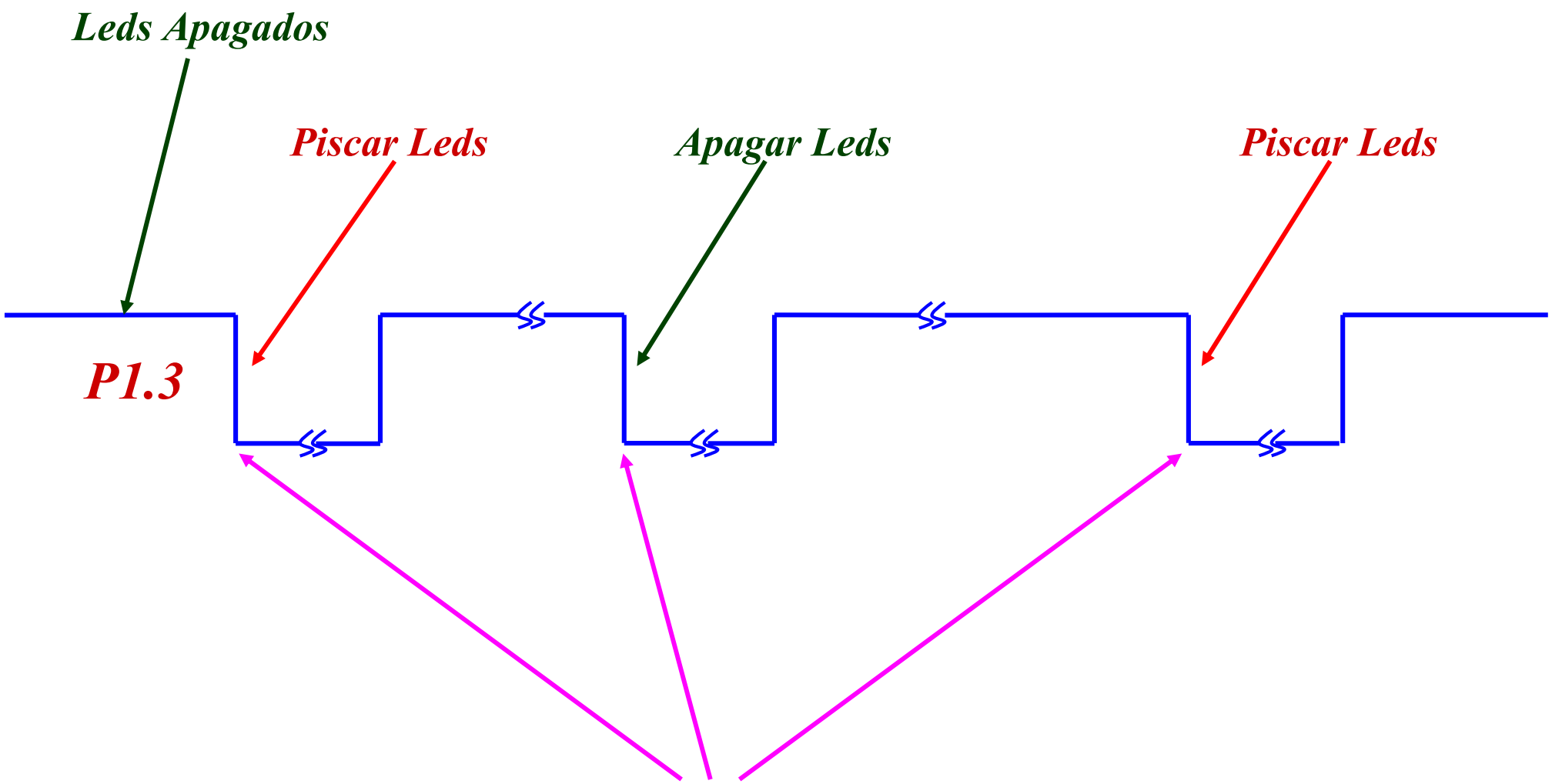
Exercício 08:

- Escrever um programa para alternar o estado dos LEDs vermelho e verde da placa MSP-EXP430G2 a cada 250ms, considerando uma frequência de clock de 1MHz.

