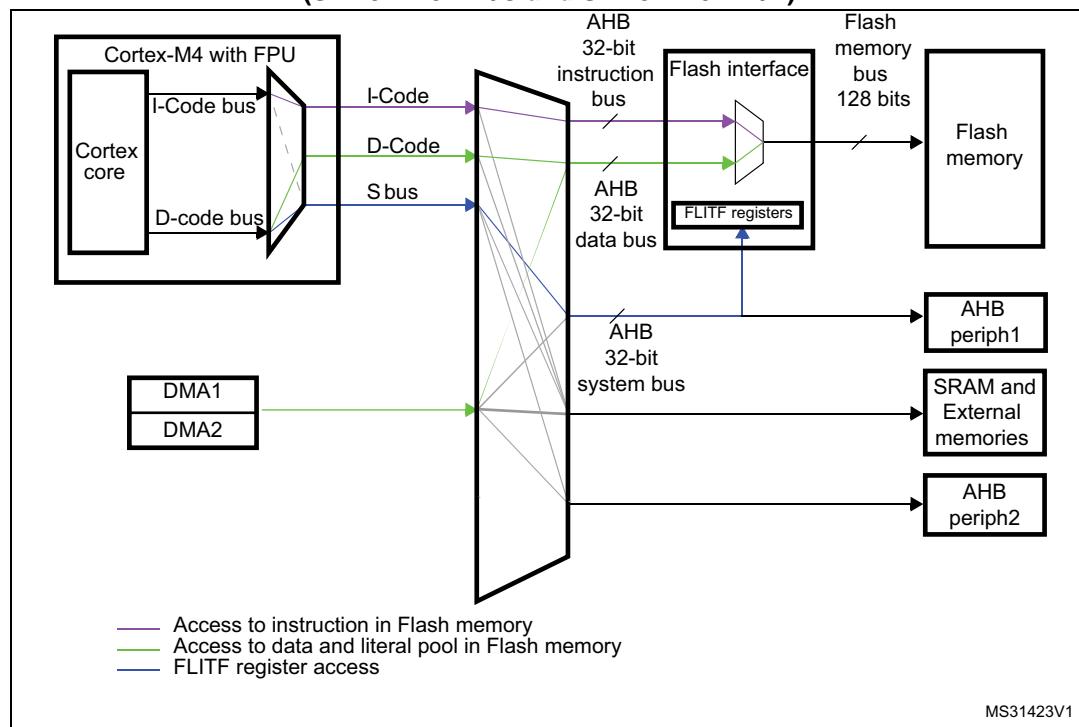
The Flash memory interface accelerates code execution with a system of instruction prefetch and cache lines.

### 3.2 Main features

- Flash memory read operations
- Flash memory program/erase operations
- Read / write protections
- Prefetch on I-Code
- 64 cache lines of 128 bits on I-Code
- 8 cache lines of 128 bits on D-Code

*Figure 2* shows the Flash memory interface connection inside the system architecture.

**Figure 2. Flash memory interface connection inside system architecture  
(STM32F401xB/C and STM32F401xD/E)**



### 3.3 Embedded Flash memory in STM32F401xB/C and STM32F401xD/E

The Flash memory has the following main features:

- Capacity up to 256 Kbytes for STM32F401xB/C and up to 512 KBytes for STM32F401xD/E
- 128 bits wide data read
- Byte, half-word, word and double word write
- Sector and mass erase
- Memory organization

The Flash memory is organized as follows:

- A main memory block divided into 4 sectors of 16 KBytes, 1 sector of 64 KBytes, 1 sector of 128 KBytes (STM32F401xB/C) or 3 sectors of 128 Kbytes (STM32F401xD/E)
- System memory from which the device boots in System memory boot mode
- 512 OTP (one-time programmable) bytes for user data  
The OTP area contains 16 additional bytes used to lock the corresponding OTP data block.
- Option bytes to configure read and write protection, BOR level, watchdog software/hardware and reset when the device is in Standby or Stop mode.
- Low power modes (for details refer to the Power control (PWR) section of the reference manual)

**Table 5. Flash module organization (STM32F401xB/C and STM32F401xD/E)**

Block	Name	Block base addresses	Size
Main memory	Sector 0	0x0800 0000 - 0x0800 3FFF	16 Kbytes
	Sector 1	0x0800 4000 - 0x0800 7FFF	16 Kbytes
	Sector 2	0x0800 8000 - 0x0800 BFFF	16 Kbytes
	Sector 3	0x0800 C000 - 0x0800 FFFF	16 Kbytes
	Sector 4	0x0801 0000 - 0x0801 FFFF	64 Kbytes
	Sector 5	0x0802 0000 - 0x0803 FFFF	128 Kbytes
	Sector 6	0x0804 0000 - 0x0805 FFFF	128 Kbytes
	Sector 7	0x0806 0000 - 0x0807 FFFF	128 Kbytes
System memory		0x1FFF 0000 - 0x1FFF 77FF	30 Kbytes
OTP area		0x1FFF 7800 - 0x1FFF 7A0F	528 bytes
Option bytes		0x1FFF C000 - 0x1FFF C00F	16 bytes

## 3.4 Read interface

### 3.4.1 Relation between CPU clock frequency and Flash memory read time

To correctly read data from Flash memory, the number of wait states (LATENCY) must be correctly programmed in the Flash access control register (FLASH\_ACR) according to the frequency of the CPU clock (HCLK) and the supply voltage of the device.

The prefetch buffer must be disabled when the supply voltage is below 2.1 V. The correspondence between wait states and CPU clock frequency is given in [Table 6](#).

- when  $VOS[1:0] = 0x01$ , the maximum value of  $f_{HCLK} = 60$  MHz.
- when  $VOS[1:0] = 0x10$ , the maximum value of  $f_{HCLK} = 84$  MHz.

**Table 6. Number of wait states according to CPU clock (HCLK) frequency**

Wait states (WS) (LATENCY)	HCLK (MHz)			
	Voltage range 2.7 V - 3.6 V	Voltage range 2.4 V - 2.7 V	Voltage range 2.1 V - 2.4 V	Voltage range 1.71 V - 2.1 V
0 WS (1 CPU cycle)	$0 < HCLK \leq 30$	$0 < HCLK \leq 24$	$0 < HCLK \leq 18$	$0 < HCLK \leq 16$
1 WS (2 CPU cycles)	$30 < HCLK \leq 60$	$24 < HCLK \leq 48$	$18 < HCLK \leq 36$	$16 < HCLK \leq 32$
2 WS (3 CPU cycles)	$60 < HCLK \leq 84$	$48 < HCLK \leq 72$	$36 < HCLK \leq 54$	$32 < HCLK \leq 48$
3 WS (4 CPU cycles)		$72 < HCLK \leq 84$	$54 < HCLK \leq 72$	$48 < HCLK \leq 64$
4 WS (5 CPU cycles)			$72 < HCLK \leq 84$	$64 < HCLK \leq 80$
5 WS (6 CPU cycles)				$80 < HCLK \leq 84$

After reset, the CPU clock frequency is 16 MHz and 0 wait state (WS) is configured in the FLASH\_ACR register.

It is highly recommended to use the following software sequences to tune the number of wait states needed to access the Flash memory with the CPU frequency.

#### Increasing the CPU frequency

1. Program the new number of wait states to the LATENCY bits in the FLASH\_ACR register
2. Check that the new number of wait states is taken into account to access the Flash memory by reading the FLASH\_ACR register
3. Modify the CPU clock source by writing the SW bits in the RCC\_CFGR register
4. If needed, modify the CPU clock prescaler by writing the HPRE bits in RCC\_CFGR
5. Check that the new CPU clock source or/and the new CPU clock prescaler value is/are taken into account by reading the clock source status (SWS bits) or/and the AHB prescaler value (HPRE bits), respectively, in the RCC\_CFGR register.

### Decreasing the CPU frequency

1. Modify the CPU clock source by writing the SW bits in the RCC\_CFGR register
2. If needed, modify the CPU clock prescaler by writing the HPRE bits in RCC\_CFGR
3. Check that the new CPU clock source or/and the new CPU clock prescaler value is/are taken into account by reading the clock source status (SWS bits) or/and the AHB prescaler value (HPRE bits), respectively, in the RCC\_CFGR register
4. Program the new number of wait states to the LATENCY bits in FLASH\_ACR
5. Check that the new number of wait states is used to access the Flash memory by reading the FLASH\_ACR register

Note:

*A change in CPU clock configuration or wait state (WS) configuration may not be effective straight away. To make sure that the current CPU clock frequency is the one you have configured, you can check the AHB prescaler factor and clock source status values. To make sure that the number of WS you have programmed is effective, you can read the FLASH\_ACR register.*

### 3.4.2

### Adaptive real-time memory accelerator (ART Accelerator™)

The proprietary Adaptive real-time (ART) memory accelerator is optimized for STM32 industry-standard ARM® Cortex™-M4 with FPU processors. It balances the inherent performance advantage of the ARM Cortex-M4 with FPU over Flash memory technologies, which normally requires the processor to wait for the Flash memory at higher operating frequencies.

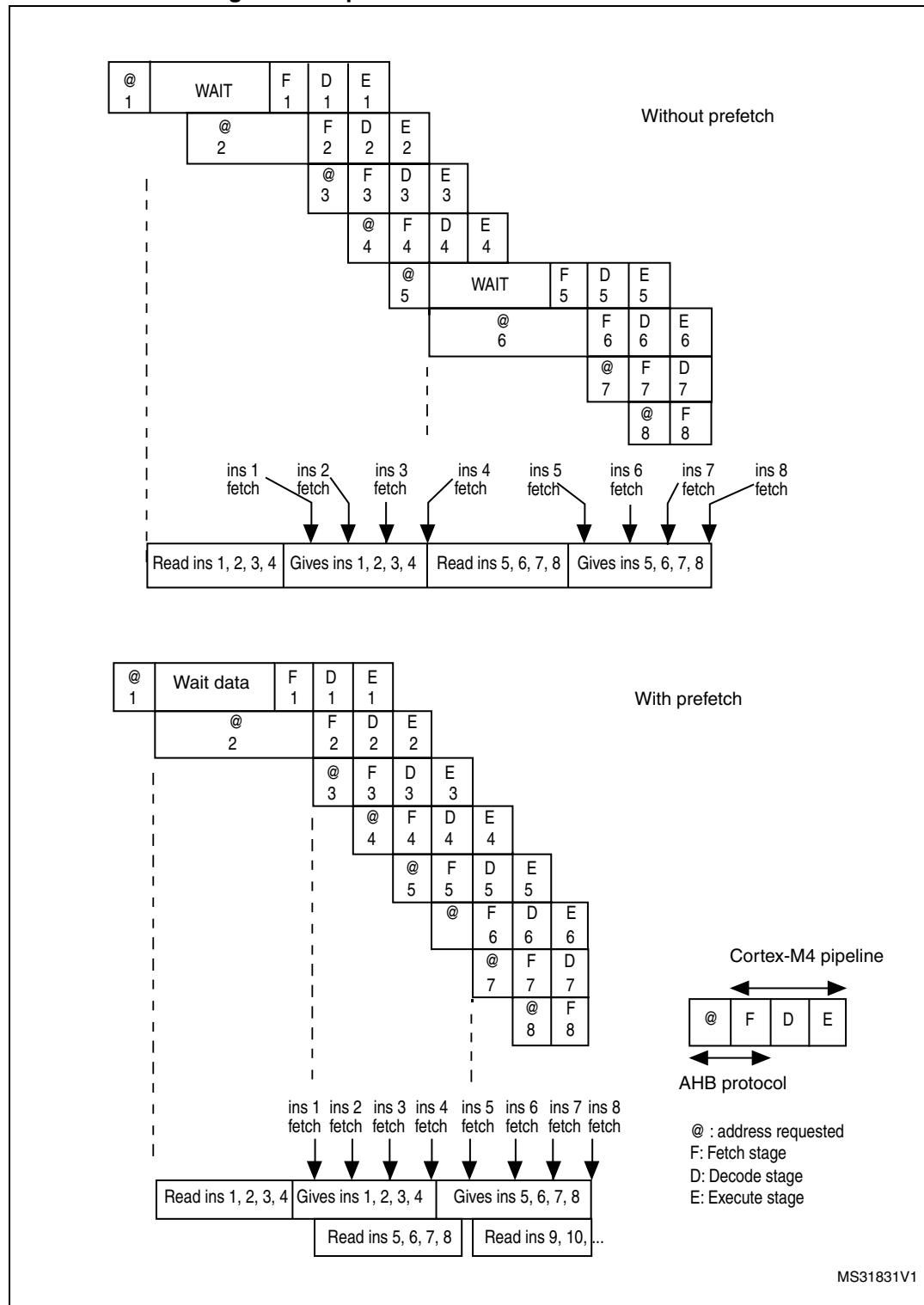
To release the processor full performance, the accelerator implements an instruction prefetch queue and branch cache which increases program execution speed from the 128-bit Flash memory. Based on CoreMark benchmark, the performance achieved thanks to the ART accelerator is equivalent to 0 wait state program execution from Flash memory at a CPU frequency up to 84 MHz.

#### Instruction prefetch

Each Flash memory read operation provides 128 bits from either four instructions of 32 bits or 8 instructions of 16 bits according to the program launched. So, in case of sequential code, at least four CPU cycles are needed to execute the previous read instruction line. Prefetch on the I-Code bus can be used to read the next sequential instruction line from the Flash memory while the current instruction line is being requested by the CPU. Prefetch is enabled by setting the PRFTEN bit in the FLASH\_ACR register. This feature is useful if at least one wait state is needed to access the Flash memory.

*Figure 3* shows the execution of sequential 32-bit instructions with and without prefetch when 3 WSs are needed to access the Flash memory.

Figure 3. Sequential 32-bit instruction execution



When the code is not sequential (branch), the instruction may not be present in the currently used instruction line or in the prefetched instruction line. In this case (miss), the penalty in terms of number of cycles is at least equal to the number of wait states.

### Instruction cache memory

To limit the time lost due to jumps, it is possible to retain 64 lines of 128 bits in an instruction cache memory. This feature can be enabled by setting the instruction cache enable (ICEN) bit in the FLASH\_ACR register. Each time a miss occurs (requested data not present in the currently used instruction line, in the prefetched instruction line or in the instruction cache memory), the line read is copied into the instruction cache memory. If some data contained in the instruction cache memory are requested by the CPU, they are provided without inserting any delay. Once all the instruction cache memory lines have been filled, the LRU (least recently used) policy is used to determine the line to replace in the instruction memory cache. This feature is particularly useful in case of code containing loops.

### Data management

Literal pools are fetched from Flash memory through the D-Code bus during the execution stage of the CPU pipeline. The CPU pipeline is consequently stalled until the requested literal pool is provided. To limit the time lost due to literal pools, accesses through the AHB databus D-Code have priority over accesses through the AHB instruction bus I-Code.

If some literal pools are frequently used, the data cache memory can be enabled by setting the data cache enable (DCEN) bit in the FLASH\_ACR register. This feature works like the instruction cache memory, but the retained data size is limited to 8 rows of 128 bits.

*Note:* *Data in user configuration sector are not cacheable.*

## 3.5 Erase and program operations

For any Flash memory program operation (erase or program), the CPU clock frequency (HCLK) must be at least 1 MHz. The contents of the Flash memory are not guaranteed if a device reset occurs during a Flash memory operation.

Any attempt to read the Flash memory on STM32F4xx while it is being written or erased, causes the bus to stall. Read operations are processed correctly once the program operation has completed. This means that code or data fetches cannot be performed while a write/erase operation is ongoing.

### 3.5.1 Unlocking the Flash control register

After reset, write is not allowed in the Flash control register (FLASH\_CR) to protect the Flash memory against possible unwanted operations due, for example, to electric disturbances. The following sequence is used to unlock this register:

1. Write KEY1 = 0x45670123 in the Flash key register (FLASH\_KEYR)
2. Write KEY2 = 0xCDEF89AB in the Flash key register (FLASH\_KEYR)

Any wrong sequence will return a bus error and lock up the FLASH\_CR register until the next reset.

The FLASH\_CR register can be locked again by software by setting the LOCK bit in the FLASH\_CR register.

*Note:* *The FLASH\_CR register is not accessible in write mode when the BSY bit in the FLASH\_SR register is set. Any attempt to write to it with the BSY bit set will cause the AHB bus to stall until the BSY bit is cleared.*

### 3.5.2 Program/erase parallelism

The Parallelism size is configured through the PSIZE field in the FLASH\_CR register. It represents the number of bytes to be programmed each time a write operation occurs to the Flash memory. PSIZE is limited by the supply voltage and by whether the external V<sub>PP</sub> supply is used or not. It must therefore be correctly configured in the FLASH\_CR register before any programming/erasing operation.

A Flash memory erase operation can only be performed by sector, or for the whole Flash memory (mass erase). The erase time depends on PSIZE programmed value. For more details on the erase time, refer to the electrical characteristics section of the device datasheet.

[Table 7](#) provides the correct PSIZE values.

**Table 7. Program/erase parallelism**

	Voltage range 2.7 - 3.6 V with External V <sub>PP</sub>	Voltage range 2.7 - 3.6 V	Voltage range 2.4 - 2.7 V	Voltage range 2.1 - 2.4 V	Voltage range 1.7 V - 2.1 V
Parallelism size	x64	x32	x16	x8	
PSIZE(1:0)	11	10	01	00	

**Note:** Any program or erase operation started with inconsistent program parallelism/voltage range settings may lead to unpredicted results. Even if a subsequent read operation indicates that the logical value was effectively written to the memory, this value may not be retained.

To use V<sub>PP</sub> an external high-voltage supply (between 8 and 9 V) must be applied to the V<sub>PP</sub> pad. The external supply must be able to sustain this voltage range even if the DC consumption exceeds 10 mA. It is advised to limit the use of V<sub>PP</sub> to initial programming on the factory line. The V<sub>PP</sub> supply must not be applied for more than an hour, otherwise the Flash memory might be damaged.

### 3.5.3 Erase

The Flash memory erase operation can be performed at sector level or on the whole Flash memory (Mass Erase). Mass Erase does not affect the OTP sector or the configuration sector.

#### Sector Erase

To erase a sector, follow the procedure below:

1. Check that no Flash memory operation is ongoing by checking the BSY bit in the FLASH\_SR register
2. Set the SER bit and select the sector out of the 5 sectors (for STM32F401xB/C) and out of 7 (for STM32F401xD/E) in the main memory block you wish to erase (SNB) in the FLASH\_CR register
3. Set the STRT bit in the FLASH\_CR register
4. Wait for the BSY bit to be cleared

#### Mass Erase

To perform Mass Erase, the following sequence is recommended:

1. Check that no Flash memory operation is ongoing by checking the BSY bit in the FLASH\_SR register
2. Set the MER bit in the FLASH\_CR register
3. Set the STRT bit in the FLASH\_CR register
4. Wait for the BSY bit to be cleared

*Note:* If MERx and SER bits are both set in the FLASH\_CR register, neither sector nor mass erase can be performed.

### 3.5.4 Programming

#### Standard programming

The Flash memory programming sequence is as follows:

1. Check that no main Flash memory operation is ongoing by checking the BSY bit in the FLASH\_SR register.
2. Set the PG bit in the FLASH\_CR register
3. Perform the data write operation(s) to the desired memory address (inside main memory block or OTP area):
  - Byte access in case of x8 parallelism
  - Half-word access in case of x16 parallelism
  - Word access in case of x32 parallelism
  - Double word access in case of x64 parallelism
4. Wait for the BSY bit to be cleared.

*Note:* Successive write operations are possible without the need of an erase operation when changing bits from '1' to '0'. Writing '1' requires a Flash memory erase operation.

*If an erase and a program operation are requested simultaneously, the erase operation is performed first.*

#### Programming errors

It is not allowed to program data to the Flash memory that would cross the 128-bit row boundary. In such a case, the write operation is not performed and a program alignment error flag (PGAERR) is set in the FLASH\_SR register.

The write access type (byte, half-word, word or double word) must correspond to the type of parallelism chosen (x8, x16, x32 or x64). If not, the write operation is not performed and a program parallelism error flag (PGPERR) is set in the FLASH\_SR register.

If the standard programming sequence is not respected (for example, if there is an attempt to write to a Flash memory address when the PG bit is not set), the operation is aborted and a program sequence error flag (PGSERR) is set in the FLASH\_SR register.

#### Programming and caches

If a Flash memory write access concerns some data in the data cache, the Flash write access modifies the data in the Flash memory and the data in the cache.

If an erase operation in Flash memory also concerns data in the data or instruction cache, you have to make sure that these data are rewritten before they are accessed during code execution. If this cannot be done safely, it is recommended to flush the caches by setting the DCRST and ICRST bits in the FLASH\_CR register.

*Note:* The I/D cache should be flushed only when it is disabled ( $I/DCEN = 0$ ).

### 3.5.5 Interrupts

Setting the end of operation interrupt enable bit (EOPIE) in the FLASH\_CR register enables interrupt generation when an erase or program operation ends, that is when the busy bit (BSY) in the FLASH\_SR register is cleared (operation completed, correctly or not). In this case, the end of operation (EOP) bit in the FLASH\_SR register is set.

If an error occurs during a program, an erase, or a read operation request, one of the following error flags is set in the FLASH\_SR register:

- PGAERR, PGPERR, PGSERR (Program error flags)
- WRPERR (Protection error flag)

In this case, if the error interrupt enable bit (ERRIE) is set in the FLASH\_SR register, an interrupt is generated and the operation error bit (OPERR) is set in the FLASH\_SR register.

*Note:* If several successive errors are detected (for example, in case of DMA transfer to the Flash memory), the error flags cannot be cleared until the end of the successive write requests.

**Table 8. Flash interrupt request**

Interrupt event	Event flag	Enable control bit
End of operation	EOP	EOPIE
Write protection error	WRPERR	ERRIE
Programming error	PGAERR, PGPERR, PGSERR	ERRIE

## 3.6 Option bytes

### 3.6.1 Description of user option bytes

The option bytes are configured by the end user depending on the application requirements. [Table 9](#) shows the organization of these bytes inside the user configuration sector.

**Table 9. Option byte organization**

Address	[63:16]	[15:0]
0x0200 0000	Reserved	ROP & user option bytes (RDP & USER)
0x0200 0008	Reserved	Write protection nWRP bits for sectors 0 to 5 (STM32F401xB/C) and for sectors 0 to 7 (STM32F401xD/E)

**Table 10. Description of the option bytes**

<b>Option bytes (word, address 0x1FFF C000)</b>	
<b>RDP:</b> Read protection option byte. The read protection is used to protect the software code stored in Flash memory.	
Bit 15:8	0xAA: Level 0, no protection 0xCC: Level 2, chip protection (debug and boot from RAM features disabled) Others: Level 1, read protection of memories (debug features limited)
<b>USER:</b> User option byte This byte is used to configure the following features: Select the watchdog event: Hardware or software Reset event when entering the Stop mode Reset event when entering the Standby mode	
Bit 7	<b>nRST_STDBY</b> 0: Reset generated when entering the Standby mode 1: No reset generated
Bit 6	<b>nRST_STOP</b> 0: Reset generated when entering the Stop mode 1: No reset generated
Bit 5	<b>WDG_SW</b> 0: Hardware watchdog 1: Software watchdog
Bit 4	0x1: Not used
Bits 3:2	<b>BOR_lev:</b> BOR reset Level These bits contain the supply level threshold that activates/releases the reset. They can be written to program a new BOR level value into Flash memory. 00: BOR Level 3 (VBOR3), brownout threshold level 3 01: BOR Level 2 (VBOR2), brownout threshold level 2 10: BOR Level 1 (VBOR1), brownout threshold level 1 11: BOR off, POR/PDR reset threshold level is applied For full details on BOR characteristics, refer to the Electrical characteristics section of the product datasheet.
Bits 1:0	0x1: Not used
<b>Option bytes (word, address 0x1FFF C008)</b>	
Bit 15	<b>SPRMOD:</b> Selection of Protection Mode of nWPRI bits 0: nWPRI bits used for sector i write protection (Default) 1: nWPRI bits used for sector i PCROP protection (Sector)
Bits 14:6	Reserved

**Table 10. Description of the option bytes (continued)**

<b>nWRP:</b> <i>Flash memory write protection option bytes</i> Sectors 0 to 5 (STM32F401xB/C) and Sectors 0 to 7 (STM32F401xD/E) can be write protected.	
Bits 5:0	<b>nWRPi</b> If SPRMOD is reset (default value) : 0: Write protection active on sector i. 1: Write protection not active on sector i. If SPRMOD is set (active): 0: PCROP protection not active on sector i. 1: PCROP protection active on sector i.

### 3.6.2 Programming user option bytes

To run any operation on this sector, the option lock bit (OPTLOCK) in the Flash option control register (FLASH\_OPTCR) must be cleared. To be allowed to clear this bit, you have to perform the following sequence:

1. Write OPTKEY1 = 0x0819 2A3B in the Flash option key register (FLASH\_OPTKEYR)
2. Write OPTKEY2 = 0x4C5D 6E7F in the Flash option key register (FLASH\_OPTKEYR)

The user option bytes can be protected against unwanted erase/program operations by setting the OPTLOCK bit by software.

#### Modifying user option bytes

To modify the user option value, follow the sequence below:

1. Check that no Flash memory operation is ongoing by checking the BSY bit in the FLASH\_SR register
2. Write the desired option value in the FLASH\_OPTCR register.
3. Set the option start bit (OPTSTRT) in the FLASH\_OPTCR register
4. Wait for the BSY bit to be cleared.

*Note:*

*The value of an option is automatically modified by first erasing the user configuration sector and then programming all the option bytes with the values contained in the FLASH\_OPTCR register.*

### 3.6.3 Read protection (RDP)

The user area in the Flash memory can be protected against read operations by an entrusted code. Three read protection levels are defined:

- Level 0: no read protection

When the read protection level is set to Level 0 by writing 0xAA into the read protection option byte (RDP), all read/write operations (if no write protection is set) from/to the

Flash memory are possible in all boot configurations (Flash user boot, debug or boot from RAM).

- Level 1: read protection enabled

It is the default read protection level after option byte erase. The read protection Level 1 is activated by writing any value (except for 0xAA and 0xCC used to set Level 0 and Level 2, respectively) into the RDP option byte. When the read protection Level 1 is set:

- No access (read, erase, program) to Flash memory can be performed while the debug feature is connected or while booting from RAM or system memory bootloader. A bus error is generated in case of read request.
- When booting from Flash memory, accesses (read, erase, program) to Flash memory from user code are allowed.

When Level 1 is active, programming the protection option byte (RDP) to Level 0 causes the Flash memory to be mass-erased. As a result the user code area is cleared before the read protection is removed. The mass erase only erases the user code area. The other option bytes including write protections remain unchanged from before the mass-erase operation. The OTP area is not affected by mass erase and remains unchanged. Mass erase is performed only when Level 1 is active and Level 0 requested. When the protection level is increased (0->1, 1->2, 0->2) there is no mass erase.

- Level 2: debug/chip read protection disabled

The read protection Level 2 is activated by writing 0xCC to the RDP option byte. When the read protection Level 2 is set:

- All protections provided by Level 1 are active.
- Booting from RAM or system memory bootloader is no more allowed.
- JTAG, SWV (single-wire viewer), ETM, and boundary scan are disabled.
- User option bytes can no longer be changed.
- When booting from Flash memory, accesses (read, erase and program) to Flash memory from user code are allowed.

Memory read protection Level 2 is an irreversible operation. When Level 2 is activated, the level of protection cannot be decreased to Level 0 or Level 1.

*Note:*

*The JTAG port is permanently disabled when Level 2 is active (acting as a JTAG fuse). As a consequence, boundary scan cannot be performed. STMicroelectronics is not able to perform analysis on defective parts on which the Level 2 protection has been set.*

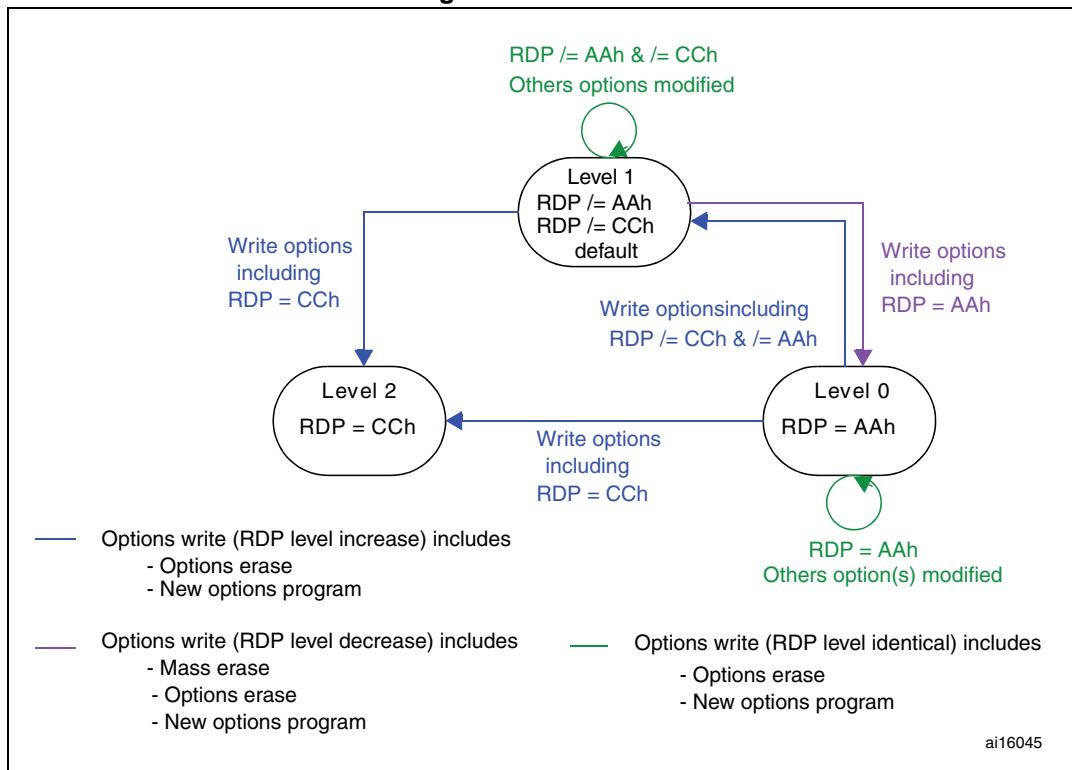
Table 11. Access versus read protection level

Memory area	Protection Level	Debug features, Boot from RAM or from System memory bootloader			Booting from Flash memory		
		Read	Write	Erase	Read	Write	Erase
Main Flash Memory	Level 1	NO		NO <sup>(1)</sup>	YES		
	Level 2	NO			YES		
Option Bytes	Level 1	YES			YES		
	Level 2	NO			NO		
OTP	Level 1	NO		NA	YES		NA
	Level 2	NO		NA	YES		NA

- The main Flash memory is only erased when the RDP changes from level 1 to 0. The OTP area remains unchanged.

*Figure 4* shows how to go from one RDP level to another.

**Figure 4. RDP levels**



### 3.6.4 Write protections

Up to 5 (STM32F401xB/C) or up to 7 (STM32F401xD/E) user sectors in Flash memory can be protected against unwanted write operations due to loss of program counter contexts. When the non-write protection nWRPi bit ( $0 \leq i \leq 7$ ) in the FLASH\_OPTCR registers is low, the corresponding sector cannot be erased or programmed. Consequently, a mass erase cannot be performed if one of the sectors is write-protected.

If an erase/program operation to a write-protected part of the Flash memory is attempted (sector protected by write protection bit, OTP part locked or part of the Flash memory that can never be written like the ICP), the write protection error flag (WRPERR) is set in the FLASH\_SR register.

*Note:*

*When the memory read protection level is selected (RDP level = 1), it is not possible to program or erase Flash memory sector i if the CPU debug features are connected (JTAG or single wire) or boot code is being executed from RAM, even if nWRPi = 1.*

#### Write protection error flag

If an erase/program operation to a write protected area of the Flash memory is performed, the Write Protection Error flag (WRPERR) is set in the FLASH\_SR register.

If an erase operation is requested, the WRPERR bit is set when:

- Mass, bank, sector erase are configured (MER or MER/MER1 and SER = 1)
- A sector erase is requested and the Sector Number SNB field is not valid
- A mass erase is requested while at least one of the user sector is write protected by option bit (MER or MER/MER1 = 1 and nWRPi = 0 with  $0 \leq i \leq 7$  bits in the FLASH\_OPTCRx register)
- A sector erase is requested on a write protected sector. (SER = 1, SNB = i and nWRPi = 0 with  $0 \leq i \leq 7$  bits in the FLASH\_OPTCRx register)
- The Flash memory is readout protected and an intrusion is detected.

If a program operation is requested, the WRPERR bit is set when:

- A write operation is performed on system memory or on the reserved part of the user specific sector.
- A write operation is performed to the user configuration sector
- A write operation is performed on a sector write protected by option bit.
- A write operation is requested on an OTP area which is already locked
- The Flash memory is read protected and an intrusion is detected.

### 3.6.5 Proprietary code readout protection (PCROP)

Flash memory user sectors (0 to 5 for STM32F401xB/C) or up to 7 for STM32F401xD/E) can be protected against D-bus read accesses by using the proprietary readout protection (PCROP).

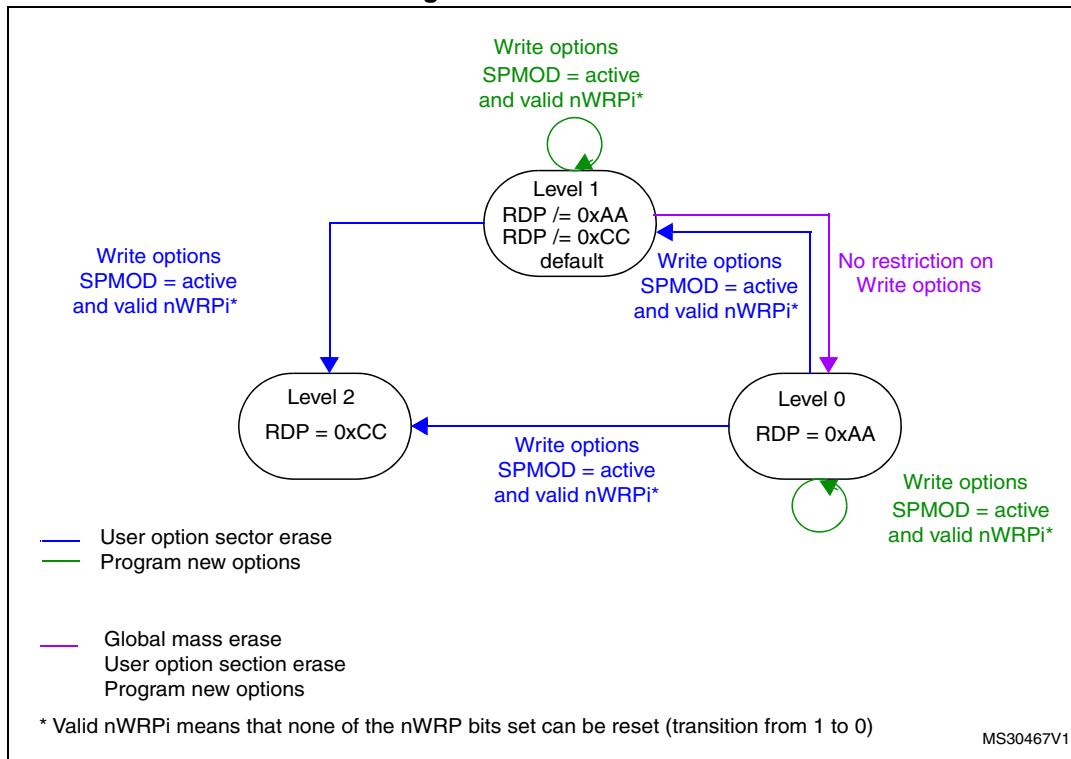
The PCROP protection is selected as follows, through the SPRMOD option bit in the FLASH\_CR register:

- SPRMOD = 0: nWRPi control the write protection of respective user sectors
- SPRMOD = 1: nWRPi control the read and write protection (PCROP) of respective user sectors.

When a sector is readout protected (PCROP mode activated), it can only be accessed for code fetch through ICODE Bus on Flash interface:

- Any read access performed through the D-bus triggers a RDERR flag error.
- Any program/erase operation on a PCROPed sector triggers a WRPERR flag error.

Figure 5. PCROP levels



The deactivation of the SPRMOD and/or the unprotection of PCROPed user sectors can only occur when the RDP changes from 1 to 0. If this condition is not respected, the user option byte modification is cancelled and the write error WRPERR flag is set. The modification of the users option bytes (BOR\_LEV, RST\_STDBY, ..) is allowed since none of the active nWRPi bits is reset and SPRMOD is kept active.

Note:

The active value of nWRPi bits is inverted when PCROP mode is active (SPRMOD =1). If SPRMOD = 1 and nWRPi=1, then user sector i of bank 1, respectively bank 2 is read/write protected (PCROP).

### 3.7 One-time programmable bytes

Table 12 shows the organization of the one-time programmable (OTP) part of the OTP area.

Table 12. OTP area organization

Block	[128:96]	[95:64]	[63:32]	[31:0]	Address byte 0
0	OTP0	OTP0	OTP0	OTP0	0x1FFF 7800
	OTP0	OTP0	OTP0	OTP0	0x1FFF 7810
1	OTP1	OTP1	OTP1	OTP1	0x1FFF 7820
	OTP1	OTP1	OTP1	OTP1	0x1FFF 7830
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

**Table 12. OTP area organization (continued)**

Block	[128:96]	[95:64]	[63:32]	[31:0]	Address byte 0
15	OTP15	OTP15	OTP15	OTP15	0x1FFF 79E0
	OTP15	OTP15	OTP15	OTP15	0x1FFF 79F0
Lock block	LOCKB15 ... LOCKB12	LOCKB11 ... LOCKB8	LOCKB7 ... LOCKB4	LOCKB3 ... LOCKB0	0x1FFF 7A00

The OTP area is divided into 16 OTP data blocks of 32 bytes and one lock OTP block of 16 bytes. The OTP data and lock blocks cannot be erased. The lock block contains 16 bytes  $LOCKBi$  ( $0 \leq i \leq 15$ ) to lock the corresponding OTP data block (blocks 0 to 15). Each OTP data block can be programmed until the value 0x00 is programmed in the corresponding OTP lock byte. The lock bytes must only contain 0x00 and 0xFF values, otherwise the OTP bytes might not be taken into account correctly.

## 3.8 Flash interface registers

### 3.8.1 Flash access control register (FLASH\_ACR)

The Flash access control register is used to enable/disable the acceleration features and control the Flash memory access time according to CPU frequency.

Address offset: 0x000

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	DCRST	ICRST	DCEN	ICEN	PRFTEN	Reserved								LATENCY	
	rw	w	rw	rw	rw									rw	rw

Bits 31:13 Reserved, must be kept cleared.

Bit 12 **DCRST:** Data cache reset

0: Data cache is not reset

1: Data cache is reset

This bit can be written only when the D cache is disabled.

Bit 11 **ICRST:** Instruction cache reset

0: Instruction cache is not reset

1: Instruction cache is reset

This bit can be written only when the I cache is disabled.

Bit 10 **DCEN:** Data cache enable

0: Data cache is disabled

1: Data cache is enabled

Bit 9 **ICEN:** Instruction cache enable

0: Instruction cache is disabled

1: Instruction cache is enabled

Bit 8 **PRFTEN**: Prefetch enable

- 0: Prefetch is disabled
- 1: Prefetch is enabled

Bits 7:4 Reserved, must be kept cleared.

Bits 3:0 **LATENCY**: Latency

These bits represent the ratio of the CPU clock period to the Flash memory access time.

- 0000: Zero wait state
- 0001: One wait state
- 0010: Two wait states
- 
- 
- 
- 1110: Fourteen wait states
- 1111: Fifteen wait states

### 3.8.2 Flash key register (FLASH\_KEYR)

The Flash key register is used to allow access to the Flash control register and so, to allow program and erase operations.

Address offset: 0x04

Reset value: 0x0000 0000

Access: no wait state, word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **FKEYR**: FPEC key

The following values must be programmed consecutively to unlock the FLASH\_CR register and allow programming/erasing it:

- a) KEY1 = 0x45670123
- b) KEY2 = 0xCDEF89AB

### 3.8.3 Flash option key register (FLASH\_OPTKEYR)

The Flash option key register is used to allow program and erase operations in the user configuration sector.

Address offset: 0x08

Reset value: 0x0000 0000

Access: no wait state, word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OPTKEYR[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OPTKEYR[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **OPTKEYR**: Option byte key

The following values must be programmed consecutively to unlock the FLASH\_OPTCR register and allow programming it:

- a) OPTKEY1 = 0x08192A3B
- b) OPTKEY2 = 0x4C5D6E7F

### 3.8.4 Flash status register (FLASH\_SR)

The Flash status register gives information on ongoing program and erase operations.

Address offset: 0x0C

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16			
Reserved																		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0			
Reserved																		
RDERR					PGSERR		PGPERR		PGAERR		WRPERR		Reserved		OPERR		EOP	
rw					rc_w1		rc_w1		rc_w1									

Bits 31:17 Reserved, must be kept cleared.

Bit 16 **BSY**: Busy

This bit indicates that a Flash memory operation is in progress. It is set at the beginning of a Flash memory operation and cleared when the operation finishes or an error occurs.

- 0: no Flash memory operation ongoing
- 1: Flash memory operation ongoing

Bits 15:9 Reserved, must be kept cleared.

Bit 8 **RDERR**: Read Protection Error (pcrop)

Set by hardware when an address to be read through the Dbus belongs to a read protected part of the flash.

Reset by writing 1.

Bit 7 **PGSERR**: Programming sequence error

Set by hardware when a write access to the Flash memory is performed by the code while the control register has not been correctly configured.

Cleared by writing 1.

Bit 6 **PGPERR**: Programming parallelism error

Set by hardware when the size of the access (byte, half-word, word, double word) during the program sequence does not correspond to the parallelism configuration PSIZE (x8, x16, x32, x64).

Cleared by writing 1.

Bit 5 **PGAERR**: Programming alignment error

Set by hardware when the data to program cannot be contained in the same 128-bit Flash memory row.

Cleared by writing 1.

Bit 4 **WRPERR**: Write protection error

Set by hardware when an address to be erased/programmed belongs to a write-protected part of the Flash memory.

Cleared by writing 1.

Bits 3:2 Reserved, must be kept cleared.

Bit 1 **OPERR**: Operation error

Set by hardware when a flash operation (programming / erase /read) request is detected and can not be run because of parallelism, alignment, or write protection error. This bit is set only if error interrupts are enabled (ERRIE = 1).

Bit 0 **EOP**: End of operation

Set by hardware when one or more Flash memory operations (program/erase) has/have completed successfully. It is set only if the end of operation interrupts are enabled (EOPIE = 1).

Cleared by writing a 1.

### 3.8.5 Flash control register (FLASH\_CR)

The Flash control register is used to configure and start Flash memory operations.

Address offset: 0x10

Reset value: 0x8000 0000

Access: no wait state when no Flash memory operation is ongoing, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
LOCK	Reserved			ERRIE	EOPIE	Reserved			Reserved			STRT	rs			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved			PSIZE[1:0]		Res.	SNB[3:0]			rw	rw	rw	rw	rw	rw	rw	

Bit 31 **LOCK**: Lock

Write to 1 only. When it is set, this bit indicates that the FLASH\_CR register is locked. It is cleared by hardware after detecting the unlock sequence.

In the event of an unsuccessful unlock operation, this bit remains set until the next reset.

Bits 30:26 Reserved, must be kept cleared.

Bit 25 **ERRIE**: Error interrupt enable

This bit enables the interrupt generation when the OPERR bit in the FLASH\_SR register is set to 1.

0: Error interrupt generation disabled  
1: Error interrupt generation enabled

Bit 24 **EOPIE:** End of operation interrupt enable

This bit enables the interrupt generation when the EOP bit in the FLASH\_SR register goes to 1.

- 0: Interrupt generation disabled
- 1: Interrupt generation enabled

Bits 23:17 Reserved, must be kept cleared.

Bit 16 **STRT:** Start

This bit triggers an erase operation when set. It is set only by software and cleared when the BSY bit is cleared.

Bits 15:10 Reserved, must be kept cleared.

Bits 9:8 **PSIZE:** Program size

These bits select the program parallelism.

- 00 program x8
- 01 program x16
- 10 program x32
- 11 program x64

Bit 7 Reserved, must be kept cleared.

Bits 6:3 **SNB:** Sector number

These bits select the sector to erase.

- 0000 sector 0
- 0001 sector 1
- ...

0101 sector 5

0110 sector 6 (STM32F401xD/E devices only)

0111 sector 7 (STM32F401xE devices only)

1000 not allowed

...

1011 not allowed

1100 user specific sector

1101 user configuration sector

1110 not allowed

1111 not allowed

Bit 2 **MER:** Mass Erase

Erase activated for all user sectors.

Bit 1 **SER:** Sector Erase

Sector Erase activated.

Bit 0 **PG:** Programming

Flash programming activated.

### 3.8.6 Flash option control register (FLASH\_OPTCR)

The FLASH\_OPTCR register is used to modify the user option bytes.

Address offset: 0x14

Reset value: 0x0FFF FFED. The option bits are loaded with values from Flash memory at reset release.

Access: no wait state when no Flash memory operation is ongoing, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16		
SPR MOD	Reserved								nWRP[7:6] <sup>(1)</sup>	nWRP[5:0]							
	rw							rw	rw	rw	rw	rw	rw	rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
RDP[7:0]								nRST <sub>STDBY</sub>	nRST <sub>STOP</sub>	WDG <sub>SW</sub>	Reserv ed	BOR_lev		OPTST RT	OPTLO CK		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rs	rs		

1. Available in STM32F401xD/E devices only

Bit 31 **SPRMOD:** Selection of Protection Mode of nWPRI bits

0: PCROP disabled, nWPRI bits used for Write Protection on sector i

1: PCROP enabled, nWPRI bits used for PCROP Protection on sector i

Bits 30:24 Reserved, must be kept cleared.

Bits 23:22 **nWRP[7:6]:** Not write protect

For STM32F401xB/C:

Reserved, must be kept cleared.

For STM32F401xD/E:

These bits contain the value of the write-protection and read-protection (PCROP) option bytes for sectors 6 and 7 after reset. (Refer to Bits 21:16 for more details)

Bits 21:16 **nWRP[5:0]:** Not write protect

These bits contain the value of the write-protection option bytes of sectors after reset. They can be written to program a new write protect value into Flash memory.

0: Write protection active on selected sector

1: Write protection not active on selected sector

These bits contain the value of the write-protection and read-protection (PCROP) option bytes for sectors 0 to 5 after reset. They can be written to program a new write-protect or PCROP value into Flash memory.

If SPRMOD is reset:

0: Write protection active on sector i

1: Write protection not active on sector i

If SPRMOD is set:

0: PCROP protection not active on sector i

1: PCROP protection active on sector i

Bits 15:8 **RDP:** Read protect

These bits contain the value of the read-protection option level after reset. They can be written to program a new read protection value into Flash memory.

0xAA: Level 0, read protection not active

0xCC: Level 2, chip read protection active

Others: Level 1, read protection of memories active

**Bits 7:5 USER:** User option bytes

These bits contain the value of the user option byte after reset. They can be written to program a new user option byte value into Flash memory.

Bit 7: nRST\_STDBY

Bit 6: nRST\_STOP

Bit 5: WDG\_SW

*Note: When changing the WDG mode from hardware to software or from software to hardware, a system reset is required to make the change effective.*

Bit 4 Reserved, must be kept cleared.

**Bits 3:2 BOR\_lev:** BOR reset Level

These bits contain the supply level threshold that activates/releases the reset. They can be written to program a new BOR level. By default, BOR is off. When the supply voltage ( $V_{DD}$ ) drops below the selected BOR level, a device reset is generated.

00: BOR Level 3 (VBOR3), brownout threshold level 3

01: BOR Level 2 (VBOR2), brownout threshold level 2

10: BOR Level 1 (VBOR1), brownout threshold level 1

11: BOR off, POR/PDR reset threshold level is applied

*Note: For full details about BOR characteristics, refer to the “Electrical characteristics” section in the device datasheet.*

**Bit 1 OPTSTRT:** Option start

This bit triggers a user option operation when set. It is set only by software and cleared when the BSY bit is cleared.

**Bit 0 OPTLOCK:** Option lock

Write to 1 only. When this bit is set, it indicates that the FLASH\_OPTCR register is locked. This bit is cleared by hardware after detecting the unlock sequence.

In the event of an unsuccessful unlock operation, this bit remains set until the next reset.

### **3.8.7 Flash interface register map**

**Table 13. Flash register map and reset values**

## 4 CRC calculation unit

### 4.1 CRC introduction

The CRC (cyclic redundancy check) calculation unit is used to get a CRC code from a 32-bit data word and a fixed generator polynomial.

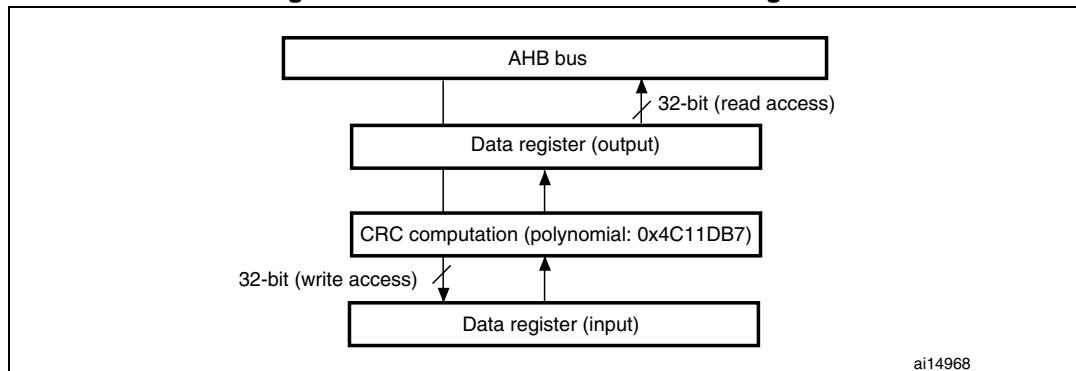
Among other applications, CRC-based techniques are used to verify data transmission or storage integrity. In the scope of the EN/IEC 60335-1 standard, they offer a means of verifying the Flash memory integrity. The CRC calculation unit helps compute a signature of the software during runtime, to be compared with a reference signature generated at link-time and stored at a given memory location.

### 4.2 CRC main features

- Uses CRC-32 (Ethernet) polynomial: 0x4C11DB7
  - $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$
- Single input/output 32-bit data register
- CRC computation done in 4 AHB clock cycles (HCLK)
- General-purpose 8-bit register (can be used for temporary storage)

The block diagram is shown in [Figure 6](#).

**Figure 6. CRC calculation unit block diagram**



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### 4.3 CRC functional description

The CRC calculation unit mainly consists of a single 32-bit data register, which:

- is used as an input register to enter new data in the CRC calculator (when writing into the register)
- holds the result of the previous CRC calculation (when reading the register)

Each write operation into the data register creates a combination of the previous CRC value and the new one (CRC computation is done on the whole 32-bit data word, and not byte per byte).

The write operation is stalled until the end of the CRC computation, thus allowing back-to-back write accesses or consecutive write and read accesses.

The CRC calculator can be reset to 0xFFFF FFFF with the RESET control bit in the CRC\_CR register. This operation does not affect the contents of the CRC\_IDR register.

## 4.4 CRC registers

The CRC calculation unit contains two data registers and a control register. The peripheral The CRC registers have to be accessed by words (32 bits).

### 4.4.1 Data register (CRC\_DR)

Address offset: 0x00

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DR [31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR [15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

#### Bits 31:0 Data register bits

Used as an input register when writing new data into the CRC calculator.

Holds the previous CRC calculation result when it is read.

### 4.4.2 Independent data register (CRC\_IDR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDR[7:0]															
Reserved								rw							

Bits 31:8 Reserved, must be kept at reset value.

#### Bits 7:0 General-purpose 8-bit data register bits

Can be used as a temporary storage location for one byte.

This register is not affected by CRC resets generated by the RESET bit in the CRC\_CR register.

### 4.4.3 Control register (CRC\_CR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															

Bits 31:1 Reserved, must be kept at reset value.

#### Bit 0 **RESET bit**

Resets the CRC calculation unit and sets the data register to 0xFFFF FFFF.  
This bit can only be set, it is automatically cleared by hardware.

#### 4.4.4 CRC register map

The following table provides the CRC register map and reset values.

**Table 14. CRC calculation unit register map and reset values**

Offset	Register	31-24	23-16	15-8	7	6	5	4	3	2	1	0
0x00	<b>CRC_DR</b>	Data register										
	Reset value	0xFFFF FFFF										
0x04	<b>CRC_IDR</b>	Reserved				Independent data register						
	Reset value					0x00						
0x08	<b>CRC_CR</b>	Reserved										RESET
	Reset value											0

## 5 Power controller (PWR)

### 5.1 Power supplies

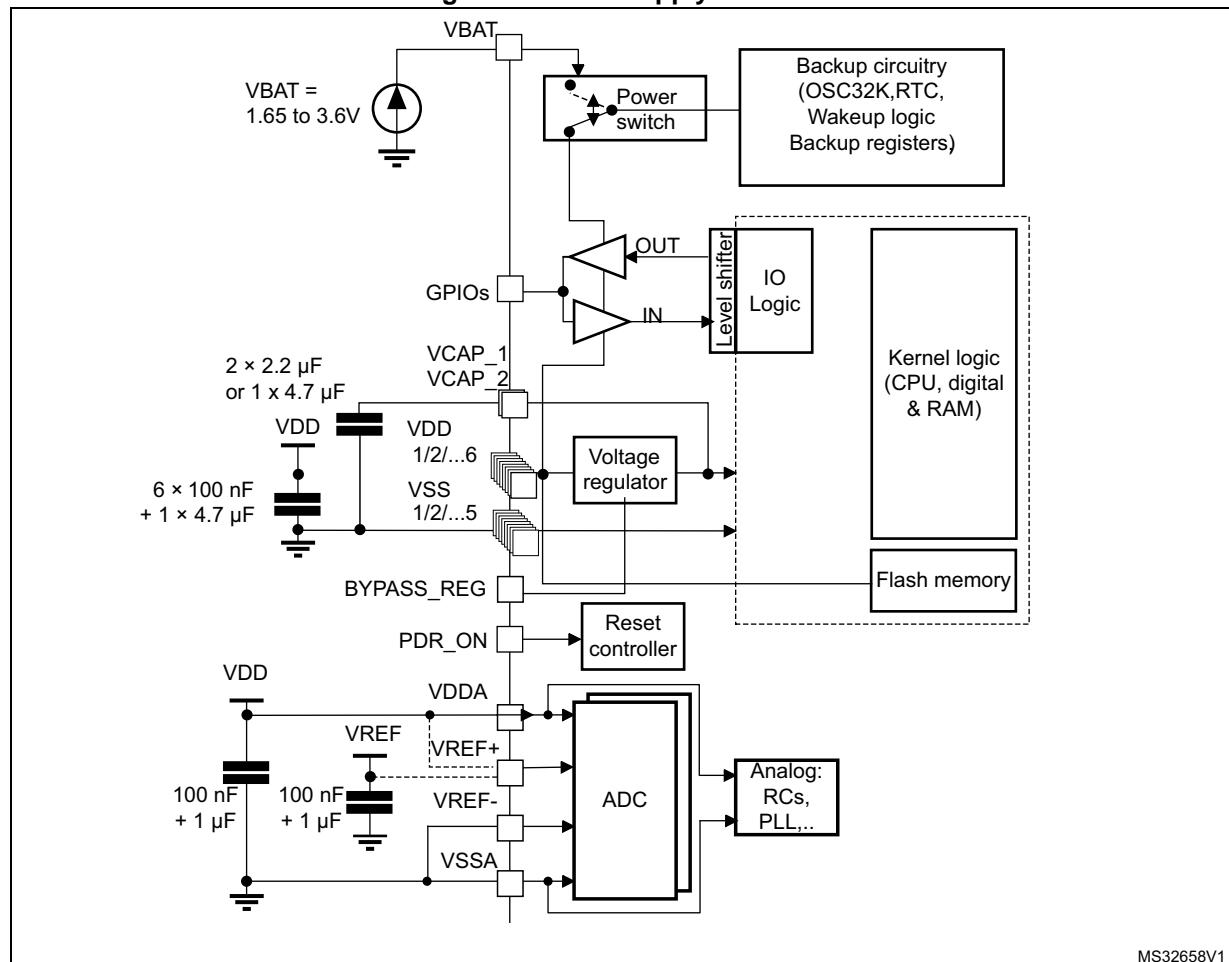
There are two main power supply schemes:

- VDD = 1.7 to 3.6 V: external power supply for I/Os with the internal regulator disabled, provided externally through VDD pins. Requires the use of an external power supply supervisor connected to the VDD and PDR\_ON pins.
- VDD = 1.8 to 3.6 V: external power supply for I/Os and the internal regulator (when enabled), provided externally through VDD pins.

The real-time clock (RTC) and the RTC backup registers can be powered from the V<sub>BAT</sub> voltage when the main V<sub>DD</sub> supply is powered off.

*Note:* Depending on the operating power supply range, some peripheral may be used with limited functionality and performance. For more details refer to section "General operating conditions" in STM32F4xx datasheets.

Figure 7. Power supply overview



1. V<sub>DDA</sub> and V<sub>SSA</sub> must be connected to V<sub>DD</sub> and V<sub>SS</sub>, respectively.

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### 5.1.1 Independent A/D converter supply and reference voltage

To improve conversion accuracy, the ADC has an independent power supply which can be separately filtered and shielded from noise on the PCB.

- The ADC voltage supply input is available on a separate  $V_{DDA}$  pin.
- An isolated supply ground connection is provided on pin  $V_{SSA}$ .

To ensure a better accuracy of low voltage inputs, the user can connect a separate external reference voltage ADC input on  $V_{REF}$ . The voltage on  $V_{REF}$  ranges from 1.7 V to  $V_{DDA}$ .

### 5.1.2 Battery backup domain

#### Backup domain description

To retain the content of the RTC backup registers and supply the RTC when  $V_{DD}$  is turned off,  $V_{BAT}$  pin can be connected to an optional standby voltage supplied by a battery or by another source.

To allow the RTC to operate even when the main digital supply ( $V_{DD}$ ) is turned off, the  $V_{BAT}$  pin powers the following blocks:

- The RTC
- The LSE oscillator
- PC13 to PC15 I/Os

The switch to the  $V_{BAT}$  supply is controlled by the power-down reset embedded in the Reset block.

---

**Warning:** During  $t_{RSTTEMPO}$  (temporization at  $V_{DD}$  startup) or after a PDR is detected, the power switch between  $V_{BAT}$  and  $V_{DD}$  remains connected to  $V_{BAT}$ .

During the startup phase, if  $V_{DD}$  is established in less than  $t_{RSTTEMPO}$  (Refer to the datasheet for the value of  $t_{RSTTEMPO}$ ) and  $V_{DD} > V_{BAT} + 0.6$  V, a current may be injected into  $V_{BAT}$  through an internal diode connected between  $V_{DD}$  and the power switch ( $V_{BAT}$ ).

If the power supply/battery connected to the  $V_{BAT}$  pin cannot support this current injection, it is strongly recommended to connect an external low-drop diode between this power supply and the  $V_{BAT}$  pin.

---

If no external battery is used in the application, it is recommended to connect the  $V_{BAT}$  pin to  $V_{DD}$  with a 100 nF external decoupling ceramic capacitor in parallel.

When the backup domain is supplied by  $V_{DD}$  (analog switch connected to  $V_{DD}$ ), the following functions are available:

- PC14 and PC15 can be used as either GPIO or LSE pins
- PC13 can be used as a GPIO or additional functions can be configured (refer to [Table 26: RTC additional functions](#) for more details about this pin configuration)

**Note:** Due to the fact that the switch only sinks a limited amount of current (3 mA), the use of GPIOs PC13 to PC15 are restricted: only one I/O at a time can be used as an output, the

*speed has to be limited to 2 MHz with a maximum load of 30 pF and these I/Os must not be used as a current source (e.g. to drive an LED).*

When the backup domain is supplied by  $V_{BAT}$  (analog switch connected to  $V_{BAT}$  because  $V_{DD}$  is not present), the following functions are available:

- PC14 and PC15 can be used as LSE pins only
- PC13 can be used as the RTC additional function pin (refer to [Table 26: RTC additional functions](#) for more details about this pin configuration)

### Backup domain access

After reset, the backup domain (RTC registers and RTC backup register) is protected against possible unwanted write accesses. To enable access to the backup domain, proceed as follows:

- Access to the RTC and RTC backup registers
- 1. Enable the power interface clock by setting the PWREN bits in the RCC\_APB1ENR register (see [Section 7.3.13](#))
- 2. Set the DBP bit in the *PWR power control register (PWR\_CR)* to enable access to the backup domain
- 3. Select the RTC clock source: see [Section 7.2.8: RTC/AWU clock](#)
- 4. Enable the RTC clock by programming the RTCEN [15] bit in the *RCC Backup domain control register (RCC\_BDCR)*

### RTC and RTC backup registers

The real-time clock (RTC) is an independent BCD timer/counter. The RTC provides a time-of-day clock/calendar, two programmable alarm interrupts, and a periodic programmable wakeup flag with interrupt capability. The RTC contains 20 backup data registers (80 bytes) which are reset when a tamper detection event occurs. For more details refer to [Section 17: Real-time clock \(RTC\)](#).

## 5.1.3 Voltage regulator

An embedded linear voltage regulator supplies all the digital circuitries except for the backup domain and the Standby circuitry. The regulator output voltage is around 1.2 V.

This voltage regulator requires one or two external capacitors to be connected to one or two dedicated pins,  $V_{CAP\_1}$  and for some packages  $V_{CAP\_2}$ . Specific pins must be connected either to  $V_{SS}$  or  $V_{DD}$  to activate or deactivate the voltage regulator. These pins depend on the package.

When activated by software, the voltage regulator is always enabled after Reset. It works in three different modes depending on the application modes.

- In **Run mode**, the regulator supplies full power to the 1.2 V domain (core, memories and digital peripherals). In this mode, the regulator output voltage (around 1.2 V) can be scaled by software to different voltage values:

Scale 2, or scale 3 can be configured through the VOS[1:0] bits of the PWR\_CR register (scale 1 is not used in this product). After reset the VOS register is set to scale 2. When the PLL is OFF, the voltage regulator is set to scale 3 independently

of the VOS register content. The VOS register content is only taken into account once the PLL is activated and the HSI or HSE is selected as clock source.

The voltage scaling allows optimizing the power consumption when the device is clocked below the maximum system frequency.

- In **Stop mode**, the main regulator or the low-power regulator supplies low power to the 1.2 V domain, thus preserving the content of registers and internal SRAM. The voltage regulator can be put either in main regulator mode (MR) or in low-power mode (LPR). The programmed voltage scale remains the same during Stop mode:

Voltage scale 3 is automatically selected when the microcontroller enters Stop mode (see [Section 5.4.1: PWR power control register \(PWR\\_CR\)](#)).

- In **Standby mode**, the regulator is powered down. The content of the registers and SRAM are lost except for the Standby circuitry and the backup domain.

*Note:* For more details, refer to the voltage regulator section in the STM32F401xB/C datasheet.

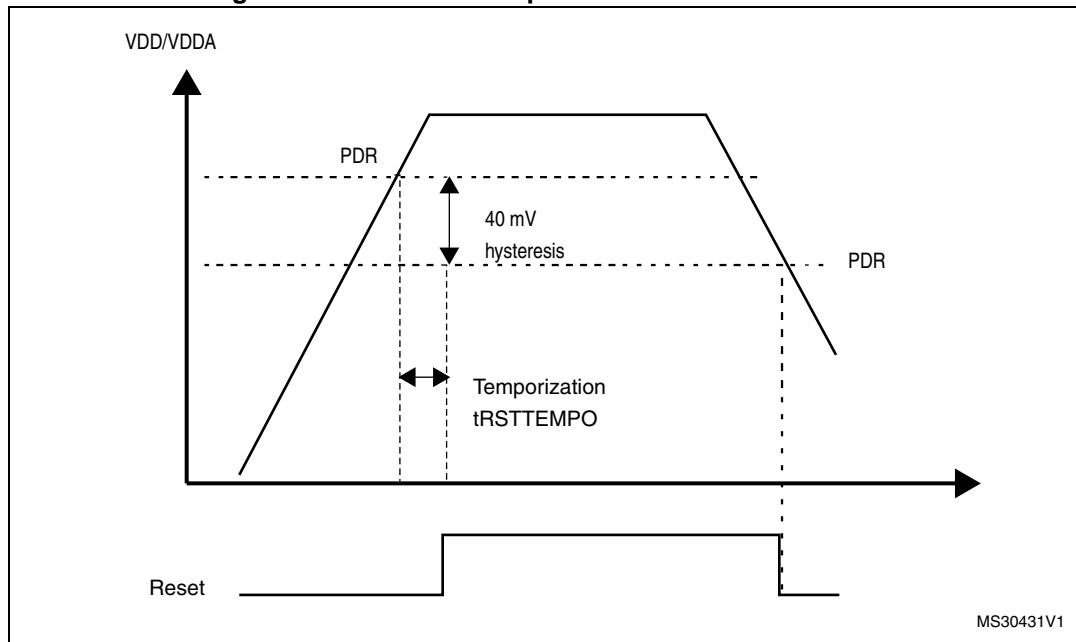
## 5.2 Power supply supervisor

### 5.2.1 Power-on reset (POR)/power-down reset (PDR)

The device has an integrated POR/PDR circuitry that allows proper operation starting from 1.8 V.

To use the device below 1.8 V, the internal power supervisor must be switched off using the PDR\_ON pin (please refer to section Power supply supervisor of the STM32F401xB/C datasheet). The device remains in Reset mode when  $V_{DD}/V_{DDA}$  is below a specified threshold,  $V_{POR/PDR}$ , without the need for an external reset circuit. For more details concerning the power on/power-down reset threshold, refer to the electrical characteristics of the datasheet.

**Figure 8. Power-on reset/power-down reset waveform**



## 5.2.2 Brownout reset (BOR)

During power on, the Brownout reset (BOR) keeps the device under reset until the supply voltage reaches the specified  $V_{BOR}$  threshold.

$V_{BOR}$  is configured through device option bytes. By default, BOR is off. 3 programmable  $V_{BOR}$  threshold levels can be selected:

- BOR Level 3 (VBOR3). Brownout threshold level 3.
- BOR Level 2 (VBOR2). Brownout threshold level 2.
- BOR Level 1 (VBOR1). Brownout threshold level 1.

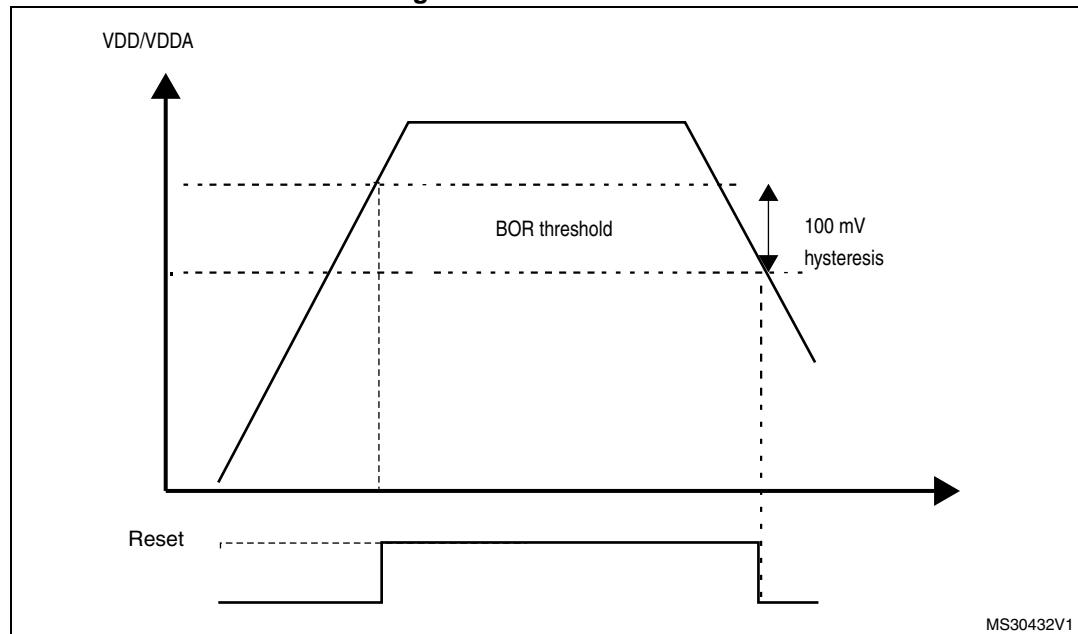
**Note:** *For full details about BOR characteristics, refer to the "Electrical characteristics" section in the device datasheet.*

When the supply voltage ( $V_{DD}$ ) drops below the selected  $V_{BOR}$  threshold, a device reset is generated.

The BOR can be disabled by programming the device option bytes. In this case, the power-on and power-down is then monitored by the POR/PDR or by an external power supervisor if the PDR is switched off through the PDR\_ON pin (see [Section 5.2.1: Power-on reset \(POR\)/power-down reset \(PDR\)](#)).

The BOR threshold hysteresis is ~100 mV (between the rising and the falling edge of the supply voltage).

**Figure 9. BOR thresholds**



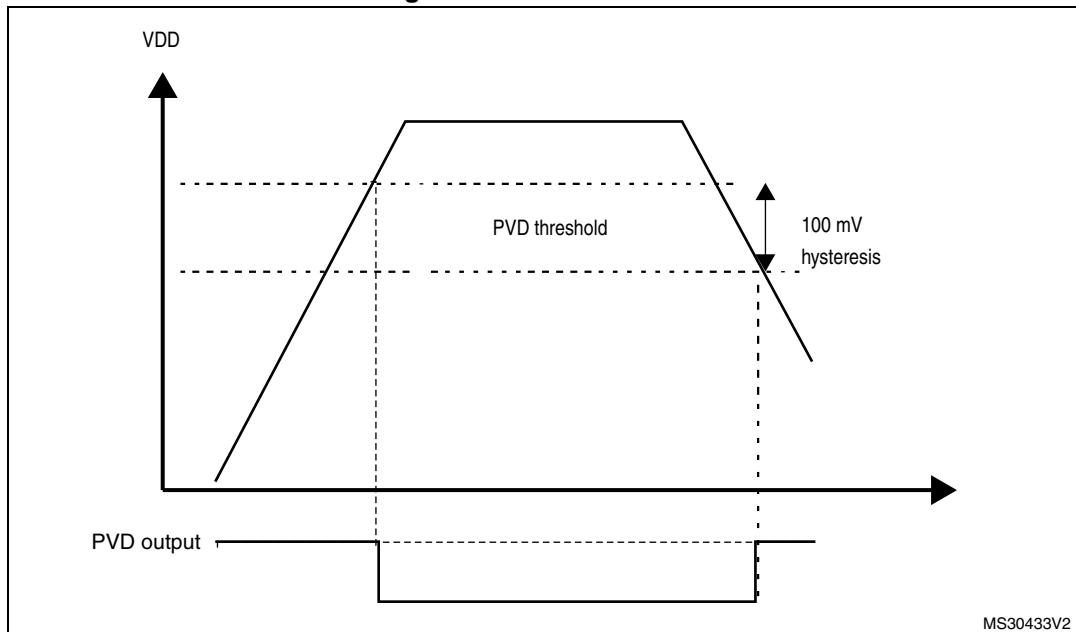
## 5.2.3 Programmable voltage detector (PWD)

You can use the PVD to monitor the  $V_{DD}$  power supply by comparing it to a threshold selected by the PLS[2:0] bits in the [PWR power control register \(PWR\\_CR\)](#).

The PVD is enabled by setting the PVDE bit.

A PVDO flag is available, in the *PWR power control/status register (PWR\_CSR)*, to indicate if  $V_{DD}$  is higher or lower than the PVD threshold. This event is internally connected to the EXTI line16 and can generate an interrupt if enabled through the EXTI registers. The PVD output interrupt can be generated when  $V_{DD}$  drops below the PVD threshold and/or when  $V_{DD}$  rises above the PVD threshold depending on EXTI line16 rising/falling edge configuration. As an example the service routine could perform emergency shutdown tasks.

**Figure 10. PVD thresholds**



## 5.3 Low-power modes

By default, the microcontroller is in Run mode after a system or a power-on reset. In Run mode the CPU is clocked by HCLK and the program code is executed. Several low-power modes are available to save power when the CPU does not need to be kept running, for example when waiting for an external event. It is up to the user to select the mode that gives the best compromise between low-power consumption, short startup time and available wakeup sources.

The devices feature three low-power modes:

- Sleep mode (Cortex™-M4 with FPU core stopped, peripherals kept running)
- Stop mode (all clocks are stopped)
- Standby mode (1.2 V domain powered off)

In addition, the power consumption in Run mode can be reduced by one of the following means:

- Slowing down the system clocks
- Gating the clocks to the APBx and AHBx peripherals when they are unused.

**Table 15. Low-power mode summary**

Mode name	Entry	Wakeup	Effect on 1.2 V domain clocks	Effect on V <sub>DD</sub> domain clocks	Voltage regulator
<b>Sleep (Sleep now or Sleep-on-exit)</b>	WFI	Any interrupt	CPU CLK OFF no effect on other clocks or analog clock sources	None	ON
	WFE	Wakeup event			
<b>Stop</b>	PDDS bit + STOP mode configuration + SLEEPDEEP bit + WFI or WFE	Any EXTI line (configured in the EXTI registers, internal and external lines)	All 1.2 V domain clocks OFF	HSI and HSE oscillators OFF	Main regulator or Low-Power regulator (depends on <i>PWR power control register (PWR_CR)</i> )
<b>Standby</b>	PDDS bit + SLEEPDEEP bit + WFI or WFE	WKUP pin rising edge, RTC alarm (Alarm A or Alarm B), RTC Wakeup event, RTC tamper events, RTC time stamp event, external reset in NRST pin, IWDG reset			OFF

### 5.3.1 Slowing down system clocks

In Run mode the speed of the system clocks (SYSCLK, HCLK, PCLK1, PCLK2) can be reduced by programming the prescaler registers. These prescalers can also be used to slow down peripherals before entering Sleep mode.

For more details refer to [Section 7.3.3: RCC clock configuration register \(RCC\\_CFGR\)](#).

### 5.3.2 Peripheral clock gating

In Run mode, the HCLKx and PCLKx for individual peripherals and memories can be stopped at any time to reduce power consumption.

To further reduce power consumption in Sleep mode the peripheral clocks can be disabled prior to executing the WFI or WFE instructions.

Peripheral clock gating is controlled by the AHB1 peripheral clock enable register (RCC\_AHB1ENR), AHB2 peripheral clock enable register (RCC\_AHB2ENR) (see [Section 7.3.10: RCC AHB1 peripheral clock enable register \(RCC\\_AHB1ENR\)](#), [Section 7.3.11: RCC AHB2 peripheral clock enable register \(RCC\\_AHB2ENR\)](#)).

Disabling the peripherals clocks in Sleep mode can be performed automatically by resetting the corresponding bit in RCC\_AHBxLPENR and RCC\_APBxLPENR registers.

### 5.3.3 Sleep mode

#### Entering Sleep mode

The Sleep mode is entered by executing the WFI (Wait For Interrupt) or WFE (Wait for Event) instructions. Two options are available to select the Sleep mode entry mechanism, depending on the SLEEPONEXIT bit in the Cortex™-M4 with FPU System Control register:

- Sleep-now: if the SLEEPONEXIT bit is cleared, the MCU enters Sleep mode as soon as WFI or WFE instruction is executed.
- Sleep-on-exit: if the SLEEPONEXIT bit is set, the MCU enters Sleep mode as soon as it exits the lowest priority ISR.

Refer to [Table 16](#) and [Table 17](#) for details on how to enter Sleep mode.

#### Exiting Sleep mode

If the WFI instruction is used to enter Sleep mode, any peripheral interrupt acknowledged by the nested vectored interrupt controller (NVIC) can wake up the device from Sleep mode.

If the WFE instruction is used to enter Sleep mode, the MCU exits Sleep mode as soon as an event occurs. The wakeup event can be generated either by:

- Enabling an interrupt in the peripheral control register but not in the NVIC, and enabling the SEVONPEND bit in the Cortex™-M4 with FPU System Control register. When the MCU resumes from WFE, the peripheral interrupt pending bit and the peripheral NVIC IRQ channel pending bit (in the NVIC interrupt clear pending register) have to be cleared.
- Or configuring an external or internal EXTI line in event mode. When the CPU resumes from WFE, it is not necessary to clear the peripheral interrupt pending bit or the NVIC IRQ channel pending bit as the pending bit corresponding to the event line is not set.

This mode offers the lowest wakeup time as no time is wasted in interrupt entry/exit.

Refer to [Table 16](#) and [Table 17](#) for more details on how to exit Sleep mode.

**Table 16. Sleep-now entry and exit**

Sleep-now mode	Description
<b>Mode entry</b>	WFI (Wait for Interrupt) or WFE (Wait for Event) while: – SLEEPDEEP = 0 and – SLEEPONEXIT = 0 Refer to the Cortex™-M4 with FPU System Control register.
<b>Mode exit</b>	If WFI was used for entry: Interrupt: Refer to <a href="#">Table 38: Vector table</a> If WFE was used for entry Wakeup event: Refer to <a href="#">Section 10.2.3: Wakeup event management</a>
<b>Wakeup latency</b>	None

**Table 17. Sleep-on-exit entry and exit**

Sleep-on-exit	Description
<b>Mode entry</b>	WFI (wait for interrupt) while: – SLEEPDEEP = 0 and – SLEEPONEXIT = 1 Refer to the Cortex™-M4 with FPU System Control register.
<b>Mode exit</b>	Interrupt: refer to <a href="#">Table 38: Vector table</a>
<b>Wakeup latency</b>	None

### 5.3.4 Stop mode

The Stop mode is based on the Cortex™-M4 with FPU deepsleep mode combined with peripheral clock gating. The voltage regulator can be configured either in normal or low-power mode. In Stop mode, all clocks in the 1.2 V domain are stopped, the PLLs, the HSI and the HSE RC oscillators are disabled. Internal SRAM and register contents are preserved.

Some settings in the PWR\_CR register allow to further reduce the power consumption. When the Flash memory is in power-down mode, an additional startup delay is incurred when waking up from Stop mode (see [Table 18: Stop operating modes](#) and [Section 5.4.1: PWR power control register \(PWR\\_CR\)](#)).

**Table 18. Stop operating modes**

	Stop mode	MRLV bit	LPLV bit	FPDS bit	LPDS bit	Wakeup latency
Normal mode	STOP MR	0	-	0	0	HSI RC startup time
	STOP MRFPD	0	-	1	0	HSI RC startup time + Flash wakeup time from Deep Power Down mode
	STOP LP	0	0	0	1	HSI RC startup time + regulator wakeup time from LP mode
	STOP LPFPD	-	0	1	1	HSI RC startup time + Flash wakeup time from Deep Power Down mode + regulator wakeup time from LP mode
	STOP MRLV	1	-	-	0	HSI RC startup time + Flash wakeup time from Deep Power Down mode + Main regulator from low voltage mode
	STOP LPLV	-	1	-	1	HSI RC startup time + Flash wakeup time from Deep Power Down mode + regulator wakeup time from Low Voltage LP mode

## Entering Stop mode

Refer to [Table 19](#) for details on how to enter the Stop mode.

To further reduce power consumption in Stop mode, the internal voltage regulator can be put in low power mode. This is configured by the LPDS bit of the [PWR power control register \(PWR\\_CR\)](#).

If Flash memory programming is ongoing, the Stop mode entry is delayed until the memory access is finished.

If an access to the APB domain is ongoing, The Stop mode entry is delayed until the APB access is finished.

In Stop mode, the following features can be selected by programming individual control bits:

- Independent watchdog (IWDG): the IWDG is started by writing to its Key register or by hardware option. Once started it cannot be stopped except by a Reset. See [Section 15.3 in Section 15: Independent watchdog \(IWDG\)](#).
- Real-time clock (RTC): this is configured by the RTCEN bit in the [RCC Backup domain control register \(RCC\\_BDCR\)](#)
- Internal RC oscillator (LSI RC): this is configured by the LSION bit in the [RCC clock control & status register \(RCC\\_CSR\)](#).
- External 32.768 kHz oscillator (LSE OSC): this is configured by the LSEON bit in the [RCC Backup domain control register \(RCC\\_BDCR\)](#).

The ADC can also consume power during the Stop mode, unless it is disabled before entering it. To disable it, the ADON bit in the ADC\_CR2 register must be written to 0.

Note:

*If the application needs to disable the external clock before entering Stop mode, the HSEON bit must first be disabled and the system clock switched to HSI.*

*Otherwise, if the HSEON bit is kept enabled while the external clock (external oscillator) can be removed before entering stop mode, the clock security system (CSS) feature must be enabled to detect any external oscillator failure and avoid a malfunction behavior when entering stop mode.*

## Exiting Stop mode

Refer to [Table 19](#) for more details on how to exit Stop mode.

When exiting Stop mode by issuing an interrupt or a wakeup event, the HSI RC oscillator is selected as system clock.

When the voltage regulator operates in low power mode, an additional startup delay is incurred when waking up from Stop mode. By keeping the internal regulator ON during Stop mode, the consumption is higher although the startup time is reduced.

**Table 19. Stop mode entry and exit**

Stop mode	Description
<b>Mode entry</b>	WFI (Wait for Interrupt) or WFE (Wait for Event) while: – Set SLEEPDEEP bit in Cortex™-M4 with FPU System Control register – Clear PDDS bit in Power Control register (PWR_CR) – Select the voltage regulator mode by configuring LPDS bit in PWR_CR. <b>Note:</b> To enter the Stop mode, all EXTI Line pending bits (in <a href="#">Pending register (EXTI_PR)</a> ), all peripheral interrupts pending bits, the RTC Alarm (Alarm A and Alarm B), RTC wakeup, RTC tamper, and RTC time stamp flags, must be reset. Otherwise, the Stop mode entry procedure is ignored and program execution continues.
<b>Mode exit</b>	If WFI was used for entry: All EXTI lines configured in Interrupt mode (the corresponding EXTI Interrupt vector must be enabled in the NVIC). Refer to <a href="#">Table 38: Vector table</a> . If WFE was used for entry: All EXTI Lines configured in event mode. Refer to <a href="#">Section 10.2.3: Wakeup event management on page 200</a>
<b>Wakeup latency</b>	<a href="#">Table 18: Stop operating modes</a>

### 5.3.5 Standby mode

The Standby mode allows to achieve the lowest power consumption. It is based on the Cortex™-M4 with FPU deepsleep mode, with the voltage regulator disabled. The 1.2 V domain is consequently powered off. The PLLs, the HSI oscillator and the HSE oscillator are also switched off. SRAM and register contents are lost except for registers in the backup domain (RTC registers and RTC backup register), and Standby circuitry (see [Figure 7](#)).

#### Entering Standby mode

Refer to [Table 20](#) for more details on how to enter Standby mode.

In Standby mode, the following features can be selected by programming individual control bits:

- Independent watchdog (IWDG): the IWDG is started by writing to its Key register or by hardware option. Once started it cannot be stopped except by a reset. See [Section 15.3 in Section 15: Independent watchdog \(IWDG\)](#).
- Real-time clock (RTC): this is configured by the RTCEN bit in the backup domain control register (RCC\_BDCR)
- Internal RC oscillator (LSI RC): this is configured by the LSION bit in the Control/status register (RCC\_CSR).
- External 32.768 kHz oscillator (LSE OSC): this is configured by the LSEON bit in the backup domain control register (RCC\_BDCR)

#### Exiting Standby mode

The microcontroller exits Standby mode when an external Reset (NRST pin), an IWDG Reset, a rising edge on WKUP pin, an RTC alarm, a tamper event, or a time stamp event is detected. All registers are reset after wakeup from Standby except for [PWR power control/status register \(PWR\\_CSR\)](#).

After waking up from Standby mode, program execution restarts in the same way as after a Reset (boot pins sampling, vector reset is fetched, etc.). The SBF status flag in the [PWR power control/status register \(PWR\\_CSR\)](#) indicates that the MCU was in Standby mode.

Refer to [Table 20](#) for more details on how to exit Standby mode.

**Table 20. Standby mode entry and exit**

Standby mode	Description
<b>Mode entry</b>	WFI (Wait for Interrupt) or WFE (Wait for Event) while: – Set SLEEPDEEP in Cortex™-M4 with FPU System Control register – Set PDDS bit in Power Control register (PWR_CR) – Clear WUF bit in Power Control/Status register (PWR_CSR) – Clear the RTC flag corresponding to the chosen wakeup source (RTC Alarm A, RTC Alarm B, RTC wakeup, Tamper or Timestamp flags)
<b>Mode exit</b>	WKUP pin rising edge, RTC alarm (Alarm A and Alarm B), RTC wakeup, tamper event, time stamp event, external reset in NRST pin, IWDG reset.
<b>Wakeup latency</b>	Reset phase.

### I/O states in Standby mode

In Standby mode, all I/O pins are high impedance except for:

- Reset pad (still available)
- RTC\_AF1 pin (PC13) if configured for tamper, time stamp, RTC Alarm out, or RTC clock calibration out
- WKUP pin (PA0), if enabled

### Debug mode

By default, the debug connection is lost if the application puts the MCU in Stop or Standby mode while the debug features are used. This is due to the fact that the Cortex™-M4 with FPU core is no longer clocked.

However, by setting some configuration bits in the DBGMCU\_CR register, the software can be debugged even when using the low-power modes extensively. For more details, refer to [Section 23.16.1: Debug support for low-power modes](#).

## 5.3.6 Programming the RTC alternate functions to wake up the device from the Stop and Standby modes

The MCU can be woken up from a low-power mode by an RTC alternate function.

The RTC alternate functions are the RTC alarms (Alarm A and Alarm B), RTC wakeup, RTC tamper event detection and RTC time stamp event detection.

These RTC alternate functions can wake up the system from the Stop and Standby low-power modes.

The system can also wake up from low-power modes without depending on an external interrupt (Auto-wakeup mode), by using the RTC alarm or the RTC wakeup events.

The RTC provides a programmable time base for waking up from the Stop or Standby mode at regular intervals.

For this purpose, two of the three alternate RTC clock sources can be selected by programming the RTCSEL[1:0] bits in the *RCC Backup domain control register (RCC\_BDCR)*:

- Low-power 32.768 kHz external crystal oscillator (LSE OSC)  
This clock source provides a precise time base with a very low-power consumption (additional consumption of less than 1 µA under typical conditions)
- Low-power internal RC oscillator (LSI RC)  
This clock source has the advantage of saving the cost of the 32.768 kHz crystal. This internal RC oscillator is designed to use minimum power.

### RTC alternate functions to wake up the device from the Stop mode

- To wake up the device from the Stop mode with an RTC alarm event, it is necessary to:
  - a) Configure the EXTI Line 17 to be sensitive to rising edges (Interrupt or Event modes)
  - b) Enable the RTC Alarm Interrupt in the RTC\_CR register
  - c) Configure the RTC to generate the RTC alarm
- To wake up the device from the Stop mode with an RTC tamper or time stamp event, it is necessary to:
  - a) Configure the EXTI Line 21 to be sensitive to rising edges (Interrupt or Event modes)
  - b) Enable the RTC time stamp Interrupt in the RTC\_CR register or the RTC tamper interrupt in the RTC\_TAFCR register
  - c) Configure the RTC to detect the tamper or time stamp event
- To wake up the device from the Stop mode with an RTC wakeup event, it is necessary to:
  - a) Configure the EXTI Line 22 to be sensitive to rising edges (Interrupt or Event modes)
  - b) Enable the RTC wakeup interrupt in the RTC\_CR register
  - c) Configure the RTC to generate the RTC Wakeup event

### RTC alternate functions to wake up the device from the Standby mode

- To wake up the device from the Standby mode with an RTC alarm event, it is necessary to:
  - a) Enable the RTC alarm interrupt in the RTC\_CR register
  - b) Configure the RTC to generate the RTC alarm
- To wake up the device from the Standby mode with an RTC tamper or time stamp event, it is necessary to:
  - a) Enable the RTC time stamp interrupt in the RTC\_CR register or the RTC tamper interrupt in the RTC\_TAFCR register
  - b) Configure the RTC to detect the tamper or time stamp event
- To wake up the device from the Standby mode with an RTC wakeup event, it is necessary to:
  - a) Enable the RTC wakeup interrupt in the RTC\_CR register
  - b) Configure the RTC to generate the RTC wakeup event

### Safe RTC alternate function wakeup flag clearing sequence

If the selected RTC alternate function is set before the PWR wakeup flag (WUTF) is cleared, it will not be detected on the next event as detection is made once on the rising edge.

To avoid bouncing on the pins onto which the RTC alternate functions are mapped, and exit correctly from the Stop and Standby modes, it is recommended to follow the sequence below before entering the Standby mode:

- When using RTC alarm to wake up the device from the low-power modes:
  - a) Disable the RTC alarm interrupt (ALRAIE or ALRBIE bits in the RTC\_CR register)
  - b) Clear the RTC alarm (ALRAF/ALRBF) flag
  - c) Clear the PWR Wakeup (WUF) flag
  - d) Enable the RTC alarm interrupt
  - e) Re-enter the low-power mode
- When using RTC wakeup to wake up the device from the low-power modes:
  - a) Disable the RTC Wakeup interrupt (WUTIE bit in the RTC\_CR register)
  - b) Clear the RTC Wakeup (WUTF) flag
  - c) Clear the PWR Wakeup (WUF) flag
  - d) Enable the RTC Wakeup interrupt
  - e) Re-enter the low power mode
- When using RTC tamper to wake up the device from the low-power modes:
  - a) Disable the RTC tamper interrupt (TAMPIE bit in the RTC\_TAFCR register)
  - b) Clear the Tamper (TAMP1F/TSF) flag
  - c) Clear the PWR Wakeup (WUF) flag
  - d) Enable the RTC tamper interrupt
  - e) Re-enter the low-power mode
- When using RTC time stamp to wake up the device from the low-power modes:
  - a) Disable the RTC time stamp interrupt (TSIE bit in RTC\_CR)
  - b) Clear the RTC time stamp (TSF) flag
  - c) Clear the PWR Wakeup (WUF) flag
  - d) Enable the RTC TimeStamp interrupt
  - e) Re-enter the low-power mode

## 5.4 Power control registers

### 5.4.1 PWR power control register (PWR\_CR)

Address offset: 0x000

Reset value: 0x0000 8000 (reset by wakeup from Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VOS	ADCDC1	Res	MRLV DS	LPLV DS	FPDS	DBP	PLS[2:0]			PVDE	CSBF	CWUF	PDDS	LPDS	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	w	rw	rw	

Bits 31:16 Reserved, must be kept at reset value.

Bits15:14 **VOS[1:0]**: Regulator voltage scaling output selection

These bits control the main internal voltage regulator output voltage to achieve a trade-off between performance and power consumption when the device does not operate at the maximum frequency (refer to the corresponding datasheet for more details).

These bits can be modified only when the PLL is OFF. The new value programmed is active only when the PLL is ON. When the PLL is OFF, the voltage regulator is set to scale 3 independently of the VOS register content.

00: Reserved (Scale 3 mode selected)

01: Scale 3 mode

10: Scale 2 mode

11: Reserved (Scale 2 mode selected)

Bit 13 **ADCDC1**:

0: No effect.

1: Refer to AN4073 for details on how to use this bit.

*Note:* This bit can only be set when operating at supply voltage range 2.7 to 3.6V and when the Prefetch is OFF.

Bit 12 Reserved, must be kept at reset value.

Bit 11 **MRLVDS**: Main regulator Low Voltage in Deep Sleep

0: Main regulator in Voltage scale 3 when the device is in Stop mode.

1: Main regulator in Low Voltage and Flash memory in Deep Sleep mode when the device is in Stop mode.

Bit 10 **LPLVDS**: Low Power regulator Low Voltage in Deep Sleep

0: Low Power regulator on if LPDS bit is set when the device is in Stop mode.

1: Low Power regulator in Low Voltage and Flash memory in Deep Sleep mode if LPDS bit is set when device is in Stop mode.

Bit 9 **FPDS**: Flash power-down in Stop mode

When set, the Flash memory enters power-down mode when the device enters Stop mode. This allows to achieve a lower consumption in stop mode but a longer restart time.

0: Flash memory not in power-down when the device is in Stop mode

1: Flash memory in power-down when the device is in Stop mode

**Bit 8 **DBP**: Disable backup domain write protection**

In reset state, the RCC\_BDCR register, the RTC registers (including the backup registers), and the BRE bit of the PWR\_CSR register, are protected against parasitic write access. This bit must be set to enable write access to these registers.

- 0: Access to RTC and RTC Backup registers and backup SRAM disabled
- 1: Access to RTC and RTC Backup registers and backup SRAM enabled

**Bits 7:5 **PLS[2:0]**: PVD level selection**

These bits are written by software to select the voltage threshold detected by the Power Voltage Detector

- 000: 2.2 V
- 001: 2.3 V
- 010: 2.4 V
- 011: 2.5 V
- 100: 2.6 V
- 101: 2.7 V
- 110: 2.8 V
- 111: 2.9 V

*Note: Refer to the electrical characteristics of the datasheet for more details.*

**Bit 4 **PVDE**: Power voltage detector enable**

This bit is set and cleared by software.

- 0: PVD disabled
- 1: PVD enabled

**Bit 3 **CSBF**: Clear standby flag**

This bit is always read as 0.

- 0: No effect.
- 1: Clear the SBF Standby Flag (write).

**Bit 2 **CWUF**: Clear wakeup flag**

This bit is always read as 0.

- 0: No effect.
- 1: Clear the WUF Wakeup Flag **after 2 System clock cycles**.

**Bit 1 **PDDS**: Power-down deepsleep**

This bit is set and cleared by software. It works together with the LPDS bit.

- 0: Enter Stop mode when the CPU enters deepsleep. The regulator status depends on the LPDS bit.
- 1: Enter Standby mode when the CPU enters deepsleep.

**Bit 0 **LPDS**: Low-power deepsleep**

This bit is set and cleared by software. It works together with the PDDS bit.

- 0: Voltage regulator on during Stop mode.
- 1: Low-power Voltage regulator on during Stop mode.

### 5.4.2 PWR power control/status register (PWR\_CSR)

Address offset: 0x04

Reset value: 0x0000 0000 (not reset by wakeup from Standby mode)

Additional APB cycles are needed to read this register versus a standard APB read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res	VOS RDY	Reserved			BRE	EWUP	Reserved			BRR	PVDO	SBF	WUF		
	r				rw	rw				r	r	r	r		

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **VOSRDY**: Regulator voltage scaling output selection ready bit

- 0: Not ready
- 1: Ready

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **BRE**: Backup regulator enable

When set, the Backup regulator (used to maintain the backup domain content) is enabled. If BRE is reset, the backup regulator is switched off. Once set, the application must wait that the Backup Regulator Ready flag (BRR) is set to indicate that the data written into the backup registers will be maintained in the Standby and V<sub>BAT</sub> modes.

- 0: Backup regulator disabled
- 1: Backup regulator enabled

*Note: This bit is not reset when the device wakes up from Standby mode, by a system reset, or by a power reset.*

Bit 8 **EWUP**: Enable WKUP pin

This bit is set and cleared by software.

- 0: WKUP pin is used for general purpose I/O. An event on the WKUP pin does not wakeup the device from Standby mode.
- 1: WKUP pin is used for wakeup from Standby mode and forced in input pull down configuration (rising edge on WKUP pin wakes-up the system from Standby mode).

*Note: This bit is reset by a system reset.*

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **BRR**: Backup regulator ready

Set by hardware to indicate that the Backup Regulator is ready.

- 0: Backup Regulator not ready
- 1: Backup Regulator ready

*Note: This bit is not reset when the device wakes up from Standby mode or by a system reset or power reset.*

Bit 2 **PVDO**: PVD output

This bit is set and cleared by hardware. It is valid only if PVD is enabled by the PVDE bit.

- 0: V<sub>DD</sub> is higher than the PVD threshold selected with the PLS[2:0] bits.
- 1: V<sub>DD</sub> is lower than the PVD threshold selected with the PLS[2:0] bits.

*Note: The PVD is stopped by Standby mode. For this reason, this bit is equal to 0 after Standby or reset until the PVDE bit is set.*

**Bit 1 SBF:** Standby flag

This bit is set by hardware and cleared only by a POR/PDR (power-on reset/power-down reset) or by setting the CSBF bit in the PWR\_CR register.

- 0: Device has not been in Standby mode
- 1: Device has been in Standby mode

**Bit 0 WUF:** Wakeup flag

This bit is set by hardware and cleared either by a system reset or by setting the CWUF bit in the PWR\_CR register.

- 0: No wakeup event occurred
- 1: A wakeup event was received from the WKUP pin or from the RTC alarm (Alarm A or Alarm B), RTC Tamper event, RTCTimeStamp event or RTC Wakeup).

*Note: An additional wakeup event is detected if the WKUP pin is enabled (by setting the EWUP bit) when the WKUP pin level is already high.*

## 5.5 PWR register map

The following table summarizes the PWR registers.

**Table 21. PWR - register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0			
0x000	<b>PWR_CR</b> Reset value	Reserved										[VOSI[1:0]]	1	1	0	ADCD1	Reserved	MRLVDS	MRVLVDS	LPILVDS	PLS[2:0]	FPS	0	0	0	0	0	PVDE	0	0	0	0	0			
0x004	<b>PWR_CSR</b> Reset value	Reserved										[VOSRDY]	0	Reserved	BRE	EWUP	DBP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 6 Reset and clock control (RCC) for STM32F401xB/C and STM32F401xD/E

### 6.1 Reset

There are three types of reset, defined as system Reset, power Reset and backup domain Reset.

#### 6.1.1 System reset

A system reset sets all registers to their reset values except the reset flags in the clock controller CSR register and the registers in the Backup domain.

A system reset is generated when one of the following events occurs:

1. A low level on the NRST pin (external reset)
2. Window watchdog end of count condition (WWDG reset)
3. Independent watchdog end of count condition (IWDG reset)
4. A software reset (SW reset) (see [Software reset](#))
5. Low-power management reset (see [Low-power management reset](#))

#### Software reset

The reset source can be identified by checking the reset flags in the [\*RCC clock control & status register \(RCC\\_CSR\)\*](#).

The SYSRESETREQ bit in Cortex™-M4 with FPU Application Interrupt and Reset Control Register must be set to force a software reset on the device. Refer to the Cortex™-M4 with FPU technical reference manual for more details.

### Low-power management reset

There are two ways of generating a low-power management reset:

1. Reset generated when entering the Standby mode:

This type of reset is enabled by resetting the nRST\_STDBY bit in the user option bytes. In this case, whenever a Standby mode entry sequence is successfully executed, the device is reset instead of entering the Standby mode.

2. Reset when entering the Stop mode:

This type of reset is enabled by resetting the nRST\_STOP bit in the user option bytes. In this case, whenever a Stop mode entry sequence is successfully executed, the device is reset instead of entering the Stop mode.

For further information on the user option bytes, refer to the STM32F401xB/C and STM32F401xD/E Flash programming manual available from your ST sales office.

### 6.1.2 Power reset

A power reset is generated when one of the following events occurs:

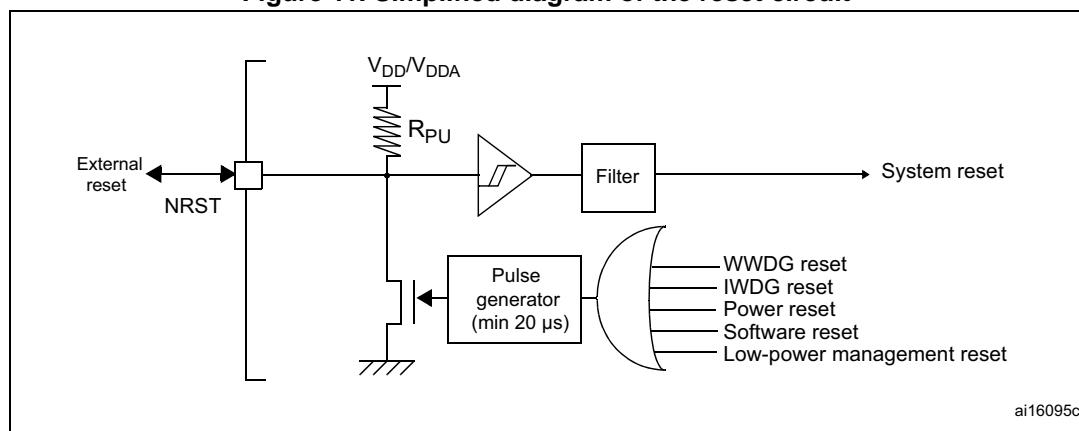
1. Power-on/power-down reset (POR/PDR reset) or brownout (BOR) reset
2. When exiting the Standby mode

A power reset sets all registers to their reset values except the Backup domain.

These sources act on the NRST pin and it is always kept low during the delay phase. The RESET service routine vector is fixed at address 0x0000\_0004 in the memory map.

The system reset signal provided to the device is output on the NRST pin. The pulse generator guarantees a minimum reset pulse duration of 20 µs for each internal reset source. In case of an external reset, the reset pulse is generated while the NRST pin is asserted low.

**Figure 11. Simplified diagram of the reset circuit**



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### 6.1.3 Backup domain reset

The backup domain reset sets all RTC registers and the RCC\_BDCR register to their reset values.

A backup domain reset is generated when one of the following events occurs:

1. Software reset, triggered by setting the BDRST bit in the *RCC Backup domain control register (RCC\_BDCR)*.
2.  $V_{DD}$  or  $V_{BAT}$  power on, if both supplies have previously been powered off.

## 6.2 Clocks

Three different clock sources can be used to drive the system clock (SYSCLK):

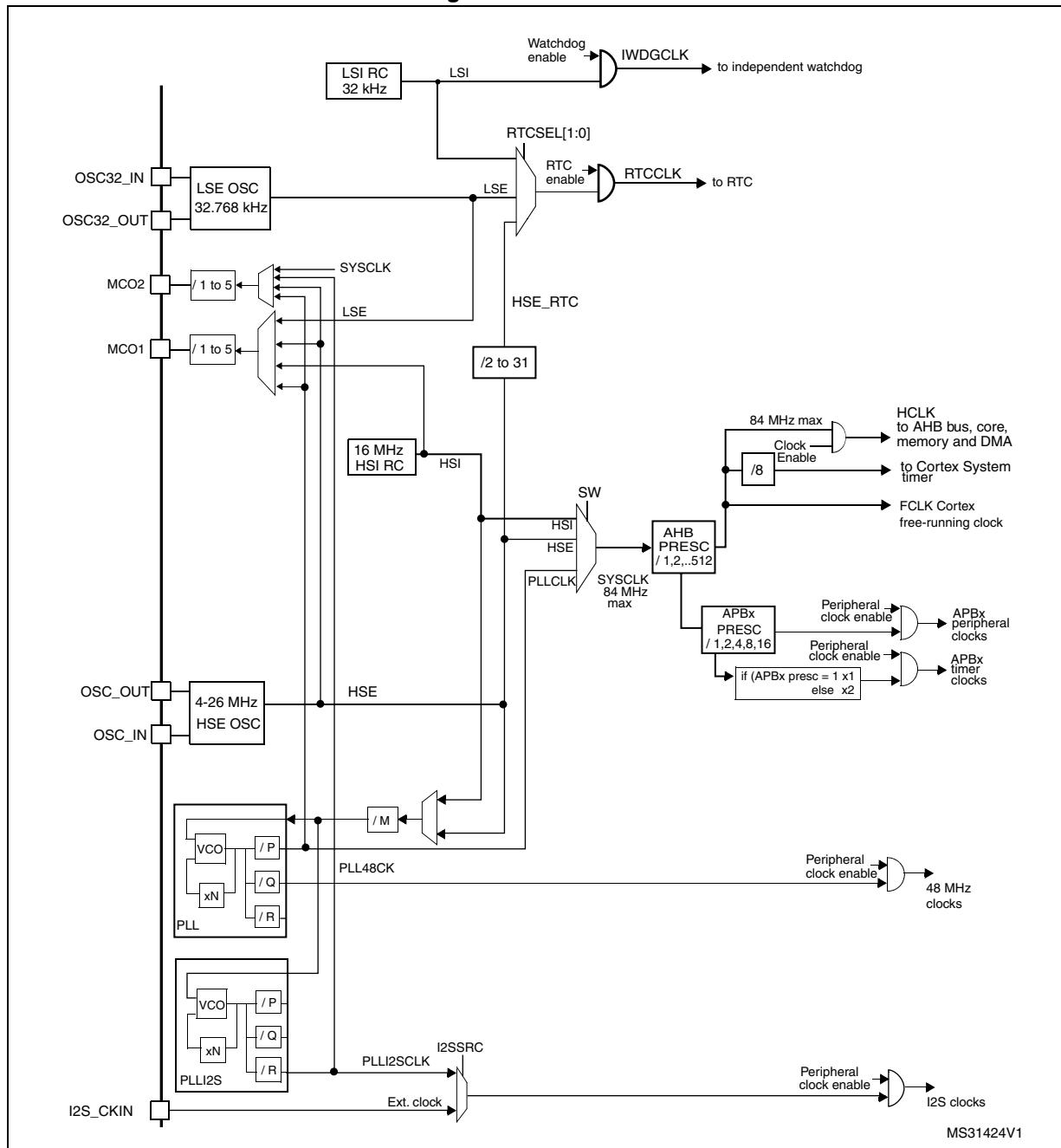
- HSI oscillator clock
- HSE oscillator clock
- Main PLL (PLL) clock

The devices have the two following secondary clock sources:

- 32 kHz low-speed internal RC (LSI RC) which drives the independent watchdog and, optionally, the RTC used for Auto-wakeup from the Stop/Standy mode.
- 32.768 kHz low-speed external crystal (LSE crystal) which optionally drives the RTC clock (RTCCLK)

Each clock source can be switched on or off independently when it is not used, to optimize power consumption.

Figure 12. Clock tree



- For full details about the internal and external clock source characteristics, refer to the Electrical characteristics section in the device datasheet.

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The clock controller provides a high degree of flexibility to the application in the choice of the external crystal or the oscillator to run the core and peripherals at the highest frequency and, guarantee the appropriate frequency for peripherals that need a specific clock like USB OTG FS, I2S and SDIO.

Several prescalers are used to configure the AHB frequency, the high-speed APB (APB2) and the low-speed APB (APB1) domains. The maximum frequency of the AHB domain is 84 MHz. The maximum allowed frequency of the high-speed APB2 domain is 84 MHz. The maximum allowed frequency of the low-speed APB1 domain is 42 MHz

All peripheral clocks are derived from the system clock (SYSCLK) except for:

- The USB OTG FS clock (48 MHz) and the SDIO clock ( $\leq 48$  MHz) which are coming from a specific output of PLL (PLL48CLK)
- The I2S clock

To achieve high-quality audio performance, the I2S clock can be derived either from a specific PLL (PLLI2S) or from an external clock mapped on the I2S\_CKIN pin. For more information about I2S clock frequency and precision, refer to [Section 20.4.4: Clock generator](#).

The RCC feeds the external clock of the Cortex System Timer (SysTick) with the AHB clock (HCLK) divided by 8. The SysTick can work either with this clock or with the Cortex clock (HCLK), configurable in the SysTick control and status register.

The timer clock frequencies for STM32F401xB/C and STM32F401xD/E are automatically set by hardware. There are two cases:

1. If the APB prescaler is 1, the timer clock frequencies are set to the same frequency as that of the APB domain to which the timers are connected.
2. Otherwise, they are set to twice ( $\times 2$ ) the frequency of the APB domain to which the timers are connected.

The timer clock frequencies are automatically set by hardware. There are two cases depending on the value of TIMPRE bit in RCC\_DCKCFGR register:

- If TIMPRE bit is reset:  
If the APB prescaler is configured to a division factor of 1, the timer clock frequencies (TIMxCLK) are set to HCLK. Otherwise, the timer clock frequencies are twice the frequency of the APB domain to which the timers are connected:  $\text{TIMxCLK} = 2 \times \text{PCLKx}$ .
- If TIMPRE bit is set:  
If the APB prescaler is configured to a division factor of 1 or 2, the timer clock frequencies (TIMxCLK) are set to HCLK. Otherwise, the timer clock frequencies is four times the frequency of the APB domain to which the timers are connected:  $\text{TIMxCLK} = 4 \times \text{PCLKx}$ .

FCLK acts as Cortex™-M4 with FPU free-running clock. For more details, refer to the Cortex™-M4 with FPU technical reference manual.

## 6.2.1 HSE clock

The high speed external clock signal (HSE) can be generated from two possible clock sources:

- HSE external crystal/ceramic resonator
- HSE external user clock

The resonator and the load capacitors have to be placed as close as possible to the oscillator pins in order to minimize output distortion and startup stabilization time. The loading capacitance values must be adjusted according to the selected oscillator.

**Figure 13. HSE/ LSE clock sources**

Hardware configuration	
<b>External clock</b>	
<b>Crystal/ceramic resonators</b>	

### External source (HSE bypass)

In this mode, an external clock source must be provided. You select this mode by setting the HSEBYP and HSEON bits in the [RCC clock control register \(RCC\\_CR\)](#). The external clock signal (square, sinus or triangle) with ~50% duty cycle has to drive the OSC\_IN pin while the OSC\_OUT pin should be left HI-Z. See [Figure 13](#).

### External crystal/ceramic resonator (HSE crystal)

The HSE has the advantage of producing a very accurate rate on the main clock.

The associated hardware configuration is shown in [Figure 13](#). Refer to the electrical characteristics section of the *datasheet* for more details.

The HSERDY flag in the [RCC clock control register \(RCC\\_CR\)](#) indicates if the high-speed external oscillator is stable or not. At startup, the clock is not released until this bit is set by hardware. An interrupt can be generated if enabled in the [RCC clock interrupt register \(RCC\\_CIR\)](#).

The HSE Crystal can be switched on and off using the HSEON bit in the [RCC clock control register \(RCC\\_CR\)](#).

## 6.2.2 HSI clock

The HSI clock signal is generated from an internal 16 MHz RC oscillator and can be used directly as a system clock, or used as PLL input.

The HSI RC oscillator has the advantage of providing a clock source at low cost (no external components). It also has a faster startup time than the HSE crystal oscillator however, even

with calibration the frequency is less accurate than an external crystal oscillator or ceramic resonator.

### Calibration

RC oscillator frequencies can vary from one chip to another due to manufacturing process variations, this is why each device is factory calibrated by ST for 1% accuracy at  $T_A = 25^\circ\text{C}$ .

After reset, the factory calibration value is loaded in the HSICAL[7:0] bits in the [RCC clock control register \(RCC\\_CR\)](#).

If the application is subject to voltage or temperature variations this may affect the RC oscillator speed. You can trim the HSI frequency in the application using the HSITRIM[4:0] bits in the [RCC clock control register \(RCC\\_CR\)](#).

The HSIRDY flag in the [RCC clock control register \(RCC\\_CR\)](#) indicates if the HSI RC is stable or not. At startup, the HSI RC output clock is not released until this bit is set by hardware.

The HSI RC can be switched on and off using the HSION bit in the [RCC clock control register \(RCC\\_CR\)](#).

The HSI signal can also be used as a backup source (Auxiliary clock) if the HSE crystal oscillator fails. Refer to [Section 6.2.7: Clock security system \(CSS\) on page 95](#).

### 6.2.3 PLL configuration

The STM32F401xB/C and STM32F401xD/E devices feature two PLLs:

- A main PLL (PLL) clocked by the HSE or HSI oscillator and featuring two different output clocks:
  - The first output is used to generate the high speed system clock (up to 84 MHz)
  - The second output is used to generate the clock for the USB OTG FS (48 MHz), the random analog generator ( $\leq 48$  MHz) and the SDIO ( $\leq 48$  MHz).
- A dedicated PLL (PLLI2S) used to generate an accurate clock to achieve high-quality audio performance on the I2S interface.

Since the main-PLL configuration parameters cannot be changed once PLL is enabled, it is recommended to configure PLL before enabling it (selection of the HSI or HSE oscillator as PLL clock source, and configuration of division factors M, P, Q and multiplication factor N).

The PLLI2S uses the same input clock as PLL (PLLM[5:0] and PLLSRC bits are common to both PLLs). However, the PLLI2S has dedicated enable/disable and division factors configuration bits. Refer to [Section 6.3.1: RCC clock control register \(RCC\\_CR\)](#) and [Section 6.3.2: RCC PLL configuration register \(RCC\\_PLLCFGR\)](#). Once the PLLI2S is enabled, the configuration parameters cannot be changed.

The two PLLs are disabled by hardware when entering Stop and Standby modes, or when an HSE failure occurs when HSE or PLL (clocked by HSE) are used as system clock. [RCC PLL configuration register \(RCC\\_PLLCFGR\)](#) and [RCC clock configuration register \(RCC\\_CFGR\)](#) can be used to configure PLL and PLLI2S, respectively.

### 6.2.4 LSE clock

The LSE clock is generated using a 32.768kHz low speed external crystal or ceramic resonator. It has the advantage providing a low-power but highly accurate clock source to the real-time clock peripheral (RTC) for clock/calendar or other timing functions.

The LSE oscillator is switched on and off using the LSEON bit in [RCC Backup domain control register \(RCC\\_BDCR\)](#).

The LSERDY flag in the [RCC Backup domain control register \(RCC\\_BDCR\)](#) indicates if the LSE crystal is stable or not. At startup, the LSE crystal output clock signal is not released until this bit is set by hardware. An interrupt can be generated if enabled in the [RCC clock interrupt register \(RCC\\_CIR\)](#).

### External source (LSE bypass)

In this mode, an external clock source must be provided. It must have a frequency up to 1 MHz. You select this mode by setting the LSEBYP and LSEON bits in the [RCC Backup domain control register \(RCC\\_BDCR\)](#). The external clock signal (square, sinus or triangle) with ~50% duty cycle has to drive the OSC32\_IN pin while the OSC32\_OUT pin should be left HI-Z. See [Figure 13](#).

## 6.2.5 LSI clock

The LSI RC acts as an low-power clock source that can be kept running in Stop and Standby mode for the independent watchdog (IWDG) and Auto-wakeup unit (AWU). The clock frequency is around 32 kHz. For more details, refer to the electrical characteristics section of the datasheets.

The LSI RC can be switched on and off using the LSION bit in the [RCC clock control & status register \(RCC\\_CSR\)](#).

The LSIRDY flag in the [RCC clock control & status register \(RCC\\_CSR\)](#) indicates if the low-speed internal oscillator is stable or not. At startup, the clock is not released until this bit is set by hardware. An interrupt can be generated if enabled in the [RCC clock interrupt register \(RCC\\_CIR\)](#).

## 6.2.6 System clock (SYSCLK) selection

After a system reset, the HSI oscillator is selected as the system clock. When a clock source is used directly or through PLL as the system clock, it is not possible to stop it.

A switch from one clock source to another occurs only if the target clock source is ready (clock stable after startup delay or PLL locked). If a clock source that is not yet ready is selected, the switch occurs when the clock source is ready. Status bits in the [RCC clock control register \(RCC\\_CR\)](#) indicate which clock(s) is (are) ready and which clock is currently used as the system clock.

## 6.2.7 Clock security system (CSS)

The clock security system can be activated by software. In this case, the clock detector is enabled after the HSE oscillator startup delay, and disabled when this oscillator is stopped.

If a failure is detected on the HSE clock, this oscillator is automatically disabled, a clock failure event is sent to the break inputs of advanced-control timer TIM1, and an interrupt is generated to inform the software about the failure (clock security system interrupt CSSI), allowing the MCU to perform rescue operations. The CSSI is linked to the Cortex™-M4 with FPU NMI (non-maskable interrupt) exception vector.

**Note:** *When the CSS is enabled, if the HSE clock happens to fail, the CSS generates an interrupt, which causes the automatic generation of an NMI. The NMI is executed indefinitely unless the CSS interrupt pending bit is cleared. As a consequence, the application has to clear the*

*CSS interrupt in the NMI ISR by setting the CSSC bit in the Clock interrupt register (RCC\_CIR).*

If the HSE oscillator is used directly or indirectly as the system clock (indirectly meaning that it is directly used as PLL input clock, and that PLL clock is the system clock) and a failure is detected, then the system clock switches to the HSI oscillator and the HSE oscillator is disabled.

If the HSE oscillator clock was the clock source of PLL used as the system clock when the failure occurred, PLL is also disabled. In this case, if the PLLI2S was enabled, it is also disabled when the HSE fails.

## 6.2.8 RTC/AWU clock

Once the RTCCLK clock source has been selected, the only possible way of modifying the selection is to reset the power domain.

The RTCCLK clock source can be either the HSE 1 MHz (HSE divided by a programmable prescaler), the LSE or the LSI clock. This is selected by programming the RTCSEL[1:0] bits in the *RCC Backup domain control register (RCC\_BDCR)* and the RTCPRE[4:0] bits in *RCC clock configuration register (RCC\_CFGR)*. This selection cannot be modified without resetting the Backup domain.

If the LSE is selected as the RTC clock, the RTC will work normally if the backup or the system supply disappears. If the LSI is selected as the AWU clock, the AWU state is not guaranteed if the system supply disappears. If the HSE oscillator divided by a value between 2 and 31 is used as the RTC clock, the RTC state is not guaranteed if the backup or the system supply disappears.

The LSE clock is in the Backup domain, whereas the HSE and LSI clocks are not. As a consequence:

- If LSE is selected as the RTC clock:
  - The RTC continues to work even if the  $V_{DD}$  supply is switched off, provided the  $V_{BAT}$  supply is maintained.
- If LSI is selected as the Auto-wakeup unit (AWU) clock:
  - The AWU state is not guaranteed if the  $V_{DD}$  supply is powered off. Refer to [Section 6.2.5: LSI clock on page 95](#) for more details on LSI calibration.
- If the HSE clock is used as the RTC clock:
  - The RTC state is not guaranteed if the  $V_{DD}$  supply is powered off or if the internal voltage regulator is powered off (removing power from the 1.2 V domain).

Note:

*To read the RTC calendar register when the APB1 clock frequency is less than seven times the RTC clock frequency ( $f_{APB1} < 7 \times f_{RTCLCK}$ ), the software must read the calendar time and date registers twice. The data are correct if the second read access to RTC\_TR gives the same result than the first one. Otherwise a third read access must be performed.*

## 6.2.9 Watchdog clock

If the independent watchdog (IWDG) is started by either hardware option or software access, the LSI oscillator is forced ON and cannot be disabled. After the LSI oscillator temporization, the clock is provided to the IWDG.

## 6.2.10 Clock-out capability

Two microcontroller clock output (MCO) pins are available:

- MCO1

You can output four different clock sources onto the MCO1 pin (PA8) using the configurable prescaler (from 1 to 5):

- HSI clock
- LSE clock
- HSE clock
- PLL clock

The desired clock source is selected using the MCO1PRE[2:0] and MCO1[1:0] bits in the *RCC clock configuration register (RCC\_CFGR)*.

- MCO2

You can output four different clock sources onto the MCO2 pin (PC9) using the configurable prescaler (from 1 to 5):

- HSE clock
- PLL clock
- System clock (SYSCLK)
- PLLI2S clock

The desired clock source is selected using the MCO2PRE[2:0] and MCO2 bits in the *RCC clock configuration register (RCC\_CFGR)*.

For the different MCO pins, the corresponding GPIO port has to be programmed in alternate function mode.

The selected clock to output onto MCO must not exceed 100 MHz (the maximum I/O speed).

## 6.2.11 Internal/external clock measurement using TIM5/TIM11

It is possible to indirectly measure the frequencies of all on-board clock source generators by means of the input capture of TIM5 channel4 and TIM11 channel1 as shown in *Figure 14* and *Figure 15*.

### Internal/external clock measurement using TIM5 channel4

TIM5 has an input multiplexer which allows choosing whether the input capture is triggered by the I/O or by an internal clock. This selection is performed through the TI4\_RMP [1:0] bits in the TIM5\_OR register.

The primary purpose of having the LSE connected to the channel4 input capture is to be able to precisely measure the HSI (this requires to have the HSI used as the system clock source). The number of HSI clock counts between consecutive edges of the LSE signal provides a measurement of the internal clock period. Taking advantage of the high precision of LSE crystals (typically a few tens of ppm) we can determine the internal clock frequency with the same resolution, and trim the source to compensate for manufacturing-process and/or temperature- and voltage-related frequency deviations.

The HSI oscillator has dedicated, user-accessible calibration bits for this purpose.

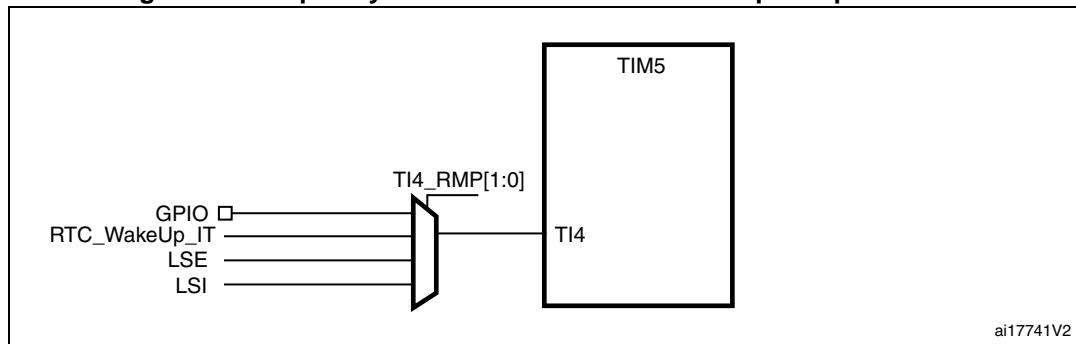
The basic concept consists in providing a relative measurement (e.g. HSI/LSE ratio): the precision is therefore tightly linked to the ratio between the two clock sources. The greater the ratio, the better the measurement.

It is also possible to measure the LSI frequency: this is useful for applications that do not have a crystal. The ultralow-power LSI oscillator has a large manufacturing process deviation: by measuring it versus the HSI clock source, it is possible to determine its frequency with the precision of the HSI. The measured value can be used to have more accurate RTC time base timeouts (when LSI is used as the RTC clock source) and/or an IWDG timeout with an acceptable accuracy.

Use the following procedure to measure the LSI frequency:

1. Enable the TIM5 timer and configure channel4 in Input capture mode.
2. Set the TI4\_RMP bits in the TIM5\_OR register to 0x01 to connect the LSI clock internally to TIM5 channel4 input capture for calibration purposes.
3. Measure the LSI clock frequency using the TIM5 capture/compare 4 event or interrupt.
4. Use the measured LSI frequency to update the prescaler of the RTC depending on the desired time base and/or to compute the IWDG timeout.

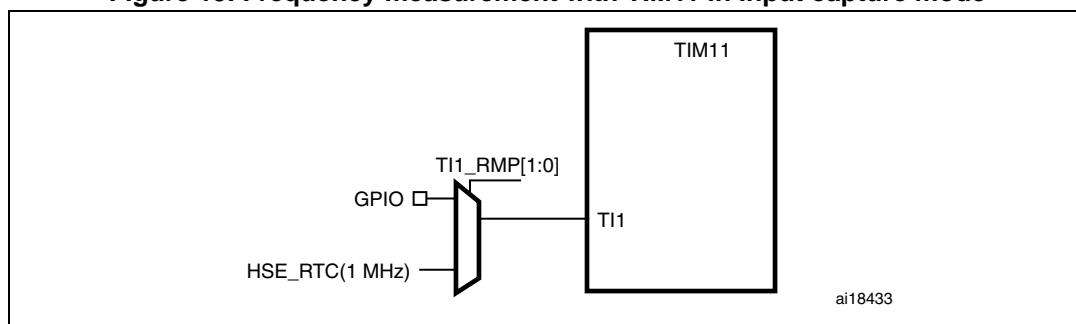
**Figure 14. Frequency measurement with TIM5 in Input capture mode**



#### Internal/external clock measurement using TIM11 channel1

TIM11 has an input multiplexer which allows choosing whether the input capture is triggered by the I/O or by an internal clock. This selection is performed through TI1\_RMP [1:0] bits in the TIM11\_OR register. The HSE\_RTC clock (HSE divided by a programmable prescaler) is connected to channel 1 input capture to have a rough indication of the external crystal frequency. This requires that the HSI is the system clock source. This can be useful for instance to ensure compliance with the IEC 60730/IEC 61335 standards which require to be able to determine harmonic or subharmonic frequencies (-50/+100% deviations).

**Figure 15. Frequency measurement with TIM11 in Input capture mode**



## 6.3 RCC registers

Refer to [Section 1.1: List of abbreviations for registers](#) for a list of abbreviations used in register descriptions.

### 6.3.1 RCC clock control register (RCC\_CR)

Address offset: 0x00

Reset value: 0x0000 XX81 where X is undefined.

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				PLL2S RDY	PLL2S ON	PLLRDY	PLLON	Reserved				CSS ON	HSE BYP	HSE RDY	HSE ON
				r	rw	r	rw					rw	rw	r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HSICAL[7:0]								HSITRIM[4:0]				Res.	HSI RDY	HSION	
r	r	r	r	r	r	r	r	rw	rw	rw	rw		r	rw	

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **PLL2SRDY**: PLLI2S clock ready flag

Set by hardware to indicate that the PLLI2S is locked.

0: PLLI2S unlocked

1: PLLI2S locked

Bit 26 **PLL2SON**: PLLI2S enable

Set and cleared by software to enable PLLI2S.

Cleared by hardware when entering Stop or Standby mode.

0: PLLI2S OFF

1: PLLI2S ON

Bit 25 **PLLRDY**: Main PLL (PLL) clock ready flag

Set by hardware to indicate that PLL is locked.

0: PLL unlocked

1: PLL locked

Bit 24 **PLLON**: Main PLL (PLL) enable

Set and cleared by software to enable PLL.

Cleared by hardware when entering Stop or Standby mode. This bit cannot be reset if PLL clock is used as the system clock.

0: PLL OFF

1: PLL ON

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **CSSON**: Clock security system enable

Set and cleared by software to enable the clock security system. When CSSON is set, the clock detector is enabled by hardware when the HSE oscillator is ready, and disabled by hardware if an oscillator failure is detected.

0: Clock security system OFF (Clock detector OFF)

1: Clock security system ON (Clock detector ON if HSE oscillator is stable, OFF if not)

**Bit 18 HSEBYP:** HSE clock bypass

Set and cleared by software to bypass the oscillator with an external clock. The external clock must be enabled with the HSEON bit, to be used by the device.

The HSEBYP bit can be written only if the HSE oscillator is disabled.

0: HSE oscillator not bypassed

1: HSE oscillator bypassed with an external clock

**Bit 17 HSERDY:** HSE clock ready flag

Set by hardware to indicate that the HSE oscillator is stable. After the HSEON bit is cleared, HSERDY goes low after 6 HSE oscillator clock cycles.

0: HSE oscillator not ready

1: HSE oscillator ready

**Bit 16 HSEON:** HSE clock enable

Set and cleared by software.

Cleared by hardware to stop the HSE oscillator when entering Stop or Standby mode. This bit cannot be reset if the HSE oscillator is used directly or indirectly as the system clock.

0: HSE oscillator OFF

1: HSE oscillator ON

**Bits 15:8 HSICAL[7:0]:** Internal high-speed clock calibration

These bits are initialized automatically at startup.

**Bits 7:3 HSITRIM[4:0]:** Internal high-speed clock trimming

These bits provide an additional user-programmable trimming value that is added to the HSICAL[7:0] bits. It can be programmed to adjust to variations in voltage and temperature that influence the frequency of the internal HSI RC.

Bit 2 Reserved, must be kept at reset value.

**Bit 1 HSIRDY:** Internal high-speed clock ready flag

Set by hardware to indicate that the HSI oscillator is stable. After the HSION bit is cleared, HSIRDY goes low after 6 HSI clock cycles.

0: HSI oscillator not ready

1: HSI oscillator ready

**Bit 0 HSION:** Internal high-speed clock enable

Set and cleared by software.

Set by hardware to force the HSI oscillator ON when leaving the Stop or Standby mode or in case of a failure of the HSE oscillator used directly or indirectly as the system clock. This bit cannot be cleared if the HSI is used directly or indirectly as the system clock.

0: HSI oscillator OFF

1: HSI oscillator ON

### 6.3.2 RCC PLL configuration register (RCC\_PLLCFGR)

Address offset: 0x04

Reset value: 0x2400 3010

Access: no wait state, word, half-word and byte access.

This register is used to configure the PLL clock outputs according to the formulas:

- $f_{(VCO\ clock)} = f_{(PLL\ clock\ input)} \times (PLLN / PLLM)$
- $f_{(PLL\ general\ clock\ output)} = f_{(VCO\ clock)} / PLLP$
- $f_{(USB\ OTG\ FS,\ SDIO,\ RNG\ clock\ output)} = f_{(VCO\ clock)} / PLLQ$

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				PLLQ3	PLLQ2	PLLQ1	PLLQ0	Reserv ed	PLLSRC	Reserved			PLLP1	PLLP0	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserv ed	PLLN								PLLM5	PLLM4	PLLM3	PLLM2	PLLM1	PLLM0	
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31:28 Reserved, must be kept at reset value.

Bits 27:24 **PLLQ**: Main PLL (PLL) division factor for USB OTG FS, SDIO and random number generator clocks

Set and cleared by software to control the frequency of USB OTG FS clock, the random number generator clock and the SDIO clock. These bits should be written only if PLL is disabled.

**Caution:** The USB OTG FS requires a 48 MHz clock to work correctly. The SDIO and the random number generator need a frequency lower than or equal to 48 MHz to work correctly.

USB OTG FS clock frequency = VCO frequency / PLLQ with  $2 \leq PLLQ \leq 15$

0000: PLLQ = 0, wrong configuration

0001: PLLQ = 1, wrong configuration

0010: PLLQ = 2

0011: PLLQ = 3

0100: PLLQ = 4

...

1111: PLLQ = 15

Bit 23 Reserved, must be kept at reset value.

Bit 22 **PLLSRC**: Main PLL(PLL) and audio PLL (PLLI2S) entry clock source

Set and cleared by software to select PLL and PLLI2S clock source. This bit can be written only when PLL and PLLI2S are disabled.

0: HSI clock selected as PLL and PLLI2S clock entry

1: HSE oscillator clock selected as PLL and PLLI2S clock entry

Bits 21:18 Reserved, must be kept at reset value.

Bits 17:16 **PLLP**: Main PLL (PLL) division factor for main system clock

Set and cleared by software to control the frequency of the general PLL output clock. These bits can be written only if PLL is disabled.

**Caution:** The software has to set these bits correctly not to exceed 84 MHz on this domain.

PLL output clock frequency = VCO frequency / PLLP with PLLP = 2, 4, 6, or 8

- 00: PLLP = 2
- 01: PLLP = 4
- 10: PLLP = 6
- 11: PLLP = 8

Bits 14:6 **PLLN**: Main PLL (PLL) multiplication factor for VCO

Set and cleared by software to control the multiplication factor of the VCO. These bits can be written only when PLL is disabled. Only half-word and word accesses are allowed to write these bits.

**Caution:** The software has to set these bits correctly to ensure that the VCO output frequency is between 192 and 432 MHz. (check also [Section 6.3.20: RCC PLLI2S configuration register \(RCC\\_PLLI2SCFGR\)](#))

VCO output frequency = VCO input frequency × PLLN with  $192 \leq \text{PLLN} \leq 432$

00000000: PLLN = 0, wrong configuration

00000001: PLLN = 1, wrong configuration

...

011000000: PLLN = 192

...

110110000: PLLN = 432

110110001: PLLN = 433, wrong configuration

...

111111111: PLLN = 511, wrong configuration

Bits 5:0 **PLLM**: Division factor for the main PLL (PLL) and audio PLL (PLLI2S) input clock

Set and cleared by software to divide the PLL and PLLI2S input clock before the VCO. These bits can be written only when the PLL and PLLI2S are disabled.

**Caution:** The software has to set these bits correctly to ensure that the VCO input frequency ranges from 1 to 2 MHz. It is recommended to select a frequency of 2 MHz to limit PLL jitter.

VCO input frequency = PLL input clock frequency / PLLM with  $2 \leq \text{PLLM} \leq 63$

000000: PLLM = 0, wrong configuration

000001: PLLM = 1, wrong configuration

000010: PLLM = 2

000011: PLLM = 3

000100: PLLM = 4

...

111110: PLLM = 62

111111: PLLM = 63

### 6.3.3 RCC clock configuration register (RCC\_CFGR)

Address offset: 0x08

Reset value: 0x0000 0000

Access: 0 ≤ wait state ≤ 2, word, half-word and byte access

1 or 2 wait states inserted only if the access occurs during a clock source switch.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MCO2		MCO2 PRE[2:0]			MCO1 PRE[2:0]			I2SSC R	MCO1		RTCPRE[4:0]				
rw		rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PPRE2[2:0]			PPRE1[2:0]			Reserved	HPRE[3:0]				SWS1	SWS0	SW1	SW0	
rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	r	r	rw	rw	

Bits 31:30 **MCO2[1:0]:** Microcontroller clock output 2

Set and cleared by software. Clock source selection may generate glitches on MCO2. It is highly recommended to configure these bits only after reset before enabling the external oscillators and the PLLs.

- 00: System clock (SYSCLK) selected
- 01: PLLI2S clock selected
- 10: HSE oscillator clock selected
- 11: PLL clock selected

Bits 27:29 **MCO2PRE:** MCO2 prescaler

Set and cleared by software to configure the prescaler of the MCO2. Modification of this prescaler may generate glitches on MCO2. It is highly recommended to change this prescaler only after reset before enabling the external oscillators and the PLLs.

- 0xx: no division
- 100: division by 2
- 101: division by 3
- 110: division by 4
- 111: division by 5

Bits 24:26 **MCO1PRE:** MCO1 prescaler

Set and cleared by software to configure the prescaler of the MCO1. Modification of this prescaler may generate glitches on MCO1. It is highly recommended to change this prescaler only after reset before enabling the external oscillators and the PLL.

- 0xx: no division
- 100: division by 2
- 101: division by 3
- 110: division by 4
- 111: division by 5

Bit 23 **I2SSRC:** I2S clock selection

Set and cleared by software. This bit allows to select the I2S clock source between the PLLI2S clock and the external clock. It is highly recommended to change this bit only after reset and before enabling the I2S module.

- 0: PLLI2S clock used as I2S clock source
- 1: External clock mapped on the I2S\_CKIN pin used as I2S clock source

Bits 22:21 **MCO1:** Microcontroller clock output 1

Set and cleared by software. Clock source selection may generate glitches on MCO1. It is highly recommended to configure these bits only after reset before enabling the external oscillators and PLL.

- 00: HSI clock selected
- 01: LSE oscillator selected
- 10: HSE oscillator clock selected
- 11: PLL clock selected

Bits 20:16 **RTCPRE:** HSE division factor for RTC clock

Set and cleared by software to divide the HSE clock input clock to generate a 1 MHz clock for RTC.

**Caution:** The software has to set these bits correctly to ensure that the clock supplied to the RTC is 1 MHz. These bits must be configured if needed before selecting the RTC clock source.

- 00000: no clock
- 00001: no clock
- 00010: HSE/2
- 00011: HSE/3
- 00100: HSE/4
- ...
- 11110: HSE/30
- 11111: HSE/31

Bits 15:13 **PPRE2:** APB high-speed prescaler (APB2)

Set and cleared by software to control APB high-speed clock division factor.

**Caution:** The software has to set these bits correctly not to exceed 84 MHz on this domain. The clocks are divided with the new prescaler factor from 1 to 16 AHB cycles after PPRE2 write.

- 0xx: AHB clock not divided
- 100: AHB clock divided by 2
- 101: AHB clock divided by 4
- 110: AHB clock divided by 8
- 111: AHB clock divided by 16

Bits 12:10 **PPRE1:** APB Low speed prescaler (APB1)

Set and cleared by software to control APB low-speed clock division factor.

**Caution:** The software has to set these bits correctly not to exceed 42 MHz on this domain. The clocks are divided with the new prescaler factor from 1 to 16 AHB cycles after PPRE1 write.

- 0xx: AHB clock not divided
- 100: AHB clock divided by 2
- 101: AHB clock divided by 4
- 110: AHB clock divided by 8
- 111: AHB clock divided by 16

Bits 9:8 Reserved, must be kept at reset value.

**Bits 7:4 HPRE:** AHB prescaler

Set and cleared by software to control AHB clock division factor.

**Caution:** The clocks are divided with the new prescaler factor from 1 to 16 AHB cycles after HPRE write.

**Caution:** The AHB clock frequency must be at least 25 MHz when the Ethernet is used.

0xxx: system clock not divided

1000: system clock divided by 2

1001: system clock divided by 4

1010: system clock divided by 8

1011: system clock divided by 16

1100: system clock divided by 64

1101: system clock divided by 128

1110: system clock divided by 256

1111: system clock divided by 512

**Bits 3:2 SWS:** System clock switch status

Set and cleared by hardware to indicate which clock source is used as the system clock.

00: HSI oscillator used as the system clock

01: HSE oscillator used as the system clock

10: PLL used as the system clock

11: not applicable

**Bits 1:0 SW:** System clock switch

Set and cleared by software to select the system clock source.

Set by hardware to force the HSI selection when leaving the Stop or Standby mode or in case of failure of the HSE oscillator used directly or indirectly as the system clock.

00: HSI oscillator selected as system clock

01: HSE oscillator selected as system clock

10: PLL selected as system clock

11: not allowed

### 6.3.4 RCC clock interrupt register (RCC\_CIR)

Address offset: 0x0C

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								CSSC	Reserved	PLL12S RDYC	PLL RDYC	HSE RDYC	HSI RDYC	LSE RDYC	LSI RDYC
								w		w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	PLL12S RDYIE	PLL RDYIE	HSE RDYIE	HSI RDYIE	LSE RDYIE	LSI RDYIE	CSSF	Reserved	PLL12S RDYF	PLL RDYF	HSE RDYF	HSI RDYF	LSE RDYF	LSI RDYF	
	rw	rw	rw	rw	rw	rw	r		r	r	r	r	r	r	

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **CSSC:** Clock security system interrupt clear

This bit is set by software to clear the CSSF flag.

0: No effect

1: Clear CSSF flag

Bits 22 Reserved, must be kept at reset value.

Bit 21 **PLL2SRDYC:** PLLI2S ready interrupt clear

This bit is set by software to clear the PLLI2SRDYF flag.

0: No effect

1: PLLI2SRDYF cleared

Bit 20 **PLLRDYC:** Main PLL(PLL) ready interrupt clear

This bit is set by software to clear the PLLRDYF flag.

0: No effect

1: PLLRDYF cleared

Bit 19 **HSERDYC:** HSE ready interrupt clear

This bit is set by software to clear the HSERDYF flag.

0: No effect

1: HSERDYF cleared

Bit 18 **HSIRDYC:** HSI ready interrupt clear

This bit is set software to clear the HSIRDYF flag.

0: No effect

1: HSIRDYF cleared

Bit 17 **LSERDYC:** LSE ready interrupt clear

This bit is set by software to clear the LSERDYF flag.

0: No effect

1: LSERDYF cleared

Bit 16 **LSIRDYC:** LSI ready interrupt clear

This bit is set by software to clear the LSIRDYF flag.

0: No effect

1: LSIRDYF cleared

Bits 15:12 Reserved, must be kept at reset value.

Bit 13 **PLL2SRDYIE:** PLLI2S ready interrupt enable

Set and cleared by software to enable/disable interrupt caused by PLLI2S lock.

0: PLLI2S lock interrupt disabled

1: PLLI2S lock interrupt enabled

Bit 12 **PLLRDYIE:** Main PLL (PLL) ready interrupt enable

Set and cleared by software to enable/disable interrupt caused by PLL lock.

0: PLL lock interrupt disabled

1: PLL lock interrupt enabled

Bit 11 **HSERDYIE:** HSE ready interrupt enable

Set and cleared by software to enable/disable interrupt caused by the HSE oscillator stabilization.

0: HSE ready interrupt disabled

1: HSE ready interrupt enabled

- Bit 10 **HSIRDYIE:** HSI ready interrupt enable  
Set and cleared by software to enable/disable interrupt caused by the HSI oscillator stabilization.  
0: HSI ready interrupt disabled  
1: HSI ready interrupt enabled
- Bit 9 **LSERDYIE:** LSE ready interrupt enable  
Set and cleared by software to enable/disable interrupt caused by the LSE oscillator stabilization.  
0: LSE ready interrupt disabled  
1: LSE ready interrupt enabled
- Bit 8 **LSIRDYIE:** LSI ready interrupt enable  
Set and cleared by software to enable/disable interrupt caused by LSI oscillator stabilization.  
0: LSI ready interrupt disabled  
1: LSI ready interrupt enabled
- Bit 7 **CSSF:** Clock security system interrupt flag  
Set by hardware when a failure is detected in the HSE oscillator.  
Cleared by software setting the CSSC bit.  
0: No clock security interrupt caused by HSE clock failure  
1: Clock security interrupt caused by HSE clock failure
- Bits 6 Reserved, must be kept at reset value.
- Bit 5 **PLL2SRDYF:** PLLI2S ready interrupt flag  
Set by hardware when the PLLI2S locks and PLLI2SRDYDIE is set.  
Cleared by software setting the PLLRI2SDYC bit.  
0: No clock ready interrupt caused by PLLI2S lock  
1: Clock ready interrupt caused by PLLI2S lock
- Bit 4 **PLLRDYF:** Main PLL (PLL) ready interrupt flag  
Set by hardware when PLL locks and PLLRDYDIE is set.  
Cleared by software setting the PLLRDYC bit.  
0: No clock ready interrupt caused by PLL lock  
1: Clock ready interrupt caused by PLL lock
- Bit 3 **HSERDYF:** HSE ready interrupt flag  
Set by hardware when External High Speed clock becomes stable and HSERDYDIE is set.  
Cleared by software setting the HSERDYC bit.  
0: No clock ready interrupt caused by the HSE oscillator  
1: Clock ready interrupt caused by the HSE oscillator
- Bit 2 **HSIRDYF:** HSI ready interrupt flag  
Set by hardware when the Internal High Speed clock becomes stable and HSIRDYDIE is set.  
Cleared by software setting the HSIRDYC bit.  
0: No clock ready interrupt caused by the HSI oscillator  
1: Clock ready interrupt caused by the HSI oscillator
- Bit 1 **LSERDYF:** LSE ready interrupt flag  
Set by hardware when the External Low Speed clock becomes stable and LSERDYDIE is set.  
Cleared by software setting the LSERDYC bit.  
0: No clock ready interrupt caused by the LSE oscillator  
1: Clock ready interrupt caused by the LSE oscillator

Bit 0 **LSIRDYF:** LSI ready interrupt flag

Set by hardware when the internal low speed clock becomes stable and LSIRDYDIE is set.

Cleared by software setting the LSIRDYC bit.

0: No clock ready interrupt caused by the LSI oscillator

1: Clock ready interrupt caused by the LSI oscillator

### 6.3.5 RCC AHB1 peripheral reset register (RCC\_AHB1RSTR)

Address offset: 0x10

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved										DMA2 RST	DMA1 RST	Reserved			
										rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	CRCRST	Reserved			GPIOH RST	Reserved		GPIOE RST	GPIOD RST	GPIOC RST	GPIOB RST	GPIOA RST			
					rw			rw	rw	rw	rw	rw			

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **DMA2RST:** DMA2 reset

Set and cleared by software.

0: does not reset DMA2

1: resets DMA2

Bit 21 **DMA1RST:** DMA1 reset

Set and cleared by software.

0: does not reset DMA1

1: resets DMA1

Bits 20:13 Reserved, must be kept at reset value.

Bit 12 **CRCRST:** CRC reset

Set and cleared by software.

0: does not reset CRC

1: resets CRC

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **GPIOHRST:** IO port H reset

Set and cleared by software.

0: does not reset IO port H

1: resets IO port H

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **GPIOERST:** IO port E reset

Set and cleared by software.

0: does not reset IO port E

1: resets IO port E

Bit 3 **GPIODRST:** IO port D reset

Set and cleared by software.

0: does not reset IO port D

1: resets IO port D

Bit 2 **GPIOCRST:** IO port C reset

Set and cleared by software.

0: does not reset IO port C

1: resets IO port C

Bit 1 **GPIOBRST:** IO port B reset

Set and cleared by software.

0: does not reset IO port B

1: resets IO port B

Bit 0 **GPIOARST:** IO port A reset

Set and cleared by software.

0: does not reset IO port A

1: resets IO port A

### 6.3.6 RCC AHB2 peripheral reset register (RCC\_AHB2RSTR)

Address offset: 0x14

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															
OTGFS RST								Reserved							
rw															

Bits 31:8 Reserved, must be kept at reset value.

Bit 6:0 Reserved, must be kept at reset value.

### 6.3.7 RCC APB1 peripheral reset register for (RCC\_APB1RSTR)

Address offset: 0x20

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved				PWR RST	Reserved				I2C3 RST	I2C2 RST	I2C1 RST	Reserved				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved		Reserved		WWDG RST	Reserved								TIM5 RST	TIM4 RST	TIM3 RST	TIM2 RST
SPI3 RST	SPI2 RST	Reserved		rw									rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **PWRRST:** Power interface reset

Set and cleared by software.

0: does not reset the power interface

1: resets the power interface

Bit 27:24 Reserved, must be kept at reset value.

Bit 23 **I2C3RST:** I2C3 reset

Set and cleared by software.

0: does not reset I2C3

1: resets I2C3

Bit 22 **I2C2RST:** I2C2 reset

Set and cleared by software.

0: does not reset I2C2

1: resets I2C2

Bit 21 **I2C1RST:** I2C1 reset

Set and cleared by software.

0: does not reset I2C1

1: resets I2C1

Bits 20:18 Reserved, must be kept at reset value.

Bit 17 **USART2RST:** USART2 reset

Set and cleared by software.

0: does not reset USART2

1: resets USART2

Bit 16 Reserved, must be kept at reset value.

Bit 15 **SPI3RST:** SPI3 reset

Set and cleared by software.

0: does not reset SPI3

1: resets SPI3

Bit 14 **SPI2RST:** SPI2 reset

Set and cleared by software.

0: does not reset SPI2

1: resets SPI2

Bits 13:12 Reserved, must be kept at reset value.

Bit 11 **WWDGRST:** Window watchdog reset

Set and cleared by software.

0: does not reset the window watchdog

1: resets the window watchdog

Bits 10:4 Reserved, must be kept at reset value.

Bit 3 **TIM5RST:** TIM5 reset

Set and cleared by software.

0: does not reset TIM5

1: resets TIM5

Bit 2 **TIM4RST:** TIM4 reset

Set and cleared by software.

0: does not reset TIM4

1: resets TIM4

Bit 1 **TIM3RST:** TIM3 reset

Set and cleared by software.

0: does not reset TIM3

1: resets TIM3

Bit 0 **TIM2RST:** TIM2 reset

Set and cleared by software.

0: does not reset TIM2

1: resets TIM2

### 6.3.8 RCC APB2 peripheral reset register (RCC\_APB2RSTR)

Address offset: 0x24

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved														TIM11 RST	TIM10 RST	TIM9 RST
														rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reser- ved	SYSCFG RST	SPI4 RST	SPI1 RST	SDIO RST	Reserved	ADC1 RST	Reserved	USART6 RST	USART1 RST	Reserved	Reserved	Reserved	Reserved	TIM1 RST	rw	
	rw	rw	rw	rw		rw		rw	rw						rw	

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **TIM11RST:** TIM11 reset

Set and cleared by software.

0: does not reset TIM11

1: resets TIM11

Bit 17 **TIM10RST:** TIM10 reset

Set and cleared by software.

0: does not reset TIM10

1: resets TIM10

Bit 16 **TIM9RST:** TIM9 reset

Set and cleared by software.

0: does not reset TIM9

1: resets TIM9

Bit 15 Reserved, must be kept at reset value.

Bit 14 **SYSCFGRST:** System configuration controller reset

Set and cleared by software.

0: does not reset the System configuration controller

1: resets the System configuration controller

Bit 13 **SPI4RST:** SPI4 reset

Set and reset by software.

0: does not reset SPI4

1: resets SPI4

Bit 12 **SPI1RST:** SPI1 reset

Set and cleared by software.

0: does not reset SPI1

1: resets SPI1

Bit 11 **SDIORST:** SDIO reset

Set and cleared by software.

0: does not reset the SDIO module

1: resets the SDIO module

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **ADC1RST:** ADC interface reset

Set and cleared by software.

0: does not reset the ADC interface

1: resets the ADC interface

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **USART6RST:** USART6 reset

Set and cleared by software.

0: does not reset USART6

1: resets USART6

Bit 4 **USART1RST:** USART1 reset

Set and cleared by software.

0: does not reset USART1

1: resets USART1

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **TIM1RST:** TIM1 reset

Set and cleared by software.

0: does not reset TIM1

1: resets TIM1

### 6.3.9 RCC AHB1 peripheral clock enable register (RCC\_AHB1ENR)

Address offset: 0x30

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16			
Reserved										DMA2EN	DMA1EN	Reserved						
										rw	rw							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0			
Reserved	CRCEN		Reserved		GPIOH EN		Reserved		GPIOEEN		GPIOD EN		GPIOC EN		GPIOB EN		GPIOA EN	
	rw		rw		rw		rw		rw		rw		rw		rw			

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **DMA2EN**: DMA2 clock enable

Set and cleared by software.

0: DMA2 clock disabled

1: DMA2 clock enabled

Bit 21 **DMA1EN**: DMA1 clock enable

Set and cleared by software.

0: DMA1 clock disabled

1: DMA1 clock enabled

Bits 20:13 Reserved, must be kept at reset value.

Bit 12 **CRCEN**: CRC clock enable

Set and cleared by software.

0: CRC clock disabled

1: CRC clock enabled

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **GPIOHEN**: IO port H clock enable

Set and reset by software.

0: IO port H clock disabled

1: IO port H clock enabled

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **GPIOEEN**: IO port E clock enable

Set and cleared by software.

0: IO port E clock disabled

1: IO port E clock enabled

Bit 3 **GPIODEN**: IO port D clock enable

Set and cleared by software.

0: IO port D clock disabled

1: IO port D clock enabled

Bit 2 **GPIOCEN**: IO port C clock enable

Set and cleared by software.

0: IO port C clock disabled

1: IO port C clock enabled

Bit 1 **GPIOBEN**: IO port B clock enable

Set and cleared by software.

0: IO port B clock disabled

1: IO port B clock enabled

Bit 0 **GPIOAEN**: IO port A clock enable

Set and cleared by software.

0: IO port A clock disabled

1: IO port A clock enabled

### 6.3.10 RCC AHB2 peripheral clock enable register (RCC\_AHB2ENR)

Address offset: 0x34

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															
OTGFS EN								Reserved							
rw															

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **OTGFSEN**: USB OTG FS clock enable

Set and cleared by software.

0: USB OTG FS clock disabled

1: USB OTG FS clock enabled

Bit6:0 Reserved, must be kept at reset value.

### 6.3.11 RCC APB1 peripheral clock enable register (RCC\_APB1ENR)

Address offset: 0x40

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved			PWR EN		Reserved			I2C3 EN			I2C2 EN			I2C1 EN		
								rw			rw			rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
SPI3 EN	SPI2 EN	Reserved		WWDG EN		Reserved								TIM5 EN	TIM4 EN	TIM3 EN
rw	rw			rw										rw	rw	rw

- Bit 28 **PWREN:** Power interface clock enable  
Set and cleared by software.  
0: Power interface clock disabled  
1: Power interface clock enable
- Bit 27 Reserved, must be kept at reset value.
- Bit 24 Reserved, must be kept at reset value.
- Bit 23 **I2C3EN:** I2C3 clock enable  
Set and cleared by software.  
0: I2C3 clock disabled  
1: I2C3 clock enabled
- Bit 22 **I2C2EN:** I2C2 clock enable  
Set and cleared by software.  
0: I2C2 clock disabled  
1: I2C2 clock enabled
- Bit 21 **I2C1EN:** I2C1 clock enable  
Set and cleared by software.  
0: I2C1 clock disabled  
1: I2C1 clock enabled
- Bit 17 **USART2EN:** USART2 clock enable  
Set and cleared by software.  
0: USART2 clock disabled  
1: USART2 clock enabled
- Bit 16 Reserved, must be kept at reset value.
- Bit 15 **SPI3EN:** SPI3 clock enable  
Set and cleared by software.  
0: SPI3 clock disabled  
1: SPI3 clock enabled
- Bit 14 **SPI2EN:** SPI2 clock enable  
Set and cleared by software.  
0: SPI2 clock disabled  
1: SPI2 clock enabled
- Bits 13:12 Reserved, must be kept at reset value.
- Bit 11 **WWDGEN:** Window watchdog clock enable  
Set and cleared by software.  
0: Window watchdog clock disabled  
1: Window watchdog clock enabled
- Bit 10:4 Reserved, must be kept at reset value.
- Bit 3 **TIM5EN:** TIM5 clock enable  
Set and cleared by software.  
0: TIM5 clock disabled  
1: TIM5 clock enabled

Bit 2 **TIM4EN:** TIM4 clock enable  
Set and cleared by software.

0: TIM4 clock disabled  
1: TIM4 clock enabled

Bit 1 **TIM3EN:** TIM3 clock enable  
Set and cleared by software.  
0: TIM3 clock disabled  
1: TIM3 clock enabled

Bit 0 **TIM2EN:** TIM2 clock enable  
Set and cleared by software.  
0: TIM2 clock disabled  
1: TIM2 clock enabled

### 6.3.12 RCC APB2 peripheral clock enable register (RCC\_APB2ENR)

Address offset: 0x44

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved														TIM11 EN	TIM10 EN	TIM9 EN
														rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved	SYSCFG GEN	SPI4EN	SPI1 EN	SDIO EN	Reserved	ADC1 EN	Reserved	USART6 EN	USART1 EN	Reserved	Reserved	Reserved	Reserved	TIM1 EN	rw	
	rw	rw	rw	rw		rw		rw	rw						rw	

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **TIM11EN:** TIM11 clock enable

Set and cleared by software.  
0: TIM11 clock disabled  
1: TIM11 clock enabled

Bit 17 **TIM10EN:** TIM10 clock enable

Set and cleared by software.  
0: TIM10 clock disabled  
1: TIM10 clock enabled

Bit 16 **TIM9EN:** TIM9 clock enable

Set and cleared by software.  
0: TIM9 clock disabled  
1: TIM9 clock enabled

Bit 15 Reserved, must be kept at reset value.

Bit 14 **SYSCFGEN:** System configuration controller clock enable

Set and cleared by software.  
0: System configuration controller clock disabled  
1: System configuration controller clock enabled

Bit 13 **SPI4EN:** SPI4 clock enable

Set and reset by software.  
0: SPI4 clock disabled  
1: SPI4 clock enable

Bit 12 **SPI1EN:** SPI1 clock enable

Set and cleared by software.  
0: SPI1 clock disabled  
1: SPI1 clock enabled

Bit 11 **SDIOEN:** SDIO clock enable

Set and cleared by software.  
0: SDIO module clock disabled  
1: SDIO module clock enabled

Bit 8 **ADC1EN:** ADC1 clock enable

Set and cleared by software.

0: ADC1 clock disabled

1: ADC1 clock disabled

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **USART6EN:** USART6 clock enable

Set and cleared by software.

0: USART6 clock disabled

1: USART6 clock enabled

Bit 4 **USART1EN:** USART1 clock enable

Set and cleared by software.

0: USART1 clock disabled

1: USART1 clock enabled

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **TIM1EN:** TIM1 clock enable

Set and cleared by software.

0: TIM1 clock disabled

1: TIM1 clock enabled

### 6.3.13 RCC AHB1 peripheral clock enable in low power mode register (RCC\_AHB1LPENR)

Address offset: 0x50

Reset value: 0x0061 900F

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16			
Reserved								DMA2 LPEN	DMA1 LPEN	Reserved								SRAM1 LPEN
								rw	rw	Reserved								rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0			
FLITF LPEN	Reserved	CRC LPEN	Reserved	Reserved	GPIOH LPEN	Reserved	Reserved	GPIOE LPEN	GPIOD LPEN	GPIOC LPEN	GPIOB LPEN	GPIOA LPEN						
rw		rw			rw			rw	rw	rw	rw	rw						

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **DMA2LPEN:** DMA2 clock enable during Sleep mode

Set and cleared by software.

0: DMA2 clock disabled during Sleep mode

1: DMA2 clock enabled during Sleep mode

Bit 21 **DMA1LPEN:** DMA1 clock enable during Sleep mode

Set and cleared by software.

0: DMA1 clock disabled during Sleep mode

1: DMA1 clock enabled during Sleep mode

Bit 17 Reserved, must be kept at reset value.

Bit 16 **SRAM1LPEN:** SRAM1interface clock enable during Sleep mode

Set and cleared by software.

0: SRAM1 interface clock disabled during Sleep mode

1: SRAM1 interface clock enabled during Sleep mode

Bit 15 **FLITFLPEN:** Flash interface clock enable during Sleep mode

Set and cleared by software.

0: Flash interface clock disabled during Sleep mode

1: Flash interface clock enabled during Sleep mode

Bits 14:13 Reserved, must be kept at reset value.

Bit 12 **CRCLPEN:** CRC clock enable during Sleep mode

Set and cleared by software.

0: CRC clock disabled during Sleep mode

1: CRC clock enabled during Sleep mode

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **GPIOHLPEN:** IO port H clock enable during sleep mode

Set and reset by software.

0: IO port H clock disabled during sleep mode

1: IO port H clock enabled during sleep mode

Bits 6:5 Reserved, must be kept at reset value.

- Bit 4 **GPIOELPEN:** IO port E clock enable during Sleep mode  
Set and cleared by software.  
0: IO port E clock disabled during Sleep mode  
1: IO port E clock enabled during Sleep mode
- Bit 3 **GPIODLPEN:** IO port D clock enable during Sleep mode  
Set and cleared by software.  
0: IO port D clock disabled during Sleep mode  
1: IO port D clock enabled during Sleep mode
- Bit 2 **GPIOCLPEN:** IO port C clock enable during Sleep mode  
Set and cleared by software.  
0: IO port C clock disabled during Sleep mode  
1: IO port C clock enabled during Sleep mode
- Bit 1 **GPIOBLPEN:** IO port B clock enable during Sleep mode  
Set and cleared by software.  
0: IO port B clock disabled during Sleep mode  
1: IO port B clock enabled during Sleep mode
- Bit 0 **GPIOALPEN:** IO port A clock enable during sleep mode  
Set and cleared by software.  
0: IO port A clock disabled during Sleep mode  
1: IO port A clock enabled during Sleep mode

### 6.3.14 RCC AHB2 peripheral clock enable in low power mode register (RCC\_AHB2LPENR)

Address offset: 0x54

Reset value: 0x0000 0080

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved																
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved								OTGFS LPEN	Reserved							
rw																

Bits 31:8 Reserved, must be kept at reset value.

- Bit 7 **OTGFSLPEN:** USB OTG FS clock enable during Sleep mode  
Set and cleared by software.  
0: USB OTG FS clock disabled during Sleep mode  
1: USB OTG FS clock enabled during Sleep mode

Bit 6:0 Reserved, must be kept at reset value.

### 6.3.15 RCC APB1 peripheral clock enable in low power mode register (RCC\_APB1LPENR)

Address offset: 0x60

Reset value: 0x10E2 C80F

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved			PWR LPEN	RESER VED	Reserved			I2C3 LPEN	I2C2 LPEN	I2C1 LPEN	Reserved			USART2 LPEN	Reserved
			rw					rw	rw	rw				rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3 LPEN	SPI2 LPEN	Reserved		WWDG LPEN	Reserved							TIM5 LPEN	TIM4 LPEN	TIM3 LPEN	TIM2 LPEN
rw	rw			rw								rw	rw	rw	rw

Bit 31:27 Reserved, must be kept at reset value.

Bit 28 **PWRLPEN:** Power interface clock enable during Sleep mode

Set and cleared by software.

0: Power interface clock disabled during Sleep mode

1: Power interface clock enabled during Sleep mode

Bit 27:24 Reserved, must be kept at reset value.

Bit 23 **I2C3LPEN:** I2C3 clock enable during Sleep mode

Set and cleared by software.

0: I2C3 clock disabled during Sleep mode

1: I2C3 clock enabled during Sleep mode

Bit 22 **I2C2LPEN:** I2C2 clock enable during Sleep mode

Set and cleared by software.

0: I2C2 clock disabled during Sleep mode

1: I2C2 clock enabled during Sleep mode

Bit 21 **I2C1LPEN:** I2C1 clock enable during Sleep mode

Set and cleared by software.

0: I2C1 clock disabled during Sleep mode

1: I2C1 clock enabled during Sleep mode

Bit 17 **USART2LPEN:** USART2 clock enable during Sleep mode

Set and cleared by software.

0: USART2 clock disabled during Sleep mode

1: USART2 clock enabled during Sleep mode

Bit 16 Reserved, must be kept at reset value.

Bit 15 **SPI3LPEN:** SPI3 clock enable during Sleep mode

Set and cleared by software.

0: SPI3 clock disabled during Sleep mode

1: SPI3 clock enabled during Sleep mode

Bit 14 **SPI2LPEN:** SPI2 clock enable during Sleep mode

Set and cleared by software.

0: SPI2 clock disabled during Sleep mode

1: SPI2 clock enabled during Sleep mode

Bits 13:12 Reserved, must be kept at reset value.

Bit 11 **WWDGLPEN**: Window watchdog clock enable during Sleep mode

Set and cleared by software.

0: Window watchdog clock disabled during sleep mode

1: Window watchdog clock enabled during sleep mode

Bits 10:4 Reserved, must be kept at reset value.

Bit 3 **TIM5LPEN**: TIM5 clock enable during Sleep mode

Set and cleared by software.

0: TIM5 clock disabled during Sleep mode

1: TIM5 clock enabled during Sleep mode

Bit 2 **TIM4LPEN**: TIM4 clock enable during Sleep mode

Set and cleared by software.

0: TIM4 clock disabled during Sleep mode

1: TIM4 clock enabled during Sleep mode

Bit 1 **TIM3LPEN**: TIM3 clock enable during Sleep mode

Set and cleared by software.

0: TIM3 clock disabled during Sleep mode

1: TIM3 clock enabled during Sleep mode

Bit 0 **TIM2LPEN**: TIM2 clock enable during Sleep mode

Set and cleared by software.

0: TIM2 clock disabled during Sleep mode

1: TIM2 clock enabled during Sleep mode

### 6.3.16 RCC APB2 peripheral clock enabled in low power mode register (RCC\_APB2LPENR)

Address offset: 0x64

Reset value: 0x0007 7930

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved														TIM11 LPEN	TIM10 LPEN	TIM9 LPEN
														rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved	SYSCFG LPEN	SPI4LPEN	SPI1LPEN	SDIO LPEN	Reserved	ADC1 LPEN	Reserved	USART6 LPEN	USART1 LPEN	Reserved	Reserved	Reserved	Reserved	TIM1 LPEN	rw	
	rw	rw	rw	rw		rw		rw	rw						rw	

Bits 31:22 Reserved, must be kept at reset value.

Bit 19 Reserved, must be kept at reset value.

Bit 18 **TIM11LPEN:** TIM11 clock enable during Sleep mode

Set and cleared by software.

0: TIM11 clock disabled during Sleep mode

1: TIM11 clock enabled during Sleep mode

Bit 17 **TIM10LPEN:** TIM10 clock enable during Sleep mode

Set and cleared by software.

0: TIM10 clock disabled during Sleep mode

1: TIM10 clock enabled during Sleep mode

Bit 16 **TIM9LPEN:** TIM9 clock enable during sleep mode

Set and cleared by software.

0: TIM9 clock disabled during Sleep mode

1: TIM9 clock enabled during Sleep mode

Bit 15 Reserved, must be kept at reset value.

Bit 14 **SYSCFGLPEN:** System configuration controller clock enable during Sleep mode

Set and cleared by software.

0: System configuration controller clock disabled during Sleep mode

1: System configuration controller clock enabled during Sleep mode

Bit 13 **SPI4LPEN:** SPI4 clock enable during sleep mode

Set and reset by software.

0: SPI4 clock disabled during sleep mode

1: SPI4 clock enabled during sleep mode

Bit 12 **SPI1LPEN:** SPI1 clock enable during Sleep mode

Set and cleared by software.

0: SPI1 clock disabled during Sleep mode

1: SPI1 clock enabled during Sleep mode

Bit 11 **SDIOLPEN:** SDIO clock enable during Sleep mode

Set and cleared by software.

0: SDIO module clock disabled during Sleep mode

1: SDIO module clock enabled during Sleep mode

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **ADC1LPEN:** ADC1 clock enable during Sleep mode

Set and cleared by software.

0: ADC1 clock disabled during Sleep mode

1: ADC1 clock enabled during Sleep mode

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **USART6LPEN:** USART6 clock enable during Sleep mode

Set and cleared by software.

0: USART6 clock disabled during Sleep mode

1: USART6 clock enabled during Sleep mode

Bit 4 **USART1LPEN:** USART1 clock enable during Sleep mode

Set and cleared by software.

0: USART1 clock disabled during Sleep mode

1: USART1 clock enabled during Sleep mode

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **TIM1LPEN:** TIM1 clock enable during Sleep mode

Set and cleared by software.

0: TIM1 clock disabled during Sleep mode

1: TIM1 clock enabled during Sleep mode

### 6.3.17 RCC Backup domain control register (RCC\_BDCR)

Address offset: 0x70

Reset value: 0x0000 0000, reset by Backup domain reset.

Access:  $0 \leq$  wait state  $\leq 3$ , word, half-word and byte access

Wait states are inserted in case of successive accesses to this register.

The LSEON, LSEBYP, RTCSEL and RTCEN bits in the [RCC Backup domain control register \(RCC\\_BDCR\)](#) are in the Backup domain. As a result, after Reset, these bits are write-protected and the DBP bit in the [Power control register \(PWR\\_CR\)](#) has to be set before these can be modified. Refer to [Section 5.1.2 on page 67](#) for further information. These bits are only reset after a Backup domain Reset (see [Section 6.1.3: Backup domain reset](#)). Any internal or external Reset will not have any effect on these bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															BDRST
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RTCEN	Reserved				RTCSEL[1:0]		Reserved				LSEBYP	LSERDY	LSEON		
rw					rw	rw					rw	r	rw		

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **BDRST**: Backup domain software reset

Set and cleared by software.

0: Reset not activated

1: Resets the entire Backup domain

Bit 15 **RTCEN**: RTC clock enable

Set and cleared by software.

0: RTC clock disabled

1: RTC clock enabled

Bits 14:10 Reserved, must be kept at reset value.

Bits 9:8 **RTCSEL[1:0]**: RTC clock source selection

Set by software to select the clock source for the RTC. Once the RTC clock source has been selected, it cannot be changed anymore unless the Backup domain is reset. The BDRST bit can be used to reset them.

00: No clock

01: LSE oscillator clock used as the RTC clock

10: LSI oscillator clock used as the RTC clock

11: HSE oscillator clock divided by a programmable prescaler (selection through the RTCPRE[4:0] bits in the RCC clock configuration register (RCC\_CFGR)) used as the RTC clock

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **LSEBYP**: External low-speed oscillator bypass

Set and cleared by software to bypass oscillator in debug mode. This bit can be written only when the LSE clock is disabled.

0: LSE oscillator not bypassed

1: LSE oscillator bypassed

Bit 1 **LSERDY**: External low-speed oscillator ready

Set and cleared by hardware to indicate when the external 32 kHz oscillator is stable. After the LSEON bit is cleared, LSERDY goes low after 6 external low-speed oscillator clock cycles.

0: LSE clock not ready  
1: LSE clock ready

Bit 0 **LSEON**: External low-speed oscillator enable

Set and cleared by software.  
0: LSE clock OFF  
1: LSE clock ON

### 6.3.18 RCC clock control & status register (RCC\_CSR)

Address offset: 0x74

Reset value: 0x0E00 0000, reset by system reset, except reset flags by power reset only.

Access:  $0 \leq$  wait state  $\leq 3$ , word, half-word and byte access

Wait states are inserted in case of successive accesses to this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LPWR RSTF	WWDG RSTF	IWDG RSTF	SFT RSTF	POR RSTF	PIN RSTF	BORRS TF	RMVF	Reserved							
rw	rw	rw	rw	rw	rw	rw	rw	15	14	13	12	11	10	9	8
								7	6	5	4	3	2	1	0
Reserved														LSIRDY	LSION
														r	rw

Bit 31 **LPWRRSTF**: Low-power reset flag

Set by hardware when a Low-power management reset occurs.

Cleared by writing to the RMVF bit.

0: No Low-power management reset occurred

1: Low-power management reset occurred

For further information on Low-power management reset, refer to [Low-power management reset](#).

Bit 30 **WWDGRSTF**: Window watchdog reset flag

Set by hardware when a window watchdog reset occurs.

Cleared by writing to the RMVF bit.

0: No window watchdog reset occurred

1: Window watchdog reset occurred

Bit 29 **IWDGRSTF**: Independent watchdog reset flag

Set by hardware when an independent watchdog reset from V<sub>DD</sub> domain occurs.

Cleared by writing to the RMVF bit.

0: No watchdog reset occurred

1: Watchdog reset occurred

Bit 28 **SFTRSTF**: Software reset flag

Set by hardware when a software reset occurs.

Cleared by writing to the RMVF bit.

0: No software reset occurred

1: Software reset occurred

**Bit 27 PORRSTF:** POR/PDR reset flag

Set by hardware when a POR/PDR reset occurs.

Cleared by writing to the RMVF bit.

0: No POR/PDR reset occurred

1: POR/PDR reset occurred

**Bit 26 PINRSTF:** PIN reset flag

Set by hardware when a reset from the NRST pin occurs.

Cleared by writing to the RMVF bit.

0: No reset from NRST pin occurred

1: Reset from NRST pin occurred

**Bit 25 BORRSTF:** BOR reset flag

Cleared by software by writing the RMVF bit.

Set by hardware when a POR/PDR or BOR reset occurs.

0: No POR/PDR or BOR reset occurred

1: POR/PDR or BOR reset occurred

**Bit 24 RMVF:** Remove reset flag

Set by software to clear the reset flags.

0: No effect

1: Clear the reset flags

Bits 23:2 Reserved, must be kept at reset value.

**Bit 1 LSIRDY:** Internal low-speed oscillator ready

Set and cleared by hardware to indicate when the internal RC 40 kHz oscillator is stable.

After the LSION bit is cleared, LSIRDY goes low after 3 LSI clock cycles.

0: LSI RC oscillator not ready

1: LSI RC oscillator ready

**Bit 0 LSION:** Internal low-speed oscillator enable

Set and cleared by software.

0: LSI RC oscillator OFF

1: LSI RC oscillator ON

### 6.3.19 RCC spread spectrum clock generation register (RCC\_SSCGR)

Address offset: 0x80

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

The spread spectrum clock generation is available only for the main PLL.

The RCC\_SSCGR register must be written either before the main PLL is enabled or after the main PLL disabled.

**Note:** *For full details about PLL spread spectrum clock generation (SSCG) characteristics, refer to the “Electrical characteristics” section in your device datasheet.*

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16		
SSCG EN	SPR EAD SEL	Reserved	INCSTEP														
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
INCSTEP				MODPER													
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31 **SSCGEN**: Spread spectrum modulation enable

Set and cleared by software.

0: Spread spectrum modulation DISABLE. (To write after clearing CR[24]=PLLON bit)

1: Spread spectrum modulation ENABLE. (To write before setting CR[24]=PLLON bit)

Bit 30 **SPREADSEL**: Spread Select

Set and cleared by software.

To write before to set CR[24]=PLLON bit.

0: Center spread

1: Down spread

Bit 29:28 Reserved, must be kept at reset value.

Bit 27:13 **INCSTEP**: Incrementation step

Set and cleared by software. To write before setting CR[24]=PLLON bit.

Configuration input for modulation profile amplitude.

Bit 12:0 **MODPER**: Modulation period

Set and cleared by software. To write before setting CR[24]=PLLON bit.

Configuration input for modulation profile period.

### 6.3.20 RCC PLLI2S configuration register (RCC\_PLLI2SCFGR)

Address offset: 0x84

Reset value: 0x2400 3000

Access: no wait state, word, half-word and byte access.

This register is used to configure the PLLI2S clock outputs according to the formulas:

- $f_{(VCO\ clock)} = f_{(PLL\ clock\ input)} \times (PLLISN / PLLM)$
- $f_{(PLL\ I2S\ clock\ output)} = f_{(VCO\ clock)} / PLLISR$

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved	PLLISR2	PLLISR1	PLLISR0	Reserved													
	rw	rw	rw	Reserved													
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved	PLLISN8	PLLISN7	PLLISN6	PLLISN5	PLLISN4	PLLISN3	PLLISN2	PLLISN1	PLLISN0	Reserved							
	rw	rw	rw	rw	rw	rw	rw	rw	rw	Reserved							

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **PLLISR**: PLLI2S division factor for I2S clocks

Set and cleared by software to control the I2S clock frequency. These bits should be written only if the PLLI2S is disabled. The factor must be chosen in accordance with the prescaler values inside the I2S peripherals, to reach 0.3% error when using standard crystals and 0% error with audio crystals. For more information about I2S clock frequency and precision, refer to [Section 20.4.4: Clock generator](#) in the I2S chapter.

**Caution:** The I2Ss requires a frequency lower than or equal to 192 MHz to work correctly.

I2S clock frequency = VCO frequency / PLLR with  $2 \leq PLLR \leq 7$

000: PLLR = 0, wrong configuration

001: PLLR = 1, wrong configuration

010: PLLR = 2

...

111: PLLR = 7

Bits 27:15 Reserved, must be kept at reset value.

Bits 14:6 **PLLI2SN:** PLLI2S multiplication factor for VCO

Set and cleared by software to control the multiplication factor of the VCO. These bits can be written only when the PLLI2S is disabled. Only half-word and word accesses are allowed to write these bits.

**Caution:** The software has to set these bits correctly to ensure that the VCO output frequency is between 192 and 432 MHz. With VCO input frequency ranges from 1 to 2 MHz (refer to [Figure 13](#) and divider factor M of the *RCC PLL configuration register (RCC\_PLLCFGR)*)

VCO output frequency = VCO input frequency × PLLI2SN with  $192 \leq \text{PLLI2SN} \leq 432$

00000000: PLLI2SN = 0, wrong configuration

00000001: PLLI2SN = 1, wrong configuration

...

01100000: PLLI2SN = 192

01100001: PLLI2SN = 193

01100010: PLLI2SN = 194

...

11011000: PLLI2SN = 432

11011000: PLLI2SN = 433, wrong configuration

...

11111111: PLLI2SN = 511, wrong configuration

Bits 5:0 Reserved, must be kept at reset value.

### 6.3.21 RCC Dedicated Clocks Configuration Register (RCC\_DCKCFGR)

Address offset: 0x8C

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved								TIMPRE	Reserved							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved																

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **TIMPRE:** Timers clocks prescalers selection

Set and reset by software to control the clock frequency of all the timers connected to APB1 and APB2 domain.

0: If the APB prescaler (PPRE1, PPRE2 in the RCC\_CFGR register) is configured to a division factor of 1, TIMxCLK = HCKL . Otherwise, the timer clock frequencies are set to twice to the frequency of the APB domain to which the timers are connected:  
 $\text{TIMxCLK} = 2 \times \text{PCLK}_x$ .

1: If the APB prescaler (PPRE1, PPRE2 in the RCC\_CFGR register) is configured to a division factor of 1 or 2, TIMxCLK = HCKL. Otherwise, the timer clock frequencies are set to four times to the frequency of the APB domain to which the timers are connected:  
 $\text{TIMxCLK} = 4 \times \text{PCLK}_x$ .

Bits 23: 0 Reserved, must be kept at reset value.

### 6.3.22 RCC register map

*Table 22* gives the register map and reset values

**Table 22. RCC register map and reset values for STM32F401xB/C and STM32F401xD/E**

Addr. offset	Register name								
0x00	<b>RCC_CR</b>	MCO21 MCO20 MCO2PRE2 MCO2PRE1 MCO2PRE0	PLLQ 3 PLLQ 2 PLLQ 1 PLLQ 0	PLL'12SRDY PLL'12SON PLL RDY PLL ON	31 30 29 28 27				
0x04	<b>RCC_PLLCFGR</b>	Reserved	Reserved	Reserved	Reserved	31 30 29 28 27			
0x08	<b>RCC_CFGR</b>	Reserved	Reserved	Reserved	Reserved	26 25 24			
0x0C	<b>RCC_CIR</b>	Reserved	Reserved	Reserved	Reserved	23 22			
0x10	<b>RCC_AHB1RSTR</b>	Reserved	DMA1RST DMA2RST	MCO11 MCO10	RTCPRE 4 RTCPRE 3 RTCPRE 2 RTCPRE 1	19 18 17			
0x14	<b>RCC_AHB2RSTR</b>	Reserved	Reserved	Reserved	HSERDYC LSERDYC LSERDYC LSERDYC	16 15 14 13			
0x18	Reserved	Reserved	DMA2EN DMA1EN	PPRE2 2 PPRE2 1	PLL0 PLL1 PLL2 PLL3	12 11 10			
0x1C	Reserved	Reserved	Reserved	Reserved	PLL0 PLL1 PLL2 PLL3	12 11 10			
0x20	<b>RCC_APB1RSTR</b>	Reserved	I2C3RST I2C2RST I2C1RST	Reserved	PPRE1 2 PPRE1 1 PPRE1 0	HSICAL 4 HSICAL 3 HSICAL 2			
0x24	<b>RCC_APB2RSTR</b>	Reserved	Reserved	Reserved	PLL0 PLL1 PLL2 PLL3	HSICAL 5 HSICAL 6 HSICAL 7 HSICAL 8			
0x28	Reserved	Reserved	Reserved	Reserved	PLL0 PLL1 PLL2 PLL3	HSICAL 9 HSICAL 10 HSICAL 11 HSICAL 12			
0x2C	Reserved	Reserved	Reserved	Reserved	PLL0 PLL1 PLL2 PLL3	HSICAL 13 HSICAL 14 HSICAL 15 HSICAL 16			
0x30	<b>RCC_AHB1ENR</b>	Reserved	Reserved	CRCEEN	PLL0 PLL1 PLL2 PLL3	HSICAL 17 HSICAL 18 HSICAL 19 HSICAL 20			
0x34	<b>RCC_AHB2ENR</b>	Reserved	Reserved	OTGFSRST	PLL0 PLL1 PLL2 PLL3	HSICAL 21 HSICAL 22 HSICAL 23 HSICAL 24			
0x38	Reserved	Reserved	Reserved	GPIOHEN	PLL0 PLL1 PLL2 PLL3	HSICAL 25 HSICAL 26 HSICAL 27 HSICAL 28			
0x3C	Reserved	Reserved	Reserved	GPIOERST	PLL0 PLL1 PLL2 PLL3	HSICAL 29 HSICAL 30 HSICAL 31 HSICAL 32			

**Table 22. RCC register map and reset values for STM32F401xB/C and STM32F401xD/E (continued)**

Addr. offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0							
0x40	<b>RCC_APB1ENR</b>	Reserved	PWRREN	Reserved	I2C3EN	I2C2EN	I2C1EN	I2C0EN	Reserved	TIM11EN	TIM10EN	TIM9EN	Reserved	SPI3EN	SPI2EN	SPI4EN	SPI1EN	SDIOEN	WWDGGEN	OTGFSLPEN	GPIOHLPEN	Reserved	USART6EN	USART1EN	Reserved	GPIOE1PEN	GPIOD1PEN	GPIOC1PEN	GPIOB1PEN	GPIOA1PEN	TIM5EN	TIM4EN	Reserved	TIM3EN	TIM2EN	0				
0x44	<b>RCC_APB2ENR</b>	Reserved	Reserved	Reserved	I2C3EN	I2C2EN	I2C1EN	I2C0EN	Reserved	TIM11EN	TIM10EN	TIM9EN	Reserved	SPI3EN	SPI2EN	SPI4EN	SPI1EN	SDIOEN	WWDGGEN	OTGFSLPEN	GPIOHLPEN	Reserved	USART6EN	USART1EN	Reserved	GPIOE1PEN	GPIOD1PEN	GPIOC1PEN	GPIOB1PEN	GPIOA1PEN	TIM5EN	TIM4EN	Reserved	TIM3EN	TIM2EN	0				
0x48	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved						
0x4C	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved						
0x50	<b>RCC_AHB1LPENR</b>	Reserved	Reserved	Reserved	DMA2LPEN	DMA1LPEN	Reserved	Reserved	SRAM1LPEN	FLITFLPEN	Reserved	Reserved	Reserved																											
0x54	<b>RCC_AHB2LPENR</b>	Reserved	Reserved	Reserved																																				
0x58	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved						
0x5C	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved						
0x60	<b>RCC_APB1LPENR</b>	Reserved	PWRLPEN	Reserved	I2C3LPEN	I2C2LPEN	I2C1LPEN	Reserved	TIM11LPEN	TIM10LPEN	Reserved	Reserved	Reserved																											
0x64	<b>RCC_APB2LPENR</b>	Reserved	Reserved	Reserved																																				
0x68	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved						
0x6C	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved						
0x70	<b>RCC_BDCR</b>	Reserved	Reserved	Reserved	BDRST	RTCEN	Reserved	Reserved																																
0x74	<b>RCC_CSR</b>	SSCGEN	SPREADSEL	PLL12SRx	PLL12SRx																																			
0x78	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved					
0x7C	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved					
0x80	<b>RCC_SSCGR</b>	INCSTEP	MODPER	Reserved	Reserved																																			
0x84	<b>RCC_PLLI2SFCFGR</b>	PLL12SNx	PLL12SNx	PLL12SNx																																				
	<b>LSEBYP</b>	<b>LSERDY</b>	<b>LSEON</b>	<b>LSEOFF</b>																																				

**Table 22. RCC register map and reset values for STM32F401xB/C  
and STM32F401xD/E (continued)**

Addr. offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x88																																	
0x8C	RCC_DCKCF GR																																

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 7 System configuration controller (SYSCFG)

The system configuration controller is mainly used to remap the memory accessible in the code area and manage the external interrupt line connection to the GPIOs.

### 7.1 I/O compensation cell

By default the I/O compensation cell is not used. However when the I/O output buffer speed is configured in 50 MHz or 100 MHz mode, it is recommended to use the compensation cell for slew rate control on I/O  $t_{f(IO)out}/t_{r(IO)out}$  commutation to reduce the I/O noise on power supply.

When the compensation cell is enabled, a READY flag is set to indicate that the compensation cell is ready and can be used. The I/O compensation cell can be used only when the supply voltage ranges from 2.4 to 3.6 V.

### 7.2 SYSCFG registers

#### 7.2.1 SYSCFG memory remap register (SYSCFG\_MEMRMP)

This register is used for specific configurations on memory remap:

- Two bits are used to configure the type of memory accessible at address 0x0000 0000. These bits are used to select the physical remap by software and so, bypass the BOOT pins.
- After reset these bits take the value selected by the BOOT pins. When booting from main Flash memory with BOOT0 pin set to 0 this register takes the value 0x00.

In remap mode, the CPU can access the external memory via ICode bus instead of System bus which boosts up the performance.

Address offset: 0x00

Reset value: 0x0000 000X (X is the memory mode selected by the BOOT pins)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														MEM_MODE	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **MEM\_MODE**: Memory mapping selection

Set and cleared by software. This bit controls the memory internal mapping at address 0x0000 0000. After reset these bits take the value selected by the Boot pins .

00: Main Flash memory mapped at 0x0000 0000

01: System Flash memory mapped at 0x0000 0000

11: Embedded SRAM mapped at 0x0000 0000

*Note:* Refer to [Section 2.3: Memory map](#) for details about the memory mapping at address 0x0000 0000.

## 7.2.2 SYSCFG peripheral mode configuration register (SYSCFG\_PMC)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved															ADC1D C2	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	rw
Reserved																

Bits 31:17 Reserved, must be kept at reset value.

Bits 16 **ADCxDC2**:

0: No effect.

1: Refer to AN4073 on how to use this bit .

*Note:* These bits can be set only if the following conditions are met:

- ADC clock higher or equal to 30 MHz.

- Only one ADCxDC2 bit must be selected if ADC conversions do not start at the same time and the sampling times differ.

- These bits must not be set when the ADCDC1 bit is set in PWR\_CR register.

Bits 15:0 Reserved, must be kept at reset value.

## 7.2.3 SYSCFG external interrupt configuration register 1 (SYSCFG\_EXTICR1)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved																
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
EXTI3[3:0]				EXTI2[3:0]				EXTI1[3:0]				EXTI0[3:0]				
rw	rw	rw	rw													

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTIx[3:0]**: EXTI x configuration (x = 0 to 3)

These bits are written by software to select the source input for the EXTIx external interrupt.

- 0000: PA[x] pin
- 0001: PB[x] pin
- 0010: PC[x] pin
- 0011: PD[x] pin
- 0100: PE[x] pin
- 0101: Reserved
- 0110: Reserved
- 0111: PH[x] pin

#### 7.2.4 SYSCFG external interrupt configuration register 2 (SYSCFG\_EXTICR2)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI7[3:0]				EXTI6[3:0]				EXTI5[3:0]				EXTI4[3:0]			
rw	rw	rw	rw												

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTIx[3:0]**: EXTI x configuration (x = 4 to 7)

These bits are written by software to select the source input for the EXTIx external interrupt.

- 0000: PA[x] pin
- 0001: PB[x] pin
- 0010: PC[x] pin
- 0011: PD[x] pin
- 0100: PE[x] pin
- 0101: Reserved
- 0110: Reserved
- 0111: PH[x] pin

### 7.2.5 SYSCFG external interrupt configuration register 3 (SYSCFG\_EXTICR3)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI11[3:0]				EXTI10[3:0]				EXTI9[3:0]				EXTI8[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTIx[3:0]**: EXTI x configuration (x = 8 to 11)

These bits are written by software to select the source input for the EXTIx external interrupt.

- 0000: PA[x] pin
- 0001: PB[x] pin
- 0010: PC[x] pin
- 0011: PD[x] pin
- 0100: PE[x] pin
- 0101: Reserved
- 0110: Reserved
- 0111: PH[x] pin

### 7.2.6 SYSCFG external interrupt configuration register 4 (SYSCFG\_EXTICR4)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI15[3:0]				EXTI14[3:0]				EXTI13[3:0]				EXTI12[3:0]			
rw	rw	rw	rw												

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTIx[3:0]**: EXTI x configuration (x = 12 to 15)

These bits are written by software to select the source input for the EXTIx external interrupt.

- 0000: PA[x] pin
- 0001: PB[x] pin
- 0010: PC[x] pin
- 0011: PD[x] pin
- 0100: PE[x] pin
- 0101: Reserved
- 0110: Reserved
- 0111: PH[x] pin

### 7.2.7 Compensation cell control register (SYSCFG\_CMPCR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															
READY								Reserved							
r								CMP_PD							
rw															

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **READY**: Compensation cell ready flag

0: I/O compensation cell not ready

1: I/O compensation cell ready

Bits 7:2 Reserved, must be kept at reset value.

Bit 0 **CMP\_PD**: Compensation cell power-down

0: I/O compensation cell power-down mode

1: I/O compensation cell enabled

### 7.2.8 SYSCFG register map

The following table gives the SYSCFG register map and the reset values.

Table 23. SYSCFG register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0				
0x00	<b>SYSCFG_MEMRM</b>	Reserved																MEM_MODE																			
		x x																																			
0x08	<b>SYSCFG_EXTICR1</b> Reset value	Reserved								EXTI3[3:0]		EXTI2[3:0]		EXTI1[3:0]		EXTI0[3:0]																					
		0 0 0 0								0 0 0 0		0 0 0 0		0 0 0 0		0 0 0 0																					
0x0C	<b>SYSCFG_EXTICR2</b> Reset value	Reserved								EXTI7[3:0]		EXTI6[3:0]		EXTI5[3:0]		EXTI4[3:0]																					
		0 0 0 0								0 0 0 0		0 0 0 0		0 0 0 0		0 0 0 0																					
0x10	<b>SYSCFG_EXTICR3</b> Reset value	Reserved								EXTI11[3:0]		EXTI10[3:0]		EXTI9[3:0]		EXTI8[3:0]																					
		0 0 0 0								0 0 0 0		0 0 0 0		0 0 0 0		0 0 0 0																					
0x14	<b>SYSCFG_EXTICR4</b> Reset value	Reserved								EXTI15[3:0]		EXTI14[3:0]		EXTI13[3:0]		EXTI12[3:0]																					
		0 0 0 0								0 0 0 0		0 0 0 0		0 0 0 0		0 0 0 0																					
0x20	<b>SYSCFG_CMPCR</b> Reset value	Reserved																READY		Reserved								CMP_PD									
		0																0										0									

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 8 General-purpose I/Os (GPIO)

GPIO F/G/H/I/J/K (except GPIOH0 and GPIOH1) are not available in STM32F401xB/C and STM32F401xD/E.

### 8.1 GPIO introduction

Each general-purpose I/O port has four 32-bit configuration registers (GPIOx\_MODER, GPIOx\_OTYPER, GPIOx\_OSPEEDR and GPIOx\_PUPDR), two 32-bit data registers (GPIOx\_IDR and GPIOx\_ODR), a 32-bit set/reset register (GPIOx\_BSRR), a 32-bit locking register (GPIOx\_LCKR) and two 32-bit alternate function selection register (GPIOx\_AFRL and GPIOx\_AFRH).

### 8.2 GPIO main features

- Up to 16 I/Os under control
- Output states: push-pull or open drain + pull-up/down
- Output data from output data register (GPIOx\_ODR) or peripheral (alternate function output)
- Speed selection for each I/O
- Input states: floating, pull-up/down, analog
- Input data to input data register (GPIOx\_IDR) or peripheral (alternate function input)
- Bit set and reset register (GPIOx\_BSRR) for bitwise write access to GPIOx\_ODR
- Locking mechanism (GPIOx\_LCKR) provided to freeze the I/O configuration
- Analog function
- Alternate function input/output selection registers (at most 16 AFs per I/O)
- Fast toggle capable of changing every two clock cycles
- Highly flexible pin multiplexing allows the use of I/O pins as GPIOs or as one of several peripheral functions

### 8.3 GPIO functional description

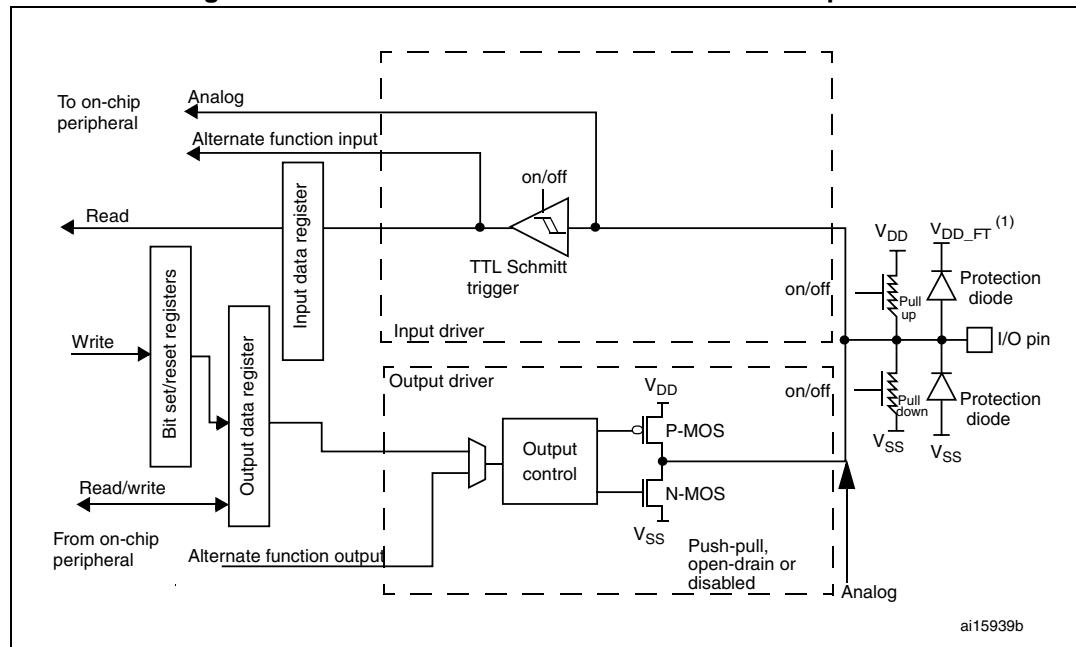
Subject to the specific hardware characteristics of each I/O port listed in the datasheet, each port bit of the general-purpose I/O (GPIO) ports can be individually configured by software in several modes:

- Input floating
- Input pull-up
- Input-pull-down
- Analog
- Output open-drain with pull-up or pull-down capability
- Output push-pull with pull-up or pull-down capability
- Alternate function push-pull with pull-up or pull-down capability
- Alternate function open-drain with pull-up or pull-down capability

Each I/O port bit is freely programmable, however the I/O port registers have to be accessed as 32-bit words, half-words or bytes. The purpose of the GPIOx\_BSRR register is to allow atomic read/modify accesses to any of the GPIO registers. In this way, there is no risk of an IRQ occurring between the read and the modify access.

Figure 16 shows the basic structure of a 5 V tolerant I/O port bit. Table 27 gives the possible port bit configurations.

**Figure 16. Basic structure of a five-volt tolerant I/O port bit**



1.  $V_{DD\_FT}$  is a potential specific to five-volt tolerant I/Os and different from  $V_{DD}$ .

**Table 24. Port bit configuration table<sup>(1)</sup>**

MODER(i) [1:0]	OTYPER(i)	OSPEEDR(i) [B:A]	PUPDR(i) [1:0]		I/O configuration	
01	0	SPEED [B:A]	0	0	GP output	PP
	0		0	1	GP output	PP + PU
	0		1	0	GP output	PP + PD
	0		1	1	Reserved	
	1		0	0	GP output	OD
	1		0	1	GP output	OD + PU
	1		1	0	GP output	OD + PD
	1		1	1	Reserved (GP output OD)	

Table 24. Port bit configuration table<sup>(1)</sup> (continued)

MODER(i) [1:0]	OTYPER(i)	OSPEEDR(i) [B:A]	PUPDR(i) [1:0]		I/O configuration	
10	0	SPEED [B:A]	0	0	AF	PP
	0		0	1	AF	PP + PU
	0		1	0	AF	PP + PD
	0		1	1	Reserved	
	1		0	0	AF	OD
	1		0	1	AF	OD + PU
	1		1	0	AF	OD + PD
	1		1	1	Reserved	
	x	x	x	0	0	Input
00	x	x	x	0	1	Input
	x	x	x	1	0	Input
	x	x	x	1	1	Reserved (input floating)
	x	x	x	0	0	Input/output
11	x	x	x	0	1	Reserved
	x	x	x	1	0	
	x	x	x	1	1	
	x	x	x	1	1	

1. GP = general-purpose, PP = push-pull, PU = pull-up, PD = pull-down, OD = open-drain, AF = alternate function.

### 8.3.1 General-purpose I/O (GPIO)

During and just after reset, the alternate functions are not active and the I/O ports are configured in input floating mode.

The debug pins are in AF pull-up/pull-down after reset:

- PA15: JTDI in pull-up
- PA14: JTCK/SWCLK in pull-down
- PA13: JTMS/SWDAT in pull-up
- PB4: NJTRST in pull-up
- PB3: JTDO in floating state

When the pin is configured as output, the value written to the output data register (GPIOx\_ODR) is output on the I/O pin. It is possible to use the output driver in push-pull mode or open-drain mode (only the N-MOS is activated when 0 is output).

The input data register (GPIOx\_IDR) captures the data present on the I/O pin at every AHB clock cycle.

All GPIO pins have weak internal pull-up and pull-down resistors, which can be activated or not depending on the value in the GPIOx\_PUPDR register.

### 8.3.2 I/O pin multiplexer and mapping

The microcontroller I/O pins are connected to onboard peripherals/modules through a multiplexer that allows only one peripheral's alternate function (AF) connected to an I/O pin at a time. In this way, there can be no conflict between peripherals sharing the same I/O pin.

Each I/O pin has a multiplexer with sixteen alternate function inputs (AF0 to AF15) that can be configured through the GPIOx\_AFRL (for pin 0 to 7) and GPIOx\_AFRH (for pin 8 to 15) registers:

- After reset all I/Os are connected to the system's alternate function 0 (AF0)
- The peripherals' alternate functions are mapped from AF1 to AF13
- Cortex™-M4 with FPU EVENTOUT is mapped on AF15

This structure is shown in [Figure 17](#) below.

In addition to this flexible I/O multiplexing architecture, each peripheral has alternate functions mapped onto different I/O pins to optimize the number of peripherals available in smaller packages.

To use an I/O in a given configuration, proceed as follows:

- **System function**

Connect the I/O to AF0 and configure it depending on the function used:

- JTAG/SWD, after each device reset these pins are assigned as dedicated pins immediately usable by the debugger host (not controlled by the GPIO controller)
- RTC\_REFIN: this pin should be configured in Input floating mode
- MCO1 and MCO2: these pins have to be configured in alternate function mode.

Note:

You can disable some or all of the JTAG/SWD pins and so release the associated pins for GPIO usage.

For more details please refer to [Section 6.2.10: Clock-out capability](#).

**Table 25. Flexible SWJ-DP pin assignment**

Available debug ports	SWJ I/O pin assigned				
	PA13 / JTMS/ SWDIO	PA14 / JTCK/ SWCLK	PA15 / JTDI	PB3 / JTDO	PB4/ NJTRST
Full SWJ (JTAG-DP + SW-DP) - Reset state	X	X	X	X	X
Full SWJ (JTAG-DP + SW-DP) but without NJTRST	X	X	X	X	
JTAG-DP Disabled and SW-DP Enabled	X	X			
JTAG-DP Disabled and SW-DP Disabled					Released

- **GPIO**

Configure the desired I/O as output or input in the GPIOx\_MODER register.

- **Peripheral alternate function**

For the ADC, configure the desired I/O as analog in the GPIOx\_MODER register.

For other peripherals:

- Configure the desired I/O as an alternate function in the GPIOx\_MODER register
- Select the type, pull-up/pull-down and output speed via the GPIOx\_OTYPER, GPIOx\_PUPDR and GPIOx\_OSPEEDER registers, respectively
- Connect the I/O to the desired AFx in the GPIOx\_AFRL or GPIOx\_AFRH register

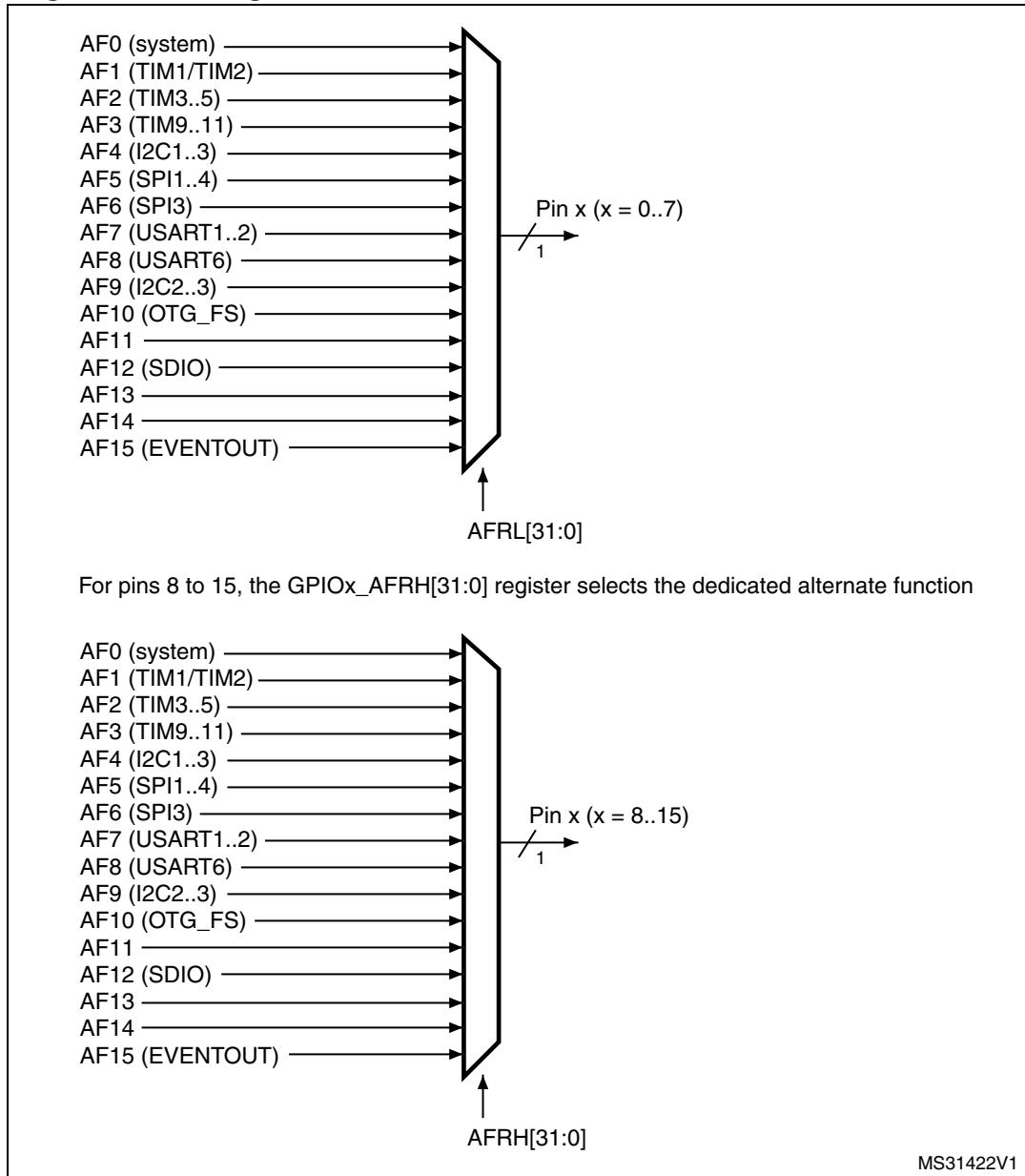
- **EVENTOUT**

Configure the I/O pin used to output the Cortex™-M4 with FPU EVENTOUT signal by connecting it to AF15

Note:

*EVENTOUT is not mapped onto the following I/O pins: PC13, PC14, PC15, PH0 and PH1.*

Please refer to the “Alternate function mapping” table in the datasheets for the detailed mapping of the system and peripherals’ alternate function I/O pins.

**Figure 17. Selecting an alternate function on STM32F401xB/C and STM32F401xD/E**

1. Configured in FS.

### 8.3.3 I/O port control registers

Each of the GPIOs has four 32-bit memory-mapped control registers (GPIO<sub>x</sub>\_MODER, GPIO<sub>x</sub>\_OTYPER, GPIO<sub>x</sub>\_OSPEEDR, GPIO<sub>x</sub>\_PUPDR) to configure up to 16 I/Os. The GPIO<sub>x</sub>\_MODER register is used to select the I/O direction (input, output, AF, analog). The GPIO<sub>x</sub>\_OTYPER and GPIO<sub>x</sub>\_OSPEEDR registers are used to select the output type (push-pull or open-drain) and speed (the I/O speed pins are directly connected to the corresponding GPIO<sub>x</sub>\_OSPEEDR register bits whatever the I/O direction). The GPIO<sub>x</sub>\_PUPDR register is used to select the pull-up/pull-down whatever the I/O direction.

### 8.3.4 I/O port data registers

Each GPIO has two 16-bit memory-mapped data registers: input and output data registers (GPIO<sub>x</sub>\_IDR and GPIO<sub>x</sub>\_ODR). GPIO<sub>x</sub>\_ODR stores the data to be output, it is read/write accessible. The data input through the I/O are stored into the input data register (GPIO<sub>x</sub>\_IDR), a read-only register.

See [Section 8.4.5: GPIO port input data register \(GPIO<sub>x</sub>\\_IDR\) \(x = A..E and H\)](#) and [Section 8.4.6: GPIO port output data register \(GPIO<sub>x</sub>\\_ODR\) \(x = A..E and H\)](#) for the register descriptions.

### 8.3.5 I/O data bitwise handling

The bit set reset register (GPIO<sub>x</sub>\_BSRR) is a 32-bit register which allows the application to set and reset each individual bit in the output data register (GPIO<sub>x</sub>\_ODR). The bit set reset register has twice the size of GPIO<sub>x</sub>\_ODR.

To each bit in GPIO<sub>x</sub>\_ODR, correspond two control bits in GPIO<sub>x</sub>\_BSRR: BSRR(i) and BSRR(i+SIZE). When written to 1, bit BSRR(i) **sets** the corresponding ODR(i) bit. When written to 1, bit BSRR(i+SIZE) **resets** the ODR(i) corresponding bit.

Writing any bit to 0 in GPIO<sub>x</sub>\_BSRR does not have any effect on the corresponding bit in GPIO<sub>x</sub>\_ODR. If there is an attempt to both set and reset a bit in GPIO<sub>x</sub>\_BSRR, the set action takes priority.

Using the GPIO<sub>x</sub>\_BSRR register to change the values of individual bits in GPIO<sub>x</sub>\_ODR is a “one-shot” effect that does not lock the GPIO<sub>x</sub>\_ODR bits. The GPIO<sub>x</sub>\_ODR bits can always be accessed directly. The GPIO<sub>x</sub>\_BSRR register provides a way of performing atomic bitwise handling.

There is no need for the software to disable interrupts when programming the GPIO<sub>x</sub>\_ODR at bit level: it is possible to modify one or more bits in a single atomic AHB1 write access.

### 8.3.6 GPIO locking mechanism

It is possible to freeze the GPIO control registers by applying a specific write sequence to the GPIO<sub>x</sub>\_LCKR register. The frozen registers are GPIO<sub>x</sub>\_MODER, GPIO<sub>x</sub>\_OTYPER, GPIO<sub>x</sub>\_OSPEEDR, GPIO<sub>x</sub>\_PUPDR, GPIO<sub>x</sub>\_AFRL and GPIO<sub>x</sub>\_AFRH.

To write the GPIO<sub>x</sub>\_LCKR register, a specific write / read sequence has to be applied. When the right LOCK sequence is applied to bit 16 in this register, the value of LCKR[15:0] is used to lock the configuration of the I/Os (during the write sequence the LCKR[15:0] value must be the same). When the LOCK sequence has been applied to a port bit, the value of the port bit can no longer be modified until the next reset. Each GPIO<sub>x</sub>\_LCKR bit freezes the corresponding bit in the control registers (GPIO<sub>x</sub>\_MODER, GPIO<sub>x</sub>\_OTYPER, GPIO<sub>x</sub>\_OSPEEDR, GPIO<sub>x</sub>\_PUPDR, GPIO<sub>x</sub>\_AFRL and GPIO<sub>x</sub>\_AFRH).

The LOCK sequence (refer to [Section 8.4.8: GPIO port configuration lock register \(GPIO<sub>x</sub>\\_LCKR\) \(x = A..E and H\)](#)) can only be performed using a word (32-bit long) access to the GPIO<sub>x</sub>\_LCKR register due to the fact that GPIO<sub>x</sub>\_LCKR bit 16 has to be set at the same time as the [15:0] bits.

For more details please refer to LCKR register description in [Section 8.4.8: GPIO port configuration lock register \(GPIO<sub>x</sub>\\_LCKR\) \(x = A..E and H\)](#).

### 8.3.7 I/O alternate function input/output

Two registers are provided to select one out of the sixteen alternate function inputs/outputs available for each I/O. With these registers, you can connect an alternate function to some other pin as required by your application.

This means that a number of possible peripheral functions are multiplexed on each GPIO using the GPIOx\_AFRL and GPIOx\_AFRH alternate function registers. The application can thus select any one of the possible functions for each I/O. The AF selection signal being common to the alternate function input and alternate function output, a single channel is selected for the alternate function input/output of one I/O.

To know which functions are multiplexed on each GPIO pin, refer to the datasheets.

*Note:*

*The application is allowed to select one of the possible peripheral functions for each I/O at a time.*

### 8.3.8 External interrupt/wakeup lines

All ports have external interrupt capability. To use external interrupt lines, the port must be configured in input mode, refer to [Section 10.2: External interrupt/event controller \(EXTI\)](#) and [Section 10.2.3: Wakeup event management](#).

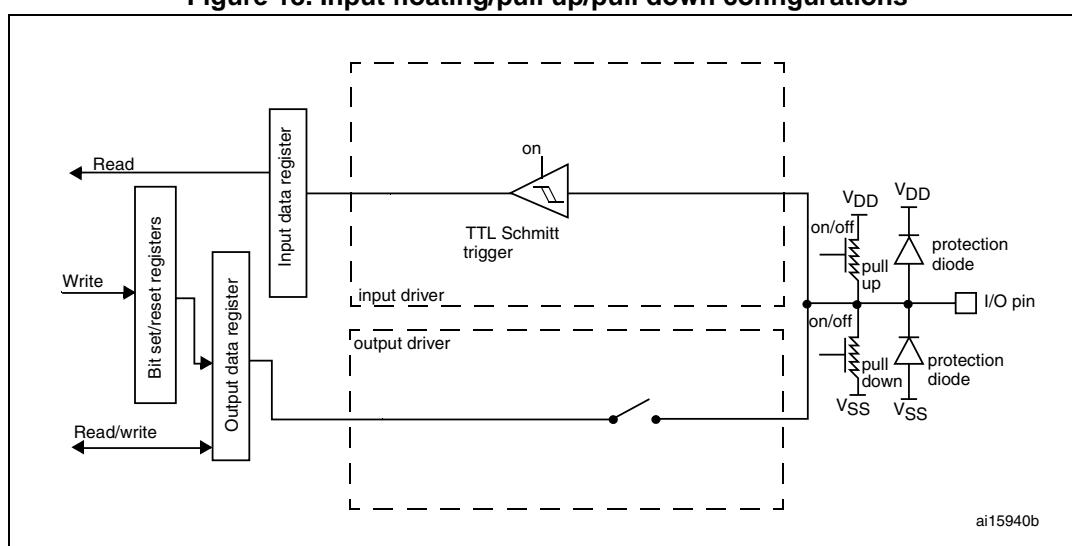
### 8.3.9 Input configuration

When the I/O port is programmed as Input:

- the output buffer is disabled
- the Schmitt trigger input is activated
- the pull-up and pull-down resistors are activated depending on the value in the GPIOx\_PUPDR register
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle
- A read access to the input data register provides the I/O State

[Figure 18](#) shows the input configuration of the I/O port bit.