- Inicialmente os LEDs deverão estar apagados;

- Sempre que a interrupção do pino *P1.3* (*Botão S2*) for ativada, o estado dos LEDs deverá alternar entre apagado e piscante;

- A temporização deverá ser feita através do *Timer1_A*



Configurar a interrupção do pino P1.3 para a borda negativa.

Vetores de Interrupções do MSP430G2553

INTERRUPT SOURCE	INTERRUPT FLAG	SYSTEM INTERRUPT	WORD ADDRESS	PRIORITY
Power-Up External Reset Watchdog Timer+ Flash key violation PC out-of-range(1)	PORIFG RSTIFG WDTIFG KEYV(2)	Reset	0FFFEh	31, highest
NMI Oscillator fault Flash memory access violation	NMIIFG OFIFG ACCVIFG(2)(3)	(non)-maskable (non)-maskable (non)-maskable	0FFFCh	30
Timer1_A3	TA1CCR0 CCIFG(4)	maskable	0FFFAh	29
Timer1_A3	TA1CCR2 TA1CCR1 CCIFG, TAIFG(2)(4)	maskable	0FFF8h	28
Comparator_A+	CAIFG(4)	maskable	0FFF6h	27
Watchdog Timer+	WDTIFG	maskable	0FFF4h	26
Timer0_A3	TA0CCR0 CCIFG(4)	maskable	0FFF2h	25
Timer0_A3	TA0CCR2 TA0CCR1 CCIFG, TAIFG (5)(4)	maskable	0FFF0h	24
USCI_A0/USCI_B0 receive USCI_B0 I2C status	UCA0RXIFG, UCB0RXIFG(2)(5)	maskable	0FFEEh	23
USCI_A0/USCI_B0 transmit USCI_B0 I2C receive/transmit	UCA0TXIFG, UCB0TXIFG(2)(6)	maskable	0FFECh	22
ADC10 (MSP430G2x53 only)	ADC10IFG(4)	maskable	0FFEAh	21
			0FFE8h	20
I/O Port P2 (up to eight flags)	P2IFG.0 to P2IFG.7(2)(4)	maskable	0FFE6h	19
I/O Port P1 (up to eight flags)	P1IFG.0 to P1IFG.7(2)(4)	maskable	0FFE4h	18

Interrupções das portas P1 e P2

Todos os pinos das portas *P1* e *P2* podem gerar interrupções.

A configuração das interrupções é feita através dos registradores *PxIFG*, *PxIE* e *PxIES*.

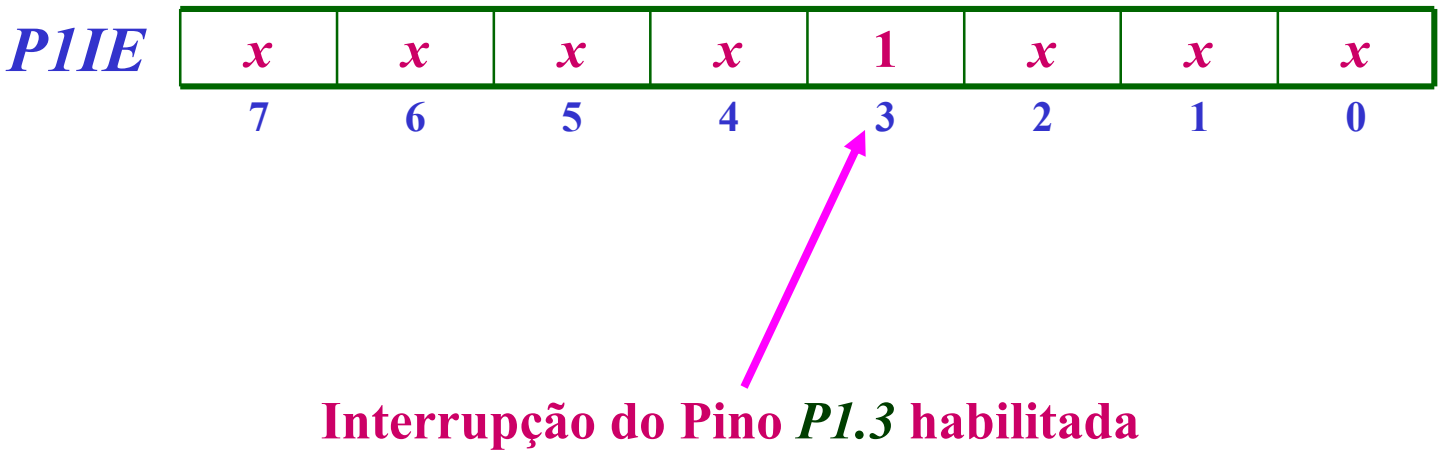
Existe um único *Vetor de Interrupção* para todos os pinos de cada porta. O Registrador *PxIFG* pode ser testado para verificar qual pino ativou a interrupção.

Port	Register	Short Form	Address	Register Type	Initial State
P1	Input	P1IN	020h	Read only	–
	Output	P1OUT	021h	Read/write	Unchanged
	Direction	P1DIR	022h	Read/write	Reset with PUC
	Interrupt Flag	P1IFG	023h	Read/write	Reset with PUC
	Interrupt Edge Select	P1IES	024h	Read/write	Unchanged
	Interrupt Enable	P1IE	025h	Read/write	Reset with PUC
	Port Select	P1SEL	026h	Read/write	Reset with PUC
	Port Select 2	P1SEL2	041h	Read/write	Reset with PUC
	Resistor Enable	P1REN	027h	Read/write	Reset with PUC

Registradores *PxIE* – Habilitação das Interrupções

Cada bit do registrador *PxIE* habilita a interrupção de um pino

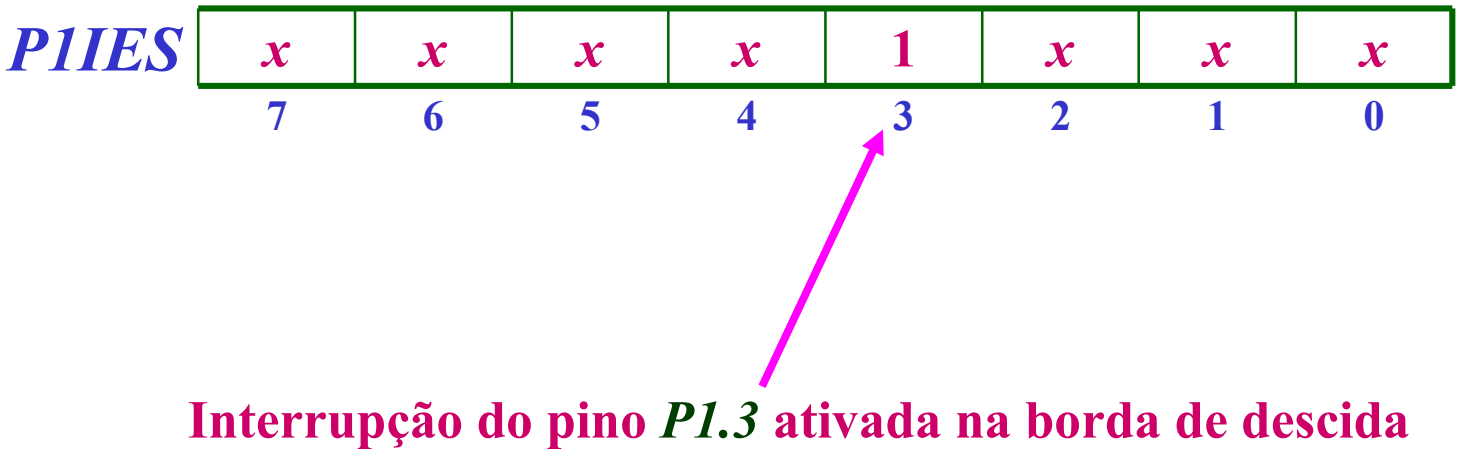
- **Bit = 1: Interrupção habilitada**
- **Bit = 0: Interrupção desabilitada**