**Figure 18. Input floating/pull up/pull down configurations**



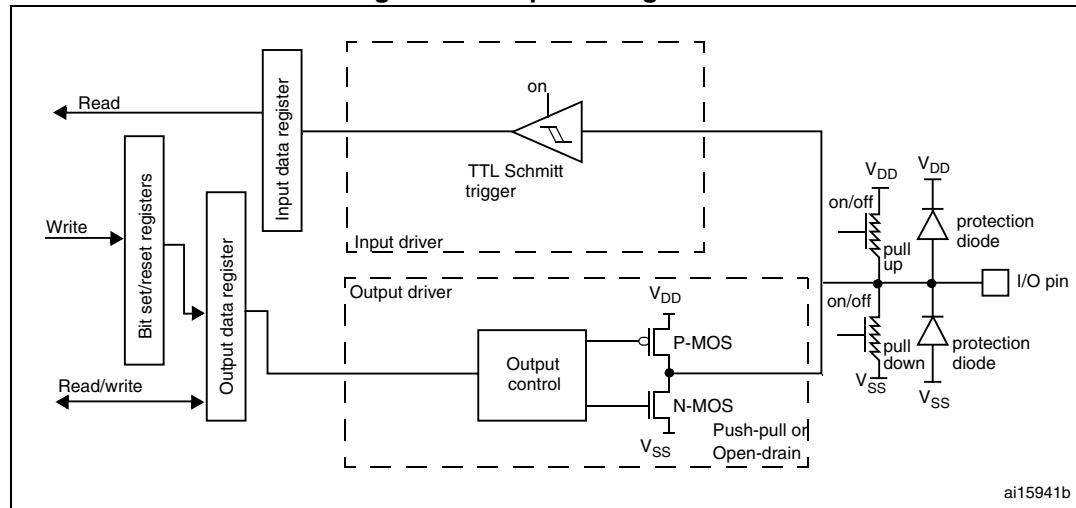
### 8.3.10 Output configuration

When the I/O port is programmed as output:

- The output buffer is enabled:
  - Open drain mode: A “0” in the Output register activates the N-MOS whereas a “1” in the Output register leaves the port in Hi-Z (the P-MOS is never activated)
  - Push-pull mode: A “0” in the Output register activates the N-MOS whereas a “1” in the Output register activates the P-MOS
- The Schmitt trigger input is activated
- The weak pull-up and pull-down resistors are activated or not depending on the value in the GPIOx\_PUPDR register
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle
- A read access to the input data register gets the I/O state
- A read access to the output data register gets the last written value

*Figure 19* shows the output configuration of the I/O port bit.

**Figure 19. Output configuration**

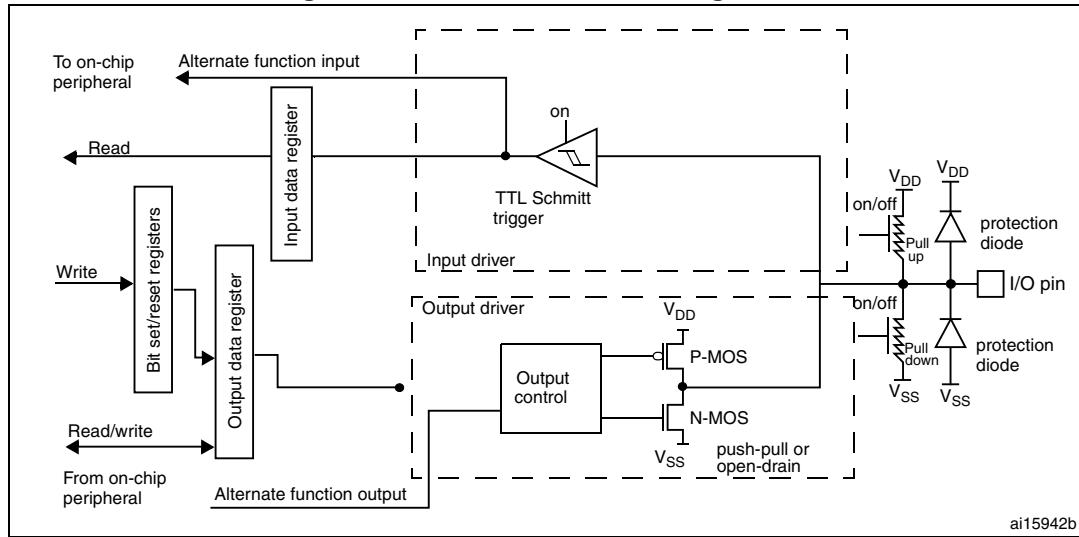


### 8.3.11 Alternate function configuration

When the I/O port is programmed as alternate function:

- The output buffer can be configured as open-drain or push-pull
- The output buffer is driven by the signal coming from the peripheral (transmitter enable and data)
- The Schmitt trigger input is activated
- The weak pull-up and pull-down resistors are activated or not depending on the value in the GPIOx\_PUPDR register
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle
- A read access to the input data register gets the I/O state

*Figure 20* shows the Alternate function configuration of the I/O port bit.

**Figure 20. Alternate function configuration**

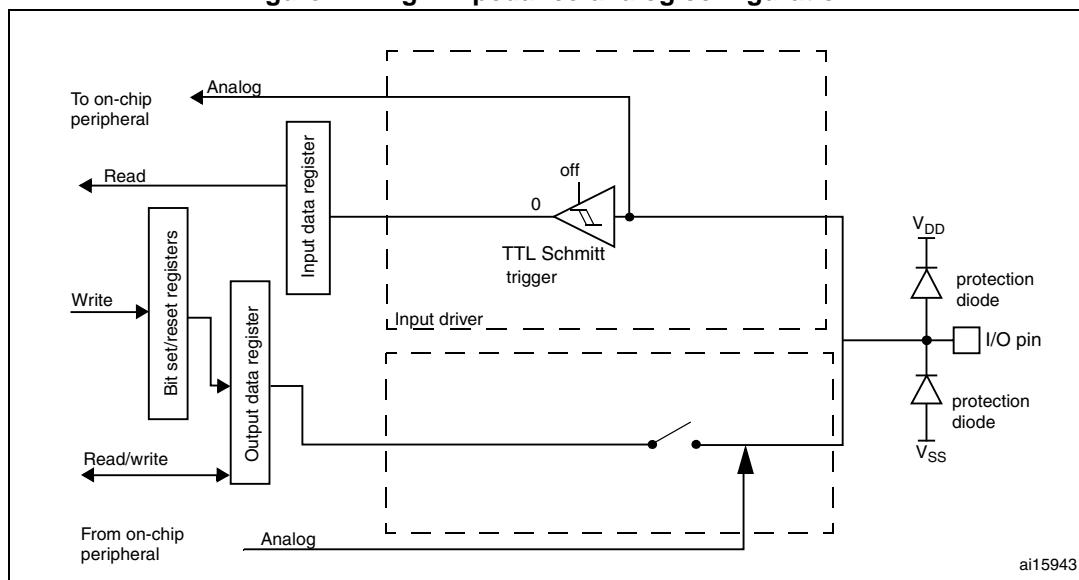
### 8.3.12 Analog configuration

When the I/O port is programmed as analog configuration:

- The output buffer is disabled
- The Schmitt trigger input is deactivated, providing zero consumption for every analog value of the I/O pin. The output of the Schmitt trigger is forced to a constant value (0).
- The weak pull-up and pull-down resistors are disabled
- Read access to the input data register gets the value "0"

*Note:* In the analog configuration, the I/O pins cannot be 5 Volt tolerant.

Figure 21 shows the high-impedance-analog configuration of the I/O port bit.

**Figure 21. High impedance-analog configuration**

### 8.3.13 Using the OSC32\_IN/OSC32\_OUT pins as GPIO PC14/PC15 port pins

The LSE oscillator pins OSC32\_IN and OSC32\_OUT can be used as general-purpose PC14 and PC15 I/Os, respectively, when the LSE oscillator is off. The PC14 and PC15 I/Os are only configured as LSE oscillator pins OSC32\_IN and OSC32\_OUT when the LSE oscillator is ON. This is done by setting the LSEON bit in the RCC\_BDCR register. The LSE has priority over the GPIO function.

*Note:* *The PC14/PC15 GPIO functionality is lost when the 1.2 V domain is powered off (by the device entering the standby mode) or when the backup domain is supplied by  $V_{BAT}$  ( $V_{DD}$  no more supplied). In this case the I/Os are set in analog input mode.*

### 8.3.14 Using the OSC\_IN/OSC\_OUT pins as GPIO PH0/PH1 port pins

The HSE oscillator pins OSC\_IN/OSC\_OUT can be used as general-purpose PH0/PH1 I/Os, respectively, when the HSE oscillator is OFF. (after reset, the HSE oscillator is off). The PH0/PH1 I/Os are only configured as OSC\_IN/OSC\_OUT HSE oscillator pins when the HSE oscillator is ON. This is done by setting the HSEON bit in the RCC\_CR register. The HSE has priority over the GPIO function.

### 8.3.15 Selection of RTC additional functions

The STM32F4xx feature two GPIO pins RTC\_AF1 and RTC\_AF2 that can be used for the detection of a tamper or time stamp event, or RTC\_ALARM, or RTC\_CALIB RTC outputs.

- The RTC\_AF1 (PC13) can be used for the following purposes:

RTC\_ALARM output: this output can be RTC Alarm A, RTC Alarm B or RTC Wakeup depending on the OSEL[1:0] bits in the RTC\_CR register

- RTC\_CALIB output: this feature is enabled by setting the COE[23] in the RTC\_CR register
- RTC\_TAMP1: tamper event detection
- RTC\_TS: time stamp event detection

The selection of the corresponding pin is performed through the RTC\_TAFCR register as follows:

- TAMP1INSEL is used to select which pin is used as the RTC\_TAMP1 tamper input
- TSINSEL is used to select which pin is used as the RTC\_TS time stamp input
- ALARMOUTTYPE is used to select whether the RTC\_ALARM is output in push-pull or open-drain mode

The output mechanism follows the priority order listed in [Table 26](#).

Table 26. RTC additional functions<sup>(1)</sup>

Pin configuration and function	RTC_ALARM enabled	RTC_CALIB enabled	Tamper enabled	Time stamp enabled	TAMP1INSEL TAMPER1 pin selection	TSINSEL TIMESTAMP pin selection	ALARMOUTTYPE RTC_ALARM configuration
Alarm out output OD	1	Don't care	Don't care	Don't care	Don't care	Don't care	0
Alarm out output PP	1	Don't care	Don't care	Don't care	Don't care	Don't care	1
Calibration out output PP	0	1	Don't care	Don't care	Don't care	Don't care	Don't care
TAMPER1 input floating	0	0	1	0	0	Don't care	Don't care
TIMESTAMP and TAMPER1 input floating	0	0	1	1	0	0	Don't care
TIMESTAMP input floating	0	0	0	1	Don't care	0	Don't care
Standard GPIO	0	0	0	0	Don't care	Don't care	Don't care

1. OD: open drain; PP: push-pull.

## 8.4 GPIO registers

This section gives a detailed description of the GPIO registers.

For a summary of register bits, register address offsets and reset values, refer to [Table 27](#).

The GPIO registers can be accessed by byte (8 bits), half-words (16 bits) or words (32 bits).

### 8.4.1 GPIO port mode register (GPIOx\_MODER) (x = A..E and H)

Address offset: 0x00

Reset values:

- 0x0C00 0000 for port A
- 0x0000 0280 for port B
- 0x0000 0000 for other ports

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]	
rw	rw	rw	rw	rw	rw										
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODERO[1:0]	
rw	rw	rw	rw	rw	rw										

Bits 2y:2y+1 **MODER<sub>y[1:0]</sub>**: Port x configuration bits (y = 0..15)

These bits are written by software to configure the I/O direction mode.

00: Input (reset state)

01: General purpose output mode

10: Alternate function mode

11: Analog mode

### 8.4.2 GPIO port output type register (GPIO<sub>x</sub>\_OTYPER) (x = A..E and H)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **OT<sub>y</sub>**: Port x configuration bits (y = 0..15)

These bits are written by software to configure the output type of the I/O port.

0: Output push-pull (reset state)

1: Output open-drain

### 8.4.3 GPIO port output speed register (GPIO<sub>x</sub>\_OSPEEDR) (x = A..E and H)

Address offset: 0x08

Reset values:

- 0x0C00 0000 for port A
- 0x0000 00C0 for port B
- 0x0000 0000 for other ports

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSPEEDR15 [1:0]		OSPEEDR14 [1:0]		OSPEEDR13 [1:0]		OSPEEDR12 [1:0]		OSPEEDR11 [1:0]		OSPEEDR10 [1:0]		OSPEEDR9 [1:0]		OSPEEDR8 [1:0]	
rw	rw	rw	rw	rw	rw										
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSPEEDR7[1:0]		OSPEEDR6[1:0]		OSPEEDR5[1:0]		OSPEEDR4[1:0]		OSPEEDR3[1:0]		OSPEEDR2[1:0]		OSPEEDR1 [1:0]		OSPEEDR0 [1:0]	
rw	rw	rw	rw	rw	rw										

Bits 2y:2y+1 **OSPEEDR<sub>y</sub>[1:0]**: Port x configuration bits ( $y = 0..15$ )

These bits are written by software to configure the I/O output speed.

- 00: Low speed
- 01: Medium speed
- 10: Fast speed
- 11: High speed

*Note:* Refer to the product datasheets for the values of OSPEEDR<sub>y</sub> bits versus  $V_{DD}$  range and external load.

#### 8.4.4 GPIO port pull-up/pull-down register (GPIO<sub>x</sub>\_PUPDR) (x = A..E and H)

Address offset: 0x0C

Reset values:

- 0x6400 0000 for port A
- 0x0000 0100 for port B
- 0x0000 0000 for other ports

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PUPDR15[1:0]	PUPDR14[1:0]	PUPDR13[1:0]	PUPDR12[1:0]	PUPDR11[1:0]	PUPDR10[1:0]	PUPDR9[1:0]	PUPDR8[1:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PUPDR7[1:0]	PUPDR6[1:0]	PUPDR5[1:0]	PUPDR4[1:0]	PUPDR3[1:0]	PUPDR2[1:0]	PUPDR1[1:0]	PUPDR0[1:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 2y:2y+1 **PUPDR<sub>y</sub>[1:0]**: Port x configuration bits (y = 0..15)

These bits are written by software to configure the I/O pull-up or pull-down

- 00: No pull-up, pull-down
- 01: Pull-up
- 10: Pull-down
- 11: Reserved

#### 8.4.5 GPIO port input data register (GPIO<sub>x</sub>\_IDR) (x = A..E and H)

Address offset: 0x10

Reset value: 0x0000 XXXX (where X means undefined)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDR15	IDR14	IDR13	IDR12	IDR11	IDR10	IDR9	IDR8	IDR7	IDR6	IDR5	IDR4	IDR3	IDR2	IDR1	IDR0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **IDR<sub>y</sub>**: Port input data (y = 0..15)

These bits are read-only and can be accessed in word mode only. They contain the input value of the corresponding I/O port.

### 8.4.6 GPIO port output data register (GPIOx\_ODR) ( $x = A..E$ and $H$ )

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ODR15	ODR14	ODR13	ODR12	ODR11	ODR10	ODR9	ODR8	ODR7	ODR6	ODR5	ODR4	ODR3	ODR2	ODR1	ODR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **ODRy**: Port output data ( $y = 0..15$ )

These bits can be read and written by software.

*Note:* For atomic bit set/reset, the ODR bits can be individually set and reset by writing to the GPIOx\_BSRR register ( $x = A..E$  and  $H$ ).

### 8.4.7 GPIO port bit set/reset register (GPIOx\_BSRR) ( $x = A..E$ and $H$ )

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BS15	BS14	BS13	BS12	BS11	BS10	BS9	BS8	BS7	BS6	BS5	BS4	BS3	BS2	BS1	BS0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 **BRy**: Port x reset bit y ( $y = 0..15$ )

These bits are write-only and can be accessed in word, half-word or byte mode. A read to these bits returns the value 0x0000.

0: No action on the corresponding ODRx bit  
1: Resets the corresponding ODRx bit

*Note:* If both BSx and BRx are set, BSx has priority.

Bits 15:0 **BSy**: Port x set bit y ( $y = 0..15$ )

These bits are write-only and can be accessed in word, half-word or byte mode. A read to these bits returns the value 0x0000.

0: No action on the corresponding ODRx bit  
1: Sets the corresponding ODRx bit

### 8.4.8 GPIO port configuration lock register (GPIOx\_LCKR) ( $x = A..E$ and $H$ )

This register is used to lock the configuration of the port bits when a correct write sequence is applied to bit 16 (LCKK). The value of bits [15:0] is used to lock the configuration of the GPIO. During the write sequence, the value of LCKR[15:0] must not change. When the

LOCK sequence has been applied on a port bit, the value of this port bit can no longer be modified until the next reset.

**Note:** A specific write sequence is used to write to the GPIOx\_LCKR register. Only word access (32-bit long) is allowed during this write sequence.

Each lock bit freezes a specific configuration register (control and alternate function registers).

Address offset: 0x1C

Reset value: 0x0000 0000

Access: 32-bit word only, read/write register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															LCKK
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LCK15	LCK14	LCK13	LCK12	LCK11	LCK10	LCK9	LCK8	LCK7	LCK6	LCK5	LCK4	LCK3	LCK2	LCK1	LCK0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **LCKK[16]: Lock key**

This bit can be read any time. It can only be modified using the lock key write sequence.

0: Port configuration lock key not active

1: Port configuration lock key active. The GPIOx\_LCKR register is locked until an MCU reset occurs.

LOCK key write sequence:

WR LCKR[16] = '1' + LCKR[15:0]

WR LCKR[16] = '0' + LCKR[15:0]

WR LCKR[16] = '1' + LCKR[15:0]

RD LCKR

RD LCKR[16] = '1' (this read operation is optional but it confirms that the lock is active)

**Note:** During the LOCK key write sequence, the value of LCK[15:0] must not change.

Any error in the lock sequence aborts the lock.

After the first lock sequence on any bit of the port, any read access on the LCKK bit will return '1' until the next CPU reset.

Bits 15:0 **LCKy: Port x lock bit y (y= 0..15)**

These bits are read/write but can only be written when the LCKK bit is '0.

0: Port configuration not locked

1: Port configuration locked

### 8.4.9 GPIO alternate function low register (GPIOx\_AFRL) (x = A..E and H)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFRL7[3:0]				AFRL6[3:0]				AFRL5[3:0]				AFRL4[3:0]			
rw	rw	rw	rw												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AFRL3[3:0]				AFRL2[3:0]				AFRL1[3:0]				AFRL0[3:0]			
rw	rw	rw	rw												

Bits 31:0 **AFRLy**: Alternate function selection for port x bit y (y = 0..7)

These bits are written by software to configure alternate function I/Os

AFRLy selection:

0000: AF0	1000: AF8
0001: AF1	1001: AF9
0010: AF2	1010: AF10
0011: AF3	1011: AF11
0100: AF4	1100: AF12
0101: AF5	1101: AF13
0110: AF6	1110: AF14
0111: AF7	1111: AF15

### 8.4.10 GPIO alternate function high register (GPIOx\_AFRH) (x = A..E and H)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFRH15[3:0]				AFRH14[3:0]				AFRH13[3:0]				AFRH12[3:0]			
rw	rw	rw	rw												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AFRH11[3:0]				AFRH10[3:0]				AFRH9[3:0]				AFRH8[3:0]			
rw	rw	rw	rw												

Bits 31:0 **AFRH<sub>y</sub>**: Alternate function selection for port x bit y (y = 8..15)

These bits are written by software to configure alternate function I/Os

AFRH<sub>y</sub> selection:

0000: AF0	1000: AF8
0001: AF1	1001: AF9
0010: AF2	1010: AF10
0011: AF3	1011: AF11
0100: AF4	1100: AF12
0101: AF5	1101: AF13
0110: AF6	1110: AF14
0111: AF7	1111: AF15

### 8.4.11 GPIO register map

The following table gives the GPIO register map and the reset values.

**Table 27. GPIO register map and reset values**

Offset	Register	Reset value	31
0x00	GPIOA_MODER	0 MODER[15:0] 0	MODER[15:0]
0x00	GPIOB_MODER	0 MODER[14:0] 0	MODER[14:0]
0x00	GPIOx_MODER (where x = C..E and H)	0 MODER[13:0] 0	MODER[13:0]
0x04	GPIOx_OTYPER (where x = A..E and H)	0 MODER[12:0] 0	MODER[12:0]
0x08	GPIOx_OSPEEDER (where x = C..E and H )	0 MODER[11:0] 0	MODER[11:0]
0x08	GPIOA_OSPEEDER	0 OSPEEDR[15:0] 0	OSPEEDR[15:0]
0x08	GPIOB_OSPEEDER	0 OSPEEDR[14:0] 0	OSPEEDR[14:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[13:0] 0	OSPEEDR[13:0]
0x08	GPIOx_OSPEEDER	1 OSPEEDR[13:0] 0	OSPEEDR[13:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[12:0] 0	OSPEEDR[12:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[11:0] 0	OSPEEDR[11:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[10:0] 0	OSPEEDR[10:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[9:0] 0	OSPEEDR[9:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[8:0] 0	OSPEEDR[8:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[7:0] 0	OSPEEDR[7:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[6:0] 0	OSPEEDR[6:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[5:0] 0	OSPEEDR[5:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[4:0] 0	OSPEEDR[4:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[3:0] 0	OSPEEDR[3:0]
0x08	GPIOx_OSPEEDER	1 OSPEEDR[3:0] 0	OSPEEDR[3:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[2:0] 0	OSPEEDR[2:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[1:0] 0	OSPEEDR[1:0]
0x08	GPIOx_OSPEEDER	0 OSPEEDR[0:0] 0	OSPEEDR[0:0]

Table 27. GPIO register map and reset values (continued)

Offset	Register	Reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0						
0x0C	<b>GPIOA_PUPDR</b>	0 PUPDR15[1:0]	PUPDR15[1:0]	1	1	PUPDR14[1:0]	0	PUPDR13[1:0]	1	0	PUPDR12[1:0]	0	PUPDR11[1:0]	0	PUPDR10[1:0]	0	PUPDR9[1:0]	0	PUPDR8[1:0]	0	PUPDR7[1:0]	0	PUPDR6[1:0]	0	PUPDR5[1:0]	0	PUPDR4[1:0]	0	PUPDR3[1:0]	0	PUPDR2[1:0]	0	PUPDR1[1:0]	0	PUPDR0[1:0]					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
0x0C	<b>GPIOB_PUPDR</b>	0 PUPDR15[1:0]	PUPDR15[1:0]	0	0	PUPDR14[1:0]	0	PUPDR13[1:0]	0	0	PUPDR12[1:0]	0	PUPDR11[1:0]	0	PUPDR10[1:0]	0	PUPDR9[1:0]	0	PUPDR8[1:0]	0	PUPDR7[1:0]	0	PUPDR6[1:0]	0	PUPDR5[1:0]	0	PUPDR4[1:0]	0	PUPDR3[1:0]	0	PUPDR2[1:0]	0	PUPDR1[1:0]	0	PUPDR0[1:0]					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
0x0C	<b>GPIOx_PUPDR</b> (where x = C..E and H)	0 PUPDR15[1:0]	PUPDR15[1:0]	0	0	PUPDR14[1:0]	0	PUPDR13[1:0]	0	0	PUPDR12[1:0]	0	PUPDR11[1:0]	0	PUPDR10[1:0]	0	PUPDR9[1:0]	0	PUPDR8[1:0]	0	PUPDR7[1:0]	0	PUPDR6[1:0]	0	PUPDR5[1:0]	0	PUPDR4[1:0]	0	PUPDR3[1:0]	0	PUPDR2[1:0]	0	PUPDR1[1:0]	0	PUPDR0[1:0]					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
0x10	<b>GPIOx_IDR</b> (where x = A..E and H)	Reserved																																						
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
0x14	<b>GPIOx_ODR</b> (where x = A..E and H)	Reserved																																						
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
0x18	<b>GPIOx_BSRR</b> (where x = A..E and H)	BR15	BR0	BS15	0	ODR15	x	IDR15	0	PUPDR15[1:0]	0	PUPDR14[1:0]	0	PUPDR13[1:0]	0	PUPDR12[1:0]	0	PUPDR11[1:0]	0	PUPDR10[1:0]	0	PUPDR9[1:0]	0	PUPDR8[1:0]	0	PUPDR7[1:0]	0	PUPDR6[1:0]	0	PUPDR5[1:0]	0	PUPDR4[1:0]	0	PUPDR3[1:0]	0	PUPDR2[1:0]	0	PUPDR1[1:0]	0	PUPDR0[1:0]
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0x1C	<b>GPIOx_LCKR</b> (where x = A..E and H)	Reserved																																						
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0x20	<b>GPIOx_AFRL</b> (where x = A..E and H)	AFRL7[3:0]				AFRL6[3:0]				AFRL5[3:0]				AFRL4[3:0]				AFRL3[3:0]				AFRL2[3:0]				AFRL1[3:0]				AFRL0[3:0]										
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0x24	<b>GPIOx_AFRH</b> (where x = A..E and H)	AFRH15[3:0]				AFRH14[3:0]				AFRH13[3:0]				AFRH12[3:0]				AFRH11[3:0]				AFRH10[3:0]				AFRH9[3:0]				AFRH8[3:0]										
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 9 DMA controller (DMA)

### 9.1 DMA introduction

Direct memory access (DMA) is used in order to provide high-speed data transfer between peripherals and memory and between memory and memory. Data can be quickly moved by DMA without any CPU action. This keeps CPU resources free for other operations.

The DMA controller combines a powerful dual AHB master bus architecture with independent FIFO to optimize the bandwidth of the system, based on a complex bus matrix architecture.

The two DMA controllers have 16 streams in total (8 for each controller), each dedicated to managing memory access requests from one or more peripherals. Each stream can have up to 8 channels (requests) in total. And each has an arbiter for handling the priority between DMA requests.

### 9.2 DMA main features

The main DMA features are:

- Dual AHB master bus architecture, one dedicated to memory accesses and one dedicated to peripheral accesses
- AHB slave programming interface supporting only 32-bit accesses
- 8 streams for each DMA controller, up to 8 channels (requests) per stream
- Four-word depth 32 first-in, first-out memory buffers (FIFOs) per stream, that can be used in FIFO mode or direct mode:
  - FIFO mode: with threshold level software selectable between 1/4, 1/2 or 3/4 of the FIFO size
  - Direct mode

Each DMA request immediately initiates a transfer from/to the memory. When it is configured in direct mode (FIFO disabled), to transfer data in memory-to-peripheral mode, the DMA preloads only one data from the memory to the internal

FIFO to ensure an immediate data transfer as soon as a DMA request is triggered by a peripheral.

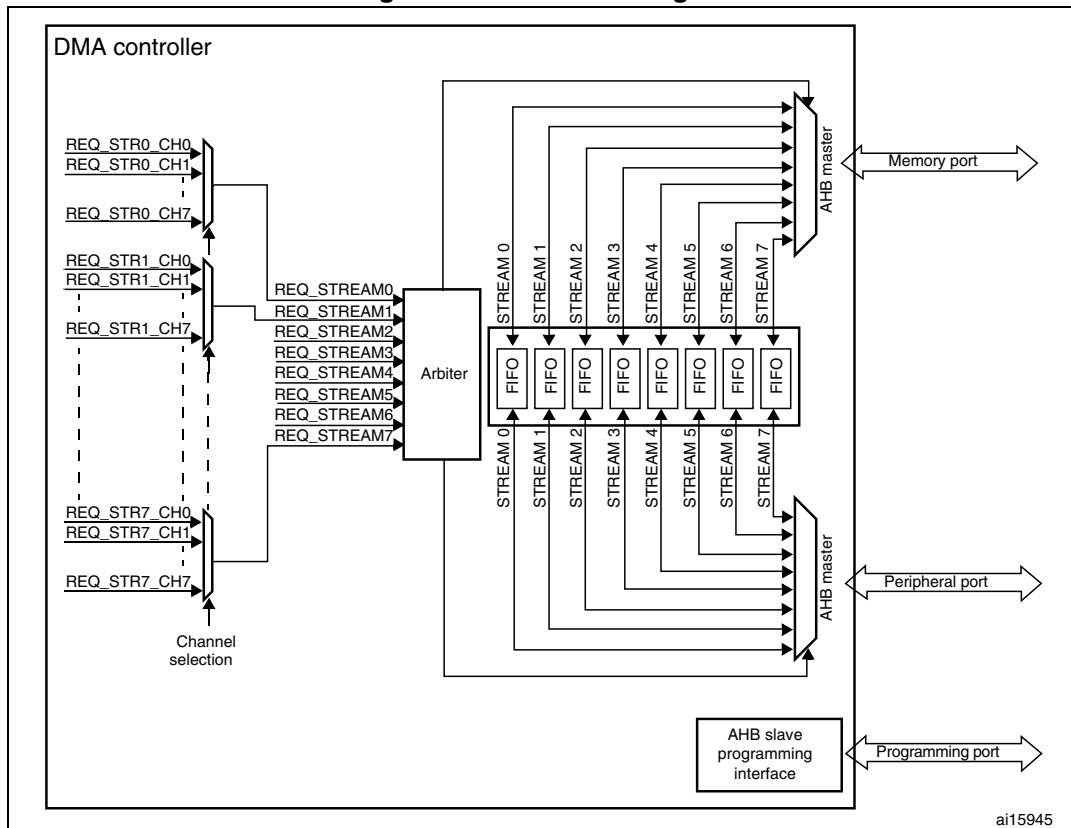
- Each stream can be configured by hardware to be:
  - a regular channel that supports peripheral-to-memory, memory-to-peripheral and memory-to-memory transfers
  - a double buffer channel that also supports double buffering on the memory side
- Each of the 8 streams are connected to dedicated hardware DMA channels (requests)
- Priorities between DMA stream requests are software-programmable (4 levels consisting of very high, high, medium, low) or hardware in case of equality (request 0 has priority over request 1, etc.)
- Each stream also supports software trigger for memory-to-memory transfers (only available for the DMA2 controller)
- Each stream request can be selected among up to 8 possible channel requests. This selection is software-configurable and allows several peripherals to initiate DMA requests
- The number of data items to be transferred can be managed either by the DMA controller or by the peripheral:
  - DMA flow controller: the number of data items to be transferred is software-programmable from 1 to 65535
  - Peripheral flow controller: the number of data items to be transferred is unknown and controlled by the source or the destination peripheral that signals the end of the transfer by hardware
- Independent source and destination transfer width (byte, half-word, word): when the data widths of the source and destination are not equal, the DMA automatically packs/unpacks the necessary transfers to optimize the bandwidth. This feature is only available in FIFO mode
- Incrementing or nonincrementing addressing for source and destination
- Supports incremental burst transfers of 4, 8 or 16 beats. The size of the burst is software-configurable, usually equal to half the FIFO size of the peripheral
- Each stream supports circular buffer management
- 5 event flags (DMA Half Transfer, DMA Transfer complete, DMA Transfer Error, DMA FIFO Error, Direct Mode Error) logically ORed together in a single interrupt request for each stream

## 9.3 DMA functional description

### 9.3.1 General description

*Figure 22* shows the block diagram of a DMA.

**Figure 22. DMA block diagram**



The DMA controller performs direct memory transfer: as an AHB master, it can take the control of the AHB bus matrix to initiate AHB transactions.

It can carry out the following transactions:

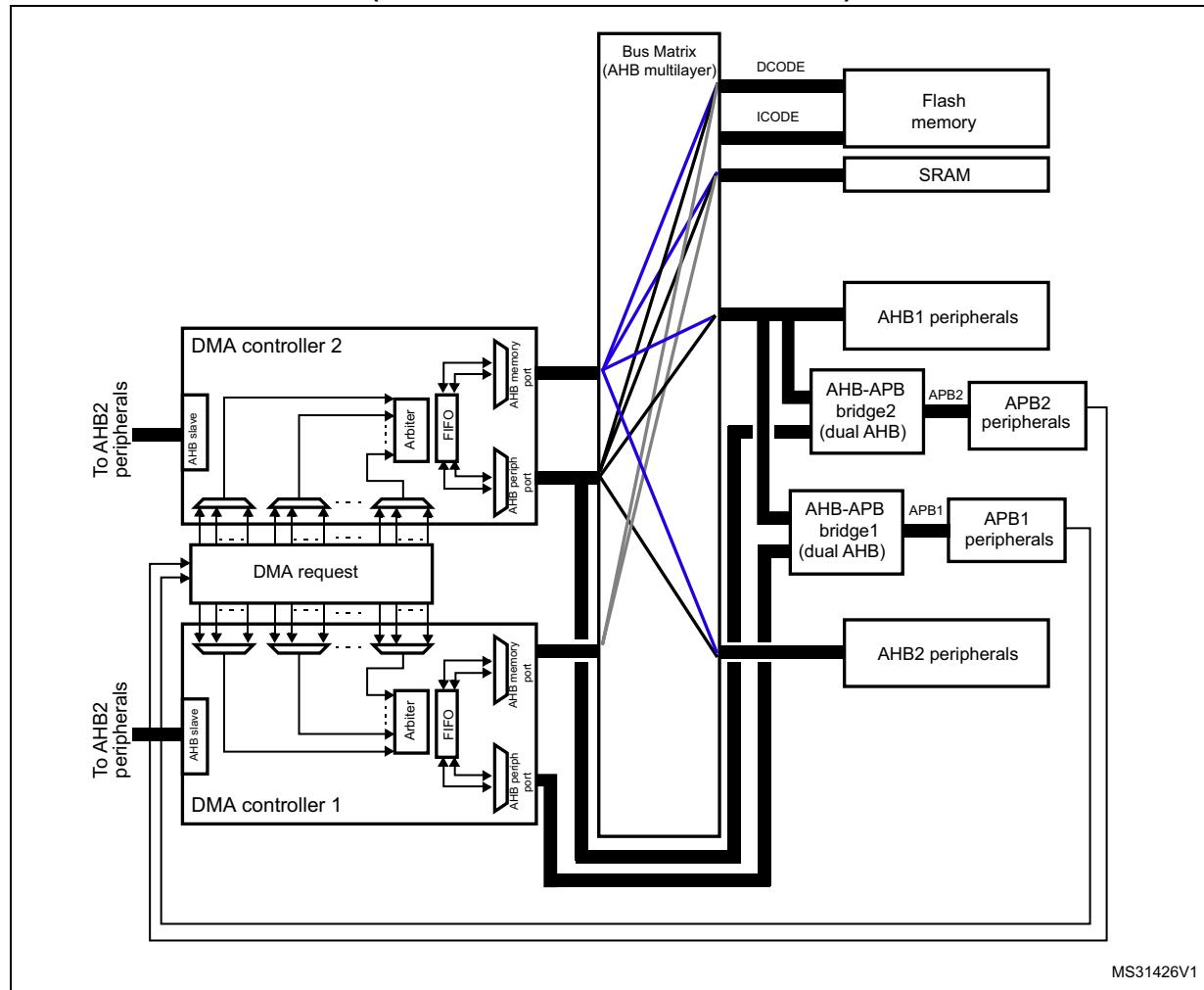
- peripheral-to-memory
- memory-to-peripheral
- memory-to-memory

The DMA controller provides two AHB master ports: the *AHB memory port*, intended to be connected to memories and the *AHB peripheral port*, intended to be connected to peripherals. However, to allow memory-to-memory transfers, the *AHB peripheral port* must also have access to the memories.

The AHB slave port is used to program the DMA controller (it supports only 32-bit accesses).

See *Figure 23* for the implementation of the system of two DMA controllers.

**Figure 23. System implementation of the two DMA controllers  
(STM32F401xB/C and STM32F401xD/E)**



MS31426V1

1. The DMA1 controller AHB peripheral port is not connected to the bus matrix like in the case of the DMA2 controller, thus only DMA2 streams are able to perform memory-to-memory transfers.

### 9.3.2 DMA transactions

A DMA transaction consists of a sequence of a given number of data transfers. The number of data items to be transferred and their width (8-bit, 16-bit or 32-bit) are software-programmable.

Each DMA transfer consists of three operations:

- A loading from the peripheral data register or a location in memory, addressed through the DMA\_SxPAR or DMA\_SxM0AR register
- A storage of the data loaded to the peripheral data register or a location in memory addressed through the DMA\_SxPAR or DMA\_SxM0AR register
- A post-decrement of the DMA\_SxNDTR register, which contains the number of transactions that still have to be performed

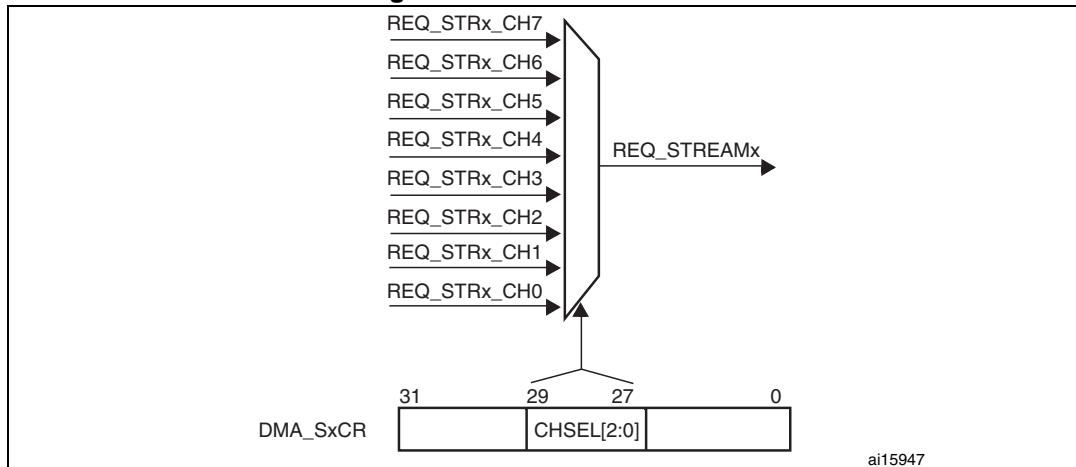
After an event, the peripheral sends a request signal to the DMA controller. The DMA controller serves the request depending on the channel priorities. As soon as the DMA

controller accesses the peripheral, an Acknowledge signal is sent to the peripheral by the DMA controller. The peripheral releases its request as soon as it gets the Acknowledge signal from the DMA controller. Once the request has been deasserted by the peripheral, the DMA controller releases the Acknowledge signal. If there are more requests, the peripheral can initiate the next transaction.

### 9.3.3 Channel selection

Each stream is associated with a DMA request that can be selected out of 8 possible channel requests. The selection is controlled by the CHSEL[2:0] bits in the DMA\_SxCR register.

**Figure 24. Channel selection**



The 8 requests from the peripherals (TIM, ADC, SPI, I2C, etc.) are independently connected to each channel and their connection depends on the product implementation.

[Table 28](#) and [Table 29](#) give examples of DMA request mappings.

**Table 28. DMA1 request mapping (STM32F401xB/C and STM32F401xD/E)**

Peripheral requests	Stream 0	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7
Channel 0	SPI3_RX		SPI3_RX	SPI2_RX	SPI2_TX	SPI3_TX		SPI3_TX
Channel 1	I2C1_RX	I2C3_RX				I2C1_RX	I2C1_TX	I2C1_TX
Channel 2	TIM4_CH1		I2S3_EXT_RX	TIM4_CH2	I2S2_EXT_RX	I2S3_EXT_RX	TIM4_UP	TIM4_CH3
Channel 3	I2S3_EXT_RX	TIM2_UP TIM2_CH3	I2C3_RX	I2S2_EXT_RX	I2C3_TX	TIM2_CH1	TIM2_CH2 TIM2_CH4	TIM2_UP TIM2_CH4
Channel 4						USART2_RX	USART2_TX	
Channel 5			TIM3_CH4 TIM3_UP		TIM3_CH1 TIM3_TRIG	TIM3_CH2		TIM3_CH3
Channel 6	TIM5_CH3 TIM5_UP	TIM5_CH4 TIM5_TRIG	TIM5_CH1	TIM5_CH4 TIM5_TRIG	TIM5_CH2	I2C3_TX	TIM5_UP	
Channel 7			I2C2_RX	I2C2_RX				I2C2_TX

**Table 29. DMA2 request mapping (STM32F401xB/C and STM32F401xD/E)**

<b>Peripheral requests</b>	<b>Stream 0</b>	<b>Stream 1</b>	<b>Stream 2</b>	<b>Stream 3</b>	<b>Stream 4</b>	<b>Stream 5</b>	<b>Stream 6</b>	<b>Stream 7</b>
Channel 0	ADC1				ADC1		TIM1_CH1 TIM1_CH2 TIM1_CH3	
Channel 1								
Channel 2								
Channel 3	SPI1_RX		SPI1_RX	SPI1_TX		SPI1_TX		
Channel 4	SPI4_RX	SPI4_TX	USART1_RX	SDIO		USART1_RX	SDIO	USART1_TX
Channel 5		USART6_RX	USART6_RX	SPI4_RX	SPI4_TX		USART6_TX	USART6_TX
Channel 6	TIM1_TRIG	TIM1_CH1	TIM1_CH2	TIM1_CH1	TIM1_CH4 TIM1_TRIG TIM1_COM	TIM1_UP	TIM1_CH3	
Channel 7								

### 9.3.4 Arbiter

An arbiter manages the 8 DMA stream requests based on their priority for each of the two AHB master ports (memory and peripheral ports) and launches the peripheral/memory access sequences.

Priorities are managed in two stages:

- Software: each stream priority can be configured in the DMA\_SxCR register. There are four levels:
  - Very high priority
  - High priority
  - Medium priority
  - Low priority
- Hardware: If two requests have the same software priority level, the stream with the lower number takes priority over the stream with the higher number. For example, Stream 2 takes priority over Stream 4.

### 9.3.5 DMA streams

Each of the 8 DMA controller streams provides a unidirectional transfer link between a source and a destination.

Each stream can be configured to perform:

- Regular type transactions: memory-to-peripherals, peripherals-to-memory or memory-to-memory transfers
- Double-buffer type transactions: double buffer transfers using two memory pointers for the memory (while the DMA is reading/writing from/to a buffer, the application can write/read to/from the other buffer).

The amount of data to be transferred (up to 65535) is programmable and related to the source width of the peripheral that requests the DMA transfer connected to the peripheral AHB port. The register that contains the amount of data items to be transferred is decremented after each transaction.

### 9.3.6 Source, destination and transfer modes

Both source and destination transfers can address peripherals and memories in the entire 4 GB area, at addresses comprised between 0x0000 0000 and 0xFFFF FFFF.

The direction is configured using the DIR[1:0] bits in the DMA\_SxCR register and offers three possibilities: memory-to-peripheral, peripheral-to-memory or memory-to-memory transfers. *Table 30* describes the corresponding source and destination addresses.

**Table 30. Source and destination address**

Bits DIR[1:0] of the DMA_SxCR register	Direction	Source address	Destination address
00	Peripheral-to-memory	DMA_SxPAR	DMA_SxM0AR
01	Memory-to-peripheral	DMA_SxM0AR	DMA_SxPAR
10	Memory-to-memory	DMA_SxPAR	DMA_SxM0AR
11	reserved	-	-

When the data width (programmed in the PSIZE or MSIZE bits in the DMA\_SxCR register) is a half-word or a word, respectively, the peripheral or memory address written into the DMA\_SxPAR or DMA\_SxM0AR/M1AR registers has to be aligned on a word or half-word address boundary, respectively.

#### Peripheral-to-memory mode

*Figure 25* describes this mode.

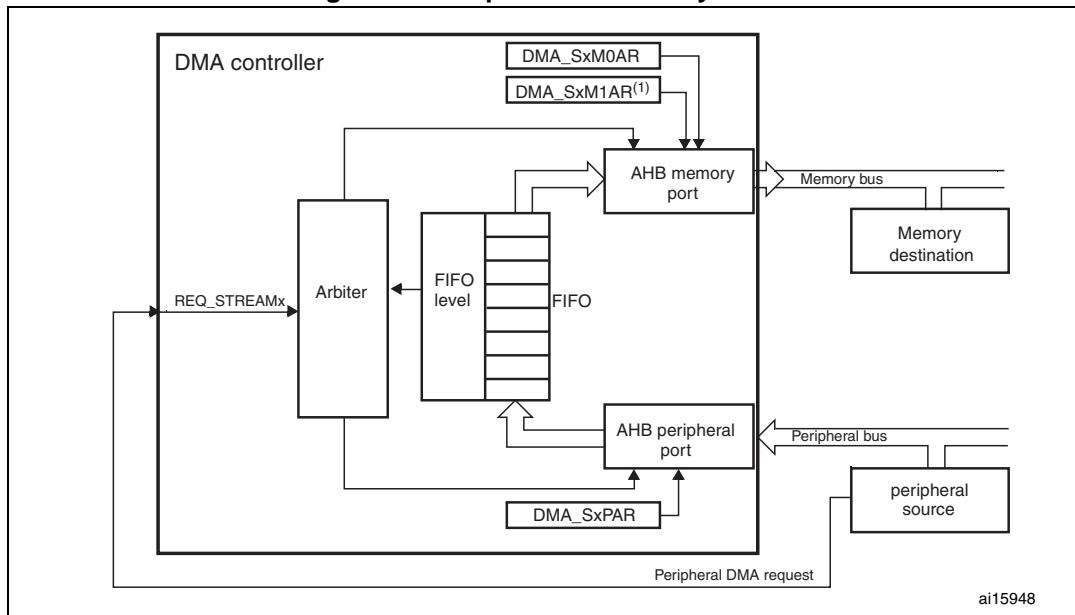
When this mode is enabled (by setting the bit EN in the DMA\_SxCR register), each time a peripheral request occurs, the stream initiates a transfer from the source to fill the FIFO.

When the threshold level of the FIFO is reached, the contents of the FIFO are drained and stored into the destination.

The transfer stops once the DMA\_SxNDTR register reaches zero, when the peripheral requests the end of transfers (in case of a peripheral flow controller) or when the EN bit in the DMA\_SxCR register is cleared by software.

In direct mode (when the DMDIS value in the DMA\_SxFcR register is '0'), the threshold level of the FIFO is not used: after each single data transfer from the peripheral to the FIFO, the corresponding data are immediately drained and stored into the destination.

The stream has access to the AHB source or destination port only if the arbitration of the corresponding stream is won. This arbitration is performed using the priority defined for each stream using the PL[1:0] bits in the DMA\_SxCR register.

**Figure 25. Peripheral-to-memory mode**

1. For double-buffer mode.

### Memory-to-peripheral mode

*Figure 26 describes this mode.*

When this mode is enabled (by setting the EN bit in the DMA\_SxCR register), the stream immediately initiates transfers from the source to entirely fill the FIFO.

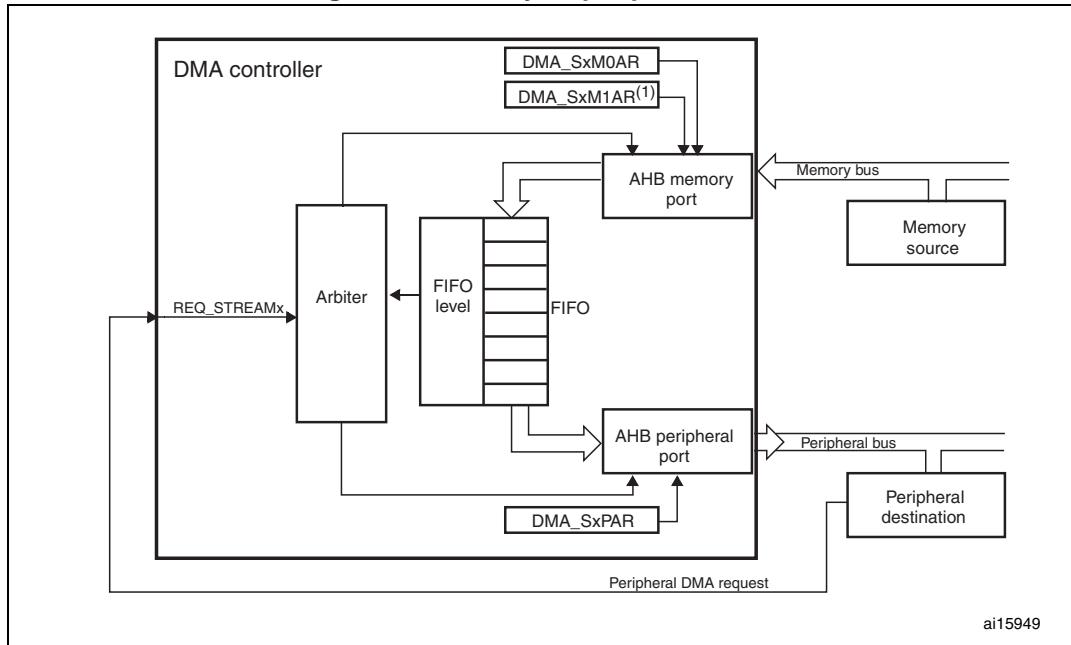
Each time a peripheral request occurs, the contents of the FIFO are drained and stored into the destination. When the level of the FIFO is lower than or equal to the predefined threshold level, the FIFO is fully reloaded with data from the memory.

The transfer stops once the DMA\_SxNDTR register reaches zero, when the peripheral requests the end of transfers (in case of a peripheral flow controller) or when the EN bit in the DMA\_SxCR register is cleared by software.

In direct mode (when the DMDIS value in the DMA\_SxFcR register is '0'), the threshold level of the FIFO is not used. Once the stream is enabled, the DMA preloads the first data to transfer into an internal FIFO. As soon as the peripheral requests a data transfer, the DMA transfers the preloaded value into the configured destination. It then reloads again the empty internal FIFO with the next data to be transfer. The preloaded data size corresponds to the value of the PSIZE bitfield in the DMA\_SxCR register.

The stream has access to the AHB source or destination port only if the arbitration of the corresponding stream is won. This arbitration is performed using the priority defined for each stream using the PL[1:0] bits in the DMA\_SxCR register.

Figure 26. Memory-to-peripheral mode



1. For double-buffer mode.

### Memory-to-memory mode

The DMA channels can also work without being triggered by a request from a peripheral. This is the memory-to-memory mode, described in [Figure 27](#).

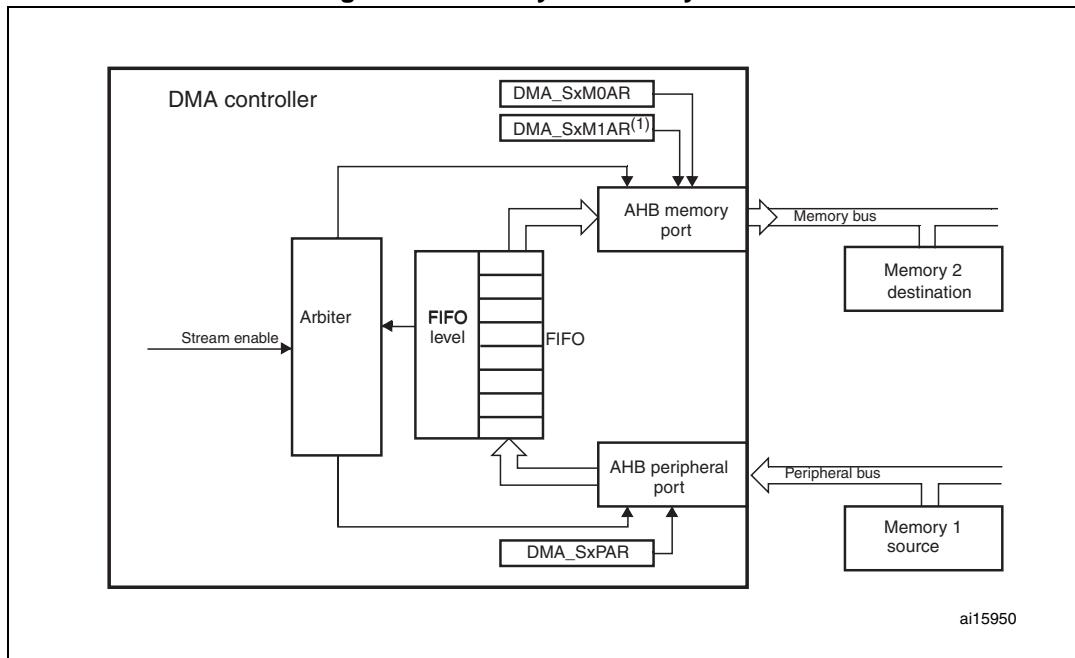
When the stream is enabled by setting the Enable bit (EN) in the DMA\_SxCR register, the stream immediately starts to fill the FIFO up to the threshold level. When the threshold level is reached, the FIFO contents are drained and stored into the destination.

The transfer stops once the DMA\_SxNDTR register reaches zero or when the EN bit in the DMA\_SxCR register is cleared by software.

The stream has access to the AHB source or destination port only if the arbitration of the corresponding stream is won. This arbitration is performed using the priority defined for each stream using the PL[1:0] bits in the DMA\_SxCR register.

**Note:** *When memory-to-memory mode is used, the Circular and direct modes are not allowed. Only the DMA2 controller is able to perform memory-to-memory transfers.*

Figure 27. Memory-to-memory mode



1. For double-buffer mode.

### 9.3.7 Pointer incrementation

Peripheral and memory pointers can optionally be automatically post-incremented or kept constant after each transfer depending on the PINC and MINC bits in the DMA\_SxCR register.

Disabling the Increment mode is useful when the peripheral source or destination data are accessed through a single register.

If the Increment mode is enabled, the address of the next transfer will be the address of the previous one incremented by 1 (for bytes), 2 (for half-words) or 4 (for words) depending on the data width programmed in the PSIZE or MSIZE bits in the DMA\_SxCR register.

In order to optimize the packing operation, it is possible to fix the increment offset size for the peripheral address whatever the size of the data transferred on the AHB peripheral port. The PINCOS bit in the DMA\_SxCR register is used to align the increment offset size with the data size on the peripheral AHB port, or on a 32-bit address (the address is then incremented by 4). The PINCOS bit has an impact on the AHB peripheral port only.

If PINCOS bit is set, the address of the next transfer is the address of the previous one incremented by 4 (automatically aligned on a 32-bit address) whatever the PSIZE value. The AHB memory port, however, is not impacted by this operation.

### 9.3.8 Circular mode

The Circular mode is available to handle circular buffers and continuous data flows (e.g. ADC scan mode). This feature can be enabled using the CIRC bit in the DMA\_SxCR register.

When the circular mode is activated, the number of data items to be transferred is automatically reloaded with the initial value programmed during the stream configuration phase, and the DMA requests continue to be served.

**Note:** *In the circular mode, it is mandatory to respect the following rule in case of a burst mode configured for memory:*

$$\text{DMA\_SxNDTR} = \text{Multiple of } ((\text{Mburst beat}) \times (\text{Msize})/(\text{Psize})), \text{ where:}$$

- $(\text{Mburst beat}) = 4, 8 \text{ or } 16$  (depending on the MBURST bits in the DMA\_SxCR register)
- $((\text{Msize})/(\text{Psize})) = 1, 2, 4, 1/2 \text{ or } 1/4$  (Msize and Psize represent the MSIZE and PSIZE bits in the DMA\_SxCR register. They are byte dependent)
- $\text{DMA\_SxNDTR} = \text{Number of data items to transfer on the AHB peripheral port}$

For example: Mburst beat = 8 (INCR8), MSIZE = '00' (byte) and PSIZE = '01' (half-word), in this case: DMA\_SxNDTR must be a multiple of  $(8 \times 1/2 = 4)$ .

If this formula is not respected, the DMA behavior and data integrity are not guaranteed.

NDTR must also be a multiple of the Peripheral burst size multiplied by the peripheral data size, otherwise this could result in a bad DMA behavior.

### 9.3.9 Double buffer mode

This mode is available for all the DMA1 and DMA2 streams.

The Double buffer mode is enabled by setting the DBM bit in the DMA\_SxCR register.

A double-buffer stream works as a regular (single buffer) stream with the difference that it has two memory pointers. When the Double buffer mode is enabled, the Circular mode is automatically enabled (CIRC bit in DMA\_SxCR is don't care) and at each end of transaction, the memory pointers are swapped.

In this mode, the DMA controller swaps from one memory target to another at each end of transaction. This allows the software to process one memory area while the second memory area is being filled/used by the DMA transfer. The double-buffer stream can work in both directions (the memory can be either the source or the destination) as described in

*Table 31: Source and destination address registers in Double buffer mode (DBM=1).*

**Note:** *In Double buffer mode, it is possible to update the base address for the AHB memory port on-the-fly (DMA\_SxM0AR or DMA\_SxM1AR) when the stream is enabled, by respecting the following conditions:*

- When the CT bit is '0' in the DMA\_SxCR register, the DMA\_SxM1AR register can be written. Attempting to write to this register while CT = '1' sets an error flag (TEIF) and the stream is automatically disabled.
- When the CT bit is '1' in the DMA\_SxCR register, the DMA\_SxM0AR register can be written. Attempting to write to this register while CT = '0', sets an error flag (TEIF) and the stream is automatically disabled.

To avoid any error condition, it is advised to change the base address as soon as the TCIF flag is asserted because, at this point, the targeted memory must have changed from memory 0 to 1 (or from 1 to 0) depending on the value of CT in the DMA\_SxCR register in accordance with one of the two above conditions.

For all the other modes (except the Double buffer mode), the memory address registers are write-protected as soon as the stream is enabled.

**Table 31. Source and destination address registers in Double buffer mode (DBM=1)**

Bits DIR[1:0] of the DMA_SxCR register	Direction	Source address	Destination address
00	Peripheral-to-memory	DMA_SxPAR	DMA_SxM0AR / DMA_SxM1AR
01	Memory-to-peripheral	DMA_SxM0AR / DMA_SxM1AR	DMA_SxPAR
10	Not allowed <sup>(1)</sup>		
11	Reserved	-	-

- When the Double buffer mode is enabled, the Circular mode is automatically enabled. Since the memory-to-memory mode is not compatible with the Circular mode, when the Double buffer mode is enabled, it is not allowed to configure the memory-to-memory mode.

### 9.3.10 Programmable data width, packing/unpacking, endianess

The number of data items to be transferred has to be programmed into DMA\_SxNDTR (number of data items to transfer bit, NDT) before enabling the stream (except when the flow controller is the peripheral, PFCTRL bit in DMA\_SxCR is set).

When using the internal FIFO, the data widths of the source and destination data are programmable through the PSIZE and MSIZE bits in the DMA\_SxCR register (can be 8-, 16- or 32-bit).

When PSIZE and MSIZE are not equal:

- The data width of the number of data items to transfer, configured in the DMA\_SxNDTR register is equal to the width of the peripheral bus (configured by the PSIZE bits in the DMA\_SxCR register). For instance, in case of peripheral-to-memory, memory-to-peripheral or memory-to-memory transfers and if the PSIZE[1:0] bits are configured for half-word, the number of bytes to be transferred is equal to  $2 \times \text{NDT}$ .
- The DMA controller only copes with little-endian addressing for both source and destination. This is described in [Table 32: Packing/unpacking & endian behavior \(bit PINC = MINC = 1\)](#).

This packing/unpacking procedure may present a risk of data corruption when the operation is interrupted before the data are completely packed/unpacked. So, to ensure data coherence, the stream may be configured to generate burst transfers: in this case, each group of transfers belonging to a burst are indivisible (refer to [Section 9.3.11: Single and burst transfers](#)).

In direct mode (DMDIS = 0 in the DMA\_SxFCR register), the packing/unpacking of data is not possible. In this case, it is not allowed to have different source and destination transfer data widths: both are equal and defined by the PSIZE bits in the DMA\_SxCR MSIZE bits are don't care).

Table 32. Packing/unpacking &amp; endian behavior (bit PINC = MINC = 1)

AHB memory port width	AHB peripheral port width	Number of data items to transfer (NDT)	Memory transfer number	Memory port address / byte lane	Peripheral transfer number	Peripheral port address / byte lane	
						PINCOS = 1	PINCOS = 0
8	8	4	1	0x0 / B0[7:0]	1	0x0 / B0[7:0]	0x0 / B0[7:0]
			2	0x1 / B1[7:0]	2	0x4 / B1[7:0]	0x1 / B1[7:0]
			3	0x2 / B2[7:0]	3	0x8 / B2[7:0]	0x2 / B2[7:0]
			4	0x3 / B3[7:0]	4	0xC / B3[7:0]	0x3 / B3[7:0]
8	16	2	1	0x0 / B0[7:0]	1	0x0 / B1 B0[15:0]	0x0 / B1 B0[15:0]
			2	0x1 / B1[7:0]	2	0x4 / B3 B2[15:0]	0x2 / B3 B2[15:0]
			3	0x2 / B2[7:0]			
			4	0x3 / B3[7:0]			
8	32	1	1	0x0 / B0[7:0]	1	0x0 / B3 B2 B1 B0[31:0]	0x0 / B3 B2 B1 B0[31:0]
			2	0x1 / B1[7:0]			
			3	0x2 / B2[7:0]			
			4	0x3 / B3[7:0]			
16	8	4	1	0x0 / B1 B0[15:0]	1	0x0 / B0[7:0]	0x0 / B0[7:0]
			2	0x2 / B3 B2[15:0]	2	0x4 / B1[7:0]	0x1 / B1[7:0]
			3		3	0x8 / B2[7:0]	0x2 / B2[7:0]
			4		4	0xC / B3[7:0]	0x3 / B3[7:0]
16	16	2	1	0x0 / B1 B0[15:0]	1	0x0 / B1 B0[15:0]	0x0 / B1 B0[15:0]
			2	0x2 / B1 B0[15:0]	2	0x4 / B3 B2[15:0]	0x2 / B3 B2[15:0]
16	32	1	1	0x0 / B1 B0[15:0]	1	0x0 / B3 B2 B1 B0[31:0]	0x0 / B3 B2 B1 B0[31:0]
			2	0x2 / B3 B2[15:0]			
32	8	4	1	0x0 / B3 B2 B1 B0[31:0]	1	0x0 / B0[7:0]	0x0 / B0[7:0]
			2		2	0x4 / B1[7:0]	0x1 / B1[7:0]
			3		3	0x8 / B2[7:0]	0x2 / B2[7:0]
			4		4	0xC / B3[7:0]	0x3 / B3[7:0]
32	16	2	1	0x0 / B3 B2 B1 B0[31:0]	1	0x0 / B1 B0[15:0]	0x0 / B1 B0[15:0]
32	32	1	1	0x0 / B3 B2 B1 B0[31:0]	1	0x4 / B3 B2[15:0]	0x2 / B3 B2[15:0]

Note: Peripheral port may be the source or the destination (it could also be the memory source in the case of memory-to-memory transfer).

PSIZE, MSIZE and NDT[15:0] have to be configured so as to ensure that the last transfer will not be incomplete. This can occur when the data width of the peripheral port (PSIZE bits) is lower than the data width of the memory port (MSIZE bits). This constraint is summarized in [Table 33](#).

Table 33. Restriction on NDT versus PSIZE and MSIZE

PSIZE[1:0] of DMA_SxCR	MSIZE[1:0] of DMA_SxCR	NDT[15:0] of DMA_SxNDTR
00 (8-bit)	01 (16-bit)	must be a multiple of 2
00 (8-bit)	10 (32-bit)	must be a multiple of 4
01 (16-bit)	10 (32-bit)	must be a multiple of 2

### 9.3.11 Single and burst transfers

The DMA controller can generate single transfers or incremental burst transfers of 4, 8 or 16 beats.

The size of the burst is configured by software independently for the two AHB ports by using the MBURST[1:0] and PBURST[1:0] bits in the DMA\_SxCR register.

The burst size indicates the number of beats in the burst, not the number of bytes transferred.

To ensure data coherence, each group of transfers that form a burst are indivisible: AHB transfers are locked and the arbiter of the AHB bus matrix does not degrant the DMA master during the sequence of the burst transfer.

Depending on the single or burst configuration, each DMA request initiates a different number of transfers on the AHB peripheral port:

- When the AHB peripheral port is configured for single transfers, each DMA request generates a data transfer of a byte, half-word or word depending on the PSIZE[1:0] bits in the DMA\_SxCR register
- When the AHB peripheral port is configured for burst transfers, each DMA request generates 4,8 or 16 beats of byte, half word or word transfers depending on the PBURST[1:0] and PSIZE[1:0] bits in the DMA\_SxCR register.

The same as above has to be considered for the AHB memory port considering the MBURST and MSIZE bits.

In direct mode, the stream can only generate single transfers and the MBURST[1:0] and PBURST[1:0] bits are forced by hardware.

The address pointers (DMA\_SxPAR or DMA\_SxM0AR registers) must be chosen so as to ensure that all transfers within a burst block are aligned on the address boundary equal to the size of the transfer.

The burst configuration has to be selected in order to respect the AHB protocol, where bursts must *not* cross the 1 KB address boundary because the minimum address space that can be allocated to a single slave is 1 KB. This means that the 1 KB address boundary should not be crossed by a burst block transfer, otherwise an AHB error would be generated, that is not reported by the DMA registers.

### 9.3.12 FIFO

#### FIFO structure

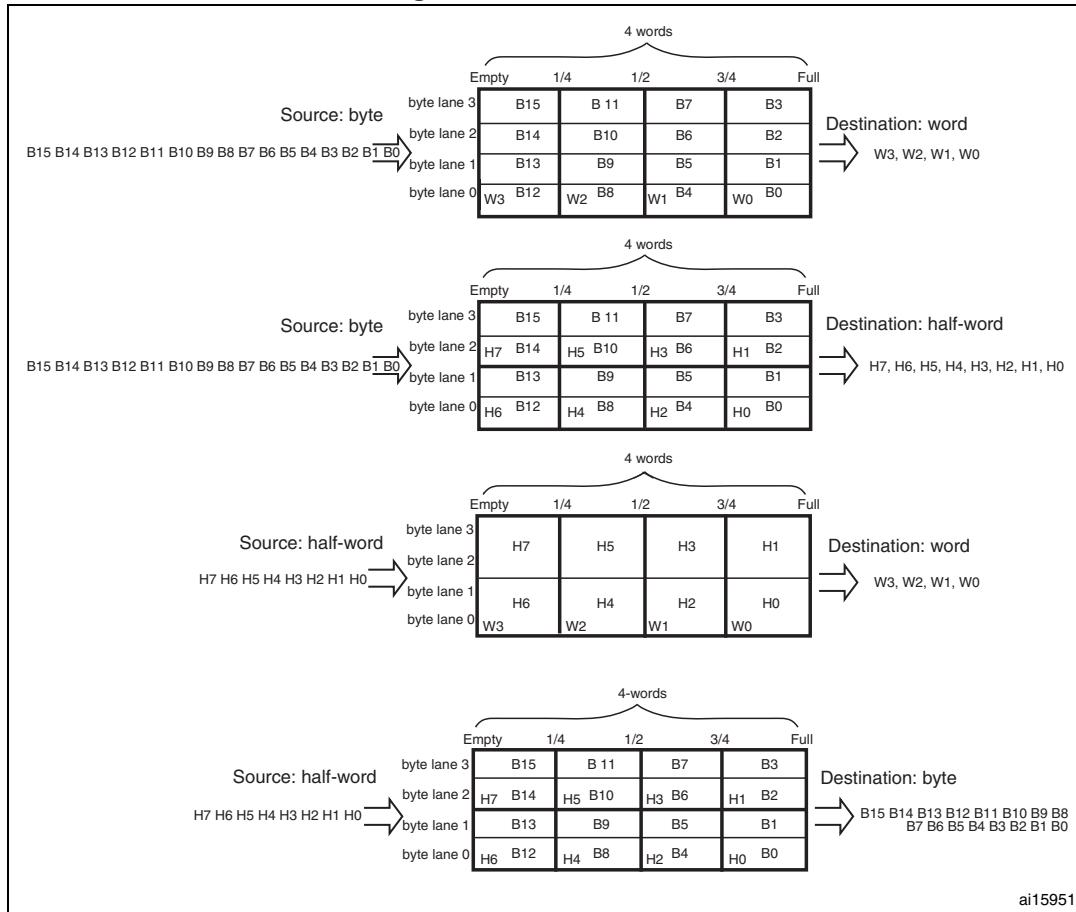
The FIFO is used to temporarily store data coming from the source before transmitting them to the destination.

Each stream has an independent 4-word FIFO and the threshold level is software-configurable between 1/4, 1/2, 3/4 or full.

To enable the use of the FIFO threshold level, the direct mode must be disabled by setting the DMDIS bit in the DMA\_SxFCR register.

The structure of the FIFO differs depending on the source and destination data widths, and is described in [Figure 28: FIFO structure](#).

Figure 28. FIFO structure



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### FIFO threshold and burst configuration

Caution is required when choosing the FIFO threshold (bits FTH[1:0] of the DMA\_SxFCR register) and the size of the memory burst (MBURST[1:0] of the DMA\_SxCR register): The content pointed by the FIFO threshold must exactly match to an integer number of memory burst transfers. If this is not in the case, a FIFO error (flag FEIFx of the DMA\_HISR or DMA\_LISR register) will be generated when the stream is enabled, then the stream will be automatically disabled. The allowed and forbidden configurations are described in the [Table 34: FIFO threshold configurations](#).

Table 34. FIFO threshold configurations

MSIZE	FIFO level	MBURST = INCR4	MBURST = INCR8	MBURST = INCR16
Byte	1/4	1 burst of 4 beats	forbidden	forbidden
	1/2	2 bursts of 4 beats	1 burst of 8 beats	
	3/4	3 bursts of 4 beats	forbidden	
	Full	4 bursts of 4 beats	2 bursts of 8 beats	1 burst of 16 beats

Table 34. FIFO threshold configurations (continued)

MSIZE	FIFO level	MBURST = INCR4	MBURST = INCR8	MBURST = INCR16
Half-word	1/4	forbidden	forbidden	forbidden
	1/2	1 burst of 4 beats		
	3/4	forbidden		
	Full	2 bursts of 4 beats	1 burst of 8 beats	
Word	1/4	forbidden	forbidden	forbidden
	1/2			
	3/4			
	Full	1 burst of 4 beats		

In all cases, the burst size multiplied by the data size must not exceed the FIFO size (data size can be: 1 (byte), 2 (half-word) or 4 (word)).

Incomplete Burst transfer at the end of a DMA transfer may happen if one of the following conditions occurs:

- For the AHB peripheral port configuration: the total number of data items (set in the DMA\_SxNDTR register) is not a multiple of the burst size multiplied by the data size
- For the AHB memory port configuration: the number of remaining data items in the FIFO to be transferred to the memory is not a multiple of the burst size multiplied by the data size

In such cases, the remaining data to be transferred will be managed in single mode by the DMA, even if a burst transaction was requested during the DMA stream configuration.

#### Note:

*When burst transfers are requested on the peripheral AHB port and the FIFO is used (DMDIS = 1 in the DMA\_SxCR register), it is mandatory to respect the following rule to avoid permanent underrun or overrun conditions, depending on the DMA stream direction:*

*If  $(PBURST \times PSIZE) = FIFO\_SIZE$  (4 words), FIFO\_Threshold = 3/4 is forbidden with PSIZE = 1, 2 or 4 and PBURST = 4, 8 or 16.*

*This rule ensures that enough FIFO space at a time will be free to serve the request from the peripheral.*

### FIFO flush

The FIFO can be flushed when the stream is disabled by resetting the EN bit in the DMA\_SxCR register and when the stream is configured to manage peripheral-to-memory or memory-to-memory transfers: If some data are still present in the FIFO when the stream is disabled, the DMA controller continues transferring the remaining data to the destination (even though stream is effectively disabled). When this flush is completed, the transfer complete status bit (TCIFx) in the DMA\_LISR or DMA\_HISR register is set.

The remaining data counter DMA\_SxNDTR keeps the value in this case to indicate how many data items are currently available in the destination memory.

Note that during the FIFO flush operation, if the number of remaining data items in the FIFO to be transferred to memory (in bytes) is less than the memory data width (for example 2 bytes in FIFO while MSIZE is configured to word), data will be sent with the data width set in the MSIZE bit in the DMA\_SxCR register. This means that memory will be written with an

undesired value. The software may read the DMA\_SxNDTR register to determine the memory area that contains the good data (start address and last address).

If the number of remaining data items in the FIFO is lower than a burst size (if the MBURST bits in DMA\_SxCR register are set to configure the stream to manage burst on the AHB memory port), single transactions will be generated to complete the FIFO flush.

### Direct mode

By default, the FIFO operates in direct mode (DMDIS bit in the DMA\_SxFIFO register is reset) and the FIFO threshold level is not used. This mode is useful when the system requires an immediate and single transfer to or from the memory after each DMA request.

When the DMA is configured in direct mode (FIFO disabled), to transfer data in memory-to-peripheral mode, the DMA preloads one data from the memory to the internal FIFO to ensure an immediate data transfer as soon as a DMA request is triggered by a peripheral.

To avoid saturating the FIFO, it is recommended to configure the corresponding stream with a high priority.

This mode is restricted to transfers where:

- The source and destination transfer widths are equal and both defined by the PSIZE[1:0] bits in DMA\_SxCR (MSIZE[1:0] bits are don't care)
- Burst transfers are not possible (PBURST[1:0] and MBURST[1:0] bits in DMA\_SxCR are don't care)

Direct mode must not be used when implementing memory-to-memory transfers.

### 9.3.13 DMA transfer completion

Different events can generate an end of transfer by setting the TCIFx bit in the DMA\_LISR or DMA\_HISR status register:

- In DMA flow controller mode:
  - The DMA\_SxNDTR counter has reached zero in the memory-to-peripheral mode
  - The stream is disabled before the end of transfer (by clearing the EN bit in the DMA\_SxCR register) and (when transfers are peripheral-to-memory or memory-to-memory) all the remaining data have been flushed from the FIFO into the memory
- In Peripheral flow controller mode:
  - The last external burst or single request has been generated from the peripheral and (when the DMA is operating in peripheral-to-memory mode) the remaining data have been transferred from the FIFO into the memory
  - The stream is disabled by software, and (when the DMA is operating in peripheral-to-memory mode) the remaining data have been transferred from the FIFO into the memory

*Note:* The transfer completion is dependent on the remaining data in FIFO to be transferred into memory only in the case of peripheral-to-memory mode. This condition is not applicable in memory-to-peripheral mode.

If the stream is configured in noncircular mode, after the end of the transfer (that is when the number of data to be transferred reaches zero), the DMA is stopped (EN bit in DMA\_SxCR register is cleared by Hardware) and no DMA request is served unless the software reprograms the stream and re-enables it (by setting the EN bit in the DMA\_SxCR register).

### 9.3.14 DMA transfer suspension

At any time, a DMA transfer can be suspended to be restarted later on or to be definitively disabled before the end of the DMA transfer.

There are two cases:

- The stream disables the transfer with no later-on restart from the point where it was stopped. There is no particular action to do, except to clear the EN bit in the DMA\_SxCR register to disable the stream. The stream may take time to be disabled (ongoing transfer is completed first). The transfer complete interrupt flag (TCIF in the DMA\_LISR or DMA\_HISR register) is set in order to indicate the end of transfer. The value of the EN bit in DMA\_SxCR is now '0' to confirm the stream interruption. The DMA\_SxNDTR register contains the number of remaining data items at the moment when the stream was stopped so that the software can determine how many data items have been transferred before the stream was interrupted.
- The stream suspends the transfer before the number of remaining data items to be transferred in the DMA\_SxNDTR register reaches 0. The aim is to restart the transfer later by re-enabling the stream. In order to restart from the point where the transfer was stopped, the software has to read the DMA\_SxNDTR register after disabling the stream by writing the EN bit in DMA\_SxCR register (and then checking that it is at '0') to know the number of data items already collected. Then:
  - The peripheral and/or memory addresses have to be updated in order to adjust the address pointers
  - The SxNDTR register has to be updated with the remaining number of data items to be transferred (the value read when the stream was disabled)
  - The stream may then be re-enabled to restart the transfer from the point it was stopped

**Note:** Note that a Transfer complete interrupt flag (TCIF in DMA\_LISR or DMA\_HISR) is set to indicate the end of transfer due to the stream interruption.

### 9.3.15 Flow controller

The entity that controls the number of data to be transferred is known as the flow controller. This flow controller is configured independently for each stream using the PFCTRL bit in the DMA\_SxCR register.

The flow controller can be:

- The DMA controller: in this case, the number of data items to be transferred is programmed by software into the DMA\_SxNDTR register before the DMA stream is enabled.
- The peripheral source or destination: this is the case when the number of data items to be transferred is unknown. The peripheral indicates by hardware to the DMA controller when the last data are being transferred. This feature is only supported for peripherals which are able to signal the end of the transfer, that is:
  - SDIO

When the peripheral flow controller is used for a given stream, the value written into the DMA\_SxNDTR has no effect on the DMA transfer. Actually, whatever the value written, it will

be forced by hardware to 0xFFFF as soon as the stream is enabled, to respect the following schemes:

- Anticipated stream interruption: EN bit in DMA\_SxCR register is reset to 0 by the software to stop the stream before the last data hardware signal (single or burst) is sent by the peripheral. In such a case, the stream is switched off and the FIFO flush is triggered in the case of a peripheral-to-memory DMA transfer. The TCIFx flag of the corresponding stream is set in the status register to indicate the DMA completion. To know the number of data items transferred during the DMA transfer, read the DMA\_SxNDTR register and apply the following formula:
  - Number\_of\_data\_transferred = 0xFFFF – DMA\_SxNDTR
- Normal stream interruption due to the reception of a last data hardware signal: the stream is automatically interrupted when the peripheral requests the last transfer (single or burst) and when this transfer is complete. the TCIFx flag of the corresponding stream is set in the status register to indicate the DMA transfer completion. To know the number of data items transferred, read the DMA\_SxNDTR register and apply the same formula as above.
- The DMA\_SxNDTR register reaches 0: the TCIFx flag of the corresponding stream is set in the status register to indicate the forced DMA transfer completion. The stream is automatically switched off even though the last data hardware signal (single or burst) has not been yet asserted. The already transferred data will not be lost. This means that a maximum of 65535 data items can be managed by the DMA in a single transaction, even in peripheral flow control mode.

**Note:** When configured in memory-to-memory mode, the DMA is always the flow controller and the PFCTRL bit is forced to 0 by hardware.

The Circular mode is forbidden in the peripheral flow controller mode.

### 9.3.16 Summary of the possible DMA configurations

*Table 35* summarizes the different possible DMA configurations.

**Table 35. Possible DMA configurations**

DMA transfer mode	Source	Destination	Flow controller	Circular mode	Transfer type	Direct mode	Double buffer mode
Peripheral-to-memory	AHB peripheral port	AHB memory port	DMA	possible	single	possible	possible
					burst	forbidden	
	Peripheral		Peripheral	forbidden	single	possible	forbidden
					burst	forbidden	
Memory-to-peripheral	AHB memory port	AHB peripheral port	DMA	possible	single	possible	possible
					burst	forbidden	
	Peripheral		Peripheral	forbidden	single	possible	forbidden
					burst	forbidden	
Memory-to-memory	AHB peripheral port	AHB memory port	DMA only	forbidden	single	forbidden	forbidden
					burst		

### 9.3.17 Stream configuration procedure

The following sequence should be followed to configure a DMA stream x (where x is the stream number):

1. If the stream is enabled, disable it by resetting the EN bit in the DMA\_SxCR register, then read this bit in order to confirm that there is no ongoing stream operation. Writing this bit to 0 is not immediately effective since it is actually written to 0 once all the current transfers have finished. When the EN bit is read as 0, this means that the stream is ready to be configured. It is therefore necessary to wait for the EN bit to be cleared before starting any stream configuration. All the stream dedicated bits set in the status register (DMA\_LISR and DMA\_HISR) from the previous data block DMA transfer should be cleared before the stream can be re-enabled.
2. Set the peripheral port register address in the DMA\_SxPAR register. The data will be moved from/ to this address to/ from the peripheral port after the peripheral event.
3. Set the memory address in the DMA\_SxMA0R register (and in the DMA\_SxMA1R register in the case of a double buffer mode). The data will be written to or read from this memory after the peripheral event.
4. Configure the total number of data items to be transferred in the DMA\_SxNDTR register. After each peripheral event or each beat of the burst, this value is decremented.
5. Select the DMA channel (request) using CHSEL[2:0] in the DMA\_SxCR register.
6. If the peripheral is intended to be the flow controller and if it supports this feature, set the PFCTRL bit in the DMA\_SxCR register.
7. Configure the stream priority using the PL[1:0] bits in the DMA\_SxCR register.
8. Configure the FIFO usage (enable or disable, threshold in transmission and reception)
9. Configure the data transfer direction, peripheral and memory incremented/fixed mode, single or burst transactions, peripheral and memory data widths, Circular mode, Double buffer mode and interrupts after half and/or full transfer, and/or errors in the DMA\_SxCR register.
10. Activate the stream by setting the EN bit in the DMA\_SxCR register.

As soon as the stream is enabled, it can serve any DMA request from the peripheral connected to the stream.

Once half the data have been transferred on the AHB destination port, the half-transfer flag (HTIF) is set and an interrupt is generated if the half-transfer interrupt enable bit (HTIE) is set. At the end of the transfer, the transfer complete flag (TCIF) is set and an interrupt is generated if the transfer complete interrupt enable bit (TCIE) is set.

---

**Warning:** To switch off a peripheral connected to a DMA stream request, it is mandatory to, first, switch off the DMA stream to which the peripheral is connected, then to wait for EN bit = 0. Only then can the peripheral be safely disabled.

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### 9.3.18 Error management

The DMA controller can detect the following errors:

- **Transfer error:** the transfer error interrupt flag (TEIFx) is set when:
  - A bus error occurs during a DMA read or a write access
  - A write access is requested by software on a memory address register in Double buffer mode whereas the stream is enabled and the current target memory is the one impacted by the write into the memory address register (refer to [Section 9.3.9: Double buffer mode](#))
- **FIFO error:** the FIFO error interrupt flag (FEIFx) is set if:
  - A FIFO underrun condition is detected
  - A FIFO overrun condition is detected (no detection in memory-to-memory mode because requests and transfers are internally managed by the DMA)
  - The stream is enabled while the FIFO threshold level is not compatible with the size of the memory burst (refer to [Table 34: FIFO threshold configurations](#))
- **Direct mode error:** the direct mode error interrupt flag (DMEIFx) can only be set in the peripheral-to-memory mode while operating in direct mode and when the MINC bit in the DMA\_SxCR register is cleared. This flag is set when a DMA request occurs while the previous data have not yet been fully transferred into the memory (because the memory bus was not granted). In this case, the flag indicates that 2 data items were be transferred successively to the same destination address, which could be an issue if the destination is not able to manage this situation

In direct mode, the FIFO error flag can also be set under the following conditions:

- In the peripheral-to-memory mode, the FIFO can be saturated (overrun) if the memory bus is not granted for several peripheral requests
- In the memory-to-peripheral mode, an underrun condition may occur if the memory bus has not been granted before a peripheral request occurs

If the TEIFx or the FEIFx flag is set due to incompatibility between burst size and FIFO threshold level, the faulty stream is automatically disabled through a hardware clear of its EN bit in the corresponding stream configuration register (DMA\_SxCR).

If the DMEIFx or the FEIFx flag is set due to an overrun or underrun condition, the faulty stream is not automatically disabled and it is up to the software to disable or not the stream by resetting the EN bit in the DMA\_SxCR register. This is because there is no data loss when this kind of errors occur.

When the stream's error interrupt flag (TEIF, FEIF, DMEIF) in the DMA\_LISR or DMA\_HISR register is set, an interrupt is generated if the corresponding interrupt enable bit (TEIE, FEIE, DMIE) in the DMA\_SxCR or DMA\_SxFCR register is set.

Note:

*When a FIFO overrun or underrun condition occurs, the data are not lost because the peripheral request is not acknowledged by the stream until the overrun or underrun condition is cleared. If this acknowledge takes too much time, the peripheral itself may detect an overrun or underrun condition of its internal buffer and data might be lost.*

## 9.4 DMA interrupts

For each DMA stream, an interrupt can be produced on the following events:

- Half-transfer reached
- Transfer complete
- Transfer error
- Fifo error (overrun, underrun or FIFO level error)
- Direct mode error

Separate interrupt enable control bits are available for flexibility as shown in [Table 36](#).

**Table 36. DMA interrupt requests**

Interrupt event	Event flag	Enable control bit
Half-transfer	HTIF	HTIE
Transfer complete	TCIF	TCIE
Transfer error	TEIF	TEIE
FIFO overrun/underrun	FEIF	FEIE
Direct mode error	DMEIF	DMEIE

**Note:** Before setting an Enable control bit to '1', the corresponding event flag should be cleared, otherwise an interrupt is immediately generated.

## 9.5 DMA registers

The DMA registers have to be accessed by words (32 bits).

### 9.5.1 DMA low interrupt status register (DMA\_LISR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				TCIF3	HTIF3	TEIF3	DMEIF3	Reserv ed	FEIF3	TCIF2	HTIF2	TEIF2	DMEIF2	Reserv ed	FEIF2
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				TCIF1	HTIF1	TEIF1	DMEIF1	Reserv ed	FEIF1	TCIF0	HTIF0	TEIF0	DMEIF0	Reserv ed	FEIF0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **TCIF<sub>x</sub>**: Stream x transfer complete interrupt flag (x = 3..0)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_LIFCR register.

0: No transfer complete event on stream x

1: A transfer complete event occurred on stream x

- Bits 26, 20, 10, 4 **HTIF<sub>x</sub>**: Stream x half transfer interrupt flag ( $x=3..0$ )  
 This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_LIFCR register.  
 0: No half transfer event on stream x  
 1: A half transfer event occurred on stream x
- Bits 25, 19, 9, 3 **TEIF<sub>x</sub>**: Stream x transfer error interrupt flag ( $x=3..0$ )  
 This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_LIFCR register.  
 0: No transfer error on stream x  
 1: A transfer error occurred on stream x
- Bits 24, 18, 8, 2 **DMEIF<sub>x</sub>**: Stream x direct mode error interrupt flag ( $x=3..0$ )  
 This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_LIFCR register.  
 0: No Direct Mode Error on stream x  
 1: A Direct Mode Error occurred on stream x
- Bits 23, 17, 7, 1 Reserved, must be kept at reset value.
- Bits 22, 16, 6, 0 **FEIF<sub>x</sub>**: Stream x FIFO error interrupt flag ( $x=3..0$ )  
 This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_LIFCR register.  
 0: No FIFO Error event on stream x  
 1: A FIFO Error event occurred on stream x

### 9.5.2 DMA high interrupt status register (DMA\_HISR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				TCIF7	HTIF7	TEIF7	DMEIF7	Reserved	FEIF7	TCIF6	HTIF6	TEIF6	DMEIF6	Reserved	FEIF6
15	14	13	12	11	10	9	8		r	r	r	r	r		r
Reserved				TCIF5	HTIF5	TEIF5	DMEIF5	Reserved	FEIF5	TCIF4	HTIF4	TEIF4	DMEIF4	Reserved	FEIF4
15	14	13	12	11	10	9	8		r	r	r	r	r		r

Bits 31:28, 15:12 Reserved, must be kept at reset value.

- Bits 27, 21, 11, 5 **TCIF<sub>x</sub>**: Stream x transfer complete interrupt flag ( $x=7..4$ )  
 This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_HIFCR register.  
 0: No transfer complete event on stream x  
 1: A transfer complete event occurred on stream x
- Bits 26, 20, 10, 4 **HTIF<sub>x</sub>**: Stream x half transfer interrupt flag ( $x=7..4$ )  
 This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_HIFCR register.  
 0: No half transfer event on stream x  
 1: A half transfer event occurred on stream x

Bits 25, 19, 9, 3 **TEIFx**: Stream x transfer error interrupt flag (x=7..4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_HIFCR register.

- 0: No transfer error on stream x
- 1: A transfer error occurred on stream x

Bits 24, 18, 8, 2 **DMEIFx**: Stream x direct mode error interrupt flag (x=7..4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_HIFCR register.

- 0: No Direct mode error on stream x
- 1: A Direct mode error occurred on stream x

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **FEIFx**: Stream x FIFO error interrupt flag (x=7..4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA\_HIFCR register.

- 0: No FIFO error event on stream x
- 1: A FIFO error event occurred on stream x

### 9.5.3 DMA low interrupt flag clear register (DMA\_LIFCR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
				Reserved	CTCIF3	CHTIF3	CTEIF3	CDMEIF3	Reserved	CFEIF3	CTCIF2	CHTIF2	CTEIF2	CDMEIF2	Reserved	CFEIF2
					w	w	w	w		w	w	w	w	w		w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
				Reserved	CTCIF1	CHTIF1	CTEIF1	CDMEIF1	Reserved	CFEIF1	CTCIF0	CHTIF0	CTEIF0	CDMEIF0	Reserved	CFEIF0
					w	w	w	w		w	w	w	w	w		w

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **CTCIFx**: Stream x clear transfer complete interrupt flag (x = 3..0)

Writing 1 to this bit clears the corresponding TCIFx flag in the DMA\_LISR register

Bits 26, 20, 10, 4 **CHTIFx**: Stream x clear half transfer interrupt flag (x = 3..0)

Writing 1 to this bit clears the corresponding HTIFx flag in the DMA\_LISR register

Bits 25, 19, 9, 3 **CTEIFx**: Stream x clear transfer error interrupt flag (x = 3..0)

Writing 1 to this bit clears the corresponding TEIFx flag in the DMA\_LISR register

Bits 24, 18, 8, 2 **CDMEIFx**: Stream x clear direct mode error interrupt flag (x = 3..0)

Writing 1 to this bit clears the corresponding DMEIFx flag in the DMA\_LISR register

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **CFEIFx**: Stream x clear FIFO error interrupt flag (x = 3..0)

Writing 1 to this bit clears the corresponding CFEIFx flag in the DMA\_LISR register

### 9.5.4 DMA high interrupt flag clear register (DMA\_HIFCR)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				CTCIF7	CHTIF7	CTEIF7	CDMEIF7	Reserved	CFEIF7	CTCIF6	CHTIF6	CTEIF6	CDMEIF6	Reserved	CFEIF6
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				CTCIF5	CHTIF5	CTEIF5	CDMEIF5	Reserved	CFEIF5	CTCIF4	CHTIF4	CTEIF4	CDMEIF4	Reserved	CFEIF4
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **CTCIFx**: Stream x clear transfer complete interrupt flag (x = 7..4)

Writing 1 to this bit clears the corresponding TCIFx flag in the DMA\_HISR register

Bits 26, 20, 10, 4 **CHTIFx**: Stream x clear half transfer interrupt flag (x = 7..4)

Writing 1 to this bit clears the corresponding HTIFx flag in the DMA\_HISR register

Bits 25, 19, 9, 3 **CTEIFx**: Stream x clear transfer error interrupt flag (x = 7..4)

Writing 1 to this bit clears the corresponding TEIFx flag in the DMA\_HISR register

Bits 24, 18, 8, 2 **CDMEIFx**: Stream x clear direct mode error interrupt flag (x = 7..4)

Writing 1 to this bit clears the corresponding DMEIFx flag in the DMA\_HISR register

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **CFEIFx**: Stream x clear FIFO error interrupt flag (x = 7..4)

Writing 1 to this bit clears the corresponding CFEIFx flag in the DMA\_HISR register

### 9.5.5 DMA stream x configuration register (DMA\_SxCR) (x = 0..7)

This register is used to configure the concerned stream.

Address offset:  $0x10 + 0x18 \times \text{stream number}$

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				CHSEL[3:0]			MBURST [1:0]		PBURST[1:0]		Reserved	CT	DBM or reserved	PL[1:0]	
				rw	rw	rw	rw	rw	rw	rw		rw	rw or r	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PINCO	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:25 **CHSEL[2:0]: Channel selection**

These bits are set and cleared by software.

000: channel 0 selected

001: channel 1 selected

010: channel 2 selected

011: channel 3 selected

100: channel 4 selected

101: channel 5 selected

110: channel 6 selected

111: channel 7 selected

These bits are protected and can be written only if EN is '0'

Bits 24:23 **MBURST:** Memory burst transfer configuration

These bits are set and cleared by software.

00: single transfer

01: INCR4 (incremental burst of 4 beats)

10: INCR8 (incremental burst of 8 beats)

11: INCR16 (incremental burst of 16 beats)

These bits are protected and can be written only if EN is '0'

In direct mode, these bits are forced to 0x0 by hardware as soon as bit EN= '1'.

Bits 22:21 **PBURST[1:0]:** Peripheral burst transfer configuration

These bits are set and cleared by software.

00: single transfer

01: INCR4 (incremental burst of 4 beats)

10: INCR8 (incremental burst of 8 beats)

11: INCR16 (incremental burst of 16 beats)

These bits are protected and can be written only if EN is '0'

In direct mode, these bits are forced to 0x0 by hardware.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CT:** Current target (only in double buffer mode)

This bits is set and cleared by hardware. It can also be written by software.

0: The current target memory is Memory 0 (addressed by the DMA\_SxM0AR pointer)

1: The current target memory is Memory 1 (addressed by the DMA\_SxM1AR pointer)

This bit can be written only if EN is '0' to indicate the target memory area of the first transfer. Once the stream is enabled, this bit operates as a status flag indicating which memory area is the current target.

Bit 18 **DBM**: Double buffer mode

This bits is set and cleared by software.

0: No buffer switching at the end of transfer

1: Memory target switched at the end of the DMA transfer

This bit is protected and can be written only if EN is '0'.

Bits 17:16 **PL[1:0]**: Priority level

These bits are set and cleared by software.

00: Low

01: Medium

10: High

11: Very high

These bits are protected and can be written only if EN is '0'.

Bit 15 **PINCOS**: Peripheral increment offset size

This bit is set and cleared by software

0: The offset size for the peripheral address calculation is linked to the PSIZE

1: The offset size for the peripheral address calculation is fixed to 4 (32-bit alignment).

This bit has no meaning if bit PINC = '0'.

This bit is protected and can be written only if EN = '0'.

This bit is forced low by hardware when the stream is enabled (bit EN = '1') if the direct mode is selected or if PBURST are different from "00".

Bits 14:13 **MSIZE[1:0]**: Memory data size

These bits are set and cleared by software.

00: byte (8-bit)

01: half-word (16-bit)

10: word (32-bit)

11: reserved

These bits are protected and can be written only if EN is '0'.

In direct mode, MSIZE is forced by hardware to the same value as PSIZE as soon as bit EN = '1'.

Bits 12:11 **PSIZE[1:0]**: Peripheral data size

These bits are set and cleared by software.

00: Byte (8-bit)

01: Half-word (16-bit)

10: Word (32-bit)

11: reserved

These bits are protected and can be written only if EN is '0'

Bit 10 **MINC**: Memory increment mode

This bit is set and cleared by software.

0: Memory address pointer is fixed

1: Memory address pointer is incremented after each data transfer (increment is done according to MSIZE)

This bit is protected and can be written only if EN is '0'.

Bit 9 **PINC**: Peripheral increment mode

This bit is set and cleared by software.

0: Peripheral address pointer is fixed

1: Peripheral address pointer is incremented after each data transfer (increment is done according to PSIZE)

This bit is protected and can be written only if EN is '0'.

**Bit 8 CIRC:** Circular mode

This bit is set and cleared by software and can be cleared by hardware.

0: Circular mode disabled

1: Circular mode enabled

When the peripheral is the flow controller (bit PFCTRL=1) and the stream is enabled (bit EN=1), then this bit is automatically forced by hardware to 0.

It is automatically forced by hardware to 1 if the DBM bit is set, as soon as the stream is enabled (bit EN ='1').

**Bits 7:6 DIR[1:0]:** Data transfer direction

These bits are set and cleared by software.

00: Peripheral-to-memory

01: Memory-to-peripheral

10: Memory-to-memory

11: reserved

These bits are protected and can be written only if EN is '0'.

**Bit 5 PFCTRL:** Peripheral flow controller

This bit is set and cleared by software.

0: The DMA is the flow controller

1: The peripheral is the flow controller

This bit is protected and can be written only if EN is '0'.

When the memory-to-memory mode is selected (bits DIR[1:0]=10), then this bit is automatically forced to 0 by hardware.

**Bit 4 TCIE:** Transfer complete interrupt enable

This bit is set and cleared by software.

0: TC interrupt disabled

1: TC interrupt enabled

**Bit 3 HTIE:** Half transfer interrupt enable

This bit is set and cleared by software.

0: HT interrupt disabled

1: HT interrupt enabled

**Bit 2 TEIE:** Transfer error interrupt enable

This bit is set and cleared by software.

0: TE interrupt disabled

1: TE interrupt enabled

**Bit 1 DMEIE:** Direct mode error interrupt enable

This bit is set and cleared by software.

0: DME interrupt disabled

1: DME interrupt enabled

Bit 0 **EN:** Stream enable / flag stream ready when read low

This bit is set and cleared by software.

0: Stream disabled

1: Stream enabled

This bit may be cleared by hardware:

- on a DMA end of transfer (stream ready to be configured)
- if a transfer error occurs on the AHB master buses
- when the FIFO threshold on memory AHB port is not compatible with the size of the burst

When this bit is read as 0, the software is allowed to program the Configuration and FIFO bits registers. It is forbidden to write these registers when the EN bit is read as 1.

*Note: Before setting EN bit to '1' to start a new transfer, the event flags corresponding to the stream in DMA\_LISR or DMA\_HISR register must be cleared.*

### 9.5.6 DMA stream x number of data register (DMA\_SxNDTR) (x = 0..7)

Address offset:  $0x14 + 0x18 \times \text{stream number}$

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **NDT[15:0]:** Number of data items to transfer

Number of data items to be transferred (0 up to 65535). This register can be written only when the stream is disabled. When the stream is enabled, this register is read-only, indicating the remaining data items to be transmitted. This register decrements after each DMA transfer.

Once the transfer has completed, this register can either stay at zero (when the stream is in normal mode) or be reloaded automatically with the previously programmed value in the following cases:

- when the stream is configured in Circular mode.
- when the stream is enabled again by setting EN bit to '1'

If the value of this register is zero, no transaction can be served even if the stream is enabled.

### 9.5.7 DMA stream x peripheral address register (DMA\_SxPAR) (x = 0..7)

Address offset:  $0x18 + 0x18 \times \text{stream number}$

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PAR[31:0]**: Peripheral address

Base address of the peripheral data register from/to which the data will be read/written.

These bits are write-protected and can be written only when bit EN = '0' in the DMA\_SxCR register.

### 9.5.8 DMA stream x memory 0 address register (DMA\_SxM0AR) (x = 0..7)

Address offset:  $0x1C + 0x18 \times \text{stream number}$

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
M0A[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M0A[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **M0A[31:0]**: Memory 0 address

Base address of Memory area 0 from/to which the data will be read/written.

These bits are write-protected. They can be written only if:

- the stream is disabled (bit EN= '0' in the DMA\_SxCR register) or
- the stream is enabled (EN='1' in DMA\_SxCR register) and bit CT = '1' in the DMA\_SxCR register (in Double buffer mode).

### 9.5.9 DMA stream x memory 1 address register (DMA\_SxM1AR) (x = 0..7)

Address offset:  $0x20 + 0x18 \times \text{stream number}$

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
M1A[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M1A[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **M1A[31:0]**: Memory 1 address (used in case of Double buffer mode)

Base address of Memory area 1 from/to which the data will be read/written.

This register is used only for the Double buffer mode.

These bits are write-protected. They can be written only if:

- the stream is disabled (bit EN= '0' in the DMA\_SxCR register) or
- the stream is enabled (EN='1' in DMA\_SxCR register) and bit CT = '0' in the DMA\_SxCR register.

### 9.5.10 DMA stream x FIFO control register (DMA\_SxFCR) (x = 0..7)

Address offset:  $0x24 + 0x24 \times \text{stream number}$

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															
								FEIE	Reser ved	FS[2:0]			DMDIS	FTH[1:0]	
								rw		r	r	r	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **FEIE**: FIFO error interrupt enable

This bit is set and cleared by software.

0: FE interrupt disabled

1: FE interrupt enabled

Bit 6 Reserved, must be kept at reset value.

**Bits 5:3 FS[2:0]: FIFO status**

These bits are read-only.

- 000:  $0 < \text{fifo\_level} < 1/4$
- 001:  $1/4 \leq \text{fifo\_level} < 1/2$
- 010:  $1/2 \leq \text{fifo\_level} < 3/4$
- 011:  $3/4 \leq \text{fifo\_level} < \text{full}$
- 100: FIFO is empty
- 101: FIFO is full
- others: no meaning

These bits are not relevant in the direct mode (DMDIS bit is zero).

**Bit 2 DMDIS: Direct mode disable**

This bit is set and cleared by software. It can be set by hardware.

- 0: Direct mode enabled
- 1: Direct mode disabled

This bit is protected and can be written only if EN is '0'.

This bit is set by hardware if the memory-to-memory mode is selected (DIR bit in DMA\_SxCR are "10") and the EN bit in the DMA\_SxCR register is '1' because the direct mode is not allowed in the memory-to-memory configuration.

**Bits 1:0 FTH[1:0]: FIFO threshold selection**

These bits are set and cleared by software.

- 00: 1/4 full FIFO
- 01: 1/2 full FIFO
- 10: 3/4 full FIFO
- 11: full FIFO

These bits are not used in the direct mode when the DMIS value is zero.

These bits are protected and can be written only if EN is '1'.

### 9.5.11 DMA register map

*Table 37* summarizes the DMA registers.

**Table 37. DMA register map and reset values**

**Table 37. DMA register map and reset values (continued)**

**Table 37. DMA register map and reset values (continued)**

**Table 37. DMA register map and reset values (continued)**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0																				
0x00B8	<b>DMA_S7CR</b>	Reserved	CHSEL[2:0]			MBURST[1:0]			PBURST[1:0]			ACK			CT			DBM			PL[1:0]			PINCOS			MSIZE[1:0]			FSIZE[1:0]			NDT[15:]																				
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
0x00BC	<b>DMA_S7NDTR</b>	Reserved													NDT[15:]																0																						
															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																		
0x00C0	<b>DMA_S7PAR</b>	PA[31:0]																																																			
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
0x00C4	<b>DMA_S7M0AR</b>	MOA[31:0]																																																			
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
0x00C8	<b>DMA_S7M1AR</b>	M1A[31:0]																																																			
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
0x00CC	<b>DMA_S7FCR</b>	Reserved													FS[2:0]			DMDIS			FTH[1:0]			PFCTRL			5			TCIE			4			HTIE			3			TEIE			2			DMEIE			1		
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 10 Interrupts and events

### 10.1 Nested vectored interrupt controller (NVIC)

#### 10.1.1 NVIC features

The nested vector interrupt controller NVIC includes the following features:

- 52 maskable interrupt channels (not including the 16 interrupt lines of Cortex™-M4 with FPU)
- 16 programmable priority levels (4 bits of interrupt priority are used)
- low-latency exception and interrupt handling
- power management control
- implementation of system control registers

The NVIC and the processor core interface are closely coupled, which enables low latency interrupt processing and efficient processing of late arriving interrupts.

All interrupts including the core exceptions are managed by the NVIC. For more information on exceptions and NVIC programming, refer to programming manual PM0214.

#### 10.1.2 SysTick calibration value register

The SysTick calibration value is fixed to 10500, which gives a reference time base of 1 ms with the SysTick clock set to 10.5 MHz (HCLK/8, with HCLK set to 84 MHz).

#### 10.1.3 Interrupt and exception vectors

See [Table 38](#), for the vector table for the STM32F401xB/C and STM32F401xD/E devices.

## 10.2 External interrupt/event controller (EXTI)

The external interrupt/event controller consists of up to 23 edge detectors for generating event/interrupt requests. Each input line can be independently configured to select the type (interrupt or event) and the corresponding trigger event (rising or falling or both). Each line can also masked independently. A pending register maintains the status line of the interrupt requests.

**Table 38. Vector table**

Position	Priority	Type of priority	Acronym	Description	Address
	-	-	-	Reserved	0x0000 0000
	-3	fixed	Reset	Reset	0x0000 0004

**Table 38. Vector table (continued)**

<b>Position</b>	<b>Priority</b>	<b>Type of priority</b>	<b>Acronym</b>	<b>Description</b>	<b>Address</b>
	-2	fixed	NMI	Non maskable interrupt, Clock Security System	0x0000 0008
	-1	fixed	HardFault	All class of fault	0x0000 000C
	0	settable	MemManage	Memory management	0x0000 0010
	1	settable	BusFault	Pre-fetch fault, memory access fault	0x0000 0014
	2	settable	UsageFault	Undefined instruction or illegal state	0x0000 0018
	-	-	-	Reserved	0x0000 001C - 0x0000 002B
	3	settable	SVCall	System Service call via SWI instruction	0x0000 002C
	4	settable	Debug Monitor	Debug Monitor	0x0000 0030
		-	-	Reserved	0x0000 0034
	5	settable	PendSV	Pendable request for system service	0x0000 0038
	6	settable	Systick	System tick timer	0x0000 003C
0	7	settable	WWDG	Window Watchdog interrupt	0x0000 0040
1	8	settable	EXTI16 / PVD	EXTI Line 16 interrupt / PVD through EXTI line detection interrupt	0x0000 0044
2	9	settable	EXTI21 / TAMP_STAMP	EXTI Line 21 interrupt / Tamper andTimeStamp interrupts through the EXTI line	0x0000 0048
3	10	settable	EXTI22 / RTC_WKUP	EXTI Line 22 interrupt / RTC Wakeup interrupt through the EXTI line	0x0000 004C
4	11	settable	FLASH	Flash global interrupt	0x0000 0050
5	12	settable	RCC	RCC global interrupt	0x0000 0054
6	13	settable	EXTI0	EXTI Line0 interrupt	0x0000 0058
7	14	settable	EXTI1	EXTI Line1 interrupt	0x0000 005C
8	15	settable	EXTI2	EXTI Line2 interrupt	0x0000 0060
9	16	settable	EXTI3	EXTI Line3 interrupt	0x0000 0064
10	17	settable	EXTI4	EXTI Line4 interrupt	0x0000 0068
11	18	settable	DMA1_Stream0	DMA1 Stream0 global interrupt	0x0000 006C
12	19	settable	DMA1_Stream1	DMA1 Stream1 global interrupt	0x0000 0070
13	20	settable	DMA1_Stream2	DMA1 Stream2 global interrupt	0x0000 0074

**Table 38. Vector table (continued)**

<b>Position</b>	<b>Priority</b>	<b>Type of priority</b>	<b>Acronym</b>	<b>Description</b>	<b>Address</b>
14	21	settable	DMA1_Stream3	DMA1 Stream3 global interrupt	0x0000 0078
15	22	settable	DMA1_Stream4	DMA1 Stream4 global interrupt	0x0000 007C
16	23	settable	DMA1_Stream5	DMA1 Stream5 global interrupt	0x0000 0080
17	24	settable	DMA1_Stream6	DMA1 Stream6 global interrupt	0x0000 0084
18	25	settable	ADC	ADC1 global interrupts	0x0000 0088
23	30	settable	EXTI9_5	EXTI Line[9:5] interrupts	0x0000 009C
24	31	settable	TIM1_BRK_TIM9	TIM1 Break interrupt and TIM9 global interrupt	0x0000 00A0
25	32	settable	TIM1_UP_TIM10	TIM1 Update interrupt and TIM10 global interrupt	0x0000 00A4
26	33	settable	TIM1_TRG_COM_TIM11	TIM1 Trigger and Commutation interrupts and TIM11 global interrupt	0x0000 00A8
27	34	settable	TIM1_CC	TIM1 Capture Compare interrupt	0x0000 00AC
28	35	settable	TIM2	TIM2 global interrupt	0x0000 00B0
29	36	settable	TIM3	TIM3 global interrupt	0x0000 00B4
30	37	settable	TIM4	TIM4 global interrupt	0x0000 00B8
31	38	settable	I2C1_EV	I <sup>2</sup> C1 event interrupt	0x0000 00BC
32	39	settable	I2C1_ER	I <sup>2</sup> C1 error interrupt	0x0000 00C0
33	40	settable	I2C2_EV	I <sup>2</sup> C2 event interrupt	0x0000 00C4
34	41	settable	I2C2_ER	I <sup>2</sup> C2 error interrupt	0x0000 00C8
35	42	settable	SPI1	SPI1 global interrupt	0x0000 00CC
36	43	settable	SPI2	SPI2 global interrupt	0x0000 00D0
37	44	settable	USART1	USART1 global interrupt	0x0000 00D4
38	45	settable	USART2	USART2 global interrupt	0x0000 00D8
40	47	settable	EXTI15_10	EXTI Line[15:10] interrupts	0x0000 00E0
41	48	settable	EXTI17 / RTC_Alarm	EXTI Line 17 interrupt / RTC Alarms (A and B) through EXTI line interrupt	0x0000 00E4
42	49	settable	EXTI18 / OTG_FS WKUP	EXTI Line 18 interrupt / USB On-The-Go FS Wakeup through EXTI line interrupt	0x0000 00E8
47	54	settable	DMA1_Stream7	DMA1 Stream7 global interrupt	0x0000 00FC
49	56	settable	SDIO	SDIO global interrupt	0x0000 0104
50	57	settable	TIM5	TIM5 global interrupt	0x0000 0108

**Table 38. Vector table (continued)**

<b>Position</b>	<b>Priority</b>	<b>Type of priority</b>	<b>Acronym</b>	<b>Description</b>	<b>Address</b>
51	58	settable	SPI3	SPI3 global interrupt	0x0000 010C
56	63	settable	DMA2_Stream0	DMA2 Stream0 global interrupt	0x0000 0120
57	64	settable	DMA2_Stream1	DMA2 Stream1 global interrupt	0x0000 0124
58	65	settable	DMA2_Stream2	DMA2 Stream2 global interrupt	0x0000 0128
59	66	settable	DMA2_Stream3	DMA2 Stream3 global interrupt	0x0000 012C
60	67	settable	DMA2_Stream4	DMA2 Stream4 global interrupt	0x0000 0130
67	74	settable	OTG_FS	USB On The Go FS global interrupt	0x0000 014C
68	75	settable	DMA2_Stream5	DMA2 Stream5 global interrupt	0x0000 0150
69	76	settable	DMA2_Stream6	DMA2 Stream6 global interrupt	0x0000 0154
70	77	settable	DMA2_Stream7	DMA2 Stream7 global interrupt	0x0000 0158
71	78	settable	USART6	USART6 global interrupt	0x0000 015C
72	79	settable	I2C3_EV	I <sup>2</sup> C3 event interrupt	0x0000 0160
73	80	settable	I2C3_ER	I <sup>2</sup> C3 error interrupt	0x0000 0164
81	88	Settable	FPU	FPU global interrupt	0x0000 0184
84	91	settable	SPI4	SPI 4 global interrupt	0x0000 0190

### 10.2.1 EXTI main features

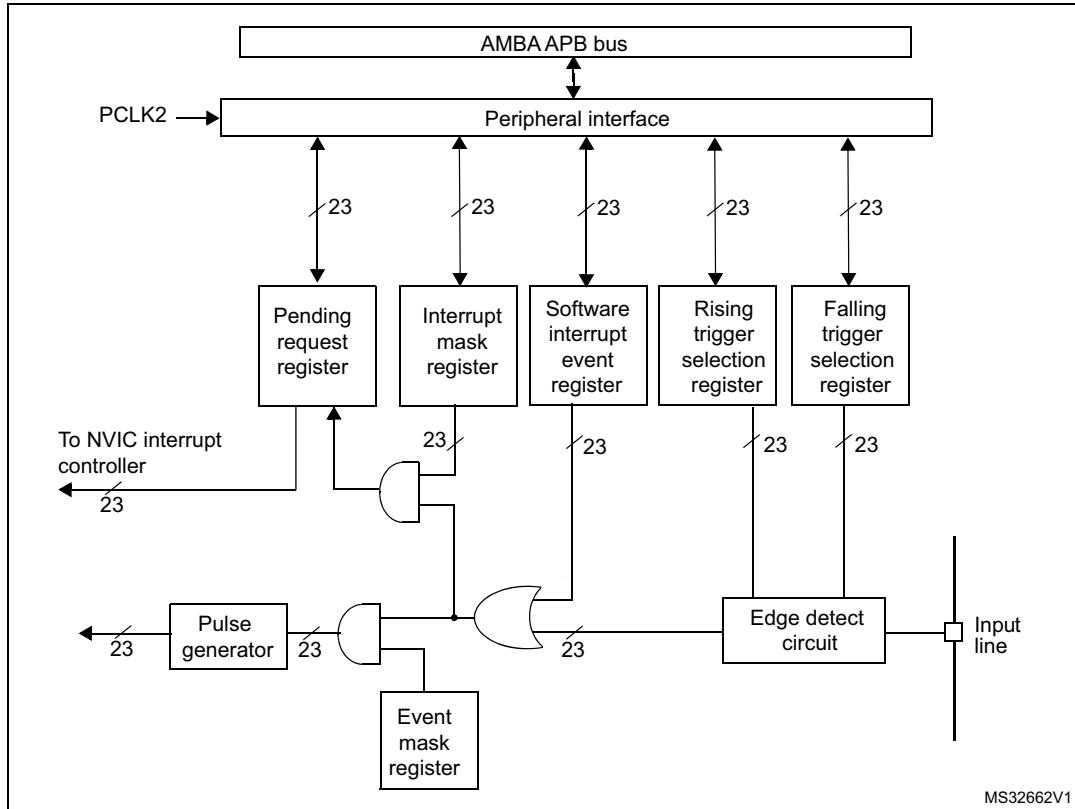
The main features of the EXTI controller are the following:

- independent trigger and mask on each interrupt/event line
- dedicated status bit for each interrupt line
- generation of up to 23 software event/interrupt requests
- detection of external signals with a pulse width lower than the APB2 clock period. Refer to the electrical characteristics section of the STM32F4xx datasheets for details on this parameter.

### 10.2.2 EXTI block diagram

*Figure 29* shows the block diagram.

**Figure 29. External interrupt/event controller block diagram**



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### 10.2.3 Wakeup event management

The STM32F4xx are able to handle external or internal events in order to wake up the core (WFE). The wakeup event can be generated either by:

- enabling an interrupt in the peripheral control register but not in the NVIC, and enabling the SEVONPEND bit in the Cortex™-M4 with FPU System Control register. When the MCU resumes from WFE, the peripheral interrupt pending bit and the peripheral NVIC IRQ channel pending bit (in the NVIC interrupt clear pending register) have to be cleared.
- or configuring an external or internal EXTI line in event mode. When the CPU resumes from WFE, it is not necessary to clear the peripheral interrupt pending bit or the NVIC IRQ channel pending bit as the pending bit corresponding to the event line is not set.

To use an external line as a wakeup event, refer to [Section 10.2.4: Functional description](#).

### 10.2.4 Functional description

To generate the interrupt, the interrupt line should be configured and enabled. This is done by programming the two trigger registers with the desired edge detection and by enabling the interrupt request by writing a '1' to the corresponding bit in the interrupt mask register. When the selected edge occurs on the external interrupt line, an interrupt request is

generated. The pending bit corresponding to the interrupt line is also set. This request is reset by writing a '1' in the pending register.

To generate the event, the event line should be configured and enabled. This is done by programming the two trigger registers with the desired edge detection and by enabling the event request by writing a '1' to the corresponding bit in the event mask register. When the selected edge occurs on the event line, an event pulse is generated. The pending bit corresponding to the event line is not set.

An interrupt/event request can also be generated by software by writing a '1' in the software interrupt/event register.

### Hardware interrupt selection

To configure the 23 lines as interrupt sources, use the following procedure:

- Configure the mask bits of the 23 interrupt lines (EXTI\_IMR)
- Configure the Trigger selection bits of the interrupt lines (EXTI\_RTSR and EXTI\_FTSR)
- Configure the enable and mask bits that control the NVIC IRQ channel mapped to the external interrupt controller (EXTI) so that an interrupt coming from one of the 23 lines can be correctly acknowledged.

### Hardware event selection

To configure the 23 lines as event sources, use the following procedure:

- Configure the mask bits of the 23 event lines (EXTI\_EMR)
- Configure the Trigger selection bits of the event lines (EXTI\_RTSR and EXTI\_FTSR)

### Software interrupt/event selection

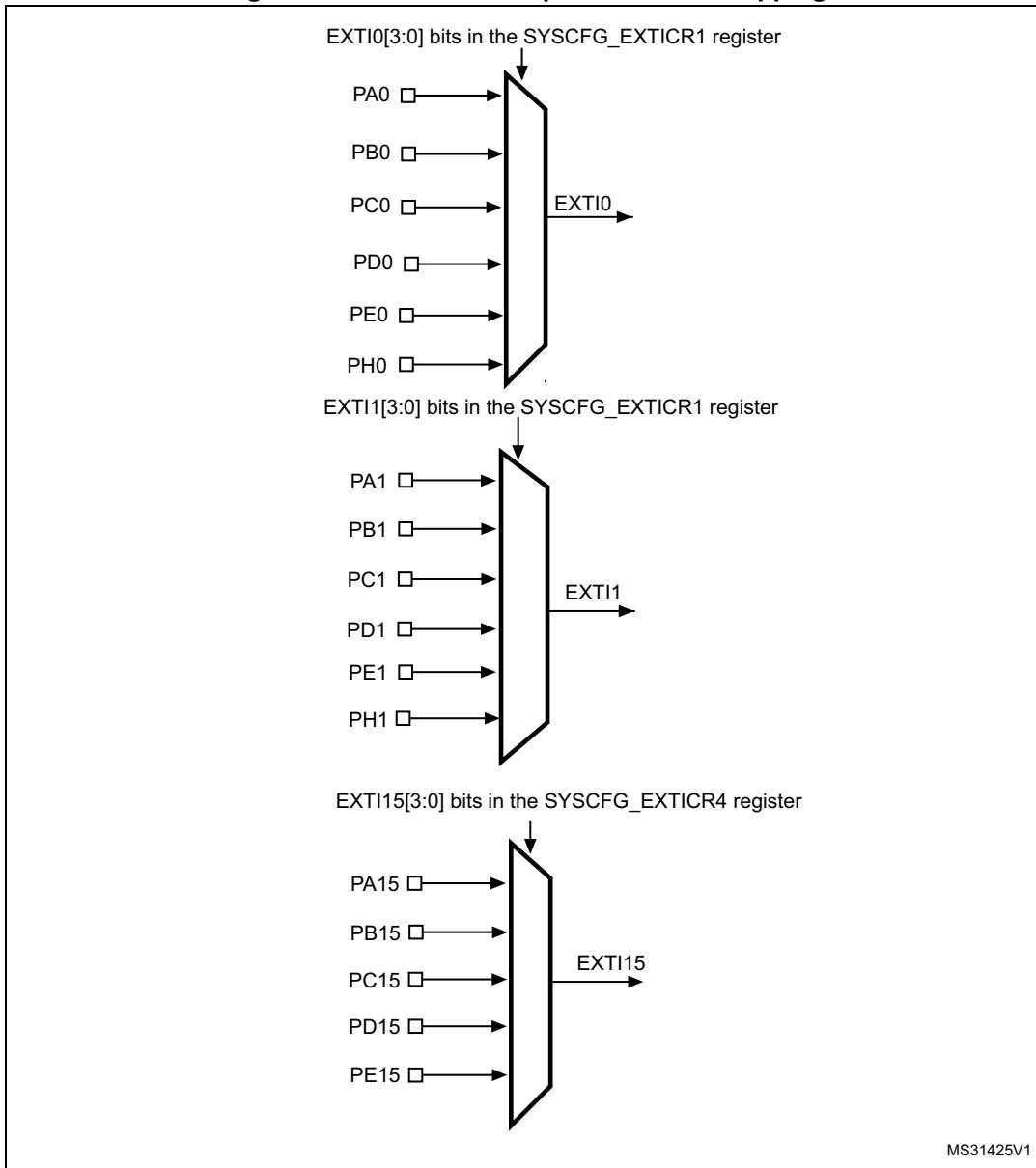
The 23 lines can be configured as software interrupt/event lines. The following is the procedure to generate a software interrupt.

- Configure the mask bits of the 23 interrupt/event lines (EXTI\_IMR, EXTI\_EMR)
- Set the required bit in the software interrupt register (EXTI\_SWIER)

### 10.2.5 External interrupt/event line mapping

Up to 81 GPIOs (STM32F401xB/C and STM32F401xD/E) are connected to the 16 external interrupt/event lines in the following manner:

**Figure 30. External interrupt/event GPIO mapping**



The five other EXTI lines are connected as follows:

- EXTI line 16 is connected to the PVD output
- EXTI line 17 is connected to the RTC Alarm event
- EXTI line 18 is connected to the USB OTG FS Wakeup event
- EXTI line 21 is connected to the RTC Tamper andTimeStamp events
- EXTI line 22 is connected to the RTC Wakeup event

## 10.3 EXTI registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

### 10.3.1 Interrupt mask register (EXTI\_IMR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved						MR22	MR21	Reserved	MR18	MR17	MR16	Reserved	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR15	MR14	MR13	MR12	MR11	MR10	MR9	MR8	MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **MRx**: Interrupt mask on line x

0: Interrupt request from line x is masked

1: Interrupt request from line x is not masked

### 10.3.2 Event mask register (EXTI\_EMR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved						MR22	MR21	Reserved	MR18	MR17	MR16	Reserved	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR15	MR14	MR13	MR12	MR11	MR10	MR9	MR8	MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **MRx**: Event mask on line x

0: Event request from line x is masked

1: Event request from line x is not masked

### 10.3.3 Rising trigger selection register (EXTI\_RTSR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								TR22	TR21	Reserved	TR18	TR17	TR16		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TR15	TR14	TR13	TR12	TR11	TR10	TR9	TR8	TR7	TR6	TR5	TR4	TR3	TR2	TR1	TR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **TRx**: Rising trigger event configuration bit of line x

- 0: Rising trigger disabled (for Event and Interrupt) for input line
- 1: Rising trigger enabled (for Event and Interrupt) for input line

**Note:** *The external wakeup lines are edge triggered, no glitch must be generated on these lines. If a rising edge occurs on the external interrupt line while writing to the EXTI\_RTSR register, the pending bit is set.*

*Rising and falling edge triggers can be set for the same interrupt line. In this configuration, both generate a trigger condition.*

### 10.3.4 Falling trigger selection register (EXTI\_FTSR)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								TR22	TR21	Reserved	TR18	TR17	TR16		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TR15	TR14	TR13	TR12	TR11	TR10	TR9	TR8	TR7	TR6	TR5	TR4	TR3	TR2	TR1	TR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **TRx**: Falling trigger event configuration bit of line x

- 0: Falling trigger disabled (for Event and Interrupt) for input line
- 1: Falling trigger enabled (for Event and Interrupt) for input line.

**Note:** *The external wakeup lines are edge triggered, no glitch must be generated on these lines. If a falling edge occurs on the external interrupt line while writing to the EXTI\_FTSR register, the pending bit is not set.*

*Rising and falling edge triggers can be set for the same interrupt line. In this configuration, both generate a trigger condition.*

### 10.3.5 Software interrupt event register (EXTI\_SWIER)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								SWIER 22	SWIER 21	Reserved	SWIER 18	SWIER 17	SWIER 16		
								rw	rw		rw	rw	rw		
15	14	13	12	11	10	9	8	7	6		4	3	2	1	0
SWIER 15	SWIER 14	SWIER 13	SWIER 12	SWIER 11	SWIER 10	SWIER 9	SWIER 8	SWIER 7	SWIER 6	SWIER 5	SWIER 4	SWIER 3	SWIER 2	SWIER 1	SWIER 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **SWIERx**: Software Interrupt on line x

If interrupt are enabled on line x in the EXTI\_IMR register, writing '1' to SWIERx bit when it is set at '0' sets the corresponding pending bit in the EXTI\_PR register, thus resulting in an interrupt request generation.

This bit is cleared by clearing the corresponding bit in EXTI\_PR (by writing a 1 to the bit).

### 10.3.6 Pending register (EXTI\_PR)

Address offset: 0x14

Reset value: undefined

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								PR22	PR21	Reserved	PR18	PR17	PR16		
								rc_w1	rc_w1		rc_w1	rc_w1	rc_w1		
15	14	13	12	11	10	9	8	7	6		4	3	2	1	0
PR15	PR14	PR13	PR12	PR11	PR10	PR9	PR8	PR7	PR6	PR5	PR4	PR3	PR2	PR1	PR0
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **PRx**: Pending bit

0: No trigger request occurred

1: selected trigger request occurred

This bit is set when the selected edge event arrives on the external interrupt line.

This bit is cleared by programming it to '1'.

### **10.3.7 EXTI register map**

*Table 39* gives the EXTI register map and the reset values.

**Table 39. External interrupt/event controller register map and reset values**

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 11 Analog-to-digital converter (ADC)

ADC2 and ADC3 are not available in STM32F401xB/C and STM32F401xD/E.

### 11.1 ADC introduction

The 12-bit ADC is a successive approximation analog-to-digital converter. It has up to 19 multiplexed channels allowing it to measure signals from 16 external sources, two internal sources, and the  $V_{BAT}$  channel. The A/D conversion of the channels can be performed in single, continuous, scan or discontinuous mode. The result of the ADC is stored into a left- or right-aligned 16-bit data register.

The analog watchdog feature allows the application to detect if the input voltage goes beyond the user-defined, higher or lower thresholds.

### 11.2 ADC main features

- 12-bit, 10-bit, 8-bit or 6-bit configurable resolution
- Interrupt generation at the end of conversion, end of injected conversion, and in case of analog watchdog or overrun events
- Single and continuous conversion modes
- Scan mode for automatic conversion of channel 0 to channel ‘n’
- Data alignment with in-built data coherency
- Channel-wise programmable sampling time
- External trigger option with configurable polarity for both regular and injected conversions
- Discontinuous mode
- ADC supply requirements: 2.4 V to 3.6 V at full speed and down to 1.8 V at slower speed
- ADC input range:  $V_{REF-} \leq V_{IN} \leq V_{REF+}$
- DMA request generation during regular channel conversion

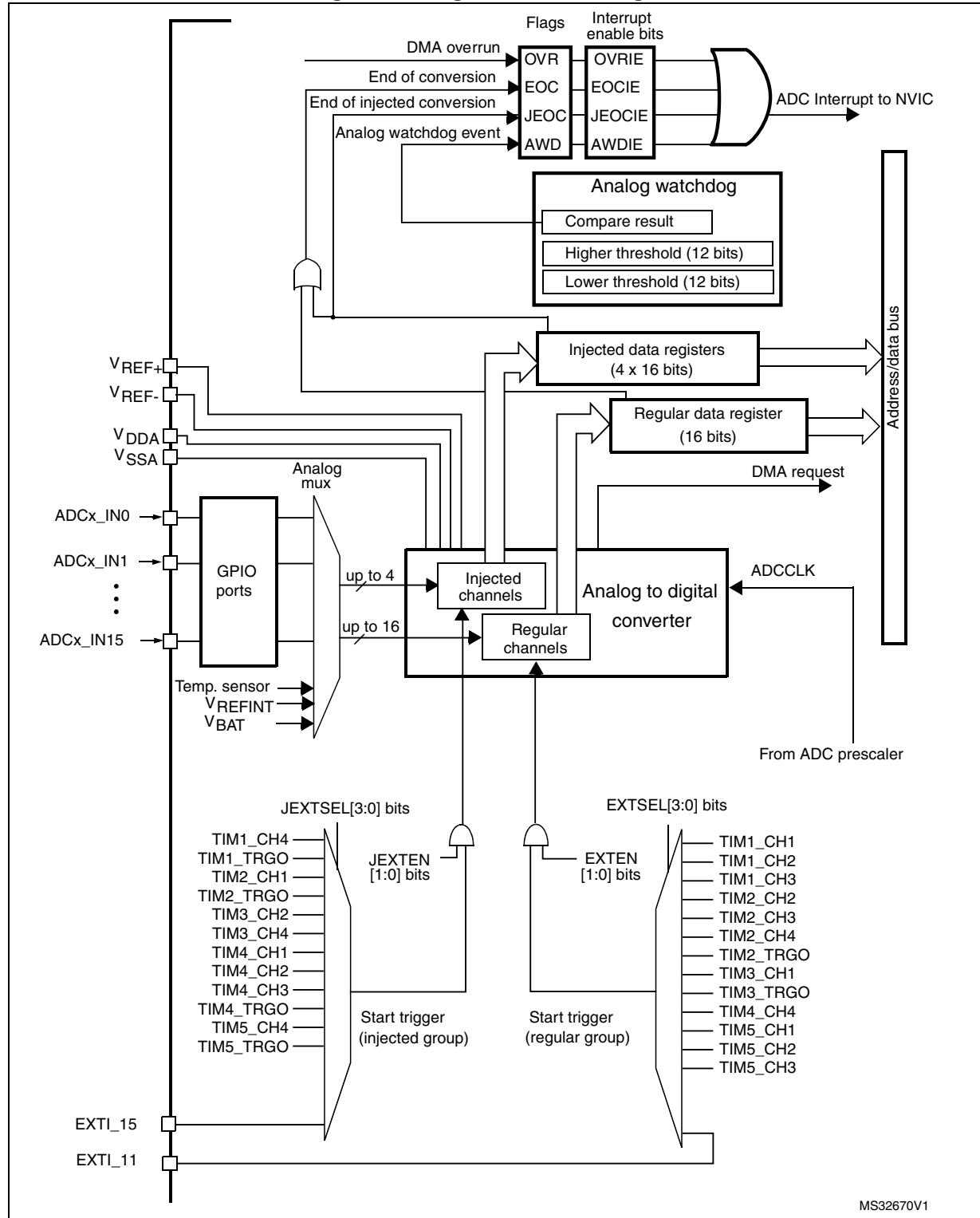
*Figure 31* shows the block diagram of the ADC.

*Note:*  $V_{REF-}$ , if available (depending on package), must be tied to  $V_{SSA}$ .

## 11.3 ADC functional description

Figure 31 shows a single ADC block diagram and Table 40 gives the ADC pin description.

**Figure 31. Single ADC block diagram**



MS32670V1

**Table 40. ADC pins**

Name	Signal type	Remarks
$V_{REF+}$	Input, analog reference positive	The higher/positive reference voltage for the ADC, $1.8 \text{ V} \leq V_{REF+} \leq V_{DDA}$
$V_{DDA}$	Input, analog supply	Analog power supply equal to $V_{DD}$ and $2.4 \text{ V} \leq V_{DDA} \leq V_{DD}$ (3.6 V) for full speed $1.8 \text{ V} \leq V_{DDA} \leq V_{DD}$ (3.6 V) for reduced speed
$V_{REF-}$	Input, analog reference negative	The lower/negative reference voltage for the ADC, $V_{REF-} = V_{SSA}$
$V_{SSA}$	Input, analog supply ground	Ground for analog power supply equal to $V_{SS}$
ADCx_IN[15:0]	Analog input signals	16 analog input channels

### 11.3.1 ADC on-off control

The ADC is powered on by setting the ADON bit in the ADC\_CR2 register. When the ADON bit is set for the first time, it wakes up the ADC from the Power-down mode.

Conversion starts when either the SWSTART or the JSWSTART bit is set.

You can stop conversion and put the ADC in power down mode by clearing the ADON bit. In this mode the ADC consumes almost no power (only a few  $\mu\text{A}$ ).

### 11.3.2 ADC clock

The ADC features two clock schemes:

- Clock for the analog circuitry: ADCCLK
 

This clock is generated from the APB2 clock divided by a programmable prescaler that allows the ADC to work at  $f_{PCLK2}/2$ , /4, /6 or /8. Refer to the datasheets for the maximum value of ADCCLK.
- Clock for the digital interface (used for registers read/write access)
 

This clock is equal to the APB2 clock. The digital interface clock can be enabled/disabled individually for each ADC through the RCC APB2 peripheral clock enable register (RCC\_APB2ENR).

### 11.3.3 Channel selection

There are 16 multiplexed channels. It is possible to organize the conversions in two groups: regular and injected. A group consists of a sequence of conversions that can be done on any channel and in any order. For instance, it is possible to implement the conversion sequence in the following order: ADC\_IN3, ADC\_IN8, ADC\_IN2, ADC\_IN2, ADC\_IN0, ADC\_IN2, ADC\_IN2, ADC\_IN15.

- A **regular group** is composed of up to 16 conversions. The regular channels and their order in the conversion sequence must be selected in the ADC\_SQRx registers. The total number of conversions in the regular group must be written in the L[3:0] bits in the ADC\_SQR1 register.
- An **injected group** is composed of up to 4 conversions. The injected channels and their order in the conversion sequence must be selected in the ADC\_JSQR register.

The total number of conversions in the injected group must be written in the L[1:0] bits in the ADC\_JSQR register.

If the ADC\_SQRx or ADC\_JSQR registers are modified during a conversion, the current conversion is reset and a new start pulse is sent to the ADC to convert the newly chosen group.

#### Temperature sensor, $V_{REFINT}$ and $V_{BAT}$ internal channels

- The temperature sensor is internally connected to ADC1\_IN18 channel which is shared with VBAT. Only one conversion, temperature sensor or VBAT, must be selected at a time. When the temperature sensor and VBAT conversion are set simultaneously, only the VBAT conversion is performed.

The internal reference voltage VREFINT is connected to ADC1\_IN17.

The  $V_{BAT}$  channel is connected to channel ADC1\_IN18. It can also be converted as an injected or regular channel.

*Note:* *The temperature sensor,  $V_{REFINT}$  and the  $V_{BAT}$  channel are available only on the master ADC1 peripheral.*

#### 11.3.4 Single conversion mode

In Single conversion mode the ADC does one conversion. This mode is started with the CONT bit at 0 by either:

- setting the SWSTART bit in the ADC\_CR2 register (for a regular channel only)
- setting the JSWSTART bit (for an injected channel)
- external trigger (for a regular or injected channel)

Once the conversion of the selected channel is complete:

- If a regular channel was converted:
  - The converted data are stored into the 16-bit ADC\_DR register
  - The EOC (end of conversion) flag is set
  - An interrupt is generated if the EOCIE bit is set
- If an injected channel was converted:
  - The converted data are stored into the 16-bit ADC\_JDR1 register
  - The JEOC (end of conversion injected) flag is set
  - An interrupt is generated if the JEOCIE bit is set

Then the ADC stops.

#### 11.3.5 Continuous conversion mode

In continuous conversion mode, the ADC starts a new conversion as soon as it finishes one. This mode is started with the CONT bit at 1 either by external trigger or by setting the SWSTRT bit in the ADC\_CR2 register (for regular channels only).

After each conversion:

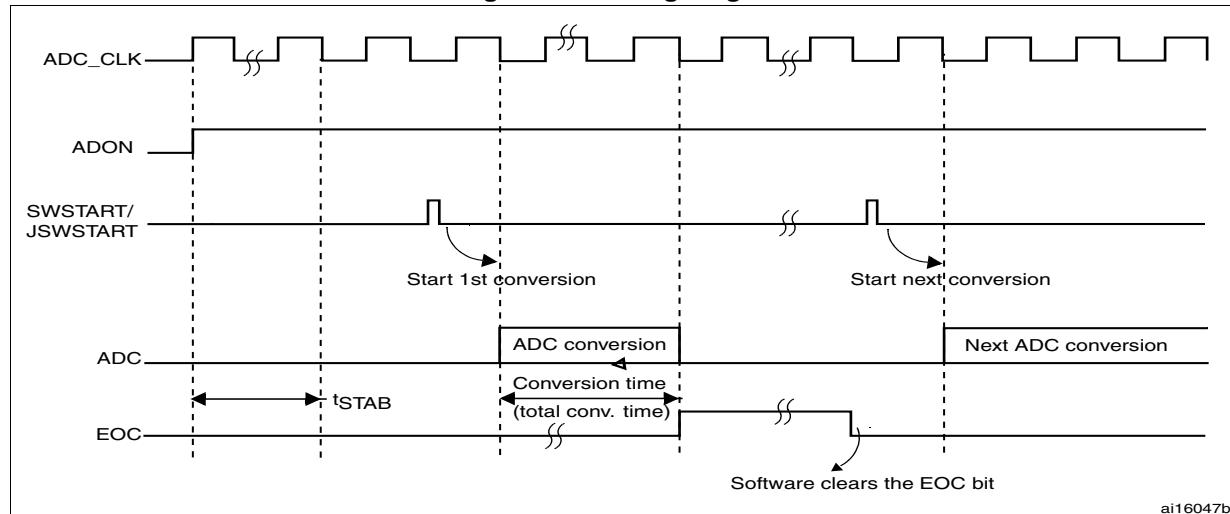
- If a regular group of channels was converted:
  - The last converted data are stored into the 16-bit ADC\_DR register
  - The EOC (end of conversion) flag is set
  - An interrupt is generated if the EOCIE bit is set

**Note:** Injected channels cannot be converted continuously. The only exception is when an injected channel is configured to be converted automatically after regular channels in continuous mode (using JAUTO bit), refer to [Auto-injection section](#).

### 11.3.6 Timing diagram

As shown in [Figure 32](#), the ADC needs a stabilization time of  $t_{STAB}$  before it starts converting accurately. After the start of the ADC conversion and after 15 clock cycles, the EOC flag is set and the 16-bit ADC data register contains the result of the conversion.

**Figure 32. Timing diagram**



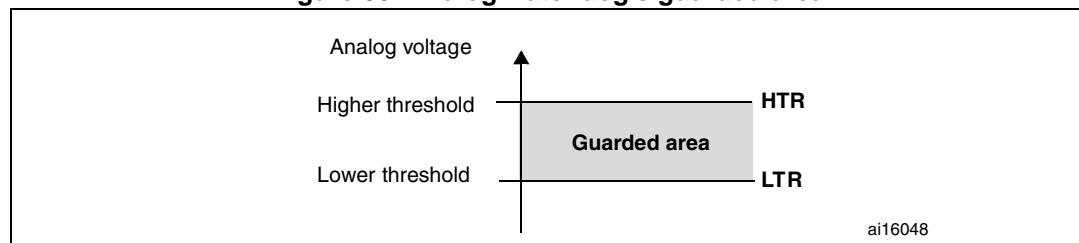
### 11.3.7 Analog watchdog

The AWD analog watchdog status bit is set if the analog voltage converted by the ADC is below a lower threshold or above a higher threshold. These thresholds are programmed in the 12 least significant bits of the ADC\_HTR and ADC\_LTR 16-bit registers. An interrupt can be enabled by using the AWDIE bit in the ADC\_CR1 register.

The threshold value is independent of the alignment selected by the ALIGN bit in the ADC\_CR2 register. The analog voltage is compared to the lower and higher thresholds before alignment.

[Table 41](#) shows how the ADC\_CR1 register should be configured to enable the analog watchdog on one or more channels.

**Figure 33. Analog watchdog's guarded area**



**Table 41. Analog watchdog channel selection**

Channels guarded by the analog watchdog	ADC_CR1 register control bits (x = don't care)		
	AWDSGL bit	AWDEN bit	JAWDEN bit
None	x	0	0
All injected channels	0	0	1
All regular channels	0	1	0
All regular and injected channels	0	1	1
Single <sup>(1)</sup> injected channel	1	0	1
Single <sup>(1)</sup> regular channel	1	1	0
Single <sup>(1)</sup> regular or injected channel	1	1	1

1. Selected by the AWDCH[4:0] bits

### 11.3.8 Scan mode

This mode is used to scan a group of analog channels.

The Scan mode is selected by setting the SCAN bit in the ADC\_CR1 register. Once this bit has been set, the ADC scans all the channels selected in the ADC\_SQRx registers (for regular channels) or in the ADC\_JSQR register (for injected channels). A single conversion is performed for each channel of the group. After each end of conversion, the next channel in the group is converted automatically. If the CONT bit is set, regular channel conversion does not stop at the last selected channel in the group but continues again from the first selected channel.

If the DMA bit is set, the direct memory access (DMA) controller is used to transfer the data converted from the regular group of channels (stored in the ADC\_DR register) to SRAM after each regular channel conversion.

The EOC bit is set in the ADC\_SR register:

- At the end of each regular group sequence if the EOCS bit is cleared to 0
- At the end of each regular channel conversion if the EOCS bit is set to 1

The data converted from an injected channel are always stored into the ADC\_JDRx registers.

### 11.3.9 Injected channel management

#### Triggered injection

To use triggered injection, the JAUTO bit must be cleared in the ADC\_CR1 register.

1. Start the conversion of a group of regular channels either by external trigger or by setting the SWSTART bit in the ADC\_CR2 register.
  2. If an external injected trigger occurs or if the JSWSTART bit is set during the conversion of a regular group of channels, the current conversion is reset and the injected channel sequence switches to Scan-once mode.
  3. Then, the regular conversion of the regular group of channels is resumed from the last interrupted regular conversion.
- If a regular event occurs during an injected conversion, the injected conversion is not

interrupted but the regular sequence is executed at the end of the injected sequence. [Figure 34](#) shows the corresponding timing diagram.

**Note:** When using triggered injection, one must ensure that the interval between trigger events is longer than the injection sequence. For instance, if the sequence length is 30 ADC clock cycles (that is two conversions with a sampling time of 3 clock periods), the minimum interval between triggers must be 31 ADC clock cycles.

### Auto-injection

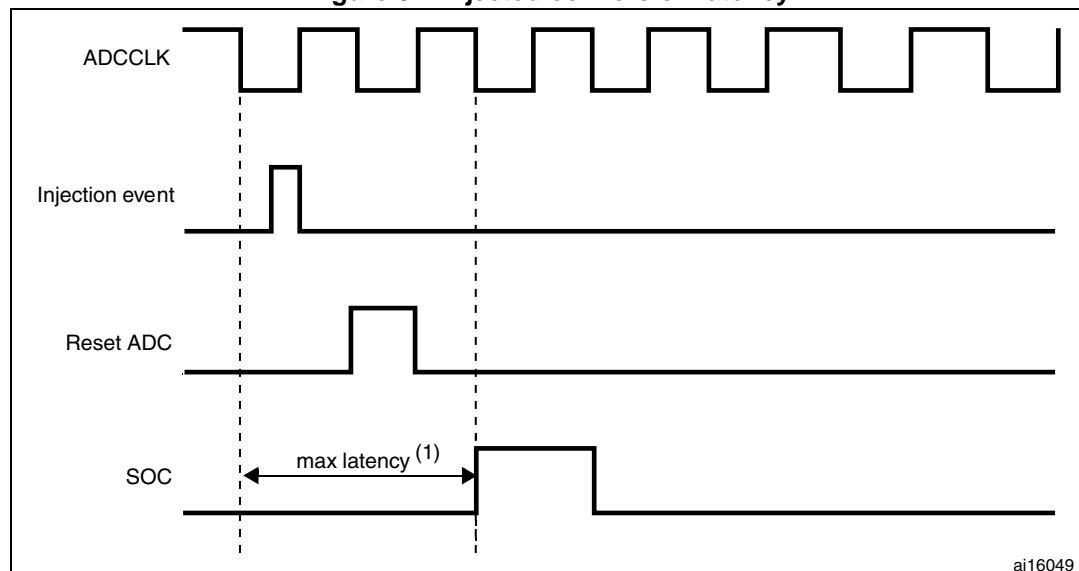
If the JAUTO bit is set, then the channels in the injected group are automatically converted after the regular group of channels. This can be used to convert a sequence of up to 20 conversions programmed in the ADC\_SQRx and ADC\_JSQR registers.

In this mode, external trigger on injected channels must be disabled.

If the CONT bit is also set in addition to the JAUTO bit, regular channels followed by injected channels are continuously converted.

**Note:** It is not possible to use both the auto-injected and discontinuous modes simultaneously.

**Figure 34. Injected conversion latency**



ai16049

1. The maximum latency value can be found in the electrical characteristics of the STM32F401xB/C and STM32F401xD/E datasheets.

### 11.3.10 Discontinuous mode

#### Regular group

This mode is enabled by setting the DISCEN bit in the ADC\_CR1 register. It can be used to convert a short sequence of n conversions ( $n \leq 8$ ) that is part of the sequence of conversions selected in the ADC\_SQRx registers. The value of n is specified by writing to the DISCNUM[2:0] bits in the ADC\_CR1 register.

When an external trigger occurs, it starts the next n conversions selected in the ADC\_SQRx registers until all the conversions in the sequence are done. The total sequence length is defined by the L[3:0] bits in the ADC\_SQR1 register.

Example:

- n = 3, channels to be converted = 0, 1, 2, 3, 6, 7, 9, 10
- 1st trigger: sequence converted 0, 1, 2. An EOC event is generated at each conversion.
- 2nd trigger: sequence converted 3, 6, 7. An EOC event is generated at each conversion
- 3rd trigger: sequence converted 9, 10. An EOC event is generated at each conversion
- 4th trigger: sequence converted 0, 1, 2. An EOC event is generated at each conversion

Note:

*When a regular group is converted in discontinuous mode, no rollover occurs.*

*When all subgroups are converted, the next trigger starts the conversion of the first subgroup. In the example above, the 4th trigger reconverts the channels 0, 1 and 2 in the 1st subgroup.*

### Injected group

This mode is enabled by setting the JDISCEN bit in the ADC\_CR1 register. It can be used to convert the sequence selected in the ADC\_JSQR register, channel by channel, after an external trigger event.

When an external trigger occurs, it starts the next channel conversions selected in the ADC\_JSQR registers until all the conversions in the sequence are done. The total sequence length is defined by the JL[1:0] bits in the ADC\_JSQR register.

Example:

- n = 1, channels to be converted = 1, 2, 3  
1st trigger: channel 1 converted  
2nd trigger: channel 2 converted  
3rd trigger: channel 3 converted and JEOC event generated  
4th trigger: channel 1

Note:

*When all injected channels are converted, the next trigger starts the conversion of the first injected channel. In the example above, the 4th trigger reconverts the 1st injected channel 1.*

*It is not possible to use both the auto-injected and discontinuous modes simultaneously.*

*Discontinuous mode must not be set for regular and injected groups at the same time.*

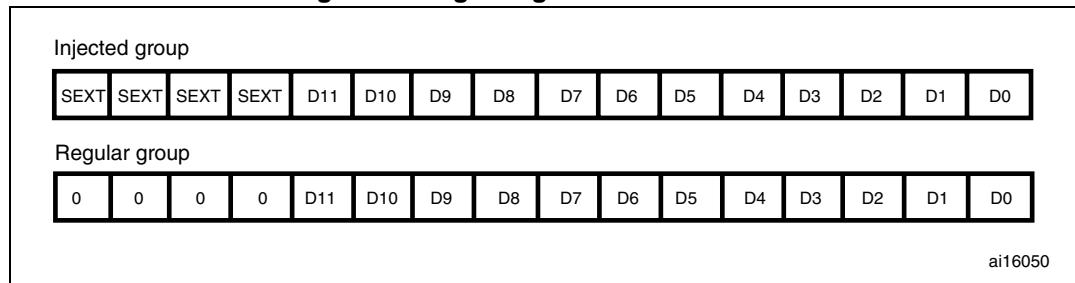
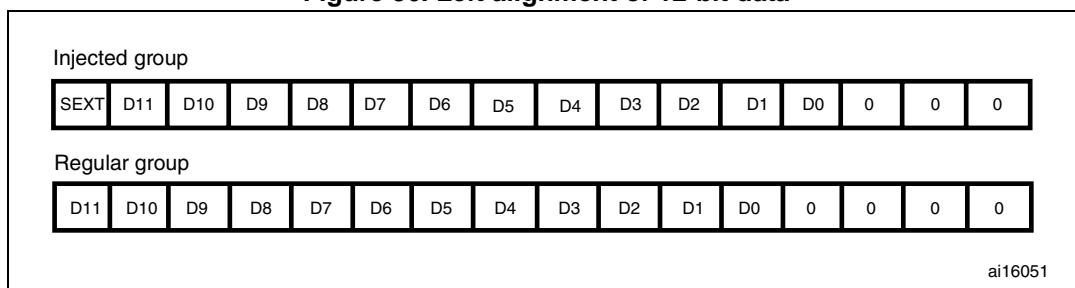
*Discontinuous mode must be enabled only for the conversion of one group.*

## 11.4 Data alignment

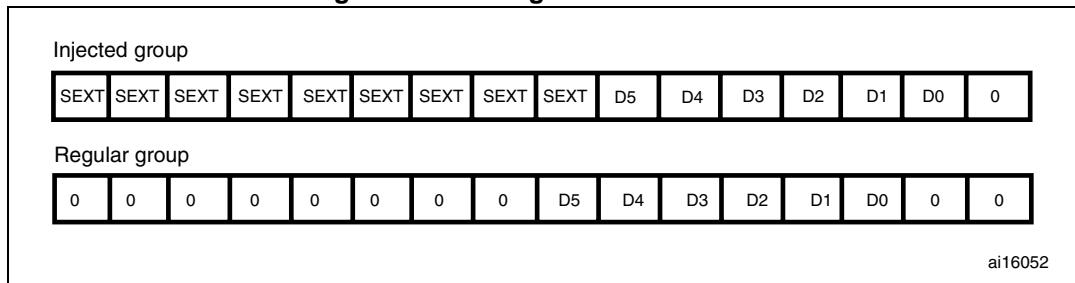
The ALIGN bit in the ADC\_CR2 register selects the alignment of the data stored after conversion. Data can be right- or left-aligned as shown in [Figure 35](#) and [Figure 36](#).

The converted data value from the injected group of channels is decreased by the user-defined offset written in the ADC\_JOFRx registers so the result can be a negative value. The SEXT bit represents the extended sign value.

For channels in a regular group, no offset is subtracted so only twelve bits are significant.

**Figure 35. Right alignment of 12-bit data****Figure 36. Left alignment of 12-bit data**

Special case: when left-aligned, the data are aligned on a half-word basis except when the resolution is set to 6-bit. in that case, the data are aligned on a byte basis as shown in [Figure 37](#).

**Figure 37. Left alignment of 6-bit data**

## 11.5 Channel-wise programmable sampling time

The ADC samples the input voltage for a number of ADCCLK cycles that can be modified using the SMP[2:0] bits in the ADC\_SMPR1 and ADC\_SMPR2 registers. Each channel can be sampled with a different sampling time.

The total conversion time is calculated as follows:

$$T_{\text{conv}} = \text{Sampling time} + 12 \text{ cycles}$$

Example:

With ADCCLK = 30 MHz and sampling time = 3 cycles:

$$T_{\text{conv}} = 3 + 12 = 15 \text{ cycles} = 0.5 \mu\text{s} \text{ with APB2 at } 60 \text{ MHz}$$

## 11.6 Conversion on external trigger and trigger polarity

Conversion can be triggered by an external event (e.g. timer capture, EXTI line). If the EXTEN[1:0] control bits (for a regular conversion) or JEXTEN[1:0] bits (for an injected conversion) are different from “0b00”, then external events are able to trigger a conversion with the selected polarity. [Table 42](#) provides the correspondence between the EXTEN[1:0] and JEXTEN[1:0] values and the trigger polarity.

**Table 42. Configuring the trigger polarity**

Source	EXTEN[1:0] / JEXTEN[1:0]
Trigger detection disabled	00
Detection on the rising edge	01
Detection on the falling edge	10
Detection on both the rising and falling edges	11

**Note:** *The polarity of the external trigger can be changed on the fly.*

The EXTSEL[3:0] and JEXTSEL[3:0] control bits are used to select which out of 16 possible events can trigger conversion for the regular and injected groups.

[Table 43](#) gives the possible external trigger for regular conversion.

**Table 43. External trigger for regular channels**

Source	Type	EXTSEL[3:0]
TIM1_CH1 event	Internal signal from on-chip timers	0000
TIM1_CH2 event		0001
TIM1_CH3 event		0010
TIM2_CH2 event		0011
TIM2_CH3 event		0100
TIM2_CH4 event		0101
TIM2_TRGO event		0110
TIM3_CH1 event		0111
TIM3_TRGO event		1000
TIM4_CH4 event		1001
TIM5_CH1 event		1010
TIM5_CH2 event		1011
TIM5_CH3 event		1100
Reserved		1101
Reserved		1110
EXTI line11	External pin	1111

[Table 44](#) gives the possible external trigger for injected conversion.

**Table 44. External trigger for injected channels**

Source	Connection type	JEXTSEL[3:0]
TIM1_CH4 event	Internal signal from on-chip timers	0000
TIM1_TRGO event		0001
TIM2_CH1 event		0010
TIM2_TRGO event		0011
TIM3_CH2 event		0100
TIM3_CH4 event		0101
TIM4_CH1 event		0110
TIM4_CH2 event		0111
TIM4_CH3 event		1000
TIM4_TRGO event		1001
TIM5_CH4 event		1010
TIM5_TRGO event		1011
Reserved		1100
Reserved		1101
Reserved		1110
EXTI line15	External pin	1111

Software source trigger events can be generated by setting SWSTART (for regular conversion) or JSWSTART (for injected conversion) in ADC\_CR2.

A regular group conversion can be interrupted by an injected trigger.

*Note:*

*The trigger selection can be changed on the fly. However, when the selection changes, there is a time frame of 1 APB clock cycle during which the trigger detection is disabled. This is to avoid spurious detection during transitions.*

## 11.7 Fast conversion mode

It is possible to perform faster conversion by reducing the ADC resolution. The RES bits are used to select the number of bits available in the data register. The minimum conversion time for each resolution is then as follows:

- 12 bits:  $3 + 12 = 15$  ADCCLK cycles
- 10 bits:  $3 + 10 = 13$  ADCCLK cycles
- 8 bits:  $3 + 8 = 11$  ADCCLK cycles
- 6 bits:  $3 + 6 = 9$  ADCCLK cycles

## 11.8 Data management

### 11.8.1 Using the DMA

Since converted regular channel values are stored into a unique data register, it is useful to use DMA for conversion of more than one regular channel. This avoids the loss of the data already stored in the ADC\_DR register.

When the DMA mode is enabled (DMA bit set to 1 in the ADC\_CR2 register), after each conversion of a regular channel, a DMA request is generated. This allows the transfer of the converted data from the ADC\_DR register to the destination location selected by the software.

Despite this, if data are lost (overrun), the OVR bit in the ADC\_SR register is set and an interrupt is generated (if the OVRIE enable bit is set). DMA transfers are then disabled and DMA requests are no longer accepted. In this case, if a DMA request is made, the regular conversion in progress is aborted and further regular triggers are ignored. It is then necessary to clear the OVR flag and the DMAEN bit in the used DMA stream, and to re-initialize both the DMA and the ADC to have the wanted converted channel data transferred to the right memory location. Only then can the conversion be resumed and the data transfer, enabled again. Injected channel conversions are not impacted by overrun errors.

When OVR = 1 in DMA mode, the DMA requests are blocked after the last valid data have been transferred, which means that all the data transferred to the RAM can be considered as valid.

At the end of the last DMA transfer (number of transfers configured in the DMA controller's DMA\_SxNTR register):

- No new DMA request is issued to the DMA controller if the DDS bit is cleared to 0 in the ADC\_CR2 register (this avoids generating an overrun error). However the DMA bit is not cleared by hardware. It must be written to 0, then to 1 to start a new transfer.
- Requests can continue to be generated if the DDS bit is set to 1. This allows configuring the DMA in double-buffer circular mode.

To recover the ADC from OVR state when the DMA is used, follow the steps below:

1. Reinitialize the DMA (adjust destination address and NDTR counter)
2. Clear the ADC OVR bit in ADC\_SR register
3. Trigger the ADC to start the conversion.

### 11.8.2 Managing a sequence of conversions without using the DMA

If the conversions are slow enough, the conversion sequence can be handled by the software. In this case the EOCS bit must be set in the ADC\_CR2 register for the EOC status bit to be set at the end of each conversion, and not only at the end of the sequence. When EOCS = 1, overrun detection is automatically enabled. Thus, each time a conversion is complete, EOC is set and the ADC\_DR register can be read. The overrun management is the same as when the DMA is used.

To recover the ADC from OVR state when the EOCS is set, follow the steps below:

1. Clear the ADC OVR bit in ADC\_SR register
2. Trigger the ADC to start the conversion.

### 11.8.3 Conversions without DMA and without overrun detection

It may be useful to let the ADC convert one or more channels without reading the data each time (if there is an analog watchdog for instance). For that, the DMA must be disabled (DMA = 0) and the EOC bit must be set at the end of a sequence only (EOCS = 0). In this configuration, overrun detection is disabled.

## 11.9 Temperature sensor

The temperature sensor can be used to measure the ambient temperature ( $T_A$ ) of the device.

*Figure 38* shows the block diagram of the temperature sensor.

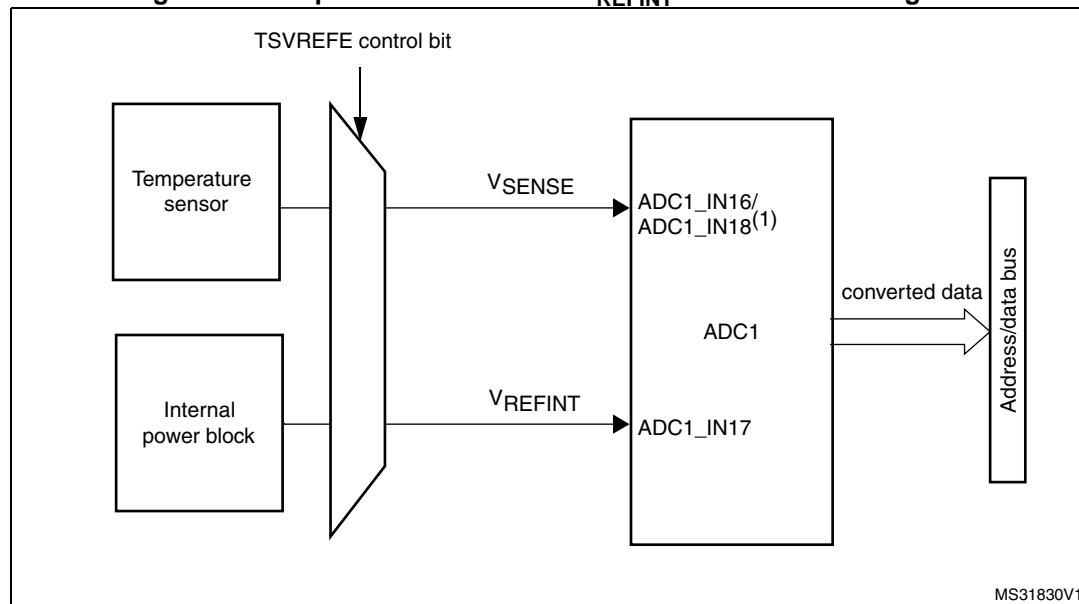
When not in use, the sensor can be put in power down mode.

*Note:* The TSVREFE bit must be set to enable the conversion of both internal channels: the ADC1\_IN16 or ADC1\_IN18 (temperature sensor) and the ADC1\_IN17 (VREFINT).

### Main features

- Supported temperature range: -40 to 125 °C
- Precision: ±1.5 °C

**Figure 38. Temperature sensor and V<sub>REFINT</sub> channel block diagram**



1. V<sub>SENSE</sub> is input to ADC1\_IN18

### Reading the temperature

To use the sensor:

3. Select ADC1\_IN16 or ADC1\_IN18 input channel.
4. Select a sampling time greater than the minimum sampling time specified in the datasheet.
5. Set the TSVREFE bit in the ADC\_CCR register to wake up the temperature sensor from power down mode
6. Start the ADC conversion by setting the SWSTART bit (or by external trigger)
7. Read the resulting  $V_{SENSE}$  data in the ADC data register
8. Calculate the temperature using the following formula:

$$\text{Temperature (in } ^\circ\text{C)} = \{(V_{SENSE} - V_{25}) / \text{Avg\_Slope}\} + 25$$

Where:

- $V_{25}$  =  $V_{SENSE}$  value for  $25^\circ\text{C}$
- Avg\_Slope = average slope of the temperature vs.  $V_{SENSE}$  curve (given in  $\text{mV}/^\circ\text{C}$  or  $\mu\text{V}/^\circ\text{C}$ )

Refer to the datasheet's electrical characteristics section for the actual values of  $V_{25}$  and Avg\_Slope.

**Note:**

*The sensor has a startup time after waking from power down mode before it can output  $V_{SENSE}$  at the correct level. The ADC also has a startup time after power-on, so to minimize the delay, the ADON and TSVREFE bits should be set at the same time.*

The temperature sensor output voltage changes linearly with temperature. The offset of this linear function depends on each chip due to process variation (up to  $45^\circ\text{C}$  from one chip to another).

The internal temperature sensor is more suited for applications that detect temperature variations instead of absolute temperatures. If accurate temperature reading is required, an external temperature sensor should be used.

## 11.10 Battery charge monitoring

The VBATE bit in the ADC\_CCR register is used to switch to the battery voltage. As the  $V_{BAT}$  voltage could be higher than  $V_{DDA}$ , to ensure the correct operation of the ADC, the  $V_{BAT}$  pin is internally connected to a bridge divider.

When the VBATE is set, the bridge is automatically enabled to connect:

- $V_{BAT}/4$  to the ADC1\_IN18 input channel

**Note:**

*The  $V_{BAT}$  and temperature sensor are connected to the same ADC internal channel (ADC1\_IN18). Only one conversion, either temperature sensor or  $V_{BAT}$ , must be selected at a time. When both conversion are enabled simultaneously, only the  $V_{BAT}$  conversion is performed.*

## 11.11 ADC interrupts

An interrupt can be produced on the end of conversion for regular and injected groups, when the analog watchdog status bit is set and when the overrun status bit is set. Separate interrupt enable bits are available for flexibility.

Two other flags are present in the ADC\_SR register, but there is no interrupt associated with them:

- JSTRT (Start of conversion for channels of an injected group)
- STRT (Start of conversion for channels of a regular group)

**Table 45. ADC interrupts**

Interrupt event	Event flag	Enable control bit
End of conversion of a regular group	EOC	EOCIE
End of conversion of an injected group	JEOC	JEOCIE
Analog watchdog status bit is set	AWD	AWDIE
Overrun	OVR	OVRIE

## 11.12 ADC registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers must be written at word level (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits) or words (32 bits).

### 11.12.1 ADC status register (ADC\_SR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															
								OVR	STRT	JSTRT	JEOC	EOC	AWD		
								rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0		

Bits 31:6 Reserved, must be kept at reset value.

#### Bit 5 **OVR**: Overrun

This bit is set by hardware when data are lost. It is cleared by software. Overrun detection is enabled only when DMA = 1 or EOCS = 1.

- 0: No overrun occurred
- 1: Overrun has occurred

#### Bit 4 **STRT**: Regular channel start flag

This bit is set by hardware when regular channel conversion starts. It is cleared by software.

- 0: No regular channel conversion started
- 1: Regular channel conversion has started

#### Bit 3 **JSTRT**: Injected channel start flag

This bit is set by hardware when injected group conversion starts. It is cleared by software.

- 0: No injected group conversion started
- 1: Injected group conversion has started

#### Bit 2 **JEOC**: Injected channel end of conversion

This bit is set by hardware at the end of the conversion of all injected channels in the group. It is cleared by software.

- 0: Conversion is not complete
- 1: Conversion complete

#### Bit 1 **EOC**: Regular channel end of conversion

This bit is set by hardware at the end of the conversion of a regular group of channels. It is cleared by software or by reading the ADC\_DR register.

- 0: Conversion not complete (EOCS=0), or sequence of conversions not complete (EOCS=1)
- 1: Conversion complete (EOCS=0), or sequence of conversions complete (EOCS=1)

#### Bit 0 **AWD**: Analog watchdog flag

This bit is set by hardware when the converted voltage crosses the values programmed in the ADC\_LTR and ADC\_HTR registers. It is cleared by software.

- 0: No analog watchdog event occurred
- 1: Analog watchdog event occurred

### 11.12.2 ADC control register 1 (ADC\_CR1)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				OVRIE	RES		AWDEN	JAWDEN	Reserved						
rw	rw	rw	rw	rw	rw	rw	rw	rw							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DISCNUM[2:0]			JDISCEN	DISCEN	JAUTO	AWDSGL	SCAN	JEOCIE	AWDIE	EOCIE	AWDCH[4:0]				
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **OVRIE**: Overrun interrupt enable

This bit is set and cleared by software to enable/disable the Overrun interrupt.

0: Overrun interrupt disabled

1: Overrun interrupt enabled. An interrupt is generated when the OVR bit is set.

Bits 25:24 **RES[1:0]**: Resolution

These bits are written by software to select the resolution of the conversion.

00: 12-bit (15 ADCCLK cycles)

01: 10-bit (13 ADCCLK cycles)

10: 8-bit (11 ADCCLK cycles)

11: 6-bit (9 ADCCLK cycles)

Bit 23 **AWDEN**: Analog watchdog enable on regular channels

This bit is set and cleared by software.

0: Analog watchdog disabled on regular channels

1: Analog watchdog enabled on regular channels

Bit 22 **JAWDEN**: Analog watchdog enable on injected channels

This bit is set and cleared by software.

0: Analog watchdog disabled on injected channels

1: Analog watchdog enabled on injected channels

Bits 21:16 Reserved, must be kept at reset value.

Bits 15:13 **DISCNUM[2:0]**: Discontinuous mode channel count

These bits are written by software to define the number of regular channels to be converted in discontinuous mode, after receiving an external trigger.

000: 1 channel

001: 2 channels

...

111: 8 channels

Bit 12 **JDISCEN**: Discontinuous mode on injected channels

This bit is set and cleared by software to enable/disable discontinuous mode on the injected channels of a group.

0: Discontinuous mode on injected channels disabled

1: Discontinuous mode on injected channels enabled

Bit 11 **DISCEN:** Discontinuous mode on regular channels

This bit is set and cleared by software to enable/disable Discontinuous mode on regular channels.

- 0: Discontinuous mode on regular channels disabled
- 1: Discontinuous mode on regular channels enabled

Bit 10 **JAUTO:** Automatic injected group conversion

This bit is set and cleared by software to enable/disable automatic injected group conversion after regular group conversion.

- 0: Automatic injected group conversion disabled
- 1: Automatic injected group conversion enabled

Bit 9 **AWDSGL:** Enable the watchdog on a single channel in scan mode

This bit is set and cleared by software to enable/disable the analog watchdog on the channel identified by the AWDCH[4:0] bits.

- 0: Analog watchdog enabled on all channels
- 1: Analog watchdog enabled on a single channel

Bit 8 **SCAN:** Scan mode

This bit is set and cleared by software to enable/disable the Scan mode. In Scan mode, the inputs selected through the ADC\_SQRx or ADC\_JSQRx registers are converted.

- 0: Scan mode disabled
- 1: Scan mode enabled

*Note: An EOC interrupt is generated if the EOCS bit is set:*

- At the end of each regular group sequence if the EOCS bit is cleared to 0
- At the end of each regular channel conversion if the EOCS bit is set to 1

*Note: A JEOC interrupt is generated only on the end of conversion of the last channel if the JEOCIE bit is set.*

Bit 7 **JEOCIE:** Interrupt enable for injected channels

This bit is set and cleared by software to enable/disable the end of conversion interrupt for injected channels.

- 0: JEOC interrupt disabled
- 1: JEOC interrupt enabled. An interrupt is generated when the JEOC bit is set.

Bit 6 **AWDIE:** Analog watchdog interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog interrupt.

- 0: Analog watchdog interrupt disabled
- 1: Analog watchdog interrupt enabled

Bit 5 **EOCIE:** Interrupt enable for EOC

This bit is set and cleared by software to enable/disable the end of conversion interrupt.

- 0: EOC interrupt disabled
- 1: EOC interrupt enabled. An interrupt is generated when the EOC bit is set.

Bits 4:0 **AWDCH[4:0]:** Analog watchdog channel select bits

These bits are set and cleared by software. They select the input channel to be guarded by the analog watchdog.

*Note: 00000: ADC analog input Channel0  
00001: ADC analog input Channel1*

...

- 01111: ADC analog input Channel15
- 10000: ADC analog input Channel16
- 10001: ADC analog input Channel17
- 10010: ADC analog input Channel18
- Other values reserved

### 11.12.3 ADC control register 2 (ADC\_CR2)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16								
reserved	SWST ART	EXTEN		EXTSEL[3:0]				reserved	JSWST ART	JEXTEN			JEXTSEL[3:0]										
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0								
reserved			ALIGN	EOCS	DDS	DMA		Reserved						CONT	ADON								
			rw	rw	rw	rw								rw	rw								

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SWSTART:** Start conversion of regular channels

This bit is set by software to start conversion and cleared by hardware as soon as the conversion starts.

0: Reset state

1: Starts conversion of regular channels

*Note: This bit can be set only when ADON = 1 otherwise no conversion is launched.*

Bits 29:28 **EXTEN:** External trigger enable for regular channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of a regular group.

00: Trigger detection disabled

01: Trigger detection on the rising edge

10: Trigger detection on the falling edge

11: Trigger detection on both the rising and falling edges

Bits 27:24 **EXTSEL[3:0]:** External event select for regular group

These bits select the external event used to trigger the start of conversion of a regular group:

0000: Timer 1 CC1 event

0001: Timer 1 CC2 event

0010: Timer 1 CC3 event

0011: Timer 2 CC2 event

0100: Timer 2 CC3 event

0101: Timer 2 CC4 event

0110: Timer 2 TRGO event

0111: Timer 3 CC1 event

1000: Timer 3 TRGO event

1001: Timer 4 CC4 event

1010: Timer 5 CC1 event

1011: Timer 5 CC2 event

1100: Timer 5 CC3 event

1101: Reserved

1110: Reserved

1111: EXTI line11

Bit 23 Reserved, must be kept at reset value.

Bit 22 **JSWSTART:** Start conversion of injected channels

This bit is set by software and cleared by hardware as soon as the conversion starts.

0: Reset state

1: Starts conversion of injected channels

*Note: This bit can be set only when ADON = 1 otherwise no conversion is launched.*

Bits 21:20 **JEXTEN:** External trigger enable for injected channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of an injected group.

00: Trigger detection disabled

01: Trigger detection on the rising edge

10: Trigger detection on the falling edge

11: Trigger detection on both the rising and falling edges

Bits 19:16 **JEXTSEL[3:0]:** External event select for injected group

These bits select the external event used to trigger the start of conversion of an injected group.

0000: Timer 1 CC4 event

0001: Timer 1 TRGO event

0010: Timer 2 CC1 event

0011: Timer 2 TRGO event

0100: Timer 3 CC2 event

0101: Timer 3 CC4 event

0110: Timer 4 CC1 event

0111: Timer 4 CC2 event

1000: Timer 4 CC3 event

1001: Timer 4 TRGO event

1010: Timer 5 CC4 event

1011: Timer 5 TRGO event

1100: Reserved

1101: Reserved

1110: Reserved

1111: EXTI line15

## Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **ALIGN:** Data alignment

This bit is set and cleared by software. Refer to [Figure 35](#) and [Figure 36](#).

0: Right alignment

1: Left alignment

Bit 10 **EOCS:** End of conversion selection

This bit is set and cleared by software.

0: The EOC bit is set at the end of each sequence of regular conversions. Overrun detection is enabled only if DMA=1.

1: The EOC bit is set at the end of each regular conversion. Overrun detection is enabled.

Bit 9 **DDS:** DMA disable selection (for single ADC mode)

This bit is set and cleared by software.

0: No new DMA request is issued after the last transfer (as configured in the DMA controller)

1: DMA requests are issued as long as data are converted and DMA=1

Bit 8 **DMA:** Direct memory access mode (for single ADC mode)

This bit is set and cleared by software. Refer to the DMA controller chapter for more details.

0: DMA mode disabled

1: DMA mode enabled

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **CONT**: Continuous conversion

This bit is set and cleared by software. If it is set, conversion takes place continuously until it is cleared.

0: Single conversion mode

1: Continuous conversion mode

Bit 0 **ADON**: A/D Converter ON / OFF

This bit is set and cleared by software.

Note: 0: Disable ADC conversion and go to power down mode

1: Enable ADC

#### 11.12.4 ADC sample time register 1 (ADC\_SMPR1)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				SMP18[2:0]			SMP17[2:0]			SMP16[2:0]			SMP15[2:1]		
				rw	rw	rw									
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP15_0		SMP14[2:0]			SMP13[2:0]			SMP12[2:0]			SMP11[2:0]			SMP10[2:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31: 27 Reserved, must be kept at reset value.

Bits 26:0 **SMPx[2:0]**: Channel x sampling time selection

These bits are written by software to select the sampling time individually for each channel.

During sampling cycles, the channel selection bits must remain unchanged.

Note: 000: 3 cycles

001: 15 cycles

010: 28 cycles

011: 56 cycles

100: 84 cycles

101: 112 cycles

110: 144 cycles

111: 480 cycles

#### 11.12.5 ADC sample time register 2 (ADC\_SMPR2)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved		SMP9[2:0]			SMP8[2:0]			SMP7[2:0]			SMP6[2:0]			SMP5[2:1]	
				rw	rw	rw									
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP5_0		SMP4[2:0]			SMP3[2:0]			SMP2[2:0]			SMP1[2:0]			SMP0[2:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:0 **SMPx[2:0]**: Channel x sampling time selection

These bits are written by software to select the sampling time individually for each channel.  
During sample cycles, the channel selection bits must remain unchanged.

Note: 000: 3 cycles  
001: 15 cycles  
010: 28 cycles  
011: 56 cycles  
100: 84 cycles  
101: 112 cycles  
110: 144 cycles  
111: 480 cycles

### 11.12.6 ADC injected channel data offset register x (ADC\_JOFRx) (x=1..4)

Address offset: 0x14-0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		JOFFSETx[11:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **JOFFSETx[11:0]**: Data offset for injected channel x

These bits are written by software to define the offset to be subtracted from the raw converted data when converting injected channels. The conversion result can be read from in the ADC\_JDRx registers.

### 11.12.7 ADC watchdog higher threshold register (ADC\_HTR)

Address offset: 0x24

Reset value: 0x0000 0FFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		HT[11:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **HT[11:0]**: Analog watchdog higher threshold

These bits are written by software to define the higher threshold for the analog watchdog.

### 11.12.8 ADC watchdog lower threshold register (ADC\_LTR)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		LT[11:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **LT[11:0]**: Analog watchdog lower threshold

These bits are written by software to define the lower threshold for the analog watchdog.

### 11.12.9 ADC regular sequence register 1 (ADC\_SQR1)

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								L[3:0]				SQ16[4:1]			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ16_0	SQ15[4:0]				SQ14[4:0]				SQ13[4:0]						
rw	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:20 **L[3:0]**: Regular channel sequence length

These bits are written by software to define the total number of conversions in the regular channel conversion sequence.

0000: 1 conversion

0001: 2 conversions

...

1111: 16 conversions

Bits 19:15 **SQ16[4:0]**: 16th conversion in regular sequence

These bits are written by software with the channel number (0..18) assigned as the 16th in the conversion sequence.

Bits 14:10 **SQ15[4:0]**: 15th conversion in regular sequence

Bits 9:5 **SQ14[4:0]**: 14th conversion in regular sequence

Bits 4:0 **SQ13[4:0]**: 13th conversion in regular sequence

### 11.12.10 ADC regular sequence register 2 (ADC\_SQR2)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved		SQ12[4:0]					SQ11[4:0]					SQ10[4:1]			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ10_0		SQ9[4:0]					SQ8[4:0]					SQ7[4:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:26 **SQ12[4:0]**: 12th conversion in regular sequence

These bits are written by software with the channel number (0..18) assigned as the 12th in the sequence to be converted.

Bits 24:20 **SQ11[4:0]**: 11th conversion in regular sequence

Bits 19:15 **SQ10[4:0]**: 10th conversion in regular sequence

Bits 14:10 **SQ9[4:0]**: 9th conversion in regular sequence

Bits 9:5 **SQ8[4:0]**: 8th conversion in regular sequence

Bits 4:0 **SQ7[4:0]**: 7th conversion in regular sequence

### 11.12.11 ADC regular sequence register 3 (ADC\_SQR3)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved		SQ6[4:0]					SQ5[4:0]					SQ4[4:1]			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ4_0		SQ3[4:0]					SQ2[4:0]					SQ1[4:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:25 **SQ6[4:0]**: 6th conversion in regular sequence

These bits are written by software with the channel number (0..18) assigned as the 6th in the sequence to be converted.

Bits 24:20 **SQ5[4:0]**: 5th conversion in regular sequence

Bits 19:15 **SQ4[4:0]**: 4th conversion in regular sequence

Bits 14:10 **SQ3[4:0]**: 3rd conversion in regular sequence

Bits 9:5 **SQ2[4:0]**: 2nd conversion in regular sequence

Bits 4:0 **SQ1[4:0]**: 1st conversion in regular sequence

### 11.12.12 ADC injected sequence register (ADC\_JSQR)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved										JL[1:0]	JSQ4[4:1]				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JSQ4[0]	JSQ3[4:0]						JSQ2[4:0]						JSQ1[4:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:20 **JL[1:0]:** Injected sequence length

These bits are written by software to define the total number of conversions in the injected channel conversion sequence.

00: 1 conversion

01: 2 conversions

10: 3 conversions

11: 4 conversions

Bits 19:15 **JSQ4[4:0]:** 4th conversion in injected sequence (when JL[1:0]=3, see note below)

These bits are written by software with the channel number (0..18) assigned as the 4th in the sequence to be converted.

Bits 14:10 **JSQ3[4:0]:** 3rd conversion in injected sequence (when JL[1:0]=3, see note below)

Bits 9:5 **JSQ2[4:0]:** 2nd conversion in injected sequence (when JL[1:0]=3, see note below)

Bits 4:0 **JSQ1[4:0]:** 1st conversion in injected sequence (when JL[1:0]=3, see note below)

**Note:** When JL[1:0]=3 (4 injected conversions in the sequencer), the ADC converts the channels in the following order: JSQ1[4:0], JSQ2[4:0], JSQ3[4:0], and JSQ4[4:0].

When JL=2 (3 injected conversions in the sequencer), the ADC converts the channels in the following order: JSQ2[4:0], JSQ3[4:0], and JSQ4[4:0].

When JL=1 (2 injected conversions in the sequencer), the ADC converts the channels in starting from JSQ3[4:0], and then JSQ4[4:0].

When JL=0 (1 injected conversion in the sequencer), the ADC converts only JSQ4[4:0] channel.

### 11.12.13 ADC injected data register x (ADC\_JDRx) (x= 1..4)

Address offset: 0x3C - 0x48

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **JDATA[15:0]**: Injected data

These bits are read-only. They contain the conversion result from injected channel x. The data are left -or right-aligned as shown in [Figure 35](#) and [Figure 36](#).

#### 11.12.14 ADC regular data register (ADC\_DR)

Address offset: 0x4C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **DATA[15:0]**: Regular data

These bits are read-only. They contain the conversion result from the regular channels. The data are left- or right-aligned as shown in [Figure 35](#) and [Figure 36](#).

### 11.12.15 ADC common control register (ADC\_CCR)

Address offset: 0x04 (this offset address is relative to ADC1 base address + 0x300)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								TSVREFE	VBATE	Reserved				ADCPRE	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TSVREFE**: Temperature sensor and V<sub>REFINT</sub> enable

This bit is set and cleared by software to enable/disable the temperature sensor and the V<sub>REFINT</sub> channel.

0: Temperature sensor and V<sub>REFINT</sub> channel disabled  
1: Temperature sensor and V<sub>REFINT</sub> channel enabled

Note: VBATE must be disabled when TSVREFE is set. If both bits are set, only the VBAT conversion is performed.

Bit 22 **VBATE**: V<sub>BAT</sub> enable

This bit is set and cleared by software to enable/disable the V<sub>BAT</sub> channel.

0: V<sub>BAT</sub> channel disabled  
1: V<sub>BAT</sub> channel enabled

Bits 21:18 Reserved, must be kept at reset value.

Bits 17:16 **ADCPRE**: ADC prescaler

Set and cleared by software to select the frequency of the clock to the ADC. .

Note: 00: PCLK2 divided by 2  
01: PCLK2 divided by 4  
10: PCLK2 divided by 6  
11: PCLK2 divided by 8

Bits 15:0 Reserved, must be kept at reset value.

### 11.12.16 ADC register map

The following table summarizes the ADC registers.

Table 46. ADC global register map

Offset	Register
0x000 - 0x04C	ADC1
0x050 - 0x0FC	Reserved
0x100 - 0x14C	Reserved
0x118 - 0x1FC	Reserved
0x200 - 0x24C	Reserved
0x250 - 0x2FC	Reserved
0x300 - 0x308	Common registers

**Table 47. ADC register map and reset values for each ADC**

**Table 48. ADC register map and reset values (common ADC registers)**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x04	ADC_CCR	Reserved				TSVREFE 0	VBATE 0	Reserved				ADCPRE[1:0] 0	Reserved																				
		Reset value																															

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 12 Advanced-control timer (TIM1)

TIM8 is not available in STM32F401xB/C and STM32F401xD/E.

### 12.1 TIM1 introduction

The advanced-control timers (TIM1) consist of a 16-bit auto-reload counter driven by a programmable prescaler.

It may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM, complementary PWM with dead-time insertion).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The advanced-control (TIM1) and general-purpose (TIMx) timers are completely independent, and do not share any resources. They can be synchronized together as described in [Section 12.3.20](#).

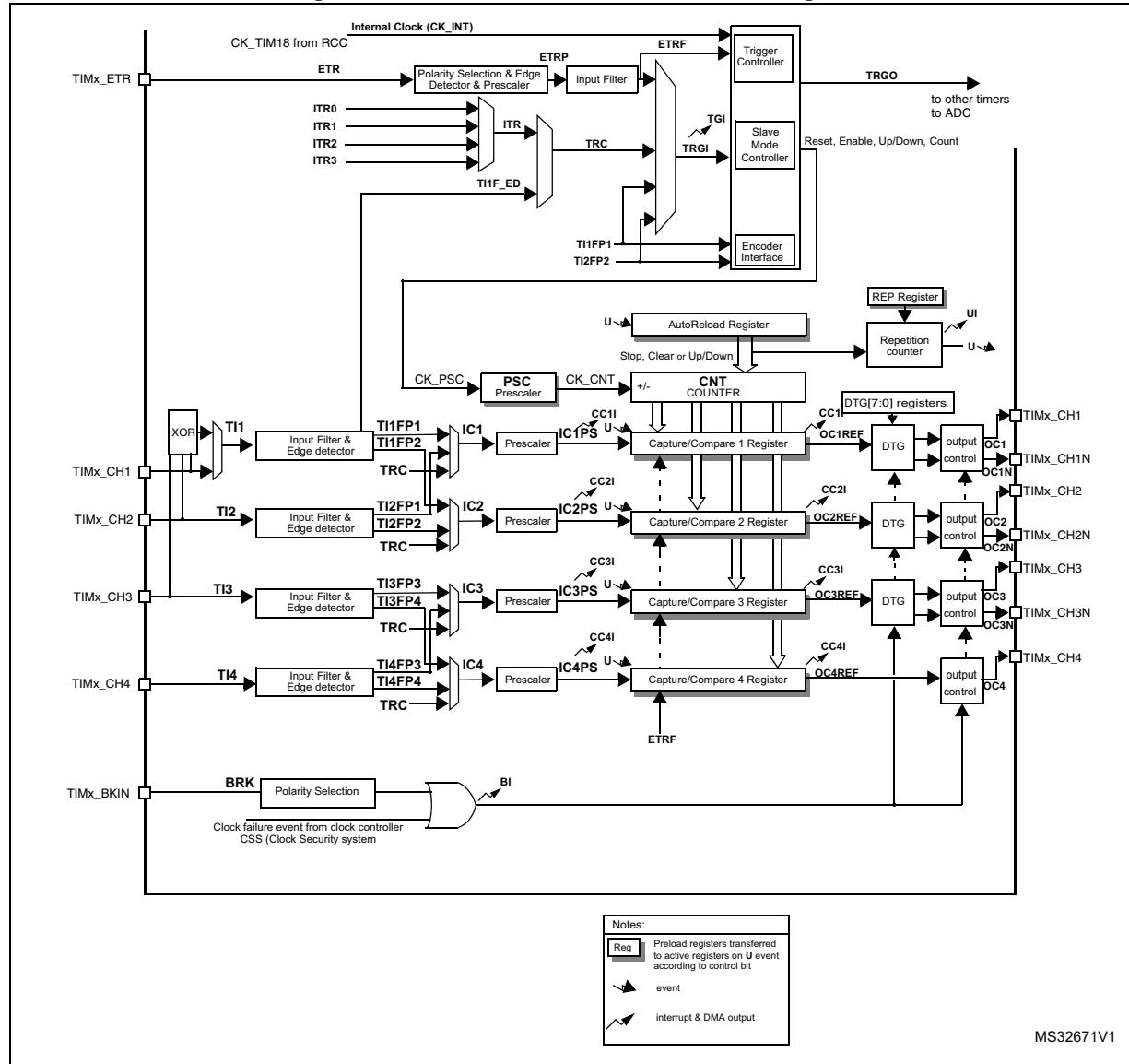
### 12.2 TIM1 main features

TIM1 timer features include:

- 16-bit up, down, up/down auto-reload counter.
- 16-bit programmable prescaler allowing dividing (also “on the fly”) the counter clock frequency either by any factor between 1 and 65536.
- Up to 4 independent channels for:
  - Input Capture
  - Output Compare
  - PWM generation (Edge and Center-aligned Mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time
- Synchronization circuit to control the timer with external signals and to interconnect several timers together.
- Repetition counter to update the timer registers only after a given number of cycles of the counter.
- Break input to put the timer’s output signals in reset state or in a known state.

- Interrupt/DMA generation on the following events:
  - Update: counter overflow/underflow, counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization or count by internal/external trigger)
  - Input capture
  - Output compare
  - Break input
- Supports incremental (quadrature) encoder and hall-sensor circuitry for positioning purposes
- Trigger input for external clock or cycle-by-cycle current management

Figure 39. Advanced-control timer block diagram



## 12.3 TIM1 functional description

### 12.3.1 Time-base unit

The main block of the programmable advanced-control timer is a 16-bit counter with its related auto-reload register. The counter can count up, down or both up and down. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx\_CNT)
- Prescaler register (TIMx\_PSC)
- Auto-reload register (TIMx\_ARR)
- Repetition counter register (TIMx\_RCR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx\_CR1 register. The update event is sent when the counter reaches the overflow (or underflow when downcounting) and if the UDIS bit equals 0 in the TIMx\_CR1 register. It can also be generated by software. The generation of the update event is described in detailed for each configuration.

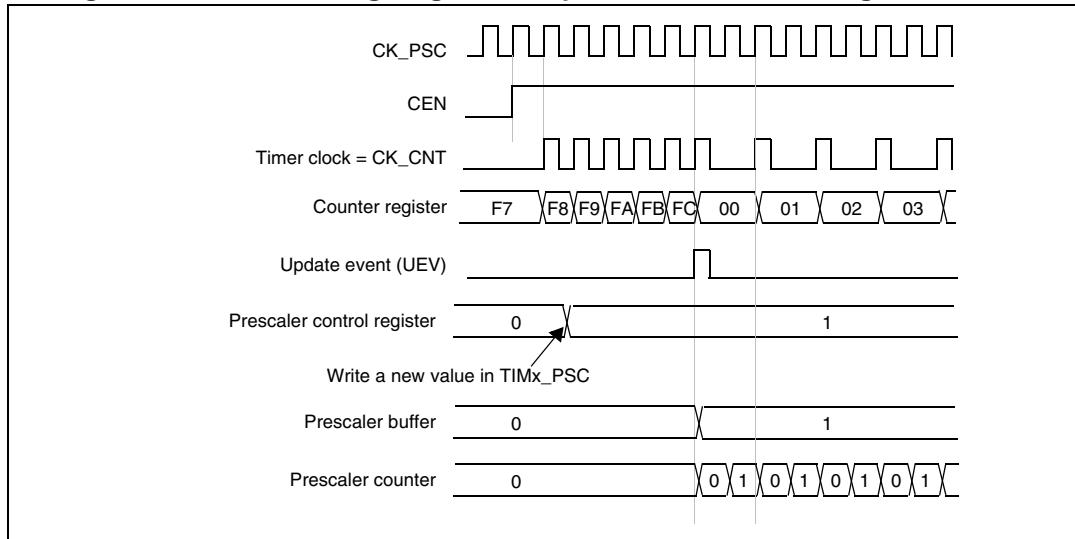
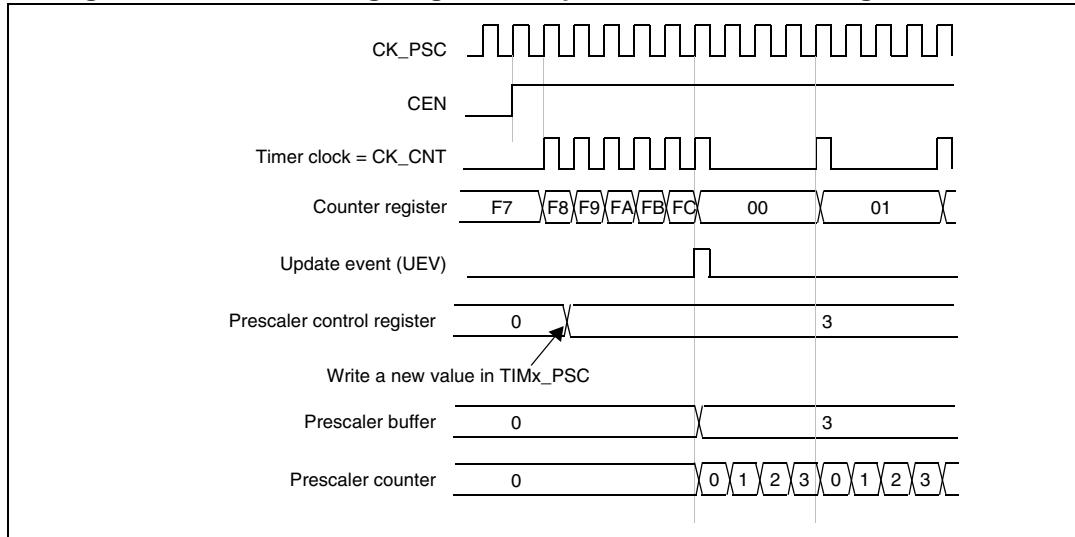
The counter is clocked by the prescaler output CK\_CNT, which is enabled only when the counter enable bit (CEN) in TIMx\_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the counter starts counting 1 clock cycle after setting the CEN bit in the TIMx\_CR1 register.

#### Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx\_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

*Figure 40* and *Figure 41* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

**Figure 40. Counter timing diagram with prescaler division change from 1 to 2****Figure 41. Counter timing diagram with prescaler division change from 1 to 4**

### 12.3.2 Counter modes

#### Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx\_ARR register), then restarts from 0 and generates a counter overflow event.

If the repetition counter is used, the update event (UEV) is generated after upcounting is repeated for the number of times programmed in the repetition counter register (TIMx\_RCR). Else the update event is generated at each counter overflow.

Setting the UG bit in the TIMx\_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the

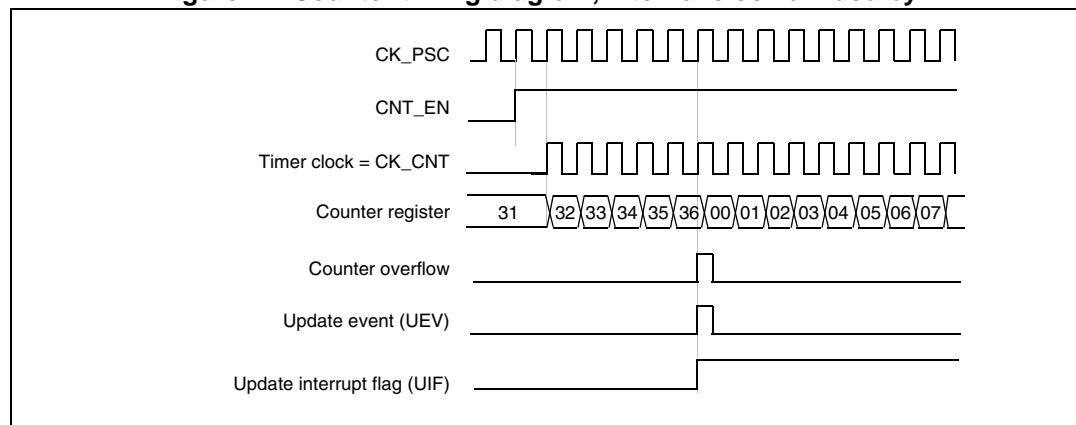
preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

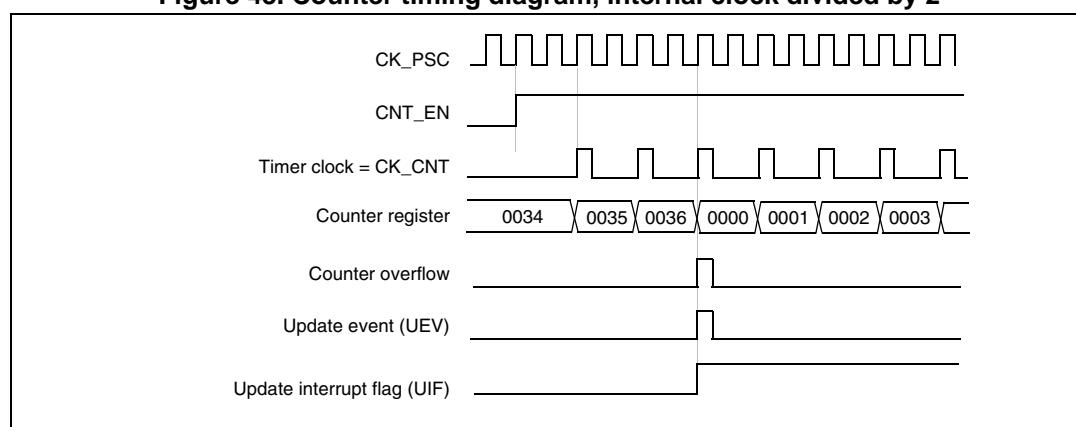
- The repetition counter is reloaded with the content of TIMx\_RCR register,
- The auto-reload shadow register is updated with the preload value (TIMx\_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register).

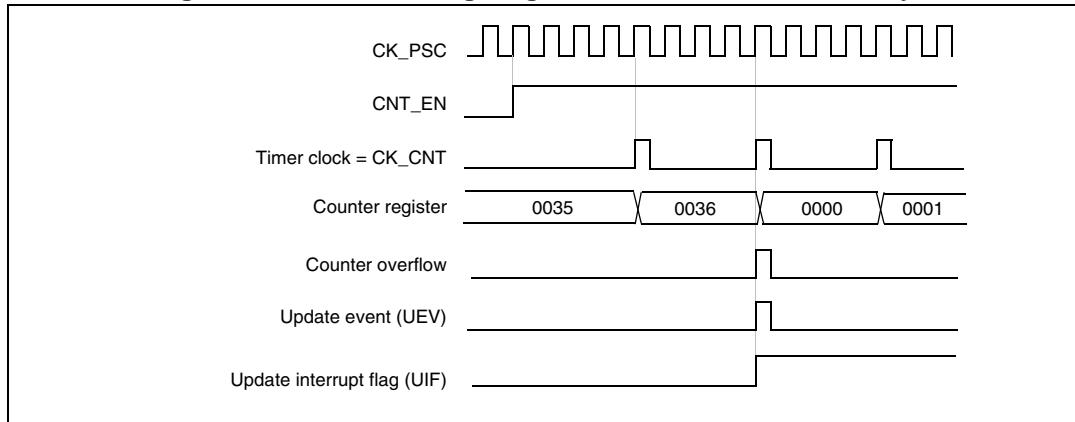
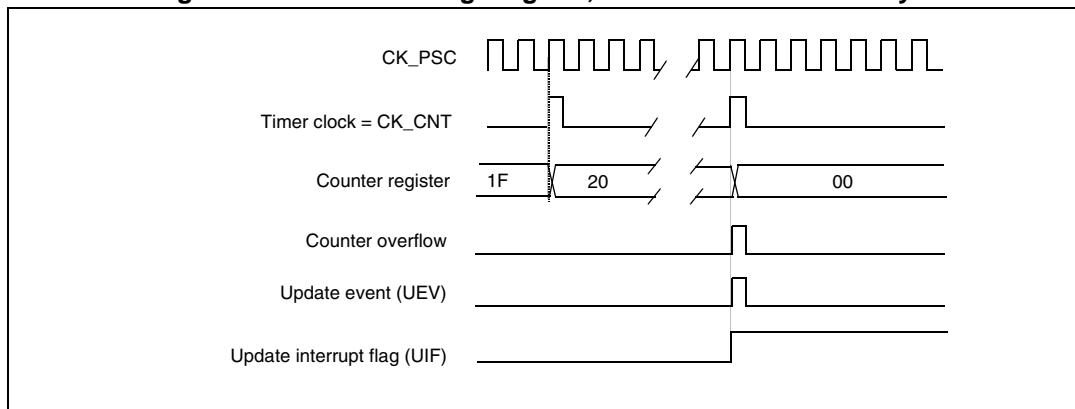
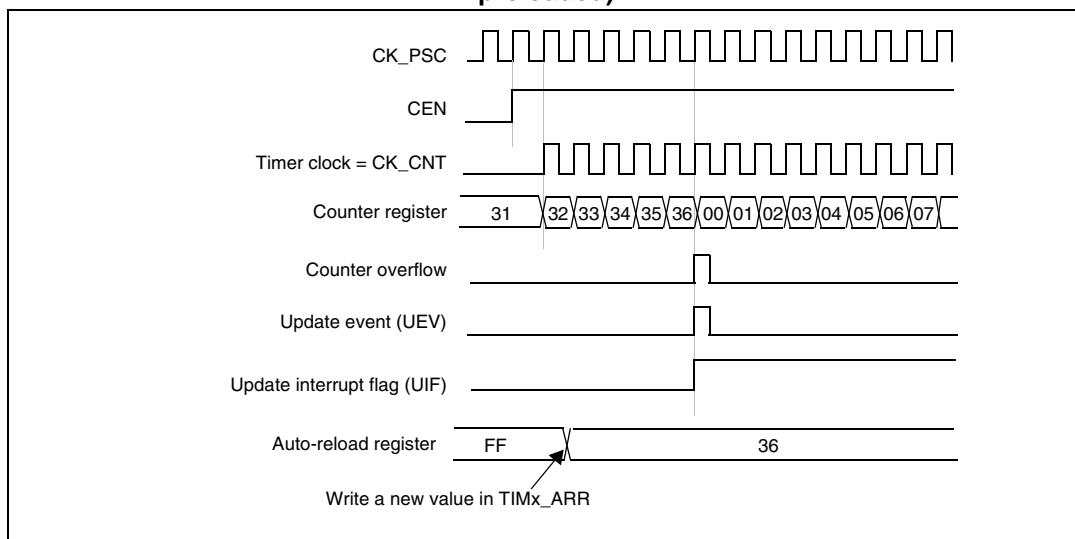
The following figures show some examples of the counter behavior for different clock frequencies when TIMx\_ARR=0x36.

**Figure 42. Counter timing diagram, internal clock divided by 1**

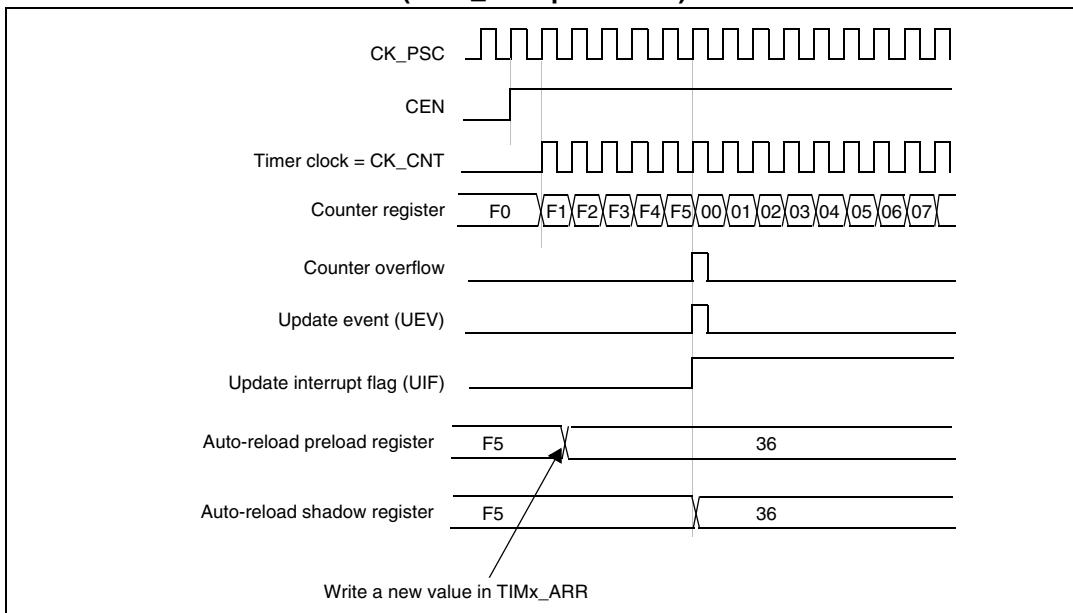


**Figure 43. Counter timing diagram, internal clock divided by 2**



**Figure 44. Counter timing diagram, internal clock divided by 4****Figure 45. Counter timing diagram, internal clock divided by N****Figure 46. Counter timing diagram, update event when ARPE=0 (TIMx\_ARR not preloaded)**

**Figure 47. Counter timing diagram, update event when ARPE=1  
(TIMx\_ARR preloaded)**



### Downcounting mode

In downcounting mode, the counter counts from the auto-reload value (content of the TIMx\_ARR register) down to 0, then restarts from the auto-reload value and generates a counter underflow event.

If the repetition counter is used, the update event (UEV) is generated after downcounting is repeated for the number of times programmed in the repetition counter register plus one (TIMx\_RCR+1). Else the update event is generated at each counter underflow.

Setting the UG bit in the TIMx\_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV update event can be disabled by software by setting the UDIS bit in TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter restarts from the current auto-reload value, whereas the counter of the prescaler restarts from 0 (but the prescale rate doesn't change).

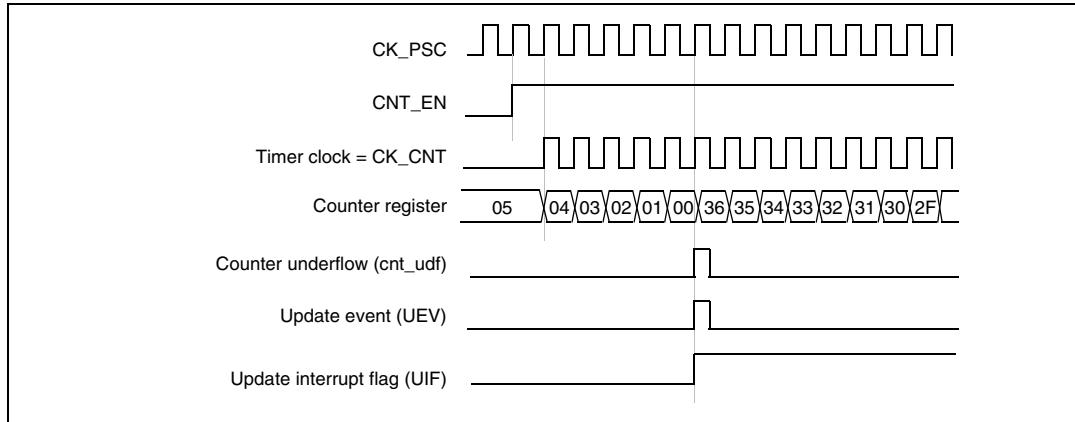
In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

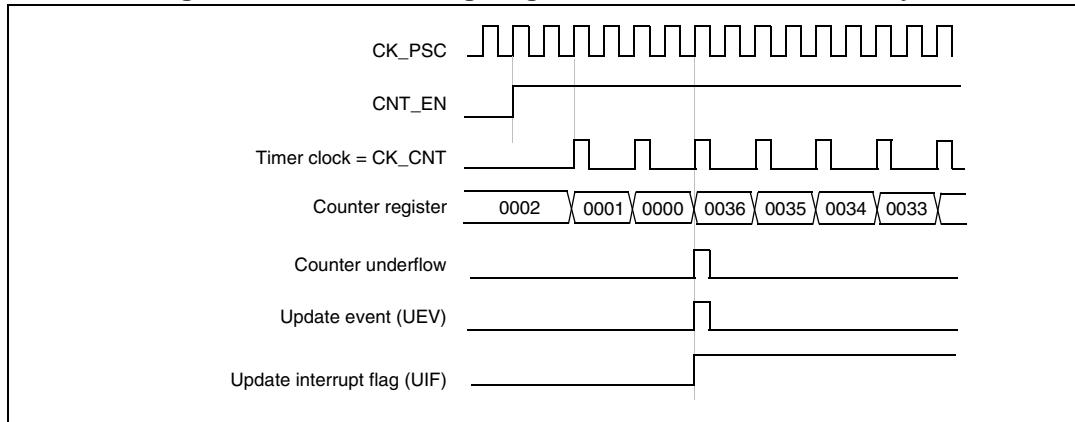
- The repetition counter is reloaded with the content of TIMx\_RCR register
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register)
- The auto-reload active register is updated with the preload value (content of the TIMx\_ARR register). Note that the auto-reload is updated before the counter is reloaded, so that the next period is the expected one

The following figures show some examples of the counter behavior for different clock frequencies when TIMx\_ARR=0x36.

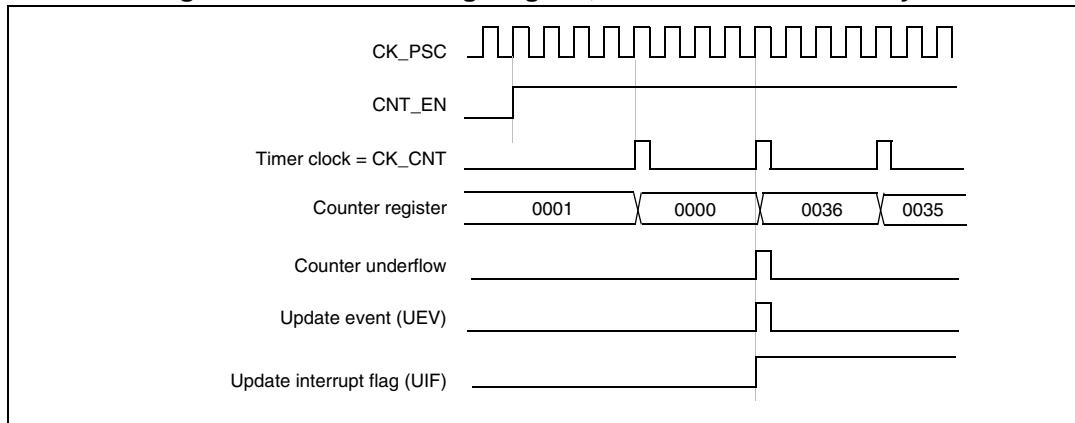
**Figure 48. Counter timing diagram, internal clock divided by 1**

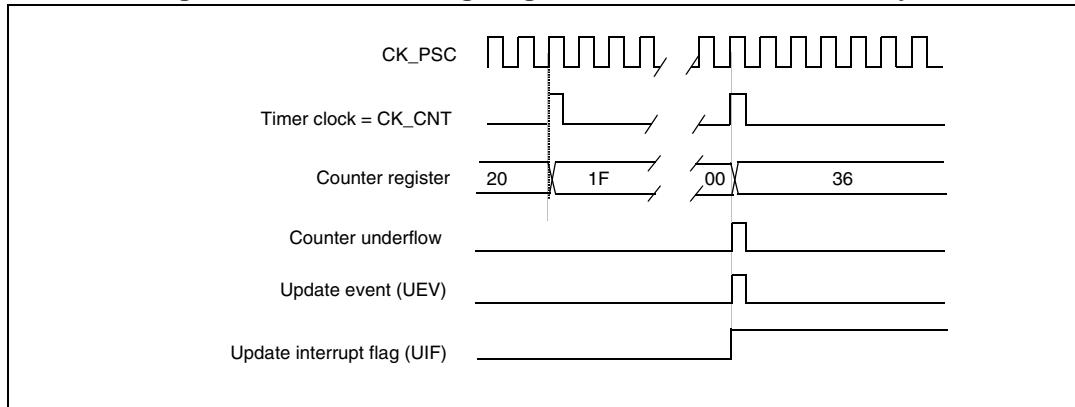
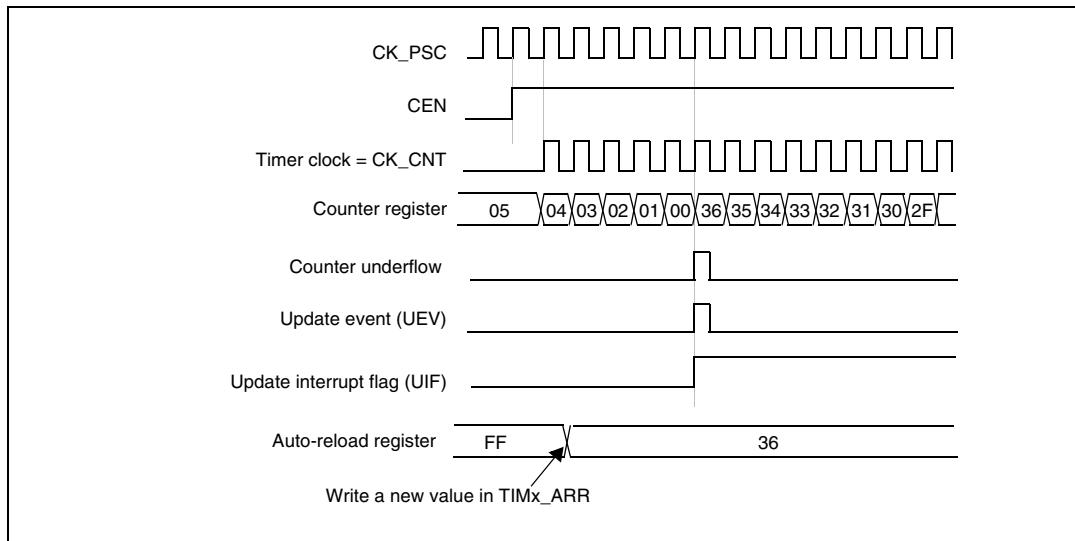


**Figure 49. Counter timing diagram, internal clock divided by 2**



**Figure 50. Counter timing diagram, internal clock divided by 4**



**Figure 51. Counter timing diagram, internal clock divided by N****Figure 52. Counter timing diagram, update event when repetition counter is not used**

### Center-aligned mode (up/down counting)

In center-aligned mode, the counter counts from 0 to the auto-reload value (content of the TIMx\_ARR register) – 1, generates a counter overflow event, then counts from the auto-reload value down to 1 and generates a counter underflow event. Then it restarts counting from 0.

Center-aligned mode is active when the CMS bits in TIMx\_CR1 register are not equal to '00'. The Output compare interrupt flag of channels configured in output is set when: the counter counts down (Center aligned mode 1, CMS = "01"), the counter counts up (Center aligned mode 2, CMS = "10") or the counter counts up and down (Center aligned mode 3, CMS = "11").

In this mode, the DIR direction bit in the TIMx\_CR1 register cannot be written. It is updated by hardware and gives the current direction of the counter.

The update event can be generated at each counter overflow and at each counter underflow or by setting the UG bit in the TIMx\_EGR register (by software or by using the slave mode controller) also generates an update event. In this case, the counter restarts counting from 0, as well as the counter of the prescaler.

The UEV update event can be disabled by software by setting the UDIS bit in the TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter continues counting up and down, based on the current auto-reload value.

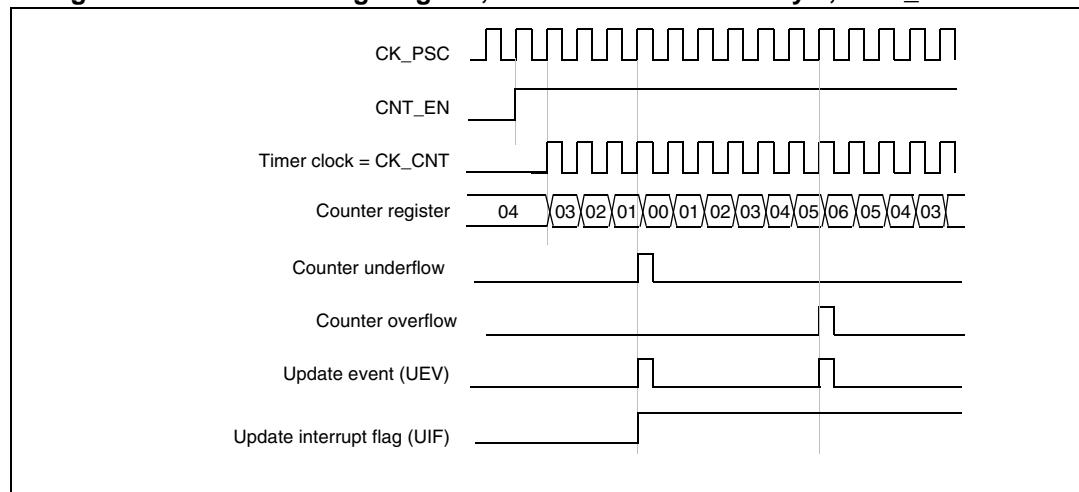
In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an UEV update event but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

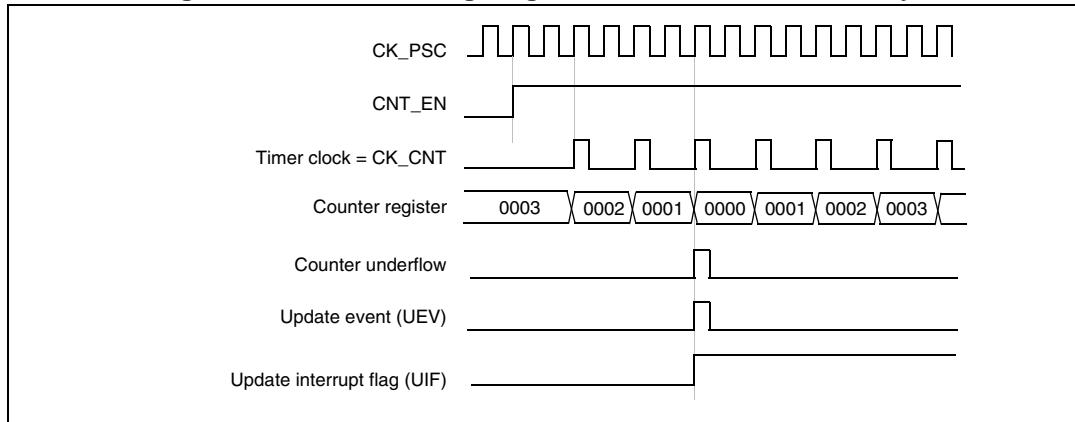
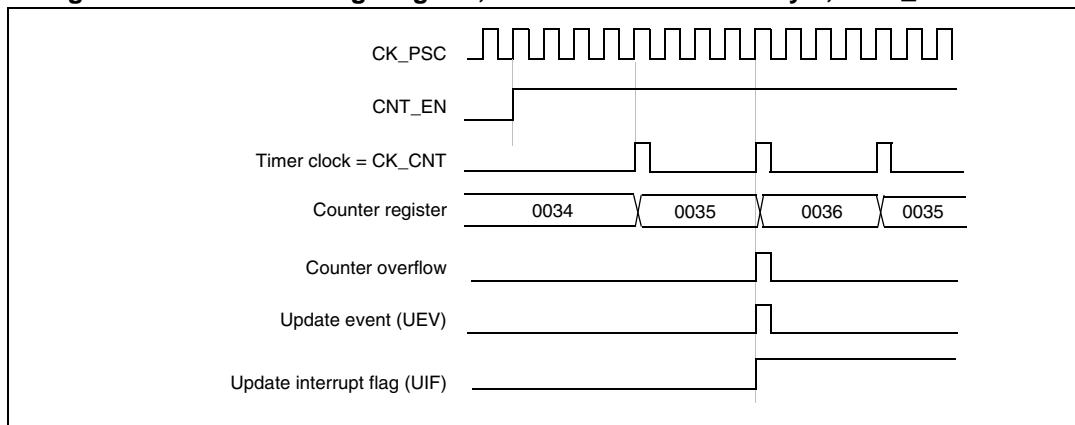
- The repetition counter is reloaded with the content of TIMx\_RCR register
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register)
- The auto-reload active register is updated with the preload value (content of the TIMx\_ARR register). Note that if the update source is a counter overflow, the auto-reload is updated before the counter is reloaded, so that the next period is the expected one (the counter is loaded with the new value).

The following figures show some examples of the counter behavior for different clock frequencies.

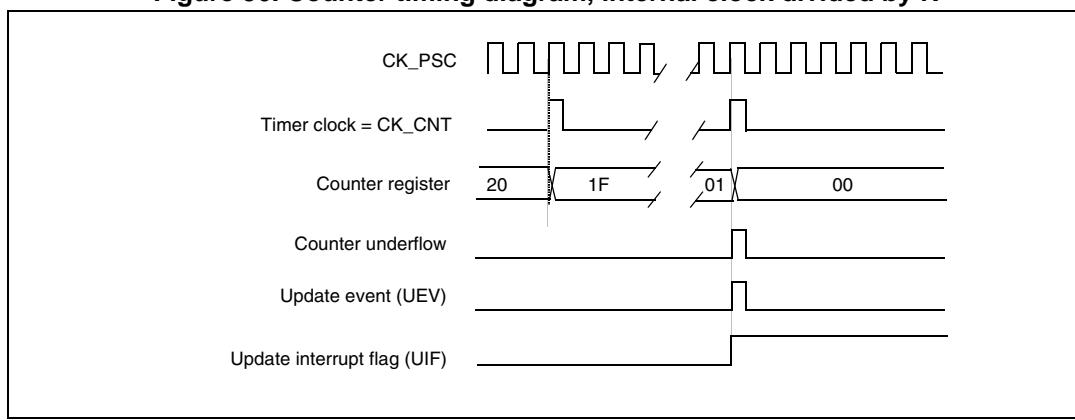
**Figure 53. Counter timing diagram, internal clock divided by 1, TIMx\_ARR = 0x6**

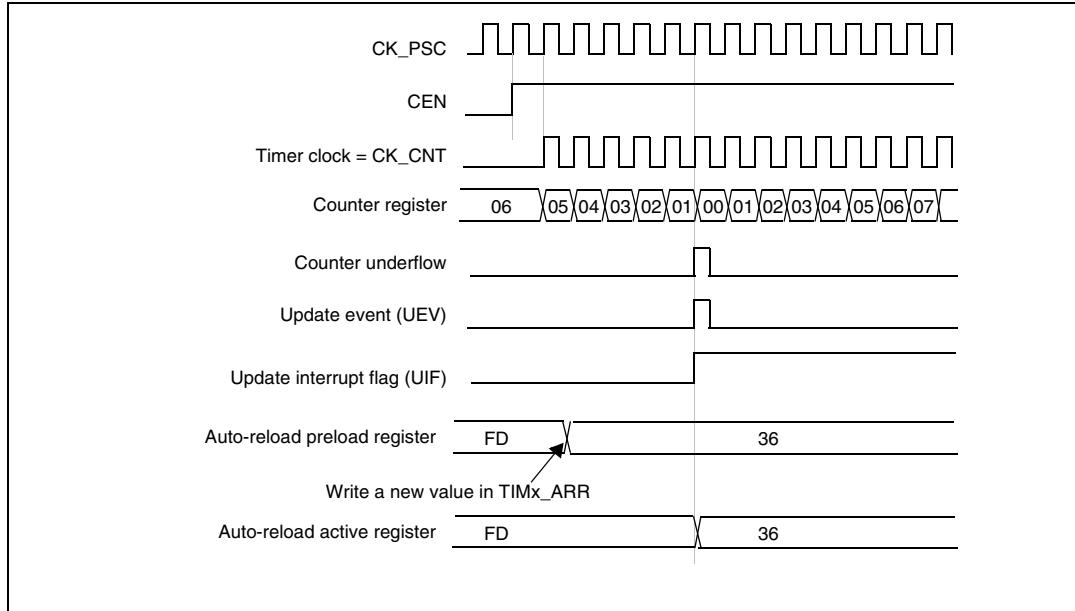
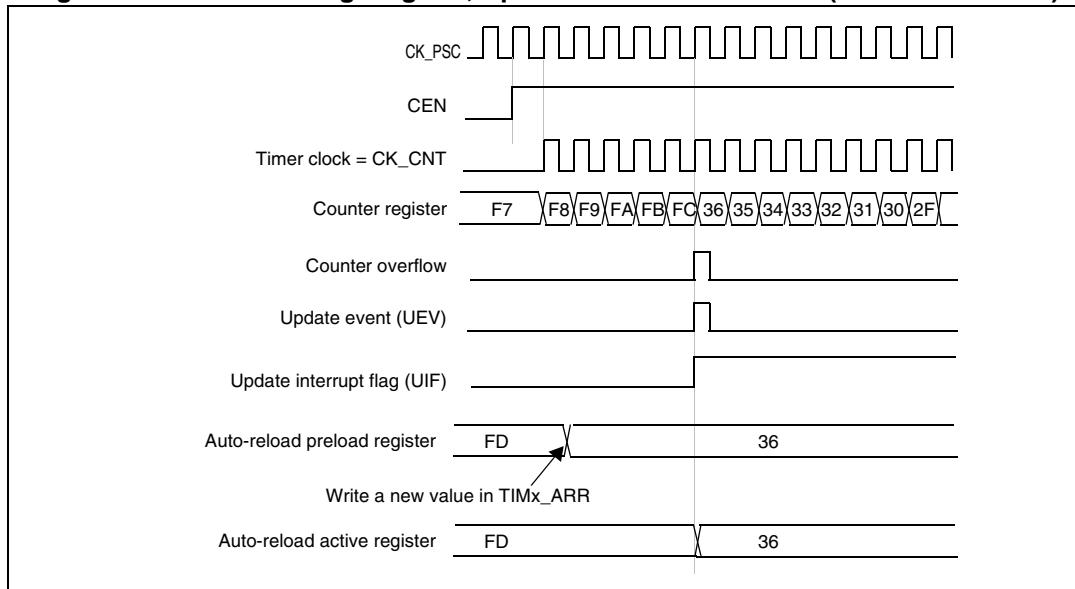


1. Here, center-aligned mode 1 is used (for more details refer to [Section 12.4: TIM1 registers on page 276](#)).

**Figure 54. Counter timing diagram, internal clock divided by 2****Figure 55. Counter timing diagram, internal clock divided by 4, TIMx\_ARR=0x36**

1. Center-aligned mode 2 or 3 is used with an UIF on overflow.

**Figure 56. Counter timing diagram, internal clock divided by N**

**Figure 57. Counter timing diagram, update event with ARPE=1 (counter underflow)****Figure 58. Counter timing diagram, Update event with ARPE=1 (counter overflow)**

### 12.3.3 Repetition counter

[Section 12.3.1: Time-base unit](#) describes how the update event (UEV) is generated with respect to the counter overflows/underflows. It is actually generated only when the repetition counter has reached zero. This can be useful when generating PWM signals.

This means that data are transferred from the preload registers to the shadow registers (TIMx\_ARR auto-reload register, TIMx\_PSC prescaler register, but also TIMx\_CCRx capture/compare registers in compare mode) every N+1 counter overflows or underflows, where N is the value in the TIMx\_RCR repetition counter register.

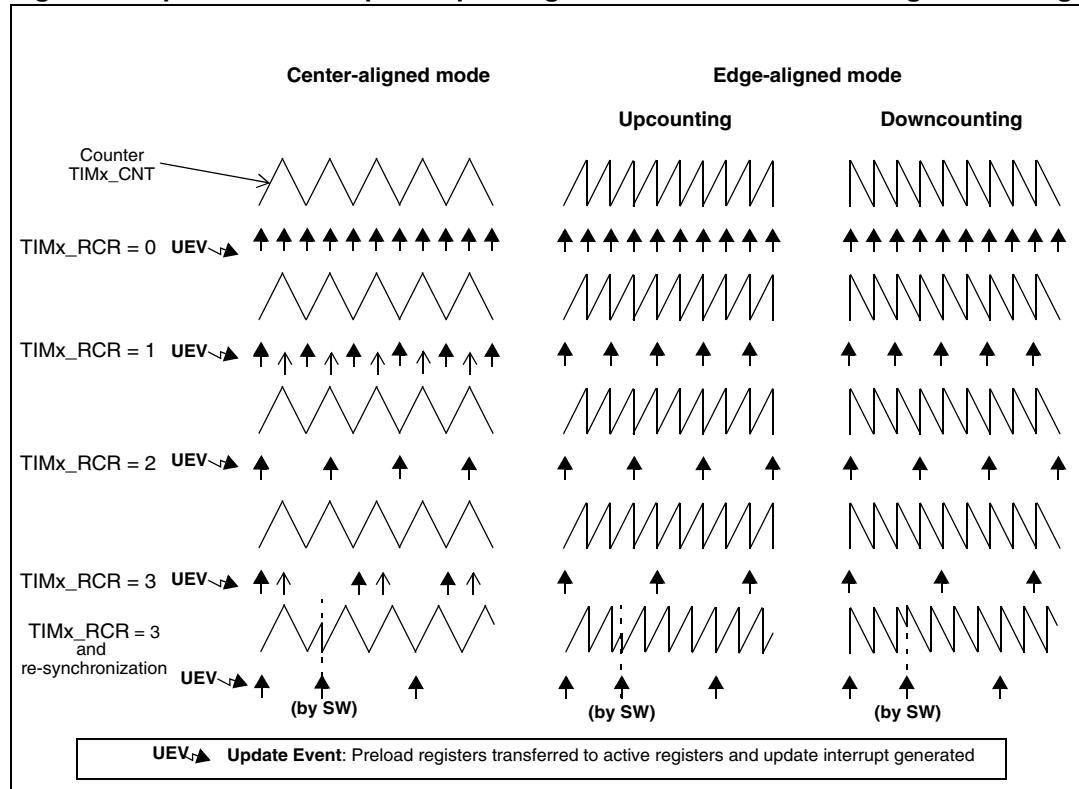
The repetition counter is decremented:

- At each counter overflow in upcounting mode,
  - At each counter underflow in downcounting mode,
  - At each counter overflow and at each counter underflow in center-aligned mode.
- Although this limits the maximum number of repetition to 128 PWM cycles, it makes it possible to update the duty cycle twice per PWM period. When refreshing compare registers only once per PWM period in center-aligned mode, maximum resolution is  $2 \times T_{ck}$ , due to the symmetry of the pattern.

The repetition counter is an auto-reload type; the repetition rate is maintained as defined by the TIMx\_RCR register value (refer to [Figure 59](#)). When the update event is generated by software (by setting the UG bit in TIMx\_EGR register) or by hardware through the slave mode controller, it occurs immediately whatever the value of the repetition counter is and the repetition counter is reloaded with the content of the TIMx\_RCR register.

In center-aligned mode, for odd values of RCR, the update event occurs either on the overflow or on the underflow depending on when the RCR register was written and when the counter was started. If the RCR was written before starting the counter, the UEV occurs on the overflow. If the RCR was written after starting the counter, the UEV occurs on the underflow. For example for RCR = 3, the UEV is generated on each 4th overflow or underflow event depending on when RCR was written.

**Figure 59. Update rate examples depending on mode and TIMx\_RCR register settings**



### 12.3.4 Clock selection

The counter clock can be provided by the following clock sources:

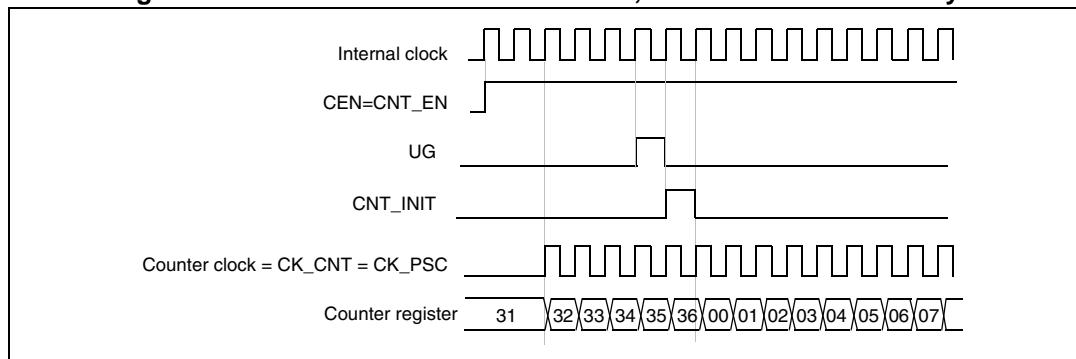
- Internal clock (CK\_INT)
- External clock mode1: external input pin
- External clock mode2: external trigger input ETR
- Internal trigger inputs (ITRx): using one timer as prescaler for another timer, for example, you can configure Timer 1 to act as a prescaler for Timer 2. Refer to [Using one timer as prescaler for another](#) for more details.

#### Internal clock source (CK\_INT)

If the slave mode controller is disabled (SMS=000), then the CEN, DIR (in the TIMx\_CR1 register) and UG bits (in the TIMx\_EGR register) are actual control bits and can be changed only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock CK\_INT.

[Figure 60](#) shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

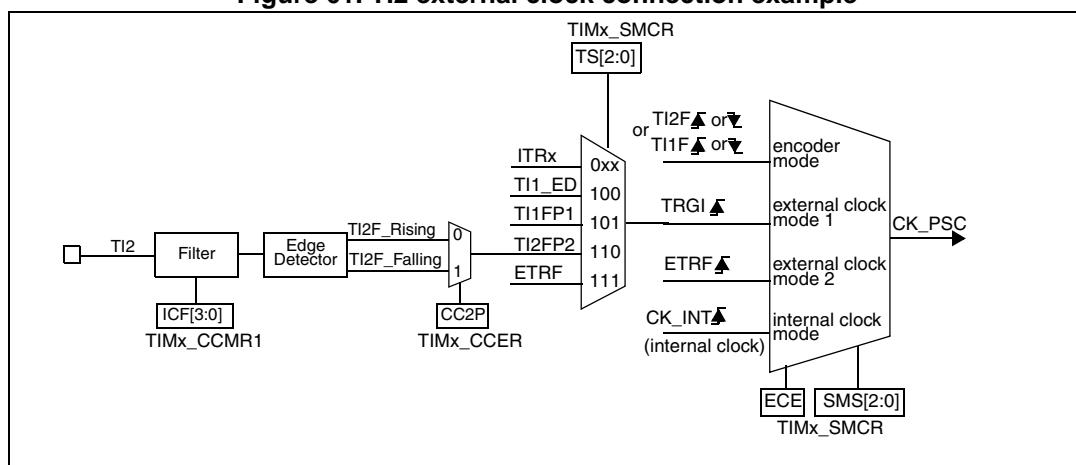
**Figure 60. Control circuit in normal mode, internal clock divided by 1**



#### External clock source mode 1

This mode is selected when SMS=111 in the TIMx\_SMCR register. The counter can count at each rising or falling edge on a selected input.

**Figure 61. TI2 external clock connection example**



For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

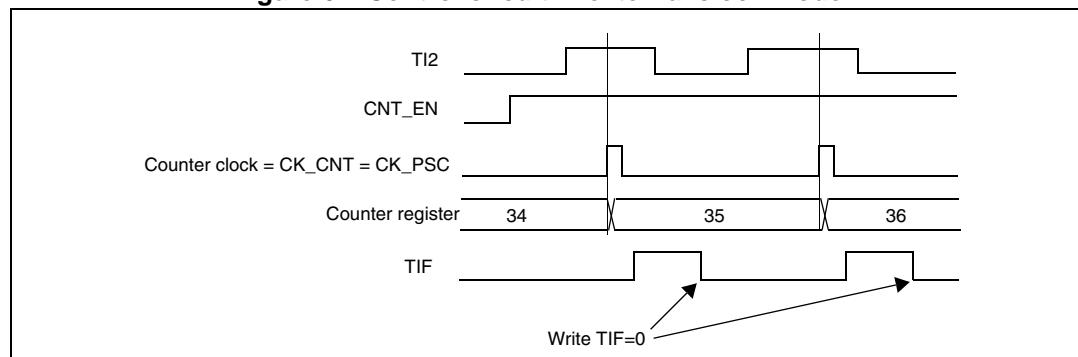
1. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S = '01' in the TIMx\_CCMR1 register.
2. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx\_CCMR1 register (if no filter is needed, keep IC2F=0000).
3. Select rising edge polarity by writing CC2P=0 and CC2NP=0 in the TIMx\_CCER register.
4. Configure the timer in external clock mode 1 by writing SMS=111 in the TIMx\_SMCR register.
5. Select TI2 as the trigger input source by writing TS=110 in the TIMx\_SMCR register.
6. Enable the counter by writing CEN=1 in the TIMx\_CR1 register.

*Note:* The capture prescaler is not used for triggering, so you don't need to configure it.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

**Figure 62. Control circuit in external clock mode 1**



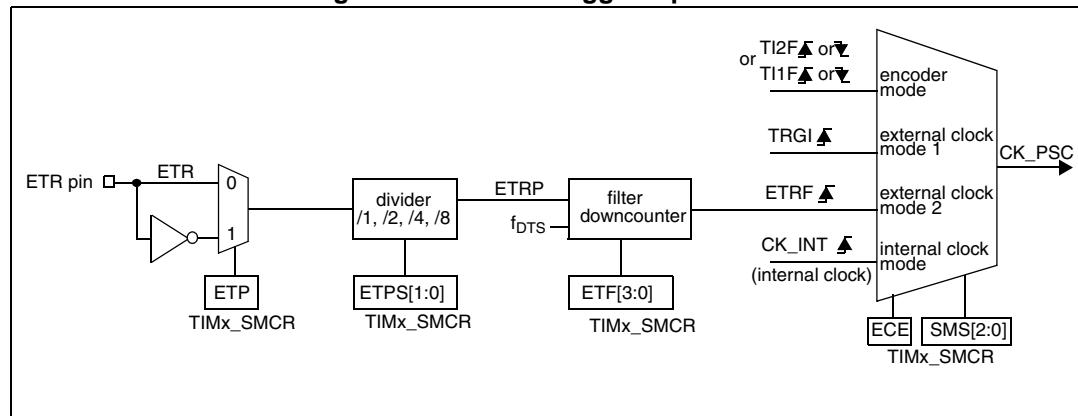
## External clock source mode 2

This mode is selected by writing ECE=1 in the TIMx\_SMCR register.

The counter can count at each rising or falling edge on the external trigger input ETR.

*Figure 63* gives an overview of the external trigger input block.

**Figure 63. External trigger input block**



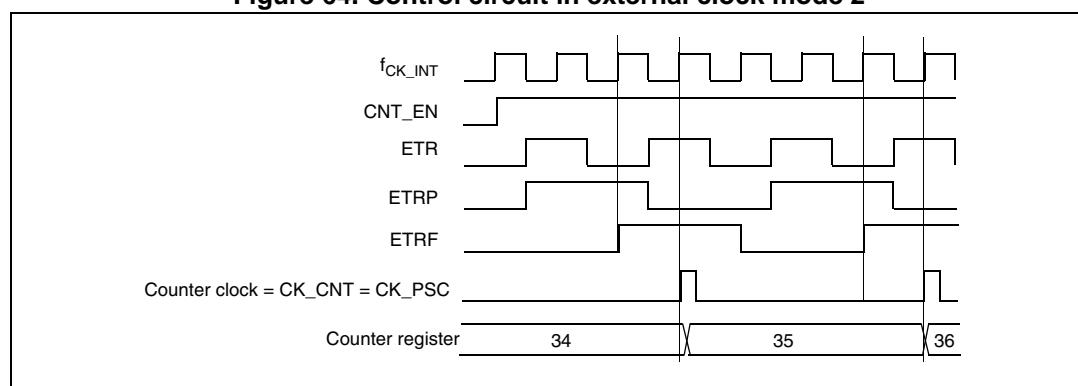
For example, to configure the upcounter to count each 2 rising edges on ETR, use the following procedure:

1. As no filter is needed in this example, write ETF[3:0]=0000 in the TIMx\_SMCR register.
2. Set the prescaler by writing ETSPS[1:0]=01 in the TIMx\_SMCR register
3. Select rising edge detection on the ETR pin by writing ETP=0 in the TIMx\_SMCR register
4. Enable external clock mode 2 by writing ECE=1 in the TIMx\_SMCR register.
5. Enable the counter by writing CEN=1 in the TIMx\_CR1 register.

The counter counts once each 2 ETR rising edges.

The delay between the rising edge on ETR and the actual clock of the counter is due to the resynchronization circuit on the ETRP signal.

**Figure 64. Control circuit in external clock mode 2**



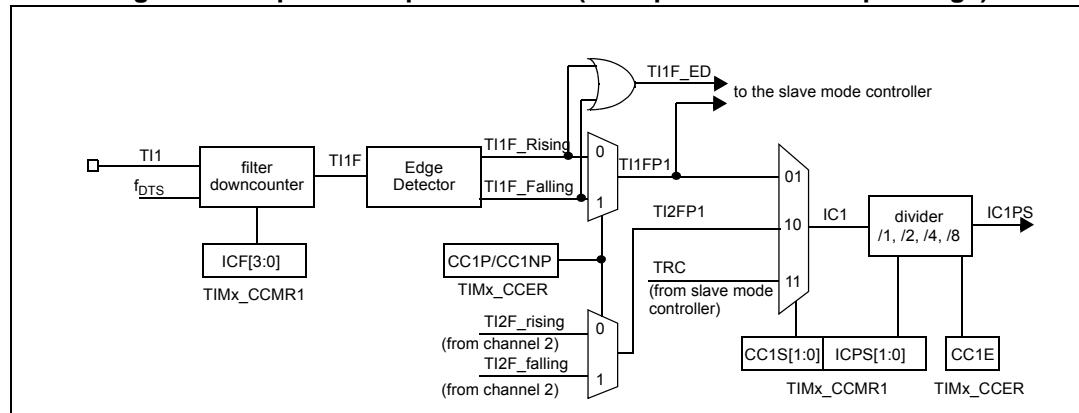
### 12.3.5 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

*Figure 65 to Figure 68* give an overview of one Capture/Compare channel.

The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

**Figure 65. Capture/compare channel (example: channel 1 input stage)**



The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

**Figure 66. Capture/compare channel 1 main circuit**

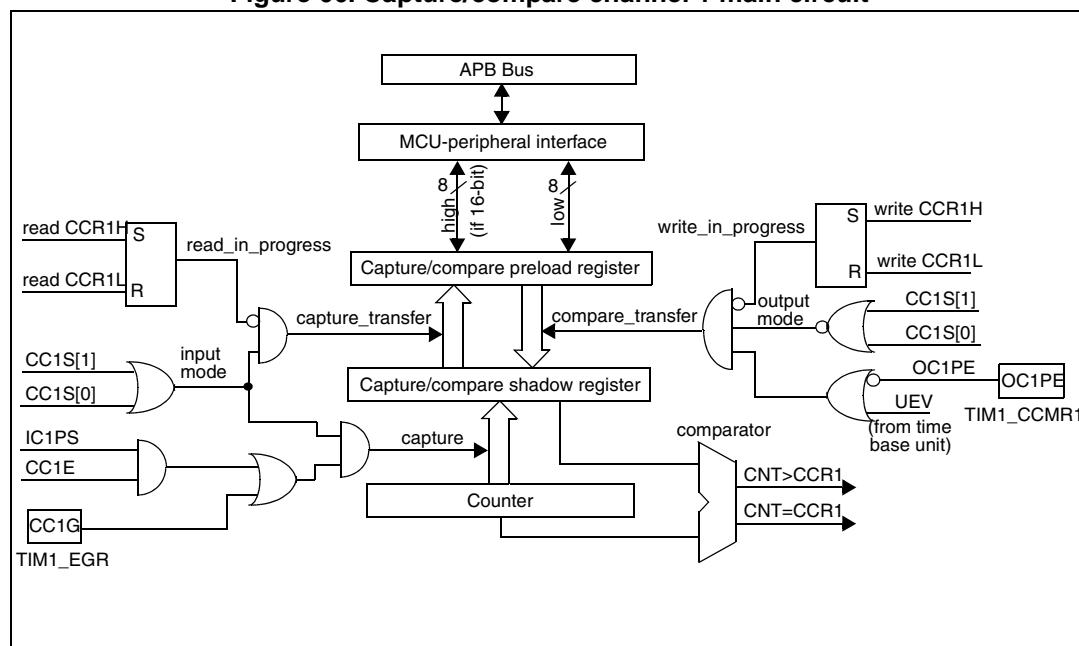


Figure 67. Output stage of capture/compare channel (channel 1 to 3)

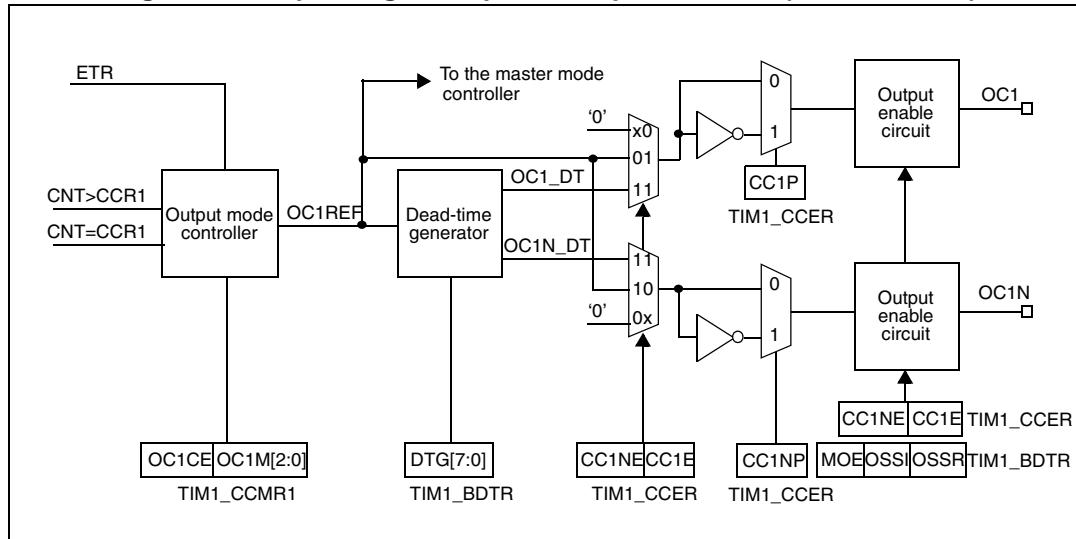
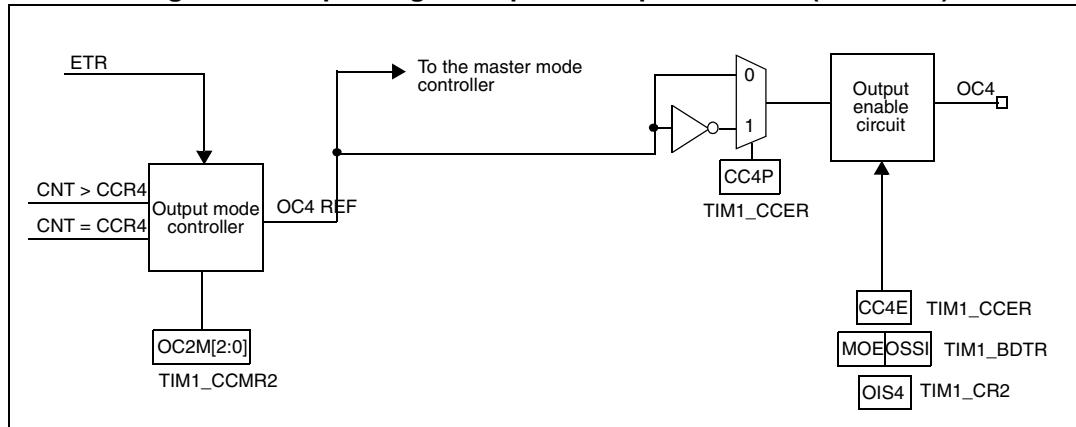


Figure 68. Output stage of capture/compare channel (channel 4)



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

### 12.3.6 Input capture mode

In Input capture mode, the Capture/Compare Registers (TIMx\_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx\_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the over-capture flag CCxOF (TIMx\_SR register) is set. CCxIF can be cleared by software by writing it to '0' or by reading the captured data stored in the TIMx\_CCRx register. CCxOF is cleared when you write it to '0'.

The following example shows how to capture the counter value in TIMx\_CCR1 when TI1 input rises. To do this, use the following procedure:

- Select the active input: TIMx\_CCR1 must be linked to the TI1 input, so write the CC1S bits to 01 in the TIMx\_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input and the TIMx\_CCR1 register becomes read-only.
- Program the input filter duration you need with respect to the signal you connect to the timer (by programming ICxF bits in the TIMx\_CCMRx register if the input is a TIx input). Let's imagine that, when toggling, the input signal is not stable during at most 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the new level have been detected (sampled at  $f_{DTS}$  frequency). Then write IC1F bits to 0011 in the TIMx\_CCMR1 register.
- Select the edge of the active transition on the TI1 channel by writing CC1P and CC1NP bits to 0 in the TIMx\_CCER register (rising edge in this case).
- Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to '00' in the TIMx\_CCMR1 register).
- Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx\_CCER register.
- If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx\_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx\_DIER register.

When an input capture occurs:

- The TIMx\_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

*Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx\_EGR register.*

### 12.3.7 PWM input mode

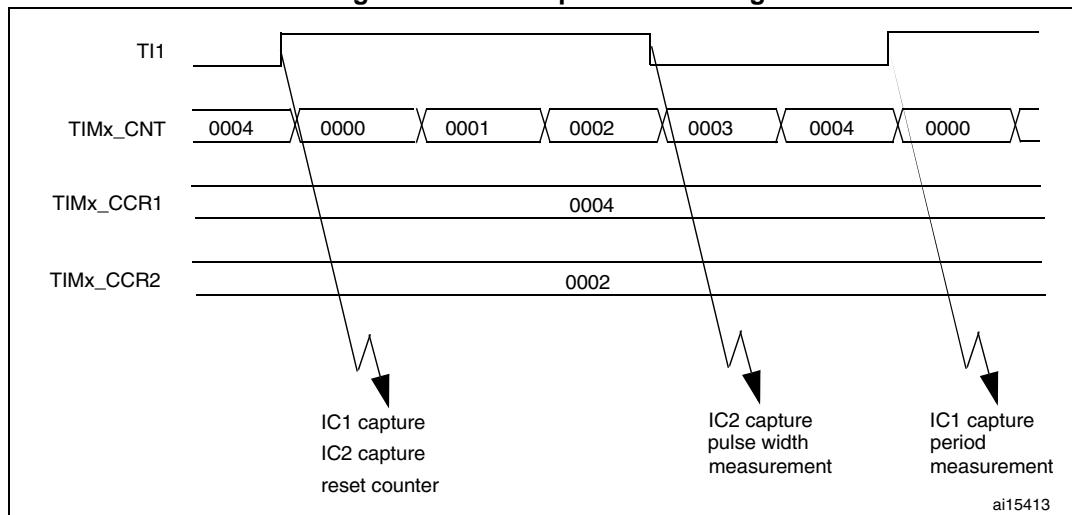
This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, you can measure the period (in TIMx\_CCR1 register) and the duty cycle (in TIMx\_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK\_INT frequency and prescaler value):

- Select the active input for TIMx\_CCR1: write the CC1S bits to 01 in the TIMx\_CCMR1 register (TI1 selected).
- Select the active polarity for TI1FP1 (used both for capture in TIMx\_CCR1 and counter clear): write the CC1P and CC1NP bits to '0' (active on rising edge).
- Select the active input for TIMx\_CCR2: write the CC2S bits to 10 in the TIMx\_CCMR1 register (TI1 selected).
- Select the active polarity for TI1FP2 (used for capture in TIMx\_CCR2): write the CC2P and CC2NP bits to '1' (active on falling edge).
- Select the valid trigger input: write the TS bits to 101 in the TIMx\_SMCR register (TI1FP1 selected).
- Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx\_SMCR register.
- Enable the captures: write the CC1E and CC2E bits to '1' in the TIMx\_CCER register.

**Figure 69. PWM input mode timing**



### 12.3.8 Forced output mode

In output mode (CCxS bits = 00 in the TIMx\_CCMRx register), each output compare signal (OCxREF and then OCx/OCxN) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (OCXREF/OCx) to its active level, you just need to write 101 in the OCxM bits in the corresponding TIMx\_CCMRx register. Thus OCXREF is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

For example: CCxP=0 (OCx active high) => OCx is forced to high level.

The OCxREF signal can be forced low by writing the OCxM bits to 100 in the TIMx\_CCMRx register.

Anyway, the comparison between the TIMx\_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the output compare mode section below.

### 12.3.9 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx\_CCMRx register) and the output polarity (CCxP bit in the TIMx\_CCER register). The output pin can keep its level (OCXM=000), be set active (OCXM=001), be set inactive (OCXM=010) or can toggle (OCXM=011) on match.
- Sets a flag in the interrupt status register (CCxIF bit in the TIMx\_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx\_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx\_DIER register, CCDS bit in the TIMx\_CR2 register for the DMA request selection).

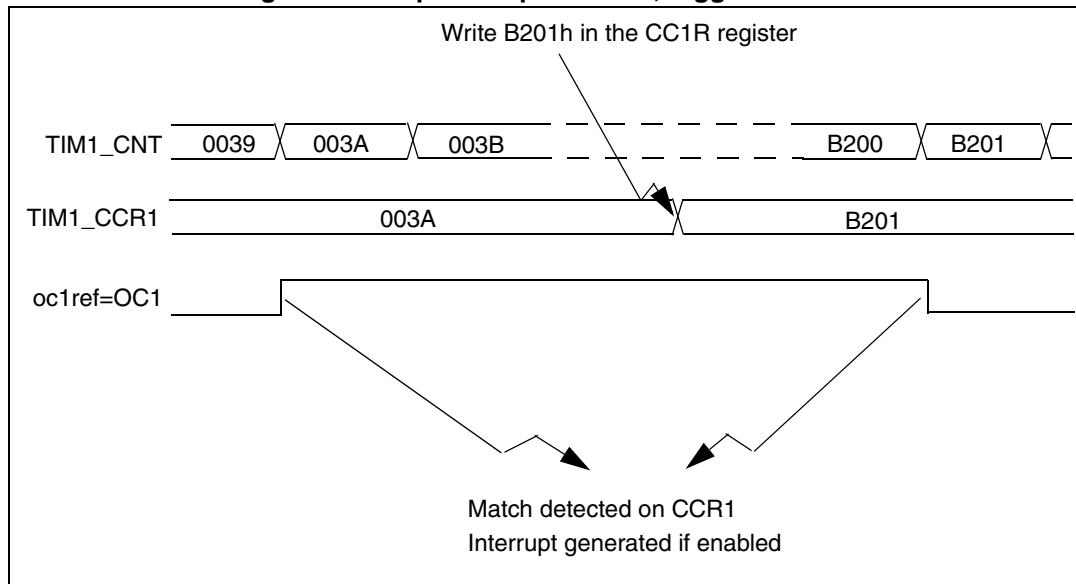
The TIMx\_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx\_CCMRx register.

In output compare mode, the update event UEV has no effect on OCxREF and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One Pulse mode).

Procedure:

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx\_ARR and TIMx\_CCRx registers.
3. Set the CCXIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
  - Write OCxM = 011 to toggle OCx output pin when CNT matches CCRx
  - Write OCxPE = 0 to disable preload register
  - Write CCxP = 0 to select active high polarity
  - Write CCxE = 1 to enable the output
5. Enable the counter by setting the CEN bit in the TIMx\_CR1 register.

The TIMx\_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE='0', else TIMx\_CCRx shadow register is updated only at the next update event UEV). An example is given in [Figure 70](#).

**Figure 70. Output compare mode, toggle on OC1.**

### 12.3.10 PWM mode

Pulse Width Modulation mode allows you to generate a signal with a frequency determined by the value of the TIMx\_ARR register and a duty cycle determined by the value of the TIMx\_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing ‘110’ (PWM mode 1) or ‘111’ (PWM mode 2) in the OCxM bits in the TIMx\_CCMRx register. You must enable the corresponding preload register by setting the OCxPE bit in the TIMx\_CCMRx register, and eventually the auto-reload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx\_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, you have to initialize all the registers by setting the UG bit in the TIMx\_EGR register.

OCx polarity is software programmable using the CCxP bit in the TIMx\_CCER register. It can be programmed as active high or active low. OCx output is enabled by a combination of the CCxE, CCxNE, MOE, OSS1 and OSSR bits (TIMx\_CCER and TIMx\_BDTR registers). Refer to the TIMx\_CCER register description for more details.

In PWM mode (1 or 2), TIMx\_CNT and TIMx\_CCRx are always compared to determine whether  $\text{TIMx\_CCRx} \leq \text{TIMx\_CNT}$  or  $\text{TIMx\_CNT} \leq \text{TIMx\_CCRx}$  (depending on the direction of the counter).

The timer is able to generate PWM in edge-aligned mode or center-aligned mode depending on the CMS bits in the TIMx\_CR1 register.

### PWM edge-aligned mode

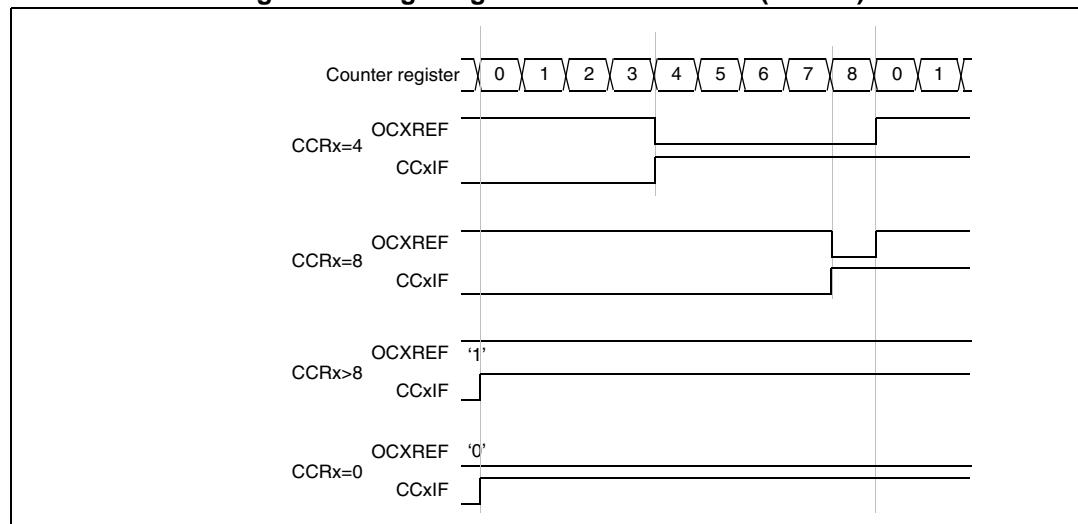
- Upcounting configuration

Upcounting is active when the DIR bit in the TIMx\_CR1 register is low. Refer to [Section : Upcounting mode on page 239](#).

In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as  $\text{TIMx\_CNT} < \text{TIMx\_CCR}_x$  else it becomes low. If the compare value in  $\text{TIMx\_CCR}_x$  is greater than the auto-reload value (in  $\text{TIMx\_ARR}$ ) then OCxREF is held at '1'. If the compare value is 0 then OCxRef is held at '0'.

*Figure 71* shows some edge-aligned PWM waveforms in an example where  $\text{TIMx\_ARR}=8$ .

**Figure 71. Edge-aligned PWM waveforms (ARR=8)**



- Downcounting configuration

Downcounting is active when DIR bit in TIMx\_CR1 register is high. Refer to [Section : Downcounting mode on page 242](#).

In PWM mode 1, the reference signal OCxRef is low as long as  $\text{TIMx\_CNT} > \text{TIMx\_CCR}_x$  else it becomes high. If the compare value in  $\text{TIMx\_CCR}_x$  is greater than the auto-reload value in  $\text{TIMx\_ARR}$ , then OCxREF is held at '1'. 0% PWM is not possible in this mode.

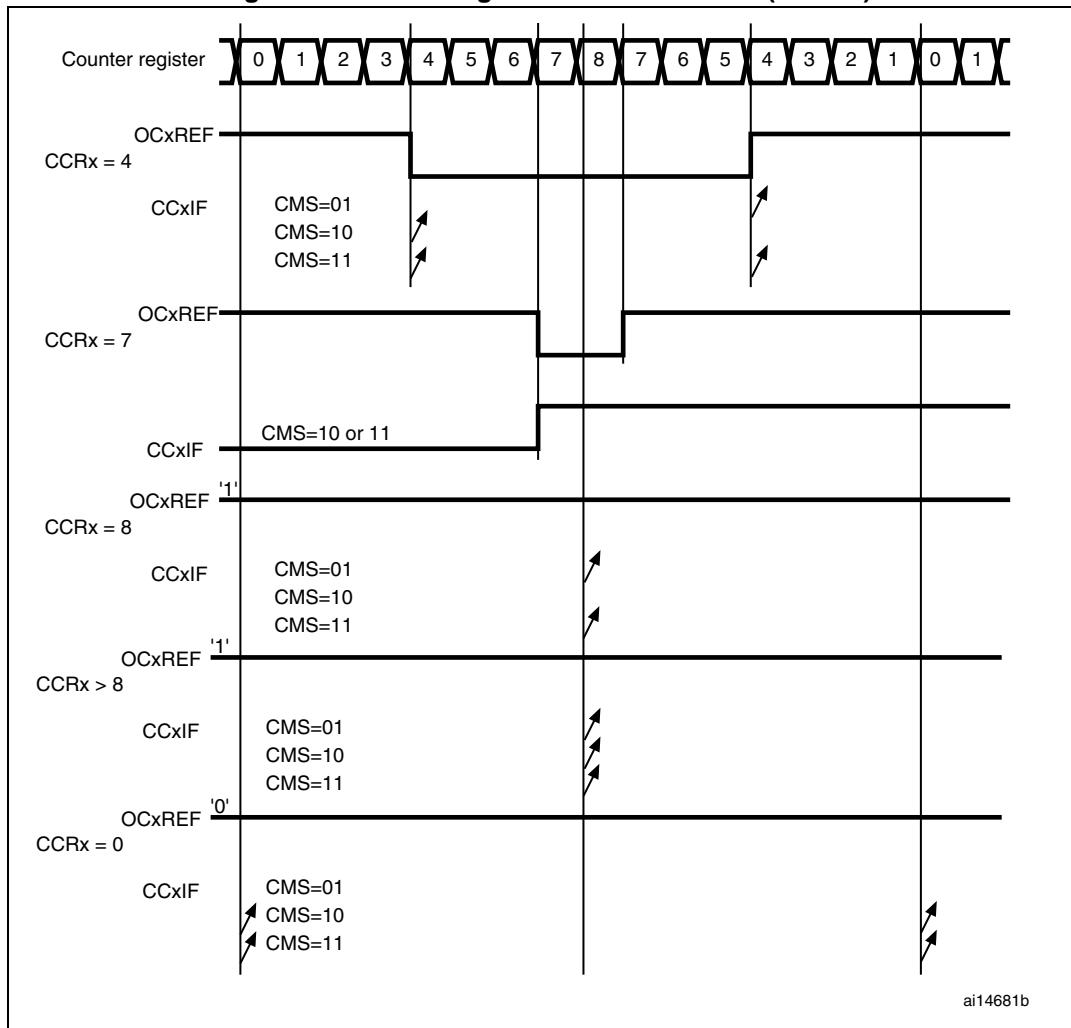
### PWM center-aligned mode

Center-aligned mode is active when the CMS bits in TIMx\_CR1 register are different from '00' (all the remaining configurations having the same effect on the OCxRef/OCx signals). The compare flag is set when the counter counts up, when it counts down or both when it counts up and down depending on the CMS bits configuration. The direction bit (DIR) in the TIMx\_CR1 register is updated by hardware and must not be changed by software. Refer to [Section : Center-aligned mode \(up/down counting\) on page 244](#).

*Figure 72* shows some center-aligned PWM waveforms in an example where:

- $\text{TIMx\_ARR}=8$ ,
- PWM mode is the PWM mode 1,
- The flag is set when the counter counts down corresponding to the center-aligned mode 1 selected for CMS=01 in TIMx\_CR1 register.

Figure 72. Center-aligned PWM waveforms (ARR=8)

**Hints on using center-aligned mode:**

- When starting in center-aligned mode, the current up-down configuration is used. It means that the counter counts up or down depending on the value written in the DIR bit in the TIMx\_CR1 register. Moreover, the DIR and CMS bits must not be changed at the same time by the software.
- Writing to the counter while running in center-aligned mode is not recommended as it can lead to unexpected results. In particular:
  - The direction is not updated if you write a value in the counter that is greater than the auto-reload value (TIMx\_CNT>TIMx\_ARR). For example, if the counter was counting up, it continues to count up.
  - The direction is updated if you write 0 or write the TIMx\_ARR value in the counter but no Update Event UEV is generated.
- The safest way to use center-aligned mode is to generate an update by software (setting the UG bit in the TIMx\_EGR register) just before starting the counter and not to write the counter while it is running.

### 12.3.11 Complementary outputs and dead-time insertion

The advanced-control timers (TIM1) can output two complementary signals and manage the switching-off and the switching-on instants of the outputs.

This time is generally known as dead-time and you have to adjust it depending on the devices you have connected to the outputs and their characteristics (intrinsic delays of level-shifters, delays due to power switches...)

You can select the polarity of the outputs (main output OC<sub>x</sub> or complementary OC<sub>xN</sub>) independently for each output. This is done by writing to the CC<sub>xP</sub> and CC<sub>xNP</sub> bits in the TIM<sub>x</sub>\_CCER register.

The complementary signals OC<sub>x</sub> and OC<sub>xN</sub> are activated by a combination of several control bits: the CC<sub>xE</sub> and CC<sub>xNE</sub> bits in the TIM<sub>x</sub>\_CCER register and the MOE, OIS<sub>x</sub>, OIS<sub>xN</sub>, OSSI and OSSR bits in the TIM<sub>x</sub>\_BDTR and TIM<sub>x</sub>\_CR2 registers. Refer to [Table 51: Output control bits for complementary OC<sub>x</sub> and OC<sub>xN</sub> channels with break feature on page 294](#) for more details. In particular, the dead-time is activated when switching to the IDLE state (MOE falling down to 0).

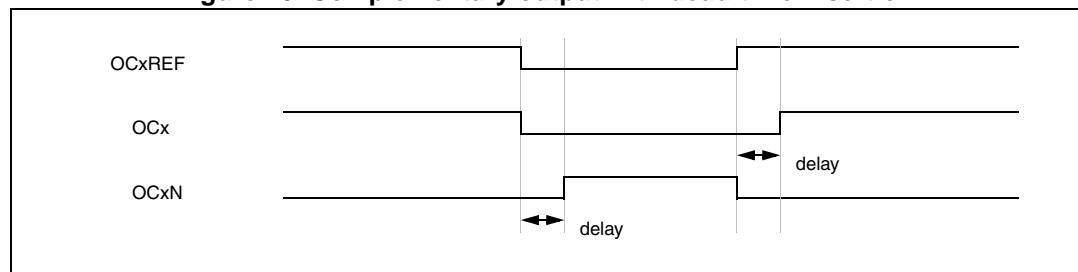
Dead-time insertion is enabled by setting both CC<sub>xE</sub> and CC<sub>xNE</sub> bits, and the MOE bit if the break circuit is present. DTG[7:0] bits of the TIM<sub>x</sub>\_BDTR register are used to control the dead-time generation for all channels. From a reference waveform OC<sub>x</sub>REF, it generates 2 outputs OC<sub>x</sub> and OC<sub>xN</sub>. If OC<sub>x</sub> and OC<sub>xN</sub> are active high:

- The OC<sub>x</sub> output signal is the same as the reference signal except for the rising edge, which is delayed relative to the reference rising edge.
- The OC<sub>xN</sub> output signal is the opposite of the reference signal except for the rising edge, which is delayed relative to the reference falling edge.

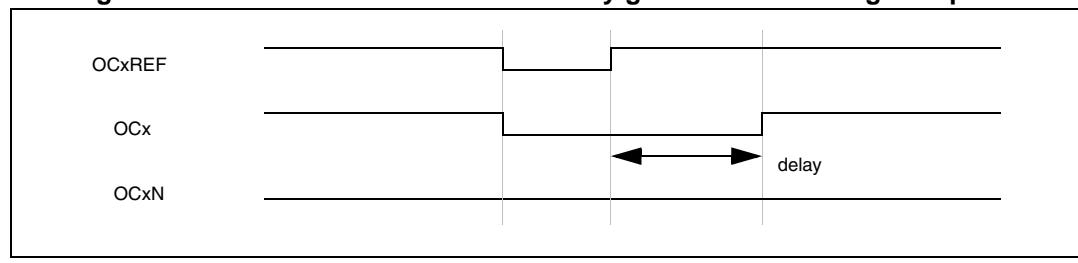
If the delay is greater than the width of the active output (OC<sub>x</sub> or OC<sub>xN</sub>) then the corresponding pulse is not generated.

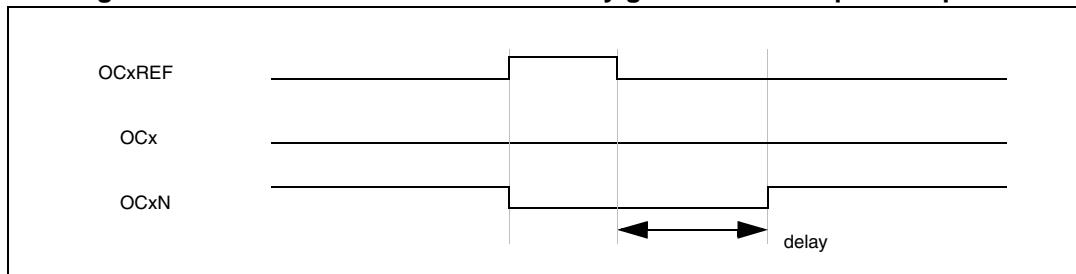
The following figures show the relationships between the output signals of the dead-time generator and the reference signal OC<sub>x</sub>REF. (we suppose CC<sub>xP</sub>=0, CC<sub>xNP</sub>=0, MOE=1, CC<sub>xE</sub>=1 and CC<sub>xNE</sub>=1 in these examples)

**Figure 73. Complementary output with dead-time insertion.**



**Figure 74. Dead-time waveforms with delay greater than the negative pulse.**



**Figure 75. Dead-time waveforms with delay greater than the positive pulse.**

The dead-time delay is the same for each of the channels and is programmable with the DTG bits in the TIMx\_BDTR register. Refer to [Section 12.4.18: TIM1 break and dead-time register \(TIMx\\_BDTR\) on page 298](#) for delay calculation.

#### Re-directing OCxREF to OCx or OCxN

In output mode (forced, output compare or PWM), OCxREF can be re-directed to the OCx output or to OCxN output by configuring the CCxE and CCxNE bits in the TIMx\_CCER register.

This allows you to send a specific waveform (such as PWM or static active level) on one output while the complementary remains at its inactive level. Other alternative possibilities are to have both outputs at inactive level or both outputs active and complementary with dead-time.

**Note:**

*When only OCxN is enabled (CCxE=0, CCxNE=1), it is not complemented and becomes active as soon as OCxREF is high. For example, if CCxNP=0 then OCxN=OCxRef. On the other hand, when both OCx and OCxN are enabled (CCxE=CCxNE=1) OCx becomes active when OCxREF is high whereas OCxN is complemented and becomes active when OCxREF is low.*

#### 12.3.12 Using the break function

When using the break function, the output enable signals and inactive levels are modified according to additional control bits (MOE, OSS1 and OSSR bits in the TIMx\_BDTR register, OISx and OISxN bits in the TIMx\_CR2 register). In any case, the OCx and OCxN outputs cannot be set both to active level at a given time. Refer to [Table 51: Output control bits for complementary OCx and OCxN channels with break feature on page 294](#) for more details.

The break source can be either the break input pin or a clock failure event, generated by the Clock Security System (CSS), from the Reset Clock Controller. For further information on the Clock Security System, refer to [Section 6.2.7: Clock security system \(CSS\)](#).

When exiting from reset, the break circuit is disabled and the MOE bit is low. You can enable the break function by setting the BKE bit in the TIMx\_BDTR register. The break input polarity can be selected by configuring the BKP bit in the same register. BKE and BKP can be modified at the same time. When the BKE and BKP bits are written, a delay of 1 APB clock cycle is applied before the writing is effective. Consequently, it is necessary to wait 1 APB clock period to correctly read back the bit after the write operation.

Because MOE falling edge can be asynchronous, a resynchronization circuit has been inserted between the actual signal (acting on the outputs) and the synchronous control bit (accessed in the TIMx\_BDTR register). It results in some delays between the asynchronous and the synchronous signals. In particular, if you write MOE to 1 whereas it was low, you

must insert a delay (dummy instruction) before reading it correctly. This is because you write the asynchronous signal and read the synchronous signal.

When a break occurs (selected level on the break input):

- The MOE bit is cleared asynchronously, putting the outputs in inactive state, idle state or in reset state (selected by the OSS1 bit). This feature functions even if the MCU oscillator is off.
- Each output channel is driven with the level programmed in the OISx bit in the TIMx\_CR2 register as soon as MOE=0. If OSS1=0 then the timer releases the enable output else the enable output remains high.
- When complementary outputs are used:
  - The outputs are first put in reset state inactive state (depending on the polarity). This is done asynchronously so that it works even if no clock is provided to the timer.
  - If the timer clock is still present, then the dead-time generator is reactivated in order to drive the outputs with the level programmed in the OISx and OISxN bits after a dead-time. Even in this case, OCx and OCxN cannot be driven to their active level together. Note that because of the resynchronization on MOE, the dead-time duration is a bit longer than usual (around 2 ck\_tim clock cycles).
  - If OSS1=0 then the timer releases the enable outputs else the enable outputs remain or become high as soon as one of the CCxE or CCxNE bits is high.
- The break status flag (BIF bit in the TIMx\_SR register) is set. An interrupt can be generated if the BIE bit in the TIMx\_DIER register is set. A DMA request can be sent if the BDE bit in the TIMx\_DIER register is set.
- If the AOE bit in the TIMx\_BDTR register is set, the MOE bit is automatically set again at the next update event UEV. This can be used to perform a regulation, for instance. Else, MOE remains low until you write it to '1' again. In this case, it can be used for security and you can connect the break input to an alarm from power drivers, thermal sensors or any security components.

Note:

*The break inputs is acting on level. Thus, the MOE cannot be set while the break input is active (neither automatically nor by software). In the meantime, the status flag BIF cannot be cleared.*

The break can be generated by the BRK input which has a programmable polarity and an enable bit BKE in the TIMx\_BDTR Register.

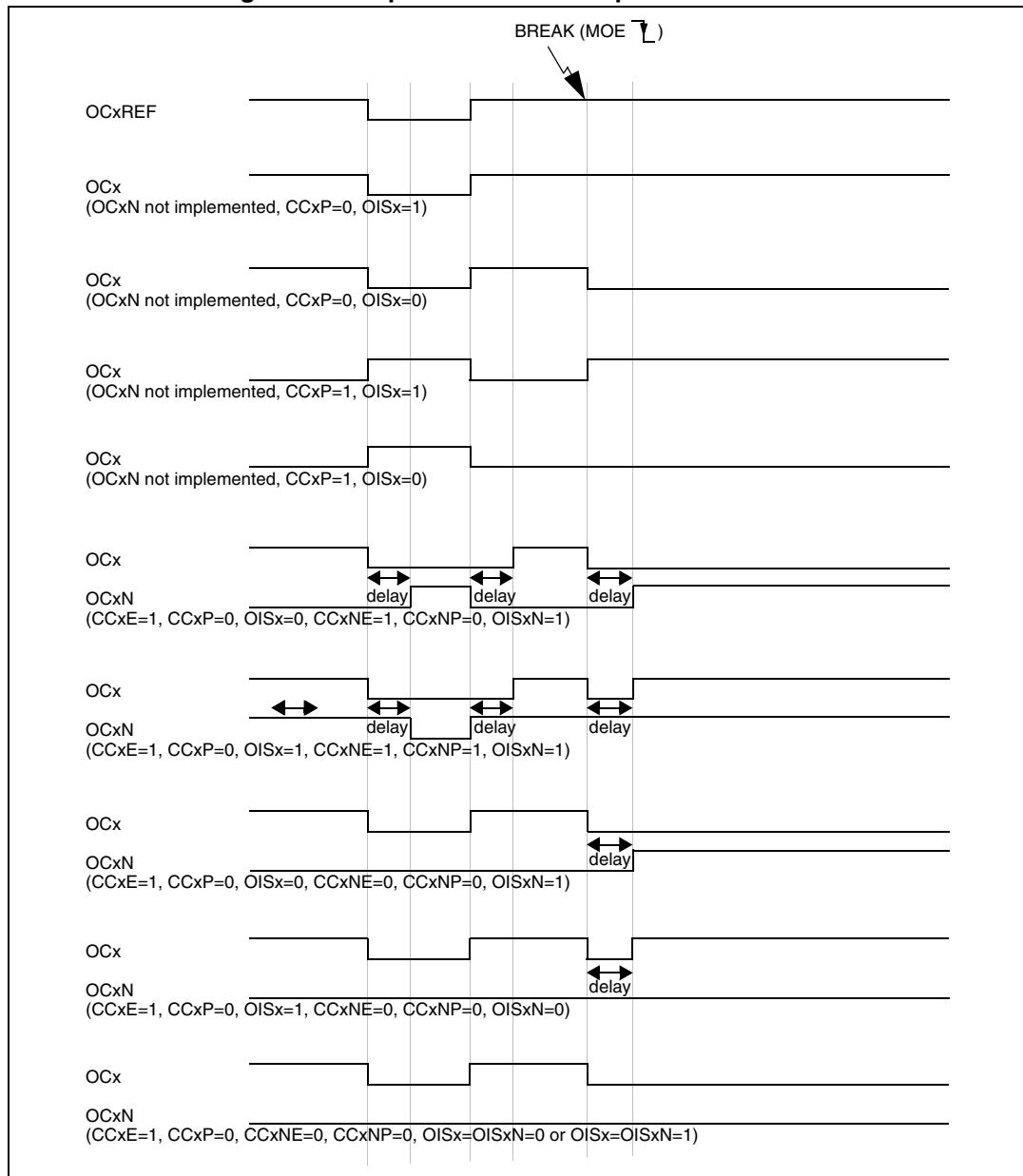
There are two solutions to generate a break:

- By using the BRK input which has a programmable polarity and an enable bit BKE in the TIMx\_BDTR register
- By software through the BG bit of the TIMx\_EGR register.

In addition to the break input and the output management, a write protection has been implemented inside the break circuit to safeguard the application. It allows you to freeze the configuration of several parameters (dead-time duration, OCx/OCxN polarities and state when disabled, OCxM configurations, break enable and polarity). You can choose from 3 levels of protection selected by the LOCK bits in the TIMx\_BDTR register. Refer to

[Section 12.4.18: TIM1 break and dead-time register \(TIMx\\_BDTR\) on page 298](#). The LOCK bits can be written only once after an MCU reset.

*Figure 76 shows an example of behavior of the outputs in response to a break.*

**Figure 76. Output behavior in response to a break.**

### 12.3.13 Clearing the OCxREF signal on an external event

The OC<sub>x</sub>REF signal for a given channel can be driven Low by applying a High level to the ETRF input (OC<sub>x</sub>CE enable bit of the corresponding TIM<sub>x</sub>\_CCMR<sub>x</sub> register set to '1'). The OC<sub>x</sub>REF signal remains Low until the next update event, UEV, occurs.

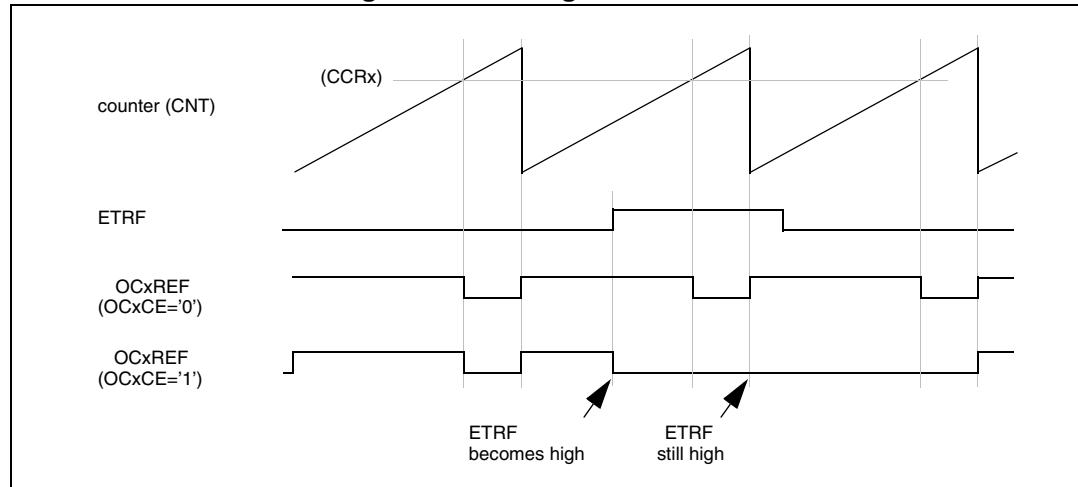
This function can only be used in output compare and PWM modes, and does not work in forced mode.

For example, the ETR signal can be connected to the output of a comparator to be used for current handling. In this case, the ETR must be configured as follow:

1. The External Trigger Prescaler should be kept off: bits ETPS[1:0] of the TIM<sub>x</sub>\_SMCR register set to '00'.
2. The external clock mode 2 must be disabled: bit ECE of the TIM<sub>x</sub>\_SMCR register set to '0'.
3. The External Trigger Polarity (ETP) and the External Trigger Filter (ETF) can be configured according to the user needs.

*Figure 77* shows the behavior of the OC<sub>x</sub>REF signal when the ETRF Input becomes High, for both values of the enable bit OC<sub>x</sub>CE. In this example, the timer TIM<sub>x</sub> is programmed in PWM mode.

**Figure 77. Clearing TIM<sub>x</sub> OC<sub>x</sub>REF**



**Note:** *In case of a PWM with a 100% duty cycle (if CCR<sub>x</sub>>ARR), then OC<sub>x</sub>REF is enabled again at the next counter overflow.*

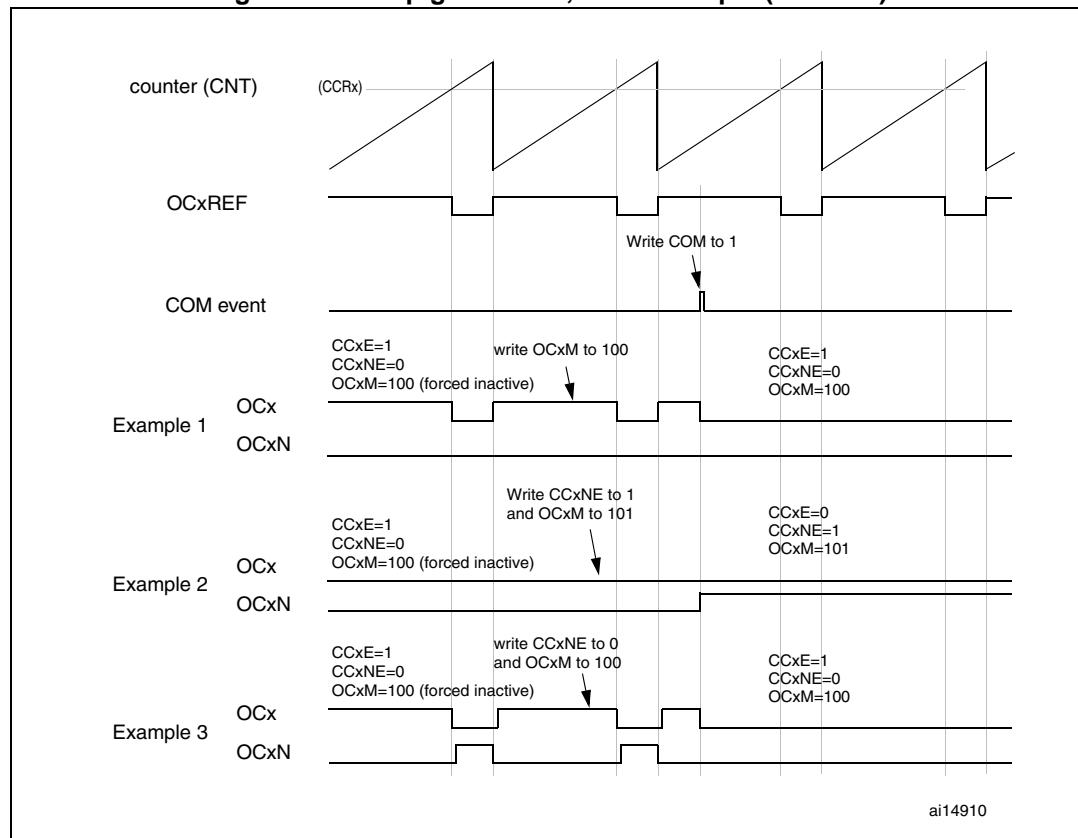
### 12.3.14 6-step PWM generation

When complementary outputs are used on a channel, preload bits are available on the OCxM, CCxE and CCxNE bits. The preload bits are transferred to the shadow bits at the COM commutation event. Thus you can program in advance the configuration for the next step and change the configuration of all the channels at the same time. COM can be generated by software by setting the COM bit in the TIMx\_EGR register or by hardware (on TRGI rising edge).

A flag is set when the COM event occurs (COMIF bit in the TIMx\_SR register), which can generate an interrupt (if the COMIE bit is set in the TIMx\_DIER register) or a DMA request (if the COMDE bit is set in the TIMx\_DIER register).

*Figure 78* describes the behavior of the OCx and OCxN outputs when a COM event occurs, in 3 different examples of programmed configurations.

**Figure 78. 6-step generation, COM example (OSSR=1)**



### 12.3.15 One-pulse mode

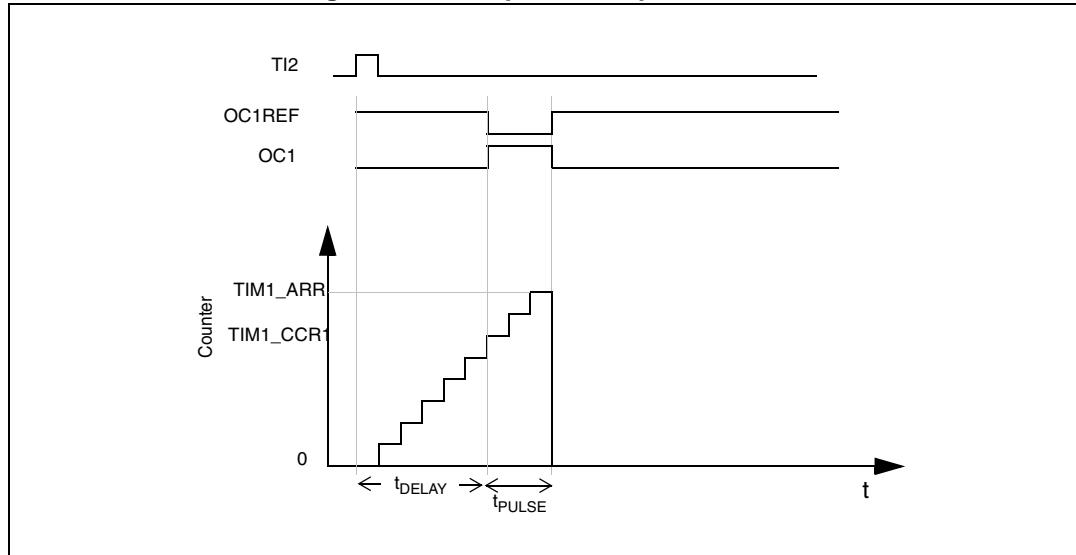
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. You select One-pulse mode by setting the OPM bit in the TIMx\_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- In upcounting: CNT < CCRx  $\leq$  ARR (in particular, 0 < CCRx)
- In downcounting: CNT > CCRx

**Figure 79. Example of one pulse mode.**



For example you may want to generate a positive pulse on OC1 with a length of  $t_{PULSE}$  and after a delay of  $t_{DELAY}$  as soon as a positive edge is detected on the TI2 input pin.

Let's use TI2FP2 as trigger 1:

- Map TI2FP2 to TI2 by writing CC2S='01' in the TIMx\_CCMR1 register.
- TI2FP2 must detect a rising edge, write CC2P='0' and CC2NP='0' in the TIMx\_CCER register.
- Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS='110' in the TIMx\_SMCR register.
- TI2FP2 is used to start the counter by writing SMS to '110' in the TIMx\_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The  $t_{DELAY}$  is defined by the value written in the TIMx\_CCR1 register.
- The  $t_{PULSE}$  is defined by the difference between the auto-reload value and the compare value (TIMx\_ARR - TIMx\_CCR1).
- Let's say you want to build a waveform with a transition from '0' to '1' when a compare match occurs and a transition from '1' to '0' when the counter reaches the auto-reload value. To do this you enable PWM mode 2 by writing OC1M=111 in the TIMx\_CCMR1 register. You can optionally enable the preload registers by writing OC1PE='1' in the TIMx\_CCMR1 register and ARPE in the TIMx\_CR1 register. In this case you have to write the compare value in the TIMx\_CCR1 register, the auto-reload value in the TIMx\_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0' in this example.

In our example, the DIR and CMS bits in the TIMx\_CR1 register should be low.

You only want 1 pulse (Single mode), so you write '1' in the OPM bit in the TIMx\_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0). When OPM bit in the TIMx\_CR1 register is set to '0', so the Repetitive Mode is selected.

#### **Particular case: OCx fast enable:**

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay  $t_{DELAY}$  min we can get.

If you want to output a waveform with the minimum delay, you can set the OCxFE bit in the TIMx\_CCMRx register. Then OCxRef (and OCx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

### **12.3.16 Encoder interface mode**

To select Encoder Interface mode write SMS='001' in the TIMx\_SMCR register if the counter is counting on TI2 edges only, SMS='010' if it is counting on TI1 edges only and SMS='011' if it is counting on both TI1 and TI2 edges.

Select the TI1 and TI2 polarity by programming the CC1P and CC2P bits in the TIMx\_CCER register. When needed, you can program the input filter as well. CC1NP and CC2NP must be kept low.

The two inputs TI1 and TI2 are used to interface to an incremental encoder. Refer to [Table 49](#). The counter is clocked by each valid transition on TI1FP1 or TI2FP2 (TI1 and TI2 after input filter and polarity selection, TI1FP1=TI1 if not filtered and not inverted, TI2FP2=TI2 if not filtered and not inverted) assuming that it is enabled (CEN bit in TIMx\_CR1 register written to '1'). The sequence of transitions of the two inputs is evaluated and generates count pulses as well as the direction signal. Depending on the sequence the counter counts up or down, the DIR bit in the TIMx\_CR1 register is modified by hardware accordingly. The DIR bit is calculated at each transition on any input (TI1 or TI2), whatever the counter is counting on TI1 only, TI2 only or both TI1 and TI2.

Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the auto-reload value in the TIMx\_ARR register (0 to ARR or ARR down to 0 depending on the direction). So you must

configure TIMx\_ARR before starting. in the same way, the capture, compare, prescaler, repetition counter, trigger output features continue to work as normal. Encoder mode and External clock mode 2 are not compatible and must not be selected together.

In this mode, the counter is modified automatically following the speed and the direction of the incremental encoder and its content, therefore, always represents the encoder's position. The count direction correspond to the rotation direction of the connected sensor. The table summarizes the possible combinations, assuming TI1 and TI2 don't switch at the same time.

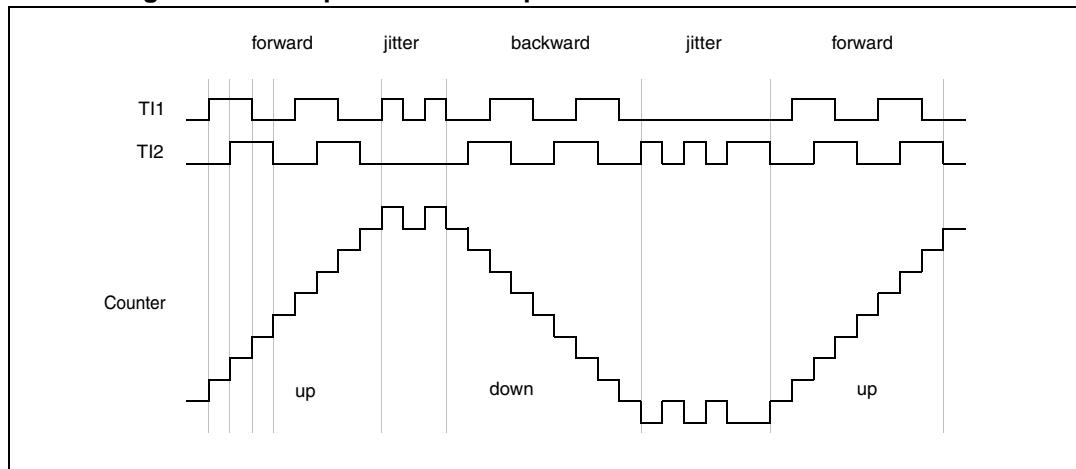
**Table 49. Counting direction versus encoder signals**

Active edge	Level on opposite signal (TI1FP1 for TI2, TI2FP2 for TI1)	TI1FP1 signal		TI2FP2 signal	
		Rising	Falling	Rising	Falling
Counting on TI1 only	High	Down	Up	No Count	No Count
	Low	Up	Down	No Count	No Count
Counting on TI2 only	High	No Count	No Count	Up	Down
	Low	No Count	No Count	Down	Up
Counting on TI1 and TI2	High	Down	Up	Up	Down
	Low	Up	Down	Down	Up

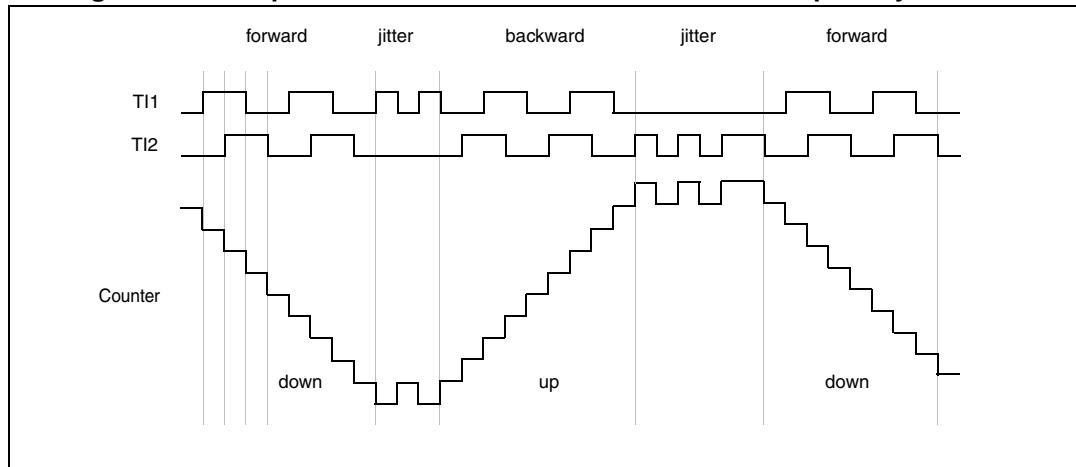
An external incremental encoder can be connected directly to the MCU without external interface logic. However, comparators are normally be used to convert the encoder's differential outputs to digital signals. This greatly increases noise immunity. The third encoder output which indicate the mechanical zero position, may be connected to an external interrupt input and trigger a counter reset.

*Figure 80* gives an example of counter operation, showing count signal generation and direction control. It also shows how input jitter is compensated where both edges are selected. This might occur if the sensor is positioned near to one of the switching points. For this example we assume that the configuration is the following:

- CC1S='01' (TIMx\_CCMR1 register, TI1FP1 mapped on TI1).
- CC2S='01' (TIMx\_CCMR2 register, TI1FP2 mapped on TI2).
- CC1P='0', CC1NP='0', and IC1F = '0000' (TIMx\_CCER register, TI1FP1 non-inverted, TI1FP1=TI1).
- CC2P='0', CC2NP='0', and IC2F = '0000' (TIMx\_CCER register, TI1FP2 non-inverted, TI1FP2= TI2).
- SMS='011' (TIMx\_SMCR register, both inputs are active on both rising and falling edges).
- CEN='1' (TIMx\_CR1 register, Counter enabled).

**Figure 80. Example of counter operation in encoder interface mode.**

*Figure 81* gives an example of counter behavior when TI1FP1 polarity is inverted (same configuration as above except CC1P='1').

**Figure 81. Example of encoder interface mode with TI1FP1 polarity inverted.**

The timer, when configured in Encoder Interface mode provides information on the sensor's current position. You can obtain dynamic information (speed, acceleration, deceleration) by measuring the period between two encoder events using a second timer configured in capture mode. The output of the encoder which indicates the mechanical zero can be used for this purpose. Depending on the time between two events, the counter can also be read at regular times. You can do this by latching the counter value into a third input capture register if available (then the capture signal must be periodic and can be generated by another timer). When available, it is also possible to read its value through a DMA request generated by a real-time clock.

### 12.3.17 Timer input XOR function

The TI1S bit in the TIMx\_CR2 register, allows the input filter of channel 1 to be connected to the output of a XOR gate, combining the three input pins TIMx\_CH1, TIMx\_CH2 and TIMx\_CH3.

The XOR output can be used with all the timer input functions such as trigger or input capture. An example of this feature used to interface Hall sensors is given in [Section 12.3.18](#) below.

### 12.3.18 Interfacing with Hall sensors

This is done using the advanced-control timers (TIM1) to generate PWM signals to drive the motor and another timer TIMx (TIM2, TIM3, TIM4 or TIM5) referred to as “interfacing timer” in [Figure 82](#). The “interfacing timer” captures the 3 timer input pins (TIMx\_CH1, TIMx\_CH2, and TIMx\_CH3) connected through a XOR to the TI1 input channel (selected by setting the TI1S bit in the TIMx\_CR2 register).

The slave mode controller is configured in reset mode; the slave input is TI1F\_ED. Thus, each time one of the 3 inputs toggles, the counter restarts counting from 0. This creates a time base triggered by any change on the Hall inputs.

On the “interfacing timer”, capture/compare channel 1 is configured in capture mode, capture signal is TRC (see [Figure 65: Capture/compare channel \(example: channel 1 input stage\) on page 252](#)). The captured value, which corresponds to the time elapsed between 2 changes on the inputs, gives information about motor speed.

The “interfacing timer” can be used in output mode to generate a pulse which changes the configuration of the channels of the advanced-control timer (TIM1) (by triggering a COM event). The TIM1 timer is used to generate PWM signals to drive the motor. To do this, the interfacing timer channel must be programmed so that a positive pulse is generated after a programmed delay (in output compare or PWM mode). This pulse is sent to the advanced-control timer (TIM1) through the TRGO output.

Example: you want to change the PWM configuration of your advanced-control timer TIM1 after a programmed delay each time a change occurs on the Hall inputs connected to one of the TIMx timers.

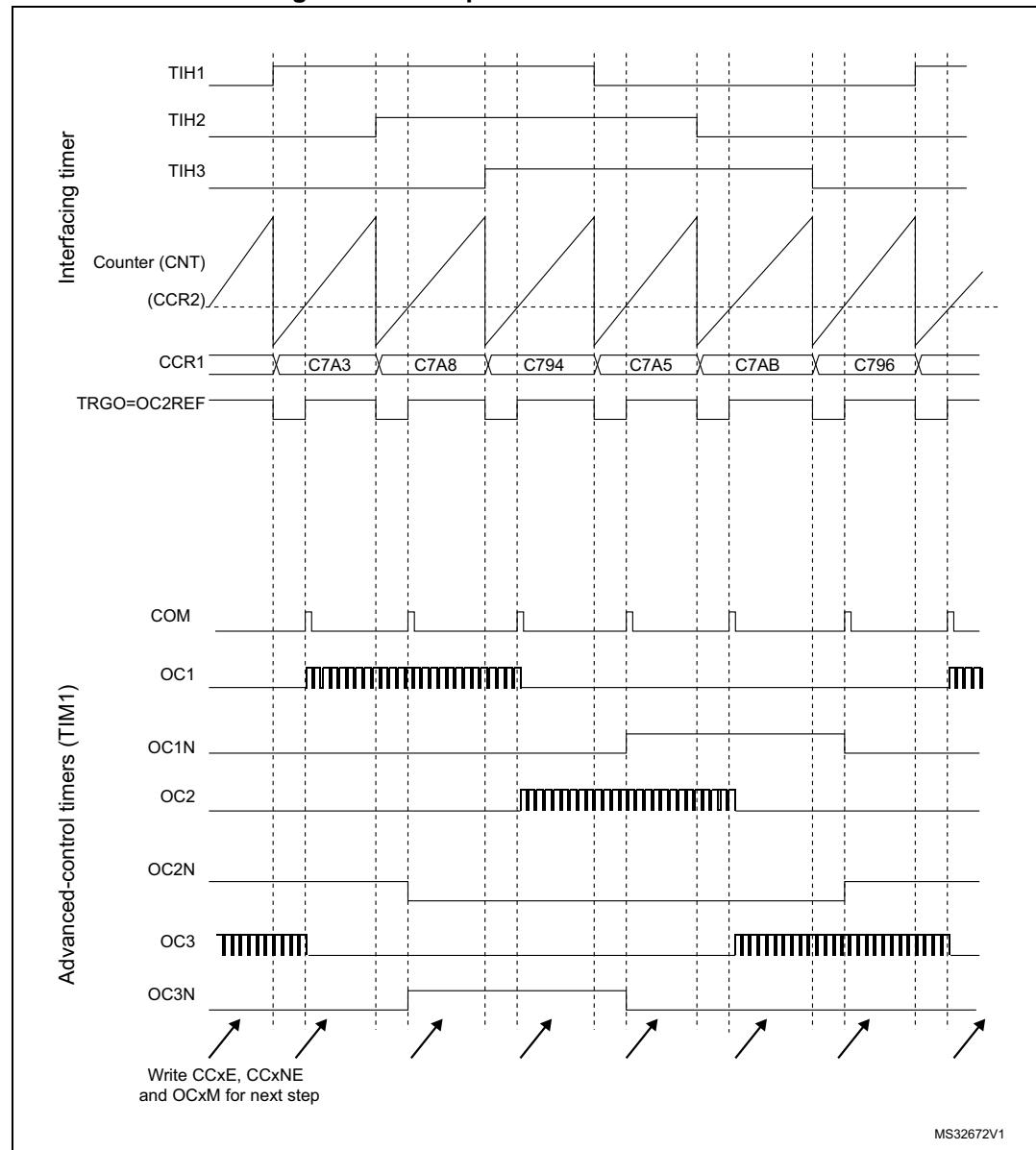
- Configure 3 timer inputs ORed to the TI1 input channel by writing the TI1S bit in the TIMx\_CR2 register to ‘1’,
- Program the time base: write the TIMx\_ARR to the max value (the counter must be cleared by the TI1 change. Set the prescaler to get a maximum counter period longer than the time between 2 changes on the sensors,
- Program channel 1 in capture mode (TRC selected): write the CC1S bits in the TIMx\_CCMR1 register to ‘11’. You can also program the digital filter if needed,
- Program channel 2 in PWM 2 mode with the desired delay: write the OC2M bits to ‘111’ and the CC2S bits to ‘00’ in the TIMx\_CCMR1 register,
- Select OC2REF as trigger output on TRGO: write the MMS bits in the TIMx\_CR2 register to ‘101’,

In the advanced-control timer TIM1, the right ITR input must be selected as trigger input, the timer is programmed to generate PWM signals, the capture/compare control signals are preloaded (CCPC=1 in the TIMx\_CR2 register) and the COM event is controlled by the trigger input (CCUS=1 in the TIMx\_CR2 register). The PWM control bits (CCxE, OCxM) are

written after a COM event for the next step (this can be done in an interrupt subroutine generated by the rising edge of OC2REF).

*Figure 82* describes this example.

**Figure 82. Example of hall sensor interface**



### 12.3.19 TIMx and external trigger synchronization

The TIMx timer can be synchronized with an external trigger in several modes: Reset mode, Gated mode and Trigger mode.

#### Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx\_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx\_ARR, TIMx\_CCRx) are updated.

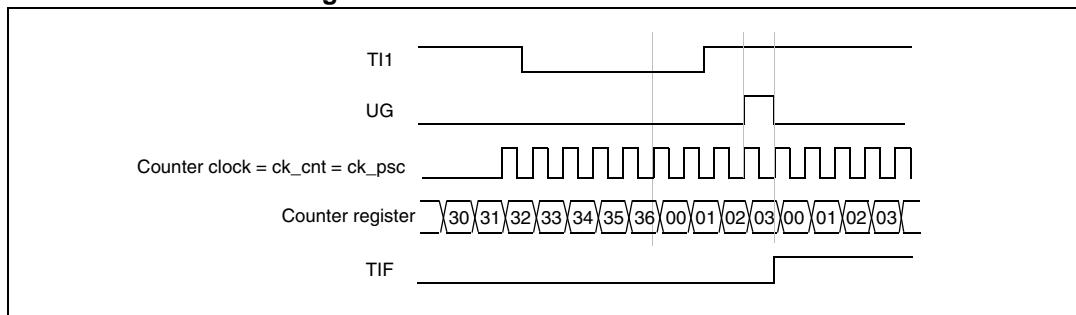
In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

- Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we don't need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so you don't need to configure it. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx\_CCMR1 register. Write CC1P=0 and CC1NP='0' in TIMx\_CCER register to validate the polarity (and detect rising edges only).
- Configure the timer in reset mode by writing SMS=100 in TIMx\_SMCR register. Select TI1 as the input source by writing TS=101 in TIMx\_SMCR register.
- Start the counter by writing CEN=1 in the TIMx\_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx\_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx\_DIER register).

The following figure shows this behavior when the auto-reload register TIMx\_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

**Figure 83. Control circuit in reset mode**



### Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

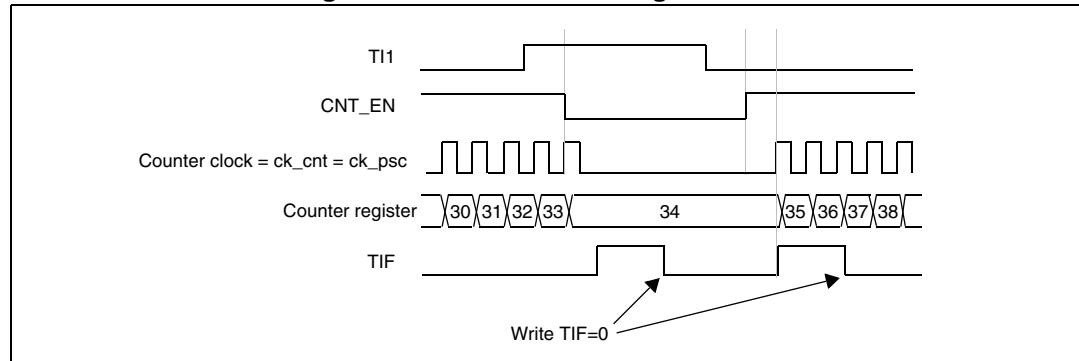
In the following example, the upcounter counts only when TI1 input is low:

- Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we don't need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so you don't need to configure it. The CC1S bits select the input capture source only, CC1S=01 in TIMx\_CCMR1 register. Write CC1P=1 and CC1NP='0' in TIMx\_CCER register to validate the polarity (and detect low level only).
- Configure the timer in gated mode by writing SMS=101 in TIMx\_SMCR register. Select TI1 as the input source by writing TS=101 in TIMx\_SMCR register.
- Enable the counter by writing CEN=1 in the TIMx\_CR1 register (in gated mode, the counter doesn't start if CEN=0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx\_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

**Figure 84. Control circuit in gated mode**



### Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

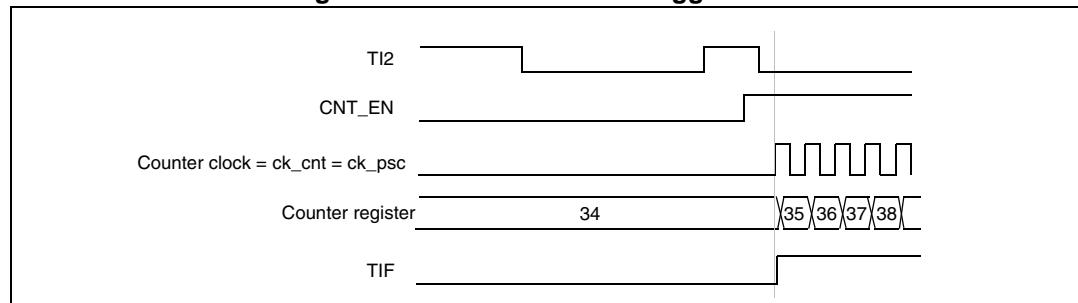
In the following example, the upcounter starts in response to a rising edge on TI2 input:

- Configure the channel 2 to detect rising edges on TI2. Configure the input filter duration (in this example, we don't need any filter, so we keep IC2F=0000). The capture prescaler is not used for triggering, so you don't need to configure it. The CC2S bits are configured to select the input capture source only, CC2S=01 in TIMx\_CCMR1 register. Write CC2P=1 and CC2NP=0 in TIMx\_CCER register to validate the polarity (and detect low level only).
- Configure the timer in trigger mode by writing SMS=110 in TIMx\_SMCR register. Select TI2 as the input source by writing TS=110 in TIMx\_SMCR register.

When a rising edge occurs on TI2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on TI2 and the actual start of the counter is due to the resynchronization circuit on TI2 input.

**Figure 85. Control circuit in trigger mode**



### Slave mode: external clock mode 2 + trigger mode

The external clock mode 2 can be used in addition to another slave mode (except external clock mode 1 and encoder mode). In this case, the ETR signal is used as external clock input, and another input can be selected as trigger input (in reset mode, gated mode or trigger mode). It is recommended not to select ETR as TRGI through the TS bits of TIMx\_SMCR register.

In the following example, the upcounter is incremented at each rising edge of the ETR signal as soon as a rising edge of TI1 occurs:

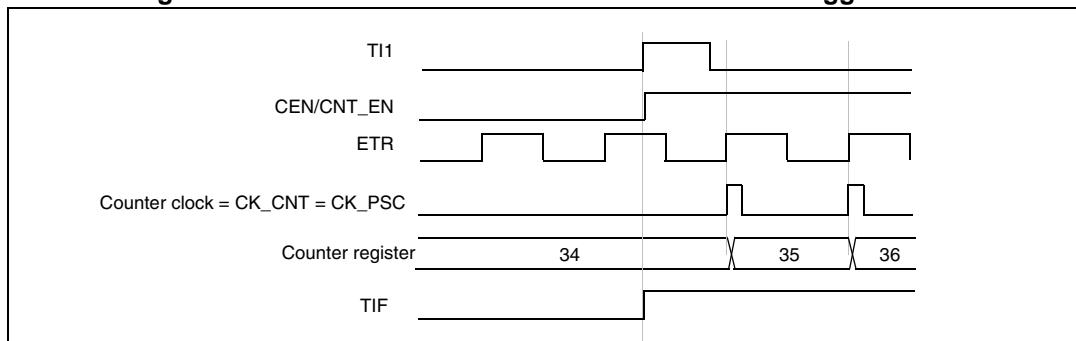
- Configure the external trigger input circuit by programming the TIMx\_SMCR register as follows:
  - ETF = 0000: no filter
  - ETPS = 00: prescaler disabled
  - ETP = 0: detection of rising edges on ETR and ECE=1 to enable the external clock mode 2.

2. Configure the channel 1 as follows, to detect rising edges on TI:
  - IC1F=0000: no filter.
  - The capture prescaler is not used for triggering and does not need to be configured.
  - CC1S=01 in TIMx\_CCMR1 register to select only the input capture source
  - CC1P=0 and CC1NP='0' in TIMx\_CCER register to validate the polarity (and detect rising edge only).
3. Configure the timer in trigger mode by writing SMS=110 in TIMx\_SMCR register. Select TI1 as the input source by writing TS=101 in TIMx\_SMCR register.

A rising edge on TI1 enables the counter and sets the TIF flag. The counter then counts on ETR rising edges.

The delay between the rising edge of the ETR signal and the actual reset of the counter is due to the resynchronization circuit on ETRP input.

**Figure 86. Control circuit in external clock mode 2 + trigger mode**



### 12.3.20 Timer synchronization

The TIM timers are linked together internally for timer synchronization or chaining. Refer to [Section 13.3.15: Timer synchronization on page 333](#) for details.

### 12.3.21 Debug mode

When the microcontroller enters debug mode (Cortex™-M4 with FPU core halted), the TIMx counter either continues to work normally or stops, depending on DBG\_TIMx\_STOP configuration bit in DBG module. For more details, refer to [Section 23.16.2: Debug support for timers, watchdog and I2C](#).

## 12.4 TIM1 registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers must be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-word (16 bits) or words (32 bits).

### 12.4.1 TIM1 control register 1 (TIMx\_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved					CKD[1:0]	ARPE	CMS[1:0]	DIR	OPM	URS	UDIS	CEN			
					<small>rw</small>										

Bits 15:10 Reserved, must be kept at reset value.

#### Bits 9:8 CKD[1:0]: Clock division

This bit-field indicates the division ratio between the timer clock (CK\_INT) frequency and the dead-time and sampling clock ( $t_{DTS}$ ) used by the dead-time generators and the digital filters (ETR, TIx),

00:  $t_{DTS}=t_{CK\_INT}$

01:  $t_{DTS}=2*t_{CK\_INT}$

10:  $t_{DTS}=4*t_{CK\_INT}$

11: Reserved, do not program this value

#### Bit 7 ARPE: Auto-reload preload enable

0: TIMx\_ARR register is not buffered

1: TIMx\_ARR register is buffered

#### Bits 6:5 CMS[1:0]: Center-aligned mode selection

00: Edge-aligned mode. The counter counts up or down depending on the direction bit (DIR).

01: Center-aligned mode 1. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx\_CCMRx register) are set only when the counter is counting down.

10: Center-aligned mode 2. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx\_CCMRx register) are set only when the counter is counting up.

11: Center-aligned mode 3. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx\_CCMRx register) are set both when the counter is counting up or down.

*Note:* It is not allowed to switch from edge-aligned mode to center-aligned mode as long as the counter is enabled (CEN=1)

#### Bit 4 DIR: Direction

0: Counter used as upcounter

1: Counter used as downcounter

*Note:* This bit is read only when the timer is configured in Center-aligned mode or Encoder mode.

Bit 3 **OPM**: One pulse mode

- 0: Counter is not stopped at update event
- 1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generate an update interrupt or DMA request if enabled.

These events can be:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

*Note: External clock, gated mode and encoder mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.*

## 12.4.2 TIM1 control register 2 (TIMx\_CR2)

Address offset: 0x04

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.		OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	TI1S		MMS[2:0]		CCDS	CCUS	Res.	CCPC
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 15 Reserved, must be kept at reset value.

Bit 14 **OIS4**: Output Idle state 4 (OC4 output)

refer to OIS1 bit

Bit 13 **OIS3N**: Output Idle state 3 (OC3N output)

refer to OIS1N bit

Bit 12 **OIS3**: Output Idle state 3 (OC3 output)

refer to OIS1 bit

Bit 11 **OIS2N**: Output Idle state 2 (OC2N output)  
refer to OIS1N bit

Bit 10 **OIS2**: Output Idle state 2 (OC2 output)  
refer to OIS1 bit

Bit 9 **OIS1N**: Output Idle state 1 (OC1N output)  
0: OC1N=0 after a dead-time when MOE=0  
1: OC1N=1 after a dead-time when MOE=0

*Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx\_BDTR register).*

Bit 8 **OIS1**: Output Idle state 1 (OC1 output)  
0: OC1=0 (after a dead-time if OC1N is implemented) when MOE=0  
1: OC1=1 (after a dead-time if OC1N is implemented) when MOE=0

*Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx\_BDTR register).*

Bit 7 **TI1S**: TI1 selection  
0: The TIMx\_CH1 pin is connected to TI1 input  
1: The TIMx\_CH1, CH2 and CH3 pins are connected to the TI1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits allow to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:

000: **Reset** - the UG bit from the TIMx\_EGR register is used as trigger output (TRGO). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.

001: **Enable** - the Counter Enable signal CNT\_EN is used as trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic OR between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in TIMx\_SMCR register).

010: **Update** - The update event is selected as trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.

011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred (TRGO).

100: **Compare** - OC1REF signal is used as trigger output (TRGO)

101: **Compare** - OC2REF signal is used as trigger output (TRGO)

110: **Compare** - OC3REF signal is used as trigger output (TRGO)

111: **Compare** - OC4REF signal is used as trigger output (TRGO)

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs  
1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection

- 0: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit only
- 1: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit or when an rising edge occurs on TRGI

*Note: This bit acts only on channels that have a complementary output.*

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control

- 0: CCxE, CCxNE and OCxM bits are not preloaded
- 1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when a commutation event (COM) occurs (COMG bit set or rising edge detected on TRGI, depending on the CCUS bit).

*Note: This bit acts only on channels that have a complementary output.*

### 12.4.3 TIM1 slave mode control register (TIMx\_SMCR)

Address offset: 0x08

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETP	ECE	ETPS[1:0]		ETF[3:0]				MSM	TS[2:0]				Res.	SMS[2:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	Res.	rw	rw

Bit 15 **ETP**: External trigger polarity

This bit selects whether ETR or  $\overline{ETR}$  is used for trigger operations

0: ETR is non-inverted, active at high level or rising edge.

1: ETR is inverted, active at low level or falling edge.

Bit 14 **ECE**: External clock enable

This bit enables External clock mode 2.

0: External clock mode 2 disabled

1: External clock mode 2 enabled. The counter is clocked by any active edge on the ETRF signal.

*Note:* 1: Setting the ECE bit has the same effect as selecting external clock mode 1 with TRGI connected to ETRF (SMS=111 and TS=111).

2: It is possible to simultaneously use external clock mode 2 with the following slave modes: reset mode, gated mode and trigger mode. Nevertheless, TRGI must not be connected to ETRF in this case (TS bits must not be 111).

3: If external clock mode 1 and external clock mode 2 are enabled at the same time, the external clock input is ETRF.

Bits 13:12 **ETPS[1:0]**: External trigger prescaler

External trigger signal ETRP frequency must be at most 1/4 of TIMxCLK frequency. A prescaler can be enabled to reduce ETRP frequency. It is useful when inputting fast external clocks.

00: Prescaler OFF

01: ETRP frequency divided by 2

10: ETRP frequency divided by 4

11: ETRP frequency divided by 8

Bits 11:8 **ETF[3:0]**: External trigger filter

This bit-field then defines the frequency used to sample ETRP signal and the length of the digital filter applied to ETRP. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

- 0000: No filter, sampling is done at  $f_{DTS}$
- 0001:  $f_{SAMPLING} = f_{CK\_INT}$ , N=2
- 0010:  $f_{SAMPLING} = f_{CK\_INT}$ , N=4
- 0011:  $f_{SAMPLING} = f_{CK\_INT}$ , N=8
- 0100:  $f_{SAMPLING} = f_{DTS}/2$ , N=6
- 0101:  $f_{SAMPLING} = f_{DTS}/2$ , N=8
- 0110:  $f_{SAMPLING} = f_{DTS}/4$ , N=6
- 0111:  $f_{SAMPLING} = f_{DTS}/4$ , N=8
- 1000:  $f_{SAMPLING} = f_{DTS}/8$ , N=6
- 1001:  $f_{SAMPLING} = f_{DTS}/8$ , N=8
- 1010:  $f_{SAMPLING} = f_{DTS}/16$ , N=5
- 1011:  $f_{SAMPLING} = f_{DTS}/16$ , N=6
- 1100:  $f_{SAMPLING} = f_{DTS}/16$ , N=8
- 1101:  $f_{SAMPLING} = f_{DTS}/32$ , N=5
- 1110:  $f_{SAMPLING} = f_{DTS}/32$ , N=6
- 1111:  $f_{SAMPLING} = f_{DTS}/32$ , N=8

Bit 7 **MSM**: Master/slave mode

- 0: No action
- 1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful if we want to synchronize several timers on a single external event.

Bits 6:4 **TS[2:0]**: Trigger selection

This bit-field selects the trigger input to be used to synchronize the counter.

- 000: Internal Trigger 0 (ITR0)
- 001: Internal Trigger 1 (ITR1)
- 010: Internal Trigger 2 (ITR2)
- 011: Internal Trigger 3 (ITR3)
- 100: TI1 Edge Detector (TI1F\_ED)
- 101: Filtered Timer Input 1 (TI1FP1)
- 110: Filtered Timer Input 2 (TI2FP2)
- 111: External Trigger input (ETRF)

See [Table 50: TIMx Internal trigger connection on page 282](#) for more details on ITRx meaning for each Timer.

*Note: These bits must be changed only when they are not used (e.g. when SMS=000) to avoid wrong edge detections at the transition.*

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **SMS:** Slave mode selection

When external signals are selected the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input Control register and Control Register description).

000: Slave mode disabled - if CEN = '1' then the prescaler is clocked directly by the internal clock.

001: Encoder mode 1 - Counter counts up/down on TI2FP2 edge depending on TI1FP1 level.

010: Encoder mode 2 - Counter counts up/down on TI1FP1 edge depending on TI2FP2 level.

011: Encoder mode 3 - Counter counts up/down on both TI1FP1 and TI2FP2 edges depending on the level of the other input.

100: Reset Mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers.

101: Gated Mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

110: Trigger Mode - The counter starts at a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled.

111: External Clock Mode 1 - Rising edges of the selected trigger (TRGI) clock the counter.

*Note: The gated mode must not be used if TI1F\_ED is selected as the trigger input (TS='100'). Indeed, TI1F\_ED outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.*

**Table 50. TIMx Internal trigger connection**

Slave TIM	ITR0 (TS = 000)	ITR1 (TS = 001)	ITR2 (TS = 010)	ITR3 (TS = 011)
TIM1	TIM5	TIM2	TIM3	TIM4

#### 12.4.4 TIM1 DMA/interrupt enable register (TIMx\_DIER)

Address offset: 0x0C

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	COMDE	CC4DE	CC3DE	CC2DE	CC1DE	UDE	BIE	TIE	COMIE	CC4IE	CC3IE	CC2IE	CC1IE	UIE	
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TDE:** Trigger DMA request enable

- 0: Trigger DMA request disabled
- 1: Trigger DMA request enabled

Bit 13 **COMDE:** COM DMA request enable

- 0: COM DMA request disabled
- 1: COM DMA request enabled

Bit 12 **CC4DE:** Capture/Compare 4 DMA request enable

- 0: CC4 DMA request disabled
- 1: CC4 DMA request enabled

- Bit 11 **CC3DE**: Capture/Compare 3 DMA request enable  
0: CC3 DMA request disabled  
1: CC3 DMA request enabled
- Bit 10 **CC2DE**: Capture/Compare 2 DMA request enable  
0: CC2 DMA request disabled  
1: CC2 DMA request enabled
- Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable  
0: CC1 DMA request disabled  
1: CC1 DMA request enabled
- Bit 8 **UDE**: Update DMA request enable  
0: Update DMA request disabled  
1: Update DMA request enabled
- Bit 7 **BIE**: Break interrupt enable  
0: Break interrupt disabled  
1: Break interrupt enabled
- Bit 6 **TIE**: Trigger interrupt enable  
0: Trigger interrupt disabled  
1: Trigger interrupt enabled
- Bit 5 **COMIE**: COM interrupt enable  
0: COM interrupt disabled  
1: COM interrupt enabled
- Bit 4 **CC4IE**: Capture/Compare 4 interrupt enable  
0: CC4 interrupt disabled  
1: CC4 interrupt enabled
- Bit 3 **CC3IE**: Capture/Compare 3 interrupt enable  
0: CC3 interrupt disabled  
1: CC3 interrupt enabled
- Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable  
0: CC2 interrupt disabled  
1: CC2 interrupt enabled
- Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable  
0: CC1 interrupt disabled  
1: CC1 interrupt enabled
- Bit 0 **UIE**: Update interrupt enable  
0: Update interrupt disabled  
1: Update interrupt enabled

### 12.4.5 TIM1 status register (TIMx\_SR)

Address offset: 0x10

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				CC4OF	CC3OF	CC2OF	CC1OF	Res.	BIF	TIF	COMIF	CC4IF	CC3IF	CC2IF	CC1IF	UIF
				rc_w0	rc_w0	rc_w0	rc_w0	Res.	rc_w0							

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **CC4OF**: Capture/Compare 4 overcapture flag  
refer to CC1OF description

Bit 11 **CC3OF**: Capture/Compare 3 overcapture flag  
refer to CC1OF description

Bit 10 **CC2OF**: Capture/Compare 2 overcapture flag  
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to '0'.  
0: No overcapture has been detected.  
1: The counter value has been captured in TIMx\_CCR1 register while CC1IF flag was already set

Bit 8 Reserved, must be kept at reset value.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the break input goes active. It can be cleared by software if the break input is not active.  
0: No break event occurred.  
1: An active level has been detected on the break input.

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected). It is cleared by software.  
0: No trigger event occurred.  
1: Trigger interrupt pending.

Bit 5 **COMIF**: COM interrupt flag

This flag is set by hardware on COM event (when Capture/compare Control bits - CCxE, CCxNE, OCxM - have been updated). It is cleared by software.  
0: No COM event occurred.  
1: COM interrupt pending.

Bit 4 **CC4IF**: Capture/Compare 4 interrupt flag  
refer to CC1IF description

Bit 3 **CC3IF**: Capture/Compare 3 interrupt flag  
refer to CC1IF description

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag  
refer to CC1IF description

Bit 1 **CC1IF**: Capture/Compare 1 interrupt flag

**If channel CC1 is configured as output:**

This flag is set by hardware when the counter matches the compare value, with some exception in center-aligned mode (refer to the CMS bits in the TIMx\_CR1 register description). It is cleared by software.

0: No match.

1: The content of the counter TIMx\_CNT matches the content of the TIMx\_CCR1 register. When the contents of TIMx\_CCR1 are greater than the contents of TIMx\_ARR, the CC1IF bit goes high on the counter overflow (in upcounting and up/down-counting modes) or underflow (in downcounting mode)

**If channel CC1 is configured as input:**

This bit is set by hardware on a capture. It is cleared by software or by reading the TIMx\_CCR1 register.

0: No input capture occurred

1: The counter value has been captured in TIMx\_CCR1 register (An edge has been detected on IC1 which matches the selected polarity)

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

- At overflow or underflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS=0 in the TIMx\_CR1 register.

- When CNT is reinitialized by software using the UG bit in TIMx\_EGR register, if URS=0 and UDIS=0 in the TIMx\_CR1 register.

- When CNT is reinitialized by a trigger event (refer to [Section 12.4.3: TIM1 slave mode control register \(TIMx\\_SMCR\)](#)), if URS=0 and UDIS=0 in the TIMx\_CR1 register.

## 12.4.6 TIM1 event generation register (TIMx\_EGR)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								BG	TG	COMG	CC4G	CC3G	CC2G	CC1G	UG
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **BG**: Break generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

**Bit 6 **TG**: Trigger generation**

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in TIMx\_SR register. Related interrupt or DMA transfer can occur if enabled.

**Bit 5 **COMG**: Capture/Compare control update generation**

This bit can be set by software, it is automatically cleared by hardware

0: No action

1: When CCPC bit is set, it allows to update CCxE, CCxNE and OCxM bits

*Note: This bit acts only on channels having a complementary output.*

**Bit 4 **CC4G**: Capture/Compare 4 generation**

refer to CC1G description

**Bit 3 **CC3G**: Capture/Compare 3 generation**

refer to CC1G description

**Bit 2 **CC2G**: Capture/Compare 2 generation**

refer to CC1G description

**Bit 1 **CC1G**: Capture/Compare 1 generation**

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A capture/compare event is generated on channel 1:

**If channel CC1 is configured as output:**

CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.

**If channel CC1 is configured as input:**

The current value of the counter is captured in TIMx\_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

**Bit 0 **UG**: Update generation**

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Reinitialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared if the center-aligned mode is selected or if DIR=0 (upcounting), else it takes the auto-reload value (TIMx\_ARR) if DIR=1 (downcounting).

### 12.4.7 TIM1 capture/compare mode register 1 (TIMx\_CCMR1)

Address offset: 0x18

Reset value: 0x0000

The channels can be used in input (capture mode) or in output (compare mode). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode. For a given bit, OCxx describes its function when the channel is configured in output, ICxx describes its function when the channel is configured in input. So you must take care that the same bit can have a different meaning for the input stage and for the output stage.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2 CE	OC2M[2:0]			OC2 PE	OC2 FE	CC2S[1:0]	OC1 CE	OC1M[2:0]			OC1 PE	OC1 FE	CC1S[1:0]		
IC2F[3:0]			IC2PSC[1:0]		IC1F[3:0]			IC1PSC[1:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

#### Output compare mode:

Bit 15 **OC2CE**: Output Compare 2 clear enable

Bits 14:12 **OC2M[2:0]**: Output Compare 2 mode

Bit 11 **OC2PE**: Output Compare 2 preload enable

Bit 10 **OC2FE**: Output Compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, IC2 is mapped on TI2

10: CC2 channel is configured as input, IC2 is mapped on TI1

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through the TS bit (TIMx\_SMCR register)

*Note: CC2S bits are writable only when the channel is OFF (CC2E = '0' in TIMx\_CCER).*

Bit 7 **OC1CE**: Output Compare 1 clear enable

OC1CE: Output Compare 1 Clear Enable

0: OC1Ref is not affected by the ETRF Input

1: OC1Ref is cleared as soon as a High level is detected on ETRF input

Bits 6:4 **OC1M**: Output Compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas OC1 and OC1N active level depends on CC1P and CC1NP bits.

000: Frozen - The comparison between the output compare register TIMx\_CCR1 and the counter TIMx\_CNT has no effect on the outputs.(this mode is used to generate a timing base).

001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx\_CNT matches the capture/compare register 1 (TIMx\_CCR1).

010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx\_CNT matches the capture/compare register 1 (TIMx\_CCR1).

011: Toggle - OC1REF toggles when TIMx\_CNT=TIMx\_CCR1.

100: Force inactive level - OC1REF is forced low.

101: Force active level - OC1REF is forced high.

110: PWM mode 1 - In upcounting, channel 1 is active as long as TIMx\_CNT<TIMx\_CCR1 else inactive. In downcounting, channel 1 is inactive (OC1REF='0') as long as TIMx\_CNT>TIMx\_CCR1 else active (OC1REF='1').

111: PWM mode 2 - In upcounting, channel 1 is inactive as long as TIMx\_CNT<TIMx\_CCR1 else active. In downcounting, channel 1 is active as long as TIMx\_CNT>TIMx\_CCR1 else inactive.

*Note: 1: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx\_BDTR register) and CC1S='00' (the channel is configured in output).*

*2: In PWM mode 1 or 2, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.*

*3: On channels having a complementary output, this bit field is preloaded. If the CCPC bit is set in the TIMx\_CR2 register then the OC1M active bits take the new value from the preloaded bits only when a COM event is generated.*

Bit 3 **OC1PE**: Output Compare 1 preload enable

0: Preload register on TIMx\_CCR1 disabled. TIMx\_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx\_CCR1 enabled. Read/Write operations access the preload register. TIMx\_CCR1 preload value is loaded in the active register at each update event.

*Note: 1: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx\_BDTR register) and CC1S='00' (the channel is configured in output).*

*2: The PWM mode can be used without validating the preload register only in one pulse mode (OPM bit set in TIMx\_CR1 register). Else the behavior is not guaranteed.*

Bit 2 **OC1FE**: Output Compare 1 fast enable

This bit is used to accelerate the effect of an event on the trigger input on the CC output.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently from the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx\_CCER).*

### Input capture mode

Bits 15:12 **IC2F**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S**: Capture/Compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, IC2 is mapped on TI2

10: CC2 channel is configured as input, IC2 is mapped on TI1

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC2S bits are writable only when the channel is OFF (CC2E = '0' in TIMx\_CCER).*

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

0000: No filter, sampling is done at  $f_{DTS}$

0001:  $f_{SAMPLING} = f_{CK\_INT}$ , N=2

0010:  $f_{SAMPLING} = f_{CK\_INT}$ , N=4

0011:  $f_{SAMPLING} = f_{CK\_INT}$ , N=8

0100:  $f_{SAMPLING} = f_{DTS}/2$ , N=6

0101:  $f_{SAMPLING} = f_{DTS}/2$ , N=8

0110:  $f_{SAMPLING} = f_{DTS}/4$ , N=6

0111:  $f_{SAMPLING} = f_{DTS}/4$ , N=8

1000:  $f_{SAMPLING} = f_{DTS}/8$ , N=6

1001:  $f_{SAMPLING} = f_{DTS}/8$ , N=8

1010:  $f_{SAMPLING} = f_{DTS}/16$ , N=5

1011:  $f_{SAMPLING} = f_{DTS}/16$ , N=6

1100:  $f_{SAMPLING} = f_{DTS}/16$ , N=8

1101:  $f_{SAMPLING} = f_{DTS}/32$ , N=5

1110:  $f_{SAMPLING} = f_{DTS}/32$ , N=6

1111:  $f_{SAMPLING} = f_{DTS}/32$ , N=8

*Note: Care must be taken that  $f_{DTS}$  is replaced in the formula by CK\_INT when ICxF[3:0]= 1, 2 or 3.*

Bits 3:2 **IC1PSC**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1).

The prescaler is reset as soon as CC1E='0' (TIMx\_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input

01: capture is done once every 2 events

10: capture is done once every 4 events

11: capture is done once every 8 events

Bits 1:0 **CC1S**: Capture/Compare 1 Selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx\_CCER).*

## 12.4.8 TIM1 capture/compare mode register 2 (TIMx\_CCMR2)

Address offset: 0x1C

Reset value: 0x0000

Refer to the above CCMR1 register description.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC4 CE	OC4M[2:0]			OC4 PE	OC4 FE	CC4S[1:0]	OC3 CE.	OC3M[2:0]			OC3 PE	OC3 FE	CC3S[1:0]		
IC4F[3:0]			IC4PSC[1:0]		IC3F[3:0]			IC3PSC[1:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

### Output compare mode

Bit 15 **OC4CE**: Output compare 4 clear enable

Bits 14:12 **OC4M**: Output compare 4 mode

Bit 11 **OC4PE**: Output compare 4 preload enable

Bit 10 **OC4FE**: Output compare 4 fast enable

Bits 9:8 **CC4S**: Capture/Compare 4 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC4 channel is configured as output

01: CC4 channel is configured as input, IC4 is mapped on TI4

10: CC4 channel is configured as input, IC4 is mapped on TI3

11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC4S bits are writable only when the channel is OFF (CC4E = '0' in TIMx\_CCER).*

Bit 7 **OC3CE**: Output compare 3 clear enable

Bits 6:4 **OC3M**: Output compare 3 mode

Bit 3 **OC3PE**: Output compare 3 preload enable

Bit 2 **OC3FE**: Output compare 3 fast enable

Bits 1:0 **CC3S**: Capture/Compare 3 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC3 channel is configured as output

01: CC3 channel is configured as input, IC3 is mapped on TI3

10: CC3 channel is configured as input, IC3 is mapped on TI4

11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC3S bits are writable only when the channel is OFF (CC3E = '0' in TIMx\_CCER).*

### Input capture mode

Bits 15:12 **IC4F**: Input capture 4 filter

Bits 11:10 **IC4PSC**: Input capture 4 prescaler

Bits 9:8 **CC4S**: Capture/Compare 4 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC4 channel is configured as output

01: CC4 channel is configured as input, IC4 is mapped on TI4

10: CC4 channel is configured as input, IC4 is mapped on TI3

11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC4S bits are writable only when the channel is OFF (CC4E = '0' in TIMx\_CCER).*

Bits 7:4 **IC3F**: Input capture 3 filter

Bits 3:2 **IC3PSC**: Input capture 3 prescaler

Bits 1:0 **CC3S**: Capture/compare 3 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC3 channel is configured as output

01: CC3 channel is configured as input, IC3 is mapped on TI3

10: CC3 channel is configured as input, IC3 is mapped on TI4

11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC3S bits are writable only when the channel is OFF (CC3E = '0' in TIMx\_CCER).*

## 12.4.9 TIM1 capture/compare enable register (TIMx\_CCER)

Address offset: 0x20

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **CC4P**: Capture/Compare 4 output polarity

refer to CC1P description

- Bit 12 **CC4E**: Capture/Compare 4 output enable  
refer to CC1E description
- Bit 11 **CC3NP**: Capture/Compare 3 complementary output polarity  
refer to CC1NP description
- Bit 10 **CC3NE**: Capture/Compare 3 complementary output enable  
refer to CC1NE description
- Bit 9 **CC3P**: Capture/Compare 3 output polarity  
refer to CC1P description
- Bit 8 **CC3E**: Capture/Compare 3 output enable  
refer to CC1E description
- Bit 7 **CC2NP**: Capture/Compare 2 complementary output polarity  
refer to CC1NP description
- Bit 6 **CC2NE**: Capture/Compare 2 complementary output enable  
refer to CC1NE description
- Bit 5 **CC2P**: Capture/Compare 2 output polarity  
refer to CC1P description
- Bit 4 **CC2E**: Capture/Compare 2 output enable  
refer to CC1E description
- Bit 3 **CC1NP**: Capture/Compare 1 complementary output polarity  
**CC1 channel configured as output:**  
0: OC1N active high.  
1: OC1N active low.  
**CC1 channel configured as input:**  
This bit is used in conjunction with CC1P to define the polarity of TI1FP1 and TI2FP1. Refer to CC1P description.
- Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx\_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a Commutation event is generated.*
- Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx\_BDTR register) and CC1S="00" (the channel is configured in output).*
- Bit 2 **CC1NE**: Capture/Compare 1 complementary output enable  
0: Off - OC1N is not active. OC1N level is then function of MOE, OSS1, OSSR, OIS1, OIS1N and CC1E bits.  
1: On - OC1N signal is output on the corresponding output pin depending on MOE, OSS1, OSSR, OIS1, OIS1N and CC1E bits.
- Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx\_CR2 register then the CC1NE active bit takes the new value from the preloaded bit only when a Commutation event is generated.*

Bit 1 **CC1P**: Capture/Compare 1 output polarity

**CC1 channel configured as output:**

0: OC1 active high

1: OC1 active low

**CC1 channel configured as input:**

CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

00: non-inverted/rising edge

The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

01: inverted/falling edge

The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

10: reserved, do not use this configuration.

11: non-inverted/both edges

The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

*Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx\_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.*

*Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx\_BDTR register).*

Bit 0 **CC1E**: Capture/Compare 1 output enable

**CC1 channel configured as output:**

0: Off - OC1 is not active. OC1 level is then function of MOE, OSS1, OSSR, OIS1, OIS1N and CC1NE bits.

1: On - OC1 signal is output on the corresponding output pin depending on MOE, OSS1, OSSR, OIS1, OIS1N and CC1NE bits.

**CC1 channel configured as input:**

This bit determines if a capture of the counter value can actually be done into the input capture/compare register 1 (TIMx\_CCR1) or not.

0: Capture disabled.

1: Capture enabled.

*Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx\_CR2 register then the CC1E active bit takes the new value from the preloaded bit only when a Commutation event is generated.*

**Table 51. Output control bits for complementary OCx and OCxN channels with break feature**

Control bits					Output states <sup>(1)</sup>	
MOE bit	OSSI bit	OSSR bit	CCxE bit	CCxNE bit	OCx output state	OCxN output state
1	X	0	0	0	Output Disabled (not driven by the timer) OCx=0, OCx_EN=0	Output Disabled (not driven by the timer) OCxN=0, OCxN_EN=0
		0	0	1	Output Disabled (not driven by the timer) OCx=0, OCx_EN=0	OCxREF + Polarity OCxN=OCxREF xor CCxNP, OCxN_EN=1
		0	1	0	OCxREF + Polarity OCx=OCxREF xor CCxP, OCx_EN=1	Output Disabled (not driven by the timer) OCxN=0, OCxN_EN=0
		0	1	1	OCREF + Polarity + dead-time OCx_EN=1	Complementary to OCREF (not OCREF) + Polarity + dead-time OCxN_EN=1
		1	0	0	Output Disabled (not driven by the timer) OCx=CCxP, OCx_EN=0	Output Disabled (not driven by the timer) OCxN=CCxNP, OCxN_EN=0
		1	0	1	Off-State (output enabled with inactive state) OCx=CCxP, OCx_EN=1	OCxREF + Polarity OCxN=OCxREF xor CCxNP, OCxN_EN=1
		1	1	0	OCxREF + Polarity OCx=OCxREF xor CCxP, OCx_EN=1	Off-State (output enabled with inactive state) OCxN=CCxNP, OCxN_EN=1
		1	1	1	OCREF + Polarity + dead-time OCx_EN=1	Complementary to OCREF (not OCREF) + Polarity + dead-time OCxN_EN=1
0	X	0	0	0	Output Disabled (not driven by the timer) OCx=CCxP, OCx_EN=0	Output Disabled (not driven by the timer) OCxN=CCxNP, OCxN_EN=0
		0	0	1	Output Disabled (not driven by the timer)	
		0	1	0	Asynchronously: OCx=CCxP, OCx_EN=0, OCxN=CCxNP, OCxN_EN=0	
		0	1	1	Then if the clock is present: OCx=OISx and OCxN=OISxN after a dead-time, assuming that OISx and OISxN do not correspond to OCX and OCxN both in active state.	
		1	0	0	Output Disabled (not driven by the timer) OCx=CCxP, OCx_EN=0	Output Disabled (not driven by the timer) OCxN=CCxNP, OCxN_EN=0
		1	0	1	Off-State (output enabled with inactive state) Asynchronously: OCx=CCxP, OCx_EN=1, OCxN=CCxNP, OCxN_EN=1	
		1	1	0	Asynchronously: OCx=CCxP, OCx_EN=1, OCxN=CCxNP, OCxN_EN=1	
		1	1	1	Then if the clock is present: OCx=OISx and OCxN=OISxN after a dead-time, assuming that OISx and OISxN do not correspond to OCX and OCxN both in active state	

- When both outputs of a channel are not used ( $CCxE = CCxNE = 0$ ), the  $OISx$ ,  $OISxN$ ,  $CCxP$  and  $CCxNP$  bits must be kept cleared.

**Note:** *The state of the external I/O pins connected to the complementary  $OCx$  and  $OCxN$  channels depends on the  $OCx$  and  $OCxN$  channel state and the GPIO registers.*

#### 12.4.10 TIM1 counter (TIMx\_CNT)

Address offset: 0x24

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CNT[15:0]**: Counter value

#### 12.4.11 TIM1 prescaler (TIMx\_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency ( $CK_{CNT}$ ) is equal to  $f_{CK\_PSC} / (PSC[15:0] + 1)$ .

PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx\_EGR register or through trigger controller when configured in “reset mode”).

#### 12.4.12 TIM1 auto-reload register (TIMx\_ARR)

Address offset: 0x2C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to [Section 12.3.1: Time-base unit on page 238](#) for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

### 12.4.13 TIM1 repetition counter register (TIMx\_RCR)

Address offset: 0x30

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								REP[7:0]							
rw								rw							

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 REP[7:0]: Repetition counter value

These bits allow the user to set-up the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable, as well as the update interrupt generation rate, if this interrupt is enable.

Each time the REP\_CNT related downcounter reaches zero, an update event is generated and it restarts counting from REP value. As REP\_CNT is reloaded with REP value only at the repetition update event U\_RC, any write to the TIMx\_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to:

- the number of PWM periods in edge-aligned mode
- the number of half PWM period in center-aligned mode.

### 12.4.14 TIM1 capture/compare register 1 (TIMx\_CCR1)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 CCR1[15:0]: Capture/Compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signaled on OC1 output.

If channel CC1 is configured as input:

CCR1 is the counter value transferred by the last input capture 1 event (IC1).

### 12.4.15 TIM1 capture/compare register 2 (TIMx\_CCR2)

Address offset: 0x38

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR2[15:0]**: Capture/Compare 2 value

**If channel CC2 is configured as output:**

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR2 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signalled on OC2 output.

**If channel CC2 is configured as input:**

CCR2 is the counter value transferred by the last input capture 2 event (IC2).

### 12.4.16 TIM1 capture/compare register 3 (TIMx\_CCR3)

Address offset: 0x3C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR3[15:0]**: Capture/Compare value

**If channel CC3 is configured as output:**

CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR3 register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signalled on OC3 output.

**If channel CC3 is configured as input:**

CCR3 is the counter value transferred by the last input capture 3 event (IC3).

### 12.4.17 TIM1 capture/compare register 4 (TIMx\_CCR4)

Address offset: 0x40

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR4[15:0]**: Capture/Compare value

**If channel CC4 is configured as output:**

CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR4 register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signalled on OC4 output.

**If channel CC4 is configured as input:**

CCR4 is the counter value transferred by the last input capture 4 event (IC4).

### 12.4.18 TIM1 break and dead-time register (TIMx\_BDTR)

Address offset: 0x44

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DTG[7:0]															
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

**Note:** As the bits AOE, BKP, BKE, OSSR and DTG[7:0] can be write-locked depending on the LOCK configuration, it can be necessary to configure all of them during the first write access to the TIMx\_BDTR register.

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as the break input is active. It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.

0: OC and OCN outputs are disabled or forced to idle state.

1: OC and OCN outputs are enabled if their respective enable bits are set (CCxE, CCxNE in TIMx\_CCER register).

See OC/OCN enable description for more details ([Section 12.4.9: TIM1 capture/compare enable register \(TIMx\\_CCER\) on page 291](#)).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software

1: MOE can be set by software or automatically at the next update event (if the break input is not be active)

**Note:** This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx\_BDTR register).

Bit 13 **BKP**: Break polarity

- 0: Break input BRK is active low
- 1: Break input BRK is active high

*Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx\_BDTR register).*

*Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.*

Bit 12 **BKE**: Break enable

- 0: Break inputs (BRK and CSS clock failure event) disabled
- 1: Break inputs (BRK and CSS clock failure event) enabled

*Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx\_BDTR register).*

*Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.*

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE=1 on channels having a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.

See OC/OCN enable description for more details ([Section 12.4.9: TIM1 capture/compare enable register \(TIMx\\_CCER\) on page 291](#)).

- 0: When inactive, OC/OCN outputs are disabled (OC/OCN enable output signal=0).
- 1: When inactive, OC/OCN outputs are enabled with their inactive level as soon as CCxE=1 or CCxNE=1. Then, OC/OCN enable output signal=1

*Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx\_BDTR register).*

Bit 10 **OSSI**: Off-state selection for Idle mode

This bit is used when MOE=0 on channels configured as outputs.

See OC/OCN enable description for more details ([Section 12.4.9: TIM1 capture/compare enable register \(TIMx\\_CCER\) on page 291](#)).

- 0: When inactive, OC/OCN outputs are disabled (OC/OCN enable output signal=0).
- 1: When inactive, OC/OCN outputs are forced first with their idle level as soon as CCxE=1 or CCxNE=1. OC/OCN enable output signal=1

*Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx\_BDTR register).*

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.

00: LOCK OFF - No bit is write protected.

01: LOCK Level 1 = DTG bits in TIMx\_BDTR register, OISx and OISxN bits in TIMx\_CR2 register and BKE/BKP/AOE bits in TIMx\_BDTR register can no longer be written.

10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIMx\_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.

11: LOCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIMx\_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

*Note: The LOCK bits can be written only once after the reset. Once the TIMx\_BDTR register has been written, their content is frozen until the next reset.*

**Bits 7:0 DTG[7:0]: Dead-time generator setup**

This bit-field defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.

DTG[7:5]=0xx => DT=DTG[7:0]x t<sub>dtg</sub> with t<sub>dtg</sub>=t<sub>DTS</sub>.

DTG[7:5]=10x => DT=(64+DTG[5:0])x t<sub>dtg</sub> with T<sub>dtg</sub>=2x t<sub>DTS</sub>.

DTG[7:5]=110 => DT=(32+DTG[4:0])x t<sub>dtg</sub> with T<sub>dtg</sub>=8x t<sub>DTS</sub>.

DTG[7:5]=111 => DT=(32+DTG[4:0])x t<sub>dtg</sub> with T<sub>dtg</sub>=16x t<sub>DTS</sub>.

Example if T<sub>DTS</sub>=125ns (8MHz), dead-time possible values are:

0 to 15875 ns by 125 ns steps,

16 us to 31750 ns by 250 ns steps,

32 us to 63us by 1 us steps,

64 us to 126 us by 2 us steps

*Note: This bit-field can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx\_BDTR register).*

#### 12.4.19 TIM1 DMA control register (TIMx\_DCR)

Address offset: 0x48

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	DBL[4:0]					Reserved	DBA[4:0]					rw	rw	rw	rw
	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw				

Bits 15:13 Reserved, must be kept at reset value.

**Bits 12:8 DBL[4:0]: DMA burst length**

This 5-bit vector defines the number of DMA transfers (the timer detects a burst transfer when a read or a write access to the TIMx\_DMAR register address is performed).

the TIMx\_DMAR address)

00000: 1 transfer

00001: 2 transfers

00010: 3 transfers

...

10001: 18 transfers

Bits 7:5 Reserved, must be kept at reset value.

**Bits 4:0 DBA[4:0]: DMA base address**

This 5-bits vector defines the base-address for DMA transfers (when read/write access are done through the TIMx\_DMAR address). DBA is defined as an offset starting from the address of the TIMx\_CR1 register.

Example:

00000: TIMx\_CR1,

00001: TIMx\_CR2,

00010: TIMx\_SMCR,

...

**Example:** Let us consider the following transfer: DBL = 7 transfers and DBA = TIMx\_CR1. In this case the transfer is done to/from 7 registers starting from the TIMx\_CR1 address.

### 12.4.20 TIM1 DMA address for full transfer (TIMx\_DMAR)

Address offset: 0x4C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **DMAB[15:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address  
 $(\text{TIMx\_CR1 address}) + (\text{DBA} + \text{DMA index}) \times 4$

where TIMx\_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx\_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx\_DCR).

#### Example of how to use the DMA burst feature

In this example the timer DMA burst feature is used to update the contents of the CCRx registers ( $x = 2, 3, 4$ ) with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
  - DMA channel peripheral address is the DMAR register address
  - DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into CCRx registers.
  - Number of data to transfer = 3 (See note below).
  - Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bit fields as follows:  
 $\text{DBL} = 3$  transfers,  $\text{DBA} = 0xE$ .
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx
5. Enable the DMA channel

Note:

*This example is for the case where every CCRx register to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer should be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5 and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3 and data6 is transferred to CCR4.*

### 12.4.21 TIM1 register map

TIM1 registers are mapped as 16-bit addressable registers as described in the table below:

**Table 52. TIM1 register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
0x00	TIMx_CR1	Reserved												CKD [1:0]	ARPE	CMS [1:0]	DIR	OPM	CCDS	URS	Reserved	UDIS	CCUS	0	0	0	0	0	0	0	0	0			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x04	TIMx_CR2	Reserved												OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	MMS[2:0]		CCDS	0	0	0	0	0	0	0	0	0			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x08	TIMx_SMCR	Reserved												ETP	ECE	ETPS [1:0]	ETF[3:0]		MSM	TS[2:0]		SMS[2:0]		0	0	0	0	0	0	0	0	0	0		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x0C	TIMx_DIER	Reserved												TDE	COMDE	CC4DE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x10	TIMx_SR	Reserved												CC4OF	0	CC4DE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x14	TIMx_EGR	Reserved												Reserved	BG	TG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x18	TIMx_CCMR1 Output Compare mode	Reserved												OC2CE	OC2M [2:0]	OC2PE	OC2FE	CC2S [1:0]	OC1CE	OC1M [2:0]	OC1PE	OC1FE	CC1S [1:0]	0	0	0	0	0	0	0	0	0	0	0	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x1C	TIMx_CCMR1 Input Capture mode	Reserved												IC2F[3:0]	IC2 PSC [1:0]	CC2S [1:0]	IC1F[3:0]		IC1	PSC [1:0]	CC1S [1:0]	0	0	0	0	0	0	0	0	0	0	0	0		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x20	TIMx_CCMR2 Output Compare mode	Reserved												O24CE	OC4M [2:0]	OC4PE	OC4FE	CC4S [1:0]	OC3CE	OC3M [2:0]	OC3PE	OC3FE	CC3S [1:0]	0	0	0	0	0	0	0	0	0	0	0	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x20	TIMx_CCMR2 Input Capture mode	Reserved												IC4F[3:0]	IC4 PSC [1:0]	CC4S [1:0]	IC3F[3:0]		IC3	PSC [1:0]	CC3S [1:0]	0	0	0	0	0	0	0	0	0	0	0	0		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x24	TIMx_CCER	Reserved												CC4P	CC4E	CC3NP	CC3NE	CC3P	CC3E	CC2NP	CC2NE	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E	0	0	0	0	0	0		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x28	TIMx_PSC	Reserved												PSC[15:0]												0	0	0	0	0	0	0	0	0	0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x2C	TIMx_ARR	Reserved												ARR[15:0]												0	0	0	0	0	0	0	0	0	0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x30	TIMx_RCR	Reserved												REP[7:0]												0	0	0	0	0	0	0	0	0	0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

**Table 52. TIM1 register map and reset values (continued)**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x34	TIMx_CCR1	Reserved										CCR1[15:0]																					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x38	TIMx_CCR2	Reserved										CCR2[15:0]																					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x3C	TIMx_CCR3	Reserved										CCR3[15:0]																					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x40	TIMx_CCR4	Reserved										CCR4[15:0]																					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x44	TIMx_BDTR	Reserved										MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]	DT[7:0]														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x48	TIMx_DCR	Reserved										DBL[4:0]						Reserved	DBA[4:0]														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x4C	TIMx_DMAR	Reserved										DMAB[15:0]																					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 13 General-purpose timers (TIM2 to TIM5)

### 13.1 TIM2 to TIM5 introduction

The general-purpose timers consist of a 16-bit or 32-bit auto-reload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (*input capture*) or generating output waveforms (*output compare and PWM*).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

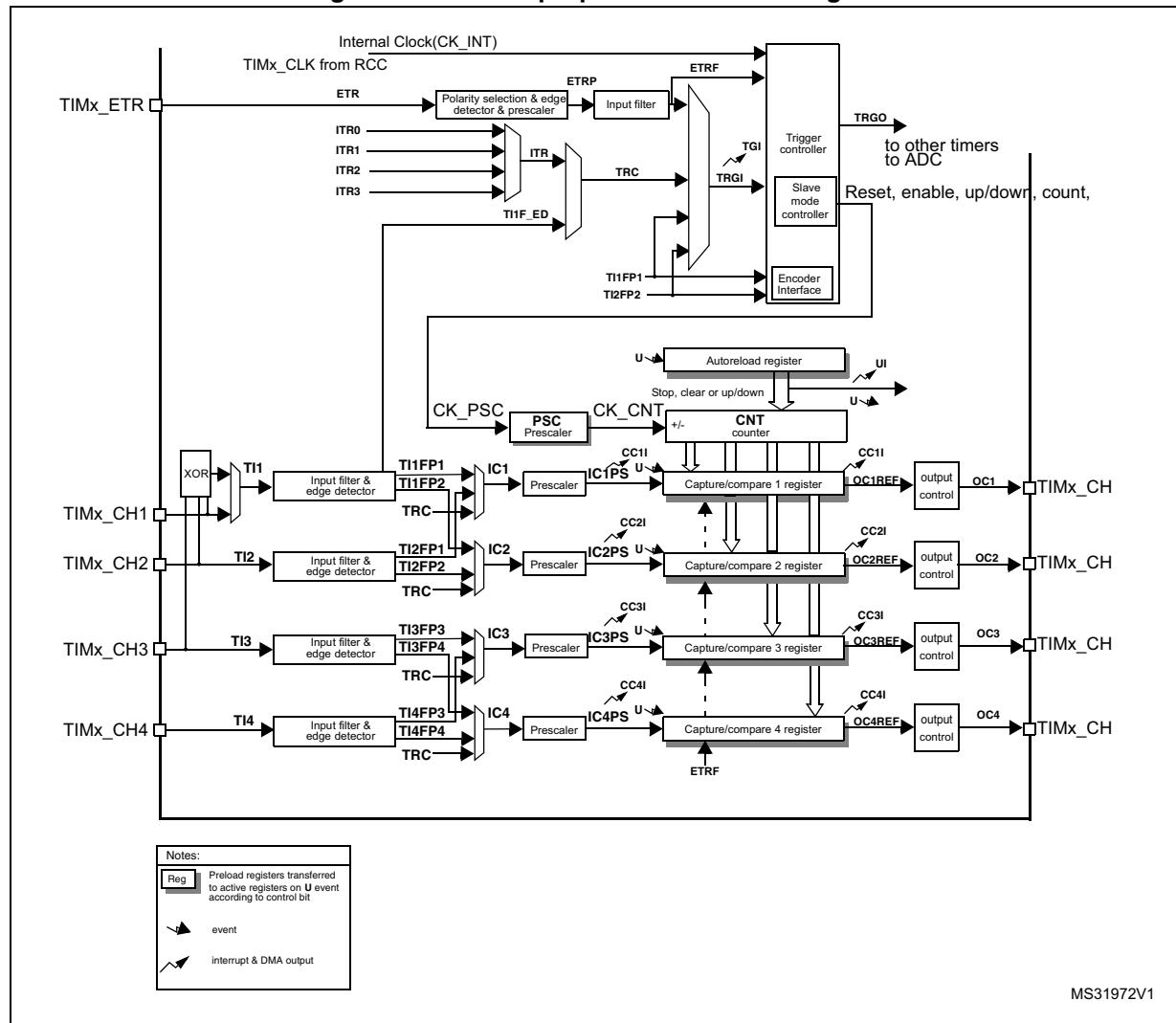
The timers are completely independent, and do not share any resources. They can be synchronized together as described in [Section 13.3.15](#).

### 13.2 TIM2 to TIM5 main features

General-purpose TIMx timer features include:

- 16-bit (TIM3 and TIM4) or 32-bit (TIM2 and TIM5) up, down, up/down auto-reload counter.
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65536.
- Up to 4 independent channels for:
  - Input capture
  - Output compare
  - PWM generation (Edge- and Center-aligned modes)
  - One-pulse mode output
- Synchronization circuit to control the timer with external signals and to interconnect several timers.
- Interrupt/DMA generation on the following events:
  - Update: counter overflow/underflow, counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization or count by internal/external trigger)
  - Input capture
  - Output compare
- Supports incremental (quadrature) encoder and hall-sensor circuitry for positioning purposes
- Trigger input for external clock or cycle-by-cycle current management

Figure 87. General-purpose timer block diagram



## 13.3 TIM2 to TIM5 functional description

### 13.3.1 Time-base unit

The main block of the programmable timer is a 16-bit/32-bit counter with its related auto-reload register. The counter can count up. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter Register (TIMx\_CNT)
- Prescaler Register (TIMx\_PSC):
- Auto-Reload Register (TIMx\_ARR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx\_CR1 register. The update event is sent when the counter reaches the overflow (or underflow when downcounting) and if the UDIS bit equals 0 in the TIMx\_CR1 register. It can also be generated by software. The generation of the update event is described in detail for each configuration.

The counter is clocked by the prescaler output CK\_CNT, which is enabled only when the counter enable bit (CEN) in TIMx\_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

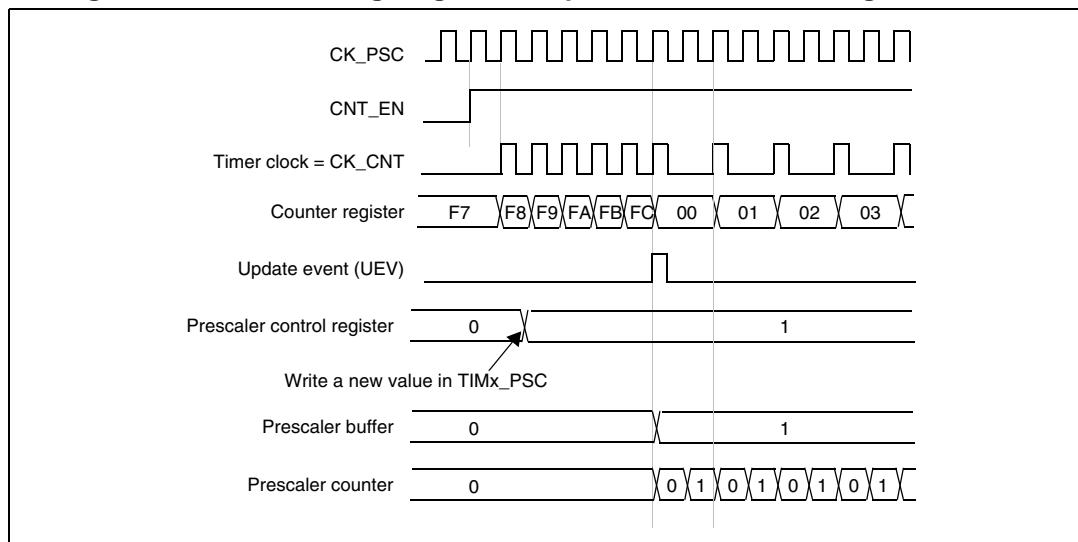
Note that the actual counter enable signal CNT\_EN is set 1 clock cycle after CEN.

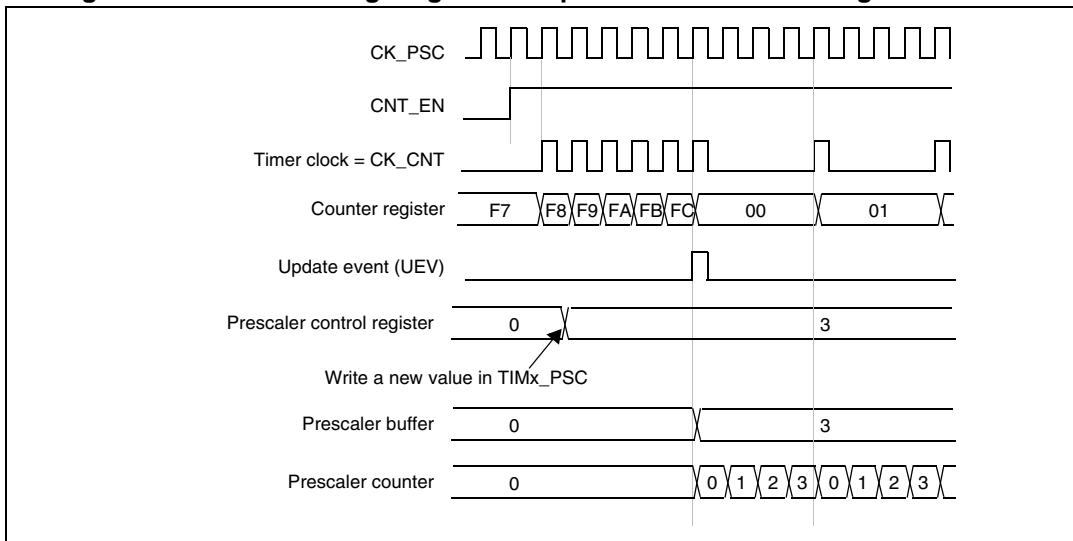
### Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit/32-bit register (in the TIMx\_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

*Figure 88* and *Figure 89* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

**Figure 88. Counter timing diagram with prescaler division change from 1 to 2**



**Figure 89. Counter timing diagram with prescaler division change from 1 to 4**

### 13.3.2 Counter modes

#### Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx\_ARR register), then restarts from 0 and generates a counter overflow event.

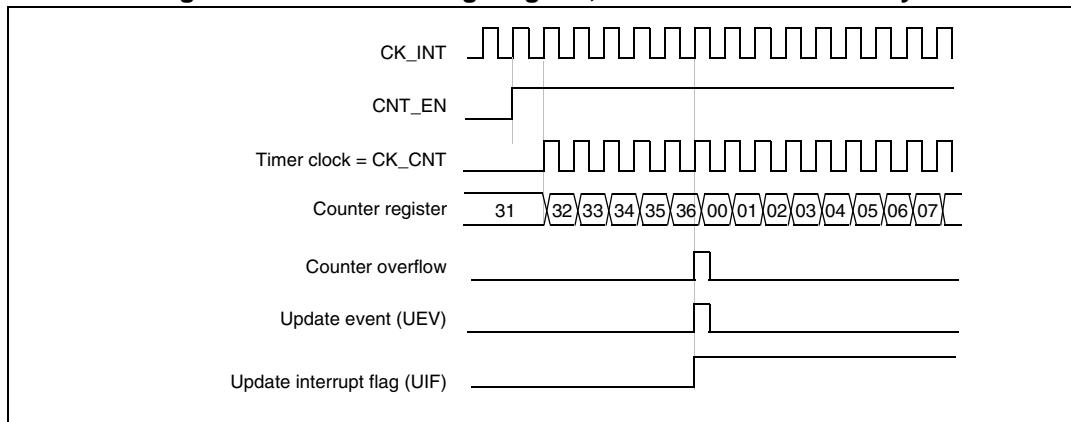
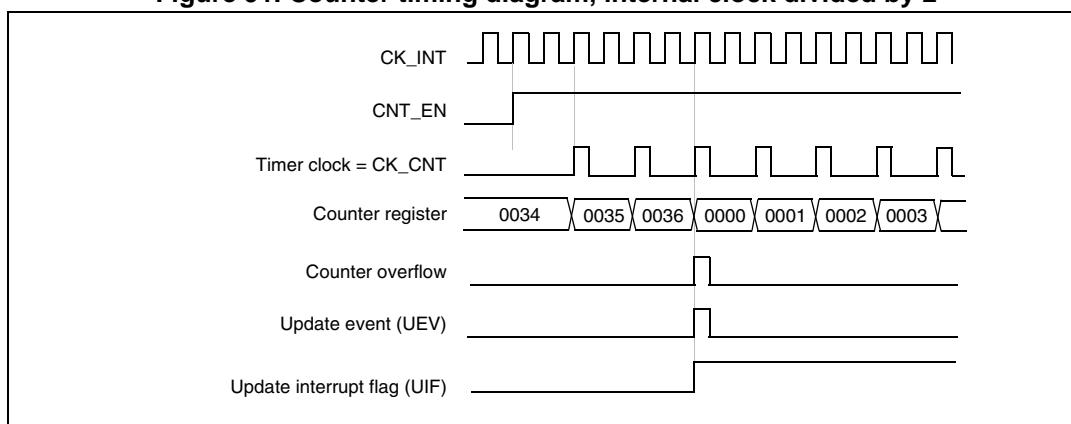
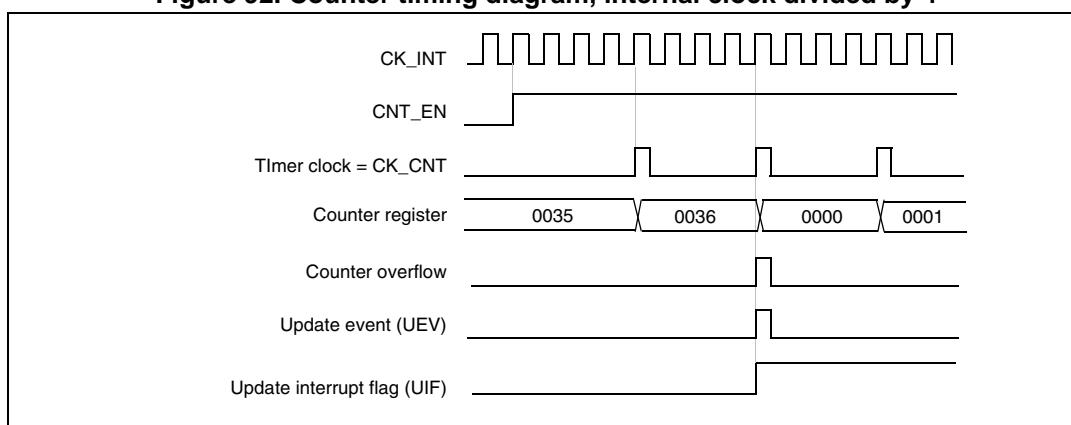
An Update event can be generated at each counter overflow or by setting the UG bit in the TIMx\_EGR register (by software or by using the slave mode controller).

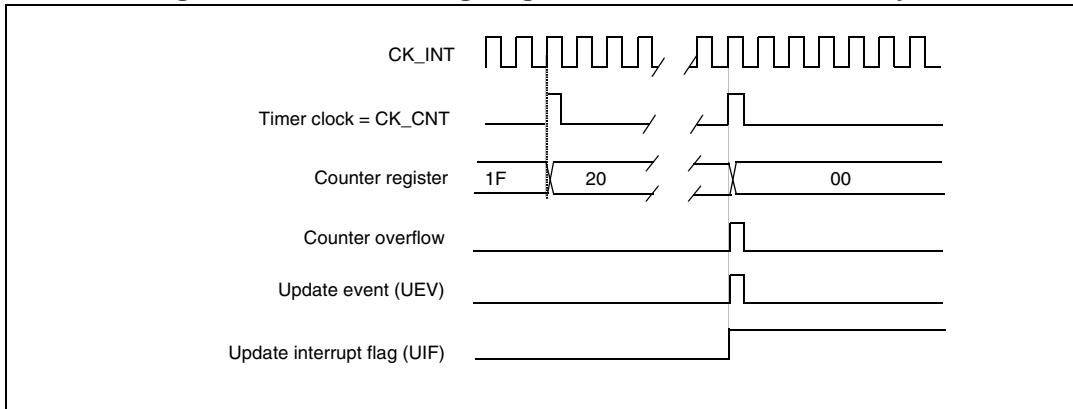
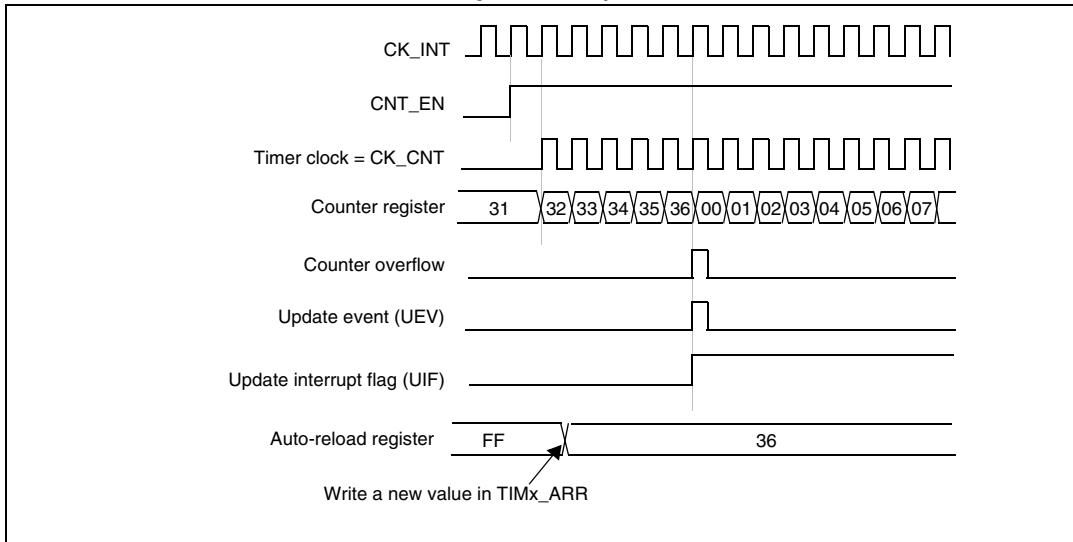
The UEV event can be disabled by software by setting the UDIS bit in TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

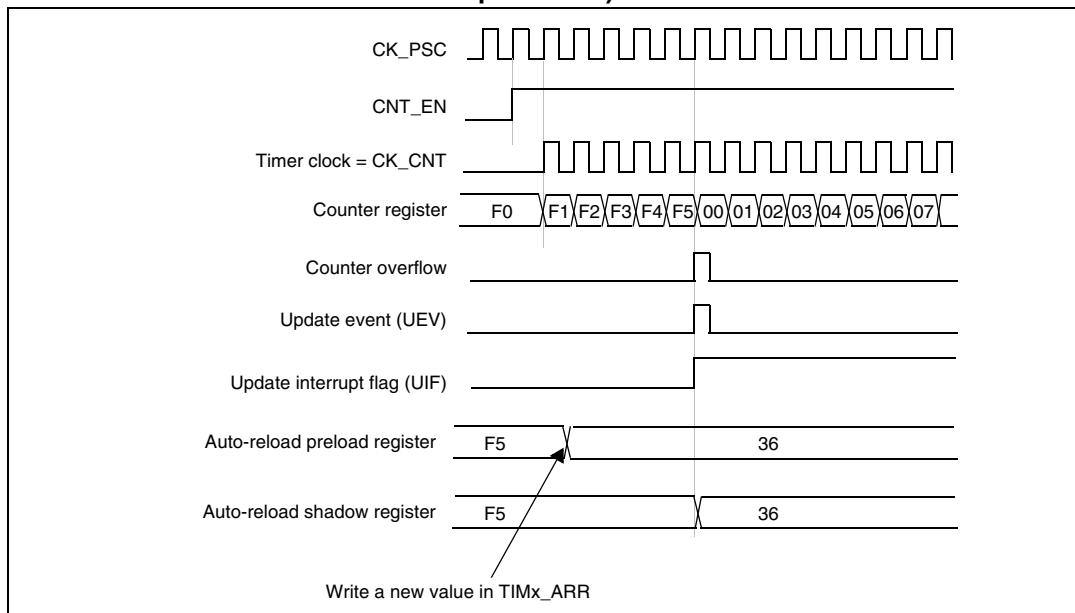
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register)
- The auto-reload shadow register is updated with the preload value (TIMx\_ARR)

The following figures show some examples of the counter behavior for different clock frequencies when TIMx\_ARR=0x36.

**Figure 90. Counter timing diagram, internal clock divided by 1****Figure 91. Counter timing diagram, internal clock divided by 2****Figure 92. Counter timing diagram, internal clock divided by 4**

**Figure 93. Counter timing diagram, internal clock divided by N****Figure 94. Counter timing diagram, Update event when ARPE=0 (TIMx\_ARR not preloaded)**

**Figure 95. Counter timing diagram, Update event when ARPE=1 (TIMx\_ARR preloaded)**



### Downcounting mode

In downcounting mode, the counter counts from the auto-reload value (content of the TIMx\_ARR register) down to 0, then restarts from the auto-reload value and generates a counter underflow event.

An Update event can be generated at each counter underflow or by setting the UG bit in the TIMx\_EGR register (by software or by using the slave mode controller).

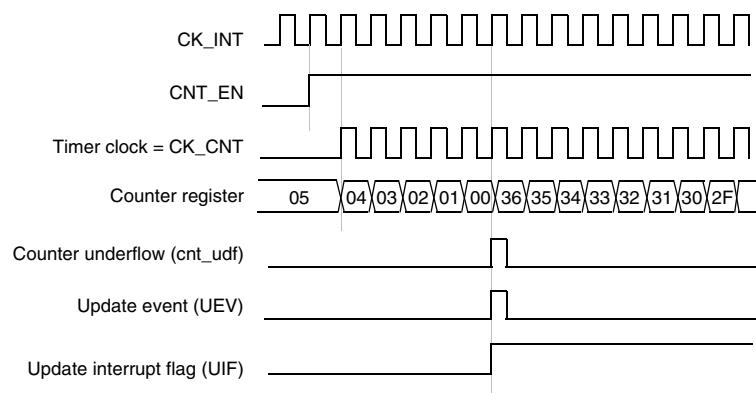
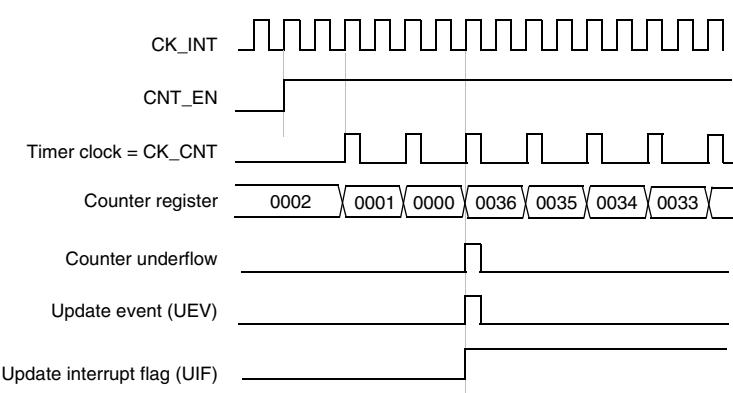
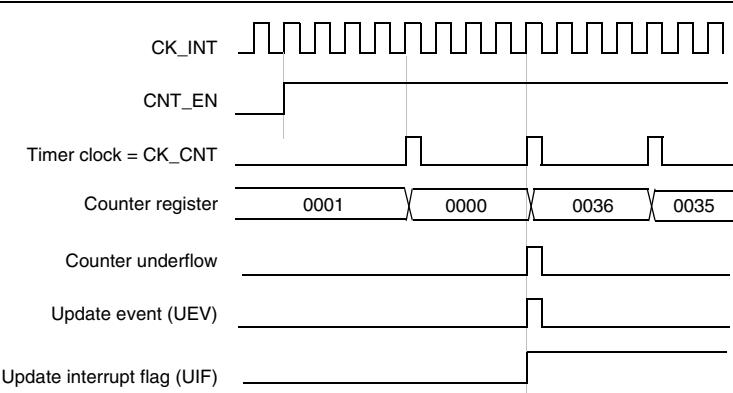
The UEV update event can be disabled by software by setting the UDIS bit in TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter restarts from the current auto-reload value, whereas the counter of the prescaler restarts from 0 (but the prescale rate doesn't change).

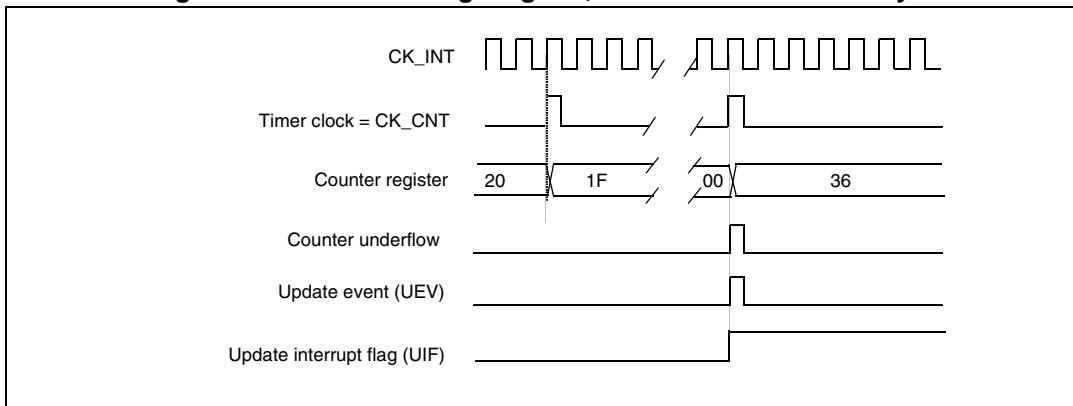
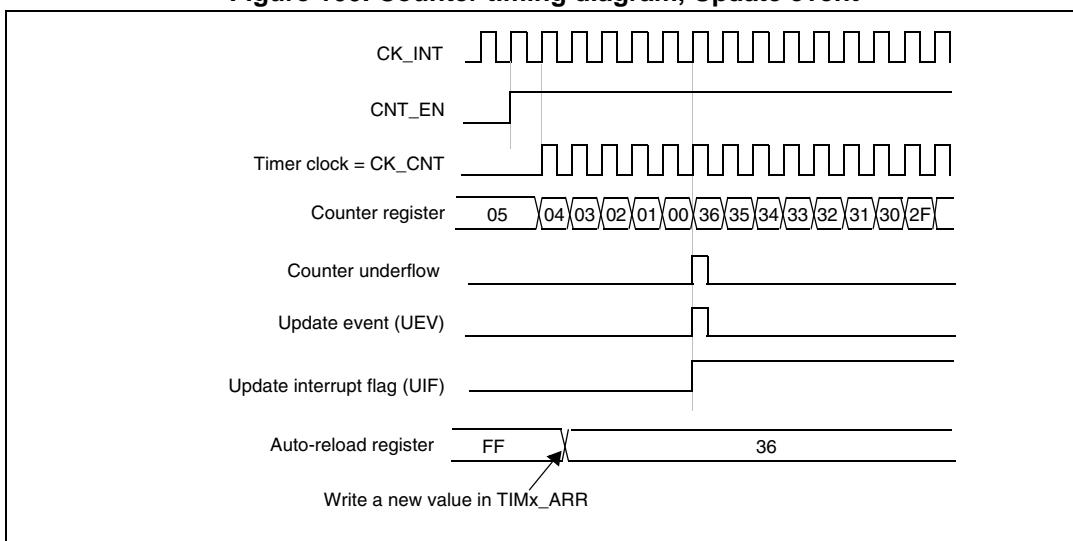
In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register).
- The auto-reload active register is updated with the preload value (content of the TIMx\_ARR register). Note that the auto-reload is updated before the counter is reloaded, so that the next period is the expected one.

The following figures show some examples of the counter behavior for different clock frequencies when TIMx\_ARR=0x36.

**Figure 96. Counter timing diagram, internal clock divided by 1****Figure 97. Counter timing diagram, internal clock divided by 2****Figure 98. Counter timing diagram, internal clock divided by 4**

**Figure 99. Counter timing diagram, internal clock divided by N****Figure 100. Counter timing diagram, Update event**

### Center-aligned mode (up/down counting)

In center-aligned mode, the counter counts from 0 to the auto-reload value (content of the TIMx\_ARR register) – 1, generates a counter overflow event, then counts from the auto-reload value down to 1 and generates a counter underflow event. Then it restarts counting from 0.

Center-aligned mode is active when the CMS bits in TIMx\_CR1 register are not equal to '00'. The Output compare interrupt flag of channels configured in output is set when: the counter counts down (Center aligned mode 1, CMS = "01"), the counter counts up (Center aligned mode 2, CMS = "10") or the counter counts up and down (Center aligned mode 3, CMS = "11").

In this mode, the direction bit (DIR from TIMx\_CR1 register) cannot be written. It is updated by hardware and gives the current direction of the counter.

The update event can be generated at each counter overflow and at each counter underflow or by setting the UG bit in the TIMx\_EGR register (by software or by using the slave mode controller) also generates an update event. In this case, the counter restarts counting from 0, as well as the counter of the prescaler.

The UEV update event can be disabled by software by setting the UDIS bit in TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter continues counting up and down, based on the current auto-reload value.

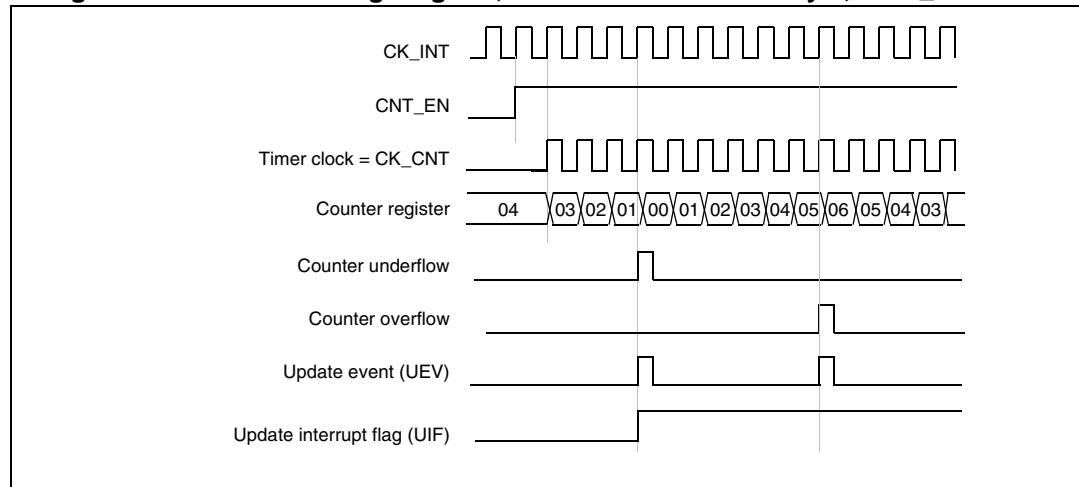
In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupt when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

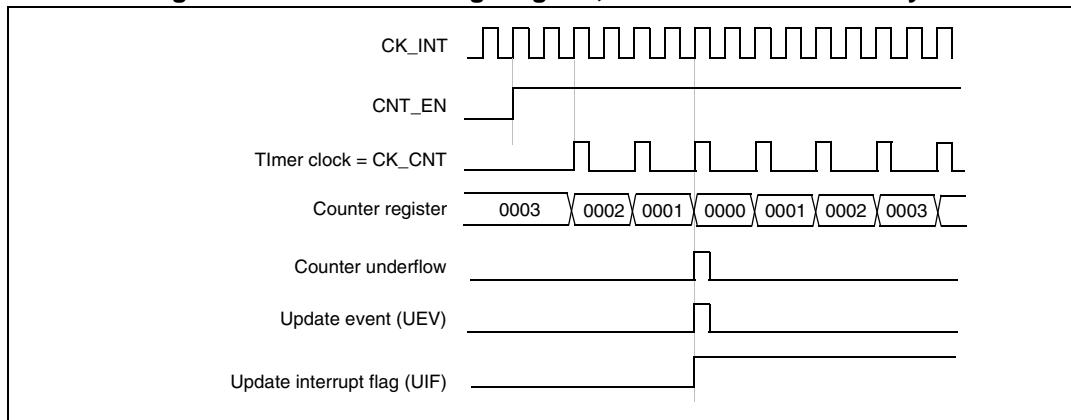
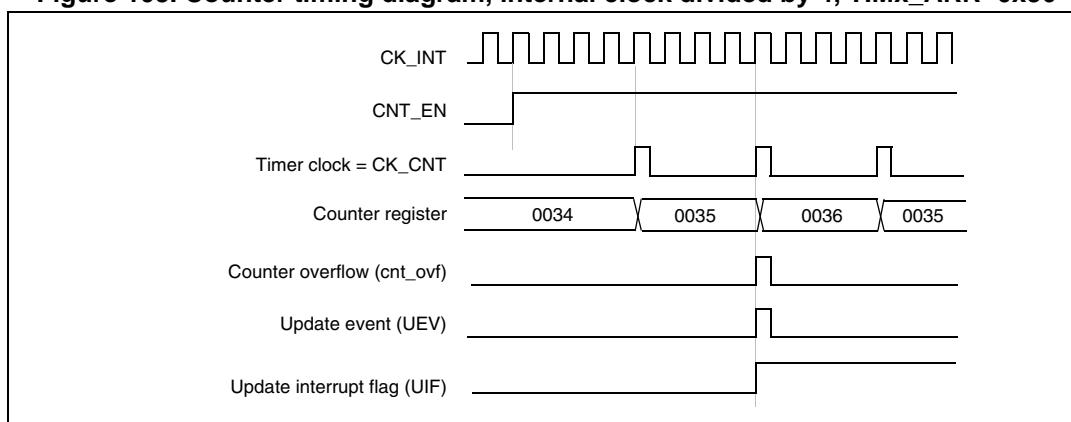
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register).
- The auto-reload active register is updated with the preload value (content of the TIMx\_ARR register). Note that if the update source is a counter overflow, the auto-reload is updated before the counter is reloaded, so that the next period is the expected one (the counter is loaded with the new value).

The following figures show some examples of the counter behavior for different clock frequencies.

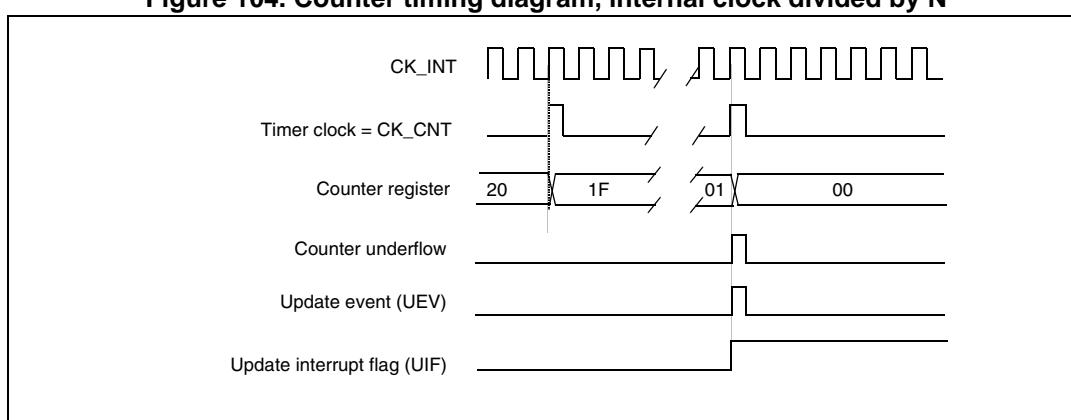
**Figure 101. Counter timing diagram, internal clock divided by 1, TIMx\_ARR=0x6**

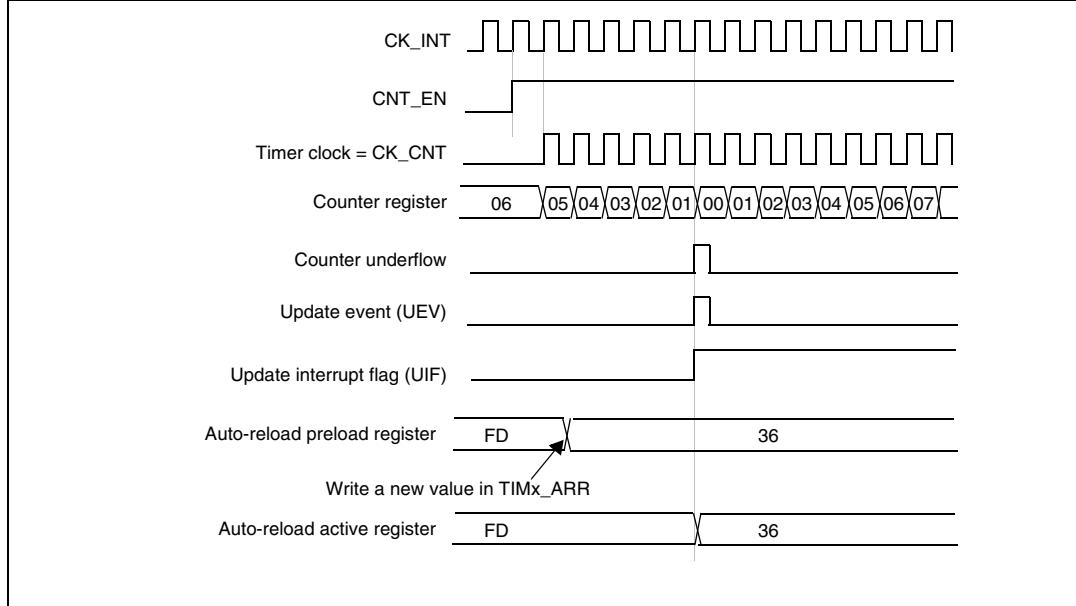
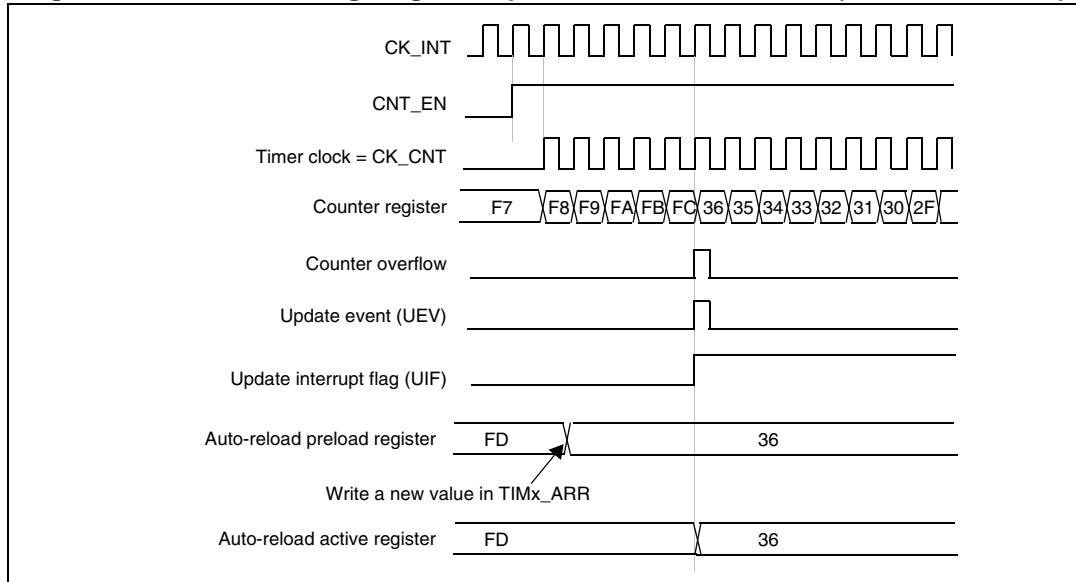


1. Here, center-aligned mode 1 is used (for more details refer to [Section 13.4.1: TIMx control register 1 \(TIMx\\_CR1\) on page 339](#)).

**Figure 102. Counter timing diagram, internal clock divided by 2****Figure 103. Counter timing diagram, internal clock divided by 4, TIMx\_ARR=0x36**

1. Center-aligned mode 2 or 3 is used with an UIF on overflow.

**Figure 104. Counter timing diagram, internal clock divided by N**

**Figure 105. Counter timing diagram, Update event with ARPE=1 (counter underflow)****Figure 106. Counter timing diagram, Update event with ARPE=1 (counter overflow)**

### 13.3.3 Clock selection

The counter clock can be provided by the following clock sources:

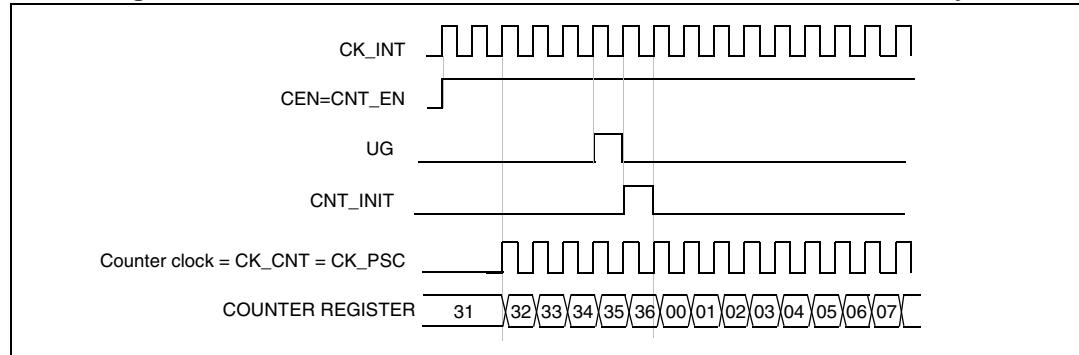
- Internal clock (CK\_INT)
- External clock mode1: external input pin (TIx)
- External clock mode2: external trigger input (ETR) available on TIM2, TIM3 and TIM4 only.
- Internal trigger inputs (ITRx): using one timer as prescaler for another timer, for example, you can configure Timer to act as a prescaler for Timer 2. Refer to : [Using one timer as prescaler for another on page 334](#) for more details.

### Internal clock source (CK\_INT)

If the slave mode controller is disabled (SMS=000 in the TIMx\_SMCR register), then the CEN, DIR (in the TIMx\_CR1 register) and UG bits (in the TIMx\_EGR register) are actual control bits and can be changed only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock CK\_INT.

*Figure 107* shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

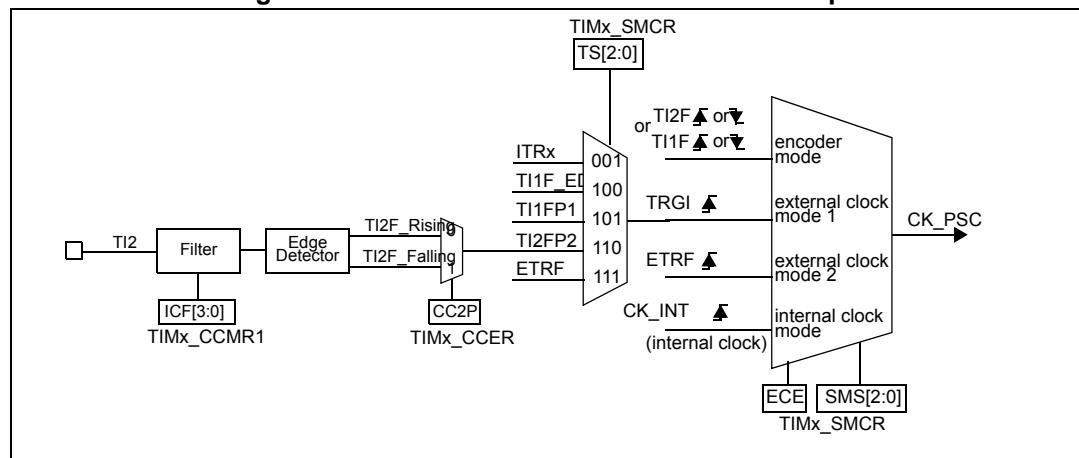
**Figure 107. Control circuit in normal mode, internal clock divided by 1**



### External clock source mode 1

This mode is selected when SMS=111 in the TIMx\_SMCR register. The counter can count at each rising or falling edge on a selected input.

**Figure 108. TI2 external clock connection example**



For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

1. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S= '01 in the **TIMx\_CCMR1** register.
2. Configure the input filter duration by writing the IC2F[3:0] bits in the **TIMx\_CCMR1** register (if no filter is needed, keep IC2F=0000).

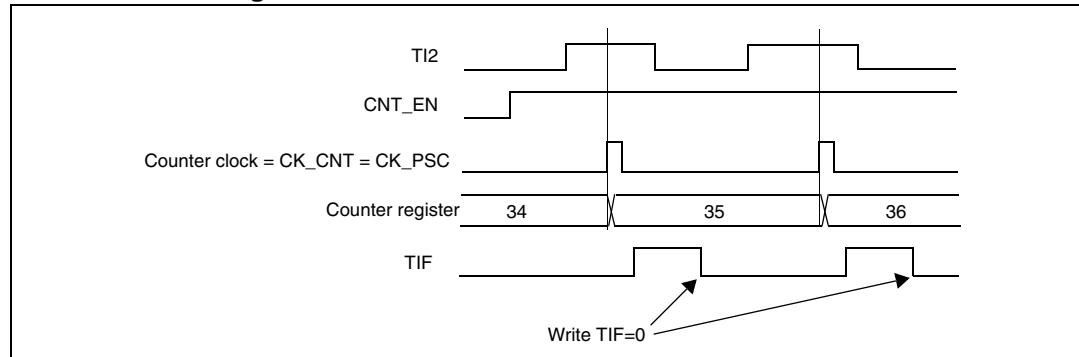
**Note:** The capture prescaler is not used for triggering, so you don't need to configure it.

3. Select rising edge polarity by writing CC2P=0 and CC2NP=0 in the TIMx\_CCER register.
4. Configure the timer in external clock mode 1 by writing SMS=111 in the TIMx\_SMCR register.
5. Select TI2 as the input source by writing TS=110 in the TIMx\_SMCR register.
6. Enable the counter by writing CEN=1 in the TIMx\_CR1 register.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

**Figure 109. Control circuit in external clock mode 1**



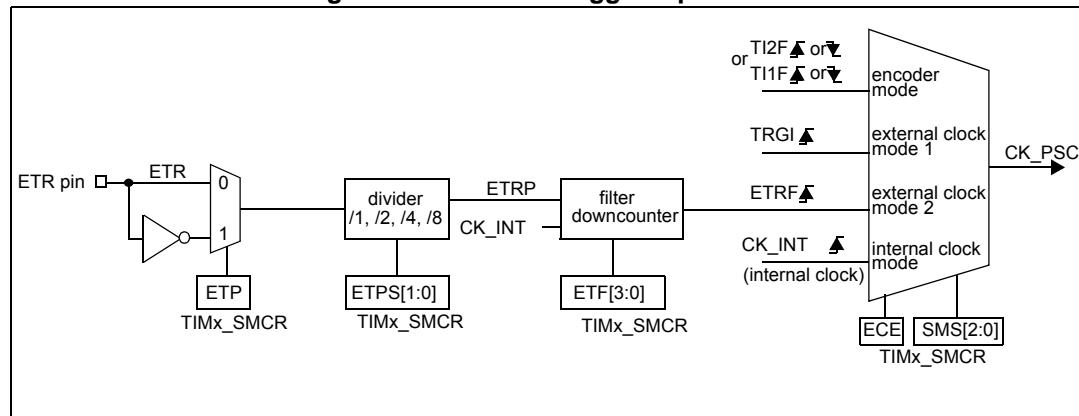
### External clock source mode 2

This mode is selected by writing ECE=1 in the TIMx\_SMCR register.

The counter can count at each rising or falling edge on the external trigger input ETR.

[Figure 110](#) gives an overview of the external trigger input block.

**Figure 110. External trigger input block**



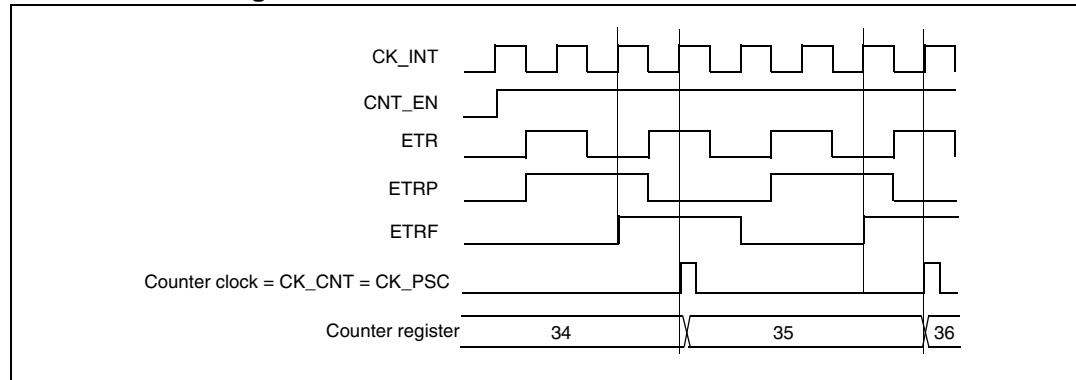
For example, to configure the upcounter to count each 2 rising edges on ETR, use the following procedure:

1. As no filter is needed in this example, write ETF[3:0]=0000 in the TIMx\_SMCR register.
2. Set the prescaler by writing ETPS[1:0]=01 in the TIMx\_SMCR register
3. Select rising edge detection on the ETR pin by writing ETP=0 in the TIMx\_SMCR register
4. Enable external clock mode 2 by writing ECE=1 in the TIMx\_SMCR register.
5. Enable the counter by writing CEN=1 in the TIMx\_CR1 register.

The counter counts once each 2 ETR rising edges.

The delay between the rising edge on ETR and the actual clock of the counter is due to the resynchronization circuit on the ETRP signal.

**Figure 111. Control circuit in external clock mode 2**



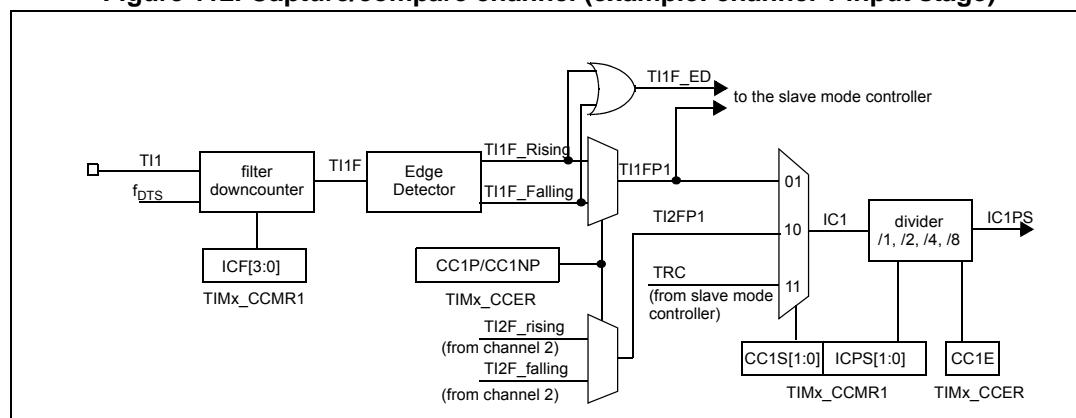
### 13.3.4 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

The following figure gives an overview of one Capture/Compare channel.

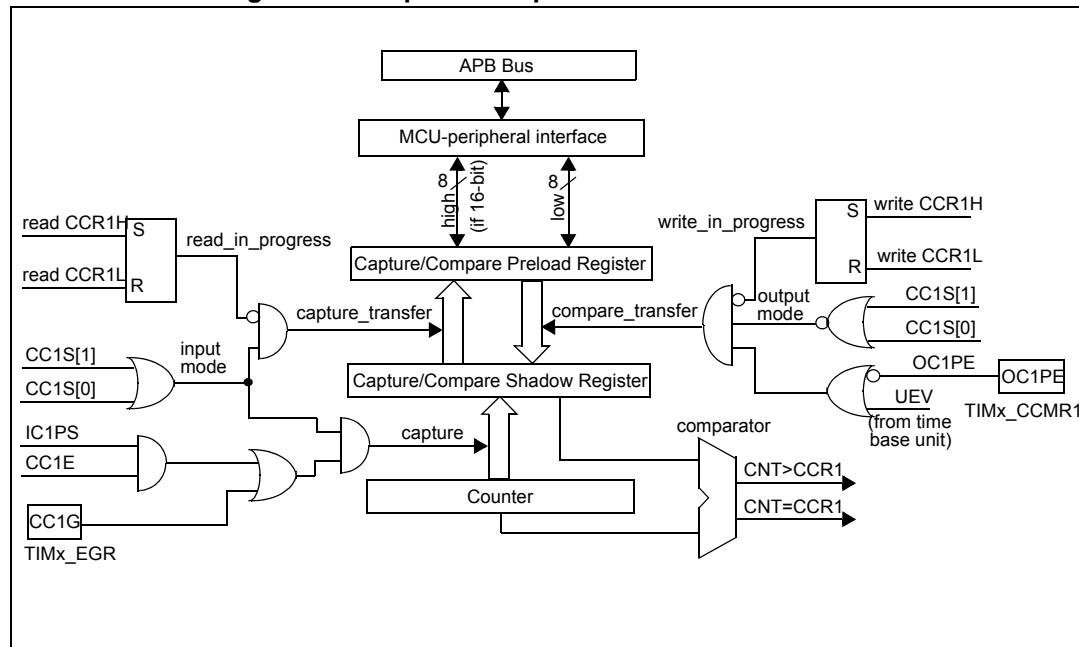
The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

**Figure 112. Capture/compare channel (example: channel 1 input stage)**

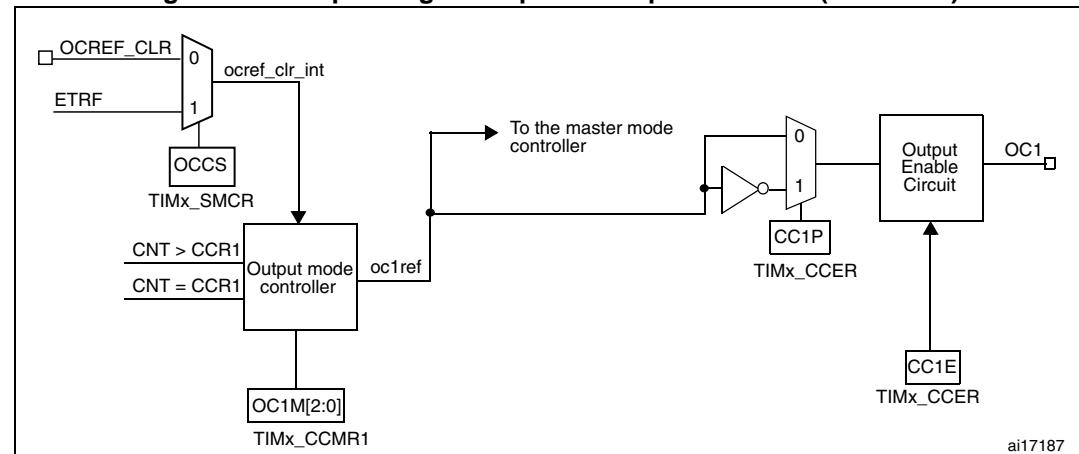


The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

**Figure 113. Capture/compare channel 1 main circuit**



**Figure 114. Output stage of capture/compare channel (channel 1)**



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

### 13.3.5 Input capture mode

In Input capture mode, the Capture/Compare Registers (TIMx\_CCRx) are used to latch the value of the counter after a transition detected by the corresponding IC<sub>x</sub> signal. When a capture occurs, the corresponding CC<sub>x</sub>IF flag (TIMx\_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CC<sub>x</sub>IF flag was already high, then the over-capture flag CC<sub>x</sub>OF (TIMx\_SR register) is set. CC<sub>x</sub>IF can be cleared by software by writing it to 0 or by reading the captured data stored in the TIMx\_CCRx register. CC<sub>x</sub>OF is cleared when you write it to 0.

The following example shows how to capture the counter value in TIMx\_CCR1 when TI1 input rises. To do this, use the following procedure:

- Select the active input: TIMx\_CCR1 must be linked to the TI1 input, so write the CC1S bits to 01 in the TIMx\_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input and the TIMx\_CCR1 register becomes read-only.
- Program the input filter duration you need with respect to the signal you connect to the timer (by programming the ICxF bits in the TIMx\_CCMRx register if the input is one of the TI<sub>x</sub> inputs). Let's imagine that, when toggling, the input signal is not stable during at most 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the new level have been detected (sampled at f<sub>DTS</sub> frequency). Then write IC1F bits to 0011 in the TIMx\_CCMR1 register.
- Select the edge of the active transition on the TI1 channel by writing the CC1P and CC1NP bits to 00 in the TIMx\_CCER register (rising edge in this case).
- Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to 00 in the TIMx\_CCMR1 register).
- Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx\_CCER register.
- If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx\_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx\_DIER register.

When an input capture occurs:

- The TIMx\_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

*Note:*

*IC interrupt and/or DMA requests can be generated by software by setting the corresponding CC<sub>x</sub>G bit in the TIMx\_EGR register.*

### 13.3.6 PWM input mode

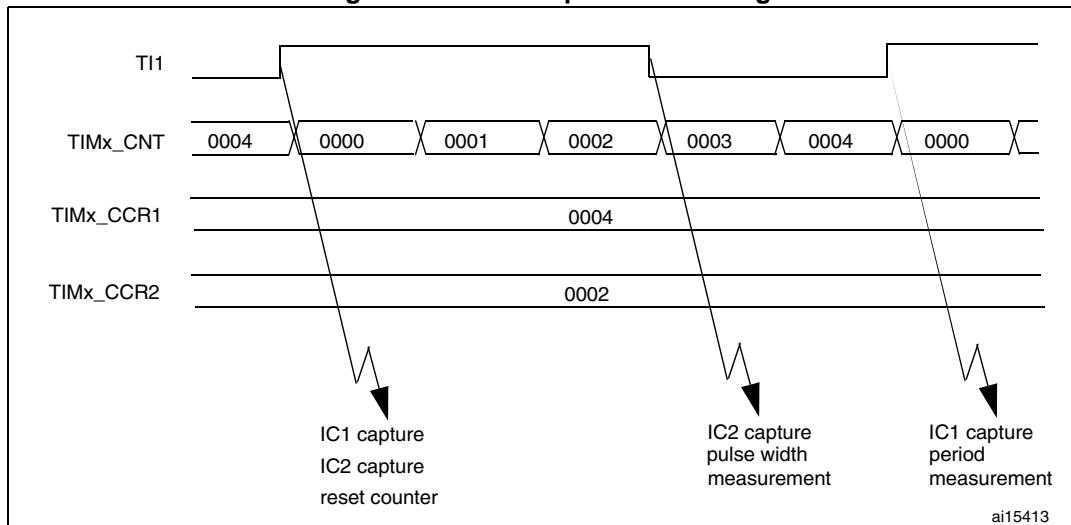
This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, you can measure the period (in TIMx\_CCR1 register) and the duty cycle (in TIMx\_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK\_INT frequency and prescaler value):

- Select the active input for TIMx\_CCR1: write the CC1S bits to 01 in the TIMx\_CCMR1 register (TI1 selected).
- Select the active polarity for TI1FP1 (used both for capture in TIMx\_CCR1 and counter clear): write the CC1P to '0' and the CC1NP bit to '0' (active on rising edge).
- Select the active input for TIMx\_CCR2: write the CC2S bits to 10 in the TIMx\_CCMR1 register (TI1 selected).
- Select the active polarity for TI1FP2 (used for capture in TIMx\_CCR2): write the CC2P bit to '1' and the CC2NP bit to '0' (active on falling edge).
- Select the valid trigger input: write the TS bits to 101 in the TIMx\_SMCR register (TI1FP1 selected).
- Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx\_SMCR register.
- Enable the captures: write the CC1E and CC2E bits to '1' in the TIMx\_CCER register.

**Figure 115. PWM input mode timing**



### 13.3.7 Forced output mode

In output mode (CCxS bits = 00 in the TIMx\_CCMRx register), each output compare signal (OCxREF and then OCx) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (ocxref/OCx) to its active level, you just need to write 101 in the OCxM bits in the corresponding TIMx\_CCMRx register. Thus ocxref is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

e.g.: CCxP=0 (OCx active high) => OCx is forced to high level.

ocxref signal can be forced low by writing the OCxM bits to 100 in the TIMx\_CCMRx register.

Anyway, the comparison between the TIMx\_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the Output Compare Mode section.

### 13.3.8 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx\_CCMRx register) and the output polarity (CCxP bit in the TIMx\_CCER register). The output pin can keep its level (OCXM=000), be set active (OCxM=001), be set inactive (OCxM=010) or can toggle (OCxM=011) on match.
- Sets a flag in the interrupt status register (CCxIF bit in the TIMx\_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCxEIE bit in the TIMx\_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx\_DIER register, CCDS bit in the TIMx\_CR2 register for the DMA request selection).

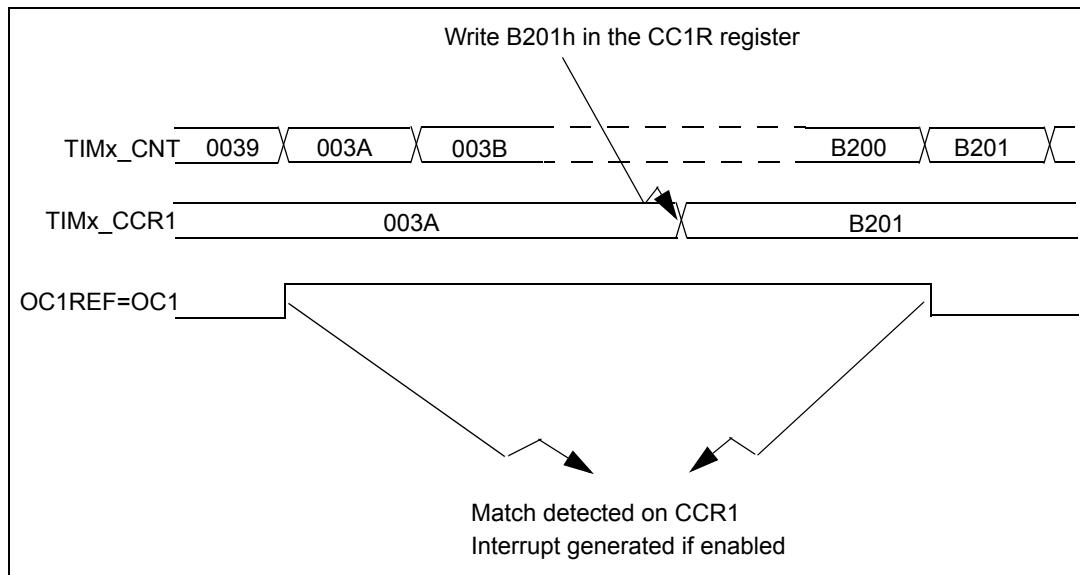
The TIMx\_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx\_CCMRx register.

In output compare mode, the update event UEV has no effect on ocxref and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure:

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx\_ARR and TIMx\_CCRx registers.
3. Set the CCxEIE and/or CCxDE bits if an interrupt and/or a DMA request is to be generated.
4. Select the output mode. For example, you must write OCxM=011, OCxPE=0, CCxP=0 and CCxE=1 to toggle OCx output pin when CNT matches CCRx, CCRx preload is not used, OCx is enabled and active high.
5. Enable the counter by setting the CEN bit in the TIMx\_CR1 register.

The TIMx\_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE=0, else TIMx\_CCRx shadow register is updated only at the next update event UEV). An example is given in [Figure 116](#).

**Figure 116. Output compare mode, toggle on OC1**

### 13.3.9 PWM mode

Pulse width modulation mode allows you to generate a signal with a frequency determined by the value of the TIMx\_ARR register and a duty cycle determined by the value of the TIMx\_CC Rx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing 110 (PWM mode 1) or '111 (PWM mode 2) in the OCxM bits in the TIMx\_CCMRx register. You must enable the corresponding preload register by setting the OCxPE bit in the TIMx\_CCMRx register, and eventually the auto-reload preload register by setting the ARPE bit in the TIMx\_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, you have to initialize all the registers by setting the UG bit in the TIMx\_EGR register.

OCx polarity is software programmable using the CCxP bit in the TIMx\_CCER register. It can be programmed as active high or active low. OCx output is enabled by the CCxE bit in the TIMx\_CCER register. Refer to the TIMx\_CCERx register description for more details.

In PWM mode (1 or 2), TIMx\_CNT and TIMx\_CC Rx are always compared to determine whether TIMx\_CC Rx ≤ TIMx\_CNT or TIMx\_CNT ≤ TIMx\_CC Rx (depending on the direction of the counter). However, to comply with the ETRF (OCREF can be cleared by an external event through the ETR signal until the next PWM period), the OCREF signal is asserted only:

- When the result of the comparison changes, or
- When the output compare mode (OCxM bits in TIMx\_CCMRx register) switches from the “frozen” configuration (no comparison, OCxM='000) to one of the PWM modes (OCxM='110 or '111).

This forces the PWM by software while the timer is running.

The timer is able to generate PWM in edge-aligned mode or center-aligned mode depending on the CMS bits in the TIMx\_CR1 register.

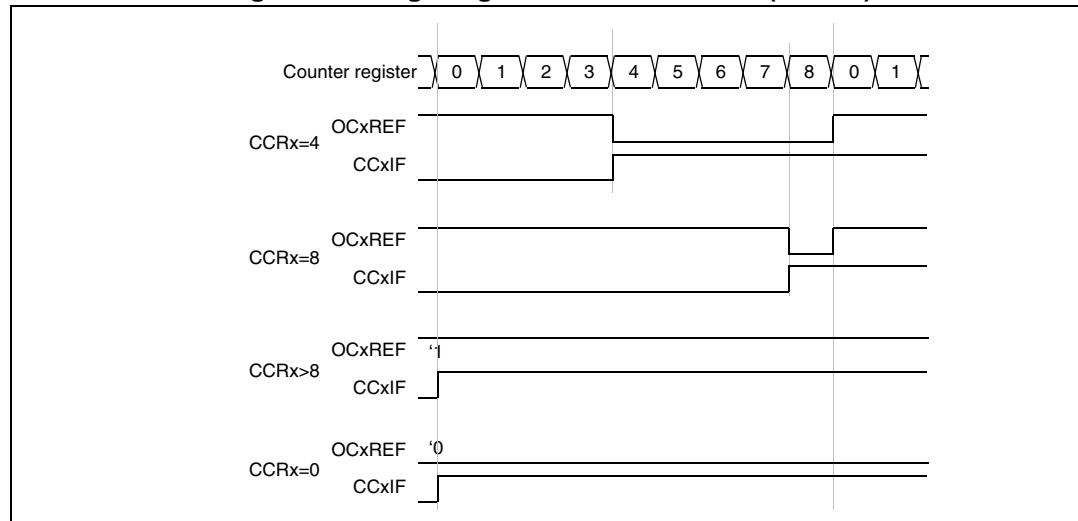
## PWM edge-aligned mode

### Upcounting configuration

Upcounting is active when the DIR bit in the TIMx\_CR1 register is low. Refer to [Section : Upcounting mode on page 307](#).

In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as TIMx\_CNT < TIMx\_CCRx else it becomes low. If the compare value in TIMx\_CCRx is greater than the auto-reload value (in TIMx\_ARR) then OCxREF is held at '1. If the compare value is 0 then OCxREF is held at '0. [Figure 117](#) shows some edge-aligned PWM waveforms in an example where TIMx\_ARR=8.

**Figure 117. Edge-aligned PWM waveforms (ARR=8)**



### Downcounting configuration

Downcounting is active when DIR bit in TIMx\_CR1 register is high. Refer to [Section : Downcounting mode on page 310](#).

In PWM mode 1, the reference signal ocxref is low as long as TIMx\_CNT>TIMx\_CCRx else it becomes high. If the compare value in TIMx\_CCRx is greater than the auto-reload value in TIMx\_ARR, then ocxref is held at '1. 0% PWM is not possible in this mode.

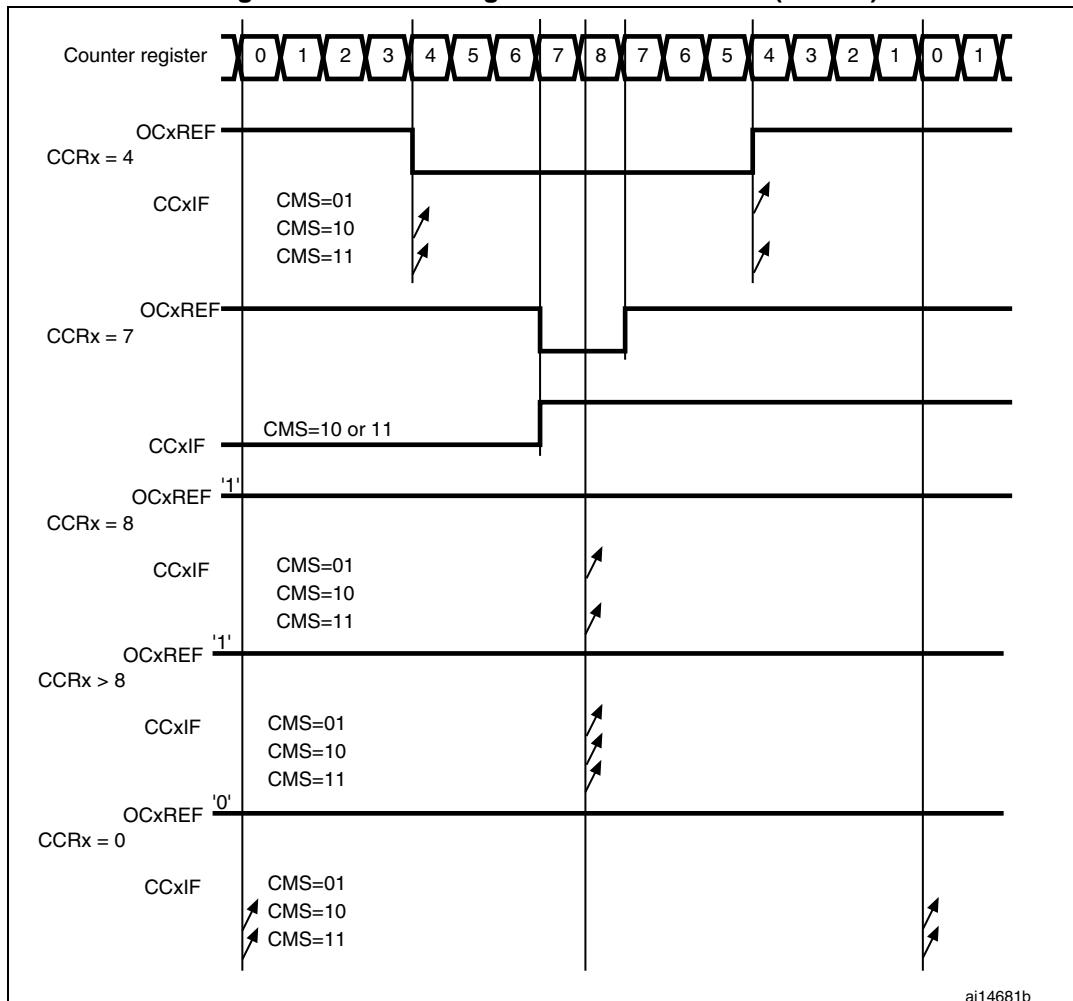
## PWM center-aligned mode

Center-aligned mode is active when the CMS bits in TIMx\_CR1 register are different from '00 (all the remaining configurations having the same effect on the ocxref/OCx signals). The compare flag is set when the counter counts up, when it counts down or both when it counts up and down depending on the CMS bits configuration. The direction bit (DIR) in the TIMx\_CR1 register is updated by hardware and must not be changed by software. Refer to [Section : Center-aligned mode \(up/down counting\) on page 312](#).

[Figure 118](#) shows some center-aligned PWM waveforms in an example where:

- TIMx\_ARR=8,
- PWM mode is the PWM mode 1,
- The flag is set when the counter counts down corresponding to the center-aligned mode 1 selected for CMS=01 in TIMx\_CR1 register.

Figure 118. Center-aligned PWM waveforms (ARR=8)



Hints on using center-aligned mode:

- When starting in center-aligned mode, the current up-down configuration is used. It means that the counter counts up or down depending on the value written in the DIR bit in the TIMx\_CR1 register. Moreover, the DIR and CMS bits must not be changed at the same time by the software.
- Writing to the counter while running in center-aligned mode is not recommended as it can lead to unexpected results. In particular:
  - The direction is not updated if you write a value in the counter that is greater than the auto-reload value (TIMx\_CNT>TIMx\_ARR). For example, if the counter was counting up, it continues to count up.
  - The direction is updated if you write 0 or write the TIMx\_ARR value in the counter but no Update Event UEV is generated.
- The safest way to use center-aligned mode is to generate an update by software (setting the UG bit in the TIMx\_EGR register) just before starting the counter and not to write the counter while it is running.

### 13.3.10 One-pulse mode

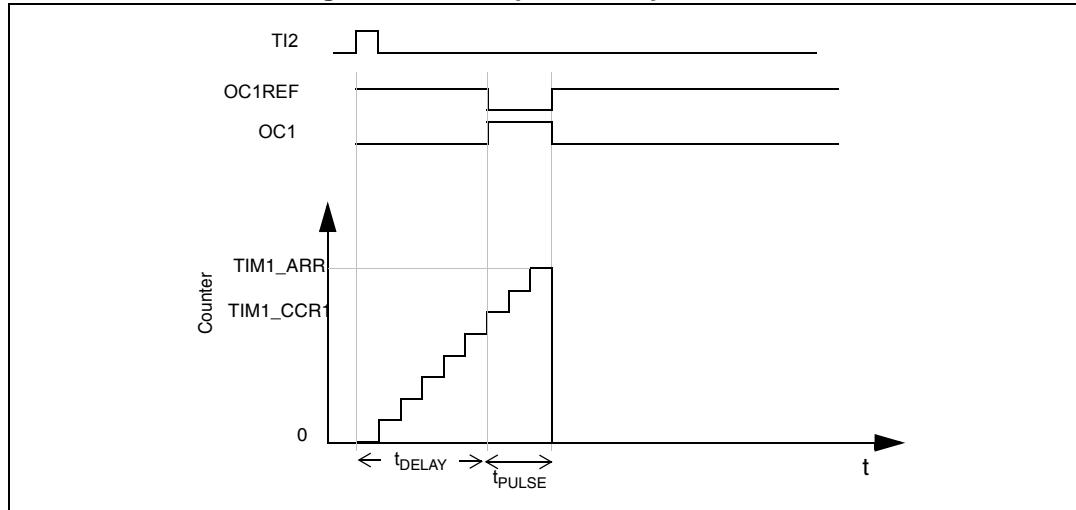
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. You select One-pulse mode by setting the OPM bit in the TIMx\_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- In upcounting:  $CNT < CCRx \leq ARR$  (in particular,  $0 < CCRx$ ),
- In downcounting:  $CNT > CCRx$ .

**Figure 119. Example of one-pulse mode**



For example you may want to generate a positive pulse on OC1 with a length of  $t_{PULSE}$  and after a delay of  $t_{DELAY}$  as soon as a positive edge is detected on the TI2 input pin.

Let's use TI2FP2 as trigger 1:

- Map TI2FP2 on TI2 by writing IC2S=01 in the TIMx\_CCMR1 register.
- TI2FP2 must detect a rising edge, write CC2P=0 and CC2NP='0' in the TIMx\_CCER register.
- Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS=110 in the TIMx\_SMCR register.
- TI2FP2 is used to start the counter by writing SMS to '110 in the TIMx\_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The  $t_{DELAY}$  is defined by the value written in the TIMx\_CCR1 register.
- The  $t_{PULSE}$  is defined by the difference between the auto-reload value and the compare value (TIMx\_ARR - TIMx\_CCR1).
- Let's say you want to build a waveform with a transition from '0 to '1 when a compare match occurs and a transition from '1 to '0 when the counter reaches the auto-reload value. To do this you enable PWM mode 2 by writing OC1M=111 in the TIMx\_CCMR1 register. You can optionally enable the preload registers by writing OC1PE=1 in the TIMx\_CCMR1 register and ARPE in the TIMx\_CR1 register. In this case you have to write the compare value in the TIMx\_CCR1 register, the auto-reload value in the TIMx\_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0 in this example.