Registradores *PxIES* – Seleciona borda de ativação da interrupção

Cada bit do registrador *PxIES* seleciona a borda de ativação da interrupção de cada um dos pinos

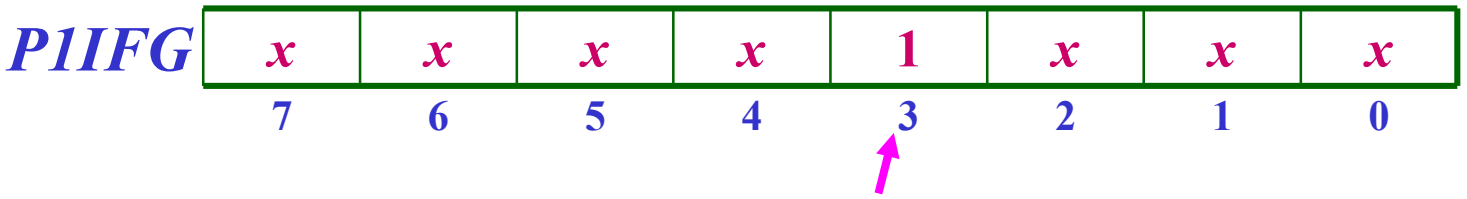
- **Bit = 0: Interrupção ativada na borda positiva**
- **Bit = 1: Interrupção ativada na borda negativa**



Registradores *P1IFG – Flags* que indicam qual pino ativou a interrupção

Cada bit do registrador *P1IFG* é um flag que indica qual dos pinos da Porta 1 que ativou a interrupção.

- Bit = 0: O pino não ativou a interrupção
- Bit = 1: O pino correspondente ativou a interrupção

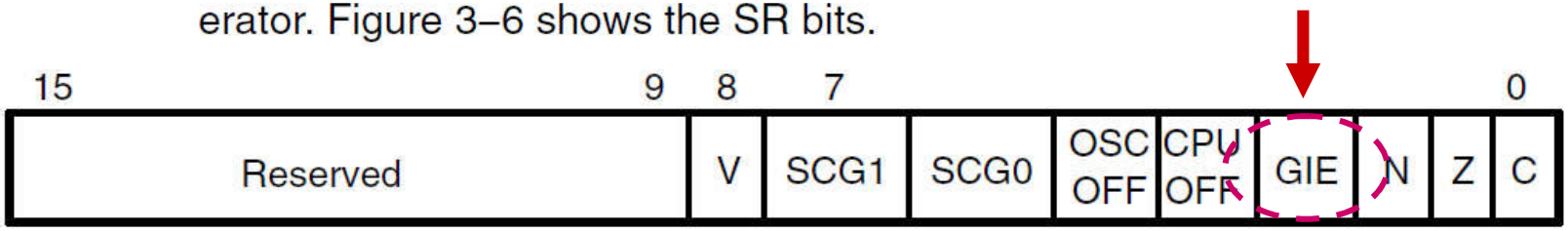


A interrupção do pino *P1.3* foi ativada e está pendente.

Esse bit de flag deve ser resetado pelo programa

Status Register (SR)

The status register (SR/R2), used as a source or destination register, can be used in the register mode only addressed with word instructions. The remaining combinations of addressing modes are used to support the constant generator. Figure 3–6 shows the SR bits.



GIE — General interrupt enable. This bit, when set, enables maskable interrupts. When reset, all maskable interrupts are disabled.

N — Negative bit. This bit is set when the result of a byte or word operation is negative and cleared when the result is not negative.