In our example, the DIR and CMS bits in the TIMx\_CR1 register should be low.

You only want 1 pulse (Single mode), so you write '1 in the OPM bit in the TIMx\_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0). When OPM bit in the TIMx\_CR1 register is set to '0', so the Repetitive Mode is selected.

#### **Particular case: OCx fast enable:**

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay  $t_{DELAY}$  min we can get.

If you want to output a waveform with the minimum delay, you can set the OCxFE bit in the TIMx\_CCMRx register. Then OCxRef (and OCx) is forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

### **13.3.11 Clearing the OCxREF signal on an external event**

The OCxREF signal for a given channel can be driven Low by applying a High level to the ETRF input (OCxCE enable bit of the corresponding TIMx\_CCMRx register set to '1'). The OCxREF signal remains Low until the next update event, UEV, occurs.

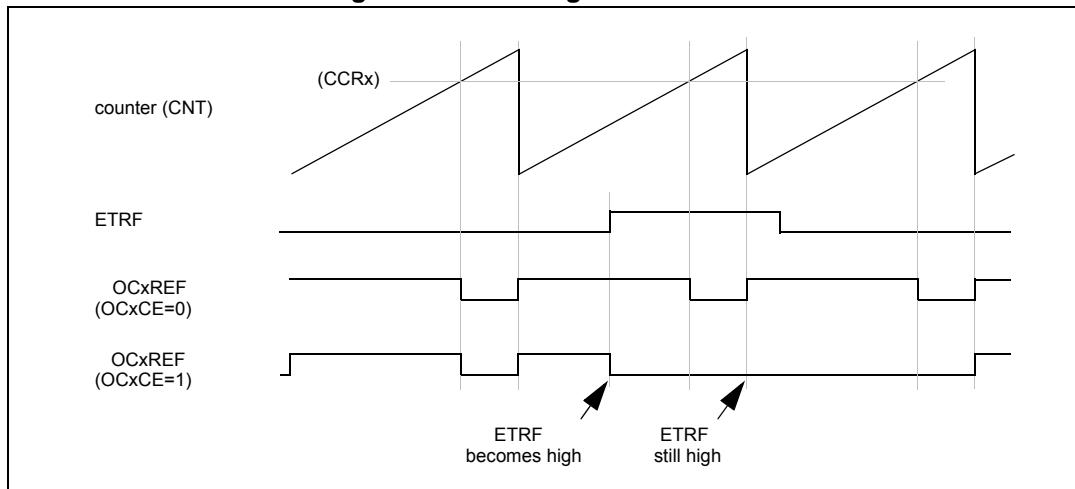
This function can only be used in output compare and PWM modes, and does not work in forced mode.

For example, the ETR signal can be connected to the output of a comparator to be used for current handling. In this case, ETR must be configured as follows:

1. The external trigger prescaler should be kept off: bits ETPS[1:0] in the TIMx\_SMCR register are cleared to 00.
2. The external clock mode 2 must be disabled: bit ECE in the TIM1\_SMCR register is cleared to 0.
3. The external trigger polarity (ETP) and the external trigger filter (ETF) can be configured according to the application's needs.

*Figure 120* shows the behavior of the OCxREF signal when the ETRF input becomes high, for both values of the OCxCE enable bit. In this example, the timer TIMx is programmed in PWM mode.

Figure 120. Clearing TIMx OCxREF



1. In case of a PWM with a 100% duty cycle (if  $CCR_x > ARR$ ), OCxREF is enabled again at the next counter overflow.

### 13.3.12 Encoder interface mode

To select Encoder Interface mode write SMS='001 in the TIMx\_SMCR register if the counter is counting on TI2 edges only, SMS=010 if it is counting on TI1 edges only and SMS=011 if it is counting on both TI1 and TI2 edges.

Select the TI1 and TI2 polarity by programming the CC1P and CC2P bits in the TIMx\_CCER register. When needed, you can program the input filter as well.

The two inputs TI1 and TI2 are used to interface to an incremental encoder. Refer to [Table 53](#). The counter is clocked by each valid transition on TI1FP1 or TI2FP2 (TI1 and TI2 after input filter and polarity selection, TI1FP1=TI1 if not filtered and not inverted, TI2FP2=TI2 if not filtered and not inverted) assuming that it is enabled (CEN bit in TIMx\_CR1 register written to '1'). The sequence of transitions of the two inputs is evaluated and generates count pulses as well as the direction signal. Depending on the sequence the counter counts up or down, the DIR bit in the TIMx\_CR1 register is modified by hardware accordingly. The DIR bit is calculated at each transition on any input (TI1 or TI2), whatever the counter is counting on TI1 only, TI2 only or both TI1 and TI2.

Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the auto-reload value in the TIMx\_ARR register (0 to ARR or ARR down to 0 depending on the direction). So you must configure TIMx\_ARR before starting. In the same way, the capture, compare, prescaler, trigger output features continue to work as normal.

In this mode, the counter is modified automatically following the speed and the direction of the incremental encoder and its content, therefore, always represents the encoder's position. The count direction correspond to the rotation direction of the connected sensor. The table summarizes the possible combinations, assuming TI1 and TI2 don't switch at the same time.

Table 53. Counting direction versus encoder signals

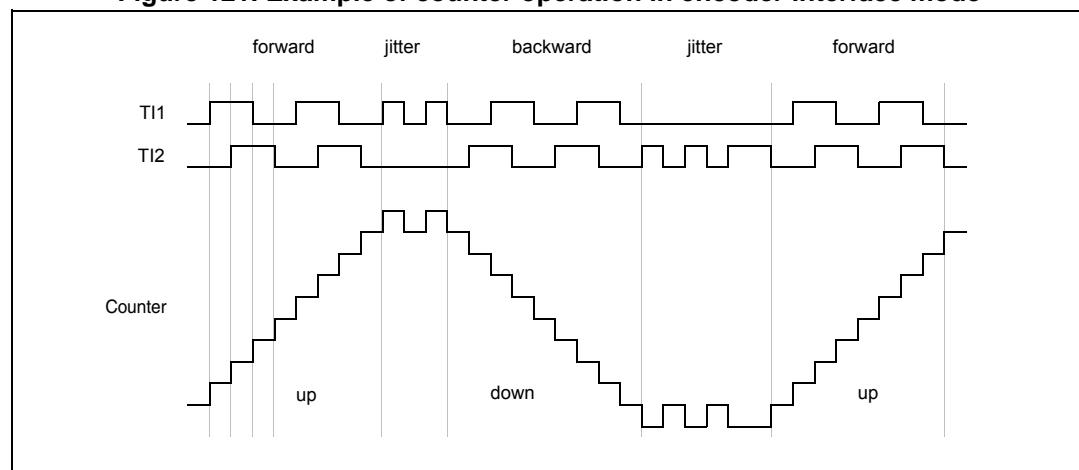
Active edge	Level on opposite signal (TI1FP1 for TI2, TI2FP2 for TI1)	TI1FP1 signal		TI2FP2 signal	
		Rising	Falling	Rising	Falling
Counting on TI1 only	High	Down	Up	No Count	No Count
	Low	Up	Down	No Count	No Count
Counting on TI2 only	High	No Count	No Count	Up	Down
	Low	No Count	No Count	Down	Up
Counting on TI1 and TI2	High	Down	Up	Up	Down
	Low	Up	Down	Down	Up

An external incremental encoder can be connected directly to the MCU without external interface logic. However, comparators are normally be used to convert the encoder's differential outputs to digital signals. This greatly increases noise immunity. The third encoder output which indicate the mechanical zero position, may be connected to an external interrupt input and trigger a counter reset.

*Figure 121* gives an example of counter operation, showing count signal generation and direction control. It also shows how input jitter is compensated where both edges are selected. This might occur if the sensor is positioned near to one of the switching points. For this example we assume that the configuration is the following:

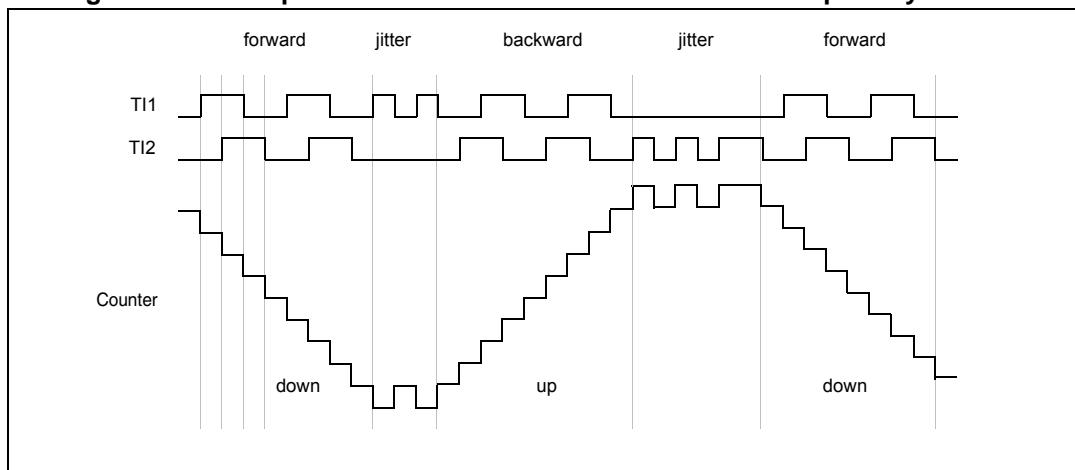
- CC1S= '01' (TIMx\_CCMR1 register, TI1FP1 mapped on TI1)
- CC2S= '01' (TIMx\_CCMR2 register, TI2FP2 mapped on TI2)
- CC1P= '0', CC1NP = '0', IC1F ='0000' (TIMx\_CCER register, TI1FP1 noninverted, TI1FP1=TI1)
- CC2P= '0', CC2NP = '0', IC2F ='0000' (TIMx\_CCER register, TI2FP2 noninverted, TI2FP2=TI2)
- SMS= '011' (TIMx\_SMCR register, both inputs are active on both rising and falling edges)
- CEN = 1 (TIMx\_CR1 register, Counter is enabled)

Figure 121. Example of counter operation in encoder interface mode



*Figure 122* gives an example of counter behavior when TI1FP1 polarity is inverted (same configuration as above except CC1P=1).

**Figure 122. Example of encoder interface mode with TI1FP1 polarity inverted**



The timer, when configured in Encoder Interface mode provides information on the sensor's current position. You can obtain dynamic information (speed, acceleration, deceleration) by measuring the period between two encoder events using a second timer configured in capture mode. The output of the encoder which indicates the mechanical zero can be used for this purpose. Depending on the time between two events, the counter can also be read at regular times. You can do this by latching the counter value into a third input capture register if available (then the capture signal must be periodic and can be generated by another timer). when available, it is also possible to read its value through a DMA request generated by a Real-Time clock.

### 13.3.13 Timer input XOR function

The TI1S bit in the TIM\_CR2 register, allows the input filter of channel 1 to be connected to the output of a XOR gate, combining the three input pins TIMx\_CH1 to TIMx\_CH3.

The XOR output can be used with all the timer input functions such as trigger or input capture.

### 13.3.14 Timers and external trigger synchronization

The TIMx Timers can be synchronized with an external trigger in several modes: Reset mode, Gated mode and Trigger mode.

#### Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx\_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx\_ARR, TIMx\_CC Rx) are updated.

In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

- Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we don't need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so you don't need to configure it. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx\_CCMR1 register. Write

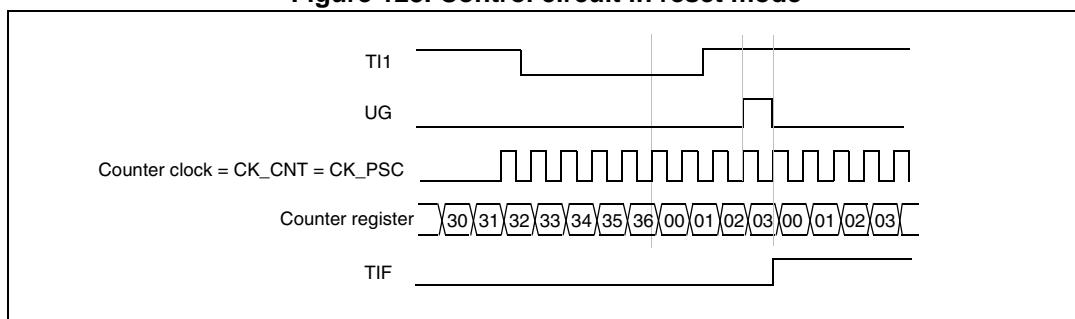
CC1P=0 and CC1NP=0 in TIMx\_CCER register to validate the polarity (and detect rising edges only).

- Configure the timer in reset mode by writing SMS=100 in TIMx\_SMCR register. Select TI1 as the input source by writing TS=101 in TIMx\_SMCR register.
- Start the counter by writing CEN=1 in the TIMx\_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx\_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx\_DIER register).

The following figure shows this behavior when the auto-reload register TIMx\_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

**Figure 123. Control circuit in reset mode**



### Slave mode: Gated mode

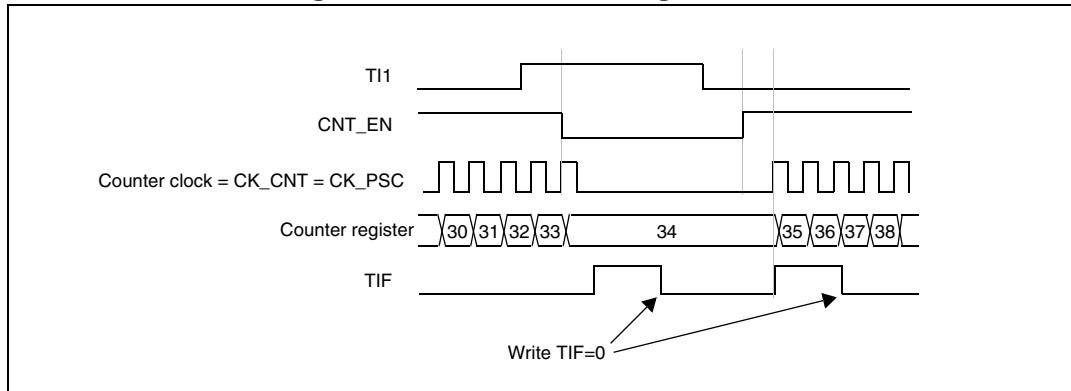
The counter can be enabled depending on the level of a selected input.

In the following example, the upcounter counts only when TI1 input is low:

- Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we don't need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so you don't need to configure it. The CC1S bits select the input capture source only, CC1S=01 in TIMx\_CCMR1 register. Write CC1P=1 in TIMx\_CCER register to validate the polarity (and detect low level only).
- Configure the timer in gated mode by writing SMS=101 in TIMx\_SMCR register. Select TI1 as the input source by writing TS=101 in TIMx\_SMCR register.
- Enable the counter by writing CEN=1 in the TIMx\_CR1 register (in gated mode, the counter doesn't start if CEN=0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx\_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

**Figure 124. Control circuit in gated mode**

1. The configuration “CCxP=CCxNP=1” (detection of both rising and falling edges) does not have any effect in gated mode because gated mode acts on a level and not on an edge.

### Slave mode: Trigger mode

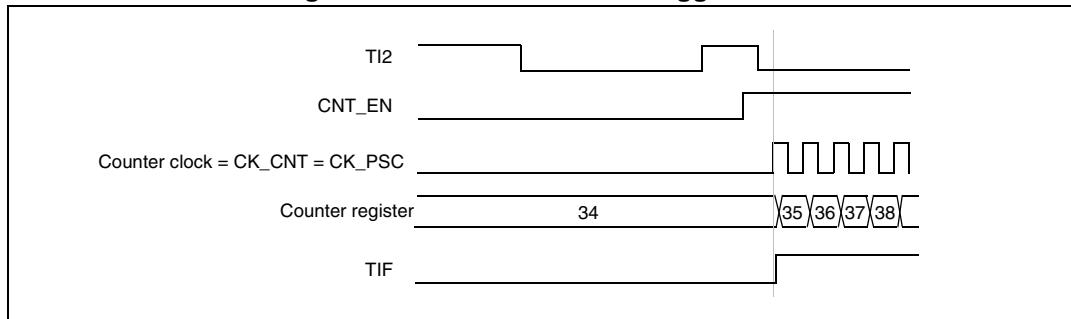
The counter can start in response to an event on a selected input.

In the following example, the upcounter starts in response to a rising edge on TI2 input:

- Configure the channel 2 to detect rising edges on TI2. Configure the input filter duration (in this example, we don't need any filter, so we keep IC2F=0000). The capture prescaler is not used for triggering, so you don't need to configure it. CC2S bits are selecting the input capture source only, CC2S=01 in TIMx\_CCMR1 register. Write CC2P=1 in TIMx\_CCER register to validate the polarity (and detect low level only).
- Configure the timer in trigger mode by writing SMS=110 in TIMx\_SMCR register. Select TI2 as the input source by writing TS=110 in TIMx\_SMCR register.

When a rising edge occurs on TI2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on TI2 and the actual start of the counter is due to the resynchronization circuit on TI2 input.

**Figure 125. Control circuit in trigger mode**

### Slave mode: External Clock mode 2 + trigger mode

The external clock mode 2 can be used in addition to another slave mode (except external clock mode 1 and encoder mode). In this case, the ETR signal is used as external clock input, and another input can be selected as trigger input when operating in reset mode, gated mode or trigger mode. It is recommended not to select ETR as TRGI through the TS bits of TIMx\_SMCR register.

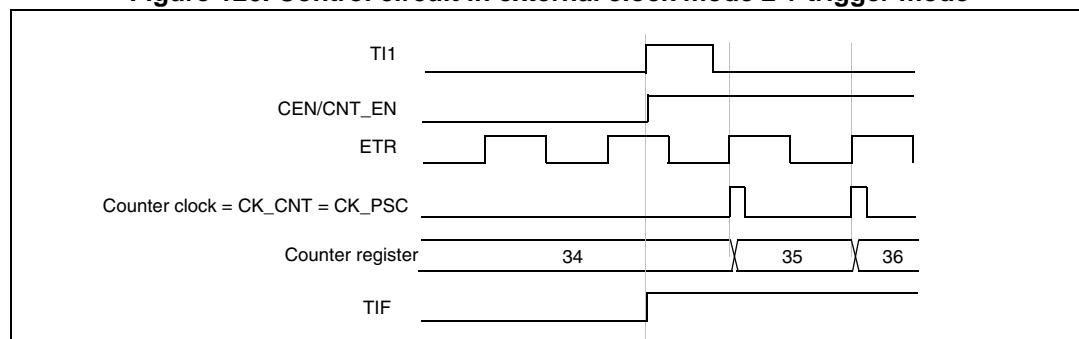
In the following example, the upcounter is incremented at each rising edge of the ETR signal as soon as a rising edge of TI1 occurs:

1. Configure the external trigger input circuit by programming the TIMx\_SMCR register as follows:
  - ETF = 0000: no filter
  - ETPS = 00: prescaler disabled
  - ETP = 0: detection of rising edges on ETR and ECE=1 to enable the external clock mode 2.
2. Configure the channel 1 as follows, to detect rising edges on TI:
  - IC1F = 0000: no filter.
  - The capture prescaler is not used for triggering and does not need to be configured.
  - CC1S = 01 in TIMx\_CCMR1 register to select only the input capture source
  - CC1P = 0 in TIMx\_CCER register to validate the polarity (and detect rising edge only).
3. Configure the timer in trigger mode by writing SMS=110 in TIMx\_SMCR register. Select TI1 as the input source by writing TS=101 in TIMx\_SMCR register.

A rising edge on TI1 enables the counter and sets the TIF flag. The counter then counts on ETR rising edges.

The delay between the rising edge of the ETR signal and the actual reset of the counter is due to the resynchronization circuit on ETRP input.

**Figure 126. Control circuit in external clock mode 2 + trigger mode**



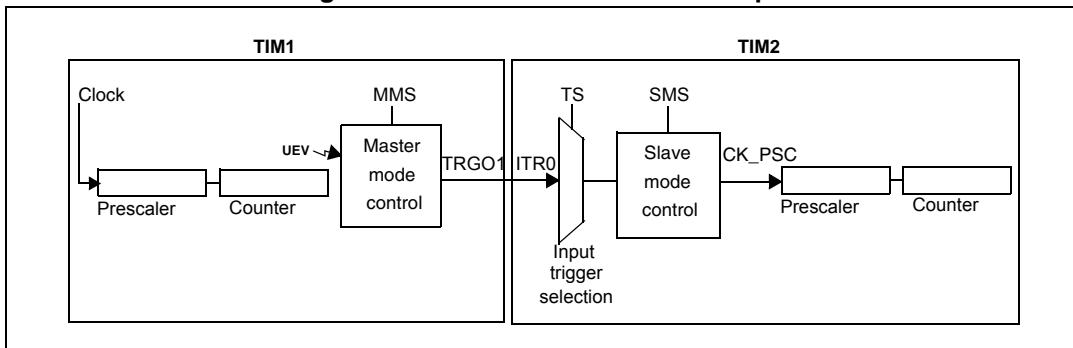
### 13.3.15 Timer synchronization

The TIMx timers are linked together internally for timer synchronization or chaining. When one Timer is configured in Master Mode, it can reset, start, stop or clock the counter of another Timer configured in Slave Mode.

*Figure 127: Master/Slave timer example* presents an overview of the trigger selection and the master mode selection blocks.

### Using one timer as prescaler for another

Figure 127. Master/Slave timer example



For example, you can configure Timer 1 to act as a prescaler for Timer 2. Refer to [Figure 127](#). To do this:

- Configure Timer 1 in master mode so that it outputs a periodic trigger signal on each update event UEV. If you write MMS=010 in the TIM1\_CR2 register, a rising edge is output on TRGO1 each time an update event is generated.
- To connect the TRGO1 output of Timer 1 to Timer 2, Timer 2 must be configured in slave mode using ITR0 as internal trigger. You select this through the TS bits in the TIM2\_SMCR register (writing TS=000).
- Then you put the slave mode controller in external clock mode 1 (write SMS=111 in the TIM2\_SMCR register). This causes Timer 2 to be clocked by the rising edge of the periodic Timer 1 trigger signal (which correspond to the timer 1 counter overflow).
- Finally both timers must be enabled by setting their respective CEN bits (TIMx\_CR1 register).

*Note:* If OCx is selected on Timer 1 as trigger output (MMS=1xx), its rising edge is used to clock the counter of timer 2.

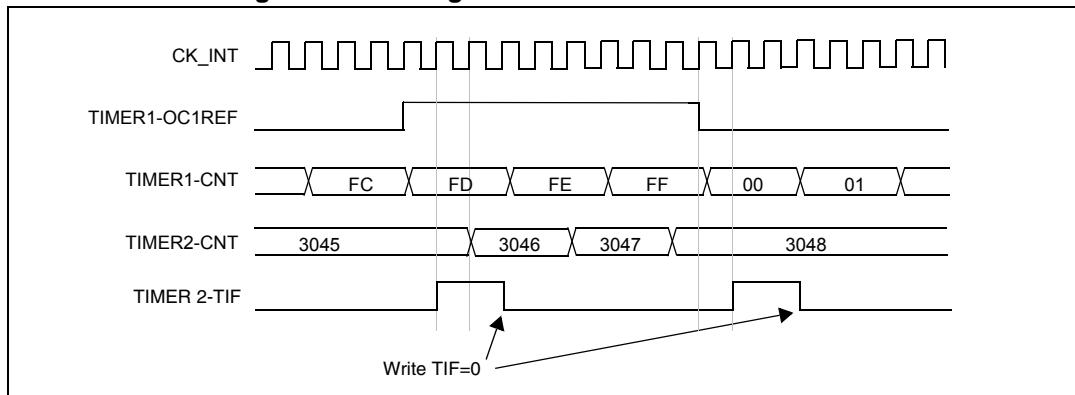
### Using one timer to enable another timer

In this example, we control the enable of Timer 2 with the output compare 1 of Timer 1. Refer to [Figure 127](#) for connections. Timer 2 counts on the divided internal clock only when OC1REF of Timer 1 is high. Both counter clock frequencies are divided by 3 by the prescaler compared to CK\_INT ( $f_{CK\_CNT} = f_{CK\_INT}/3$ ).

- Configure Timer 1 master mode to send its Output Compare 1 Reference (OC1REF) signal as trigger output (MMS=100 in the TIM1\_CR2 register).
- Configure the Timer 1 OC1REF waveform (TIM1\_CCMR1 register).
- Configure Timer 2 to get the input trigger from Timer 1 (TS=000 in the TIM2\_SMCR register).
- Configure Timer 2 in gated mode (SMS=101 in TIM2\_SMCR register).
- Enable Timer 2 by writing '1 in the CEN bit (TIM2\_CR1 register).
- Start Timer 1 by writing '1 in the CEN bit (TIM1\_CR1 register).

*Note:* The counter 2 clock is not synchronized with counter 1, this mode only affects the Timer 2 counter enable signal.

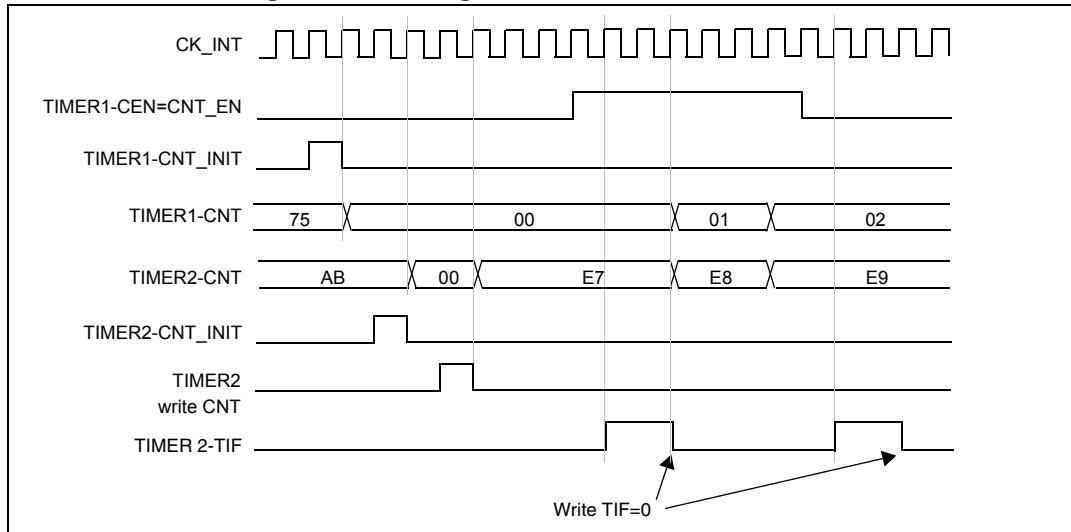
Figure 128. Gating timer 2 with OC1REF of timer 1



In the example in [Figure 128](#), the Timer 2 counter and prescaler are not initialized before being started. So they start counting from their current value. It is possible to start from a given value by resetting both timers before starting Timer 1. You can then write any value you want in the timer counters. The timers can easily be reset by software using the UG bit in the TIMx\_EGR registers.

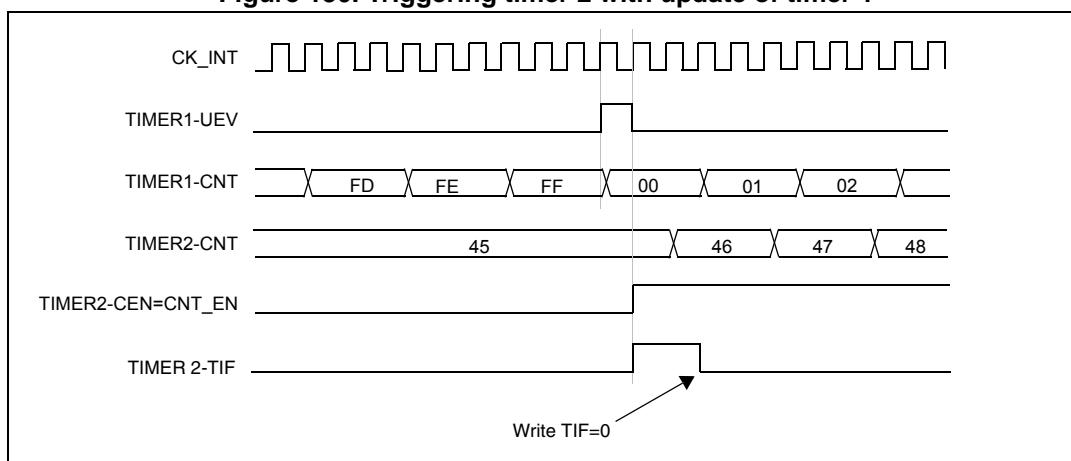
In the next example, we synchronize Timer 1 and Timer 2. Timer 1 is the master and starts from 0. Timer 2 is the slave and starts from 0xE7. The prescaler ratio is the same for both timers. Timer 2 stops when Timer 1 is disabled by writing '0' to the CEN bit in the TIM1\_CR1 register:

- Configure Timer 1 master mode to send its Output Compare 1 Reference (OC1REF) signal as trigger output (MMS=100 in the TIM1\_CR2 register).
- Configure the Timer 1 OC1REF waveform (TIM1\_CCMR1 register).
- Configure Timer 2 to get the input trigger from Timer 1 (TS=000 in the TIM2\_SMCR register).
- Configure Timer 2 in gated mode (SMS=101 in TIM2\_SMCR register).
- Reset Timer 1 by writing '1' in UG bit (TIM1\_EGR register).
- Reset Timer 2 by writing '1' in UG bit (TIM2\_EGR register).
- Initialize Timer 2 to 0xE7 by writing '0xE7' in the timer 2 counter (TIM2\_CNTL).
- Enable Timer 2 by writing '1' in the CEN bit (TIM2\_CR1 register).
- Start Timer 1 by writing '1' in the CEN bit (TIM1\_CR1 register).
- Stop Timer 1 by writing '0' in the CEN bit (TIM1\_CR1 register).

**Figure 129. Gating timer 2 with Enable of timer 1****Using one timer to start another timer**

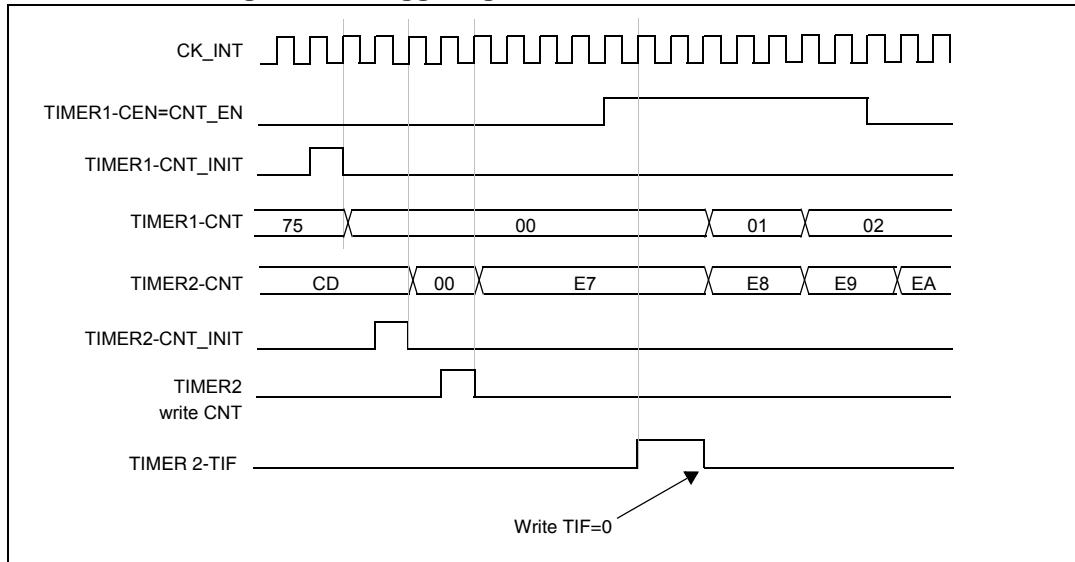
In this example, we set the enable of Timer 2 with the update event of Timer 1. Refer to [Figure 127](#) for connections. Timer 2 starts counting from its current value (which can be nonzero) on the divided internal clock as soon as the update event is generated by Timer 1. When Timer 2 receives the trigger signal its CEN bit is automatically set and the counter counts until we write '0 to the CEN bit in the TIM2\_CR1 register. Both counter clock frequencies are divided by 3 by the prescaler compared to CK\_INT ( $f_{CK\_CNT} = f_{CK\_INT}/3$ ).

- Configure Timer 1 master mode to send its Update Event (UEV) as trigger output (MMS=010 in the TIM1\_CR2 register).
- Configure the Timer 1 period (TIM1\_ARR registers).
- Configure Timer 2 to get the input trigger from Timer 1 (TS=000 in the TIM2\_SMCR register).
- Configure Timer 2 in trigger mode (SMS=110 in TIM2\_SMCR register).
- Start Timer 1 by writing '1 in the CEN bit (TIM1\_CR1 register).

**Figure 130. Triggering timer 2 with update of timer 1**

As in the previous example, you can initialize both counters before starting counting. [Figure 131](#) shows the behavior with the same configuration as in [Figure 128](#) but in trigger mode instead of gated mode (SMS=110 in the TIM2\_SMCR register).

**Figure 131. Triggering timer 2 with Enable of timer 1**



### Using one timer as prescaler for another timer

For example, you can configure Timer 1 to act as a prescaler for Timer 2. Refer to [Figure 127](#) for connections. To do this:

- Configure Timer 1 master mode to send its Update Event (UEV) as trigger output (MMS=010 in the TIM1\_CR2 register). then it outputs a periodic signal on each counter overflow.
- Configure the Timer 1 period (TIM1\_ARR registers).
- Configure Timer 2 to get the input trigger from Timer 1 (TS=000 in the TIM2\_SMCR register).
- Configure Timer 2 in external clock mode 1 (SMS=111 in TIM2\_SMCR register).
- Start Timer 2 by writing '1 in the CEN bit (TIM2\_CR1 register).
- Start Timer 1 by writing '1 in the CEN bit (TIM1\_CR1 register).

### Starting 2 timers synchronously in response to an external trigger

In this example, we set the enable of timer 1 when its TI1 input rises, and the enable of Timer 2 with the enable of Timer 1. Refer to [Figure 127](#) for connections. To ensure the

counters are aligned, Timer 1 must be configured in Master/Slave mode (slave with respect to TI1, master with respect to Timer 2):

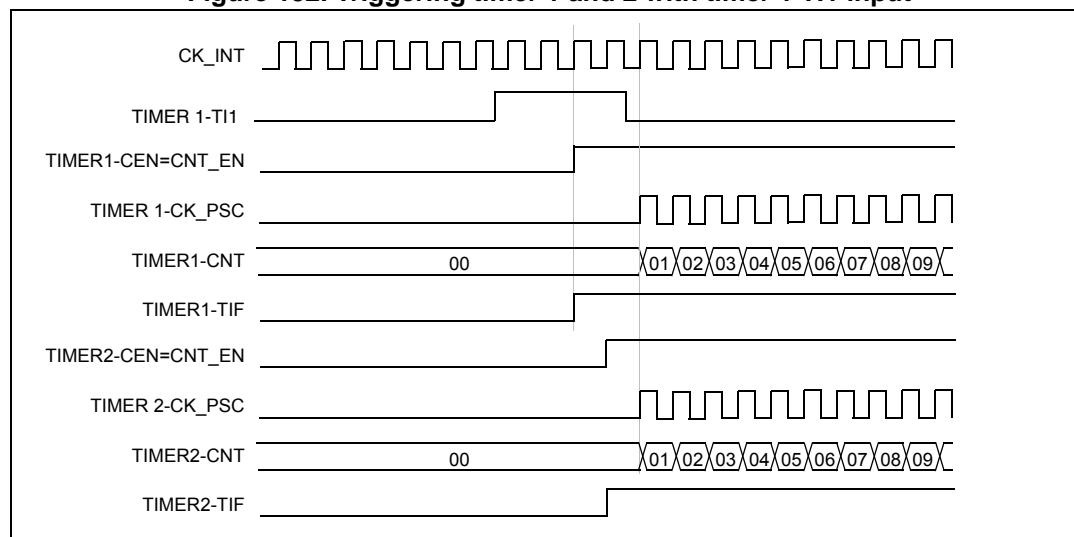
- Configure Timer 1 master mode to send its Enable as trigger output (MMS=001 in the TIM1\_CR2 register).
- Configure Timer 1 slave mode to get the input trigger from TI1 (TS=100 in the TIM1\_SMCR register).
- Configure Timer 1 in trigger mode (SMS=110 in the TIM1\_SMCR register).
- Configure the Timer 1 in Master/Slave mode by writing MSM=1 (TIM1\_SMCR register).
- Configure Timer 2 to get the input trigger from Timer 1 (TS=000 in the TIM2\_SMCR register).
- Configure Timer 2 in trigger mode (SMS=110 in the TIM2\_SMCR register).

When a rising edge occurs on TI1 (Timer 1), both counters starts counting synchronously on the internal clock and both TIF flags are set.

**Note:**

*In this example both timers are initialized before starting (by setting their respective UG bits). Both counters starts from 0, but you can easily insert an offset between them by writing any of the counter registers (TIMx\_CNT). You can see that the master/slave mode insert a delay between CNT\_EN and CK\_PSC on timer 1.*

**Figure 132. Triggering timer 1 and 2 with timer 1 TI1 input**



### 13.3.16 Debug mode

When the microcontroller enters debug mode (Cortex™-M4 with FPU core - halted), the TIMx counter either continues to work normally or stops, depending on DBG\_TIMx\_STOP configuration bit in DBGMCU module. For more details, refer to [Section 23.16.2: Debug support for timers, watchdog and I2C](#).

## 13.4 TIM2 to TIM5 registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The 32-bit peripheral registers have to be written by words (32 bits). All other peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits) or words (32 bits).

### 13.4.1 TIMx control register 1 (TIMx\_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0					
Reserved					CKD[1:0]		ARPE		CMS		DIR		OPM		URS		UDIS		CEN	
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **CKD**: Clock division

This bit-field indicates the division ratio between the timer clock (CK\_INT) frequency and sampling clock used by the digital filters (ETR, TIx),

- 00:  $t_{DTS} = t_{CK\_INT}$
- 01:  $t_{DTS} = 2 \times t_{CK\_INT}$
- 10:  $t_{DTS} = 4 \times t_{CK\_INT}$
- 11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable

- 0: TIMx\_ARR register is not buffered
- 1: TIMx\_ARR register is buffered

Bits 6:5 **CMS**: Center-aligned mode selection

00: Edge-aligned mode. The counter counts up or down depending on the direction bit (DIR).

01: Center-aligned mode 1. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx\_CCMRx register) are set only when the counter is counting down.

10: Center-aligned mode 2. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx\_CCMRx register) are set only when the counter is counting up.

11: Center-aligned mode 3. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx\_CCMRx register) are set both when the counter is counting up or down.

*Note:* It is not allowed to switch from edge-aligned mode to center-aligned mode as long as the counter is enabled (CEN=1)

Bit 4 **DIR**: Direction

- 0: Counter used as upcounter
- 1: Counter used as downcounter

*Note:* This bit is read only when the timer is configured in Center-aligned mode or Encoder mode.

Bit 3 **OPM**: One-pulse mode

- 0: Counter is not stopped at update event
- 1: Counter stops counting at the next update event (clearing the bit CEN)

**Bit 2 URS:** Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generate an update interrupt or DMA request if enabled.

These events can be:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

**Bit 1 UDIS:** Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

**Bit 0 CEN:** Counter enable

0: Counter disabled

1: Counter enabled

*Note: External clock, gated mode and encoder mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.*

CEN is cleared automatically in one-pulse mode, when an update event occurs.

### 13.4.2 TIMx control register 2 (TIMx\_CR2)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								TI1S	MMS[2:0]			CCDS	Reserved		
								rw	rw	rw	rw	rw			

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TI1S**: TI1 selection

- 0: The TIMx\_CH1 pin is connected to TI1 input
- 1: The TIMx\_CH1, CH2 and CH3 pins are connected to the TI1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits allow to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:

000: **Reset** - the UG bit from the TIMx\_EGR register is used as trigger output (TRGO). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.

001: **Enable** - the Counter enable signal, CNT\_EN, is used as trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated by a logic OR between CEN control bit and the trigger input when configured in gated mode.

When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in TIMx\_SMCR register).

010: **Update** - The update event is selected as trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.

011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred. (TRGO)

100: **Compare** - OC1REF signal is used as trigger output (TRGO)

101: **Compare** - OC2REF signal is used as trigger output (TRGO)

110: **Compare** - OC3REF signal is used as trigger output (TRGO)

111: **Compare** - OC4REF signal is used as trigger output (TRGO)

Bit 3 **CCDS**: Capture/compare DMA selection

- 0: CCx DMA request sent when CCx event occurs
- 1: CCx DMA requests sent when update event occurs

Bits 2:0 Reserved, must be kept at reset value.

### 13.4.3 TIMx slave mode control register (TIMx\_SMCR)

Address offset: 0x08

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETP	ECE	ETPS[1:0]		ETF[3:0]				MSM	TS[2:0]				Res.	SMS[2:0]	
RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW

Bit 15 **ETP**: External trigger polarity

This bit selects whether ETR or  $\overline{ETR}$  is used for trigger operations

0: ETR is noninverted, active at high level or rising edge

1: ETR is inverted, active at low level or falling edge

Bit 14 **ECE**: External clock enable

This bit enables External clock mode 2.

0: External clock mode 2 disabled

1: External clock mode 2 enabled. The counter is clocked by any active edge on the ETRF signal.

1: Setting the ECE bit has the same effect as selecting external clock mode 1 with TRGI connected to ETRF (SMS=111 and TS=111).

2: It is possible to simultaneously use external clock mode 2 with the following slave modes: reset mode, gated mode and trigger mode. Nevertheless, TRGI must not be connected to ETRF in this case (TS bits must not be 111).

3: If external clock mode 1 and external clock mode 2 are enabled at the same time, the external clock input is ETRF.

Bits 13:12 **ETPS**: External trigger prescaler

External trigger signal ETRP frequency must be at most 1/4 of CK\_INT frequency. A prescaler can be enabled to reduce ETRP frequency. It is useful when inputting fast external clocks.

00: Prescaler OFF

01: ETRP frequency divided by 2

10: ETRP frequency divided by 4

11: ETRP frequency divided by 8

Bits 11:8 **ETF[3:0]**: External trigger filter

This bit-field then defines the frequency used to sample ETRP signal and the length of the digital filter applied to ETRP. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

0000: No filter, sampling is done at  $f_{DTS}$

0001:  $f_{SAMPLING}=f_{CK\_INT}$ , N=2

0010:  $f_{SAMPLING}=f_{CK\_INT}$ , N=4

0011:  $f_{SAMPLING}=f_{CK\_INT}$ , N=8

0100:  $f_{SAMPLING}=f_{DTS}/2$ , N=6

0101:  $f_{SAMPLING}=f_{DTS}/2$ , N=8

0110:  $f_{SAMPLING}=f_{DTS}/4$ , N=6

0111:  $f_{SAMPLING}=f_{DTS}/4$ , N=8

1000:  $f_{SAMPLING}=f_{DTS}/8$ , N=6

1001:  $f_{SAMPLING}=f_{DTS}/8$ , N=8

1010:  $f_{SAMPLING}=f_{DTS}/16$ , N=5

1011:  $f_{SAMPLING}=f_{DTS}/16$ , N=6

1100:  $f_{SAMPLING}=f_{DTS}/16$ , N=8

1101:  $f_{SAMPLING}=f_{DTS}/32$ , N=5

1110:  $f_{SAMPLING}=f_{DTS}/32$ , N=6

1111:  $f_{SAMPLING}=f_{DTS}/32$ , N=8

Bit 7 **MSM:** Master/Slave mode

0: No action

1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful if we want to synchronize several timers on a single external event.

Bits 6:4 **TS:** Trigger selection

This bit-field selects the trigger input to be used to synchronize the counter.

000: Internal Trigger 0 (ITR0).

001: Internal Trigger 1 (ITR1).

010: Internal Trigger 2 (ITR2).

011: Internal Trigger 3 (ITR3).

100: TI1 Edge Detector (TI1F\_ED)

101: Filtered Timer Input 1 (TI1FP1)

110: Filtered Timer Input 2 (TI2FP2)

111: External Trigger input (ETRF)

See [Table 54: TIMx internal trigger connection on page 344](#) for more details on ITRx meaning for each Timer.

*Note: These bits must be changed only when they are not used (e.g. when SMS=000) to avoid wrong edge detections at the transition.*

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **SMS:** Slave mode selection

When external signals are selected the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input Control register and Control Register description).

000: Slave mode disabled - if CEN = '1 then the prescaler is clocked directly by the internal clock.

001: Encoder mode 1 - Counter counts up/down on TI2FP2 edge depending on TI1FP1 level.

010: Encoder mode 2 - Counter counts up/down on TI1FP1 edge depending on TI2FP2 level.

011: Encoder mode 3 - Counter counts up/down on both TI1FP1 and TI2FP2 edges depending on the level of the other input.

100: Reset Mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers.

101: Gated Mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

110: Trigger Mode - The counter starts at a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled.

111: External Clock Mode 1 - Rising edges of the selected trigger (TRGI) clock the counter.

*Note: The gated mode must not be used if TI1F\_ED is selected as the trigger input (TS=100). Indeed, TI1F\_ED outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.*

**Table 54. TIMx internal trigger connection**

Slave TIM	ITR0 (TS = 000)	ITR1 (TS = 001)	ITR2 (TS = 010)	ITR3 (TS = 011)
TIM2	TIM1	Reserved	TIM3	TIM4
TIM3	TIM1	TIM2	TIM5	TIM4
TIM4	TIM1	TIM2	TIM3	Reserved
TIM5	TIM2	TIM3	TIM4	Reserved

### 13.4.4 TIMx DMA/Interrupt enable register (TIMx\_DIER)

Address offset: 0x0C

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	Res	CC4DE	CC3DE	CC2DE	CC1DE	UDE		Res.	TIE	Res	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	RW		RW	RW	RW	RW	RW		RW		RW	RW	RW	RW	RW	

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable

- 0: Trigger DMA request disabled.
- 1: Trigger DMA request enabled.

Bit 13 Reserved, always read as 0

Bit 12 **CC4DE**: Capture/Compare 4 DMA request enable

- 0: CC4 DMA request disabled.
- 1: CC4 DMA request enabled.

Bit 11 **CC3DE**: Capture/Compare 3 DMA request enable

- 0: CC3 DMA request disabled.
- 1: CC3 DMA request enabled.

Bit 10 **CC2DE**: Capture/Compare 2 DMA request enable

- 0: CC2 DMA request disabled.
- 1: CC2 DMA request enabled.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable

- 0: CC1 DMA request disabled.
- 1: CC1 DMA request enabled.

Bit 8 **UDE**: Update DMA request enable

- 0: Update DMA request disabled.
- 1: Update DMA request enabled.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **TIE**: Trigger interrupt enable

- 0: Trigger interrupt disabled.
- 1: Trigger interrupt enabled.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4IE**: Capture/Compare 4 interrupt enable

- 0: CC4 interrupt disabled.
- 1: CC4 interrupt enabled.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable

- 0: CC2 interrupt disabled
- 1: CC2 interrupt enabled

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable

- 0: CC1 interrupt disabled
- 1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable

- 0: Update interrupt disabled
- 1: Update interrupt enabled

### 13.4.5 TIMx status register (TIMx\_SR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		CC4OF	CC3OF	CC2OF	CC1OF	Reserved	TIF	Res	CC4IF	CC3IF	CC2IF	CC1IF	UIF		
		rc_w0	rc_w0	rc_w0	rc_w0		rc_w0		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0		

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **CC4OF**: Capture/Compare 4 overcapture flag  
refer to CC1OF description

Bit 11 **CC3OF**: Capture/Compare 3 overcapture flag  
refer to CC1OF description

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag  
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to '0'.  
0: No overcapture has been detected  
1: The counter value has been captured in TIMx\_CCR1 register while CC1IF flag was already set

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.  
0: No trigger event occurred  
1: Trigger interrupt pending

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4IF**: Capture/Compare 4 interrupt flag  
refer to CC1IF description

Bit 3 **CC3IF**: Capture/Compare 3 interrupt flag  
refer to CC1IF description

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag  
refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag

**If channel CC1 is configured as output:**

This flag is set by hardware when the counter matches the compare value, with some exception in center-aligned mode (refer to the CMS bits in the TIMx\_CR1 register description). It is cleared by software.

0: No match

1: The content of the counter TIMx\_CNT matches the content of the TIMx\_CCR1 register. When the contents of TIMx\_CCR1 are greater than the contents of TIMx\_ARR, the CC1IF bit goes high on the counter overflow (in upcounting and up/down-counting modes) or underflow (in downcounting mode)

**If channel CC1 is configured as input:**

This bit is set by hardware on a capture. It is cleared by software or by reading the TIMx\_CCR1 register.

0: No input capture occurred

1: The counter value has been captured in TIMx\_CCR1 register (An edge has been detected on IC1 which matches the selected polarity)

Bit 0 **UIF**: Update interrupt flag

“ This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

“ At overflow or underflow (for TIM2 to TIM5) and if UDIS=0 in the TIMx\_CR1 register.

“ When CNT is reinitialized by software using the UG bit in TIMx\_EGR register, if URS=0 and UDIS=0 in the TIMx\_CR1 register.

When CNT is reinitialized by a trigger event (refer to the synchro control register description), if URS=0 and UDIS=0 in the TIMx\_CR1 register.

### 13.4.6 TIMx event generation register (TIMx\_EGR)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
									TG	Res.	CC4G	CC3G	CC2G	CC1G	UG
									w		w	w	w	w	w

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in TIMx\_SR register. Related interrupt or DMA transfer can occur if enabled.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4G**: Capture/compare 4 generation

refer to CC1G description

Bit 3 **CC3G**: Capture/compare 3 generation

refer to CC1G description

Bit 2 **CC2G**: Capture/compare 2 generation

refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A capture/compare event is generated on channel 1:

**If channel CC1 is configured as output:**

CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.

**If channel CC1 is configured as input:**

The current value of the counter is captured in TIMx\_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Re-initialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared if the center-aligned mode is selected or if DIR=0 (upcounting), else it takes the auto-reload value (TIMx\_ARR) if DIR=1 (downcounting).

### 13.4.7 TIMx capture/compare mode register 1 (TIMx\_CCMR1)

Address offset: 0x18

Reset value: 0x0000

The channels can be used in input (capture mode) or in output (compare mode). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode. For a given bit, OCxx describes its function when the channel is configured in output, ICxx describes its function when the channel is configured in input. So you must take care that the same bit can have a different meaning for the input stage and for the output stage.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2CE	OC2M[2:0]			OC2PE	OC2FE	CC2S[1:0]	OC1CE	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]		
	IC2F[3:0]			IC2PSC[1:0]			IC1F[3:0]			IC1PSC[1:0]					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

#### Output compare mode

Bit 15 **OC2CE**: Output compare 2 clear enable

Bits 14:12 **OC2M[2:0]**: Output compare 2 mode

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, IC2 is mapped on TI2

10: CC2 channel is configured as input, IC2 is mapped on TI1

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through the TS bit (TIMx\_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx\_CCER).

Bit 7 **OC1CE**: Output compare 1 clear enable

OC1CE: Output Compare 1 Clear Enable

0: OC1Ref is not affected by the ETRF input

1: OC1Ref is cleared as soon as a High level is detected on ETRF input

Bits 6:4 **OC1M**: Output compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas OC1 and OC1N active level depends on CC1P and CC1NP bits.

000: Frozen - The comparison between the output compare register TIMx\_CCR1 and the counter TIMx\_CNT has no effect on the outputs.(this mode is used to generate a timing base).

001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx\_CNT matches the capture/compare register 1 (TIMx\_CCR1).

010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx\_CNT matches the capture/compare register 1 (TIMx\_CCR1).

011: Toggle - OC1REF toggles when TIMx\_CNT=TIMx\_CCR1.

100: Force inactive level - OC1REF is forced low.

101: Force active level - OC1REF is forced high.

110: PWM mode 1 - In upcounting, channel 1 is active as long as TIMx\_CNT<TIMx\_CCR1 else inactive. In downcounting, channel 1 is inactive (OC1REF='0) as long as TIMx\_CNT>TIMx\_CCR1 else active (OC1REF=1).

111: PWM mode 2 - In upcounting, channel 1 is inactive as long as TIMx\_CNT<TIMx\_CCR1 else active. In downcounting, channel 1 is active as long as TIMx\_CNT>TIMx\_CCR1 else inactive.

*Note: In PWM mode 1 or 2, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.*

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx\_CCR1 disabled. TIMx\_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx\_CCR1 enabled. Read/Write operations access the preload register. TIMx\_CCR1 preload value is loaded in the active register at each update event.

*Note: 1: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx\_BDTR register) and CC1S=00 (the channel is configured in output).*

*2: The PWM mode can be used without validating the preload register only in one-pulse mode (OPM bit set in TIMx\_CR1 register). Else the behavior is not guaranteed.*

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit is used to accelerate the effect of an event on the trigger input on the CC output.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently from the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output.

01: CC1 channel is configured as input, IC1 is mapped on TI1.

10: CC1 channel is configured as input, IC1 is mapped on TI2.

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx\_CCER).*

## Input capture mode

Bits 15:12 **IC2F**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S**: Capture/compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output.

01: CC2 channel is configured as input, IC2 is mapped on TI2.

10: CC2 channel is configured as input, IC2 is mapped on TI1.

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx\_CCER).*

Bits 7:4 **IC1F**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

0000: No filter, sampling is done at  $f_{DTS}$

0001:  $f_{SAMPLING} = f_{CK\_INT}$ , N=2

0010:  $f_{SAMPLING} = f_{CK\_INT}$ , N=4

0011:  $f_{SAMPLING} = f_{CK\_INT}$ , N=8

0100:  $f_{SAMPLING} = f_{DTS}/2$ , N=6

0101:  $f_{SAMPLING} = f_{DTS}/2$ , N=8

0110:  $f_{SAMPLING} = f_{DTS}/4$ , N=6

0111:  $f_{SAMPLING} = f_{DTS}/4$ , N=8

1000:  $f_{SAMPLING} = f_{DTS}/8$ , N=6

1001:  $f_{SAMPLING} = f_{DTS}/8$ , N=8

1010:  $f_{SAMPLING} = f_{DTS}/16$ , N=5

1011:  $f_{SAMPLING} = f_{DTS}/16$ , N=6

1100:  $f_{SAMPLING} = f_{DTS}/16$ , N=8

1101:  $f_{SAMPLING} = f_{DTS}/32$ , N=5

1110:  $f_{SAMPLING} = f_{DTS}/32$ , N=6

1111:  $f_{SAMPLING} = f_{DTS}/32$ , N=8

*Note: Care must be taken that  $f_{DTS}$  is replaced in the formula by CK\_INT when ICxF[3:0]= 1, 2 or 3.*

Bits 3:2 **IC1PSC**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1).

The prescaler is reset as soon as CC1E=0 (TIMx\_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input

01: capture is done once every 2 events

10: capture is done once every 4 events

11: capture is done once every 8 events

Bits 1:0 **CC1S**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx\_CCER).*

### 13.4.8 TIMx capture/compare mode register 2 (TIMx\_CCMR2)

Address offset: 0x1C

Reset value: 0x0000

Refer to the above CCMR1 register description.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC4CE	OC4M[2:0]			OC4PE	OC4FE	CC4S[1:0]		OC3CE	OC3M[2:0]			OC3PE	OC3FE	CC3S[1:0]	
IC4F[3:0]			IC4PSC[1:0]					IC3F[3:0]			IC3PSC[1:0]				
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

#### Output compare mode

Bit 15 **OC4CE**: Output compare 4 clear enable

Bits 14:12 **OC4M**: Output compare 4 mode

Bit 11 **OC4PE**: Output compare 4 preload enable

Bit 10 **OC4FE**: Output compare 4 fast enable

Bits 9:8 **CC4S**: Capture/Compare 4 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC4 channel is configured as output

01: CC4 channel is configured as input, IC4 is mapped on TI4

10: CC4 channel is configured as input, IC4 is mapped on TI3

11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx\_CCER).

Bit 7 **OC3CE**: Output compare 3 clear enable

Bits 6:4 **OC3M**: Output compare 3 mode

Bit 3 **OC3PE**: Output compare 3 preload enable

Bit 2 **OC3FE**: Output compare 3 fast enable

Bits 1:0 **CC3S**: Capture/Compare 3 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC3 channel is configured as output

01: CC3 channel is configured as input, IC3 is mapped on TI3

10: CC3 channel is configured as input, IC3 is mapped on TI4

11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx\_CCER).

### Input capture mode

Bits 15:12 **IC4F**: Input capture 4 filter

Bits 11:10 **IC4PSC**: Input capture 4 prescaler

Bits 9:8 **CC4S**: Capture/Compare 4 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC4 channel is configured as output

01: CC4 channel is configured as input, IC4 is mapped on TI4

10: CC4 channel is configured as input, IC4 is mapped on TI3

11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx\_CCER).*

Bits 7:4 **IC3F**: Input capture 3 filter

Bits 3:2 **IC3PSC**: Input capture 3 prescaler

Bits 1:0 **CC3S**: Capture/Compare 3 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC3 channel is configured as output

01: CC3 channel is configured as input, IC3 is mapped on TI3

10: CC3 channel is configured as input, IC3 is mapped on TI4

11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx\_CCER).*

### 13.4.9 TIMx capture/compare enable register (TIMx\_CCER)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC4NP rw	Res. rw	CC4P rw	CC4E rw	CC3NP rw	Res. rw	CC3P rw	CC3E rw	CC2NP rw	Res. rw	CC2P rw	CC2E rw	CC1NP rw	Res. rw	CC1P rw	CC1E rw

Bit 15 **CC4NP**: Capture/Compare 4 output Polarity.

Refer to CC1NP description

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC4P**: Capture/Compare 4 output Polarity.

refer to CC1P description

Bit 12 **CC4E**: Capture/Compare 4 output enable.

refer to CC1E description

Bit 11 **CC3NP**: Capture/Compare 3 output Polarity.

refer to CC1NP description

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC3P**: Capture/Compare 3 output Polarity.

refer to CC1P description

Bit 8 **CC3E**: Capture/Compare 3 output enable.

refer to CC1E description

- Bit 7 **CC2NP**: *Capture/Compare 2 output Polarity.*  
refer to CC1NP description
- Bit 6 Reserved, must be kept at reset value.
- Bit 5 **CC2P**: *Capture/Compare 2 output Polarity.*  
refer to CC1P description
- Bit 4 **CC2E**: *Capture/Compare 2 output enable.*  
refer to CC1E description
- Bit 3 **CC1NP**: *Capture/Compare 1 output Polarity.*
  - CC1 channel configured as output:  
CC1NP must be kept cleared in this case.
  - CC1 channel configured as input:  
This bit is used in conjunction with CC1P to define TI1FP1/TI2FP1 polarity. refer to CC1P description.
- Bit 2 Reserved, must be kept at reset value.
- Bit 1 **CC1P**: *Capture/Compare 1 output Polarity.*
  - CC1 channel configured as output:**
    - 0: OC1 active high
    - 1: OC1 active low
  - CC1 channel configured as input:**  
CC1NP/CC1P bits select TI1FP1 and TI2FP1 polarity for trigger or capture operations.
    - 00: noninverted/rising edge  
Circuit is sensitive to TIxFP1 rising edge (capture, trigger in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger in gated mode, encoder mode).
    - 01: inverted/falling edge  
Circuit is sensitive to TIxFP1 falling edge (capture, trigger in reset, external clock or trigger mode), TIxFP1 is inverted (trigger in gated mode, encoder mode).
    - 10: reserved, do not use this configuration.
    - 11: noninverted/both edges  
Circuit is sensitive to both TIxFP1 rising and falling edges (capture, trigger in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger in gated mode). This configuration must not be used for encoder mode.
- Bit 0 **CC1E**: *Capture/Compare 1 output enable.*
  - CC1 channel configured as output:**
    - 0: Off - OC1 is not active
    - 1: On - OC1 signal is output on the corresponding output pin
  - CC1 channel configured as input:**  
This bit determines if a capture of the counter value can actually be done into the input capture/compare register 1 (TIMx\_CCR1) or not.
    - 0: Capture disabled
    - 1: Capture enabled

**Table 55. Output control bit for standard OCx channels**

CCxE bit	OCx output state
0	Output Disabled (OCx=0, OCx_EN=0)
1	OCx=OCxREF + Polarity, OCx_EN=1

**Note:** The state of the external IO pins connected to the standard OC<sub>x</sub> channels depends on the OC<sub>x</sub> channel state and the GPIO registers.

### 13.4.10 TIMx counter (TIMx\_CNT)

Address offset: 0x24

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CNT[15:0]**: Counter value

### 13.4.11 TIMx prescaler (TIMx\_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency CK\_CNT is equal to  $f_{CK\_PSC} / (PSC[15:0] + 1)$ .

PSC contains the value to be loaded in the active prescaler register at each update event.

### 13.4.12 TIMx auto-reload register (TIMx\_ARR)

Address offset: 0x2C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to the [Section 13.3.1: Time-base unit on page 305](#) for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

### 13.4.13 TIMx capture/compare register 1 (TIMx\_CCR1)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR1[31:16] (depending on timers)															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR1[31:16]**: High Capture/Compare 1 value (on TIM2 and TIM5).

Bits 15:0 **CCR1[15:0]**: Low Capture/Compare 1 value

**If channel CC1 is configured as output:**

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signaled on OC1 output.

**If channel CC1 is configured as input:**

CCR1 is the counter value transferred by the last input capture 1 event (IC1).

### 13.4.14 TIMx capture/compare register 2 (TIMx\_CCR2)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR2[31:16] (depending on timers)															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR2[31:16]**: High Capture/Compare 2 value (on TIM2 and TIM5).

Bits 15:0 **CCR2[15:0]**: Low Capture/Compare 2 value

**If channel CC2 is configured as output:**

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signalled on OC2 output.

**If channel CC2 is configured as input:**

CCR2 is the counter value transferred by the last input capture 2 event (IC2).

### 13.4.15 TIMx capture/compare register 3 (TIMx\_CCR3)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR3[31:16] (depending on timers)															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR3[31:16]**: High Capture/Compare 3 value (on TIM2 and TIM5).

Bits 15:0 **CCR3[15:0]**: Low Capture/Compare value

**If channel CC3 is configured as output:**

CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signaled on OC3 output.

**If channel CC3 is configured as input:**

CCR3 is the counter value transferred by the last input capture 3 event (IC3).

### 13.4.16 TIMx capture/compare register 4 (TIMx\_CCR4)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR4[31:16] (depending on timers)															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR4[31:16]**: High Capture/Compare 4 value (on TIM2 and TIM5).

Bits 15:0 **CCR4[15:0]**: Low Capture/Compare value

- if CC4 channel is configured as output (CC4S bits):

CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signalled on OC4 output.

- if CC4 channel is configured as input (CC4S bits in TIMx\_CCMR4 register):

CCR4 is the counter value transferred by the last input capture 4 event (IC4).

### 13.4.17 TIMx DMA control register (TIMx\_DCR)

Address offset: 0x48

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
Reserved	DBL[4:0]								Reserved	DBA[4:0]							
	rw	rw	rw	rw	rw					rw	rw	rw	rw	rw			

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit vector defines the number of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx\_DMAR address).

00000: 1 transfer,  
00001: 2 transfers,  
00010: 3 transfers,

...

10001: 18 transfers.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bit vector defines the base-address for DMA transfers (when read/write access are done through the TIMx\_DMAR address). DBA is defined as an offset starting from the address of the TIMx\_CR1 register.

Example:

00000: TIMx\_CR1,  
00001: TIMx\_CR2,  
00010: TIMx\_SMCR,

...

**Example:** Let us consider the following transfer: DBL = 7 transfers & DBA = TIMx\_CR1. In this case the transfer is done to/from 7 registers starting from the TIMx\_CR1 address.

### 13.4.18 TIMx DMA address for full transfer (TIMx\_DMAR)

Address offset: 0x4C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **DMAB[15:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address  
(TIMx\_CR1 address) + (DBA + DMA index) × 4

where TIMx\_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx\_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx\_DCR).

### Example of how to use the DMA burst feature

In this example the timer DMA burst feature is used to update the contents of the CCRx registers ( $x = 2, 3, 4$ ) with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
  - DMA channel peripheral address is the DMAR register address
  - DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into CCRx registers.
  - Number of data to transfer = 3 (See note below).
  - Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bit fields as follows:  
DBL = 3 transfers, DBA = 0xE.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx
5. Enable the DMA channel

Note:

*This example is for the case where every CCRx register to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer should be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5 and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3 and data6 is transferred to CCR4.*

### 13.4.19 TIM2 option register (TIM2\_OR)

Address offset: 0x50

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				ITR1_RMP		Reserved									
				rw	rw										

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:10 **ITR1\_RMP**: Internal trigger 1 remap

Set and cleared by software.

00: Reserved

01: PTP trigger output is connected to TIM2\_ITR1

10: OTG FS SOF is connected to the TIM2\_ITR1 input

11: OTG HS SOF is connected to the TIM2\_ITR1 input

Bits 9:0 Reserved, must be kept at reset value.

### 13.4.20 TIM5 option register (TIM5\_OR)

Address offset: 0x50

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								TI4_RMP		Reserved					
								rw	rw						

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:6 **TI4\_RMP**: Timer Input 4 remap

Set and cleared by software.

00: TIM5 Channel4 is connected to the GPIO: Refer to the Alternate function mapping table in the datasheets.

01: the LSI internal clock is connected to the TIM5\_CH4 input for calibration purposes

10: the LSE internal clock is connected to the TIM5\_CH4 input for calibration purposes

11: the RTC wakeup interrupt is connected to TIM5\_CH4 input for calibration purposes.

Wakeup interrupt should be enabled.

Bits 5:0 Reserved, must be kept at reset value.

### 13.4.21 TIMx register map

TIMx registers are mapped as described in the table below:

**Table 56. TIM2 to TIM5 register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
0x00	TIMx_CR1	Reserved												CKD [1:0]		ARPE		CMS [1:0]		DIR		OPM		CCDS		URS		UDIS		CEN					
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x04	TIMx_CR2	Reserved												MMS[2:0]		T1S		0		0		0		0		0		0		0					
	Reset value													Reserved		0		0		0		0		0		0		0		0					
0x08	TIMx_SMCR	Reserved												0	ETP	0	ECE	ETPS [1:0]	ETF[3:0]		0		0		0		0		0		SMS[2:0]				
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x0C	TIMx_DIER	Reserved												0	TDE	0	COMDE	0	CC4DE	0	CC3DE	0	CC2DE	0	CC1DE	0	UDE	0	Reserved	0	TS[2:0]	0			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x10	TIMx_SR	Reserved												0	CC4OF	0	CC3OF	0	CC2OF	0	CC1OF	0	CC1OF	0	CC1OF	0	TG	0	TIF	0	Reserved	0			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x14	TIMx_EGR	Reserved												0	CC4G	0	CC3G	0	CC2G	0	CC1G	0	CC1G	0	CC1G	0	UG	0	UG	0	Reserved	0			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x18	TIMx_CCMR1 Output Compare mode	Reserved												0	OC2CE	OC2M [2:0]		OC2PE		OC2FE		CC2S [1:0]		OC1CE		OC1M [2:0]		CC1S [1:0]		Reserved		Reserved			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x18	TIMx_CCMR1 Input Capture mode	Reserved												0	IC2F[3:0]	0	IC2PSC [1:0]	CC2S [1:0]		IC1F[3:0]		IC1PSC [1:0]		CC1S [1:0]		Reserved		Reserved		Reserved		Reserved			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x1C	TIMx_CCMR2 Output Compare mode	Reserved												0	OC2CE	OC4M [2:0]		OC4PE		OC4FE		CC4S [1:0]		OC3CE		OC3M [2:0]		OC3PE		CC3S [1:0]		Reserved		Reserved	
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x1C	TIMx_CCMR2 Input Capture mode	Reserved												0	IC4F[3:0]	0	IC4PSC [1:0]	CC4S [1:0]		IC3F[3:0]		IC3PSC [1:0]		CC3S [1:0]		Reserved		Reserved		Reserved		Reserved			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x20	TIMx_CCER	Reserved												0	CC4NP	0	CC4P	0	CC4E	0	CC3NP	0	CC3P	0	CC3E	0	CC2NP	0	CC2P	0	CC1NP	0	CC1P	0	
	Reset value													0	Reserved	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0x24	TIMx_CNT	CNT[31:16] (TIM2 and TIM5 only, reserved on the other timers)												CNT[15:0]												Reserved		Reserved		Reserved					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

**Table 56. TIM2 to TIM5 register map and reset values (continued)**

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 14 General-purpose timers (TIM9 to TIM11)

TIM12, TIM13 and TIM14 are not available in STM32F401xB/C and STM32F401xD/E.

### 14.1 TIM9/10/11 introduction

The TIM9/10/11 general-purpose timers consist of a 16-bit auto-reload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The TIM9/10/11 timers are completely independent, and do not share any resources. They can be synchronized together as described in [Section 14.3.12](#).

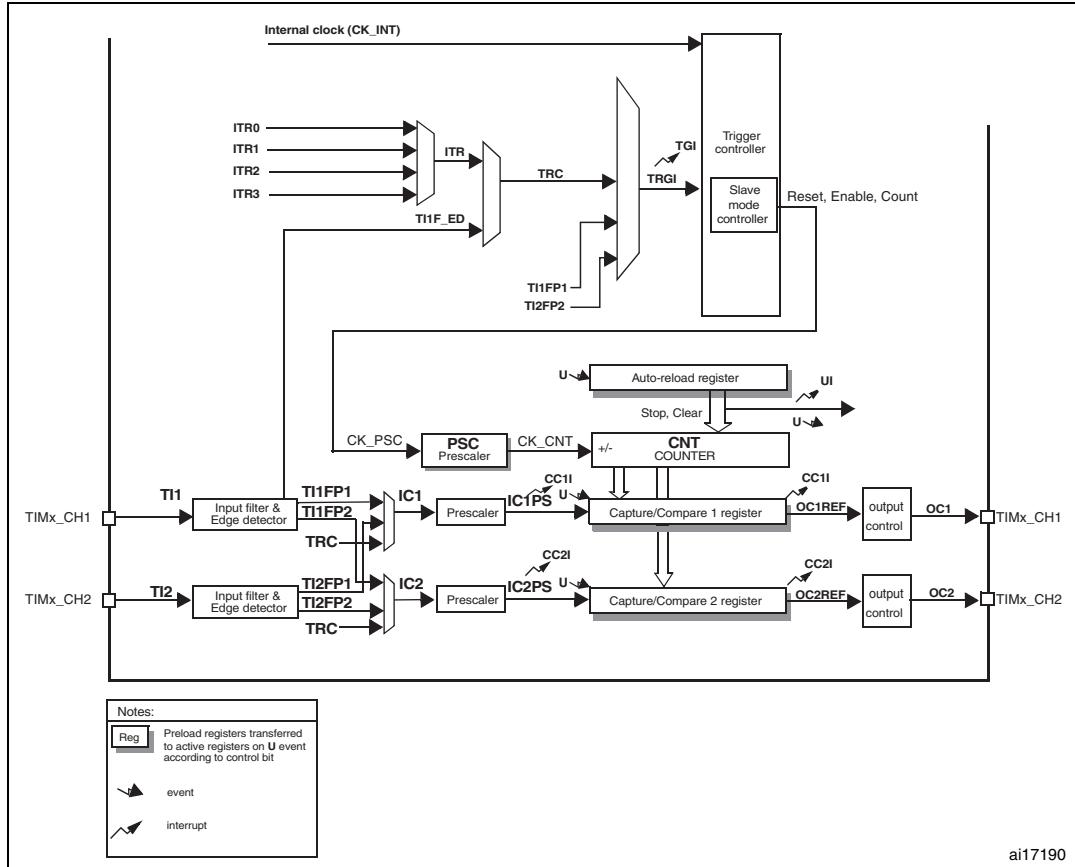
### 14.2 TIM9/10/11 main features

#### 14.2.1 TIM9 main features

The features of the TIM9 general-purpose timer include:

- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide the counter clock frequency by any factor between 1 and 65536 (can be changed “on the fly”)
- Up to 2 independent channels for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Synchronization circuit to control the timer with external signals and to interconnect several timers together
- Interrupt generation on the following events:
  - Update: counter overflow, counter initialization (by software or internal trigger)
  - Trigger event (counter start, stop, initialization or count by internal trigger)
  - Input capture
  - Output compare

Figure 133. General-purpose timer block diagram (TIM9)

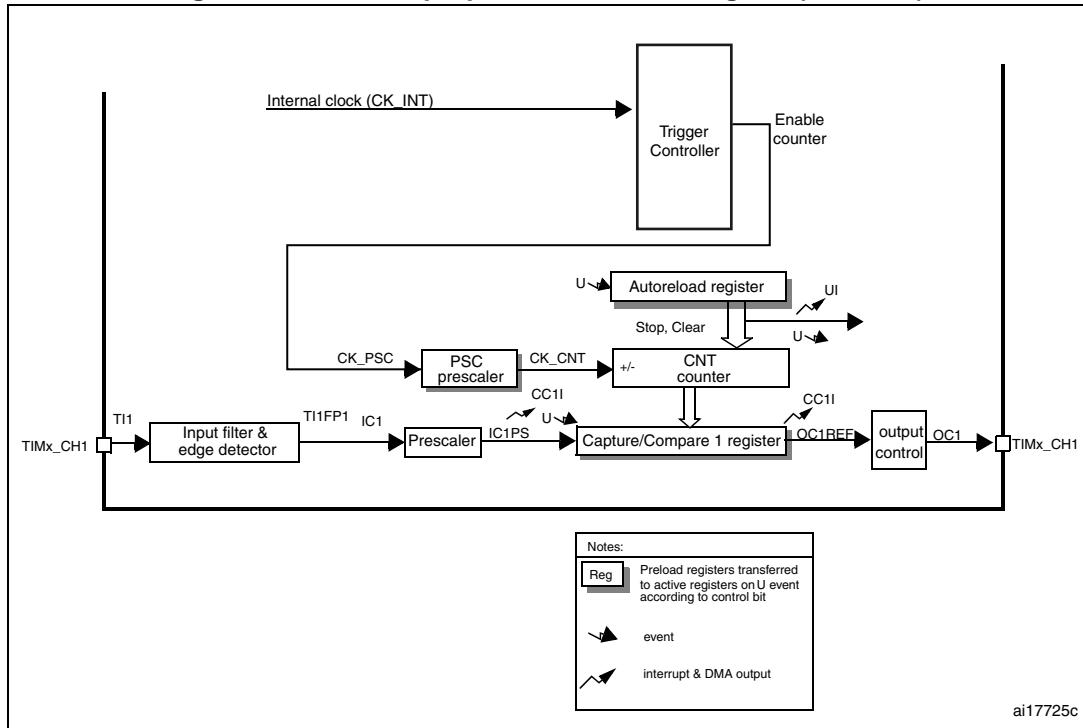


#### 14.2.2 TIM10/TIM11 main features

The features of general-purpose timers TIM10/TIM11 include:

- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide the counter clock frequency by any factor between 1 and 65536 (can be changed “on the fly”)
- independent channel for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Interrupt generation on the following events:
  - Update: counter overflow, counter initialization (by software)
  - Input capture
  - Output compare

Figure 134. General-purpose timer block diagram (TIM10/11)



## 14.3 TIM9 to TIM11 functional description

### 14.3.1 Time-base unit

The main block of the timer is a 16-bit counter with its related auto-reload register.

The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx\_CNT)
- Prescaler register (TIMx\_PSC)
- Auto-reload register (TIMx\_ARR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx\_CR1 register. The update event is sent when the counter reaches the overflow and if the UDIS bit equals 0 in the TIMx\_CR1 register. It can also be generated by software. The generation of the update event is described in details for each configuration.

The counter is clocked by the prescaler output CK\_CNT, which is enabled only when the counter enable bit (CEN) in TIMx\_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

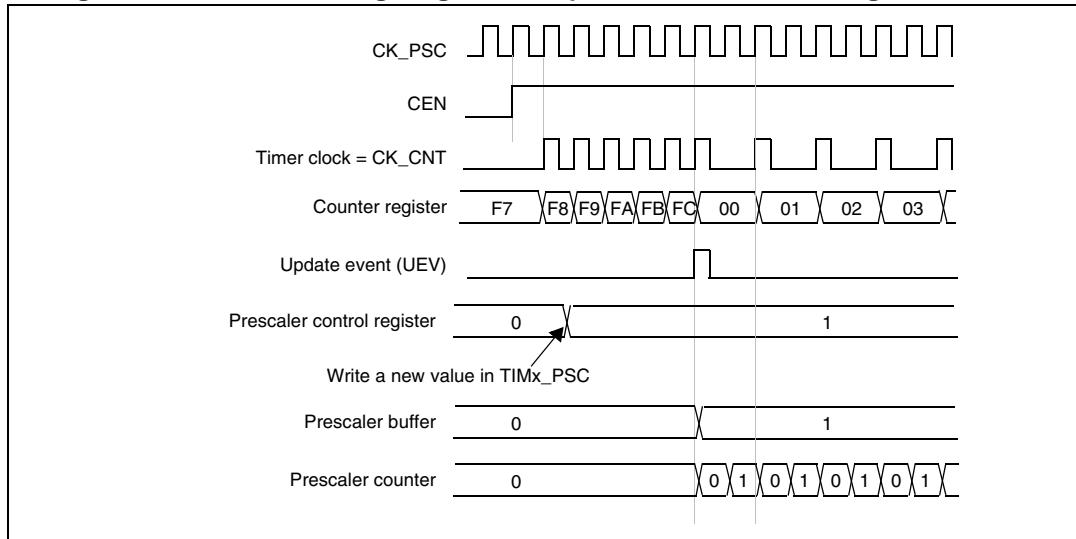
Note that the counter starts counting 1 clock cycle after setting the CEN bit in the TIMx\_CR1 register.

#### Prescaler description

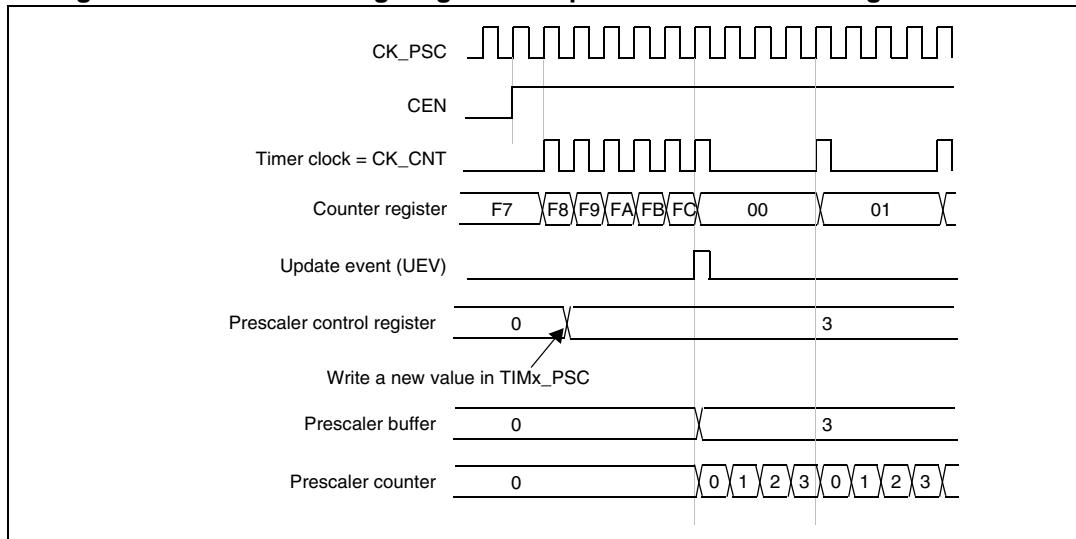
The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx\_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

*Figure 135* and *Figure 136* give some examples of the counter behavior when the prescaler ratio is changed on the fly.

**Figure 135.** Counter timing diagram with prescaler division change from 1 to 2



**Figure 136.** Counter timing diagram with prescaler division change from 1 to 4



### 14.3.2 Counter modes

## Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx\_ARR register), then restarts from 0 and generates a counter overflow event.

Setting the UG bit in the TIMx\_EGR register (by software) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx\_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx\_CR1 register is set, setting the UG bit generates an update event UEV but without

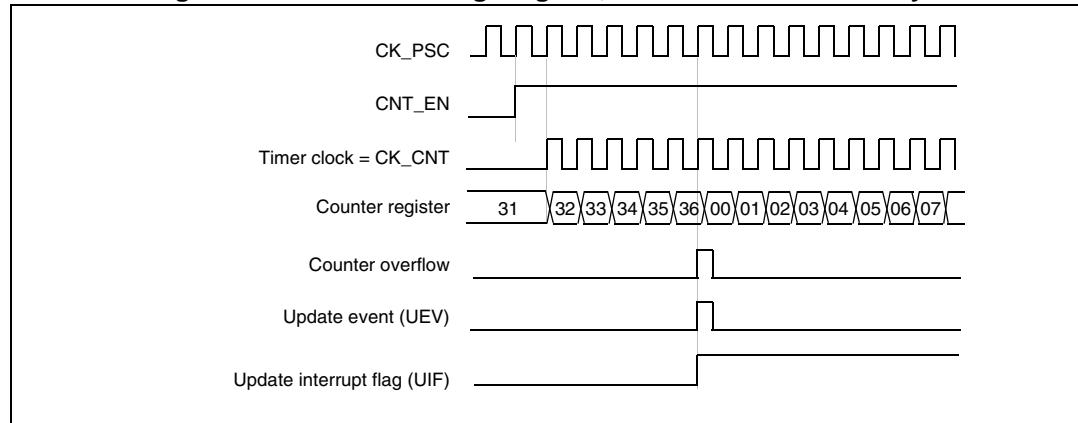
setting the UIF flag (thus no interrupt is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx\_SR register) is set (depending on the URS bit):

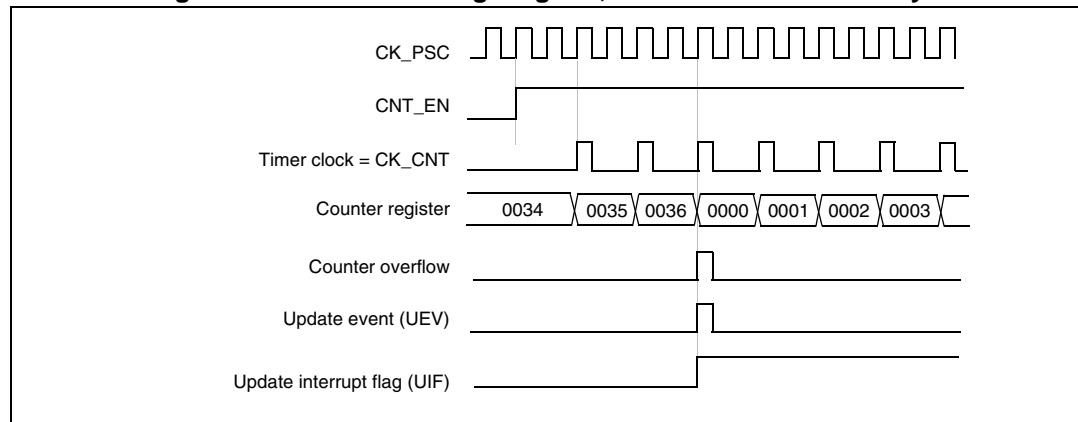
- The auto-reload shadow register is updated with the preload value (TIMx\_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx\_PSC register).

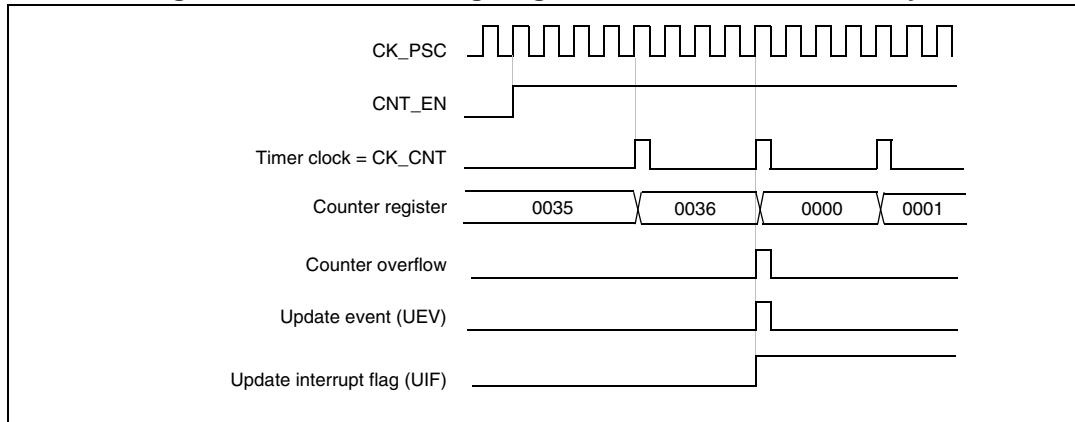
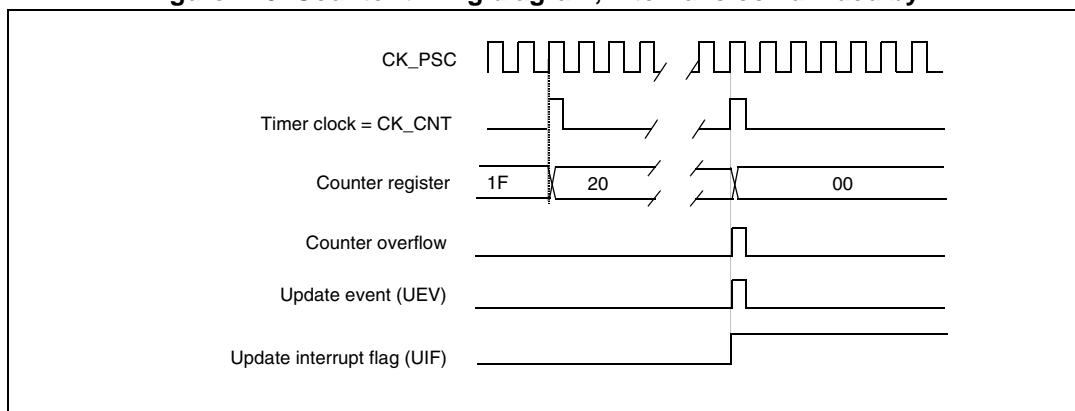
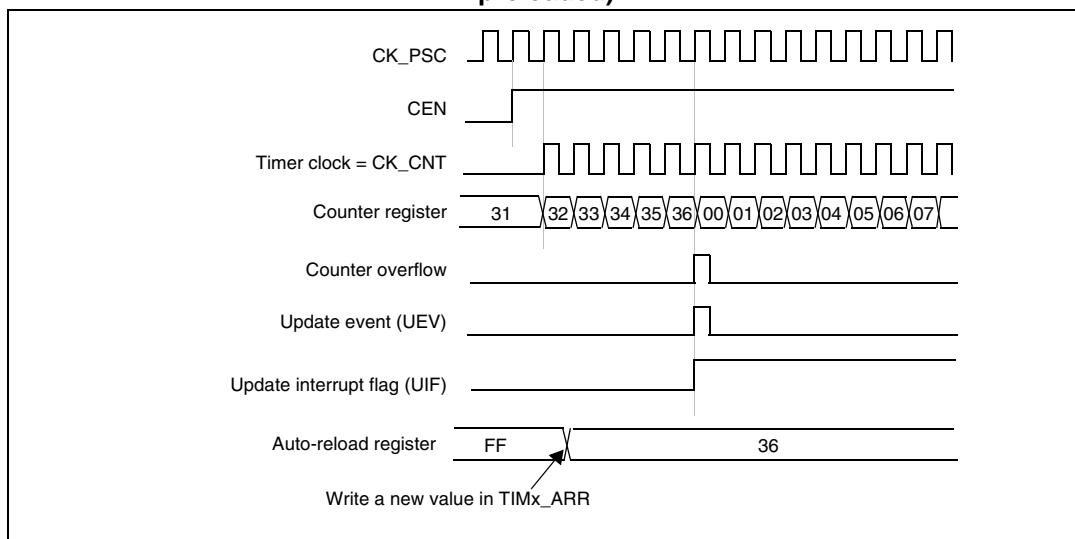
The following figures show some examples of the counter behavior for different clock frequencies when TIMx\_ARR=0x36.

**Figure 137. Counter timing diagram, internal clock divided by 1**

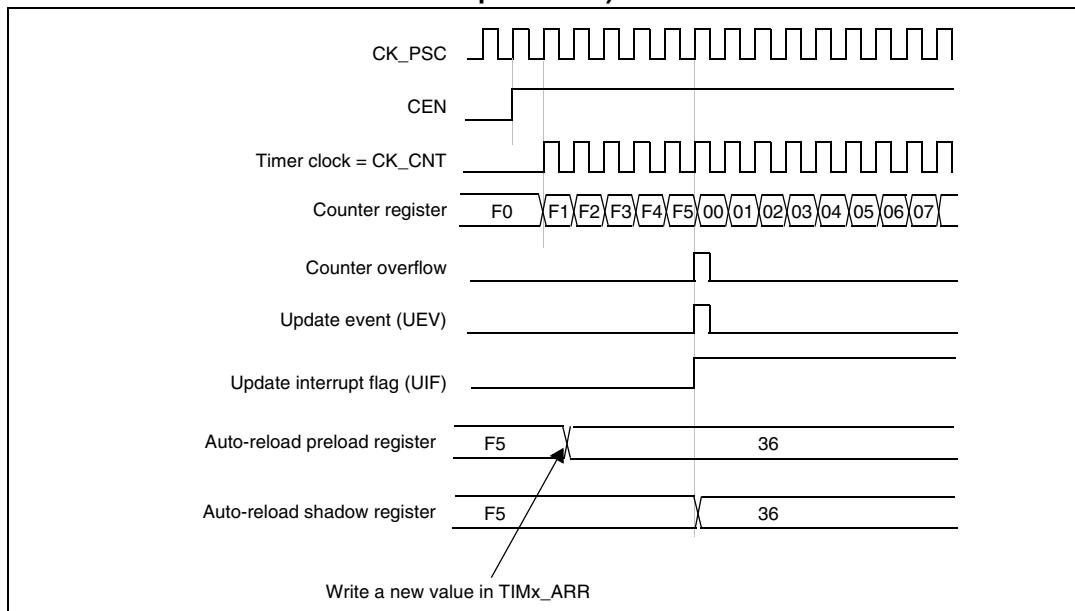


**Figure 138. Counter timing diagram, internal clock divided by 2**



**Figure 139. Counter timing diagram, internal clock divided by 4****Figure 140. Counter timing diagram, internal clock divided by N****Figure 141. Counter timing diagram, update event when ARPE=0 (TIMx\_ARR not preloaded)**

**Figure 142. Counter timing diagram, update event when ARPE=1 (TIMx\_ARR preloaded)**



### 14.3.3 Clock selection

The counter clock can be provided by the following clock sources:

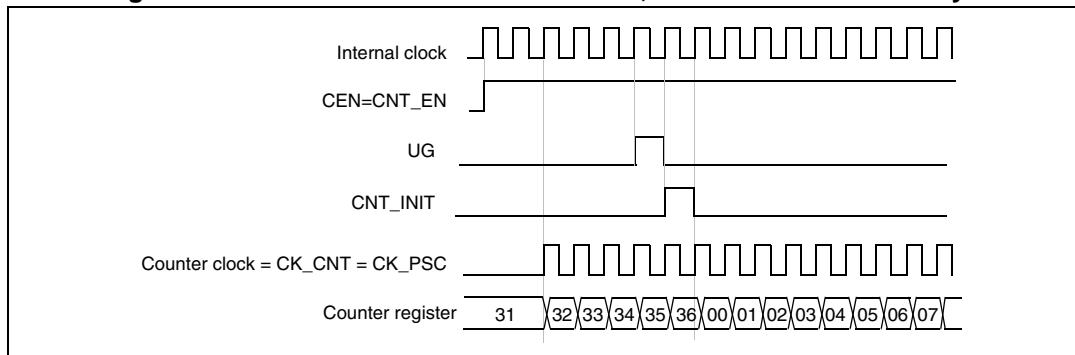
- Internal clock (CK\_INT)
- External clock mode1 (for **TIM9** and **TIM11**): external input pin (TIx)
- Internal trigger inputs (ITRx) (for **TIM9** and **TIM11**): connecting the trigger output from another timer. Refer to [Section : Using one timer as prescaler for another](#) for more details.

#### Internal clock source (CK\_INT)

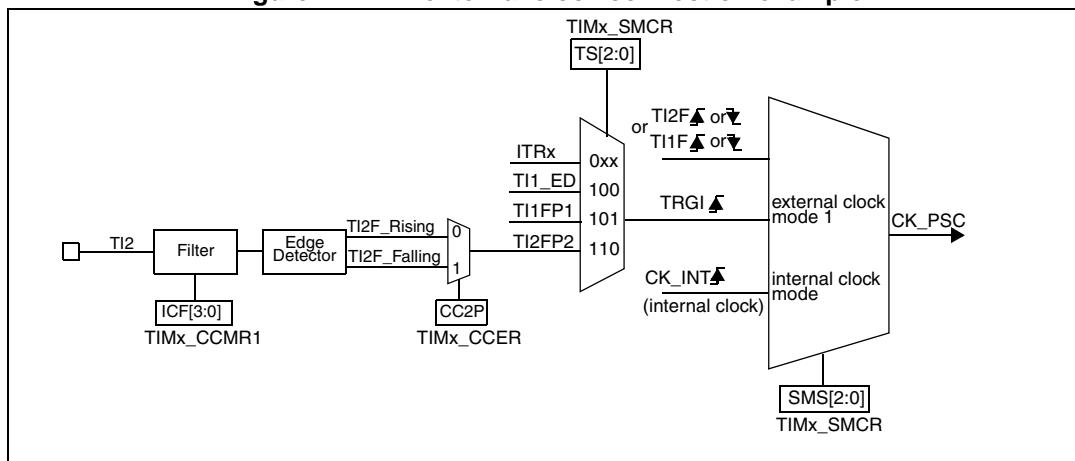
The internal clock source is the default clock source for TIM10/TIM11.

For TIM9 and TIM12, the internal clock source is selected when the slave mode controller is disabled (SMS='000'). The CEN bit in the TIMx\_CR1 register and the UG bit in the TIMx\_EGR register are then used as control bits and can be changed only by software (except for UG which remains cleared). As soon as the CEN bit is programmed to 1, the prescaler is clocked by the internal clock CK\_INT.

[Figure 143](#) shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

**Figure 143. Control circuit in normal mode, internal clock divided by 1****External clock source mode 1(TIM9 and TIM11)**

This mode is selected when SMS='111' in the TIMx\_SMCR register. The counter can count at each rising or falling edge on a selected input.

**Figure 144. TI2 external clock connection example**

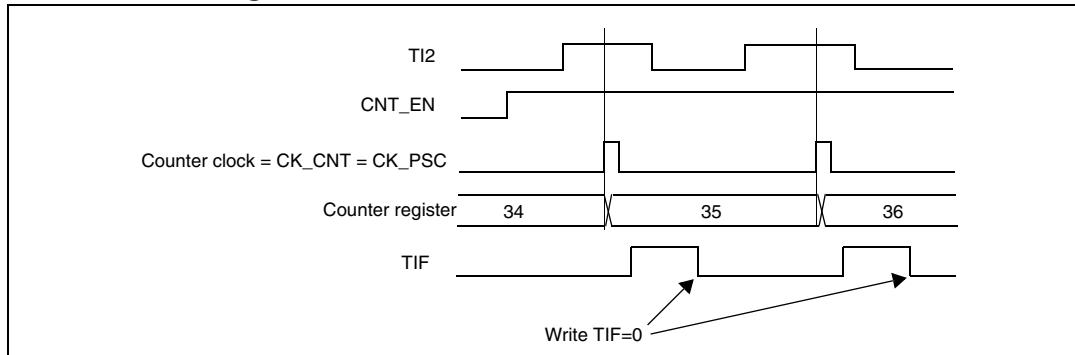
For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

1. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S = '01' in the TIMx\_CCMR1 register.
2. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx\_CCMR1 register (if no filter is needed, keep IC2F='0000').
3. Select the rising edge polarity by writing CC2P='0' and CC2NP='0' in the TIMx\_CCER register.
4. Configure the timer in external clock mode 1 by writing SMS='111' in the TIMx\_SMCR register.
5. Select TI2 as the trigger input source by writing TS='110' in the TIMx\_SMCR register.
6. Enable the counter by writing CEN='1' in the TIMx\_CR1 register.

*Note:* The capture prescaler is not used for triggering, so you don't need to configure it.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

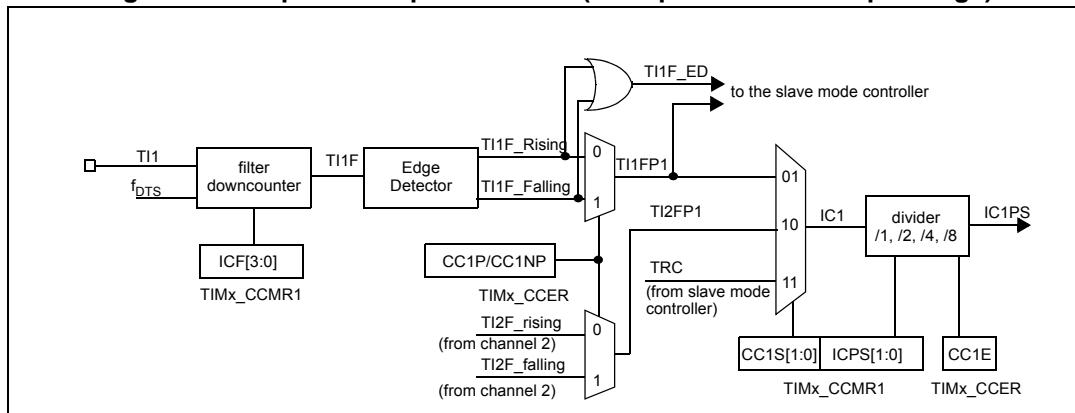
**Figure 145. Control circuit in external clock mode 1**

#### 14.3.4 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

*Figure 146 to Figure 148* give an overview of one capture/compare channel.

The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

**Figure 146. Capture/compare channel (example: channel 1 input stage)**

The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

Figure 147. Capture/compare channel 1 main circuit

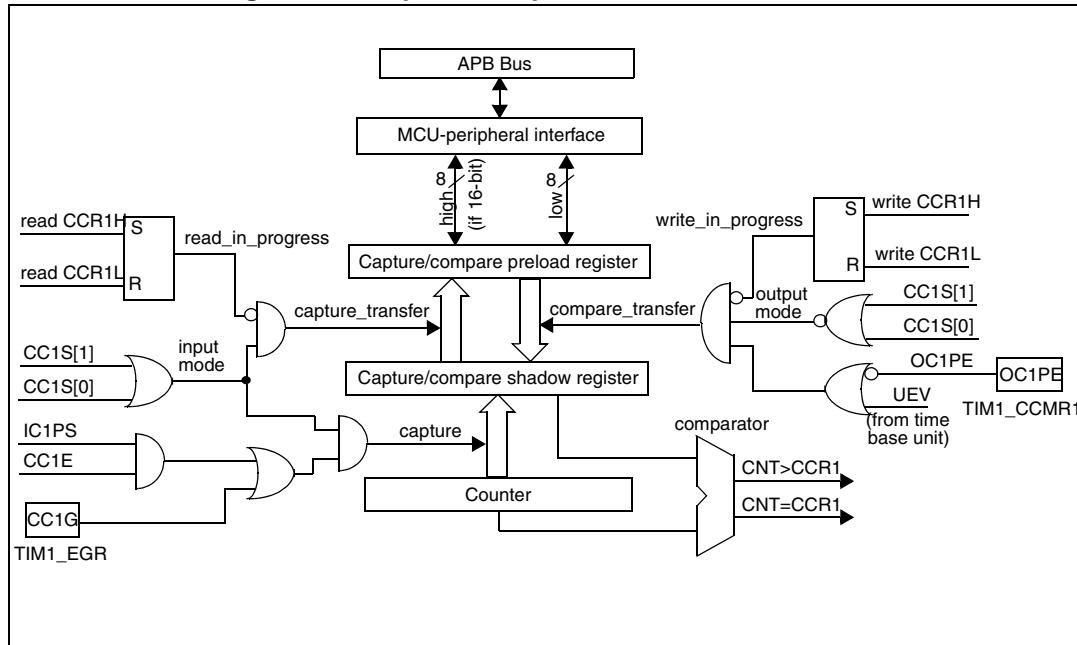
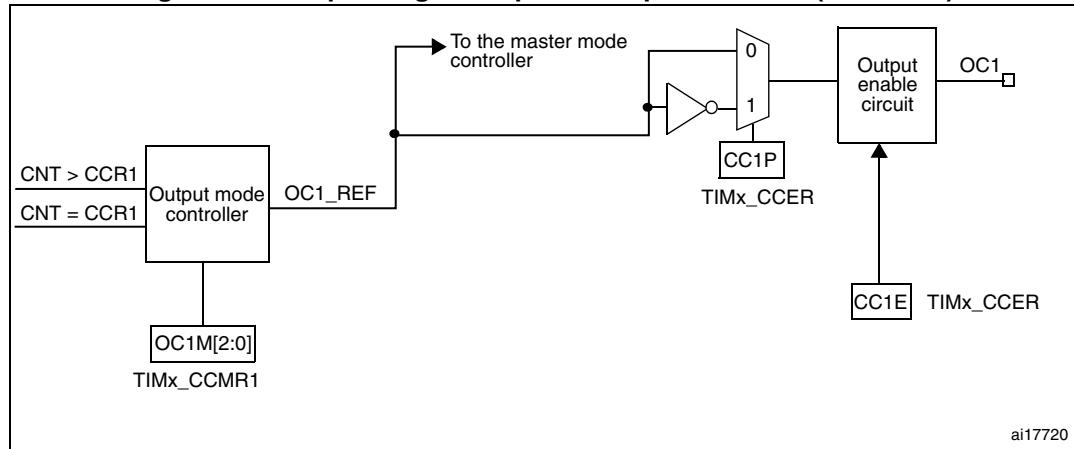


Figure 148. Output stage of capture/compare channel (channel 1)



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

#### 14.3.5 Input capture mode

In Input capture mode, the Capture/Compare Registers (TIMx\_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx\_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the over-capture flag CCxOF (TIMx\_SR register) is set. CCxIF can be

cleared by software by writing it to '0' or by reading the captured data stored in the TIMx\_CCRx register. CCxOF is cleared when you write it to '0'.

The following example shows how to capture the counter value in TIMx\_CCR1 when TI1 input rises. To do this, use the following procedure:

1. Select the active input: TIMx\_CCR1 must be linked to the TI1 input, so write the CC1S bits to '01' in the TIMx\_CCMR1 register. As soon as CC1S becomes different from '00', the channel is configured in input mode and the TIMx\_CCR1 register becomes read-only.
2. Program the input filter duration you need with respect to the signal you connect to the timer (by programming the ICxF bits in the TIMx\_CCMRx register if the input is one of the TIx inputs). Let's imagine that, when toggling, the input signal is not stable during at most 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the new level have been detected (sampled at  $f_{DTS}$  frequency). Then write IC1F bits to '0011' in the TIMx\_CCMR1 register.
3. Select the edge of the active transition on the TI1 channel by programming CC1P and CC1NP bits to '00' in the TIMx\_CCER register (rising edge in this case).
4. Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to '00' in the TIMx\_CCMR1 register).
5. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx\_CCER register.
6. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx\_DIER register.

When an input capture occurs:

- The TIMx\_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

*Note:* *IC interrupt requests can be generated by software by setting the corresponding CCxG bit in the TIMx\_EGR register.*

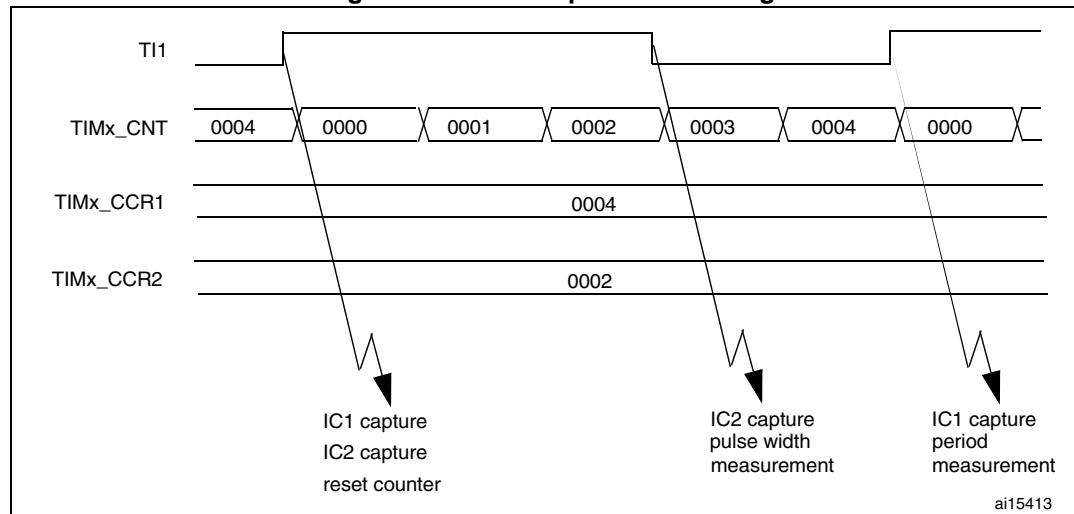
#### 14.3.6 PWM input mode (only for TIM9/11)

This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, you can measure the period (in TIMx\_CCR1 register) and the duty cycle (in TIMx\_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK\_INT frequency and prescaler value):

1. Select the active input for TIMx\_CCR1: write the CC1S bits to '01' in the TIMx\_CCMR1 register (TI1 selected).
2. Select the active polarity for TI1FP1 (used both for capture in TIMx\_CCR1 and counter clear): program the CC1P and CC1NP bits to '00' (active on rising edge).
3. Select the active input for TIMx\_CCR2: write the CC2S bits to '10' in the TIMx\_CCMR1 register (TI1 selected).
4. Select the active polarity for TI1FP2 (used for capture in TIMx\_CCR2): program the CC2P and CC2NP bits to '11' (active on falling edge).
5. Select the valid trigger input: write the TS bits to '101' in the TIMx\_SMCR register (TI1FP1 selected).
6. Configure the slave mode controller in reset mode: write the SMS bits to '100' in the TIMx\_SMCR register.
7. Enable the captures: write the CC1E and CC2E bits to '1' in the TIMx\_CCER register.

**Figure 149. PWM input mode timing**

1. The PWM input mode can be used only with the TIMx\_CH1/TIMx\_CH2 signals due to the fact that only TI1FP1 and TI2FP2 are connected to the slave mode controller.

#### 14.3.7 Forced output mode

In output mode (CCxS bits = '00' in the TIMx\_CCMRx register), each output compare signal (OCxREF and then OCx) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (OCXREF/OCx) to its active level, you just need to write '101' in the OCxM bits in the corresponding TIMx\_CCMRx register. Thus OCXREF is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

For example: CCxP='0' (OCx active high) => OCx is forced to high level.

The OCxREF signal can be forced low by writing the OCxM bits to '100' in the TIMx\_CCMRx register.

Anyway, the comparison between the TIMx\_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt requests can be sent accordingly. This is described in the output compare mode section below.

### 14.3.8 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

1. Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx\_CCMRx register) and the output polarity (CCxP bit in the TIMx\_CCER register). The output pin can keep its level (OCXM='000'), be set active (OCXM='001'), be set inactive (OCXM='010') or can toggle (OCXM='011') on match.
2. Sets a flag in the interrupt status register (CCxIF bit in the TIMx\_SR register).
3. Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx\_DIER register).

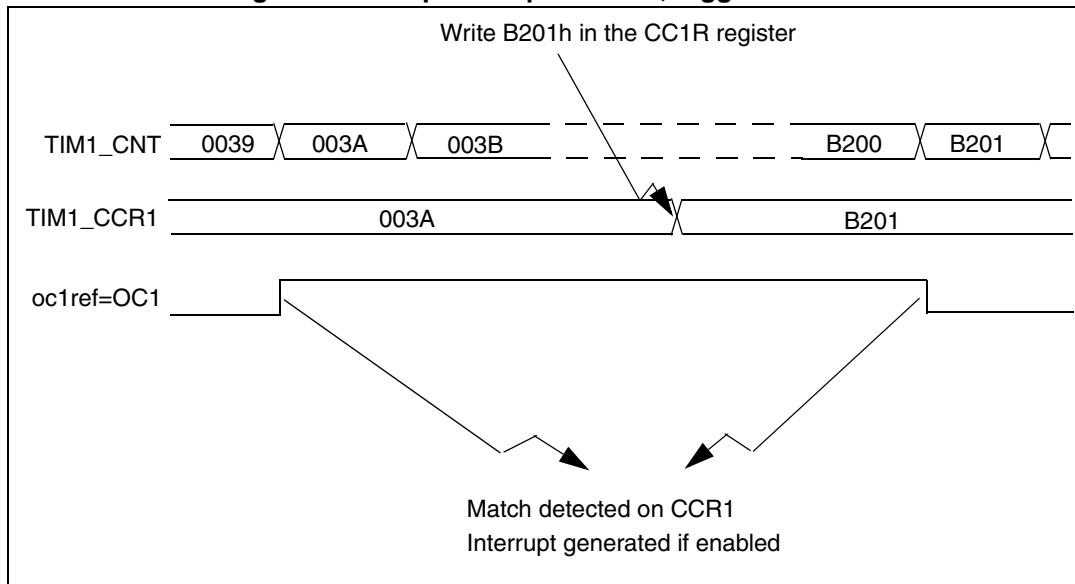
The TIMx\_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx\_CCMRx register.

In output compare mode, the update event UEV has no effect on OCxREF and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure:

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx\_ARR and TIMx\_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
  - Write OCxM = '011' to toggle OCx output pin when CNT matches CCRx
  - Write OCxPE = '0' to disable preload register
  - Write CCxP = '0' to select active high polarity
  - Write CCxE = '1' to enable the output
5. Enable the counter by setting the CEN bit in the TIMx\_CR1 register.

The TIMx\_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE='0', else TIMx\_CCRx shadow register is updated only at the next update event UEV). An example is given in [Figure 150](#).

**Figure 150. Output compare mode, toggle on OC1.**

#### 14.3.9 PWM mode

Pulse Width Modulation mode allows you to generate a signal with a frequency determined by the value of the TIMx\_ARR register and a duty cycle determined by the value of the TIMx\_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing ‘110’ (PWM mode 1) or ‘111’ (PWM mode 2) in the OCxM bits in the TIMx\_CCMRx register. You must enable the corresponding preload register by setting the OCxPE bit in the TIMx\_CCMRx register, and eventually the auto-reload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx\_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, you have to initialize all the registers by setting the UG bit in the TIMx\_EGR register.

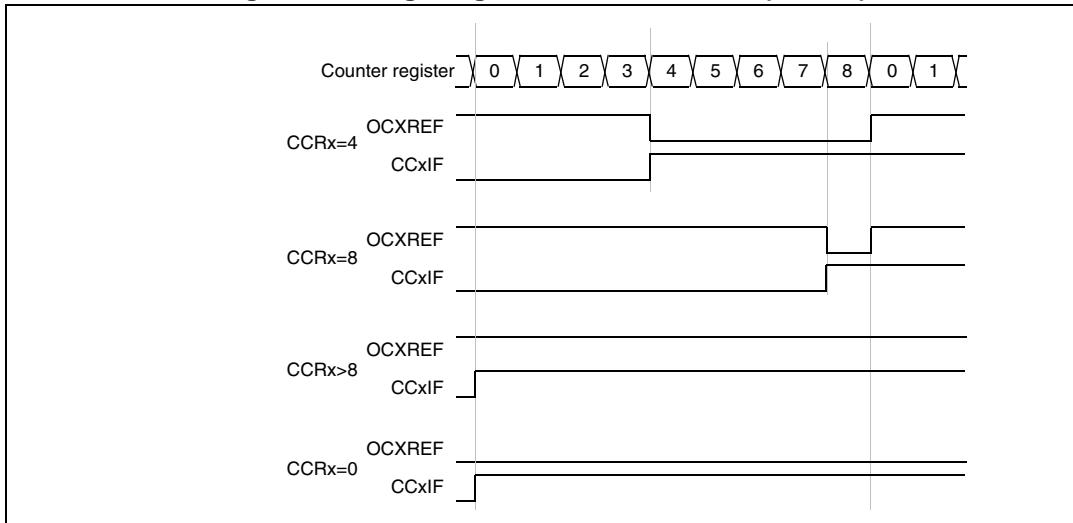
The OCx polarity is software programmable using the CCxP bit in the TIMx\_CCER register. It can be programmed as active high or active low. The OCx output is enabled by the CCxE bit in the TIMx\_CCER register. Refer to the TIMx\_CCERx register description for more details.

In PWM mode (1 or 2), TIMx\_CNT and TIMx\_CCRx are always compared to determine whether  $\text{TIMx\_CNT} \leq \text{TIMx\_CCRx}$ .

The timer is able to generate PWM in edge-aligned mode only since the counter is upcounting.

#### PWM edge-aligned mode

In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as  $\text{TIMx\_CNT} < \text{TIMx\_CCRx}$  else it becomes low. If the compare value in TIMx\_CCRx is greater than the auto-reload value (in TIMx\_ARR) then OCxREF is held at ‘1’. If the compare value is 0 then OCxRef is held at ‘0’. [Figure 151](#) shows some edge-aligned PWM waveforms in an example where TIMx\_ARR=8.

**Figure 151. Edge-aligned PWM waveforms (ARR=8)**

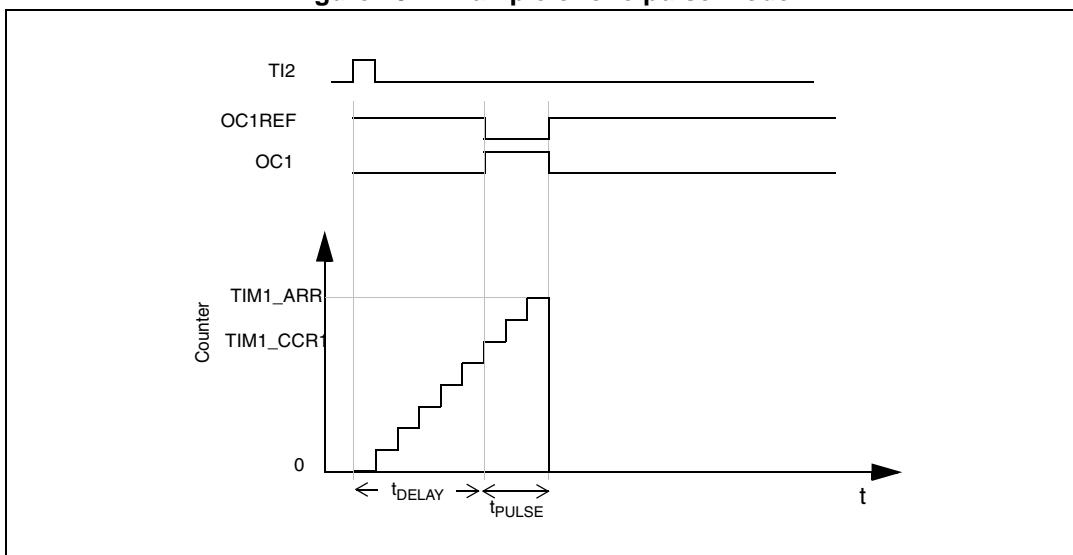
#### 14.3.10 One-pulse mode

One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. You select One-pulse mode by setting the OPM bit in the TIMx\_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be as follows:

$$\text{CNT} < \text{CCR}_x \leq \text{ARR} \text{ (in particular, } 0 < \text{CCR}_x\text{)}$$

**Figure 152. Example of one pulse mode.**

For example you may want to generate a positive pulse on OC1 with a length of  $t_{PULSE}$  and after a delay of  $t_{DELAY}$  as soon as a positive edge is detected on the TI2 input pin.

Use TI2FP2 as trigger 1:

1. Map TI2FP2 to TI2 by writing CC2S='01' in the TIMx\_CCMR1 register.
2. TI2FP2 must detect a rising edge, write CC2P='0' and CC2NP = '0' in the TIMx\_CCER register.
3. Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS='110' in the TIMx\_SMCR register.
4. TI2FP2 is used to start the counter by writing SMS to '110' in the TIMx\_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The  $t_{DELAY}$  is defined by the value written in the TIMx\_CCR1 register.
- The  $t_{PULSE}$  is defined by the difference between the auto-reload value and the compare value (TIMx\_ARR - TIMx\_CCR1).
- Let's say you want to build a waveform with a transition from '0' to '1' when a compare match occurs and a transition from '1' to '0' when the counter reaches the auto-reload value. To do this you enable PWM mode 2 by writing OC1M='111' in the TIMx\_CCMR1 register. You can optionally enable the preload registers by writing OC1PE='1' in the TIMx\_CCMR1 register and ARPE in the TIMx\_CR1 register. In this case you have to write the compare value in the TIMx\_CCR1 register, the auto-reload value in the TIMx\_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0' in this example.

You only want 1 pulse (Single mode), so you write '1' in the OPM bit in the TIMx\_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0). When OPM bit in the TIMx\_CR1 register is set to '0', so the Repetitive Mode is selected.

#### **Particular case: OCx fast enable**

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay  $t_{DELAY}$  min we can get.

If you want to output a waveform with the minimum delay, you can set the OCxFE bit in the TIMx\_CCMRx register. Then OCxRef (and OCx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

### **14.3.11 TIM9/11 external trigger synchronization**

The TIM9/11 timer can be synchronized with an external trigger in several modes: Reset mode, Gated mode and Trigger mode.

#### **Slave mode: Reset mode**

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx\_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx\_ARR, TIMx\_CCRx) are updated.

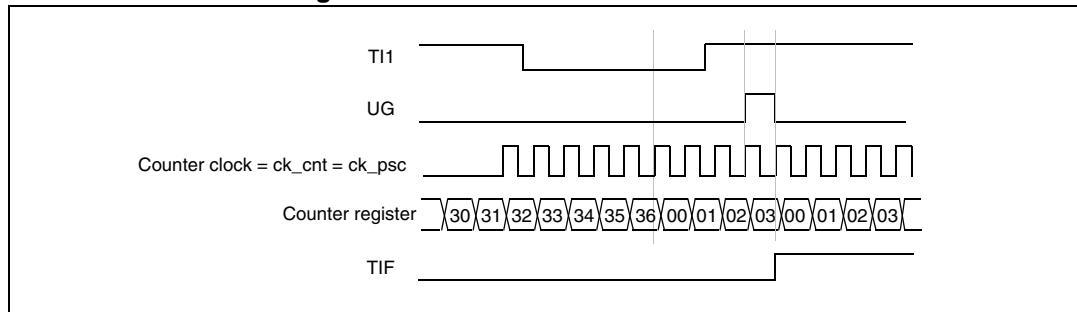
In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

1. Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we don't need any filter, so we keep IC1F='0000'). The capture prescaler is not used for triggering, so you don't need to configure it. The CC1S bits select the input capture source only, CC1S = '01' in the TIMx\_CCMR1 register. Program CC1P and CC1NP to '00' in TIMx\_CCER register to validate the polarity (and detect rising edges only).
2. Configure the timer in reset mode by writing SMS='100' in TIMx\_SMCR register. Select TI1 as the input source by writing TS='101' in TIMx\_SMCR register.
3. Start the counter by writing CEN='1' in the TIMx\_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx\_SR register) and an interrupt request can be sent if enabled (depending on the TIE bit in TIMx\_DIER register).

The following figure shows this behavior when the auto-reload register TIMx\_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

**Figure 153. Control circuit in reset mode**



### Slave mode: Gated mode

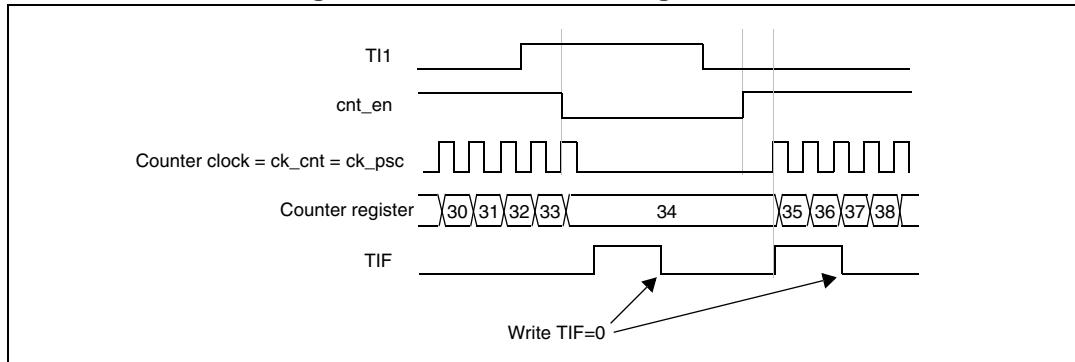
The counter can be enabled depending on the level of a selected input.

In the following example, the upcounter counts only when TI1 input is low:

1. Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we don't need any filter, so we keep IC1F='0000'). The capture prescaler is not used for triggering, so you don't need to configure it. The CC1S bits select the input capture source only, CC1S='01' in TIMx\_CCMR1 register. Program CC1P='1' and CC1NP='0' in TIMx\_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS='101' in TIMx\_SMCR register. Select TI1 as the input source by writing TS='101' in TIMx\_SMCR register.
3. Enable the counter by writing CEN='1' in the TIMx\_CR1 register (in gated mode, the counter doesn't start if CEN='0', whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx\_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

**Figure 154. Control circuit in gated mode****Slave mode: Trigger mode**

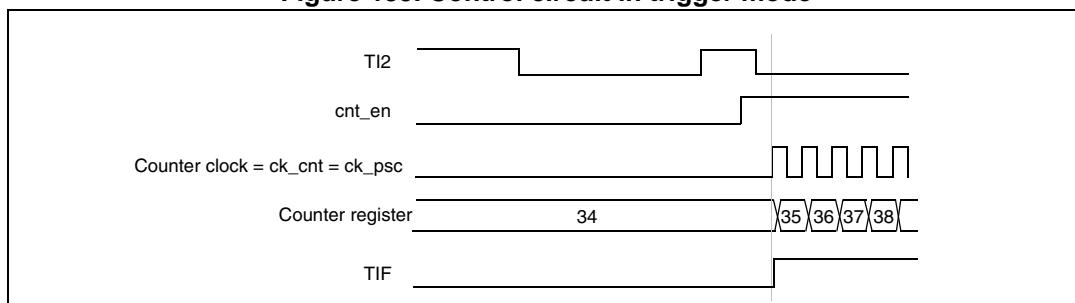
The counter can start in response to an event on a selected input.

In the following example, the upcounter starts in response to a rising edge on **TI2** input:

1. Configure the channel 2 to detect rising edges on **TI2**. Configure the input filter duration (in this example, we don't need any filter, so we keep **IC2F='0000'**). The capture prescaler is not used for triggering, so you don't need to configure it. The **CC2S** bits are configured to select the input capture source only, **CC2S='01'** in **TIMx\_CCMR1** register. Program **CC2P='1'** and **CC2NP='0'** in **TIMx\_CCER** register to validate the polarity (and detect low level only).
2. Configure the timer in trigger mode by writing **SMS='110'** in **TIMx\_SMCR** register. Select **TI2** as the input source by writing **TS='110'** in **TIMx\_SMCR** register.

When a rising edge occurs on **TI2**, the counter starts counting on the internal clock and the **TIF** flag is set.

The delay between the rising edge on **TI2** and the actual start of the counter is due to the resynchronization circuit on **TI2** input.

**Figure 155. Control circuit in trigger mode**

### 14.3.12 Timer synchronization (TIM9/11)

The TIM timers are linked together internally for timer synchronization or chaining. Refer to [Section 13.3.15: Timer synchronization on page 333](#) for details.

### 14.3.13 Debug mode

When the microcontroller enters debug mode (Cortex™-M4 with FPU core halted), the TIMx counter either continues to work normally or stops, depending on DBG\_TIMx\_STOP configuration bit in DBG module. For more details, refer to [Section 23.16.2: Debug support for timers, watchdog and I2C](#).

## 14.4 TIM9 and TIM11 registers

Refer to [Section 1.1](#) for a list of abbreviations used in register descriptions.

The peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits) or words (32 bits).

### 14.4.1 TIM9/11 control register 1 (TIMx\_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		CKD[1:0]		ARPE		Reserved		OPM		URS		UDIS		CEN	
		rw		rw		rw		rw		rw		rw		rw	

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **CKD**: Clock division

This bit-field indicates the division ratio between the timer clock (CK\_INT) frequency and sampling clock used by the digital filters (TIx),

- 00:  $t_{DTS} = t_{CK\_INT}$
- 01:  $t_{DTS} = 2 \times t_{CK\_INT}$
- 10:  $t_{DTS} = 4 \times t_{CK\_INT}$
- 11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable

- 0: TIMx\_ARR register is not buffered.
- 1: TIMx\_ARR register is buffered.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode

- 0: Counter is not stopped on the update event
- 1: Counter stops counting on the next update event (clearing the CEN bit).

**Bit 2 URS:** Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generates an update interrupt if enabled:

- Counter overflow
- Setting the UG bit

1: Only counter overflow generates an update interrupt if enabled.

**Bit 1 UDIS:** Update disable

This bit is set and cleared by software to enable/disable update event (UEV) generation.

0: UEV enabled. An UEV is generated by one of the following events:

- Counter overflow
- Setting the UG bit

Buffered registers are then loaded with their preload values.

1: UEV disabled. No UEV is generated, shadow registers keep their value (ARR, PSC, CCRx). The counter and the prescaler are reinitialized if the UG bit is set.

**Bit 0 CEN:** Counter enable

0: Counter disabled

1: Counter enabled

CEN is cleared automatically in one-pulse mode, when an update event occurs.

### 14.4.2 TIM9/11 slave mode control register (TIMx\_SMCR)

Address offset: 0x08

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								MSM	TS[2:0]			Res.	SMS[2:0]		
rw								rw					rw		

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **MSM**: Master/Slave mode

- 0: No action
- 1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful in order to synchronize several timers on a single external event.

Bits 6:4 **TS**: Trigger selection

This bitfield selects the trigger input to be used to synchronize the counter.

- 000: Internal Trigger 0 (ITR0)
- 001: Internal Trigger 1 (ITR1)
- 010: Internal Trigger 2 (ITR2)
- 011: Internal Trigger 3 (ITR3)
- 100: TI1 Edge Detector (TI1F\_ED)
- 101: Filtered Timer Input 1 (TI1FP1)
- 110: Filtered Timer Input 2 (TI2FP2)
- 111: Reserved.

See [Table 57: TIMx internal trigger connection on page 386](#) for more details on the meaning of ITRx for each timer.

*Note:* These bits must be changed only when they are not used (e.g. when SMS='000') to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **SMS**: Slave mode selection

When external signals are selected, the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input control register and Control register descriptions).

- 000: Slave mode disabled - if CEN = 1 then the prescaler is clocked directly by the internal clock
- 001: Reserved
- 010: Reserved
- 011: Reserved
- 100: Reset mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers
- 101: Gated mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Counter starts and stops are both controlled
- 110: Trigger mode - The counter starts on a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled
- 111: External clock mode 1 - Rising edges of the selected trigger (TRGI) clock the counter

*Note:* The Gated mode must not be used if TI1F\_ED is selected as the trigger input (TS='100'). Indeed, TI1F\_ED outputs 1 pulse for each transition on TI1F, whereas the Gated mode checks the level of the trigger signal.

**Table 57. TIMx internal trigger connection**

Slave TIM	ITR0 (TS = '000')	ITR1 (TS = '001')	ITR2 (TS = '010')	ITR3 (TS = '011')
TIM2	TIM1	Reserved	TIM3	TIM4
TIM3	TIM1	TIM2	TIM5	TIM4
TIM4	TIM1	TIM2	TIM3	Reserved
TIM5	TIM2	TIM3	TIM4	Reserved
TIM9	TIM2	TIM3	TIM10	TIM11

#### 14.4.3 TIM9/11 Interrupt enable register (TIMx\_DIER)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				TIE		Res		CC2IE		CC1IE		UIE			
				rw		rw		rw		rw		rw			

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TIE**: Trigger interrupt enable

- 0: Trigger interrupt disabled.
- 1: Trigger interrupt enabled.

Bit 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable

- 0: CC2 interrupt disabled.
- 1: CC2 interrupt enabled.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable

- 0: CC1 interrupt disabled.
- 1: CC1 interrupt enabled.

Bit 0 **UIE**: Update interrupt enable

- 0: Update interrupt disabled.
- 1: Update interrupt enabled.

#### 14.4.4 TIM9/11 status register (TIMx\_SR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved					CC2OF	CC1OF	Reserved	TIF	Reserved	Reserved	CC2IF	CC1IF	UIF		
					rc_w0	rc_w0		rc_w0			rc_w0	rc_w0	rc_w0		

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag  
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to '0'.

0: No overcapture has been detected.

1: The counter value has been captured in TIMx\_CCR1 register while CC1IF flag was already set

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.

0: No trigger event occurred.

1: Trigger interrupt pending.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag  
refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag

**If channel CC1 is configured as output:**

This flag is set by hardware when the counter matches the compare value. It is cleared by software.

0: No match.

1: The content of the counter TIMx\_CNT matches the content of the TIMx\_CCR1 register. When the contents of TIMx\_CCR1 are greater than the contents of TIMx\_ARR, the CC1IF bit goes high on the counter overflow.

**If channel CC1 is configured as input:**

This bit is set by hardware on a capture. It is cleared by software or by reading the TIMx\_CCR1 register.

0: No input capture occurred.

1: The counter value has been captured in TIMx\_CCR1 register (an edge has been detected on IC1 which matches the selected polarity).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

- At overflow and if UDIS='0' in the TIMx\_CR1 register.
- When CNT is reinitialized by software using the UG bit in TIMx\_EGR register, if URS='0' and UDIS='0' in the TIMx\_CR1 register.
- When CNT is reinitialized by a trigger event (refer to the synchro control register description), if URS='0' and UDIS='0' in the TIMx\_CR1 register.

#### 14.4.5 TIM9/11 event generation register (TIMx\_EGR)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				TG	Reserved				CC2G	CC1G	UG				
				W					W	W	W				

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in the TIMx\_SR register. Related interrupt can occur if enabled

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2G**: Capture/compare 2 generation  
refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation

This bit is set by software to generate an event, it is automatically cleared by hardware.

0: No action

1: A capture/compare event is generated on channel 1:

**If channel CC1 is configured as output:**

the CC1IF flag is set, the corresponding interrupt is sent if enabled.

**If channel CC1 is configured as input:**

The current counter value is captured in the TIMx\_CCR1 register. The CC1IF flag is set, the corresponding interrupt is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Re-initializes the counter and generates an update of the registers. The prescaler counter is also cleared and the prescaler ratio is not affected. The counter is cleared.

#### 14.4.6 TIM9/11 capture/compare mode register 1 (TIMx\_CCMR1)

Address offset: 0x18

Reset value: 0x0000

The channels can be used in input (capture mode) or in output (compare mode). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits in this register have different functions in input and output modes. For a given bit, OCxx describes its function when the channel is configured in output mode, ICxx describes its function when the channel is configured in input mode. So you must take care that the same bit can have different meanings for the input stage and the output stage.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
rw															

##### Output compare mode

Bits 14:12 **OC2M[2:0]**: Output compare 2 mode

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, IC2 is mapped on TI2

10: CC2 channel is configured as input, IC2 is mapped on TI1

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode works only if an internal trigger input is selected through the TS bit (TIMx\_SMCR register)

*Note: The CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx\_CCER).*

Bits 6:4 **OC1M**: Output compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas the active levels of OC1 and OC1N depend on the CC1P and CC1NP bits, respectively.

000: Frozen - The comparison between the output compare register TIMx\_CCR1 and the counter TIMx\_CNT has no effect on the outputs.(this mode is used to generate a timing base).

001: Set channel 1 to active level on match. The OC1REF signal is forced high when the TIMx\_CNT counter matches the capture/compare register 1 (TIMx\_CCR1).

010: Set channel 1 to inactive level on match. The OC1REF signal is forced low when the TIMx\_CNT counter matches the capture/compare register 1 (TIMx\_CCR1).

011: Toggle - OC1REF toggles when TIMx\_CNT=TIMx\_CCR1

100: Force inactive level - OC1REF is forced low

101: Force active level - OC1REF is forced high

110: PWM mode 1 - In upcounting, channel 1 is active as long as TIMx\_CNT<TIMx\_CCR1 else it is inactive. In downcounting, channel 1 is inactive (OC1REF='0) as long as TIMx\_CNT>TIMx\_CCR1, else it is active (OC1REF='1)

111: PWM mode 2 - In upcounting, channel 1 is inactive as long as TIMx\_CNT<TIMx\_CCR1 else it is active. In downcounting, channel 1 is active as long as TIMx\_CNT>TIMx\_CCR1 else it is inactive.

*Note: In PWM mode 1 or 2, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.*

**Bit 3 OC1PE:** Output compare 1 preload enable

0: Preload register on TIMx\_CCR1 disabled. TIMx\_CCR1 can be written at anytime, the new value is taken into account immediately

1: Preload register on TIMx\_CCR1 enabled. Read/Write operations access the preload register. TIMx\_CCR1 preload value is loaded into the active register at each update event

*Note: The PWM mode can be used without validating the preload register only in one-pulse mode (OPM bit set in the TIMx\_CR1 register). Else the behavior is not guaranteed.*

**Bit 2 OC1FE:** Output compare 1 fast enable

This bit is used to accelerate the effect of an event on the trigger input on the CC output.  
0: CC1 behaves normally depending on the counter and CCR1 values even when the trigger is ON. The minimum delay to activate the CC1 output when an edge occurs on the trigger input is 5 clock cycles

1: An active edge on the trigger input acts like a compare match on the CC1 output. Then, OC is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

**Bits 1:0 CC1S:** Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode works only if an internal trigger input is selected through the TS bit (TIMx\_SMCR register)

*Note: The CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx\_CCER).*

## Input capture mode

Bits 15:12 **IC2F**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S**: Capture/compare 2 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, IC2 is mapped on TI2

10: CC2 channel is configured as input, IC2 is mapped on TI1

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode works only if an internal trigger input is selected through the TS bit (TIMx\_SMCR register)

*Note: The CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx\_CCER).*

Bits 7:4 **IC1F**: Input capture 1 filter

This bitfield defines the frequency used to sample the TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

0000: No filter, sampling is done at  $f_{DTS}$

1000:  $f_{SAMPLING} = f_{CK\_INT}$ , N=21

1001:  $f_{SAMPLING} = f_{CK\_INT}$ , N=41

1010:  $f_{SAMPLING} = f_{CK\_INT}$ , N=8

1011:  $f_{SAMPLING} = f_{CK\_INT}$ , N=10

1100:  $f_{SAMPLING} = f_{DTS}/2$ , N=61

1101:  $f_{SAMPLING} = f_{DTS}/2$ , N=81

1110:  $f_{SAMPLING} = f_{DTS}/4$ , N=61

1111:  $f_{SAMPLING} = f_{DTS}/4$ , N=81

*Note: Care must be taken that  $f_{DTS}$  is replaced in the formula by CK\_INT when ICxF[3:0]= 1, 2 or 3.*

Bits 3:2 **IC1PSC**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on the CC1 input (IC1).

The prescaler is reset as soon as CC1E='0' (TIMx\_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input

01: capture is done once every 2 events

10: capture is done once every 4 events

11: capture is done once every 8 events

Bits 1:0 **CC1S**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx\_SMCR register)

*Note: The CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx\_CCER).*

#### 14.4.7 TIM9/11 capture/compare enable register (TIMx\_CCER)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
								CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
								rw		rw	rw	rw		rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **CC2NP**: Capture/Compare 2 output Polarity  
refer to CC1NP description

Bits 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: Capture/Compare 2 output Polarity  
refer to CC1P description

Bit 4 **CC2E**: Capture/Compare 2 output enable  
refer to CC1E description

Bit 3 **CC1NP**: Capture/Compare 1 complementary output Polarity  
CC1 channel configured as output: CC1NP must be kept cleared  
CC1 channel configured as input: CC1NP is used in conjunction with CC1P to define TI1FP1/TI2FP1 polarity (refer to CC1P description).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: Capture/Compare 1 output Polarity.

**CC1 channel configured as output:**

0: OC1 active high.

1: OC1 active low.

**CC1 channel configured as input:**

CC1NP/CC1P bits select TI1FP1 and TI2FP1 polarity for trigger or capture operations.

00: noninverted/rising edge

Circuit is sensitive to TIxFP1 rising edge (capture, trigger in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger in gated mode, encoder mode).

01: inverted/falling edge

Circuit is sensitive to TIxFP1 falling edge (capture, trigger in reset, external clock or trigger mode), TIxFP1 is inverted (trigger in gated mode, encoder mode).

10: reserved, do not use this configuration.

*Note: 11: noninverted/both edges*

*Circuit is sensitive to both TIxFP1 rising and falling edges (capture, trigger in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger in gated mode). This configuration must not be used for encoder mode.*

Bit 0 **CC1E**: Capture/Compare 1 output enable.

**CC1 channel configured as output:**

0: Off - OC1 is not active.

1: On - OC1 signal is output on the corresponding output pin.

**CC1 channel configured as input:**

This bit determines if a capture of the counter value can actually be done into the input capture/compare register 1 (TIMx\_CCR1) or not.

0: Capture disabled.

1: Capture enabled.

**Table 58. Output control bit for standard OCx channels**

CCxE bit	OCx output state
0	Output disabled ( $OCx='0'$ , $OCx\_EN='0'$ )
1	$OCx=OCxREF + \text{Polarity}$ , $OCx\_EN='1'$

**Note:** The states of the external I/O pins connected to the standard OCx channels depend on the state of the OCx channel and on the GPIO registers.

#### 14.4.8 TIM9/11 counter (TIMx\_CNT)

Address offset: 0x24

Reset value: 0x0000 0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CNT[15:0]**: Counter value

#### 14.4.9 TIM9/11 prescaler (TIMx\_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency CK\_CNT is equal to  $f_{CK\_PSC} / (PSC[15:0] + 1)$ .

PSC contains the value to be loaded into the active prescaler register at each update event.

#### 14.4.10 TIM9/11 auto-reload register (TIMx\_ARR)

Address offset: 0x2C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded into the actual auto-reload register.

Refer to the [Section 14.3.1: Time-base unit on page 367](#) for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

#### 14.4.11 TIM9/11 capture/compare register 1 (TIMx\_CCR1)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

**If channel CC1 is configured as output:**

CCR1 is the value to be loaded into the actual capture/compare 1 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR1 register (OC1PE bit). Else the preload value is copied into the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the TIMx\_CNT counter and signaled on the OC1 output.

**If channel CC1 is configured as input:**

CCR1 is the counter value transferred by the last input capture 1 event (IC1).

#### 14.4.12 TIM9/11 capture/compare register 2 (TIMx\_CCR2)

Address offset: 0x38

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR2[15:0]**: Capture/Compare 2 value

**If channel CC2 is configured as output:**

CCR2 is the value to be loaded into the actual capture/compare 2 register (preload value). It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR2 register (OC2PE bit). Else the preload value is copied into the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the TIMx\_CNT counter and signalled on the OC2 output.

**If channel CC2 is configured as input:**

CCR2 is the counter value transferred by the last input capture 2 event (IC2).

#### 14.4.13 TIM9/11 register map

TIM9/11 registers are mapped as 16-bit addressable registers as described below:

Table 59. TIM9/11 register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0C	<b>TIMx_DIER</b> Reset value																																

**Table 59. TIM9/11 register map and reset values (continued)**

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 14.5 TIM10/11 registers

The peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits) or words (32 bits).

### 14.5.1 TIM10/11 control register 1 (TIMx\_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved					CKD[1:0]		ARPE		Reserved				URS	UDIS	CEN
					rw	rw	rw						rw	rw	rw

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **CKD**: Clock division

This bit-field indicates the division ratio between the timer clock (CK\_INT) frequency and sampling clock used by the digital filters (ETR, TIx),

- 00:  $t_{DTS} = t_{CK\_INT}$
- 01:  $t_{DTS} = 2 \times t_{CK\_INT}$
- 10:  $t_{DTS} = 4 \times t_{CK\_INT}$
- 11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable

- 0: TIMx\_ARR register is not buffered
- 1: TIMx\_ARR register is buffered

Bits 6:3 Reserved, must be kept at reset value.

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the update interrupt (UEV) sources.

0: Any of the following events generate an UEV if enabled:

- Counter overflow
  - Setting the UG bit
- 1: Only counter overflow generates an UEV if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable update interrupt (UEV) event generation.

0: UEV enabled. An UEV is generated by one of the following events:

- Counter overflow
- Setting the UG bit.

Buffered registers are then loaded with their preload values.

1: UEV disabled. No UEV is generated, shadow registers keep their value (ARR, PSC, CCRx). The counter and the prescaler are reinitialized if the UG bit is set.

Bit 0 **CEN**: Counter enable

- 0: Counter disabled
- 1: Counter enabled

### 14.5.2 TIM status register (TIMx\_SR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved					CC1OF rc_w0	Reserved		CC1IF rc_w0		UIF rc_w0					

Bits 15:10 Reserved, must be kept at reset value.

**Bit 9 CC1OF:** Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to '0'.

0: No overcapture has been detected.

1: The counter value has been captured in TIMx\_CCR1 register while CC1IF flag was already set

Bits 8:2 Reserved, must be kept at reset value.

**Bit 1 CC1IF:** Capture/compare 1 interrupt flag**If channel CC1 is configured as output:**

This flag is set by hardware when the counter matches the compare value. It is cleared by software.

0: No match.

1: The content of the counter TIMx\_CNT matches the content of the TIMx\_CCR1 register. When the contents of TIMx\_CCR1 are greater than the contents of TIMx\_ARR, the CC1IF bit goes high on the counter overflow.

**If channel CC1 is configured as input:**

This bit is set by hardware on a capture. It is cleared by software or by reading the TIMx\_CCR1 register.

0: No input capture occurred.

1: The counter value has been captured in TIMx\_CCR1 register (an edge has been detected on IC1 which matches the selected polarity).

**Bit 0 UIF:** Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

- At overflow and if UDIS='0' in the TIMx\_CR1 register.
- When CNT is reinitialized by software using the UG bit in TIMx\_EGR register, if URS='0' and UDIS='0' in the TIMx\_CR1 register.

**14.5.3 TIM event generation register (TIMx\_EGR)**

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														CC1G W	UG W

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **CC1G**: Capture/compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A capture/compare event is generated on channel 1:

**If channel CC1 is configured as output:**

CC1IF flag is set, Corresponding interrupt or is sent if enabled.

**If channel CC1 is configured as input:**

The current value of the counter is captured in TIMx\_CCR1 register. The CC1IF flag is set, the corresponding interrupt is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Re-initialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared.

#### 14.5.4 TIM10/11 capture/compare mode register 1 (TIMx\_CCMR1)

Address offset: 0x18

Reset value: 0x0000

The channels can be used in input (capture mode) or in output (compare mode). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode. For a given bit, OCxx describes its function when the channel is configured in output, ICxx describes its function when the channel is configured in input. So you must take care that the same bit can have a different meaning for the input stage and for the output stage.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				OC1M[2:0]				OC1PE		OC1FE	CC1S[1:0]				
Reserved				IC1F[3:0]				IC1PSC[1:0]							
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

#### Output compare mode

Bits 15:7 Reserved, must be kept at reset value.

**Bits 6:4 OC1M:** Output compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 is derived. OC1REF is active high whereas OC1 active level depends on CC1P bit.

000: Frozen. The comparison between the output compare register TIMx\_CCR1 and the counter TIMx\_CNT has no effect on the outputs.

001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx\_CNT matches the capture/compare register 1 (TIMx\_CCR1).

010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx\_CNT matches the capture/compare register 1 (TIMx\_CCR1).

011: Toggle - OC1REF toggles when TIMx\_CNT = TIMx\_CCR1.

100: Force inactive level - OC1REF is forced low.

101: Force active level - OC1REF is forced high.

110: PWM mode 1 - Channel 1 is active as long as TIMx\_CNT < TIMx\_CCR1 else inactive.

111: PWM mode 2 - Channel 1 is inactive as long as TIMx\_CNT < TIMx\_CCR1 else active.

*Note: In PWM mode 1 or 2, the OCREF level changes when the result of the comparison changes or when the output compare mode switches from frozen to PWM mode.*

**Bit 3 OC1PE:** Output compare 1 preload enable

0: Preload register on TIMx\_CCR1 disabled. TIMx\_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx\_CCR1 enabled. Read/Write operations access the preload register. TIMx\_CCR1 preload value is loaded in the active register at each update event.

*Note: The PWM mode can be used without validating the preload register only in one pulse mode (OPM bit set in TIMx\_CR1 register). Else the behavior is not guaranteed.*

**Bit 2 OC1FE:** Output compare 1 fast enable

This bit is used to accelerate the effect of an event on the trigger in input on the CC output.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. OC is then set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

**Bits 1:0 CC1S:** Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output.

01: CC1 channel is configured as input, IC1 is mapped on TI1.

10:

11:

*Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx\_CCER).*

## Input capture mode

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:4 **IC1F**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:

0000: No filter, sampling is done at $f_{DTS}$	$f_{SAMPLING}=f_{DTS}/8$ , N=6
0001: $f_{SAMPLING}=f_{CK\_INT}$	N=21001: $f_{SAMPLING}=f_{DTS}/8$ , N=8
0010: $f_{SAMPLING}=f_{CK\_INT}$	N=41010: $f_{SAMPLING}=f_{DTS}/16$ , N=5
0011: $f_{SAMPLING}=f_{CK\_INT}$	N=81011: $f_{SAMPLING}=f_{DTS}/16$ , N=6
0100: $f_{SAMPLING}=f_{DTS}/2$	N=61100: $f_{SAMPLING}=f_{DTS}/16$ , N=8
0101: $f_{SAMPLING}=f_{DTS}/2$	N=81101: $f_{SAMPLING}=f_{DTS}/32$ , N=5
0110: $f_{SAMPLING}=f_{DTS}/4$	N=61110: $f_{SAMPLING}=f_{DTS}/32$ , N=6
0111: $f_{SAMPLING}=f_{DTS}/4$	N=81111: $f_{SAMPLING}=f_{DTS}/32$ , N=8

*Note: In current silicon revision,  $f_{DTS}$  is replaced in the formula by CK\_INT when ICxF[3:0]= 1, 2 or 3.*

Bits 3:2 **IC1PSC**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1).

The prescaler is reset as soon as CC1E='0' (TIMx\_CCER register).

- 00: no prescaler, capture is done each time an edge is detected on the capture input
- 01: capture is done once every 2 events
- 10: capture is done once every 4 events
- 11: capture is done once every 8 events

Bits 1:0 **CC1S**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

- 00: CC1 channel is configured as output
- 01: CC1 channel is configured as input, IC1 is mapped on TI1
- 10: Reserved
- 11: Reserved

*Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx\_CCER).*

### 14.5.5 TIM10/11 capture/compare enable register (TIMx\_CCER)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved										CC1NP	Res.	CC1P	CC1E		
										rw		rw	rw		

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CC1NP**: Capture/Compare 1 complementary output Polarity.

CC1 channel configured as output: CC1NP must be kept cleared.

CC1 channel configured as input: CC1NP bit is used in conjunction with CC1P to define TI1FP1 polarity (refer to CC1P description).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: Capture/Compare 1 output Polarity.

**CC1 channel configured as output:**

0: OC1 active high

1: OC1 active low

**CC1 channel configured as input:**

The CC1P bit selects TI1FP1 and TI2FP1 polarity for trigger or capture operations.

00: noninverted/rising edge

Circuit is sensitive to TI1FP1 rising edge (capture mode), TI1FP1 is not inverted.

01: inverted/falling edge

Circuit is sensitive to TI1FP1 falling edge (capture mode), TI1FP1 is inverted.

10: reserved, do not use this configuration.

11: noninverted/both edges

Circuit is sensitive to both TI1FP1 rising and falling edges (capture mode), TI1FP1 is not inverted.

Bit 0 **CC1E**: Capture/Compare 1 output enable.

**CC1 channel configured as output:**

0: Off - OC1 is not active

1: On - OC1 signal is output on the corresponding output pin

**CC1 channel configured as input:**

This bit determines if a capture of the counter value can actually be done into the input capture/compare register 1 (TIMx\_CCR1) or not.

0: Capture disabled

1: Capture enabled

**Table 60. Output control bit for standard OCx channels**

CCxE bit	OCx output state
0	Output Disabled (OCx='0', OCx_EN='0')
1	OCx=OCxREF + Polarity, OCx_EN='1'

**Note:** The state of the external I/O pins connected to the standard OCx channels depends on the OCx channel state and the GPIO registers.

### 14.5.6 TIM10/11 counter (TIMx\_CNT)

Address offset: 0x24

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CNT[15:0]**: Counter value

### 14.5.7 TIM10/11 prescaler (TIMx\_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency CK\_CNT is equal to  $f_{CK\_PSC} / (PSC[15:0] + 1)$ .

PSC contains the value to be loaded in the active prescaler register at each update event.

### 14.5.8 TIM10/11 auto-reload register (TIMx\_ARR)

Address offset: 0x2C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to [Section 14.3.1: Time-base unit on page 367](#) for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

### 14.5.9 TIM10/11 capture/compare register 1 (TIMx\_CCR1)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

**If channel CC1 is configured as output:**

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx\_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx\_CNT and signaled on OC1 output.

**If channel CC1 is configured as input:**

CCR1 is the counter value transferred by the last input capture 1 event (IC1).

### 14.5.10 TIM10/11 register map

TIMx registers are mapped as 16-bit addressable registers as described in the tables below:

**Table 61. TIM10/11 register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0						
0x00	TIMx_CR1	Reserved																CKD [1:0]		ARPE	Reserved				URS	UDIS	CEN												
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
0x08	TIMx_SMCR	Reserved																																					
	Reset value	Reserved																																					
0x0C	TIMx_DIER	Reserved																										CC1IE	UIE	0	0	0							
	Reset value	Reserved																																					
0x10	TIMx_SR	Reserved																CC1OF	Reserved				CC1IF	UIF	0	0	0												
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		Reserved																				
0x14	TIMx_EGR	Reserved																										CC1G	UG	0	0	0							
	Reset value	Reserved																																					

**Table 61. TIM10/11 register map and reset values (continued)**

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 15 Independent watchdog (IWDG)

### 15.1 IWDG introduction

The STM32F401xB/C and STM32F401xD/E devices have two embedded watchdog peripherals which offer a combination of high safety level, timing accuracy and flexibility of use. Both watchdog peripherals (Independent and Window) serve to detect and resolve malfunctions due to software failure, and to trigger system reset or an interrupt (window watchdog only) when the counter reaches a given timeout value.

The independent watchdog (IWDG) is clocked by its own dedicated low-speed clock (LSI) and thus stays active even if the main clock fails. The window watchdog (WWDG) clock is prescaled from the APB1 clock and has a configurable time-window that can be programmed to detect abnormally late or early application behavior.

The IWDG is best suited to applications which require the watchdog to run as a totally independent process outside the main application, but have lower timing accuracy constraints. The WWDG is best suited to applications which require the watchdog to react within an accurate timing window. For further information on the window watchdog, refer to [Section 16 on page 412](#).

### 15.2 IWDG main features

- Free-running downcounter
- clocked from an independent RC oscillator (can operate in Standby and Stop modes)
- Reset (if watchdog activated) when the downcounter value of 0x000 is reached

### 15.3 IWDG functional description

[Figure 156](#) shows the functional blocks of the independent watchdog module.

When the independent watchdog is started by writing the value 0xCCCC in the Key register (IWDG\_KR), the counter starts counting down from the reset value of 0xFFFF. When it reaches the end of count value (0x000) a reset signal is generated (IWDG reset).

Whenever the key value 0xAAAA is written in the IWDG\_KR register, the IWDG\_RLR value is reloaded in the counter and the watchdog reset is prevented.

#### 15.3.1 Hardware watchdog

If the “Hardware watchdog” feature is enabled through the device option bits, the watchdog is automatically enabled at power-on, and will generate a reset unless the Key register is written by the software before the counter reaches end of count.

#### 15.3.2 Register access protection

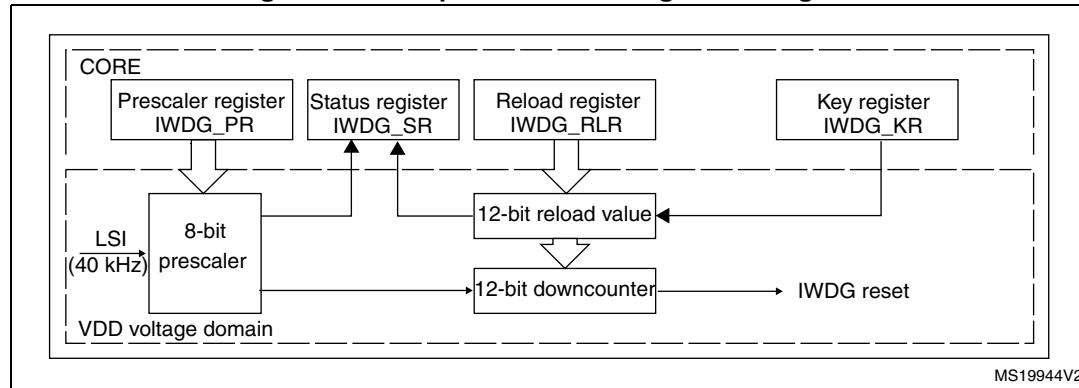
Write access to the IWDG\_PR and IWDG\_RLR registers is protected. To modify them, you must first write the code 0x5555 in the IWDG\_KR register. A write access to this register with a different value will break the sequence and register access will be protected again. This implies that it is the case of the reload operation (writing 0xAAAA).

A status register is available to indicate that an update of the prescaler or the down-counter reload value is on going.

### 15.3.3 Debug mode

When the microcontroller enters debug mode (Cortex™-M4 with FPU core halted), the IWDG counter either continues to work normally or stops, depending on DBG\_IWDG\_STOP configuration bit in DBG module. For more details, refer to [Section 23.16.2: Debug support for timers, watchdog and I2C](#).

**Figure 156. Independent watchdog block diagram**



Note:

The watchdog function is implemented in the  $V_{DD}$  voltage domain that is still functional in Stop and Standby modes.

**Table 62. Min/max IWDG timeout period at 32 kHz (LSI)<sup>(1)</sup>**

Prescaler divider	PR[2:0] bits	Min timeout (ms) RL[11:0]= 0x000	Max timeout (ms) RL[11:0]= 0xFFFF
/4	0	0.125	512
/8	1	0.25	1024
/16	2	0.5	2048
/32	3	1	4096
/64	4	2	8192
/128	5	4	16384
/256	6		32768

- These timings are given for a 32 kHz clock but the microcontroller's internal RC frequency can vary from 30 to 60 kHz. Moreover, given an exact RC oscillator frequency, the exact timings still depend on the phasing of the APB interface clock versus the LSI clock so that there is always a full RC period of uncertainty.

## 15.4 IWDG registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by half-words (16 bits) or words (32 bits).

### 15.4.1 Key register (IWDG\_KR)

Address offset: 0x00

Reset value: 0x0000 0000 (reset by Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																KEY[15:0]															

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **KEY[15:0]**: Key value (write only, read 0000h)

These bits must be written by software at regular intervals with the key value AAAAh, otherwise the watchdog generates a reset when the counter reaches 0.

Writing the key value 5555h to enable access to the IWDG\_PR and IWDG\_RLR registers (see [Section 15.3.2](#))

Writing the key value CCCCh starts the watchdog (except if the hardware watchdog option is selected)

### 15.4.2 Prescaler register (IWDG\_PR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																														PR[2:0]	

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **PR[2:0]: Prescaler divider**

These bits are write access protected see [Section 15.3.2](#). They are written by software to select the prescaler divider feeding the counter clock. PVU bit of IWDG\_SR must be reset in order to be able to change the prescaler divider.

- 000: divider /4
- 001: divider /8
- 010: divider /16
- 011: divider /32
- 100: divider /64
- 101: divider /128
- 110: divider /256
- 111: divider /256

*Note:* Reading this register returns the prescaler value from the VDD voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing. For this reason the value read from this register is valid only when the PVU bit in the IWDG\_SR register is reset.

### 15.4.3 Reload register (IWDG\_RLR)

Address offset: 0x08

Reset value: 0x0000 0FFF (reset by Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																													RL[11:0]		

Bits 31:12 Reserved, must be kept at reset value.

Bits11:0 **RL[11:0]: Watchdog counter reload value**

These bits are write access protected see [Section 15.3.2](#). They are written by software to define the value to be loaded in the watchdog counter each time the value AAAAh is written in the IWDG\_KR register. The watchdog counter counts down from this value. The timeout period is a function of this value and the clock prescaler. Refer to [Table 62](#).

The RVU bit in the IWDG\_SR register must be reset in order to be able to change the reload value.

*Note:* Reading this register returns the reload value from the VDD voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing on this register. For this reason the value read from this register is valid only when the RVU bit in the IWDG\_SR register is reset.

### 15.4.4 Status register (IWDG\_SR)

Address offset: 0x0C

Reset value: 0x0000 0000 (not reset by Standby mode)

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 RVU: Watchdog counter reload value update

This bit is set by hardware to indicate that an update of the reload value is ongoing. It is reset by hardware when the reload value update operation is completed in the V<sub>DD</sub> voltage domain (takes up to 5 RC 40 kHz cycles).

Reload value can be updated only when RVU bit is reset.

Bit 0 **PVU**: Watchdog prescaler value update

This bit is set by hardware to indicate that an update of the prescaler value is ongoing. It is reset by hardware when the prescaler update operation is completed in the V<sub>DD</sub> voltage domain (takes up to 5 RC 40 kHz cycles).

Prescaler value can be updated only when PVU bit is reset.

**Note:** If several reload values or prescaler values are used by application, it is mandatory to wait until RVU bit is reset before changing the reload value and to wait until PVU bit is reset before changing the prescaler value. However, after updating the prescaler and/or the reload value it is not necessary to wait until RVU or PVU is reset before continuing code execution (even in case of low-power mode entry, the write operation is taken into account and will complete)

### 15.4.5 IWDG register map

The following table gives the IWDG register map and reset values.

**Table 63. IWDG register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	IWDG_KR	Reserved																								KEY[15:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
0x04	IWDG_PR	Reserved																									PR[2:0]						
	Reset value	0	0	0	0	0																											
0x08	IWDG_RLR	Reserved																								RL[11:0]							
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1															
0x0C	IWDG_SR	Reserved																									RVU		PVU				
	Reset value	0	0	0	0	0																											

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 16 Window watchdog (WWDG)

### 16.1 WWDG introduction

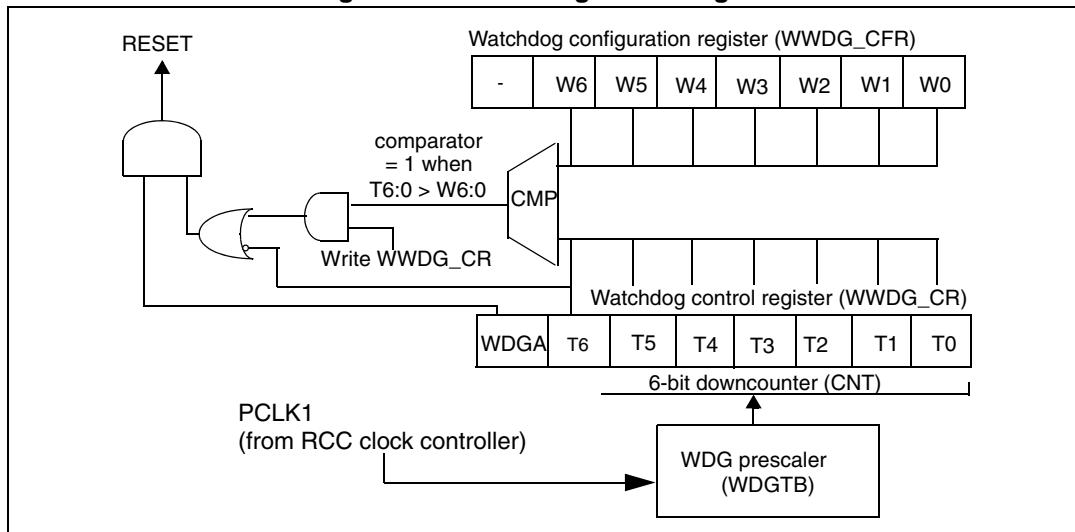
The window watchdog is used to detect the occurrence of a software fault, usually generated by external interference or by unforeseen logical conditions, which causes the application program to abandon its normal sequence. The watchdog circuit generates an MCU reset on expiry of a programmed time period, unless the program refreshes the contents of the downcounter before the T6 bit becomes cleared. An MCU reset is also generated if the 7-bit downcounter value (in the control register) is refreshed before the downcounter has reached the window register value. This implies that the counter must be refreshed in a limited window.

### 16.2 WWDG main features

- Programmable free-running downcounter
- Conditional reset
  - Reset (if watchdog activated) when the downcounter value becomes less than 0x40
  - Reset (if watchdog activated) if the downcounter is reloaded outside the window (see [Figure 158](#))
- Early wakeup interrupt (EWI): triggered (if enabled and the watchdog activated) when the downcounter is equal to 0x40.

### 16.3 WWDG functional description

If the watchdog is activated (the WDGA bit is set in the WWDG\_CR register) and when the 7-bit downcounter (T[6:0] bits) rolls over from 0x40 to 0x3F (T6 becomes cleared), it initiates a reset. If the software reloads the counter while the counter is greater than the value stored in the window register, then a reset is generated.

**Figure 157. Watchdog block diagram**

The application program must write in the WWDG\_CR register at regular intervals during normal operation to prevent an MCU reset. This operation must occur only when the counter value is lower than the window register value. The value to be stored in the WWDG\_CR register must be between 0xFF and 0xC0:

### Enabling the watchdog

The watchdog is always disabled after a reset. It is enabled by setting the WDGA bit in the WWDG\_CR register, then it cannot be disabled again except by a reset.

### Controlling the downcounter

This downcounter is free-running: It counts down even if the watchdog is disabled. When the watchdog is enabled, the T6 bit must be set to prevent generating an immediate reset.

The T[5:0] bits contain the number of increments which represents the time delay before the watchdog produces a reset. The timing varies between a minimum and a maximum value due to the unknown status of the prescaler when writing to the WWDG\_CR register (see [Figure 158](#)). The Configuration register (WWDG\_CFR) contains the high limit of the window: To prevent a reset, the downcounter must be reloaded when its value is lower than the window register value and greater than 0x3F. [Figure 158](#) describes the window watchdog process.

*Note:* The T6 bit can be used to generate a software reset (the WDGA bit is set and the T6 bit is cleared).

### Advanced watchdog interrupt feature

The Early Wakeup Interrupt (EWI) can be used if specific safety operations or data logging must be performed before the actual reset is generated. The EWI interrupt is enabled by setting the EWI bit in the WWDG\_CFR register. When the downcounter reaches the value 0x40, an EWI interrupt is generated and the corresponding interrupt service routine (ISR) can be used to trigger specific actions (such as communications or data logging), before resetting the device.

In some applications, the EWI interrupt can be used to manage a software system check and/or system recovery/graceful degradation, without generating a WWDG reset. In this

case, the corresponding interrupt service routine (ISR) should reload the WWDG counter to avoid the WWDG reset, then trigger the required actions.

The EWI interrupt is cleared by writing '0' to the EWIF bit in the WWDG\_SR register.

**Note:** When the EWI interrupt cannot be served, e.g. due to a system lock in a higher priority task, the WWDG reset will eventually be generated.

## 16.4 How to program the watchdog timeout

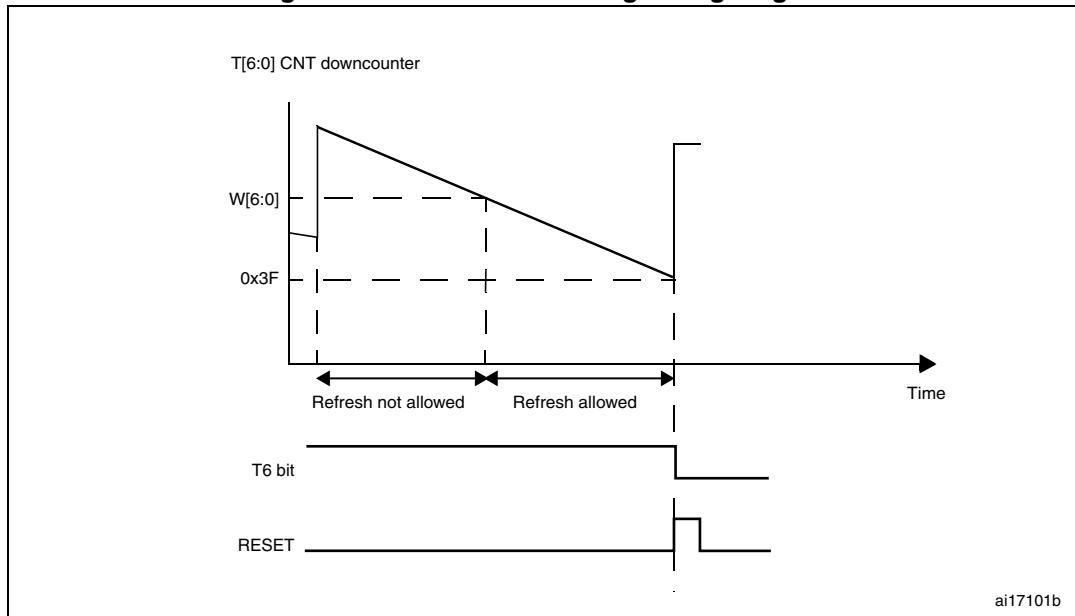
You can use the formula in [Figure 158](#) to calculate the WWDG timeout.

---

**Warning:** When writing to the WWDG\_CR register, always write 1 in the T6 bit to avoid generating an immediate reset.

---

**Figure 158. Window watchdog timing diagram**



The formula to calculate the timeout value is given by:

$$t_{\text{WWDG}} = t_{\text{PCLK1}} \times 4096 \times 2^{\text{WDGTB}} \times (t[5:0] + 1) \quad (\text{ms})$$

where:

$t_{\text{WWDG}}$ : WWDG timeout

$t_{\text{PCLK1}}$ : APB1 clock period measured in ms

Refer to the table below for the minimum and maximum values of the  $T_{\text{WWDG}}$ .

## 16.5 Debug mode

When the microcontroller enters debug mode (Cortex™-M4 with FPU core halted), the WWDG counter either continues to work normally or stops, depending on DBG\_WWDG\_STOP configuration bit in DBG module. For more details, refer to [Section 23.16.2: Debug support for timers, watchdog and I2C](#).

## 16.6 WWDG registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by half-words (16 bits) or words (32 bits).

### 16.6.1 Control register (WWDG\_CR)

Address offset: 0x00

Reset value: 0x0000 007F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved																
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved								WDGA	T[6:0]							
								rs	rw							

Bits 31:8 Reserved, must be kept at reset value.

#### Bit 7 WDGA: Activation bit

This bit is set by software and only cleared by hardware after a reset. When WDGA = 1, the watchdog can generate a reset.

- 0: Watchdog disabled
- 1: Watchdog enabled

#### Bits 6:0 T[6:0]: 7-bit counter (MSB to LSB)

These bits contain the value of the watchdog counter. It is decremented every  $(4096 \times 2^{\text{WDGTB}})$  PCLK1 cycles. A reset is produced when it rolls over from 0x40 to 0x3F (T6 becomes cleared).

## 16.6.2 Configuration register (WWDG\_CFR)

Address offset: 0x04

Reset value: 0x0000 007F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16		
Reserved																	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
Reserved								EWI	WDGTB[1:0]	W[6:0]							
								rs	rw	rw							

Bit 31:10 Reserved, must be kept at reset value.

Bit 9 **EWI**: Early wakeup interrupt

When set, an interrupt occurs whenever the counter reaches the value 0x40. This interrupt is only cleared by hardware after a reset.

Bits 8:7 **WDGTB[1:0]**: Timer base

The time base of the prescaler can be modified as follows:

- 00: CK Counter Clock (PCLK1 div 4096) div 1
- 01: CK Counter Clock (PCLK1 div 4096) div 2
- 10: CK Counter Clock (PCLK1 div 4096) div 4
- 11: CK Counter Clock (PCLK1 div 4096) div 8

Bits 6:0 **W[6:0]**: 7-bit window value

These bits contain the window value to be compared to the downcounter.

## 16.6.3 Status register (WWDG\_SR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															EWIF
															rc_w0

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **EWIF**: Early wakeup interrupt flag

This bit is set by hardware when the counter has reached the value 0x40. It must be cleared by software by writing '0'. A write of '1' has no effect. This bit is also set if the interrupt is not enabled.

### 16.6.4 WWDG register map

The following table gives the WWDG register map and reset values.

**Table 64. WWDG register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	WWDG_CR	Reserved																		WDGA		T[6:0]											
	Reset value	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
0x04	WWDG_CFR	Reserved																		EWI		W[6:0]											
	Reset value	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
0x08	WWDG_SR	Reserved																		EWIF													
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 17 Real-time clock (RTC)

### 17.1 Introduction

The real-time clock (RTC) is an independent BCD timer/counter. The RTC provides a time-of-day clock/calendar, two programmable alarm interrupts, and a periodic programmable wakeup flag with interrupt capability. The RTC also includes an automatic wakeup unit to manage low power modes.

Two 32-bit registers contain the seconds, minutes, hours (12- or 24-hour format), day (day of week), date (day of month), month, and year, expressed in binary coded decimal format (BCD). The sub-seconds value is also available in binary format

Compensations for 28-, 29- (leap year), 30-, and 31-day months are performed automatically. Daylight saving time compensation can also be performed.

Additional 32-bit registers contain the programmable alarm subseconds, seconds, minutes, hours, day, and date.

A digital calibration feature is available to compensate for any deviation in crystal oscillator accuracy.

After backup domain reset, all RTC registers are protected against possible parasitic write accesses.

As long as the supply voltage remains in the operating range, the RTC never stops, regardless of the device status (Run mode, low power mode or under reset).

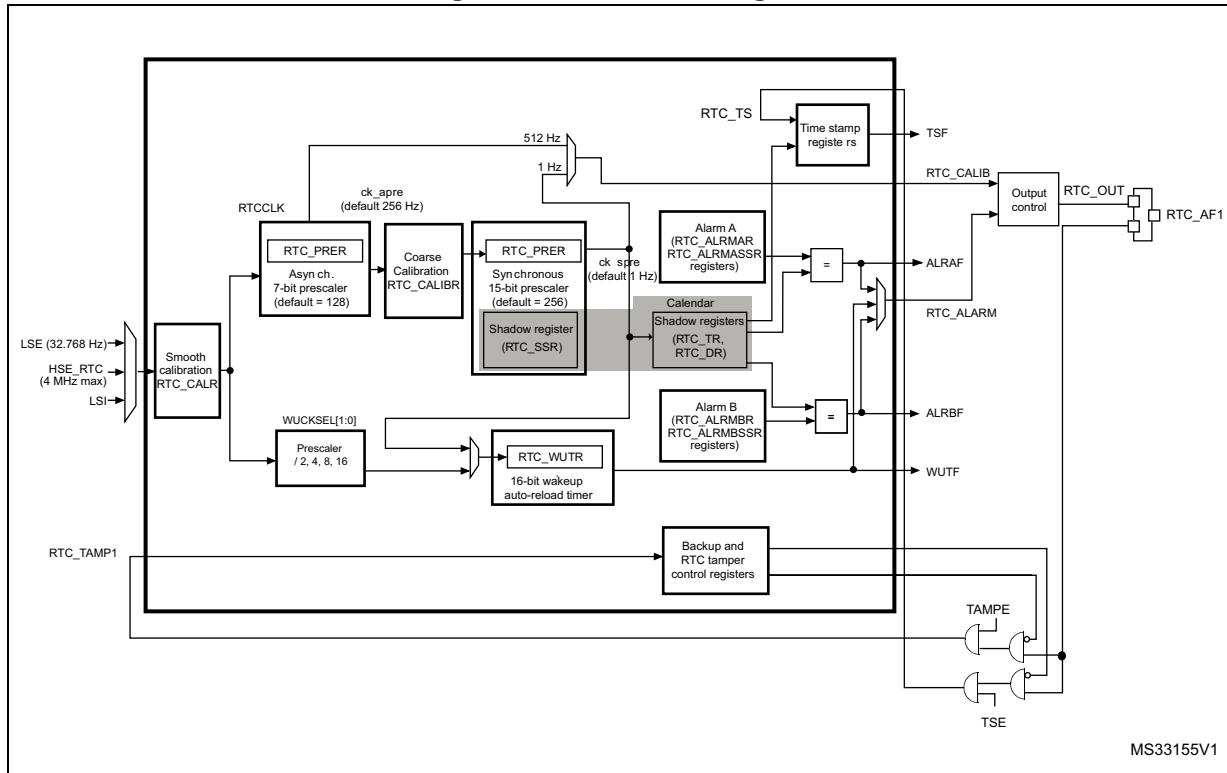
## 17.2 RTC main features

The RTC unit main features are the following (see [Figure 159: RTC block diagram](#)):

- Calendar with subseconds, seconds, minutes, hours (12 or 24 format), day (day of week), date (day of month), month, and year.
- Daylight saving compensation programmable by software.
- Two programmable alarms with interrupt function. The alarms can be triggered by any combination of the calendar fields.
- Automatic wakeup unit generating a periodic flag that triggers an automatic wakeup interrupt.
- Reference clock detection: a more precise second source clock (50 or 60 Hz) can be used to enhance the calendar precision.
- Accurate synchronization with an external clock using the subsecond shift feature.
- Maskable interrupts/events:
  - Alarm A
  - Alarm B
  - Wakeup interrupt
  - Timestamp
  - Tamper detection
- Digital calibration circuit (periodic counter correction)
  - 5 ppm accuracy
  - 0.95 ppm accuracy, obtained in a calibration window of several seconds
- Timestamp function for event saving (1 event)
- Tamper detection:
  - Tamper event with configurable filter and internal pull-up.
- 20 backup registers (80 bytes). The backup registers are reset when a tamper detection event occurs.
- Alternate function output (RTC\_OUT) which selects one of the following two outputs:
  - RTC\_CALIB: 512 Hz or 1 Hz clock output (with an LSE frequency of 32.768 kHz). This output is enabled by setting the COE bit in the RTC\_CR register. It is routed to the device RTC\_AF1 function.
  - RTC\_ALARM (Alarm A, Alarm B or wakeup). This output is selected by configuring the OSEL[1:0] bits in the RTC\_CR register. It is routed to the device RTC\_AF1 function.
- RTC additional function inputs:
  - RTC\_TS: timestamp event detection. It is routed to the device RTC\_AF1 function.
  - RTC\_TAMP1: TAMPER1 event detection. It is routed to the device RTC\_AF1 function.
  - RTC\_REFIN: reference clock input (usually the mains, 50 or 60 Hz).

Refer to [Section 8.3.15: Selection of RTC additional functions](#) and the STM32F401xx datasheet pin definition table.

**Figure 159. RTC block diagram**



1. The RTC\_AF1 additional function is connected to PC13.

## 17.3 RTC functional description

### 17.3.1 Clock and prescalers

The RTC clock source (RTCCLK) is selected through the clock controller among the LSE clock, the LSI oscillator clock, and the HSE clock. For more information on the RTC clock source configuration, refer to [Section 6: Reset and clock control \(RCC\) for STM32F401xB/C and STM32F401xD/E](#).

A programmable prescaler stage generates a 1 Hz clock which is used to update the calendar. To minimize power consumption, the prescaler is split into 2 programmable prescalers (see [Figure 159: RTC block diagram](#)):

- A 7-bit asynchronous prescaler configured through the PREDIV\_A bits of the RTC\_PRER register.
  - A 15-bit synchronous prescaler configured through the PREDIV\_S bits of the RTC\_PRER register.

*Note:*

*When both prescalers are used, it is recommended to configure the asynchronous prescaler to a high value to minimize consumption.*

The asynchronous prescaler division factor is set to 128, and the synchronous division factor to 256, to obtain an internal clock frequency of 1 Hz (ck\_spre) with an LSE frequency of 32.768 kHz.

The minimum division factor is 1 and the maximum division factor is  $2^{22}$ .

This corresponds to a maximum input frequency of around 4 MHz.

$f_{CK\_APRE}$  is given by the following formula:

$$f_{CK\_APRE} = \frac{f_{RTCCLK}}{\text{PREDIV\_A} + 1}$$

The  $ck\_apre$  clock is used to clock the binary RTC\_SSR subseconds downcounter. When it reaches 0, RTC\_SSR is reloaded with the content of PREDIV\_S.

$f_{CK\_SPRE}$  is given by the following formula:

$$f_{CK\_SPRE} = \frac{f_{RTCCLK}}{(\text{PREDIV\_S} + 1) \times (\text{PREDIV\_A} + 1)}$$

The  $ck\_spre$  clock can be used either to update the calendar or as timebase for the 16-bit wakeup auto-reload timer. To obtain short timeout periods, the 16-bit wakeup auto-reload timer can also run with the RTCCLK divided by the programmable 4-bit asynchronous prescaler (see [Section 17.3.4: Periodic auto-wakeup](#) for details).

### 17.3.2 Real-time clock and calendar

The RTC calendar time and date registers are accessed through shadow registers which are synchronized with PCLK1 (APB1 clock). They can also be accessed directly in order to avoid waiting for the synchronization duration.

- RTC\_SSR for the subseconds
- RTC\_TR for the time
- RTC\_DR for the date

Every two RTCCLK periods, the current calendar value is copied into the shadow registers, and the RSF bit of RTC\_ISR register is set (see [Section 17.6.4](#)). The copy is not performed in Stop and Standby mode. When exiting these modes, the shadow registers are updated after up to 2 RTCCLK periods.

When the application reads the calendar registers, it accesses the content of the shadow registers. It is possible to make a direct access to the calendar registers by setting the BYPSHAD control bit in the RTC\_CR register. By default, this bit is cleared, and the user accesses the shadow registers.

When reading the RTC\_SSR, RTC\_TR or RTC\_DR registers in BYPSHAD=0 mode, the frequency of the APB clock ( $f_{APB}$ ) must be at least 7 times the frequency of the RTC clock ( $f_{RTCCLK}$ ).

The shadow registers are reset by system reset.

### 17.3.3 Programmable alarms

The RTC unit provides two programmable alarms, Alarm A and Alarm B.

The programmable alarm functions are enabled through the ALRAIE and ALRBIE bits in the RTC\_CR register. The ALRAF and ALRBF flags are set to 1 if the calendar subseconds, seconds, minutes, hours, date or day match the values programmed in the alarm registers RTC\_ALRMASSR/RTC\_ALRMAR and RTC\_ALRMBSSR/RTC\_ALRMBR, respectively. Each calendar field can be independently selected through the MSKx bits of the

RTC\_ALRMAR and RTC\_ALRMBR registers, and through the MASKSSx bits of the RTC\_ALRMASSR and RTC\_ALRMBSSR registers. The alarm interrupts are enabled through the ALRAIE and ALRBIE bits in the RTC\_CR register.

Alarm A and Alarm B (if enabled by bits OSEL[1:0] in RTC\_CR register) can be routed to the RTC\_ALARM output. RTC\_ALARM polarity can be configured through bit POL in the RTC\_CR register.

**Caution:** If the seconds field is selected (MSK0 bit reset in RTC\_ALRMAR or RTC\_ALRMBR), the synchronous prescaler division factor set in the RTC\_PRER register must be at least 3 to ensure correct behavior.

#### 17.3.4 Periodic auto-wakeup

The periodic wakeup flag is generated by a 16-bit programmable auto-reload down-counter. The wakeup timer range can be extended to 17 bits.

The wakeup function is enabled through the WUTE bit in the RTC\_CR register.

The wakeup timer clock input can be:

- RTC clock (RTCCLK) divided by 2, 4, 8, or 16.  
When RTCCLK is LSE(32.768kHz), this allows to configure the wakeup interrupt period from 122 µs to 32 s, with a resolution down to 61µs.
- ck\_spre (usually 1 Hz internal clock)  
When ck\_spre frequency is 1Hz, this allows to achieve a wakeup time from 1 s to around 36 hours with one-second resolution. This large programmable time range is divided in 2 parts:
  - from 1s to 18 hours when WUCKSEL [2:1] = 10
  - and from around 18h to 36h when WUCKSEL[2:1] = 11. In this last case 2<sup>16</sup> is added to the 16-bit counter current value. When the initialization sequence is complete (see [Programming the wakeup timer on page 425](#)), the timer starts counting down. When the wakeup function is enabled, the down-counting remains active in low power modes. In addition, when it reaches 0, the WUTF flag is set in the RTC\_ISR register, and the wakeup counter is automatically reloaded with its reload value (RTC\_WUTR register value).

The WUTF flag must then be cleared by software.

When the periodic wakeup interrupt is enabled by setting the WUTIE bit in the RTC\_CR2 register, it can exit the device from low power modes.

The periodic wakeup flag can be routed to the RTC\_ALARM output provided it has been enabled through bits OSEL[1:0] of RTC\_CR register. RTC\_ALARM polarity can be configured through the POL bit in the RTC\_CR register.

System reset, as well as low power modes (Sleep, Stop and Standby) have no influence on the wakeup timer.

#### 17.3.5 RTC initialization and configuration

##### RTC register access

The RTC registers are 32-bit registers. The APB interface introduces 2 wait-states in RTC register accesses except on read accesses to calendar shadow registers when BYPSHAD=0.

## RTC register write protection

After system reset, the RTC registers are protected against parasitic write access with the DBP bit of the PWR power control register (PWR\_CR). The DBP bit must be set to enable RTC registers write access.

After backup domain reset, all the RTC registers are write-protected. Writing to the RTC registers is enabled by writing a key into the Write Protection register, RTC\_WPR.

The following steps are required to unlock the write protection on all the RTC registers except for RTC\_ISR[13:8], RTC\_TAFCR, and RTC\_BKPxR.

1. Write '0xCA' into the RTC\_WPR register.
2. Write '0x53' into the RTC\_WPR register.

Writing a wrong key reactivates the write protection.

The protection mechanism is not affected by system reset.

## Calendar initialization and configuration

To program the initial time and date calendar values, including the time format and the prescaler configuration, the following sequence is required:

1. Set INIT bit to 1 in the RTC\_ISR register to enter initialization mode. In this mode, the calendar counter is stopped and its value can be updated.
2. Poll INITF bit of in the RTC\_ISR register. The initialization phase mode is entered when INITF is set to 1. It takes around 2 RTCCLK clock cycles (due to clock synchronization).
3. To generate a 1 Hz clock for the calendar counter, program first the synchronous prescaler factor in RTC\_PRER register, and then program the asynchronous prescaler factor. Even if only one of the two fields needs to be changed, 2 separate write accesses must be performed to the RTC\_PRER register.
4. Load the initial time and date values in the shadow registers (RTC\_TR and RTC\_DR), and configure the time format (12 or 24 hours) through the FMT bit in the RTC\_CR register.
5. Exit the initialization mode by clearing the INIT bit. The actual calendar counter value is then automatically loaded and the counting restarts after 4 RTCCLK clock cycles.

When the initialization sequence is complete, the calendar starts counting.

Note:

*After a system reset, the application can read the INITS flag in the RTC\_ISR register to check if the calendar has been initialized or not. If this flag equals 0, the calendar has not been initialized since the year field is set at its backup domain reset default value (0x00).*

*To read the calendar after initialization, the software must first check that the RSF flag is set in the RTC\_ISR register.*

## Daylight saving time

The daylight saving time management is performed through bits SUB1H, ADD1H, and BKP of the RTC\_CR register.

Using SUB1H or ADD1H, the software can subtract or add one hour to the calendar in one single operation without going through the initialization procedure.

In addition, the software can use the BKP bit to memorize this operation.

## Programming the alarm

A similar procedure must be followed to program or update the programmable alarm (Alarm A or Alarm B):

1. Clear ALRAE or ALRBIE in RTC\_CR to disable Alarm A or Alarm B.
2. Poll ALRAWF or ALRBWF in RTC\_ISR until it is set to make sure the access to alarm registers is allowed. This takes around 2 RTCCLK clock cycles (due to clock synchronization).
3. Program the Alarm A or Alarm B registers (RTC\_ALRMASSR/RTC\_ALRMAR or RTC\_ALRMBSSR/RTC\_ALRMBR).
4. Set ALRAE or ALRBIE in the RTC\_CR register to enable Alarm A or Alarm B again.

*Note:*

*Each change of the RTC\_CR register is taken into account after around 2 RTCCLK clock cycles due to clock synchronization.*

## Programming the wakeup timer

The following sequence is required to configure or change the wakeup timer auto-reload value (WUT[15:0] in RTC\_WUTR):

1. Clear WUTE in RTC\_CR to disable the wakeup timer.
2. Poll WUTWF until it is set in RTC\_ISR to make sure the access to wakeup auto-reload counter and to WUCKSEL[2:0] bits is allowed. It takes around 2 RTCCLK clock cycles (due to clock synchronization).
3. Program the wakeup auto-reload value WUT[15:0], and the wakeup clock selection (WUCKSEL[2:0] bits in RTC\_CR). Set WUTE in RTC\_CR to enable the timer again. The wakeup timer restarts down-counting.

### 17.3.6 Reading the calendar

To read the RTC calendar registers (RTC\_SSR, RTC\_TR and RTC\_DR) properly, the APB1 clock frequency ( $f_{PCLK1}$ ) must be equal to or greater than seven times the  $f_{RTCCLK}$  RTC clock frequency. This ensures a secure behavior of the synchronization mechanism.

If the APB1 clock frequency is less than seven times the RTC clock frequency, the software must read the calendar time and date registers twice. If the second read of the RTC\_TR gives the same result as the first read, this ensures that the data is correct. Otherwise a third read access must be done. In any case the APB1 clock frequency must never be lower than the RTC clock frequency.

The RSF bit is set in RTC\_ISR register each time the calendar registers are copied into the RTC\_SSR, RTC\_TR and RTC\_DR shadow registers. The copy is performed every two RTCCLK cycles. To ensure consistency between the 3 values, reading either RTC\_SSR or RTC\_TR locks the values in the higher-order calendar shadow registers until RTC\_DR is read. In case the software makes read accesses to the calendar in a time interval smaller than 2 RTCCLK periods: RSF must be cleared by software after the first calendar read, and then the software must wait until RSF is set before reading again the RTC\_SSR, RTC\_TR and RTC\_DR registers.

After waking up from low power mode (Stop or Standby), RSF must be cleared by software. The software must then wait until it is set again before reading the RTC\_SSR, RTC\_TR and RTC\_DR registers.

The RSF bit must be cleared after wakeup and not before entering low power mode.

**Note:** After a system reset, the software must wait until RSF is set before reading the RTC\_SSR, RTC\_TR and RTC\_DR registers. Indeed, a system reset resets the shadow registers to their default values.

After an initialization (refer to [Calendar initialization and configuration on page 424](#)): the software must wait until RSF is set before reading the RTC\_SSR, RTC\_TR and RTC\_DR registers.

After synchronization (refer to [Section 17.3.8: RTC synchronization](#)): the software must wait until RSF is set before reading the RTC\_SSR, RTC\_TR and RTC\_DR registers.

### When the BYPSHAD control bit is set in the RTC\_CR register (bypass shadow registers)

Reading the calendar registers gives the values from the calendar counters directly, thus eliminating the need to wait for the RSF bit to be set. This is especially useful after exiting from low power modes (STOP or Standby), since the shadow registers are not updated during these modes.

When the BYPSHAD bit is set to 1, the results of the different registers might not be coherent with each other if an RTCCLK edge occurs between two read accesses to the registers. Additionally, the value of one of the registers may be incorrect if an RTCCLK edge occurs during the read operation. The software must read all the registers twice, and then compare the results to confirm that the data is coherent and correct. Alternatively, the software can just compare the two results of the least-significant calendar register.

**Note:** While BYPSHAD=1, instructions which read the calendar registers require one extra APB cycle to complete.

## 17.3.7 Resetting the RTC

The calendar shadow registers (RTC\_SSR, RTC\_TR and RTC\_DR) and some bits of the RTC status register (RTC\_ISR) are reset to their default values by all available system reset sources.

On the contrary, the following registers are reset to their default values by a backup domain reset and are not affected by a system reset: the RTC current calendar registers, the RTC control register (RTC\_CR), the prescaler register (RTC\_PRER), the RTC calibration registers (RTC\_CALIBR or RTC\_CALR), the RTC shift register (RTC\_SHIFTR), the RTC timestamp registers (RTC\_TSSSR, RTC\_TSTR and RTC\_TSDDR), the RTC tamper and alternate function configuration register (RTC\_TAFCR), the RTC backup registers (RTC\_BKPxR), the wakeup timer register (RTC\_WUTR), the Alarm A and Alarm B registers (RTC\_ALRMASSR/RTC\_ALRMAR and RTC\_ALRMBSSR/RTC\_ALRMBR).

In addition, the RTC keeps on running under system reset if the reset source is different from a backup domain reset. When a backup domain reset occurs, the RTC is stopped and all the RTC registers are set to their reset values.

## 17.3.8 RTC synchronization

The RTC can be synchronized to a remote clock with a high degree of precision. After reading the sub-second field (RTC\_SSR or RTC\_TSSSR), a calculation can be made of the precise offset between the times being maintained by the remote clock and the RTC. The RTC can then be adjusted to eliminate this offset by “shifting” its clock by a fraction of a second using RTC\_SHIFTR.

RTC\_SSR contains the value of the synchronous prescaler's counter. This allows one to calculate the exact time being maintained by the RTC down to a resolution of  $1 / (\text{PREDIV\_S} + 1)$  seconds. As a consequence, the resolution can be improved by increasing the synchronous prescaler value (PREDIV\_S[14:0]. The maximum resolution allowed (30.52  $\mu$ s with a 32768 Hz clock) is obtained with PREDIV\_S set to 0x7FFF.

However, increasing PREDIV\_S means that PREDIV\_A must be decreased in order to maintain the synchronous prescaler's output at 1 Hz. In this way, the frequency of the asynchronous prescaler's output increases, which may increase the RTC dynamic consumption.

The RTC can be finely adjusted using the RTC shift control register (RTC\_SHIFTR). Writing to RTC\_SHIFTR can shift (either delay or advance) the clock by up to a second with a resolution of  $1 / (\text{PREDIV\_S} + 1)$  seconds. The shift operation consists of adding the SUBFS[14:0] value to the synchronous prescaler counter SS[15:0]: this will delay the clock. If at the same time the ADD1S bit is set, this results in adding one second and at the same time subtracting a fraction of second, so this will advance the clock.

**Caution:** Before initiating a shift operation, the user must check that SS[15] = 0 in order to ensure that no overflow will occur.

As soon as a shift operation is initiated by a write to the RTC\_SHIFTR register, the SHPF flag is set by hardware to indicate that a shift operation is pending. This bit is cleared by hardware as soon as the shift operation has completed.

**Caution:** This synchronization feature is not compatible with the reference clock detection feature: firmware must not write to RTC\_SHIFTR when REFCKON=1.

### 17.3.9 RTC reference clock detection

The RTC calendar update can be synchronized to a reference clock RTC\_REFIN, usually the mains (50 or 60 Hz). The RTC\_REFIN reference clock should have a higher precision than the 32.768 kHz LSE clock. When the RTC\_REFIN detection is enabled (REFCKON bit of RTC\_CR set to 1), the calendar is still clocked by the LSE, and RTC\_REFIN is used to compensate for the imprecision of the calendar update frequency (1 Hz).

Each 1 Hz clock edge is compared to the nearest reference clock edge (if one is found within a given time window). In most cases, the two clock edges are properly aligned. When the 1 Hz clock becomes misaligned due to the imprecision of the LSE clock, the RTC shifts the 1 Hz clock a bit so that future 1 Hz clock edges are aligned. Thanks to this mechanism, the calendar becomes as precise as the reference clock.

The RTC detects if the reference clock source is present by using the 256 Hz clock (ck\_apre) generated from the 32.768 kHz quartz. The detection is performed during a time window around each of the calendar updates (every 1 s). The window equals 7 ck\_apre periods when detecting the first reference clock edge. A smaller window of 3 ck\_apre periods is used for subsequent calendar updates.

Each time the reference clock is detected in the window, the asynchronous prescaler which outputs the ck\_apre clock is forced to reload. This has no effect when the reference clock and the 1 Hz clock are aligned because the prescaler is being reloaded at the same moment. When the clocks are not aligned, the reload shifts future 1 Hz clock edges a little for them to be aligned with the reference clock.

If the reference clock halts (no reference clock edge occurred during the 3 ck\_apre window), the calendar is updated continuously based solely on the LSE clock. The RTC then waits for

the reference clock using a large 7 ck\_apre period detection window centered on the ck\_spre edge.

When the reference clock detection is enabled, PREDIV\_A and PREDIV\_S must be set to their default values:

- PREDIV\_A = 0x007F
- PREDIV\_S = 0x00FF

**Note:** *The reference clock detection is not available in Standby mode.*

**Caution:** The reference clock detection feature cannot be used in conjunction with the coarse digital calibration: RTC\_CALIBR must be kept at 0x0000 0000 when REFCKON=1.

### 17.3.10 RTC coarse digital calibration

Two digital calibration methods are available: coarse and smooth calibration. To perform coarse calibration refer to [Section 17.6.7: RTC calibration register \(RTC\\_CALIBR\)](#).

The two calibration methods are not intended to be used together, the application must select one of the two methods. Coarse calibration is provided for compatibility reasons. To perform smooth calibration refer to [Section 17.3.11: RTC smooth digital calibration](#) and the [Section 17.6.16: RTC calibration register \(RTC\\_CALR\)](#)

The coarse digital calibration can be used to compensate crystal inaccuracy by adding (positive calibration) or masking (negative calibration) clock cycles at the output of the asynchronous prescaler (ck\_apre).

Positive and negative calibration are selected by setting the DCS bit in RTC\_CALIBR register to '0' and '1', respectively.

When positive calibration is enabled (DCS = '0'), 2 ck\_apre cycles are added every minute (around 15360 ck\_apre cycles) for 2xDC minutes. This causes the calendar to be updated sooner, thereby adjusting the effective RTC frequency to be a bit higher.

When negative calibration is enabled (DCS = '1'), 1 ck\_apre cycle is removed every minute (around 15360 ck\_apre cycles) for 2xDC minutes. This causes the calendar to be updated later, thereby adjusting the effective RTC frequency to be a bit lower.

DC is configured through bits DC[4:0] of RTC\_CALIBR register. This number ranges from 0 to 31 corresponding to a time interval (2xDC) ranging from 0 to 62.

The coarse digital calibration can be configured only in initialization mode, and starts when the INIT bit is cleared. The full calibration cycle lasts 64 minutes. The first 2xDC minutes of the 64 -minute cycle are modified as just described.

Negative calibration can be performed with a resolution of about 2 ppm while positive calibration can be performed with a resolution of about 4 ppm. The maximum calibration ranges from -63 ppm to 126 ppm.

The calibration can be performed either on the LSE or on the HSE clock.

**Caution:** Digital calibration may not work correctly if PREDIV\_A < 6.

#### Case of RTCCLK=32.768 kHz and PREDIV\_A+1=128

The following description assumes that ck\_apre frequency is 256 Hz obtained with an LSE clock nominal frequency of 32.768 kHz, and PREDIV\_A set to 127 (default value).

The ck\_spre clock frequency is only modified during the first 2xDC minutes of the 64-minute cycle. For example, when DC equals 1, only the first 2 minutes are modified. This means that the first 2xDC minutes of each 64-minute cycle have, once per minute, one second either shortened by 256 or lengthened by 128 RTCCLK cycles, given that each ck\_apre cycle represents 128 RTCCLK cycles (with PREDIV\_A+1=128).

Therefore each calibration step has the effect of adding 512 or subtracting 256 oscillator cycles for every 125829120 RTCCLK cycles (64min x 60 s/min x 32768 cycles/s). This is equivalent to +4.069 ppm or -2.035 ppm per calibration step. As a result, the calibration resolution is +10.5 or -5.27 seconds per month, and the total calibration ranges from +5.45 to -2.72 minutes per month.

In order to measure the clock deviation, a 512 Hz clock is output for calibration. Refer to [Section 17.3.14: Calibration clock output](#).

### 17.3.11 RTC smooth digital calibration

RTC frequency can be digitally calibrated with a resolution of about 0.954 ppm with a range from -487.1 ppm to +488.5 ppm. The correction of the frequency is performed using series of small adjustments (adding and/or subtracting individual RTCCLK pulses). These adjustments are fairly well distributed so that the RTC is well calibrated even when observed over short durations of time.

The smooth digital calibration is performed during a cycle of about  $2^{20}$  RTCCLK pulses, or 32 seconds when the input frequency is 32768 Hz. [This cycle is maintained by a 20-bit counter, cal\\_cnt\[19:0\], clocked by RTCCLK](#).

The smooth calibration register (RTC\_CALR) specifies the number of RTCCLK clock cycles to be masked during the 32-second cycle:

- Setting the bit CALM[0] to 1 causes exactly one pulse to be masked during the 32-second cycle.
- Setting CALM[1] to 1 causes two additional cycles to be masked
- Setting CALM[2] to 1 causes four additional cycles to be masked
- and so on up to CALM[8] set to 1 which causes 256 clocks to be masked.

**Note:** [CALM\[8:0\] \(RTC\\_CALRx\) specifies the number of RTCCLK pulses to be masked during the 32-second cycle. Setting the bit CALM\[0\] to '1' causes exactly one pulse to be masked during the 32-second cycle at the moment when cal\\_cnt\[19:0\] is 0x80000; CALM\[1\]=1 causes two other cycles to be masked \(when cal\\_cnt is 0x40000 and 0xC0000\); CALM\[2\]=1 causes four other cycles to be masked \(cal\\_cnt = 0x20000/0x60000/0xA0000/ 0xE0000\); and so on up to CALM\[8\]=1 which causes 256 clocks to be masked \(cal\\_cnt = 0xXX800\).](#)

While CALM allows the RTC frequency to be reduced by up to 487.1 ppm with fine resolution, the bit CALP can be used to increase the frequency by 488.5 ppm. Setting CALP to '1' effectively inserts an extra RTCCLK pulse every  $2^{11}$  RTCCLK cycles, which means that 512 clocks are added during every 32-second cycle.

Using CALM together with CALP, an offset ranging from -511 to +512 RTCCLK cycles can be added during the 32-second cycle, which translates to a calibration range of -487.1 ppm to +488.5 ppm with a resolution of about 0.954 ppm.

The formula to calculate the effective calibrated frequency ( $F_{CAL}$ ) given the input frequency ( $F_{RTCCLK}$ ) is as follows:

$$F_{CAL} = F_{RTCCLK} \times [1 + (CALP \times 512 - CALM) / (2^{20} + CALM - CALP \times 512)]$$

### Calibration when PREDIV\_A<3

The CALP bit can not be set to 1 when the asynchronous prescaler value (PREDIV\_A bits in RTC\_PRER register) is less than 3. If CALP was already set to 1 and PREDIV\_A bits are set to a value less than 3, CALP is ignored and the calibration operates as if CALP was equal to 0.

To perform a calibration with PREDIV\_A less than 3, the synchronous prescaler value (PREDIV\_S) should be reduced so that each second is accelerated by 8 RTCCLK clock cycles, which is equivalent to adding 256 clock cycles every 32 seconds. As a result, between 255 and 256 clock pulses (corresponding to a calibration range from 243.3 to 244.1 ppm) can effectively be added during each 32-second cycle using only the CALM bits.

With a nominal RTCCLK frequency of 32768 Hz, when PREDIV\_A equals 1 (division factor of 2), PREDIV\_S should be set to 16379 rather than 16383 (4 less). The only other interesting case is when PREDIV\_A equals 0, PREDIV\_S should be set to 32759 rather than 32767 (8 less).

If PREDIV\_S is reduced in this way, the formula given the effective frequency of the calibrated input clock is as follows:

$$F_{\text{CAL}} = F_{\text{RTCCLK}} \times [1 + (256 - \text{CALM}) / (2^{20} + \text{CALM} - 256)]$$

In this case, CALM[7:0] equals 0x100 (the midpoint of the CALM range) is the correct setting if RTCCLK is exactly 32768.00 Hz.

### Verifying the RTC calibration

RTC precision is performed by measuring the precise frequency of RTCCLK and calculating the correct CALM value and CALP values. An optional 1 Hz output is provided to allow applications to measure and verify the RTC precision. Measuring the precise frequency of the RTC over a limited interval can result in a measurement error of up to 2 RTCCLK clock cycles over the measurement period, depending on how the digital calibration cycle is aligned with the measurement period.

However, this measurement error can be eliminated if the measurement period is the same length as the calibration cycle period. In this case, the only error observed is the error due to the resolution of the digital calibration.

- By default, the calibration cycle period is 32 seconds.  
Using this mode and measuring the accuracy of the 1 Hz output over exactly 32 seconds guarantees that the measure is within 0.477 ppm (0.5 RTCCLK cycles over 32 seconds, due to the limitation of the calibration resolution).
- CALW16 bit of the RTC\_CALR register can be set to 1 to force a 16- second calibration cycle period.  
In this case, the RTC precision can be measured during 16 seconds with a maximum error of 0.954 ppm (0.5 RTCCLK cycles over 16 seconds). However, since the calibration resolution is reduced, the long term RTC precision is also reduced to 0.954 ppm: CALM[0] bit is stuck at 0 when CALW16 is set to 1.
- CALW8 bit of the RTC\_CALR register can be set to 1 to force a 8- second calibration cycle period.  
In this case, the RTC precision can be measured during 8 seconds with a maximum error of 1.907 ppm (0.5 RTCCLK cycles over 8s). The long term RTC precision is also reduced to 1.907 ppm: CALM[1:0] bits are stuck at 00 when CALW8 is set to 1.

### Re-calibration on-the-fly

The calibration register (RTC\_CALR) can be updated on-the-fly while RTC\_ISR/INITF=0, by using the follow process:

1. Poll the RTC\_ISR/RECALPF (re-calibration pending flag).
2. If it is set to 0, write a new value to RTC\_CALR, if necessary. RECALPF is then automatically set to 1
3. Within three ck\_apre cycles after the write operation to RTC\_CALR, the new calibration settings take effect.

### 17.3.12 Timestamp function

Timestamp is enabled by setting the TSE bit of RTC\_CR register to 1.

The calendar is saved in the timestamp registers (RTC\_TSSSR, RTC\_TSTR, RTC\_TSDR) when a timestamp event is detected on the pin to which the TIMESTAMP additional function is mapped. When a timestamp event occurs, the timestamp flag bit (TSF) in RTC\_ISR register is set.

By setting the TSIE bit in the RTC\_CR register, an interrupt is generated when a timestamp event occurs.

If a new timestamp event is detected while the timestamp flag (TSF) is already set, the timestamp overflow flag (TSOVF) flag is set and the timestamp registers (RTC\_TSTR and RTC\_TSDR) maintain the results of the previous event.

**Note:** *TSF is set 2 ck\_apre cycles after the timestamp event occurs due to synchronization process.*

*There is no delay in the setting of TSOVF. This means that if two timestamp events are close together, TSOVF can be seen as '1' while TSF is still '0'. As a consequence, it is recommended to poll TSOVF only after TSF has been set.*

**Caution:** If a timestamp event occurs immediately after the TSF bit is supposed to be cleared, then both TSF and TSOVF bits are set. To avoid masking a timestamp event occurring at the same moment, the application must not write '0' into TSF bit unless it has already read it to '1'.

Optionally, a tamper event can cause a timestamp to be recorded. See the description of the TAMPTS control bit in [Section 17.6.17: RTC tamper and alternate function configuration register \(RTC\\_TAFCR\)](#). If the timestamp event is on the same pin as a tamper event configured in filtered mode (TAMPFLT set to a non-zero value), the timestamp on tamper detection event mode must be selected by setting TAMPTS='1' in RTC\_TAFCR register.

### TIMESTAMP additional function

The TIMESTAMP additional function is mapped to RTC\_AF1.

### 17.3.13 Tamper detection

One tamper detection input is available. It can be configured either for edge detection, or for level detection with filtering.

### RTC backup registers

The backup registers (RTC\_BKPxR) are twenty 32-bit registers for storing 80 bytes of user application data. They are implemented in the backup domain that remains powered-on by

$V_{BAT}$  when the  $V_{DD}$  power is switched off. They are not reset by system reset or when the device wakes up from Standby mode. They are reset by a backup domain reset.

The backup registers are reset when a tamper detection event occurs (see [Section 17.6.20: RTC backup registers \(RTC\\_BKPxR\)](#) and [Tamper detection initialization on page 432](#)).

### Tamper detection initialization

The tamper detection input is associated with the TAMP1F flag in the RTC\_ISR register. The input can be enabled by setting the TAMP1E bit to 1 in the RTC\_TAFCR register.

A tamper detection event resets all backup registers (RTC\_BKPxR).

By setting the TAMPIE bit in the RTC\_TAFCR register, an interrupt is generated when a tamper detection event occurs.

### Timestamp on tamper event

With TAMPPTS set to '1', any tamper event causes a timestamp to occur. In this case, either the TSF bit or the TSOVF bit are set in RTC\_ISR, in the same manner as if a normal timestamp event occurs. The tamper flag register (TAMP1F) is set at the same time that TSF or TSOVF is set.

### Edge detection on tamper inputs

If the TAMPFLT bits are "00", the TAMPER pin generates tamper detection events (RTC\_TAMP[2:1]) when either a rising edge is observed or a falling edge is observed depending on the corresponding TAMPxTRG bit. The internal pull-up resistors on the TAMPER input are deactivated when edge detection is selected.

**Caution:** To avoid losing tamper detection events, the signal used for edge detection is logically ANDed with TAMPxE in order to detect a tamper detection event in case it occurs before the TAMPERx pin is enabled.

- When TAMPxTRG = 0: if the TAMPERx additional function is already high before tamper detection is enabled (TAMPxE bit set to 1), a tamper event is detected as soon as TAMPERx is enabled, even if there was no rising edge on TAMPERx after TAMPxE was set.
- When TAMPxTRG = 1: if the TAMPERx additional function is already low before tamper detection is enabled, a tamper event is detected as soon as TAMPERx is enabled (even if there was no falling edge on TAMPERx after TAMPxE was set).

After a tamper event has been detected and cleared, the TAMPERx additional function should be disabled and then re-enabled (TAMPxE set to 1) before re-programming the backup registers (RTC\_BKPxR). This prevents the application from writing to the backup registers while the TAMPERx value still indicates a tamper detection. This is equivalent to a level detection on the TAMPERx additional function.

**Note:** *Tamper detection is still active when  $V_{DD}$  power is switched off. To avoid unwanted resetting of the backup registers, the pin to which the TAMPER additional function is mapped should be externally tied to the correct level.*

### Level detection with filtering on tamper input

Level detection with filtering is performed by setting TAMPFLT to a non-zero value. A tamper detection event is generated when either 2, 4, or 8 (depending on TAMPFLT) consecutive samples are observed at the level designated by the TAMPxTRG bits (TAMP1TRG).

The TAMPER input is pre-charged through the I/O internal pull-up resistance before its state is sampled, unless disabled by setting TAMPPUDIS to 1. The duration of the precharge is determined by the TAMPPRCH bits, allowing for larger capacitances on the tamper inputs.

The trade-off between tamper detection latency and power consumption through the pull-up can be optimized by using TAMPFREQ to determine the frequency of the sampling for level detection.

**Note:** Refer to the datasheets for the electrical characteristics of the pull-up resistors.

### TAMPER additional function detection

The TAMPER1 additional function is mapped to the RTC\_AF1 pin.

#### 17.3.14 Calibration clock output

When the COE bit is set to 1 in the RTC\_CR register, a reference clock is provided on the RTC\_CALIB device output. If the COSEL bit in the RTC\_CR register is reset and PREDIV\_A = 0x7F, the RTC\_CALIB frequency is  $f_{RTCCLK/64}$ . This corresponds to a calibration output at 512 Hz for an RTCCLK frequency at 32.768 kHz.

The RTC\_CALIB output is not impacted by the calibration value programmed in RTC\_CALIBR register. The RTC\_CALIB duty cycle is irregular: there is a light jitter on falling edges. It is therefore recommended to use rising edges.

If COSEL is set and “PREDIV\_S+1” is a non-zero multiple of 256 (i.e: PREDIV\_S[7:0] = 0xFF), the RTC\_CALIB frequency is  $f_{RTCCLK}/(256 * (PREDIV_A+1))$ . This corresponds to a calibration output at 1 Hz for prescaler default values (PREDIV\_A = 0x7F, PREDIV\_S = 0xFF), with an RTCCLK frequency at 32.768 kHz.

### Calibration alternate function output

When the COE bit in the RTC\_CR register is set to 1, the calibration alternate function (RTC\_CALIB) is enabled on RTC\_OUT.

#### 17.3.15 Alarm output

Three functions can be selected on Alarm output: ALRAF. These functions reflect the contents of the corresponding flags in the RTC\_ISR register.

The OSEL[1:0] control bits in the RTC\_CR register are used to activate the alarm alternate function output (RTC\_ALARM) in RTC\_AF1, and to select the function which is output on RTC\_ALARM.

The polarity of the output is determined by the POL control bit in RTC\_CR so that the opposite of the selected flag bit is output when POL is set to 1.

### Alarm alternate function output

RTC\_ALARM can be configured in output open drain or output push-pull using the control bit ALARMOUTTYPE in the RTC\_TAFCR register.

**Note:** Once RTC\_ALARM is enabled, it has priority over RTC\_CALIB (COE bit is don't care on RTC\_AF1).

When RTC\_CALIB or RTC\_ALARM is selected, RTC\_OUT is automatically configured in output alternate function.

## 17.4 RTC and low power modes

**Table 65. Effect of low power modes on RTC**

Mode	Description
Sleep	No effect RTC interrupts cause the device to exit the Sleep mode.
Stop	The RTC remains active when the RTC clock source is LSE or LSI. RTC alarm, RTC tamper event, RTC time stamp event, and RTC Wakeup cause the device to exit the Stop mode.
Standby	The RTC remains active when the RTC clock source is LSE or LSI. RTC alarm, RTC tamper event, RTC time stamp event, and RTC Wakeup cause the device to exit the Standby mode.

## 17.5 RTC interrupts

All RTC interrupts are connected to the EXTI controller.

To enable the RTC Alarm interrupt, the following sequence is required:

1. Configure and enable the EXTI Line 17 in interrupt mode and select the rising edge sensitivity.
2. Configure and enable the RTC\_Alarm IRQ channel in the NVIC.
3. Configure the RTC to generate RTC alarms (Alarm A or Alarm B).

To enable the RTC Wakeup interrupt, the following sequence is required:

1. Configure and enable the EXTI Line 22 in interrupt mode and select the rising edge sensitivity.
2. Configure and enable the RTC\_WKUP IRQ channel in the NVIC.
3. Configure the RTC to generate the RTC wakeup timer event.

To enable the RTC Tamper interrupt, the following sequence is required:

1. Configure and enable the EXTI Line 21 in interrupt mode and select the rising edge sensitivity.
2. Configure and Enable the TAMP\_STAMP IRQ channel in the NVIC.
3. Configure the RTC to detect the RTC tamper event.

To enable the RTC TimeStamp interrupt, the following sequence is required:

1. Configure and enable the EXTI Line 21 in interrupt mode and select the rising edge sensitivity.
2. Configure and Enable the TAMP\_STAMP IRQ channel in the NVIC.
3. Configure the RTC to detect the RTC timestamp event.

**Table 66. Interrupt control bits**

Interrupt event	Event flag	Enable control bit	Exit the Sleep mode	Exit the Stop mode	Exit the Standby mode
Alarm A	ALRAF	ALRAIE	yes	yes <sup>(1)</sup>	yes <sup>(1)</sup>
Alarm B	ALRBF	ALRBIE	yes	yes <sup>(1)</sup>	yes <sup>(1)</sup>
Wakeup	WUTF	WUTIE	yes	yes <sup>(1)</sup>	yes <sup>(1)</sup>
TimeStamp	TSF	TSIE	yes	yes <sup>(1)</sup>	yes <sup>(1)</sup>
Tamper1 detection	TAMP1F	TAMPIE	yes	yes <sup>(1)</sup>	yes <sup>(1)</sup>

1. Wakeup from STOP and Standby modes is possible only when the RTC clock source is LSE or LSI.

## 17.6 RTC registers

Refer to [Section 1.1](#) of the reference manual for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32 bits).

### 17.6.1 RTC time register (RTC\_TR)

The RTC\_TR is the calendar time shadow register. This register must be written in initialization mode only. Refer to [Calendar initialization and configuration on page 424](#) and [Reading the calendar on page 425](#).

Address offset: 0x00

Backup domain reset value: 0x0000 0000

System reset: 0x0000 0000 when BYPSHAD = 0. Not affected when BYPSHAD = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								PM	HT[1:0]		HU[3:0]				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.								ST[2:0]		SU[3:0]					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31-24 Reserved

Bit 23 Reserved, must be kept at reset value.

Bit 22 **PM**: AM/PM notation

- 0: AM or 24-hour format
- 1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bit 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ST[2:0]**: Second tens in BCD format

Bits 3:0 **SU[3:0]**: Second units in BCD format

**Note:** *This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).*

## 17.6.2 RTC date register (RTC\_DR)

The RTC\_DR is the calendar date shadow register. This register must be written in initialization mode only. Refer to [Calendar initialization and configuration on page 424](#) and [Reading the calendar on page 425](#).

Address offset: 0x04

Backup domain reset value: 0x0000\_2101

System reset: 0x0000 2101 when BYPSHAD = 0. Not affected when BYPSHAD = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								YT[3:0]				YU[3:0]			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDU[2:0]			MT		MU[3:0]				Reserved	DT[1:0]		DU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw

Bits 31-24 Reserved

Bits 23:20 **YT[3:0]**: Year tens in BCD format

Bits 19:16 **YU[3:0]**: Year units in BCD format

Bits 15:13 **WDU[2:0]**: Week day units

000: forbidden

001: Monday

...

111: Sunday

Bit 12 **MT**: Month tens in BCD format

Bits 11:8 **MU**: Month units in BCD format

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **DT[1:0]**: Date tens in BCD format

Bits 3:0 **DU[3:0]**: Date units in BCD format

**Note:** *This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).*

### 17.6.3 RTC control register (RTC\_CR)

Address offset: 0x08

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved						COE	OSEL[1:0]		POL		BKP	SUB1H	ADD1H		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIE	WUTIE	ALRBIE	ALRAIE	TSE	WUTE	ALRBE	ALRAE	DCE	FMT	BYPS HAD	REFCKON	TSEDGE	WUCKSEL[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **COE**: Calibration output enable

This bit enables the RTC\_CALIB output

0: Calibration output disabled

1: Calibration output enabled

Bits 22:21 **OSEL[1:0]**: Output selection

These bits are used to select the flag to be routed to RTC\_ALARM output

00: Output disabled

01: Alarm A output enabled

10:Alarm B output enabled

11: Wakeup output enabled

Bit 20 **POL**: Output polarity

This bit is used to configure the polarity of RTC\_ALARM output

0: The pin is high when ALRAF/ALRBF/WUTF is asserted (depending on OSEL[1:0])

1: The pin is low when ALRAF/ALRBF/WUTF is asserted (depending on OSEL[1:0]).

Bit 19 **COSEL**: Calibration output selection

When COE=1, this bit selects which signal is output on RTC\_CALIB.

0: Calibration output is 512 Hz

1: Calibration output is 1 Hz

These frequencies are valid for RTCCLK at 32.768 kHz and prescalers at their default values (PREDIV\_A=127 and PREDIV\_S=255). Refer to [Section 17.3.14: Calibration clock output](#)

Bit 18 **BKP**: Backup

This bit can be written by the user to memorize whether the daylight saving time change has been performed or not.

Bit 17 **SUB1H**: Subtract 1 hour (winter time change)

When this bit is set outside initialization mode, 1 hour is subtracted to the calendar time if the current hour is not 0. This bit is always read as 0.

Setting this bit has no effect when current hour is 0.

0: No effect

1: Subtracts 1 hour to the current time. This can be used for winter time change.

Bit 16 **ADD1H**: Add 1 hour (summer time change)

When this bit is set outside initialization mode, 1 hour is added to the calendar time. This bit is always read as 0.

0: No effect

1: Adds 1 hour to the current time. This can be used for summer time change

Bit 15 **TSIE**: Timestamp interrupt enable

0: Timestamp Interrupt disable

1: Timestamp Interrupt enable

Bit 14 **WUTIE**: Wakeup timer interrupt enable

0: Wakeup timer interrupt disabled

1: Wakeup timer interrupt enabled

Bit 13 **ALRBIE**: Alarm B interrupt enable

0: Alarm B Interrupt disable

1: Alarm B Interrupt enable

Bit 12 **ALRAIE**: Alarm A interrupt enable

0: Alarm A interrupt disabled

1: Alarm A interrupt enabled

Bit 11 **TSE**: Time stamp enable

0: Time stamp disable

1: Time stamp enable

Bit 10 **WUTE**: Wakeup timer enable

0: Wakeup timer disabled

1: Wakeup timer enabled

Bit 9 **ALRBE**: Alarm B enable

0: Alarm B disabled

1: Alarm B enabled

Bit 8 **ALRAE**: Alarm A enable

0: Alarm A disabled

1: Alarm A enabled

Bit 7 **DCE**: Coarse digital calibration enable

0: Digital calibration disabled

1: Digital calibration enabled

PREDIV\_A must be 6 or greater

Bit 6 **FMT**: Hour format

0: 24 hour/day format

1: AM/PM hour format

Bit 5 **BYPSHAD**: Bypass the shadow registers

0: Calendar values (when reading from RTC\_SSR, RTC\_TR, and RTC\_DR) are taken from the shadow registers, which are updated once every two RTCCLK cycles.

1: Calendar values (when reading from RTC\_SSR, RTC\_TR, and RTC\_DR) are taken directly from the calendar counters.

*Note: If the frequency of the APB1 clock is less than seven times the frequency of RTCCLK, BYPSHAD must be set to '1'.*

Bit 4 **REFCKON**: Reference clock detection enable (50 or 60 Hz)

- 0: Reference clock detection disabled
- 1: Reference clock detection enabled

*Note:* *PREDIV\_S* must be 0x00FF.

Bit 3 **TSEDGE**: Timestamp event active edge

- 0: TIMESTAMP rising edge generates a timestamp event
- 1: TIMESTAMP falling edge generates a timestamp event

TSE must be reset when TSEDGE is changed to avoid unwanted TSF setting

Bits 2:0 **WUCKSEL[2:0]**: Wakeup clock selection

- 000: RTC/16 clock is selected
- 001: RTC/8 clock is selected
- 010: RTC/4 clock is selected
- 011: RTC/2 clock is selected
- 10x: ck\_spre (usually 1 Hz) clock is selected
- 11x: ck\_spre (usually 1 Hz) clock is selected and  $2^{16}$  is added to the WUT counter value (see note below)

*Note:* *WUT* = Wakeup unit counter value. *WUT* = (0x0000 to 0xFFFF) + 0x10000 added when *WUCKSEL[2:1] = 11*.

Bits 7, 6 and 4 of this register can be written in initialization mode only (RTC\_ISR/INITF = 1).

Bits 2 to 0 of this register can be written only when RTC\_CR WUTE bit = 0 and RTC\_ISR WUTWF bit = 1.

*It is recommended not to change the hour during the calendar hour increment as it could mask the incrementation of the calendar hour.*

*ADD1H and SUB1H changes are effective in the next second.*

*This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).*

#### 17.6.4 RTC initialization and status register (RTC\_ISR)

Address offset: 0x0C

Backup domain reset value: 0x0000 0007

System reset value: Not affected except INIT, INITF and RSF which are cleared to 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	RECAL PF
Reserved															r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Res.	Res.	TAMP 1F	TSOVF	TSF	WUTF	ALRBF	ALRAF	INIT	INITF	RSF	INITS	SHPF	WUT WF	ALRB WF	ALRA WF	
		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rw	r	rc_w0	r	r	r	r	r	

Bits 31:17 Reserved

Bit 16 **RECALPF**: Recalibration pending Flag

The RECALPF status flag is automatically set to '1' when software writes to the RTC\_CALR register, indicating that the RTC\_CALR register is blocked. When the new calibration settings are taken into account, this bit returns to '0'. Refer to [Section : Re-calibration on-the-fly](#).

Bit 15:14 Reserved, must be kept at reset value.

Bit 13 **TAMP1F**: Tamper detection flag

This flag is set by hardware when a tamper detection event is detected.  
It is cleared by software writing 0.

Bit 12 **TSOVF**: Timestamp overflow flag

This flag is set by hardware when a timestamp event occurs while TSF is already set.  
This flag is cleared by software by writing 0. It is recommended to check and then clear TSOVF only after clearing the TSF bit. Otherwise, an overflow might not be noticed if a timestamp event occurs immediately before the TSF bit is cleared.

Bit 11 **TSF**: Timestamp flag

This flag is set by hardware when a timestamp event occurs.  
This flag is cleared by software by writing 0.

Bit 10 **WUTF**: Wakeup timer flag

This flag is set by hardware when the wakeup auto-reload counter reaches 0.  
This flag is cleared by software by writing 0.  
This flag must be cleared by software at least 1.5 RTCCCLK periods before WUTF is set to 1 again.

Bit 9 **ALRBF**: Alarm B flag

This flag is set by hardware when the time/date registers (RTC\_TR and RTC\_DR) match the Alarm B register (RTC\_ALRMBR).  
This flag is cleared by software by writing 0.

Bit 8 **ALRAF**: Alarm A flag

This flag is set by hardware when the time/date registers (RTC\_TR and RTC\_DR) match the Alarm A register (RTC\_ALRMAR).  
This flag is cleared by software by writing 0.

Bit 7 **INIT**: Initialization mode

0: Free running mode  
1: Initialization mode used to program time and date register (RTC\_TR and RTC\_DR), and prescaler register (RTC\_PRER). Counters are stopped and start counting from the new value when INIT is reset.

Bit 6 **INITF**: Initialization flag

When this bit is set to 1, the RTC is in initialization state, and the time, date and prescaler registers can be updated.  
0: Calendar registers update is not allowed  
1: Calendar registers update is allowed.

Bit 5 **RSF**: Registers synchronization flag

This bit is set by hardware each time the calendar registers are copied into the shadow registers (RTC\_SSRx, RTC\_TRx and RTC\_DRx). This bit is cleared by hardware in initialization mode, while a shift operation is pending (SHPF=1), or when in bypass shadow register mode (BYPSHAD=1). This bit can also be cleared by software.  
0: Calendar shadow registers not yet synchronized  
1: Calendar shadow registers synchronized

Bit 4 **INITS**: Initialization status flag

This bit is set by hardware when the calendar year field is different from 0 (backup domain reset value state).

- 0: Calendar has not been initialized
- 1: Calendar has been initialized

Bit 3 **SHPF**: Shift operation pending

- 0: No shift operation is pending
- 1: A shift operation is pending

This flag is set by hardware as soon as a shift operation is initiated by a write to the RTC\_SHIFTR. It is cleared by hardware when the corresponding shift operation has been executed. Writing to SHPF has no effect.

Bit 2 **WUTWF**: Wakeup timer write flag

This bit is set by hardware when the wakeup timer values can be changed, after the WUTE bit has been set to 0 in RTC\_CR.

- 0: Wakeup timer configuration update not allowed
- 1: Wakeup timer configuration update allowed

Bit 1 **ALRBWF**: Alarm B write flag

This bit is set by hardware when Alarm B values can be changed, after the ALRBIE bit has been set to 0 in RTC\_CR.

- It is cleared by hardware in initialization mode.
- 0: Alarm B update not allowed
- 1: Alarm B update allowed.

Bit 0 **ALRAWF**: Alarm A write flag

This bit is set by hardware when Alarm A values can be changed, after the ALRAE bit has been set to 0 in RTC\_CR.

- It is cleared by hardware in initialization mode.
- 0: Alarm A update not allowed
- 1: Alarm A update allowed

**Note:** The ALRAF, ALRBF, WUTF and TSF bits are cleared 2 APB clock cycles after programming them to 0.

This register is write protected (except for RTC\_ISR[13:8] bits). The write access procedure is described in [RTC register write protection on page 424](#).

### 17.6.5 RTC prescaler register (RTC\_PRER)

Address offset: 0x10

Backup domain reset value: 0x007F 00FF

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16					
Reserved														PREDIV_A[6:0]						
														<input type="rw"/>						
Res.														PREDIV_S[14:0]						
														<input type="rw"/>						

Bits 31:24 Reserved

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **PREDIV\_A[6:0]**: Asynchronous prescaler factor

This is the asynchronous division factor:

$$\text{ck_apre frequency} = \text{RTCCLK frequency}/(\text{PREDIV\_A}+1)$$

Bit 15 Reserved, must be kept at reset value.

Bits 14:0 **PREDIV\_S[14:0]**: Synchronous prescaler factor

This is the synchronous division factor:

$$\text{ck_spre frequency} = \text{ck_apre frequency}/(\text{PREDIV\_S}+1)$$

**Note:** *This register must be written in initialization mode only. The initialization must be performed in two separate write accesses. Refer to [Calendar initialization and configuration on page 424](#)*

*This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).*

## 17.6.6 RTC wakeup timer register (RTC\_WUTR)

Address offset: 0x14

Backup domain reset value: 0x0000 FFFF

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WUT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved

Bits 15:0 **WUT[15:0]**: Wakeup auto-reload value bits

When the wakeup timer is enabled (WUTE set to 1), the WUTF flag is set every (WUT[15:0] + 1) ck\_wut cycles. The ck\_wut period is selected through WUCKSEL[2:0] bits of the RTC\_CR register

When WUCKSEL[2] = 1, the wakeup timer becomes 17-bits and WUCKSEL[1] effectively becomes WUT[16] the most-significant bit to be reloaded into the timer.

**Note:** *The first assertion of WUTF occurs (WUT+1) ck\_wut cycles after WUTE is set. Setting WUT[15:0] to 0x0000 with WUCKSEL[2:0]=011 (RTCCLK/2) is forbidden.*

**Note:** *This register can be written only when WUTWF is set to 1 in RTC\_ISR.*

*This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).*

## 17.6.7 RTC calibration register (RTC\_CALIBR)

Address offset: 0x18

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved																
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved								DCS	Reserved		DC[4:0]					
								rw			rw			rw		

Bits 31:8 Reserved

Bit 7 **DCS**: Digital calibration sign

0: Positive calibration: calendar update frequency is increased

1: Negative calibration: calendar update frequency is decreased

Bits 6:5 Reserved, must be kept at reset value.

Bits 4:0 **DC[4:0]**: Digital calibration

DCS = 0 (positive calibration)

00000: + 0 ppm

00001: + 4 ppm (rounded value)

00010: + 8 ppm (rounded value)

..

11111: + 126 ppm (rounded value)

DCS = 1 (negative calibration)

00000: - 0 ppm

00001: - 2 ppm (rounded value)

00010: - 4 ppm (rounded value)

..

11111: - 63 ppm (rounded value)

Refer to [Case of RTCCLK=32.768 kHz and PREDIV\\_A+1=128 on page 428](#) for the exact step value.

**Note:** This register can be written in initialization mode only (RTC\_ISR/INITF = '1').

This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).

### 17.6.8 RTC alarm A register (RTC\_ALRMAR)

Address offset: 0x1C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MSK4	WDSEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

- Bit 31 **MSK4**: Alarm A date mask  
 0: Alarm A set if the date/day match  
 1: Date/day don't care in Alarm A comparison
- Bit 30 **WDSEL**: Week day selection  
 0: DU[3:0] represents the date units  
 1: DU[3:0] represents the week day. DT[1:0] is don't care.
- Bits 29:28 **DT[1:0]**: Date tens in BCD format.
- Bits 27:24 **DU[3:0]**: Date units or day in BCD format.
- Bit 23 **MSK3**: Alarm A hours mask  
 0: Alarm A set if the hours match  
 1: Hours don't care in Alarm A comparison
- Bit 22 **PM**: AM/PM notation  
 0: AM or 24-hour format  
 1: PM
- Bits 21:20 **HT[1:0]**: Hour tens in BCD format.
- Bits 19:16 **HU[3:0]**: Hour units in BCD format.
- Bit 15 **MSK2**: Alarm A minutes mask  
 0: Alarm A set if the minutes match  
 1: Minutes don't care in Alarm A comparison
- Bits 14:12 **MNT[2:0]**: Minute tens in BCD format.
- Bits 11:8 **MNU[3:0]**: Minute units in BCD format.
- Bit 7 **MSK1**: Alarm A seconds mask  
 0: Alarm A set if the seconds match  
 1: Seconds don't care in Alarm A comparison
- Bits 6:4 **ST[2:0]**: Second tens in BCD format.
- Bits 3:0 **SU[3:0]**: Second units in BCD format.

**Note:** This register can be written only when ALRAWF is set to 1 in RTC\_ISR, or in initialization mode.

This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).

### 17.6.9 RTC alarm B register (RTC\_ALRMBR)

Address offset: 0x20

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MSK4	WDSEL	<b>DT[1:0]</b>		<b>DU[3:0]</b>				MSK3	PM	<b>HT[1:0]</b>		<b>HU[3:0]</b>			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSK2	MNT[2:0]				MNU[3:0]				MSK1	ST[2:0]				SU[3:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **MSK4**: Alarm B date mask

- 0: Alarm B set if the date and day match
- 1: Date and day don't care in Alarm B comparison

Bit 30 **WDSEL**: Week day selection

- 0: DU[3:0] represents the date units
- 1: DU[3:0] represents the week day. DT[1:0] is don't care.

Bits 29:28 **DT[1:0]**: Date tens in BCD format

Bits 27:24 **DU[3:0]**: Date units or day in BCD format

Bit 23 **MSK3**: Alarm B hours mask

- 0: Alarm B set if the hours match
- 1: Hours don't care in Alarm B comparison

Bit 22 **PM**: AM/PM notation

- 0: AM or 24-hour format
- 1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 **MSK2**: Alarm B minutes mask

- 0: Alarm B set if the minutes match
- 1: Minutes don't care in Alarm B comparison

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bits 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 **MSK1**: Alarm B seconds mask

- 0: Alarm B set if the seconds match
- 1: Seconds don't care in Alarm B comparison

Bits 6:4 **ST[2:0]**: Second tens in BCD format

Bits 3:0 **SU[3:0]**: Second units in BCD format

**Note:** This register can be written only when ALRBWF is set to 1 in RTC\_ISR, or in initialization mode.

This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#).

### 17.6.10 RTC write protection register (RTC\_WPR)

Address offset: 0x24

Backup domain reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								KEY							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **KEY**: Write protection key

This byte is written by software.

Reading this byte always returns 0x00.

Refer to [RTC register write protection](#) for a description of how to unlock RTC register write protection.

### 17.6.11 RTC sub second register (RTC\_SSR)

Address offset: 0x28

Backup domain reset value: 0x0000 0000

System reset: 0x0000 0000 when BYPSHAD = 0. Not affected when BYPSHAD = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved

Bits 15:0 **SS**: Sub second value

SS[15:0] is the value in the synchronous prescaler's counter. The fraction of a second is given by the formula below:

Second fraction = ( PREDIV\_S - SS ) / ( PREDIV\_S + 1 )

*Note: SS can be larger than PREDIV\_S only after a shift operation. In that case, the correct time/date is one second less than as indicated by RTC\_TR/RTC\_DR.*

### 17.6.12 RTC shift control register (RTC\_SHIFTR)

Address offset: 0x2C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD1S	Reserved														
w	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SUBFS[14:0]														
r	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **ADD1S**: Add one second

0: No effect

1: Add one second to the clock/calendar

This bit is write only and is always read as zero. Writing to this bit has no effect when a shift operation is pending (when SHPF=1, in RTC\_ISR).

This function is intended to be used with SUBFS (see description below) in order to effectively add a fraction of a second to the clock in an atomic operation.

Bits 30:15 Reserved

Bits 14:0 **SUBFS**: Subtract a fraction of a second

These bits are write only and is always read as zero. Writing to this bit has no effect when a shift operation is pending (when SHPF=1, in RTC\_ISR).

The value which is written to SUBFS is added to the synchronous prescaler's counter. Since this counter counts down, this operation effectively subtracts from (delays) the clock by:

Delay (seconds) = SUBFS / ( PREDIV\_S + 1 )

A fraction of a second can effectively be added to the clock (advancing the clock) when the ADD1S function is used in conjunction with SUBFS, effectively advancing the clock by:

Advance (seconds) = ( 1 - ( SUBFS / ( PREDIV\_S + 1 ) ) ).

*Note: Writing to SUBFS causes RSF to be cleared. Software can then wait until RSF=1 to be sure that the shadow registers have been updated with the shifted time.*

Refer to [Section 17.3.8: RTC synchronization](#).

**Note:** This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#)

### 17.6.13 RTC time stamp time register (RTC\_TSTR)

Address offset: 0x30

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved									PM	HT[1:0]		HU[3:0]			
									r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	r	r	r	r	r	r	r		r	r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **PM**: AM/PM notation

- 0: AM or 24-hour format
- 1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format.

Bits 19:16 **HU[3:0]**: Hour units in BCD format.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format.

Bits 11:8 **MNU[3:0]**: Minute units in BCD format.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ST[2:0]**: Second tens in BCD format.

Bits 3:0 **SU[3:0]**: Second units in BCD format.

**Note:** *The content of this register is valid only when TSF is set to 1 in RTC\_ISR. It is cleared when TSF bit is reset.*

#### 17.6.14 RTC time stamp date register (RTC\_TSDR)

Address offset: 0x34

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDU[1:0]	MT		MU[3:0]				Reserved	DT[1:0]			DU[3:0]				
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:13 **WDU[1:0]**: Week day units

Bit 12 **MT**: Month tens in BCD format

Bits 11:8 **MU[3:0]**: Month units in BCD format

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **DT[1:0]**: Date tens in BCD format

Bit 3:0 **DU[3:0]**: Date units in BCD format

**Note:** *The content of this register is valid only when TSF is set to 1 in RTC\_ISR. It is cleared when TSF bit is reset.*

### 17.6.15 RTC timestamp sub second register (RTC\_TSSSR)

Address offset: 0x38

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved

Bits 15:0 **SS**: Sub second value

SS[15:0] is the value of the synchronous prescaler's counter when the timestamp event occurred.

**Note:** The content of this register is valid only when RTC\_ISR/TSF is set. It is cleared when the RTC\_ISR/TSF bit is reset.

### 17.6.16 RTC calibration register (RTC\_CALR)

Address offset: 0x3C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CALP	CALW8	CALW16	Reserved				CALM[8:0]								
rw	rw	rw	r	r	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31:16 Reserved

Bit 15 **CALP**: Increase frequency of RTC by 488.5 ppm

0: No RTCCLK pulses are added.

1: One RTCCLK pulse is effectively inserted every  $2^{11}$  pulses (frequency increased by 488.5 ppm).

This feature is intended to be used in conjunction with CALM, which lowers the frequency of the calendar with a fine resolution. If the input frequency is 32768 Hz, the number of RTCCLK pulses added during a 32-second window is calculated as follows:  $(512 * \text{CALP}) - \text{CALM}$ .

Refer to [Section 17.3.11: RTC smooth digital calibration](#).

Bit 14 **CALW8**: Use an 8-second calibration cycle period

When CALW8 is set to '1', the 8-second calibration cycle period is selected.

CALM[1:0] are stuck at "00" when CALW8='1'.

Refer to [Section 17.3.11: RTC smooth digital calibration](#).

Bit 13 **CALW16**: Use a 16-second calibration cycle period

When CALW16 is set to '1', the 16-second calibration cycle period is selected. This bit must not be set to '1' if CALW8=1.

Note: CALM[0] is stuck at '0' when CALW16='1'.

Refer to [Section 17.3.11: RTC smooth digital calibration](#).

Bits 12:9 Reserved

Bits 8:0 **CALM[8:0]**: Calibration minus

The frequency of the calendar is reduced by masking CALM out of  $2^{20}$  RTCCLK pulses (32 seconds if the input frequency is 32768 Hz). This decreases the frequency of the calendar with a resolution of 0.9537 ppm.

To increase the frequency of the calendar, this feature should be used in conjunction with CALP.

See [Section 17.3.11: RTC smooth digital calibration on page 429](#).

**Note:** This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#)

### 17.6.17 RTC tamper and alternate function configuration register (RTC\_TAFCR)

Address offset: 0x40

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
ALARMOUT TYPE										TSIN SEL		TAMP1 INSEL			
rw										rw		rw			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TAMP- PUDIS	TAMP- PRCH[1:0]		TAMPFLT[1:0]		TAMPFREQ[2:0]			TAMPT S	Reserved				TAMPIE	TAMP1 TRG	TAMP1 E
rw	rw	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw

Bits 31:19 Reserved. Always read as 0.

Bit 18 **ALARMOUTTYPE**: RTC\_ALARM output type

- 0: RTC\_ALARM is an open-drain output
- 1: RTC\_ALARM is a push-pull output

Bit 17 **TSINSEL**: TIMESTAMP mapping

- 0: RTC\_AF1 used as TIMESTAMP
- 1: Reserved

Bit 16 **TAMP1INSEL**: TAMPER1 mapping

- 0: RTC\_AF1 used as TAMPER1
- 1: Reserved

Bit 15 **TAMPPUDIS**: TAMPER pull-up disable

This bit determines if each of the tamper pins are pre-charged before each sample.

- 0: Precharge tamper pins before sampling (enable internal pull-up)

- 1: Disable precharge of tamper pins

*Note:*

Bits 14:13 **TAMPPRCH[1:0]**: Tamper precharge duration

These bit determines the duration of time during which the pull-up/is activated before each sample. TAMPPRCH is valid for each of the tamper inputs.

0x0: 1 RTCCLK cycle

0x1: 2 RTCCLK cycles

0x2: 4 RTCCLK cycles

0x3: 8 RTCCLK cycles

Bits 12:11 **TAMPFLT[1:0]**: Tamper filter count

These bits determines the number of consecutive samples at the specified level (TAMP\*TRG) necessary to activate a Tamper event. TAMPFLT is valid for each of the tamper inputs.

0x0: Tamper is activated on edge of tamper input transitions to the active level (no internal pull-up on tamper input).

0x1: Tamper is activated after 2 consecutive samples at the active level.

0x2: Tamper is activated after 4 consecutive samples at the active level.

0x3: Tamper is activated after 8 consecutive samples at the active level.

Bits 10:8 **TAMPFREQ[2:0]**: Tamper sampling frequency

Determines the frequency at which each of the tamper inputs are sampled.  
 0x0: RTCCLK / 32768 (1 Hz when RTCCLK = 32768 Hz)  
 0x1: RTCCLK / 16384 (2 Hz when RTCCLK = 32768 Hz)  
 0x2: RTCCLK / 8192 (4 Hz when RTCCLK = 32768 Hz)  
 0x3: RTCCLK / 4096 (8 Hz when RTCCLK = 32768 Hz)  
 0x4: RTCCLK / 2048 (16 Hz when RTCCLK = 32768 Hz)  
 0x5: RTCCLK / 1024 (32 Hz when RTCCLK = 32768 Hz)  
 0x6: RTCCLK / 512 (64 Hz when RTCCLK = 32768 Hz)  
 0x7: RTCCLK / 256 (128 Hz when RTCCLK = 32768 Hz)

Bit 7 **TAMPTS**: Activate timestamp on tamper detection event

0: Tamper detection event does not cause a timestamp to be saved  
 1: Save timestamp on tamper detection event  
 TAMPTS is valid even if TSE=0 in the RTC\_CR register.

Bits 6:3 Reserved. Always read as 0.

Bit 2 **TAMPIE**: Tamper interrupt enable

0: Tamper interrupt disabled  
 1: Tamper interrupt enabled

Bit 1 **TAMP1TRG**: Active level for tamper 1

if TAMPFLT != 00 (Cat.4 and Cat.3 device only)  
 0: TAMPER1 staying low triggers a tamper detection event.  
 1: TAMPER1 staying high triggers a tamper detection event.  
if TAMPFLT = 00:  
 0: TAMPER1 rising edge triggers a tamper detection event.  
 1: TAMPER1 falling edge triggers a tamper detection event.

**Caution:** When TAMPFLT = 0, TAMP1E must be reset when TAMP1TRG is changed to avoid spuriously setting TAMP1F.

Bit 0 **TAMP1E**: Tamper 1 detection enable

0: Tamper 1 detection disabled  
 1: Tamper 1 detection enabled

### 17.6.18 RTC alarm A sub second register (RTC\_ALRMASSR)

Address offset: 0x44

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				MASKSS[3:0]				Reserved							
r	r	r	r	rw	rw	rw	rw	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		SS[14:0]													
r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw	rw

Bits 31:28 Reserved

Bits 27:24 **MASKSS[3:0]**: Mask the most-significant bits starting at this bit

0: No comparison on sub seconds for Alarm A. The alarm is set when the seconds unit is incremented (assuming that the rest of the fields match).

1: SS[14:1] are don't care in Alarm A comparison. Only SS[0] is compared.

2: SS[14:2] are don't care in Alarm A comparison. Only SS[1:0] are compared.

3: SS[14:3] are don't care in Alarm A comparison. Only SS[2:0] are compared.

...

12: SS[14:12] are don't care in Alarm A comparison. SS[11:0] are compared.

13: SS[14:13] are don't care in Alarm A comparison. SS[12:0] are compared.

14: SS[14] is don't care in Alarm A comparison. SS[13:0] are compared.

15: All 15 SS bits are compared and must match to activate alarm.

The overflow bits of the synchronous counter (bits 15) is never compared. This bit can be different from 0 only after a shift operation.

Bits 23:15 Reserved

Bits 14:0 **SS[14:0]**: Sub seconds value

This value is compared with the contents of the synchronous prescaler's counter to determine if Alarm A is to be activated. Only bits 0 up MASKSS-1 are compared.

**Note:** *This register can be written only when ALRAE is reset in RTC\_CR register, or in initialization mode.*

*This register is write protected. The write access procedure is described in [RTC register write protection on page 424](#)*

### 17.6.19 RTC alarm B sub second register (RTC\_ALRMBSSR)

Address offset: 0x48

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved				MASKSS[3:0]				Reserved							
r	r	r	r	rw	rw	rw	rw	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	SS[14:0]														
r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bits 31:28 Reserved

Bits 27:24 **MASKSS[3:0]**: Mask the most-significant bits starting at this bit

0x0: No comparison on sub seconds for Alarm B. The alarm is set when the seconds unit is incremented (assuming that the rest of the fields match).

0x1: SS[14:1] are don't care in Alarm B comparison. Only SS[0] is compared.

0x2: SS[14:2] are don't care in Alarm B comparison. Only SS[1:0] are compared.

0x3: SS[14:3] are don't care in Alarm B comparison. Only SS[2:0] are compared.

...

0xC: SS[14:12] are don't care in Alarm B comparison. SS[11:0] are compared.

0xD: SS[14:13] are don't care in Alarm B comparison. SS[12:0] are compared.

0xE: SS[14] is don't care in Alarm B comparison. SS[13:0] are compared.

0xF: All 15 SS bits are compared and must match to activate alarm.

The overflow bits of the synchronous counter (bits 15) is never compared. This bit can be different from 0 only after a shift operation.

Bits 23:15 Reserved

Bits 14:0 **SS[14:0]**: Sub seconds value

This value is compared with the contents of the synchronous prescaler's counter to determine if Alarm B is to be activated. Only bits 0 up to MASKSS-1 are compared.

**Note:** *This register can be written only when ALRBIE is reset in RTC\_CR register, or in initialization mode.*

*This register is write protected. The write access procedure is described in [Section : RTC register write protection](#)*

### 17.6.20 RTC backup registers (RTC\_BKPxR)

Address offset: 0x50 to 0x9C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BKP[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BKP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bits 31:0 BKP[31:0]

The application can write or read data to and from these registers.

They are powered-on by V<sub>BAT</sub> when V<sub>DD</sub> is switched off, so that they are not reset by System reset, and their contents remain valid when the device operates in low-power mode. This register is reset on a tamper detection event, as long as TAMPxF=1

### 17.6.21 RTC register map

Table 67. RTC register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
0x00	RTC_TR	Reserved				PM	HT [1:0]		HU[3:0]			Reserved	MNT[2:0]			MNU[3:0]			Reserved	ST[2:0]			SU[3:0]			DT [1:0]			DU[3:0]					
	Reset value	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0x04	RTC_DR	Reserved				YT[3:0]			YU[3:0]			WDU[2:0]	MT		MU[3:0]			Reserved	DT [1:0]			DU[3:0]			DT [1:0]			DU[3:0]						
	Reset value	0	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1					
0x08	RTC_CR	Reserved				COE	OSEL [1:0]		POL	COSEL	BKP	SUB1H		ADD1H		TSIE	WUTIE		ALRBIE	ALRAIE		TSE	WUTE		ALRBEE	ALRAEE		DCE	FMT		WCKSEL [2:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0x0C	RTC_ISR	Reserved																																
	Reset value																																	
0x10	RTC_PRER	Reserved				PREDIV_A[6:0]						Reserved	PREDIV_S[14:0]																					
	Reset value					1	1	1	1	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0x14	RTC_WUTR	Reserved												WUT[15:0]																				
	Reset value													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		

Table 67. RTC register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
0x18	RTC_CALIBR	Reserved																				DCS	DC[4:0]		0	0	0	0	0					
	Reset value																																	
0x1C	RTC_ALRMAR	MSK4	WDSEL	DT [1:0]	DU[3:0]			MSK3	PM	HT [1:0]	HU[3:0]			MSK2	MNT[2:0]			MNU[3:0]	MSK1			ST[2:0]	SU[3:0]			Reserved		DCS						
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x20	RTC_ALRMBR	MSK4	WDSEL	DT [1:0]	DU[3:0]			MSK3	PM	HT [1:0]	HU[3:0]			MSK2	MNT[2:0]			MNU[3:0]	MSK1			ST[2:0]	SU[3:0]			Reserved		DCS						
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x24	RTC_WPR	Reserved																											KEY[7:0]					
	Reset value																												0	0	0	0	0	
0x28	RTC_SSR	Reserved												SS[15:0]															Reserved					
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x30	RTC_TSTR	Reserved						PM	HT[1:0]		HU[3:0]			Reserved	MNT[2:0]			MNU[3:0]			Reserved	ST[2:0]		SU[3:0]			Reserved		Reserved					
	Reset value							0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x38	RTC_TSSSR	Reserved												SS[15:0]															Reserved					
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x3C	RTC_CALR	Reserved												CALP	CALW8		CALW16	Reserved			CALM[8:0]		Reserved		Reserved		Reserved		Reserved					
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x40	RTC_TAFCR	Reserved												ALARMOUTTYPE	TINSEL		TAMP1INSEL	TAMPPRCH[1:0]			TAMPFLT[1:0]	TAMPFREQ[2:0]			TAMPSTS	Reserved			TAMPIE		TAMP1ETRG		TAMP1IE	
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x44	RTC_ALRMASSR	Reserved				MASKSS[3:0]				Reserved												SS[14:0]							Reserved					
	Reset value					0	0	0	0													0	0	0	0	0	0	0	0	0	0			
0x48	RTC_ALRMBSSR	Reserved				MASKSS[3:0]				Reserved												SS[14:0]							Reserved					
	Reset value					0	0	0	0													0	0	0	0	0	0	0	0	0	0			

Table 67. RTC register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x50 to 0x9C	RTC_BKP0R																																
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	to RTC_BKP19R																																
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Refer to [Table 1 on page 38](#) for the register boundary addresses.

**Caution:** In [Table 67](#), the reset value is the value after a backup domain reset. The majority of the registers are not affected by a system reset. For more information, please refer to [Section 17.3.7: Resetting the RTC](#).

## 18 Inter-integrated circuit ( $I^2C$ ) interface

### 18.1 $I^2C$ introduction

$I^2C$  (inter-integrated circuit) bus Interface serves as an interface between the microcontroller and the serial  $I^2C$  bus. It provides multimaster capability, and controls all  $I^2C$  bus-specific sequencing, protocol, arbitration and timing. It supports the standard mode (Sm, up to 100 kHz) and Fm mode (Fm, up to 400 kHz). The I $^2$ C bus frequency can be increased up to 1 MHz. For more details about the complete solution, please contact your local ST sales representative.

It may be used for a variety of purposes, including CRC generation and verification, SMBus (system management bus) and PMBus (power management bus).

## 18.2 I<sup>2</sup>C main features

- Parallel-bus/I<sup>2</sup>C protocol converter
- Multimaster capability: the same interface can act as Master or Slave
- I<sup>2</sup>C Master features:
  - Clock generation
  - Start and Stop generation
- I<sup>2</sup>C Slave features:
  - Programmable I<sup>2</sup>C Address detection
  - Dual Addressing Capability to acknowledge 2 slave addresses
  - Stop bit detection
- Generation and detection of 7-bit/10-bit addressing and General Call
- Supports different communication speeds:
  - Standard Speed (up to 100 kHz)
  - Fast Speed (up to 400 kHz)
  - The I<sup>2</sup>C bus frequency can be increased up to 1 MHz. For more details about the complete solution, please contact your local ST sales representative
- Analog noise filter
- Programmable digital noise filter
- Status flags:
  - Transmitter/Receiver mode flag
  - End-of-Byte transmission flag
  - I<sup>2</sup>C busy flag
- Error flags:
  - Arbitration lost condition for master mode
  - Acknowledgment failure after address/ data transmission
  - Detection of misplaced start or stop condition
  - Overrun/Underrun if clock stretching is disabled
- 2 Interrupt vectors:
  - 1 Interrupt for successful address/ data communication
  - 1 Interrupt for error condition
- Optional clock stretching
- 1-byte buffer with DMA capability
- Configurable PEC (packet error checking) generation or verification:
  - PEC value can be transmitted as last byte in Tx mode
  - PEC error checking for last received byte
- SMBus 2.0 Compatibility:
  - 25 ms clock low timeout delay
  - 10 ms master cumulative clock low extend time
  - 25 ms slave cumulative clock low extend time
  - Hardware PEC generation/verification with ACK control
  - Address Resolution Protocol (ARP) supported
- PMBus Compatibility

**Note:** Some of the above features may not be available in certain products. The user should refer to the product data sheet, to identify the specific features supported by the  $I^2C$  interface implementation.

## 18.3 $I^2C$ functional description

In addition to receiving and transmitting data, this interface converts it from serial to parallel format and vice versa. The interrupts are enabled or disabled by software. The interface is connected to the  $I^2C$  bus by a data pin (SDA) and by a clock pin (SCL). It can be connected with a standard (up to 100 kHz) or fast (up to 400 kHz)  $I^2C$  bus.

### 18.3.1 Mode selection

The interface can operate in one of the four following modes:

- Slave transmitter
- Slave receiver
- Master transmitter
- Master receiver

By default, it operates in slave mode. The interface automatically switches from slave to master, after it generates a START condition and from master to slave, if an arbitration loss or a Stop generation occurs, allowing multimaster capability.

#### Communication flow

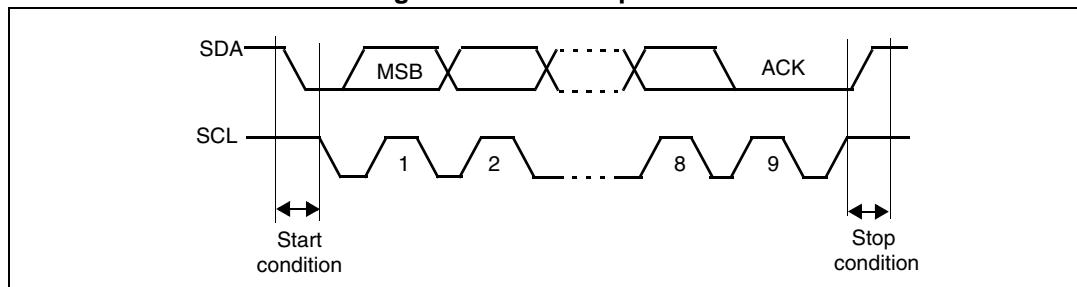
In Master mode, the  $I^2C$  interface initiates a data transfer and generates the clock signal. A serial data transfer always begins with a start condition and ends with a stop condition. Both start and stop conditions are generated in master mode by software.

In Slave mode, the interface is capable of recognizing its own addresses (7 or 10-bit), and the General Call address. The General Call address detection may be enabled or disabled by software.

Data and addresses are transferred as 8-bit bytes, MSB first. The first byte(s) following the start condition contain the address (one in 7-bit mode, two in 10-bit mode). The address is always transmitted in Master mode.

A 9th clock pulse follows the 8 clock cycles of a byte transfer, during which the receiver must send an acknowledge bit to the transmitter. Refer to [Figure 160](#).

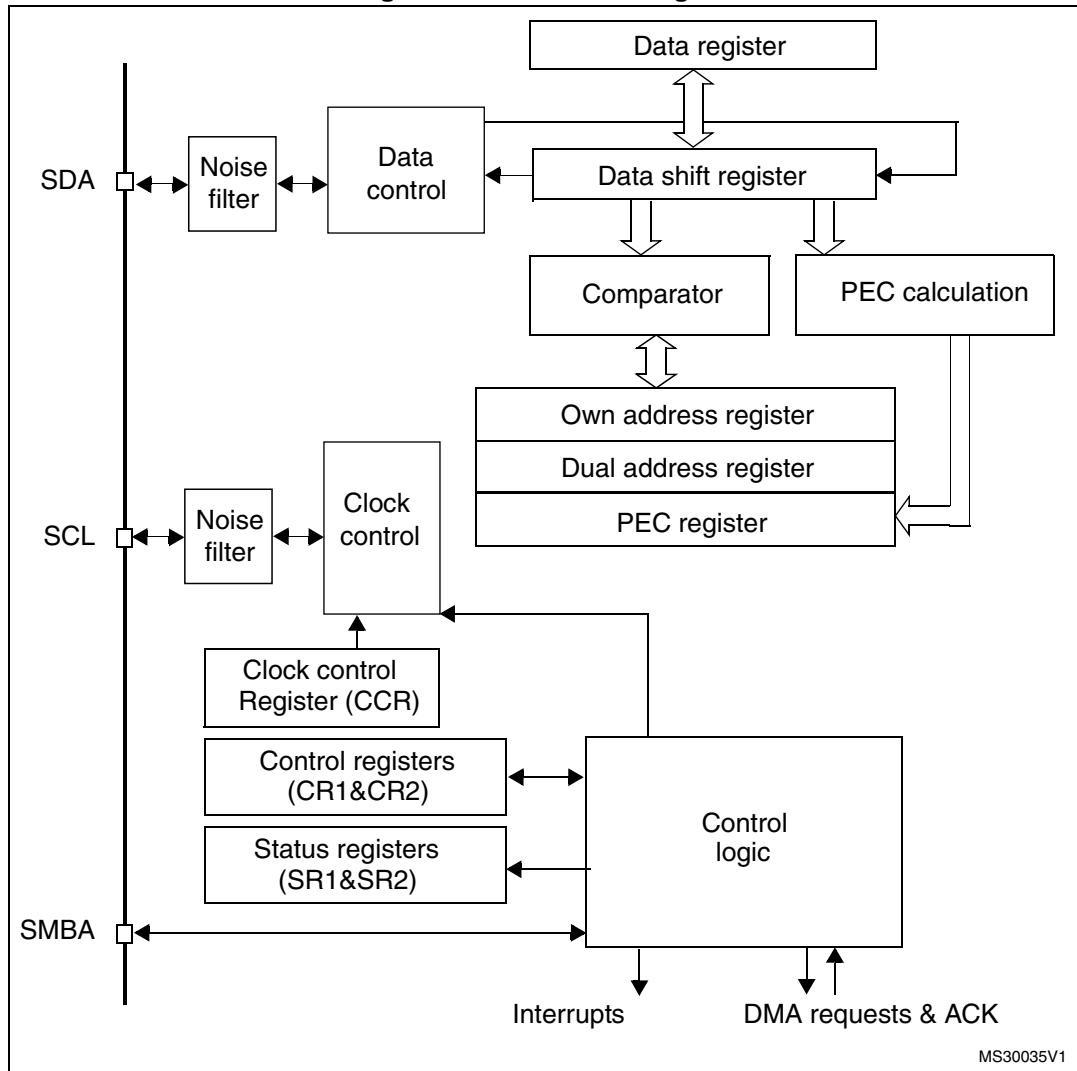
**Figure 160.  $I^2C$  bus protocol**



Acknowledge may be enabled or disabled by software. The  $I^2C$  interface addresses (dual addressing 7-bit/ 10-bit and/or general call address) can be selected by software.

The block diagram of the I<sup>2</sup>C interface is shown in [Figure 161](#).

**Figure 161. I<sup>2</sup>C block diagram**



1. SMBA is an optional signal in SMBus mode. This signal is not applicable if SMBus is disabled.

### 18.3.2 I<sup>2</sup>C slave mode

By default the I<sup>2</sup>C interface operates in Slave mode. To switch from default Slave mode to Master mode a Start condition generation is needed.

The peripheral input clock must be programmed in the I2C\_CR2 register in order to generate correct timings. The peripheral input clock frequency must be at least:

- 2 MHz in Sm mode
- 4 MHz in Fm mode

As soon as a start condition is detected, the address is received from the SDA line and sent to the shift register. Then it is compared with the address of the interface (OAR1) and with OAR2 (if ENDUAL=1) or the General Call address (if ENGC = 1).

**Note:** In 10-bit addressing mode, the comparison includes the header sequence (11110xx0), where xx denotes the two most significant bits of the address.

**Header or address not matched:** the interface ignores it and waits for another Start condition.

**Header matched** (10-bit mode only): the interface generates an acknowledge pulse if the ACK bit is set and waits for the 8-bit slave address.

**Address matched:** the interface generates in sequence:

- An acknowledge pulse if the ACK bit is set
- The ADDR bit is set by hardware and an interrupt is generated if the ITEVFEN bit is set.
- If ENDUAL=1, the software has to read the DUALF bit to check which slave address has been acknowledged.

In 10-bit mode, after receiving the address sequence the slave is always in Receiver mode. It will enter Transmitter mode on receiving a repeated Start condition followed by the header sequence with matching address bits and the least significant bit set (11110xx1).

The TRA bit indicates whether the slave is in Receiver or Transmitter mode.

### Slave transmitter

Following the address reception and after clearing ADDR, the slave sends bytes from the DR register to the SDA line via the internal shift register.

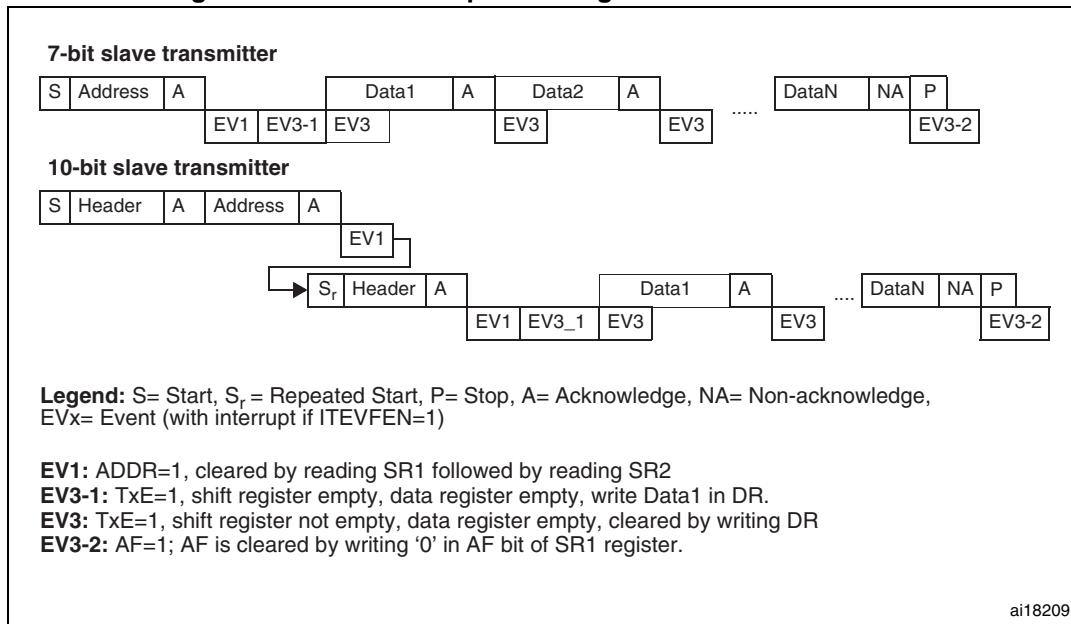
The slave stretches SCL low until ADDR is cleared and DR filled with the data to be sent (see [Figure 162 Transfer sequencing EV1 EV3](#)).

When the acknowledge pulse is received:

- The TxE bit is set by hardware with an interrupt if the ITEVFEN and the ITBUFEN bits are set.

If TxE is set and some data were not written in the I2C\_DR register before the end of the next data transmission, the BTF bit is set and the interface waits until BTF is cleared by a read to I2C\_SR1 followed by a write to the I2C\_DR register, stretching SCL low.

Figure 162. Transfer sequence diagram for slave transmitter



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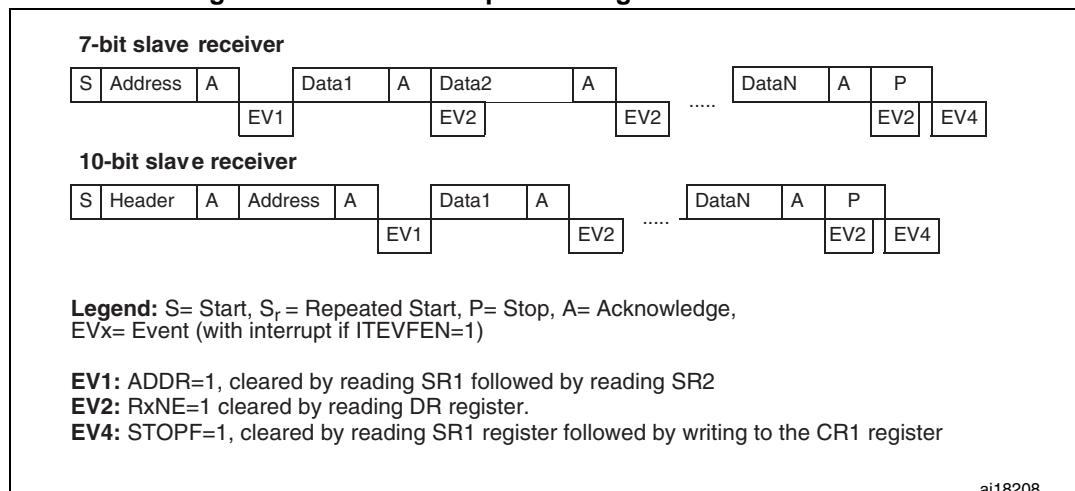
1. The EV1 and EV3\_1 events stretch SCL low until the end of the corresponding software sequence.
2. The EV3 event stretches SCL low if the software sequence is not completed before the end of the next byte transmission

### Slave receiver

Following the address reception and after clearing ADDR, the slave receives bytes from the SDA line into the DR register via the internal shift register. After each byte the interface generates in sequence:

- An acknowledge pulse if the ACK bit is set
- The RxNE bit is set by hardware and an interrupt is generated if the ITEVFEN and ITBUFEN bit is set.

If RxNE is set and the data in the DR register is not read before the end of the next data reception, the BTF bit is set and the interface waits until BTF is cleared by a read from the I2C\_DR register, stretching SCL low (see [Figure 163 Transfer sequencing](#)).

**Figure 163. Transfer sequence diagram for slave receiver**

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1. The EV1 event stretches SCL low until the end of the corresponding software sequence.
2. The EV2 event stretches SCL low if the software sequence is not completed before the end of the next byte reception.
3. After checking the SR1 register content, the user should perform the complete clearing sequence for each flag found set.  
Thus, for ADDR and STOPF flags, the following sequence is required inside the I2C interrupt routine:  
READ SR1  
if (ADDR == 1) {READ SR1; READ SR2}  
if (STOPF == 1) {READ SR1; WRITE CR1}  
The purpose is to make sure that both ADDR and STOPF flags are cleared if both are found set.

### Closing slave communication

After the last data byte is transferred a Stop Condition is generated by the master. The interface detects this condition and sets:

- The STOPF bit and generates an interrupt if the ITEVFEN bit is set.

The STOPF bit is cleared by a read of the SR1 register followed by a write to the CR1 register (see [Figure 163: Transfer sequence diagram for slave receiver](#) EV4).

### 18.3.3 I<sup>2</sup>C master mode

In Master mode, the I<sup>2</sup>C interface initiates a data transfer and generates the clock signal. A serial data transfer always begins with a Start condition and ends with a Stop condition. Master mode is selected as soon as the Start condition is generated on the bus with a START bit.

The following is the required sequence in master mode.

- Program the peripheral input clock in I2C\_CR2 Register in order to generate correct timings
- Configure the clock control registers
- Configure the rise time register
- Program the I2C\_CR1 register to enable the peripheral
- Set the START bit in the I2C\_CR1 register to generate a Start condition

The peripheral input clock frequency must be at least:

- 2 MHz in Sm mode
- 4 MHz in Fm mode

## SCL master clock generation

The CCR bits are used to generate the high and low level of the SCL clock, starting from the generation of the rising and falling edge (respectively). As a slave may stretch the SCL line, the peripheral checks the SCL input from the bus at the end of the time programmed in TRISE bits after rising edge generation.

- If the SCL line is low, it means that a slave is stretching the bus, and the high level counter stops until the SCL line is detected high. This allows to guarantee the minimum HIGH period of the SCL clock parameter.
- If the SCL line is high, the high level counter keeps on counting.

Indeed, the feedback loop from the SCL rising edge generation by the peripheral to the SCL rising edge detection by the peripheral takes time even if no slave stretches the clock. This loopback duration is linked to the SCL rising time (impacting SCL VIH input detection), plus delay due to the noise filter present on the SCL input path, plus delay due to internal SCL input synchronization with APB clock. The maximum time used by the feedback loop is programmed in the TRISE bits, so that the SCL frequency remains stable whatever the SCL rising time.

## Start condition

Setting the START bit causes the interface to generate a Start condition and to switch to Master mode (MSL bit set) when the BUSY bit is cleared.

*Note:* In master mode, setting the START bit causes the interface to generate a ReStart condition at the end of the current byte transfer.

Once the Start condition is sent:

- The SB bit is set by hardware and an interrupt is generated if the ITEVFEN bit is set.

Then the master waits for a read of the SR1 register followed by a write in the DR register with the Slave address (see [Figure 164](#) and [Figure 165](#) Transfer sequencing EV5).

## Slave address transmission

Then the slave address is sent to the SDA line via the internal shift register.

- In 10-bit addressing mode, sending the header sequence causes the following event:
  - The ADD10 bit is set by hardware and an interrupt is generated if the ITEVFEN bit is set.

Then the master waits for a read of the SR1 register followed by a write in the DR register with the second address byte (see [Figure 164](#) and [Figure 165](#) Transfer sequencing).

- The ADDR bit is set by hardware and an interrupt is generated if the ITEVFEN bit is set.

Then the master waits for a read of the SR1 register followed by a read of the SR2 register (see [Figure 164](#) and [Figure 165](#) Transfer sequencing).

- In 7-bit addressing mode, one address byte is sent.

As soon as the address byte is sent,

- The ADDR bit is set by hardware and an interrupt is generated if the ITEVFEN bit is set.

Then the master waits for a read of the SR1 register followed by a read of the SR2 register (see [Figure 164](#) and [Figure 165](#) Transfer sequencing).

The master can decide to enter Transmitter or Receiver mode depending on the LSB of the slave address sent.

- In 7-bit addressing mode,
  - To enter Transmitter mode, a master sends the slave address with LSB reset.
  - To enter Receiver mode, a master sends the slave address with LSB set.
- In 10-bit addressing mode,
  - To enter Transmitter mode, a master sends the header (11110xx0) and then the slave address, (where xx denotes the two most significant bits of the address).
  - To enter Receiver mode, a master sends the header (11110xx0) and then the slave address. Then it should send a repeated Start condition followed by the header (11110xx1), (where xx denotes the two most significant bits of the address).

The TRA bit indicates whether the master is in Receiver or Transmitter mode.

### Master transmitter

Following the address transmission and after clearing ADDR, the master sends bytes from the DR register to the SDA line via the internal shift register.

The master waits until the first data byte is written into I2C\_DR (see [Figure 164 Transfer sequencing EV8\\_1](#)).

When the acknowledge pulse is received, the TxE bit is set by hardware and an interrupt is generated if the ITEVFEN and ITBUFEN bits are set.

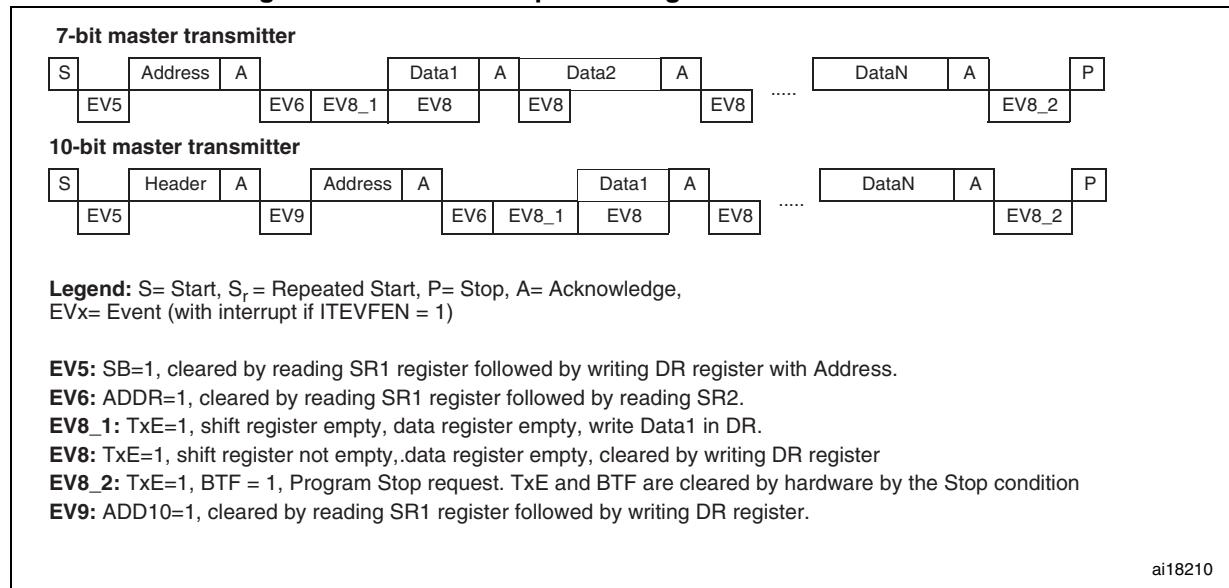
If TxE is set and a data byte was not written in the DR register before the end of the last data transmission, BTF is set and the interface waits until BTF is cleared by a write to I2C\_DR, stretching SCL low.

### Closing the communication

After the last byte is written to the DR register, the STOP bit is set by software to generate a Stop condition (see [Figure 164 Transfer sequencing EV8\\_2](#)). The interface automatically goes back to slave mode (MSL bit cleared).

*Note:* *Stop condition should be programmed during EV8\_2 event, when either TxE or BTF is set.*

Figure 164. Transfer sequence diagram for master transmitter



1. The EV5, EV6, EV9, EV8\_1 and EV8\_2 events stretch SCL low until the end of the corresponding software sequence.
2. The EV8 event stretches SCL low if the software sequence is not complete before the end of the next byte transmission.

### Master receiver

Following the address transmission and after clearing ADDR, the I<sup>2</sup>C interface enters Master Receiver mode. In this mode the interface receives bytes from the SDA line into the DR register via the internal shift register. After each byte the interface generates in sequence:

1. An acknowledge pulse if the ACK bit is set
2. The RxNE bit is set and an interrupt is generated if the ITEVFEN and ITBUFEN bits are set (see [Figure 165 Transfer sequencing EV7](#)).

If the RxNE bit is set and the data in the DR register is not read before the end of the last data reception, the BTF bit is set by hardware and the interface waits until BTF is cleared by a read in the DR register, stretching SCL low.

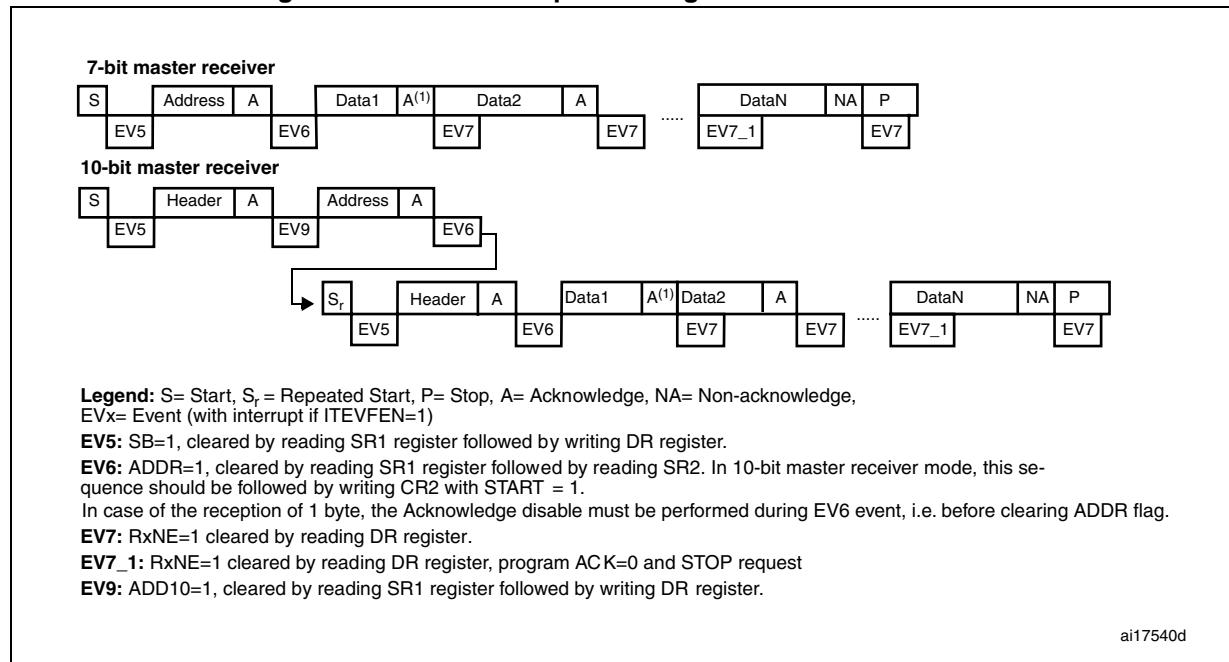
### Closing the communication

The master sends a NACK for the last byte received from the slave. After receiving this NACK, the slave releases the control of the SCL and SDA lines. Then the master can send a Stop/Restart condition.

1. To generate the nonacknowledge pulse after the last received data byte, the ACK bit must be cleared just after reading the second last data byte (after second last RxNE event).
2. In order to generate the Stop/Restart condition, software must set the STOP/START bit after reading the second last data byte (after the second last RxNE event).
3. In case a single byte has to be received, the Acknowledge disable is made during EV6 (before ADDR flag is cleared) and the STOP condition generation is made after EV6.

After the Stop condition generation, the interface goes automatically back to slave mode (MSL bit cleared).

Figure 165. Transfer sequence diagram for master receiver



ai17540d

1. If a single byte is received, it is NA.
2. The EV5, EV6 and EV9 events stretch SCL low until the end of the corresponding software sequence.
3. The EV7 event stretches SCL low if the software sequence is not completed before the end of the next byte reception.
4. The EV7\_1 software sequence must be completed before the ACK pulse of the current byte transfer.

The procedures described below are recommended if the EV7-1 software sequence is not completed before the ACK pulse of the current byte transfer.

These procedures must be followed to make sure:

- The ACK bit is set low on time before the end of the last data reception
- The STOP bit is set high after the last data reception without reception of supplementary data.

#### For 2-byte reception:

- Wait until ADDR = 1 (SCL stretched low until the ADDR flag is cleared)
- Set ACK low, set POS high
- Clear ADDR flag
- Wait until BTF = 1 (Data 1 in DR, Data2 in shift register, SCL stretched low until a data 1 is read)
- Set STOP high
- Read data 1 and 2

**For N > 2 -byte reception, from N-2 data reception**

- Wait until BTF = 1 (data N-2 in DR, data N-1 in shift register, SCL stretched low until data N-2 is read)
- Set ACK low
- Read data N-2
- Wait until BTF = 1 (data N-1 in DR, data N in shift register, SCL stretched low until a data N-1 is read)
- Set STOP high
- Read data N-1 and N

### 18.3.4 Error conditions

The following are the error conditions which may cause communication to fail.

**Bus error (BERR)**

This error occurs when the  $I^2C$  interface detects an external Stop or Start condition during an address or a data transfer. In this case:

- the BERR bit is set and an interrupt is generated if the ITERREN bit is set
- in Slave mode: data are discarded and the lines are released by hardware:
  - in case of a misplaced Start, the slave considers it is a restart and waits for an address, or a Stop condition
  - in case of a misplaced Stop, the slave behaves like for a Stop condition and the lines are released by hardware
- In Master mode: the lines are not released and the state of the current transmission is not affected. It is up to the software to abort or not the current transmission

**Acknowledge failure (AF)**

This error occurs when the interface detects a nonacknowledge bit. In this case:

- the AF bit is set and an interrupt is generated if the ITERREN bit is set
- a transmitter which receives a NACK must reset the communication:
  - If Slave: lines are released by hardware
  - If Master: a Stop or repeated Start condition must be generated by software

**Arbitration lost (ARLO)**

This error occurs when the  $I^2C$  interface detects an arbitration lost condition. In this case,

- the ARLO bit is set by hardware (and an interrupt is generated if the ITERREN bit is set)
- the  $I^2C$  Interface goes automatically back to slave mode (the MSL bit is cleared). When the  $I^2C$  loses the arbitration, it is not able to acknowledge its slave address in the same transfer, but it can acknowledge it after a repeated Start from the winning master.
- lines are released by hardware

### Overrun/underrun error (OVR)

An overrun error can occur in slave mode when clock stretching is disabled and the I<sup>2</sup>C interface is receiving data. The interface has received a byte (RxNE=1) and the data in DR has not been read, before the next byte is received by the interface. In this case,

- The last received byte is lost.
- In case of Overrun error, software should clear the RxNE bit and the transmitter should re-transmit the last received byte.

Underrun error can occur in slave mode when clock stretching is disabled and the I<sup>2</sup>C interface is transmitting data. The interface has not updated the DR with the next byte (TxEN=1), before the clock comes for the next byte. In this case,

- The same byte in the DR register will be sent again
- The user should make sure that data received on the receiver side during an underrun error are discarded and that the next bytes are written within the clock low time specified in the I<sup>2</sup>C bus standard.

For the first byte to be transmitted, the DR must be written after ADDR is cleared and before the first SCL rising edge. If not possible, the receiver must discard the first data.

### 18.3.5 Programmable noise filter

In Fm mode, the I<sup>2</sup>C standard requires that spikes are suppressed to a length of 50 ns on SDA and SCL lines.

An analog noise filter is implemented in the SDA and SCL I/Os. This filter is enabled by default and can be disabled by setting the ANOFF bit in the I2C\_FLTR register.

A digital noise filter can be enabled by configuring the DNF[3:0] bits to a non-zero value. This suppresses the spikes on SDA and SCL inputs with a length of up to  $DNF[3:0] * T_{PCLK1}$ .

Enabling the digital noise filter increases the SDA hold time by  $(DNF[3:0] + 1) * T_{PCLK}$ .

To be compliant with the maximum hold time of the I<sup>2</sup>C-bus specification version 2.1 (Thd:dat), the DNF bits must be programmed using the constraints shown in [Table 68](#), and assuming that the analog filter is disabled.

*Note:* *DNF[3:0] must only be configured when the I<sup>2</sup>C is disabled (PE = 0). If the analog filter is also enabled, the digital filter is added to the analog filter.*

**Table 68. Maximum DNF[3:0] value to be compliant with Thd:dat(max)**

PCLK1 frequency	Maximum DNF value	
	Sm mode	Fm mode
$2 \leq F_{PCLK1} \leq 5$	2	0
$5 < F_{PCLK1} \leq 10$	12	0
$10 < F_{PCLK1} \leq 20$	15	1
$20 < F_{PCLK1} \leq 30$	15	7
$30 < F_{PCLK1} \leq 40$	15	13
$40 < F_{PCLK1} \leq 50$	15	15

**Note:** For each frequency range, the constraint is given based on the worst case which is the minimum frequency of the range. Greater DNF values can be used if the system can support maximum hold time violation.

### 18.3.6 SDA/SCL line control

- If clock stretching is enabled:
  - Transmitter mode: If TxE=1 and BTF=1: the interface holds the clock line low before transmission to wait for the microcontroller to write the byte in the Data Register (both buffer and shift register are empty).
  - Receiver mode: If RxNE=1 and BTF=1: the interface holds the clock line low after reception to wait for the microcontroller to read the byte in the Data Register (both buffer and shift register are full).
- If clock stretching is disabled in Slave mode:
  - Overrun Error in case of RxNE=1 and no read of DR has been done before the next byte is received. The last received byte is lost.
  - Underrun Error in case TxE=1 and no write into DR has been done before the next byte must be transmitted. The same byte will be sent again.
  - Write Collision not managed.

### 18.3.7 SMBus

#### Introduction

The System Management Bus (SMBus) is a two-wire interface through which various devices can communicate with each other and with the rest of the system. It is based on I<sup>2</sup>C principles of operation. SMBus provides a control bus for system and power management related tasks. A system may use SMBus to pass messages to and from devices instead of toggling individual control lines.

The System Management Bus Specification refers to three types of devices. A *slave* is a device that is receiving or responding to a command. A *master* is a device that issues commands, generates the clocks, and terminates the transfer. A *host* is a specialized master that provides the main interface to the system's CPU. A host must be a master-slave and must support the SMBus host notify protocol. Only one host is allowed in a system.

#### Similarities between SMBus and I<sup>2</sup>C

- 2 wire bus protocol (1 Clk, 1 Data) + SMBus Alert line optional
- Master-slave communication, Master provides clock
- Multi master capability
- SMBus data format similar to I<sup>2</sup>C 7-bit addressing format ([Figure 160](#)).

#### Differences between SMBus and I<sup>2</sup>C

The following table describes the differences between SMBus and I<sup>2</sup>C.

**Table 69. SMBus vs. I<sup>2</sup>C**

SMBus	I <sup>2</sup> C
Max. speed 100 kHz	Max. speed 400 kHz
Min. clock speed 10 kHz	No minimum clock speed
35 ms clock low timeout	No timeout
Logic levels are fixed	Logic levels are V <sub>DD</sub> dependent
Different address types (reserved, dynamic etc.)	7-bit, 10-bit and general call slave address types
Different bus protocols (quick command, process call etc.)	No bus protocols

### SMBus application usage

With System Management Bus, a device can provide manufacturer information, tell the system what its model/part number is, save its state for a suspend event, report different types of errors, accept control parameters, and return its status. SMBus provides a control bus for system and power management related tasks.

### Device identification

Any device that exists on the System Management Bus as a slave has a unique address called the Slave Address. For the list of reserved slave addresses, refer to the SMBus specification version. 2.0 (<http://smbus.org/specs/>).

### Bus protocols

The SMBus specification supports up to 9 bus protocols. For more details of these protocols and SMBus address types, refer to SMBus specification version. 2.0 (<http://smbus.org/specs/>). These protocols should be implemented by the user software.

### Address resolution protocol (ARP)

SMBus slave address conflicts can be resolved by dynamically assigning a new unique address to each slave device. The Address Resolution Protocol (ARP) has the following attributes:

- Address assignment uses the standard SMBus physical layer arbitration mechanism
- Assigned addresses remain constant while device power is applied; address retention through device power loss is also allowed
- No additional SMBus packet overhead is incurred after address assignment. (i.e. subsequent accesses to assigned slave addresses have the same overhead as accesses to fixed address devices.)
- Any SMBus master can enumerate the bus

### Unique device identifier (UDID)

In order to provide a mechanism to isolate each device for the purpose of address assignment, each device must implement a unique device identifier (UDID).

For the details on 128 bit UDID and more information on ARP, refer to SMBus specification version 2.0 (<http://smbus.org/specs/>).

### SMBus alert mode

SMBus Alert is an optional signal with an interrupt line for devices that want to trade their ability to master for a pin. SMBA is a wired-AND signal just as the SCL and SDA signals are. SMBA is used in conjunction with the SMBus General Call Address. Messages invoked with the SMBus are 2 bytes long.

A slave-only device can signal the host through SMBA that it wants to talk by setting ALERT bit in I2C\_CR1 register. The host processes the interrupt and simultaneously accesses all SMBA devices through the *Alert Response Address* (known as ARA having a value 0001 100X). Only the device(s) which pulled SMBA low will acknowledge the Alert Response Address. This status is identified using SMBALERT Status flag in I2C\_SR1 register. The host performs a modified Receive Byte operation. The 7 bit device address provided by the slave transmit device is placed in the 7 most significant bits of the byte. The eighth bit can be a zero or one.

If more than one device pulls SMBA low, the highest priority (lowest address) device will win communication rights via standard arbitration during the slave address transfer. After acknowledging the slave address the device must disengage its SMBA pull-down. If the host still sees SMBA low when the message transfer is complete, it knows to read the ARA again.

A host which does not implement the SMBA signal may periodically access the ARA.

For more details on SMBus Alert mode, refer to SMBus specification version 2.0 (<http://smbus.org/specs/>).

### Timeout error

There are differences in the timing specifications between  $I^2C$  and SMBus. SMBus defines a clock low timeout, TIMEOUT of 35 ms. Also SMBus specifies TLOW: SEXT as the cumulative clock low extend time for a slave device. SMBus specifies TLOW: MEXT as the cumulative clock low extend time for a master device. For more details on these timeouts, refer to SMBus specification version 2.0 (<http://smbus.org/specs/>).

The status flag Timeout or Tlow Error in I2C\_SR1 shows the status of this feature.

### How to use the interface in SMBus mode

To switch from  $I^2C$  mode to SMBus mode, the following sequence should be performed.

- Set the SMBus bit in the I2C\_CR1 register
- Configure the SMBTYPE and ENARP bits in the I2C\_CR1 register as required for the application

If you want to configure the device as a master, follow the Start condition generation procedure in [Section 18.3.3: I<sup>2</sup>C master mode](#). Otherwise, follow the sequence in [Section 18.3.2: I<sup>2</sup>C slave mode](#).

The application has to control the various SMBus protocols by software.

- SMB Device Default Address acknowledged if ENARP=1 and SMBTYPE=0
- SMB Host Header acknowledged if ENARP=1 and SMBTYPE=1
- SMB Alert Response Address acknowledged if SMBALERT=1

### 18.3.8 DMA requests

DMA requests (when enabled) are generated only for data transfer. DMA requests are generated by Data Register becoming empty in transmission and Data Register becoming full in reception. The DMA must be initialized and enabled before the I<sup>2</sup>C data transfer. The DMAEN bit must be set in the I2C\_CR2 register before the ADDR event. In master mode or in slave mode when clock stretching is enabled, the DMAEN bit can also be set during the ADDR event, before clearing the ADDR flag. The DMA request must be served before the end of the current byte transfer. When the number of data transfers which has been programmed for the corresponding DMA stream is reached, the DMA controller sends an End of Transfer EOT signal to the I<sup>2</sup>C interface and generates a Transfer Complete interrupt if enabled:

- Master transmitter: In the interrupt routine after the EOT interrupt, disable DMA requests then wait for a BTF event before programming the Stop condition.
- Master receiver
  - When the number of bytes to be received is equal to or greater than two, the DMA controller sends a hardware signal, EOT\_1, corresponding to the last but one data byte (number\_of\_bytes – 1). If, in the I2C\_CR2 register, the LAST bit is set, I<sup>2</sup>C automatically sends a NACK after the next byte following EOT\_1. The user can generate a Stop condition in the DMA Transfer Complete interrupt routine if enabled.
  - When a single byte must be received: the NACK must be programmed during EV6 event, i.e. program ACK=0 when ADDR=1, before clearing ADDR flag. Then the user can program the STOP condition either after clearing ADDR flag, or in the DMA Transfer Complete interrupt routine.

### Transmission using DMA

DMA mode can be enabled for transmission by setting the DMAEN bit in the I2C\_CR2 register. Data will be loaded from a Memory area configured using the DMA peripheral (refer to the DMA specification) to the I2C\_DR register whenever the TxE bit is set. To map a DMA stream x for I<sup>2</sup>C transmission (where x is the stream number), perform the following sequence:

1. Set the I2C\_DR register address in the DMA\_SxPAR register. The data will be moved to this address from the memory after each TxE event.
2. Set the memory address in the DMA\_SxMA0R register (and in DMA\_SxMA1R register in the case of a double buffer mode). The data will be loaded into I2C\_DR from this memory after each TxE event.
3. Configure the total number of bytes to be transferred in the DMA\_SxNDTR register. After each TxE event, this value will be decremented.
4. Configure the DMA stream priority using the PL[0:1] bits in the DMA\_SxCR register
5. Set the DIR bit in the DMA\_SxCR register and configure interrupts after half transfer or full transfer depending on application requirements.
6. Activate the stream by setting the EN bit in the DMA\_SxCR register.

When the number of data transfers which has been programmed in the DMA Controller registers is reached, the DMA controller sends an End of Transfer EOT/ EOT\_1 signal to the I<sup>2</sup>C interface and the DMA generates an interrupt, if enabled, on the DMA stream interrupt vector.

*Note:* Do not enable the ITBUFEN bit in the I2C\_CR2 register if DMA is used for transmission.

### Reception using DMA

DMA mode can be enabled for reception by setting the DMAEN bit in the I2C\_CR2 register. Data will be loaded from the I2C\_DR register to a Memory area configured using the DMA peripheral (refer to the DMA specification) whenever a data byte is received. To map a DMA stream x for I<sup>2</sup>C reception (where x is the stream number), perform the following sequence:

1. Set the I2C\_DR register address in DMA\_SxPAR register. The data will be moved from this address to the memory after each RxNE event.
2. Set the memory address in the DMA\_SxMA0R register (and in DMA\_SxMA1R register in the case of a double buffer mode). The data will be loaded from the I2C\_DR register to this memory area after each RxNE event.
3. Configure the total number of bytes to be transferred in the DMA\_SxNDTR register. After each RxNE event, this value will be decremented.
4. Configure the stream priority using the PL[0:1] bits in the DMA\_SxCR register
5. Reset the DIR bit and configure interrupts in the DMA\_SxCR register after half transfer or full transfer depending on application requirements.
6. Activate the stream by setting the EN bit in the DMA\_SxCR register.

When the number of data transfers which has been programmed in the DMA Controller registers is reached, the DMA controller sends an End of Transfer EOT/ EOT\_1 signal to the I<sup>2</sup>C interface and DMA generates an interrupt, if enabled, on the DMA stream interrupt vector.

*Note:* *Do not enable the ITBUFEN bit in the I2C\_CR2 register if DMA is used for reception.*

### 18.3.9 Packet error checking

A PEC calculator has been implemented to improve the reliability of communication. The PEC is calculated by using the  $C(x) = x^8 + x^2 + x + 1$  CRC-8 polynomial serially on each bit.

- PEC calculation is enabled by setting the ENPEC bit in the I2C\_CR1 register. PEC is a CRC-8 calculated on all message bytes including addresses and R/W bits.
  - In transmission: set the PEC transfer bit in the I2C\_CR1 register after the TxE event corresponding to the last byte. The PEC will be transferred after the last transmitted byte.
  - In reception: set the PEC bit in the I2C\_CR1 register after the RxNE event corresponding to the last byte so that the receiver sends a NACK if the next received byte is not equal to the internally calculated PEC. In case of Master-Receiver, a NACK must follow the PEC whatever the check result. The PEC must

be set before the ACK of the CRC reception in slave mode. It must be set when the ACK is set low in master mode.

- A PECERR error flag/interrupt is also available in the I2C\_SR1 register.
- If DMA and PEC calculation are both enabled:-

  - In transmission: when the I<sup>2</sup>C interface receives an EOT signal from the DMA controller, it automatically sends a PEC after the last byte.
  - In reception: when the I<sup>2</sup>C interface receives an EOT\_1 signal from the DMA controller, it will automatically consider the next byte as a PEC and will check it. A DMA request is generated after PEC reception.

- To allow intermediate PEC transfers, a control bit is available in the I2C\_CR2 register (LAST bit) to determine if it is really the last DMA transfer or not. If it is the last DMA request for a master receiver, a NACK is automatically sent after the last received byte.
- PEC calculation is corrupted by an arbitration loss.

## 18.4 I<sup>2</sup>C interrupts

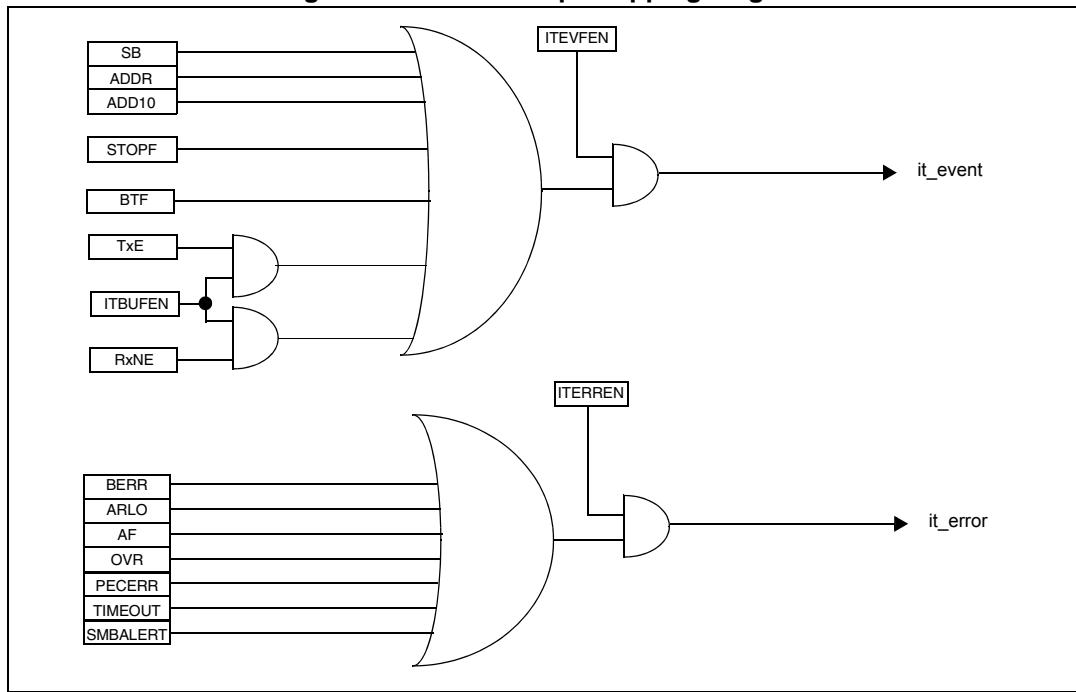
The table below gives the list of I<sup>2</sup>C interrupt requests.

**Table 70. I<sup>2</sup>C Interrupt requests**

Interrupt event	Event flag	Enable control bit
Start bit sent (Master)	SB	ITEVFEN
Address sent (Master) or Address matched (Slave)	ADDR	
10-bit header sent (Master)	ADD10	
Stop received (Slave)	STOPF	
Data byte transfer finished	BTF	
Receive buffer not empty	RxNE	ITEVFEN and ITBUFEN
Transmit buffer empty	TxE	
Bus error	BERR	ITERREN
Arbitration loss (Master)	ARLO	
Acknowledge failure	AF	
Overrun/Underrun	OVR	
PEC error	PECERR	
Timeout/Tlow error	TIMEOUT	
SMBus Alert	SMBALERT	

Note: SB, ADDR, ADD10, STOPF, BTF, RxNE and TxE are logically ORed on the same interrupt channel.

BERR, ARLO, AF, OVR, PECERR, TIMEOUT and SMBALERT are logically ORed on the same interrupt channel.

**Figure 166.  $I^2C$  interrupt mapping diagram**

## 18.5 I<sup>2</sup>C debug mode

When the microcontroller enters the debug mode (Cortex™-M4 with FPU core halted), the SMBUS timeout either continues to work normally or stops, depending on the DBG\_I2Cx\_SMBUS\_TIMEOUT configuration bits in the DBG module. For more details, refer to [Section 23.16.2: Debug support for timers, watchdog and I<sup>2</sup>C on page 816](#).

## 18.6 I<sup>2</sup>C registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by half-words (16 bits) or words (32 bits).

### 18.6.1 I<sup>2</sup>C Control register 1 (I<sup>2</sup>C\_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWRST	Res.	ALERT	PEC	POS	ACK	STOP	START	NO STRETCH	ENGC	ENPEC	ENARP	SMB TYPE	Res.	SMBUS	PE
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw

Bit 15 **SWRST**: Software reset

When set, the I<sup>2</sup>C is under reset state. Before resetting this bit, make sure the I<sup>2</sup>C lines are released and the bus is free.

0: I<sup>2</sup>C Peripheral not under reset

1: I<sup>2</sup>C Peripheral under reset state

*Note:* This bit can be used to reinitialize the peripheral after an error or a locked state. As an example, if the BUSY bit is set and remains locked due to a glitch on the bus, the SWRST bit can be used to exit from this state.

Bit 14 Reserved, must be kept at reset value

Bit 13 **ALERT**: SMBus alert

This bit is set and cleared by software, and cleared by hardware when PE=0.

0: Releases SMBA pin high. Alert Response Address Header followed by NACK.

1: Drives SMBA pin low. Alert Response Address Header followed by ACK.

Bit 12 **PEC**: Packet error checking

This bit is set and cleared by software, and cleared by hardware when PEC is transferred or by a START or Stop condition or when PE=0.

0: No PEC transfer

1: PEC transfer (in Tx or Rx mode)

*Note:* PEC calculation is corrupted by an arbitration loss.

Bit 11 **POS**: Acknowledge/PEC Position (for data reception)

This bit is set and cleared by software and cleared by hardware when PE=0.

0: ACK bit controls the (N)ACK of the current byte being received in the shift register. The PEC bit indicates that current byte in shift register is a PEC.

1: ACK bit controls the (N)ACK of the next byte which will be received in the shift register. The PEC bit indicates that the next byte in the shift register is a PEC

*Note:* The POS bit must be used only in 2-byte reception configuration in master mode. It must be configured before data reception starts, as described in the 2-byte reception procedure recommended in [Section : Master receiver on page 469](#).

**Bit 10 ACK:** Acknowledge enable

This bit is set and cleared by software and cleared by hardware when PE=0.

0: No acknowledge returned

1: Acknowledge returned after a byte is received (matched address or data)

**Bit 9 STOP:** Stop generation

The bit is set and cleared by software, cleared by hardware when a Stop condition is detected, set by hardware when a timeout error is detected.

In Master Mode:

0: No Stop generation.

1: Stop generation after the current byte transfer or after the current Start condition is sent.

In Slave mode:

0: No Stop generation.

1: Release the SCL and SDA lines after the current byte transfer.

**Bit 8 START:** Start generation

This bit is set and cleared by software and cleared by hardware when start is sent or PE=0.

In Master Mode:

0: No Start generation

1: Repeated start generation

In Slave mode:

0: No Start generation

1: Start generation when the bus is free

**Bit 7 NOSTRETCH:** Clock stretching disable (Slave mode)

This bit is used to disable clock stretching in slave mode when ADDR or BTF flag is set, until it is reset by software.

0: Clock stretching enabled

1: Clock stretching disabled

**Bit 6 ENGC:** General call enable

0: General call disabled. Address 00h is NACKed.

1: General call enabled. Address 00h is ACKed.

**Bit 5 ENPEC:** PEC enable

0: PEC calculation disabled

1: PEC calculation enabled

**Bit 4 ENARP:** ARP enable

0: ARP disable

1: ARP enable

SMBus Device default address recognized if SMBTYPE=0

SMBus Host address recognized if SMBTYPE=1

**Bit 3 SMBTYPE:** SMBus type

0: SMBus Device

1: SMBus Host

Bit 2 Reserved, must be kept at reset value

Bit 1 **SMBUS**: SMBus mode

0: I<sup>2</sup>C mode

1: SMBus mode

Bit 0 **PE**: Peripheral enable

0: Peripheral disable

1: Peripheral enable

*Note: If this bit is reset while a communication is on going, the peripheral is disabled at the end of the current communication, when back to IDLE state.*

*All bit resets due to PE=0 occur at the end of the communication.*

*In master mode, this bit must not be reset before the end of the communication.*

**Note:** When the STOP, START or PEC bit is set, the software must not perform any write access to I2C\_CR1 before this bit is cleared by hardware. Otherwise there is a risk of setting a second STOP, START or PEC request.

## 18.6.2 I<sup>2</sup>C Control register 2 (I2C\_CR2)

Address offset: 0x04

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	LAST DMA EN ITBUF EN ITEVTE N ITERREN					Reserved	FREQ[5:0]							rw	rw	rw
	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw			

Bits 15:13 Reserved, must be kept at reset value

Bit 12 **LAST**: DMA last transfer

0: Next DMA EOT is not the last transfer

1: Next DMA EOT is the last transfer

*Note: This bit is used in master receiver mode to permit the generation of a NACK on the last received data.*

Bit 11 **DMAEN**: DMA requests enable

0: DMA requests disabled

1: DMA request enabled when TxE=1 or RxNE =1

Bit 10 **ITBUFEN**: Buffer interrupt enable

0: TxE = 1 or RxNE = 1 does not generate any interrupt.

1: TxE = 1 or RxNE = 1 generates Event Interrupt (whatever the state of DMAEN)

Bit 9 **ITEVTEN**: Event interrupt enable

- 0: Event interrupt disabled
- 1: Event interrupt enabled

This interrupt is generated when:

- SB = 1 (Master)
- ADDR = 1 (Master/Slave)
- ADD10= 1 (Master)
- STOPF = 1 (Slave)
- BTF = 1 with no TxE or RxNE event
- TxE event to 1 if ITBUFEN = 1
- RxNE event to 1if ITBUFEN = 1

**ITERREN**: Error interrupt enable

- 0: Error interrupt disabled
- 1: Error interrupt enabled

This interrupt is generated when:

- BERR = 1
- ARLO = 1
- AF = 1
- OVR = 1
- PECERR = 1
- TIMEOUT = 1
- SMBALERT = 1

Bits 7:6 Reserved, must be kept at reset value

Bits 5:0 **FREQ[5:0]**: Peripheral clock frequency

The FREQ bits must be configured with the APB clock frequency value (I2C peripheral connected to APB). The FREQ field is used by the peripheral to generate data setup and hold times compliant with the I2C specifications. The minimum allowed frequency is 2 MHz, the maximum frequency is limited by the maximum APB frequency (42 MHz) and an intrinsic limitation of 46 MHz.

0b000000: Not allowed

0b000001: Not allowed

0b000010: 2 MHz

...

0b101010: 42MHz

Higher than 0b101010: Not allowed

### 18.6.3 I<sup>2</sup>C Own address register 1 (I2C\_OAR1)

Address offset: 0x08

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADD MODE rw	Reserved					ADD[9:8]		ADD[7:1]								ADD0 rw
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bit 15 **ADDMODE** Addressing mode (slave mode)

0: 7-bit slave address (10-bit address not acknowledged)

1: 10-bit slave address (7-bit address not acknowledged)

Bit 14 Should always be kept at 1 by software.

Bits 13:10 Reserved, must be kept at reset value

Bits 9:8 **ADD[9:8]**: Interface address

7-bit addressing mode: don't care

10-bit addressing mode: bits9:8 of address

Bits 7:1 **ADD[7:1]**: Interface address

bits 7:1 of address

Bit 0 **ADD0**: Interface address

7-bit addressing mode: don't care

10-bit addressing mode: bit 0 of address

### 18.6.4 I<sup>2</sup>C Own address register 2 (I2C\_OAR2)

Address offset: 0x0C

Reset value: 0x0000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								ADD2[7:1]								ENDUAL rw
								rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value

Bits 7:1 **ADD2[7:1]**: Interface address

bits 7:1 of address in dual addressing mode

Bit 0 **ENDUAL**: Dual addressing mode enable

0: Only OAR1 is recognized in 7-bit addressing mode

1: Both OAR1 and OAR2 are recognized in 7-bit addressing mode

### 18.6.5 I<sup>2</sup>C Data register (I2C\_DR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								DR[7:0]							

Bits 15:8 Reserved, must be kept at reset value

Bits 7:0 DR[7:0] 8-bit data register

Byte received or to be transmitted to the bus.

- Transmitter mode: Byte transmission starts automatically when a byte is written in the DR register. A continuous transmit stream can be maintained if the next data to be transmitted is put in DR once the transmission is started (TxE=1)
- Receiver mode: Received byte is copied into DR (RxNE=1). A continuous transmit stream can be maintained if DR is read before the next data byte is received (RxNE=1).

Note: *In slave mode, the address is not copied into DR.*

Note: *Write collision is not managed (DR can be written if TxE=0).*

Note: *If an ARLO event occurs on ACK pulse, the received byte is not copied into DR and so cannot be read.*

### 18.6.6 I<sup>2</sup>C Status register 1 (I2C\_SR1)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMB ALERT	TIME OUT	Res.	PEC ERR	OVR	AF	ARLO	BERR	TxE	RxNE	Res.	STOPF	ADD10	BTF	ADDR	SB
rc_w0	rc_w0		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	r	r		r	r	r	r	r

**Bit 15 SMBALERT:** SMBus alert

In SMBus host mode:

0: no SMBALERT

1: SMBALERT event occurred on pin

In SMBus slave mode:

0: no SMBALERT response address header

1: SMBALERT response address header to SMBALERT LOW received

- Cleared by software writing 0, or by hardware when PE=0.

**Bit 14 TIMEOUT:** Timeout or Tlow error

0: No timeout error

1: SCL remained LOW for 25 ms (Timeout)

or

Master cumulative clock low extend time more than 10 ms (Tlow:mext)

or

Slave cumulative clock low extend time more than 25 ms (Tlow:sext)

- When set in slave mode: slave resets the communication and lines are released by hardware
- When set in master mode: Stop condition sent by hardware
- Cleared by software writing 0, or by hardware when PE=0.

*Note: This functionality is available only in SMBus mode.*

**Bit 13 Reserved, must be kept at reset value****Bit 12 PECERR:** PEC Error in reception

0: no PEC error: receiver returns ACK after PEC reception (if ACK=1)

1: PEC error: receiver returns NACK after PEC reception (whatever ACK)

- Cleared by software writing 0, or by hardware when PE=0.

- Note: When the received CRC is wrong, PECERR is not set in slave mode if the PEC control bit is not set before the end of the CRC reception. Nevertheless, reading the PEC value determines whether the received CRC is right or wrong.

**Bit 11 OVR:** Overrun/Underrun

0: No overrun/underrun

1: Overrun or underrun

- Set by hardware in slave mode when NOSTRETCH=1 and:
- In reception when a new byte is received (including ACK pulse) and the DR register has not been read yet. New received byte is lost.
- In transmission when a new byte should be sent and the DR register has not been written yet. The same byte is sent twice.
- Cleared by software writing 0, or by hardware when PE=0.

*Note: If the DR write occurs very close to SCL rising edge, the sent data is unspecified and a hold timing error occurs*

**Bit 10 AF:** Acknowledge failure

0: No acknowledge failure

1: Acknowledge failure

- Set by hardware when no acknowledge is returned.

- Cleared by software writing 0, or by hardware when PE=0.

Bit 9 **ARLO**: Arbitration lost (master mode)

0: No Arbitration Lost detected

1: Arbitration Lost detected

Set by hardware when the interface loses the arbitration of the bus to another master

– Cleared by software writing 0, or by hardware when PE=0.

After an ARLO event the interface switches back automatically to Slave mode (MSL=0).

*Note: In SMBUS, the arbitration on the data in slave mode occurs only during the data phase, or the acknowledge transmission (not on the address acknowledge).*

Bit 8 **BERR**: Bus error

0: No misplaced Start or Stop condition

1: Misplaced Start or Stop condition

– Set by hardware when the interface detects an SDA rising or falling edge while SCL is high, occurring in a non-valid position during a byte transfer.

– Cleared by software writing 0, or by hardware when PE=0.

Bit 7 **TxE**: Data register empty (transmitters)

0: Data register not empty

1: Data register empty

– Set when DR is empty in transmission. TxE is not set during address phase.

– Cleared by software writing to the DR register or by hardware after a start or a stop condition or when PE=0.

TxE is not set if either a NACK is received, or if next byte to be transmitted is PEC (PEC=1)

*Note: TxE is not cleared by writing the first data being transmitted, or by writing data when BTF is set, as in both cases the data register is still empty.*

Bit 6 **RxNE**: Data register not empty (receivers)

0: Data register empty

1: Data register not empty

– Set when data register is not empty in receiver mode. RxNE is not set during address phase.

– Cleared by software reading or writing the DR register or by hardware when PE=0.

RxNE is not set in case of ARLO event.

*Note: RxNE is not cleared by reading data when BTF is set, as the data register is still full.*

Bit 5 Reserved, must be kept at reset value

Bit 4 **STOPF**: Stop detection (slave mode)

0: No Stop condition detected

1: Stop condition detected

– Set by hardware when a Stop condition is detected on the bus by the slave after an acknowledge (if ACK=1).

– Cleared by software reading the SR1 register followed by a write in the CR1 register, or by hardware when PE=0

*Note: The STOPF bit is not set after a NACK reception.*

*It is recommended to perform the complete clearing sequence (READ SR1 then WRITE CR1) after the STOPF is set. Refer to [Figure 163: Transfer sequence diagram for slave receiver on page 465](#).*

Bit 3 **ADD10**: 10-bit header sent (Master mode)

- 0: No ADD10 event occurred.
- 1: Master has sent first address byte (header).
- Set by hardware when the master has sent the first byte in 10-bit address mode.
- Cleared by software reading the SR1 register followed by a write in the DR register of the second address byte, or by hardware when PE=0.

*Note: ADD10 bit is not set after a NACK reception*

Bit 2 **BTF**: Byte transfer finished

- 0: Data byte transfer not done
- 1: Data byte transfer succeeded
- Set by hardware when NOSTRETCH=0 and:
- In reception when a new byte is received (including ACK pulse) and DR has not been read yet (RxNE=1).
- In transmission when a new byte should be sent and DR has not been written yet (TxEN=1).
- Cleared by software by either a read or write in the DR register or by hardware after a start or a stop condition in transmission or when PE=0.

*Note: The BTF bit is not set after a NACK reception*

*The BTF bit is not set if next byte to be transmitted is the PEC (TRA=1 in I2C\_SR2 register and PEC=1 in I2C\_CR1 register)*

Bit 1 **ADDR**: Address sent (master mode)/matched (slave mode)

This bit is cleared by software reading SR1 register followed reading SR2, or by hardware when PE=0.

Address matched (Slave)

- 0: Address mismatched or not received.
- 1: Received address matched.

- Set by hardware as soon as the received slave address matched with the OAR registers content or a general call or a SMBus Device Default Address or SMBus Host or SMBus Alert is recognized. (when enabled depending on configuration).

*Note: In slave mode, it is recommended to perform the complete clearing sequence (READ SR1 then READ SR2) after ADDR is set. Refer to [Figure 163: Transfer sequence diagram for slave receiver on page 465](#).*

Address sent (Master)

- 0: No end of address transmission
- 1: End of address transmission

- For 10-bit addressing, the bit is set after the ACK of the 2nd byte.
- For 7-bit addressing, the bit is set after the ACK of the byte.

*Note: ADDR is not set after a NACK reception*

Bit 0 **SB**: Start bit (Master mode)

- 0: No Start condition
- 1: Start condition generated.
- Set when a Start condition generated.
- Cleared by software by reading the SR1 register followed by writing the DR register, or by hardware when PE=0

### 18.6.7 I<sup>2</sup>C Status register 2 (I<sup>2</sup>C\_SR2)

Address offset: 0x18

Reset value: 0x0000

**Note:** *Reading I<sup>2</sup>C\_SR2 after reading I<sup>2</sup>C\_SR1 clears the ADDR flag, even if the ADDR flag was set after reading I<sup>2</sup>C\_SR1. Consequently, I<sup>2</sup>C\_SR2 must be read only when ADDR is found set in I<sup>2</sup>C\_SR1 or when the STOPF bit is cleared.*

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
								PEC[7:0]	DUALF	SMB HOST	SMBDE FAULT	GEN CALL	Res.	TRA	BUSY	MSL
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	

Bits 15:8 **PEC[7:0]** Packet error checking register

This register contains the internal PEC when ENPEC=1.

Bit 7 **DUALF**: Dual flag (Slave mode)

- 0: Received address matched with OAR1
- 1: Received address matched with OAR2

– Cleared by hardware after a Stop condition or repeated Start condition, or when PE=0.

Bit 6 **SMBHOST**: SMBus host header (Slave mode)

- 0: No SMBus Host address
- 1: SMBus Host address received when SMBTYPE=1 and ENARP=1.

– Cleared by hardware after a Stop condition or repeated Start condition, or when PE=0.

Bit 5 **SMBDEFAULT**: SMBus device default address (Slave mode)

- 0: No SMBus Device Default address
- 1: SMBus Device Default address received when ENARP=1

– Cleared by hardware after a Stop condition or repeated Start condition, or when PE=0.

Bit 4 **GENCALL**: General call address (Slave mode)

- 0: No General Call
- 1: General Call Address received when ENGC=1

– Cleared by hardware after a Stop condition or repeated Start condition, or when PE=0.

Bit 3 Reserved, must be kept at reset value

Bit 2 **TRA**: Transmitter/receiver

- 0: Data bytes received
- 1: Data bytes transmitted

This bit is set depending on the R/W bit of the address byte, at the end of total address phase.

It is also cleared by hardware after detection of Stop condition (STOPF=1), repeated Start condition, loss of bus arbitration (ARLO=1), or when PE=0.

Bit 1 **BUSY**: Bus busy

- 0: No communication on the bus
- 1: Communication ongoing on the bus
- Set by hardware on detection of SDA or SCL low
- Cleared by hardware on detection of a Stop condition.

It indicates a communication in progress on the bus. This information is still updated when the interface is disabled (PE=0).

Bit 0 **MSL**: Master/slave

- 0: Slave Mode
- 1: Master Mode
- Set by hardware as soon as the interface is in Master mode (SB=1).
- Cleared by hardware after detecting a Stop condition on the bus or a loss of arbitration (ARLO=1), or by hardware when PE=0.

**Note:** *Reading I2C\_SR2 after reading I2C\_SR1 clears the ADDR flag, even if the ADDR flag was set after reading I2C\_SR1. Consequently, I2C\_SR2 must be read only when ADDR is found set in I2C\_SR1 or when the STOPF bit is cleared.*

### 18.6.8 I<sup>2</sup>C Clock control register (I2C\_CCR)

Address offset: 0x1C

Reset value: 0x0000

**Note:** *f<sub>PCLK1</sub> must be at least 2 MHz to achieve Sm mode I<sup>2</sup>C frequencies. It must be at least 4 MHz to achieve Fm mode I<sup>2</sup>C frequencies. It must be a multiple of 10MHz to reach the 400 kHz maximum I<sup>2</sup>C Fm mode clock.*

*The CCR register must be configured only when the I<sup>2</sup>C is disabled (PE = 0).*

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
F/S	DUTY	Reserved	CCR[11:0]													
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 15 **F/S**: I<sup>2</sup>C master mode selection

- 0: Sm mode I<sup>2</sup>C
- 1: Fm mode I<sup>2</sup>C

Bit 14 **DUTY:** Fm mode duty cycle

0: Fm mode  $t_{low}/t_{high} = 2$

1: Fm mode  $t_{low}/t_{high} = 16/9$  (see CCR)

Bits 13:12 Reserved, must be kept at reset value

Bits 11:0 **CCR[11:0]:** Clock control register in Fm/Sm mode (Master mode)

Controls the SCL clock in master mode.

Sm mode or SMBus:

$$T_{high} = CCR * T_{PCLK1}$$

$$T_{low} = CCR * T_{PCLK1}$$

Fm mode:

If DUTY = 0:

$$T_{high} = CCR * T_{PCLK1}$$

$$T_{low} = 2 * CCR * T_{PCLK1}$$

If DUTY = 1: (to reach 400 kHz)

$$T_{high} = 9 * CCR * T_{PCLK1}$$

$$T_{low} = 16 * CCR * T_{PCLK1}$$

For instance: in Sm mode, to generate a 100 kHz SCL frequency:

If FREQR = 08,  $T_{PCLK1} = 125$  ns so CCR must be programmed with 0x28  
(0x28 => 40d x 125 ns = 5000 ns.)

*Note: The minimum allowed value is 0x04, except in FAST DUTY mode where the minimum allowed value is 0x01*

*Note:  $t_{high} = t_r(SCL) + t_w(SCLH)$ . See device datasheet for the definitions of parameters.*

*$t_{low} = t_r(SCL) + t_w(SCLL)$ . See device datasheet for the definitions of parameters.*

*I<sup>2</sup>C communication speed,  $f_{SCL} \sim 1/(t_{high} + t_{low})$ . The real frequency may differ due to the analog noise filter input delay*

*Note: The CCR register must be configured only when the I<sup>2</sup>C is disabled (PE = 0).*

## 18.6.9 I<sup>2</sup>C TRISE register (I2C\_TRISE)

Address offset: 0x20

Reset value: 0x0002

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								TRISE[5:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:6 Reserved, must be kept at reset value

Bits 5:0 **TRISE[5:0]:** Maximum rise time in Fm/Sm mode (Master mode)

These bits should provide the maximum duration of the SCL feedback loop in master mode.

The purpose is to keep a stable SCL frequency whatever the SCL rising edge duration.

These bits must be programmed with the maximum SCL rise time given in the I<sup>2</sup>C bus specification, incremented by 1.

For instance: in Sm mode, the maximum allowed SCL rise time is 1000 ns.

If, in the I2C\_CR2 register, the value of FREQ[5:0] bits is equal to 0x08 and  $T_{PCLK1} = 125$  ns therefore the TRISE[5:0] bits must be programmed with 09h.

$$(1000 \text{ ns} / 125 \text{ ns} = 8 + 1)$$

The filter value can also be added to TRISE[5:0].

If the result is not an integer, TRISE[5:0] must be programmed with the integer part, in order to respect the  $t_{HIGH}$  parameter.

*Note: TRISE[5:0] must be configured only when the I<sup>2</sup>C is disabled (PE = 0).*

### 18.6.10 I<sup>2</sup>C FLTR register (I2C\_FLTR)

Address offset: 0x24

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved												ANOFF	DNF[3:0]		
												rw	rw	rw	rw

Bits 15:5 Reserved, must be kept at reset value

Bit 4 **ANOFF**: Analog noise filter OFF

- 0: Analog noise filter enable
- 1: Analog noise filter disable

*Note:* ANOFF must be configured only when the I<sup>2</sup>C is disabled (PE = 0).

Bits 3:0 **DNF[3:0]**: Digital noise filter

These bits are used to configure the digital noise filter on SDA and SCL inputs. The digital filter will suppress the spikes with a length of up to DNF[3:0] \* TPCLK1.

0000: Digital noise filter disable

0001: Digital noise filter enabled and filtering capability up to 1\* TPCLK1.

...

1111: Digital noise filter enabled and filtering capability up to 15\* TPCLK1.

*Note:* DNF[3:0] must be configured only when the I<sup>2</sup>C is disabled (PE = 0). If the analog filter is also enabled, the digital filter is added to the analog filter.

### 18.6.11 I<sup>2</sup>C register map

The table below provides the I<sup>2</sup>C register map and reset values.

**Table 71. I<sup>2</sup>C register map and reset values**

**Table 71. I<sup>2</sup>C register map and reset values (continued)**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x24	I <sup>2</sup> C_FLTR	Reserved																								ANOFF	DNF[3:0]						
	Reset value																											0	0	0	0	0	

Refer to [Table 1 on page 38](#)for the register boundary addresses table.

## 19 Universal synchronous asynchronous receiver transmitter (USART)

### 19.1 USART introduction

The universal synchronous asynchronous receiver transmitter (USART) offers a flexible means of full-duplex data exchange with external equipment requiring an industry standard NRZ asynchronous serial data format. The USART offers a very wide range of baud rates using a fractional baud rate generator.

It supports synchronous one-way communication and half-duplex single wire communication. It also supports the LIN (local interconnection network), Smartcard Protocol and IrDA (infrared data association) SIR ENDEC specifications, and modem operations (CTS/RTS). It allows multiprocessor communication.

High speed data communication is possible by using the DMA for multibuffer configuration.

## 19.2 USART main features

- Full duplex, asynchronous communications
- NRZ standard format (Mark/Space)
- Configurable oversampling method by 16 or by 8 to give flexibility between speed and clock tolerance
- Fractional baud rate generator systems
  - Common programmable transmit and receive baud rate (refer to the datasheets for the value of the baud rate at the maximum APB frequency).
- Programmable data word length (8 or 9 bits)
- Configurable stop bits - support for 1 or 2 stop bits
- LIN Master Synchronous Break send capability and LIN slave break detection capability
  - 13-bit break generation and 10/11 bit break detection when USART is hardware configured for LIN
- Transmitter clock output for synchronous transmission
- IrDA SIR encoder decoder
  - Support for 3/16 bit duration for normal mode
- Smartcard emulation capability
  - The Smartcard interface supports the asynchronous protocol Smartcards as defined in the ISO 7816-3 standards
  - 0.5, 1.5 stop bits for Smartcard operation
- Single-wire half-duplex communication
- Configurable multibuffer communication using DMA (direct memory access)
  - Buffering of received/transmitted bytes in reserved SRAM using centralized DMA
- Separate enable bits for transmitter and receiver
- Transfer detection flags:
  - Receive buffer full
  - Transmit buffer empty
  - End of transmission flags
- Parity control:
  - Transmits parity bit
  - Checks parity of received data byte
- Four error detection flags:
  - Overrun error
  - Noise detection
  - Frame error
  - Parity error
- Ten interrupt sources with flags:
  - CTS changes
  - LIN break detection
  - Transmit data register empty
  - Transmission complete

- Receive data register full
- Idle line received
- Overrun error
- Framing error
- Noise error
- Parity error
- Multiprocessor communication - enter into mute mode if address match does not occur
- Wake up from mute mode (by idle line detection or address mark detection)
- Two receiver wakeup modes: Address bit (MSB, 9<sup>th</sup> bit), Idle line

## 19.3 USART functional description

The interface is externally connected to another device by three pins (see [Figure 167](#)). Any USART bidirectional communication requires a minimum of two pins: Receive Data In (RX) and Transmit Data Out (TX):

**RX:** Receive Data Input is the serial data input. Oversampling techniques are used for data recovery by discriminating between valid incoming data and noise.

**TX:** Transmit Data Output. When the transmitter is disabled, the output pin returns to its I/O port configuration. When the transmitter is enabled and nothing is to be transmitted, the TX pin is at high level. In single-wire and smartcard modes, this I/O is used to transmit and receive the data (at USART level, data are then received on SW\_RX).

Through these pins, serial data is transmitted and received in normal USART mode as frames comprising:

- An Idle Line prior to transmission or reception
- A start bit
- A data word (8 or 9 bits) least significant bit first
- 0.5, 1, 1.5, 2 Stop bits indicating that the frame is complete
- This interface uses a fractional baud rate generator - with a 12-bit mantissa and 4-bit fraction
- A status register (USART\_SR)
- Data Register (USART\_DR)
- A baud rate register (USART\_BRR) - 12-bit mantissa and 4-bit fraction.
- A Guardtime Register (USART\_GTPR) in case of Smartcard mode.

Refer to [Section 19.6: USART registers on page 535](#) for the definitions of each bit.

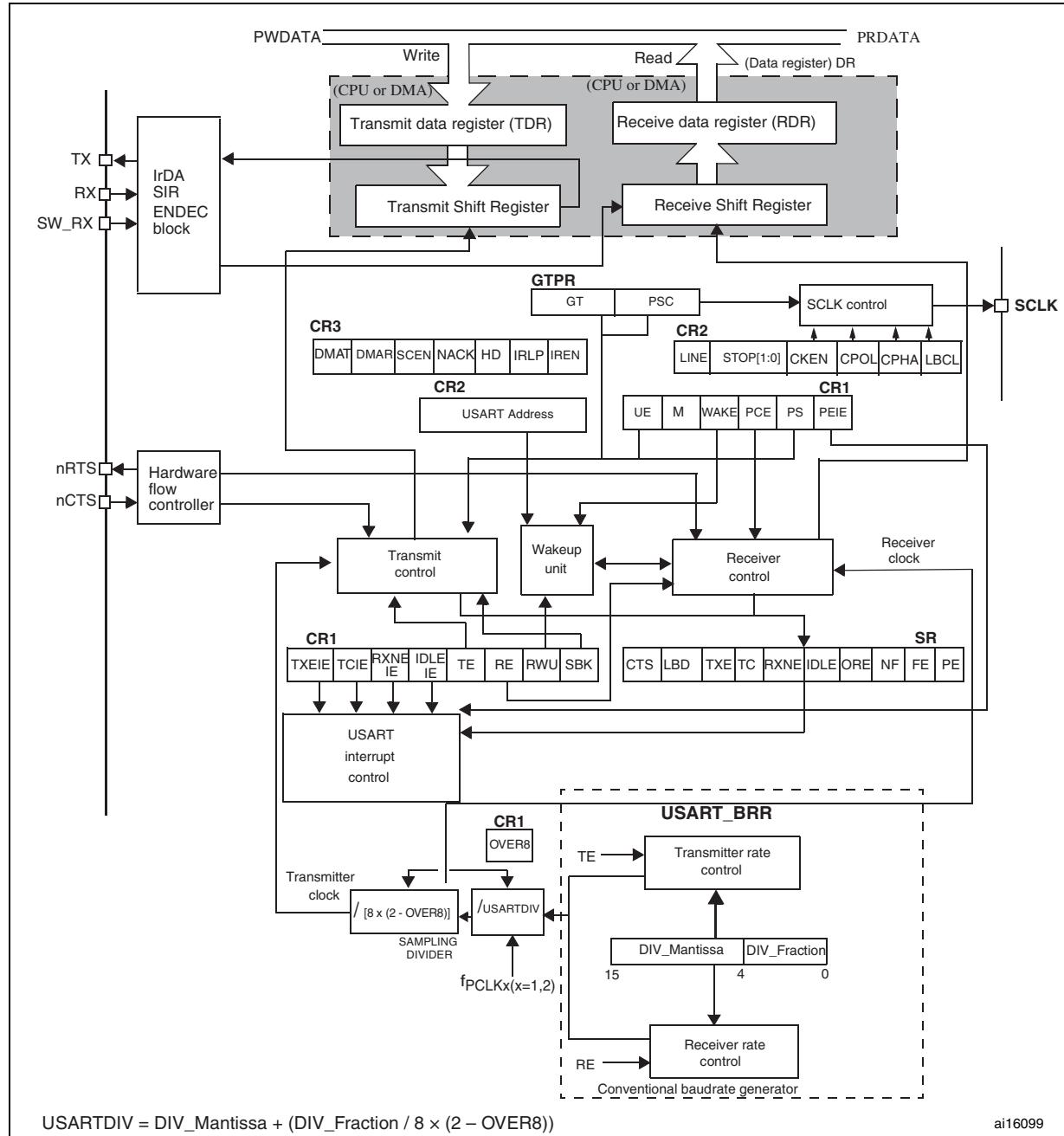
The following pin is required to interface in synchronous mode:

- **SCLK:** Transmitter clock output. This pin outputs the transmitter data clock for synchronous transmission corresponding to SPI master mode (no clock pulses on start bit and stop bit, and a software option to send a clock pulse on the last data bit). In parallel data can be received synchronously on RX. This can be used to control peripherals that have shift registers (e.g. LCD drivers). The clock phase and polarity are software programmable. In smartcard mode, SCLK can provide the clock to the smartcard.

The following pins are required in Hardware flow control mode:

- **nCTS:** Clear To Send blocks the data transmission at the end of the current transfer when high
- **nRTS:** Request to send indicates that the USART is ready to receive a data (when low).

**Figure 167. USART block diagram**



### 19.3.1 USART character description

Word length may be selected as being either 8 or 9 bits by programming the M bit in the USART\_CR1 register (see [Figure 168](#)).

The TX pin is in low state during the start bit. It is in high state during the stop bit.

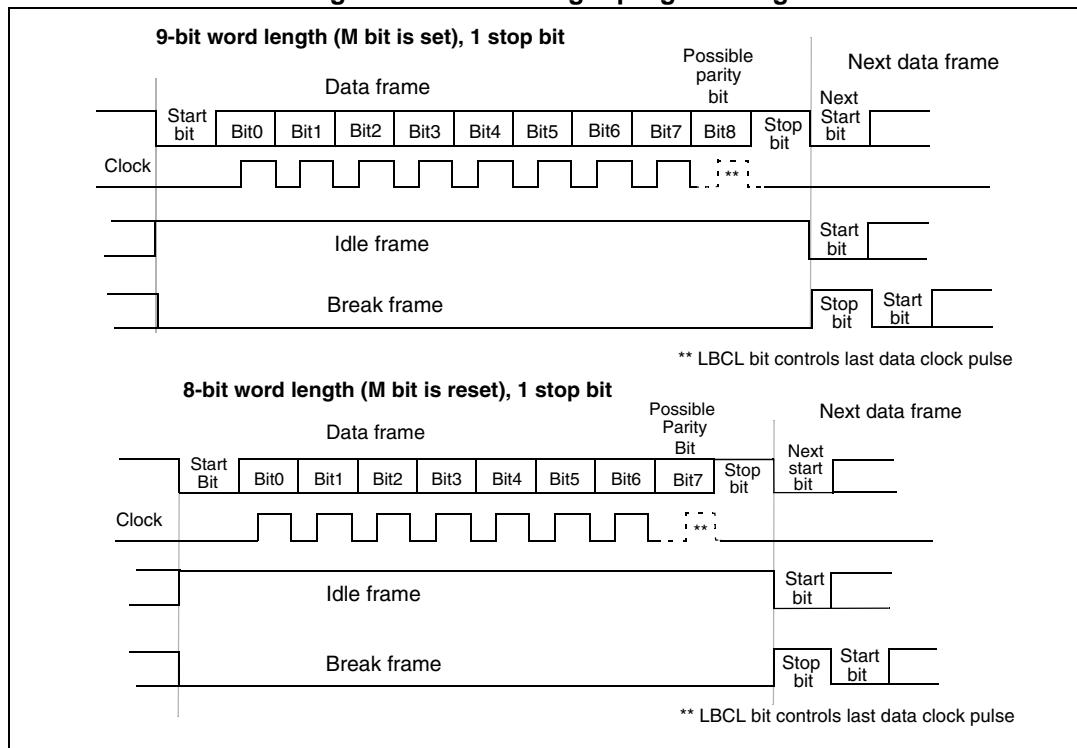
An **Idle character** is interpreted as an entire frame of “1”s followed by the start bit of the next frame which contains data (The number of “1”’s will include the number of stop bits).

A **Break character** is interpreted on receiving “0”s for a frame period. At the end of the break frame the transmitter inserts either 1 or 2 stop bits (logic “1” bit) to acknowledge the start bit.

Transmission and reception are driven by a common baud rate generator, the clock for each is generated when the enable bit is set respectively for the transmitter and receiver.

The details of each block is given below.

**Figure 168. Word length programming**



### 19.3.2 Transmitter

The transmitter can send data words of either 8 or 9 bits depending on the M bit status. When the transmit enable bit (TE) is set, the data in the transmit shift register is output on the TX pin and the corresponding clock pulses are output on the SCLK pin.

#### Character transmission

During an USART transmission, data shifts out least significant bit first on the TX pin. In this mode, the USART\_DR register consists of a buffer (TDR) between the internal bus and the transmit shift register (see [Figure 167](#)).

Every character is preceded by a start bit which is a logic level low for one bit period. The character is terminated by a configurable number of stop bits.

The following stop bits are supported by USART: 0.5, 1, 1.5 and 2 stop bits.

*Note:* *The TE bit should not be reset during transmission of data. Resetting the TE bit during the transmission will corrupt the data on the TX pin as the baud rate counters will get frozen. The current data being transmitted will be lost.*

*An idle frame will be sent after the TE bit is enabled.*

#### Configurable stop bits

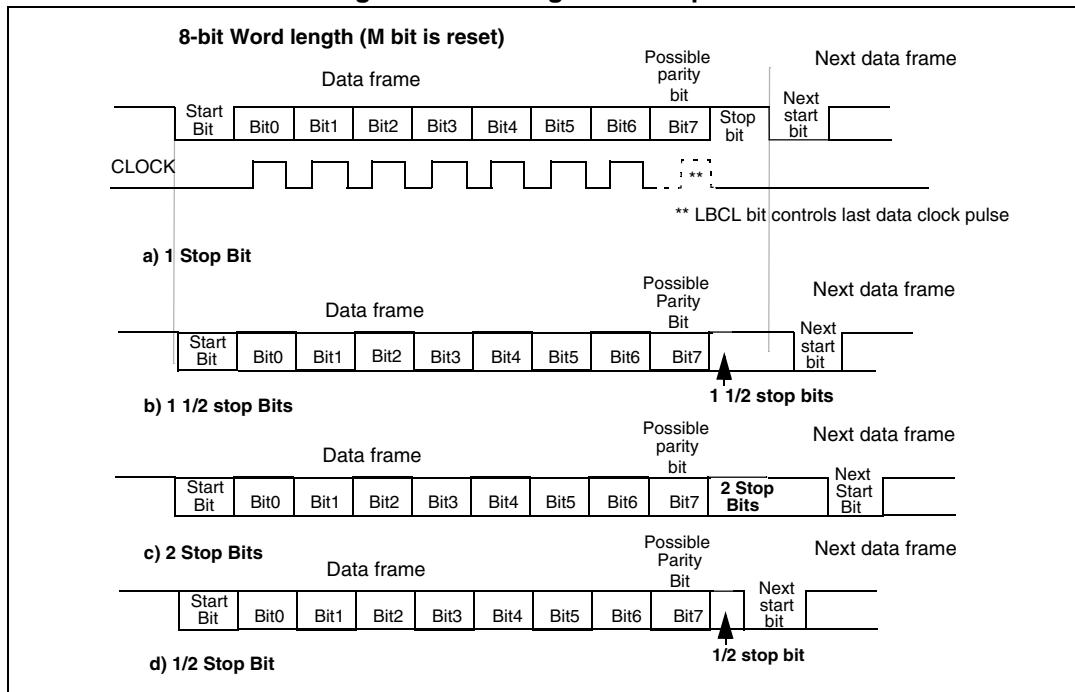
The number of stop bits to be transmitted with every character can be programmed in Control register 2, bits 13,12.

- **1 stop bit:** This is the default value of number of stop bits.
- **2 Stop bits:** This will be supported by normal USART, single-wire and modem modes.
- **0.5 stop bit:** To be used when receiving data in Smartcard mode.
- **1.5 stop bits:** To be used when transmitting and receiving data in Smartcard mode.

An idle frame transmission will include the stop bits.

A break transmission will be 10 low bits followed by the configured number of stop bits (when m = 0) and 11 low bits followed by the configured number of stop bits (when m = 1). It is not possible to transmit long breaks (break of length greater than 10/11 low bits).

Figure 169. Configurable stop bits



Procedure:

1. Enable the USART by writing the UE bit in USART\_CR1 register to 1.
2. Program the M bit in USART\_CR1 to define the word length.
3. Program the number of stop bits in USART\_CR2.
4. Select DMA enable (DMAT) in USART\_CR3 if Multi buffer Communication is to take place. Configure the DMA register as explained in multibuffer communication.
5. Select the desired baud rate using the USART\_BRR register.
6. Set the TE bit in USART\_CR1 to send an idle frame as first transmission.
7. Write the data to send in the USART\_DR register (this clears the TXE bit). Repeat this for each data to be transmitted in case of single buffer.
8. After writing the last data into the USART\_DR register, wait until TC=1. This indicates that the transmission of the last frame is complete. This is required for instance when the USART is disabled or enters the Halt mode to avoid corrupting the last transmission.

### Single byte communication

Clearing the TXE bit is always performed by a write to the data register.

The TXE bit is set by hardware and it indicates:

- The data has been moved from TDR to the shift register and the data transmission has started.
- The TDR register is empty.
- The next data can be written in the USART\_DR register without overwriting the previous data.

This flag generates an interrupt if the TXEIE bit is set.

When a transmission is taking place, a write instruction to the USART\_DR register stores the data in the TDR register and which is copied in the shift register at the end of the current transmission.

When no transmission is taking place, a write instruction to the USART\_DR register places the data directly in the shift register, the data transmission starts, and the TXE bit is immediately set.

If a frame is transmitted (after the stop bit) and the TXE bit is set, the TC bit goes high. An interrupt is generated if the TCIE bit is set in the USART\_CR1 register.

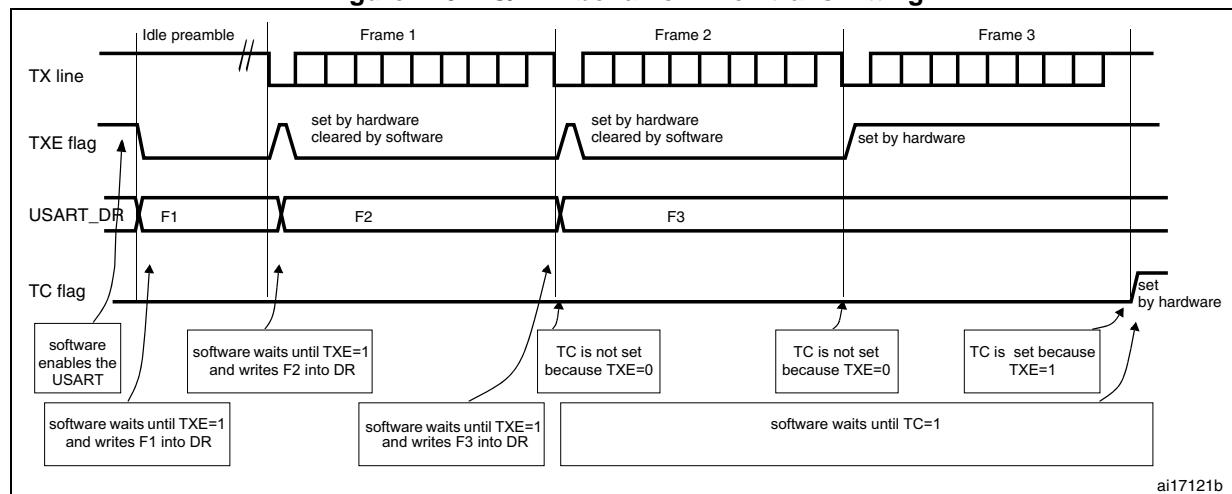
After writing the last data into the USART\_DR register, it is mandatory to wait for TC=1 before disabling the USART or causing the microcontroller to enter the low power mode (see [Figure 170: TC/TXE behavior when transmitting](#)).

The TC bit is cleared by the following software sequence:

1. A read from the USART\_SR register
2. A write to the USART\_DR register

**Note:** *The TC bit can also be cleared by writing a '0' to it. This clearing sequence is recommended only for Multibuffer communication.*

**Figure 170. TC/TXE behavior when transmitting**



### Break characters

Setting the SBK bit transmits a break character. The break frame length depends on the M bit (see [Figure 168](#)).

If the SBK bit is set to '1' a break character is sent on the TX line after completing the current character transmission. This bit is reset by hardware when the break character is completed (during the stop bit of the break character). The USART inserts a logic 1 bit at the end of the last break frame to guarantee the recognition of the start bit of the next frame.

**Note:** *If the software resets the SBK bit before the commencement of break transmission, the break character will not be transmitted. For two consecutive breaks, the SBK bit should be set after the stop bit of the previous break.*

### Idle characters

Setting the TE bit drives the USART to send an idle frame before the first data frame.

### 19.3.3 Receiver

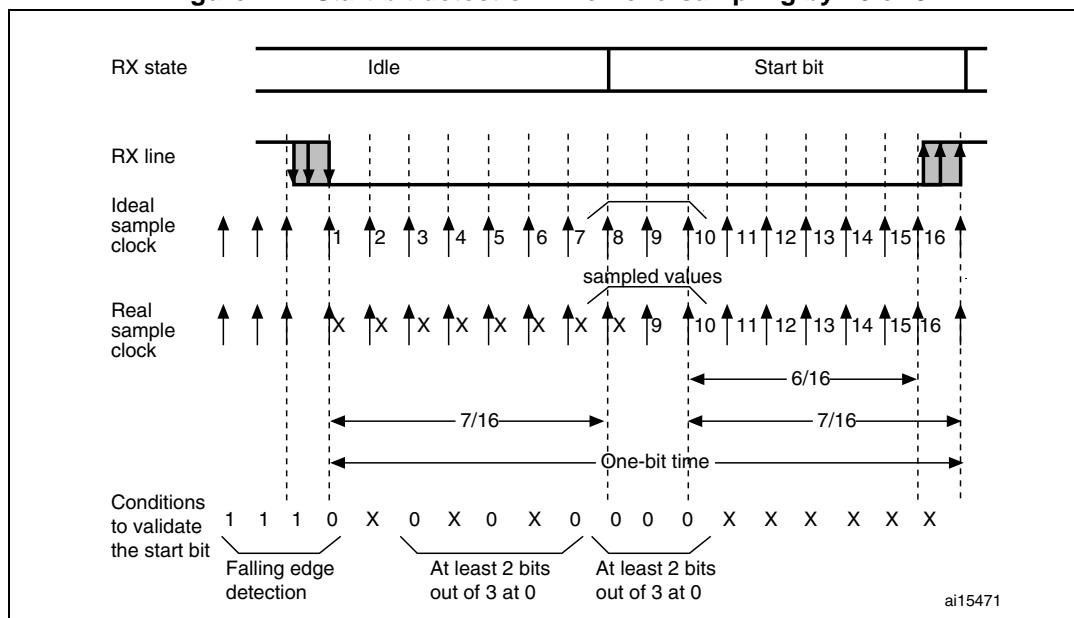
The USART can receive data words of either 8 or 9 bits depending on the M bit in the USART\_CR1 register.

#### Start bit detection

The start bit detection sequence is the same when oversampling by 16 or by 8.

In the USART, the start bit is detected when a specific sequence of samples is recognized. This sequence is: 1 1 1 0 X 0 X 0 X 0 0 0.

**Figure 171. Start bit detection when oversampling by 16 or 8**



Note:

If the sequence is not complete, the start bit detection aborts and the receiver returns to the idle state (no flag is set) where it waits for a falling edge.

The start bit is confirmed (RXNE flag set, interrupt generated if RXNEIE=1) if the 3 sampled bits are at 0 (first sampling on the 3rd, 5th and 7th bits finds the 3 bits at 0 and second sampling on the 8th, 9th and 10th bits also finds the 3 bits at 0).

The start bit is validated (RXNE flag set, interrupt generated if RXNEIE=1) but the NE noise flag is set if, for both samplings, at least 2 out of the 3 sampled bits are at 0 (sampling on the 3rd, 5th and 7th bits and sampling on the 8th, 9th and 10th bits). If this condition is not met, the start detection aborts and the receiver returns to the idle state (no flag is set).

If, for one of the samplings (sampling on the 3rd, 5th and 7th bits or sampling on the 8th, 9th and 10th bits), 2 out of the 3 bits are found at 0, the start bit is validated but the NE noise flag bit is set.

#### Character reception

During an USART reception, data shifts in least significant bit first through the RX pin. In this mode, the USART\_DR register consists of a buffer (RDR) between the internal bus and the received shift register.

Procedure:

1. Enable the USART by writing the UE bit in USART\_CR1 register to 1.
2. Program the M bit in USART\_CR1 to define the word length.
3. Program the number of stop bits in USART\_CR2.
4. Select DMA enable (DMAR) in USART\_CR3 if multibuffer communication is to take place. Configure the DMA register as explained in multibuffer communication. STEP 3
5. Select the desired baud rate using the baud rate register USART\_BRR
6. Set the RE bit USART\_CR1. This enables the receiver which begins searching for a start bit.

When a character is received

- The RXNE bit is set. It indicates that the content of the shift register is transferred to the RDR. In other words, data has been received and can be read (as well as its associated error flags).
- An interrupt is generated if the RXNEIE bit is set.
- The error flags can be set if a frame error, noise or an overrun error has been detected during reception.
- In multibuffer, RXNE is set after every byte received and is cleared by the DMA read to the Data Register.
- In single buffer mode, clearing the RXNE bit is performed by a software read to the USART\_DR register. The RXNE flag can also be cleared by writing a zero to it. The RXNE bit must be cleared before the end of the reception of the next character to avoid an overrun error.

**Note:**

*The RE bit should not be reset while receiving data. If the RE bit is disabled during reception, the reception of the current byte will be aborted.*

### **Break character**

When a break character is received, the USART handles it as a framing error.

### **Idle character**

When an idle frame is detected, there is the same procedure as a data received character plus an interrupt if the IDLEIE bit is set.

### **Overrun error**

An overrun error occurs when a character is received when RXNE has not been reset. Data can not be transferred from the shift register to the RDR register until the RXNE bit is cleared.

The RXNE flag is set after every byte received. An overrun error occurs if RXNE flag is set when the next data is received or the previous DMA request has not been serviced. When an overrun error occurs:

- The ORE bit is set.
- The RDR content will not be lost. The previous data is available when a read to USART\_DR is performed.
- The shift register will be overwritten. After that point, any data received during overrun is lost.
- An interrupt is generated if either the RXNEIE bit is set or both the EIE and DMAR bits are set.
- The ORE bit is reset by a read to the USART\_SR register followed by a USART\_DR register read operation.

**Note:** *The ORE bit, when set, indicates that at least 1 data has been lost. There are two possibilities:*

- if RXNE=1, then the last valid data is stored in the receive register RDR and can be read,
- if RXNE=0, then it means that the last valid data has already been read and thus there is nothing to be read in the RDR. This case can occur when the last valid data is read in the RDR at the same time as the new (and lost) data is received. It may also occur when the new data is received during the reading sequence (between the USART\_SR register read access and the USART\_DR read access).

### Selecting the proper oversampling method

The receiver implements different user-configurable oversampling techniques (except in synchronous mode) for data recovery by discriminating between valid incoming data and noise.

The oversampling method can be selected by programming the OVER8 bit in the USART\_CR1 register and can be either 16 or 8 times the baud rate clock ([Figure 172](#) and [Figure 173](#)).

Depending on the application:

- select oversampling by 8 (OVER8=1) to achieve higher speed (up to  $f_{PCLK}/8$ ). In this case the maximum receiver tolerance to clock deviation is reduced (refer to [Section 19.3.5: USART receiver tolerance to clock deviation on page 518](#))
- select oversampling by 16 (OVER8=0) to increase the tolerance of the receiver to clock deviations. In this case, the maximum speed is limited to maximum  $f_{PCLK}/16$

Programming the ONEBIT bit in the USART\_CR3 register selects the method used to evaluate the logic level. There are two options:

- the majority vote of the three samples in the center of the received bit. In this case, when the 3 samples used for the majority vote are not equal, the NF bit is set
- a single sample in the center of the received bit

Depending on the application:

- select the three samples' majority vote method (ONEBIT=0) when operating in a noisy environment and reject the data when a noise is detected (refer to [Figure 72](#)) because this indicates that a glitch occurred during the sampling.
- select the single sample method (ONEBIT=1) when the line is noise-free to increase the receiver's tolerance to clock deviations (see [Section 19.3.5: USART receiver tolerance to clock deviation on page 518](#))

[receiver tolerance to clock deviation on page 518](#)). In this case the NF bit will never be set.

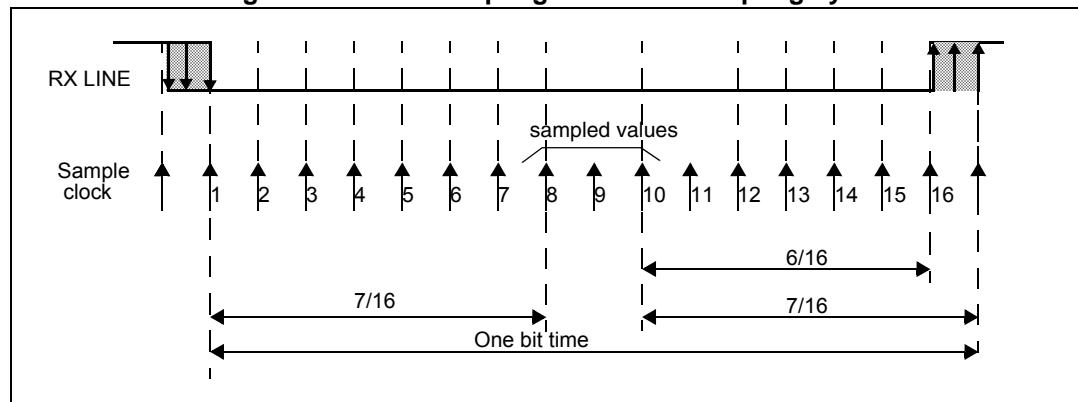
When noise is detected in a frame:

- The NF bit is set at the rising edge of the RXNE bit.
- The invalid data is transferred from the Shift register to the USART\_DR register.
- No interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit which itself generates an interrupt. In case of multibuffer communication an interrupt will be issued if the EIE bit is set in the USART\_CR3 register.

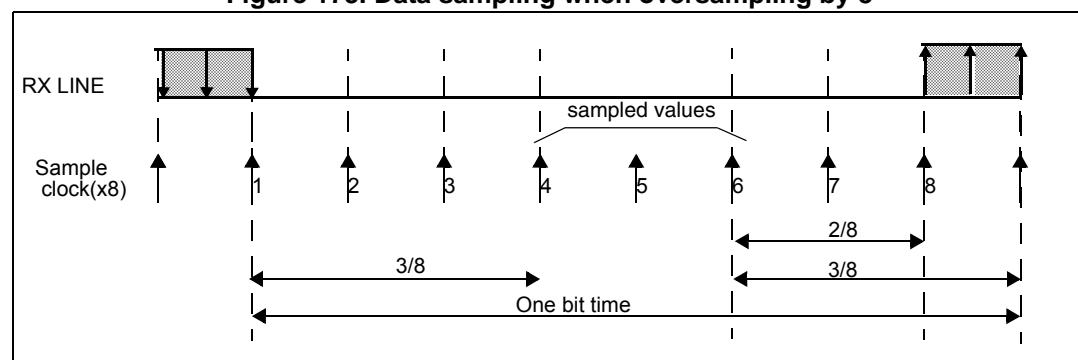
The NF bit is reset by a USART\_SR register read operation followed by a USART\_DR register read operation.

**Note:** *Oversampling by 8 is not available in the Smartcard, IrDA and LIN modes. In those modes, the OVER8 bit is forced to '0' by hardware.*

**Figure 172. Data sampling when oversampling by 16**



**Figure 173. Data sampling when oversampling by 8**



**Table 72. Noise detection from sampled data**

Sampled value	NE status	Received bit value
000	0	0
001	1	0
010	1	0
011	1	1

**Table 72. Noise detection from sampled data (continued)**

Sampled value	NE status	Received bit value
100	1	0
101	1	1
110	1	1
111	0	1

### Framing error

A framing error is detected when:

The stop bit is not recognized on reception at the expected time, following either a de-synchronization or excessive noise.

When the framing error is detected:

- The FE bit is set by hardware
- The invalid data is transferred from the Shift register to the USART\_DR register.
- No interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit which itself generates an interrupt. In case of multibuffer communication an interrupt will be issued if the EIE bit is set in the USART\_CR3 register.

The FE bit is reset by a USART\_SR register read operation followed by a USART\_DR register read operation.

### Configurable stop bits during reception

The number of stop bits to be received can be configured through the control bits of Control Register 2 - it can be either 1 or 2 in normal mode and 0.5 or 1.5 in Smartcard mode.

1. **0.5 stop bit (reception in Smartcard mode):** No sampling is done for 0.5 stop bit. As a consequence, no framing error and no break frame can be detected when 0.5 stop bit is selected.
2. **1 stop bit:** Sampling for 1 stop Bit is done on the 8th, 9th and 10th samples.
3. **1.5 stop bits (Smartcard mode):** When transmitting in smartcard mode, the device must check that the data is correctly sent. Thus the receiver block must be enabled (RE =1 in the USART\_CR1 register) and the stop bit is checked to test if the smartcard has detected a parity error. In the event of a parity error, the smartcard forces the data signal low during the sampling - NACK signal-, which is flagged as a framing error. Then, the FE flag is set with the RXNE at the end of the 1.5 stop bit. Sampling for 1.5 stop bits is done on the 16th, 17th and 18th samples (1 baud clock period after the beginning of the stop bit). The 1.5 stop bit can be decomposed into 2 parts: one 0.5 baud clock period during which nothing happens, followed by 1 normal stop bit period during which sampling occurs halfway through. Refer to [Section 19.3.11: Smartcard on page 526](#) for more details.
4. **2 stop bits:** Sampling for 2 stop bits is done on the 8th, 9th and 10th samples of the first stop bit. If a framing error is detected during the first stop bit the framing error flag will be set. The second stop bit is not checked for framing error. The RXNE flag will be set at the end of the first stop bit.

### 19.3.4 Fractional baud rate generation

The baud rate for the receiver and transmitter (Rx and Tx) are both set to the same value as programmed in the Mantissa and Fraction values of USARTDIV.

#### Equation 1: Baud rate for standard USART (SPI mode included)

$$\text{Tx/Rx baud} = \frac{f_{CK}}{8 \times (2 - \text{OVER8}) \times \text{USARTDIV}}$$

#### Equation 2: Baud rate in Smartcard, LIN and IrDA modes

$$\text{Tx/Rx baud} = \frac{f_{CK}}{16 \times \text{USARTDIV}}$$

USARTDIV is an unsigned fixed point number that is coded on the USART\_BRR register.

- When OVER8=0, the fractional part is coded on 4 bits and programmed by the DIV\_fraction[3:0] bits in the USART\_BRR register
- When OVER8=1, the fractional part is coded on 3 bits and programmed by the DIV\_fraction[2:0] bits in the USART\_BRR register, and bit DIV\_fraction[3] must be kept cleared.

*Note:* The baud counters are updated to the new value in the baud registers after a write operation to USART\_BRR. Hence the baud rate register value should not be changed during communication.

#### How to derive USARTDIV from USART\_BRR register values when OVER8=0

##### Example 1:

If DIV\_Mantissa = 0d27 and DIV\_Fraction = 0d12 (USART\_BRR = 0x1BC), then

Mantissa (USARTDIV) = 0d27

Fraction (USARTDIV) = 12/16 = 0d0.75

Therefore USARTDIV = 0d27.75

##### Example 2:

To program USARTDIV = 0d25.62

This leads to:

DIV\_Fraction = 16 \* 0d0.62 = 0d9.92

The nearest real number is 0d10 = 0xA

DIV\_Mantissa = mantissa (0d25.620) = 0d25 = 0x19

Then, USART\_BRR = 0x19A hence USARTDIV = 0d25.625

##### Example 3:

To program USARTDIV = 0d50.99

This leads to:

$$\text{DIV\_Fraction} = 16 * 0d0.99 = 0d15.84$$

The nearest real number is 0d16 = 0x10 => overflow of DIV\_frac[3:0] => carry must be added up to the mantissa

$$\text{DIV\_Mantissa} = \text{mantissa } (0d50.990 + \text{carry}) = 0d51 = 0x33$$

Then, USART\_BRR = 0x330 hence USARTDIV = 0d51.000

### How to derive USARTDIV from USART\_BRR register values when OVER8=1

*Example 1:*

If DIV\_Mantissa = 0x27 and DIV\_Fraction[2:0]= 0d6 (USART\_BRR = 0x1B6), then

$$\text{Mantissa (USARTDIV)} = 0d27$$

$$\text{Fraction (USARTDIV)} = 6/8 = 0d0.75$$

Therefore USARTDIV = 0d27.75

*Example 2:*

To program USARTDIV = 0d25.62

This leads to:

$$\text{DIV\_Fraction} = 8 * 0d0.62 = 0d4.96$$

The nearest real number is 0d5 = 0x5

$$\text{DIV\_Mantissa} = \text{mantissa } (0d25.620) = 0d25 = 0x19$$

Then, USART\_BRR = 0x195 => USARTDIV = 0d25.625

*Example 3:*

To program USARTDIV = 0d50.99

This leads to:

$$\text{DIV\_Fraction} = 8 * 0d0.99 = 0d7.92$$

The nearest real number is 0d8 = 0x8 => overflow of the DIV\_frac[2:0] => carry must be added up to the mantissa

$$\text{DIV\_Mantissa} = \text{mantissa } (0d50.990 + \text{carry}) = 0d51 = 0x33$$

Then, USART\_BRR = 0x0330 => USARTDIV = 0d51.000

**Table 73. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 12 \text{ MHz}$ , oversampling by 16<sup>(1)</sup>**

Oversampling by 16 (OVER8=0)							
Baud rate7		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 12 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate	Actual	Value programmed in the baud rate register	% Error
1	1.2 KBps	1.2 KBps	416.6875	0	1.2 KBps	625	0
2	2.4 KBps	2.4 KBps	208.3125	0.01	2.4 KBps	312.5	0

**Table 73. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 12 \text{ MHz}$ , oversampling by 16<sup>(1)</sup> (continued)**

Oversampling by 16 (OVER8=0)							
Baud rate7		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 12 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate	Actual	Value programmed in the baud rate register	% Error
3	9.6 KBps	9.604 KBps	52.0625	0.04	9.6 KBps	78.125	0
4	19.2 KBps	19.185 KBps	26.0625	0.08	19.2 KBps	39.0625	0
5	38.4 KBps	38.462 KBps	13	0.16	38.339 KBps	19.5625	0.16
6	57.6 KBps	57.554 KBps	8.6875	0.08	57.692 KBps	13	0.16
7	115.2 KBps	115.942 KBps	4.3125	0.64	115.385 KBps	6.5	0.16
8	230.4 KBps	228.571 KBps	2.1875	0.79	230.769 KBps	3.25	0.16
9	460.8 KBps	470.588 KBps	1.0625	2.12	461.538 KBps	1.625	0.16
10	921.6 KBps	NA	NA	NA	NA	NA	NA
11	2 MBps	NA	NA	NA	NA	NA	NA
12	3 MBps	NA	NA	NA	NA	NA	NA

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

**Table 74. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 12 \text{ MHz}$ , oversampling by 8<sup>(1)</sup>**

Oversampling by 8 (OVER8 = 1)							
Baud rate		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 12 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate	Actual	Value programmed in the baud rate register	% Error
1	1.2 KBps	1.2 KBps	833.375	0	1.2 KBps	1250	0
2	2.4 KBps	2.4 KBps	416.625	0.01	2.4 KBps	625	0
3	9.6 KBps	9.604 KBps	104.125	0.04	9.6 KBps	156.25	0
4	19.2 KBps	19.185 KBps	52.125	0.08	19.2 KBps	78.125	0
5	38.4 KBps	38.462 KBps	26	0.16	38.339 KBps	39.125	0.16
6	57.6 KBps	57.554 KBps	17.375	0.08	57.692 KBps	26	0.16
7	115.2 KBps	115.942 KBps	8.625	0.64	115.385 KBps	13	0.16
8	230.4 KBps	228.571 KBps	4.375	0.79	230.769 KBps	6.5	0.16
9	460.8 KBps	470.588 KBps	2.125	2.12	461.538 KBps	3.25	0.16

**Table 74. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 12 \text{ MHz}$ , oversampling by 8<sup>(1)</sup> (continued)**

Oversampling by 8 (OVER8 = 1)							
Baud rate		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 12 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate	Actual	Value programmed in the baud rate register	% Error
10	921.6 KBps	888.889 KBps	1.125	3.55	923.077 KBps	1.625	0.16
11	2 MBps	NA	NA	NA	NA	NA	NA
12	3 MBps	NA	NA	NA	NA	NA	NA

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

**Table 75. Error calculation for programmed baud rates at  $f_{PCLK} = 16 \text{ MHz}$  or  $f_{PCLK} = 24 \text{ MHz}$ , oversampling by 16<sup>(1)</sup>**

Oversampling by 16 (OVER8 = 0)							
Baud rate		$f_{PCLK} = 16 \text{ MHz}$			$f_{PCLK} = 24 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate	Actual	Value programmed in the baud rate register	% Error
1	1.2 KBps	1.2 KBps	833.3125	0	1.2	1250	0
2	2.4 KBps	2.4 KBps	416.6875	0	2.4	625	0
3	9.6 KBps	9.598 KBps	104.1875	0.02	9.6	156.25	0
4	19.2 KBps	19.208 KBps	52.0625	0.04	19.2	78.125	0
5	38.4 KBps	38.369 KBps	26.0625	0.08	38.4	39.0625	0
6	57.6 KBps	57.554 KBps	17.375	0.08	57.554	26.0625	0.08
7	115.2 KBps	115.108 KBps	8.6875	0.08	115.385	13	0.16
8	230.4 KBps	231.884 KBps	4.3125	0.64	230.769	6.5	0.16
9	460.8 KBps	457.143 KBps	2.1875	0.79	461.538	3.25	0.16
10	921.6 KBps	941.176 KBps	1.0625	2.12	923.077	1.625	0.16
11	2 MBps	NA	NA	NA	NA	NA	NA
12	3 MBps	NA	NA	NA	NA	NA	NA

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

**Table 76. Error calculation for programmed baud rates at  $f_{PCLK} = 16$  MHz or  $f_{PCLK} = 24$  MHz, oversampling by 8<sup>(1)</sup>**

Oversampling by 8 (OVER8=1)							
Baud rate		$f_{PCLK} = 16$ MHz			$f_{PCLK} = 24$ MHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate	Actual	Value programmed in the baud rate register	% Error
1	1.2 KBps	1.2 KBps	1666.625	0	1.2 KBps	2500	0
2	2.4 KBps	2.4 KBps	833.375	0	2.4 KBps	1250	0
3	9.6 KBps	9.598 KBps	208.375	0.02	9.6 KBps	312.5	0
4	19.2 KBps	19.208 KBps	104.125	0.04	19.2 KBps	156.25	0
5	38.4 KBps	38.369 KBps	52.125	0.08	38.4 KBps	78.125	0
6	57.6 KBps	57.554 KBps	34.75	0.08	57.554 KBps	52.125	0.08
7	115.2 KBps	115.108 KBps	17.375	0.08	115.385 KBps	26	0.16
8	230.4 KBps	231.884 KBps	8.625	0.64	230.769 KBps	13	0.16
9	460.8 KBps	457.143 KBps	4.375	0.79	461.538 KBps	6.5	0.16
10	921.6 KBps	941.176 KBps	2.125	2.12	923.077 KBps	3.25	0.16
11	2 MBps	2000 KBps	1	0	2000 KBps	1.5	0
12	3 MBps	NA	NA	NA	3000 KBps	1	0

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

**Table 77. Error calculation for programmed baud rates at  $f_{PCLK} = 8$  MHz or  $f_{PCLK} = 16$  MHz, oversampling by 16<sup>(1)</sup>**

Oversampling by 16 (OVER8=0)							
Baud rate		$f_{PCLK} = 8$ MHz			$f_{PCLK} = 16$ MHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.Rate / Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
1.	2.4 KBps	2.400 KBps	208.3125	0.00%	2.400 KBps	416.6875	0.00%
2.	9.6 KBps	9.604 KBps	52.0625	0.04%	9.598 KBps	104.1875	0.02%
3.	19.2 KBps	19.185 KBps	26.0625	0.08%	19.208 KBps	52.0625	0.04%
4.	57.6 KBps	57.554 KBps	8.6875	0.08%	57.554 KBps	17.3750	0.08%
5.	115.2 KBps	115.942 KBps	4.3125	0.64%	115.108 KBps	8.6875	0.08%
6.	230.4 KBps	228.571 KBps	2.1875	0.79%	231.884 KBps	4.3125	0.64%

**Table 77. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 16 \text{ MHz}$ , oversampling by 16<sup>(1)</sup> (continued)**

Oversampling by 16 (OVER8=0)							
Baud rate		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 16 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
7.	460.8 Kbps	470.588 Kbps	1.0625	2.12%	457.143 Kbps	2.1875	0.79%
8.	896 Kbps	NA	NA	NA	888.889 Kbps	1.1250	0.79%
9.	921.6 Kbps	NA	NA	NA	941.176 Kbps	1.0625	2.12%
10.	1.792 MBps	NA	NA	NA	NA	NA	NA
11.	1.8432 MBps	NA	NA	NA	NA	NA	NA
12.	3.584 MBps	NA	NA	NA	NA	NA	NA
13.	3.6864 MBps	NA	NA	NA	NA	NA	NA
14.	7.168 MBps	NA	NA	NA	NA	NA	NA
15.	7.3728 MBps	NA	NA	NA	NA	NA	NA

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

**Table 78. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 16 \text{ MHz}$ , oversampling by 8<sup>(1)</sup>**

Oversampling by 8 (OVER8=1)							
Baud rate		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 16 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
1.	2.4 Kbps	2.400 Kbps	416.625	0.01%	2.400 Kbps	833.375	0.00%
2.	9.6 Kbps	9.604 Kbps	104.125	0.04%	9.598 Kbps	208.375	0.02%
3.	19.2 Kbps	19.185 Kbps	52.125	0.08%	19.208 Kbps	104.125	0.04%
4.	57.6 Kbps	57.557 Kbps	17.375	0.08%	57.554 Kbps	34.750	0.08%
5.	115.2 Kbps	115.942 Kbps	8.625	0.64%	115.108 Kbps	17.375	0.08%
6.	230.4 Kbps	228.571 Kbps	4.375	0.79%	231.884 Kbps	8.625	0.64%
7.	460.8 Kbps	470.588 Kbps	2.125	2.12%	457.143 Kbps	4.375	0.79%
8.	896 Kbps	888.889 Kbps	1.125	0.79%	888.889 Kbps	2.250	0.79%
9.	921.6 Kbps	888.889 Kbps	1.125	3.55%	941.176 Kbps	2.125	2.12%
10.	1.792 MBps	NA	NA	NA	1.7777 MBps	1.125	0.79%

**Table 78. Error calculation for programmed baud rates at  $f_{PCLK} = 8 \text{ MHz}$  or  $f_{PCLK} = 16 \text{ MHz}$ , oversampling by 8<sup>(1)</sup> (continued)**

Oversampling by 8 (OVER8=1)							
Baud rate		$f_{PCLK} = 8 \text{ MHz}$			$f_{PCLK} = 16 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
11.	1.8432 MBps	NA	NA	NA	1.7777 MBps	1.125	3.55%
12.	3.584 MBps	NA	NA	NA	NA	NA	NA
13.	3.6864 MBps	NA	NA	NA	NA	NA	NA
14.	7.168 MBps	NA	NA	NA	NA	NA	NA
15.	7.3728 MBps	NA	NA	NA	NA	NA	NA

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

**Table 79. Error calculation for programmed baud rates at  $f_{PCLK} = 30 \text{ MHz}$  or  $f_{PCLK} = 60 \text{ MHz}$ , oversampling by 16<sup>(1)(2)</sup>**

Oversampling by 16 (OVER8=0)							
Baud rate		$f_{PCLK} = 30 \text{ MHz}$			$f_{PCLK} = 60 \text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
1.	2.4 KBps	2.400 KBps	781.2500	0.00%	2.400 KBps	1562.5000	0.00%
2.	9.6 KBps	9.600 KBps	195.3125	0.00%	9.600 KBps	390.6250	0.00%
3.	19.2 KBps	19.194 KBps	97.6875	0.03%	19.200 KBps	195.3125	0.00%
4.	57.6 KBps	57.582 KBps	32.5625	0.03%	57.582 KBps	65.1250	0.03%
5.	115.2 KBps	115.385 KBps	16.2500	0.16%	115.163 KBps	32.5625	0.03%
6.	230.4 KBps	230.769 KBps	8.1250	0.16%	230.769 KBps	16.2500	0.16%
7.	460.8 KBps	461.538 KBps	4.0625	0.16%	461.538 KBps	8.1250	0.16%
8.	896 KBps	909.091 KBps	2.0625	1.46%	895.522 KBps	4.1875	0.05%
9.	921.6 KBps	909.091 KBps	2.0625	1.36%	923.077 KBps	4.0625	0.16%
10.	1.792 MBps	1.1764 MBps	1.0625	1.52%	1.8182 MBps	2.0625	1.36%
11.	1.8432 MBps	1.8750 MBps	1.0000	1.73%	1.8182 MBps	2.0625	1.52%
12.	3.584 MBps	NA	NA	NA	3.2594 MBps	1.0625	1.52%
13.	3.6864 MBps	NA	NA	NA	3.7500 MBps	1.0000	1.73%

**Table 79. Error calculation for programmed baud rates at  $f_{PCLK} = 30$  MHz or  $f_{PCLK} = 60$  MHz, oversampling by 16<sup>(1)(2)</sup> (continued)**

Oversampling by 16 (OVER8=0)							
Baud rate		$f_{PCLK} = 30$ MHz			$f_{PCLK} = 60$ MHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
14.	7.168 MBps	NA	NA	NA	NA	NA	NA
15.	7.3728 MBps	NA	NA	NA	NA	NA	NA

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.
2. Only USART1 and USART6 are clocked with PCLK2. Other USARTs are clocked with PCLK1. Refer to the device datasheets for the maximum values for PCLK1 and PCLK2.

**Table 80. Error calculation for programmed baud rates at  $f_{PCLK} = 30$  MHz or  $f_{PCLK} = 60$  MHz, oversampling by 8<sup>(1)(2)</sup>**

Oversampling by 8 (OVER8=1)							
Baud rate		$f_{PCLK} = 30$ MHz			$f_{PCLK} = 60$ MHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
1.	2.4 KBps	2.400 KBps	1562.5000	0.00%	2.400 KBps	3125.0000	0.00%
2.	9.6 KBps	9.600 KBps	390.6250	0.00%	9.600 KBps	781.2500	0.00%
3.	19.2 KBps	19.194 KBps	195.3750	0.03%	19.200 KBps	390.6250	0.00%
4.	57.6 KBps	57.582 KBps	65.1250	0.16%	57.582 KBps	130.2500	0.03%
5.	115.2 KBps	115.385 KBps	32.5000	0.16%	115.163 KBps	65.1250	0.03%
6.	230.4 KBps	230.769 KBps	16.2500	0.16%	230.769 KBps	32.5000	0.16%
7.	460.8 KBps	461.538 KBps	8.1250	0.16%	461.538 KBps	16.2500	0.16%
8.	896 KBps	909.091 KBps	4.1250	1.46%	895.522 KBps	8.3750	0.05%
9.	921.6 KBps	909.091 KBps	4.1250	1.36%	923.077 KBps	8.1250	0.16%
10.	1.792 MBps	1.7647 MBps	2.1250	1.52%	1.8182 MBps	4.1250	1.46%
11.	1.8432 MBps	1.8750 MBps	2.0000	1.73%	1.8182 MBps	4.1250	1.36%
12.	3.584 MBps	3.7500 MBps	1.0000	4.63%	3.5294 MBps	2.1250	1.52%
13.	3.6864 MBps	3.7500 MBps	1.0000	1.73%	3.7500 MBps	2.0000	1.73%
14.	7.168 MBps	NA	NA	NA	7.5000 MBps	1.0000	4.63%
15.	7.3728 MBps	NA	NA	NA	7.5000 MBps	1.0000	1.73%

- The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.
- Only USART1 and USART6 are clocked with PCLK2. Other USARTs are clocked with PCLK1. Refer to the device datasheets for the maximum values for PCLK1 and PCLK2.

**Table 81. Error calculation for programmed baud rates at  $f_{PCLK} = 42\text{ MHz}$  or  $f_{PCLK} = 84\text{ Hz}$ , oversampling by 16<sup>(1)(2)</sup>**

Oversampling by 16 (OVER8=0)							
Baud rate		$f_{PCLK} = 42\text{ MHz}$			$f_{PCLK} = 84\text{ MHz}$		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
1	1.2 KBps	1.2 KBps	2187.5	0	1.2 KBps	4375	0
2	2.4 KBps	2.4 KBps	1093.75	0	2.4 KBps	2187.5	0
3	9.6 KBps	9.6 KBps	273.4375	0	9.6 KBps	546.875	0
4	19.2 KBps	19.195 KBps	136.75	0.02	19.2 KBps	273.4375	0
5	38.4 KBps	38.391 KBps	68.375	0.02	38.391 KBps	136.75	0.02
6	57.6 KBps	57.613 KBps	45.5625	0.02	57.613 KBps	91.125	0.02
7	115.2 KBps	115.068 KBps	22.8125	0.11	115.226 KBps	45.5625	0.02
8	230.4 KBps	230.769 KBps	11.375	0.16	230.137 KBps	22.8125	0.11
9	460.8 KBps	461.538 KBps	5.6875	0.16	461.538 KBps	11.375	0.16
10	921.6 KBps	913.043 KBps	2.875	0.93	923.076 KBps	5.6875	0.93
11	1.792 MBps	1.826 MBps	1.4375	1.9	1.787 MBps	2.9375	0.27
12	1.8432 MBps	1.826 MBps	1.4375	0.93	1.826 MBps	2.875	0.93
13	3.584 MBps	N.A	N.A	N.A	3.652 MBps	1.4375	1.9
14	3.6864 MBps	N.A	N.A	N.A	3.652 MBps	1.4375	0.93
15	7.168 MBps	N.A	N.A	N.A	N.A	N.A	N.A
16	7.3728 MBps	N.A	N.A	N.A	N.A	N.A	N.A
18	9 MBps	N.A	N.A	N.A	N.A	N.A	N.A
20	10.5 MBps	N.A	N.A	N.A	N.A	N.A	N.A

- The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.
- Only USART1 and USART6 are clocked with PCLK2. Other USARTs are clocked with PCLK1. Refer to the device datasheets for the maximum values for PCLK1 and PCLK2.

**Table 82. Error calculation for programmed baud rates at  $f_{PCLK} = 42$  MHz or  $f_{PCLK} = 84$  MHz, oversampling by 8<sup>(1)(2)</sup>**

Oversampling by 8 (OVER8=1)							
Baud rate		$f_{PCLK} = 42$ MHz			$f_{PCLK} = 84$ MHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired)B.Rate /Desired B.Rate	Actual	Value programmed in the baud rate register	% Error
1.	1.2 KBps	1.2 KBps	4375	0	1.2 KBps	8750	0
2.	2.4 KBps	2.4 KBps	2187.5	0	2.4 KBps	4375	0
3.	9.6 KBps	9.6 KBps	546.875	0	9.6 KBps	1093.75	0
4.	19.2 KBps	19.195 KBps	273.5	0.02	19.2 KBps	546.875	0
5.	38.4 KBps	38.391 KBps	136.75	0.02	38.391 KBps	273.5	0.02
6.	57.6 KBps	57.613 KBps	91.125	0.02	57.613 KBps	182.25	0.02
7.	115.2 KBps	115.068 KBps	45.625	0.11	115.226 KBps	91.125	0.02
8.	230.4 KBps	230.769 KBps	22.75	0.11	230.137 KBps	45.625	0.11
9.	460.8 KBps	461.538 KBps	11.375	0.16	461.538 KBps	22.75	0.16
10.	921.6 KBps	913.043 KBps	5.75	0.93	923.076 KBps	11.375	0.93
11.	1.792 MBps	1.826 MBps	2.875	1.9	1.787MBps	5.875	0.27
12.	1.8432 MBps	1.826 MBps	2.875	0.93	1.826 MBps	5.75	0.93
13.	3.584 MBps	3.5 MBps	1.5	2.34	3.652 MBps	2.875	1.9
14.	3.6864 MBps	3.82 MBps	1.375	3.57	3.652 MBps	2.875	0.93
15.	7.168 MBps	N.A	N.A	N.A	7 MBps	1.5	2.34
16.	7.3728 MBps	N.A	N.A	N.A	7.636 MBps	1.375	3.57
18.	9 MBps	N.A	N.A	N.A	9.333 MBps	1.125	3.7
20.	10.5 MBps	N.A	N.A	N.A	10.5 MBps	1	0

1. The lower the CPU clock the lower the accuracy for a particular baud rate. The upper limit of the achievable baud rate can be fixed with these data.

2. Only USART1 and USART6 are clocked with PCLK2. Other USARTs are clocked with PCLK1. Refer to the device datasheets for the maximum values for PCLK1 and PCLK2.

### 19.3.5 USART receiver tolerance to clock deviation

The USART asynchronous receiver works correctly only if the total clock system deviation is smaller than the USART receiver's tolerance. The causes which contribute to the total deviation are:

- DTRA: Deviation due to the transmitter error (which also includes the deviation of the transmitter's local oscillator)
- DQUANT: Error due to the baud rate quantization of the receiver
- DREC: Deviation of the receiver's local oscillator
- DTCL: Deviation due to the transmission line (generally due to the transceivers which can introduce an asymmetry between the low-to-high transition timing and the high-to-low transition timing)

$$\text{DTRA} + \text{DQUANT} + \text{DREC} + \text{DTCL} < \text{USART receiver's tolerance}$$

The USART receiver's tolerance to properly receive data is equal to the maximum tolerated deviation and depends on the following choices:

- 10- or 11-bit character length defined by the M bit in the USART\_CR1 register
- oversampling by 8 or 16 defined by the OVER8 bit in the USART\_CR1 register
- use of fractional baud rate or not
- use of 1 bit or 3 bits to sample the data, depending on the value of the ONEBIT bit in the USART\_CR3 register

**Table 83. USART receiver's tolerance when DIV fraction is 0**

M bit	OVER8 bit = 0		OVER8 bit = 1	
	ONEBIT=0	ONEBIT=1	ONEBIT=0	ONEBIT=1
0	3.75%	4.375%	2.50%	3.75%
1	3.41%	3.97%	2.27%	3.41%

**Table 84. USART receiver tolerance when DIV\_Fraction is different from 0**

M bit	OVER8 bit = 0		OVER8 bit = 1	
	ONEBIT=0	ONEBIT=1	ONEBIT=0	ONEBIT=1
0	3.33%	3.88%	2%	3%
1	3.03%	3.53%	1.82%	2.73%

Note:

The figures specified in [Table 83](#) and [Table 84](#) may slightly differ in the special case when the received frames contain some Idle frames of exactly 10-bit times when M=0 (11-bit times when M=1).

### 19.3.6 Multiprocessor communication

There is a possibility of performing multiprocessor communication with the USART (several USARTs connected in a network). For instance one of the USARTs can be the master, its TX output is connected to the RX input of the other USART. The others are slaves, their respective TX outputs are logically ANDed together and connected to the RX input of the master.

In multiprocessor configurations it is often desirable that only the intended message recipient should actively receive the full message contents, thus reducing redundant USART service overhead for all non addressed receivers.

The non addressed devices may be placed in mute mode by means of the muting function. In mute mode:

- None of the reception status bits can be set.
- All the receive interrupts are inhibited.
- The RWU bit in USART\_CR1 register is set to 1. RWU can be controlled automatically by hardware or written by the software under certain conditions.

The USART can enter or exit from mute mode using one of two methods, depending on the WAKE bit in the USART\_CR1 register:

- Idle Line detection if the WAKE bit is reset,
- Address Mark detection if the WAKE bit is set.

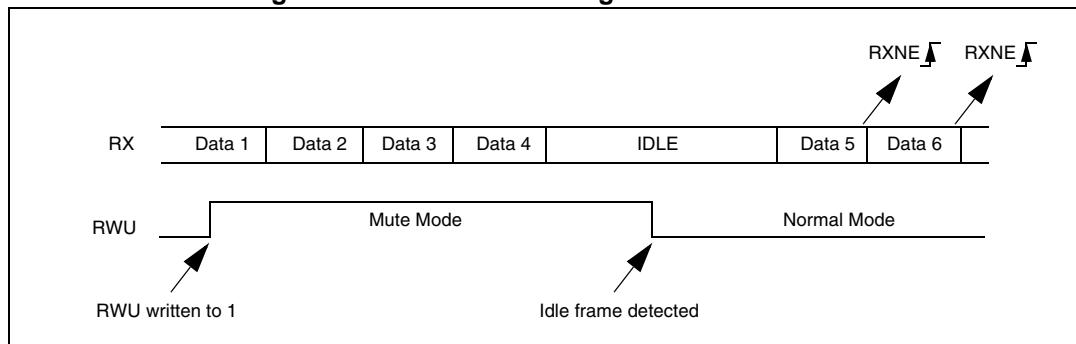
### Idle line detection (WAKE=0)

The USART enters mute mode when the RWU bit is written to 1.

It wakes up when an Idle frame is detected. Then the RWU bit is cleared by hardware but the IDLE bit is not set in the USART\_SR register. RWU can also be written to 0 by software.

An example of mute mode behavior using Idle line detection is given in [Figure 174](#).

**Figure 174. Mute mode using Idle line detection**



### Address mark detection (WAKE=1)

In this mode, bytes are recognized as addresses if their MSB is a '1' else they are considered as data. In an address byte, the address of the targeted receiver is put on the 4 LSB. This 4-bit word is compared by the receiver with its own address which is programmed in the ADD bits in the USART\_CR2 register.

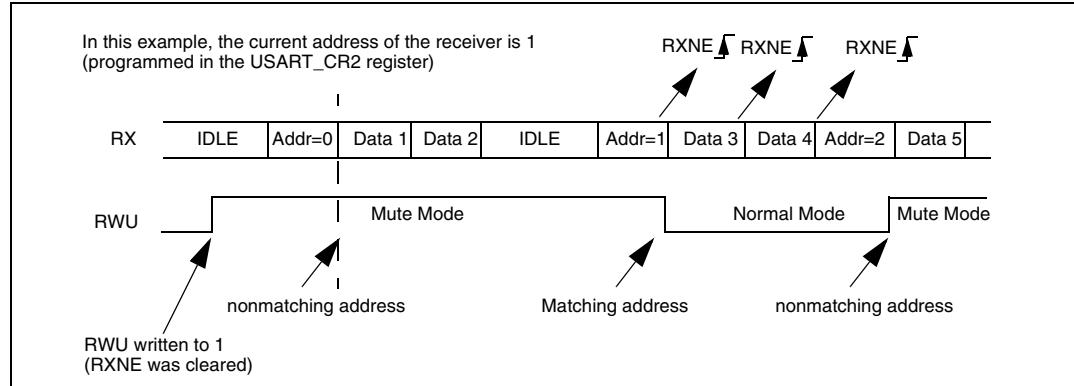
The USART enters mute mode when an address character is received which does not match its programmed address. In this case, the RWU bit is set by hardware. The RXNE flag is not set for this address byte and no interrupt nor DMA request is issued as the USART would have entered mute mode.

It exits from mute mode when an address character is received which matches the programmed address. Then the RWU bit is cleared and subsequent bytes are received normally. The RXNE bit is set for the address character since the RWU bit has been cleared.

The RWU bit can be written to as 0 or 1 when the receiver buffer contains no data (RXNE=0 in the USART\_SR register). Otherwise the write attempt is ignored.

An example of mute mode behavior using address mark detection is given in [Figure 175](#).

**Figure 175. Mute mode using address mark detection**



### 19.3.7 Parity control

Parity control (generation of parity bit in transmission and parity checking in reception) can be enabled by setting the PCE bit in the USART\_CR1 register. Depending on the frame length defined by the M bit, the possible USART frame formats are as listed in [Table 85](#).

**Table 85. Frame formats**

M bit	PCE bit	USART frame <sup>(1)</sup>
0	0	SB   8 bit data   STB
0	1	SB   7-bit data   PB   STB
1	0	SB   9-bit data   STB
1	1	SB   8-bit data PB   STB

1. Legends: SB: start bit, STB: stop bit, PB: parity bit.

#### Even parity

The parity bit is calculated to obtain an even number of “1s” inside the frame made of the 7 or 8 LSB bits (depending on whether M is equal to 0 or 1) and the parity bit.

E.g.: data=00110101; 4 bits set => parity bit will be 0 if even parity is selected (PS bit in USART\_CR1 = 0).

#### Odd parity

The parity bit is calculated to obtain an odd number of “1s” inside the frame made of the 7 or 8 LSB bits (depending on whether M is equal to 0 or 1) and the parity bit.

E.g.: data=00110101; 4 bits set => parity bit will be 1 if odd parity is selected (PS bit in USART\_CR1 = 1).

### Parity checking in reception

If the parity check fails, the PE flag is set in the USART\_SR register and an interrupt is generated if PEIE is set in the USART\_CR1 register. The PE flag is cleared by a software sequence (a read from the status register followed by a read or write access to the USART\_DR data register).

**Note:** *In case of wakeup by an address mark: the MSB bit of the data is taken into account to identify an address but not the parity bit. And the receiver does not check the parity of the address data (PE is not set in case of a parity error).*

### Parity generation in transmission

If the PCE bit is set in USART\_CR1, then the MSB bit of the data written in the data register is transmitted but is changed by the parity bit (even number of “1s” if even parity is selected (PS=0) or an odd number of “1s” if odd parity is selected (PS=1)).

**Note:** *The software routine that manages the transmission can activate the software sequence which clears the PE flag (a read from the status register followed by a read or write access to the data register). When operating in half-duplex mode, depending on the software, this can cause the PE flag to be unexpectedly cleared.*

## 19.3.8 LIN (local interconnection network) mode

The LIN mode is selected by setting the LINEN bit in the USART\_CR2 register. In LIN mode, the following bits must be kept cleared:

- STOP[1:0] and CLKEN in the USART\_CR2 register
- SCEN, HDSEL and IREN in the USART\_CR3 register.

### LIN transmission

The same procedure explained in [Section 19.3.2](#) has to be applied for LIN Master transmission than for normal USART transmission with the following differences:

- Clear the M bit to configure 8-bit word length.
- Set the LINEN bit to enter LIN mode. In this case, setting the SBK bit sends 13 ‘0’ bits as a break character. Then a bit of value ‘1’ is sent to allow the next start detection.

### LIN reception

A break detection circuit is implemented on the USART interface. The detection is totally independent from the normal USART receiver. A break can be detected whenever it occurs, during Idle state or during a frame.

When the receiver is enabled (RE=1 in USART\_CR1), the circuit looks at the RX input for a start signal. The method for detecting start bits is the same when searching break characters or data. After a start bit has been detected, the circuit samples the next bits exactly like for the data (on the 8th, 9th and 10th samples). If 10 (when the LBDL = 0 in USART\_CR2) or 11 (when LBDL=1 in USART\_CR2) consecutive bits are detected as ‘0’, and are followed by a delimiter character, the LBD flag is set in USART\_SR. If the LBDIE bit=1, an interrupt is generated. Before validating the break, the delimiter is checked for as it signifies that the RX line has returned to a high level.

If a ‘1’ is sampled before the 10 or 11 have occurred, the break detection circuit cancels the current detection and searches for a start bit again.

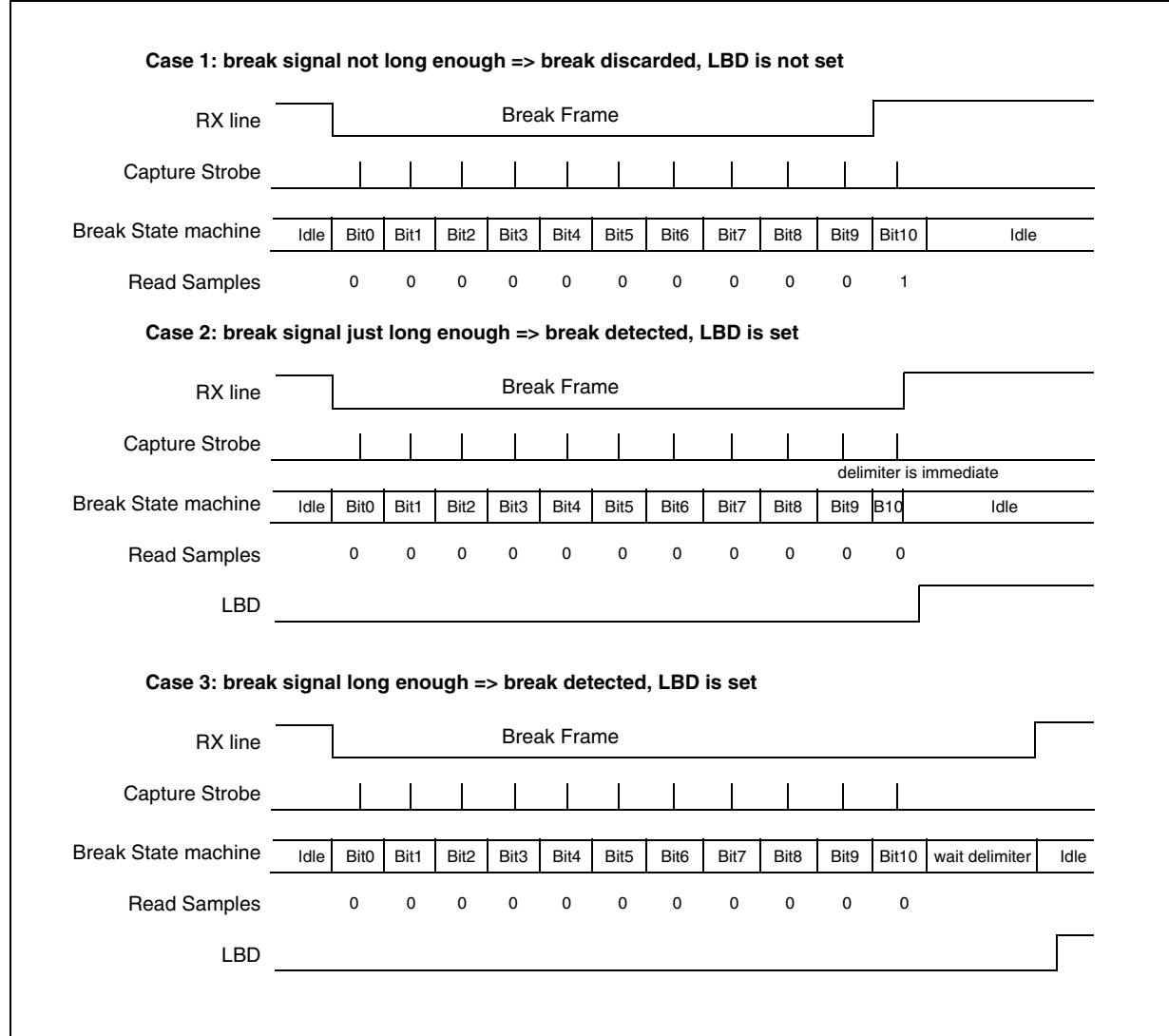
If the LIN mode is disabled (LINEN=0), the receiver continues working as normal USART, without taking into account the break detection.

If the LIN mode is enabled (LINEN=1), as soon as a framing error occurs (i.e. stop bit detected at '0, which will be the case for any break frame), the receiver stops until the break detection circuit receives either a '1, if the break word was not complete, or a delimiter character if a break has been detected.

The behavior of the break detector state machine and the break flag is shown on the [Figure 176: Break detection in LIN mode \(11-bit break length - LBDL bit is set\) on page 522](#).

Examples of break frames are given on [Figure 177: Break detection in LIN mode vs. Framing error detection on page 523](#).

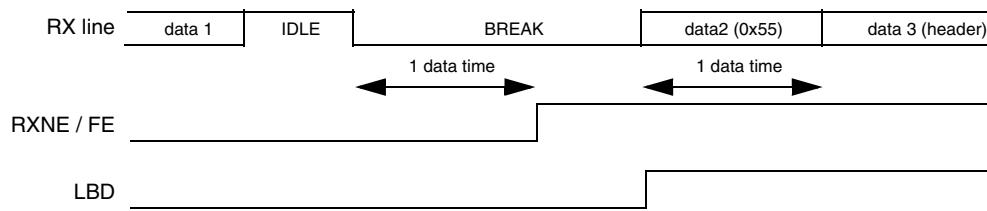
**Figure 176. Break detection in LIN mode (11-bit break length - LBDL bit is set)**



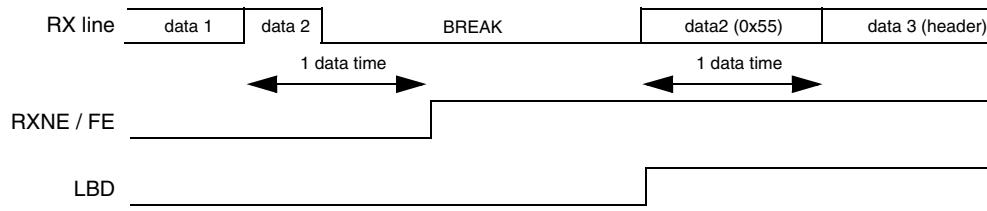
**Figure 177. Break detection in LIN mode vs. Framing error detection**

In these examples, we suppose that LBDL=1 (11-bit break length), M=0 (8-bit data)

**Case 1: break occurring after an Idle**



**Case 1: break occurring while a data is being received**



### 19.3.9 USART synchronous mode

The synchronous mode is selected by writing the CLKEN bit in the USART\_CR2 register to 1. In synchronous mode, the following bits must be kept cleared:

- LINEN bit in the USART\_CR2 register,
- SCEN, HDSEL and IREN bits in the USART\_CR3 register.

The USART allows the user to control a bidirectional synchronous serial communications in master mode. The SCLK pin is the output of the USART transmitter clock. No clock pulses are sent to the SCLK pin during start bit and stop bit. Depending on the state of the LBCL bit in the USART\_CR2 register clock pulses will or will not be generated during the last valid data bit (address mark). The CPOL bit in the USART\_CR2 register allows the user to select the clock polarity, and the CPHA bit in the USART\_CR2 register allows the user to select the phase of the external clock (see [Figure 178](#), [Figure 179](#) & [Figure 180](#)).

During the Idle state, preamble and send break, the external SCLK clock is not activated.

In synchronous mode the USART transmitter works exactly like in asynchronous mode. But as SCLK is synchronized with TX (according to CPOL and CPHA), the data on TX is synchronous.

In this mode the USART receiver works in a different manner compared to the asynchronous mode. If RE=1, the data is sampled on SCLK (rising or falling edge, depending on CPOL and CPHA), without any oversampling. A setup and a hold time must be respected (which depends on the baud rate: 1/16 bit time).

**Note:** *The SCLK pin works in conjunction with the TX pin. Thus, the clock is provided only if the transmitter is enabled (TE=1) and a data is being transmitted (the data register USART\_DR*

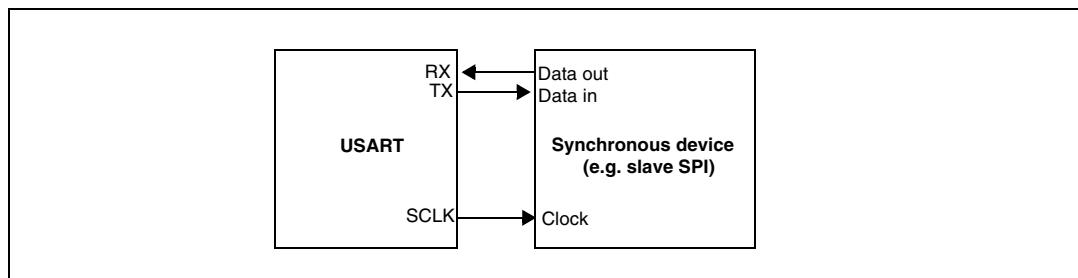
*(has been written). This means that it is not possible to receive a synchronous data without transmitting data.*

*The LBCL, CPOL and CPHA bits have to be selected when both the transmitter and the receiver are disabled ( $TE=RE=0$ ) to ensure that the clock pulses function correctly. These bits should not be changed while the transmitter or the receiver is enabled.*

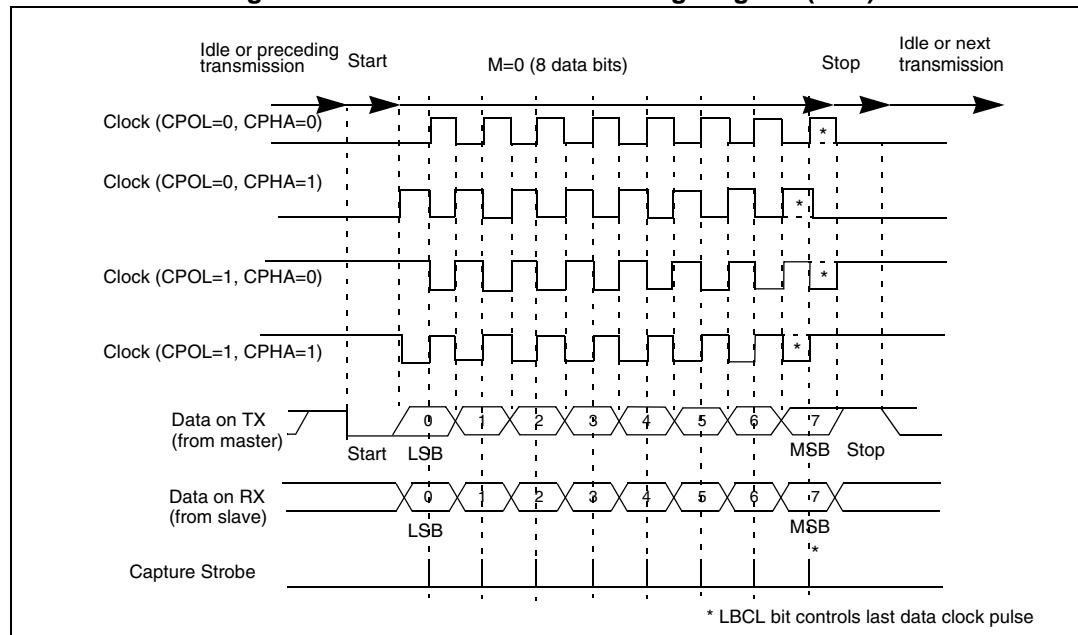
*It is advised that TE and RE are set in the same instruction in order to minimize the setup and the hold time of the receiver.*

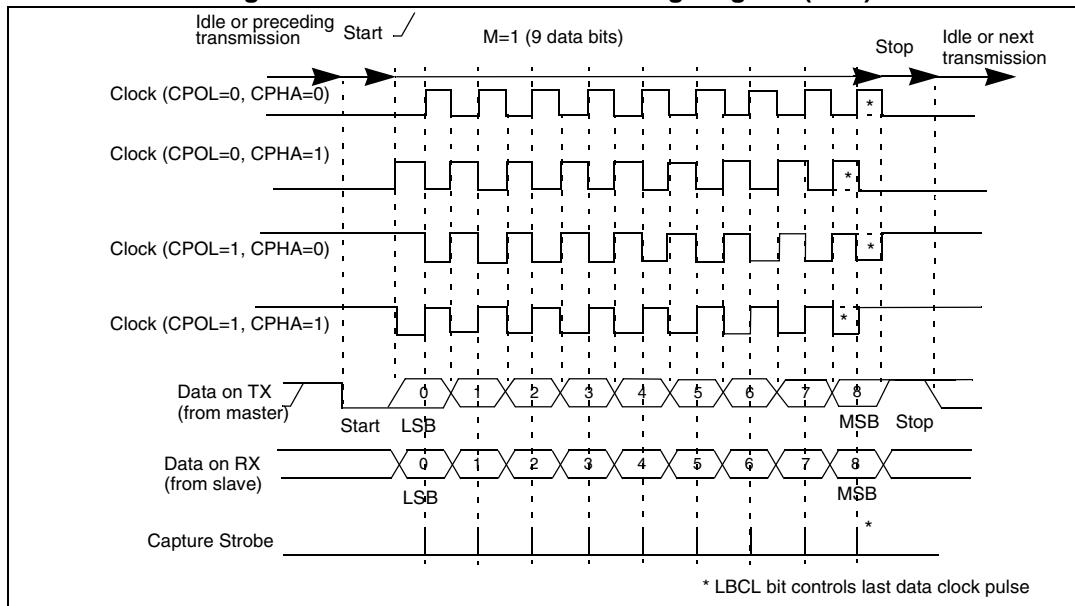
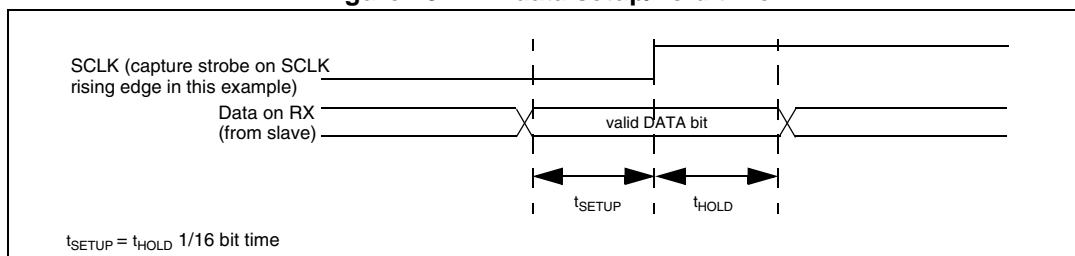
*The USART supports master mode only: it cannot receive or send data related to an input clock (SCLK is always an output).*

**Figure 178. USART example of synchronous transmission**



**Figure 179. USART data clock timing diagram (M=0)**



**Figure 180. USART data clock timing diagram (M=1)****Figure 181. RX data setup/hold time**

**Note:** The function of SCLK is different in Smartcard mode. Refer to the Smartcard mode chapter for more details.

### 19.3.10 Single-wire half-duplex communication

The single-wire half-duplex mode is selected by setting the HDSEL bit in the USART\_CR3 register. In this mode, the following bits must be kept cleared:

- LINEN and CLKEN bits in the USART\_CR2 register,
- SCEN and IREN bits in the USART\_CR3 register.

The USART can be configured to follow a single-wire half-duplex protocol where the TX and RX lines are internally connected. The selection between half- and full-duplex communication is made with a control bit 'HALF DUPLEX SEL' (HDSEL in USART\_CR3).

As soon as HDSEL is written to 1:

- the TX and RX lines are internally connected
- the RX pin is no longer used
- the TX pin is always released when no data is transmitted. Thus, it acts as a standard I/O in idle or in reception. It means that the I/O must be configured so that TX is configured as floating input (or output high open-drain) when not driven by the USART.

Apart from this, the communications are similar to what is done in normal USART mode. The conflicts on the line must be managed by the software (by the use of a centralized arbiter, for instance). In particular, the transmission is never blocked by hardware and continue to occur as soon as a data is written in the data register while the TE bit is set.

### 19.3.11 Smartcard

The Smartcard mode is selected by setting the SCEN bit in the USART\_CR3 register. In smartcard mode, the following bits must be kept cleared:

- LINEN bit in the USART\_CR2 register,
- HDSEL and IREN bits in the USART\_CR3 register.

Moreover, the CLKEN bit may be set in order to provide a clock to the smartcard.

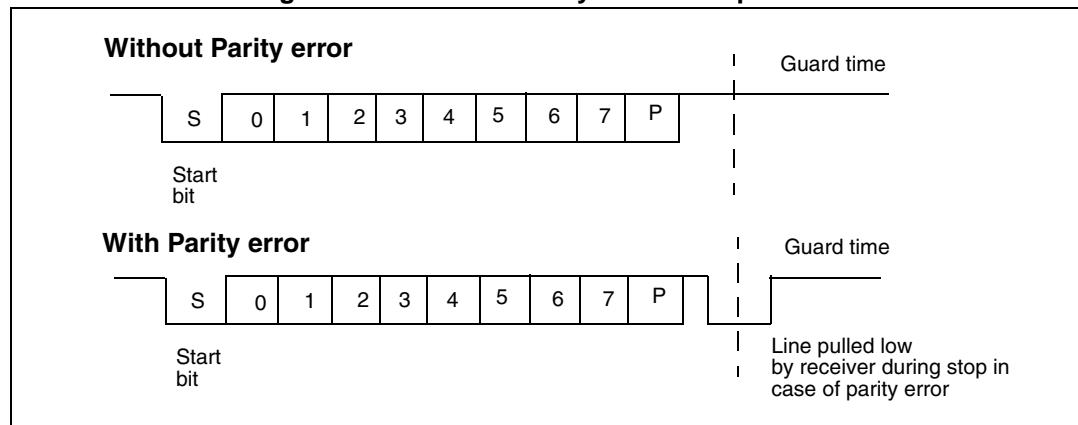
The Smartcard interface is designed to support asynchronous protocol Smartcards as defined in the ISO 7816-3 standard. The USART should be configured as:

- 8 bits plus parity: where M=1 and PCE=1 in the USART\_CR1 register
- 1.5 stop bits when transmitting and receiving: where STOP=11 in the USART\_CR2 register.

*Note:* It is also possible to choose 0.5 stop bit for receiving but it is recommended to use 1.5 stop bits for both transmitting and receiving to avoid switching between the two configurations.

[Figure 182](#) shows examples of what can be seen on the data line with and without parity error.

Figure 182. ISO 7816-3 asynchronous protocol



When connected to a Smartcard, the TX output of the USART drives a bidirectional line that is also driven by the Smartcard. The TX pin must be configured as open-drain.

Smartcard is a single wire half duplex communication protocol.

- Transmission of data from the transmit shift register is guaranteed to be delayed by a minimum of 1/2 baud clock. In normal operation a full transmit shift register will start shifting on the next baud clock edge. In Smartcard mode this transmission is further delayed by a guaranteed 1/2 baud clock.
- If a parity error is detected during reception of a frame programmed with a 0.5 or 1.5 stop bit period, the transmit line is pulled low for a baud clock period after the completion of the receive frame. This is to indicate to the Smartcard that the data transmitted to USART has not been correctly received. This NACK signal (pulling transmit line low for 1 baud clock) will cause a framing error on the transmitter side

(configured with 1.5 stop bits). The application can handle re-sending of data according to the protocol. A parity error is ‘NACK’ed by the receiver if the NACK control bit is set, otherwise a NACK is not transmitted.

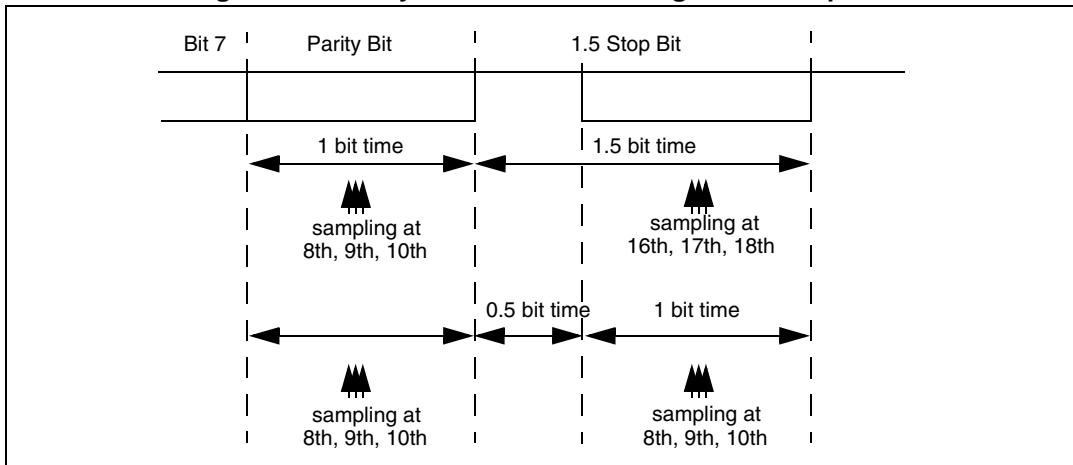
- The assertion of the TC flag can be delayed by programming the Guard Time register. In normal operation, TC is asserted when the transmit shift register is empty and no further transmit requests are outstanding. In Smartcard mode an empty transmit shift register triggers the guard time counter to count up to the programmed value in the Guard Time register. TC is forced low during this time. When the guard time counter reaches the programmed value TC is asserted high.
- The de-assertion of TC flag is unaffected by Smartcard mode.
- If a framing error is detected on the transmitter end (due to a NACK from the receiver), the NACK will not be detected as a start bit by the receive block of the transmitter. According to the ISO protocol, the duration of the received NACK can be 1 or 2 baud clock periods.
- On the receiver side, if a parity error is detected and a NACK is transmitted the receiver will not detect the NACK as a start bit.

**Note:** A break character is not significant in Smartcard mode. A 0x00 data with a framing error will be treated as data and not as a break.

No Idle frame is transmitted when toggling the TE bit. The Idle frame (as defined for the other configurations) is not defined by the ISO protocol.

*Figure 183* details how the NACK signal is sampled by the USART. In this example the USART is transmitting a data and is configured with 1.5 stop bits. The receiver part of the USART is enabled in order to check the integrity of the data and the NACK signal.

**Figure 183. Parity error detection using the 1.5 stop bits**



The USART can provide a clock to the smartcard through the SCLK output. In smartcard mode, SCLK is not associated to the communication but is simply derived from the internal peripheral input clock through a 5-bit prescaler. The division ratio is configured in the prescaler register USART\_GTPR. SCLK frequency can be programmed from  $f_{CK}/2$  to  $f_{CK}/62$ , where  $f_{CK}$  is the peripheral input clock.

### 19.3.12 IrDA SIR ENDEC block

The IrDA mode is selected by setting the IREN bit in the USART\_CR3 register. In IrDA mode, the following bits must be kept cleared:

- LINEN, STOP and CLKEN bits in the USART\_CR2 register,
- SCEN and HDSEL bits in the USART\_CR3 register.

The IrDA SIR physical layer specifies use of a Return to Zero, Inverted (RZI) modulation scheme that represents logic 0 as an infrared light pulse (see [Figure 184](#)).

The SIR Transmit encoder modulates the Non Return to Zero (NRZ) transmit bit stream output from USART. The output pulse stream is transmitted to an external output driver and infrared LED. USART supports only bit rates up to 115.2Kbps for the SIR ENDEC. In normal mode the transmitted pulse width is specified as 3/16 of a bit period.

The SIR receive decoder demodulates the return-to-zero bit stream from the infrared detector and outputs the received NRZ serial bit stream to USART. The decoder input is normally HIGH (marking state) in the Idle state. The transmit encoder output has the opposite polarity to the decoder input. A start bit is detected when the decoder input is low.

- IrDA is a half duplex communication protocol. If the Transmitter is busy (i.e. the USART is sending data to the IrDA encoder), any data on the IrDA receive line will be ignored by the IrDA decoder and if the Receiver is busy (USART is receiving decoded data from the USART), data on the TX from the USART to IrDA will not be encoded by IrDA. While receiving data, transmission should be avoided as the data to be transmitted could be corrupted.
- A '0 is transmitted as a high pulse and a '1 is transmitted as a '0. The width of the pulse is specified as 3/16th of the selected bit period in normal mode (see [Figure 185](#)).
- The SIR decoder converts the IrDA compliant receive signal into a bit stream for USART.
- The SIR receive logic interprets a high state as a logic one and low pulses as logic zeros.
- The transmit encoder output has the opposite polarity to the decoder input. The SIR output is in low state when Idle.
- The IrDA specification requires the acceptance of pulses greater than 1.41 us. The acceptable pulse width is programmable. Glitch detection logic on the receiver end filters out pulses of width less than 2 PSC periods (PSC is the prescaler value programmed in the IrDA low-power Baud Register, USART\_GTPR). Pulses of width less than 1 PSC period are always rejected, but those of width greater than one and less than two periods may be accepted or rejected, those greater than 2 periods will be accepted as a pulse. The IrDA encoder/decoder doesn't work when PSC=0.
- The receiver can communicate with a low-power transmitter.
- In IrDA mode, the STOP bits in the USART\_CR2 register must be configured to "1 stop bit".

### IrDA low-power mode

#### *Transmitter:*

In low-power mode the pulse width is not maintained at 3/16 of the bit period. Instead, the width of the pulse is 3 times the low-power baud rate which can be a minimum of 1.42 MHz. Generally this value is 1.8432 MHz ( $1.42 \text{ MHz} < \text{PSC} < 2.12 \text{ MHz}$ ). A low-power mode programmable divisor divides the system clock to achieve this value.

#### *Receiver:*

Receiving in low-power mode is similar to receiving in normal mode. For glitch detection the USART should discard pulses of duration shorter than  $1/\text{PSC}$ . A valid low is accepted only if its duration is greater than 2 periods of the IrDA low-power Baud clock (PSC value in USART\_GTPR).

**Note:** *A pulse of width less than two and greater than one PSC period(s) may or may not be rejected.*

*The receiver set up time should be managed by software. The IrDA physical layer specification specifies a minimum of 10 ms delay between transmission and reception (IrDA is a half duplex protocol).*

Figure 184. IrDA SIR ENDEC- block diagram

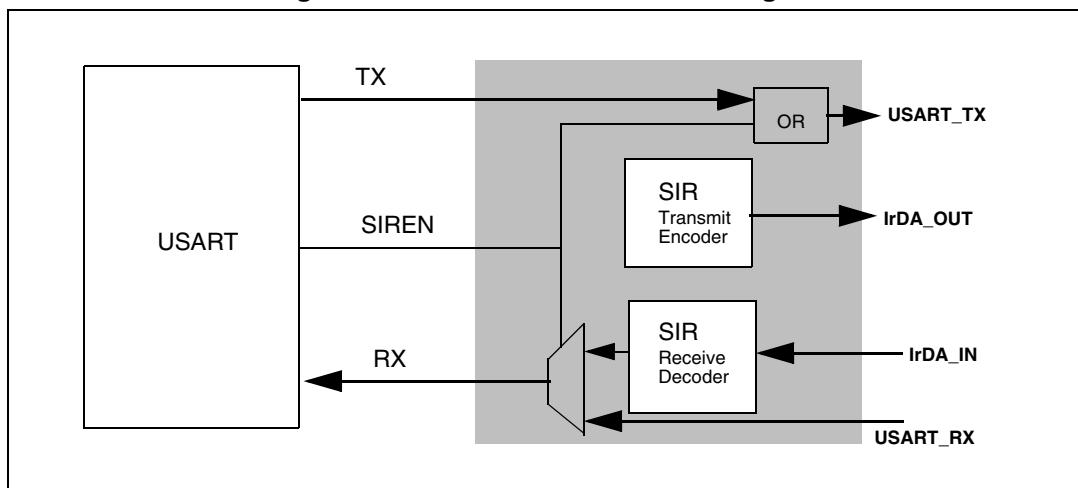
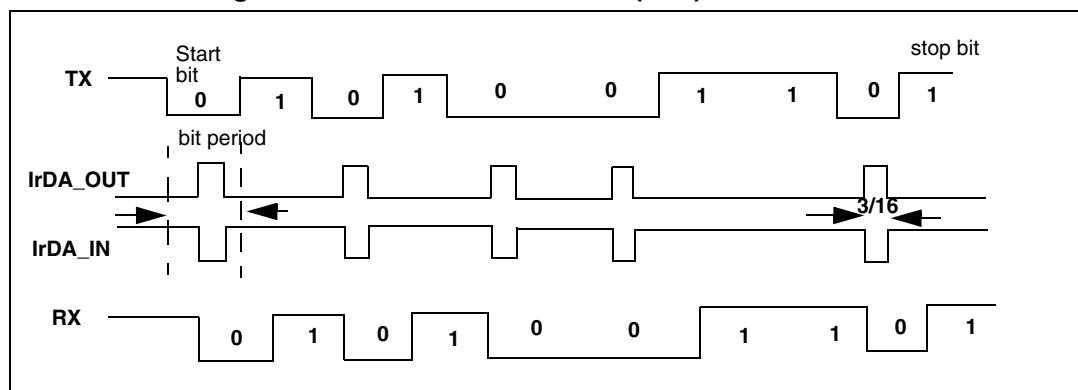


Figure 185. IrDA data modulation (3/16) -Normal mode



### 19.3.13 Continuous communication using DMA

The USART is capable of continuous communication using the DMA. The DMA requests for Rx buffer and Tx buffer are generated independently.

#### Transmission using DMA

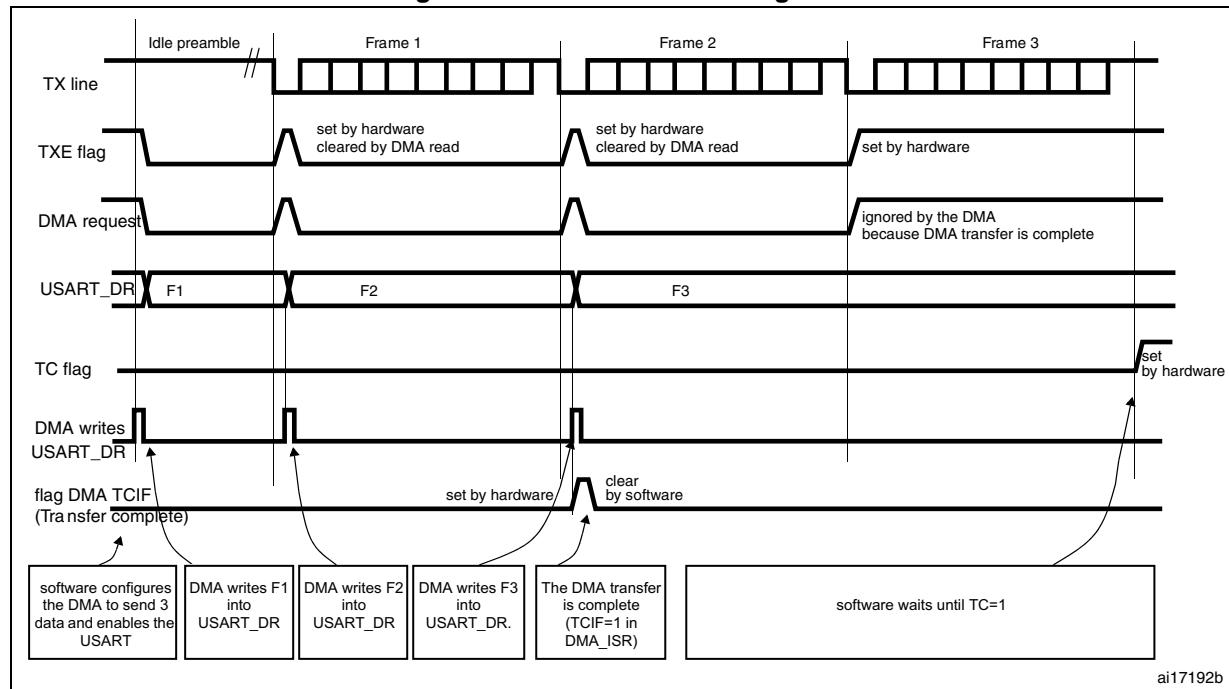
DMA mode can be enabled for transmission by setting DMAT bit in the USART\_CR3 register. Data is loaded from a SRAM area configured using the DMA peripheral (refer to the DMA specification) to the USART\_DR register whenever the TXE bit is set. To map a DMA channel for USART transmission, use the following procedure (x denotes the channel number):

1. Write the USART\_DR register address in the DMA control register to configure it as the destination of the transfer. The data will be moved to this address from memory after each TXE event.
2. Write the memory address in the DMA control register to configure it as the source of the transfer. The data will be loaded into the USART\_DR register from this memory area after each TXE event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA register
5. Configure DMA interrupt generation after half/ full transfer as required by the application.
6. Clear the TC bit in the SR register by writing 0 to it.
7. Activate the channel in the DMA register.

When the number of data transfers programmed in the DMA Controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

In transmission mode, once the DMA has written all the data to be transmitted (the TCIF flag is set in the DMA\_ISR register), the TC flag can be monitored to make sure that the USART communication is complete. This is required to avoid corrupting the last transmission before disabling the USART or entering the Stop mode. The software must wait until TC=1. The TC flag remains cleared during all data transfers and it is set by hardware at the last frame's end of transmission.

Figure 186. Transmission using DMA



ai17192b

### Reception using DMA

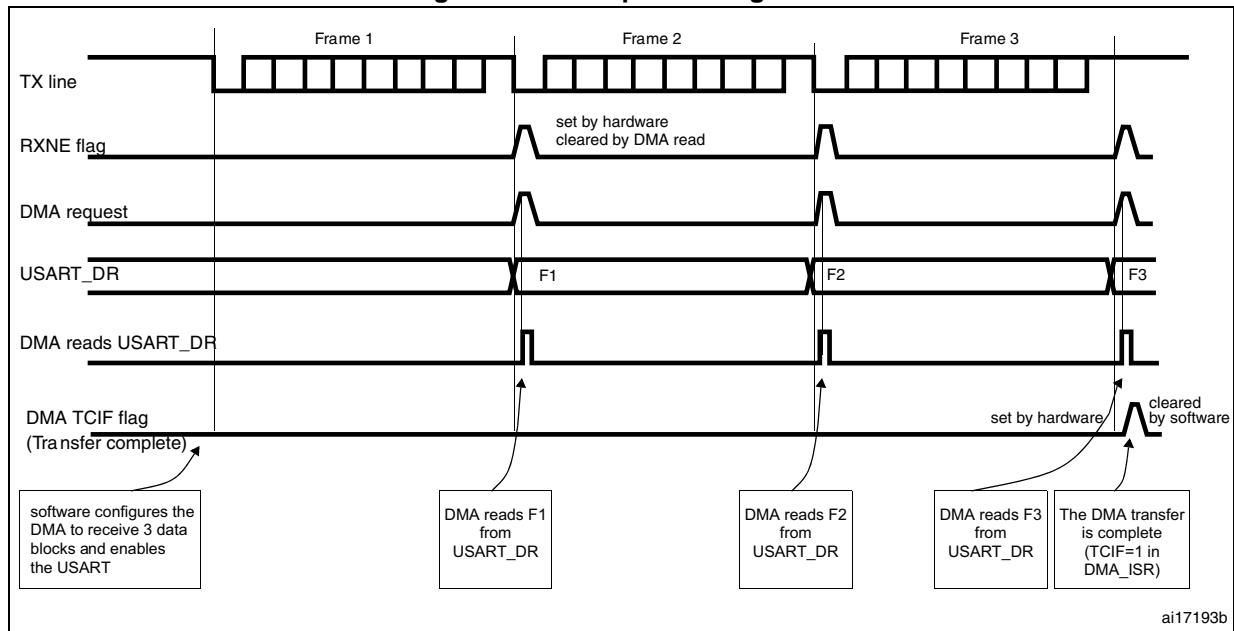
DMA mode can be enabled for reception by setting the DMAR bit in USART\_CR3 register. Data is loaded from the USART\_DR register to a SRAM area configured using the DMA peripheral (refer to the DMA specification) whenever a data byte is received. To map a DMA channel for USART reception, use the following procedure:

1. Write the USART\_DR register address in the DMA control register to configure it as the source of the transfer. The data will be moved from this address to the memory after each RXNE event.
2. Write the memory address in the DMA control register to configure it as the destination of the transfer. The data will be loaded from USART\_DR to this memory area after each RXNE event.
3. Configure the total number of bytes to be transferred in the DMA control register.
4. Configure the channel priority in the DMA control register
5. Configure interrupt generation after half/ full transfer as required by the application.
6. Activate the channel in the DMA control register.

When the number of data transfers programmed in the DMA Controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector. The DMAR bit should be cleared by software in the USART\_CR3 register during the interrupt subroutine.