- Word operation: N is set to the value of bit 15 of the result
- Byte operation: N is set to the value of bit 7 of the result

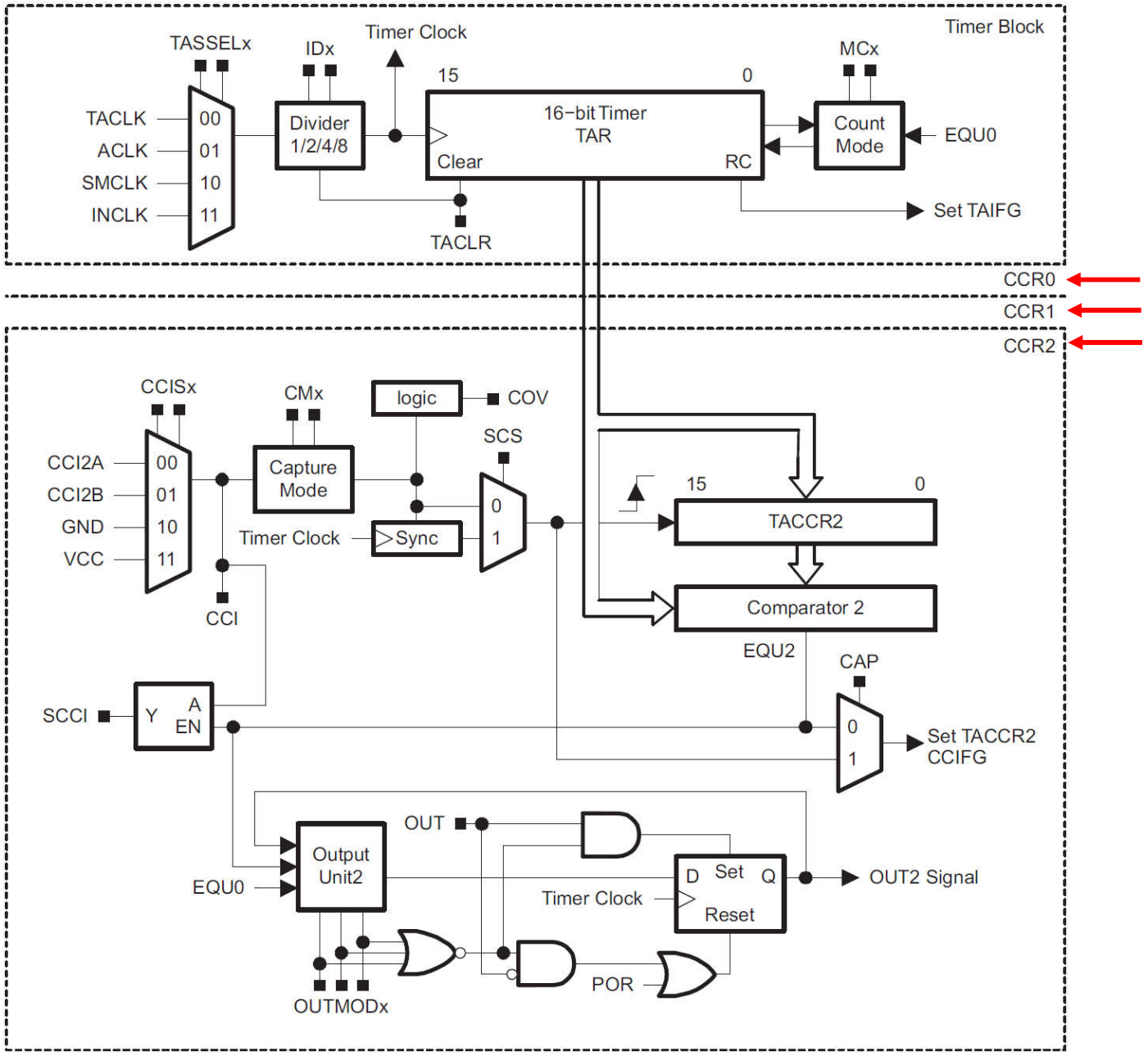
Z — Zero bit. This bit is set when the result of a byte or word operation is 0 and cleared when the result is not 0.

C — Carry bit. This bit is set when the result of a byte or word operation produced a carry and cleared when no carry occurred.