*Note: If DMA is used for reception, do not enable the RXNEIE bit.*

Figure 187. Reception using DMA



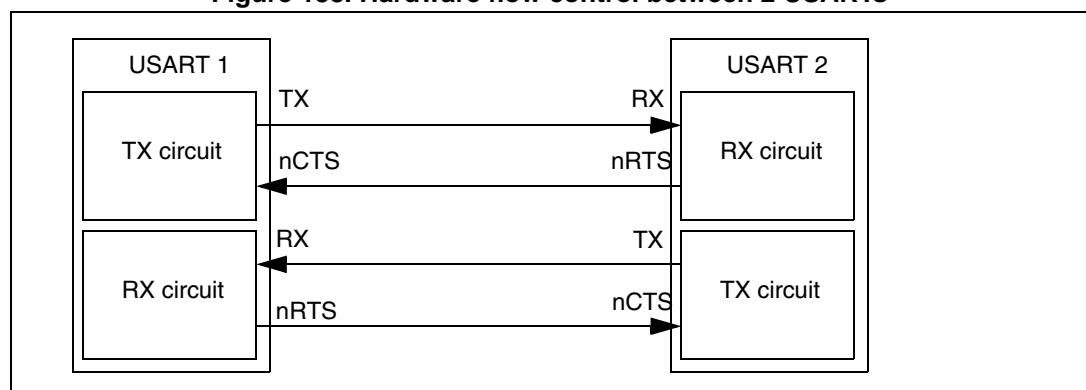
### Error flagging and interrupt generation in multibuffer communication

In case of multibuffer communication if any error occurs during the transaction the error flag will be asserted after the current byte. An interrupt will be generated if the interrupt enable flag is set. For framing error, overrun error and noise flag which are asserted with RXNE in case of single byte reception, there will be separate error flag interrupt enable bit (EIE bit in the USART\_CR3 register), which if set will issue an interrupt after the current byte with either of these errors.

#### 19.3.14 Hardware flow control

It is possible to control the serial data flow between 2 devices by using the nCTS input and the nRTS output. The [Figure 188](#) shows how to connect 2 devices in this mode:

Figure 188. Hardware flow control between 2 USARTs

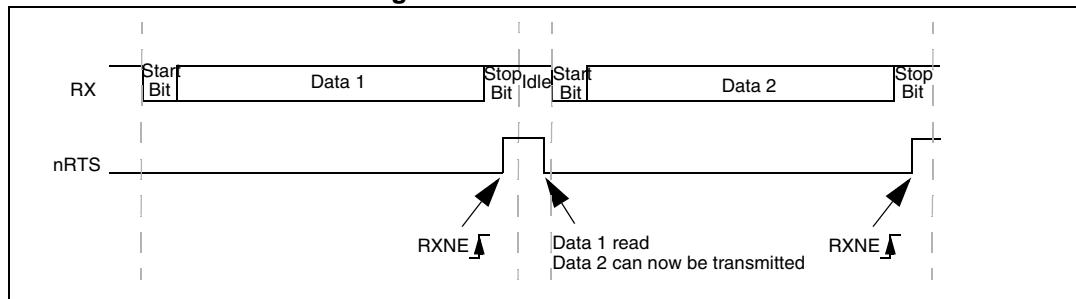


RTS and CTS flow control can be enabled independently by writing respectively RTSE and CTSE bits to 1 (in the USART\_CR3 register).

### RTS flow control

If the RTS flow control is enabled ( $RTSE=1$ ), then nRTS is asserted (tied low) as long as the USART receiver is ready to receive a new data. When the receive register is full, nRTS is deasserted, indicating that the transmission is expected to stop at the end of the current frame. [Figure 189](#) shows an example of communication with RTS flow control enabled.

**Figure 189. RTS flow control**

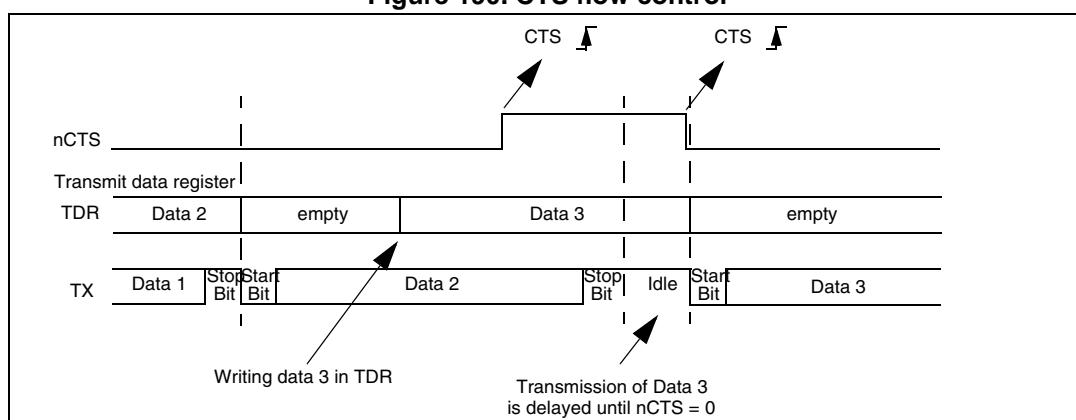


### CTS flow control

If the CTS flow control is enabled ( $CTSE=1$ ), then the transmitter checks the nCTS input before transmitting the next frame. If nCTS is asserted (tied low), then the next data is transmitted (assuming that a data is to be transmitted, in other words, if  $TXE=0$ ), else the transmission does not occur. When nCTS is deasserted during a transmission, the current transmission is completed before the transmitter stops.

When  $CTSE=1$ , the CTSIF status bit is automatically set by hardware as soon as the nCTS input toggles. It indicates when the receiver becomes ready or not ready for communication. An interrupt is generated if the CTSIE bit in the USART\_CR3 register is set. The figure below shows an example of communication with CTS flow control enabled.

**Figure 190. CTS flow control**



Note:

**Special behavior of break frames:** when the CTS flow is enabled, the transmitter does not check the nCTS input state to send a break.

## 19.4 USART interrupts

Table 86. USART interrupt requests

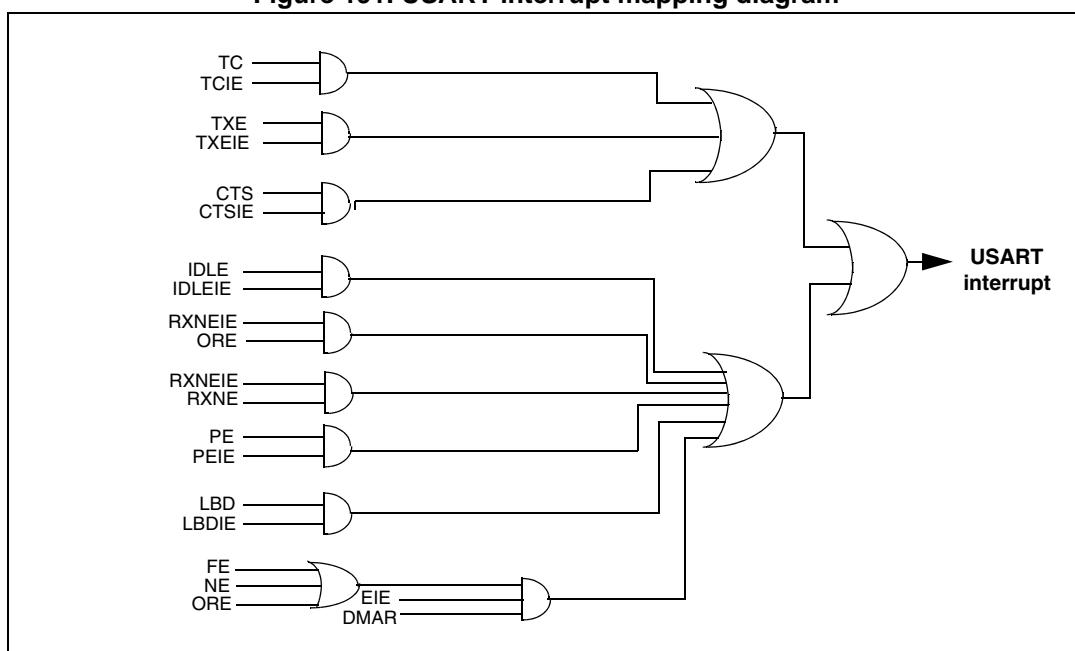
Interrupt event	Event flag	Enable control bit
Transmit Data Register Empty	TXE	TXEIE
CTS flag	CTS	CTSIE
Transmission Complete	TC	TCIE
Received Data Ready to be Read	RXNE	RXNEIE
Overrun Error Detected	ORE	
Idle Line Detected	IDLE	IDLEIE
Parity Error	PE	PEIE
Break Flag	LBD	LBDIE
Noise Flag, Overrun error and Framing Error in multibuffer communication	NF or ORE or FE	EIE

The USART interrupt events are connected to the same interrupt vector (see [Figure 191](#)).

- During transmission: Transmission Complete, Clear to Send or Transmit Data Register empty interrupt.
- While receiving: Idle Line detection, Overrun error, Receive Data register not empty, Parity error, LIN break detection, Noise Flag (only in multi buffer communication) and Framing Error (only in multi buffer communication).

These events generate an interrupt if the corresponding Enable Control Bit is set.

Figure 191. USART interrupt mapping diagram



## 19.5 USART mode configuration

Table 87. USART mode configuration<sup>(1)</sup>

USART modes	USART1	USART2	USART6
Asynchronous mode	X	X	X
Hardware flow control	X	X	X
Multibuffer communication (DMA)	X	X	X
Multiprocessor communication	X	X	X
Synchronous	X	X	X
Smartcard	X	X	X
Half-duplex (single-wire mode)	X	X	X
IrDA	X	X	X
LIN	X	X	X

1. X = supported; NA = not applicable.

## 19.6 USART registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by half-words (16 bits) or words (32 bits).

### 19.6.1 Status register (USART\_SR)

Address offset: 0x00

Reset value: 0x00C0 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				CTS	LBD	TXE	TC	RXNE	IDLE	ORE	NF	FE	PE		
				rc_w0	rc_w0	r	rc_w0	rc_w0	r	r	r	r	r		

Bits 31:10 Reserved, must be kept at reset value

#### Bit 9 CTS: CTS flag

This bit is set by hardware when the nCTS input toggles, if the CTSE bit is set. It is cleared by software (by writing it to 0). An interrupt is generated if CTSIE=1 in the USART\_CR3 register.

Note: 0: No change occurred on the nCTS status line

1: A change occurred on the nCTS status line

#### Bit 8 LBD: LIN break detection flag

This bit is set by hardware when the LIN break is detected. It is cleared by software (by writing it to 0). An interrupt is generated if LBDIE = 1 in the USART\_CR2 register.

0: LIN Break not detected

1: LIN break detected

Note: An interrupt is generated when LBD=1 if LBDIE=1

**Bit 7 TXE:** Transmit data register empty

This bit is set by hardware when the content of the TDR register has been transferred into the shift register. An interrupt is generated if the TXEIE bit =1 in the USART\_CR1 register. It is cleared by a write to the USART\_DR register.

0: Data is not transferred to the shift register

1: Data is transferred to the shift register

*Note: This bit is used during single buffer transmission.*

**Bit 6 TC:** Transmission complete

This bit is set by hardware if the transmission of a frame containing data is complete and if TXE is set. An interrupt is generated if TCIE=1 in the USART\_CR1 register. It is cleared by a software sequence (a read from the USART\_SR register followed by a write to the USART\_DR register). The TC bit can also be cleared by writing a '0' to it. This clearing sequence is recommended only for multibuffer communication.

0: Transmission is not complete

1: Transmission is complete

**Bit 5 RXNE:** Read data register not empty

This bit is set by hardware when the content of the RDR shift register has been transferred to the USART\_DR register. An interrupt is generated if RXNEIE=1 in the USART\_CR1 register. It is cleared by a read to the USART\_DR register. The RXNE flag can also be cleared by writing a zero to it. This clearing sequence is recommended only for multibuffer communication.

0: Data is not received

1: Received data is ready to be read.

**Bit 4 IDLE:** IDLE line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if the IDLEIE=1 in the USART\_CR1 register. It is cleared by a software sequence (an read to the USART\_SR register followed by a read to the USART\_DR register).

0: No Idle Line is detected

1: Idle Line is detected

*Note: The IDLE bit will not be set again until the RXNE bit has been set itself (i.e. a new idle line occurs).*

**Bit 3 ORE:** Overrun error

This bit is set by hardware when the word currently being received in the shift register is ready to be transferred into the RDR register while RXNE=1. An interrupt is generated if RXNEIE=1 in the USART\_CR1 register. It is cleared by a software sequence (an read to the USART\_SR register followed by a read to the USART\_DR register).

0: No Overrun error

1: Overrun error is detected

*Note: When this bit is set, the RDR register content will not be lost but the shift register will be overwritten. An interrupt is generated on ORE flag in case of Multi Buffer communication if the EIE bit is set.*

**Bit 2 NF:** Noise detected flag

This bit is set by hardware when noise is detected on a received frame. It is cleared by a software sequence (an read to the USART\_SR register followed by a read to the USART\_DR register).

- 0: No noise is detected
- 1: Noise is detected

*Note: This bit does not generate interrupt as it appears at the same time as the RXNE bit which itself generates an interrupt. If the word currently being transferred causes both noise detection and overrun error, the ORE bit will be set.*

*Note: When the line is noise-free, the NF flag can be disabled by programming the ONEBIT bit to 1 to increase the USART tolerance to deviations (Refer to [Section 19.3.5: USART receiver tolerance to clock deviation on page 518](#)).*

**Bit 1 FE:** Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by a software sequence (an read to the USART\_SR register followed by a read to the USART\_DR register).

- 0: No Framing error is detected
- 1: Framing error or break character is detected

*Note: This bit does not generate interrupt as it appears at the same time as the RXNE bit which itself generates an interrupt. If the word currently being transferred causes both frame error and overrun error, it will be transferred and only the ORE bit will be set.*

*An interrupt is generated on FE flag in case of Multi Buffer communication if the EIE bit is set.*

**Bit 0 PE:** Parity error

This bit is set by hardware when a parity error occurs in receiver mode. It is cleared by a software sequence (a read from the status register followed by a read or write access to the USART\_DR data register). The software must wait for the RXNE flag to be set before clearing the PE bit.

An interrupt is generated if PEIE = 1 in the USART\_CR1 register.

- 0: No parity error
- 1: Parity error

## 19.6.2 Data register (USART\_DR)

Address offset: 0x04

Reset value: 0xFFFF XXXX

Bits 31:9 Reserved, must be kept at reset value

Bits 8:0 **DR[8:0]**: Data value

Contains the Received or Transmitted data character, depending on whether it is read from or written to.

The Data register performs a double function (read and write) since it is composed of two registers, one for transmission (TDR) and one for reception (RDR)

The TDR register provides the parallel interface between the internal bus and the output shift register (see Figure 1).

The RDR register provides the parallel interface between the input shift register and the internal bus.

When transmitting with the parity enabled (PCE bit set to 1 in the USART\_CR1 register), the value written in the MSB (bit 7 or bit 8 depending on the data length) has no effect because it is replaced by the parity.

When receiving with the parity enabled, the value read in the MSB bit is the received parity bit.

## 19.6.3 Baud rate register (USART\_BRR)

*Note:* The baud counters stop counting if the TE or RE bits are disabled respectively.

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIV_Mantissa[11:0]												DIV_Fraction[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value

Bits 15:4 **DIV\_Mantissa[11:0]**: mantissa of USARTDIV

These 12 bits define the mantissa of the USART Divider (USARTDIV)

Bits 3:0 **DIV\_Fraction[3:0]**: fraction of USARTDIV

These 4 bits define the fraction of the USART Divider (USARTDIV). When OVER8=1, the DIV\_Fraction3 bit is not considered and must be kept cleared.

## 19.6.4 Control register 1 (USART\_CR1)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OVER8	Reserved	UE	M	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	RWU	SBK
rw	Res.	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value

Bit 15 **OVER8**: Oversampling mode

- 0: oversampling by 16
- 1: oversampling by 8

*Note: Oversampling by 8 is not available in the Smartcard, IrDA and LIN modes: when SCEN=1,IREN=1 or LINEN=1 then OVER8 is forced to '0 by hardware.*

Bit 14 Reserved, must be kept at reset value

Bit 13 **UE**: USART enable

When this bit is cleared the USART prescalers and outputs are stopped and the end of the current byte transfer in order to reduce power consumption. This bit is set and cleared by software.  
 0: USART prescaler and outputs disabled  
 1: USART enabled

Bit 12 **M**: Word length

This bit determines the word length. It is set or cleared by software.  
 0: 1 Start bit, 8 Data bits, n Stop bit  
 1: 1 Start bit, 9 Data bits, n Stop bit

*Note: The M bit must not be modified during a data transfer (both transmission and reception)*

Bit 11 **WAKE**: Wakeup method

This bit determines the USART wakeup method, it is set or cleared by software.  
 0: Idle Line  
 1: Address Mark

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M=1; 8th bit if M=0) and parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).  
 0: Parity control disabled  
 1: Parity control enabled

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity will be selected after the current byte.  
 0: Even parity  
 1: Odd parity

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.  
 0: Interrupt is inhibited  
 1: An USART interrupt is generated whenever PE=1 in the USART\_SR register

Bit 7 **TXEIE**: TXE interrupt enable

This bit is set and cleared by software.  
 0: Interrupt is inhibited  
 1: An USART interrupt is generated whenever TXE=1 in the USART\_SR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.  
 0: Interrupt is inhibited  
 1: An USART interrupt is generated whenever TC=1 in the USART\_SR register

**Bit 5 RXNEIE:** RXNE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An USART interrupt is generated whenever ORE=1 or RXNE=1 in the USART\_SR register

**Bit 4 IDLEIE:** IDLE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An USART interrupt is generated whenever IDLE=1 in the USART\_SR register

**Bit 3 TE:** Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

*Note: 1: During transmission, a “0” pulse on the TE bit (“0” followed by “1”) sends a preamble (idle line) after the current word, except in smartcard mode.*

*2: When TE is set there is a 1 bit-time delay before the transmission starts.*

**Bit 2 RE:** Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

**Bit 1 RWU:** Receiver wakeup

This bit determines if the USART is in mute mode or not. It is set and cleared by software and can be cleared by hardware when a wakeup sequence is recognized.

0: Receiver in active mode

1: Receiver in mute mode

*Note: 1: Before selecting Mute mode (by setting the RWU bit) the USART must first receive a data byte, otherwise it cannot function in Mute mode with wakeup by Idle line detection.*

*2: In Address Mark Detection wakeup configuration (WAKE bit=1) the RWU bit cannot be modified by software while the RXNE bit is set.*

**Bit 0 SBK:** Send break

This bit set is used to send break characters. It can be set and cleared by software. It should be set by software, and will be reset by hardware during the stop bit of break.

0: No break character is transmitted

1: Break character will be transmitted

### 19.6.5 Control register 2 (USART\_CR2)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	LINEN	STOP[1:0]		CLKEN	CPOL	CPHA	LBCL	Res.	LBDIE	LBDL	Res.	ADD[3:0]			
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value

Bit 14 **LINEN**: LIN mode enable

This bit is set and cleared by software.

0: LIN mode disabled

1: LIN mode enabled

The LIN mode enables the capability to send LIN Sync Breaks (13 low bits) using the SBK bit in the USART\_CR1 register, and to detect LIN Sync breaks.

Bits 13:12 **STOP**: STOP bits

These bits are used for programming the stop bits.

00: 1 Stop bit

01: 0.5 Stop bit

10: 2 Stop bits

*Note:* 11: 1.5 Stop bit

Bit 11 **CLKEN**: Clock enable

This bit allows the user to enable the SCLK pin.

0: SCLK pin disabled

1: SCLK pin enabled

Bit 10 **CPOL**: Clock polarity

This bit allows the user to select the polarity of the clock output on the SCLK pin in synchronous mode. It works in conjunction with the CPHA bit to produce the desired clock/data relationship

0: Steady low value on SCLK pin outside transmission window.

1: Steady high value on SCLK pin outside transmission window.

Bit 9 **CPHA**: Clock phase

This bit allows the user to select the phase of the clock output on the SCLK pin in synchronous mode. It works in conjunction with the CPOL bit to produce the desired clock/data relationship (see figures 179 to 180)

*Note:* 0: The first clock transition is the first data capture edge

1: The second clock transition is the first data capture edge

Bit 8 **LBCL**: Last bit clock pulse

This bit allows the user to select whether the clock pulse associated with the last data bit transmitted (MSB) has to be output on the SCLK pin in synchronous mode.

0: The clock pulse of the last data bit is not output to the SCLK pin

1: The clock pulse of the last data bit is output to the SCLK pin

*1: The last bit is the 8th or 9th data bit transmitted depending on the 8 or 9 bit format selected by the M bit in the USART\_CR1 register.*

Bit 7 Reserved, must be kept at reset value

Bit 6 **LBDIE**: LIN break detection interrupt enable

Break interrupt mask (break detection using break delimiter).

0: Interrupt is inhibited

1: An interrupt is generated whenever LBD=1 in the USART\_SR register

Bit 5 **LBDL**: lin break detection length

This bit is for selection between 11 bit or 10 bit break detection.

0: 10-bit break detection

1: 11-bit break detection

Bit 4 Reserved, must be kept at reset value

Bits 3:0 **ADD[3:0]**: Address of the USART node

This bit-field gives the address of the USART node.

This is used in multiprocessor communication during mute mode, for wake up with address mark detection.

*Note:* These 3 bits (CPOL, CPHA, LBCL) should not be written while the transmitter is enabled.

### 19.6.6 Control register 3 (USART\_CR3)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	ONEBIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HDSEL	IRLP	IREN	EIE			
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:12 Reserved, must be kept at reset value

Bit 11 **ONEBIT**: One sample bit method enable

This bit allows the user to select the sample method. When the one sample bit method is selected the noise detection flag (NF) is disabled.

0: Three sample bit method

1: One sample bit method

Bit 10 **CTSIE**: CTS interrupt enable

*Note:* 0: Interrupt is inhibited

1: An interrupt is generated whenever CTS=1 in the USART\_SR register

Bit 9 **CTSE**: CTS enable

0: CTS hardware flow control disabled

*Note:* 1: CTS mode enabled, data is only transmitted when the nCTS input is asserted (tied to 0). If the nCTS input is deasserted while a data is being transmitted, then the transmission is completed before stopping. If a data is written into the data register while nCTS is asserted, the transmission is postponed until nCTS is asserted.

Bit 8 **RTSE**: RTS enable

0: RTS hardware flow control disabled

*Note:* 1: RTS interrupt enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The nRTS output is asserted (tied to 0) when a data can be received.

**Bit 7 DMAT:** DMA enable transmitter

This bit is set/reset by software

1: DMA mode is enabled for transmission.

0: DMA mode is disabled for transmission.

**Bit 6 DMAR:** DMA enable receiver

This bit is set/reset by software

1: DMA mode is enabled for reception

0: DMA mode is disabled for reception

**Bit 5 SCEN:** Smartcard mode enable

This bit is used for enabling Smartcard mode.

*Note:* 0: Smartcard Mode disabled

1: Smartcard Mode enabled

**Bit 4 NACK:** Smartcard NACK enable

*Note:* 0: NACK transmission in case of parity error is disabled

1: NACK transmission during parity error is enabled

**Bit 3 HDSEL:** Half-duplex selection

Selection of Single-wire Half-duplex mode

0: Half duplex mode is not selected

1: Half duplex mode is selected

**Bit 2 IRLP:** IrDA low-power

This bit is used for selecting between normal and low-power IrDA modes

0: Normal mode

1: Low-power mode

**Bit 1 IREN:** IrDA mode enable

This bit is set and cleared by software.

0: IrDA disabled

1: IrDA enabled

**Bit 0 EIE:** Error interrupt enable

Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error or noise flag (FE=1 or ORE=1 or NF=1 in the USART\_SR register) in case of Multi Buffer Communication (DMAR=1 in the USART\_CR3 register).

0: Interrupt is inhibited

1: An interrupt is generated whenever DMAR=1 in the USART\_CR3 register and FE=1 or ORE=1 or NF=1 in the USART\_SR register.

### 19.6.7 Guard time and prescaler register (USART\_GTPR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GT[7:0]								PSC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value

Bits 15:8 **GT[7:0]**: Guard time value

This bit-field gives the Guard time value in terms of number of baud clocks.

Note: This is used in Smartcard mode. The Transmission Complete flag is set after this guard time value.

Bits 7:0 **PSC[7:0]**: Prescaler value

– In IrDA Low-power mode:

**PSC[7:0]** = IrDA Low-Power Baud Rate

Used for programming the prescaler for dividing the system clock to achieve the low-power frequency:

The source clock is divided by the value given in the register (8 significant bits):

00000000: Reserved - do not program this value

00000001: divides the source clock by 1

00000010: divides the source clock by 2

...

– In normal IrDA mode: PSC must be set to 00000001.

– In smartcard mode:

**PSC[4:0]**: Prescaler value

Used for programming the prescaler for dividing the system clock to provide the smartcard clock.

The value given in the register (5 significant bits) is multiplied by 2 to give the division factor of the source clock frequency:

00000: Reserved - do not program this value

00001: divides the source clock by 2

00010: divides the source clock by 4

00011: divides the source clock by 6

...

Note: 1: Bits [7:5] have no effect if Smartcard mode is used.

## 19.6.8 USART register map

The table below gives the USART register map and reset values.

**Table 88. USART register map and reset values**

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 20 Serial peripheral interface (SPI)

### 20.1 SPI introduction

The SPI interface provides two main functions, supporting either the SPI protocol or the I<sup>2</sup>S audio protocol. By default, it is the SPI function that is selected. It is possible to switch the interface from SPI to I<sup>2</sup>S by software.

The serial peripheral interface (SPI) allows half/ full-duplex, synchronous, serial communication with external devices. The interface can be configured as the master and in this case it provides the communication clock (SCK) to the external slave device. The interface is also capable of operating in multimaster configuration.

It may be used for a variety of purposes, including simplex synchronous transfers on two lines with a possible bidirectional data line or reliable communication using CRC checking.

The I<sup>2</sup>S is also a synchronous serial communication interface. It can address four different audio standards including the I<sup>2</sup>S Philips standard, the MSB- and LSB-justified standards, and the PCM standard. It can operate as a slave or a master device in full-duplex mode (using 4 pins) or in half-duplex mode (using 3 pins). Master clock can be provided by the interface to an external slave component when the I<sup>2</sup>S is configured as the communication master.

---

**Warning:** Since some SPI1 and SPI3/I2S3 pins may be mapped onto some pins used by the JTAG interface (SPI1\_NSS onto JTDI, SPI3\_NSS/I2S3\_WS onto JTDO and SPI3\_SCK/I2S3\_CK onto JTDO), you may either:

- map SPI/I2S onto other pins
- disable the JTAG and use the SWD interface prior to configuring the pins listed as SPI I/Os (when debugging the application) or
- disable both JTAG/SWD interfaces (for standalone applications).

For more information on the configuration of the JTAG/SWD interface pins, please refer to [Section 8.3.2: I/O pin multiplexer and mapping](#).

---

## 20.2 SPI and I<sup>2</sup>S main features

### 20.2.1 SPI features

- Full-duplex synchronous transfers on three lines
- Simplex synchronous transfers on two lines with or without a bidirectional data line
- 8- or 16-bit transfer frame format selection
- Master or slave operation
- Multimaster mode capability
- 8 master mode baud rate prescalers ( $f_{PCLK}/2$  max.)
- Slave mode frequency ( $f_{PCLK}/2$  max)
- Faster communication for both master and slave
- NSS management by hardware or software for both master and slave: dynamic change of master/slave operations
- Programmable clock polarity and phase
- Programmable data order with MSB-first or LSB-first shifting
- Dedicated transmission and reception flags with interrupt capability
- SPI bus busy status flag
- SPI TI mode
- Hardware CRC feature for reliable communication:
  - CRC value can be transmitted as last byte in Tx mode
  - Automatic CRC error checking for last received byte
- Master mode fault, overrun and CRC error flags with interrupt capability
- 1-byte transmission and reception buffer with DMA capability: Tx and Rx requests

## 20.2.2 I<sup>2</sup>S features

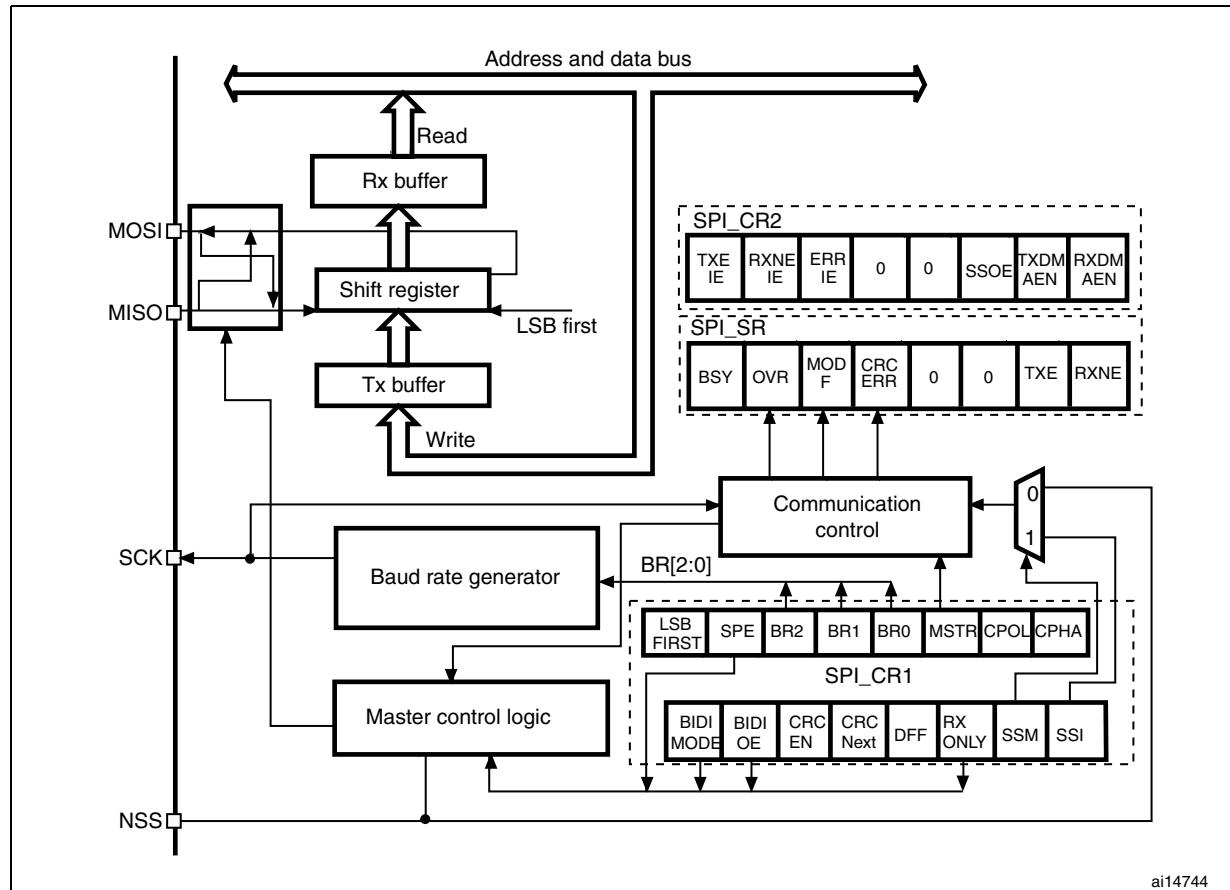
- Full duplex communication
- Half-duplex communication (only transmitter or receiver)
- Master or slave operations
- 8-bit programmable linear prescaler to reach accurate audio sample frequencies (from 8 kHz to 192 kHz)
- Data format may be 16-bit, 24-bit or 32-bit
- Packet frame is fixed to 16-bit (16-bit data frame) or 32-bit (16-bit, 24-bit, 32-bit data frame) by audio channel
- Programmable clock polarity (steady state)
- Underrun flag in slave transmission mode, overrun flag in reception mode (master and slave), and Frame Error flag in reception and transmission mode (slave only)
- 16-bit register for transmission and reception with one data register for both channel sides
- Supported I<sup>2</sup>S protocols:
  - I<sup>2</sup>S Phillips standard
  - MSB-justified standard (left-justified)
  - LSB-justified standard (right-justified)
  - PCM standard (with short and long frame synchronization on 16-bit channel frame or 16-bit data frame extended to 32-bit channel frame)
- Data direction is always MSB first
- DMA capability for transmission and reception (16-bit wide)
- Master clock may be output to drive an external audio component. Ratio is fixed at  $256 \times F_S$  (where  $F_S$  is the audio sampling frequency)
- Both I<sup>2</sup>S (I2S2 and I2S3) have a dedicated PLL (PLLI2S) to generate an even more accurate clock.
- I<sup>2</sup>S (I2S2 and I2S3) clock can be derived from an external clock mapped on the I2S\_CKIN pin.

## 20.3 SPI functional description

### 20.3.1 General description

The block diagram of the SPI is shown in [Figure 192](#).

**Figure 192. SPI block diagram**



ai14744

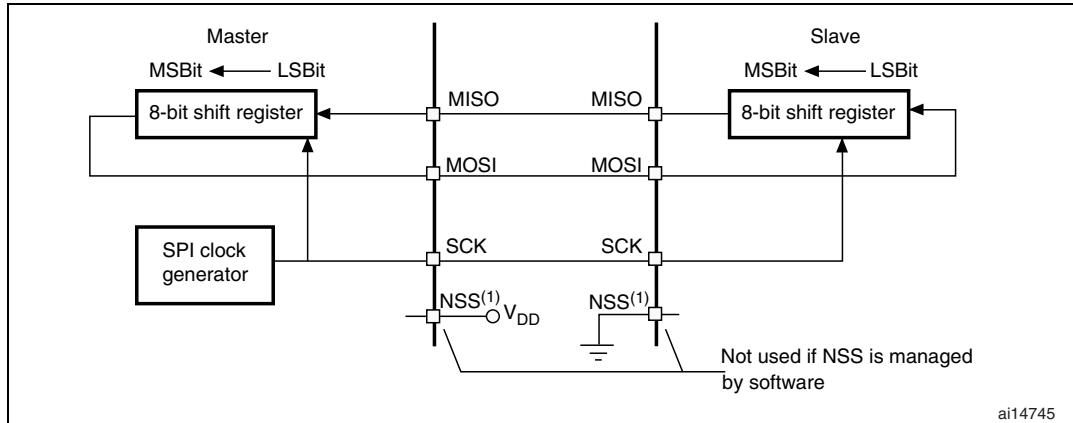
Usually, the SPI is connected to external devices through 4 pins:

- MISO: Master In / Slave Out data. This pin can be used to transmit data in slave mode and receive data in master mode.
- MOSI: Master Out / Slave In data. This pin can be used to transmit data in master mode and receive data in slave mode.
- SCK: Serial Clock output for SPI masters and input for SPI slaves.
- NSS: Slave select. This is an optional pin to select a slave device. This pin acts as a 'chip select' to let the SPI master communicate with slaves individually and to avoid contention on the data lines. Slave NSS inputs can be driven by standard IO ports on the master device. The NSS pin may also be used as an output if enabled (SSOE bit) and driven low if the SPI is in master configuration. In this manner, all NSS pins from devices connected to the Master NSS pin see a low level and become slaves when they are configured in NSS hardware mode. When configured in master mode with NSS configured as an input (MSTR=1 and SSOE=0) and if NSS is pulled low, the SPI

enters the master mode fault state: the MSTR bit is automatically cleared and the device is configured in slave mode (refer to [Section 20.3.10: Error flags on page 570](#)).

A basic example of interconnections between a single master and a single slave is illustrated in [Figure 193](#).

**Figure 193. Single master/ single slave application**



1. Here, the NSS pin is configured as an input.

The MOSI pins are connected together and the MISO pins are connected together. In this way data is transferred serially between master and slave (most significant bit first).

The communication is always initiated by the master. When the master device transmits data to a slave device via the MOSI pin, the slave device responds via the MISO pin. This implies full-duplex communication with both data out and data in synchronized with the same clock signal (which is provided by the master device via the SCK pin).

### Slave select (NSS) pin management

Hardware or software slave select management can be set using the SSM bit in the SPI\_CR1 register.

- Software NSS management (SSM = 1)
 

The slave select information is driven internally by the value of the SSI bit in the SPI\_CR1 register. The external NSS pin remains free for other application uses.
- Hardware NSS management (SSM = 0)
  - NSS output enabled (SSM = 0, SSOE = 1)
 

This configuration is used only when the device operates in master mode. The NSS signal is driven low when the master starts the communication and is kept low until the SPI is disabled.
  - NSS output disabled (SSM = 0, SSOE = 0)
 

This configuration allows multimaster capability for devices operating in master mode. For devices set as slave, the NSS pin acts as a classical NSS input: the slave is selected when NSS is low and deselected when NSS high.

### Clock phase and clock polarity

Four possible timing relationships may be chosen by software, using the CPOL and CPHA bits in the SPI\_CR1 register. The CPOL (clock polarity) bit controls the steady state value of the clock when no data is being transferred. This bit affects both master and slave modes. If CPOL is reset, the SCK pin has a low-level idle state. If CPOL is set, the SCK pin has a high-level idle state.

If the CPHA (clock phase) bit is set, the second edge on the SCK pin (falling edge if the CPOL bit is reset, rising edge if the CPOL bit is set) is the MSBit capture strobe. Data are latched on the occurrence of the second clock transition. If the CPHA bit is reset, the first edge on the SCK pin (falling edge if CPOL bit is set, rising edge if CPOL bit is reset) is the MSBit capture strobe. Data are latched on the occurrence of the first clock transition.

The combination of the CPOL (clock polarity) and CPHA (clock phase) bits selects the data capture clock edge.

*Figure 194*, shows an SPI transfer with the four combinations of the CPHA and CPOL bits. The diagram may be interpreted as a master or slave timing diagram where the SCK pin, the MISO pin, the MOSI pin are directly connected between the master and the slave device.

Note:

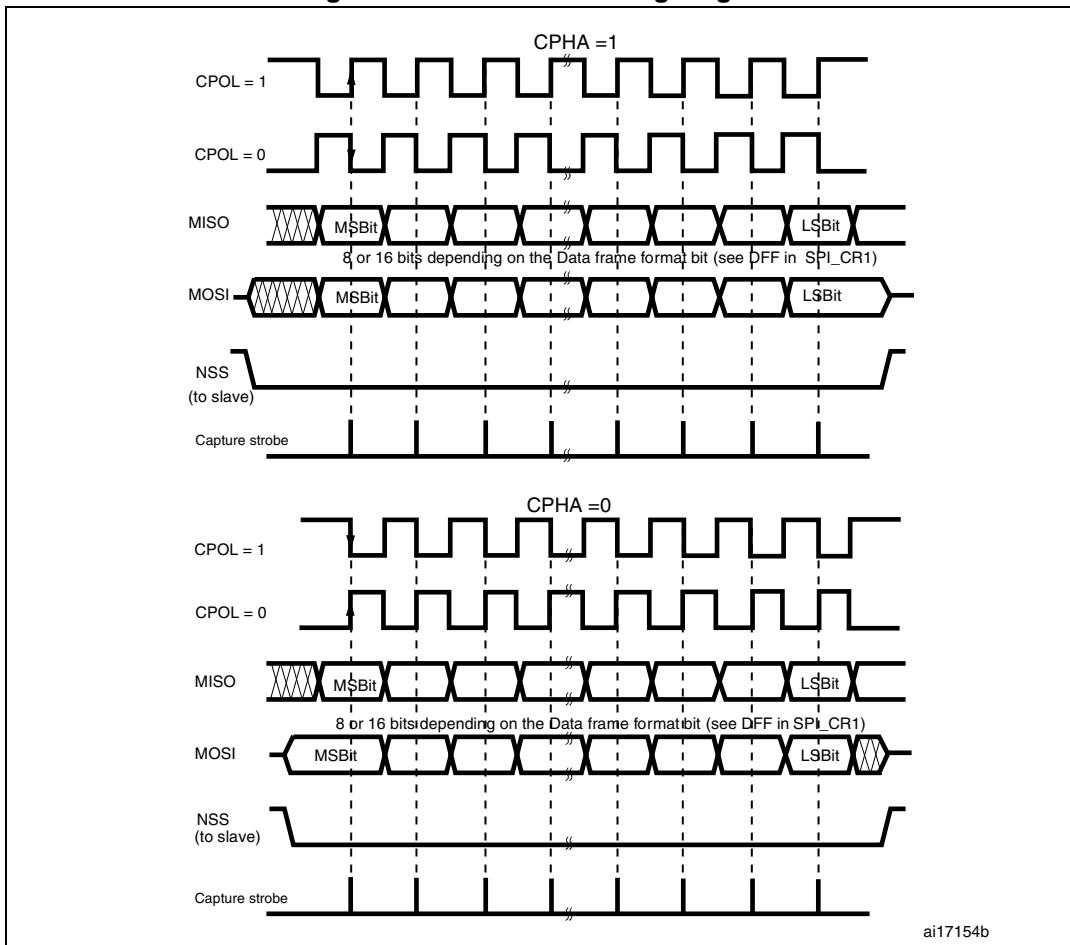
*Prior to changing the CPOL/CPHA bits the SPI must be disabled by resetting the SPE bit.*

*Master and slave must be programmed with the same timing mode.*

*The idle state of SCK must correspond to the polarity selected in the SPI\_CR1 register (by pulling up SCK if CPOL=1 or pulling down SCK if CPOL=0).*

*The Data Frame Format (8- or 16-bit) is selected through the DFF bit in SPI\_CR1 register, and determines the data length during transmission/reception.*

Figure 194. Data clock timing diagram



1. These timings are shown with the LSBFIRST bit reset in the SPI\_CR1 register.

### Data frame format

Data can be shifted out either MSB-first or LSB-first depending on the value of the LSBFIRST bit in the SPI\_CR1 Register.

Each data frame is 8 or 16 bits long depending on the size of the data programmed using the DFF bit in the SPI\_CR1 register. The selected data frame format is applicable for transmission and/or reception.

### 20.3.2 Configuring the SPI in slave mode

In the slave configuration, the serial clock is received on the SCK pin from the master device. The value set in the BR[2:0] bits in the SPI\_CR1 register, does not affect the data transfer rate.

**Note:** *It is recommended to enable the SPI slave before the master sends the clock. If not, undesired data transmission might occur. The data register of the slave needs to be ready before the first edge of the communication clock or before the end of the ongoing communication. It is mandatory to have the polarity of the communication clock set to the steady state value before the slave and the master are enabled.*

Follow the procedure below to configure the SPI in slave mode:

## Procedure

1. Set the DFF bit to define 8- or 16-bit data frame format
2. Select the CPOL and CPHA bits to define one of the four relationships between the data transfer and the serial clock (see [Figure 194](#)). For correct data transfer, the CPOL and CPHA bits must be configured in the same way in the slave device and the master device. This step is not required when the TI mode is selected through the FRF bit in the SPI\_CR2 register.
3. The frame format (MSB-first or LSB-first depending on the value of the LSBFIRST bit in the SPI\_CR1 register) must be the same as the master device. This step is not required when TI mode is selected.
4. In Hardware mode (refer to [Slave select \(NSS\) pin management on page 550](#)), the NSS pin must be connected to a low level signal during the complete byte transmit sequence. In NSS software mode, set the SSM bit and clear the SSI bit in the SPI\_CR1 register. This step is not required when TI mode is selected.
5. Set the FRF bit in the SPI\_CR2 register to select the TI mode protocol for serial communications.
6. Clear the MSTR bit and set the SPE bit (both in the SPI\_CR1 register) to assign the pins to alternate functions.

In this configuration the MOSI pin is a data input and the MISO pin is a data output.

## Transmit sequence

The data byte is parallel-loaded into the Tx buffer during a write cycle.

The transmit sequence begins when the slave device receives the clock signal and the most significant bit of the data on its MOSI pin. The remaining bits (the 7 bits in 8-bit data frame format, and the 15 bits in 16-bit data frame format) are loaded into the shift-register. The TXE flag in the SPI\_SR register is set on the transfer of data from the Tx Buffer to the shift register and an interrupt is generated if the TXIE bit in the SPI\_CR2 register is set.

## Receive sequence

For the receiver, when data transfer is complete:

- The Data in shift register is transferred to Rx Buffer and the RXNE flag (SPI\_SR register) is set
- An Interrupt is generated if the RXNEIE bit is set in the SPI\_CR2 register.

After the last sampling clock edge the RXNE bit is set, a copy of the data byte received in the shift register is moved to the Rx buffer. When the SPI\_DR register is read, the SPI peripheral returns this buffered value.

Clearing of the RXNE bit is performed by reading the SPI\_DR register.

## SPI TI protocol in slave mode

In slave mode, the SPI interface is compatible with the TI protocol. The FRF bit of the SPI\_CR2 register can be used to configure the slave SPI serial communications to be compliant with this protocol.

The clock polarity and phase are forced to conform to the TI protocol requirements whatever the values set in the SPI\_CR1 register. NSS management is also specific to the TI protocol which makes the configuration of NSS management through the SPI\_CR1 and SPI\_CR2 registers (such as SSM, SSI, SSOE) transparent for the user.

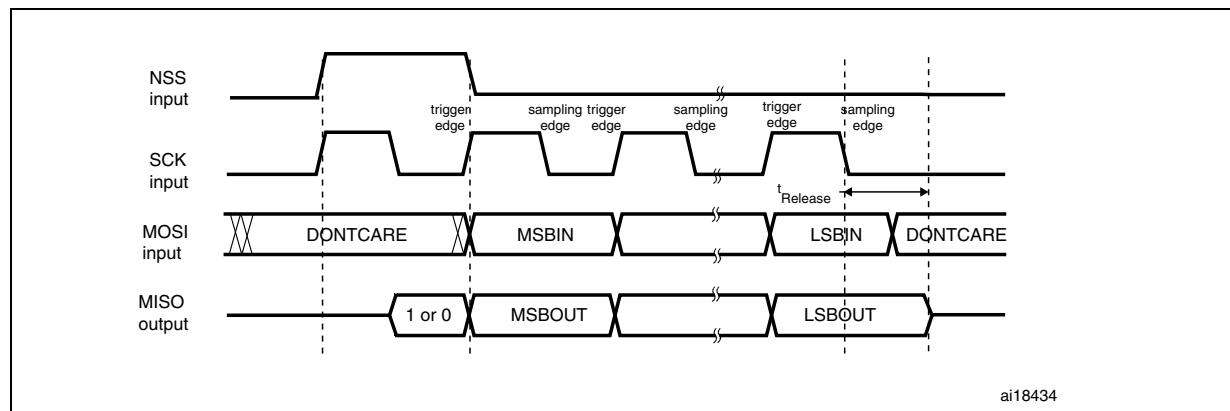
In Slave mode ([Figure 195: TI mode - Slave mode, single transfer](#) and [Figure 196: TI mode - Slave mode, continuous transfer](#)), the SPI baud rate prescaler is used to control the moment when the MISO pin state changes to HI-Z. Any baud rate can be used thus allowing to determine this moment with optimal flexibility. However, the baud rate is generally set to the external master clock baud rate. The time for the MISO signal to become HI-Z ( $t_{release}$ ) depends on internal resynchronizations and on the baud rate value set in through BR[2:0] of SPI\_CR1 register. It is given by the formula:

$$\frac{t_{baud\_rate}}{2} + 4 \times t_{pcclk} < t_{release} < \frac{t_{baud\_rate}}{2} + 6 \times t_{pcclk}$$

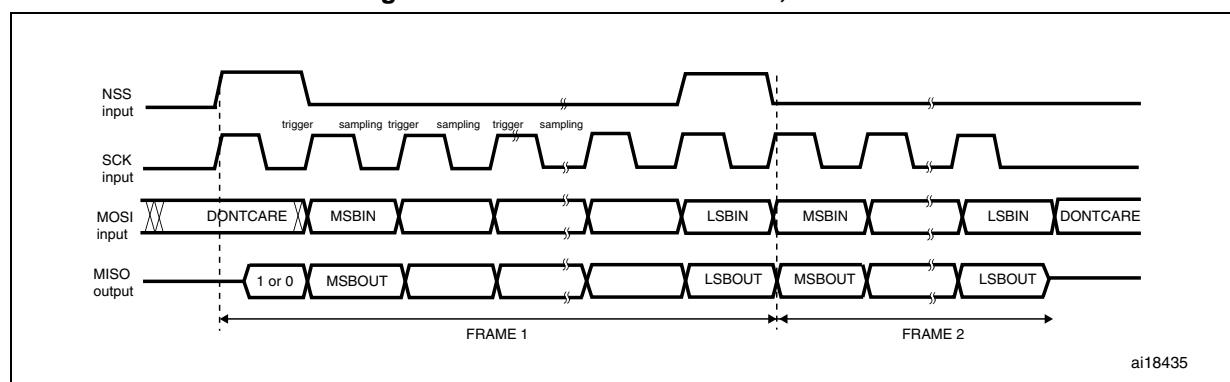
*Note:* This feature is not available for Motorola SPI communications (FRF bit set to 0).

To detect TI frame errors in Slave transmitter only mode by using the Error interrupt (ERRIE = 1), the SPI must be configured in 2-line unidirectional mode by setting BIDIMODE and BIDIOE to 1 in the SPI\_CR1 register. When BIDIMODE is set to 0, OVR is set to 1 because the data register is never read and error interrupt are always generated, while when BIDIMODE is set to 1, data are not received and OVR is never set.

**Figure 195. TI mode - Slave mode, single transfer**



**Figure 196. TI mode - Slave mode, continuous transfer**



### 20.3.3 Configuring the SPI in master mode

In the master configuration, the serial clock is generated on the SCK pin.

#### Procedure

1. Select the BR[2:0] bits to define the serial clock baud rate (see SPI\_CR1 register).
2. Select the CPOL and CPHA bits to define one of the four relationships between the data transfer and the serial clock (see [Figure 194](#)). This step is not required when the TI mode is selected.
3. Set the DFF bit to define 8- or 16-bit data frame format
4. Configure the LSBFIRST bit in the SPI\_CR1 register to define the frame format. This step is not required when the TI mode is selected.
5. If the NSS pin is required in input mode, in hardware mode, connect the NSS pin to a high-level signal during the complete byte transmit sequence. In NSS software mode, set the SSM and SSI bits in the SPI\_CR1 register. If the NSS pin is required in output mode, the SSOE bit only should be set. This step is not required when the TI mode is selected.
6. Set the FRF bit in SPI\_CR2 to select the TI protocol for serial communications.
7. The MSTR and SPE bits must be set (they remain set only if the NSS pin is connected to a high-level signal).

In this configuration the MOSI pin is a data output and the MISO pin is a data input.

#### Transmit sequence

The transmit sequence begins when a byte is written in the Tx Buffer.

The data byte is parallel-loaded into the shift register (from the internal bus) during the first bit transmission and then shifted out serially to the MOSI pin MSB first or LSB first depending on the LSBFIRST bit in the SPI\_CR1 register. The TXE flag is set on the transfer of data from the Tx Buffer to the shift register and an interrupt is generated if the TXEIE bit in the SPI\_CR2 register is set.

#### Receive sequence

For the receiver, when data transfer is complete:

- The data in the shift register is transferred to the RX Buffer and the RXNE flag is set
- An interrupt is generated if the RXNEIE bit is set in the SPI\_CR2 register

At the last sampling clock edge the RXNE bit is set, a copy of the data byte received in the shift register is moved to the Rx buffer. When the SPI\_DR register is read, the SPI peripheral returns this buffered value.

Clearing the RXNE bit is performed by reading the SPI\_DR register.

A continuous transmit stream can be maintained if the next data to be transmitted is put in the Tx buffer once the transmission is started. Note that TXE flag should be '1' before any attempt to write the Tx buffer is made.

**Note:**

*When a master is communicating with SPI slaves which need to be de-selected between transmissions, the NSS pin must be configured as GPIO or another GPIO must be used and toggled by software.*

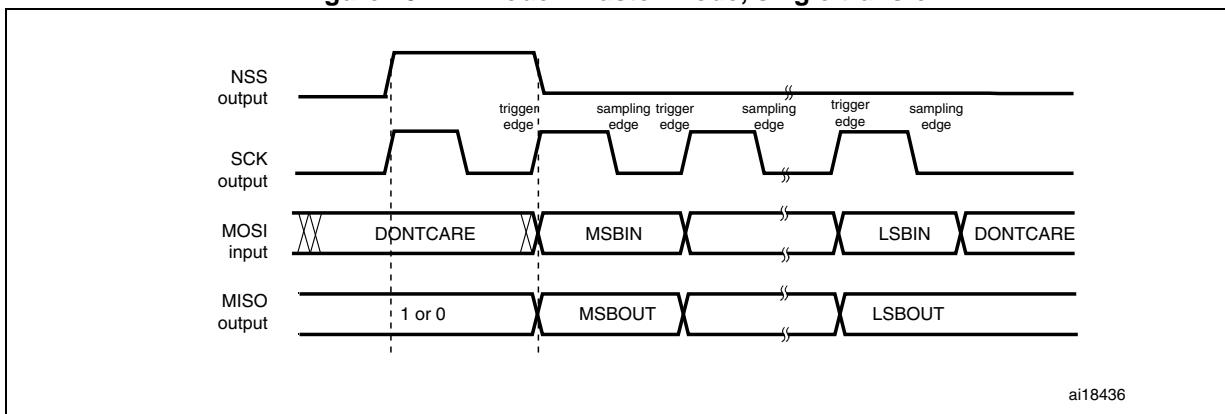
### SPI TI protocol in master mode

In master mode, the SPI interface is compatible with the TI protocol. The FRF bit of the SPI\_CR2 register can be used to configure the master SPI serial communications to be compliant with this protocol.

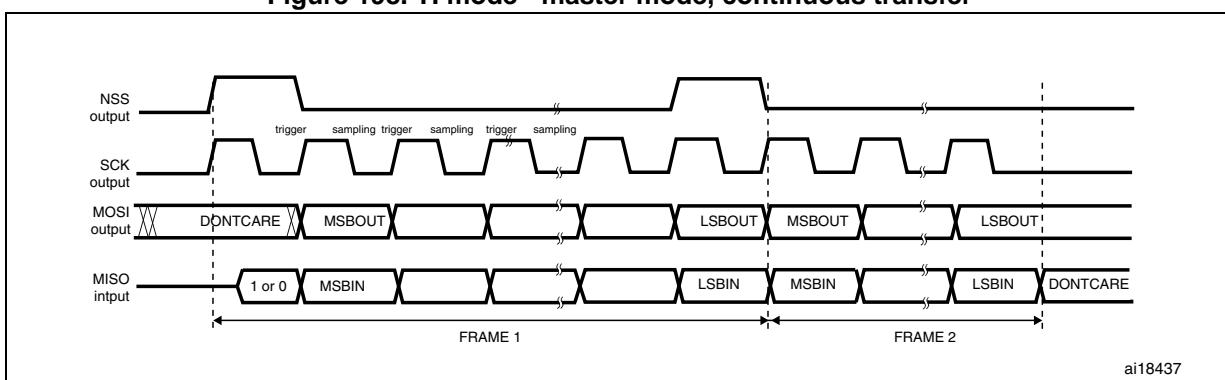
The clock polarity and phase are forced to conform to the TI protocol requirements whatever the values set in the SPI\_CR1 register. NSS management is also specific to the TI protocol which makes the configuration of NSS management through the SPI\_CR1 and SPI\_CR2 registers (SSM, SSI, SSOE) transparent for the user.

*Figure 197: TI mode - master mode, single transfer* and *Figure 198: TI mode - master mode, continuous transfer*) show the SPI master communication waveforms when the TI mode is selected in master mode.

**Figure 197. TI mode - master mode, single transfer**



**Figure 198. TI mode - master mode, continuous transfer**



### 20.3.4 Configuring the SPI for half-duplex communication

The SPI is capable of operating in half-duplex mode in 2 configurations.

- 1 clock and 1 bidirectional data wire
- 1 clock and 1 data wire (receive-only or transmit-only)

#### 1 clock and 1 bidirectional data wire (BIDIMODE=1)

This mode is enabled by setting the BIDIMODE bit in the SPI\_CR1 register. In this mode SCK is used for the clock and MOSI in master or MISO in slave mode is used for data communication. The transfer direction (Input/Output) is selected by the BIDIOE bit in the SPI\_CR1 register. When this bit is 1, the data line is output otherwise it is input.

#### 1 clock and 1 unidirectional data wire (BIDIMODE=0)

In this mode, the application can use the SPI either in transmit-only mode or in receive-only mode.

- Transmit-only mode is similar to full-duplex mode (BIDIMODE=0, RXONLY=0): the data are transmitted on the transmit pin (MOSI in master mode or MISO in slave mode) and the receive pin (MISO in master mode or MOSI in slave mode) can be used as a general-purpose IO. In this case, the application just needs to ignore the Rx buffer (if the data register is read, it does not contain the received value).
- In receive-only mode, the application can disable the SPI output function by setting the RXONLY bit in the SPI\_CR2 register. In this case, it frees the transmit IO pin (MOSI in master mode or MISO in slave mode), so it can be used for other purposes.

To start the communication in receive-only mode, configure and enable the SPI:

- In master mode, the communication starts immediately and stops when the SPE bit is cleared and the current reception stops. There is no need to read the BSY flag in this mode. It is always set when an SPI communication is ongoing.
- In slave mode, the SPI continues to receive as long as the NSS is pulled down (or the SSI bit is cleared in NSS software mode) and the SCK is running.

### 20.3.5 Data transmission and reception procedures

#### Rx and Tx buffers

In reception, data are received and then stored into an internal Rx buffer while in transmission, data are first stored into an internal Tx buffer before being transmitted.

A read access of the SPI\_DR register returns the Rx buffered value whereas a write access to the SPI\_DR stores the written data into the Tx buffer.

**Start sequence in master mode**

- In full-duplex (BIDIMODE=0 and RXONLY=0)
  - The sequence begins when data are written into the SPI\_DR register (Tx buffer).
  - The data are then parallel loaded from the Tx buffer into the 8-bit shift register during the first bit transmission and then shifted out serially to the MOSI pin.
  - At the same time, the received data on the MISO pin is shifted in serially to the 8-bit shift register and then parallel loaded into the SPI\_DR register (Rx buffer).
- In unidirectional receive-only mode (BIDIMODE=0 and RXONLY=1)
  - The sequence begins as soon as SPE=1
  - Only the receiver is activated and the received data on the MISO pin are shifted in serially to the 8-bit shift register and then parallel loaded into the SPI\_DR register (Rx buffer).
- In bidirectional mode, when transmitting (BIDIMODE=1 and BIDIOE=1)
  - The sequence begins when data are written into the SPI\_DR register (Tx buffer).
  - The data are then parallel loaded from the Tx buffer into the 8-bit shift register during the first bit transmission and then shifted out serially to the MOSI pin.
  - No data are received.
- In bidirectional mode, when receiving (BIDIMODE=1 and BIDIOE=0)
  - The sequence begins as soon as SPE=1 and BIDIOE=0.
  - The received data on the MOSI pin are shifted in serially to the 8-bit shift register and then parallel loaded into the SPI\_DR register (Rx buffer).
  - The transmitter is not activated and no data are shifted out serially to the MOSI pin.

**Start sequence in slave mode**

- In full-duplex mode (BIDIMODE=0 and RXONLY=0)
  - The sequence begins when the slave device receives the clock signal and the first bit of the data on its MOSI pin. The 7 remaining bits are loaded into the shift register.
  - At the same time, the data are parallel loaded from the Tx buffer into the 8-bit shift register during the first bit transmission, and then shifted out serially to the MISO pin. The software must have written the data to be sent before the SPI master device initiates the transfer.
- In unidirectional receive-only mode (BIDIMODE=0 and RXONLY=1)
  - The sequence begins when the slave device receives the clock signal and the first bit of the data on its MOSI pin. The 7 remaining bits are loaded into the shift register.
  - The transmitter is not activated and no data are shifted out serially to the MISO pin.
- In bidirectional mode, when transmitting (BIDIMODE=1 and BIDIOE=1)
  - The sequence begins when the slave device receives the clock signal and the first bit in the Tx buffer is transmitted on the MISO pin.
  - The data are then parallel loaded from the Tx buffer into the 8-bit shift register during the first bit transmission and then shifted out serially to the MISO pin. The

software must have written the data to be sent before the SPI master device initiates the transfer.

- No data are received.
- In bidirectional mode, when receiving (BIDIMODE=1 and BIDIOE=0)
  - The sequence begins when the slave device receives the clock signal and the first bit of the data on its MISO pin.
  - The received data on the MISO pin are shifted in serially to the 8-bit shift register and then parallel loaded into the SPI\_DR register (Rx buffer).
  - The transmitter is not activated and no data are shifted out serially to the MISO pin.

### Handling data transmission and reception

The TXE flag (Tx buffer empty) is set when the data are transferred from the Tx buffer to the shift register. It indicates that the internal Tx buffer is ready to be loaded with the next data. An interrupt can be generated if the TXIE bit in the SPI\_CR2 register is set. Clearing the TXE bit is performed by writing to the SPI\_DR register.

*Note:* The software must ensure that the TXE flag is set to 1 before attempting to write to the Tx buffer. Otherwise, it overwrites the data previously written to the Tx buffer.

The RXNE flag (Rx buffer not empty) is set on the last sampling clock edge, when the data are transferred from the shift register to the Rx buffer. It indicates that data are ready to be read from the SPI\_DR register. An interrupt can be generated if the RXNEIE bit in the SPI\_CR2 register is set. Clearing the RXNE bit is performed by reading the SPI\_DR register.

For some configurations, the BSY flag can be used during the last data transfer to wait until the completion of the transfer.

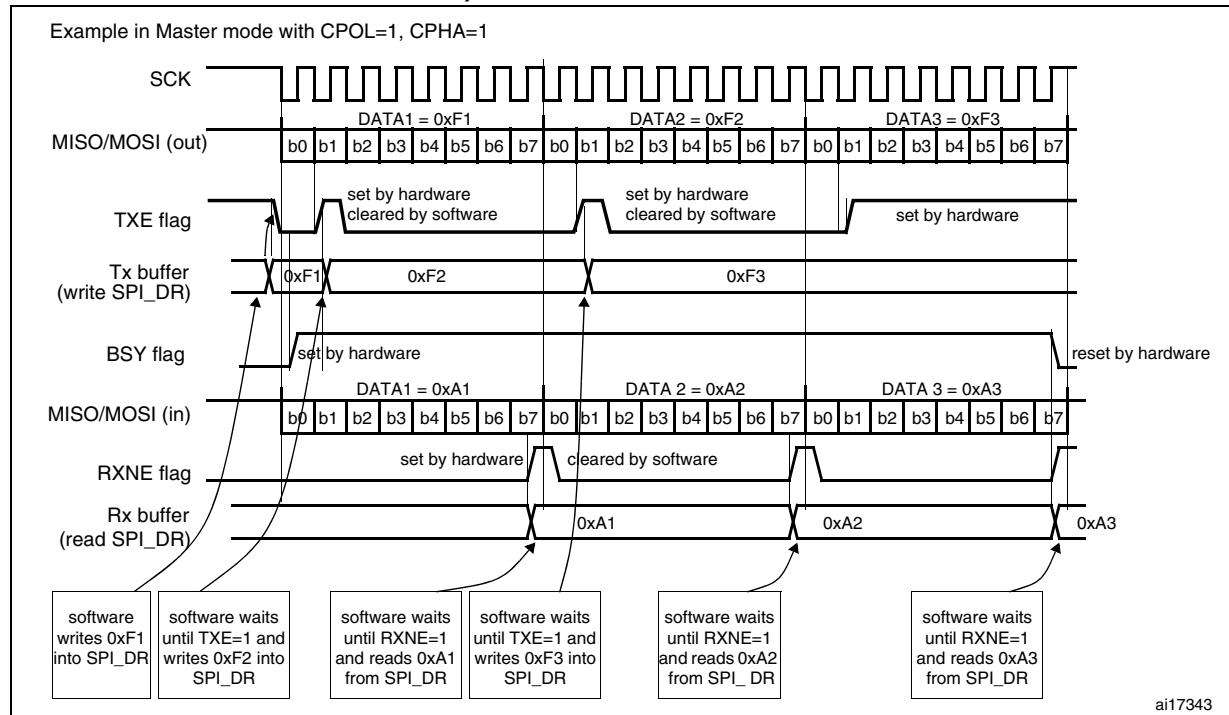
Full-duplex transmit and receive procedure in master or slave mode (BIDIMODE=0 and RXONLY=0)

The software has to follow this procedure to transmit and receive data (see [Figure 199](#) and [Figure 200](#)):

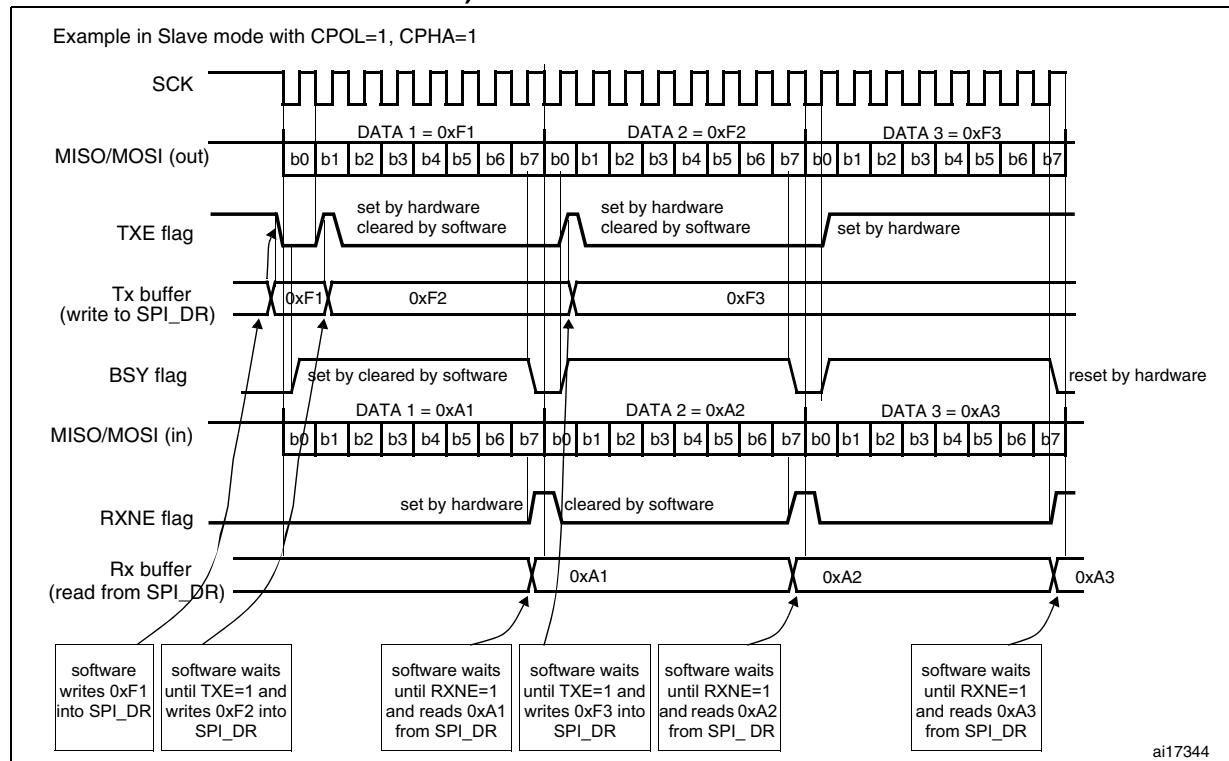
1. Enable the SPI by setting the SPE bit to 1.
2. Write the first data item to be transmitted into the SPI\_DR register (this clears the TXE flag).
3. Wait until TXE=1 and write the second data item to be transmitted. Then wait until RXNE=1 and read the SPI\_DR to get the first received data item (this clears the RXNE bit). Repeat this operation for each data item to be transmitted/received until the n-1 received data.
4. Wait until RXNE=1 and read the last received data.
5. Wait until TXE=1 and then wait until BSY=0 before disabling the SPI.

This procedure can also be implemented using dedicated interrupt subroutines launched at each rising edges of the RXNE or TXE flag.

**Figure 199. TXE/RXNE/BSY behavior in Master / full-duplex mode (BIDIMODE=0 and RXONLY=0) in the case of continuous transfers**



**Figure 200. TXE/RXNE/BSY behavior in Slave / full-duplex mode (BIDIMODE=0, RXONLY=0) in the case of continuous transfers**



### Transmit-only procedure (BIDIMODE=0 RXONLY=0)

In this mode, the procedure can be reduced as described below and the BSY bit can be used to wait until the completion of the transmission (see [Figure 201](#) and [Figure 202](#)).

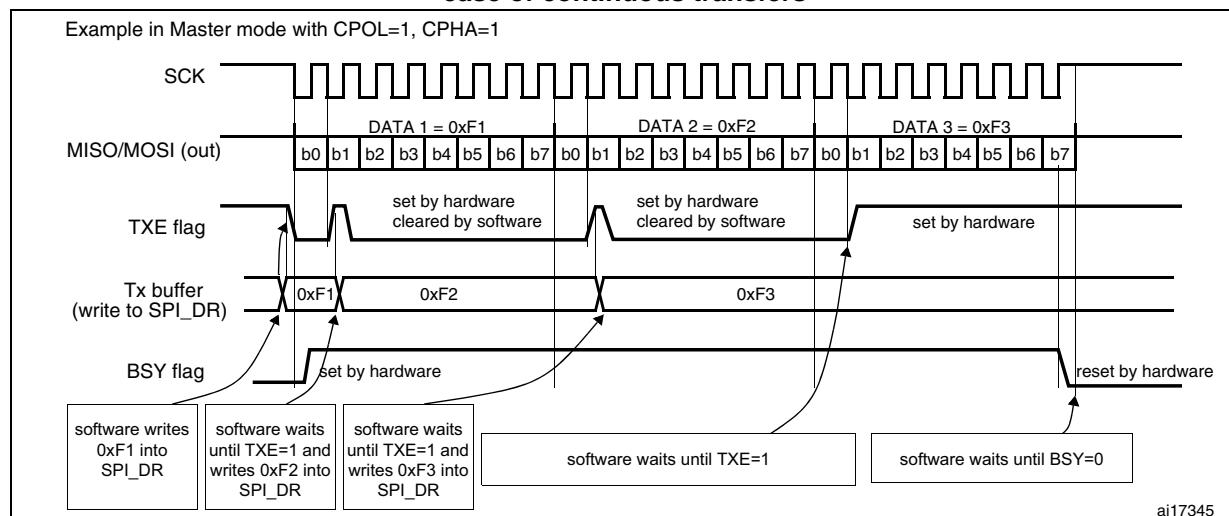
1. Enable the SPI by setting the SPE bit to 1.
2. Write the first data item to send into the SPI\_DR register (this clears the TXE bit).
3. Wait until TXE=1 and write the next data item to be transmitted. Repeat this step for each data item to be transmitted.
4. After writing the last data item into the SPI\_DR register, wait until TXE=1, then wait until BSY=0, this indicates that the transmission of the last data is complete.

This procedure can be also implemented using dedicated interrupt subroutines launched at each rising edge of the TXE flag.

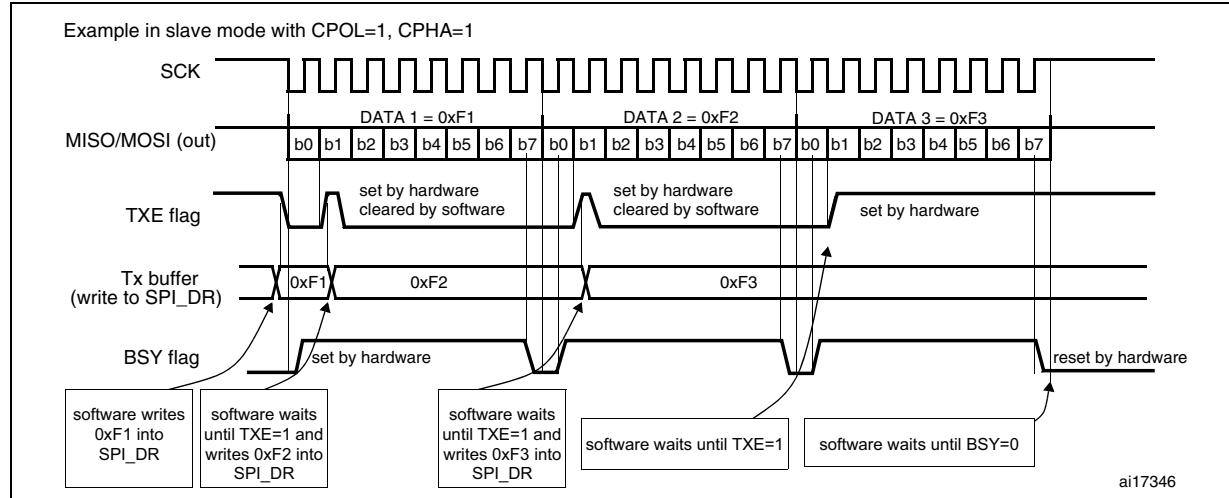
**Note:** *During discontinuous communications, there is a 2 APB clock period delay between the write operation to SPI\_DR and the BSY bit setting. As a consequence, in transmit-only mode, it is mandatory to wait first until TXE is set and then until BSY is cleared after writing the last data.*

*After transmitting two data items in transmit-only mode, the OVR flag is set in the SPI\_SR register since the received data are never read.*

**Figure 201. TXE/BSY behavior in Master transmit-only mode (BIDIMODE=0 and RXONLY=0) in case of continuous transfers**



**Figure 202. TXE/BSY in Slave transmit-only mode (BIDIMODE=0 and RXONLY=0) in the case of continuous transfers**



### Bidirectional transmit procedure (BIDIMODE=1 and BIDIOE=1)

In this mode, the procedure is similar to the procedure in Transmit-only mode except that the BIDIMODE and BIDIOE bits both have to be set in the SPI\_CR2 register before enabling the SPI.

### Unidirectional receive-only procedure (BIDIMODE=0 and RXONLY=1)

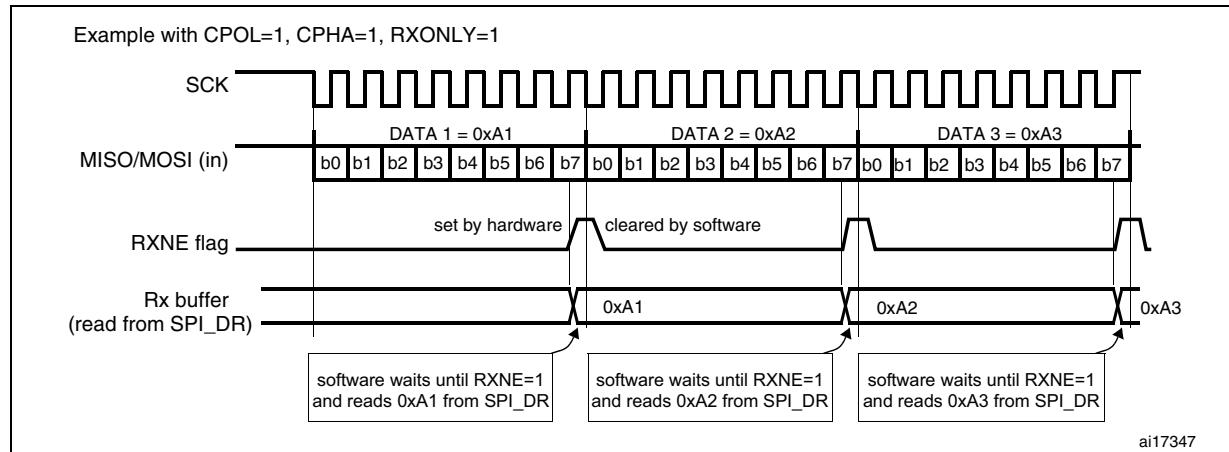
In this mode, the procedure can be reduced as described below (see [Figure 203](#)):

1. Set the RXONLY bit in the SPI\_CR2 register.
2. Enable the SPI by setting the SPE bit to 1:
  - a) In master mode, this immediately activates the generation of the SCK clock, and data are serially received until the SPI is disabled (SPE=0).
  - b) In slave mode, data are received when the SPI master device drives NSS low and generates the SCK clock.
3. Wait until RXNE=1 and read the SPI\_DR register to get the received data (this clears the RXNE bit). Repeat this operation for each data item to be received.

This procedure can also be implemented using dedicated interrupt subroutines launched at each rising edge of the RXNE flag.

**Note:** If it is required to disable the SPI after the last transfer, follow the recommendation described in [Section 20.3.8: Disabling the SPI on page 567](#).

**Figure 203. RXNE behavior in receive-only mode (BIDIMODE=0 and RXONLY=1) in the case of continuous transfers**



### Bidirectional receive procedure (BIDIMODE=1 and BIDIOE=0)

In this mode, the procedure is similar to the Receive-only mode procedure except that the BIDIMODE bit has to be set and the BIDIOE bit cleared in the SPI\_CR2 register before enabling the SPI.

### Continuous and discontinuous transfers

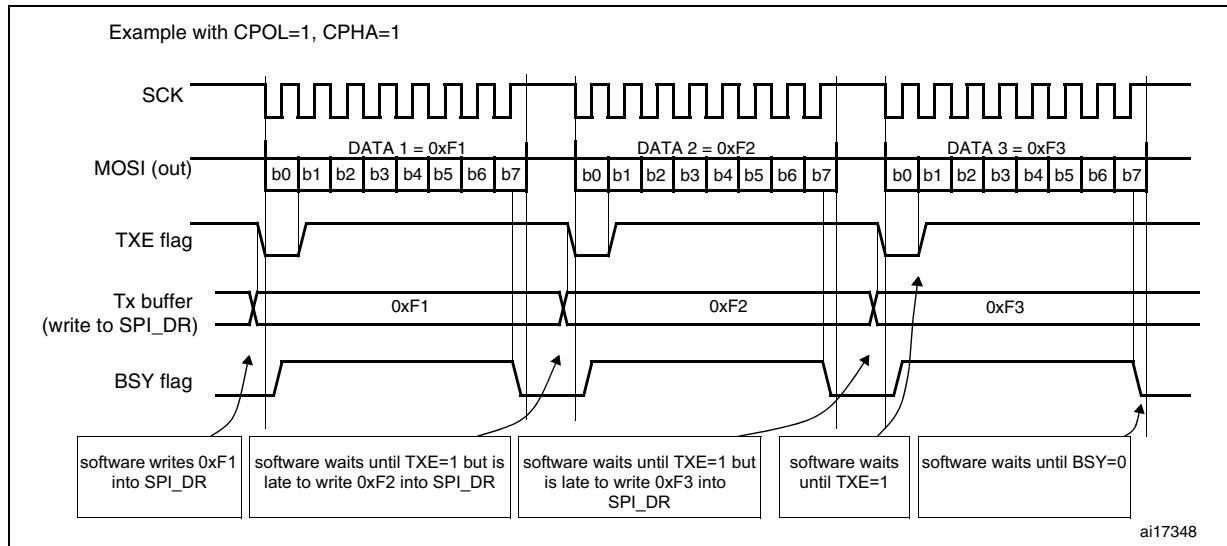
When transmitting data in master mode, if the software is fast enough to detect each rising edge of TXE (or TXE interrupt) and to immediately write to the SPI\_DR register before the ongoing data transfer is complete, the communication is said to be continuous. In this case, there is no discontinuity in the generation of the SPI clock between each data item and the BSY bit is never cleared between each data transfer.

On the contrary, if the software is not fast enough, this can lead to some discontinuities in the communication. In this case, the BSY bit is cleared between each data transmission (see [Figure 204](#)).

In Master receive-only mode (RXONLY=1), the communication is always continuous and the BSY flag is always read at 1.

In slave mode, the continuity of the communication is decided by the SPI master device. In any case, even if the communication is continuous, the BSY flag goes low between each transfer for a minimum duration of one SPI clock cycle (see [Figure 202](#)).

**Figure 204. TXE/BSY behavior when transmitting (BIDIRMODE=0 and RXONLY=0) in the case of discontinuous transfers**



### 20.3.6 CRC calculation

A CRC calculator has been implemented for communication reliability. Separate CRC calculators are implemented for transmitted data and received data. The CRC is calculated using a programmable polynomial serially on each bit. It is calculated on the sampling clock edge defined by the CPHA and CPOL bits in the SPI\_CR1 register.

*Note:* This SPI offers two kinds of CRC calculation standard which depend directly on the data frame format selected for the transmission and/or reception: 8-bit data (CR8) and 16-bit data (CRC16).

CRC calculation is enabled by setting the CRCEN bit in the SPI\_CR1 register. This action resets the CRC registers (SPI\_RXCRCR and SPI\_TXCRCR). In full duplex or transmitter only mode, when the transfers are managed by the software (CPU mode), it is necessary to write the bit CRCNEXT immediately after the last data to be transferred is written to the SPI\_DR. At the end of this last data transfer, the SPI\_TXCRCR value is transmitted.

In receive only mode and when the transfers are managed by software (CPU mode), it is necessary to write the CRCNEXT bit after the second last data has been received. The CRC is received just after the last data reception and the CRC check is then performed.

At the end of data and CRC transfers, the CRCERR flag in the SPI\_SR register is set if corruption occurs during the transfer.

If data are present in the TX buffer, the CRC value is transmitted only after the transmission of the data byte. During CRC transmission, the CRC calculator is switched off and the register value remains unchanged.

SPI communication using the CRC is possible through the following procedure:

1. Program the CPOL, CPHA, LSBFirst, BR, SSM, SSI and MSTR values.
2. Program the polynomial in the SPI\_CRCPR register.
3. Enable the CRC calculation by setting the CRCEN bit in the SPI\_CR1 register. This also clears the SPI\_RXCRCR and SPI\_TXCRCR registers.
4. Enable the SPI by setting the SPE bit in the SPI\_CR1 register.
5. Start the communication and sustain the communication until all but one byte or half-word have been transmitted or received.
  - In full duplex or transmitter-only mode, when the transfers are managed by software, when writing the last byte or half word to the Tx buffer, set the CRCNEXT bit in the SPI\_CR1 register to indicate that the CRC will be transmitted after the transmission of the last byte.
  - In receiver only mode, set the bit CRCNEXT just after the reception of the second to last data to prepare the SPI to enter in CRC Phase at the end of the reception of the last data. CRC calculation is frozen during the CRC transfer.
6. After the transfer of the last byte or half word, the SPI enters the CRC transfer and check phase. In full duplex mode or receiver-only mode, the received CRC is compared to the SPI\_RXCRCR value. If the value does not match, the CRCERR flag in SPI\_SR is set and an interrupt can be generated when the ERRIE bit in the SPI\_CR2 register is set.

**Note:** *When the SPI is in slave mode, be careful to enable CRC calculation only when the clock is stable, that is, when the clock is in the steady state. If not, a wrong CRC calculation may be done. In fact, the CRC is sensitive to the SCK slave input clock as soon as CRCEN is set, and this, whatever the value of the SPE bit.*

*With high bitrate frequencies, be careful when transmitting the CRC. As the number of used CPU cycles has to be as low as possible in the CRC transfer phase, it is forbidden to call software functions in the CRC transmission sequence to avoid errors in the last data and CRC reception. In fact, CRCNEXT bit has to be written before the end of the transmission/reception of the last data.*

*For high bit rate frequencies, it is advised to use the DMA mode to avoid the degradation of the SPI speed performance due to CPU accesses impacting the SPI bandwidth.*

*When the devices are configured as slaves and the NSS hardware mode is used, the NSS pin needs to be kept low between the data phase and the CRC phase.*

When the SPI is configured in slave mode with the CRC feature enabled, CRC calculation takes place even if a high level is applied on the NSS pin. This may happen for example in case of a multislave environment where the communication master addresses slaves alternately.

Between a slave deselection (high level on NSS) and a new slave selection (low level on NSS), the CRC value should be cleared on both master and slave sides in order to resynchronize the master and slave for their respective CRC calculation.

To clear the CRC, follow the procedure below:

1. Disable SPI (SPE = 0)
2. Clear the CRCEN bit
3. Set the CRCEN bit
4. Enable the SPI (SPE = 1)

### 20.3.7 Status flags

Four status flags are provided for the application to completely monitor the state of the SPI bus.

#### Tx buffer empty flag (TXE)

When it is set, this flag indicates that the Tx buffer is empty and the next data to be transmitted can be loaded into the buffer. The TXE flag is cleared when writing to the SPI\_DR register.

#### Rx buffer not empty (RXNE)

When set, this flag indicates that there are valid received data in the Rx buffer. It is cleared when SPI\_DR is read.

#### BSY flag

This BSY flag is set and cleared by hardware (writing to this flag has no effect). The BSY flag indicates the state of the communication layer of the SPI.

When BSY is set, it indicates that the SPI is busy communicating. There is one exception in master mode / bidirectional receive mode (MSTR=1 and BDM=1 and BDOE=0) where the BSY flag is kept low during reception.

The BSY flag is useful to detect the end of a transfer if the software wants to disable the SPI and enter Halt mode (or disable the peripheral clock). This avoids corrupting the last transfer. For this, the procedure described below must be strictly respected.

The BSY flag is also useful to avoid write collisions in a multimaster system.

The BSY flag is set when a transfer starts, with the exception of master mode / bidirectional receive mode (MSTR=1 and BDM=1 and BDOE=0).

It is cleared:

- when a transfer is finished (except in master mode if the communication is continuous)
- when the SPI is disabled
- when a master mode fault occurs (MODF=1)

When communication is not continuous, the BSY flag is low between each communication.

When communication is continuous:

- in master mode, the BSY flag is kept high during all the transfers
- in slave mode, the BSY flag goes low for one SPI clock cycle between each transfer

*Note:* Do not use the BSY flag to handle each data transmission or reception. It is better to use the TXE and RXNE flags instead.

### 20.3.8 Disabling the SPI

When a transfer is terminated, the application can stop the communication by disabling the SPI peripheral. This is done by clearing the SPE bit.

For some configurations, disabling the SPI and entering the Halt mode while a transfer is ongoing can cause the current transfer to be corrupted and/or the BSY flag might become unreliable.

To avoid any of those effects, it is recommended to respect the following procedure when disabling the SPI:

#### In master or slave full-duplex mode (BIDIMODE=0, RXONLY=0)

1. Wait until RXNE=1 to receive the last data
2. Wait until TXE=1
3. Then wait until BSY=0
4. Disable the SPI (SPE=0) and, eventually, enter the Halt mode (or disable the peripheral clock)

#### In master or slave unidirectional transmit-only mode (BIDIMODE=0, RXONLY=0) or bidirectional transmit mode (BIDIMODE=1, BIDIOE=1)

After the last data is written into the SPI\_DR register:

1. Wait until TXE=1
2. Then wait until BSY=0
3. Disable the SPI (SPE=0) and, eventually, enter the Halt mode (or disable the peripheral clock)

#### In master unidirectional receive-only mode (MSTR=1, BIDIMODE=0, RXONLY=1) or bidirectional receive mode (MSTR=1, BIDIMODE=1, BIDIOE=0)

This case must be managed in a particular way to ensure that the SPI does not initiate a new transfer. The sequence below is valid only for SPI Motorola configuration (FRF bit set to 0):

1. Wait for the second to last occurrence of RXNE=1 (n-1)
2. Then wait for one SPI clock cycle (using a software loop) before disabling the SPI (SPE=0)
3. Then wait for the last RXNE=1 before entering the Halt mode (or disabling the peripheral clock)

When the SPI is configured in TI mode (Bit FRF set to 1), the following procedure has to be respected to avoid generating an undesired pulse on NSS when the SPI is disabled:

1. Wait for the second to last occurrence of RXNE = 1 (n-1).
2. Disable the SPI (SPE = 0) in the following window frame using a software loop:
  - After at least one SPI clock cycle,
  - Before the beginning of the LSB data transfer.

*Note: In master bidirectional receive mode (MSTR=1 and BDM=1 and BDOE=0), the BSY flag is kept low during transfers.*

**In slave receive-only mode (MSTR=0, BIDIMODE=0, RXONLY=1) or bidirectional receive mode (MSTR=0, BIDIMODE=1, BDOE=0)**

1. You can disable the SPI (write SPE=1) at any time: the current transfer will complete before the SPI is effectively disabled
2. Then, if you want to enter the Halt mode, you must first wait until BSY = 0 before entering the Halt mode (or disabling the peripheral clock).

### 20.3.9 SPI communication using DMA (direct memory addressing)

To operate at its maximum speed, the SPI needs to be fed with the data for transmission and the data received on the Rx buffer should be read to avoid overrun. To facilitate the transfers, the SPI features a DMA capability implementing a simple request/acknowledge protocol.

A DMA access is requested when the enable bit in the SPI\_CR2 register is enabled. Separate requests must be issued to the Tx and Rx buffers (see [Figure 205](#) and [Figure 206](#)):

- In transmission, a DMA request is issued each time TXE is set to 1. The DMA then writes to the SPI\_DR register (this clears the TXE flag).
- In reception, a DMA request is issued each time RXNE is set to 1. The DMA then reads the SPI\_DR register (this clears the RXNE flag).

When the SPI is used only to transmit data, it is possible to enable only the SPI Tx DMA channel. In this case, the OVR flag is set because the data received are not read.

When the SPI is used only to receive data, it is possible to enable only the SPI Rx DMA channel.

In transmission mode, when the DMA has written all the data to be transmitted (flag TCIF is set in the DMA\_ISR register), the BSY flag can be monitored to ensure that the SPI communication is complete. This is required to avoid corrupting the last transmission before disabling the SPI or entering the Stop mode. The software must first wait until TXE=1 and then until BSY=0.

**Note:** *During discontinuous communications, there is a 2 APB clock period delay between the write operation to SPI\_DR and the BSY bit setting. As a consequence, it is mandatory to wait first until TXE=1 and then until BSY=0 after writing the last data.*

Figure 205. Transmission using DMA

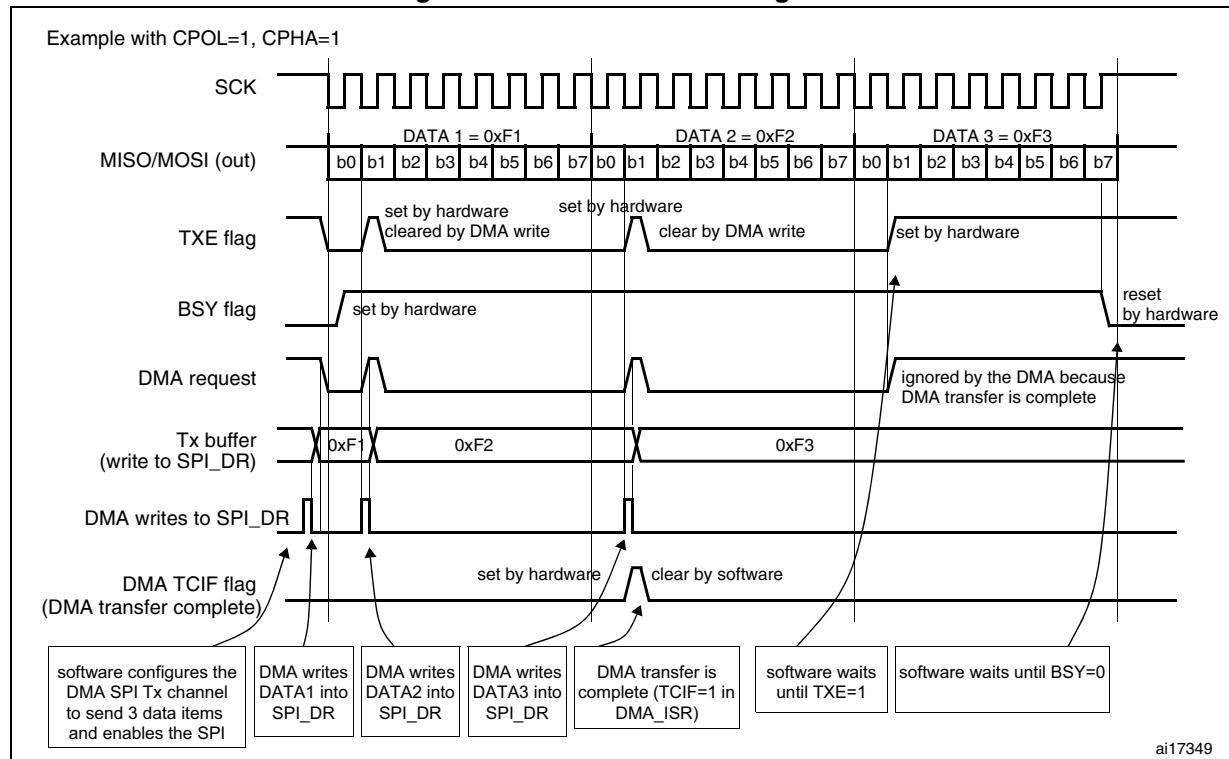
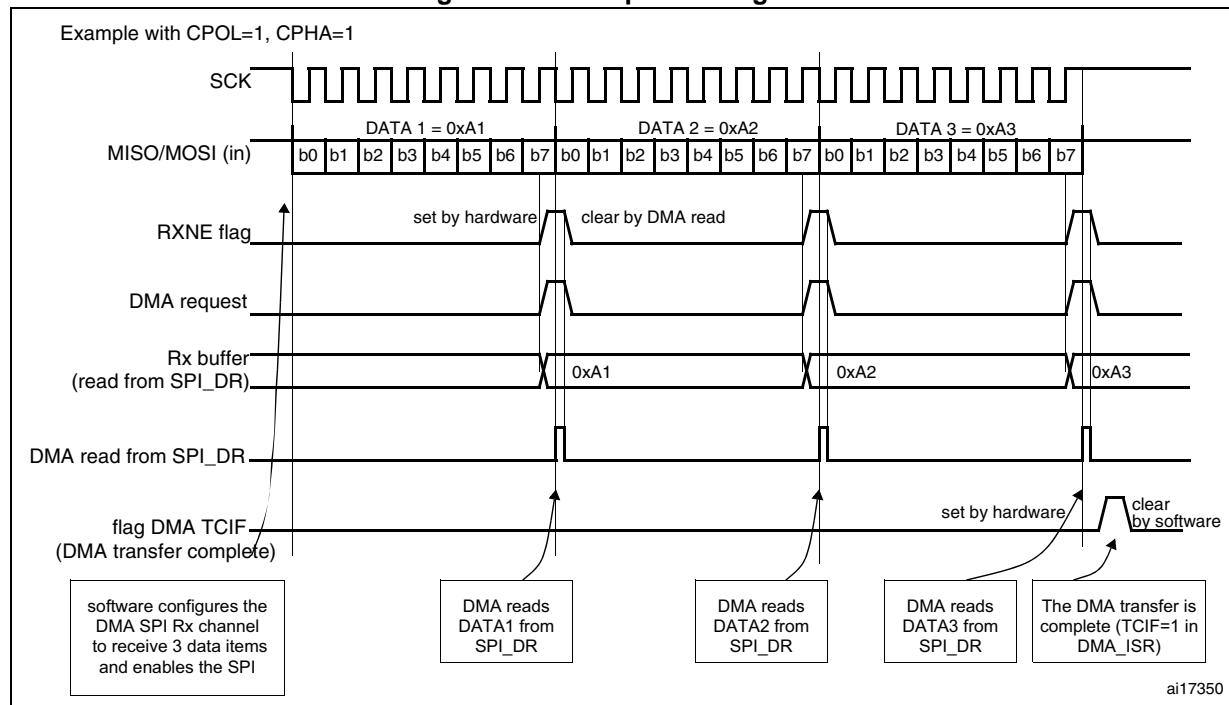


Figure 206. Reception using DMA



### DMA capability with CRC

When SPI communication is enabled with CRC communication and DMA mode, the transmission and reception of the CRC at the end of communication are automatic that is without using the bit CRCNEXT. After the CRC reception, the CRC must be read in the SPI\_DR register to clear the RXNE flag.

At the end of data and CRC transfers, the CRCERR flag in SPI\_SR is set if corruption occurs during the transfer.

## 20.3.10 Error flags

### Master mode fault (MODF)

Master mode fault occurs when the master device has its NSS pin pulled low (in NSS hardware mode) or SSI bit low (in NSS software mode), this automatically sets the MODF bit. Master mode fault affects the SPI peripheral in the following ways:

- The MODF bit is set and an SPI interrupt is generated if the ERRIE bit is set.
- The SPE bit is cleared. This blocks all output from the device and disables the SPI interface.
- The MSTR bit is cleared, thus forcing the device into slave mode.

Use the following software sequence to clear the MODF bit:

1. Make a read or write access to the SPI\_SR register while the MODF bit is set.
2. Then write to the SPI\_CR1 register.

To avoid any multiple slave conflicts in a system comprising several MCUs, the NSS pin must be pulled high during the MODF bit clearing sequence. The SPE and MSTR bits can be restored to their original state after this clearing sequence.

As a security, hardware does not allow the setting of the SPE and MSTR bits while the MODF bit is set.

In a slave device the MODF bit cannot be set. However, in a multimaster configuration, the device can be in slave mode with this MODF bit set. In this case, the MODF bit indicates that there might have been a multimaster conflict for system control. An interrupt routine can be used to recover cleanly from this state by performing a reset or returning to a default state.

### Overrun condition

An overrun condition occurs when the master device has sent data bytes and the slave device has not cleared the RXNE bit resulting from the previous data byte transmitted.

When an overrun condition occurs:

- the OVR bit is set and an interrupt is generated if the ERRIE bit is set.

In this case, the receiver buffer contents will not be updated with the newly received data from the master device. A read from the SPI\_DR register returns this byte. All other subsequently transmitted bytes are lost.

Clearing the OVR bit is done by a read from the SPI\_DR register followed by a read access to the SPI\_SR register.

### CRC error

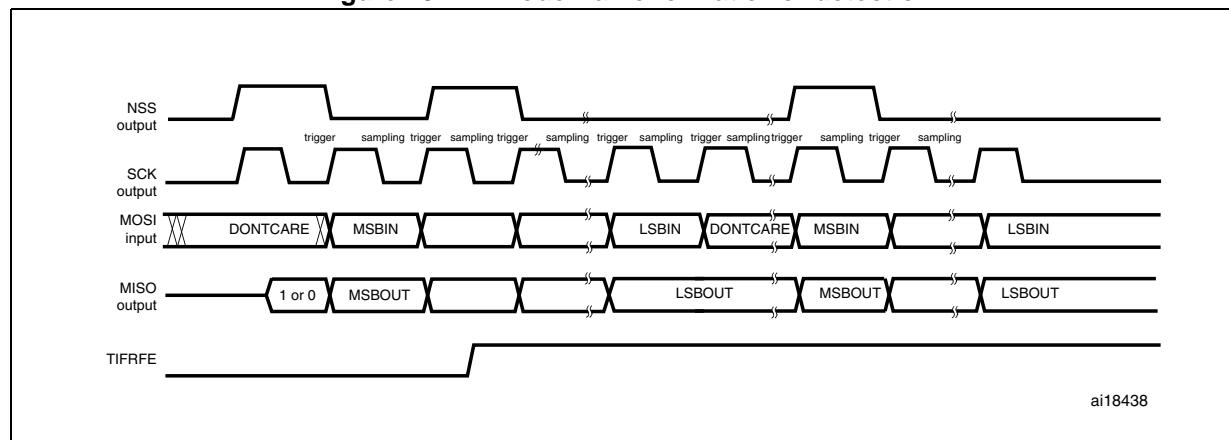
This flag is used to verify the validity of the value received when the CRCEN bit in the SPI\_CR1 register is set. The CRCERR flag in the SPI\_SR register is set if the value received in the shift register does not match the receiver SPI\_RXCRCR value.

### TI mode frame format error

A TI mode frame format error is detected when an NSS pulse occurs during an ongoing communication when the SPI is acting in slave mode and configured to conform to the TI mode protocol. When this error occurs, the FRE flag is set in the SPI\_SR register. The SPI is not disabled when an error occurs, the NSS pulse is ignored, and the SPI waits for the next NSS pulse before starting a new transfer. The data may be corrupted since the error detection may result in the lost of two data bytes.

The FRE flag is cleared when SPI\_SR register is read. If the bit ERRIE is set, an interrupt is generated on the NSS error detection. In this case, the SPI should be disabled because data consistency is no more guaranteed and communications should be reinitiated by the master when the slave SPI is re-enabled.

**Figure 207. TI mode frame format error detection**



### 20.3.11 SPI interrupts

**Table 89. SPI interrupt requests**

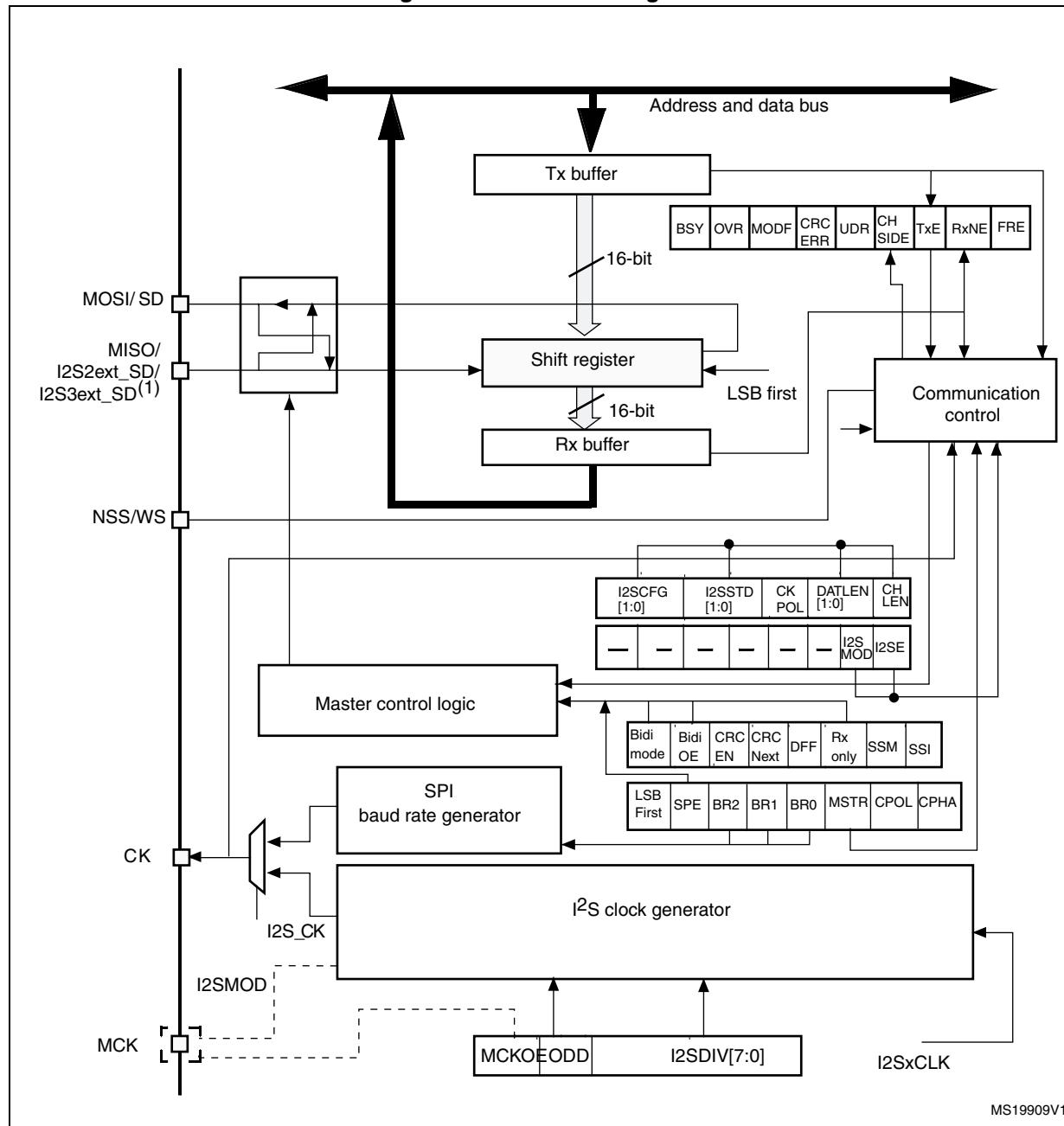
Interrupt event	Event flag	Enable Control bit
Transmit buffer empty flag	TXE	TXEIE
Receive buffer not empty flag	RXNE	RXNEIE
Master Mode fault event	MODF	ERRIE
Overrun error	OVR	
CRC error flag	CRCERR	
TI frame format error	FRE	ERRIE

## 20.4 I<sup>2</sup>S functional description

### 20.4.1 I<sup>2</sup>S general description

The block diagram of the I<sup>2</sup>S is shown in [Figure 208](#).

**Figure 208. I<sup>2</sup>S block diagram**



1. I<sup>2</sup>Sext\_SD and I<sup>2</sup>S3ext\_SD are the extended SD pins that control the I<sup>2</sup>S full duplex mode.

MS19909V1

The SPI could function as an audio I<sup>2</sup>S interface when the I<sup>2</sup>S capability is enabled (by setting the I2SMOD bit in the SPI\_I2SCFGR register). This interface uses almost the same pins, flags and interrupts as the SPI.

The I<sup>2</sup>S shares three common pins with the SPI:

- SD: Serial Data (mapped on the MOSI pin) to transmit or receive the two time-multiplexed data channels (in half-duplex mode only).
- WS: Word Select (mapped on the NSS pin) is the data control signal output in master mode and input in slave mode.
- CK: Serial Clock (mapped on the SCK pin) is the serial clock output in master mode and serial clock input in slave mode.
- I2S2ext\_SD and I2S3ext\_SD: additional pins (mapped on the MISO pin) to control the I<sup>2</sup>S full duplex mode.

An additional pin could be used when a master clock output is needed for some external audio devices:

- MCK: Master Clock (mapped separately) is used, when the I<sup>2</sup>S is configured in master mode (and when the MCKOE bit in the SPI\_I2SPR register is set), to output this additional clock generated at a preconfigured frequency rate equal to  $256 \times F_S$ , where  $F_S$  is the audio sampling frequency.

The I<sup>2</sup>S uses its own clock generator to produce the communication clock when it is set in master mode. This clock generator is also the source of the master clock output. Two additional registers are available in I<sup>2</sup>S mode. One is linked to the clock generator configuration SPI\_I2SPR and the other one is a generic I<sup>2</sup>S configuration register SPI\_I2SCFGR (audio standard, slave/master mode, data format, packet frame, clock polarity, etc.).

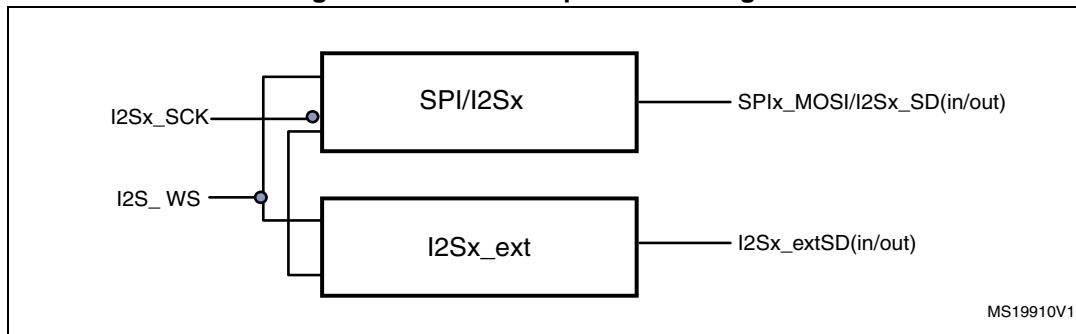
The SPI\_CR1 register and all CRC registers are not used in the I<sup>2</sup>S mode. Likewise, the SSOE bit in the SPI\_CR2 register and the MODF and CRCERR bits in the SPI\_SR are not used.

The I<sup>2</sup>S uses the same SPI register for data transfer (SPI\_DR) in 16-bit wide mode.

## 20.4.2 I<sup>2</sup>S full duplex

To support I<sup>2</sup>S full duplex mode, two extra I<sup>2</sup>S instances called extended I<sup>2</sup>Ss (I2S2\_ext, I2S3\_ext) are available in addition to I<sup>2</sup>S2 and I<sup>2</sup>S3 (see [Figure 209](#)). The first I<sup>2</sup>S full-duplex interface is consequently based on I<sup>2</sup>S2 and I<sup>2</sup>S2\_ext, and the second one on I<sup>2</sup>S3 and I<sup>2</sup>S3\_ext.

*Note: I2S2\_ext and I2S3\_ext are used only in full-duplex mode.*

**Figure 209. I<sup>2</sup>S full duplex block diagram**

1. Where x can be 2 or 3.

I2Sx can operate in master mode. As a result:

- Only I2Sx can output SCK and WS in half duplex mode
- Only I2Sx can deliver SCK and WS to I2S2\_ext and I2S3\_ext in full duplex mode.

The extended I2Ss (I2Sx\_ext) can be used only in full duplex mode. The I2Sx\_ext operate always in slave mode.

Both I2Sx and I2Sx\_ext can be configured as transmitters or receivers.

#### 20.4.3 Supported audio protocols

The four-line bus has to handle only audio data generally time-multiplexed on two channels: the right channel and the left channel. However there is only one 16-bit register for the transmission and the reception. So, it is up to the software to write into the data register the adequate value corresponding to the considered channel side, or to read the data from the data register and to identify the corresponding channel by checking the CHSIDE bit in the SPI\_SR register. Channel Left is always sent first followed by the channel right (CHSIDE has no meaning for the PCM protocol).

Four data and packet frames are available. Data may be sent with a format of:

- 16-bit data packed in 16-bit frame
- 16-bit data packed in 32-bit frame
- 24-bit data packed in 32-bit frame
- 32-bit data packed in 32-bit frame

When using 16-bit data extended on 32-bit packet, the first 16 bits (MSB) are the significant bits, the 16-bit LSB is forced to 0 without any need for software action or DMA request (only one read/write operation).

The 24-bit and 32-bit data frames need two CPU read or write operations to/from the SPI\_DR or two DMA operations if the DMA is preferred for the application. For 24-bit data frame specifically, the 8 nonsignificant bits are extended to 32 bits with 0-bits (by hardware).

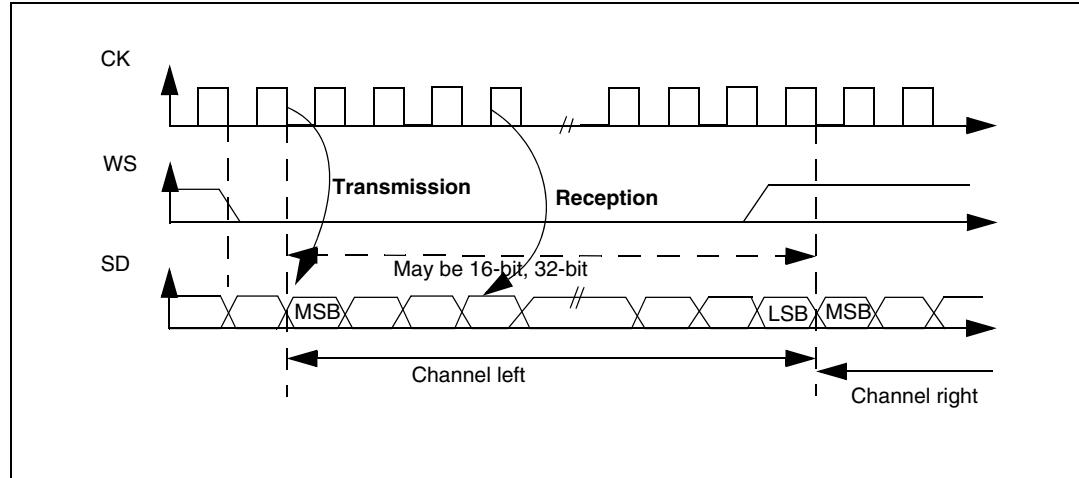
For all data formats and communication standards, the most significant bit is always sent first (MSB first).

The I<sup>2</sup>S interface supports four audio standards, configurable using the I2SSSTD[1:0] and PCMSYNC bits in the SPI\_I2SCFGR register.

## I<sup>2</sup>S Philips standard

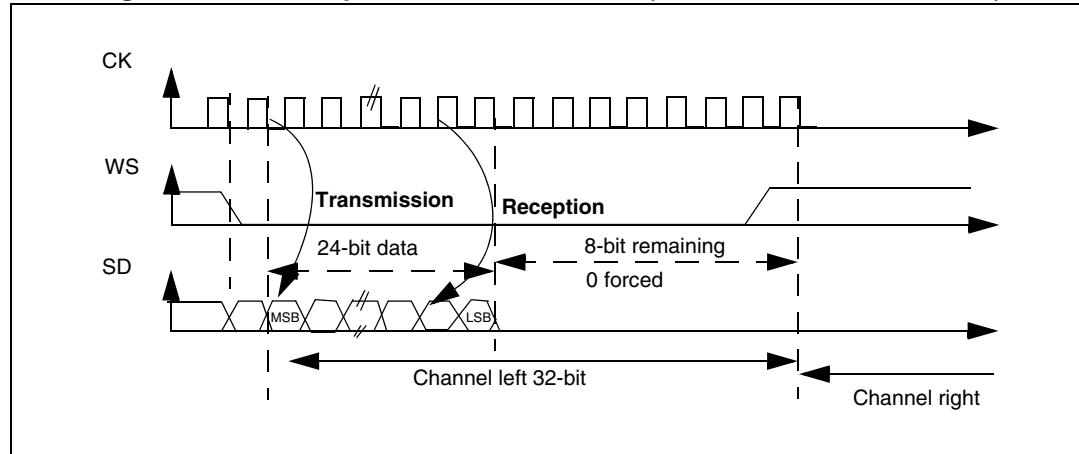
For this standard, the WS signal is used to indicate which channel is being transmitted. It is activated one CK clock cycle before the first bit (MSB) is available.

**Figure 210. I<sup>2</sup>S Philips protocol waveforms (16/32-bit full accuracy, CPOL = 0)**



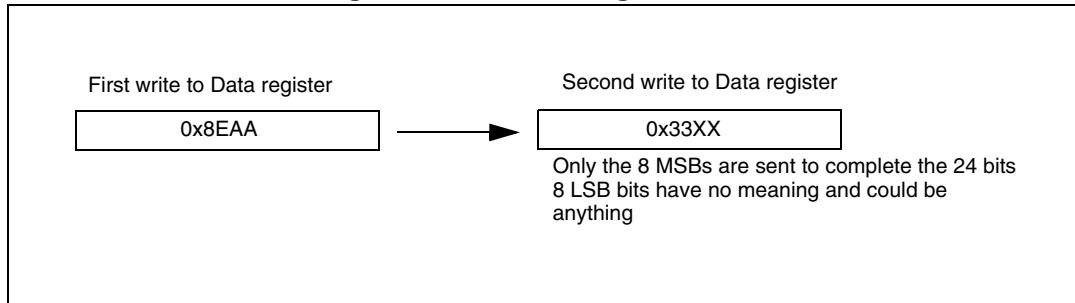
Data are latched on the falling edge of CK (for the transmitter) and are read on the rising edge (for the receiver). The WS signal is also latched on the falling edge of CK.

**Figure 211. I<sup>2</sup>S Philips standard waveforms (24-bit frame with CPOL = 0)**

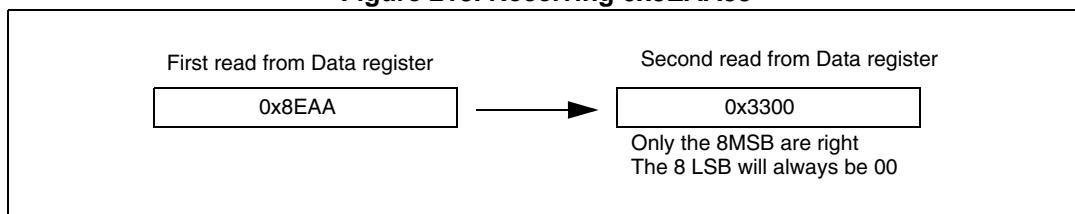
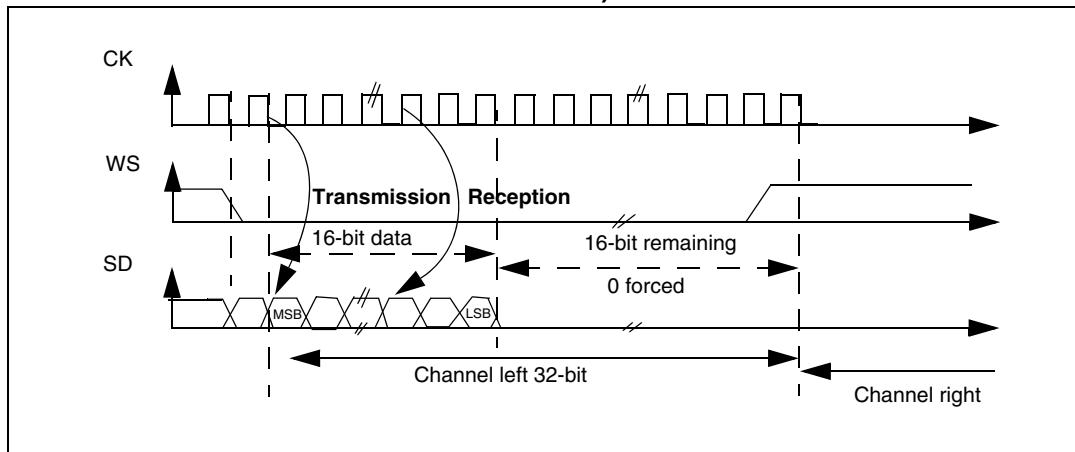


This mode needs two write or read operations to/from the SPI\_DR.

- In transmission mode:  
if 0x8EAA33 has to be sent (24-bit):

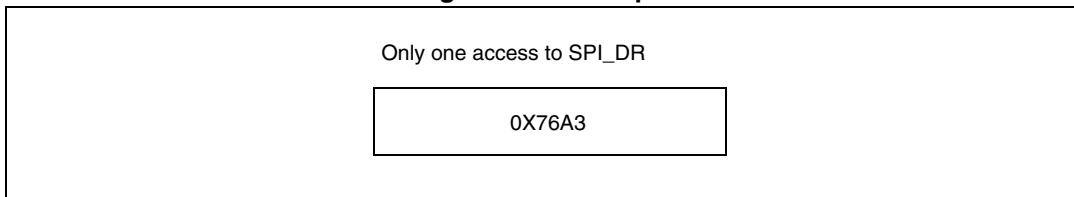
**Figure 212. Transmitting 0x8EAA33**

- In reception mode:  
if data 0x8EAA33 is received:

**Figure 213. Receiving 0x8EAA33****Figure 214. I<sup>2</sup>S Philips standard (16-bit extended to 32-bit packet frame with CPOL = 0)**

When 16-bit data frame extended to 32-bit channel frame is selected during the I<sup>2</sup>S configuration phase, only one access to SPI\_DR is required. The 16 remaining bits are forced by hardware to 0x0000 to extend the data to 32-bit format.

If the data to transmit or the received data are 0x76A3 (0x76A30000 extended to 32-bit), the operation shown in [Figure 215](#) is required.

**Figure 215. Example**

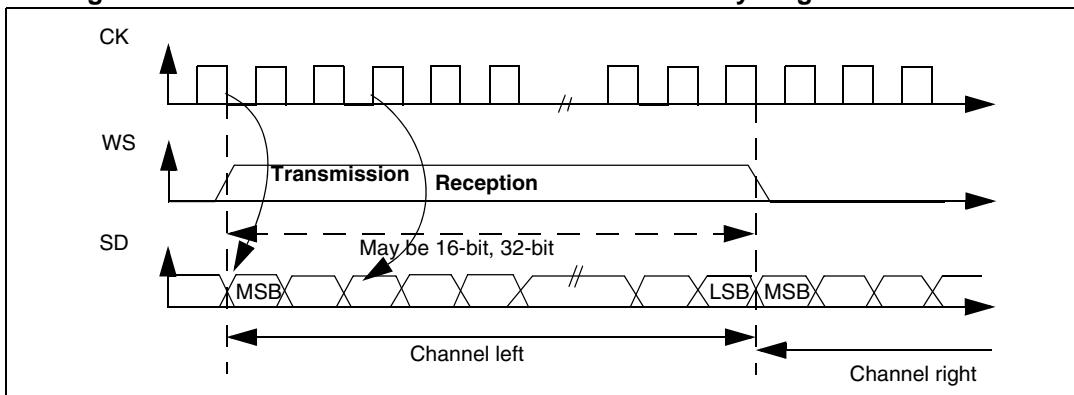
For transmission, each time an MSB is written to SPI\_DR, the TXE flag is set and its interrupt, if allowed, is generated to load SPI\_DR with the new value to send. This takes place even if 0x0000 have not yet been sent because it is done by hardware.

For reception, the RXNE flag is set and its interrupt, if allowed, is generated when the first 16 MSB half-word is received.

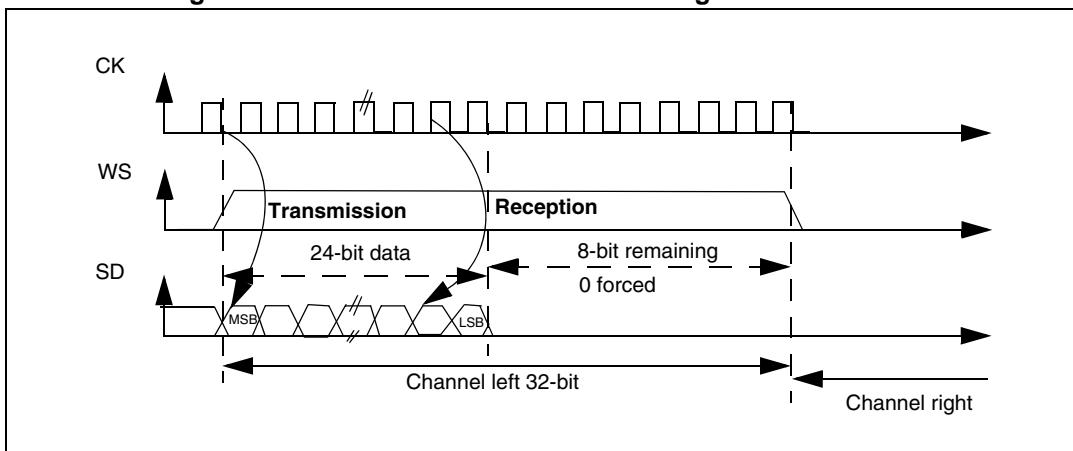
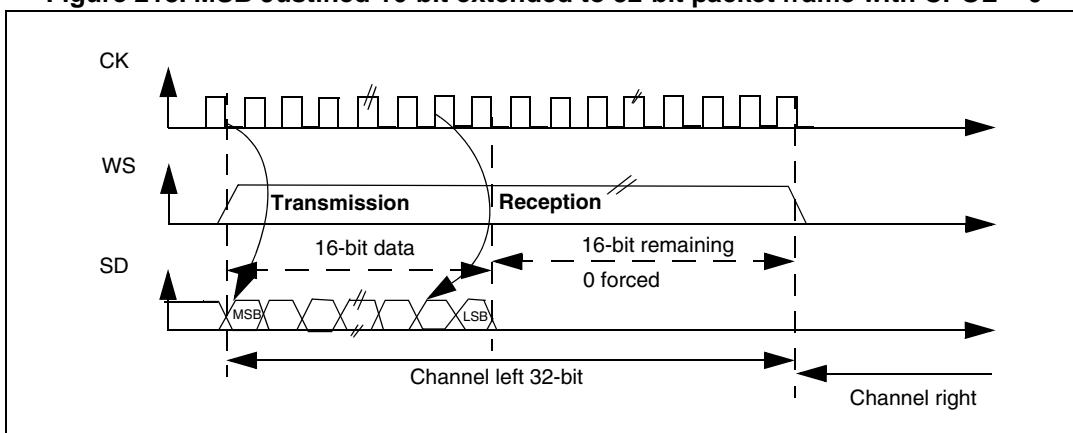
In this way, more time is provided between two write or read operations, which prevents underrun or overrun conditions (depending on the direction of the data transfer).

### MSB justified standard

For this standard, the WS signal is generated at the same time as the first data bit, which is the MSBit.

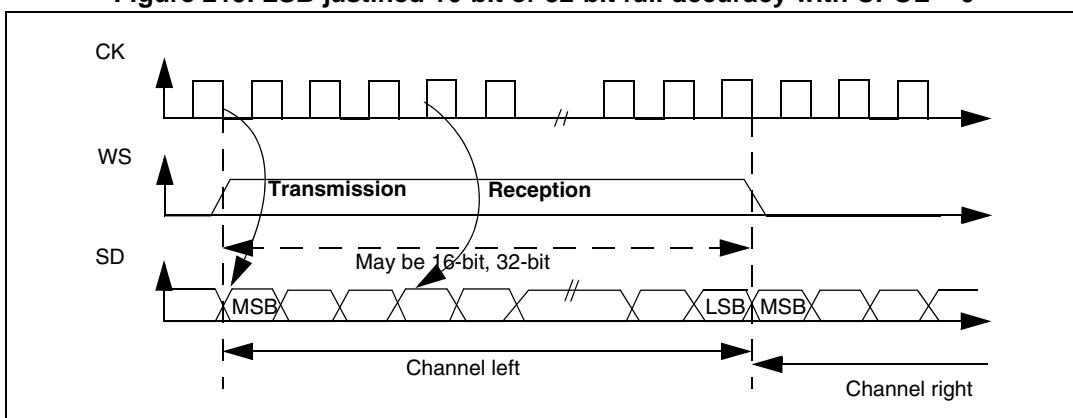
**Figure 216. MSB Justified 16-bit or 32-bit full-accuracy length with CPOL = 0**

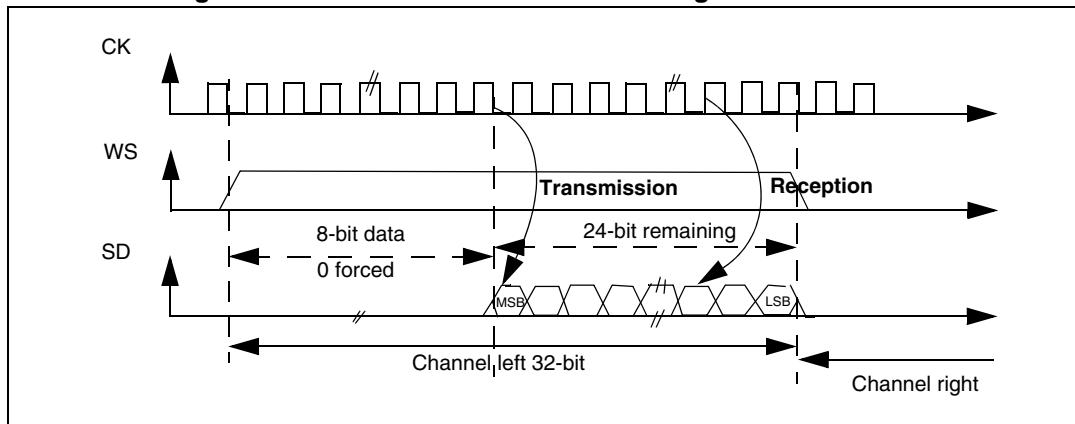
Data are latched on the falling edge of CK (for transmitter) and are read on the rising edge (for the receiver).

**Figure 217. MSB Justified 24-bit frame length with CPOL = 0****Figure 218. MSB Justified 16-bit extended to 32-bit packet frame with CPOL = 0**

### LSB justified standard

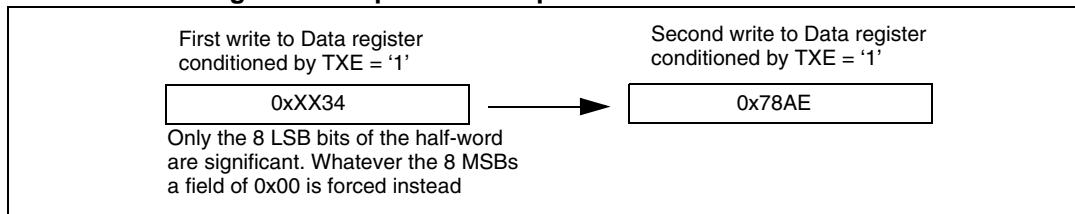
This standard is similar to the MSB justified standard (no difference for the 16-bit and 32-bit full-accuracy frame formats).

**Figure 219. LSB justified 16-bit or 32-bit full-accuracy with CPOL = 0**

**Figure 220. LSB Justified 24-bit frame length with CPOL = 0**

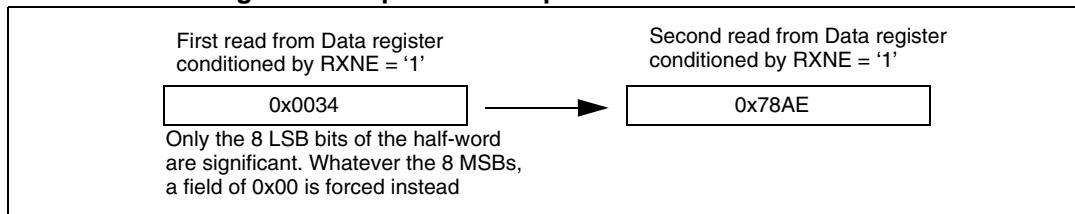
- In transmission mode:

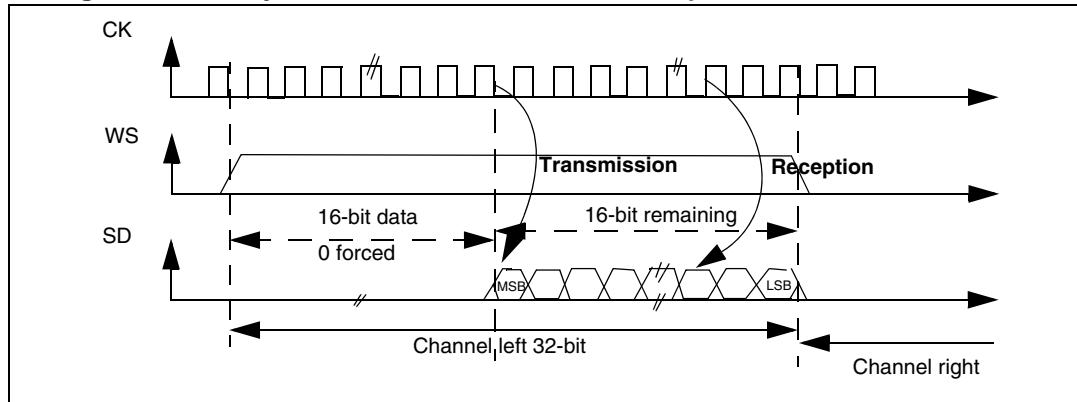
If data 0x3478AE have to be transmitted, two write operations to the SPI\_DR register are required from software or by DMA. The operations are shown below.

**Figure 221. Operations required to transmit 0x3478AE**

- In reception mode:

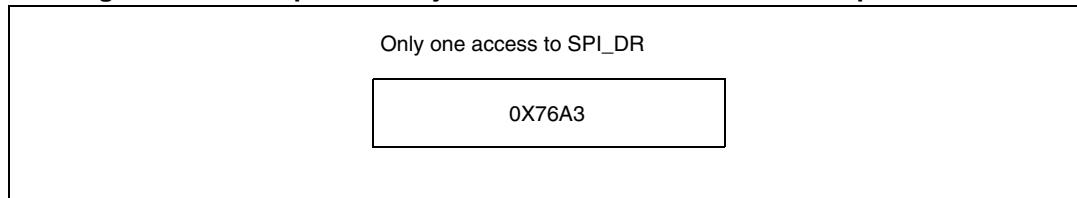
If data 0x3478AE are received, two successive read operations from SPI\_DR are required on each RXNE event.

**Figure 222. Operations required to receive 0x3478AE**

**Figure 223. LSB justified 16-bit extended to 32-bit packet frame with CPOL = 0**

When 16-bit data frame extended to 32-bit channel frame is selected during the I<sup>2</sup>S configuration phase, Only one access to SPI\_DR is required. The 16 remaining bits are forced by hardware to 0x0000 to extend the data to 32-bit format. In this case it corresponds to the half-word MSB.

If the data to transmit or the received data are 0x76A3 (0x0000 76A3 extended to 32-bit), the operation shown in [Figure 224](#) is required.

**Figure 224. Example of LSB justified 16-bit extended to 32-bit packet frame**

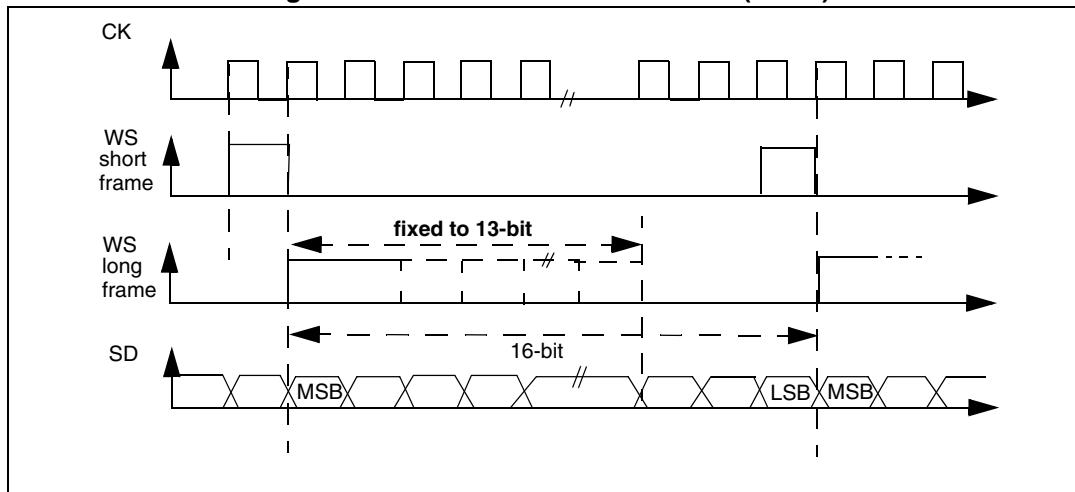
In transmission mode, when TXE is asserted, the application has to write the data to be transmitted (in this case 0x76A3). The 0x000 field is transmitted first (extension on 32-bit). TXE is asserted again as soon as the effective data (0x76A3) is sent on SD.

In reception mode, RXNE is asserted as soon as the significant half-word is received (and not the 0x0000 field).

In this way, more time is provided between two write or read operations to prevent underrun or overrun conditions.

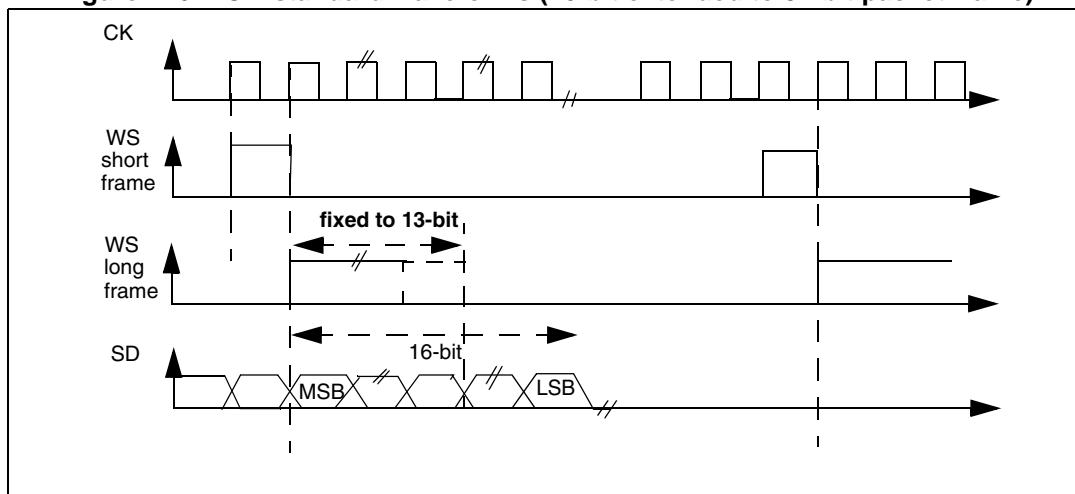
### PCM standard

For the PCM standard, there is no need to use channel-side information. The two PCM modes (short and long frame) are available and configurable using the PCMSYNC bit in SPI\_I2SCFGR.

**Figure 225. PCM standard waveforms (16-bit)**

For long frame synchronization, the WS signal assertion time is fixed 13 bits in master mode.

For short frame synchronization, the WS synchronization signal is only one cycle long.

**Figure 226. PCM standard waveforms (16-bit extended to 32-bit packet frame)**

**Note:** For both modes (master and slave) and for both synchronizations (short and long), the number of bits between two consecutive pieces of data (and so two synchronization signals) needs to be specified (DATLEN and CHLEN bits in the SPI\_I2SCFGR register) even in slave mode.

#### 20.4.4 Clock generator

The I<sup>2</sup>S bitrate determines the dataflow on the I<sup>2</sup>S data line and the I<sup>2</sup>S clock signal frequency.

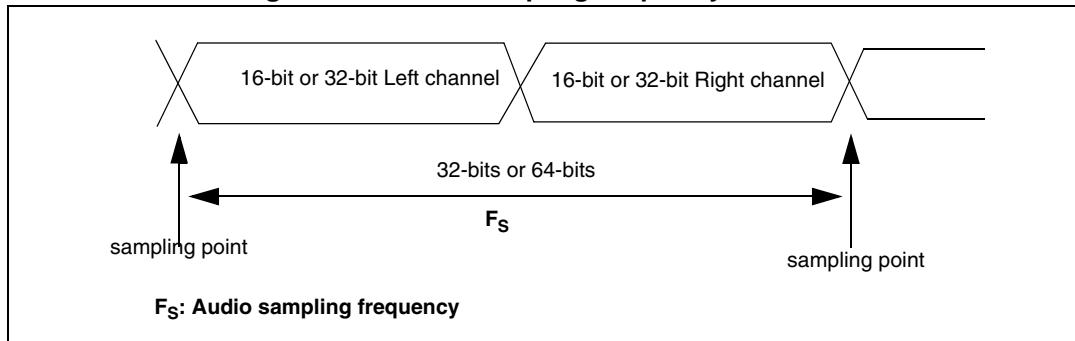
I<sup>2</sup>S bitrate = number of bits per channel × number of channels × sampling audio frequency

For a 16-bit audio, left and right channel, the I<sup>2</sup>S bitrate is calculated as follows:

$$\text{I}^2\text{S bitrate} = 16 \times 2 \times F_S$$

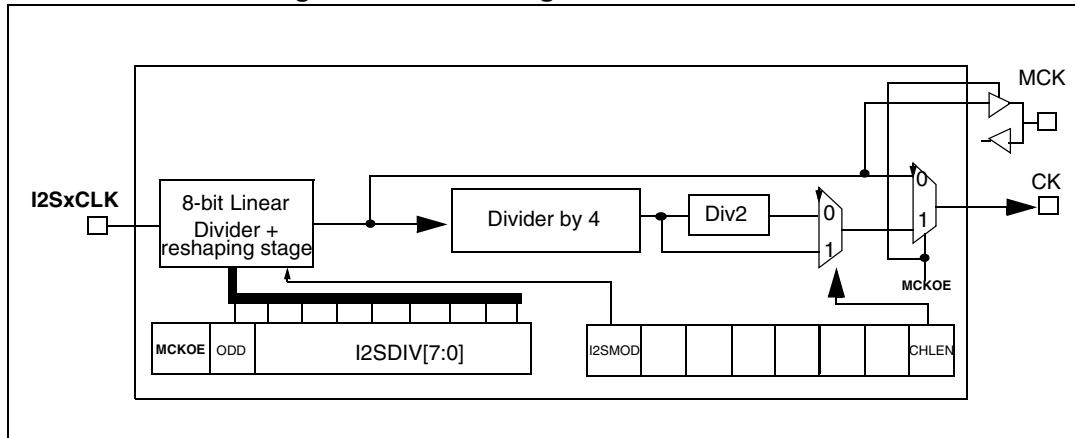
It will be:  $I^2S$  bitrate =  $32 \times 2 \times F_S$  if the packet length is 32-bit wide.

**Figure 227. Audio sampling frequency definition**



When the master mode is configured, a specific action needs to be taken to properly program the linear divider in order to communicate with the desired audio frequency.

**Figure 228. I<sup>2</sup>S clock generator architecture**



1. Where x could be 2 or 3.

*Figure 227* presents the communication clock architecture. To achieve high-quality audio performance, the I2SxCLK clock source can be either the PLLI2S output (through R division factor) or an external clock (mapped to I2S\_CKIN pin).

The audio sampling frequency can be 192 kHz, 96 kHz, or 48 kHz. In order to reach the desired frequency, the linear divider needs to be programmed according to the formulas below:

When the master clock is generated (MCKOE in the SPI\_I2SPR register is set):

$$F_S = I2SxCLK / [(16*2)*((2*I2SDIV)+ODD)*8] \text{ when the channel frame is 16-bit wide}$$

$$F_S = I2SxCLK / [(32*2)*((2*I2SDIV)+ODD)*4] \text{ when the channel frame is 32-bit wide}$$

When the master clock is disabled (MCKOE bit cleared):

$$F_S = I2SxCLK / [(16*2)*((2*I2SDIV)+ODD)] \text{ when the channel frame is 16-bit wide}$$

$$F_S = I2SxCLK / [(32*2)*((2*I2SDIV)+ODD)] \text{ when the channel frame is 32-bit wide}$$

*Table 90* provides example precision values for different clock configurations.

Note:

*Other configurations are possible that allow optimum clock precision.*

**Table 90. Audio frequency precision (for PLLM VCO = 1 MHz or 2 MHz)<sup>(1)</sup>**

Master clock	Target $f_S$ (Hz)	Data format	PLL12SN	PLL12SR	I2SDIV	I2SODD	Real $f_S$ (Hz)	Error
Disabled	8000	16-bit	192	2	187	1	8000	0.0000%
		32-bit	192	3	62	1	8000	0.0000%
	16000	16-bit	192	3	62	1	16000	0.0000%
		32-bit	256	2	62	1	16000	0.0000%
	32000	16-bit	256	2	62	1	32000	0.0000%
		32-bit	256	5	12	1	32000	0.0000%
	48000	16-bit	192	5	12	1	48000	0.0000%
		32-bit	384	5	12	1	48000	0.0000%
	96000	16-bit	384	5	12	1	96000	0.0000%
		32-bit	424	3	11	1	96014.49219	0.0151%
	22050	16-bit	290	3	68	1	22049.87695	0.0006%
		32-bit	302	2	53	1	22050.23438	0.0011%
	44100	16-bit	302	2	53	1	44100.46875	0.0011%
		32-bit	429	4	19	0	44099.50781	0.0011%
	192000	16-bit	424	3	11	1	192028.9844	0.0151%
		32-bit	258	3	3	1	191964.2813	0.0186%
Enabled	8000	don't care	256	5	12	1	8000	0.0000%
	16000	don't care	213	2	13	0	16000.60059	0.0038%
	32000	don't care	213	2	6	1	32001.20117	0.0038%
	48000	don't care	258	3	3	1	47991.07031	0.0186%
	96000	don't care	344	2	3	1	95982.14063	0.0186%
	22050	don't care	429	4	9	1	22049.75391	0.0011%
	44100	don't care	271	2	6	0	44108.07422	0.0183%

1. This table gives only example values for different clock configurations. Other configurations allowing optimum clock precision are possible.

#### 20.4.5 I<sup>2</sup>S master mode

The I<sup>2</sup>S can be configured as follows:

- In master mode for transmission or reception (half-duplex mode using I2Sx)
- In master mode transmission and reception (full duplex mode using I2Sx and I2Sx\_ext).

This means that the serial clock is generated on the CK pin as well as the Word Select signal WS. Master clock (MCK) may be output or not, thanks to the MCKOE bit in the SPI\_I2SPR register.

## Procedure

1. Select the I2SDIV[7:0] bits in the SPI\_I2SPR register to define the serial clock baud rate to reach the proper audio sample frequency. The ODD bit in the SPI\_I2SPR register also has to be defined.
2. Select the CKPOL bit to define the steady level for the communication clock. Set the MCKOE bit in the SPI\_I2SPR register if the master clock MCK needs to be provided to the external DAC/ADC audio component (the I2SDIV and ODD values should be computed depending on the state of the MCK output, for more details refer to [Section 20.4.4: Clock generator](#)).
3. Set the I2SMOD bit in SPI\_I2SCFGR to activate the I<sup>2</sup>S functionalities and choose the I<sup>2</sup>S standard through the I2SSTD[1:0] and PCMSYNC bits, the data length through the DATLEN[1:0] bits and the number of bits per channel by configuring the CHLEN bit. Select also the I<sup>2</sup>S master mode and direction (Transmitter or Receiver) through the I2SCFG[1:0] bits in the SPI\_I2SCFGR register.
4. If needed, select all the potential interruption sources and the DMA capabilities by writing the SPI\_CR2 register.
5. The I2SE bit in SPI\_I2SCFGR register must be set.

WS and CK are configured in output mode. MCK is also an output, if the MCKOE bit in SPI\_I2SPR is set.

## Transmission sequence

The transmission sequence begins when a half-word is written into the Tx buffer.

Assumedly, the first data written into the Tx buffer correspond to the channel Left data. When data are transferred from the Tx buffer to the shift register, TXE is set and data corresponding to the channel Right have to be written into the Tx buffer. The CHSIDE flag indicates which channel is to be transmitted. It has a meaning when the TXE flag is set because the CHSIDE flag is updated when TXE goes high.

A full frame has to be considered as a Left channel data transmission followed by a Right channel data transmission. It is not possible to have a partial frame where only the left channel is sent.

The data half-word is parallel loaded into the 16-bit shift register during the first bit transmission, and then shifted out, serially, to the MOSI/SD pin, MSB first. The TXE flag is set after each transfer from the Tx buffer to the shift register and an interrupt is generated if the TXEIE bit in the SPI\_CR2 register is set.

For more details about the write operations depending on the I<sup>2</sup>S standard mode selected, refer to [Section 20.4.3: Supported audio protocols](#)).

To ensure a continuous audio data transmission, it is mandatory to write the SPI\_DR with the next data to transmit before the end of the current transmission.

To switch off the I<sup>2</sup>S, by clearing I2SE, it is mandatory to wait for TXE = 1 and BSY = 0.

## Reception sequence

The operating mode is the same as for the transmission mode except for the point 3 (refer to the procedure described in [Section 20.4.5: I2S master mode](#)), where the configuration should set the master reception mode through the I2SCFG[1:0] bits.

Whatever the data or channel length, the audio data are received by 16-bit packets. This means that each time the Rx buffer is full, the RXNE flag is set and an interrupt is generated

if the RXNEIE bit is set in SPI\_CR2 register. Depending on the data and channel length configuration, the audio value received for a right or left channel may result from one or two receptions into the Rx buffer.

Clearing the RXNE bit is performed by reading the SPI\_DR register.

CHSIDE is updated after each reception. It is sensitive to the WS signal generated by the I<sup>2</sup>S cell.

For more details about the read operations depending on the I<sup>2</sup>S standard mode selected, refer to [Section 20.4.3: Supported audio protocols](#).

If data are received while the previously received data have not been read yet, an overrun is generated and the OVR flag is set. If the ERRIE bit is set in the SPI\_CR2 register, an interrupt is generated to indicate the error.

To switch off the I<sup>2</sup>S, specific actions are required to ensure that the I<sup>2</sup>S completes the transfer cycle properly without initiating a new data transfer. The sequence depends on the configuration of the data and channel lengths, and on the audio protocol mode selected. In the case of:

- 16-bit data length extended on 32-bit channel length (DATLEN = 00 and CHLEN = 1) using the LSB justified mode (I2SSTD = 10)
  - a) Wait for the second to last RXNE = 1 ( $n - 1$ )
  - b) Then wait 17 I<sup>2</sup>S clock cycles (using a software loop)
  - c) Disable the I<sup>2</sup>S (I2SE = 0)
- 16-bit data length extended on 32-bit channel length (DATLEN = 00 and CHLEN = 1) in MSB justified, I<sup>2</sup>S or PCM modes (I2SSTD = 00, I2SSTD = 01 or I2SSTD = 11, respectively)
  - a) Wait for the last RXNE
  - b) Then wait 1 I<sup>2</sup>S clock cycle (using a software loop)
  - c) Disable the I<sup>2</sup>S (I2SE = 0)
- For all other combinations of DATLEN and CHLEN, whatever the audio mode selected through the I2SSTD bits, carry out the following sequence to switch off the I<sup>2</sup>S:
  - a) Wait for the second to last RXNE = 1 ( $n - 1$ )
  - b) Then wait one I<sup>2</sup>S clock cycle (using a software loop)
  - c) Disable the I<sup>2</sup>S (I2SE = 0)

*Note:* The BSY flag is kept low during transfers.

## 20.4.6 I<sup>2</sup>S slave mode

The I<sup>2</sup>S can be configured as follows:

- In slave mode for transmission or reception (half-duplex mode using I2Sx)
- In slave mode transmission and reception (full duplex mode using I2Sx and I2Sx\_ext).

The operating mode is following mainly the same rules as described for the I<sup>2</sup>S master configuration. In slave mode, there is no clock to be generated by the I<sup>2</sup>S interface. The clock and WS signals are input from the external master connected to the I<sup>2</sup>S interface. There is then no need, for the user, to configure the clock.

The configuration steps to follow are listed below:

1. Set the I2SMOD bit in the SPI\_I2SCFGR register to reach the I<sup>2</sup>S functionalities and choose the I<sup>2</sup>S standard through the I2SSTD[1:0] bits, the data length through the DATLEN[1:0] bits and the number of bits per channel for the frame configuring the CHLEN bit. Select also the mode (transmission or reception) for the slave through the I2SCFG[1:0] bits in SPI\_I2SCFGR register.
2. If needed, select all the potential interrupt sources and the DMA capabilities by writing the SPI\_CR2 register.
3. The I2SE bit in SPI\_I2SCFGR register must be set.

### Transmission sequence

The transmission sequence begins when the external master device sends the clock and when the NSS\_WS signal requests the transfer of data. The slave has to be enabled before the external master starts the communication. The I<sup>2</sup>S data register has to be loaded before the master initiates the communication.

For the I<sup>2</sup>S, MSB justified and LSB justified modes, the first data item to be written into the data register corresponds to the data for the left channel. When the communication starts, the data are transferred from the Tx buffer to the shift register. The TXE flag is then set in order to request the right channel data to be written into the I<sup>2</sup>S data register.

The CHSIDE flag indicates which channel is to be transmitted. Compared to the master transmission mode, in slave mode, CHSIDE is sensitive to the WS signal coming from the external master. This means that the slave needs to be ready to transmit the first data before the clock is generated by the master. WS assertion corresponds to left channel transmitted first.

**Note:** *The I2SE has to be written at least two PCLK cycles before the first clock of the master comes on the CK line.*

The data half-word is parallel-loaded into the 16-bit shift register (from the internal bus) during the first bit transmission, and then shifted out serially to the MOSI/SD pin MSB first. The TXE flag is set after each transfer from the Tx buffer to the shift register and an interrupt is generated if the TXEIE bit in the SPI\_CR2 register is set.

Note that the TXE flag should be checked to be at 1 before attempting to write the Tx buffer.

For more details about the write operations depending on the I<sup>2</sup>S standard mode selected, refer to [Section 20.4.3: Supported audio protocols](#).

To secure a continuous audio data transmission, it is mandatory to write the SPI\_DR register with the next data to transmit before the end of the current transmission. An underrun flag is set and an interrupt may be generated if the data are not written into the SPI\_DR register before the first clock edge of the next data communication. This indicates to the software that the transferred data are wrong. If the ERRIE bit is set into the SPI\_CR2 register, an interrupt is generated when the UDR flag in the SPI\_SR register goes high. In this case, it is mandatory to switch off the I<sup>2</sup>S and to restart a data transfer starting from the left channel.

To switch off the I<sup>2</sup>S, by clearing the I2SE bit, it is mandatory to wait for TXE = 1 and BSY = 0.

### Reception sequence

The operating mode is the same as for the transmission mode except for the point 1 (refer to the procedure described in [Section 20.4.6: I2S slave mode](#)), where the configuration should set the master reception mode using the I2SCFG[1:0] bits in the SPI\_I2SCFGR register.

Whatever the data length or the channel length, the audio data are received by 16-bit packets. This means that each time the RX buffer is full, the RXNE flag in the SPI\_SR register is set and an interrupt is generated if the RXNEIE bit is set in the SPI\_CR2 register. Depending on the data length and channel length configuration, the audio value received for a right or left channel may result from one or two receptions into the RX buffer.

The CHSIDE flag is updated each time data are received to be read from SPI\_DR. It is sensitive to the external WS line managed by the external master component.

Clearing the RXNE bit is performed by reading the SPI\_DR register.

For more details about the read operations depending the I<sup>2</sup>S standard mode selected, refer to [Section 20.4.3: Supported audio protocols](#).

If data are received while the precedent received data have not yet been read, an overrun is generated and the OVR flag is set. If the bit ERRIE is set in the SPI\_CR2 register, an interrupt is generated to indicate the error.

To switch off the I<sup>2</sup>S in reception mode, I2SE has to be cleared immediately after receiving the last RXNE = 1.

**Note:** *The external master components should have the capability of sending/receiving data in 16-bit or 32-bit packets via an audio channel.*

## 20.4.7 Status flags

Three status flags are provided for the application to fully monitor the state of the I<sup>2</sup>S bus.

### Busy flag (BSY)

The BSY flag is set and cleared by hardware (writing to this flag has no effect). It indicates the state of the communication layer of the I<sup>2</sup>S.

When BSY is set, it indicates that the I<sup>2</sup>S is busy communicating. There is one exception in master receive mode (I2SCFG = 11) where the BSY flag is kept low during reception.

The BSY flag is useful to detect the end of a transfer if the software needs to disable the I<sup>2</sup>S. This avoids corrupting the last transfer. For this, the procedure described below must be strictly respected.

The BSY flag is set when a transfer starts, except when the I<sup>2</sup>S is in master receiver mode.

The BSY flag is cleared:

- when a transfer completes (except in master transmit mode, in which the communication is supposed to be continuous)
- when the I<sup>2</sup>S is disabled

When communication is continuous:

- In master transmit mode, the BSY flag is kept high during all the transfers
- In slave mode, the BSY flag goes low for one I<sup>2</sup>S clock cycle between each transfer

**Note:** *Do not use the BSY flag to handle each data transmission or reception. It is better to use the TXE and RXNE flags instead.*

### Tx buffer empty flag (TXE)

When set, this flag indicates that the Tx buffer is empty and the next data to be transmitted can then be loaded into it. The TXE flag is reset when the Tx buffer already contains data to be transmitted. It is also reset when the I<sup>2</sup>S is disabled (I<sup>2</sup>SE bit is reset).

### RX buffer not empty (RXNE)

When set, this flag indicates that there are valid received data in the RX Buffer. It is reset when SPI\_DR register is read.

### Channel Side flag (CHSIDE)

In transmission mode, this flag is refreshed when TXE goes high. It indicates the channel side to which the data to transfer on SD has to belong. In case of an underrun error event in slave transmission mode, this flag is not reliable and I<sup>2</sup>S needs to be switched off and switched on before resuming the communication.

In reception mode, this flag is refreshed when data are received into SPI\_DR. It indicates from which channel side data have been received. Note that in case of error (like OVR) this flag becomes meaningless and the I<sup>2</sup>S should be reset by disabling and then enabling it (with configuration if it needs changing).

This flag has no meaning in the PCM standard (for both Short and Long frame modes).

When the OVR or UDR flag in the SPI\_SR is set and the ERRIE bit in SPI\_CR2 is also set, an interrupt is generated. This interrupt can be cleared by reading the SPI\_SR status register (once the interrupt source has been cleared).

## 20.4.8 Error flags

There are three error flags for the I<sup>2</sup>S cell.

### Underrun flag (UDR)

In slave transmission mode this flag is set when the first clock for data transmission appears while the software has not yet loaded any value into SPI\_DR. It is available when the I2SMOD bit in SPI\_I2SCFGR is set. An interrupt may be generated if the ERRIE bit in SPI\_CR2 is set.

The UDR bit is cleared by a read operation on the SPI\_SR register.

### Overrun flag (OVR)

This flag is set when data are received and the previous data have not yet been read from SPI\_DR. As a result, the incoming data are lost. An interrupt may be generated if the ERRIE bit is set in SPI\_CR2.

In this case, the receive buffer contents are not updated with the newly received data from the transmitter device. A read operation to the SPI\_DR register returns the previous correctly received data. All other subsequently transmitted half-words are lost.

Clearing the OVR bit is done by a read operation on the SPI\_DR register followed by a read access to the SPI\_SR register.

### Frame error flag (FRE)

This flag can be set by hardware only if the I<sup>2</sup>S is configured in Slave mode. It is set if the external master is changing the WS line at a moment when the slave is not expected this

change. If the synchronization is lost, to recover from this state and resynchronize the external master device with the I<sup>2</sup>S slave device, follow the steps below:

1. Disable the I<sup>2</sup>S
2. Re-enable it when the correct level is detected on the WS line (WS line is high in I<sup>2</sup>S mode, or low for MSB- or LSB-justified or PCM modes).

Desynchronization between the master and slave device may be due to noisy environment on the SCK communication clock or on the WS frame synchronization line. An error interrupt can be generated if the ERRIE bit is set. The desynchronization flag (FRE) is cleared by software when the status register is read.

#### 20.4.9 I<sup>2</sup>S interrupts

*Table 91* provides the list of I<sup>2</sup>S interrupts.

**Table 91. I<sup>2</sup>S interrupt requests**

Interrupt event	Event flag	Enable Control bit
Transmit buffer empty flag	TXE	TXEIE
Receive buffer not empty flag	RXNE	RXNEIE
Overrun error	OVR	ERRIE
Underrun error	UDR	
Frame error flag	FRE	ERRIE

#### 20.4.10 DMA features

DMA is working in exactly the same way as for the SPI mode. There is no difference on the I<sup>2</sup>S. Only the CRC feature is not available in I<sup>2</sup>S mode since there is no data transfer protection system.

## 20.5 SPI and I<sup>2</sup>S registers

Refer to [Section 1.1 on page 34](#) for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by half-words (16 bits) or words (32 bits).

### 20.5.1 SPI control register 1 (SPI\_CR1)(not used in I<sup>2</sup>S mode)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BIDI MODE	BIDI OE	CRC EN	CRC NEXT	DFF	RX ONLY	SSM	SSI	LSB FIRST	SPE	BR [2:0]			MSTR	CPOL	CPHA

**Bit 15 BIDIMODE:** Bidirectional data mode enable

0: 2-line unidirectional data mode selected

1: 1-line bidirectional data mode selected

*Note: This bit is not used in I<sup>2</sup>S mode*

**Bit 14 BIDIOE:** Output enable in bidirectional mode

This bit combined with the BIDI mode bit selects the direction of transfer in bidirectional mode

0: Output disabled (receive-only mode)

1: Output enabled (transmit-only mode)

*Note: This bit is not used in I<sup>2</sup>S mode.*

*In master mode, the MOSI pin is used while the MISO pin is used in slave mode.*

**Bit 13 CRCEN:** Hardware CRC calculation enable

0: CRC calculation disabled

1: CRC calculation enabled

*Note: This bit should be written only when SPI is disabled (SPE = '0') for correct operation.*

*It is not used in I<sup>2</sup>S mode.*

**Bit 12 CRCNEXT:** CRC transfer next

0: Data phase (no CRC phase)

1: Next transfer is CRC (CRC phase)

*Note: When the SPI is configured in full duplex or transmitter only modes, CRCNEXT must be written as soon as the last data is written to the SPI\_DR register.*

*When the SPI is configured in receiver only mode, CRCNEXT must be set after the second last data reception.*

*This bit should be kept cleared when the transfers are managed by DMA.*

*It is not used in I<sup>2</sup>S mode.*

**Bit 11 DFF:** Data frame format

0: 8-bit data frame format is selected for transmission/reception

1: 16-bit data frame format is selected for transmission/reception

*Note: This bit should be written only when SPI is disabled (SPE = '0') for correct operation.*

*It is not used in I<sup>2</sup>S mode.*

**Bit 10 RXONLY:** Receive only

This bit combined with the BIDI mode bit selects the direction of transfer in 2-line unidirectional mode. This bit is also useful in a multislave system in which this particular slave is not accessed, the output from the accessed slave is not corrupted.

- 0: Full duplex (Transmit and receive)
- 1: Output disabled (Receive-only mode)

*Note: This bit is not used in I<sup>2</sup>S mode*

**Bit 9 SSM:** Software slave management

When the SSM bit is set, the NSS pin input is replaced with the value from the SSI bit.

- 0: Software slave management disabled
- 1: Software slave management enabled

*Note: This bit is not used in I<sup>2</sup>S mode and SPI TI mode*

**Bit 8 SSI:** Internal slave select

This bit has an effect only when the SSM bit is set. The value of this bit is forced onto the NSS pin and the IO value of the NSS pin is ignored.

*Note: This bit is not used in I<sup>2</sup>S mode and SPI TI mode*

**Bit 7 LSBFIRST:** Frame format

- 0: MSB transmitted first
- 1: LSB transmitted first

*Note: This bit should not be changed when communication is ongoing.*

*It is not used in I<sup>2</sup>S mode and SPI TI mode*

**Bit 6 SPE:** SPI enable

- 0: Peripheral disabled
- 1: Peripheral enabled

*Note: This bit is not used in I<sup>2</sup>S mode.*

*When disabling the SPI, follow the procedure described in [Section 20.3.8: Disabling the SPI](#).*

**Bits 5:3 BR[2:0]:** Baud rate control

- |      |                        |
|------|------------------------|
| 000: | f <sub>PCLK</sub> /2   |
| 001: | f <sub>PCLK</sub> /4   |
| 010: | f <sub>PCLK</sub> /8   |
| 011: | f <sub>PCLK</sub> /16  |
| 100: | f <sub>PCLK</sub> /32  |
| 101: | f <sub>PCLK</sub> /64  |
| 110: | f <sub>PCLK</sub> /128 |
| 111: | f <sub>PCLK</sub> /256 |

*Note: These bits should not be changed when communication is ongoing.*

*They are not used in I<sup>2</sup>S mode.*

Bit 2 **MSTR**: Master selection

- 0: Slave configuration
- 1: Master configuration

*Note: This bit should not be changed when communication is ongoing.  
It is not used in I<sup>2</sup>S mode.*

Bit1 **CPOL**: Clock polarity

- 0: CK to 0 when idle
- 1: CK to 1 when idle

*Note: This bit should not be changed when communication is ongoing.  
It is not used in I<sup>2</sup>S mode and SPI TI mode.*

Bit 0 **CPHA**: Clock phase

- 0: The first clock transition is the first data capture edge
- 1: The second clock transition is the first data capture edge

*Note: This bit should not be changed when communication is ongoing.  
It is not used in I<sup>2</sup>S mode and SPI TI mode.*

## 20.5.2 SPI control register 2 (SPI\_CR2)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								TXEIE	RXNEIE	ERRIE	FRF	Res.	SSOE	TXDMAEN	RXDMAEN
								rw	rw	rw	rw		rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TXEIE**: Tx buffer empty interrupt enable

- 0: TXE interrupt masked
- 1: TXE interrupt not masked. Used to generate an interrupt request when the TXE flag is set.

Bit 6 **RXNEIE**: RX buffer not empty interrupt enable

- 0: RXNE interrupt masked
- 1: RXNE interrupt not masked. Used to generate an interrupt request when the RXNE flag is set.

Bit 5 **ERRIE**: Error interrupt enable

This bit controls the generation of an interrupt when an error condition occurs (CRCERR, OVR, MODF in SPI mode, FRE in TI mode and UDR, OVR, and FRE in I<sup>2</sup>S mode).

- 0: Error interrupt is masked
- 1: Error interrupt is enabled

Bit 4 **FRF**: Frame format

- 0: SPI Motorola mode
- 1 SPI TI mode

*Note: This bit is not used in I<sup>2</sup>S mode.*

Bit 3 Reserved. Forced to 0 by hardware.

**Bit 2 SSOE:** SS output enable

0: SS output is disabled in master mode and the cell can work in multimaster configuration  
1: SS output is enabled in master mode and when the cell is enabled. The cell cannot work in a multimaster environment.

*Note: This bit is not used in I<sup>2</sup>S mode and SPI TI mode.*

**Bit 1 TXDMAEN:** Tx buffer DMA enable

When this bit is set, the DMA request is made whenever the TXE flag is set.  
0: Tx buffer DMA disabled  
1: Tx buffer DMA enabled

**Bit 0 RXDMAEN:** Rx buffer DMA enable

When this bit is set, the DMA request is made whenever the RXNE flag is set.  
0: Rx buffer DMA disabled  
1: Rx buffer DMA enabled

### 20.5.3 SPI status register (SPI\_SR)

Address offset: 0x08

Reset value: 0x0002

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
							FRE	BSY	OVR	MODF	CRC ERR	UDR	CHSID E	TXE	RXNE
Reserved							r	r	r	r	rc_w0	r	r	r	r

Bits 15:9 Reserved. Forced to 0 by hardware.

Bit 8 **FRE**: Frame format error

0: No frame format error

1: A frame format error occurred

This flag is set by hardware and cleared by software when the SPIx\_SR register is read.

*Note:* This flag is used when the SPI operates in TI slave mode or I2S slave mode (refer to Section 20.3.10).

Bit 7 **BSY**: Busy flag

0: SPI(or I2S) not busy

1: SPI(or I2S)is busy in communication or Tx buffer is not empty

This flag is set and cleared by hardware.

*Note:* BSY flag must be used with caution: refer to Section 20.3.7: Status flags and Section 20.3.8: Disabling the SPI.

Bit 6 **OVR**: Overrun flag

0: No overrun occurred

1: Overrun occurred

This flag is set by hardware and reset by a software sequence. Refer to Section 20.4.8 on page 588 for the software sequence.

Bit 5 **MODF**: Mode fault

0: No mode fault occurred

1: Mode fault occurred

This flag is set by hardware and reset by a software sequence. Refer to Section 20.3.10 on page 570 for the software sequence.

*Note:* This bit is not used in I<sup>2</sup>S mode

Bit 4 **CRCERR**: CRC error flag

0: CRC value received matches the SPI\_RXCRCR value

1: CRC value received does not match the SPI\_RXCRCR value

This flag is set by hardware and cleared by software writing 0.

*Note:* This bit is not used in I<sup>2</sup>S mode.

Bit 3 **UDR**: Underrun flag

0: No underrun occurred

1: Underrun occurred

This flag is set by hardware and reset by a software sequence. Refer to Section 20.4.8 on page 588 for the software sequence.

*Note:* This bit is not used in SPI mode.

Bit 2 **CHSIDE**: Channel side

- 0: Channel Left has to be transmitted or has been received
- 1: Channel Right has to be transmitted or has been received

*Note: This bit is not used for SPI mode and is meaningless in PCM mode.*

Bit 1 **TXE**: Transmit buffer empty

- 0: Tx buffer not empty
- 1: Tx buffer empty

Bit 0 **RXNE**: Receive buffer not empty

- 0: Rx buffer empty
- 1: Rx buffer not empty

#### 20.5.4 SPI data register (SPI\_DR)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **DR[15:0]**: Data register

Data received or to be transmitted.

The data register is split into 2 buffers - one for writing (Transmit Buffer) and another one for reading (Receive buffer). A write to the data register will write into the Tx buffer and a read from the data register will return the value held in the Rx buffer.

*Note: These notes apply to SPI mode:*

*Depending on the data frame format selection bit (DFF in SPI\_CR1 register), the data sent or received is either 8-bit or 16-bit. This selection has to be made before enabling the SPI to ensure correct operation.*

*For an 8-bit data frame, the buffers are 8-bit and only the LSB of the register (SPI\_DR[7:0]) is used for transmission/reception. When in reception mode, the MSB of the register (SPI\_DR[15:8]) is forced to 0.*

*For a 16-bit data frame, the buffers are 16-bit and the entire register, SPI\_DR[15:0] is used for transmission/reception.*

### 20.5.5 SPI CRC polynomial register (SPI\_CRCPR)(not used in I<sup>2</sup>S mode)

Address offset: 0x10

Reset value: 0x0007

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRCPOLY[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CRCPOLY[15:0]**: CRC polynomial register

This register contains the polynomial for the CRC calculation.

The CRC polynomial (0007h) is the reset value of this register. Another polynomial can be configured as required.

*Note: These bits are not used for the I<sup>2</sup>S mode.*

## 20.5.6 SPI RX CRC register (SPI\_RXCRCR)(not used in I<sup>2</sup>S mode)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 15:0 **RXCRC[15:0]:** Rx CRC register

When CRC calculation is enabled, the RxCRC[15:0] bits contain the computed CRC value of the subsequently received bytes. This register is reset when the CRCEN bit in SPI\_CR1 register is written to 1. The CRC is calculated serially using the polynomial programmed in the SPI\_CRCPR register.

Only the 8 LSB bits are considered when the data frame format is set to be 8-bit data (DFF bit of SPI\_CR1 is cleared). CRC calculation is done based on any CRC8 standard.

The entire 16-bits of this register are considered when a 16-bit data frame format is selected (DFF bit of the SPI\_CR1 register is set). CRC calculation is done based on any CRC16 standard.

*Note: A read to this register when the BSY Flag is set could return an incorrect value.  
These bits are not used for I<sup>2</sup>S mode*

## 20.5.7 SPI TX CRC register (SPI\_TXCRCR)(not used in I<sup>2</sup>S mode)

Address offset: 0x18

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXCRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 15:0 **TXCRC[15:0]:** Tx CRC register

When CRC calculation is enabled, the TxCRC[7:0] bits contain the computed CRC value of the subsequently transmitted bytes. This register is reset when the CRCEN bit of SPI\_CR1 is written to 1. The CRC is calculated serially using the polynomial programmed in the SPI\_CRCPR register.

Only the 8 LSB bits are considered when the data frame format is set to be 8-bit data (DFF bit of SPI\_CR1 is cleared). CRC calculation is done based on any CRC8 standard.

The entire 16-bits of this register are considered when a 16-bit data frame format is selected (DFF bit of the SPI\_CR1 register is set). CRC calculation is done based on any CRC16 standard.

*Note: A read to this register when the BSY flag is set could return an incorrect value.  
These bits are not used for I<sup>2</sup>S mode.*

### 20.5.8 SPI\_I<sup>2</sup>S configuration register (SPI\_I2SCFGR)

Address offset: 0x1C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
				I2SMOD	I2SE	I2SCFG		PCMSYNC		I2SSTD		CKPOL	DATLEN		CHLEN
Reserved				rw	rW	rw	rw	rw	Res.	rw	rw	rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **I2SMOD**: I2S mode selection

- 0: SPI mode is selected
- 1: I2S mode is selected

*Note: This bit should be configured when the SPI or I<sup>2</sup>S is disabled*

Bit 10 **I2SE**: I2S Enable

- 0: I<sup>2</sup>S peripheral is disabled
- 1: I<sup>2</sup>S peripheral is enabled

*Note: This bit is not used in SPI mode.*

Bits 9:8 **I2SCFG**: I2S configuration mode

- 00: Slave - transmit
- 01: Slave - receive
- 10: Master - transmit
- 11: Master - receive

*Note: This bit should be configured when the I<sup>2</sup>S is disabled.*

*It is not used in SPI mode.*

Bit 7 **PCMSYNC**: PCM frame synchronization

- 0: Short frame synchronization
- 1: Long frame synchronization

*Note: This bit has a meaning only if I2SSTD = 11 (PCM standard is used)*

*It is not used in SPI mode.*

Bit 6 Reserved: forced at 0 by hardware

Bits 5:4 **I2SSTD**: I2S standard selection

- 00: I<sup>2</sup>S Philips standard.
- 01: MSB justified standard (left justified)
- 10: LSB justified standard (right justified)
- 11: PCM standard

For more details on I<sup>2</sup>S standards, refer to [Section 20.4.3 on page 574](#). Not used in SPI mode.

*Note: For correct operation, these bits should be configured when the I<sup>2</sup>S is disabled.*

Bit 3 **CKPOL**: Steady state clock polarity

- 0: I<sup>2</sup>S clock steady state is low level
- 1: I<sup>2</sup>S clock steady state is high level

*Note: For correct operation, this bit should be configured when the I<sup>2</sup>S is disabled.*

*This bit is not used in SPI mode*

Bits 2:1 **DATLEN**: Data length to be transferred

- 00: 16-bit data length
- 01: 24-bit data length
- 10: 32-bit data length
- 11: Not allowed

*Note: For correct operation, these bits should be configured when the I<sup>2</sup>S is disabled.*

*This bit is not used in SPI mode.*

Bit 0 **CHLEN**: Channel length (number of bits per audio channel)

- 0: 16-bit wide
- 1: 32-bit wide

The bit write operation has a meaning only if DATLEN = 00 otherwise the channel length is fixed to 32-bit by hardware whatever the value filled in. *Not used in SPI mode.*

*Note: For correct operation, this bit should be configured when the I<sup>2</sup>S is disabled.*

## 20.5.9 SPI\_I<sup>2</sup>S prescaler register (SPI\_I2SPR)

Address offset: 0x20

Reset value: 0000 0010 (0x0002)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						MCKOE	ODD				I2SDIV				
Reserved						rw	rw				rw				

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **MCKOE**: Master clock output enable

- 0: Master clock output is disabled
- 1: Master clock output is enabled

*Note: This bit should be configured when the I<sup>2</sup>S is disabled. It is used only when the I<sup>2</sup>S is in master mode.*

*This bit is not used in SPI mode.*

Bit 8 **ODD**: Odd factor for the prescaler

- 0: real divider value is = I2SDIV \*2
- 1: real divider value is = (I2SDIV \* 2)+1

Refer to [Section 20.4.4 on page 581](#). *Not used in SPI mode.*

*Note: This bit should be configured when the I<sup>2</sup>S is disabled. It is used only when the I<sup>2</sup>S is in master mode.*

Bits 7:0 **I2SDIV**: I2S Linear prescaler

I2SDIV [7:0] = 0 or I2SDIV [7:0] = 1 are forbidden values.

Refer to [Section 20.4.4 on page 581](#). *Not used in SPI mode.*

*Note: These bits should be configured when the I<sup>2</sup>S is disabled. It is used only when the I<sup>2</sup>S is in master mode.*

### 20.5.10 SPI register map

The table provides shows the SPI register map and reset values.

**Table 92. SPI register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
0x00	<b>SPI_CR1</b>	Reserved																																
0x08	<b>SPI_SR</b>	Reserved																																
0x0C	<b>SPI_DR</b>	Reserved											DR[15:0]											0	0	0	0	0	0	0	0	0	0	
													CRCNPOLY[15:0]											0	0	0	0	0	0	0	0	0	0	
0x10	<b>SPI_CRCPCR</b>	Reserved											RxCRC[15:0]											0	0	0	0	0	0	0	0	0	0	
													TxCRC[15:0]											0	0	0	0	0	0	0	0	0	0	
0x14	<b>SPI_RXCRCR</b>	Reserved											I2SDIV											0	0	0	0	0	0	0	0	0	0	
													I2SMD	I2SCFG	PCMST/NC	Reserved	I2SSTD	CKPOL	DATLEN	CHLEN	MSTR	TXE	C POL	CPHA	0	0	0	0	0	0	0	0	0	0
0x1C	<b>SPI_I2SCFGR</b>	Reserved											I2SMD	I2SCFG	PCMST/NC	Reserved	I2SSTD	CKPOL	DATLEN	CHLEN	MSTR	TXE	C POL	CPHA	0	0	0	0	0	0	0	0	0	0
													I2SMD	I2SCFG	PCMST/NC	Reserved	I2SSTD	CKPOL	DATLEN	CHLEN	MSTR	TXE	C POL	CPHA	0	0	0	0	0	0	0	0	0	0
0x20	<b>SPI_I2SPR</b>	Reserved											MCKOE	ODD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Reset value																																	

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 21 Secure digital input/output interface (SDIO)

### 21.1 SDIO main features

The SD/SDIO MMC card host interface (SDIO) provides an interface between the APB2 peripheral bus and MultiMediaCards (MMCs), SD memory cards, SDIO cards and CE-ATA devices.

The MultiMediaCard system specifications are available through the MultiMediaCard Association website at [www.mmca.org](http://www.mmca.org), published by the MMCA technical committee.

SD memory card and SD I/O card system specifications are available through the SD card Association website at [www.sdcards.org](http://www.sdcards.org).

CE-ATA system specifications are available through the CE-ATA workgroup website at [www.ce-ata.org](http://www.ce-ata.org).

The SDIO features include the following:

- Full compliance with *MultiMediaCard System Specification Version 4.2*. Card support for three different databus modes: 1-bit (default), 4-bit and 8-bit
- Full compatibility with previous versions of MultiMediaCards (forward compatibility)
- Full compliance with *SD Memory Card Specifications Version 2.0*
- Full compliance with *SD I/O Card Specification Version 2.0*: card support for two different databus modes: 1-bit (default) and 4-bit
- Full support of the CE-ATA features (full compliance with *CE-ATA digital protocol Rev1.1*)
- Data transfer up to 48 MHz for the 8 bit mode
- Data and command output enable signals to control external bidirectional drivers.

Note:

*The SDIO does not have an SPI-compatible communication mode.*

*The SD memory card protocol is a superset of the MultiMediaCard protocol as defined in the MultiMediaCard system specification V2.11. Several commands required for SD memory devices are not supported by either SD I/O-only cards or the I/O portion of combo cards. Some of these commands have no use in SD I/O devices, such as erase commands, and thus are not supported in the SDIO. In addition, several commands are different between SD memory cards and SD I/O cards and thus are not supported in the SDIO. For details refer to SD I/O card Specification Version 1.0. CE-ATA is supported over the MMC electrical interface using a protocol that utilizes the existing MMC access primitives. The interface electrical and signaling definition is as defined in the MMC reference.*

The MultiMediaCard/SD bus connects cards to the controller.

The current version of the SDIO supports only one SD/SDIO/MMC4.2 card at any one time and a stack of MMC4.1 or previous.

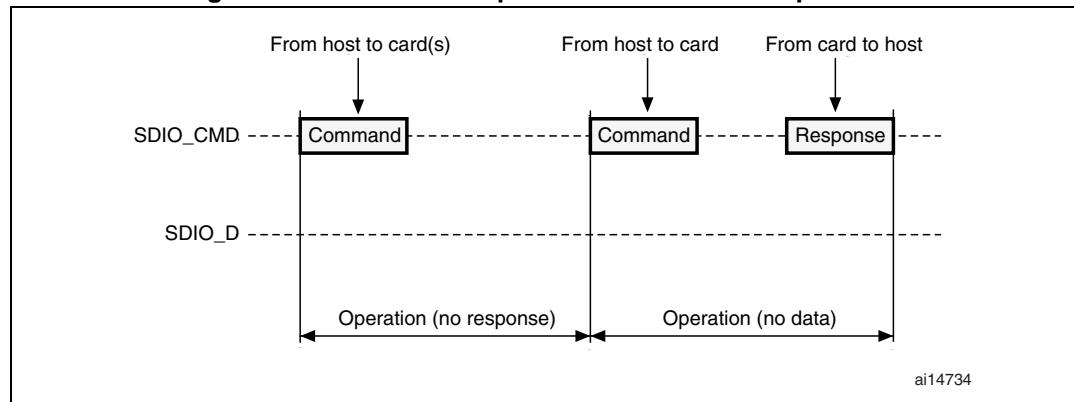
### 21.2 SDIO bus topology

Communication over the bus is based on command and data transfers.

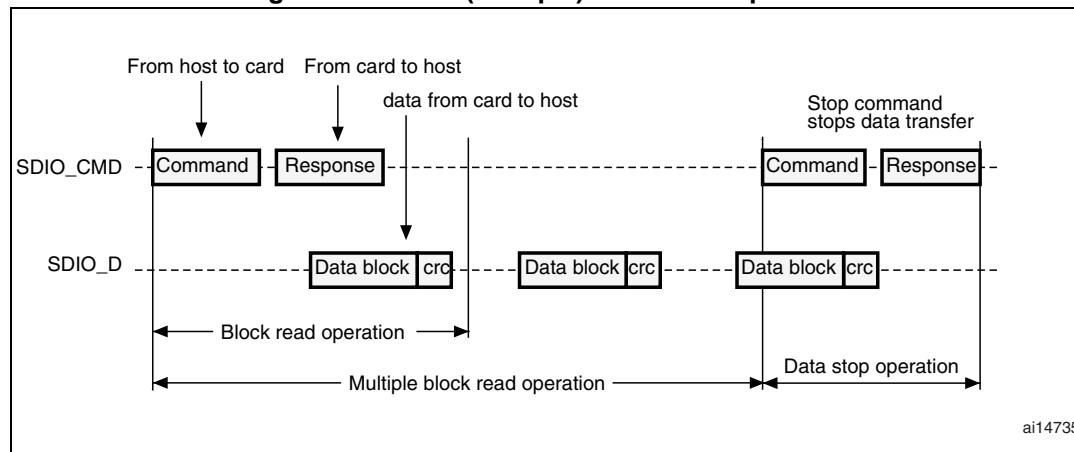
The basic transaction on the MultiMediaCard/SD/SD I/O bus is the command/response transaction. These types of bus transaction transfer their information directly within the command or response structure. In addition, some operations have a data token.

Data transfers to/from SD/SDIO memory cards are done in data blocks. Data transfers to/from MMC are done data blocks or streams. Data transfers to/from the CE-ATA Devices are done in data blocks.

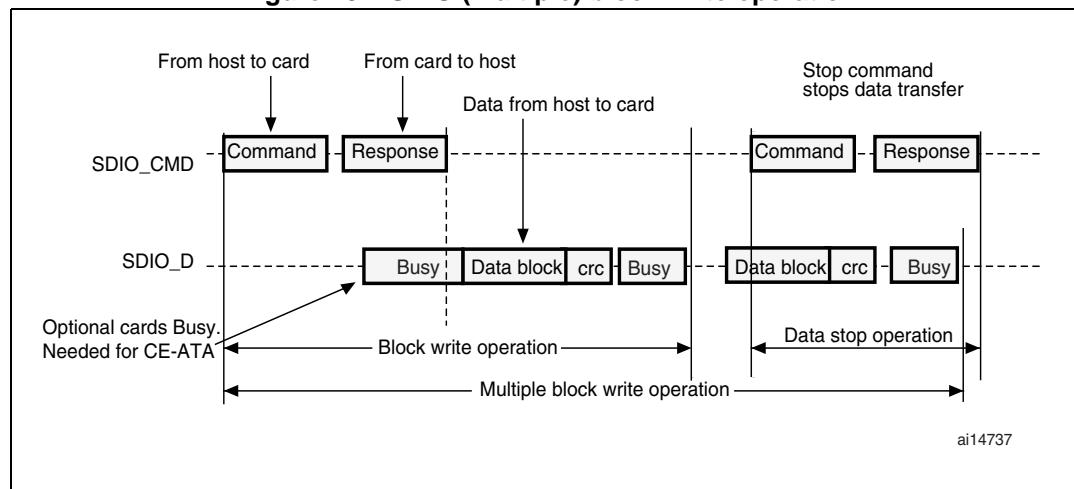
**Figure 229. SDIO “no response” and “no data” operations**



**Figure 230. SDIO (multiple) block read operation**

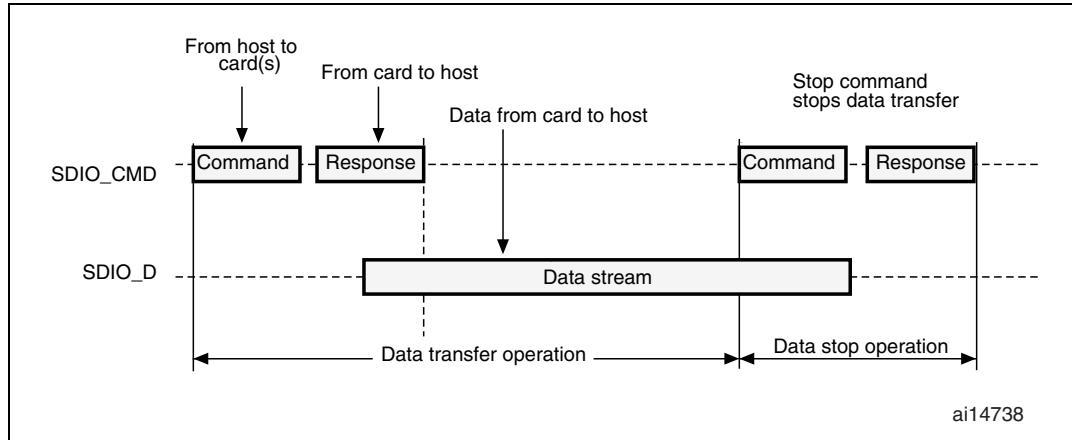


**Figure 231. SDIO (multiple) block write operation**

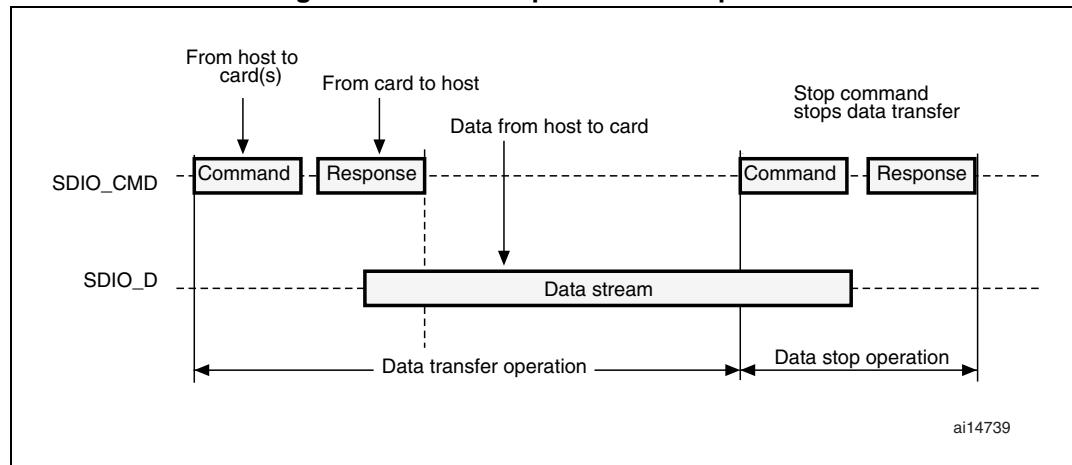


**Note:** The SDIO will not send any data as long as the Busy signal is asserted (SDIO\_D0 pulled low).

**Figure 232. SDIO sequential read operation**



**Figure 233. SDIO sequential write operation**

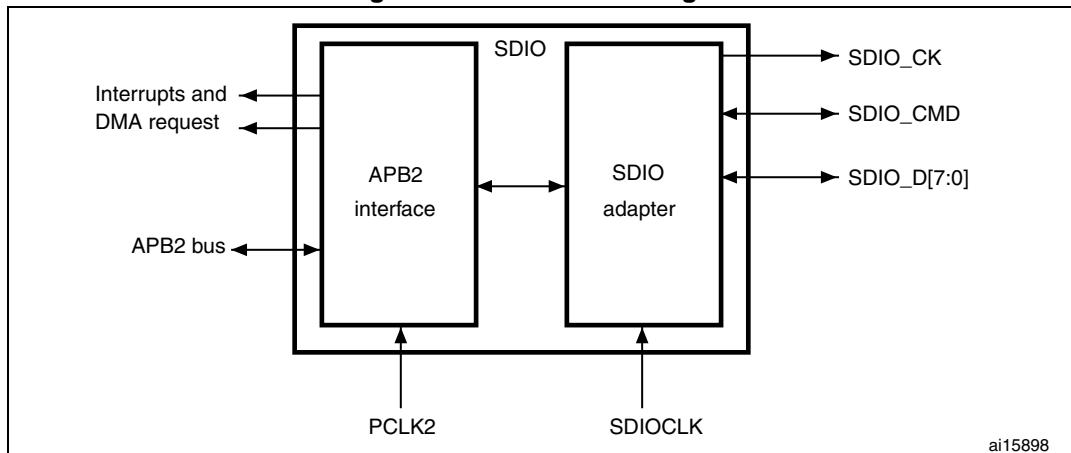


## 21.3 SDIO functional description

The SDIO consists of two parts:

- The SDIO adapter block provides all functions specific to the MMC/SD/SD I/O card such as the clock generation unit, command and data transfer.
- The APB2 interface accesses the SDIO adapter registers, and generates interrupt and DMA request signals.

Figure 234. SDIO block diagram



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By default SDIO\_D0 is used for data transfer. After initialization, the host can change the databus width.

If a MultiMediaCard is connected to the bus, SDIO\_D0, SDIO\_D[3:0] or SDIO\_D[7:0] can be used for data transfer. MMC V3.31 or previous, supports only 1 bit of data so only SDIO\_D0 can be used.

If an SD or SD I/O card is connected to the bus, data transfer can be configured by the host to use SDIO\_D0 or SDIO\_D[3:0]. All data lines are operating in push-pull mode.

**SDIO\_CMD** has two operational modes:

- Open-drain for initialization (only for MMCV3.31 or previous)
- Push-pull for command transfer (SD/SD I/O card MMC4.2 use push-pull drivers also for initialization)

**SDIO\_CK** is the clock to the card: one bit is transferred on both command and data lines with each clock cycle. The clock frequency can vary between 0 MHz and 20 MHz (for a MultiMediaCard V3.31), between 0 and 48 MHz for a MultiMediaCard V4.0/4.2, or between 0 and 25 MHz (for an SD/SD I/O card).

The SDIO uses two clock signals:

- SDIO adapter clock (SDIOCLK = 48 MHz)
- APB2 bus clock (PCLK2)

PCLK2 and SDIO\_CK clock frequencies must respect the following condition:

$$\text{Frequenc}(PCLK2) \geq 3/8 \times \text{Frequency}(SDIO\_CK)$$

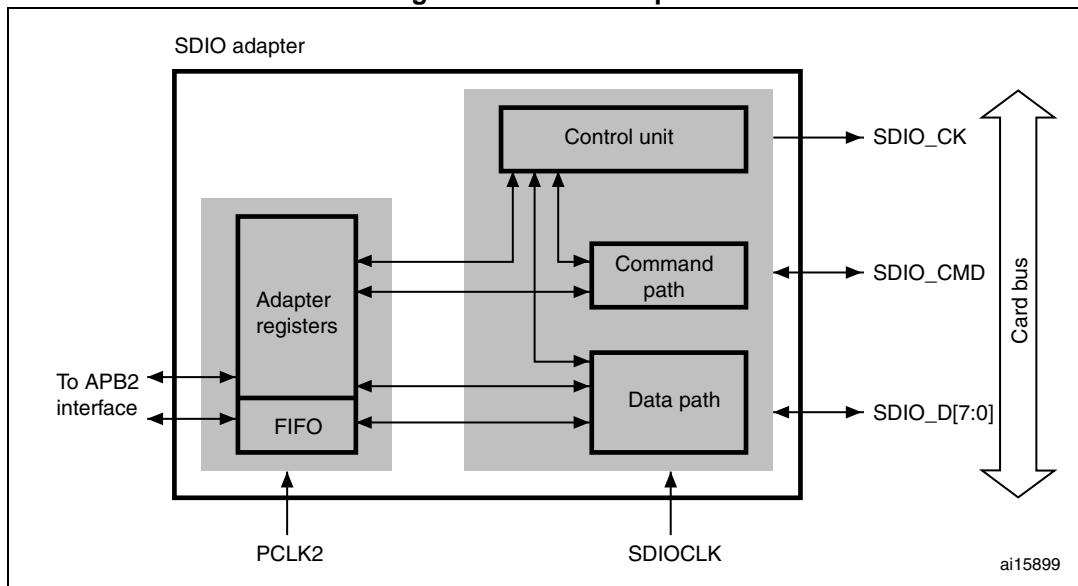
The signals shown in [Table 93](#) are used on the MultiMediaCard/SD/SD I/O card bus.

**Table 93. SDIO I/O definitions**

Pin	Direction	Description
SDIO_CK	Output	MultiMediaCard/SD/SDIO card clock. This pin is the clock from host to card.
SDIO_CMD	Bidirectional	MultiMediaCard/SD/SDIO card command. This pin is the bidirectional command/response signal.
SDIO_D[7:0]	Bidirectional	MultiMediaCard/SD/SDIO card data. These pins are the bidirectional databus.

### 21.3.1 SDIO adapter

*Figure 235* shows a simplified block diagram of an SDIO adapter.

**Figure 235. SDIO adapter**

The SDIO adapter is a multimedia/secure digital memory card bus master that provides an interface to a multimedia card stack or to a secure digital memory card. It consists of five subunits:

- Adapter register block
- Control unit
- Command path
- Data path
- Data FIFO

Note:

*The adapter registers and FIFO use the APB2 bus clock domain (PCLK2). The control unit, command path and data path use the SDIO adapter clock domain (SDIOCLK).*

#### Adapter register block

The adapter register block contains all system registers. This block also generates the signals that clear the static flags in the multimedia card. The clear signals are generated when 1 is written into the corresponding bit location in the SDIO Clear register.

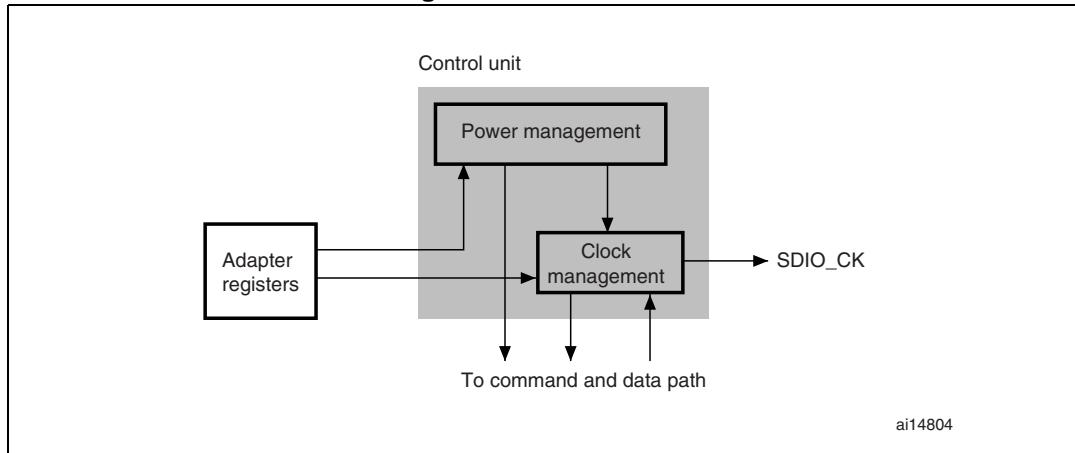
## Control unit

The control unit contains the power management functions and the clock divider for the memory card clock.

There are three power phases:

- power-off
- power-up
- power-on

**Figure 236. Control unit**



The control unit is illustrated in [Figure 236](#). It consists of a power management subunit and a clock management subunit.

The power management subunit disables the card bus output signals during the power-off and power-up phases.

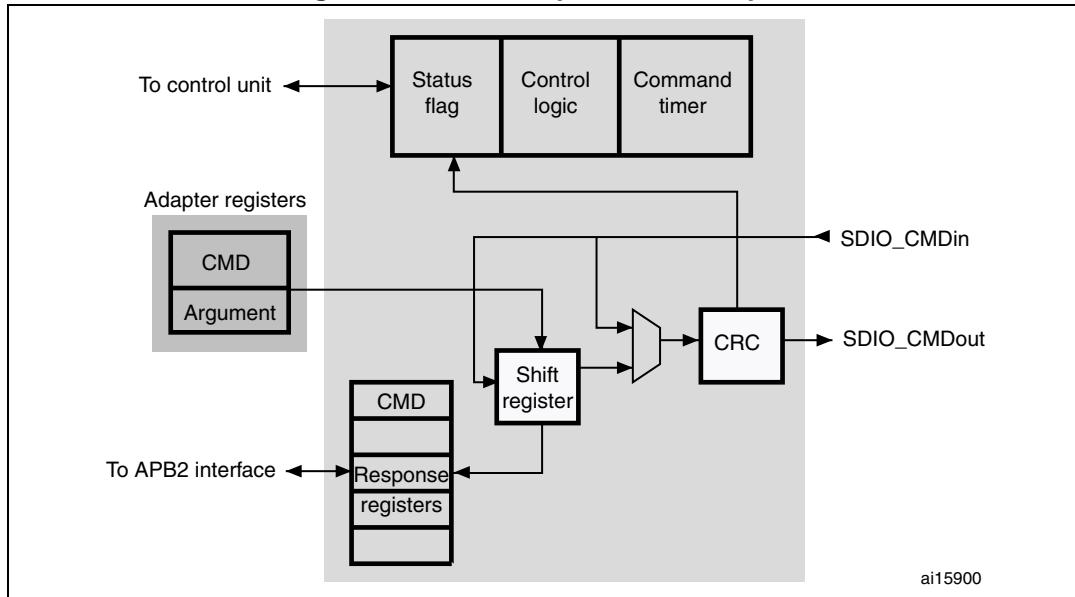
The clock management subunit generates and controls the SDIO\_CK signal. The SDIO\_CK output can use either the clock divide or the clock bypass mode. The clock output is inactive:

- after reset
- during the power-off or power-up phases
- if the power saving mode is enabled and the card bus is in the Idle state (eight clock periods after both the command and data path subunits enter the Idle phase)

## Command path

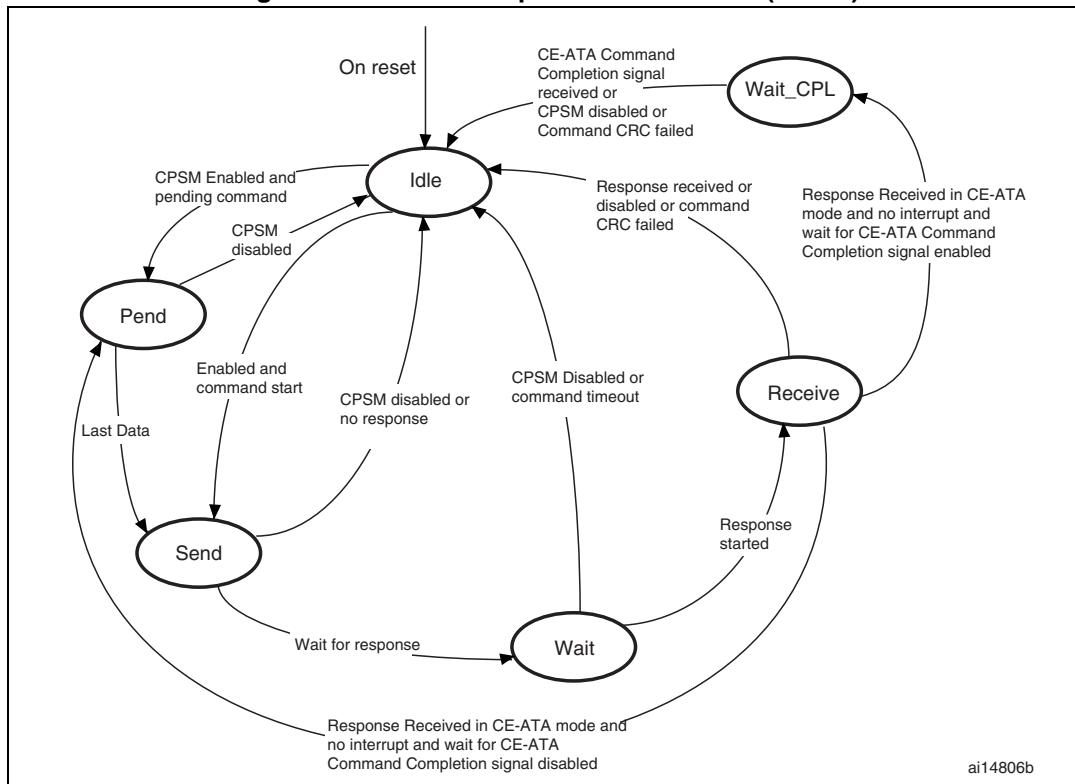
The command path unit sends commands to and receives responses from the cards.

Figure 237. SDIO adapter command path



- Command path state machine (CPSM)
  - When the command register is written to and the enable bit is set, command transfer starts. When the command has been sent, the command path state machine (CPSM) sets the status flags and enters the Idle state if a response is not required. If a response is required, it waits for the response (see [Figure 238 on page 608](#)). When the response is received, the received CRC code and the internally generated code are compared, and the appropriate status flags are set.

Figure 238. Command path state machine (CPSM)



When the Wait state is entered, the command timer starts running. If the timeout is reached before the CPSM moves to the Receive state, the timeout flag is set and the Idle state is entered.

**Note:**

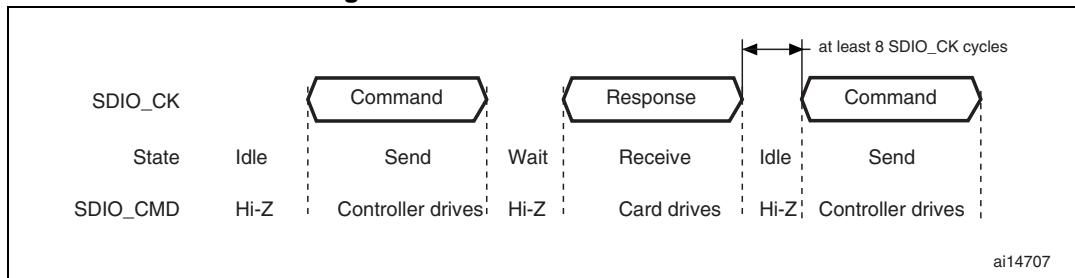
*The command timeout has a fixed value of 64 SDIO\_CK clock periods.*

If the interrupt bit is set in the command register, the timer is disabled and the CPSM waits for an interrupt request from one of the cards. If a pending bit is set in the command register, the CPSM enters the **Pend** state, and waits for a CmdPend signal from the data path subunit. When CmdPend is detected, the CPSM moves to the **Send** state. This enables the data counter to trigger the stop command transmission.

**Note:**

*The CPSM remains in the Idle state for at least eight SDIO\_CK periods to meet the  $N_{CC}$  and  $N_{RC}$  timing constraints.  $N_{CC}$  is the minimum delay between two host commands, and  $N_{RC}$  is the minimum delay between the host command and the card response.*

Figure 239. SDIO command transfer



- Command format

- Command: a command is a token that starts an operation. Commands are sent from the host either to a single card (addressed command) or to all connected cards (broadcast command are available for MMC V3.31 or previous). Commands are transferred serially on the CMD line. All commands have a fixed length of 48 bits. The general format for a command token for MultiMediaCards, SD-Memory cards and SDIO-Cards is shown in [Table 94](#). CE-ATA commands are an extension of MMC commands V4.2, and so have the same format.

The command path operates in a half-duplex mode, so that commands and responses can either be sent or received. If the CPSM is not in the Send state, the SDIO\_CMD output is in the Hi-Z state, as shown in [Figure 239 on page 609](#). Data on SDIO\_CMD are synchronous with the rising edge of SDIO\_CK. [Table](#) shows the command format.

Table 94. Command format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	1	Transmission bit
[45:40]	6	-	Command index
[39:8]	32	-	Argument
[7:1]	7	-	CRC7
0	1	1	End bit

- Response: a response is a token that is sent from an addressed card (or synchronously from all connected cards for MMC V3.31 or previous), to the host as an answer to a previously received command. Responses are transferred serially on the CMD line.

The SDIO supports two response types. Both use CRC error checking:

- 48 bit short response
- 136 bit long response

**Note:** *If the response does not contain a CRC (CMD1 response), the device driver must ignore the CRC failed status.*

**Table 95. Short response format**

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	-	Command index
[39:8]	32	-	Argument
[7:1]	7	-	CRC7(or 1111111)
0	1	1	End bit

**Table 96. Long response format**

Bit position	Width	Value	Description
135	1	0	Start bit
134	1	0	Transmission bit
[133:128]	6	111111	Reserved
[127:1]	127	-	CID or CSD (including internal CRC7)
0	1	1	End bit

The command register contains the command index (six bits sent to a card) and the command type. These determine whether the command requires a response, and whether the response is 48 or 136 bits long (see [Section 21.9.4 on page 644](#)). The command path implements the status flags shown in [Table 97](#):

**Table 97. Command path status flags**

Flag	Description
CMDREND	Set if response CRC is OK.
CCRCFAIL	Set if response CRC fails.
CMDSENT	Set when command (that does not require response) is sent
CTIMEOUT	Response timeout.
CMDACT	Command transfer in progress.

The CRC generator calculates the CRC checksum for all bits before the CRC code. This includes the start bit, transmitter bit, command index, and command argument (or card status). The CRC checksum is calculated for the first 120 bits of CID or CSD for the long response format. Note that the start bit, transmitter bit and the six reserved bits are not used in the CRC calculation.

The CRC checksum is a 7-bit value:

$$\text{CRC}[6:0] = \text{Remainder } [(M(x) * x^7) / G(x)]$$

$$G(x) = x^7 + x^3 + 1$$

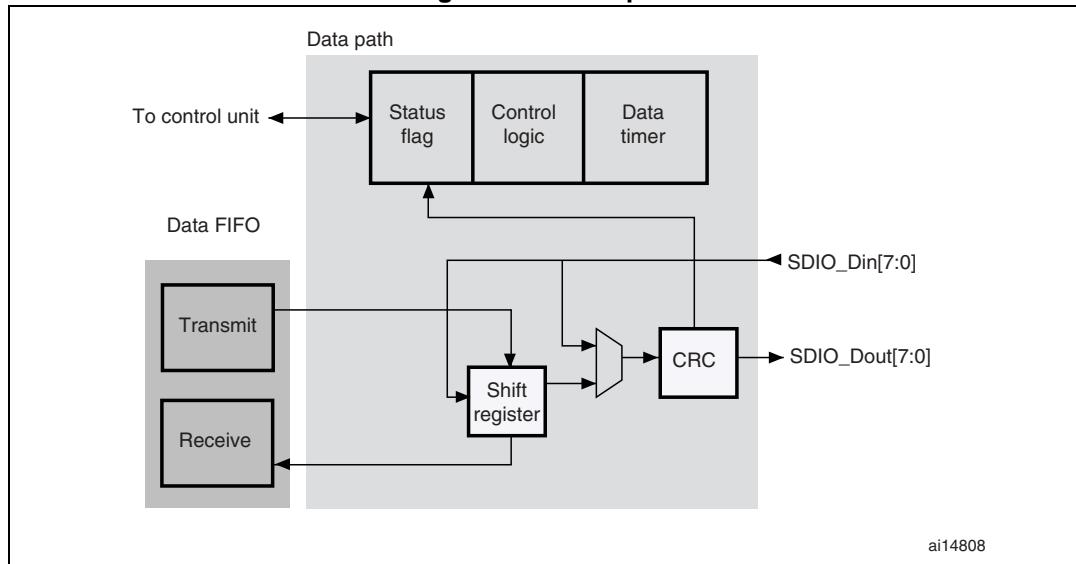
$$M(x) = (\text{start bit}) * x^{39} + \dots + (\text{last bit before CRC}) * x^0, \text{ or}$$

$$M(x) = (\text{start bit}) * x^{119} + \dots + (\text{last bit before CRC}) * x^0$$

## Data path

The data path subunit transfers data to and from cards. [Figure 240](#) shows a block diagram of the data path.

**Figure 240. Data path**



The card databus width can be programmed using the clock control register. If the 4-bit wide bus mode is enabled, data is transferred at four bits per clock cycle over all four data signals (SDIO\_D[3:0]). If the 8-bit wide bus mode is enabled, data is transferred at eight bits per clock cycle over all eight data signals (SDIO\_D[7:0]). If the wide bus mode is not enabled, only one bit per clock cycle is transferred over SDIO\_D0.

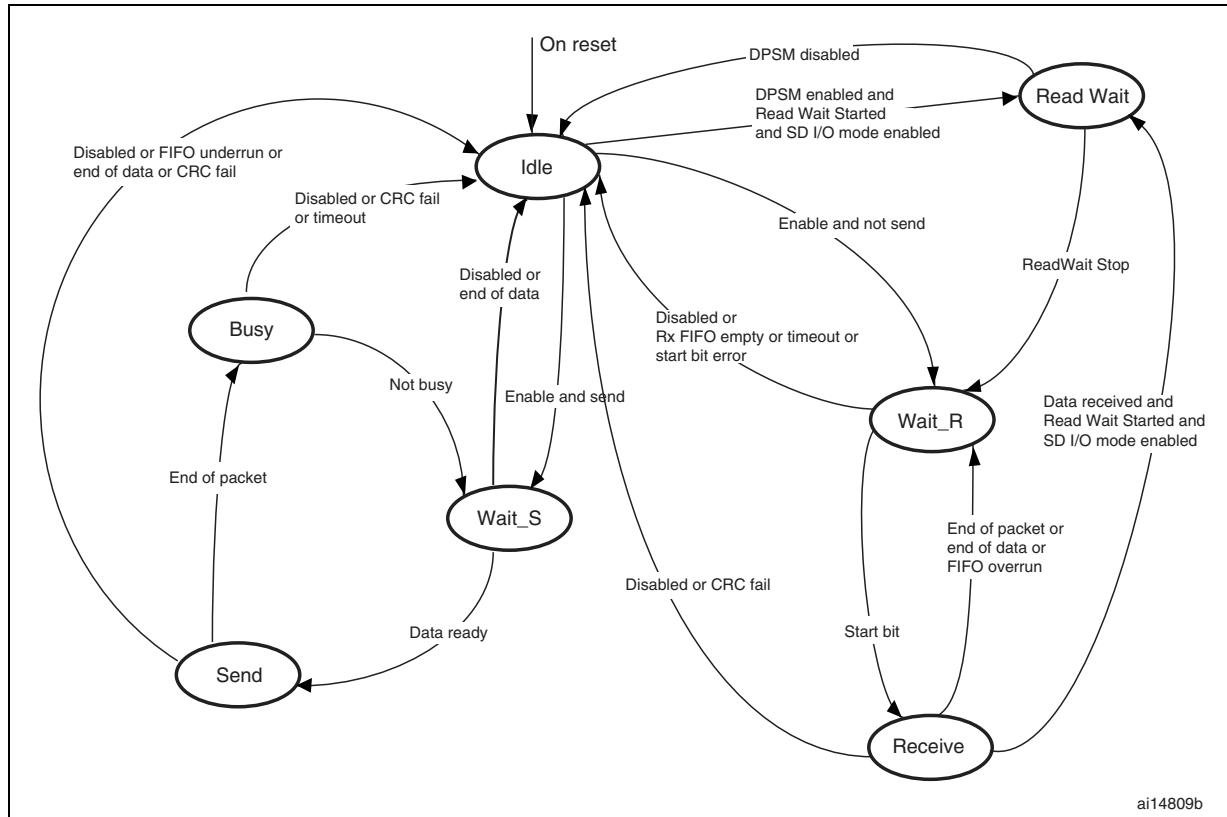
Depending on the transfer direction (send or receive), the data path state machine (DPSM) moves to the Wait\_S or Wait\_R state when it is enabled:

- Send: the DPSM moves to the Wait\_S state. If there is data in the transmit FIFO, the DPSM moves to the Send state, and the data path subunit starts sending data to a card.
- Receive: the DPSM moves to the Wait\_R state and waits for a start bit. When it receives a start bit, the DPSM moves to the Receive state, and the data path subunit starts receiving data from a card.

### Data path state machine (DPSM)

The DPSM operates at SDIO\_CK frequency. Data on the card bus signals is synchronous to the rising edge of SDIO\_CK. The DPSM has six states, as shown in [Figure 241: Data path state machine \(DPSM\)](#).

Figure 241. Data path state machine (DPSM)



- **Idle**: the data path is inactive, and the SDIO\_D[7:0] outputs are in Hi-Z. When the data control register is written and the enable bit is set, the DPSM loads the data counter with a new value and, depending on the data direction bit, moves to either the **Wait\_S** or the **Wait\_R** state.
- **Wait\_R**: if the data counter equals zero, the DPSM moves to the **Idle** state when the receive FIFO is empty. If the data counter is not zero, the DPSM waits for a start bit on SDIO\_D. The DPSM moves to the **Receive** state if it receives a start bit before a timeout, and loads the data block counter. If it reaches a timeout before it detects a start bit, or a start bit error occurs, it moves to the **Idle** state and sets the timeout status flag.
- **Receive**: serial data received from a card is packed in bytes and written to the data FIFO. Depending on the transfer mode bit in the data control register, the data transfer mode can be either block or stream:
  - In block mode, when the data block counter reaches zero, the DPSM waits until it receives the CRC code. If the received code matches the internally generated CRC code, the DPSM moves to the **Wait\_R** state. If not, the CRC fail status flag is set and the DPSM moves to the **Idle** state.
  - In stream mode, the DPSM receives data while the data counter is not zero. When the counter is zero, the remaining data in the shift register is written to the data FIFO, and the DPSM moves to the **Wait\_R** state.
- If a FIFO overrun error occurs, the DPSM sets the FIFO error flag and moves to the **Idle** state:
- **Wait\_S**: the DPSM moves to the **Idle** state if the data counter is zero. If not, it waits until the data FIFO empty flag is deasserted, and moves to the **Send** state.

**Note:** The DPSM remains in the Wait\_S state for at least two clock periods to meet the  $N_{WR}$  timing requirements, where  $N_{WR}$  is the number of clock cycles between the reception of the card response and the start of the data transfer from the host.

- Send: the DPSM starts sending data to a card. Depending on the transfer mode bit in the data control register, the data transfer mode can be either block or stream:
  - In block mode, when the data block counter reaches zero, the DPSM sends an internally generated CRC code and end bit, and moves to the Busy state.
  - In stream mode, the DPSM sends data to a card while the enable bit is high and the data counter is not zero. It then moves to the Idle state.
 If a FIFO underrun error occurs, the DPSM sets the FIFO error flag and moves to the Idle state.
- Busy: the DPSM waits for the CRC status flag:
  - If it does not receive a positive CRC status, it moves to the Idle state and sets the CRC fail status flag.
  - If it receives a positive CRC status, it moves to the Wait\_S state if SDIO\_D0 is not low (the card is not busy).
 If a timeout occurs while the DPSM is in the Busy state, it sets the data timeout flag and moves to the Idle state.
- The data timer is enabled when the DPSM is in the Wait\_R or Busy state, and generates the data timeout error:
  - When transmitting data, the timeout occurs if the DPSM stays in the Busy state for longer than the programmed timeout period
  - When receiving data, the timeout occurs if the end of the data is not true, and if the DPSM stays in the Wait\_R state for longer than the programmed timeout period.
- **Data:** data can be transferred from the card to the host or vice versa. Data is transferred via the data lines. They are stored in a FIFO of 32 words, each word is 32 bits wide.

Table 98. Data token format

Description	Start bit	Data	CRC16	End bit
Block Data	0	-	yes	1
Stream Data	0	-	no	1

## Data FIFO

The data FIFO (first-in-first-out) subunit is a data buffer with a transmit and receive unit.

The FIFO contains a 32-bit wide, 32-word deep data buffer, and transmit and receive logic. Because the data FIFO operates in the APB2 clock domain (PCLK2), all signals from the subunits in the SDIO clock domain (SDIOCLK) are resynchronized.

Depending on the TXACT and RXACT flags, the FIFO can be disabled, transmit enabled, or receive enabled. TXACT and RXACT are driven by the data path subunit and are mutually exclusive:

- The transmit FIFO refers to the transmit logic and data buffer when TXACT is asserted
- The receive FIFO refers to the receive logic and data buffer when RXACT is asserted
- Transmit FIFO:  
Data can be written to the transmit FIFO through the APB2 interface when the SDIO is enabled for transmission.  
The transmit FIFO is accessible via 32 sequential addresses. The transmit FIFO contains a data output register that holds the data word pointed to by the read pointer. When the data path subunit has loaded its shift register, it increments the read pointer and drives new data out.  
If the transmit FIFO is disabled, all status flags are deasserted. The data path subunit asserts TXACT when it transmits data.

**Table 99. Transmit FIFO status flags**

Flag	Description
TXFIFOF	Set to high when all 32 transmit FIFO words contain valid data.
TXFIFOE	Set to high when the transmit FIFO does not contain valid data.
TXFIFOHE	Set to high when 8 or more transmit FIFO words are empty. This flag can be used as a DMA request.
TXDAVL	Set to high when the transmit FIFO contains valid data. This flag is the inverse of the TXFIFOE flag.
TXUNDERR	Set to high when an underrun error occurs. This flag is cleared by writing to the SDIO Clear register.

- Receive FIFO

When the data path subunit receives a word of data, it drives the data on the write databus. The write pointer is incremented after the write operation completes. On the read side, the contents of the FIFO word pointed to by the current value of the read pointer is driven onto the read databus. If the receive FIFO is disabled, all status flags are deasserted, and the read and write pointers are reset. The data path subunit asserts RXACT when it receives data. [Table 100](#) lists the receive FIFO status flags. The receive FIFO is accessible via 32 sequential addresses.

**Table 100. Receive FIFO status flags**

Flag	Description
RXFIFOF	Set to high when all 32 receive FIFO words contain valid data
RXFIFOE	Set to high when the receive FIFO does not contain valid data.
RXFIFOHF	Set to high when 8 or more receive FIFO words contain valid data. This flag can be used as a DMA request.
RXDAVL	Set to high when the receive FIFO is not empty. This flag is the inverse of the RXFIFOE flag.
RXOVERR	Set to high when an overrun error occurs. This flag is cleared by writing to the SDIO Clear register.

### 21.3.2 SDIO APB2 interface

The APB2 interface generates the interrupt and DMA requests, and accesses the SDIO adapter registers and the data FIFO. It consists of a data path, register decoder, and interrupt/DMA logic.

#### SDIO interrupts

The interrupt logic generates an interrupt request signal that is asserted when at least one of the selected status flags is high. A mask register is provided to allow selection of the conditions that will generate an interrupt. A status flag generates the interrupt request if a corresponding mask flag is set.

#### SDIO/DMA interface - procedure for data transfers between the SDIO and memory

In the example shown, the transfer is from the SDIO host controller to an MMC (512 bytes using CMD24 (WRITE\_BLOCK)). The SDIO FIFO is filled by data stored in a memory using the DMA controller.

1. Do the card identification process
2. Increase the SDIO\_CK frequency
3. Select the card by sending CMD7
4. Configure the DMA2 as follows:
  - a) Enable DMA2 controller and clear any pending interrupts.
  - b) Program the DMA2\_Stream3 or DMA2\_Stream6 Channel4 source address register with the memory location's base address and DMA2\_Stream3 or

- DMA2\_Stream6 Channel4 destination address register with the SDIO\_FIFO register address.
- c) Program DMA2\_Stream3 or DMA2\_Stream6 Channel4 control register (memory increment, not peripheral increment, peripheral and source width is word size).
  - d) Program DMA2\_Stream3 or DMA2\_Stream6 Channel4 to select the peripheral as flow controller (set PFCTRL bit in DMA\_S3CR or DMA\_S6CR configuration register).
  - e) Configure the incremental burst transfer to 4 beats (at least from peripheral side) in DMA2\_Stream3 or DMA2\_Stream6 Channel4.
  - f) Enable DMA2\_Stream3 or DMA2\_Stream6 Channel4
5. Send CMD24 (WRITE\_BLOCK) as follows:
    - a) Program the SDIO data length register (SDIO data timer register should be already programmed before the card identification process).
    - b) Program the SDIO argument register with the address location of the card where data is to be transferred.
    - c) Program the SDIO command register: CmdIndex with 24 (WRITE\_BLOCK); WaitResp with '1' (SDIO card host waits for a response); CPSMEN with '1' (SDIO card host enabled to send a command). Other fields are at their reset value.
    - d) Wait for SDIO\_STA[6] = CMDREND interrupt, then program the SDIO data control register: DTEN with '1' (SDIO card host enabled to send data); DTDIR with '0' (from controller to card); DTMODE with '0' (block data transfer); DMAEN with '1' (DMA enabled); DBLOCKSIZE with 0x9 (512 bytes). Other fields are don't care.
    - e) Wait for SDIO\_STA[10] = DBCKEND.
  6. Check that no channels are still enabled by polling the DMA Enabled Channel Status register.

## 21.4 Card functional description

### 21.4.1 Card identification mode

While in card identification mode the host resets all cards, validates the operation voltage range, identifies cards and sets a relative card address (RCA) for each card on the bus. All data communications in the card identification mode use the command line (CMD) only.

### 21.4.2 Card reset

The GO\_IDLE\_STATE command (CMD0) is the software reset command and it puts the MultiMediaCard and SD memory in the Idle state. The IO\_RW\_DIRECT command (CMD52) resets the SD I/O card. After power-up or CMD0, all cards output bus drivers are in the high-impedance state and the cards are initialized with a default relative card address (RCA=0x0001) and with a default driver stage register setting (lowest speed, highest driving current capability).

### 21.4.3 Operating voltage range validation

All cards can communicate with the SDIO card host using any operating voltage within the specification range. The supported minimum and maximum  $V_{DD}$  values are defined in the operation conditions register (OCR) on the card.

Cards that store the card identification number (CID) and card specific data (CSD) in the payload memory are able to communicate this information only under data-transfer  $V_{DD}$  conditions. When the SDIO card host module and the card have incompatible  $V_{DD}$  ranges, the card is not able to complete the identification cycle and cannot send CSD data. For this purpose, the special commands, SEND\_OP\_COND (CMD1), SD\_APP\_OP\_COND (ACMD41 for SD Memory), and IO\_SEND\_OP\_COND (CMD5 for SD I/O), are designed to provide a mechanism to identify and reject cards that do not match the  $V_{DD}$  range desired by the SDIO card host. The SDIO card host sends the required  $V_{DD}$  voltage window as the operand of these commands. Cards that cannot perform data transfer in the specified range disconnect from the bus and go to the inactive state.

By using these commands without including the voltage range as the operand, the SDIO card host can query each card and determine the common voltage range before placing out-of-range cards in the inactive state. This query is used when the SDIO card host is able to select a common voltage range or when the user requires notification that cards are not usable.

#### 21.4.4 Card identification process

The card identification process differs for MultiMediaCards and SD cards. For MultiMediaCard cards, the identification process starts at clock rate  $F_{od}$ . The SDIO\_CMD line output drivers are open-drain and allow parallel card operation during this process. The registration process is accomplished as follows:

1. The bus is activated.
2. The SDIO card host broadcasts SEND\_OP\_COND (CMD1) to receive operation conditions.
3. The response is the wired AND operation of the operation condition registers from all cards.
4. Incompatible cards are placed in the inactive state.
5. The SDIO card host broadcasts ALL\_SEND\_CID (CMD2) to all active cards.
6. The active cards simultaneously send their CID numbers serially. Cards with outgoing CID bits that do not match the bits on the command line stop transmitting and must wait for the next identification cycle. One card successfully transmits a full CID to the SDIO card host and enters the Identification state.
7. The SDIO card host issues SET\_RELATIVE\_ADDR (CMD3) to that card. This new address is called the relative card address (RCA); it is shorter than the CID and addresses the card. The assigned card changes to the Standby state, it does not react to further identification cycles, and its output switches from open-drain to push-pull.
8. The SDIO card host repeats steps 5 through 7 until it receives a timeout condition.

For the SD card, the identification process starts at clock rate  $F_{od}$ , and the SDIO\_CMD line output drives are push-pull drivers instead of open-drain. The registration process is accomplished as follows:

1. The bus is activated.
2. The SDIO card host broadcasts SD\_APP\_OP\_COND (ACMD41).
3. The cards respond with the contents of their operation condition registers.
4. The incompatible cards are placed in the inactive state.
5. The SDIO card host broadcasts ALL\_SEND\_CID (CMD2) to all active cards.
6. The cards send back their unique card identification numbers (CIDs) and enter the Identification state.
7. The SDIO card host issues SET\_RELATIVE\_ADDR (CMD3) to an active card with an address. This new address is called the relative card address (RCA); it is shorter than the CID and addresses the card. The assigned card changes to the Standby state. The SDIO card host can reissue this command to change the RCA. The RCA of the card is the last assigned value.
8. The SDIO card host repeats steps 5 through 7 with all active cards.

For the SD I/O card, the registration process is accomplished as follows:

1. The bus is activated.
2. The SDIO card host sends IO\_SEND\_OP\_COND (CMD5).
3. The cards respond with the contents of their operation condition registers.
4. The incompatible cards are set to the inactive state.
5. The SDIO card host issues SET\_RELATIVE\_ADDR (CMD3) to an active card with an address. This new address is called the relative card address (RCA); it is shorter than the CID and addresses the card. The assigned card changes to the Standby state. The SDIO card host can reissue this command to change the RCA. The RCA of the card is the last assigned value.

#### 21.4.5 Block write

During block write (CMD24 - 27) one or more blocks of data are transferred from the host to the card with a CRC appended to the end of each block by the host. A card supporting block write is always able to accept a block of data defined by WRITE\_BL\_LEN. If the CRC fails, the card indicates the failure on the SDIO\_D line and the transferred data are discarded and not written, and all further transmitted blocks (in multiple block write mode) are ignored.

If the host uses partial blocks whose accumulated length is not block aligned and, block misalignment is not allowed (CSD parameter WRITE\_BLK\_MISALIGN is not set), the card will detect the block misalignment error before the beginning of the first misaligned block. (ADDRESS\_ERROR error bit is set in the status register). The write operation will also be aborted if the host tries to write over a write-protected area. In this case, however, the card will set the WP\_VIOLATION bit.

Programming of the CID and CSD registers does not require a previous block length setting. The transferred data is also CRC protected. If a part of the CSD or CID register is stored in ROM, then this unchangeable part must match the corresponding part of the receive buffer. If this match fails, then the card reports an error and does not change any register contents. Some cards may require long and unpredictable times to write a block of data. After receiving a block of data and completing the CRC check, the card begins writing and holds the SDIO\_D line low if its write buffer is full and unable to accept new data from a new WRITE\_BLOCK command. The host may poll the status of the card with a SEND\_STATUS command (CMD13) at any time, and the card will respond with its status. The READY\_FOR\_DATA status bit indicates whether the card can accept new data or whether the write process is still in progress. The host may deselect the card by issuing CMD7 (to

select a different card), which will place the card in the Disconnect state and release the SDIO\_D line(s) without interrupting the write operation. When selecting the card again, it will reactivate busy indication by pulling SDIO\_D to low if programming is still in progress and the write buffer is unavailable.

#### 21.4.6 Block read

In Block read mode the basic unit of data transfer is a block whose maximum size is defined in the CSD (READ\_BL\_LEN). If READ\_BL\_PARTIAL is set, smaller blocks whose start and end addresses are entirely contained within one physical block (as defined by READ\_BL\_LEN) may also be transmitted. A CRC is appended to the end of each block, ensuring data transfer integrity. CMD17 (READ\_SINGLE\_BLOCK) initiates a block read and after completing the transfer, the card returns to the Transfer state.

CMD18 (READ\_MULTIPLE\_BLOCK) starts a transfer of several consecutive blocks.

The host can abort reading at any time, within a multiple block operation, regardless of its type. Transaction abort is done by sending the stop transmission command.

If the card detects an error (for example, out of range, address misalignment or internal error) during a multiple block read operation (both types) it stops the data transmission and remains in the data state. The host must then abort the operation by sending the stop transmission command. The read error is reported in the response to the stop transmission command.

If the host sends a stop transmission command after the card transmits the last block of a multiple block operation with a predefined number of blocks, it is responded to as an illegal command, since the card is no longer in the data state. If the host uses partial blocks whose accumulated length is not block-aligned and block misalignment is not allowed, the card detects a block misalignment error condition at the beginning of the first misaligned block (ADDRESS\_ERROR error bit is set in the status register).

#### 21.4.7 Stream access, stream write and stream read (MultiMediaCard only)

In stream mode, data is transferred in bytes and no CRC is appended at the end of each block.

##### Stream write (MultiMediaCard only)

WRITE\_DAT\_UNTIL\_STOP (CMD20) starts the data transfer from the SDIO card host to the card, beginning at the specified address and continuing until the SDIO card host issues a stop command. When partial blocks are allowed (CSD parameter WRITE\_BL\_PARTIAL is set), the data stream can start and stop at any address within the card address space, otherwise it can only start and stop at block boundaries. Because the amount of data to be transferred is not determined in advance, a CRC cannot be used. When the end of the memory range is reached while sending data and no stop command is sent by the SD card host, any additional transferred data are discarded.

The maximum clock frequency for a stream write operation is given by the following equation fields of the card-specific data register:

$$\text{Maximumspeed} = \text{MIN}(\text{TRANSPEED}, \frac{(8 \times 2^{\text{writeblen}})(-\text{NSAC})}{\text{TAAC} \times \text{R2WFACTOR}})$$

- Maximumspeed = maximum write frequency
- TRANSPEED = maximum data transfer rate
- writeblen = maximum write data block length
- NSAC = data read access time 2 in CLK cycles
- TAAC = data read access time 1
- R2WFACTOR = write speed factor

If the host attempts to use a higher frequency, the card may not be able to process the data and stop programming, set the OVERRUN error bit in the status register, and while ignoring all further data transfer, wait (in the receive data state) for a stop command. The write operation is also aborted if the host tries to write over a write-protected area. In this case, however, the card sets the WP\_VIOLATION bit.

### **Stream read (MultiMediaCard only)**

`READ_DAT_UNTIL_STOP` (CMD11) controls a stream-oriented data transfer.

This command instructs the card to send its data, starting at a specified address, until the SDIO card host sends `STOP_TRANSMISSION` (CMD12). The stop command has an execution delay due to the serial command transmission and the data transfer stops after the end bit of the stop command. When the end of the memory range is reached while sending data and no stop command is sent by the SDIO card host, any subsequent data sent are considered undefined.

The maximum clock frequency for a stream read operation is given by the following equation and uses fields of the card specific data register.

$$\text{Maximumspeed} = \text{MIN}(\text{TRANSPEED}, \frac{(8 \times 2^{\text{readblen}})(-\text{NSAC})}{\text{TAAC} \times \text{R2WFACTOR}})$$

- Maximumspeed = maximum read frequency
- TRANSPEED = maximum data transfer rate
- readblen = maximum read data block length
- writeblen = maximum write data block length
- NSAC = data read access time 2 in CLK cycles
- TAAC = data read access time 1
- R2WFACTOR = write speed factor

If the host attempts to use a higher frequency, the card is not able to sustain data transfer. If this happens, the card sets the UNDERRUN error bit in the status register, aborts the transmission and waits in the data state for a stop command.

#### **21.4.8 Erase: group erase and sector erase**

The erasable unit of the MultiMediaCard is the erase group. The erase group is measured in write blocks, which are the basic writable units of the card. The size of the erase group is a card-specific parameter and defined in the CSD.

The host can erase a contiguous range of Erase Groups. Starting the erase process is a three-step sequence.

First the host defines the start address of the range using the ERASE\_GROUP\_START (CMD35) command, next it defines the last address of the range using the ERASE\_GROUP\_END (CMD36) command and, finally, it starts the erase process by issuing the ERASE (CMD38) command. The address field in the erase commands is an Erase Group address in byte units. The card ignores all LSBs below the Erase Group size, effectively rounding the address down to the Erase Group boundary.

If an erase command is received out of sequence, the card sets the ERASE\_SEQ\_ERROR bit in the status register and resets the whole sequence.

If an out-of-sequence (neither of the erase commands, except SEND\_STATUS) command received, the card sets the ERASE\_RESET status bit in the status register, resets the erase sequence and executes the last command.

If the erase range includes write protected blocks, they are left intact and only unprotected blocks are erased. The WP\_ERASE\_SKIP status bit in the status register is set.

The card indicates that an erase is in progress by holding SDIO\_D low. The actual erase time may be quite long, and the host may issue CMD7 to deselect the card.

#### 21.4.9 Wide bus selection or deselection

Wide bus (4-bit bus width) operation mode is selected or deselected using SET\_BUS\_WIDTH (ACMD6). The default bus width after power-up or GO\_IDLE\_STATE (CMD0) is 1 bit. SET\_BUS\_WIDTH (ACMD6) is only valid in a transfer state, which means that the bus width can be changed only after a card is selected by SELECT/DESELECT\_CARD (CMD7).

#### 21.4.10 Protection management

Three write protection methods for the cards are supported in the SDIO card host module:

1. internal card write protection (card responsibility)
2. mechanical write protection switch (SDIO card host module responsibility only)
3. password-protected card lock operation

##### Internal card write protection

Card data can be protected against write and erase. By setting the permanent or temporary write-protect bits in the CSD, the entire card can be permanently write-protected by the manufacturer or content provider. For cards that support write protection of groups of sectors by setting the WP\_GRP\_ENABLE bit in the CSD, portions of the data can be protected, and the write protection can be changed by the application. The write protection is in units of WP\_GRP\_SIZE sectors as specified in the CSD. The SET\_WRITE\_PROT and CLR\_WRITE\_PROT commands control the protection of the addressed group. The SEND\_WRITE\_PROT command is similar to a single block read command. The card sends a data block containing 32 write protection bits (representing 32 write protect groups starting at the specified address) followed by 16 CRC bits. The address field in the write protect commands is a group address in byte units.

The card ignores all LSBs below the group size.

### Mechanical write protect switch

A mechanical sliding tab on the side of the card allows the user to set or clear the write protection on a card. When the sliding tab is positioned with the window open, the card is write-protected, and when the window is closed, the card contents can be changed. A matched switch on the socket side indicates to the SDIO card host module that the card is write-protected. The SDIO card host module is responsible for protecting the card. The position of the write protect switch is unknown to the internal circuitry of the card.

### Password protect

The password protection feature enables the SDIO card host module to lock and unlock a card with a password. The password is stored in the 128-bit PWD register and its size is set in the 8-bit PWD\_LEN register. These registers are nonvolatile so that a power cycle does not erase them. Locked cards respond to and execute certain commands. This means that the SDIO card host module is allowed to reset, initialize, select, and query for status, however it is not allowed to access data on the card. When the password is set (as indicated by a nonzero value of PWD\_LEN), the card is locked automatically after power-up. As with the CSD and CID register write commands, the lock/unlock commands are available in the transfer state only. In this state, the command does not include an address argument and the card must be selected before using it. The card lock/unlock commands have the structure and bus transaction types of a regular single-block write command. The transferred data block includes all of the required information for the command (the password setting mode, the PWD itself, and card lock/unlock). The command data block size is defined by the SDIO card host module before it sends the card lock/unlock command, and has the structure shown in [Table 114](#).

The bit settings are as follows:

- ERASE: setting it forces an erase operation. All other bits must be zero, and only the command byte is sent
- LOCK\_UNLOCK: setting it locks the card. LOCK\_UNLOCK can be set simultaneously with SET\_PWD, however not with CLR\_PWD
- CLR\_PWD: setting it clears the password data
- SET\_PWD: setting it saves the password data to memory
- PWD\_LEN: it defines the length of the password in bytes
- PWD: the password (new or currently used, depending on the command)

The following sections list the command sequences to set/reset a password, lock/unlock the card, and force an erase.

### Setting the password

1. Select a card (SELECT/DESELECT\_CARD, CMD7), if none is already selected.
2. Define the block length (SET\_BLOCKLEN, CMD16) to send, given by the 8-bit card lock/unlock mode, the 8-bit PWD\_LEN, and the number of bytes of the new password. When a password replacement is done, the block size must take into account that both the old and the new passwords are sent with the command.
3. Send LOCK/UNLOCK (CMD42) with the appropriate data block size on the data line including the 16-bit CRC. The data block indicates the mode (SET\_PWD = 1), the length (PWD\_LEN), and the password (PWD) itself. When a password replacement is done, the length value (PWD\_LEN) includes the length of both passwords, the old and

the new one, and the PWD field includes the old password (currently used) followed by the new password.

4. When the password is matched, the new password and its size are saved into the PWD and PWD\_LEN fields, respectively. When the old password sent does not correspond (in size and/or content) to the expected password, the LOCK\_UNLOCK\_FAILED error bit is set in the card status register, and the password is not changed.

The password length field (PWD\_LEN) indicates whether a password is currently set. When this field is nonzero, there is a password set and the card locks itself after power-up. It is possible to lock the card immediately in the current power session by setting the LOCK\_UNLOCK bit (while setting the password) or sending an additional command for card locking.

### Resetting the password

1. Select a card (SELECT/DESELECT\_CARD, CMD7), if none is already selected.
2. Define the block length (SET\_BLOCKLEN, CMD16) to send, given by the 8-bit card lock/unlock mode, the 8-bit PWD\_LEN, and the number of bytes in the currently used password.
3. Send LOCK/UNLOCK (CMD42) with the appropriate data block size on the data line including the 16-bit CRC. The data block indicates the mode (CLR\_PWD = 1), the length (PWD\_LEN) and the password (PWD) itself. The LOCK\_UNLOCK bit is ignored.
4. When the password is matched, the PWD field is cleared and PWD\_LEN is set to 0. When the password sent does not correspond (in size and/or content) to the expected password, the LOCK\_UNLOCK\_FAILED error bit is set in the card status register, and the password is not changed.

### Locking a card

1. Select a card (SELECT/DESELECT\_CARD, CMD7), if none is already selected.
2. Define the block length (SET\_BLOCKLEN, CMD16) to send, given by the 8-bit card lock/unlock mode (byte 0 in [Table 114](#)), the 8-bit PWD\_LEN, and the number of bytes of the current password.
3. Send LOCK/UNLOCK (CMD42) with the appropriate data block size on the data line including the 16-bit CRC. The data block indicates the mode (LOCK\_UNLOCK = 1), the length (PWD\_LEN), and the password (PWD) itself.
4. When the password is matched, the card is locked and the CARD\_IS\_LOCKED status bit is set in the card status register. When the password sent does not correspond (in size and/or content) to the expected password, the LOCK\_UNLOCK\_FAILED error bit is set in the card status register, and the lock fails.

It is possible to set the password and to lock the card in the same sequence. In this case, the SDIO card host module performs all the required steps for setting the password (see [Setting the password on page 622](#)), however it is necessary to set the LOCK\_UNLOCK bit in Step 3 when the new password command is sent.

When the password is previously set (PWD\_LEN is not 0), the card is locked automatically after power-on reset. An attempt to lock a locked card or to lock a card that does not have a password fails and the LOCK\_UNLOCK\_FAILED error bit is set in the card status register.

### Unlocking the card

1. Select a card (SELECT/DESELECT\_CARD, CMD7), if none is already selected.
2. Define the block length (SET\_BLOCKLEN, CMD16) to send, given by the 8-bit cardlock/unlock mode (byte 0 in [Table 114](#)), the 8-bit PWD\_LEN, and the number of bytes of the current password.
3. Send LOCK/UNLOCK (CMD42) with the appropriate data block size on the data line including the 16-bit CRC. The data block indicates the mode (LOCK\_UNLOCK = 0), the length (PWD\_LEN), and the password (PWD) itself.
4. When the password is matched, the card is unlocked and the CARD\_IS\_LOCKED status bit is cleared in the card status register. When the password sent is not correct in size and/or content and does not correspond to the expected password, the LOCK\_UNLOCK\_FAILED error bit is set in the card status register, and the card remains locked.

The unlocking function is only valid for the current power session. When the PWD field is not clear, the card is locked automatically on the next power-up.

An attempt to unlock an unlocked card fails and the LOCK\_UNLOCK\_FAILED error bit is set in the card status register.

### Forcing erase

If the user has forgotten the password (PWD content), it is possible to access the card after clearing all the data on the card. This forced erase operation erases all card data and all password data.

1. Select a card (SELECT/DESELECT\_CARD, CMD7), if none is already selected.
2. Set the block length (SET\_BLOCKLEN, CMD16) to 1 byte. Only the 8-bit card lock/unlock byte (byte 0 in [Table 114](#)) is sent.
3. Send LOCK/UNLOCK (CMD42) with the appropriate data byte on the data line including the 16-bit CRC. The data block indicates the mode (ERASE = 1). All other bits must be zero.
4. When the ERASE bit is the only bit set in the data field, all card contents are erased, including the PWD and PWD\_LEN fields, and the card is no longer locked. When any other bits are set, the LOCK\_UNLOCK\_FAILED error bit is set in the card status register and the card retains all of its data, and remains locked.

An attempt to use a force erase on an unlocked card fails and the LOCK\_UNLOCK\_FAILED error bit is set in the card status register.

#### 21.4.11 Card status register

The response format R1 contains a 32-bit field named card status. This field is intended to transmit the card status information (which may be stored in a local status register) to the host. If not specified otherwise, the status entries are always related to the previously issued command.

[Table 101](#) defines the different entries of the status. The type and clear condition fields in the table are abbreviated as follows:

Type:

- E: error bit
- S: status bit
- R: detected and set for the actual command response
- X: detected and set during command execution. The SDIO card host must poll the card by issuing the status command to read these bits.

Clear condition:

- A: according to the card current state
- B: always related to the previous command. Reception of a valid command clears it (with a delay of one command)
- C: clear by read

**Table 101. Card status**

Bits	Identifier	Type	Value	Description	Clear condition
31	ADDRESS_OUT_OF_RANGE	E R X	'0'= no error '1'= error	The command address argument was out of the allowed range for this card. A multiple block or stream read/write operation is (although started in a valid address) attempting to read or write beyond the card capacity.	C
30	ADDRESS_MISALIGN		'0'= no error '1'= error	The commands address argument (in accordance with the currently set block length) positions the first data block misaligned to the card physical blocks. A multiple block read/write operation (although started with a valid address/block-length combination) is attempting to read or write a data block which is not aligned with the physical blocks of the card.	C
29	BLOCK_LEN_ERROR		'0'= no error '1'= error	Either the argument of a SET_BLOCKLEN command exceeds the maximum value allowed for the card, or the previously defined block length is illegal for the current command (e.g. the host issues a write command, the current block length is smaller than the maximum allowed value for the card and it is not allowed to write partial blocks)	C
28	ERASE_SEQ_ERROR		'0'= no error '1'= error	An error in the sequence of erase commands occurred.	C
27	ERASE_PARAM	E X	'0'= no error '1'= error	An invalid selection of erase groups for erase occurred.	C
26	WP_VIOLATION	E X	'0'= no error '1'= error	Attempt to program a write-protected block.	C

Table 101. Card status (continued)

Bits	Identifier	Type	Value	Description	Clear condition
25	CARD_IS_LOCKED	S R	'0' = card unlocked '1' = card locked	When set, signals that the card is locked by the host	A
24	LOCK_UNLOCK_FAILED	E X	'0'= no error '1'= error	Set when a sequence or password error has been detected in lock/unlock card command	C
23	COM_CRC_ERROR	E R	'0'= no error '1'= error	The CRC check of the previous command failed.	B
22	ILLEGAL_COMMAND	E R	'0'= no error '1'= error	Command not legal for the card state	B
21	CARD_ECC FAILED	E X	'0'= success '1'= failure	Card internal ECC was applied but failed to correct the data.	C
20	CC_ERROR	E R	'0'= no error '1'= error	(Undefined by the standard) A card error occurred, which is not related to the host command.	C
19	ERROR	E X	'0'= no error '1'= error	(Undefined by the standard) A generic card error related to the (and detected during) execution of the last host command (e.g. read or write failures).	C
18	Reserved				
17	Reserved				
16	CID/CSD_OVERWRITE	E X	'0'= no error '1'= error	Can be either of the following errors: – The CID register has already been written and cannot be overwritten – The read-only section of the CSD does not match the card contents – An attempt to reverse the copy (set as original) or permanent WP (unprotected) bits was made	C
15	WP_ERASE_SKIP	E X	'0'= not protected '1'= protected	<b>Set when only partial address space was erased due to existing write</b>	C
14	CARD_ECC_DISABLED	S X	'0'= enabled '1'= disabled	The command has been executed without using the internal ECC.	A
13	ERASE_RESET		'0'= cleared '1'= set	An erase sequence was cleared before executing because an out of erase sequence command was received (commands other than CMD35, CMD36, CMD38 or CMD13)	C

**Table 101. Card status (continued)**

Bits	Identifier	Type	Value	Description	Clear condition
12:9	CURRENT_STATE	S R	0 = Idle 1 = Ready 2 = Ident 3 = Stby 4 = Tran 5 = Data 6 = Rcv 7 = Prg 8 = Dis 9 = Btst 10-15 = reserved	The state of the card when receiving the command. If the command execution causes a state change, it will be visible to the host in the response on the next command. The four bits are interpreted as a binary number between 0 and 15.	B
8	READY_FOR_DATA	S R	'0'= not ready '1' = ready	Corresponds to buffer empty signalling on the bus	
7	SWITCH_ERROR	E X	'0'= no error '1'= switch error	If set, the card did not switch to the expected mode as requested by the SWITCH command	B
6	Reserved				
5	APP_CMD	S R	'0' = Disabled '1' = Enabled	The card will expect ACMD, or an indication that the command has been interpreted as ACMD	C
4	Reserved for SD I/O Card				
3	AKE_SEQ_ERROR	E R	'0'= no error '1'= error	Error in the sequence of the authentication process	C
2	Reserved for application specific commands				
1	Reserved for manufacturer test mode				
0					

#### 21.4.12 SD status register

The SD status contains status bits that are related to the SD memory card proprietary features and may be used for future application-specific usage. The size of the SD Status is one data block of 512 bits. The contents of this register are transmitted to the SDIO card host if ACMD13 is sent (CMD55 followed with CMD13). ACMD13 can be sent to a card in transfer state only (card is selected).

*Table 102* defines the different entries of the SD status register. The type and clear condition fields in the table are abbreviated as follows:

Type:

- E: error bit
- S: status bit
- R: detected and set for the actual command response
- X: detected and set during command execution. The SDIO card Host must poll the card by issuing the status command to read these bits

Clear condition:

- A: according to the card current state
- B: always related to the previous command. Reception of a valid command clears it (with a delay of one command)
- C: clear by read

**Table 102. SD status**

Bits	Identifier	Type	Value	Description	Clear condition
511: 510	DAT_BUS_WIDTH	S R	'00'= 1 (default) '01'= reserved '10'= 4 bit width '11'= reserved	Shows the currently defined databus width that was defined by SET_BUS_WIDTH command	A
509	SECURED_MODE	S R	'0'= Not in the mode '1'= In Secured Mode	Card is in Secured Mode of operation (refer to the "SD Security Specification").	A
508: 496	Reserved				
495: 480	SD_CARD_TYPE	S R	'00xxh'= SD Memory Cards as defined in Physical Spec Ver1.01-2.00 ('x'= don't care). The following cards are currently defined: '0000'= Regular SD RD/WR Card. '0001'= SD ROM Card	In the future, the 8 LSBs will be used to define different variations of an SD memory card (each bit will define different SD types). The 8 MSBs will be used to define SD Cards that do not comply with current SD physical layer specification.	A
479: 448	SIZE_OF_PROTECT_ED_AREA	S R	Size of protected area (See below)	(See below)	A
447: 440	SPEED_CLASS	S R	Speed Class of the card (See below)	(See below)	A
439: 432	PERFORMANCE_MOVE	S R	Performance of move indicated by 1 [MB/s] step. (See below)	(See below)	A
431:428	AU_SIZE	S R	Size of AU (See below)	(See below)	A
427:424	Reserved				
423:408	ERASE_SIZE	S R	Number of AUs to be erased at a time	(See below)	A
407:402	ERASE_TIMEOUT	S R	Timeout value for erasing areas specified by UNIT_OF_ERASE_AU	(See below)	A
401:400	ERASE_OFFSET	S R	Fixed offset value added to erase time.	(See below)	A
399:312	Reserved				
311:0	Reserved for Manufacturer				

### **SIZE\_OF\_PROTECTED\_AREA**

Setting this field differs between standard- and high-capacity cards. In the case of a standard-capacity card, the capacity of protected area is calculated as follows:

$$\text{Protected area} = \text{SIZE\_OF\_PROTECTED\_AREA\_} * \text{MULT} * \text{BLOCK\_LEN}.$$

**SIZE\_OF\_PROTECTED\_AREA** is specified by the unit in **MULT\*BLOCK\_LEN**.

In the case of a high-capacity card, the capacity of protected area is specified in this field:

$$\text{Protected area} = \text{SIZE\_OF\_PROTECTED\_AREA}$$

**SIZE\_OF\_PROTECTED\_AREA** is specified by the unit in bytes.

### **SPEED\_CLASS**

This 8-bit field indicates the speed class and the value can be calculated by  $P_W/2$  (where  $P_W$  is the write performance).

**Table 103. Speed class code field**

<b>SPEED_CLASS</b>	<b>Value definition</b>
00h	Class 0
01h	Class 2
02h	Class 4
03h	Class 6
04h – FFh	Reserved

### **PERFORMANCE\_MOVE**

This 8-bit field indicates  $P_m$  (performance move) and the value can be set by 1 [MB/sec] steps. If the card does not move used RUs (recording units),  $P_m$  should be considered as infinity. Setting the field to FFh means infinity.

**Table 104. Performance move field**

<b>PERFORMANCE_MOVE</b>	<b>Value definition</b>
00h	Not defined
01h	1 [MB/sec]
02h	02h 2 [MB/sec]
-----	-----
FEh	254 [MB/sec]
FFh	Infinity

### **AU\_SIZE**

This 4-bit field indicates the AU size and the value can be selected in the power of 2 base from 16 KB.

**Table 105. AU\_SIZE field**

AU_SIZE	Value definition
00h	Not defined
01h	16 KB
02h	32 KB
03h	64 KB
04h	128 KB
05h	256 KB
06h	512 KB
07h	1 MB
08h	2 MB
09h	4 MB
Ah – Fh	Reserved

The maximum AU size, which depends on the card capacity, is defined in [Table 106](#). The card can be set to any AU size between RU size and maximum AU size.

**Table 106. Maximum AU size**

Capacity	16 MB-64 MB	128 MB-256 MB	512 MB	1 GB-32 GB
Maximum AU Size	512 KB	1 MB	2 MB	4 MB

## ERASE\_SIZE

This 16-bit field indicates  $N_{ERASE}$ . When  $N_{ERASE}$  numbers of AUs are erased, the timeout value is specified by ERASE\_TIMEOUT (Refer to [ERASE\\_TIMEOUT](#)). The host should determine the proper number of AUs to be erased in one operation so that the host can show the progress of the erase operation. If this field is set to 0, the erase timeout calculation is not supported.

**Table 107. Erase size field**

ERASE_SIZE	Value definition
0000h	Erase timeout calculation is not supported.
0001h	1 AU
0002h	2 AU
0003h	3 AU
-----	-----
FFFFh	65535 AU

## ERASE\_TIMEOUT

This 6-bit field indicates  $T_{ERASE}$  and the value indicates the erase timeout from offset when multiple AUs are being erased as specified by ERASE\_SIZE. The range of

ERASE\_TIMEOUT can be defined as up to 63 seconds and the card manufacturer can choose any combination of ERASE\_SIZE and ERASE\_TIMEOUT depending on the implementation. Determining ERASE\_TIMEOUT determines the ERASE\_SIZE.

**Table 108. Erase timeout field**

ERASE_TIMEOUT	Value definition
00	Erase timeout calculation is not supported.
01	1 [sec]
02	2 [sec]
03	3 [sec]
-----	-----
63	63 [sec]

### ERASE\_OFFSET

This 2-bit field indicates  $T_{OFFSET}$  and one of four values can be selected. This field is meaningless if the ERASE\_SIZE and ERASE\_TIMEOUT fields are set to 0.

**Table 109. Erase offset field**

ERASE_OFFSET	Value definition
0h	0 [sec]
1h	1 [sec]
2h	2 [sec]
3h	3 [sec]

## 21.4.13 SD I/O mode

### SD I/O interrupts

To allow the SD I/O card to interrupt the MultiMediaCard/SD module, an interrupt function is available on a pin on the SD interface. Pin 8, used as SDIO\_D1 when operating in the 4-bit SD mode, signals the cards interrupt to the MultiMediaCard/SD module. The use of the interrupt is optional for each card or function within a card. The SD I/O interrupt is level-sensitive, which means that the interrupt line must be held active (low) until it is either recognized and acted upon by the MultiMediaCard/SD module or deasserted due to the end of the interrupt period. After the MultiMediaCard/SD module has serviced the interrupt, the interrupt status bit is cleared via an I/O write to the appropriate bit in the SD I/O card's internal registers. The interrupt output of all SD I/O cards is active low and the application must provide external pull-up resistors on all data lines (SDIO\_D[3:0]). The MultiMediaCard/SD module samples the level of pin 8 (SDIO\_D/IRQ) into the interrupt detector only during the interrupt period. At all other times, the MultiMediaCard/SD module ignores this value.

The interrupt period is applicable for both memory and I/O operations. The definition of the interrupt period for operations with single blocks is different from the definition for multiple-block data transfers.

## SD I/O suspend and resume

Within a multifunction SD I/O or a card with both I/O and memory functions, there are multiple devices (I/O and memory) that share access to the MMC/SD bus. To share access to the MMC/SD module among multiple devices, SD I/O and combo cards optionally implement the concept of suspend/resume. When a card supports suspend/resume, the MMC/SD module can temporarily halt a data transfer operation to one function or memory (suspend) to free the bus for a higher-priority transfer to a different function or memory. After this higher-priority transfer is complete, the original transfer is resumed (restarted) where it left off. Support of suspend/resume is optional on a per-card basis. To perform the suspend/resume operation on the MMC/SD bus, the MMC/SD module performs the following steps:

1. Determines the function currently using the SDIO\_D [3:0] line(s)
2. Requests the lower-priority or slower transaction to suspend
3. Waits for the transaction suspension to complete
4. Begins the higher-priority transaction
5. Waits for the completion of the higher priority transaction
6. Restores the suspended transaction

## SD I/O ReadWait

The optional ReadWait (RW) operation is defined only for the SD 1-bit and 4-bit modes. The ReadWait operation allows the MMC/SD module to signal a card that it is reading multiple registers (IO\_RW\_EXTENDED, CMD53) to temporarily stall the data transfer while allowing the MMC/SD module to send commands to any function within the SD I/O device. To determine when a card supports the ReadWait protocol, the MMC/SD module must test capability bits in the internal card registers. The timing for ReadWait is based on the interrupt period.

### 21.4.14 Commands and responses

#### Application-specific and general commands

The SD card host module system is designed to provide a standard interface for a variety of applications types. In this environment, there is a need for specific customer/application features. To implement these features, two types of generic commands are defined in the standard: application-specific commands (ACMD) and general commands (GEN\_CMD).

When the card receives the APP\_CMD (CMD55) command, the card expects the next command to be an application-specific command. ACMDs have the same structure as regular MultiMediaCard commands and can have the same CMD number. The card recognizes it as ACMD because it appears after APP\_CMD (CMD55). When the command immediately following the APP\_CMD (CMD55) is not a defined application-specific command, the standard command is used. For example, when the card has a definition for SD\_STATUS (ACMD13), and receives CMD13 immediately following APP\_CMD (CMD55), this is interpreted as SD\_STATUS (ACMD13). However, when the card receives CMD7 immediately following APP\_CMD (CMD55) and the card does not have a definition for ACMD7, this is interpreted as the standard (SELECT/DESELECT\_CARD) CMD7.

To use one of the manufacturer-specific ACMDs the SD card Host must perform the following steps:

1. Send APP\_CMD (CMD55)

The card responds to the MultiMediaCard/SD module, indicating that the APP\_CMD bit is set and an ACMD is now expected.

2. Send the required ACMD

The card responds to the MultiMediaCard/SD module, indicating that the APP\_CMD bit is set and that the accepted command is interpreted as an ACMD. When a nonACMD is sent, it is handled by the card as a normal MultiMediaCard command and the APP\_CMD bit in the card status register stays clear.

When an invalid command is sent (neither ACMD nor CMD) it is handled as a standard MultiMediaCard illegal command error.

The bus transaction for a GEN\_CMD is the same as the single-block read or write commands (WRITE\_BLOCK, CMD24 or READ\_SINGLE\_BLOCK,CMD17). In this case, the argument denotes the direction of the data transfer rather than the address, and the data block has vendor-specific format and meaning.

The card must be selected (in transfer state) before sending GEN\_CMD (CMD56). The data block size is defined by SET\_BLOCKLEN (CMD16). The response to GEN\_CMD (CMD56) is in R1b format.

### Command types

Both application-specific and general commands are divided into the four following types:

- **broadcast command (BC):** sent to all cards; no responses returned.
- **broadcast command with response (BCR):** sent to all cards; responses received from all cards simultaneously.
- **addressed (point-to-point) command (AC):** sent to the card that is selected; does not include a data transfer on the SDIO\_D line(s).
- **addressed (point-to-point) data transfer command (ADTC):** sent to the card that is selected; includes a data transfer on the SDIO\_D line(s).

### Command formats

See [Table 94 on page 609](#) for command formats.

## Commands for the MultiMediaCard/SD module

**Table 110. Block-oriented write commands**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD23	ac	[31:16] set to 0 [15:0] number of blocks	R1	SET_BLOCK_COUNT	Defines the number of blocks which are going to be transferred in the multiple-block read or write command that follows.
CMD24	adtc	[31:0] data address	R1	WRITE_BLOCK	Writes a block of the size selected by the SET_BLOCKLEN command.
CMD25	adtc	[31:0] data address	R1	WRITE_MULTIPLE_BLOCK	Continuously writes blocks of data until a STOP_TRANSMISSION follows or the requested number of blocks has been received.

**Table 110. Block-oriented write commands (continued)**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD26	adtc	[31:0] stuff bits	R1	PROGRAM_CID	Programming of the card identification register. This command must be issued only once per card. The card contains hardware to prevent this operation after the first programming. Normally this command is reserved for manufacturer.
CMD27	adtc	[31:0] stuff bits	R1	PROGRAM_CSD	Programming of the programmable bits of the CSD.

**Table 111. Block-oriented write protection commands**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD28	ac	[31:0] data address	R1b	SET_WRITE_PROT	If the card has write protection features, this command sets the write protection bit of the addressed group. The properties of write protection are coded in the card-specific data (WP_GRP_SIZE).
CMD29	ac	[31:0] data address	R1b	CLR_WRITE_PROT	If the card provides write protection features, this command clears the write protection bit of the addressed group.
CMD30	adtc	[31:0] write protect data address	R1	SEND_WRITE_PROT	If the card provides write protection features, this command asks the card to send the status of the write protection bits.
CMD31	Reserved				

**Table 112. Erase commands**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD32 ... CMD34	Reserved. These command indexes cannot be used in order to maintain backward compatibility with older versions of the MultiMediaCard.				
CMD35	ac	[31:0] data address	R1	ERASE_GROUP_START	Sets the address of the first erase group within a range to be selected for erase.
CMD36	ac	[31:0] data address	R1	ERASE_GROUP_END	Sets the address of the last erase group within a continuous range to be selected for erase.
CMD37	Reserved. This command index cannot be used in order to maintain backward compatibility with older versions of the MultiMediaCards				
CMD38	ac	[31:0] stuff bits	R1	ERASE	Erases all previously selected write blocks.

**Table 113. I/O mode commands**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD39	ac	[31:16] RCA [15:15] register write flag [14:8] register address [7:0] register data	R4	FAST_IO	Used to write and read 8-bit (register) data fields. The command addresses a card and a register and provides the data for writing if the write flag is set. The R4 response contains data read from the addressed register. This command accesses application-dependent registers that are not defined in the MultiMediaCard standard.
CMD40	bcr	[31:0] stuff bits	R5	GO_IRQ_STATE	Places the system in the interrupt mode.
CMD41	Reserved				

**Table 114. Lock card**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD42	adtc	[31:0] stuff bits	R1b	LOCK_UNLOCK	Sets/resets the password or locks/unlocks the card. The size of the data block is set by the SET_BLOCK_LEN command.
CMD43 ... CMD54	Reserved				

**Table 115. Application-specific commands**

CMD index	Type	Argument	Response format	Abbreviation	Description
CMD55	ac	[31:16] RCA [15:0] stuff bits	R1	APP_CMD	Indicates to the card that the next command bits is an application specific command rather than a standard command
CMD56	adtc	[31:1] stuff bits [0]: RD/WR			Used either to transfer a data block to the card or to get a data block from the card for general purpose/application-specific commands. The size of the data block shall be set by the SET_BLOCK_LEN command.
CMD57 ... CMD59	Reserved.				
CMD60 ... CMD63	Reserved for manufacturer.				

## 21.5 Response formats

All responses are sent via the MCCMD command line SDIO\_CMD. The response transmission always starts with the left bit of the bit string corresponding to the response code word. The code length depends on the response type.

A response always starts with a start bit (always 0), followed by the bit indicating the direction of transmission (card = 0). A value denoted by x in the tables below indicates a variable entry. All responses, except for the R3 response type, are protected by a CRC. Every command code word is terminated by the end bit (always 1).

There are five types of responses. Their formats are defined as follows:

### 21.5.1 R1 (normal response command)

Code length = 48 bits. The 45:40 bits indicate the index of the command to be responded to, this value being interpreted as a binary-coded number (between 0 and 63). The status of the card is coded in 32 bits.

**Table 116. R1 response**

Bit position	Width (bits)	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	X	Command index
[39:8]	32	X	Card status
[7:1]	7	X	CRC7
0	1	1	End bit

### 21.5.2 R1b

It is identical to R1 with an optional busy signal transmitted on the data line. The card may become busy after receiving these commands based on its state prior to the command reception.

### 21.5.3 R2 (CID, CSD register)

Code length = 136 bits. The contents of the CID register are sent as a response to the CMD2 and CMD10 commands. The contents of the CSD register are sent as a response to CMD9. Only the bits [127...1] of the CID and CSD are transferred, the reserved bit [0] of these registers is replaced by the end bit of the response. The card indicates that an erase is in progress by holding MCDAT low. The actual erase time may be quite long, and the host may issue CMD7 to deselect the card.

**Table 117. R2 response**

Bit position	Width (bits)	Value	Description
135	1	0	Start bit
134	1	0	Transmission bit
[133:128]	6	'111111'	Command index
[127:1]	127	X	Card status
0	1	1	End bit

#### 21.5.4 R3 (OCR register)

Code length: 48 bits. The contents of the OCR register are sent as a response to CMD1. The level coding is as follows: restricted voltage windows = low, card busy = low.

**Table 118. R3 response**

Bit position	Width (bits)	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	'111111'	Reserved
[39:8]	32	X	OCR register
[7:1]	7	'1111111'	Reserved
0	1	1	End bit

#### 21.5.5 R4 (Fast I/O)

Code length: 48 bits. The argument field contains the RCA of the addressed card, the register address to be read out or written to, and its content.

**Table 119. R4 response**

Bit position	Width (bits)	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	'100111'	CMD39
[39:8] Argument field	[31:16]	16	X
	[15:8]	8	X
	[7:0]	8	X
[7:1]	7	X	CRC7
0	1	1	End bit

### 21.5.6 R4b

For SD I/O only: an SDIO card receiving the CMD5 will respond with a unique SDIO response R4. The format is:

**Table 120. R4b response**

Bit position	Width (bits)	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	x	Reserved
[39:8] Argument field	39	16	Card is ready
	[38:36]	3	Number of I/O functions
	35	1	Present memory
	[34:32]	3	Stuff bits
	[31:8]	24	I/O ORC
[7:1]	7	x	Reserved
0	1	1	End bit

Once an SD I/O card has received a CMD5, the I/O portion of that card is enabled to respond normally to all further commands. This I/O enable of the function within the I/O card will remain set until a reset, power cycle or CMD52 with write to I/O reset is received by the card. Note that an SD memory-only card may respond to a CMD5. The proper response for a memory-only card would be *Present memory* = 1 and *Number of I/O functions* = 0. A memory-only card built to meet the SD Memory Card specification version 1.0 would detect the CMD5 as an illegal command and not respond. The I/O aware host will send CMD5. If the card responds with response R4, the host determines the card's configuration based on the data contained within the R4 response.

### 21.5.7 R5 (interrupt request)

Only for MultiMediaCard. Code length: 48 bits. If the response is generated by the host, the RCA field in the argument will be 0x0.

**Table 121. R5 response**

Bit position	Width (bits)	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	'101000'	CMD40
[39:8] Argument field	[31:16]	16	RCA [31:16] of winning card or of the host
	[15:0]	16	Not defined. May be used for IRQ data
[7:1]	7	x	CRC7
0	1	1	End bit

### 21.5.8 R6

Only for SD I/O. The normal response to CMD3 by a memory device. It is shown in [Table 122](#).

**Table 122. R6 response**

Bit position	Width (bits)	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	'101000'	CMD40
[39:8] Argument field	[31:16]	16	RCA [31:16] of winning card or of the host
	[15:0]	16	Not defined. May be used for IRQ data
[7:1]	7	X	CRC7
0	1	1	End bit

The card [23:8] status bits are changed when CMD3 is sent to an I/O-only card. In this case, the 16 bits of response are the SD I/O-only values:

- Bit [15] COM\_CRC\_ERROR
- Bit [14] ILLEGAL\_COMMAND
- Bit [13] ERROR
- Bits [12:0] Reserved

## 21.6 SDIO I/O card-specific operations

The following features are SD I/O-specific operations:

- SDIO read wait operation by SDIO\_D2 signalling
- SDIO read wait operation by stopping the clock
- SDIO suspend/resume operation (write and read suspend)
- SDIO interrupts

The SDIO supports these operations only if the SDIO\_DCTRL[11] bit is set, except for read suspend that does not need specific hardware implementation.

### 21.6.1 SDIO I/O read wait operation by SDIO\_D2 signalling

It is possible to start the readwait interval before the first block is received: when the data path is enabled (SDIO\_DCTRL[0] bit set), the SDIO-specific operation is enabled (SDIO\_DCTRL[11] bit set), read wait starts (SDIO\_DCTRL[10] =0 and SDIO\_DCTRL[8] =1) and data direction is from card to SDIO (SDIO\_DCTRL[1] = 1), the DPSM directly moves from Idle to Readwait. In Readwait the DPSM drives SDIO\_D2 to 0 after 2 SDIO\_CK clock cycles. In this state, when you set the RWSTOP bit (SDIO\_DCTRL[9]), the DPSM remains in Wait for two more SDIO\_CK clock cycles to drive SDIO\_D2 to 1 for one clock cycle (in accordance with SDIO specification). The DPSM then starts waiting again until it receives data from the card. The DPSM will not start a readwait interval while receiving a block even if read wait start is set: the readwait interval will start after the CRC is received. The

RWSTOP bit has to be cleared to start a new read wait operation. During the readwait interval, the SDIO can detect SDIO interrupts on SDIO\_D1.

### 21.6.2 SDIO read wait operation by stopping SDIO\_CK

If the SDIO card does not support the previous read wait method, the SDIO can perform a read wait by stopping SDIO\_CK (SDIO\_DCTRL is set just like in the method presented in [Section 21.6.1](#), but SDIO\_DCTRL[10] =1): DPSM stops the clock two SDIO\_CK cycles after the end bit of the current received block and starts the clock again after the read wait start bit is set.

As SDIO\_CK is stopped, any command can be issued to the card. During a read/wait interval, the SDIO can detect SDIO interrupts on SDIO\_D1.

### 21.6.3 SDIO suspend/resume operation

While sending data to the card, the SDIO can suspend the write operation. the SDIO\_CMD[11] bit is set and indicates to the CPSM that the current command is a suspend command. The CPSM analyzes the response and when the ACK is received from the card (suspend accepted), it acknowledges the DPSM that goes Idle after receiving the CRC token of the current block.

The hardware does not save the number of the remaining block to be sent to complete the suspended operation (resume).

The write operation can be suspended by software, just by disabling the DPSM (SDIO\_DCTRL[0] =0) when the ACK of the suspend command is received from the card. The DPSM enters then the Idle state.

To suspend a read: the DPSM waits in the Wait\_r state as the function to be suspended sends a complete packet just before stopping the data transaction. The application continues reading RxFIFO until the FIFO is empty, and the DPSM goes Idle automatically.

### 21.6.4 SDIO interrupts

SDIO interrupts are detected on the SDIO\_D1 line once the SDIO\_DCTRL[11] bit is set.

## 21.7 CE-ATA specific operations

The following features are CE-ATA specific operations:

- sending the command completion signal disable to the CE-ATA device
- receiving the command completion signal from the CE-ATA device
- signaling the completion of the CE-ATA command to the CPU, using the status bit and/or interrupt.

The SDIO supports these operations only for the CE-ATA CMD61 command, that is, if SDIO\_CMD[14] is set.

### 21.7.1 Command completion signal disable

Command completion signal disable is sent 8 bit cycles after the reception of a **short** response if the 'enable CMD completion' bit, SDIO\_CMD[12], is not set and the 'not interrupt Enable' bit, SDIO\_CMD[13], is set.

The CPSM enters the Pend state, loading the command shift register with the disable sequence “00001” and, the command counter with 43. Eight cycles after, a trigger moves the CPSM to the Send state. When the command counter reaches 48, the CPSM becomes Idle as no response is awaited.

### 21.7.2 Command completion signal enable

If the ‘enable CMD completion’ bit SDIO\_CMD[12] is set and the ‘not interrupt Enable’ bit SDIO\_CMD[13] is set, the CPSM waits for the command completion signal in the Waitcpl state.

When ‘0’ is received on the CMD line, the CPSM enters the Idle state. No new command can be sent for 7 bit cycles. Then, for the last 5 cycles (out of the 7) the CMD line is driven to ‘1’ in push-pull mode.

### 21.7.3 CE-ATA interrupt

The command completion is signaled to the CPU by the status bit SDIO\_STA[23]. This static bit can be cleared with the clear bit SDIO\_ICR[23].

The SDIO\_STA[23] status bit can generate an interrupt on each interrupt line, depending on the mask bit SDIO\_MASKx[23].

### 21.7.4 Aborting CMD61

If the command completion disable signal has not been sent and CMD61 needs to be aborted, the command state machine must be disabled. It then becomes Idle, and the CMD12 command can be sent. No command completion disable signal is sent during the operation.

## 21.8 HW flow control

The HW flow control functionality is used to avoid FIFO underrun (TX mode) and overrun (RX mode) errors.

The behavior is to stop SDIO\_CK and freeze SDIO state machines. The data transfer is stalled while the FIFO is unable to transmit or receive data. Only state machines clocked by SDIOCLK are frozen, the APB2 interface is still alive. The FIFO can thus be filled or emptied even if flow control is activated.

To enable HW flow control, the SDIO\_CLKCR[14] register bit must be set to 1. After reset Flow Control is disabled.

## 21.9 SDIO registers

The device communicates to the system via 32-bit-wide control registers accessible via APB2.

The peripheral registers have to be accessed by words (32 bits).

### 21.9.1 SDIO power control register (SDIO\_POWER)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Reserved

PWRC	TRL
rw	rw

Bits 31:2 Reserved, must be kept at reset value

Bits 1:0 **PWRCTRL:** Power supply control bits.

These bits are used to define the current functional state of the card clock:

00: Power-off: the clock to card is stopped.

01: Reserved

10: Reserved power-up

11: Power-on: the card is clocked.

**Note:** At least seven HCLK clock periods are needed between two write accesses to this register.

**Note:** After a data write, data cannot be written to this register for three SDIOCLK (48 MHz) clock periods plus two PCLK2 clock periods.

## 21.9.2 SDI clock control register (SDIO\_CLKCR)

Address offset: 0x04

Reset value: 0x0000 0000

The SDIO\_CLKCR register controls the SDIO\_CK output clock.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Reserved

HWFC_EN	NEGEDGE				WID BUS		BYPASS		PWRSAV		CLKEN																			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bits 31:15 Reserved, must be kept at reset value

Bit 14 **HWFC\_EN:** HW Flow Control enable

0b: HW Flow Control is disabled

1b: HW Flow Control is enabled

When HW Flow Control is enabled, the meaning of the TXFIFOE and RXFIFOF interrupt signals, please see SDIO Status register definition in [Section 21.9.11](#).

Bit 13 **NEGEDGE:** SDIO\_CK dephasing selection bit

0b: SDIO\_CK generated on the rising edge of the master clock SDIOCLK

1b: SDIO\_CK generated on the falling edge of the master clock SDIOCLK

Bits 12:11 **WIDBUS:** Wide bus mode enable bit

00: Default bus mode: SDIO\_D0 used

01: 4-wide bus mode: SDIO\_D[3:0] used

10: 8-wide bus mode: SDIO\_D[7:0] used

Bit 10 **BYPASS:** Clock divider bypass enable bit

0: Disable bypass: SDIOCLK is divided according to the CLKDIV value before driving the SDIO\_CK output signal.

1: Enable bypass: SDIOCLK directly drives the SDIO\_CK output signal.

Bit 9 **PWRSAV:** Power saving configuration bit

For power saving, the SDIO\_CK clock output can be disabled when the bus is idle by setting PWRSAV:

0: SDIO\_CK clock is always enabled

1: SDIO\_CK is only enabled when the bus is active

Bit 8 **CLKEN:** Clock enable bit

0: SDIO\_CK is disabled

1: SDIO\_CK is enabled

Bits 7:0 **CLKDIV:** Clock divide factor

This field defines the divide factor between the input clock (SDIOCLK) and the output clock (SDIO\_CK): SDIO\_CK frequency = SDIOCLK / [CLKDIV + 2].

#### Note:

*While the SD/SDIO card or MultiMediaCard is in identification mode, the SDIO\_CK frequency must be less than 400 kHz.*

*The clock frequency can be changed to the maximum card bus frequency when relative card addresses are assigned to all cards.*

*After a data write, data cannot be written to this register for three SDIOCLK (48 MHz) clock periods plus two PCLK2 clock periods. SDIO\_CK can also be stopped during the read wait interval for SD I/O cards: in this case the SDIO\_CLKCR register does not control SDIO\_CK.*

### 21.9.3 SDIO argument register (SDIO\_ARG)

Address offset: 0x08

Reset value: 0x0000 0000

The SDIO\_ARG register contains a 32-bit command argument, which is sent to a card as part of a command message.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CMDARG																															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bits 31:0 **CMDARG:** Command argument

Command argument sent to a card as part of a command message. If a command contains an argument, it must be loaded into this register before writing a command to the command register.

### 21.9.4 SDIO command register (SDIO\_CMD)

Address offset: 0x0C

Reset value: 0x0000 0000

The SDIO\_CMD register contains the command index and command type bits. The command index is sent to a card as part of a command message. The command type bits control the command path state machine (CPSM).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														CE-ATACMD	nIEN	ENCMDcompl	SDIOSuspend	CPSMEN	WAITPEND	WAITINT	WAITRESP	CMDINDEX									
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:15 Reserved, must be kept at reset value

Bit 14 **ATACMD**: CE-ATA command

If ATACMD is set, the CPSM transfers CMD61.

Bit 13 **nIEN**: not Interrupt Enable

if this bit is 0, interrupts in the CE-ATA device are enabled.

Bit 12 **ENCMDcompl**: Enable CMD completion

If this bit is set, the command completion signal is enabled.

Bit 11 **SDIOSuspend**: SD I/O suspend command

If this bit is set, the command to be sent is a suspend command (to be used only with SDIO card).

Bit 10 **CPSMEN**: Command path state machine (CPSM) Enable bit

If this bit is set, the CPSM is enabled.

Bit 9 **WAITPEND**: CPSM Waits for ends of data transfer (CmdPend internal signal).

If this bit is set, the CPSM waits for the end of data transfer before it starts sending a command.

Bit 8 **WAITINT**: CPSM waits for interrupt request

If this bit is set, the CPSM disables command timeout and waits for an interrupt request.

Bits 7:6 **WAITRESP**: Wait for response bits

They are used to configure whether the CPSM is to wait for a response, and if yes, which kind of response.

00: No response, expect CMDSENT flag

01: Short response, expect CMDREND or CCRCFAIL flag

10: No response, expect CMDSENT flag

11: Long response, expect CMDREND or CCRCFAIL flag

Bits 5:0 **CMDINDEX**: Command index

The command index is sent to the card as part of a command message.

**Note:** After a data write, data cannot be written to this register for three SDIOCLK (48 MHz) clock periods plus two PCLK2 clock periods.

MultiMediaCards can send two kinds of response: short responses, 48 bits long, or long responses, 136 bits long. SD card and SD I/O card can send only short responses, the

*argument can vary according to the type of response: the software will distinguish the type of response according to the sent command. CE-ATA devices send only short responses.*

### 21.9.5 SDIO command response register (SDIO\_RESPCMD)

Address offset: 0x10

Reset value: 0x0000 0000

The SDIO\_RESPCMD register contains the command index field of the last command response received. If the command response transmission does not contain the command index field (long or OCR response), the RESPCMD field is unknown, although it must contain 111111b (the value of the reserved field from the response).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																										RESPCMD					
																										r	r	r	r	r	r

Bits 31:6 Reserved, must be kept at reset value

Bits 5:0 **RESPCMD**: Response command index

Read-only bit field. Contains the command index of the last command response received.

### 21.9.6 SDIO response 1..4 register (SDIO\_RESPx)

Address offset: (0x10 + (4 × x)); x = 1..4

Reset value: 0x0000 0000

The SDIO\_RESP1/2/3/4 registers contain the status of a card, which is part of the received response.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CARDSTATUSx																															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	

Bits 31:0 **CARDSTATUSx**: see [Table 123](#).

The Card Status size is 32 or 127 bits, depending on the response type.

**Table 123. Response type and SDIO\_RESPx registers**

Register	Short response	Long response
SDIO_RESP1	Card Status[31:0]	Card Status [127:96]
SDIO_RESP2	Unused	Card Status [95:64]
SDIO_RESP3	Unused	Card Status [63:32]
SDIO_RESP4	Unused	Card Status [31:1]0b

The most significant bit of the card status is received first. The SDIO\_RESP3 register LSB is always 0b.

### 21.9.7 SDIO data timer register (SDIO\_DTIMER)

Address offset: 0x24

Reset value: 0x0000 0000

The SDIO\_DTIMER register contains the data timeout period, in card bus clock periods.

A counter loads the value from the SDIO\_DTIMER register, and starts decrementing when the data path state machine (DPSM) enters the Wait\_R or Busy state. If the timer reaches 0 while the DPSM is in either of these states, the timeout status flag is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATATIME																															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bits 31:0 **DATATIME:** Data timeout period

Data timeout period expressed in card bus clock periods.

**Note:** A data transfer must be written to the data timer register and the data length register before being written to the data control register.

### 21.9.8 SDIO data length register (SDIO\_DLEN)

Address offset: 0x28

Reset value: 0x0000 0000

The SDIO\_DLEN register contains the number of data bytes to be transferred. The value is loaded into the data counter when data transfer starts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		DATALENGTH																													
		rw																													

Bits 31:25 Reserved, must be kept at reset value

Bits 24:0 **DATALENGTH:** Data length value

Number of data bytes to be transferred.

**Note:** For a block data transfer, the value in the data length register must be a multiple of the block size (see SDIO\_DCTRL). A data transfer must be written to the data timer register and the data length register before being written to the data control register.

For an SDIO multibyte transfer the value in the data length register must be between 1 and 512.

### 21.9.9 SDIO data control register (SDIO\_DCTRL)

Address offset: 0x2C

Reset value: 0x0000 0000

The SDIO\_DCTRL register controls the data path state machine (DPSM).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved											<b>SDIOEN</b>	<b>RWMOD</b>	<b>RWSTOP</b>	<b>RWSTART</b>	<b>DBLOCKSIZE</b>				<b>DMAEN</b>	<b>DTMODE</b>	<b>DTDIR</b>	<b>DTEN</b>									
											<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	

Bits 31:12 Reserved, must be kept at reset value

Bit 11 **SDIOEN:** SD I/O enable functions

If this bit is set, the DPSM performs an SD I/O-card-specific operation.

Bit 10 **RWMOD:** Read wait mode

- 0: Read Wait control stopping SDIO\_D2
- 1: Read Wait control using SDIO\_CK

Bit 9 **RWSTOP:** Read wait stop

- 0: Read wait in progress if RWSTART bit is set
- 1: Enable for read wait stop if RWSTART bit is set

Bit 8 **RWSTART:** Read wait start

If this bit is set, read wait operation starts.

Bits 7:4 **DBLOCKSIZE:** Data block size

Define the data block length when the block data transfer mode is selected:

- 0000: (0 decimal) lock length =  $2^0$  = 1 byte
- 0001: (1 decimal) lock length =  $2^1$  = 2 bytes
- 0010: (2 decimal) lock length =  $2^2$  = 4 bytes
- 0011: (3 decimal) lock length =  $2^3$  = 8 bytes
- 0100: (4 decimal) lock length =  $2^4$  = 16 bytes
- 0101: (5 decimal) lock length =  $2^5$  = 32 bytes
- 0110: (6 decimal) lock length =  $2^6$  = 64 bytes
- 0111: (7 decimal) lock length =  $2^7$  = 128 bytes
- 1000: (8 decimal) lock length =  $2^8$  = 256 bytes
- 1001: (9 decimal) lock length =  $2^9$  = 512 bytes
- 1010: (10 decimal) lock length =  $2^{10}$  = 1024 bytes
- 1011: (11 decimal) lock length =  $2^{11}$  = 2048 bytes
- 1100: (12 decimal) lock length =  $2^{12}$  = 4096 bytes
- 1101: (13 decimal) lock length =  $2^{13}$  = 8192 bytes
- 1110: (14 decimal) lock length =  $2^{14}$  = 16384 bytes
- 1111: (15 decimal) reserved

Bit 3 **DMAEN:** DMA enable bit

- 0: DMA disabled.
- 1: DMA enabled.

Bit 2 **DTMODE**: Data transfer mode selection 1: Stream or SDIO multibyte data transfer.

- 0: Block data transfer  
1: Stream or SDIO multibyte data transfer

Bit 1 **DTDIR**: Data transfer direction selection

- 0: From controller to card.
  - 1: From card to controller.

Bit 0 **DTEN**: Data transfer enabled bit

Data transfer starts if 1b is written to the DTEN bit. Depending on the direction bit, DTDIR, the DPSM moves to the Wait\_S, Wait\_R state or Readwait if RW Start is set immediately at the beginning of the transfer. It is not necessary to clear the enable bit after the end of a data transfer but the SDIO\_DCTRL must be updated to enable a new data transfer

**Note:** After a data write, data cannot be written to this register for three SDIOCLK (48 MHz) clock periods plus two PCLK2 clock periods.

The meaning of the DTMODE bit changes according to the value of the SDIOEN bit. When SDIOEN=0 and DTMODE=1, the MultiMediaCard stream mode is enabled, and when SDIOEN=1 and DTMODE=1, the peripheral enables an SDIO multibyte transfer.

### 21.9.10 SDIO data counter register (SDIO\_DCOUNT)

Address offset: 0x30

Reset value: 0x0000 0000

The SDIO\_DCOUNT register loads the value from the data length register (see SDIO\_DLEN) when the DPSM moves from the Idle state to the Wait\_R or Wait\_S state. As data is transferred, the counter decrements the value until it reaches 0. The DPSM then moves to the Idle state and the data status end flag, DATAEND, is set.

Bits 31:25 Reserved must be kept at reset value

Bits 24:0 **DATACOUNT**: Data count value

When this bit is read, the number of remaining data bytes to be transferred is returned. Write has no effect.

**Note:** This register should be read only when the data transfer is complete.

### 21.9.11 SDIO status register (SDIO\_STA)

Address offset: 0x34

Reset value: 0x0000 0000

The SDIO\_STA register is a read-only register. It contains two types of flag:

- Static flags (bits [23:22, 10:0]): these bits remain asserted until they are cleared by writing to the SDIO Interrupt Clear register (see SDIO\_ICR)
- Dynamic flags (bits [21:11]): these bits change state depending on the state of the underlying logic (for example, FIFO full and empty flags are asserted and deasserted as data while written to the FIFO)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved								CEATAEND	SDIOIT	RXDAVL	TXDAVL	RXFIFOE	RXFIFOE	RXFIFOF	RXFIFOF	RXFIFOHF	RXFIFOHF	RXFIFOHE	RXACT	TXACT	CMDACT	DBCKEND	STBITERR	DATAEND	CMDSENT	CMDREND	RXOVERR	TXUNDERR	DTIMEOUT	CTIMEOUT	DCRCFAIL	CCRCFAIL
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r			

Bits 31:24 Reserved, must be kept at reset value

Bit 23 **CEATAEND**: CE-ATA command completion signal received for CMD61

Bit 22 **SDIOIT**: SDIO interrupt received

Bit 21 **RXDAVL**: Data available in receive FIFO

Bit 20 **TXDAVL**: Data available in transmit FIFO

Bit 19 **RXFIFOE**: Receive FIFO empty

Bit 18 **TXFIFOE**: Transmit FIFO empty

When HW Flow Control is enabled, TXFIFOE signals becomes activated when the FIFO contains 2 words.

Bit 17 **RXFIFOF**: Receive FIFO full

When HW Flow Control is enabled, RXFIFOF signals becomes activated 2 words before the FIFO is full.

Bit 16 **TXFIFOF**: Transmit FIFO full

Bit 15 **RXFIFOHF**: Receive FIFO half full: there are at least 8 words in the FIFO

Bit 14 **TXFIFOHE**: Transmit FIFO half empty: at least 8 words can be written into the FIFO

Bit 13 **RXACT**: Data receive in progress

Bit 12 **TXACT**: Data transmit in progress

Bit 11 **CMDACT**: Command transfer in progress

Bit 10 **DBCKEND**: Data block sent/received (CRC check passed)

Bit 9 **STBITERR**: Start bit not detected on all data signals in wide bus mode

Bit 8 **DATAEND**: Data end (data counter, SDIDCOUNT, is zero)

Bit 7 **CMDSENT**: Command sent (no response required)

Bit 6 **CMDREND**: Command response received (CRC check passed)

Bit 5 **RXOVERR**: Received FIFO overrun error

- Bit 4 **TXUNDERR**: Transmit FIFO underrun error
- Bit 3 **DTIMEOUT**: Data timeout
- Bit 2 **CTIMEOUT**: Command response timeout  
The Command TimeOut period has a fixed value of 64 SDIO\_CK clock periods.
- Bit 1 **DCRCFAIL**: Data block sent/received (CRC check failed)
- Bit 0 **CCRCFAIL**: Command response received (CRC check failed)

### 21.9.12 SDIO interrupt clear register (SDIO\_ICR)

Address offset: 0x38

Reset value: 0x0000 0000

The SDIO\_ICR register is a write-only register. Writing a bit with 1b clears the corresponding bit in the SDIO\_STA Status register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	

Bits 31:24 Reserved, must be kept at reset value

Bit 23 **CEATAENDC**: CEATAEND flag clear bit

Set by software to clear the CEATAEND flag.  
0: CEATAEND not cleared  
1: CEATAEND cleared

Bit 22 **SDIOITC**: SDIOIT flag clear bit

Set by software to clear the SDIOIT flag.  
0: SDIOIT not cleared  
1: SDIOIT cleared

Bits 21:11 Reserved, must be kept at reset value

Bit 10 **DBCKENDC**: DBCKEND flag clear bit

Set by software to clear the DBCKEND flag.  
0: DBCKEND not cleared  
1: DBCKEND cleared

Bit 9 **STBITERRC**: STBITERR flag clear bit

Set by software to clear the STBITERR flag.  
0: STBITERR not cleared  
1: STBITERR cleared

Bit 8 **DATAENDC**: DATAEND flag clear bit

Set by software to clear the DATAEND flag.  
0: DATAEND not cleared  
1: DATAEND cleared

- Bit 7 **CMDSENTC:** CMDSENT flag clear bit  
Set by software to clear the CMDSENT flag.  
0: CMDSENT not cleared  
1: CMDSENT cleared
- Bit 6 **CMDRENDC:** CMDREND flag clear bit  
Set by software to clear the CMDREND flag.  
0: CMDREND not cleared  
1: CMDREND cleared
- Bit 5 **RXOVERRC:** RXOVERR flag clear bit  
Set by software to clear the RXOVERR flag.  
0: RXOVERR not cleared  
1: RXOVERR cleared
- Bit 4 **TXUNDERRC:** TXUNDERR flag clear bit  
Set by software to clear TXUNDERR flag.  
0: TXUNDERR not cleared  
1: TXUNDERR cleared
- Bit 3 **DTIMEOUTC:** DTIMEOUT flag clear bit  
Set by software to clear the DTIMEOUT flag.  
0: DTIMEOUT not cleared  
1: DTIMEOUT cleared
- Bit 2 **CTIMEOUTC:** CTIMEOUT flag clear bit  
Set by software to clear the CTIMEOUT flag.  
0: CTIMEOUT not cleared  
1: CTIMEOUT cleared
- Bit 1 **DCRCFAILC:** DCRCFAIL flag clear bit  
Set by software to clear the DCRCFAIL flag.  
0: DCRCFAIL not cleared  
1: DCRCFAIL cleared
- Bit 0 **CCRCFAILC:** CCRCFAIL flag clear bit  
Set by software to clear the CCRCFAIL flag.  
0: CCRCFAIL not cleared  
1: CCRCFAIL cleared

### 21.9.13 SDIO mask register (SDIO\_MASK)

Address offset: 0x3C

Reset value: 0x0000 0000

The interrupt mask register determines which status flags generate an interrupt request by setting the corresponding bit to 1b.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0																											
Reserved												Z	CEATAENDIE	RW	SDIOITIE	RW	RXDIAVIE	RW	TXDAVIE	RW	RXFIFOEIE	RW	TXFIFOEIE	RW	RXFIFOFIE	RW	TXFIFOFIE	RW	RXFIFOHEIE	RW	RXACTIE	RW	TXACTIE	RW	CMDACTIE	RW	DBCKENDIE	RW	STBITERRIE	RW	DATAENDIE	RW	CMDSENTE	RW	CMDRENDIE	RW	RXOVERRIE	RW	TXUNDERRIE	RW	DTIMEOUTIE	RW	CTIMEOUTIE	RW	DCRCFAILIE	RW	CCRCFAILIE	RW

Bits 31:24 Reserved, must be kept at reset value

**Bit 23 CEATAENDIE:** CE-ATA command completion signal received interrupt enable

Set and cleared by software to enable/disable the interrupt generated when receiving the CE-ATA command completion signal.

0: CE-ATA command completion signal received interrupt disabled  
1: CE-ATA command completion signal received interrupt enabled

Bit 22 **SDIOITIE**: SDIO mode interrupt received interrupt enable

Set and cleared by software to enable/disable the interrupt generated when receiving the SDIO mode interrupt.

0: SDIO Mode Interrupt Received interrupt disabled  
1: SDIO Mode Interrupt Received interrupt enabled

Bit 21 RXDAVLIE: Data available in Rx FIFO interrupt enable

Set and cleared by software to enable/disable the interrupt generated by the presence of data available in Rx FIFO

0: Data available in Rx FIFO interrupt disabled  
1: Data available in Rx FIFO interrupt enabled

Bit 20 TXDAVIIE: Data available in Tx FIFO interrupt enable

**DAVE:** Data available in Tx FIFO interrupt enable  
Set and cleared by software to enable/disable the interrupt generated by the presence of data available in Tx FIFO

0: Data available in Tx FIFO interrupt disabled  
1: Data available in Tx FIFO interrupt enabled

Bit 10: **RxFIFOEIE**: Rx FIFO empty interrupt enable

Set and cleared by software to enable/disable interrupt caused by Rx FIFO empty

Set and cleared by software to enable  
0: Rx FIFO empty interrupt disabled  
1: Rx FIFO empty interrupt enabled

Bit 18 **TXFIFOEIE**: Tx FIFO empty interrupt enable

Set and cleared by software to enable/disable interrupt caused by Tx FIFO empty

Set and cleared by software to enable  
0: Tx FIFO empty interrupt disabled  
1: Tx FIFO empty interrupt enabled

**Bit 13: RXFIFOEIE:** Rx FIFO full interrupt enable

Set up interrupt on Rx FIFO full interrupt enable

Set and cleared by software to enable

0: Rx FIFO full interrupt disabled

- Bit 16 **TXFIFOIE:** Tx FIFO full interrupt enable  
Set and cleared by software to enable/disable interrupt caused by Tx FIFO full.  
0: Tx FIFO full interrupt disabled  
1: Tx FIFO full interrupt enabled
- Bit 15 **RXFIFOHFIE:** Rx FIFO half full interrupt enable  
Set and cleared by software to enable/disable interrupt caused by Rx FIFO half full.  
0: Rx FIFO half full interrupt disabled  
1: Rx FIFO half full interrupt enabled
- Bit 14 **TXFIFOHEIE:** Tx FIFO half empty interrupt enable  
Set and cleared by software to enable/disable interrupt caused by Tx FIFO half empty.  
0: Tx FIFO half empty interrupt disabled  
1: Tx FIFO half empty interrupt enabled
- Bit 13 **RXACTIE:** Data receive acting interrupt enable  
Set and cleared by software to enable/disable interrupt caused by data being received (data receive acting).  
0: Data receive acting interrupt disabled  
1: Data receive acting interrupt enabled
- Bit 12 **TXACTIE:** Data transmit acting interrupt enable  
Set and cleared by software to enable/disable interrupt caused by data being transferred (data transmit acting).  
0: Data transmit acting interrupt disabled  
1: Data transmit acting interrupt enabled
- Bit 11 **CMDACTIE:** Command acting interrupt enable  
Set and cleared by software to enable/disable interrupt caused by a command being transferred (command acting).  
0: Command acting interrupt disabled  
1: Command acting interrupt enabled
- Bit 10 **DBCKENDIE:** Data block end interrupt enable  
Set and cleared by software to enable/disable interrupt caused by data block end.  
0: Data block end interrupt disabled  
1: Data block end interrupt enabled
- Bit 9 **STBITERRIE:** Start bit error interrupt enable  
Set and cleared by software to enable/disable interrupt caused by start bit error.  
0: Start bit error interrupt disabled  
1: Start bit error interrupt enabled
- Bit 8 **DATAENDIE:** Data end interrupt enable  
Set and cleared by software to enable/disable interrupt caused by data end.  
0: Data end interrupt disabled  
1: Data end interrupt enabled
- Bit 7 **CMDSENTIE:** Command sent interrupt enable  
Set and cleared by software to enable/disable interrupt caused by sending command.  
0: Command sent interrupt disabled  
1: Command sent interrupt enabled

- Bit 6 CMDRENDIE:** Command response received interrupt enable  
Set and cleared by software to enable/disable interrupt caused by receiving command response.  
0: Command response received interrupt disabled  
1: command Response Received interrupt enabled

**Bit 5 RXOVERRIE:** Rx FIFO overrun error interrupt enable  
Set and cleared by software to enable/disable interrupt caused by Rx FIFO overrun error.  
0: Rx FIFO overrun error interrupt disabled  
1: Rx FIFO overrun error interrupt enabled

**Bit 4 TXUNDERRIE:** Tx FIFO underrun error interrupt enable  
Set and cleared by software to enable/disable interrupt caused by Tx FIFO underrun error.  
0: Tx FIFO underrun error interrupt disabled  
1: Tx FIFO underrun error interrupt enabled

**Bit 3 DTIMEOUTIE:** Data timeout interrupt enable  
Set and cleared by software to enable/disable interrupt caused by data timeout.  
0: Data timeout interrupt disabled  
1: Data timeout interrupt enabled

**Bit 2 CTIMEOUTIE:** Command timeout interrupt enable  
Set and cleared by software to enable/disable interrupt caused by command timeout.  
0: Command timeout interrupt disabled  
1: Command timeout interrupt enabled

**Bit 1 DCRCFAILIE:** Data CRC fail interrupt enable  
Set and cleared by software to enable/disable interrupt caused by data CRC failure.  
0: Data CRC fail interrupt disabled  
1: Data CRC fail interrupt enabled

**Bit 0 CCRCFAILIE:** Command CRC fail interrupt enable  
Set and cleared by software to enable/disable interrupt caused by command CRC failure.  
0: Command CRC fail interrupt disabled  
1: Command CRC fail interrupt enabled

#### 21.9.14 SDIO FIFO counter register (SDIO\_FIFOCNT)

Address offset: 0x48

Reset value: 0x0000 0000

The SDIO\_FIFOCNT register contains the remaining number of words to be written to or read from the FIFO. The FIFO counter loads the value from the data length register (see SDIO\_DLEN) when the data transfer enable bit, DTEN, is set in the data control register (SDIO\_DCTRL register) and the DPSM is at the Idle state. If the data length is not word-aligned (multiple of 4), the remaining 1 to 3 bytes are regarded as a word.

Bits 31:24 Reserved, must be kept at reset value

Bits 23:0 **FIFOCOUNT:** Remaining number of words to be written to or read from the FIFO.

### 21.9.15 SDIO data FIFO register (SDIO\_FIFO)

Address offset: 0x80

Reset value: 0x0000 0000

The receive and transmit FIFOs can be read or written as 32-bit wide registers. The FIFOs contain 32 entries on 32 sequential addresses. This allows the CPU to use its load and store multiple operands to read from/write to the FIFO.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FIFOData																															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

bits 31:0 **FIFOData**: Receive and transmit FIFO data

The FIFO data occupies 32 entries of 32-bit words, from address:  
SDIO base + 0x080 to SDIO base + 0xFC.

### 21.9.16 SDIO register map

The following table summarizes the SDIO registers.

Table 124. SDIO register map

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	<b>SDIO_POWER</b>																																
0x04	<b>SDIO_CLKCR</b>																																
0x08	<b>SDIO_ARG</b>																																
0x0C	<b>SDIO_CMD</b>																																
0x10	<b>SDIO_RESPCMD</b>																																
0x14	<b>SDIO RESP1</b>																																
0x18	<b>SDIO RESP2</b>																																
0x1C	<b>SDIO RESP3</b>																																
0x20	<b>SDIO RESP4</b>																																
0x24	<b>SDIO_DTIMER</b>																																
0x28	<b>SDIO_DLEN</b>																																
0x2C	<b>SDIO_DCTRL</b>																																
0x30	<b>SDIO_DCOUNT</b>																																

Table 124. SDIO register map (continued)

Offset	Register	31	30	29	28	27	26	25	24
0x34	<b>SDIO_STA</b>				Reserved				
0x38	<b>SDIO_ICR</b>				Reserved				
0x3C	<b>SDIO_MASK</b>				Reserved				
0x48	<b>SDIO_FIFOCNT</b>	CEATAENDIE	CEATAENDC	CEATAEND	23				
		SDIOITIE	SDIOITC	SDIOIT	22				
		RXDAVIE		RXDAVL	21				
		TXDAVIE		TXDAVL	20				
		RXFIFOEIE		RXFIFOE	19				
		TXFIFOEIE		TXFIFOE	18				
		RXFIFOFIE		RXFIFOF	17				
		TXFIFOFIE		TXFIFOF	16				
		RXFIFOHFIE		RXFIFOHF	15				
		TXFIFOHEIE		TXFIFOHE	14				
		RXACTIE		RXACT	13				
		TXACTIE		TXACT	12				
		CMDACTIE		CMDACT	11				
		DBCKENDIE	DBCKENDC	DBCKEND	10				
		STBITERRIE	STBITERRC	STBITERR	9				
		DATAENDIE	DATAENDC	DATAEND	8				
		CMDSENTIE	CMDSENTC	CMDSENT	7				
		CMDRENDIE	CMDRENDC	CMDREND	6				
		RXOVERRIE	RXOVERRC	RXOVERR	5				
		TXUNDERRIE	TXUNDERRC	TXUNDERR	4				
		DTIMEOUTIE	DTIMEOUTC	DTIMEOUT	3				
		CTIMEOUTIE	CTIMEOUTC	CTIMEOUT	2				
		DCRCFAILIE	DCRCFAILC	DCRCFAIL	1				
		CCRCFAILIE	CCRCFAILC	CCRCFAIL	0				

FIFOData

## 22 USB on-the-go full-speed (OTG\_FS)

### 22.1 OTG\_FS introduction

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This section presents the architecture and the programming model of the OTG\_FS controller.

The following acronyms are used throughout the section:

FS	full-speed
LS	Low-speed
MAC	Media access controller
OTG	On-the-go
PFC	Packet FIFO controller
PHY	Physical layer
USB	Universal serial bus
UTMI	USB 2.0 transceiver macrocell interface (UTMI)

References are made to the following documents:

- USB On-The-Go Supplement, Revision 1.3
- Universal Serial Bus Revision 2.0 Specification

The OTG\_FS is a dual-role device (DRD) controller that supports both device and host functions and is fully compliant with the *On-The-Go Supplement to the USB 2.0 Specification*. It can also be configured as a host-only or device-only controller, fully compliant with the *USB 2.0 Specification*. In host mode, the OTG\_FS supports full-speed (FS, 12 Mbits/s) and low-speed (LS, 1.5 Mbits/s) transfers whereas in device mode, it only supports full-speed (FS, 12 Mbits/s) transfers. The OTG\_FS supports both HNP and SRP. The only external device required is a charge pump for V<sub>BUS</sub> in host mode.

## 22.2 OTG\_FS main features

The main features can be divided into three categories: general, host-mode and device-mode features.

### 22.2.1 General features

The OTG\_FS interface general features are the following:

- It is USB-IF certified to the Universal Serial Bus Specification Rev 2.0
- It includes full support (PHY) for the optional On-The-Go (OTG) protocol detailed in the On-The-Go Supplement Rev 1.3 specification
  - Integrated support for A-B Device Identification (ID line)
  - Integrated support for host Negotiation Protocol (HNP) and Session Request Protocol (SRP)
  - It allows host to turn  $V_{BUS}$  off to conserve battery power in OTG applications
  - It supports OTG monitoring of  $V_{BUS}$  levels with internal comparators
  - It supports dynamic host-peripheral switch of role
- It is software-configurable to operate as:
  - SRP capable USB FS Peripheral (B-device)
  - SRP capable USB FS/LS host (A-device)
  - USB On-The-Go Full-Speed Dual Role device
- It supports FS SOF and LS Keep-alives with
  - SOF pulse PAD connectivity
  - SOF pulse internal connection to timer2 (TIM2)
  - Configurable framing period
  - Configurable end of frame interrupt
- It includes power saving features such as system stop during USB Suspend, switch-off of clock domains internal to the digital core, PHY and DFIFO power management
- It features a dedicated RAM of 1.25 Kbytes with advanced FIFO control:
  - Configurable partitioning of RAM space into different FIFOs for flexible and efficient use of RAM
  - Each FIFO can hold multiple packets
  - Dynamic memory allocation
  - Configurable FIFO sizes that are not powers of 2 to allow the use of contiguous memory locations
- It guarantees max USB bandwidth for up to one frame (1ms) without system intervention

### 22.2.2 Host-mode features

The OTG\_FS interface main features and requirements in host-mode are the following:

- External charge pump for V<sub>BUS</sub> voltage generation.
- Up to 8 host channels (pipes): each channel is dynamically reconfigurable to allocate any type of USB transfer.
- Built-in hardware scheduler holding:
  - Up to 8 interrupt plus isochronous transfer requests in the periodic hardware queue
  - Up to 8 control plus bulk transfer requests in the non-periodic hardware queue
- Management of a shared RX FIFO, a periodic TX FIFO and a nonperiodic TX FIFO for efficient usage of the USB data RAM.

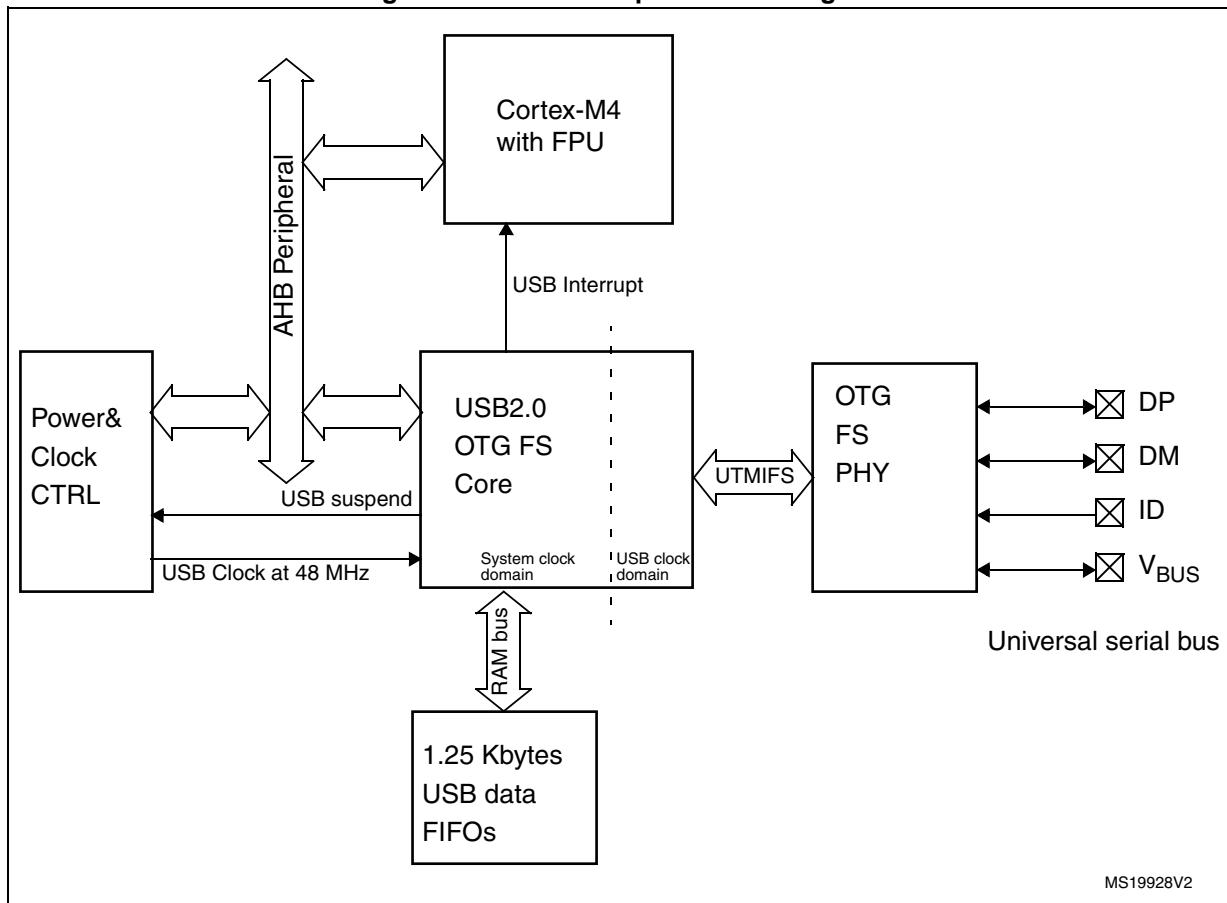
### 22.2.3 Peripheral-mode features

The OTG\_FS interface main features in peripheral-mode are the following:

- 1 bidirectional control endpoint0
- 3 IN endpoints (EPs) configurable to support Bulk, Interrupt or Isochronous transfers
- 3 OUT endpoints configurable to support Bulk, Interrupt or Isochronous transfers
- Management of a shared Rx FIFO and a Tx-OUT FIFO for efficient usage of the USB data RAM
- Management of up to 4 dedicated Tx-IN FIFOs (one for each active IN EP) to put less load on the application
- Support for the soft disconnect feature.

## 22.3 OTG\_FS functional description

Figure 242. OTG full-speed block diagram



### 22.3.1 OTG full-speed core

The USB OTG FS receives the  $48\text{ MHz} \pm 0.25\%$  clock from the reset and clock controller (RCC), via an external quartz. The USB clock is used for driving the 48 MHz domain at full-speed (12 Mbit/s) and must be enabled prior to configuring the OTG FS core.

The CPU reads and writes from/to the OTG FS core registers through the AHB peripheral bus. It is informed of USB events through the single USB OTG interrupt line described in [Section 22.15: OTG\\_FS interrupts](#).

The CPU submits data over the USB by writing 32-bit words to dedicated OTG\_FS locations (push registers). The data are then automatically stored into Tx-data FIFOs configured within the USB data RAM. There is one Tx-FIFO push register for each in-endpoint (peripheral mode) or out-channel (host mode).

The CPU receives the data from the USB by reading 32-bit words from dedicated OTG\_FS addresses (pop registers). The data are then automatically retrieved from a shared Rx-FIFO configured within the 1.25 KB USB data RAM. There is one Rx-FIFO pop register for each out-endpoint or in-channel.

The USB protocol layer is driven by the serial interface engine (SIE) and serialized over the USB by the full-/low-speed transceiver module within the on-chip physical layer (PHY).

### 22.3.2 Full-speed OTG PHY

The embedded full-speed OTG PHY is controlled by the OTG FS core and conveys USB control & data signals through the full-speed subset of the UTMI+ Bus (UTMIFS). It provides the physical support to USB connectivity.

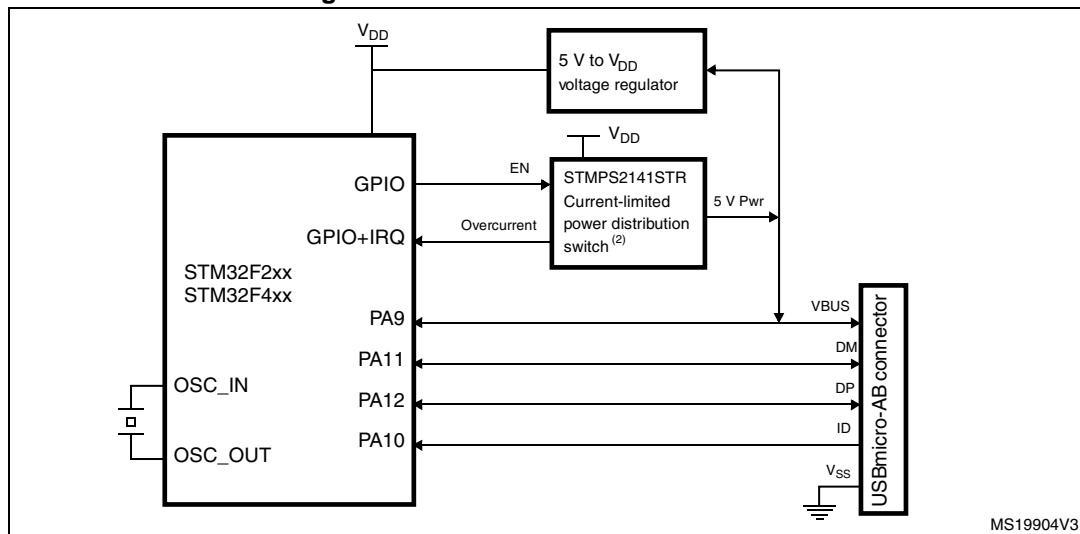
The full-speed OTG PHY includes the following components:

- FS/LS transceiver module used by both host and device. It directly drives transmission and reception on the single-ended USB lines.
- integrated ID pull-up resistor used to sample the ID line for A/B device identification.
- DP/DM integrated pull-up and pull-down resistors controlled by the OTG\_FS core depending on the current role of the device. As a peripheral, it enables the DP pull-up resistor to signal full-speed peripheral connections as soon as  $V_{BUS}$  is sensed to be at a valid level (B-session valid). In host mode, pull-down resistors are enabled on both DP/DM. Pull-up and pull-down resistors are dynamically switched when the device's role is changed via the host negotiation protocol (HNP).
- Pull-up/pull-down resistor ECN circuit. The DP pull-up consists of 2 resistors controlled separately from the OTG\_FS as per the resistor Engineering Change Notice applied to USB Rev2.0. The dynamic trimming of the DP pull-up strength allows for better noise rejection and Tx/Rx signal quality.
- $V_{BUS}$  sensing comparators with hysteresis used to detect  $V_{BUS}$  Valid, A-B Session Valid and session-end voltage thresholds. They are used to drive the session request protocol (SRP), detect valid startup and end-of-session conditions, and constantly monitor the  $V_{BUS}$  supply during USB operations.
- $V_{BUS}$  pulsing method circuit used to charge/discharge  $V_{BUS}$  through resistors during the SRP (weak drive).

**Caution:** To guarantee a correct operation for the USB OTG FS peripheral, the AHB frequency should be higher than 14.2 MHz.

## 22.4 OTG dual role device (DRD)

Figure 243. OTG A-B device connection



1. External voltage regulator only needed when building a  $V_{BUS}$  powered device
2.  $\text{STMPS2141STR}$  needed only if the application has to support a  $V_{BUS}$  powered device. A basic power switch can be used if 5 V are available on the application board.

### 22.4.1 ID line detection

The host or peripheral (the default) role is assumed depending on the ID input pin. The ID line status is determined on plugging in the USB, depending on which side of the USB cable is connected to the micro-AB receptacle.

- If the B-side of the USB cable is connected with a floating ID wire, the integrated pull-up resistor detects a high ID level and the default Peripheral role is confirmed. In this configuration the OTG\_FS complies with the standard FSM described by section 6.8.2: On-The-Go B-device of the On-The-Go Specification Rev1.3 supplement to the USB2.0.
- If the A-side of the USB cable is connected with a grounded ID, the OTG\_FS issues an ID line status change interrupt (CIDSCHG bit in OTG\_FS\_GINTSTS) for host software initialization, and automatically switches to the host role. In this configuration the OTG\_FS complies with the standard FSM described by section 6.8.1: On-The-Go A-device of the On-The-Go Specification Rev1.3 supplement to the USB2.0.

### 22.4.2 HNP dual role device

The HNP capable bit in the Global USB configuration register (HNPCAP bit in OTG\_FS\_GUSBCFG) enables the OTG\_FS core to dynamically change its role from A-host to A-peripheral and vice-versa, or from B-Peripheral to B-host and vice-versa according to the host negotiation protocol (HNP). The current device status can be read by the combined values of the Connector ID Status bit in the Global OTG control and status register (CIDSTS bit in OTG\_FS\_GOTGCTL) and the current mode of operation bit in the global interrupt and status register (CMOD bit in OTG\_FS\_GINTSTS).

The HNP program model is described in detail in [Section 22.17: OTG\\_FS programming model](#).

### 22.4.3 SRP dual role device

The SRP capable bit in the global USB configuration register (SRPCAP bit in OTG\_FS\_GUSBCFG) enables the OTG\_FS core to switch off the generation of  $V_{BUS}$  for the A-device to save power. Note that the A-device is always in charge of driving  $V_{BUS}$  regardless of the host or peripheral role of the OTG\_FS.

the SRP A/B-device program model is described in detail in [Section 22.17: OTG\\_FS programming model](#).

## 22.5 USB peripheral

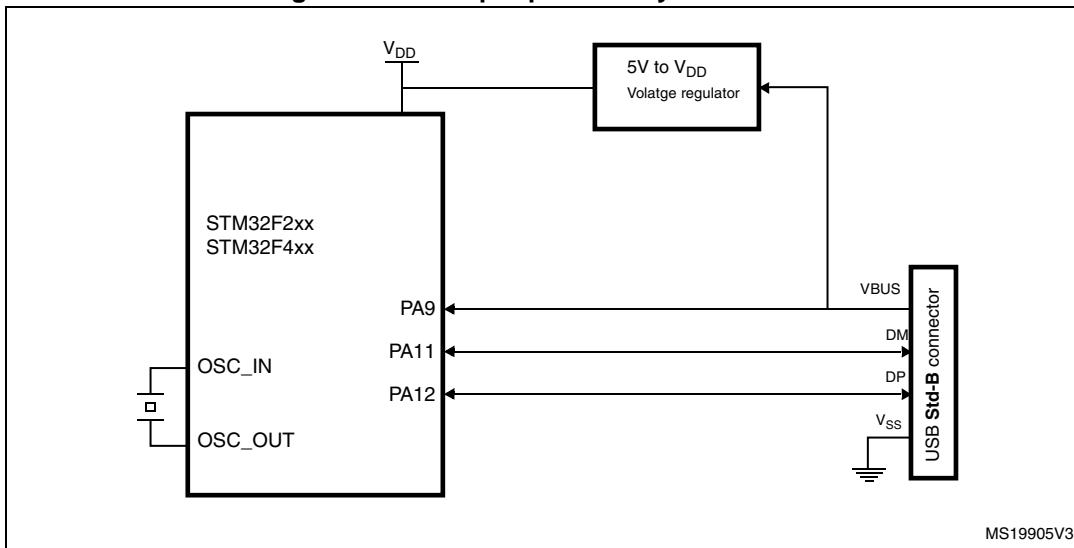
This section gives the functional description of the OTG\_FS in the USB peripheral mode. The OTG\_FS works as an USB peripheral in the following circumstances:

- OTG B-Peripheral
  - OTG B-device default state if B-side of USB cable is plugged in
- OTG A-Peripheral
  - OTG A-device state after the HNP switches the OTG\_FS to its peripheral role
- B-device
  - If the ID line is present, functional and connected to the B-side of the USB cable, and the HNP-capable bit in the Global USB Configuration register (HNPCAP bit in OTG\_FS\_GUSBCFG) is cleared (see On-The-Go Rev1.3 par. 6.8.3).
- Peripheral only (see [Figure 244: USB peripheral-only connection](#))
  - The force device mode bit in the Global USB configuration register (FDMOD in OTG\_FS\_GUSBCFG) is set to 1, forcing the OTG\_FS core to work as a USB peripheral-only (see On-The-Go Rev1.3 par. 6.8.3). In this case, the ID line is ignored even if present on the USB connector.

**Note:** To build a bus-powered device implementation in case of the B-device or peripheral-only configuration, an external regulator has to be added that generates the  $V_{DD}$  chip-supply from  $V_{BUS}$ .

The  $V_{BUS}$  pin can be freed by disabling the  $V_{BUS}$  sensing option. This is done by setting the NOVBUSSENS bit in the OTG\_FS\_GCCFG register. In this case the  $V_{BUS}$  is considered internally to be always at  $V_{BUS}$  valid level (5 V).

Figure 244. USB peripheral-only connection



1. Use a regulator to build a bus-powered device.

### 22.5.1 SRP-capable peripheral

The SRP capable bit in the Global USB configuration register (SRPCAP bit in OTG\_FS\_GUSBCFG) enables the OTG\_FS to support the session request protocol (SRP). In this way, it allows the remote A-device to save power by switching off  $V_{BUS}$  while the USB session is suspended.

The SRP peripheral mode program model is described in detail in the [B-device session request protocol](#) section.

### 22.5.2 Peripheral states

#### Powered state

The  $V_{BUS}$  input detects the B-Session valid voltage by which the USB peripheral is allowed to enter the powered state (see USB2.0 par9.1). The OTG\_FS then automatically connects the DP pull-up resistor to signal full-speed device connection to the host and generates the session request interrupt (SRQINT bit in OTG\_FS\_GINTSTS) to notify the powered state.

The  $V_{BUS}$  input also ensures that valid  $V_{BUS}$  levels are supplied by the host during USB operations. If a drop in  $V_{BUS}$  below B-session valid happens to be detected (for instance because of a power disturbance or if the host port has been switched off), the OTG\_FS automatically disconnects and the session end detected (SEDET bit in OTG\_FS\_GOTGINT) interrupt is generated to notify that the OTG\_FS has exited the powered state.

In the powered state, the OTG\_FS expects to receive some reset signaling from the host. No other USB operation is possible. When a reset signaling is received the reset detected interrupt (USBRST in OTG\_FS\_GINTSTS) is generated. When the reset signaling is complete, the enumeration done interrupt (ENUMDNE bit in OTG\_FS\_GINTSTS) is generated and the OTG\_FS enters the Default state.

### Soft disconnect

The powered state can be exited by software with the soft disconnect feature. The DP pull-up resistor is removed by setting the soft disconnect bit in the device control register (SDIS bit in OTG\_FS\_DCTL), causing a device disconnect detection interrupt on the host side even though the USB cable was not really removed from the host port.

### Default state

In the Default state the OTG\_FS expects to receive a SET\_ADDRESS command from the host. No other USB operation is possible. When a valid SET\_ADDRESS command is decoded on the USB, the application writes the corresponding number into the device address field in the device configuration register (DAD bit in OTG\_FS\_DCFG). The OTG\_FS then enters the address state and is ready to answer host transactions at the configured USB address.

### Suspended state

The OTG\_FS peripheral constantly monitors the USB activity. After counting 3 ms of USB idleness, the early suspend interrupt (ESUSP bit in OTG\_FS\_GINTSTS) is issued, and confirmed 3 ms later, if appropriate, by the suspend interrupt (USBSUSP bit in OTG\_FS\_GINTSTS). The device suspend bit is then automatically set in the device status register (SUSPSTS bit in OTG\_FS\_DSTS) and the OTG\_FS enters the suspended state.

The suspended state may optionally be exited by the device itself. In this case the application sets the remote wakeup signaling bit in the device control register (RWUSIG bit in OTG\_FS\_DCTL) and clears it after 1 to 15 ms.

When a resume signaling is detected from the host, the resume interrupt (WKUPINT bit in OTG\_FS\_GINTSTS) is generated and the device suspend bit is automatically cleared.

## 22.5.3 Peripheral endpoints

The OTG\_FS core instantiates the following USB endpoints:

- Control endpoint 0:
  - Bidirectional and handles control messages only
  - Separate set of registers to handle in and out transactions
  - Proper control (OTG\_FS\_DIEPCTL0/OTG\_FS\_DOEPCTL0), transfer configuration (OTG\_FS\_DIEPTSIZ0/OTG\_FS\_DIEPTSIZ0), and status-interrupt (OTG\_FS\_DIEPINTx)/OTG\_FS\_DOEPINT0 registers. The available set of bits inside the control and transfer size registers slightly differs from that of other endpoints
- 3 IN endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has proper control (OTG\_FS\_DIEPCTLx), transfer configuration (OTG\_FS\_DIEPTSIZx), and status-interrupt (OTG\_FS\_DIEPINTx) registers
  - The Device IN endpoints common interrupt mask register (OTG\_FS\_DIEPMISK) is available to enable/disable a single kind of endpoint interrupt source on all of the IN endpoints (EP0 included)
  - Support for incomplete isochronous IN transfer interrupt (IISOIXFR bit in OTG\_FS\_GINTSTS), asserted when there is at least one isochronous IN endpoint

on which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG\_FS\_GINTSTS/EOPF).

- 3 OUT endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has a proper control (OTG\_FS\_DOEPCTLx), transfer configuration (OTG\_FS\_DOEPTSI $x$ ) and status-interrupt (OTG\_FS\_DOEPINT $x$ ) register
  - Device Out endpoints common interrupt mask register (OTG\_FS\_DOEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the OUT endpoints (EP0 included)
  - Support for incomplete isochronous OUT transfer interrupt (INCOMPISOOUT bit in OTG\_FS\_GINTSTS), asserted when there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG\_FS\_GINTSTS/EOPF).

### Endpoint control

- The following endpoint controls are available to the application through the device endpoint- $x$  IN/OUT control register (DIEPCTL $x$ /DOEPCTL $x$ ):
  - Endpoint enable/disable
  - Endpoint activate in current configuration
  - Program USB transfer type (isochronous, bulk, interrupt)
  - Program supported packet size
  - Program Tx-FIFO number associated with the IN endpoint
  - Program the expected or transmitted data0/data1 PID (bulk/interrupt only)
  - Program the even/odd frame during which the transaction is received or transmitted (isochronous only)
  - Optionally program the NAK bit to always negative-acknowledge the host regardless of the FIFO status
  - Optionally program the STALL bit to always stall host tokens to that endpoint
  - Optionally program the SNOOP mode for OUT endpoint not to check the CRC field of received data

### Endpoint transfer

The device endpoint- $x$  transfer size registers (DIEPTSI $x$ /DOEPTSI $x$ ) allow the application to program the transfer size parameters and read the transfer status. Programming must be done before setting the endpoint enable bit in the endpoint control register. Once the endpoint is enabled, these fields are read-only as the OTG FS core updates them with the current transfer status.

The following transfer parameters can be programmed:

- Transfer size in bytes
- Number of packets that constitute the overall transfer size

### Endpoint status/interrupt

The device endpoint-x interrupt registers (DIEPINTx/DOEPINTx) indicate the status of an endpoint with respect to USB- and AHB-related events. The application must read these registers when the OUT endpoint interrupt bit or the IN endpoint interrupt bit in the core interrupt register (OEPINT bit in OTG\_FS\_GINTSTS or IEPINT bit in OTG\_FS\_GINTSTS, respectively) is set. Before the application can read these registers, it must first read the device all endpoints interrupt (OTG\_FS\_DAINT) register to get the exact endpoint number for the device endpoint-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the DAINT and GINTSTS registers.

The peripheral core provides the following status checks and interrupt generation:

- Transfer completed interrupt, indicating that data transfer was completed on both the application (AHB) and USB sides
- Setup stage has been done (control-out only)
- Associated transmit FIFO is half or completely empty (in endpoints)
- NAK acknowledge has been transmitted to the host (isochronous-in only)
- IN token received when Tx-FIFO was empty (bulk-in/interrupt-in only)
- Out token received when endpoint was not yet enabled
- Babble error condition has been detected
- Endpoint disable by application is effective
- Endpoint NAK by application is effective (isochronous-in only)
- More than 3 back-to-back setup packets were received (control-out only)
- Timeout condition detected (control-in only)
- Isochronous out packet has been dropped, without generating an interrupt

## 22.6 USB host

This section gives the functional description of the OTG\_FS in the USB host mode. The OTG\_FS works as a USB host in the following circumstances:

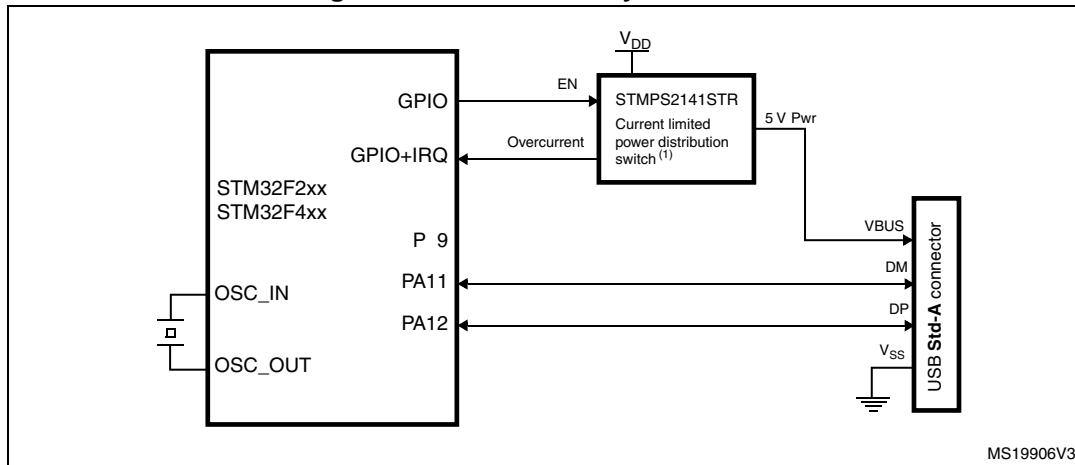
- OTG A-host
  - OTG A-device default state when the A-side of the USB cable is plugged in
- OTG B-host
  - OTG B-device after HNP switching to the host role
- A-device
  - If the ID line is present, functional and connected to the A-side of the USB cable, and the HNP-capable bit is cleared in the Global USB Configuration register (HNPCAP bit in OTG\_FS\_GUSBCFG). Integrated pull-down resistors are automatically set on the DP/DM lines.
- Host only (see figure [Figure 245: USB host-only connection](#)).
  - The force host mode bit in the global USB configuration register (FHMOD bit in OTG\_FS\_GUSBCFG) forces the OTG\_FS core to work as a USB host-only. In this case, the ID line is ignored even if present on the USB connector. Integrated pull-down resistors are automatically set on the DP/DM lines.

**Note:** *On-chip 5 V  $V_{BUS}$  generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch must be added externally to drive*

the 5 V  $V_{BUS}$  line. The external charge pump can be driven by any GPIO output. This is required for the OTG A-host, A-device and host-only configurations.

The  $V_{BUS}$  input ensures that valid  $V_{BUS}$  levels are supplied by the charge pump during USB operations while the charge pump overcurrent output can be input to any GPIO pin configured to generate port interrupts. The overcurrent ISR must promptly disable the  $V_{BUS}$  generation.

**Figure 245. USB host-only connection**



1. STMP2141STR needed only if the application has to support a  $V_{BUS}$  powered device. A basic power switch can be used if 5 V are available on the application board.
2.  $V_{DD}$  range is between 2 V and 3.6 V.

## 22.6.1 SRP-capable host

SRP support is available through the SRP capable bit in the global USB configuration register (SRPCAP bit in OTG\_FS\_GUSBCFG). With the SRP feature enabled, the host can save power by switching off the  $V_{BUS}$  power while the USB session is suspended.

The SRP host mode program model is described in detail in the [A-device session request protocol](#) section.

## 22.6.2 USB host states

### Host port power

On-chip 5 V  $V_{BUS}$  generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch, must be added externally to drive the 5 V  $V_{BUS}$  line. The external charge pump can be driven by any GPIO output. When the application decides to power on  $V_{BUS}$  using the chosen GPIO, it must also set the port power bit in the host port control and status register (PPWR bit in OTG\_FS\_HPRT).

### $V_{BUS}$ valid

When HNP or SRP is enabled the  $V_{BUS}$  sensing pin (PA9) pin should be connected to  $V_{BUS}$ . The  $V_{BUS}$  input ensures that valid  $V_{BUS}$  levels are supplied by the charge pump during USB operations. Any unforeseen  $V_{BUS}$  voltage drop below the  $V_{BUS}$  valid threshold (4.25 V) leads to an OTG interrupt triggered by the session end detected bit (SEDET bit in OTG\_FS\_GOTGINT). The application is then required to remove the  $V_{BUS}$  power and clear the port power bit.

When HNP and SRP are both disabled, the VBUS sensing pin (PA9) should not be connected to V<sub>BUS</sub>. This pin can be used as GPIO.

The charge pump overcurrent flag can also be used to prevent electrical damage. Connect the overcurrent flag output from the charge pump to any GPIO input and configure it to generate a port interrupt on the active level. The overcurrent ISR must promptly disable the V<sub>BUS</sub> generation and clear the port power bit.

### Host detection of a peripheral connection

If SRP or HNP are enabled, even if USB peripherals or B-devices can be attached at any time, the OTG\_FS will not detect any bus connection. When V<sub>BUS</sub> is at a valid level and a remote B-device is attached, the OTG\_FS core issues a host port interrupt triggered by the device connected bit in the host port control and status register (PCDET bit in OTG\_FS\_HPRT).

When HNP and SRP are both disabled, USB peripherals or B-device are detected as soon as they are connected. The OTG\_FS core issues a host port interrupt triggered by the device connected bit in the host port control and status (PCDET bit in OTG\_FS\_HPRT).

### Host detection of peripheral a disconnection

The peripheral disconnection event triggers the disconnect detected interrupt (DISCINT bit in OTG\_FS\_GINTSTS).

### Host enumeration

After detecting a peripheral connection the host must start the enumeration process by sending USB reset and configuration commands to the new peripheral.

Before starting to drive a USB reset, the application waits for the OTG interrupt triggered by the debounce done bit (DBCDNE bit in OTG\_FS\_GOTGINT), which indicates that the bus is stable again after the electrical debounce caused by the attachment of a pull-up resistor on DP (FS) or DM (LS).

The application drives a USB reset signaling (single-ended zero) over the USB by keeping the port reset bit set in the host port control and status register (PRST bit in OTG\_FS\_HPRT) for a minimum of 10 ms and a maximum of 20 ms. The application takes care of the timing count and then of clearing the port reset bit.

Once the USB reset sequence has completed, the host port interrupt is triggered by the port enable/disable change bit (PENCHNG bit in OTG\_FS\_HPRT). This informs the application that the speed of the enumerated peripheral can be read from the port speed field in the host port control and status register (PSPD bit in OTG\_FS\_HPRT) and that the host is starting to drive SOFs (FS) or Keep alives (LS). The host is now ready to complete the peripheral enumeration by sending peripheral configuration commands.

### Host suspend

The application decides to suspend the USB activity by setting the port suspend bit in the host port control and status register (PSUSP bit in OTG\_FS\_HPRT). The OTG\_FS core stops sending SOFs and enters the suspended state.

The suspended state can be optionally exited on the remote device's initiative (remote wakeup). In this case the remote wakeup interrupt (WKUPINT bit in OTG\_FS\_GINTSTS) is generated upon detection of a remote wakeup signaling, the port resume bit in the host port control and status register (PRES bit in OTG\_FS\_HPRT) self-sets, and resume signaling is

automatically driven over the USB. The application must time the resume window and then clear the port resume bit to exit the suspended state and restart the SOF.

If the suspended state is exited on the host initiative, the application must set the port resume bit to start resume signaling on the host port, time the resume window and finally clear the port resume bit.

### 22.6.3 Host channels

The OTG\_FS core instantiates 8 host channels. Each host channel supports an USB host transfer (USB pipe). The host is not able to support more than 8 transfer requests at the same time. If more than 8 transfer requests are pending from the application, the host controller driver (HCD) must re-allocate channels when they become available from previous duty, that is, after receiving the transfer completed and channel halted interrupts.

Each host channel can be configured to support in/out and any type of periodic/nonperiodic transaction. Each host channel makes use of proper control (HCCHARx), transfer configuration (HCTSIZx) and status/interrupt (HCINTx) registers with associated mask (HCINTMSKx) registers.

#### Host channel control

- The following host channel controls are available to the application through the host channel-x characteristics register (HCCHARx):
  - Channel enable/disable
  - Program the FS/LS speed of target USB peripheral
  - Program the address of target USB peripheral
  - Program the endpoint number of target USB peripheral
  - Program the transfer IN/OUT direction
  - Program the USB transfer type (control, bulk, interrupt, isochronous)
  - Program the maximum packet size (MPS)
  - Program the periodic transfer to be executed during odd/even frames

#### Host channel transfer

The host channel transfer size registers (HCTSIZx) allow the application to program the transfer size parameters, and read the transfer status. Programming must be done before setting the channel enable bit in the host channel characteristics register. Once the endpoint is enabled the packet count field is read-only as the OTG FS core updates it according to the current transfer status.

- The following transfer parameters can be programmed:
  - transfer size in bytes
  - number of packets making up the overall transfer size
  - initial data PID

#### Host channel status/interrupt

The host channel-x interrupt register (HCINTx) indicates the status of an endpoint with respect to USB- and AHB-related events. The application must read these register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG\_FS\_GINTSTS) is set. Before the application can read these registers, it must first read the host all channels interrupt (HCAINT) register to get the exact channel number for the host channel-x interrupt

register. The application must clear the appropriate bit in this register to clear the corresponding bits in the HAINT and GINTSTS registers. The mask bits for each interrupt source of each channel are also available in the OTG\_FS\_HCINTMSK-x register.

- The host core provides the following status checks and interrupt generation:
  - Transfer completed interrupt, indicating that the data transfer is complete on both the application (AHB) and USB sides
  - Channel has stopped due to transfer completed, USB transaction error or disable command from the application
  - Associated transmit FIFO is half or completely empty (IN endpoints)
  - ACK response received
  - NAK response received
  - STALL response received
  - USB transaction error due to CRC failure, timeout, bit stuff error, false EOP
  - Babble error
  - frame overrun
  - dAta toggle error

#### 22.6.4 Host scheduler

The host core features a built-in hardware scheduler which is able to autonomously re-order and manage the USB transaction requests posted by the application. At the beginning of each frame the host executes the periodic (isochronous and interrupt) transactions first, followed by the nonperiodic (control and bulk) transactions to achieve the higher level of priority granted to the isochronous and interrupt transfer types by the USB specification.

The host processes the USB transactions through request queues (one for periodic and one for nonperiodic). Each request queue can hold up to 8 entries. Each entry represents a pending transaction request from the application, and holds the IN or OUT channel number along with other information to perform a transaction on the USB. The order in which the requests are written to the queue determines the sequence of the transactions on the USB interface.

At the beginning of each frame, the host processes the periodic request queue first, followed by the nonperiodic request queue. The host issues an incomplete periodic transfer interrupt (IPXFR bit in OTG\_FS\_GINTSTS) if an isochronous or interrupt transaction scheduled for the current frame is still pending at the end of the current frame. The OTG HS core is fully responsible for the management of the periodic and nonperiodic request queues. The periodic transmit FIFO and queue status register (HPTXSTS) and nonperiodic transmit FIFO and queue status register (HNPTXSTS) are read-only registers which can be used by the application to read the status of each request queue. They contain:

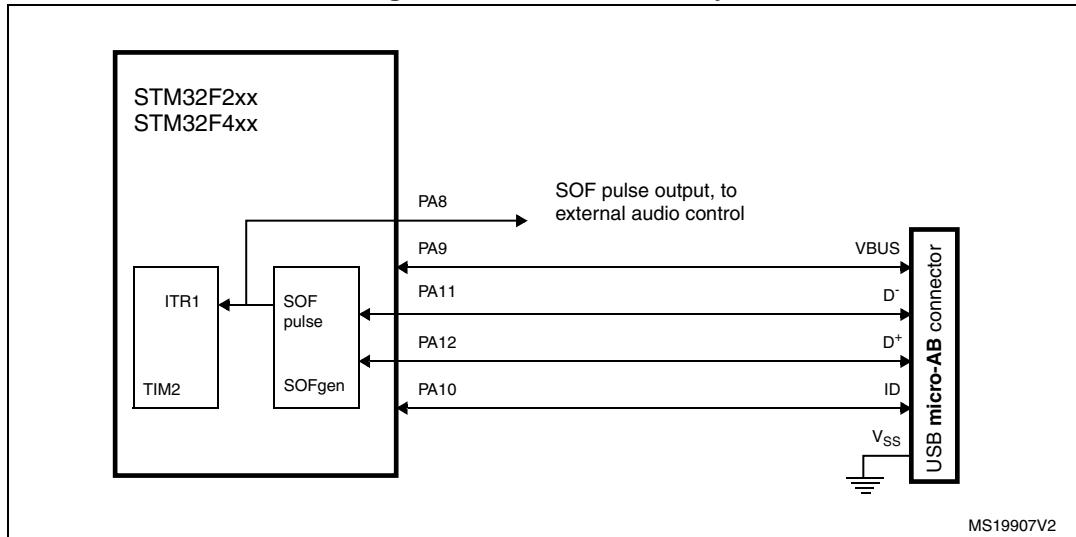
- The number of free entries currently available in the periodic (nonperiodic) request queue (8 max)
- Free space currently available in the periodic (nonperiodic) Tx-FIFO (out-transactions)
- IN/OUT token, host channel number and other status information.

As request queues can hold a maximum of 8 entries each, the application can push to schedule host transactions in advance with respect to the moment they physically reach the SB for a maximum of 8 pending periodic transactions plus 8 pending nonperiodic transactions.

To post a transaction request to the host scheduler (queue) the application must check that there is at least 1 entry available in the periodic (nonperiodic) request queue by reading the PTXQSAV bits in the OTG\_FS\_HNPTXSTS register or NPTQXSAV bits in the OTG\_FS\_HNPTXSTS register.

## 22.7 SOF trigger

**Figure 246. SOF connectivity**



The OTG FS core provides means to monitor, track and configure SOF framing in the host and peripheral, as well as an SOF pulse output connectivity feature.

Such utilities are especially useful for adaptive audio clock generation techniques, where the audio peripheral needs to synchronize to the isochronous stream provided by the PC, or the host needs to trim its framing rate according to the requirements of the audio peripheral.

### 22.7.1 Host SOFs

In host mode the number of PHY clocks occurring between the generation of two consecutive SOF (FS) or Keep-alive (LS) tokens is programmable in the host frame interval register (HFIR), thus providing application control over the SOF framing period. An interrupt is generated at any start of frame (SOF bit in OTH\_FS\_GINTSTS). The current frame number and the time remaining until the next SOF are tracked in the host frame number register (HFNUM).

An SOF pulse signal, generated at any SOF starting token and with a width of 12 system clock cycles, can be made available externally on the SOF pin using the SOFOUTEN bit in the global control and configuration register. The SOF pulse is also internally connected to the input trigger of timer 2 (TIM2), so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse. The TIM2 connection is enabled register.

### 22.7.2 Peripheral SOFs

In device mode, the start of frame interrupt is generated each time an SOF token is received on the USB (SOF bit in OTH\_FS\_GINTSTS). The corresponding frame number can be read

from the device status register (FNSOF bit in OTG\_FS\_DSTS). An SOF pulse signal with a width of 12 system clock cycles is also generated and can be made available externally on the SOF pin by using the SOF output enable bit in the global control and configuration register (SOFOUTEN bit in OTG\_FS\_GCCFG). The SOF pulse signal is also internally connected to the TIM2 input trigger, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse. The TIM2 connection is enabled.

The end of periodic frame interrupt (GINTSTS/EOPF) is used to notify the application when 80%, 85%, 90% or 95% of the time frame interval elapsed depending on the periodic frame interval field in the device configuration register (PFIVL bit in OTG\_FS\_DCFG). This feature can be used to determine if all of the isochronous traffic for that frame is complete.

## 22.8 Power options

The power consumption of the OTG PHY is controlled by three bits in the general core configuration register:

- **PHY power down (GCCFG/PWRDWN)**  
It switches on/off the full-speed transceiver module of the PHY. It must be preliminarily set to allow any USB operation.
- **A-V<sub>BUS</sub> sensing enable (GCCFG/VBUSASEN)**  
It switches on/off the V<sub>BUS</sub> comparators associated with A-device operations. It must be set when in A-device (USB host) mode and during HNP.
- **B-V<sub>BUS</sub> sensing enable (GCCFG/VBUSASEN)**  
It switches on/off the V<sub>BUS</sub> comparators associated with B-device operations. It must be set when in B-device (USB peripheral) mode and during HNP.

Power reduction techniques are available while in the USB suspended state, when the USB session is not yet valid or the device is disconnected.

- **Stop PHY clock (STPPCLK bit in OTG\_FS\_PCGCCTL)**  
When setting the stop PHY clock bit in the clock gating control register, most of the 48 MHz clock domain internal to the OTG full-speed core is switched off by clock gating. The dynamic power consumption due to the USB clock switching activity is cut even if the 48 MHz clock input is kept running by the application.  
Most of the transceiver is also disabled, and only the part in charge of detecting the asynchronous resume or remote wakeup event is kept alive.
- **Gate HCLK (GATEHCLK bit in OTG\_FS\_PCGCCTL)**  
When setting the Gate HCLK bit in the clock gating control register, most of the system clock domain internal to the OTG\_FS core is switched off by clock gating. Only the register read and write interface is kept alive. The dynamic power consumption due to the USB clock switching activity is cut even if the system clock is kept running by the application for other purposes.
- **USB system stop**  
When the OTG\_FS is in the USB suspended state, the application may decide to drastically reduce the overall power consumption by a complete shut down of all the clock sources in the system. USB System Stop is activated by first setting the Stop

PHY clock bit and then configuring the system deep sleep mode in the power control system module (PWR).

The OTG\_FS core automatically reactivates both system and USB clocks by asynchronous detection of remote wakeup (as an host) or resume (as a device) signaling on the USB.

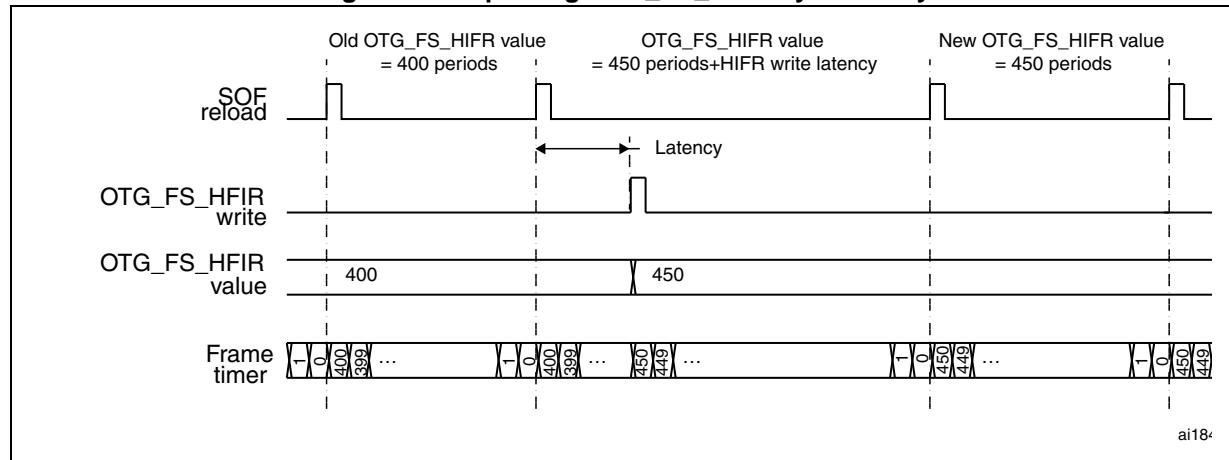
To save dynamic power, the USB data FIFO is clocked only when accessed by the OTG\_FS core.

## 22.9 Dynamic update of the OTG\_FS\_HFIR register

The USB core embeds a dynamic trimming capability of micro-SOF framing period in host mode allowing to synchronize an external device with the micro-SOF frames.

When the OTG\_HS\_HFIR register is changed within a current micro-SOF frame, the SOF period correction is applied in the next frame as described in [Figure 247](#).

**Figure 247. Updating OTG\_FS\_HFIR dynamically**

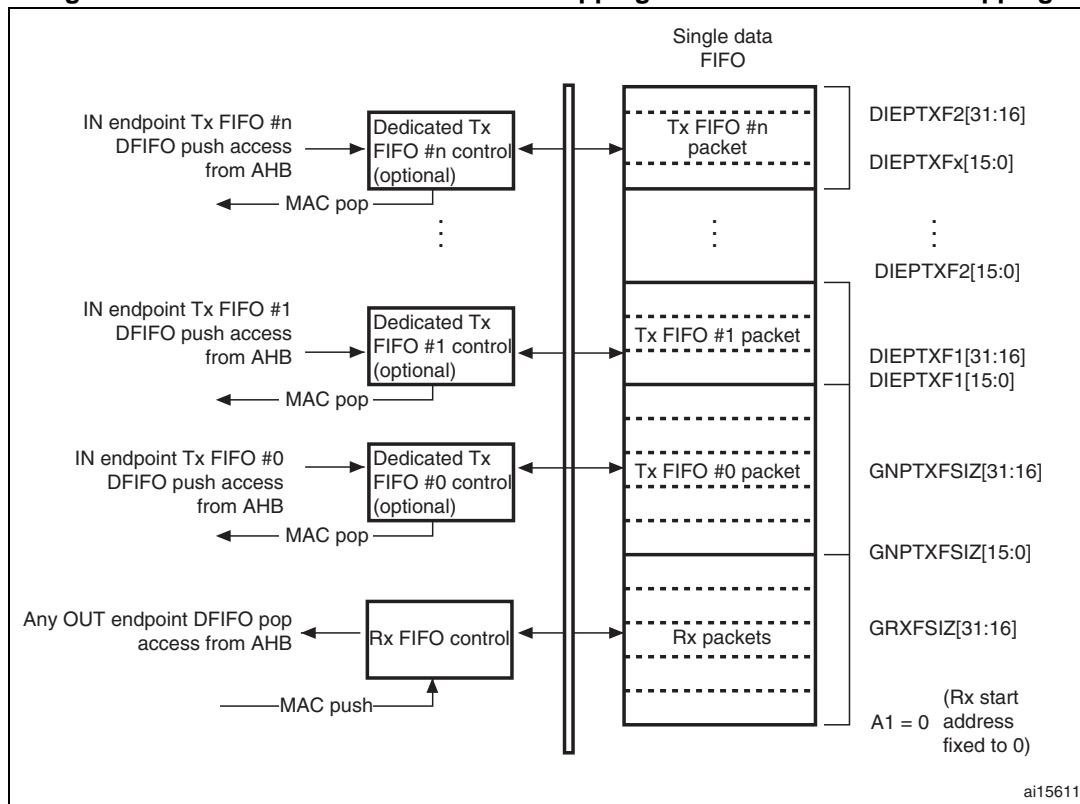


## 22.10 USB data FIFOs

The USB system features 1.25 Kbyte of dedicated RAM with a sophisticated FIFO control mechanism. The packet FIFO controller module in the OTG\_FS core organizes RAM space into Tx-FIFOs into which the application pushes the data to be temporarily stored before the USB transmission, and into a single Rx FIFO where the data received from the USB are temporarily stored before retrieval (popped) by the application. The number of instructed FIFOs and how these are organized inside the RAM depends on the device's role. In peripheral mode an additional Tx-FIFO is instructed for each active IN endpoint. Any FIFO size is software configured to better meet the application requirements.

## 22.11 Peripheral FIFO architecture

Figure 248. Device-mode FIFO address mapping and AHB FIFO access mapping



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### 22.11.1 Peripheral Rx FIFO

The OTG peripheral uses a single receive FIFO that receives the data directed to all OUT endpoints. Received packets are stacked back-to-back until free space is available in the Rx-FIFO. The status of the received packet (which contains the OUT endpoint destination number, the byte count, the data PID and the validity of the received data) is also stored by the core on top of the data payload. When no more space is available, host transactions are NACKed and an interrupt is received on the addressed endpoint. The size of the receive FIFO is configured in the receive FIFO Size register (GRXFSIZ).

The single receive FIFO architecture makes it more efficient for the USB peripheral to fill in the receive RAM buffer:

- All OUT endpoints share the same RAM buffer (shared FIFO)
- The OTG FS core can fill in the receive FIFO up to the limit for any host sequence of OUT tokens

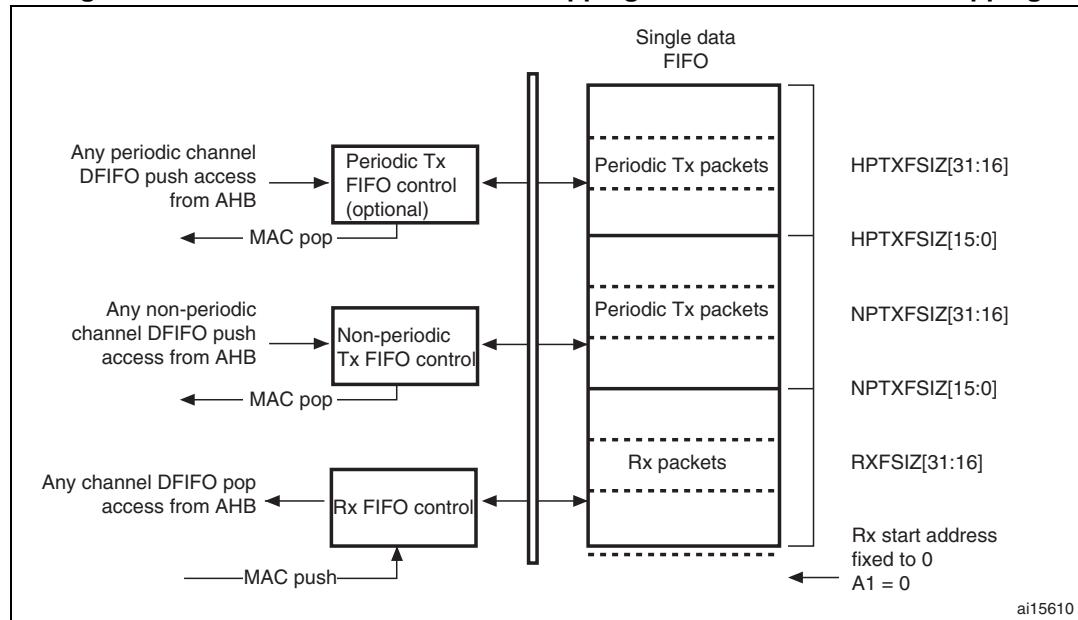
The application keeps receiving the Rx-FIFO non-empty interrupt (RXFLVL bit in OTG\_FS\_GINTSTS) as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register (GRXSTSP) and finally pops data off the receive FIFO by reading from the endpoint-related pop address.

### 22.11.2 Peripheral Tx FIFOs

The core has a dedicated FIFO for each IN endpoint. The application configures FIFO sizes by writing the non periodic transmit FIFO size register (OTG\_FS\_TX0FSIZ) for IN endpoint0 and the device IN endpoint transmit FIFOx registers (DIEPTXFx) for IN endpoint-x.

## 22.12 Host FIFO architecture

**Figure 249. Host-mode FIFO address mapping and AHB FIFO access mapping**



### 22.12.1 Host Rx FIFO

The host uses one receiver FIFO for all periodic and nonperiodic transactions. The FIFO is used as a receive buffer to hold the received data (payload of the received packet) from the USB until it is transferred to the system memory. Packets received from any remote IN endpoint are stacked back-to-back until free space is available. The status of each received packet with the host channel destination, byte count, data PID and validity of the received data are also stored into the FIFO. The size of the receive FIFO is configured in the receive FIFO size register (GRXFSIZ).

The single receive FIFO architecture makes it highly efficient for the USB host to fill in the receive data buffer:

- All IN configured host channels share the same RAM buffer (shared FIFO)
- The OTG FS core can fill in the receive FIFO up to the limit for any sequence of IN tokens driven by the host software

The application receives the Rx FIFO not-empty interrupt as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register and finally pops the data off the receive FIFO.

## 22.12.2 Host Tx FIFOs

The host uses one transmit FIFO for all non-periodic (control and bulk) OUT transactions and one transmit FIFO for all periodic (isochronous and interrupt) OUT transactions. FIFOs are used as transmit buffers to hold the data (payload of the transmit packet) to be transmitted over the USB. The size of the periodic (nonperiodic) Tx FIFO is configured in the host periodic (nonperiodic) transmit FIFO size (HPTXFSIZ/HNPTXFSIZ) register.

The two Tx FIFO implementation derives from the higher priority granted to the periodic type of traffic over the USB frame. At the beginning of each frame, the built-in host scheduler processes the periodic request queue first, followed by the nonperiodic request queue.

The two transmit FIFO architecture provides the USB host with separate optimization for periodic and nonperiodic transmit data buffer management:

- All host channels configured to support periodic (nonperiodic) transactions in the OUT direction share the same RAM buffer (shared FIFOs)
- The OTG FS core can fill in the periodic (nonperiodic) transmit FIFO up to the limit for any sequence of OUT tokens driven by the host software

The OTG\_FS core issues the periodic Tx FIFO empty interrupt (PTXFE bit in OTG\_FS\_GINTSTS) as long as the periodic Tx-FIFO is half or completely empty, depending on the value of the periodic Tx-FIFO empty level bit in the AHB configuration register (PTXFELVL bit in OTG\_FS\_GAHBCFG). The application can push the transmission data in advance as long as free space is available in both the periodic Tx FIFO and the periodic request queue. The host periodic transmit FIFO and queue status register (HPTXSTS) can be read to know how much space is available in both.

OTG\_FS core issues the non periodic Tx FIFO empty interrupt (NPTXFE bit in OTG\_FS\_GINTSTS) as long as the nonperiodic Tx FIFO is half or completely empty depending on the non periodic Tx FIFO empty level bit in the AHB configuration register (TXFELVL bit in OTG\_FS\_GAHBCFG). The application can push the transmission data as long as free space is available in both the nonperiodic Tx FIFO and nonperiodic request queue. The host nonperiodic transmit FIFO and queue status register (HNPTXSTS) can be read to know how much space is available in both.

## 22.13 FIFO RAM allocation

### 22.13.1 Device mode

**Receive FIFO RAM allocation:** the application should allocate RAM for SETUP Packets: 10 locations must be reserved in the receive FIFO to receive SETUP packets on control endpoint. The core does not use these locations, which are reserved for SETUP packets, to write any other data. One location is to be allocated for Global OUT NAK. Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (Largest Packet Size / 4) + 1 must be allocated to receive packets. If multiple isochronous endpoints are enabled, then at least two (Largest Packet Size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (Largest Packet Size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.

Along with the last packet for each endpoint, transfer complete status information is also pushed to the FIFO. Typically, one location for each OUT endpoint is recommended.

**Transmit FIFO RAM allocation:** the minimum RAM space required for each IN Endpoint Transmit FIFO is the maximum packet size for that particular IN endpoint.

*Note:* More space allocated in the transmit IN Endpoint FIFO results in better performance on the USB.

### 22.13.2 Host mode

#### Receive FIFO RAM allocation

Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (Largest Packet Size / 4) + 1 must be allocated to receive packets. If multiple isochronous channels are enabled, then at least two (Largest Packet Size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (Largest Packet Size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.

Along with the last packet in the host channel, transfer complete status information is also pushed to the FIFO. So one location must be allocated for this.

#### Transmit FIFO RAM allocation

The minimum amount of RAM required for the host Non-periodic Transmit FIFO is the largest maximum packet size among all supported non-periodic OUT channels.

Typically, two Largest Packet Sizes worth of space is recommended, so that when the current packet is under transfer to the USB, the CPU can get the next packet.

The minimum amount of RAM required for host periodic Transmit FIFO is the largest maximum packet size out of all the supported periodic OUT channels. If there is at least one Isochronous OUT endpoint, then the space must be at least two times the maximum packet size of that channel.

*Note:* More space allocated in the Transmit Non-periodic FIFO results in better performance on the USB.

## 22.14 USB system performance

Best USB and system performance is achieved owing to the large RAM buffers, the highly configurable FIFO sizes, the quick 32-bit FIFO access through AHB push/pop registers and, especially, the advanced FIFO control mechanism. Indeed, this mechanism allows the

OTG\_FS to fill in the available RAM space at best regardless of the current USB sequence. With these features:

- The application gains good margins to calibrate its intervention in order to optimize the CPU bandwidth usage:
  - It can accumulate large amounts of transmission data in advance compared to when they are effectively sent over the USB
  - It benefits of a large time margin to download data from the single receive FIFO
- The USB Core is able to maintain its full operating rate, that is to provide maximum full-speed bandwidth with a great margin of autonomy versus application intervention:
  - It has a large reserve of transmission data at its disposal to autonomously manage the sending of data over the USB
  - It has a lot of empty space available in the receive buffer to autonomously fill it in with the data coming from the USB

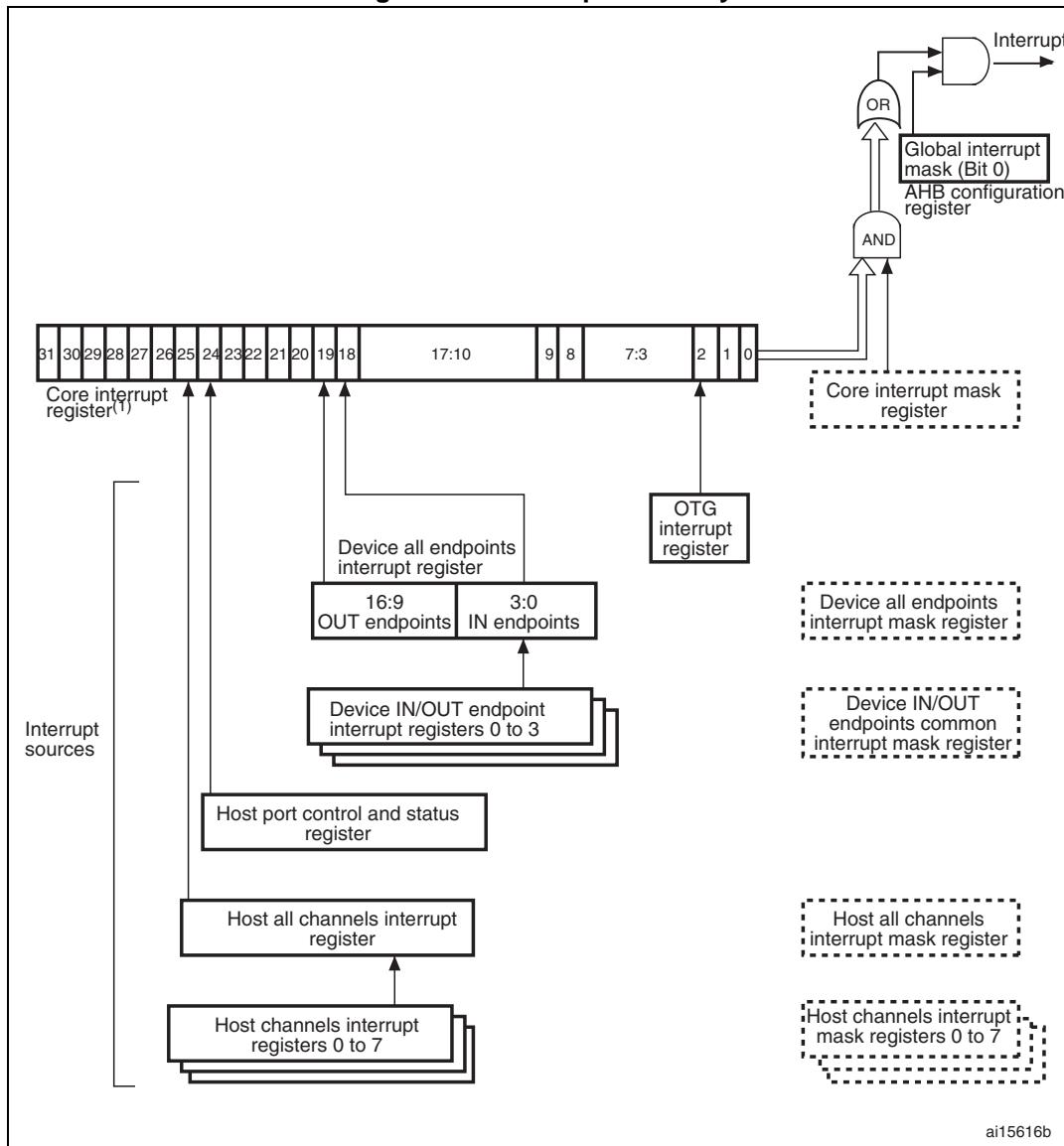
As the OTG\_FS core is able to fill in the 1.25 Kbyte RAM buffer very efficiently, and as 1.25 Kbyte of transmit/receive data is more than enough to cover a full speed frame, the USB system is able to withstand the maximum full-speed data rate for up to one USB frame (1 ms) without any CPU intervention.

## 22.15 OTG\_FS interrupts

When the OTG\_FS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the Core interrupt register (MMIS bit in the OTG\_FS\_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

*Figure 250* shows the interrupt hierarchy.

Figure 250. Interrupt hierarchy



1. The core interrupt register bits are shown in *OTG\_FS core interrupt register (OTG\_FS\_GINTSTS) on page 695*.

## 22.16 OTG\_FS control and status registers

By reading from and writing to the control and status registers (CSRs) through the AHB slave interface, the application controls the OTG\_FS controller. These registers are 32 bits wide, and the addresses are 32-bit block aligned. The OTG\_FS registers must be accessed by words (32 bits).

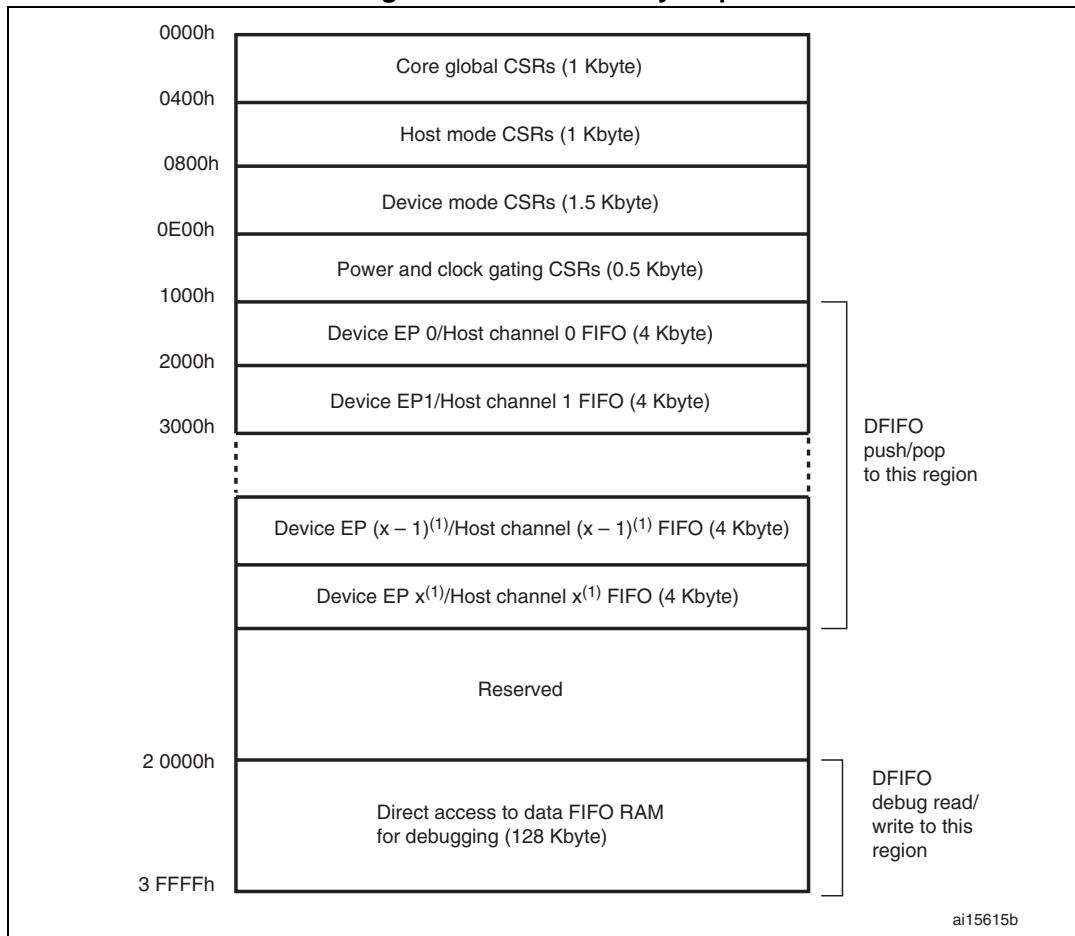
CSRs are classified as follows:

- Core global registers
- Host-mode registers
- Host global registers
- Host port CSRs
- Host channel-specific registers
- Device-mode registers
- Device global registers
- Device endpoint-specific registers
- Power and clock-gating registers
- Data FIFO (DFIFO) access registers

Only the Core global, Power and clock-gating, Data FIFO access, and host port control and status registers can be accessed in both host and device modes. When the OTG\_FS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the Core interrupt register (MMIS bit in the OTG\_FS\_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

### 22.16.1 CSR memory map

The host and device mode registers occupy different addresses. All registers are implemented in the AHB clock domain.

**Figure 251. CSR memory map**

1. x = 3 in device mode and x = 7 in host mode.

### Global CSR map

These registers are available in both host and device modes.

**Table 125. Core global control and status registers (CSRs)**

Acronym	Address offset	Register name
OTG_FS_GOTGCTL	0x000	<i>OTG_FS control and status register (OTG_FS_GOTGCTL) on page 686</i>
OTG_FS_GOTGINT	0x004	<i>OTG_FS interrupt register (OTG_FS_GOTGINT) on page 688</i>
OTG_FS_GAHBCFG	0x008	<i>OTG_FS AHB configuration register (OTG_FS_GAHBCFG) on page 690</i>
OTG_FS_GUSBCFG	0x00C	<i>OTG_FS USB configuration register (OTG_FS_GUSBCFG) on page 691</i>
OTG_FS_GRSTCTL	0x010	<i>OTG_FS reset register (OTG_FS_GRSTCTL) on page 693</i>
OTG_FS_GINTSTS	0x014	<i>OTG_FS core interrupt register (OTG_FS_GINTSTS) on page 695</i>
OTG_FS_GINTMSK	0x018	<i>OTG_FS interrupt mask register (OTG_FS_GINTMSK) on page 699</i>

**Table 125. Core global control and status registers (CSRs) (continued)**

Acronym	Address offset	Register name
OTG_FS_GRXSTSR	0x01C	<i>OTG_FS Receive status debug read/OTG status read and pop registers (OTG_FS_GRXSTSR/OTG_FS_GRXSTSP) on page 702</i>
OTG_FS_GRXSTSP	0x020	
OTG_FS_GRXFSIZ	0x024	<i>OTG_FS Receive FIFO size register (OTG_FS_GRXFSIZ) on page 703</i>
OTG_FS_HNPTXFSIZ/ OTG_FS_DIEPTXF0 <sup>(1)</sup>	0x028	<i>OTG_FS Host non-periodic transmit FIFO size register (OTG_FS_HNPTXFSIZ)/Endpoint 0 Transmit FIFO size (OTG_FS_DIEPTXF0)</i>
OTG_FS_HNPTXSTS	0x02C	<i>OTG_FS non-periodic transmit FIFO/queue status register (OTG_FS_HNPTXSTS) on page 704</i>
OTG_FS_GCCFG	0x038	<i>OTG_FS general core configuration register (OTG_FS_GCCFG) on page 705</i>
OTG_FS_CID	0x03C	<i>OTG_FS core ID register (OTG_FS_CID) on page 706</i>
OTG_FS_HPTXFSIZ	0x100	<i>OTG_FS Host periodic transmit FIFO size register (OTG_FS_HPTXFSIZ) on page 707</i>
OTG_FS_DIEPTXF <sub>x</sub>	0x104 0x124 ... 0x138	<i>OTG_FS device IN endpoint transmit FIFO size register (OTG_FS_DIEPTXF<sub>x</sub>) (x = 1..3, where x is the FIFO_number) on page 708</i>

1. The general rule is to use OTG\_FS\_HNPTXFSIZ for host mode and OTG\_FS\_DIEPTXF0 for device mode.

### Host-mode CSR map

These registers must be programmed every time the core changes to host mode.

**Table 126. Host-mode control and status registers (CSRs)**

Acronym	Offset address	Register name
OTG_FS_HCFG	0x400	<i>OTG_FS Host configuration register (OTG_FS_HCFG) on page 708</i>
OTG_FS_HFIR	0x404	<i>OTG_FS Host frame interval register (OTG_FS_HFIR) on page 709</i>
OTG_FS_HFNUM	0x408	<i>OTG_FS Host frame number/frame time remaining register (OTG_FS_HFNUM) on page 710</i>
OTG_FS_HPTXSTS	0x410	<i>OTG_FS Host periodic transmit FIFO/queue status register (OTG_FS_HPTXSTS) on page 710</i>
OTG_FS_HAINT	0x414	<i>OTG_FS Host all channels interrupt register (OTG_FS_HAINT) on page 711</i>
OTG_FS_HAINTMSK	0x418	<i>OTG_FS Host all channels interrupt mask register (OTG_FS_HAINTMSK) on page 712</i>
OTG_FS_HPRT	0x440	<i>OTG_FS Host port control and status register (OTG_FS_HPRT) on page 712</i>

**Table 126. Host-mode control and status registers (CSRs) (continued)**

Acronym	Offset address	Register name
OTG_FS_HCCHARx	0x500 0x520 ... 0x6E0h	<i>OTG_FS Host channel-x characteristics register (OTG_FS_HCCHARx) (x = 0..7, where x = Channel_number) on page 715</i>
OTG_FS_HCINTx	508h	<i>OTG_FS Host channel-x interrupt register (OTG_FS_HCINTx) (x = 0..7, where x = Channel_number) on page 716</i>
OTG_FS_HCINTMSKx	50Ch	<i>OTG_FS Host channel-x interrupt mask register (OTG_FS_HCINTMSKx) (x = 0..7, where x = Channel_number) on page 717</i>
OTG_FS_HCTSIZx	510h	<i>OTG_FS Host channel-x transfer size register (OTG_FS_HCTSIZx) (x = 0..7, where x = Channel_number) on page 718</i>

**Device-mode CSR map**

These registers must be programmed every time the core changes to device mode.

**Table 127. Device-mode control and status registers**

Acronym	Offset address	Register name
OTG_FS_DCFG	0x800	<i>OTG_FS device configuration register (OTG_FS_DCFG) on page 719</i>
OTG_FS_DCTL	0x804	<i>OTG_FS device control register (OTG_FS_DCTL) on page 720</i>
OTG_FS_DSTS	0x808	<i>OTG_FS device status register (OTG_FS_DSTS) on page 721</i>
OTG_FS_DIEPMSK	0x810	<i>OTG_FS device IN endpoint common interrupt mask register (OTG_FS_DIEPMSK) on page 722</i>
OTG_FS_DOEPMSK	0x814	<i>OTG_FS device OUT endpoint common interrupt mask register (OTG_FS_DOEPMSK) on page 723</i>
OTG_FS_DAINT	0x818	<i>OTG_FS device all endpoints interrupt register (OTG_FS_DAINT) on page 724</i>
OTG_FS_DAINTMSK	0x81C	<i>OTG_FS all endpoints interrupt mask register (OTG_FS_DAINTMSK) on page 725</i>
OTG_FS_DVBUSDIS	0x828	<i>OTG_FS device VBUS discharge time register (OTG_FS_DVBUSDIS) on page 725</i>
OTG_FS_DVBUSPULSE	0x82C	<i>OTG_FS device VBUS pulsing time register (OTG_FS_DVBUSPULSE) on page 726</i>
OTG_FS_DIEPEMPMSK	0x834	<i>OTG_FS device IN endpoint FIFO empty interrupt mask register: (OTG_FS_DIEPEMPMSK) on page 726</i>
OTG_FS_DIEPCTL0	0x900	<i>OTG_FS device control IN endpoint 0 control register (OTG_FS_DIEPCTL0) on page 727</i>

**Table 127. Device-mode control and status registers (continued)**

Acronym	Offset address	Register name
OTG_FS_DIEPCTLx	0x920 0x940 ... 0xAE0	<i>OTG device endpoint-x control register (OTG_FS_DIEPCTLx) (x = 1..3, where x = Endpoint_number) on page 728</i>
OTG_FS_DIEPINTx	0x908	<i>OTG_FS device endpoint-x interrupt register (OTG_FS_DIEPINTx) (x = 0..3, where x = Endpoint_number) on page 735</i>
OTG_FS_DIEPTSIZ0	0x910	<i>OTG_FS device IN endpoint 0 transfer size register (OTG_FS_DIEPTSIZ0) on page 737</i>
OTG_FS_DTXFSTSx	0x918	<i>OTG_FS device IN endpoint transmit FIFO status register (OTG_FS_DTXFSTSx) (x = 0..3, where x = Endpoint_number) on page 740</i>
OTG_FS_DIEPTSIZx	0x930 0x950 ... 0xAF0	<i>OTG_FS device OUT endpoint-x transfer size register (OTG_FS_DOEPTSIZx) (x = 1..3, where x = Endpoint_number) on page 740</i>
OTG_FS_DOEPCTL0	0xB00	<i>OTG_FS device control OUT endpoint 0 control register (OTG_FS_DOEPCTL0) on page 731</i>
OTG_FS_DOEPCTLx	0xB20 0xB40 ... 0xCC0 0xCE0 0xCFD	<i>OTG device endpoint-x control register (OTG_FS_DIEPCTLx) (x = 1..3, where x = Endpoint_number) on page 728</i>
OTG_FS_DOEPINTx	0xB08	<i>OTG_FS device endpoint-x interrupt register (OTG_FS_DIEPINTx) (x = 0..3, where x = Endpoint_number) on page 735</i>
OTG_FS_DOEPTSIZx	0xB10	<i>OTG_FS device OUT endpoint-x transfer size register (OTG_FS_DOEPTSIZx) (x = 1..3, where x = Endpoint_number) on page 740</i>

### Data FIFO (DFIFO) access register map

These registers, available in both host and device modes, are used to read or write the FIFO space for a specific endpoint or a channel, in a given direction. If a host channel is of type IN, the FIFO can only be read on the channel. Similarly, if a host channel is of type OUT, the FIFO can only be written on the channel.

**Table 128. Data FIFO (DFIFO) access register map**

FIFO access register section	Address range	Access
Device IN Endpoint 0/Host OUT Channel 0: DFIFO Write Access Device OUT Endpoint 0/Host IN Channel 0: DFIFO Read Access	0x1000–0x1FFC	w r
Device IN Endpoint 1/Host OUT Channel 1: DFIFO Write Access Device OUT Endpoint 1/Host IN Channel 1: DFIFO Read Access	0x2000–0x2FFC	w r
...	...	...
Device IN Endpoint x <sup>(1)</sup> /Host OUT Channel x <sup>(1)</sup> : DFIFO Write Access Device OUT Endpoint x <sup>(1)</sup> /Host IN Channel x <sup>(1)</sup> : DFIFO Read Access	0xX000–0xXFFC	w r

1. Where x is 3 in device mode and 7 in host mode.

### Power and clock gating CSR map

There is a single register for power and clock gating. It is available in both host and device modes.

**Table 129. Power and clock gating control and status registers**

Register name	Acronym	Offset address: 0xE00–0xFFFF
Power and clock gating control register	PCGCR	0xE00–0xE04
Reserved		0xE05–0xFFFF

## 22.16.2 OTG\_FS global registers

These registers are available in both host and device modes, and do not need to be reprogrammed when switching between these modes.

Bit values in the register descriptions are expressed in binary unless otherwise specified.

### OTG\_FS control and status register (OTG\_FS\_GOTGCTL)

Address offset: 0x000

Reset value: 0x0000 0800

The OTG\_FS\_GOTGCTL register controls the behavior and reflects the status of the OTG function of the core.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																															

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **BSVLD:** B-session valid

Indicates the device mode transceiver status.

0: B-session is not valid.

1: B-session is valid.

In OTG mode, you can use this bit to determine if the device is connected or disconnected.

*Note: Only accessible in device mode.*

Bit 18 **ASVLD:** A-session valid

Indicates the host mode transceiver status.

0: A-session is not valid

1: A-session is valid

*Note: Only accessible in host mode.*

Bit 17 **DBCT:** Long/short debounce time

Indicates the debounce time of a detected connection.

0: Long debounce time, used for physical connections (100 ms + 2.5 µs)

1: Short debounce time, used for soft connections (2.5 µs)

*Note: Only accessible in host mode.*

Bit 16 **CIDSTS:** Connector ID status

Indicates the connector ID status on a connect event.

0: The OTG\_FS controller is in A-device mode

1: The OTG\_FS controller is in B-device mode

*Note: Accessible in both device and host modes.*

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **DHNPEN:** Device HNP enabled

The application sets this bit when it successfully receives a SetFeature.SetHNPEnable command from the connected USB host.

0: HNP is not enabled in the application

1: HNP is enabled in the application

*Note: Only accessible in device mode.*

Bit 10 **HSHNPEN:** host set HNP enable

The application sets this bit when it has successfully enabled HNP (using the SetFeature.SetHNPEnable command) on the connected device.

0: Host Set HNP is not enabled

1: Host Set HNP is enabled

*Note: Only accessible in host mode.*

Bit 9 **HNPRQ:** HNP request

The application sets this bit to initiate an HNP request to the connected USB host. The application can clear this bit by writing a 0 when the host negotiation success status change bit in the OTG\_FS\_GOTGINT register (HNSSCHG bit in OTG\_FS\_GOTGINT) is set. The core clears this bit when the HNSSCHG bit is cleared.

0: No HNP request

1: HNP request

*Note: Only accessible in device mode.*

Bit 8 **HNGSCS:** Host negotiation success

The core sets this bit when host negotiation is successful. The core clears this bit when the HNP Request (HNPRQ) bit in this register is set.

0: Host negotiation failure

1: Host negotiation success

*Note: Only accessible in device mode.*

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **SRQ:** Session request

The application sets this bit to initiate a session request on the USB. The application can clear this bit by writing a 0 when the host negotiation success status change bit in the OTG\_FS\_GOTGINT register (HNSSCHG bit in OTG\_FS\_GOTGINT) is set. The core clears this bit when the HNSSCHG bit is cleared.

If you use the USB 1.1 full-speed serial transceiver interface to initiate the session request, the application must wait until  $V_{BUS}$  discharges to 0.2 V, after the B-Session Valid bit in this register (BSVLD bit in OTG\_FS\_GOTGCTL) is cleared. This discharge time varies between different PHYs and can be obtained from the PHY vendor.

0: No session request

1: Session request

*Note: Only accessible in device mode.*

Bit 0 **SRQSCS:** Session request success

The core sets this bit when a session request initiation is successful.

0: Session request failure

1: Session request success

*Note: Only accessible in device mode.*

**OTG\_FS interrupt register (OTG\_FS\_GOTGINT)**

Address offset: 0x04

Reset value: 0x0000 0000

The application reads this register whenever there is an OTG interrupt and clears the bits in this register to clear the OTG interrupt.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved												DBCDNE	ADTOCHG	HNGDET	Reserved				HNSSCHG	SRSSCHG	Reserved				SEDET	Res.					
												rc_w1	rc_w1	rc_w1					rc_w1	rc_w1					rc_w1						

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **DBCDNE:** Debounce done

The core sets this bit when the debounce is completed after the device connect. The application can start driving USB reset after seeing this interrupt. This bit is only valid when the HNP Capable or SRP Capable bit is set in the OTG\_FS\_GUSBCFG register (HNPCAP bit or SRPCAP bit in OTG\_FS\_GUSBCFG, respectively).

*Note: Only accessible in host mode.*

**Bit 18 ADTOCHG:** A-device timeout change

The core sets this bit to indicate that the A-device has timed out while waiting for the B-device to connect.

*Note: Accessible in both device and host modes.*

**Bit 17 HNGDET:** Host negotiation detected

The core sets this bit when it detects a host negotiation request on the USB.

*Note: Accessible in both device and host modes.*

Bits 16:10 Reserved, must be kept at reset value.

**Bit 9 HNSSCHG:** Host negotiation success status change

The core sets this bit on the success or failure of a USB host negotiation request. The application must read the host negotiation success bit of the OTG\_FS\_GOTGCTL register (HNGSCS in OTG\_FS\_GOTGCTL) to check for success or failure.

*Note: Accessible in both device and host modes.*

Bits 7:3 Reserved, must be kept at reset value.

**Bit 8 SRSSCHG:** Session request success status change

The core sets this bit on the success or failure of a session request. The application must read the session request success bit in the OTG\_FS\_GOTGCTL register (SRQSCS bit in OTG\_FS\_GOTGCTL) to check for success or failure.

*Note: Accessible in both device and host modes.*

**Bit 2 SEDET:** Session end detected

The core sets this bit to indicate that the level of the voltage on V<sub>BUS</sub> is no longer valid for a B-Peripheral session when V<sub>BUS</sub> < 0.8 V.

Bits 1:0 Reserved, must be kept at reset value.

**OTG\_FS AHB configuration register (OTG\_FS\_GAHBCFG)**

Address offset: 0x008

Reset value: 0x0000 0000

This register can be used to configure the core after power-on or a change in mode. This register mainly contains AHB system-related configuration parameters. Do not change this register after the initial programming. The application must program this register before starting any transactions on either the AHB or the USB.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																				PTXFELVL	TXFELVL	Reserved						GINTMSK			

Bits 31:20 Reserved, must be kept at reset value.

**Bit 8 PTXFELVL: Periodic TxFIFO empty level**

Indicates when the periodic TxFIFO empty interrupt bit in the OTG\_FS\_GINTSTS register (PTXFE bit in OTG\_FS\_GINTSTS) is triggered.

- 0: PTXFE (in OTG\_FS\_GINTSTS) interrupt indicates that the Periodic TxFIFO is half empty
- 1: PTXFE (in OTG\_FS\_GINTSTS) interrupt indicates that the Periodic TxFIFO is completely empty

*Note:* Only accessible in host mode.

**Bit 7 TXFELVL: TxFIFO empty level**

In device mode, this bit indicates when IN endpoint Transmit FIFO empty interrupt (TXFE in OTG\_FS\_DIEPINTx.) is triggered.

- 0: the TXFE (in OTG\_FS\_DIEPINTx) interrupt indicates that the IN Endpoint TxFIFO is half empty
- 1: the TXFE (in OTG\_FS\_DIEPINTx) interrupt indicates that the IN Endpoint TxFIFO is completely empty

In host mode, this bit indicates when the nonperiodic Tx FIFO empty interrupt (NPTXFE bit in OTG\_FS\_GINTSTS) is triggered:

- 0: the NPTXFE (in OTG\_FS\_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is half empty
- 1: the NPTXFE (in OTG\_FS\_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is completely empty

Bits 6:1 Reserved, must be kept at reset value.

**Bit 0 GINTMSK: Global interrupt mask**

The application uses this bit to mask or unmask the interrupt line assertion to itself. Irrespective of this bit's setting, the interrupt status registers are updated by the core.

- 0: Mask the interrupt assertion to the application.
- 1: Unmask the interrupt assertion to the application.

*Note:* Accessible in both device and host modes.

### OTG\_FS USB configuration register (OTG\_FS\_GUSBCFG)

Address offset: 0x00C

Reset value: 0x0000 0A00

This register can be used to configure the core after power-on or a changing to host mode or device mode. It contains USB and USB-PHY related configuration parameters. The application must program this register before starting any transactions on either the AHB or the USB. Do not make changes to this register after the initial programming.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CTXPKT	FDMOD	FHMOD																			TRDT	HNP/CAP	SRP/CAP	Res.	PHYSEL		Reserved	TOCAL			
rw	rw	rw																			rw	r/rw	r/rw		wo			rw			

Bits 31:20 Reserved, must be kept at reset value.

Bit 31 **CTXPKT:** Corrupt Tx packet

This bit is for debug purposes only. Never set this bit to 1.

*Note: Accessible in both device and host modes.*

Bit 30 **FDMOD:** Force device mode

Writing a 1 to this bit forces the core to device mode irrespective of the OTG\_FS\_ID input pin.

0: Normal mode

1: Force device mode

After setting the force bit, the application must wait at least 25 ms before the change takes effect.

*Note: Accessible in both device and host modes.*

Bit 29 **FHMOD:** Force host mode

Writing a 1 to this bit forces the core to host mode irrespective of the OTG\_FS\_ID input pin.

0: Normal mode

1: Force host mode

After setting the force bit, the application must wait at least 25 ms before the change takes effect.

*Note: Accessible in both device and host modes.*

Bits 28:14 Reserved, must be kept at reset value.

Bits 13:10 **TRDT:** USB turnaround time

Sets the turnaround time in PHY clocks.

To calculate the value of TRDT, use the following formula:

$$\text{TRDT} = 4 \times \text{AHB clock} + 1 \text{ PHY clock}$$

Examples:

1. if AHB clock = 72 MHz (PHY Clock is 48), the TRDT is set to 9.

2. if AHB clock = 48 MHz (PHY Clock is 48), the TRDT is set to 5.

*Note: Only accessible in device mode.*

**Bit 9 HNPCAP:** HNP-capable

The application uses this bit to control the OTG\_FS controller's HNP capabilities.

0: HNP capability is not enabled.

1: HNP capability is enabled.

*Note: Accessible in both device and host modes.*

**Bit 8 SRPCAP:** SRP-capable

The application uses this bit to control the OTG\_FS controller's SRP capabilities. If the core operates as a non-SRP-capable

B-device, it cannot request the connected A-device (host) to activate  $V_{BUS}$  and start a session.

0: SRP capability is not enabled.

1: SRP capability is enabled.

*Note: Accessible in both device and host modes.*

Bit 7 Reserved, must be kept at reset value.

**Bit 6 PHYSEL:** Full Speed serial transceiver select

This bit is always 1 with write-only access.

Bits5:3 Reserved, must be kept at reset value.

**Bits 2:0 TOCAL:** FS timeout calibration

The number of PHY clocks that the application programs in this field is added to the full-speed interpacket timeout duration in the core to account for any additional delays introduced by the PHY. This can be required, because the delay introduced by the PHY in generating the line state condition can vary from one PHY to another.

The USB standard timeout value for full-speed operation is 16 to 18 (inclusive) bit times. The application must program this field based on the speed of enumeration. The number of bit times added per PHY clock is 0.25 bit times.



**Bit 2 FCRST:** Host frame counter reset

The application writes this bit to reset the frame number counter inside the core. When the frame counter is reset, the subsequent SOF sent out by the core has a frame number of 0.

*Note: Only accessible in host mode.*

**Bit 1 HSRST:** HCLK soft reset

The application uses this bit to flush the control logic in the AHB Clock domain. Only AHB Clock Domain pipelines are reset.

FIFOs are not flushed with this bit.

All state machines in the AHB clock domain are reset to the Idle state after terminating the transactions on the AHB, following the protocol.

CSR control bits used by the AHB clock domain state machines are cleared.

To clear this interrupt, status mask bits that control the interrupt status and are generated by the AHB clock domain state machine are cleared.

Because interrupt status bits are not cleared, the application can get the status of any core events that occurred after it set this bit.

This is a self-clearing bit that the core clears after all necessary logic is reset in the core. This can take several clocks, depending on the core's current state.

*Note: Accessible in both device and host modes.*

**Bit 0 CSRST:** Core soft reset

Resets the HCLK and PCLK domains as follows:

Clears the interrupts and all the CSR register bits except for the following bits:

- RSTPDMDL bit in OTG\_FS\_PCGCCTL
- GAYEHCLK bit in OTG\_FS\_PCGCCTL
- PWRCLMP bit in OTG\_FS\_PCGCCTL
- STPPCLK bit in OTG\_FS\_PCGCCTL
- FSLSPCS bit in OTG\_FS\_HCFG
- DSPD bit in OTG\_FS\_DCFG

All module state machines (except for the AHB slave unit) are reset to the Idle state, and all the transmit FIFOs and the receive FIFO are flushed.

Any transactions on the AHB Master are terminated as soon as possible, after completing the last data phase of an AHB transfer. Any transactions on the USB are terminated immediately.

The application can write to this bit any time it wants to reset the core. This is a self-clearing bit and the core clears this bit after all the necessary logic is reset in the core, which can take several clocks, depending on the current state of the core. Once this bit has been cleared, the software must wait at least 3 PHY clocks before accessing the PHY domain

(synchronization delay). The software must also check that bit 31 in this register is set to 1 (AHB Master is Idle) before starting any operation.

Typically, the software reset is used during software development and also when you dynamically change the PHY selection bits in the above listed USB configuration registers. When you change the PHY, the corresponding clock for the PHY is selected and used in the PHY domain. Once a new clock is selected, the PHY domain has to be reset for proper operation.

*Note: Accessible in both device and host modes.*

### OTG\_FS core interrupt register (OTG\_FS\_GINTSTS)

Address offset: 0x014

Reset value: 0x0400 0020

This register interrupts the application for system-level events in the current mode (device mode or host mode).

Some of the bits in this register are valid only in host mode, while others are valid in device mode only. This register also indicates the current mode. To clear the interrupt status bits of the rc\_w1 type, the application must write 1 into the bit.

The FIFO status interrupts are read-only; once software reads from or writes to the FIFO while servicing these interrupts, FIFO interrupt conditions are cleared automatically.

The application must clear the OTG\_FS\_GINTSTS register at initialization before unmasking the interrupt bit to avoid any interrupts generated prior to initialization.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WKINT	SRQINT	DISCINT	CIDSCHG	Reserved	PTXFE	HCINT	HPRINT	Reserved	IPXFRI/INCOMPISOOUT	IISOIXFR	OEPINT	IEPINT	Reserved	EOPF	ISOODRP	ENUMDNE	USRST	USBUSUP	ESUSP	Reserved	GOUTNAKEFF	GINAKEFF	NPTXFE	RXFLVL	SOF	OTGINT	MMIS	CMOD			
rc_w1	r	r	r	Res.	rc_w1	r	r							rc_w1							r	r	r	r	rc_w1	r	rc_w1	r			

Bit 31 **WKUPINT:** Resume/remote wakeup detected interrupt

In device mode, this interrupt is asserted when a resume is detected on the USB. In host mode, this interrupt is asserted when a remote wakeup is detected on the USB.

*Note: Accessible in both device and host modes.*

Bit 30 **SRQINT:** Session request/new session detected interrupt

In host mode, this interrupt is asserted when a session request is detected from the device. In device mode, this interrupt is asserted when V<sub>BUS</sub> is in the valid range for a B-peripheral device. Accessible in both device and host modes.

Bit 29 **DISCINT:** Disconnect detected interrupt

Asserted when a device disconnect is detected.

*Note: Only accessible in host mode.*

Bit 28 **CIDSCHG:** Connector ID status change

The core sets this bit when there is a change in connector ID status.

*Note: Accessible in both device and host modes.*

Bit 27 Reserved, must be kept at reset value.

Bit 26 **PTXFE:** Periodic TxFIFO empty

Asserted when the periodic transmit FIFO is either half or completely empty and there is space for at least one entry to be written in the periodic request queue. The half or completely empty status is determined by the periodic TxFIFO empty level bit in the OTG\_FS\_GAHBCFG register (PTXFELVL bit in OTG\_FS\_GAHBCFG).

*Note: Only accessible in host mode.*

Bit 25 **HCINT:** Host channels interrupt

The core sets this bit to indicate that an interrupt is pending on one of the channels of the core (in host mode). The application must read the OTG\_FS\_HAINT register to determine the exact number of the channel on which the interrupt occurred, and then read the corresponding OTG\_FS\_HCINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the OTG\_FS\_HCINTx register to clear this bit.

*Note: Only accessible in host mode.*

Bit 24 **HPRTINT:** Host port interrupt

The core sets this bit to indicate a change in port status of one of the OTG\_FS controller ports in host mode. The application must read the OTG\_FS\_HPRT register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG\_FS\_HPRT register to clear this bit.

*Note: Only accessible in host mode.*

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **IPXFR:** Incomplete periodic transfer

In host mode, the core sets this interrupt bit when there are incomplete periodic transactions still pending, which are scheduled for the current frame.

**INCOMPISOOUT:** Incomplete isochronous OUT transfer

In device mode, the core sets this interrupt to indicate that there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Bit 20 **IISOIXFR:** Incomplete isochronous IN transfer

The core sets this interrupt to indicate that there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

*Note: Only accessible in device mode.*

Bit 19 **OEPINT:** OUT endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the OUT endpoints of the core (in device mode). The application must read the OTG\_FS\_DAINT register to determine the exact number of the OUT endpoint on which the interrupt occurred, and then read the corresponding OTG\_FS\_DOEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG\_FS\_DOEPINTx register to clear this bit.

*Note: Only accessible in device mode.*

Bit 18 **IEPINT:** IN endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the IN endpoints of the core (in device mode). The application must read the OTG\_FS\_DAINT register to determine the exact number of the IN endpoint on which the interrupt occurred, and then read the corresponding OTG\_FS\_DIEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG\_FS\_DIEPINTx register to clear this bit.

*Note: Only accessible in device mode.*

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPF:** End of periodic frame interrupt

Indicates that the period specified in the periodic frame interval field of the OTG\_FS\_DCFG register (PFIVL bit in OTG\_FS\_DCFG) has been reached in the current frame.

*Note: Only accessible in device mode.*

Bit 14 **ISOODRP:** Isochronous OUT packet dropped interrupt

The core sets this bit when it fails to write an isochronous OUT packet into the RxFIFO because the RxFIFO does not have enough space to accommodate a maximum size packet for the isochronous OUT endpoint.

*Note: Only accessible in device mode.*

Bit 13 **ENUMDNE:** Enumeration done

The core sets this bit to indicate that speed enumeration is complete. The application must read the OTG\_FS\_DSTS register to obtain the enumerated speed.

*Note: Only accessible in device mode.*

Bit 12 **USBRST:** USB reset

The core sets this bit to indicate that a reset is detected on the USB.

*Note: Only accessible in device mode.*

Bit 11 **USBSUSP:** USB suspend

The core sets this bit to indicate that a suspend was detected on the USB. The core enters the Suspended state when there is no activity on the data lines for a period of 3 ms.

*Note: Only accessible in device mode.*

Bit 10 **ESUSP:** Early suspend

The core sets this bit to indicate that an Idle state has been detected on the USB for 3 ms.

*Note: Only accessible in device mode.*

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFF:** Global OUT NAK effective

Indicates that the Set global OUT NAK bit in the OTG\_FS\_DCTL register (SGONAK bit in OTG\_FS\_DCTL), set by the application, has taken effect in the core. This bit can be cleared by writing the Clear global OUT NAK bit in the OTG\_FS\_DCTL register (CGONAK bit in OTG\_FS\_DCTL).

*Note: Only accessible in device mode.*

Bit 6 **GINAKEFF:** Global IN non-periodic NAK effective

Indicates that the Set global non-periodic IN NAK bit in the OTG\_FS\_DCTL register (SGINAK bit in OTG\_FS\_DCTL), set by the application, has taken effect in the core. That is, the core has sampled the Global IN NAK bit set by the application. This bit can be cleared by clearing the Clear global non-periodic IN NAK bit in the OTG\_FS\_DCTL register (CGINAK bit in OTG\_FS\_DCTL).

This interrupt does not necessarily mean that a NAK handshake is sent out on the USB. The STALL bit takes precedence over the NAK bit.

*Note: Only accessible in device mode.*

Bit 5 **NPTXFE:** Non-periodic TxFIFO empty

This interrupt is asserted when the non-periodic TxFIFO is either half or completely empty, and there is space for at least one entry to be written to the non-periodic transmit request queue. The half or completely empty status is determined by the non-periodic TxFIFO empty level bit in the OTG\_FS\_GAHBCFG register (TXFELVL bit in OTG\_FS\_GAHBCFG).

*Note: Accessible in host mode only.*

Bit 4 **RXFLVL:** RxFIFO non-empty

Indicates that there is at least one packet pending to be read from the RxFIFO.

*Note: Accessible in both host and device modes.*

**Bit 3 SOF:** Start of frame

In host mode, the core sets this bit to indicate that an SOF (FS), or Keep-Alive (LS) is transmitted on the USB. The application must write a 1 to this bit to clear the interrupt.

In device mode, in the core sets this bit to indicate that an SOF token has been received on the USB. The application can read the Device Status register to get the current frame number. This interrupt is seen only when the core is operating in FS.

*Note: Accessible in both host and device modes.*

**Bit 2 OTGINT:** OTG interrupt

The core sets this bit to indicate an OTG protocol event. The application must read the OTG Interrupt Status (OTG\_FS\_GOTGINT) register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG\_FS\_GOTGINT register to clear this bit.

*Note: Accessible in both host and device modes.*

**Bit 1 MMIS:** Mode mismatch interrupt

The core sets this bit when the application is trying to access:

- A host mode register, when the core is operating in device mode
- A device mode register, when the core is operating in host mode

The register access is completed on the AHB with an OKAY response, but is ignored by the core internally and does not affect the operation of the core.

*Note: Accessible in both host and device modes.*

**Bit 0 CMOD:** Current mode of operation

Indicates the current mode.

- 0: Device mode  
1: Host mode

*Note: Accessible in both host and device modes.*

### OTG\_FS interrupt mask register (OTG\_FS\_GINTMSK)

Address offset: 0x018

Reset value: 0x0000 0000

This register works with the Core interrupt register to interrupt the application. When an interrupt bit is masked, the interrupt associated with that bit is not generated. However, the Core Interrupt (OTG\_FS\_GINTSTS) register bit corresponding to that interrupt is still set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WUIM rw	SRQIM rw	DISCINT rw	CIDSCHGM rw	Reserved rw	PTXFEM rw	HCIM rw	PRTIM r	Reserved rw	IPXFIRM//ISO0XFIRM rw	ISOIXFIRM rw	OEPINT rw	IEPINT rw	EPMISM rw	Reserved rw	EOPFM rw	ISOODRPM rw	ENUMDNEIM rw	USBRST rw	USESUSPBM rw	ESUSPBM rw	Reserved rw	GONAKEFFM rw	GINAKEFFM rw	NPTXFEM rw	RXFLVLM rw	SOFM rw	OTGINT rw	MMISM rw	Reserved rw		

Bit 31 **WUIM:** Resume/remote wakeup detected interrupt mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Accessible in both host and device modes.*

Bit 30 **SRQIM:** Session request/new session detected interrupt mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Accessible in both host and device modes.*

Bit 29 **DISCINT:** Disconnect detected interrupt mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 28 **CIDSCHGM:** Connector ID status change mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Accessible in both host and device modes.*

Bit 27 Reserved, must be kept at reset value.

Bit 26 **PTXFEM:** Periodic TxFIFO empty mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Only accessible in host mode.*

Bit 25 **HCIM:** Host channels interrupt mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Only accessible in host mode.*

Bit 24 **PRTIM:** Host port interrupt mask

0: Masked interrupt

1: Unmasked interrupt

*Note: Only accessible in host mode.*

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **IPXFRM:** Incomplete periodic transfer mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in host mode.*

**IISOXXFRM:** Incomplete isochronous OUT transfer mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 20 **IISOIXFRM:** Incomplete isochronous IN transfer mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 19 **OEPINT:** OUT endpoints interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 18 **IEPINT:** IN endpoints interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 17 **EPMISM:** Endpoint mismatch interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 16 Reserved, must be kept at reset value.

Bit 15 **EOPFM:** End of periodic frame interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 14 **ISOODRPM:** Isochronous OUT packet dropped interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 13 **ENUMDNEM:** Enumeration done mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 12 **USBRST:** USB reset mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 11 **USBSUSPM:** USB suspend mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 10 **ESUSPM:** Early suspend mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFFM:** Global OUT NAK effective mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 6 **GINAKEFFM:** Global non-periodic IN NAK effective mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in device mode.*

Bit 5 **NPTXFEM:** Non-periodic TxFIFO empty mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Only accessible in Host mode.*

Bit 4 **RXFLVLM:** Receive FIFO non-empty mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Accessible in both device and host modes.*

Bit 3 **SOFM:** Start of frame mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Accessible in both device and host modes.*

Bit 2 **OTGINT:** OTG interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Accessible in both device and host modes.*

Bit 1 **MMISM:** Mode mismatch interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

*Note: Accessible in both device and host modes.*

Bit 0 Reserved, must be kept at reset value.

**OTG\_FS Receive status debug read/OTG status read and pop registers  
(OTG\_FS\_GRXSTSR/OTG\_FS\_GRXSTSP)**

Address offset for Read: 0x01C

Address offset for Pop: 0x020

Reset value: 0x0000 0000

A read to the Receive status debug read register returns the contents of the top of the Receive FIFO. A read to the Receive status read and pop register additionally pops the top data entry out of the RxFIFO.

The receive status contents must be interpreted differently in host and device modes. The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the Receive Status FIFO when the Receive FIFO non-empty bit of the Core interrupt register (RXFLVL bit in OTG\_FS\_GINTSTS) is asserted.

**Host mode:**

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved							PKTSTS	DPID	BCNT							CHNUM															
							r	r															r								

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS:** Packet status

Indicates the status of the received packet

- 0010: IN data packet received
- 0011: IN transfer completed (triggers an interrupt)
- 0101: Data toggle error (triggers an interrupt)
- 0111: Channel halted (triggers an interrupt)
- Others: Reserved

Bits 16:15 **DPID:** Data PID

Indicates the Data PID of the received packet

- 00: DATA0
- 10: DATA1
- 01: DATA2
- 11: MDATA

Bits 14:4 **BCNT:** Byte count

Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM:** Channel number

Indicates the channel number to which the current received packet belongs.

**Device mode:**

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved																																	
	FRMNUM	PKTSTS	DPID	BCNT					EPNUM																								
	r	r	r	r					r																								

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM:** Frame number

This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS:** Packet status

Indicates the status of the received packet

0001: Global OUT NAK (triggers an interrupt)

0010: OUT data packet received

0011: OUT transfer completed (triggers an interrupt)

0100: SETUP transaction completed (triggers an interrupt)

0110: SETUP data packet received

Others: Reserved

Bits 16:15 **DPID:** Data PID

Indicates the Data PID of the received OUT data packet

00: DATA0

10: DATA1

01: DATA2

11: MDATA

Bits 14:4 **BCNT:** Byte count

Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM:** Endpoint number

Indicates the endpoint number to which the current received packet belongs.

**OTG\_FS Receive FIFO size register (OTG\_FS\_GRXFSIZ)**

Address offset: 0x024

Reset value: 0x0000 0200

The application can program the RAM size that must be allocated to the RxFIFO.

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved																																	
	RXFD																																
	r/rw																																

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RXFD:** RxFIFO depth

This value is in terms of 32-bit words.

Minimum value is 16

Maximum value is 256

The power-on reset value of this register is specified as the largest Rx data FIFO depth.

**OTG\_FS Host non-periodic transmit FIFO size register  
(OTG\_FS\_HNPTXFSIZ)/Endpoint 0 Transmit FIFO size (OTG\_FS\_DIEPTXF0)**

Address offset: 0x028

Reset value: 0x0000 0200

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0	NPTXFD/TX0FD	NPTXFSA/TX0FSA
	r/rw	r/rw

**Host mode**

Bits 31:16 **NPTXFD**: Non-periodic TxFIFO depth

This value is in terms of 32-bit words.

Minimum value is 16

Maximum value is 256

Bits 15:0 **NPTXFSA**: Non-periodic transmit RAM start address

This field contains the memory start address for non-periodic transmit FIFO RAM.

**Device mode**

Bits 31:16 **TX0FD**: Endpoint 0 TxFIFO depth

This value is in terms of 32-bit words.

Minimum value is 16

Maximum value is 256

Bits 15:0 **TX0FSA**: Endpoint 0 transmit RAM start address

This field contains the memory start address for the endpoint 0 transmit FIFO RAM.

**OTG\_FS non-periodic transmit FIFO/queue status register  
(OTG\_FS\_HNPTXSTS)**

Address offset: 0x02C

Reset value: 0x0008 0200

*Note:* In Device mode, this register is not valid.

This read-only register contains the free space information for the non-periodic TxFIFO and the non-periodic transmit request queue.

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0	NPTXQTOP	NPTQXSAR	NPTXFSAV
Reserved	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **NPTXQTOP**: Top of the non-periodic transmit request queue

Entry in the non-periodic Tx request queue that is currently being processed by the MAC.

Bits 30:27: Channel/endpoint number

Bits 26:25:

- 00: IN/OUT token
- 01: Zero-length transmit packet (device IN/host OUT)
- 11: Channel halt command

Bit 24: Terminate (last entry for selected channel/endpoint)

Bits 23:16 **NPTQXS<sub>A</sub>V**: Non-periodic transmit request queue space available

Indicates the amount of free space available in the non-periodic transmit request queue.

This queue holds both IN and OUT requests in host mode. Device mode has only IN requests.

00: Non-periodic transmit request queue is full

01: 1 location available

10: 2 locations available

*bxn*:  $n$  locations available ( $0 \leq n \leq 8$ )

Others: Reserved

Bits 15:0 **NPTXF<sub>S</sub>A<sub>V</sub>**: Non-periodic TxFIFO space available

Indicates the amount of free space available in the non-periodic TxFIFO.

Values are in terms of 32-bit words.

00: Non-periodic TxFIFO is full

01: 1 word available

10: 2 words available

*0xn*:  $n$  words available (where  $0 \leq n \leq 256$ )

Others: Reserved

## OTG\_FS general core configuration register (OTG\_FS\_GCCFG)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		

Reserved

NOVBUSSENS	SOFOUTEN	VBUSSEN	VBUSASEN	Reserved	.PWRDWN
rw	rw	rw	rw		rw

Reserved

Bits 31:22 Reserved, must be kept at reset value.

**Bit 21 NOVBUSSENS:** V<sub>BUS</sub> sensing disable option

When this bit is set, V<sub>BUS</sub> is considered internally to be always at V<sub>BUS</sub> valid level (5 V). This option removes the need for a dedicated V<sub>BUS</sub> pad, and leave this pad free to be used for other purposes such as a shared functionality. V<sub>BUS</sub> connection can be remapped on another general purpose input pad and monitored by software.

This option is only suitable for host-only or device-only applications.

0: V<sub>BUS</sub> sensing available by hardware

1: V<sub>BUS</sub> sensing not available by hardware.

**Bit 20 SOFOUTEN:** SOF output enable

0: SOF pulse not available on PAD

1: SOF pulse available on PAD

**Bit 19 VBUSBSEN:** Enable the V<sub>BUS</sub> sensing “B” device

0: V<sub>BUS</sub> sensing “B” disabled

1: V<sub>BUS</sub> sensing “B” enabled

**Bit 18 VBUSASEN:** Enable the V<sub>BUS</sub> sensing “A” device

0: V<sub>BUS</sub> sensing “A” disabled

1: V<sub>BUS</sub> sensing “A” enabled

Bit 17 Reserved, must be kept at reset value.

**Bit 16 PWRDWN:** Power down

Used to activate the transceiver in transmission/reception

0: Power down active

1: Power down deactivated (“Transceiver active”)

Bits 15:0 Reserved, must be kept at reset value.

### OTG\_FS core ID register (OTG\_FS\_CID)

Address offset: 0x03C

Reset value: 0x0000 1100

This is a read only register containing the Product ID.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRODUCT_ID																															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bits 31:0 **PRODUCT\_ID:** Product ID field

Application-programmable ID field.

**OTG\_FS Host periodic transmit FIFO size register (OTG\_FS\_HPTXFSIZ)**

Address offset: 0x100

Reset value: 0x0200 0600

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXFSIZ															PTXSA																
r/r w																															

Bits 31:16 **PTXFDF**: Host periodic TxFIFO depth

This value is in terms of 32-bit words.

Minimum value is 16

Bits 15:0 **PTXSA**: Host periodic TxFIFO start address

The power-on reset value of this register is the sum of the largest Rx data FIFO depth and largest non-periodic Tx data FIFO depth.

**OTG\_FS device IN endpoint transmit FIFO size register (OTG\_FS\_DIEPTXF<sub>x</sub>)  
(x = 1..3, where x is the FIFO\_number)**

Address offset: 0x104 + (FIFO\_number – 1) × 0x04

Reset value: 0x020000400

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXFD														INEPTXSA																	
r/r w																															

Bits 31:16 **INEPTXFD:** IN endpoint TxFIFO depth

This value is in terms of 32-bit words.

Minimum value is 16

The power-on reset value of this register is specified as the largest IN endpoint FIFO number depth.

Bits 15:0 **INEPTXSA:** IN endpoint FIFO<sub>x</sub> transmit RAM start address

This field contains the memory start address for IN endpoint transmit FIFO<sub>x</sub>. The address must be aligned with a 32-bit memory location.

### 22.16.3 Host-mode registers

Bit values in the register descriptions are expressed in binary unless otherwise specified.

Host-mode registers affect the operation of the core in the host mode. Host mode registers must not be accessed in device mode, as the results are undefined. Host mode registers can be categorized as follows:

#### OTG\_FS Host configuration register (OTG\_FS\_HCFG)

Address offset: 0x400

Reset value: 0x0000 0000

This register configures the core after power-on. Do not make changes to this register after initializing the host.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														FSLSS FSLSPCS																	
r	rw	rw																													

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FSLSS:** FS- and LS-only support

The application uses this bit to control the core's enumeration speed. Using this bit, the application can make the core enumerate as an FS host, even if the connected device supports HS traffic. Do not make changes to this field after initial programming.

1: FS/LS-only, even if the connected device can support HS (read-only)

- Bits 1:0 **FSLSPCS:** FS/LS PHY clock select  
 When the core is in FS host mode  
 01: PHY clock is running at 48 MHz  
 Others: Reserved  
 When the core is in LS host mode  
 00: Reserved  
 01: Select 48 MHz PHY clock frequency  
 10: Select 6 MHz PHY clock frequency  
 11: Reserved

*Note: The FSLSPCS must be set on a connection event according to the speed of the connected device (after changing this bit, a software reset must be performed).*

### OTG\_FS Host frame interval register (OTG\_FS\_HFIR)

Address offset: 0x404

Reset value: 0x0000 EA60

This register stores the frame interval information for the current speed to which the OTG\_FS controller has enumerated.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															FRIVL																
															rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **FRIVL:** Frame interval

The value that the application programs to this field specifies the interval between two consecutive SOFs (FS) or Keep-Alive tokens (LS). This field contains the number of PHY clocks that constitute the required frame interval. The application can write a value to this register only after the Port enable bit of the host port control and status register (PENA bit in OTG\_FS\_HPRT) has been set. If no value is programmed, the core calculates the value based on the PHY clock specified in the FS/LS PHY Clock Select field of the host configuration register (FSLSPCS in OTG\_FS\_HCFG). Do not change the value of this field after the initial configuration.

1 ms × (PHY clock frequency)

**OTG\_FS Host frame number/frame time remaining register (OTG\_FS\_HFNUM)**

Address offset: 0x408

Reset value: 0x0000 3FFF

This register indicates the current frame number. It also indicates the time remaining (in terms of the number of PHY clocks) in the current frame.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FTREM														FRNUM																	
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r		

Bits 31:16 **FTREM**: Frame time remaining

Indicates the amount of time remaining in the current frame, in terms of PHY clocks. This field decrements on each PHY clock. When it reaches zero, this field is reloaded with the value in the Frame interval register and a new SOF is transmitted on the USB.

Bits 15:0 **FRNUM**: Frame number

This field increments when a new SOF is transmitted on the USB, and is cleared to 0 when it reaches 0x3FFF.

**OTG\_FS\_Host periodic transmit FIFO/queue status register (OTG\_FS\_HPTXSTS)**

Address offset: 0x410

Reset value: 0x0008 0100

This read-only register contains the free space information for the periodic TxFIFO and the periodic transmit request queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXQTOP										PTXQSAV										PTXFSAVL											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	rw										

Bits 31:24 **PTXQTOP**: Top of the periodic transmit request queue

This indicates the entry in the periodic Tx request queue that is currently being processed by the MAC.

This register is used for debugging.

Bit 31: Odd/Even frame

- 0: send in even frame
- 1: send in odd frame

Bits 30:27: Channel/endpoint number

Bits 26:25: Type

- 00: IN/OUT
- 01: Zero-length packet
- 11: Disable channel command

Bit 24: Terminate (last entry for the selected channel/endpoint)

Bits 23:16 **PTXQSAV:** Periodic transmit request queue space available

Indicates the number of free locations available to be written in the periodic transmit request queue. This queue holds both IN and OUT requests.

00: Periodic transmit request queue is full

01: 1 location available

10: 2 locations available

bxx: n locations available ( $0 \leq n \leq 8$ )

Others: Reserved

Bits 15:0 **PTXFSAVL:** Periodic transmit data FIFO space available

Indicates the number of free locations available to be written to in the periodic TxFIFO.

Values are in terms of 32-bit words

0000: Periodic TxFIFO is full

0001: 1 word available

0010: 2 words available

bxx: n words available (where  $0 \leq n \leq \text{PTXFD}$ )

Others: Reserved

### OTG\_FS Host all channels interrupt register (OTG\_FS\_HINT)

Address offset: 0x414

Reset value: 0x0000 000

When a significant event occurs on a channel, the host all channels interrupt register interrupts the application using the host channels interrupt bit of the Core interrupt register (HCINT bit in OTG\_FS\_GINTSTS). This is shown in [Figure 250](#). There is one interrupt bit per channel, up to a maximum of 16 bits. Bits in this register are set and cleared when the application sets and clears bits in the corresponding host channel-x interrupt register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															HINT																

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HINT:** Channel interrupts

One bit per channel: Bit 0 for Channel 0, bit 15 for Channel 15

**OTG\_FS Host all channels interrupt mask register (OTG\_FS\_HINTMSK)**

Address offset: 0x418

Reset value: 0x0000 0000

The host all channel interrupt mask register works with the host all channel interrupt register to interrupt the application when an event occurs on a channel. There is one interrupt mask bit per channel, up to a maximum of 16 bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0					
Reserved												HINTM																								

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HINTM:** Channel interrupt mask

0: Masked interrupt

1: Unmasked interrupt

One bit per channel: Bit 0 for channel 0, bit 15 for channel 15

**OTG\_FS Host port control and status register (OTG\_FS\_HPRT)**

Address offset: 0x440

Reset value: 0x0000 0000

This register is available only in host mode. Currently, the OTG host supports only one port.

A single register holds USB port-related information such as USB reset, enable, suspend, resume, connect status, and test mode for each port. It is shown in [Figure 250](#). The rc\_w1 bits in this register can trigger an interrupt to the application through the host port interrupt bit of the core interrupt register (HPRTINT bit in OTG\_FS\_GINTSTS). On a Port Interrupt, the application must read this register and clear the bit that caused the interrupt. For the rc\_w1 bits, the application must write a 1 to the bit to clear the interrupt.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0				
Reserved												PSPD PTCTL PPWR PLSTS																							

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **PSPD:** Port speed

Indicates the speed of the device attached to this port.

01: Full speed

10: Low speed

11: Reserved

Bits 16:13 **PTCTL:** Port test control

The application writes a nonzero value to this field to put the port into a Test mode, and the corresponding pattern is signaled on the port.

- 0000: Test mode disabled
- 0001: Test\_J mode
- 0010: Test\_K mode
- 0011: Test\_SE0\_NAK mode
- 0100: Test\_Packet mode
- 0101: Test\_Force\_Enable
- Others: Reserved

Bit 12 **PPWR:** Port power

The application uses this field to control power to this port, and the core clears this bit on an overcurrent condition.

- 0: Power off
- 1: Power on

Bits 11:10 **PLSTS:** Port line status

Indicates the current logic level USB data lines

- Bit 10: Logic level of OTG\_FS\_FS\_DP
- Bit 11: Logic level of OTG\_FS\_FS\_DM

Bit 9 Reserved, must be kept at reset value.

Bit 8 **PRST:** Port reset

When the application sets this bit, a reset sequence is started on this port. The application must time the reset period and clear this bit after the reset sequence is complete.

- 0: Port not in reset
- 1: Port in reset

The application must leave this bit set for a minimum duration of at least 10 ms to start a reset on the port. The application can leave it set for another 10 ms in addition to the required minimum duration, before clearing the bit, even though there is no maximum limit set by the USB standard.

Bit 7 **PSUSP:** Port suspend

The application sets this bit to put this port in Suspend mode. The core only stops sending SOFs when this is set. To stop the PHY clock, the application must set the Port clock stop bit, which asserts the suspend input pin of the PHY.

The read value of this bit reflects the current suspend status of the port. This bit is cleared by the core after a remote wakeup signal is detected or the application sets the Port reset bit or Port resume bit in this register or the Resume/remote wakeup detected interrupt bit or Disconnect detected interrupt bit in the Core interrupt register (WKUINT or DISCINT in OTG\_FS\_GINTSTS, respectively).

- 0: Port not in Suspend mode
- 1: Port in Suspend mode

Bit 6 **PRES:** Port resume

The application sets this bit to drive resume signaling on the port. The core continues to drive the resume signal until the application clears this bit.

If the core detects a USB remote wakeup sequence, as indicated by the Port resume/remote wakeup detected interrupt bit of the Core interrupt register (WKUINT bit in OTG\_FS\_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit when it detects a disconnect condition. The read value of this bit indicates whether the core is currently driving resume signaling.

- 0: No resume driven
- 1: Resume driven

**Bit 5 POCCHNG:** Port overcurrent change

The core sets this bit when the status of the Port overcurrent active bit (bit 4) in this register changes.

**Bit 4 POCA:** Port overcurrent active

Indicates the overcurrent condition of the port.

- 0: No overcurrent condition
- 1: Overcurrent condition

**Bit 3 PENCHNG:** Port enable/disable change

The core sets this bit when the status of the Port enable bit 2 in this register changes.

**Bit 2 PENA:** Port enable

A port is enabled only by the core after a reset sequence, and is disabled by an overcurrent condition, a disconnect condition, or by the application clearing this bit. The application cannot set this bit by a register write. It can only clear it to disable the port. This bit does not trigger any interrupt to the application.

- 0: Port disabled
- 1: Port enabled

**Bit 1 PCDET:** Port connect detected

The core sets this bit when a device connection is detected to trigger an interrupt to the application using the host port interrupt bit in the Core interrupt register (HPRTINT bit in OTG\_FS\_GINTSTS). The application must write a 1 to this bit to clear the interrupt.

**Bit 0 PCSTS:** Port connect status

- 0: No device is attached to the port
- 1: A device is attached to the port

**OTG\_FS Host channel-x characteristics register (OTG\_FS\_HCCHAR $x$ )**  
**( $x = 0..7$ , where  $x = \text{Channel\_number}$ )**

Address offset: 0x500 + (Channel\_number × 0x20)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CHENA	CHDIS	ODDFRM	DAD	MCNT	EPTYP	LSDEV	Reserved	EPDIR	EPNUM	MPSIZ																					
rs	rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bit 31 **CHENA:** Channel enable

This field is set by the application and cleared by the OTG host.

- 0: Channel disabled
- 1: Channel enabled

Bit 30 **CHDIS:** Channel disable

The application sets this bit to stop transmitting/receiving data on a channel, even before the transfer for that channel is complete. The application must wait for the Channel disabled interrupt before treating the channel as disabled.

Bit 29 **ODDFRM:** Odd frame

This field is set (reset) by the application to indicate that the OTG host must perform a transfer in an odd frame. This field is applicable for only periodic (isochronous and interrupt) transactions.

- 0: Even frame
- 1: Odd frame

Bits 28:22 **DAD:** Device address

This field selects the specific device serving as the data source or sink.

Bits 21:20 **MCNT:** Multicount

This field indicates to the host the number of transactions that must be executed per frame for this periodic endpoint. For non-periodic transfers, this field is not used

- 00: Reserved. This field yields undefined results
- 01: 1 transaction
- 10: 2 transactions per frame to be issued for this endpoint
- 11: 3 transactions per frame to be issued for this endpoint

*Note: This field must be set to at least 01.*

Bits 19:18 **EPTYP:** Endpoint type

Indicates the transfer type selected.

- 00: Control
- 01: Isochronous
- 10: Bulk
- 11: Interrupt

Bit 17 **LSDEV:** Low-speed device

This field is set by the application to indicate that this channel is communicating to a low-speed device.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **EPDIR:** Endpoint direction

Indicates whether the transaction is IN or OUT.

0: OUT

1: IN

Bits 14:11 **EPNUM:** Endpoint number

Indicates the endpoint number on the device serving as the data source or sink.

Bits 10:0 **MPSIZ:** Maximum packet size

Indicates the maximum packet size of the associated endpoint.

### OTG\_FS Host channel-x interrupt register (OTG\_FS\_HCINTx) (x = 0..7, where x = Channel\_number)

Address offset: 0x508 + (Channel\_number × 0x20)

Reset value: 0x0000 0000

This register indicates the status of a channel with respect to USB- and AHB-related events. It is shown in [Figure 250](#). The application must read this register when the host channels interrupt bit in the Core interrupt register (HCINT bit in OTG\_FS\_GINTSTS) is set. Before the application can read this register, it must first read the host all channels interrupt (OTG\_FS\_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG\_FS\_HAINT and OTG\_FS\_GINTSTS registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
																					DTERR	FRMOR	BBERR	TXERR	Reserved	ACK	NAK	STALL	Reserved	CCH	XFRFC
Reserved												rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1													

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DTERR:** Data toggle error

Bit 9 **FRMOR:** Frame overrun

Bit 8 **BBERR:** Babble error

Bit 7 **TXERR:** Transaction error

Indicates one of the following errors occurred on the USB.

CRC check failure

Timeout

Bit stuff error

False EOP

Bit 6 Reserved, must be kept at reset value.

Bit 5 **ACK:** ACK response received/transmitted interrupt

Bit 4 **NAK:** NAK response received interrupt

Bit 3 **STALL:** STALL response received interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CHH:** Channel halted

Indicates the transfer completed abnormally either because of any USB transaction error or in response to disable request by the application.

Bit 0 **XFC:** Transfer completed

Transfer completed normally without any errors.

### **OTG\_FS Host channel-x interrupt mask register (OTG\_FS\_HCINTMSKx) (x = 0..7, where x = Channel\_number)**

Address offset: 0x50C + (Channel\_number × 0x20)

Reset value: 0x0000 0000

This register reflects the mask for each channel status described in the previous section.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **DTERRM:** Data toggle error mask

0: Masked interrupt

1: Unmasked interrupt

Bit 9 **FRMORM:** Frame overrun mask

0: Masked interrupt

1: Unmasked interrupt

Bit 8 **BBERRM:** Babble error mask

0: Masked interrupt

1: Unmasked interrupt

Bit 7 **TXERRM:** Transaction error mask

0: Masked interrupt

1: Unmasked interrupt

Bit 6 **NYET:** response received interrupt mask

0: Masked interrupt

1: Unmasked interrupt

Bit 5 **ACKM:** ACK response received/transmitted interrupt mask

0: Masked interrupt

1: Unmasked interrupt

Bit 4 **NAKM:** NAK response received interrupt mask

0: Masked interrupt

1: Unmasked interrupt

Bit 3 **STALLM:** STALL response received interrupt mask

0: Masked interrupt

1: Unmasked interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CHHM:** Channel halted mask

0: Masked interrupt

1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed mask

0: Masked interrupt

1: Unmasked interrupt

### **OTG\_FS Host channel-x transfer size register (OTG\_FS\_HCTSIZx) (x = 0..7, where x = Channel\_number)**

Address offset: 0x510 + (Channel\_number × 0x20)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	DPID	PKTCNT												XFRSIZ																	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **DPID:** Data PID

The application programs this field with the type of PID to use for the initial transaction. The host maintains this field for the rest of the transfer.