Timer_A:

Timer0_A

Timer1_A



Três Blocos Capture/Compare

CCR0

CCR1

CCR2

Registradores do Timer_A:

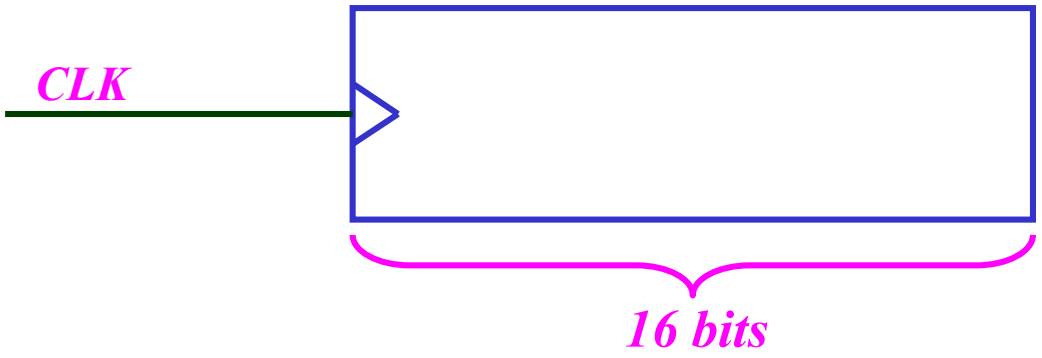
Register	Short Form	Register Type	Address	Initial State
Timer_A control	TACTL	Read/write	0160h	Reset with POR
Timer_A counter	TAR	Read/write	0170h	Reset with POR
Timer_A capture/compare control 0	TACCTL0	Read/write	0162h	Reset with POR
Timer_A capture/compare 0	TACCR0	Read/write	0172h	Reset with POR
Timer_A capture/compare control 1	TACCTL1	Read/write	0164h	Reset with POR
Timer_A capture/compare 1	TACCR1	Read/write	0174h	Reset with POR
Timer_A capture/compare control 2	TACCTL2†	Read/write	0166h	Reset with POR
Timer_A capture/compare 2	TACCR2†	Read/write	0176h	Reset with POR
Timer_A interrupt vector	TAIV	Read only	012Eh	Reset with POR