00: DATA0

01: DATA2

10: DATA1

11: MDATA (non-control)/SETUP (control)

Bits 28:19 **PKTCNT:** Packet count

This field is programmed by the application with the expected number of packets to be transmitted (OUT) or received (IN).

The host decrements this count on every successful transmission or reception of an OUT/IN packet. Once this count reaches zero, the application is interrupted to indicate normal completion.

Bits 18:0 **XFRSIZ:** Transfer size

For an OUT, this field is the number of data bytes the host sends during the transfer.

For an IN, this field is the buffer size that the application has reserved for the transfer. The application is expected to program this field as an integer multiple of the maximum packet size for IN transactions (periodic and non-periodic).

## 22.16.4 Device-mode registers

### OTG\_FS device configuration register (OTG\_FS\_DCFG)

Address offset: 0x800

Reset value: 0x0220 0000

This register configures the core in device mode after power-on or after certain control commands or enumeration. Do not make changes to this register after initial programming.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:11 **PFIVL:** Periodic frame interval

Indicates the time within a frame at which the application must be notified using the end of periodic frame interrupt. This can be used to determine if all the isochronous traffic for that frame is complete.

- 00: 80% of the frame interval
- 01: 85% of the frame interval
- 10: 90% of the frame interval
- 11: 95% of the frame interval

Bits 10:4 **DAD:** Device address

The application must program this field after every SetAddress control command.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **NZLSOHSK:** Non-zero-length status OUT handshake

The application can use this field to select the handshake the core sends on receiving a nonzero-length data packet during the OUT transaction of a control transfer's Status stage.  
1: Send a STALL handshake on a nonzero-length status OUT transaction and do not send the received OUT packet to the application.

0: Send the received OUT packet to the application (zero-length or nonzero-length) and send a handshake based on the NAK and STALL bits for the endpoint in the Device endpoint control register.

Bits 1:0 **DSPD:** Device speed

Indicates the speed at which the application requires the core to enumerate, or the maximum speed the application can support. However, the actual bus speed is determined only after the chirp sequence is completed, and is based on the speed of the USB host to which the core is connected.

- 00: Reserved
- 01: Reserved
- 10: Reserved
- 11: Full speed (USB 1.1 transceiver clock is 48 MHz)

**OTG\_FS device control register (OTG\_FS\_DCTL)**

Address offset: 0x804

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved											POPRGDNE	CGONAK	SGONAK	CGINAK	SGINAK	TCTL			GONSTS	GINSTS	SDIS	RWUSIG									
											rw	w	w	w	w	rw	rw	rw	r	r	rw	rw									

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **POPRGDNE**: Power-on programming done

The application uses this bit to indicate that register programming is completed after a wakeup from power down mode.

Bit 10 **CGONAK**: Clear global OUT NAK

A write to this field clears the Global OUT NAK.

Bit 9 **SGONAK**: Set global OUT NAK

A write to this field sets the Global OUT NAK.

The application uses this bit to send a NAK handshake on all OUT endpoints.

The application must set this bit only after making sure that the Global OUT NAK effective bit in the Core interrupt register (GONAKEFF bit in OTG\_FS\_GINTSTS) is cleared.

Bit 8 **CGINAK**: Clear global IN NAK

A write to this field clears the Global IN NAK.

Bit 7 **SGINAK**: Set global IN NAK

A write to this field sets the Global non-periodic IN NAK. The application uses this bit to send a NAK handshake on all non-periodic IN endpoints.

The application must set this bit only after making sure that the Global IN NAK effective bit in the Core interrupt register (GINAKEFF bit in OTG\_FS\_GINTSTS) is cleared.

Bits 6:4 **TCTL**: Test control

000: Test mode disabled

001: Test\_J mode

010: Test\_K mode

011: Test\_SE0\_NAK mode

100: Test\_Packet mode

101: Test\_Force\_Enable

Others: Reserved

Bit 3 **GONSTS**: Global OUT NAK status

0: A handshake is sent based on the FIFO Status and the NAK and STALL bit settings.

1: No data is written to the RxFIFO, irrespective of space availability. Sends a NAK handshake on all packets, except on SETUP transactions. All isochronous OUT packets are dropped.

Bit 2 **GINSTS**: Global IN NAK status

- 0: A handshake is sent out based on the data availability in the transmit FIFO.  
 1: A NAK handshake is sent out on all non-periodic IN endpoints, irrespective of the data availability in the transmit FIFO.

Bit 1 **SDIS**: Soft disconnect

The application uses this bit to signal the USB OTG core to perform a soft disconnect. As long as this bit is set, the host does not see that the device is connected, and the device does not receive signals on the USB. The core stays in the disconnected state until the application clears this bit.

0: Normal operation. When this bit is cleared after a soft disconnect, the core generates a device connect event to the USB host. When the device is reconnected, the USB host restarts device enumeration.

1: The core generates a device disconnect event to the USB host.

Bit 0 **RWUSIG**: Remote wakeup signaling

When the application sets this bit, the core initiates remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the Suspend state. As specified in the USB 2.0 specification, the application must clear this bit 1 ms to 15 ms after setting it.

*Table 130* contains the minimum duration (according to device state) for which the Soft disconnect (SDIS) bit must be set for the USB host to detect a device disconnect. To accommodate clock jitter, it is recommended that the application add some extra delay to the specified minimum duration.

**Table 130. Minimum duration for soft disconnect**

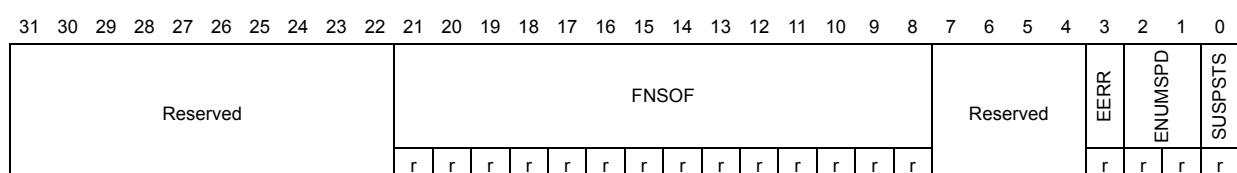
Operating speed	Device state	Minimum duration
Full speed	Suspended	1 ms + 2.5 $\mu$ s
Full speed	Idle	2.5 $\mu$ s
Full speed	Not Idle or Suspended (Performing transactions)	2.5 $\mu$ s

### OTG\_FS device status register (OTG\_FS\_DSTS)

Address offset: 0x808

Reset value: 0x0000 0010

This register indicates the status of the core with respect to USB-related events. It must be read on interrupts from the device all interrupts (OTG\_FS\_DAINT) register.



Bits 31:22 Reserved, must be kept at reset value.

Bits 21:8 **FNSOF**: Frame number of the received SOF

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **EERR:** Erratic error

The core sets this bit to report any erratic errors.

Due to erratic errors, the OTG\_FS controller goes into Suspended state and an interrupt is generated to the application with Early suspend bit of the OTG\_FS\_GINTSTS register (ESUSP bit in OTG\_FS\_GINTSTS). If the early suspend is asserted due to an erratic error, the application can only perform a soft disconnect recover.

Bits 2:1 **ENUMSPD:** Enumerated speed

Indicates the speed at which the OTG\_FS controller has come up after speed detection through a chirp sequence.

01: Reserved

10: Reserved

11: Full speed (PHY clock is running at 48 MHz)

Others: reserved

Bit 0 **SUSPSTS:** Suspend status

In device mode, this bit is set as long as a Suspend condition is detected on the USB. The core enters the Suspended state when there is no activity on the USB data lines for a period of 3 ms. The core comes out of the suspend:

- When there is an activity on the USB data lines
- When the application writes to the Remote wakeup signaling bit in the OTG\_FS\_DCTL register (RWUSIG bit in OTG\_FS\_DCTL).

### OTG\_FS device IN endpoint common interrupt mask register (OTG\_FS\_DIEPMSK)

Address offset: 0x810

Reset value: 0x0000 0000

This register works with each of the OTG\_FS\_DIEPINTx registers for all endpoints to generate an interrupt per IN endpoint. The IN endpoint interrupt for a specific status in the OTG\_FS\_DIEPINTx register can be masked by writing to the corresponding bit in this register. Status bits are masked by default.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **INEPNEM:** IN endpoint NAK effective mask

0: Masked interrupt

1: Unmasked interrupt

Bit 5 **INEPNMM:** IN token received with EP mismatch mask

0: Masked interrupt

1: Unmasked interrupt

Bit 4 **ITTXFEMSK:** IN token received when TxFIFO empty mask

0: Masked interrupt

1: Unmasked interrupt

Bit 3 **TOM:** Timeout condition mask (Non-isochronous endpoints)

- 0: Masked interrupt
- 1: Unmasked interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDM:** Endpoint disabled interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

### OTG\_FS device OUT endpoint common interrupt mask register (OTG\_FS\_DOEPMASK)

Address offset: 0x814

Reset value: 0x0000 0000

This register works with each of the OTG\_FS\_DOEPIINTx registers for all endpoints to generate an interrupt per OUT endpoint. The OUT endpoint interrupt for a specific status in the OTG\_FS\_DOEPIINTx register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Reserved

OTEPDM	STUPM	Reserved	EPDM	XFRCM
rw	rw		rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **OTEPDM:** OUT token received when endpoint disabled mask

- Applies to control OUT endpoints only.
- 0: Masked interrupt
- 1: Unmasked interrupt

Bit 3 **STUPM:** SETUP phase done mask

- Applies to control endpoints only.
- 0: Masked interrupt
- 1: Unmasked interrupt

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDM:** Endpoint disabled interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask

- 0: Masked interrupt
- 1: Unmasked interrupt

### OTG\_FS device all endpoints interrupt register (OTG\_FS\_DAINT)

Address offset: 0x818

Reset value: 0x0000 0000

When a significant event occurs on an endpoint, a OTG\_FS\_DAINT register interrupts the application using the Device OUT endpoints interrupt bit or Device IN endpoints interrupt bit of the OTG\_FS\_GINTSTS register (OEPINT or IEPINT in OTG\_FS\_GINTSTS, respectively). There is one interrupt bit per endpoint, up to a maximum of 16 bits for OUT endpoints and 16 bits for IN endpoints. For a bidirectional endpoint, the corresponding IN and OUT interrupt bits are used. Bits in this register are set and cleared when the application sets and clears bits in the corresponding Device Endpoint-x interrupt register (OTG\_FS\_DIEPINTx/OTG\_FS\_DOEPINTx).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OEPINT															IEPINT																
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r		

Bits 31:16 **OEPINT:** OUT endpoint interrupt bits

One bit per OUT endpoint:

Bit 16 for OUT endpoint 0, bit 18 for OUT endpoint 3.

Bits 15:0 **IEPINT:** IN endpoint interrupt bits

One bit per IN endpoint:

Bit 0 for IN endpoint 0, bit 3 for endpoint 3.

**OTG\_FS all endpoints interrupt mask register (OTG\_FS\_DAINTMSK)**

Address offset: 0x81C

Reset value: 0x0000 0000

The OTG\_FS\_DAINTMSK register works with the Device endpoint interrupt register to interrupt the application when an event occurs on a device endpoint. However, the OTG\_FS\_DAINT register bit corresponding to that interrupt is still set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OEPM														IEPM																	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:16 **OEPM:** OUT EP interrupt mask bits

One per OUT endpoint:

Bit 16 for OUT EP 0, bit 18 for OUT EP 3

0: Masked interrupt

1: Unmasked interrupt

Bits 15:0 **IEPM:** IN EP interrupt mask bits

One bit per IN endpoint:

Bit 0 for IN EP 0, bit 3 for IN EP 3

0: Masked interrupt

1: Unmasked interrupt

**OTG\_FS device V<sub>BUS</sub> discharge time register (OTG\_FS\_DVBUSDIS)**

Address offset: 0x0828

Reset value: 0x0000 17D7

This register specifies the V<sub>BUS</sub> discharge time after V<sub>BUS</sub> pulsing during SRP.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														VBUSDT																	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VBUSDT:** Device V<sub>BUS</sub> discharge timeSpecifies the V<sub>BUS</sub> discharge time after V<sub>BUS</sub> pulsing during SRP. This value equals:V<sub>BUS</sub> discharge time in PHY clocks / 1 024Depending on your V<sub>BUS</sub> load, this value may need adjusting.

**OTG\_FS device V<sub>BUS</sub> pulsing time register (OTG\_FS\_DVBUSPULSE)**

Address offset: 0x082C

Reset value: 0x0000 05B8

This register specifies the V<sub>BUS</sub> pulsing time during SRP.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														DVBUSP																	
														rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **DVBUSP:** Device V<sub>BUS</sub> pulsing timeSpecifies the V<sub>BUS</sub> pulsing time during SRP. This value equals:V<sub>BUS</sub> pulsing time in PHY clocks / 1 024**OTG\_FS device IN endpoint FIFO empty interrupt mask register:  
(OTG\_FS\_DIEPEMPMSK)**

Address offset: 0x834

Reset value: 0x0000 0000

This register is used to control the IN endpoint FIFO empty interrupt generation (TXFE\_OTG\_FS\_DIEPINTx).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved														INEPTXFEM																	
														rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTXFEM:** IN EP Tx FIFO empty interrupt mask bits

These bits act as mask bits for OTG\_FS\_DIEPINTx.

TXFE interrupt one bit per IN endpoint:

Bit 0 for IN endpoint 0, bit 3 for IN endpoint 3

0: Masked interrupt

1: Unmasked interrupt

### OTG\_FS device control IN endpoint 0 control register (OTG\_FS\_DIEPCTL0)

Address offset: 0x900

Reset value: 0x0000 0000

This section describes the OTG\_FS\_DIEPCTL0 register. Nonzero control endpoints use registers for endpoints 1–3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPENA	EPDIS	Reserved	SNAK	CNAK	TXFNUM				STALL	Reserved	EPTYP			NAKSTS	Reserved	USB2EP	Reserved										MPSIZ	rw	rw		

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on the endpoint 0.

The core clears this bit before setting any of the following interrupts on this endpoint:

- Endpoint disabled
- Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the Endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the Endpoint disabled interrupt. The application must set this bit only if Endpoint enable is already set for this endpoint.

Bits 29:28 Reserved, must be kept at reset value.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for an endpoint after a SETUP packet is received on that endpoint.

Bit 26 **CNAK:** Clear NAK

**A write to this bit clears the NAK bit for the endpoint.**

Bits 25:22 **TXFNUM:** TxFIFO number

This value is set to the FIFO number that is assigned to IN endpoint 0.

Bit 21 **STALL:** STALL handshake

The application can only set this bit, and the core clears it when a SETUP token is received for this endpoint. If a NAK bit, a Global IN NAK or Global OUT NAK is set along with this bit, the STALL bit takes priority.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP:** Endpoint type

Hardcoded to ‘00’ for control.

Bit 17 **NAKSTS: NAK status**

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status

1: The core is transmitting NAK handshakes on this endpoint.

When this bit is set, either by the application or core, the core stops transmitting data, even if there are data available in the TxFIFO. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **USBAEP: USB active endpoint**

This bit is always set to 1, indicating that control endpoint 0 is always active in all configurations and interfaces.

Bits 14:2 Reserved, must be kept at reset value.

Bits 1:0 **MPSIZ: Maximum packet size**

The application must program this field with the maximum packet size for the current logical endpoint.

00: 64 bytes

01: 32 bytes

10: 16 bytes

11: 8 bytes

**OTG device endpoint-x control register (OTG\_FS\_DIEPCTLx) (x = 1..3, where x = Endpoint\_number)**

Address offset: 0x900 + (Endpoint\_number × 0x20)

Reset value: 0x0000 0000

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPENA	EPDIS	SODDFRM	SD0PID/SEVNFRM	SNAK	CNAK	TXFNUM				Stall	Reserved	EPTYP	NAKSTS	EONUM/DPID	USBAEP	Reserved	MPSIZ														
rs	rs	w	w	w	w	rw	rw	rw	rw	rw/ rs		rw	rw	r	r		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bit 31 **EPENA: Endpoint enable**

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

- SETUP phase done
- Endpoint disabled
- Transfer completed

Bit 30 **EPPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the Endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the Endpoint disabled interrupt. The application must set this bit only if Endpoint enable is already set for this endpoint.

Bit 29 **SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk IN endpoints only.

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

**SEVNFRM:** Set even frame

Applies to isochronous IN endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a Transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM:** TxFIFO number

These bits specify the FIFO number associated with this endpoint. Each active IN endpoint must be programmed to a separate FIFO number.

This field is valid only for IN endpoints.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous IN endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Applies to control endpoints only (access type is rs).

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

## Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

**Bit 17 NAKSTS: NAK status**

It indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

For non-isochronous IN endpoints: The core stops transmitting any data on an IN endpoint, even if there are data available in the TxFIFO.

For isochronous IN endpoints: The core sends out a zero-length data packet, even if there are data available in the TxFIFO.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

**Bit 16 EONUM: Even/odd frame**

Applies to isochronous IN endpoints only.

Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.

0: Even frame

1: Odd frame

**DPID: Endpoint data PID**

Applies to interrupt/bulk IN endpoints only.

Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID register field to program either DATA0 or DATA1 PID.

0: DATA0

1: DATA1

**Bit 15 USBAEP: USB active endpoint**

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

**Bits 10:0 MPSIZ: Maximum packet size**

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

### OTG\_FS device control OUT endpoint 0 control register (OTG\_FS\_DOEPCTL0)

Address offset: 0xB00

Reset value: 0x0000 8000

This section describes the OTG\_FS\_DOEPCTL0 register. Nonzero control endpoints use registers for endpoints 1–3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPENA	EPDIS	Reserved	SNAK	CNAK	Reserved	Stall	SNPM	EPTYP	NAKSTS	Reserved	USBAEP	Reserved	Reserved	MPSIZ																	
w	r		w	w		rs	rw	r	r		r			r																	

#### Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on endpoint 0.

The core clears this bit before setting any of the following interrupts on this endpoint:

- SETUP phase done
- Endpoint disabled
- Transfer completed

#### Bit 30 **EPDIS:** Endpoint disable

The application cannot disable control OUT endpoint 0.

Bits 29:28 Reserved, must be kept at reset value.

#### Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit on a Transfer completed interrupt, or after a SETUP is received on the endpoint.

#### Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

#### Bit 21 **STALL:** STALL handshake

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

#### Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP:** Endpoint type

Hardcoded to 2'b00 for control.

Bit 17 **NAKSTS**: NAK status

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit, the core stops receiving data, even if there is space in the RxFIFO to accommodate the incoming packet. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **USBAEP**: USB active endpoint

This bit is always set to 1, indicating that a control endpoint 0 is always active in all configurations and interfaces.

Bits 14:2 Reserved, must be kept at reset value.

Bits 1:0 **MPSIZ**: Maximum packet size

The maximum packet size for control OUT endpoint 0 is the same as what is programmed in control IN endpoint 0.

00: 64 bytes

01: 32 bytes

10: 16 bytes

11: 8 bytes

### OTG\_FS device endpoint-x control register (OTG\_FS\_DOEPCTLx) (x = 1..3, where x = Endpoint\_number)

Address offset for OUT endpoints: 0xB00 + (Endpoint\_number × 0x20)

Reset value: 0x0000 0000

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPENA	EPDIS	SODDFRM/SD1PID	SD0PID/SEVNFRM	SNAK	CNAK	Reserved	Stall	SNPM	EPTYP	NAKSTS	EONUM/DID	USBAEP	Reserved	MPSIZ																	
rs	rs	w	w	w	w		rw/rs	rw	rw	rw	r	r	rw																		

Bit 31 **EPENA**: Endpoint enable

Applies to IN and OUT endpoints.

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

- SETUP phase done
- Endpoint disabled
- Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the Endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the Endpoint disabled interrupt. The application must set this bit only if Endpoint enable is already set for this endpoint.

Bit 29 **SD1PID:** Set DATA1 PID

Applies to interrupt/bulk IN and OUT endpoints only. Writing to this field sets the endpoint data PID (DPID) field in this register to DATA1.

**SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only. Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk OUT endpoints only.

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

**SEVNFRM:** Set even frame

Applies to isochronous OUT endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a Transfer Completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

## Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous OUT endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Applies to control endpoints only (access type is rs).

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP:** Endpoint type

This is the transfer type supported by this logical endpoint.

00: Control

01: Isochronous

10: Bulk

11: Interrupt

**Bit 17 NAKSTS: NAK status**

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit:

The core stops receiving any data on an OUT endpoint, even if there is space in the RxFIFO to accommodate the incoming packet.

Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

**Bit 16 EONUM: Even/odd frame**

Applies to isochronous IN and OUT endpoints only.

Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.

0: Even frame

1: Odd frame

**DPID: Endpoint data PID**

Applies to interrupt/bulk OUT endpoints only.

Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID register field to program either DATA0 or DATA1 PID.

0: DATA0

1: DATA1

**Bit 15 USBAEP: USB active endpoint**

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

**Bits 10:0 MPSIZ: Maximum packet size**

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

**OTG\_FS device endpoint-x interrupt register (OTG\_FS\_DIEPINTx) (x = 0..3, where x = Endpoint\_number)**

Address offset: 0x908 + (Endpoint\_number × 0x20)

Reset value: 0x0000 0080

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 250*. The application must read this register when the IN endpoints interrupt bit of the Core interrupt register (IEPINT in OTG\_FS\_GINTSTS) is set. Before the application can read this register, it must first read the device all endpoints interrupt (OTG\_FS\_DAINT) register to get the exact endpoint number for the Device endpoint-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG\_FS\_DAINT and OTG\_FS\_GINTSTS registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved																															

Bits 31:8 Reserved, must be kept at reset value.

**Bit 7 TXFE:** Transmit FIFO empty

This interrupt is asserted when the TxFIFO for this endpoint is either half or completely empty. The half or completely empty status is determined by the TxFIFO Empty Level bit in the OTG\_FS\_GAHBCFG register (TXFELVL bit in OTG\_FS\_GAHBCFG).

**Bit 6 INEPNE:** IN endpoint NAK effective

This bit can be cleared when the application clears the IN endpoint NAK by writing to the CNAK bit in OTG\_FS\_DIEPCTLx.

This interrupt indicates that the core has sampled the NAK bit set (either by the application or by the core). The interrupt indicates that the IN endpoint NAK bit set by the application has taken effect in the core.

This interrupt does not guarantee that a NAK handshake is sent on the USB. A STALL bit takes priority over a NAK bit.

Bit 5 Reserved, must be kept at reset value.

**Bit 4 ITTXFE:** IN token received when TxFIFO is empty

Applies to non-periodic IN endpoints only.

Indicates that an IN token was received when the associated TxFIFO (periodic/non-periodic) was empty. This interrupt is asserted on the endpoint for which the IN token was received.

**Bit 3 TOC:** Timeout condition

Applies only to Control IN endpoints.

Indicates that the core has detected a timeout condition on the USB for the last IN token on this endpoint.

Bit 2 Reserved, must be kept at reset value.

**Bit 1 EPDISD:** Endpoint disabled interrupt

This bit indicates that the endpoint is disabled per the application's request.

**Bit 0 XFRC:** Transfer completed interrupt

This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

**OTG\_FS device endpoint-x interrupt register (OTG\_FS\_DOEPINTx) (x = 0..3, where x = Endpoint\_number)**

Address offset: 0xB08 + (Endpoint\_number × 0x20)

Reset value: 0x0000 0080

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in [Figure 250](#). The application must read this register when the OUT Endpoints Interrupt bit of the OTG\_FS\_GINTSTS register (OEPINT bit in OTG\_FS\_GINTSTS) is set. Before the application can read this register, it must first read the OTG\_FS\_DAINT register to get the exact endpoint number for the OTG\_FS\_DOEPINTx register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG\_FS\_DAINT and OTG\_FS\_GINTSTS registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **B2BSTUP**: Back-to-back SETUP packets received

Applies to control OUT endpoint only.

This bit indicates that the core has received more than three back-to-back SETUP packets for this particular endpoint.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **OTEPEDIS**: OUT token received when endpoint disabled

Applies only to control OUT endpoints.

Indicates that an OUT token was received when the endpoint was not yet enabled. This interrupt is asserted on the endpoint for which the OUT token was received.

Bit 3 **STUP**: SETUP phase done

Applies to control OUT endpoint only.

Indicates that the SETUP phase for the control endpoint is complete and no more back-to-back SETUP packets were received for the current control transfer. On this interrupt, the application can decode the received SETUP data packet.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **EPDSD**: Endpoint disabled interrupt

This bit indicates that the endpoint is disabled per the application's request.

Bit 0 **XFR**: Transfer completed interrupt

This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

### OTG\_FS device IN endpoint 0 transfer size register (OTG\_FS\_DIEPTISIZ0)

Address offset: 0x910

Reset value: 0x0000 0000

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the device control endpoint 0 control registers (EPENA in OTG\_FS\_DIEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the Endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved										PKTCNT		Reserved										XFRSIZ									
										rw												rw									

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:19 **PKTCNT:** Packet count

Indicates the total number of USB packets that constitute the Transfer Size amount of data for endpoint 0.

This field is decremented every time a packet (maximum size or short packet) is read from the TxFIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ:** Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the TxFIFO.

**OTG\_FS device OUT endpoint 0 transfer size register (OTG\_FS\_DOEPTSIZ0)**

Address offset: 0xB10

Reset value: 0x0000 0000

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the Endpoint enable bit in the OTG\_FS\_DOEPCTL0 registers (EPENA bit in OTG\_FS\_DOEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the Endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	<b>STUPC NT</b>		Reserved										PKTCNT	Reserved										<b>XFRSIZ</b>							
	<b>rw</b>	<b>rw</b>											<b>rw</b>											<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>	<b>rw</b>		

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **STUPCNT**: SETUP packet count

This field specifies the number of back-to-back SETUP data packets the endpoint can receive.

- 01: 1 packet
- 10: 2 packets
- 11: 3 packets

Bits 28:20 Reserved, must be kept at reset value.

Bit 19 **PKTCNT**: Packet count

This field is decremented to zero after a packet is written into the RxFIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ**: Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet is read from the RxFIFO and written to the external memory.

**OTG\_FS device endpoint-x transfer size register (OTG\_FS\_DIEPTSIZx)  
(x = 1..3, where x = Endpoint\_number)**

Address offset: 0x910 + (Endpoint\_number × 0x20)

Reset value: 0x0000 0000

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using the Endpoint enable bit in the OTG\_FS\_DIEPCTLx registers (EPENA bit in OTG\_FS\_DIEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the Endpoint enable bit.

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved	MCNT		PKTCNT												XFRSIZ																	
	r/w r/r w	r/w r/r w	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **MCNT:** Multi count

For periodic IN endpoints, this field indicates the number of packets that must be transmitted per frame on the USB. The core uses this field to calculate the data PID for isochronous IN endpoints.

- 01: 1 packet
- 10: 2 packets
- 11: 3 packets

Bit 28:19 **PKTCNT:** Packet count

Indicates the total number of USB packets that constitute the Transfer Size amount of data for this endpoint.

This field is decremented every time a packet (maximum size or short packet) is read from the TxFIFO.

Bits 18:0 **XFRSIZ:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the TxFIFO.

**OTG\_FS device IN endpoint transmit FIFO status register  
(OTG\_FS\_DTXFSTS $x$ ) ( $x = 0..3$ , where  $x = \text{Endpoint\_number}$ )**

Address offset for IN endpoints:  $0x918 + (\text{Endpoint\_number} \times 0x20)$  This read-only register contains the free space information for the Device IN endpoint TxFIFO.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															INEPTFSAV																
															r	r	r	r	r	r	r	r	r	r	r	r	r	r	r		

31:16 Reserved, must be kept at reset value.

15:0 **INEPTFSAV:** IN endpoint TxFIFO space available

Indicates the amount of free space available in the Endpoint TxFIFO.

Values are in terms of 32-bit words:

0x0: Endpoint TxFIFO is full

0x1: 1 word available

0x2: 2 words available

0xn: n words available

Others: Reserved

**OTG\_FS device OUT endpoint-x transfer size register (OTG\_FS\_DOEPTSIZ $x$ )  
( $x = 1..3$ , where  $x = \text{Endpoint\_number}$ )**

Address offset:  $0xB10 + (\text{Endpoint\_number} \times 0x20)$

Reset value: 0x0000 0000

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using Endpoint Enable bit of the OTG\_FS\_DOEPCTL $x$  registers (EPENA bit in OTG\_FS\_DOEPCTL $x$ ), the core modifies this register. The application can only read this register once the core has cleared the Endpoint enable bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		RXDPID/S TUPCNT		PKTCNT															XFRSIZ												

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **RXDPID:** Received data PID

Applies to isochronous OUT endpoints only.

This is the data PID received in the last packet for this endpoint.

00: DATA0

01: DATA2

10: DATA1

11: MDATA

## **STUPCNT: SETUP packet count**

Applies to control OUT Endpoints only.

This field specifies the number of back-to-back SETUP data packets the endpoint can receive.

01: 1 packet

10: 2 packets

11: 3 packets

Bit 28:19 **PKTCNT**: Packet count

Indicates the total number of USB packets that constitute the Transfer Size amount of data for this endpoint.

This field is decremented every time a packet (maximum size or short packet) is written to the RxFIFO.

Bits 18:0 **XFRSIZ**: Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet is read from the RxFIFO and written to the external memory.

## 22.16.5 OTG\_FS power and clock gating control register (OTG\_FS\_PCGCCTL)

Address offset: 0xE00

Reset value: 0x0000 0000

This register is available in host and device modes.

Bit 31:5 Reserved, must be kept at reset value.

#### Bit 4 PHYSUSP: PHY Suspended

Indicates that the PHY has been suspended. This bit is updated once the PHY is suspended after the application has set the STPPCLK bit (bit 0).

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **GATEHCLK**: Gate HCLK

The application sets this bit to gate HCLK to modules other than the AHB Slave and Master and wakeup logic when the USB is suspended or the session is not valid. The application clears this bit when the USB is resumed or a new session starts.

Bit 0 **STPPCLK**: Stop PHY clock

The application sets this bit to stop the PHY clock when the USB is suspended, the session is not valid, or the device is disconnected. The application clears this bit when the USB is resumed or a new session starts.

## 22.16.6 OTG\_FS register map

The table below gives the USB OTG register map and reset values.

**Table 131. OTG\_FS register map and reset values**

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0									
0x000	OTG_FS_GOT_GCTL																																									
	Reset value																																									
0x004	OTG_FS_GOT_GINT																																									
	Reset value																																									
0x008	OTG_FS_GAH_BCFG																																									
	Reset value																																									
0x00C	OTG_FS_GUS_BCFG																																									
	Reset value																																									
0x010	OTG_FS_GRST_CTL																																									
	Reset value	1																																								
0x014	OTG_FS_GINT_STS																																									
	Reset value	0	0	0	0																																					
0x018	OTG_FS_GINT_MSK																																									
	Reset value	0	0	0	0																																					
0x01C	OTG_FS_GRXS_TSR (host mode)																																									
	Reset value																																									
0x020	OTG_FS_GRXS_TSR (Device mode)																																									
	Reset value																																									

**Table 131. OTG\_FS register map and reset values (continued)**

**Table 131. OTG\_FS register map and reset values (continued)**

**Table 131. OTG\_FS register map and reset values (continued)**

Table 131. OTG\_FS register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x800	<b>OTG_FS_DCFG</b>	Reserved												PFIVL		DAD												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x804	<b>OTG_FS_DCTL</b>	Reserved												POPRGDNE		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x808	<b>OTG_FS_DSTS</b>	Reserved				FNSOF												Reserved				GONSTS		GINSTS		NZLSOHSK							
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x810	<b>OTG_FS_DIEP MSK</b>	Reserved												INEPNEM		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x814	<b>OTG_FS_DOEP MSK</b>	Reserved												INEPNMM		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x818	<b>OTG_FS_DAIN T</b>	OEPINT												IEPINT		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x81C	<b>OTG_FS_DAIN TMSK</b>	OEPM												IEPM		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x828	<b>OTG_FS_DVBU SDIS</b>	Reserved												VBUSDT		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x82C	<b>OTG_FS_DVBU SPULSE</b>	Reserved												DVBUSP		TCTL												Reset value					
		0	1	0	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
0x834	<b>OTG_FS_DIEP EMPMSK</b>	Reserved												INEPTXFEM		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x900	<b>OTG_FS_DIEP CTL0</b>	EPENA	EPDIS	Reserved	SNAK	CNAK	TXFNUM		Stall	Reserved	EPTY P	NAKSTS	Reserved	USBAEP	Reserved												MPSIZ						
		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x918	<b>TG_FS_DTXFS TS0</b>	Reserved												INEPTFSAV		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x920	<b>OTG_FS_DIEP CTL1</b>	EPENA	EPDIS	Reserved	SNAK	CNAK	TXFNUM		Stall	Reserved	EPTY P	NAKSTS	Reserved	USBAEP	Reserved												MPSIZ						
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x938	<b>TG_FS_DTXFS TS1</b>	Reserved												INEPTFSAV		TCTL												Reset value					
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

**Table 131. OTG\_FS register map and reset values (continued)**

Table 131. OTG\_FS register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6																							
0x968	<b>OTG_FS_DIEPNT3</b>	Reserved																																																
		Reset value																																																
0xB08	<b>OTG_FS_DOEPINT0</b>	Reserved																																																
		Reset value																																																
0xB28	<b>OTG_FS_DOEPINT1</b>	Reserved																																																
		Reset value																																																
0xB48	<b>OTG_FS_DOEPINT2</b>	Reserved																																																
		Reset value																																																
0xB68	<b>OTG_FS_DOEPINT3</b>	Reserved																																																
		Reset value																																																
0x910	<b>OTG_FS_DIEPTSIZ0</b>	Reserved																						XFRSIZ																										
		Reset value																																																
0x930	<b>OTG_FS_DIEPTSIZ1</b>	Reserved	MCNT	PKTCNT												XFRSIZ																																		
0x950	<b>OTG_FS_DIEPTSIZ2</b>	Reserved	MCNT	PKTCNT												XFRSIZ																																		
0x970	<b>OTG_FS_DIEPTSIZ3</b>	Reserved	MCNT	PKTCNT												XFRSIZ																																		
0xB10	<b>OTG_FS_DOEPTSIZ0</b>	Reserved	STUPCNT	Reserved													XFRSIZ																																	
0xB30	<b>OTG_FS_DOEPTSIZ1</b>	Reserved	RXDPID/STUPCNT	PKTCNT												XFRSIZ																																		
0xB50	<b>OTG_FS_DOEPTSIZ2</b>	Reserved	RXDPID/STUPCNT	PKTCNT												XFRSIZ																																		
0xB70	<b>OTG_FS_DOEPTSIZ3</b>	Reserved	RXDPID/STUPCNT	PKTCNT												XFRSIZ																																		
0xE00	<b>OTG_FS_PCGCCTL</b>	Reserved																																																
		Reset value																																																

Refer to [Table 1 on page 38](#) for the register boundary addresses.

## 22.17 OTG\_FS programming model

### 22.17.1 Core initialization

The application must perform the core initialization sequence. If the cable is connected during power-up, the current mode of operation bit in the OTG\_FS\_GINTSTS (CMOD bit in OTG\_FS\_GINTSTS) reflects the mode. The OTG\_FS controller enters host mode when an "A" plug is connected or device mode when a "B" plug is connected.

This section explains the initialization of the OTG\_FS controller after power-on. The application must follow the initialization sequence irrespective of host or device mode operation. All core global registers are initialized according to the core's configuration:

1. Program the following fields in the OTG\_FS\_GAHBCFG register:
  - Global interrupt mask bit GINTMSK = 1
  - RxFIFO non-empty (RXFLVL bit in OTG\_FS\_GINTSTS)
  - Periodic TxFIFO empty level
2. Program the following fields in the OTG\_FS\_GUSBCFG register:
  - HNP capable bit
  - SRP capable bit
  - FS timeout calibration field
  - USB turnaround time field
3. The software must unmask the following bits in the OTG\_FS\_GINTMSK register:
  - OTG interrupt mask
  - Mode mismatch interrupt mask
4. The software can read the CMOD bit in OTG\_FS\_GINTSTS to determine whether the OTG\_FS controller is operating in host or device mode.

## 22.17.2 Host initialization

To initialize the core as host, the application must perform the following steps:

1. Program the HPRTINT in the OTG\_FS\_GINTMSK register to unmask
2. Program the OTG\_FS\_HCFG register to select full-speed host
3. Program the PPWR bit in OTG\_FS\_HPRT to 1. This drives V<sub>BUS</sub> on the USB.
4. Wait for the PCDET interrupt in OTG\_FS\_HPRT0. This indicates that a device is connecting to the port.
5. Program the PRST bit in OTG\_FS\_HPRT to 1. This starts the reset process.
6. Wait at least 10 ms for the reset process to complete.
7. Program the PRST bit in OTG\_FS\_HPRT to 0.
8. Wait for the PENCHNG interrupt in OTG\_FS\_HPRT.
9. Read the PSPD bit in OTG\_FS\_HPRT to get the enumerated speed.
10. Program the HFIR register with a value corresponding to the selected PHY clock 1
11. Program the FSLSPCS field in the OTG\_FS\_HCFG register following the speed of the device detected in step 9. If FSLSPCS has been changed a port reset must be performed.
12. Program the OTG\_FS\_GRXFSIZ register to select the size of the receive FIFO.
13. Program the OTG\_FS\_HNPTXFSIZ register to select the size and the start address of the Non-periodic transmit FIFO for non-periodic transactions.
14. Program the OTG\_FS\_HPTXFSIZ register to select the size and start address of the periodic transmit FIFO for periodic transactions.

To communicate with devices, the system software must initialize and enable at least one channel.

## 22.17.3 Device initialization

The application must perform the following steps to initialize the core as a device on power-up or after a mode change from host to device.

1. Program the following fields in the OTG\_FS\_DCFG register:
  - Device speed
  - Non-zero-length status OUT handshake
2. Program the OTG\_FS\_GINTMSK register to unmask the following interrupts:
  - USB reset
  - Enumeration done
  - Early suspend
  - USB suspend
  - SOF
3. Program the VBUSBSEN bit in the OTG\_FS\_GCCFG register to enable V<sub>BUS</sub> sensing in "B" device mode and supply the 5 volts across the pull-up resistor on the DP line.
4. Wait for the USBRST interrupt in OTG\_FS\_GINTSTS. It indicates that a reset has been detected on the USB that lasts for about 10 ms on receiving this interrupt.

Wait for the ENUMDNE interrupt in OTG\_FS\_GINTSTS. This interrupt indicates the end of reset on the USB. On receiving this interrupt, the application must read the OTG\_FS\_DSTS

register to determine the enumeration speed and perform the steps listed in [Endpoint initialization on enumeration completion on page 768](#).

At this point, the device is ready to accept SOF packets and perform control transfers on control endpoint 0.

## 22.17.4 Host programming model

### Channel initialization

The application must initialize one or more channels before it can communicate with connected devices. To initialize and enable a channel, the application must perform the following steps:

1. Program the OTG\_FS\_GINTMSK register to unmask the following:
  2. Channel interrupt
    - Non-periodic transmit FIFO empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
    - Non-periodic transmit FIFO half-empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
  3. Program the OTG\_FS\_HAINTMSK register to unmask the selected channels' interrupts.
  4. Program the OTG\_FS\_HCINTMSK register to unmask the transaction-related interrupts of interest given in the host channel interrupt register.
  5. Program the selected channel's OTG\_FS\_HCTSIZx register with the total transfer size, in bytes, and the expected number of packets, including short packets. The application must program the PID field with the initial data PID (to be used on the first OUT transaction or to be expected from the first IN transaction).
  6. Program the OTG\_FS\_HCCHARx register of the selected channel with the device's endpoint characteristics, such as type, speed, direction, and so forth. (The channel can be enabled by setting the channel enable bit to 1 only when the application is ready to transmit or receive any packet).

### Halting a channel

The application can disable any channel by programming the OTG\_FS\_HCCHARx register with the CHDIS and CHENA bits set to 1. This enables the OTG\_FS host to flush the posted requests (if any) and generates a channel halted interrupt. The application must wait for the CHH interrupt in OTG\_FS\_HCINTx before reallocating the channel for other transactions. The OTG\_FS host does not interrupt the transaction that has already been started on the USB.

Before disabling a channel, the application must ensure that there is at least one free space available in the non-periodic request queue (when disabling a non-periodic channel) or the periodic request queue (when disabling a periodic channel). The application can simply flush the posted requests when the Request queue is full (before disabling the channel), by programming the OTG\_FS\_HCCHARx register with the CHDIS bit set to 1, and the CHENA bit cleared to 0.

The application is expected to disable a channel on any of the following conditions:

1. When an STALL, TXERR, BBERR or DTERR interrupt in OTG\_FS\_HCINTx is received for an IN or OUT channel. The application must be able to receive other interrupts (DTERR, Nak, Data, TXERR) for the same channel before receiving the halt.
2. When a DISCINT (Disconnect Device) interrupt in OTG\_FS\_GINTSTS is received. (The application is expected to disable all enabled channels).
3. When the application aborts a transfer before normal completion.

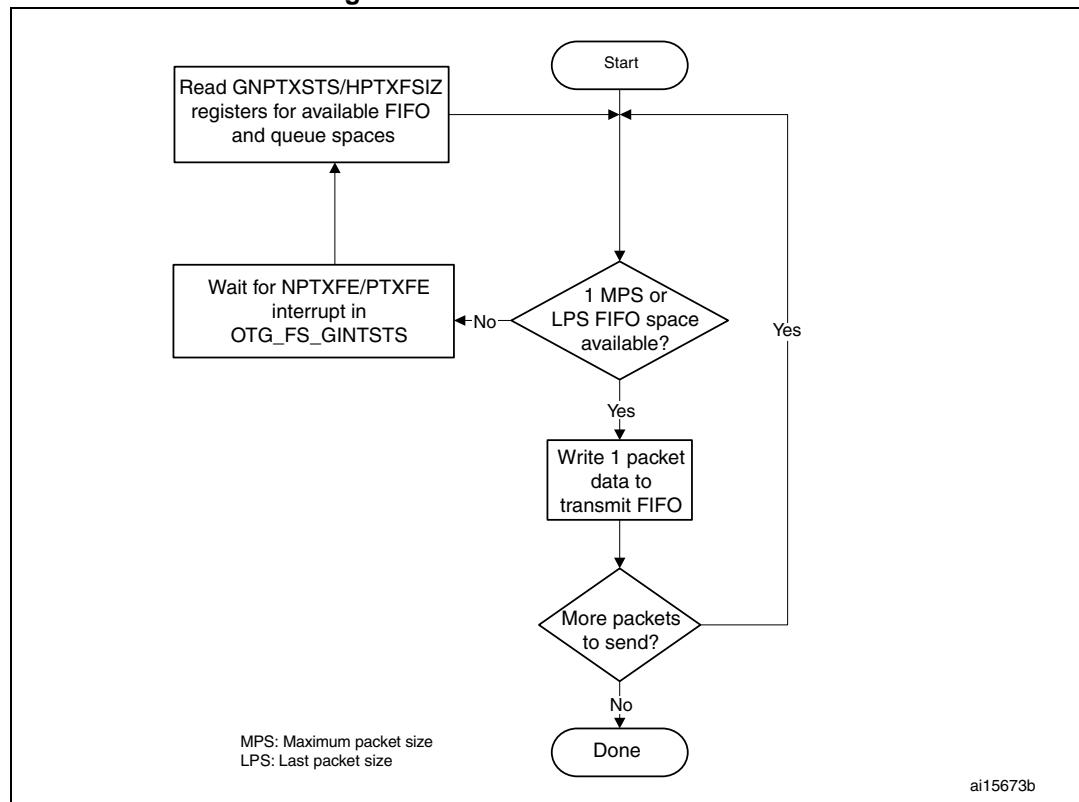
### Operational model

The application must initialize a channel before communicating to the connected device. This section explains the sequence of operation to be performed for different types of USB transactions.

- **Writing the transmit FIFO**

The OTG\_FS host automatically writes an entry (OUT request) to the periodic/non-periodic request queue, along with the last DWORD write of a packet. The application must ensure that at least one free space is available in the periodic/non-periodic request queue before starting to write to the transmit FIFO. The application must always write to the transmit FIFO in DWORDs. If the packet size is non-DWORD aligned, the application must use padding. The OTG\_FS host determines the actual packet size based on the programmed maximum packet size and transfer size.

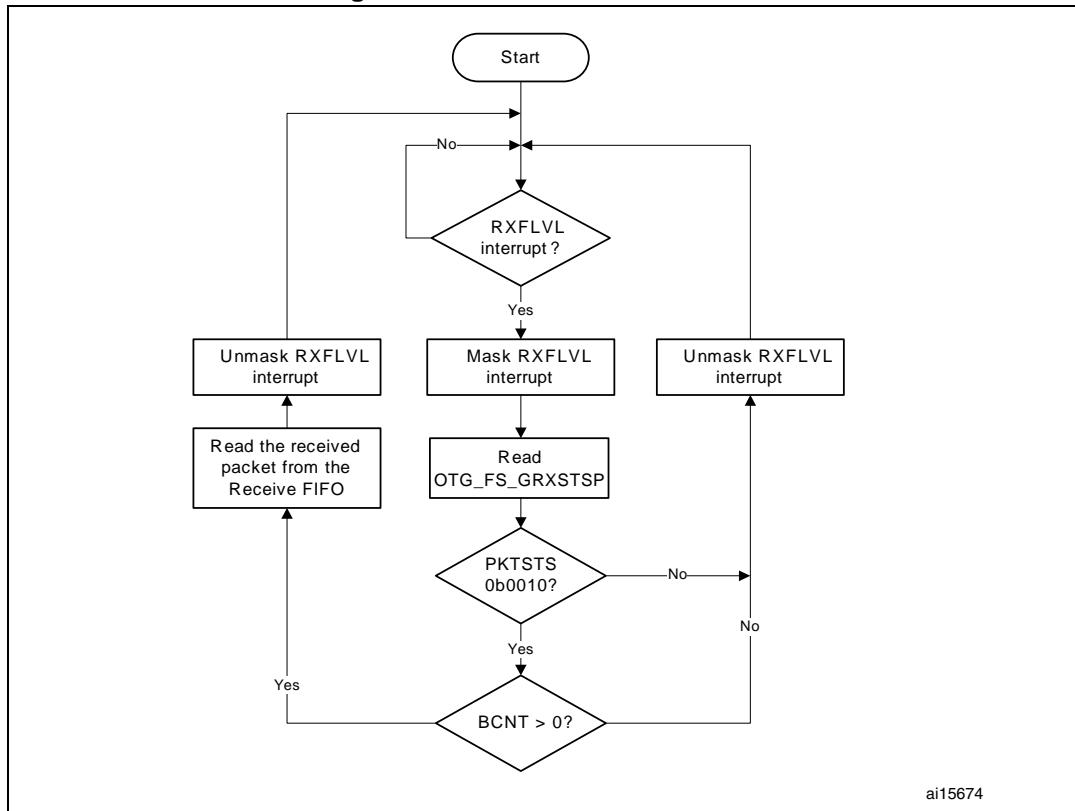
**Figure 252. Transmit FIFO write task**



- **Reading the receive FIFO**

The application must ignore all packet statuses other than IN data packet (bx0010).

**Figure 253. Receive FIFO read task**



- **Bulk and control OUT/SETUP transactions**

A typical bulk or control OUT/SETUP pipelined transaction-level operation is shown in [Figure 254](#). See channel 1 (ch\_1). Two bulk OUT packets are transmitted. A control

SETUP transaction operates in the same way but has only one packet. The assumptions are:

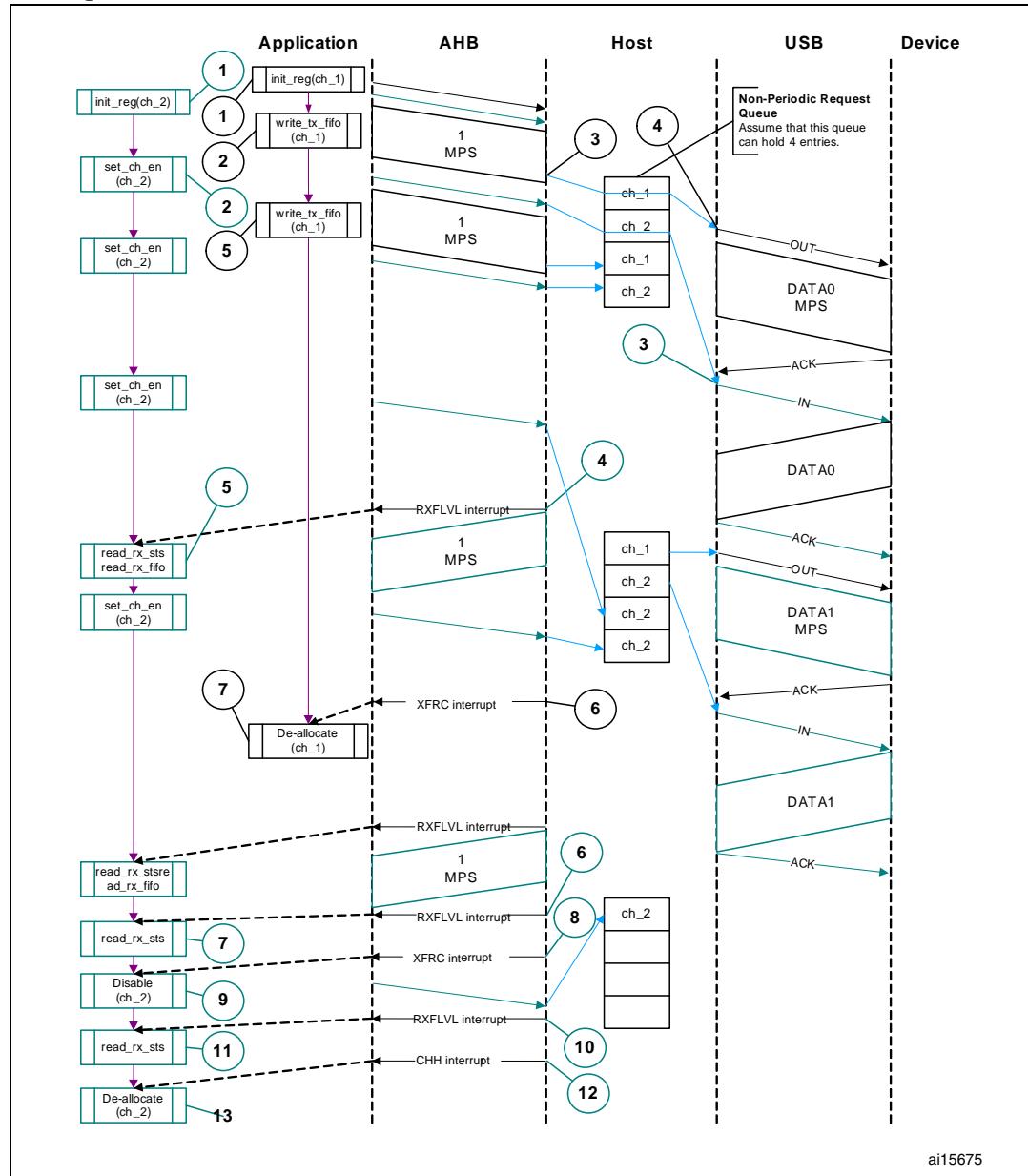
- The application is attempting to send two maximum-packet-size packets (transfer size = 1, 024 bytes).
- The non-periodic transmit FIFO can hold two packets (128 bytes for FS).
- The non-periodic request queue depth = 4.

- **Normal bulk and control OUT/SETUP operations**

The sequence of operations in (channel 1) is as follows:

- a) Initialize channel 1
- b) Write the first packet for channel 1
- c) Along with the last Word write, the core writes an entry to the non-periodic request queue
- d) As soon as the non-periodic queue becomes non-empty, the core attempts to send an OUT token in the current frame
- e) Write the second (last) packet for channel 1
- f) The core generates the XFRC interrupt as soon as the last transaction is completed successfully
- g) In response to the XFRC interrupt, de-allocate the channel for other transfers
- h) Handling non-ACK responses

Figure 254. Normal bulk/control OUT/SETUP and bulk/control IN transactions



The channel-specific interrupt service routine for bulk and control OUT/SETUP transactions is shown in the following code samples.

- **Interrupt service routine for bulk/control OUT/SETUP and bulk/control IN transactions**
  - Bulk/Control OUT/SETUP

```
Unmask (NAK/TXERR/STALL/XFRC)
if (XFRC)
{
    Reset Error Count
    Mask ACK
```

```

        De-allocate Channel
    }
else if (STALL)
{
    Transfer Done = 1
    Unmask CHH
    Disable Channel
}
else if (NAK or TXERR )
{
    Rewind Buffer Pointers
    Unmask CHH
    Disable Channel
    if (TXERR)
    {
        Increment Error Count
        Unmask ACK
    }
else
{
    Reset Error Count
}
}
else if (CHH)
{
    Mask CHH
    if (Transfer Done or (Error_count == 3))
    {
        De-allocate Channel
    }
else
{
    Re-initialize Channel
}
}
else if (ACK)
{
    Reset Error Count
    Mask ACK
}

```

The application is expected to write the data packets into the transmit FIFO as and when the space is available in the transmit FIFO and the Request queue. The application can make use of the NPTXFE interrupt in OTG\_FS\_GINTSTS to find the transmit FIFO space.

#### b) Bulk/Control IN

```

Unmask (TXERR/XFRC/BBERR/STALL/DTERR)
if (XFRC)
{
    Reset Error Count
    Unmask CHH
    Disable Channel
}

```

```

        Reset Error Count
        Mask ACK
    }
else if (TXERR or BBERR or STALL)
{
    Unmask CHH
    Disable Channel
    if (TXERR)
    {
        Increment Error Count
        Unmask ACK
    }
}
else if (CHH)
{
    Mask CHH
    if (Transfer Done or (Error_count == 3))
    {
        De-allocate Channel
    }
    else
    {
        Re-initialize Channel
    }
}
else if (ACK)
{
    Reset Error Count
    Mask ACK
}
else if (DTERR)
{
    Reset Error Count
}

```

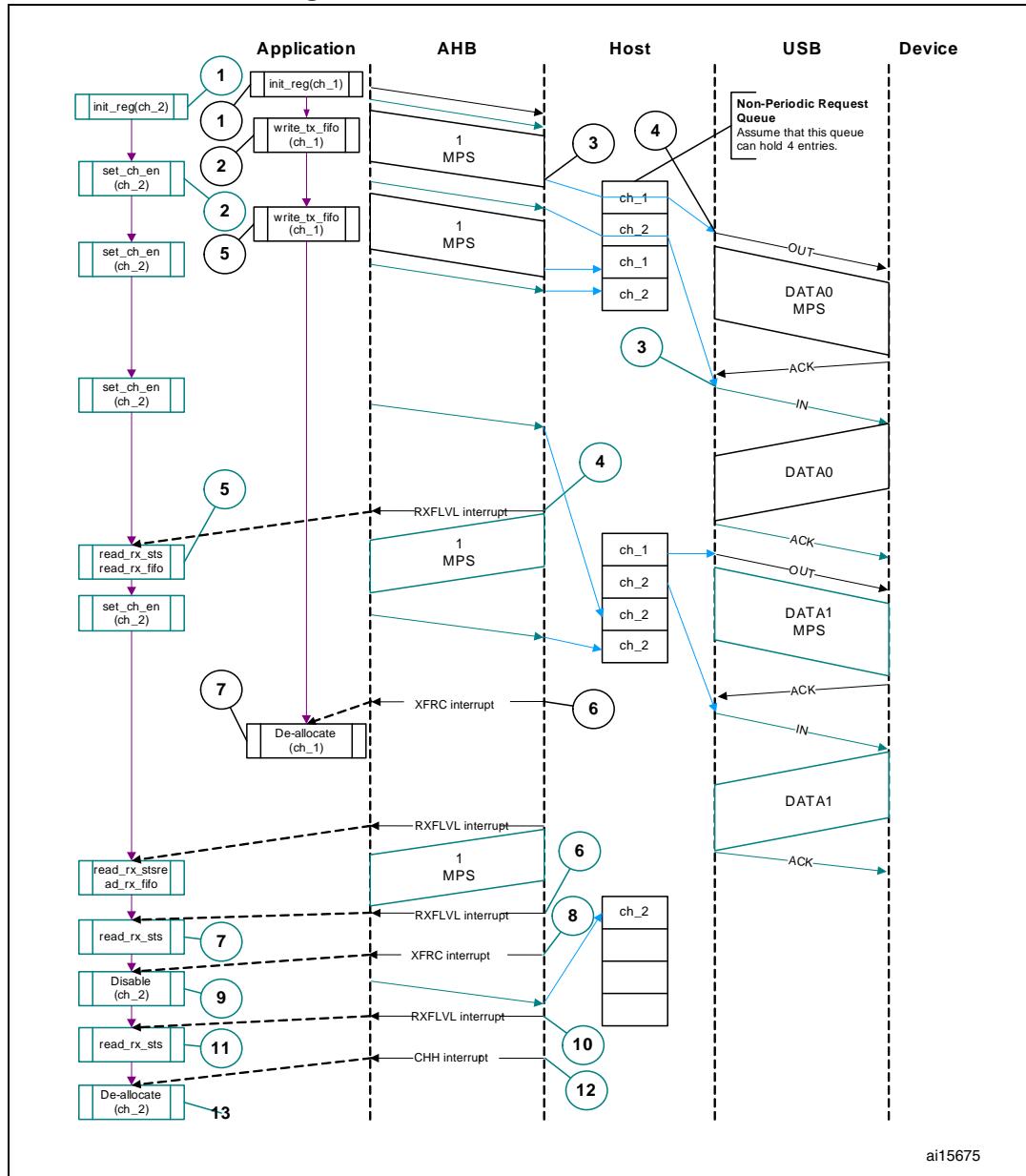
The application is expected to write the requests as and when the Request queue space is available and until the XFRC interrupt is received.

- **Bulk and control IN transactions**

A typical bulk or control IN pipelined transaction-level operation is shown in [Figure 255](#). See channel 2 (ch\_2). The assumptions are:

- The application is attempting to receive two maximum-packet-size packets (transfer size = 1 024 bytes).
- The receive FIFO can contain at least one maximum-packet-size packet and two status Words per packet (72 bytes for FS).
- The non-periodic request queue depth = 4.

Figure 255. Bulk/control IN transactions



The sequence of operations is as follows:

- Initialize channel 2.
- Set the CHENA bit in HCCHAR2 to write an IN request to the non-periodic request queue.
- The core attempts to send an IN token after completing the current OUT transaction.
- The core generates an RXFLVL interrupt as soon as the received packet is written to the receive FIFO.
- In response to the RXFLVL interrupt, mask the RXFLVL interrupt and read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. Following this, unmask the RXFLVL interrupt.

- f) The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO.
  - g) The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in GRXSTSR  $\neq$  0b0010).
  - h) The core generates the XFRC interrupt as soon as the receive packet status is read.
  - i) In response to the XFRC interrupt, disable the channel and stop writing the OTG\_FS\_HCCHAR2 register for further requests. The core writes a channel disable request to the non-periodic request queue as soon as the OTG\_FS\_HCCHAR2 register is written.
  - j) The core generates the RXFLVL interrupt as soon as the halt status is written to the receive FIFO.
  - k) Read and ignore the receive packet status.
  - l) The core generates a CHH interrupt as soon as the halt status is popped from the receive FIFO.
  - m) In response to the CHH interrupt, de-allocate the channel for other transfers.
  - n) Handling non-ACK responses
- **Control transactions**

Setup, Data, and Status stages of a control transfer must be performed as three separate transfers. Setup-, Data- or Status-stage OUT transactions are performed similarly to the bulk OUT transactions explained previously. Data- or Status-stage IN transactions are performed similarly to the bulk IN transactions explained previously. For all three stages, the application is expected to set the EPTYP field in OTG\_FS\_HCCHAR1 to Control. During the Setup stage, the application is expected to set the PID field in OTG\_FS\_HCTSIZ1 to SETUP.
  - **Interrupt OUT transactions**

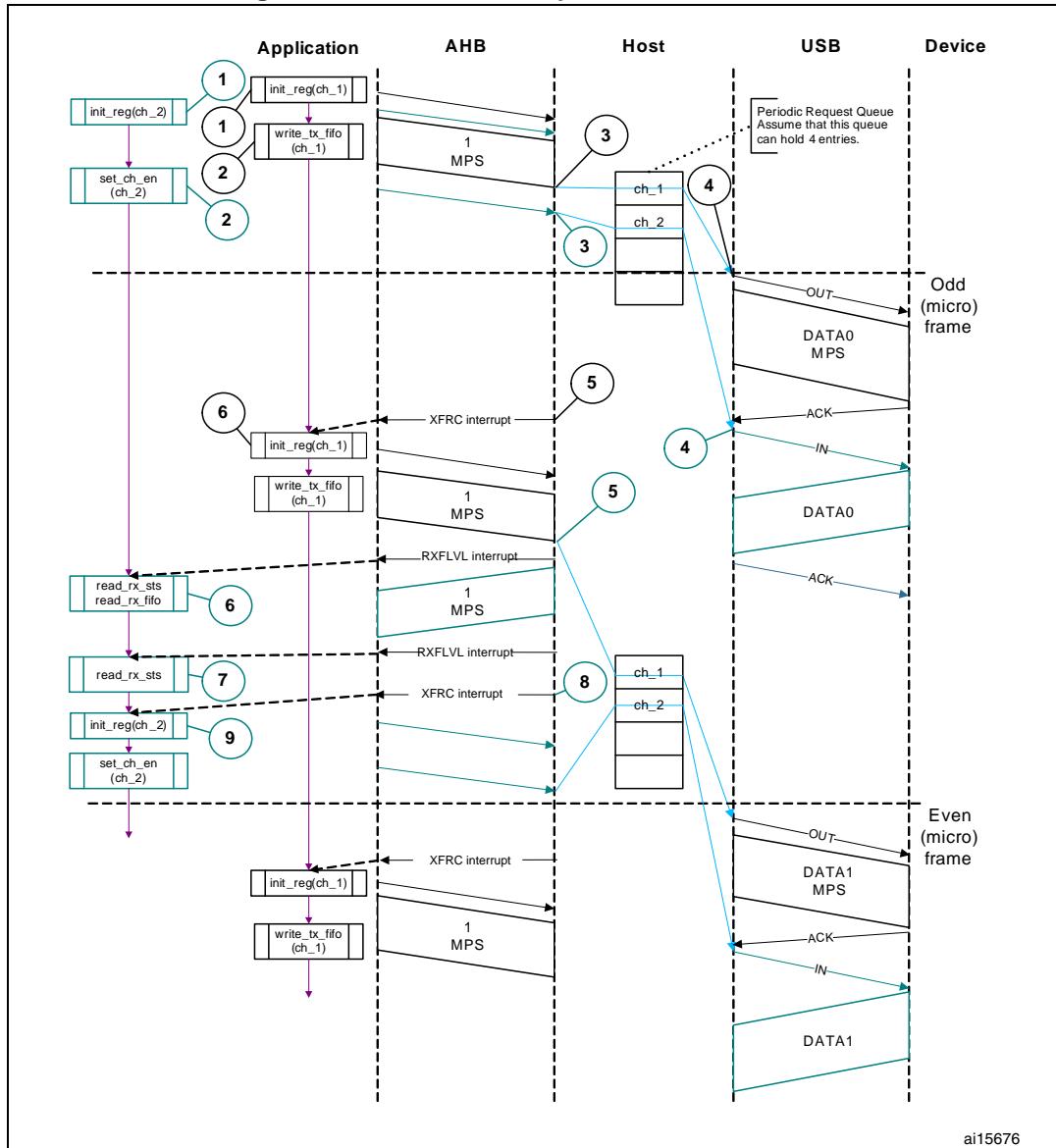
A typical interrupt OUT operation is shown in [Figure 256](#). The assumptions are:

    - The application is attempting to send one packet in every frame (up to 1 maximum packet size), starting with the odd frame (transfer size = 1 024 bytes)
    - The periodic transmit FIFO can hold one packet (1 KB)
    - Periodic request queue depth = 4

The sequence of operations is as follows:

    - a) Initialize and enable channel 1. The application must set the ODDFRM bit in OTG\_FS\_HCCHAR1.
    - b) Write the first packet for channel 1.
    - c) Along with the last Word write of each packet, the OTG\_FS host writes an entry to the periodic request queue.
    - d) The OTG\_FS host attempts to send an OUT token in the next (odd) frame.
    - e) The OTG\_FS host generates an XFRC interrupt as soon as the last packet is transmitted successfully.
    - f) In response to the XFRC interrupt, reinitialize the channel for the next transfer.

Figure 256. Normal interrupt OUT/IN transactions



- **Interrupt service routine for interrupt OUT/IN transactions**

- Interrupt OUT

```

Unmask (NAK/TXERR/STALL/XFRC/FRMOR)
if (XFRC)
{
    Reset Error Count
    Mask ACK
    De-allocate Channel
}
else
    if (STALL or FRMOR)
    {
        Mask ACK
        Unmask CHH
    }
}

```

```

        Disable Channel
        if (STALL)
        {
            Transfer Done = 1
        }
    }
else
    if (NAK or TXERR)
    {
        Rewind Buffer Pointers
        Reset Error Count
        Mask ACK
        Unmask CHH
        Disable Channel
    }
else
    if (CHH)
    {
        Mask CHH
        if (Transfer Done or (Error_count == 3))
        {
            De-allocate Channel
        }
        else
        {
            Re-initialize Channel (in next b_interval - 1 Frame)
        }
    }
else
    if (ACK)
    {
        Reset Error Count
        Mask ACK
    }

```

The application uses the NPTXFE interrupt in OTG\_FS\_GINTSTS to find the transmit FIFO space.

#### b) Interrupt IN

```

Unmask (NAK/TXERR/XFRC/BBERR/STALL/FRMOR/DTERR)
if (XFRC)
{
    Reset Error Count
    Mask ACK
    if (OTG_FS_HCTSIZx.PKTCNT == 0)
    {
        De-allocate Channel
    }
else
    {
        Transfer Done = 1
        Unmask CHH
        Disable Channel
    }
}

```

```
        }
    }
else
if (STALL or FRMOR or NAK or DTERR or BBERR)
{
    Mask ACK
    Unmask CHH
    Disable Channel
    if (STALL or BBERR)
    {
        Reset Error Count
        Transfer Done = 1
    }
    else
        if (!FRMOR)
        {
            Reset Error Count
        }
}
else
if (TXERR)
{
    Increment Error Count
    Unmask ACK
    Unmask CHH
    Disable Channel
}
else
if (CHH)
{
    Mask CHH
    if (Transfer Done or (Error_count == 3))
    {
        De-allocate Channel
    }
    else
        Re-initialize Channel (in next b_interval - 1 /Frame)
}
else
if (ACK)
{
    Reset Error Count
    Mask ACK
}
```

- **Interrupt IN transactions**

The assumptions are:

- The application is attempting to receive one packet (up to 1 maximum packet size) in every frame, starting with odd (transfer size = 1 024 bytes).
- The receive FIFO can hold at least one maximum-packet-size packet and two status Words per packet (1 031 bytes).
- Periodic request queue depth = 4.

- **Normal interrupt IN operation**

The sequence of operations is as follows:

- a) Initialize channel 2. The application must set the ODDFRM bit in OTG\_FS\_HCCHAR2.
- b) Set the CHENA bit in OTG\_FS\_HCCHAR2 to write an IN request to the periodic request queue.
- c) The OTG\_FS host writes an IN request to the periodic request queue for each OTG\_FS\_HCCHAR2 register write with the CHENA bit set.
- d) The OTG\_FS host attempts to send an IN token in the next (odd) frame.
- e) As soon as the IN packet is received and written to the receive FIFO, the OTG\_FS host generates an RXFLVL interrupt.
- f) In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask after reading the entire packet.
- g) The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in GRXSTSR ≠ 0b0010).
- h) The core generates an XFRC interrupt as soon as the receive packet status is read.
- i) In response to the XFRC interrupt, read the PKTCNT field in OTG\_FS\_HCTSIZ2. If the PKTCNT bit in OTG\_FS\_HCTSIZ2 is not equal to 0, disable the channel before re-initializing the channel for the next transfer, if any). If PKTCNT bit in OTG\_FS\_HCTSIZ2 = 0, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG\_FS\_HCCHAR2.

- **Isochronous OUT transactions**

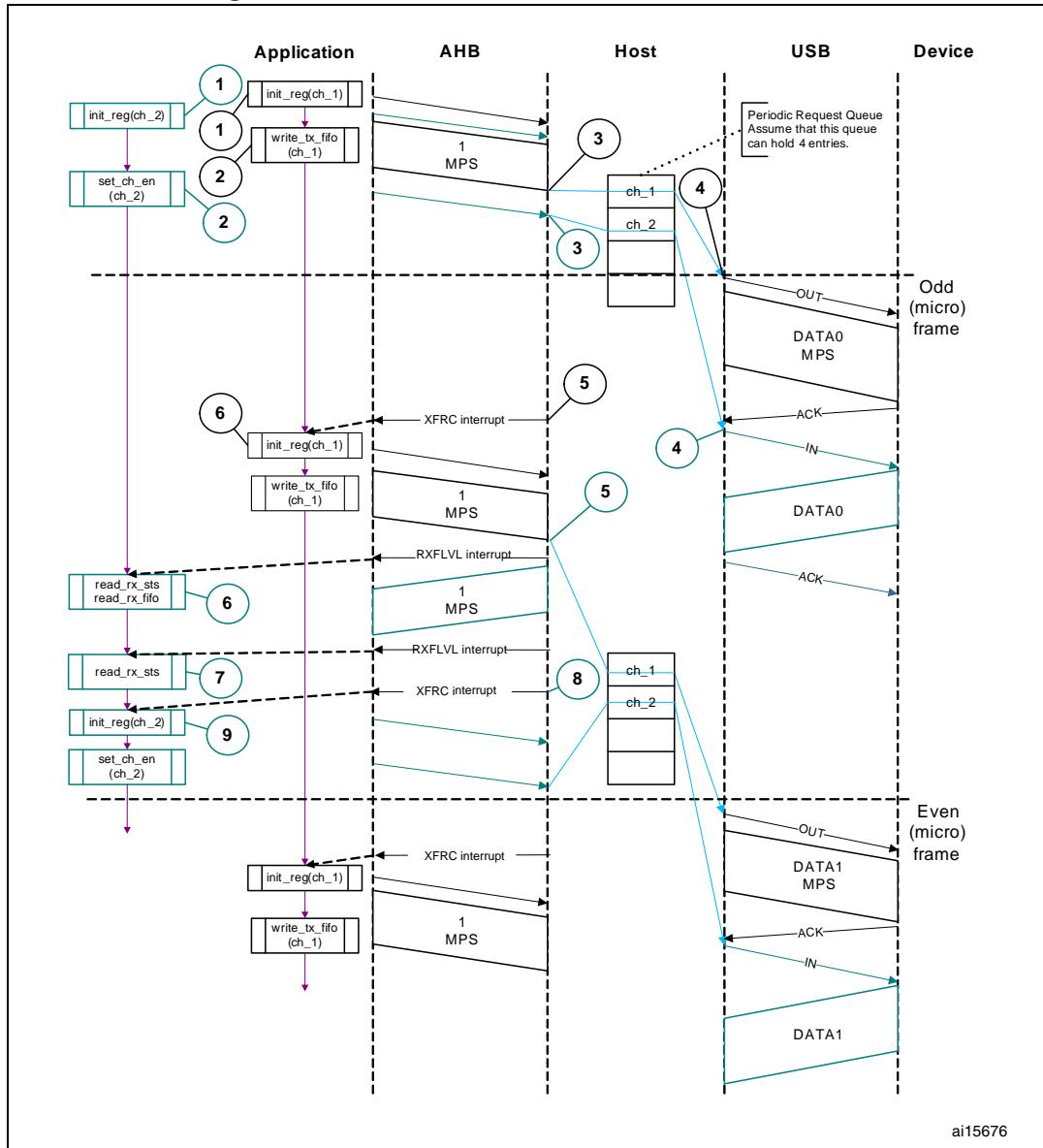
A typical isochronous OUT operation is shown in [Figure 257](#). The assumptions are:

- The application is attempting to send one packet every frame (up to 1 maximum packet size), starting with an odd frame. (transfer size = 1 024 bytes).
- The periodic transmit FIFO can hold one packet (1 KB).
- Periodic request queue depth = 4.

The sequence of operations is as follows:

- a) Initialize and enable channel 1. The application must set the ODDFRM bit in OTG\_FS\_HCCHAR1.
- b) Write the first packet for channel 1.
- c) Along with the last Word write of each packet, the OTG\_FS host writes an entry to the periodic request queue.
- d) The OTG\_FS host attempts to send the OUT token in the next frame (odd).
- e) The OTG\_FS host generates the XFRC interrupt as soon as the last packet is transmitted successfully.
- f) In response to the XFRC interrupt, reinitialize the channel for the next transfer.
- g) Handling non-ACK responses

Figure 257. Normal isochronous OUT/IN transactions



- **Interrupt service routine for isochronous OUT/IN transactions**

Code sample: Isochronous OUT

```
Unmask (FRMOR/XFRC)
if (XFRC)
{
    {
        De-allocate Channel
    }
}
else
{
    if (FRMOR)
    {
        Unmask CHH
        Disable Channel
    }
}
```

```
else
if (CHH)
{
    Mask CHH
    De-allocate Channel
}
Code sample: Isochronous IN
Unmask (TXERR/XFRC/FRMOR/BBERR)
if (XFRC or FRMOR)
{
    if (XFRC and (OTG_FS_HCTSIZx.PKTCNT == 0))
    {
        Reset Error Count
        De-allocate Channel
    }
    else
    {
        Unmask CHH
        Disable Channel
    }
}
else
if (TXERR or BBERR)
{
    Increment Error Count
    Unmask CHH
    Disable Channel
}
else
if (CHH)
{
    Mask CHH
    if (Transfer Done or (Error_count == 3))
    {
        De-allocate Channel
    }
    else
    {
        Re-initialize Channel
    }
}
```

- **Isochronous IN transactions**

The assumptions are:

- The application is attempting to receive one packet (up to 1 maximum packet size) in every frame starting with the next odd frame (transfer size = 1 024 bytes).
- The receive FIFO can hold at least one maximum-packet-size packet and two status Word per packet (1 031 bytes).
- Periodic request queue depth = 4.

The sequence of operations is as follows:

- a) Initialize channel 2. The application must set the ODDFRM bit in OTG\_FS\_HCCHAR2.
- b) Set the CHENA bit in OTG\_FS\_HCCHAR2 to write an IN request to the periodic request queue.
- c) The OTG\_FS host writes an IN request to the periodic request queue for each OTG\_FS\_HCCHAR2 register write with the CHENA bit set.
- d) The OTG\_FS host attempts to send an IN token in the next odd frame.
- e) As soon as the IN packet is received and written to the receive FIFO, the OTG\_FS host generates an RXFLVL interrupt.
- f) In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask it after reading the entire packet.
- g) The core generates an RXFLVL interrupt for the transfer completion status entry in the receive FIFO. This time, the application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS bit in OTG\_FS\_GRXSTR ≠ 0b0010).
- h) The core generates an XFRC interrupt as soon as the receive packet status is read.
- i) In response to the XFRC interrupt, read the PKTCNT field in OTG\_FS\_HCTSIZ2. If PKTCNT ≠ 0 in OTG\_FS\_HCTSIZ2, disable the channel before re-initializing the channel for the next transfer, if any. If PKTCNT = 0 in OTG\_FS\_HCTSIZ2, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG\_FS\_HCCHAR2.

- **Selecting the queue depth**

Choose the periodic and non-periodic request queue depths carefully to match the number of periodic/non-periodic endpoints accessed.

The non-periodic request queue depth affects the performance of non-periodic transfers. The deeper the queue (along with sufficient FIFO size), the more often the core is able to pipeline non-periodic transfers. If the queue size is small, the core is able to put in new requests only when the queue space is freed up.

The core's periodic request queue depth is critical to perform periodic transfers as scheduled. Select the periodic queue depth, based on the number of periodic transfers scheduled in a microframe. If the periodic request queue depth is smaller than the periodic transfers scheduled in a microframe, a frame overrun condition occurs.

- **Handling babble conditions**

OTG\_FS controller handles two cases of babble: packet babble and port babble. Packet babble occurs if the device sends more data than the maximum packet size for

the channel. Port babble occurs if the core continues to receive data from the device at EOF2 (the end of frame 2, which is very close to SOF).

When OTG\_FS controller detects a packet babble, it stops writing data into the Rx buffer and waits for the end of packet (EOP). When it detects an EOP, it flushes already written data in the Rx buffer and generates a Babble interrupt to the application.

When OTG\_FS controller detects a port babble, it flushes the RxFIFO and disables the port. The core then generates a Port disabled interrupt (HPRTINT in OTG\_FS\_GINTSTS, PENCHNG in OTG\_FS\_HPRT). On receiving this interrupt, the application must determine that this is not due to an overcurrent condition (another cause of the Port Disabled interrupt) by checking POCA in OTG\_FS\_HPRT, then perform a soft reset. The core does not send any more tokens after it has detected a port babble condition.

## 22.17.5 Device programming model

### Endpoint initialization on USB reset

1. Set the NAK bit for all OUT endpoints
  - SNAK = 1 in OTG\_FS\_DOEPCTLx (for all OUT endpoints)
2. Unmask the following interrupt bits
  - INEP0 = 1 in OTG\_FS\_DAINTMSK (control 0 IN endpoint)
  - OUTEP0 = 1 in OTG\_FS\_DAINTMSK (control 0 OUT endpoint)
  - STUP = 1 in DOEPMSK
  - XFRC = 1 in DOEPMSK
  - XFRC = 1 in DIEPMSK
  - TOC = 1 in DIEPMSK
3. Set up the Data FIFO RAM for each of the FIFOs
  - Program the OTG\_FS\_GRXFSIZ register, to be able to receive control OUT data and setup data. If thresholding is not enabled, at a minimum, this must be equal to 1 max packet size of control endpoint 0 + 2 Words (for the status of the control OUT data packet) + 10 Words (for setup packets).
  - Program the OTG\_FS\_TX0FSIZ register (depending on the FIFO number chosen) to be able to transmit control IN data. At a minimum, this must be equal to 1 max packet size of control endpoint 0.
4. Program the following fields in the endpoint-specific registers for control OUT endpoint 0 to receive a SETUP packet
  - STUPCNT = 3 in OTG\_FS\_DOEPTSIZ0 (to receive up to 3 back-to-back SETUP packets)

At this point, all initialization required to receive SETUP packets is done.

### Endpoint initialization on enumeration completion

1. On the Enumeration Done interrupt (ENUMDNE in OTG\_FS\_GINTSTS), read the OTG\_FS\_DSTS register to determine the enumeration speed.
2. Program the MPSIZ field in OTG\_FS\_DIEPCTL0 to set the maximum packet size. This step configures control endpoint 0. The maximum packet size for a control endpoint depends on the enumeration speed.

At this point, the device is ready to receive SOF packets and is configured to perform control transfers on control endpoint 0.

### Endpoint initialization on SetAddress command

This section describes what the application must do when it receives a SetAddress command in a SETUP packet.

1. Program the OTG\_FS\_DCFG register with the device address received in the SetAddress command
1. Program the core to send out a status IN packet

### Endpoint initialization on SetConfiguration/SetInterface command

This section describes what the application must do when it receives a SetConfiguration or SetInterface command in a SETUP packet.

1. When a SetConfiguration command is received, the application must program the endpoint registers to configure them with the characteristics of the valid endpoints in the new configuration.
2. When a SetInterface command is received, the application must program the endpoint registers of the endpoints affected by this command.
3. Some endpoints that were active in the prior configuration or alternate setting are not valid in the new configuration or alternate setting. These invalid endpoints must be deactivated.
4. Unmask the interrupt for each active endpoint and mask the interrupts for all inactive endpoints in the OTG\_FS\_DAINTMSK register.
5. Set up the Data FIFO RAM for each FIFO.
6. After all required endpoints are configured; the application must program the core to send a status IN packet.

At this point, the device core is configured to receive and transmit any type of data packet.

### Endpoint activation

This section describes the steps required to activate a device endpoint or to configure an existing device endpoint to a new type.

1. Program the characteristics of the required endpoint into the following fields of the OTG\_FS\_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG\_FS\_DOEPCTLx register (for OUT or bidirectional endpoints).
  - Maximum packet size
  - USB active endpoint = 1
  - Endpoint start data toggle (for interrupt and bulk endpoints)
  - Endpoint type
  - TxFIFO number
2. Once the endpoint is activated, the core starts decoding the tokens addressed to that endpoint and sends out a valid handshake for each valid token received for the endpoint.

### Endpoint deactivation

This section describes the steps required to deactivate an existing endpoint.

1. In the endpoint to be deactivated, clear the USB active endpoint bit in the OTG\_FS\_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG\_FS\_DOEPCTLx register (for OUT or bidirectional endpoints).
2. Once the endpoint is deactivated, the core ignores tokens addressed to that endpoint, which results in a timeout on the USB.

**Note:** *The application must meet the following conditions to set up the device core to handle traffic:  
NPTXFEM and RXFLVLM in the OTG\_FS\_GINTMSK register must be cleared.*

## 22.17.6 Operational model

### SETUP and OUT data transfers

This section describes the internal data flow and application-level operations during data OUT transfers and SETUP transactions.

- **Packet read**

This section describes how to read packets (OUT data and SETUP packets) from the receive FIFO.

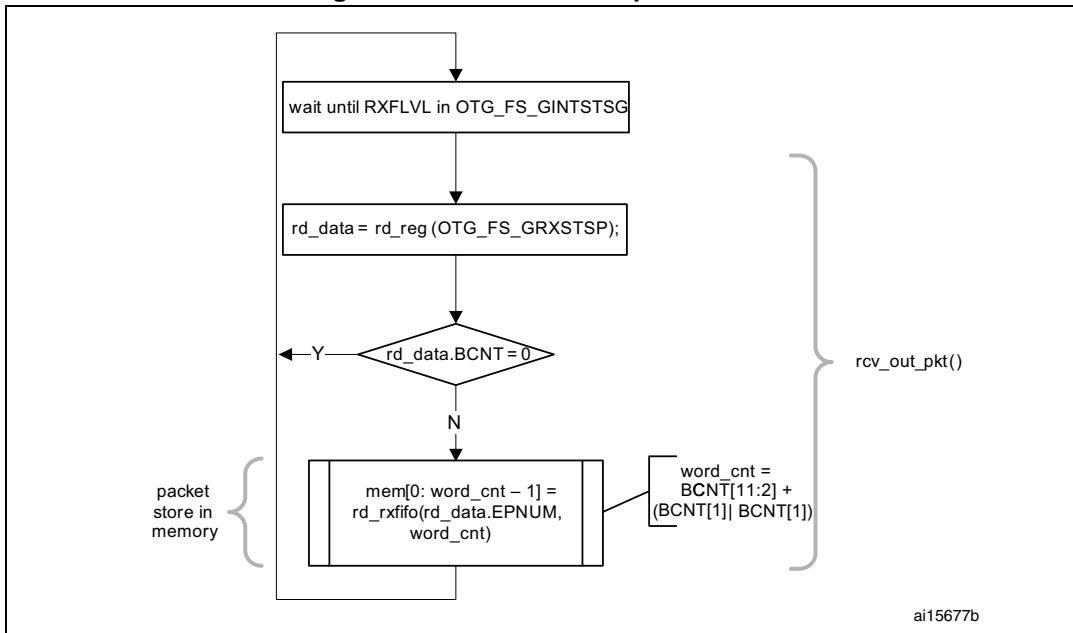
1. On catching an RXFLVL interrupt (OTG\_FS\_GINTSTS register), the application must read the Receive status pop register (OTG\_FS\_GRXSTSP).
2. The application can mask the RXFLVL interrupt (in OTG\_FS\_GINTSTS) by writing to RXFLVL = 0 (in OTG\_FS\_GINTMSK), until it has read the packet from the receive FIFO.
3. If the received packet's byte count is not 0, the byte count amount of data is popped from the receive Data FIFO and stored in memory. If the received packet byte count is 0, no data is popped from the receive data FIFO.
4. The receive FIFO's packet status readout indicates one of the following:
  - a) Global OUT NAK pattern:  
PKTSTS = Global OUT NAK, BCNT = 0x000, EPNUM = Don't Care (0x0), DPID = Don't Care (0b00).  
These data indicate that the global OUT NAK bit has taken effect.
  - b) SETUP packet pattern:  
PKTSTS = SETUP, BCNT = 0x008, EPNUM = Control EP Num, DPID = D0.  
These data indicate that a SETUP packet for the specified endpoint is now available for reading from the receive FIFO.
  - c) Setup stage done pattern:  
PKTSTS = Setup Stage Done, BCNT = 0x0, EPNUM = Control EP Num, DPID = Don't Care (0b00).  
These data indicate that the Setup stage for the specified endpoint has completed and the Data stage has started. After this entry is popped from the receive FIFO, the core asserts a Setup interrupt on the specified control OUT endpoint.
  - d) Data OUT packet pattern:  
PKTSTS = DataOUT, BCNT = size of the received data OUT packet ( $0 \leq BCNT \leq 1\,024$ ), EPNUM = EPNUM on which the packet was received, DPID = Actual Data PID.
  - e) Data transfer completed pattern:  
PKTSTS = Data OUT Transfer Done, BCNT = 0x0, EPNUM = OUT EP Num on which the data transfer is complete, DPID = Don't Care (0b00).  
These data indicate that an OUT data transfer for the specified OUT endpoint has

completed. After this entry is popped from the receive FIFO, the core asserts a Transfer Completed interrupt on the specified OUT endpoint.

5. After the data payload is popped from the receive FIFO, the RXFLVL interrupt (OTG\_FS\_GINTSTS) must be unmasked.
6. Steps 1–5 are repeated every time the application detects assertion of the interrupt line due to RXFLVL in OTG\_FS\_GINTSTS. Reading an empty receive FIFO can result in undefined core behavior.

*Figure 258* provides a flowchart of the above procedure.

**Figure 258. Receive FIFO packet read**



- **SETUP transactions**

This section describes how the core handles SETUP packets and the application's sequence for handling SETUP transactions.

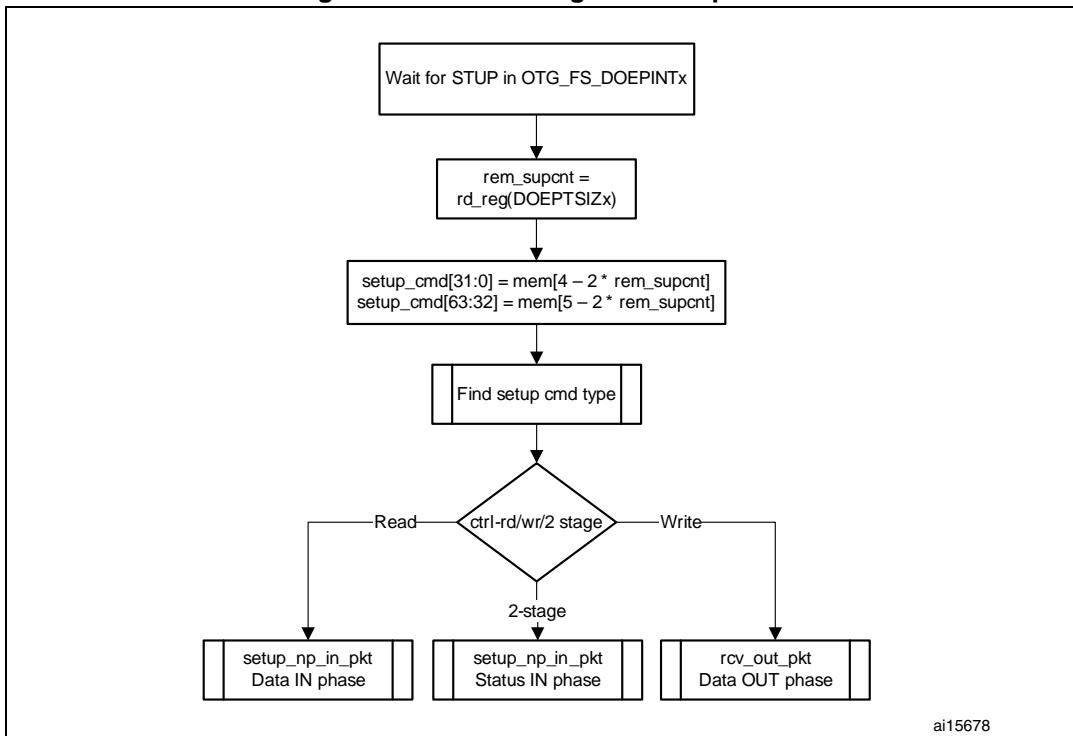
- **Application requirements**

1. To receive a SETUP packet, the STUPCNT field (OTG\_FS\_DOEPTSIZx) in a control OUT endpoint must be programmed to a non-zero value. When the application programs the STUPCNT field to a non-zero value, the core receives SETUP packets and writes them to the receive FIFO, irrespective of the NAK status and EPENA bit setting in OTG\_FS\_DOEPCTLx. The STUPCNT field is decremented every time the control endpoint receives a SETUP packet. If the STUPCNT field is not programmed to a proper value before receiving a SETUP packet, the core still receives the SETUP packet and decrements the STUPCNT field, but the application may not be able to

determine the correct number of SETUP packets received in the Setup stage of a control transfer.

- STUPCNT = 3 in OTG\_FS\_DOEPTSIZx
2. The application must always allocate some extra space in the Receive data FIFO, to be able to receive up to three SETUP packets on a control endpoint.
    - The space to be reserved is 10 Words. Three Words are required for the first SETUP packet, 1 Word is required for the Setup stage done Word and 6 Words are required to store two extra SETUP packets among all control endpoints.
    - 3 Words per SETUP packet are required to store 8 bytes of SETUP data and 4 bytes of SETUP status (Setup packet pattern). The core reserves this space in the receive data.
    - FIFO to write SETUP data only, and never uses this space for data packets.
  3. The application must read the 2 Words of the SETUP packet from the receive FIFO.
  4. The application must read and discard the Setup stage done Word from the receive FIFO.
  - **Internal data flow**
  5. When a SETUP packet is received, the core writes the received data to the receive FIFO, without checking for available space in the receive FIFO and irrespective of the endpoint's NAK and STALL bit settings.
    - The core internally sets the IN NAK and OUT NAK bits for the control IN/OUT endpoints on which the SETUP packet was received.
  6. For every SETUP packet received on the USB, 3 Words of data are written to the receive FIFO, and the STUPCNT field is decremented by 1.
    - The first Word contains control information used internally by the core
    - The second Word contains the first 4 bytes of the SETUP command
    - The third Word contains the last 4 bytes of the SETUP command
  7. When the Setup stage changes to a Data IN/OUT stage, the core writes an entry (Setup stage done Word) to the receive FIFO, indicating the completion of the Setup stage.
  8. On the AHB side, SETUP packets are emptied by the application.
  9. When the application pops the Setup stage done Word from the receive FIFO, the core interrupts the application with an STUP interrupt (OTG\_FS\_DOEPINTx), indicating it can process the received SETUP packet.
    - The core clears the endpoint enable bit for control OUT endpoints.
  - **Application programming sequence**
  1. Program the OTG\_FS\_DOEPTSIZx register.
    - STUPCNT = 3
  2. Wait for the RXFLVL interrupt (OTG\_FS\_GINTSTS) and empty the data packets from the receive FIFO.
  3. Assertion of the STUP interrupt (OTG\_FS\_DOEPINTx) marks a successful completion of the SETUP Data Transfer.
    - On this interrupt, the application must read the OTG\_FS\_DOEPTSIZx register to determine the number of SETUP packets received and process the last received SETUP packet.

Figure 259. Processing a SETUP packet



- Handling more than three back-to-back SETUP packets**

Per the USB 2.0 specification, normally, during a SETUP packet error, a host does not send more than three back-to-back SETUP packets to the same endpoint. However, the USB 2.0 specification does not limit the number of back-to-back SETUP packets a host can send to the same endpoint. When this condition occurs, the OTG\_FS controller generates an interrupt (B2BSTUP in OTG\_FS\_DOEPINTx).

- Setting the global OUT NAK**

Internal data flow:

- When the application sets the Global OUT NAK (SGONAK bit in OTG\_FS\_DCTL), the core stops writing data, except SETUP packets, to the receive FIFO. Irrespective of the space availability in the receive FIFO, non-isochronous OUT tokens receive a NAK handshake response, and the core ignores isochronous OUT data packets
- The core writes the Global OUT NAK pattern to the receive FIFO. The application must reserve enough receive FIFO space to write this data pattern.
- When the application pops the Global OUT NAK pattern Word from the receive FIFO, the core sets the GONAKEFF interrupt (OTG\_FS\_GINTSTS).
- Once the application detects this interrupt, it can assume that the core is in Global OUT NAK mode. The application can clear this interrupt by clearing the SGONAK bit in OTG\_FS\_DCTL.

Application programming sequence

1. To stop receiving any kind of data in the receive FIFO, the application must set the Global OUT NAK bit by programming the following field:
  - SGONAK = 1 in OTG\_FS\_DCTL
2. Wait for the assertion of the GONAKEFF interrupt in OTG\_FS\_GINTSTS. When asserted, this interrupt indicates that the core has stopped receiving any type of data except SETUP packets.
3. The application can receive valid OUT packets after it has set SGONAK in OTG\_FS\_DCTL and before the core asserts the GONAKEFF interrupt (OTG\_FS\_GINTSTS).
4. The application can temporarily mask this interrupt by writing to the GINAKEFFM bit in the OTG\_FS\_GINTMSK register.
  - GINAKEFFM = 0 in the OTG\_FS\_GINTMSK register
5. Whenever the application is ready to exit the Global OUT NAK mode, it must clear the SGONAK bit in OTG\_FS\_DCTL. This also clears the GONAKEFF interrupt (OTG\_FS\_GINTSTS).
  - OTG\_FS\_DCTL = 1 in CGONAK
6. If the application has masked this interrupt earlier, it must be unmasked as follows:
  - GINAKEFFM = 1 in GINTMSK

- **Disabling an OUT endpoint**

The application must use this sequence to disable an OUT endpoint that it has enabled.

Application programming sequence:

1. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core.
  - SGONAK = 1 in OTG\_FS\_DCTL
2. Wait for the GONAKEFF interrupt (OTG\_FS\_GINTSTS)
3. Disable the required OUT endpoint by programming the following fields:
  - EPDIS = 1 in OTG\_FS\_DOEPCTLx
  - SNAK = 1 in OTG\_FS\_DOEPCTLx
4. Wait for the EPDISD interrupt (OTG\_FS\_DOEPINTx), which indicates that the OUT endpoint is completely disabled. When the EPDISD interrupt is asserted, the core also clears the following bits:
  - EPDIS = 0 in OTG\_FS\_DOEPCTLx
  - EPENA = 0 in OTG\_FS\_DOEPCTLx
5. The application must clear the Global OUT NAK bit to start receiving data from other non-disabled OUT endpoints.
  - SGONAK = 0 in OTG\_FS\_DCTL

- **Generic non-isochronous OUT data transfers**

This section describes a regular non-isochronous OUT data transfer (control, bulk, or interrupt).

Application requirements:

1. Before setting up an OUT transfer, the application must allocate a buffer in the memory to accommodate all data to be received as part of the OUT transfer.
2. For OUT transfers, the transfer size field in the endpoint's transfer size register must be a multiple of the maximum packet size of the endpoint, adjusted to the Word boundary.
  - transfer size[EPNUM] =  $n \times (\text{MPSIZ}[EPNUM] + 4 - (\text{MPSIZ}[EPNUM] \bmod 4))$
  - packet count[EPNUM] =  $n$
  - $n > 0$
3. On any OUT endpoint interrupt, the application must read the endpoint's transfer size register to calculate the size of the payload in the memory. The received payload size can be less than the programmed transfer size.
  - Payload size in memory = application programmed initial transfer size – core updated final transfer size
  - Number of USB packets in which this payload was received = application programmed initial packet count – core updated final packet count

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers, clear the NAK bit, and enable the endpoint to receive the data.
2. Once the NAK bit is cleared, the core starts receiving data and writes it to the receive FIFO, as long as there is space in the receive FIFO. For every data packet received on the USB, the data packet and its status are written to the receive FIFO. Every packet (maximum packet size or short packet) written to the receive FIFO decrements the packet count field for that endpoint by 1.
  - OUT data packets received with bad data CRC are flushed from the receive FIFO automatically.
  - After sending an ACK for the packet on the USB, the core discards non-isochronous OUT data packets that the host, which cannot detect the ACK, resends. The application does not detect multiple back-to-back data OUT packets on the same endpoint with the same data PID. In this case the packet count is not decremented.
  - If there is no space in the receive FIFO, isochronous or non-isochronous data packets are ignored and not written to the receive FIFO. Additionally, non-isochronous OUT tokens receive a NAK handshake reply.
  - In all the above three cases, the packet count is not decremented because no data are written to the receive FIFO.
3. When the packet count becomes 0 or when a short packet is received on the endpoint, the NAK bit for that endpoint is set. Once the NAK bit is set, the isochronous or non-isochronous data packets are ignored and not written to the receive FIFO, and non-isochronous OUT tokens receive a NAK handshake reply.
4. After the data are written to the receive FIFO, the application reads the data from the receive FIFO and writes it to external memory, one packet at a time per endpoint.
5. At the end of every packet write on the AHB to external memory, the transfer size for the endpoint is decremented by the size of the written packet.

6. The OUT data transfer completed pattern for an OUT endpoint is written to the receive FIFO on one of the following conditions:
  - The transfer size is 0 and the packet count is 0
  - The last OUT data packet written to the receive FIFO is a short packet ( $0 \leq$  packet size < maximum packet size)
7. When either the application pops this entry (OUT data transfer completed), a transfer completed interrupt is generated for the endpoint and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG\_FS\_DOEPTSIZx register for the transfer size and the corresponding packet count.
2. Program the OTG\_FS\_DOEPCTLx register with the endpoint characteristics, and set the EPENA and CNAK bits.
  - EPENA = 1 in OTG\_FS\_DOEPCTLx
  - CNAK = 1 in OTG\_FS\_DOEPCTLx
3. Wait for the RXFLVL interrupt (in OTG\_FS\_GINTSTS) and empty the data packets from the receive FIFO.
  - This step can be repeated many times, depending on the transfer size.
4. Asserting the XFRC interrupt (OTG\_FS\_DOEPINTx) marks a successful completion of the non-isochronous OUT data transfer.
5. Read the OTG\_FS\_DOEPTSIZx register to determine the size of the received data payload.

- **Generic isochronous OUT data transfer**

This section describes a regular isochronous OUT data transfer.

Application requirements:

1. All the application requirements for non-isochronous OUT data transfers also apply to isochronous OUT data transfers.
2. For isochronous OUT data transfers, the transfer size and packet count fields must always be set to the number of maximum-packet-size packets that can be received in a single frame and no more. Isochronous OUT data transfers cannot span more than 1 frame.
3. The application must read all isochronous OUT data packets from the receive FIFO (data and status) before the end of the periodic frame (EOPF interrupt in OTG\_FS\_GINTSTS).
4. To receive data in the following frame, an isochronous OUT endpoint must be enabled after the EOPF (OTG\_FS\_GINTSTS) and before the SOF (OTG\_FS\_GINTSTS).

Internal data flow:

1. The internal data flow for isochronous OUT endpoints is the same as that for non-isochronous OUT endpoints, but for a few differences.
2. When an isochronous OUT endpoint is enabled by setting the Endpoint Enable and clearing the NAK bits, the Even/Odd frame bit must also be set appropriately. The core receives data on an isochronous OUT endpoint in a particular frame only if the following condition is met:
  - EONUM (in OTG\_FS\_DOEPCTLx) = SOFFN[0] (in OTG\_FS\_DSTS)
3. When the application completely reads an isochronous OUT data packet (data and status) from the receive FIFO, the core updates the RXDPID field in

OTG\_FS\_DOEPTSIZx with the data PID of the last isochronous OUT data packet read from the receive FIFO.

Application programming sequence:

1. Program the OTG\_FS\_DOEPTSIZx register for the transfer size and the corresponding packet count
  2. Program the OTG\_FS\_DOEPCTLx register with the endpoint characteristics and set the Endpoint Enable, ClearNAK, and Even/Odd frame bits.
    - EPENA = 1
    - CNAK = 1
    - EONUM = (0: Even/1: Odd)
  3. Wait for the RXFLVL interrupt (in OTG\_FS\_GINTSTS) and empty the data packets from the receive FIFO
    - This step can be repeated many times, depending on the transfer size.
  4. The assertion of the XFRC interrupt (in OTG\_FS\_DOEPINTx) marks the completion of the isochronous OUT data transfer. This interrupt does not necessarily mean that the data in memory are good.
  5. This interrupt cannot always be detected for isochronous OUT transfers. Instead, the application can detect the IISOXXFRM interrupt in OTG\_FS\_GINTSTS.
  6. Read the OTG\_FS\_DOEPTSIZx register to determine the size of the received transfer and to determine the validity of the data received in the frame. The application must treat the data received in memory as valid only if one of the following conditions is met:
    - RXDPID = D0 (in OTG\_FS\_DOEPTSIZx) and the number of USB packets in which this payload was received = 1
    - RXDPID = D1 (in OTG\_FS\_DOEPTSIZx) and the number of USB packets in which this payload was received = 2
    - RXDPID = D2 (in OTG\_FS\_DOEPTSIZx) and the number of USB packets in which this payload was received = 3
 The number of USB packets in which this payload was received =
 Application programmed initial packet count – Core updated final packet count
 The application can discard invalid data packets.
- **Incomplete isochronous OUT data transfers**

This section describes the application programming sequence when isochronous OUT data packets are dropped inside the core.

Internal data flow:

1. For isochronous OUT endpoints, the XFRC interrupt (in OTG\_FS\_DOEPINTx) may not always be asserted. If the core drops isochronous OUT data packets, the application could fail to detect the XFRC interrupt (OTG\_FS\_DOEPINTx) under the following circumstances:
  - When the receive FIFO cannot accommodate the complete ISO OUT data packet, the core drops the received ISO OUT data
  - When the isochronous OUT data packet is received with CRC errors
  - When the isochronous OUT token received by the core is corrupted
  - When the application is very slow in reading the data from the receive FIFO
2. When the core detects an end of periodic frame before transfer completion to all isochronous OUT endpoints, it asserts the incomplete Isochronous OUT data interrupt

(IISOOXFRM in OTG\_FS\_GINTSTS), indicating that an XFRC interrupt (in OTG\_FS\_DOEPINTx) is not asserted on at least one of the isochronous OUT endpoints. At this point, the endpoint with the incomplete transfer remains enabled, but no active transfers remain in progress on this endpoint on the USB.

Application programming sequence:

1. Asserting the IISOOXFRM interrupt (OTG\_FS\_GINTSTS) indicates that in the current frame, at least one isochronous OUT endpoint has an incomplete transfer.
2. If this occurs because isochronous OUT data is not completely emptied from the endpoint, the application must ensure that the application empties all isochronous OUT data (data and status) from the receive FIFO before proceeding.
  - When all data are emptied from the receive FIFO, the application can detect the XFRC interrupt (OTG\_FS\_DOEPINTx). In this case, the application must re-enable the endpoint to receive isochronous OUT data in the next frame.
3. When it receives an IISOOXFRM interrupt (in OTG\_FS\_GINTSTS), the application must read the control registers of all isochronous OUT endpoints (OTG\_FS\_DOEPCTLx) to determine which endpoints had an incomplete transfer in the current microframe. An endpoint transfer is incomplete if both the following conditions are met:
  - EONUM bit (in OTG\_FS\_DOEPCTLx) = SOFFN[0] (in OTG\_FS\_DSTS)
  - EPENA = 1 (in OTG\_FS\_DOEPCTLx)
4. The previous step must be performed before the SOF interrupt (in OTG\_FS\_GINTSTS) is detected, to ensure that the current frame number is not changed.
5. For isochronous OUT endpoints with incomplete transfers, the application must discard the data in the memory and disable the endpoint by setting the EPDIS bit in OTG\_FS\_DOEPCTLx.
6. Wait for the EPDIS interrupt (in OTG\_FS\_DOEPINTx) and enable the endpoint to receive new data in the next frame.
  - Because the core can take some time to disable the endpoint, the application may not be able to receive the data in the next frame after receiving bad isochronous data.

- **Stalling a non-isochronous OUT endpoint**

This section describes how the application can stall a non-isochronous endpoint.

1. Put the core in the Global OUT NAK mode.
2. Disable the required endpoint
  - When disabling the endpoint, instead of setting the SNAK bit in OTG\_FS\_DOEPCTL, set STALL = 1 (in OTG\_FS\_DOEPCTL).  
The STALL bit always takes precedence over the NAK bit.
3. When the application is ready to end the STALL handshake for the endpoint, the STALL bit (in OTG\_FS\_DOEPCTLx) must be cleared.
4. If the application is setting or clearing a STALL for an endpoint due to a SetFeature.Endpoint Halt or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the Status stage transfer on the control endpoint.

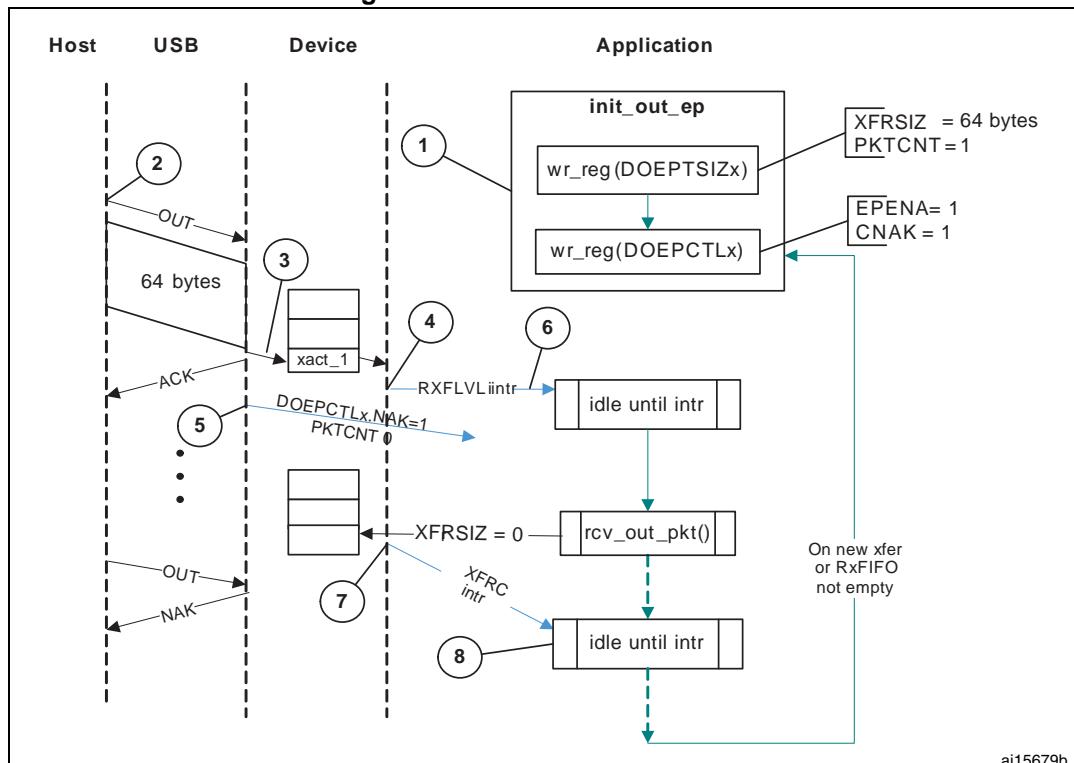
## Examples

This section describes and depicts some fundamental transfer types and scenarios.

- Bulk OUT transaction

*Figure 260* depicts the reception of a single Bulk OUT Data packet from the USB to the AHB and describes the events involved in the process.

**Figure 260. Bulk OUT transaction**



After a SetConfiguration/SetInterface command, the application initializes all OUT endpoints by setting CNAK = 1 and EPENA = 1 (in OTG\_FS\_DOEPCTLx), and setting a suitable XFRSIZ and PKTCNT in the OTG\_FS\_DOEPSIZx register.

1. host attempts to send data (OUT token) to an endpoint.
2. When the core receives the OUT token on the USB, it stores the packet in the RxFIFO because space is available there.
3. After writing the complete packet in the RxFIFO, the core then asserts the RXFLVL interrupt (in OTG\_FS\_GINTSTS).
4. On receiving the PKTCNT number of USB packets, the core internally sets the NAK bit for this endpoint to prevent it from receiving any more packets.
5. The application processes the interrupt and reads the data from the RxFIFO.
6. When the application has read all the data (equivalent to XFRSIZ), the core generates an XFRC interrupt (in OTG\_FS\_DOEPINTx).
7. The application processes the interrupt and uses the setting of the XFRC interrupt bit (in OTG\_FS\_DOEPINTx) to determine that the intended transfer is complete.

## IN data transfers

- **Packet write**

This section describes how the application writes data packets to the endpoint FIFO when dedicated transmit FIFOs are enabled.

1. The application can either choose the polling or the interrupt mode.
  - In polling mode, the application monitors the status of the endpoint transmit data FIFO by reading the OTG\_FS\_DTXFSTSx register, to determine if there is enough space in the data FIFO.
  - In interrupt mode, the application waits for the TXFE interrupt (in OTG\_FS\_DIEPINTx) and then reads the OTG\_FS\_DTXFSTSx register, to determine if there is enough space in the data FIFO.
  - To write a single non-zero length data packet, there must be space to write the entire packet in the data FIFO.
  - To write zero length packet, the application must not look at the FIFO space.
2. Using one of the above mentioned methods, when the application determines that there is enough space to write a transmit packet, the application must first write into the endpoint control register, before writing the data into the data FIFO. Typically, the application, must do a read modify write on the OTG\_FS\_DIEPCTLx register to avoid modifying the contents of the register, except for setting the Endpoint Enable bit.

The application can write multiple packets for the same endpoint into the transmit FIFO, if space is available. For periodic IN endpoints, the application must write packets only for one microframe. It can write packets for the next periodic transaction only after getting transfer complete for the previous transaction.

- **Setting IN endpoint NAK**

Internal data flow:

1. When the application sets the IN NAK for a particular endpoint, the core stops transmitting data on the endpoint, irrespective of data availability in the endpoint's transmit FIFO.
2. Non-isochronous IN tokens receive a NAK handshake reply
  - Isochronous IN tokens receive a zero-data-length packet reply
3. The core asserts the INEPNE (IN endpoint NAK effective) interrupt in OTG\_FS\_DIEPINTx in response to the SNAK bit in OTG\_FS\_DIEPCTLx.
4. Once this interrupt is seen by the application, the application can assume that the endpoint is in IN NAK mode. This interrupt can be cleared by the application by setting the CNAK bit in OTG\_FS\_DIEPCTLx.

Application programming sequence:

1. To stop transmitting any data on a particular IN endpoint, the application must set the IN NAK bit. To set this bit, the following field must be programmed.
    - SNAK = 1 in OTG\_FS\_DIEPCTLx
  2. Wait for assertion of the INEPNE interrupt in OTG\_FS\_DIEPINTx. This interrupt indicates that the core has stopped transmitting data on the endpoint.
  3. The core can transmit valid IN data on the endpoint after the application has set the NAK bit, but before the assertion of the NAK Effective interrupt.
  4. The application can mask this interrupt temporarily by writing to the INEPNEM bit in DIEPMSK.
    - INEPNEM = 0 in DIEPMSK
  5. To exit Endpoint NAK mode, the application must clear the NAK status bit (NAKSTS) in OTG\_FS\_DIEPCTLx. This also clears the INEPNE interrupt (in OTG\_FS\_DIEPINTx).
    - CNAK = 1 in OTG\_FS\_DIEPCTLx
  6. If the application masked this interrupt earlier, it must be unmasked as follows:
    - INEPNEM = 1 in DIEPMSK
- **IN endpoint disable**

Use the following sequence to disable a specific IN endpoint that has been previously enabled.

Application programming sequence:

1. The application must stop writing data on the AHB for the IN endpoint to be disabled.
2. The application must set the endpoint in NAK mode.
  - SNAK = 1 in OTG\_FS\_DIEPCTLx
3. Wait for the INEPNE interrupt in OTG\_FS\_DIEPINTx.
4. Set the following bits in the OTG\_FS\_DIEPCTLx register for the endpoint that must be disabled.
  - EPDIS = 1 in OTG\_FS\_DIEPCTLx
  - SNAK = 1 in OTG\_FS\_DIEPCTLx
5. Assertion of the EPDISD interrupt in OTG\_FS\_DIEPINTx indicates that the core has completely disabled the specified endpoint. Along with the assertion of the interrupt, the core also clears the following bits:
  - EPENA = 0 in OTG\_FS\_DIEPCTLx
  - EPDIS = 0 in OTG\_FS\_DIEPCTLx
6. The application must read the OTG\_FS\_DIEPTSIZx register for the periodic IN EP, to calculate how much data on the endpoint were transmitted on the USB.
7. The application must flush the data in the Endpoint transmit FIFO, by setting the following fields in the OTG\_FS\_GRSTCTL register:
  - TXFNUM (in OTG\_FS\_GRSTCTL) = Endpoint transmit FIFO number
  - TXFFLSH in (OTG\_FS\_GRSTCTL) = 1

The application must poll the OTG\_FS\_GRSTCTL register, until the TXFFLSH bit is cleared by the core, which indicates the end of flush operation. To transmit new data on this endpoint, the application can re-enable the endpoint at a later point.

- **Generic non-periodic IN data transfers**

Application requirements:

1. Before setting up an IN transfer, the application must ensure that all data to be transmitted as part of the IN transfer are part of a single buffer.
2. For IN transfers, the Transfer Size field in the Endpoint Transfer Size register denotes a payload that constitutes multiple maximum-packet-size packets and a single short packet. This short packet is transmitted at the end of the transfer.
  - To transmit a few maximum-packet-size packets and a short packet at the end of the transfer:  
 $\text{Transfer size[EPNUM]} = x \times \text{MPSIZ[EPNUM]} + \text{sp}$   
 If ( $\text{sp} > 0$ ), then  $\text{packet count[EPNUM]} = x + 1$ .  
 Otherwise,  $\text{packet count[EPNUM]} = x$
  - To transmit a single zero-length data packet:  
 $\text{Transfer size[EPNUM]} = 0$   
 $\text{Packet count[EPNUM]} = 1$
  - To transmit a few maximum-packet-size packets and a zero-length data packet at the end of the transfer, the application must split the transfer into two parts. The first sends maximum-packet-size data packets and the second sends the zero-length data packet alone.  
 First transfer:  $\text{transfer size[EPNUM]} = x \times \text{MPSIZ[epnum]}$ ;  $\text{packet count} = n$ ;  
 Second transfer:  $\text{transfer size[EPNUM]} = 0$ ;  $\text{packet count} = 1$ ;
3. Once an endpoint is enabled for data transfers, the core updates the Transfer size register. At the end of the IN transfer, the application must read the Transfer size register to determine how much data posted in the transmit FIFO have already been sent on the USB.
4. Data fetched into transmit FIFO = Application-programmed initial transfer size – core-updated final transfer size
  - Data transmitted on USB = (application-programmed initial packet count – Core updated final packet count)  $\times \text{MPSIZ[EPNUM]}$
  - Data yet to be transmitted on USB = (Application-programmed initial transfer size – data transmitted on USB)

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the transmit FIFO for the endpoint.
3. Every time a packet is written into the transmit FIFO by the application, the transfer size for that endpoint is decremented by the packet size. The data is fetched from the memory by the application, until the transfer size for the endpoint becomes 0. After writing the data into the FIFO, the “number of packets in FIFO” count is incremented (this is a 3-bit count, internally maintained by the core for each IN endpoint transmit FIFO. The maximum number of packets maintained by the core at any time in an IN endpoint FIFO is eight). For zero-length packets, a separate flag is set for each FIFO, without any data in the FIFO.
4. Once the data are written to the transmit FIFO, the core reads them out upon receiving an IN token. For every non-isochronous IN data packet transmitted with an ACK

- handshake, the packet count for the endpoint is decremented by one, until the packet count is zero. The packet count is not decremented on a timeout.
5. For zero length packets (indicated by an internal zero length flag), the core sends out a zero-length packet for the IN token and decrements the packet count field.
  6. If there are no data in the FIFO for a received IN token and the packet count field for that endpoint is zero, the core generates an “IN token received when TxFIFO is empty” (ITXF) Interrupt for the endpoint, provided that the endpoint NAK bit is not set. The core responds with a NAK handshake for non-isochronous endpoints on the USB.
  7. The core internally rewinds the FIFO pointers and no timeout interrupt is generated.
  8. When the transfer size is 0 and the packet count is 0, the transfer complete (XFRC) interrupt for the endpoint is generated and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG\_FS\_DIEPTSIZx register with the transfer size and corresponding packet count.
  2. Program the OTG\_FS\_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA (Endpoint Enable) bits.
  3. When transmitting non-zero length data packet, the application must poll the OTG\_FS\_DTXFSTSx register (where x is the FIFO number associated with that endpoint) to determine whether there is enough space in the data FIFO. The application can optionally use TXFE (in OTG\_FS\_DIEPINTx) before writing the data.
- **Generic periodic IN data transfers**

This section describes a typical periodic IN data transfer.

Application requirements:

1. Application requirements 1, 2, 3, and 4 of [Generic non-periodic IN data transfers on page 782](#) also apply to periodic IN data transfers, except for a slight modification of requirement 2.
  - The application can only transmit multiples of maximum-packet-size data packets or multiples of maximum-packet-size packets, plus a short packet at the end. To transmit a few maximum-packet-size packets and a short packet at the end of the transfer, the following conditions must be met:
 
$$\text{transfer size[EPNUM]} = x \times \text{MPSIZ[EPNUM]} + \text{sp}$$

(where  $x$  is an integer  $\geq 0$ , and  $0 \leq \text{sp} < \text{MPSIZ[EPNUM]}$ )

If ( $\text{sp} > 0$ ),  $\text{packet count[EPNUM]} = x + 1$   
 Otherwise,  $\text{packet count[EPNUM]} = x$ ;

$$\text{MCNT[EPNUM]} = \text{packet count[EPNUM]}$$
  - The application cannot transmit a zero-length data packet at the end of a transfer. It can transmit a single zero-length data packet by itself. To transmit a single zero-length data packet:
 
$$\text{transfer size[EPNUM]} = 0$$

$$\text{packet count[EPNUM]} = 1$$

$$\text{MCNT[EPNUM]} = \text{packet count[EPNUM]}$$

2. The application can only schedule data transfers one frame at a time.
  - $(MCNT - 1) \times MPSIZ \leq XFERSIZ \leq MCNT \times MPSIZ$
  - $PKTCNT = MCNT$  (in OTG\_FS\_DIEPTSIZx)
  - If  $XFERSIZ < MCNT \times MPSIZ$ , the last data packet of the transfer is a short packet.
  - Note that: MCNT is in OTG\_FS\_DIEPTSIZx, MPSIZ is in OTG\_FS\_DIEPCTLx, PKTCNT is in OTG\_FS\_DIEPTSIZx and XFERSIZ is in OTG\_FS\_DIEPTSIZx
3. The complete data to be transmitted in the frame must be written into the transmit FIFO by the application, before the IN token is received. Even when 1 Word of the data to be transmitted per frame is missing in the transmit FIFO when the IN token is received, the core behaves as when the FIFO is empty. When the transmit FIFO is empty:
  - A zero data length packet would be transmitted on the USB for isochronous IN endpoints
  - A NAK handshake would be transmitted on the USB for interrupt IN endpoints

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the associated transmit FIFO for the endpoint.
3. Every time the application writes a packet to the transmit FIFO, the transfer size for that endpoint is decremented by the packet size. The data are fetched from application memory until the transfer size for the endpoint becomes 0.
4. When an IN token is received for a periodic endpoint, the core transmits the data in the FIFO, if available. If the complete data payload (complete packet, in dedicated FIFO mode) for the frame is not present in the FIFO, then the core generates an IN token received when TxFIFO empty interrupt for the endpoint.
  - A zero-length data packet is transmitted on the USB for isochronous IN endpoints
  - A NAK handshake is transmitted on the USB for interrupt IN endpoints
5. The packet count for the endpoint is decremented by 1 under the following conditions:
  - For isochronous endpoints, when a zero- or non-zero-length data packet is transmitted
  - For interrupt endpoints, when an ACK handshake is transmitted
  - When the transfer size and packet count are both 0, the transfer completed interrupt for the endpoint is generated and the endpoint enable is cleared.
6. At the “Periodic frame Interval” (controlled by PFIVL in OTG\_FS\_DCFG), when the core finds non-empty any of the isochronous IN endpoint FIFOs scheduled for the current frame non-empty, the core generates an IISOIXFR interrupt in OTG\_FS\_GINTSTS.

Application programming sequence:

1. Program the OTG\_FS\_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA bits.
2. Write the data to be transmitted in the next frame to the transmit FIFO.
3. Asserting the ITTXFE interrupt (in OTG\_FS\_DIEPINTx) indicates that the application has not yet written all data to be transmitted to the transmit FIFO.
4. If the interrupt endpoint is already enabled when this interrupt is detected, ignore the interrupt. If it is not enabled, enable the endpoint so that the data can be transmitted on the next IN token attempt.
5. Asserting the XFRC interrupt (in OTG\_FS\_DIEPINTx) with no ITTXFE interrupt in OTG\_FS\_DIEPINTx indicates the successful completion of an isochronous IN transfer. A read to the OTG\_FS\_DIEPTSIz register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
6. Asserting the XFRC interrupt (in OTG\_FS\_DIEPINTx), with or without the ITTXFE interrupt (in OTG\_FS\_DIEPINTx), indicates the successful completion of an interrupt IN transfer. A read to the OTG\_FS\_DIEPTSIz register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
7. Asserting the incomplete isochronous IN transfer (IISOIXFR) interrupt in OTG\_FS\_GINTSTS with none of the aforementioned interrupts indicates the core did not receive at least 1 periodic IN token in the current frame.

- **Incomplete isochronous IN data transfers**

This section describes what the application must do on an incomplete isochronous IN data transfer.

Internal data flow:

1. An isochronous IN transfer is treated as incomplete in one of the following conditions:
  - a) The core receives a corrupted isochronous IN token on at least one isochronous IN endpoint. In this case, the application detects an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG\_FS\_GINTSTS).
  - b) The application is slow to write the complete data payload to the transmit FIFO and an IN token is received before the complete data payload is written to the FIFO. In this case, the application detects an IN token received when TxFIFO empty interrupt in OTG\_FS\_DIEPINTx. The application can ignore this interrupt, as it eventually results in an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG\_FS\_GINTSTS) at the end of periodic frame.  
The core transmits a zero-length data packet on the USB in response to the received IN token.
2. The application must stop writing the data payload to the transmit FIFO as soon as possible.
3. The application must set the NAK bit and the disable bit for the endpoint.
4. The core disables the endpoint, clears the disable bit, and asserts the Endpoint Disable interrupt for the endpoint.

**Application programming sequence:**

1. The application can ignore the IN token received when TxFIFO empty interrupt in OTG\_FS\_DIEPINTx on any isochronous IN endpoint, as it eventually results in an incomplete isochronous IN transfer interrupt (in OTG\_FS\_GINTSTS).
  2. Assertion of the incomplete isochronous IN transfer interrupt (in OTG\_FS\_GINTSTS) indicates an incomplete isochronous IN transfer on at least one of the isochronous IN endpoints.
  3. The application must read the Endpoint Control register for all isochronous IN endpoints to detect endpoints with incomplete IN data transfers.
  4. The application must stop writing data to the Periodic Transmit FIFOs associated with these endpoints on the AHB.
  5. Program the following fields in the OTG\_FS\_DIEPCTLx register to disable the endpoint:
    - SNAK = 1 in OTG\_FS\_DIEPCTLx
    - EPDIS = 1 in OTG\_FS\_DIEPCTLx
  6. The assertion of the Endpoint Disabled interrupt in OTG\_FS\_DIEPINTx indicates that the core has disabled the endpoint.
    - At this point, the application must flush the data in the associated transmit FIFO or overwrite the existing data in the FIFO by enabling the endpoint for a new transfer in the next microframe. To flush the data, the application must use the OTG\_FS\_GRSTCTL register.
- **Stalling non-isochronous IN endpoints**

This section describes how the application can stall a non-isochronous endpoint.

**Application programming sequence:**

1. Disable the IN endpoint to be stalled. Set the STALL bit as well.
2. EPDIS = 1 in OTG\_FS\_DIEPCTLx, when the endpoint is already enabled
  - STALL = 1 in OTG\_FS\_DIEPCTLx
  - The STALL bit always takes precedence over the NAK bit
3. Assertion of the Endpoint Disabled interrupt (in OTG\_FS\_DIEPINTx) indicates to the application that the core has disabled the specified endpoint.
4. The application must flush the non-periodic or periodic transmit FIFO, depending on the endpoint type. In case of a non-periodic endpoint, the application must re-enable the other non-periodic endpoints that do not need to be stalled, to transmit data.
5. Whenever the application is ready to end the STALL handshake for the endpoint, the STALL bit must be cleared in OTG\_FS\_DIEPCTLx.
6. If the application sets or clears a STALL bit for an endpoint due to a SetFeature.Endpoint Halt command or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the Status stage transfer on the control endpoint.

**Special case: stalling the control OUT endpoint**

The core must stall IN/OUT tokens if, during the data stage of a control transfer, the host sends more IN/OUT tokens than are specified in the SETUP packet. In this case, the application must enable the ITTXFE interrupt in OTG\_FS\_DIEPINTx and the OTEPDIS interrupt in OTG\_FS\_DOEPINTx during the data stage of the control transfer, after the core has transferred the amount of data specified in the SETUP packet. Then, when the

application receives this interrupt, it must set the STALL bit in the corresponding endpoint control register, and clear this interrupt.

### 22.17.7 Worst case response time

When the OTG\_FS controller acts as a device, there is a worst case response time for any tokens that follow an isochronous OUT. This worst case response time depends on the AHB clock frequency.

The core registers are in the AHB domain, and the core does not accept another token before updating these register values. The worst case is for any token following an isochronous OUT, because for an isochronous transaction, there is no handshake and the next token could come sooner. This worst case value is 7 PHY clocks when the AHB clock is the same as the PHY clock. When the AHB clock is faster, this value is smaller.

If this worst case condition occurs, the core responds to bulk/interrupt tokens with a NAK and drops isochronous and SETUP tokens. The host interprets this as a timeout condition for SETUP and retries the SETUP packet. For isochronous transfers, the Incomplete isochronous IN transfer interrupt (IISOIXFR) and Incomplete isochronous OUT transfer interrupt (IISOOXFR) inform the application that isochronous IN/OUT packets were dropped.

### Choosing the value of TRDT in OTG\_FS\_GUSBCFG

The value in TRDT (OTG\_FS\_GUSBCFG) is the time it takes for the MAC, in terms of PHY clocks after it has received an IN token, to get the FIFO status, and thus the first data from the PFC block. This time involves the synchronization delay between the PHY and AHB clocks. The worst case delay for this is when the AHB clock is the same as the PHY clock. In this case, the delay is 5 clocks.

Once the MAC receives an IN token, this information (token received) is synchronized to the AHB clock by the PFC (the PFC runs on the AHB clock). The PFC then reads the data from the SPRAM and writes them into the dual clock source buffer. The MAC then reads the data out of the source buffer (4 deep).

If the AHB is running at a higher frequency than the PHY, the application can use a smaller value for TRDT (in OTG\_FS\_GUSBCFG).

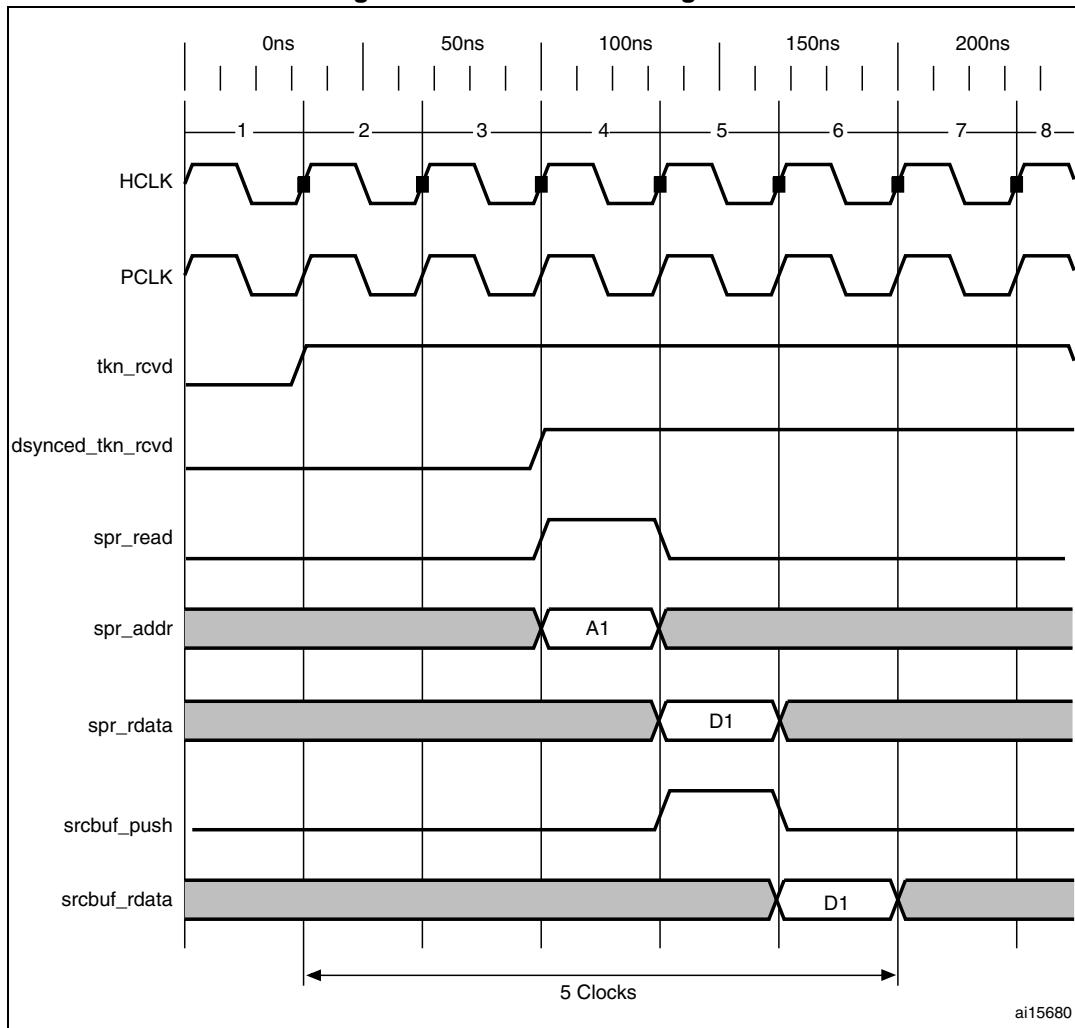
*Figure 261* has the following signals:

- tkn\_rcvd: Token received information from MAC to PFC
- dyned\_tkn\_rcvd: Doubled sync tkn\_rcvd, from PCLK to HCLK domain
- spr\_read: Read to SPRAM
- spr\_addr: Address to SPRAM
- spr\_rdata: Read data from SPRAM
- srcbuf\_push: Push to the source buffer
- srcbuf\_rdata: Read data from the source buffer. Data seen by MAC

The application can use the following formula to calculate the value of TRDT:

$$4 \times \text{AHB clock} + 1 \text{ PHY clock} = (2 \text{ clock sync} + 1 \text{ clock memory address} + 1 \text{ clock memory data from sync RAM}) + (1 \text{ PHY clock (next PHY clock MAC can sample the 2 clock FIFO outputs)})$$

Figure 261. TRDT max timing case



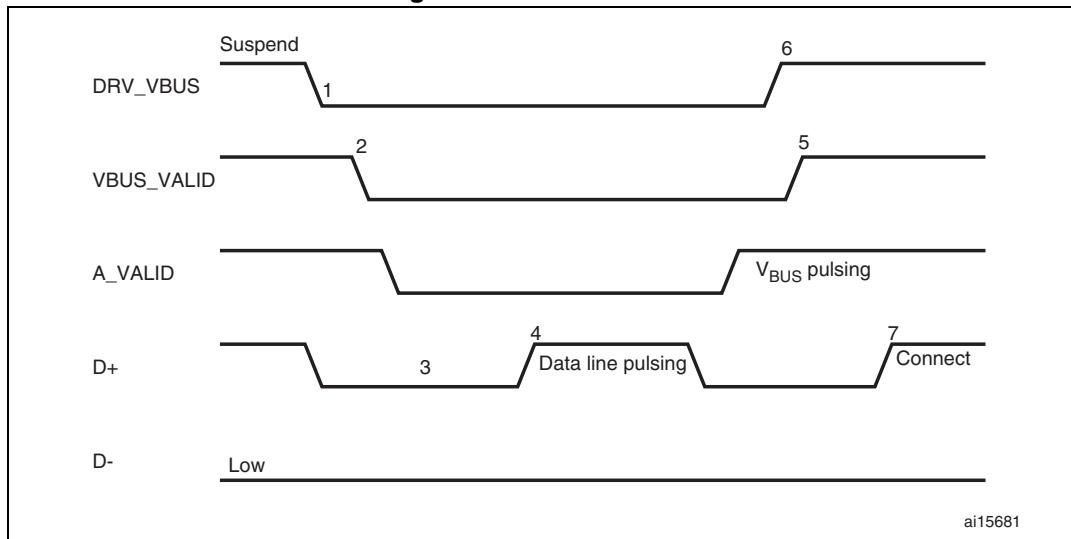
### 22.17.8 OTG programming model

The OTG\_FS controller is an OTG device supporting HNP and SRP. When the core is connected to an “A” plug, it is referred to as an A-device. When the core is connected to a “B” plug it is referred to as a B-device. In host mode, the OTG\_FS controller turns off V<sub>BUS</sub> to conserve power. SRP is a method by which the B-device signals the A-device to turn on V<sub>BUS</sub> power. A device must perform both data-line pulsing and V<sub>BUS</sub> pulsing, but a host can detect either data-line pulsing or V<sub>BUS</sub> pulsing for SRP. HNP is a method by which the B-device negotiates and switches to host role. In Negotiated mode after HNP, the B-device suspends the bus and reverts to the device role.

#### A-device session request protocol

The application must set the SRP-capable bit in the Core USB configuration register. This enables the OTG\_FS controller to detect SRP as an A-device.

Figure 262. A-device SRP

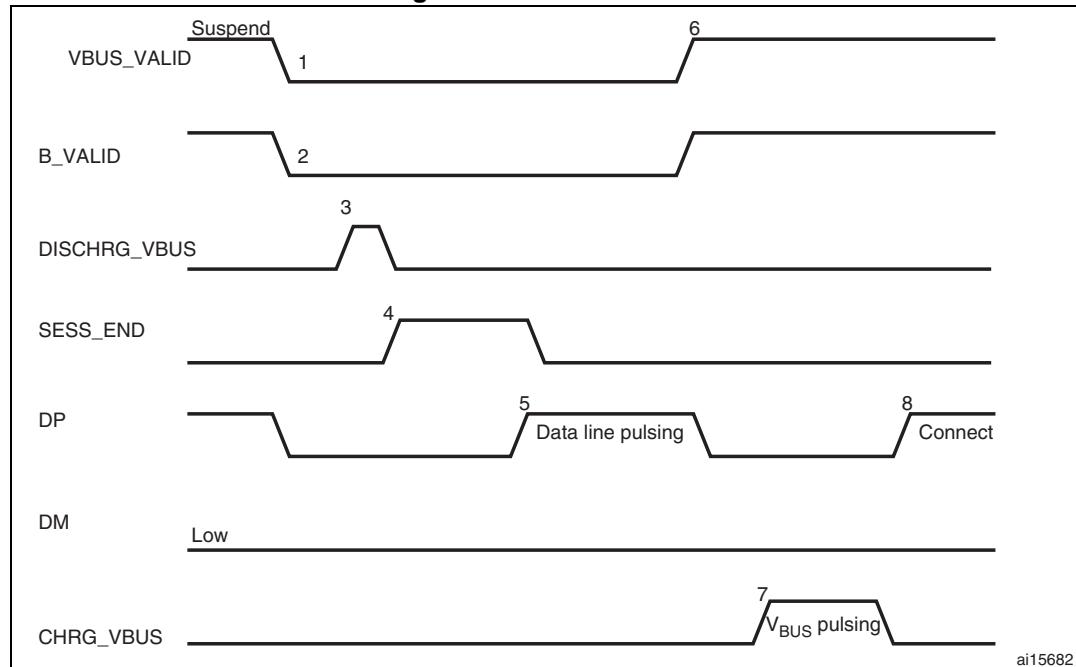


1.  $\text{DRV\_VBUS} = V_{\text{BUS}}$  drive signal to the PHY  
 $\text{VBU}_S\text{\_VALID} = V_{\text{BUS}}$  valid signal from PHY  
 $\text{A\_VALID}$  = A-peripheral  $V_{\text{BUS}}$  level signal to PHY  
 $D^+$  = Data plus line  
 $D^-$  = Data minus line
1. To save power, the application suspends and turns off port power when the bus is idle by writing the port suspend and port power bits in the host port control and status register.
  2. PHY indicates port power off by deasserting the  $\text{VBU}_S\text{\_VALID}$  signal.
  3. The device must detect SE0 for at least 2 ms to start SRP when  $V_{\text{BUS}}$  power is off.
  4. To initiate SRP, the device turns on its data line pull-up resistor for 5 to 10 ms. The OTG\_FS controller detects data-line pulsing.
  5. The device drives  $V_{\text{BUS}}$  above the A-device session valid (2.0 V minimum) for  $V_{\text{BUS}}$  pulsing.  
The OTG\_FS controller interrupts the application on detecting SRP. The Session request detected bit is set in Global interrupt status register (SRQINT set in OTG\_FS\_GINTSTS).
  6. The application must service the Session request detected interrupt and turn on the port power bit by writing the port power bit in the host port control and status register. The PHY indicates port power-on by asserting the  $\text{VBU}_S\text{\_VALID}$  signal.
  7. When the USB is powered, the device connects, completing the SRP process.

### B-device session request protocol

The application must set the SRP-capable bit in the Core USB configuration register. This enables the OTG\_FS controller to initiate SRP as a B-device. SRP is a means by which the OTG\_FS controller can request a new session from the host.

**Figure 263. B-device SRP**



1. **VBUS\_VALID =  $V_{BUS}$  valid signal from PHY**  
**B\_VALID = B-peripheral valid session to PHY**  
**DISCHRG\_VBUS = discharge signal to PHY**  
**SESS\_END = session end signal to PHY**  
**CHRG\_VBUS = charge  $V_{BUS}$  signal to PHY**  
**DP = Data plus line**  
**DM = Data minus line**
1. To save power, the host suspends and turns off port power when the bus is idle.  
The OTG\_FS controller sets the early suspend bit in the Core interrupt register after 3 ms of bus idleness. Following this, the OTG\_FS controller sets the USB suspend bit in the Core interrupt register.  
The OTG\_FS controller informs the PHY to discharge  $V_{BUS}$ .
2. The PHY indicates the session's end to the device. This is the initial condition for SRP.  
The OTG\_FS controller requires 2 ms of SE0 before initiating SRP.  
For a USB 1.1 full-speed serial transceiver, the application must wait until  $V_{BUS}$  discharges to 0.2 V after BSVLD (in OTG\_FS\_GOTGCTL) is deasserted. This

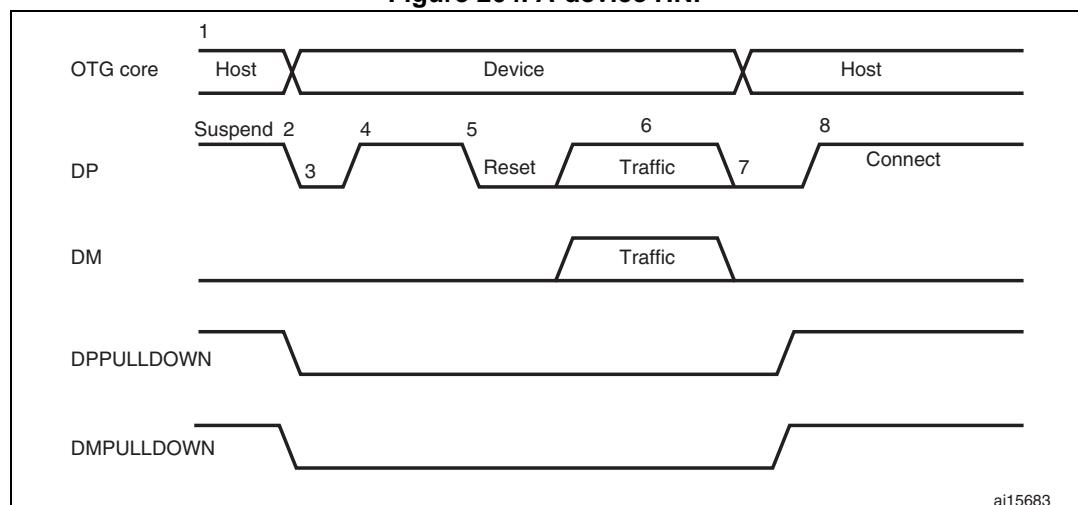
discharge time can be obtained from the transceiver vendor and varies from one transceiver to another.

3. The USB OTG core informs the PHY to speed up  $V_{BUS}$  discharge.
  4. The application initiates SRP by writing the session request bit in the OTG Control and status register. The OTG\_FS controller performs data-line pulsing followed by  $V_{BUS}$  pulsing.
  5. The host detects SRP from either the data-line or  $V_{BUS}$  pulsing, and turns on  $V_{BUS}$ . The PHY indicates  $V_{BUS}$  power-on to the device.
  6. The OTG\_FS controller performs  $V_{BUS}$  pulsing.
- The host starts a new session by turning on  $V_{BUS}$ , indicating SRP success. The OTG\_FS controller interrupts the application by setting the session request success status change bit in the OTG interrupt status register. The application reads the session request success bit in the OTG control and status register.
7. When the USB is powered, the OTG\_FS controller connects, completing the SRP process.

#### A-device host negotiation protocol

HNP switches the USB host role from the A-device to the B-device. The application must set the HNP-capable bit in the Core USB configuration register to enable the OTG\_FS controller to perform HNP as an A-device.

**Figure 264. A-device HNP**



1. DPPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DP line inside the PHY.  
DMPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DM line inside the PHY.
1. The OTG\_FS controller sends the B-device a SetFeature b\_hnp\_enable descriptor to enable HNP support. The B-device's ACK response indicates that the B-device supports HNP. The application must set host Set HNP Enable bit in the OTG Control

and status register to indicate to the OTG\_FS controller that the B-device supports HNP.

2. When it has finished using the bus, the application suspends by writing the Port suspend bit in the host port control and status register.
3. When the B-device observes a USB suspend, it disconnects, indicating the initial condition for HNP. The B-device initiates HNP only when it must switch to the host role; otherwise, the bus continues to be suspended.

The OTG\_FS controller sets the host negotiation detected interrupt in the OTG interrupt status register, indicating the start of HNP.

The OTG\_FS controller deasserts the DM pull down and DM pull up in the PHY to indicate a device role. The PHY enables the OTG\_FS\_DP pull-up resistor to indicate a connect for B-device.

The application must read the current mode bit in the OTG Control and status register to determine device mode operation.

4. The B-device detects the connection, issues a USB reset, and enumerates the OTG\_FS controller for data traffic.
5. The B-device continues the host role, initiating traffic, and suspends the bus when done.

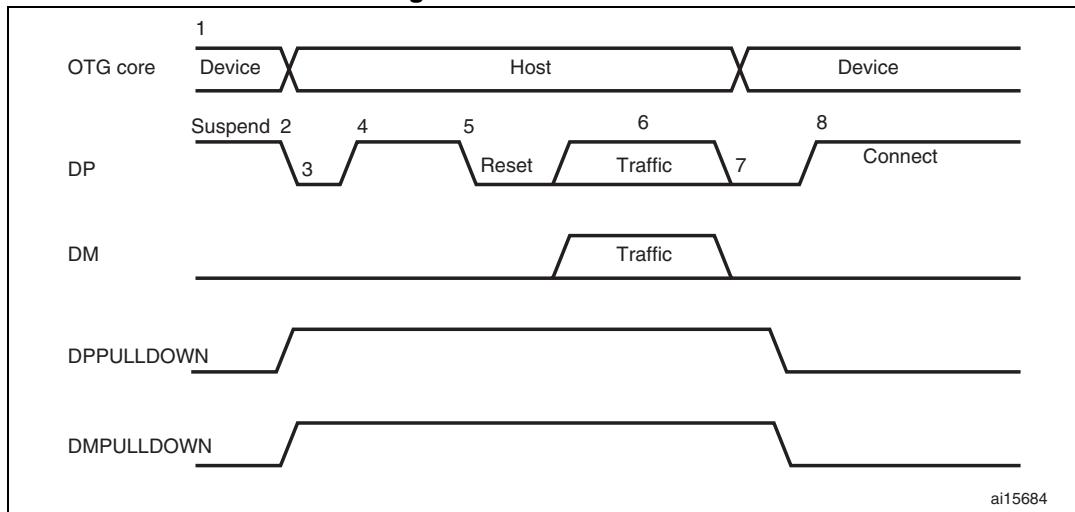
The OTG\_FS controller sets the early suspend bit in the Core interrupt register after 3 ms of bus idleness. Following this, the OTG\_FS controller sets the USB Suspend bit in the Core interrupt register.

6. In Negotiated mode, the OTG\_FS controller detects the suspend, disconnects, and switches back to the host role. The OTG\_FS controller asserts the DM pull down and DM pull up in the PHY to indicate its assumption of the host role.
7. The OTG\_FS controller sets the Connector ID status change interrupt in the OTG Interrupt Status register. The application must read the connector ID status in the OTG Control and Status register to determine the OTG\_FS controller operation as an A-device. This indicates the completion of HNP to the application. The application must read the Current mode bit in the OTG control and status register to determine host mode operation.
8. The B-device connects, completing the HNP process.

### B-device host negotiation protocol

HNP switches the USB host role from B-device to A-device. The application must set the HNP-capable bit in the Core USB configuration register to enable the OTG\_FS controller to perform HNP as a B-device.

Figure 265. B-device HNP



1. DPPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DP line inside the PHY.  
DMPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DM line inside the PHY.
1. The A-device sends the SetFeature b\_hnp\_enable descriptor to enable HNP support. The OTG\_FS controller's ACK response indicates that it supports HNP. The application must set the device HNP enable bit in the OTG Control and status register to indicate HNP support.  
The application sets the HNP request bit in the OTG Control and status register to indicate to the OTG\_FS controller to initiate HNP.
2. When it has finished using the bus, the A-device suspends by writing the Port suspend bit in the host port control and status register.  
The OTG\_FS controller sets the Early suspend bit in the Core interrupt register after 3 ms of bus idleness. Following this, the OTG\_FS controller sets the USB suspend bit in the Core interrupt register.  
The OTG\_FS controller disconnects and the A-device detects SE0 on the bus, indicating HNP. The OTG\_FS controller asserts the DP pull down and DM pull down in the PHY to indicate its assumption of the host role.  
The A-device responds by activating its OTG\_FS\_DP pull-up resistor within 3 ms of detecting SE0. The OTG\_FS controller detects this as a connect.  
The OTG\_FS controller sets the host negotiation success status change interrupt in the OTG Interrupt status register, indicating the HNP status. The application must read the host negotiation success bit in the OTG Control and status register to determine host

negotiation success. The application must read the current Mode bit in the Core interrupt register (OTG\_FS\_GINTSTS) to determine host mode operation.

3. The application sets the reset bit (PRST in OTG\_FS\_HPRT) and the OTG\_FS controller issues a USB reset and enumerates the A-device for data traffic.
4. The OTG\_FS controller continues the host role of initiating traffic, and when done, suspends the bus by writing the Port suspend bit in the host port control and status register.
5. In Negotiated mode, when the A-device detects a suspend, it disconnects and switches back to the host role. The OTG\_FS controller deasserts the DP pull down and DM pull down in the PHY to indicate the assumption of the device role.
6. The application must read the current mode bit in the Core interrupt (OTG\_FS\_GINTSTS) register to determine the host mode operation.
7. The OTG\_FS controller connects, completing the HNP process.

## 23 Debug support (DBG)

### 23.1 Overview

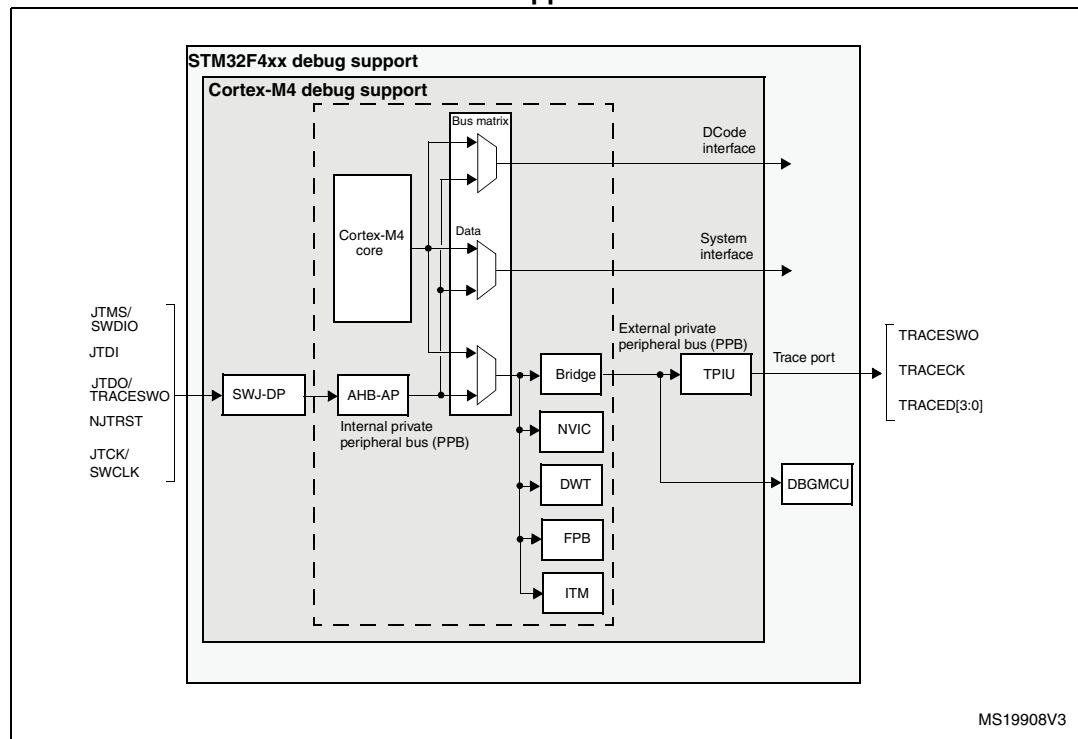
The STM32F401xB/C and STM32F401xD/E are built around a Cortex™-M4 with FPU core which contains hardware extensions for advanced debugging features. The debug extensions allow the core to be stopped either on a given instruction fetch (breakpoint) or data access (watchpoint). When stopped, the core's internal state and the system's external state may be examined. Once examination is complete, the core and the system may be restored and program execution resumed.

The debug features are used by the debugger host when connecting to and debugging the STM32F401xB/C and STM32F401xD/E MCUs.

Two interfaces for debug are available:

- Serial wire
- JTAG debug port

**Figure 266. Block diagram of STM32 MCU and Cortex™-M4 with FPU-level debug support**



Note:

*The debug features embedded in the Cortex™-M4 with FPU core are a subset of the ARM CoreSight Design Kit.*

The ARM Cortex™-M4 with FPU core provides integrated on-chip debug support. It is comprised of:

- SWJ-DP: Serial wire / JTAG debug port
- AHP-AP: AHB access port
- ITM: Instrumentation trace macrocell
- FPB: Flash patch breakpoint
- DWT: Data watchpoint trigger
- TPUI: Trace port unit interface (available on larger packages, where the corresponding pins are mapped)
- ETM: Embedded Trace Macrocell (available on larger packages, where the corresponding pins are mapped)

It also includes debug features dedicated to the STM32F401xB/C and STM32F401xD/E:

- Flexible debug pinout assignment
- MCU debug box (support for low-power modes, control over peripheral clocks, etc.)

**Note:**

*For further information on debug functionality supported by the ARM Cortex™-M4 with FPU core, refer to the Cortex™-M4 with FPU-r0p1 Technical Reference Manual and to the CoreSight Design Kit-r0p1 TRM (see [Section 23.2: Reference ARM documentation](#)).*

## 23.2 Reference ARM documentation

- Cortex™-M4 with FPU r0p1 Technical Reference Manual (TRM)  
(see Related documents on page 1)
- ARM Debug Interface V5
- ARM CoreSight Design Kit revision r0p1 Technical Reference Manual

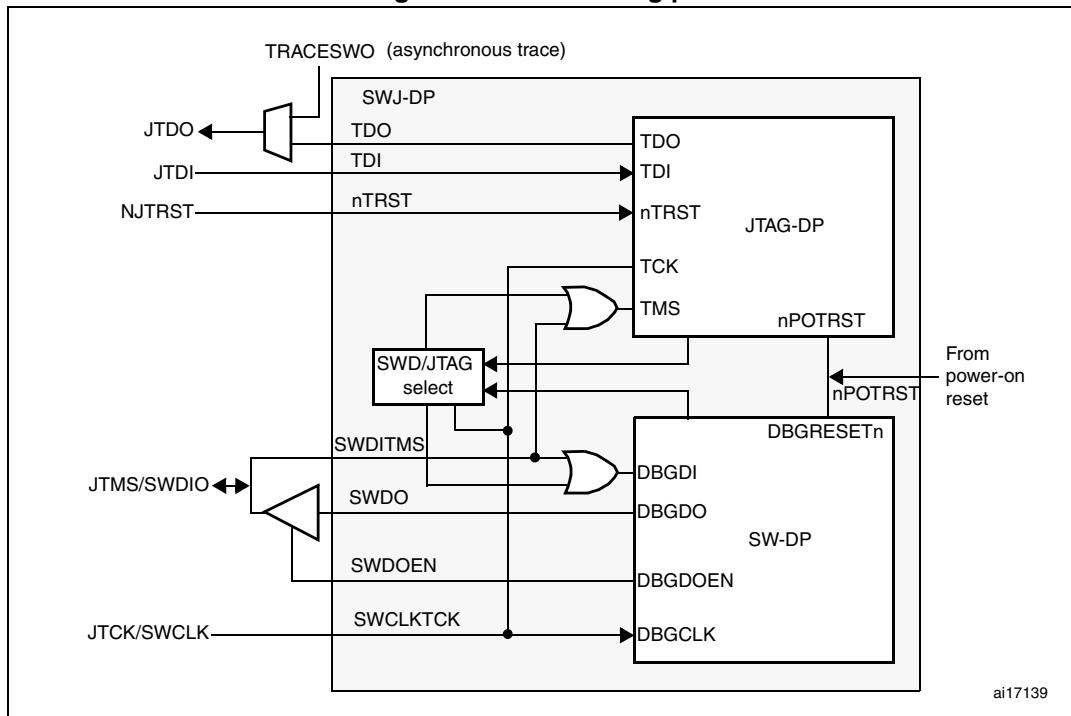
## 23.3 SWJ debug port (serial wire and JTAG)

The core of the STM32F401xB/C and STM32F401xD/E integrates the Serial Wire / JTAG Debug Port (SWJ-DP). It is an ARM standard CoreSight debug port that combines a JTAG-DP (5-pin) interface and a SW-DP (2-pin) interface.

- The JTAG Debug Port (JTAG-DP) provides a 5-pin standard JTAG interface to the AHP-AP port.
- The Serial Wire Debug Port (SW-DP) provides a 2-pin (clock + data) interface to the AHP-AP port.

In the SWJ-DP, the two JTAG pins of the SW-DP are multiplexed with some of the five JTAG pins of the JTAG-DP.

Figure 267. SWJ debug port



*Figure 267* shows that the asynchronous TRACE output (TRACESWO) is multiplexed with TDO. This means that the asynchronous trace can only be used with SW-DP, not JTAG-DP.

### 23.3.1 Mechanism to select the JTAG-DP or the SW-DP

By default, the JTAG-Debug Port is active.

If the debugger host wants to switch to the SW-DP, it must provide a dedicated JTAG sequence on TMS/TCK (respectively mapped to SWDIO and SWCLK) which disables the JTAG-DP and enables the SW-DP. This way it is possible to activate the SWDP using only the SWCLK and SWDIO pins.

This sequence is:

1. Send more than 50 TCK cycles with TMS (SWDIO) =1
2. Send the 16-bit sequence on TMS (SWDIO) = 0111100111100111 (MSB transmitted first)
3. Send more than 50 TCK cycles with TMS (SWDIO) =1

## 23.4 Pinout and debug port pins

The STM32F401xB/C and STM32F401xD/E MCUs are available in various packages with different numbers of available pins. As a result, some functionality (ETM) related to pin availability may differ between packages.

### 23.4.1 SWJ debug port pins

Five pins are used as outputs from the STM32F401xB/C and STM32F401xD/E for the SWJ-DP as *alternate functions* of general-purpose I/Os. These pins are available on all packages.

**Table 132. SWJ debug port pins**

SWJ-DP pin name	JTAG debug port		SW debug port		Pin assignment
	Type	Description	Type	Debug assignment	
JTMS/SWDIO	I	JTAG Test Mode Selection	IO	Serial Wire Data Input/Output	PA13
JTCK/SWCLK	I	JTAG Test Clock	I	Serial Wire Clock	PA14
JTDI	I	JTAG Test Data Input	-	-	PA15
JTDO/TRACESWO	O	JTAG Test Data Output	-	TRACESWO if async trace is enabled	PB3
NJTRST	I	JTAG Test nReset	-	-	PB4

### 23.4.2 Flexible SWJ-DP pin assignment

After RESET (SYSRESETn or PORESETn), all five pins used for the SWJ-DP are assigned as dedicated pins immediately usable by the debugger host (note that the trace outputs are not assigned except if explicitly programmed by the debugger host).

However, the STM32F401xB/C and STM32F401xD/E MCUs offer the possibility of disabling some or all of the SWJ-DP ports and so, of releasing the associated pins for general-purpose IO (GPIO) usage. For more details on how to disable SWJ-DP port pins, please refer to [Section 8.3.2: I/O pin multiplexer and mapping](#).

**Table 133. Flexible SWJ-DP pin assignment**

Available debug ports	SWJ IO pin assigned				
	PA13 / JTMS / SWDIO	PA14 / JTCK / SWCLK	PA15 / JTDI	PB3 / JTDO	PB4 / NJTRST
Full SWJ (JTAG-DP + SW-DP) - Reset State	X	X	X	X	X
Full SWJ (JTAG-DP + SW-DP) but without NJTRST	X	X	X	X	
JTAG-DP Disabled and SW-DP Enabled	X	X			
JTAG-DP Disabled and SW-DP Disabled					Released

**Note:**

*When the APB bridge write buffer is full, it takes one extra APB cycle when writing the GPIO\_AFR register. This is because the deactivation of the JTAGSW pins is done in two cycles to guarantee a clean level on the nTRST and TCK input signals of the core.*

- Cycle 1: the JTAGSW input signals to the core are tied to 1 or 0 (to 1 for nTRST, TDI and TMS, to 0 for TCK)
- Cycle 2: the GPIO controller takes the control signals of the SWJTAG IO pins (like controls of direction, pull-up/down, Schmitt trigger activation, etc.).

### 23.4.3 Internal pull-up and pull-down on JTAG pins

It is necessary to ensure that the JTAG input pins are not floating since they are directly connected to flip-flops to control the debug mode features. Special care must be taken with the SWCLK/TCK pin which is directly connected to the clock of some of these flip-flops.

To avoid any uncontrolled IO levels, the device embeds internal pull-ups and pull-downs on the JTAG input pins:

NJTRST: Internal pull-up  
JTDI: Internal pull-up  
JTMS/SWDIO: Internal pull-up  
TCK/SWCLK: Internal pull-down  
Once a JTAG IO is released by the user software, the GPIO controller takes control again. The reset states of the GPIO control registers put the I/Os in the equivalent state:

- NJTRST: AF input pull-up
- JTDI: AF input pull-up
- JTMS/SWDIO: AF input pull-up
- JTCK/SWCLK: AF input pull-down
- JTDO: AF output floating

The software can then use these I/Os as standard GPIOs.

Note:

*The JTAG IEEE standard recommends to add pull-ups on TDI, TMS and nTRST but there is no special recommendation for TCK. However, for JTCK, the device needs an integrated pull-down.*

*Having embedded pull-ups and pull-downs removes the need to add external resistors.*

### 23.4.4 Using serial wire and releasing the unused debug pins as GPIOs

To use the serial wire DP to release some GPIOs, the user software must change the GPIO (PA15, PB3 and PB4) configuration mode in the GPIO\_MODER register. This releases PA15, PB3 and PB4 which now become available as GPIOs.

When debugging, the host performs the following actions:

- Under system reset, all SWJ pins are assigned (JTAG-DP + SW-DP).
- Under system reset, the debugger host sends the JTAG sequence to switch from the JTAG-DP to the SW-DP.
- Still under system reset, the debugger sets a breakpoint on vector reset.
- The system reset is released and the Core halts.
- All the debug communications from this point are done using the SW-DP. The other JTAG pins can then be reassigned as GPIOs by the user software.

*Note:* For user software designs, note that:

*To release the debug pins, remember that they will be first configured either in input-pull-up ( $nTRST$ ,  $TMS$ ,  $TDI$ ) or pull-down ( $TCK$ ) or output tristate ( $TDO$ ) for a certain duration after reset until the instant when the user software releases the pins.*

*When debug pins (JTAG or SW or TRACE) are mapped, changing the corresponding IO pin configuration in the IOPORT controller has no effect.*

## 23.5 STM32F401xB/C and STM32F401xD/E JTAG TAP connection

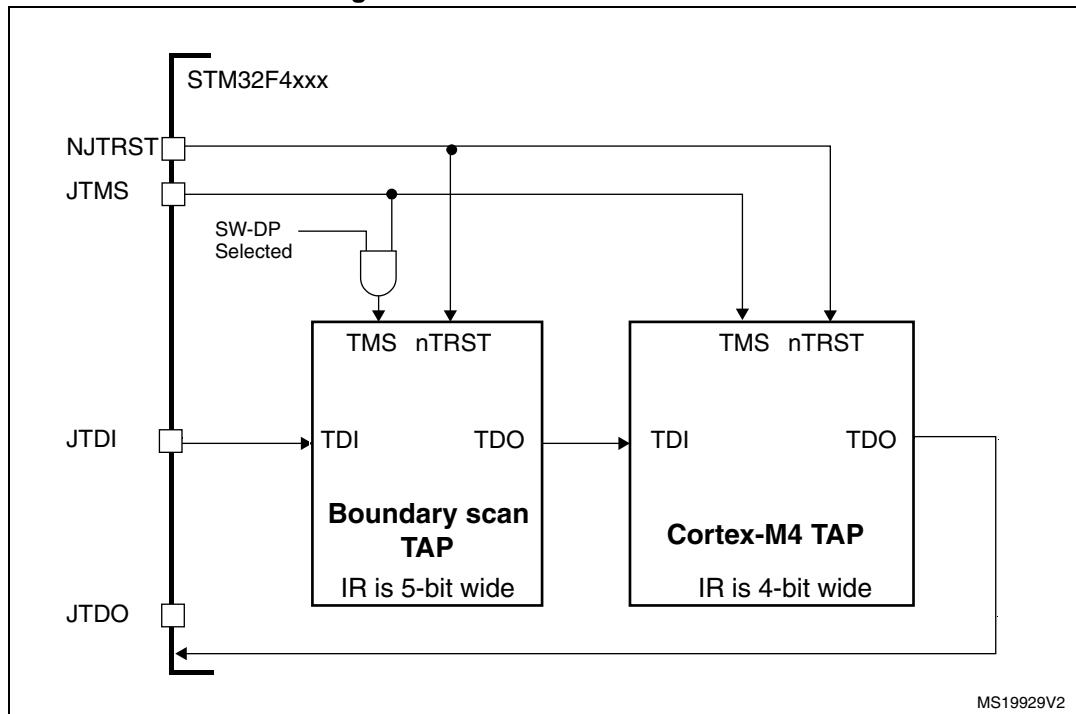
The STM32F401xB/C and STM32F401xD/E MCUs integrate two serially connected JTAG TAPs, the boundary scan TAP (IR is 5-bit wide) and the Cortex™-M4 with FPU TAP (IR is 4-bit wide).

To access the TAP of the Cortex™-M4 with FPU for debug purposes:

1. First, it is necessary to shift the BYPASS instruction of the boundary scan TAP.
2. Then, for each IR shift, the scan chain contains 9 bits (=5+4) and the unused TAP instruction must be shifted in using the BYPASS instruction.
3. For each data shift, the unused TAP, which is in BYPASS mode, adds 1 extra data bit in the data scan chain.

*Note:* **Important:** Once Serial-Wire is selected using the dedicated ARM JTAG sequence, the boundary scan TAP is automatically disabled (JTMS forced high).

Figure 268. JTAG TAP connections



## 23.6 ID codes and locking mechanism

There are several ID codes inside the STM32F401xB/C and STM32F401xD/E MCUs. ST strongly recommends tools designers to lock their debuggers using the MCU DEVICE ID code located in the external PPB memory map at address 0xE0042000.

### 23.6.1 MCU device ID code

The STM32F401xB/C and STM32F401xD/E MCUs integrate an MCU ID code. This ID identifies the ST MCU part-number and the die revision. It is part of the DBG\_MCU component and is mapped on the external PPB bus (see [Section 23.16 on page 815](#)). This code is accessible using the JTAG debug port (4 to 5 pins) or the SW debug port (two pins) or by the user software. It is even accessible while the MCU is under system reset.

#### DBGMCU\_IDCODE

Address: 0xE004 2000

Only 32-bits access supported. Read-only.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REV_ID															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEV_ID															
Reserved				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **REV\_ID(15:0)**: Revision identifier

This field indicates the revision of the device:

0x1000 = Revision A

0x1007 = Revision 1

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DEV\_ID(11:0)**: Device identifier

The device ID is 0x423.

### 23.6.2 Boundary scan TAP

#### JTAG ID code

The TAP of the STM32F401xB/C and STM32F401xD/E BSC (boundary scan) integrates a JTAG ID code equal to 0x06413041

### 23.6.3 Cortex™-M4 with FPU TAP

The TAP of the ARM Cortex™-M4 with FPU integrates a JTAG ID code. This ID code is the ARM default one and has not been modified. This code is only accessible by the JTAG Debug Port.

This code is (corresponds to Cortex™-M4 with FPU r0p1, see [Section 23.2: Reference ARM documentation](#)).

Only the DEV\_ID(11:0) should be used for identification by the debugger/programmer tools.

### 23.6.4 Cortex™-M4 with FPU JEDEC-106 ID code

The ARM Cortex™-M4 with FPU integrates a JEDEC-106 ID code. It is located in the 4KB ROM table mapped on the internal PPB bus at address 0xE00FF000\_0xE00FFFFF.

This code is accessible by the JTAG Debug Port (4 to 5 pins) or by the SW Debug Port (two pins) or by the user software.

## 23.7 JTAG debug port

A standard JTAG state machine is implemented with a 4-bit instruction register (IR) and five data registers (for full details, refer to the Cortex™-M4 with FPU r0p1 Technical Reference Manual (TRM), for references, please see [Section 23.2: Reference ARM documentation](#)).

**Table 134. JTAG debug port data registers**

IR(3:0)	Data register	Details
1111	BYPASS [1 bit]	
1110	IDCODE [32 bits]	ID CODE 0x4BA00477 (ARM Cortex™-M4 with FPU r0p1 ID Code)
1010	DPACC [35 bits]	Debug port access register This initiates a debug port and allows access to a debug port register. – When transferring data IN: Bits 34:3 = DATA[31:0] = 32-bit data to transfer for a write request Bits 2:1 = A[3:2] = 2-bit address of a debug port register. Bit 0 = RnW = Read request (1) or write request (0). – When transferring data OUT: Bits 34:3 = DATA[31:0] = 32-bit data which is read following a read request Bits 2:0 = ACK[2:0] = 3-bit Acknowledge: 010 = OK/FAULT 001 = WAIT OTHER = reserved Refer to <a href="#">Table 135</a> for a description of the A(3:2) bits

Table 134. JTAG debug port data registers (continued)

IR(3:0)	Data register	Details
1011	APACC [35 bits]	<p>Access port access register</p> <p>Initiates an access port and allows access to an access port register.</p> <ul style="list-style-type: none"> <li>– When transferring data IN:           <ul style="list-style-type: none"> <li>Bits 34:3 = DATA[31:0] = 32-bit data to shift in for a write request</li> <li>Bits 2:1 = A[3:2] = 2-bit address (sub-address AP registers).</li> <li>Bit 0 = RnW= Read request (1) or write request (0).</li> </ul> </li> <li>– When transferring data OUT:           <ul style="list-style-type: none"> <li>Bits 34:3 = DATA[31:0] = 32-bit data which is read following a read request</li> <li>Bits 2:0 = ACK[2:0] = 3-bit Acknowledge:               <ul style="list-style-type: none"> <li>010 = OK/FAULT</li> <li>001 = WAIT</li> <li>OTHER = reserved</li> </ul> </li> </ul> </li> </ul> <p>There are many AP Registers (see AHB-AP) addressed as the combination of:</p> <ul style="list-style-type: none"> <li>– The shifted value A[3:2]</li> <li>– The current value of the DP SELECT register</li> </ul>
1000	ABORT [35 bits]	<p>Abort register</p> <ul style="list-style-type: none"> <li>– Bits 31:1 = Reserved</li> <li>– Bit 0 = DAPABORT: write 1 to generate a DAP abort.</li> </ul>

**Table 135. 32-bit debug port registers addressed through the shifted value A[3:2]**

Address	A(3:2) value	Description
0x0	00	Reserved, must be kept at reset value.
0x4	01	DP CTRL/STAT register. Used to: – Request a system or debug power-up – Configure the transfer operation for AP accesses – Control the pushed compare and pushed verify operations. – Read some status flags (overrun, power-up acknowledges)
0x8	10	DP SELECT register: Used to select the current access port and the active 4-words register window. – Bits 31:24: APSEL: select the current AP – Bits 23:8: reserved – Bits 7:4: APBANKSEL: select the active 4-words register window on the current AP – Bits 3:0: reserved
0xC	11	DP RDBUFF register: Used to allow the debugger to get the final result after a sequence of operations (without requesting new JTAG-DP operation)

## 23.8 SW debug port

### 23.8.1 SW protocol introduction

This synchronous serial protocol uses two pins:

- SWCLK: clock from host to target
- SWDIO: bidirectional

The protocol allows two banks of registers (DPACC registers and APACC registers) to be read and written to.

Bits are transferred LSB-first on the wire.

For SWDIO bidirectional management, the line must be pulled-up on the board (100 KΩ recommended by ARM).

Each time the direction of SWDIO changes in the protocol, a turnaround time is inserted where the line is not driven by the host nor the target. By default, this turnaround time is one bit time, however this can be adjusted by configuring the SWCLK frequency.

### 23.8.2 SW protocol sequence

Each sequence consist of three phases:

1. Packet request (8 bits) transmitted by the host
2. Acknowledge response (3 bits) transmitted by the target
3. Data transfer phase (33 bits) transmitted by the host or the target

**Table 136. Packet request (8-bits)**

Bit	Name	Description
0	Start	Must be “1”
1	APnDP	0: DP Access 1: AP Access
2	RnW	0: Write Request 1: Read Request
4:3	A(3:2)	Address field of the DP or AP registers (refer to <a href="#">Table 135</a> )
5	Parity	Single bit parity of preceding bits
6	Stop	0
7	Park	Not driven by the host. Must be read as “1” by the target because of the pull-up

Refer to the Cortex™-M4 with FPUr0p1 *TRM* for a detailed description of DPACC and APACC registers.

The packet request is always followed by the turnaround time (default 1 bit) where neither the host nor target drive the line.

**Table 137. ACK response (3 bits)**

Bit	Name	Description
0..2	ACK	001: FAULT 010: WAIT 100: OK

The ACK Response must be followed by a turnaround time only if it is a READ transaction or if a WAIT or FAULT acknowledge has been received.

**Table 138. DATA transfer (33 bits)**

Bit	Name	Description
0..31	WDATA or RDATA	Write or Read data
32	Parity	Single parity of the 32 data bits

The DATA transfer must be followed by a turnaround time only if it is a READ transaction.

### 23.8.3 SW-DP state machine (reset, idle states, ID code)

The State Machine of the SW-DP has an internal ID code which identifies the SW-DP. It follows the JEP-106 standard. This ID code is the default ARM one and is set to **0x2BA01477** (corresponding to Cortex™-M4 with FPU r0p1).

- Note:** Note that the SW-DP state machine is inactive until the target reads this ID code.
- The SW-DP state machine is in RESET STATE either after power-on reset, or after the DP has switched from JTAG to SWD or after the line is high for more than 50 cycles
  - The SW-DP state machine is in IDLE STATE if the line is low for at least two cycles after RESET state.
  - After RESET state, it is **mandatory** to first enter into an IDLE state AND to perform a READ access of the DP-SW ID CODE register. Otherwise, the target will issue a FAULT acknowledge response on another transactions.

Further details of the SW-DP state machine can be found in the *Cortex™-M4 with FPU r0p1 TRM* and the *CoreSight Design Kit r0p1 TRM*.

### 23.8.4 DP and AP read/write accesses

- Read accesses to the DP are not posted: the target response can be immediate (if ACK=OK) or can be delayed (if ACK=WAIT).
- Read accesses to the AP are posted. This means that the result of the access is returned on the next transfer. If the next access to be done is NOT an AP access, then the DP-RDBUFF register must be read to obtain the result.  
The READOK flag of the DP-CTRL/STAT register is updated on every AP read access or RDBUFF read request to know if the AP read access was successful.
- The SW-DP implements a write buffer (for both DP or AP writes), that enables it to accept a write operation even when other transactions are still outstanding. If the write buffer is full, the target acknowledge response is “WAIT”. With the exception of IDCODE read or CTRL/STAT read or ABORT write which are accepted even if the write buffer is full.
- Because of the asynchronous clock domains SWCLK and HCLK, two extra SWCLK cycles are needed after a write transaction (after the parity bit) to make the write effective internally. These cycles should be applied while driving the line low (IDLE state)  
This is particularly important when writing the CTRL/STAT for a power-up request. If the next transaction (requiring a power-up) occurs immediately, it will fail.

### 23.8.5 SW-DP registers

Access to these registers are initiated when APnDP=0

Table 139. SW-DP registers

A(3:2)	R/W	CTRLSEL bit of SELECT register	Register	Notes
00	Read		IDCODE	The manufacturer code is not set to ST code. <b>0x2BA01477</b> (identifies the SW-DP)
00	Write		ABORT	

**Table 139. SW-DP registers (continued)**

A(3:2)	R/W	CTRLSEL bit of SELECT register	Register	Notes
01	Read/Write	0	DP- CTRL/STAT	Purpose is to: – request a system or debug power-up – configure the transfer operation for AP accesses – control the pushed compare and pushed verify operations. – read some status flags (overrun, power- up acknowledges)
01	Read/Write	1	WIRE CONTROL	Purpose is to configure the physical serial port protocol (like the duration of the turnaround time)
10	Read		READ RESEND	Enables recovery of the read data from a corrupted debugger transfer, without repeating the original AP transfer.
10	Write		SELECT	The purpose is to select the current access port and the active 4-words register window
11	Read/Write		READ BUFFER	This read buffer is useful because AP accesses are posted (the result of a read AP request is available on the next AP transaction). This read buffer captures data from the AP, presented as the result of a previous read, without initiating a new transaction

### 23.8.6 SW-AP registers

Access to these registers are initiated when APnDP=1

There are many AP Registers (see AHB-AP) addressed as the combination of:

- The shifted value A[3:2]
- The current value of the DP SELECT register

## 23.9 AHB-AP (AHB access port) - valid for both JTAG-DP and SW-DP

### Features:

- System access is independent of the processor status.
- Either SW-DP or JTAG-DP accesses AHB-AP.
- The AHB-AP is an AHB master into the Bus Matrix. Consequently, it can access all the data buses (Dcode Bus, System Bus, internal and external PPB bus) but the ICode bus.
- Bitband transactions are supported.
- AHB-AP transactions bypass the FPB.

The address of the 32-bits AHP-AP registers are 6-bits wide (up to 64 words or 256 bytes) and consists of:

- c) Bits [7:4] = the bits [7:4] APBANKSEL of the DP SELECT register
- d) Bits [3:2] = the 2 address bits of A(3:2) of the 35-bit packet request for SW-DP.

The AHB-AP of the Cortex™-M4 with FPU includes 9 x 32-bits registers:

**Table 140. Cortex™-M4 with FPU AHB-AP registers**

Address offset	Register name	Notes
0x00	AHB-AP Control and Status Word	Configures and controls transfers through the AHB interface (size, hprot, status on current transfer, address increment type)
0x04	AHB-AP Transfer Address	
0x0C	AHB-AP Data Read/Write	
0x10	AHB-AP Banked Data 0	
0x14	AHB-AP Banked Data 1	
0x18	AHB-AP Banked Data 2	
0x1C	AHB-AP Banked Data 3	
0xF8	AHB-AP Debug ROM Address	Base Address of the debug interface
0xFC	AHB-AP ID Register	

Refer to the *Cortex™-M4 with FPU r0p1 TRM* for further details.

## 23.10 Core debug

Core debug is accessed through the core debug registers. Debug access to these registers is by means of the *Advanced High-performance Bus* (AHB-AP) port. The processor can access these registers directly over the internal *Private Peripheral Bus* (PPB).

It consists of 4 registers:

**Table 141. Core debug registers**

Register	Description
DHCSR	The 32-bit Debug Halting Control and Status Register This provides status information about the state of the processor enable core debug halt and step the processor
DCRSR	The 17-bit Debug Core Register Selector Register: This selects the processor register to transfer data to or from.
DCRDR	The 32-bit Debug Core Register Data Register: This holds data for reading and writing registers to and from the processor selected by the DCRSR (Selector) register.
DEMCR	The 32-bit Debug Exception and Monitor Control Register: This provides Vector Catching and Debug Monitor Control. This register contains a bit named <b>TRCENA</b> which enable the use of a TRACE.

**Note:** *Important: these registers are not reset by a system reset. They are only reset by a power-on reset.*

Refer to the *Cortex™-M4 with FPU r0p1 TRM* for further details.

To Halt on reset, it is necessary to:

- enable the bit0 (VC\_CORRESET) of the Debug and Exception Monitor Control Register
- enable the bit0 (C\_DEBUGEN) of the Debug Halting Control and Status Register.

## 23.11 Capability of the debugger host to connect under system reset

The reset system of the STM32F401xB/C and STM32F401xD/E MCU comprises the following reset sources:

- POR (power-on reset) which asserts a RESET at each power-up.
- Internal watchdog reset
- Software reset
- External reset

The Cortex™-M4 with FPU differentiates the reset of the debug part (generally PORRESETn) and the other one (SYSRESETn)

This way, it is possible for the debugger to connect under System Reset, programming the Core Debug Registers to halt the core when fetching the reset vector. Then the host can release the system reset and the core will immediately halt without having executed any instructions. In addition, it is possible to program any debug features under System Reset.

*Note:* *It is highly recommended for the debugger host to connect (set a breakpoint in the reset vector) under system reset.*

## 23.12 FPB (Flash patch breakpoint)

The FPB unit:

- implements hardware breakpoints
- patches code and data from code space to system space. This feature gives the possibility to correct software bugs located in the Code Memory Space.

The use of a Software Patch or a Hardware Breakpoint is exclusive.

The FPB consists of:

- 2 literal comparators for matching against literal loads from Code Space and remapping to a corresponding area in the System Space.
- 6 instruction comparators for matching against instruction fetches from Code Space. They can be used either to remap to a corresponding area in the System Space or to generate a Breakpoint Instruction to the core.

## 23.13 DWT (data watchpoint trigger)

The DWT unit consists of four comparators. They are configurable as:

- a hardware watchpoint or
- a trigger to an ETM or
- a PC sampler or
- a data address sampler

The DWT also provides some means to give some profiling informations. For this, some counters are accessible to give the number of:

- Clock cycle
- Folded instructions
- Load store unit (LSU) operations
- Sleep cycles
- CPI (clock per instructions)
- Interrupt overhead

## 23.14 ITM (instrumentation trace macrocell)

### 23.14.1 General description

The ITM is an application-driven trace source that supports *printf* style debugging to trace *Operating System* (OS) and application events, and emits diagnostic system information. The ITM emits trace information as packets which can be generated as:

- **Software trace.** Software can write directly to the ITM stimulus registers to emit packets.
- **Hardware trace.** The DWT generates these packets, and the ITM emits them.
- **Time stamping.** Timestamps are emitted relative to packets. The ITM contains a 21-bit counter to generate the timestamp. The Cortex™-M4 with FPU clock or the bit clock rate of the *Serial Wire Viewer* (SWV) output clocks the counter.

The packets emitted by the ITM are output to the TPIU (Trace Port Interface Unit). The formatter of the TPIU adds some extra packets (refer to TPIU) and then output the complete packets sequence to the debugger host.

The bit TRCEN of the Debug Exception and Monitor Control Register must be enabled before you program or use the ITM.

### 23.14.2 Time stamp packets, synchronization and overflow packets

Time stamp packets encode time stamp information, generic control and synchronization. It uses a 21-bit timestamp counter (with possible prescalers) which is reset at each time stamp packet emission. This counter can be either clocked by the CPU clock or the SWV clock.

A synchronization packet consists of 6 bytes equal to 0x80\_00\_00\_00\_00\_00 which is emitted to the TPIU as 00 00 00 00 00 80 (LSB emitted first).

A synchronization packet is a timestamp packet control. It is emitted at each DWT trigger.

For this, the DWT must be configured to trigger the ITM: the bit CYCCNTENA (bit0) of the DWT Control Register must be set. In addition, the bit2 (SYNCENA) of the ITM Trace Control Register must be set.

**Note:** *If the SYNCENA bit is not set, the DWT generates Synchronization triggers to the TPIU which will send only TPIU synchronization packets and not ITM synchronization packets.*

An overflow packet consists is a special timestamp packets which indicates that data has been written but the FIFO was full.

**Table 142. Main ITM registers**

Address	Register	Details
@E0000FB0	ITM lock access	Write 0xC5ACCE55 to unlock Write Access to the other ITM registers
@E0000E80	ITM trace control	Bits 31-24 = Always 0
		Bits 23 = Busy
		Bits 22-16 = 7-bits ATB ID which identifies the source of the trace data.
		Bits 15-10 = Always 0
		Bits 9:8 = TSPrescale = Time Stamp Prescaler
		Bits 7-5 = Reserved
		Bit 4 = SWOENA = Enable SWV behavior (to clock the timestamp counter by the SWV clock).
		Bit 3 = DWTEA: Enable the DWT Stimulus
		Bit 2 = SYNCENA: this bit must be to 1 to enable the DWT to generate synchronization triggers so that the TPIU can then emit the synchronization packets.
		Bit 1 = TSENA (Timestamp Enable)
		Bit 0 = ITMENA: Global Enable Bit of the ITM
@E0000E40	ITM trace privilege	Bit 3: mask to enable tracing ports31:24
		Bit 2: mask to enable tracing ports23:16
		Bit 1: mask to enable tracing ports15:8
		Bit 0: mask to enable tracing ports7:0
@E0000E00	ITM trace enable	Each bit enables the corresponding Stimulus port to generate trace.
@E0000000-E000007C	Stimulus port registers 0-31	Write the 32-bits data on the selected Stimulus Port (32 available) to be traced out.

### Example of configuration

To output a simple value to the TPIU:

- Configure the TPIU and assign TRACE I/Os by configuring the DBGMCU\_CR (refer to [Section 23.17.2: TRACE pin assignment](#) and [Section 23.16.3: Debug MCU configuration register](#))
- Write 0xC5ACCE55 to the ITM Lock Access Register to unlock the write access to the ITM registers
- Write 0x00010005 to the ITM Trace Control Register to enable the ITM with Sync enabled and an ATB ID different from 0x00
- Write 0x1 to the ITM Trace Enable Register to enable the Stimulus Port 0
- Write 0x1 to the ITM Trace Privilege Register to unmask stimulus ports 7:0
- Write the value to output in the Stimulus Port Register 0: this can be done by software (using a printf function)

## 23.15 ETM (Embedded trace macrocell)

### 23.15.1 General description

The ETM enables the reconstruction of program execution. Data are traced using the Data Watchpoint and Trace (DWT) component or the Instruction Trace Macrocell (ITM) whereas instructions are traced using the Embedded Trace Macrocell (ETM).

The ETM transmits information as packets and is triggered by embedded resources. These resources must be programmed independently and the trigger source is selected using the Trigger Event Register (0xE0041008). An event could be a simple event (address match from an address comparator) or a logic equation between 2 events. The trigger source is one of the fourth comparators of the DWT module. The following events can be monitored:

- Clock cycle matching
- Data address matching

For more informations on the trigger resources refer to [Section 23.13: DWT \(data watchpoint trigger\)](#).

The packets transmitted by the ETM are output to the TPIU (Trace Port Interface Unit). The formatter of the TPIU adds some extra packets (refer to [Section 23.17: TPIU \(trace port interface unit\)](#)) and then outputs the complete packet sequence to the debugger host.

### 23.15.2 Signal protocol, packet types

This part is described in the chapter 7 ETMv3 Signal Protocol of the ARM IHI 0014N document.

### 23.15.3 Main ETM registers

For more information on registers refer to the chapter 3 of the ARM IHI 0014N specification.

**Table 143. Main ETM registers**

Address	Register	Details
0xE0041FB0	ETM Lock Access	Write 0xC5ACCE55 to unlock the write access to the other ETM registers.
0xE0041000	ETM Control	This register controls the general operation of the ETM, for instance how tracing is enabled.
0xE0041010	ETM Status	This register provides information about the current status of the trace and trigger logic.
0xE0041008	ETM Trigger Event	This register defines the event that will control trigger.
0xE004101C	ETM Trace Enable Control	This register defines which comparator is selected.
0xE0041020	ETM Trace Enable Event	This register defines the trace enabling event.
0xE0041024	ETM Trace Start/Stop	This register defines the traces used by the trigger source to start and stop the trace, respectively.

### 23.15.4 Configuration example

To output a simple value to the TPIU:

- Configure the TPIU and enable the I/O\_TRACEN to assign TRACE I/Os in the STM32F401xB/C and STM32F401xD/E debug configuration register.
- Write 0xC5ACCE55 to the ETM Lock Access Register to unlock the write access to the ETM registers
- Write 0x00001D1E to the control register (configure the trace)
- Write 0000406F to the Trigger Event register (define the trigger event)
- Write 0000006F to the Trace Enable Event register (define an event to start/stop)
- Write 00000001 to the Trace Start/stop register (enable the trace)
- Write 0000191E to the ETM Control Register (end of configuration)

## 23.16 MCU debug component (DBGMCU)

The MCU debug component helps the debugger provide support for:

- Low-power modes
- Clock control for timers, watchdog and I2C during a breakpoint
- Control of the trace pins assignment

### 23.16.1 Debug support for low-power modes

To enter low-power mode, the instruction WFI or WFE must be executed.

The MCU implements several low-power modes which can either deactivate the CPU clock or reduce the power of the CPU.

The core does not allow FCLK or HCLK to be turned off during a debug session. As these are required for the debugger connection, during a debug, they must remain active. The MCU integrates special means to allow the user to debug software in low-power modes.

For this, the debugger host must first set some debug configuration registers to change the low-power mode behavior:

- In Sleep mode, DBG\_SLEEP bit of DBGMCU\_CR register must be previously set by the debugger. This will feed HCLK with the same clock that is provided to FCLK (system clock previously configured by the software).
- In Stop mode, the bit DBG\_STOP must be previously set by the debugger. This will enable the internal RC oscillator clock to feed FCLK and HCLK in STOP mode.

### 23.16.2 Debug support for timers, watchdog and I<sup>2</sup>C

During a breakpoint, it is necessary to choose how the counter of timers and watchdog should behave:

- They can continue to count inside a breakpoint. This is usually required when a PWM is controlling a motor, for example.
- They can stop to count inside a breakpoint. This is required for watchdog purposes.

For the I<sup>2</sup>C, the user can choose to block the SMBUS timeout during a breakpoint.

### 23.16.3 Debug MCU configuration register

This register allows the configuration of the MCU under DEBUG. This concerns:

- Low-power mode support
- Timer and watchdog counter support
- Trace pin assignment

This DBGMCU\_CR is mapped on the External PPB bus at address 0xE0042004

It is asynchronously reset by the PORRESET (and not the system reset). It can be written by the debugger under system reset.

If the debugger host does not support these features, it is still possible for the user software to write to these registers.

#### DBGMCU\_CR register

Address: 0xE004 2004

Only 32-bit access supported

POR Reset: 0x0000 0000 (not reset by system reset)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16				
Reserved																			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0				
Reserved								TRACE_MODE [1:0]		TRACE_IOEN		Reserved		DBG_STANDBY		DBG_STOP		DBG_SLEEP	
								rw	rw	rw			rw	rw	rw				

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:5 **TRACE\_MODE[1:0] and TRACE\_IOEN**: Trace pin assignment control

- With TRACE\_IOEN=0:  
TRACE\_MODE=xx: TRACE pins not assigned (default state)
- With TRACE\_IOEN=1:
  - TRACE\_MODE=00: TRACE pin assignment for Asynchronous Mode
  - TRACE\_MODE=01: TRACE pin assignment for Synchronous Mode with a TRACEDATA size of 1
  - TRACE\_MODE=10: TRACE pin assignment for Synchronous Mode with a TRACEDATA size of 2
  - TRACE\_MODE=11: TRACE pin assignment for Synchronous Mode with a TRACEDATA size of 4

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **DBG\_STANDBY**: Debug Standby mode

0: (FCLK=Off, HCLK=Off) The whole digital part is unpowered.

From software point of view, exiting from Standby is identical than fetching reset vector (except a few status bit indicated that the MCU is resuming from Standby)

1: (FCLK=On, HCLK=On) In this case, the digital part is not unpowered and FCLK and HCLK are provided by the internal RC oscillator which remains active. In addition, the MCU generate a system reset during Standby mode so that exiting from Standby is identical than fetching from reset

Bit 1 **DBG\_STOP**: Debug Stop mode

0: (FCLK=Off, HCLK=Off) In STOP mode, the clock controller disables all clocks (including HCLK and FCLK). When exiting from STOP mode, the clock configuration is identical to the one after RESET (CPU clocked by the 8 MHz internal RC oscillator (HSI)). Consequently, the software must reprogram the clock controller to enable the PLL, the Xtal, etc.

1: (FCLK=On, HCLK=On) In this case, when entering STOP mode, FCLK and HCLK are provided by the internal RC oscillator which remains active in STOP mode. When exiting STOP mode, the software must reprogram the clock controller to enable the PLL, the Xtal, etc. (in the same way it would do in case of DBG\_STOP=0)

Bit 0 **DBG\_SLEEP**: Debug Sleep mode

0: (FCLK=On, HCLK=Off) In Sleep mode, FCLK is clocked by the system clock as previously configured by the software while HCLK is disabled.

In Sleep mode, the clock controller configuration is not reset and remains in the previously programmed state. Consequently, when exiting from Sleep mode, the software does not need to reconfigure the clock controller.

1: (FCLK=On, HCLK=On) In this case, when entering Sleep mode, HCLK is fed by the same clock that is provided to FCLK (system clock as previously configured by the software).

### 23.16.4 Debug MCU APB1 freeze register (DBGMCU\_APB1\_FZ)

The DBGMCU\_APB1\_FZ register is used to configure the MCU under Debug. It concerns APB1 peripherals. It is mapped on the external PPB bus at address 0xE004 2008.

The register is asynchronously reset by the POR (and not the system reset). It can be written by the debugger under system reset.

Address : 0xE004 2008

Only 32-bits access are supported.

Power-on reset (POR): 0x0000 0000 (not reset by system reset)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		DBG_IWDG_STOP	DBG_WWDG_STOP	DBG_RTC_STOP	Reserved						DBG_TIM5_STOP	DBG_TIM4_STOP	DBG_TIM3_STOP	DBG_TIM2_STOP	

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **DBG\_I2C3\_SMBUS\_TIMEOUT:** SMBUS timeout mode stopped when Core is halted

- 0: Same behavior as in normal mode
- 1: The SMBUS timeout is frozen

Bit 22 **DBG\_I2C2\_SMBUS\_TIMEOUT:** SMBUS timeout mode stopped when Core is halted

- 0: Same behavior as in normal mode
- 1: The SMBUS timeout is frozen

Bit 21 **DBG\_I2C1\_SMBUS\_TIMEOUT:** SMBUS timeout mode stopped when Core is halted

- 0: Same behavior as in normal mode
- 1: The SMBUS timeout is frozen

Bit 20:13 Reserved, must be kept at reset value.

Bit 12 **DBG\_IWDG\_STOP:** Debug independent watchdog stopped when core is halted

- 0: The independent watchdog counter clock continues even if the core is halted
- 1: The independent watchdog counter clock is stopped when the core is halted

Bit 11 **DBG\_WWDG\_STOP:** Debug Window Watchdog stopped when Core is halted

- 0: The window watchdog counter clock continues even if the core is halted
- 1: The window watchdog counter clock is stopped when the core is halted

Bit 10 **DBG\_RTC\_STOP:** RTC stopped when Core is halted

- 0: The RTC counter clock continues even if the core is halted
- 1: The RTC counter clock is stopped when the core is halted

Bits 9:4 Reserved, must be kept at reset value.

Bits 3:0 **DBG\_TIMx\_STOP:** TIMx counter stopped when core is halted ( $x=2..5$ )

- 0: The clock of the involved Timer Counter is fed even if the core is halted
- 1: The clock of the involved Timer counter is stopped when the core is halted

### 23.16.5 Debug MCU APB2 Freeze register (DBGMCU\_APB2\_FZ)

The DBGMCU\_APB2\_FZ register is used to configure the MCU under Debug. It concerns APB2 peripherals.

This register is mapped on the external PPB bus at address 0xE004 200C

It is asynchronously reset by the POR (and not the system reset). It can be written by the debugger under system reset.

Address: 0xE004 200C

Only 32-bit access is supported.

POR: 0x0000 0000 (not reset by system reset)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	
Reserved														DBG_TIM11_STOP	DBG_TIM10_STOP	DBG_TIM9_STOP
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Reserved														DBG_TIM1_STOP		
															rw	

### 23.17 TPIU (trace port interface unit)

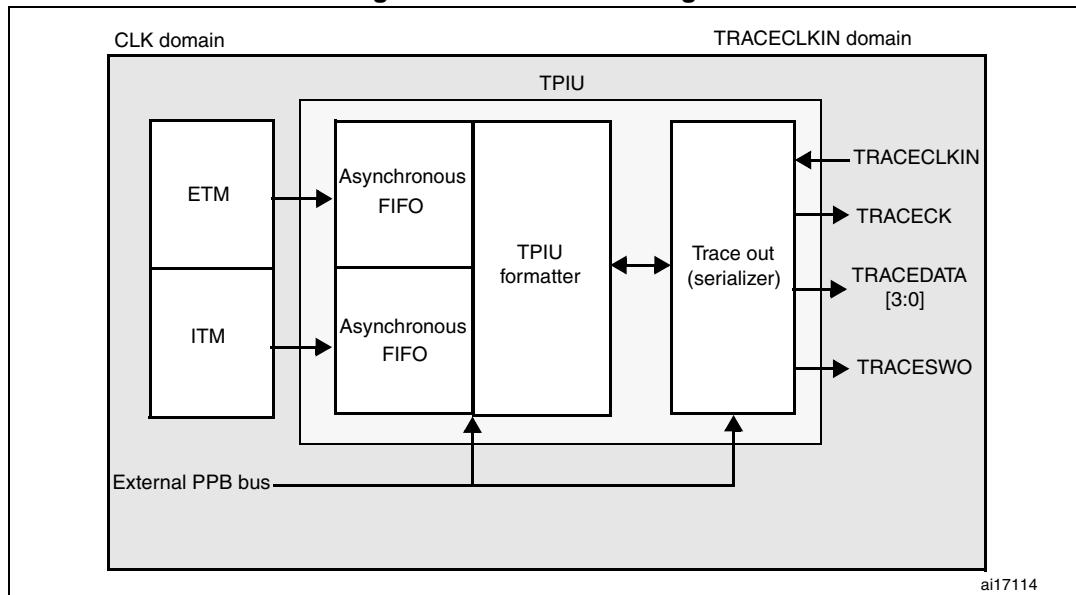
#### 23.17.1 Introduction

The TPIU acts as a bridge between the on-chip trace data from the ITM and the ETM.

The output data stream encapsulates the trace source ID, that is then captured by a *trace port analyzer* (TPA).

The core embeds a simple TPIU, especially designed for low-cost debug (consisting of a special version of the CoreSight TPIU).

Figure 269. TPIU block diagram



### 23.17.2 TRACE pin assignment

- Asynchronous mode

The asynchronous mode requires 1 extra pin and is available on all packages. It is only available if using Serial Wire mode (not in JTAG mode).

**Table 144. Asynchronous TRACE pin assignment**

TPUI pin name	Trace synchronous mode		pin assignment
	Type	Description	
TRACESWO	O	TRACE Async Data Output	PB3

- Synchronous mode

The synchronous mode requires from 2 to 6 extra pins depending on the data trace size and is only available in the larger packages. In addition it is available in JTAG mode and in Serial Wire mode and provides better bandwidth output capabilities than asynchronous trace.

**Table 145. Synchronous TRACE pin assignment**

TPUI pin name	Trace synchronous mode		STM32F401xB/C and STM32F401xC/C pin assignment
	Type	Description	
TRACECK	O	TRACE Clock	PE2
TRACED[3:0]	O	TRACE Sync Data Outputs Can be 1, 2 or 4.	PE[6:3]

### TPUI TRACE pin assignment

By default, these pins are NOT assigned. They can be assigned by setting the TRACE\_IOEN and TRACE\_MODE bits in the **MCU Debug component configuration register**. This configuration has to be done by the debugger host.

In addition, the number of pins to assign depends on the trace configuration (asynchronous or synchronous).

- **Asynchronous mode:** 1 extra pin is needed
- **Synchronous mode:** from 2 to 5 extra pins are needed depending on the size of the data trace port register (1, 2 or 4):
  - TRACECK
  - TRACED(0) if port size is configured to 1, 2 or 4
  - TRACED(1) if port size is configured to 2 or 4
  - TRACED(2) if port size is configured to 4
  - TRACED(3) if port size is configured to 4

To assign the TRACE pin, the debugger host must program the bits TRACE\_IOEN and TRACE\_MODE[1:0] of the Debug MCU configuration Register (DBGMCU\_CR). By default the TRACE pins are not assigned.

This register is mapped on the external PPB and is reset by the PORESET (and not by the SYSTEM reset). It can be written by the debugger under SYSTEM reset.

**Table 146. Flexible TRACE pin assignment**

DBGMCU_CR register		Pins assigned for:	TRACE IO pin assigned						
TRACE_IOEN	TRACE_MODE [1:0]		PB3 /JTDO/ TRACESWO	PE2/ TRACECK	PE3 / TRACED[0]	PE4 / TRACED[1]	PE5 / TRACED[2]	PE6 / TRACED[3]	
0	XX	No Trace (default state)	Released <sup>(1)</sup>						
1	00	Asynchronous Trace	TRACESWO			Released (usable as GPIO)			
1	01	Synchronous Trace 1 bit	Released <sup>(1)</sup>	TRACECK	TRACED[0]				
1	10	Synchronous Trace 2 bit		TRACECK	TRACED[0]	TRACED[1]			
1	11	Synchronous Trace 4 bit		TRACECK	TRACED[0]	TRACED[1]	TRACED[2]	TRACED[3]	

- When Serial Wire mode is used, it is released. But when JTAG is used, it is assigned to JTDO.

**Note:** By default, the TRACECLKIN input clock of the TPIU is tied to GND. It is assigned to HCLK two clock cycles after the bit TRACE\_IOEN has been set.

The debugger must then program the Trace Mode by writing the PROTOCOL[1:0] bits in the SPP\_R (Selected Pin Protocol) register of the TPIU.

- PROTOCOL=00: Trace Port Mode (synchronous)
- PROTOCOL=01 or 10: Serial Wire (Manchester or NRZ) Mode (asynchronous mode). Default state is 01

It then also configures the TRACE port size by writing the bits [3:0] in the CPSPS\_R (Current Sync Port Size Register) of the TPIU:

- 0x1 for 1 pin (default state)
- 0x2 for 2 pins
- 0x8 for 4 pins

### 23.17.3 TPUI formatter

The formatter protocol outputs data in 16-byte frames:

- seven bytes of data
- eight bytes of mixed-use bytes consisting of:
  - 1 bit (LSB) to indicate it is a DATA byte ('0) or an ID byte ('1).
  - 7 bits (MSB) which can be data or change of source ID trace.
- one byte of auxiliary bits where each bit corresponds to one of the eight mixed-use bytes:
  - if the corresponding byte was a data, this bit gives bit0 of the data.
  - if the corresponding byte was an ID change, this bit indicates when that ID change takes effect.

**Note:** Refer to the ARM CoreSight Architecture Specification v1.0 (ARM IHI 0029B) for further information

### 23.17.4 TPUI frame synchronization packets

The TPUI can generate two types of synchronization packets:

- The Frame Synchronization packet (or Full Word Synchronization packet)  
It consists of the word: 0x7F\_FF\_FF\_FF (LSB emitted first). This sequence can not occur at any other time provided that the ID source code 0x7F has not been used.  
It is output periodically ***between*** frames.  
In continuous mode, the TPA must discard all these frames once a synchronization frame has been found.
- The Half-Word Synchronization packet  
It consists of the half word: 0x7F\_FF (LSB emitted first).  
It is output periodically ***between or within*** frames.  
These packets are only generated in continuous mode and enable the TPA to detect that the TRACE port is in IDLE mode (no TRACE to be captured). When detected by the TPA, it must be discarded.

### 23.17.5 Transmission of the synchronization frame packet

There is no Synchronization Counter register implemented in the TPUI of the core. Consequently, the synchronization trigger can only be generated by the **DWT**. Refer to the registers DWT Control Register (bits SYNCTAP[11:10]) and the DWT Current PC Sampler Cycle Count Register.

The TPUI Frame synchronization packet (0x7F\_FF\_FF\_FF) is emitted:

- after each TPUI reset release. This reset is synchronously released with the rising edge of the TRACECLKIN clock. This means that this packet is transmitted when the

TRACE\_IOEN bit in the DBGMCU\_CFG register is set. In this case, the word 0x7F\_FF\_FF\_FF is not followed by any formatted packet.

- at each DWT trigger (assuming DWT has been previously configured). Two cases occur:
  - If the bit SYNENA of the ITM is reset, only the word 0x7F\_FF\_FF\_FF is emitted without any formatted stream which follows.
  - If the bit SYNENA of the ITM is set, then the ITM synchronization packets will follow (0x80\_00\_00\_00\_00\_00), formatted by the TPUI (trace source ID added).

### 23.17.6 Synchronous mode

The trace data output size can be configured to 4, 2 or 1 pin: TRACED(3:0)

The output clock is output to the debugger (TRACECK)

Here, TRACECLKIN is driven internally and is connected to HCLK only when TRACE is used.

*Note:*

*In this synchronous mode, it is not required to provide a stable clock frequency.*

The TRACE I/Os (including TRACECK) are driven by the rising edge of TRACELKIN (equal to HCLK). Consequently, the output frequency of TRACECK is equal to HCLK/2.

### 23.17.7 Asynchronous mode

This is a low cost alternative to output the trace using only 1 pin: this is the asynchronous output pin TRACESWO. Obviously there is a limited bandwidth.

TRACESWO is multiplexed with JTDO when using the SW-DP pin. This way, this functionality is available in all STM32F401xB/C and STM32F401xD/E packages.

This asynchronous mode requires a constant frequency for TRACELKIN. For the standard UART (NRZ) capture mechanism, 5% accuracy is needed. The Manchester encoded version is tolerant up to 10%.

### 23.17.8 TRACECLKIN connection inside the STM32F401xB/C and STM32F401xD/E

In the STM32F401xB/C and STM32F401xD/E, this TRACELKIN input is internally connected to HCLK. This means that when in asynchronous trace mode, the application is restricted to use time frames where the CPU frequency is stable.

*Note:*

***Important:** when using asynchronous trace: it is important to be aware that:*

*The default clock of the STM32F401xB/C and STM32F401xD/E MCUs is the internal RC oscillator. Its frequency under reset is different from the one after reset release. This is because the RC calibration is the default one under system reset and is updated at each system reset release.*

*Consequently, the trace port analyzer (TPA) should not enable the trace (with the TRACE\_IOEN bit) under system reset, because a Synchronization Frame Packet will be issued with a different bit time than trace packets which will be transmitted after reset release.*

### 23.17.9 TPIU registers

The TPIU APB registers can be read and written only if the bit TRCENA of the Debug Exception and Monitor Control Register (DEMCR) is set. Otherwise, the registers are read as zero (the output of this bit enables the PCLK of the TPIU).

**Table 147. Important TPIU registers**

Address	Register	Description
0xE0040004	Current port size	Allows the trace port size to be selected: Bit 0: Port size = 1 Bit 1: Port size = 2 Bit 2: Port size = 3, not supported Bit 3: Port Size = 4 Only 1 bit must be set. By default, the port size is one bit. (0x00000001)
0xE00400F0	Selected pin protocol	Allows the Trace Port Protocol to be selected: Bit1:0= 00: Sync Trace Port Mode 01: Serial Wire Output - manchester (default value) 10: Serial Wire Output - NRZ 11: reserved
0xE0040304	Formatter and flush control	Bit 31-9 = always '0 Bit 8 = TrigIn = always '1 to indicate that triggers are indicated Bit 7-4 = always 0 Bit 3-2 = always 0 Bit 1 = EnFCont. In Sync Trace mode (Select_Pin_Protocol register bit1:0=00), this bit is forced to '1: the formatter is automatically enabled in continuous mode. In asynchronous mode (Select_Pin_Protocol register bit1:0 > 00), this bit can be written to activate or not the formatter. Bit 0 = always 0 The resulting default value is 0x102 <b>Note:</b> In synchronous mode, because the TRACECTL pin is not mapped outside the chip, the formatter is always enabled in continuous mode -this way the formatter inserts some control packets to identify the source of the trace packets).
0xE0040300	Formatter and flush status	Not used in Cortex™-M4 with FPU, always read as 0x00000008

### 23.17.10 Example of configuration

- Set the bit TRCENA in the Debug Exception and Monitor Control Register (DEMCR)
- Write the TPIU Current Port Size Register to the desired value (default is 0x1 for a 1-bit port size)
- Write TPIU Formatter and Flush Control Register to 0x102 (default value)
- Write the TPIU Select Pin Protocol to select the sync or async mode. Example: 0x2 for async NRZ mode (UART like)
- Write the DBGMCU control register to 0x20 (bit IO\_TRACEN) to assign TRACE I/Os for async mode. A TPIU Sync packet is emitted at this time (FF\_FF\_FF\_7F)
- Configure the ITM and write the ITM Stimulus register to output a value

## 23.18 DBG register map

The following table summarizes the Debug registers

**Table 148. DBG register map and reset values**

Addr.	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xE004 2000	<b>DBGMCU_IDCODE</b>	REV_ID												Reserved	DEV_ID																		
		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
0xE004 2004	<b>DBGMCU_CR</b>	Reserved												Reserved	Reserved																		
		Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0xE004 2008	<b>DBGMCU_APB1_FZ</b>	Reserved												Reserved	Reserved																		
		Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0xE004 200C	<b>DBGMCU_APB2_FZ</b>	Reserved												Reserved	Reserved																		
		Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

1. The reset value is product dependent. For more information, refer to [Section 23.6.1: MCU device ID code](#).

## 24 Device electronic signature

The electronic signature is stored in the Flash memory area. It can be read using the JTAG/SWD or the CPU. It contains factory-programmed identification data that allow the user firmware or other external devices to automatically match its interface to the characteristics of the STM32F4xx microcontrollers.

### 24.1 Unique device ID register (96 bits)

The unique device identifier is ideally suited:

- for use as serial numbers (for example USB string serial numbers or other end applications)
- for use as security keys in order to increase the security of code in Flash memory while using and combining this unique ID with software cryptographic primitives and protocols before programming the internal Flash memory
- to activate secure boot processes, etc.

The 96-bit unique device identifier provides a reference number which is unique for any device and in any context. These bits can never be altered by the user.

The 96-bit unique device identifier can also be read in single bytes/half-words/words in different ways and then be concatenated using a custom algorithm.

**Base address: 0x1FFF 7A10**

Address offset: 0x00

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
U_ID(31:0)																															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r		

Bits 31:0 **U\_ID(31:0)**: 31:0 unique ID bits

Address offset: 0x04

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
U_ID(63:48)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
U_ID(47:32)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **U\_ID(63:32)**: 63:32 unique ID bits

Address offset: 0x08

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
U_ID(95:80)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
U_ID(79:64)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **U\_ID(95:64): 95:64 Unique ID bits.**

## 24.2 Flash size

Base address: 0x1FFF 7A22

Address offset: 0x00

Read only = 0xXXXX where X is factory-programmed

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
F_SIZE															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 15:0 **F\_ID(15:0): Flash memory size**

This bitfield indicates the size of the device Flash memory expressed in Kbytes.

As an example, 0x0400 corresponds to 1024 Kbytes.

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## Revision history

**Table 149. Document revision history**

Date	Version	Changes
07-Oct-2013	1	<p>Initial release.</p>
30-Jan-2014	2	<p>Added information for STM32F401xD/E devices throughout the manual</p> <p>Added <a href="#">Table 4: Memory mapping vs. Boot mode/physical remap in STM32F401xD/E</a></p> <p>Updated <a href="#">Table 5: Flash module organization (STM32F401xB/C and STM32F401xD/E)</a></p> <p>Updated <a href="#">Section 3.8.5: Flash control register (FLASH_CR)</a></p> <p>Updated <a href="#">Section 3.8.6: Flash option control register (FLASH_OPTCR)</a></p> <p><b>TIM1:</b> Updated <a href="#">Table 50: TIMx Internal trigger connection</a></p> <p><b>TIM9 to TIM11:</b> Added <a href="#">Table 57: TIMx internal trigger connection on page 386</a></p> <p><b>DMA:</b> Modified <a href="#">Section 9.2: DMA main features</a></p> <p>Removed sentence in <a href="#">Section 9.3.7: Pointer incrementation</a></p> <p>Removed note in <a href="#">Section 9.3.11: Single and burst transfers</a></p> <p><b>Interrupts:</b> Updated Description of MemManage exception in <a href="#">Table 38: Vector table on page 196</a></p> <p><b>RTC:</b> Corrected name of bit 9 in <a href="#">Section 17.6.3: RTC control register (RTC_CR)</a></p> <p>Modified <a href="#">Section 17.3.11: RTC smooth digital calibration</a></p> <p><b>I2C:</b> Changed acronyms for Standard mode and Fast mode to Sm and Fm in <a href="#">Section 18: Inter-integrated circuit (I2C) interface</a></p>

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