† Not present on MSP430x20xx Devices

Timer0_A: ***TA0xxxxx***

Timer1_A: ***TA1xxxxx***

Timerx_A: *Contador de 16 bits*

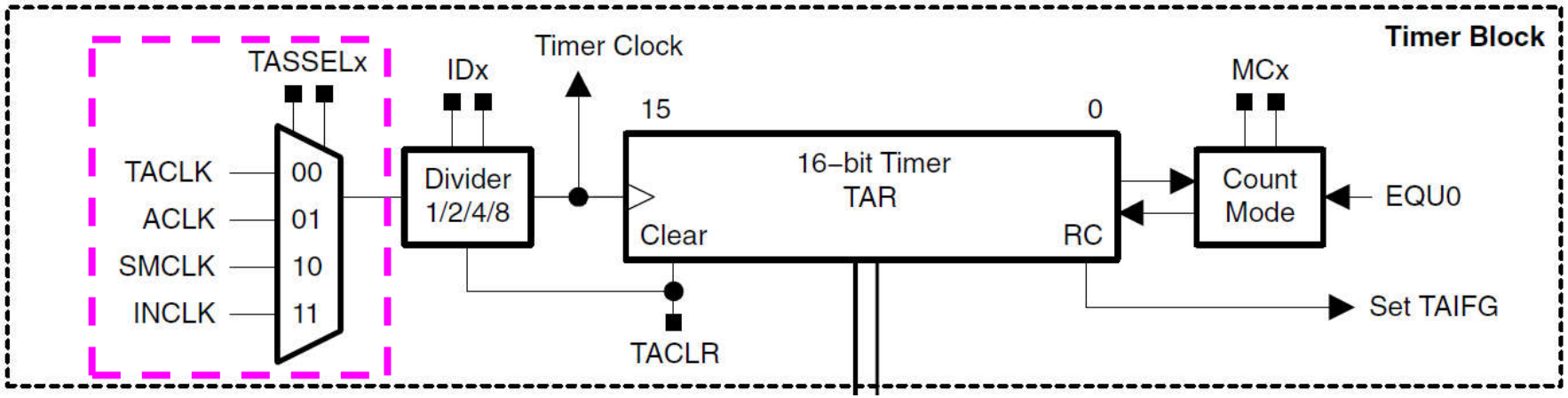


16 bits ➔ 65.535
0*x*FFFF

O *Contador* é incrementado à cada pulso de *Clock*

Se o pulso de Clock for aleatório, tem-se um contador

Se o pulso de Clock for periódico, tem-se um temporizador



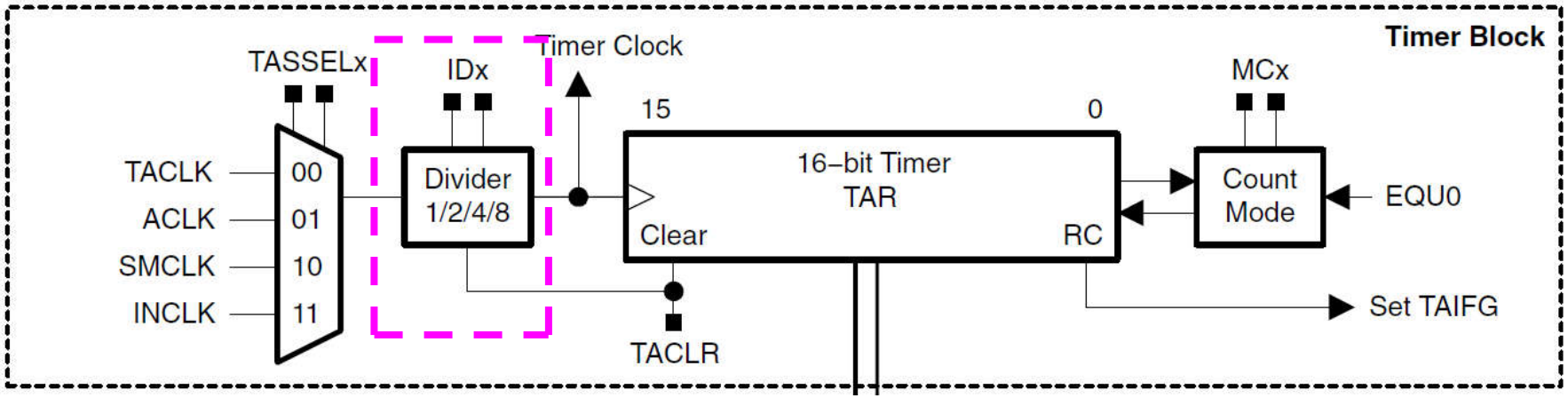
Fontes de Clock para o *Timerx_A*

TA1CTL

15	14	13	12	11	10	9	8
Unused						TASSELx	

7	6	5	4	3	2	1	0
IDx		MCx		Unused	TACLR	TAIE	TAIFG

TASSELx	Bits	Timer_A clock source select
	9-8	
	00	TACLK
	01	ACLK
	10	SMCLK
	11	INCLK



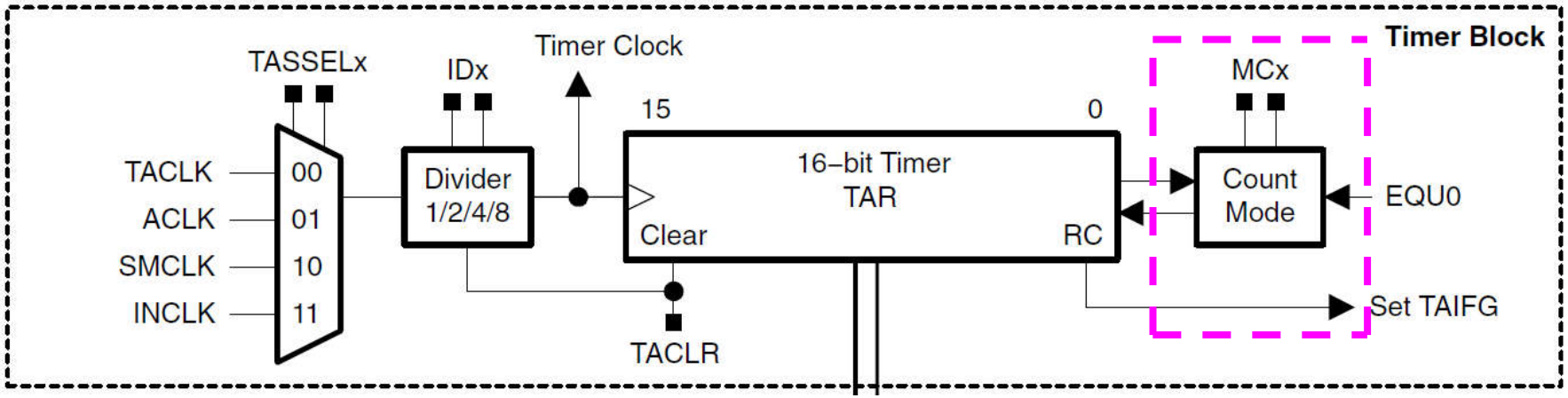
Pre-Scaler (Divisor)

TA1CTL

15	14	13	12	11	10	9	8
Unused						TASSELx	

7	6	5	4	3	2	1	0
IDx		MCx		Unused	TACLR	TAIE	TAIFG

IDx	Bits	Input divider.
	7-6	00 /1
		01 /2
		10 /4
		11 /8



Modo de Contagem

TA1CTL

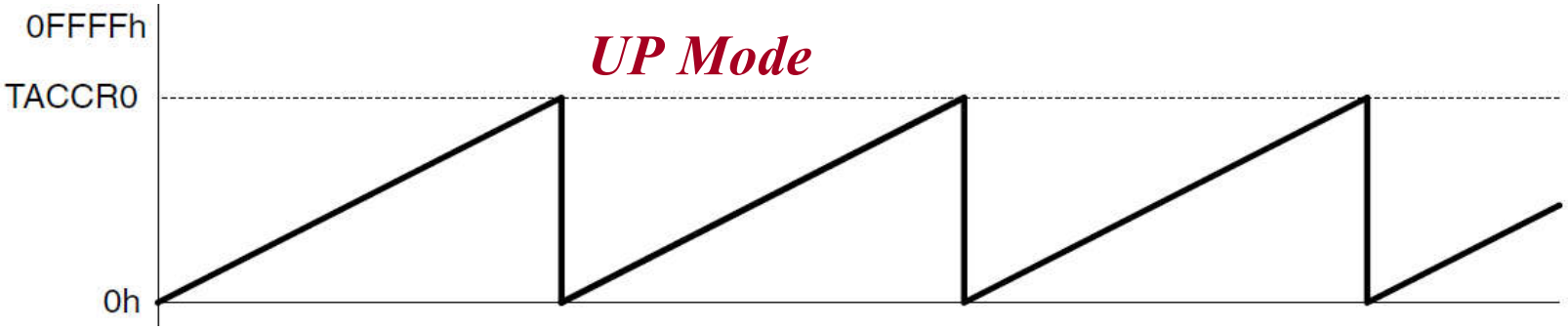
15	14	13	12	11	10	9	8
Unused						TASSELx	

7	6	5	4	3	2	1	0
IDx		MCx		Unused	TACLR	TAIE	TAIFG

MCx Bits 5-4 Mode control. Setting MCx = 00h when Timer_A is not in use conserves power.

- 00 Stop mode: the timer is halted.
- 01 Up mode: the timer counts up to TACCR0.
- 10 Continuous mode: the timer counts up to 0FFFFh.
- 11 Up/down mode: the timer counts up to TACCR0 then down to 0000h.

Modos de Contagem



O modo *Up* é utilizado quando o período do *Timer* for diferente de 0xFFFF.

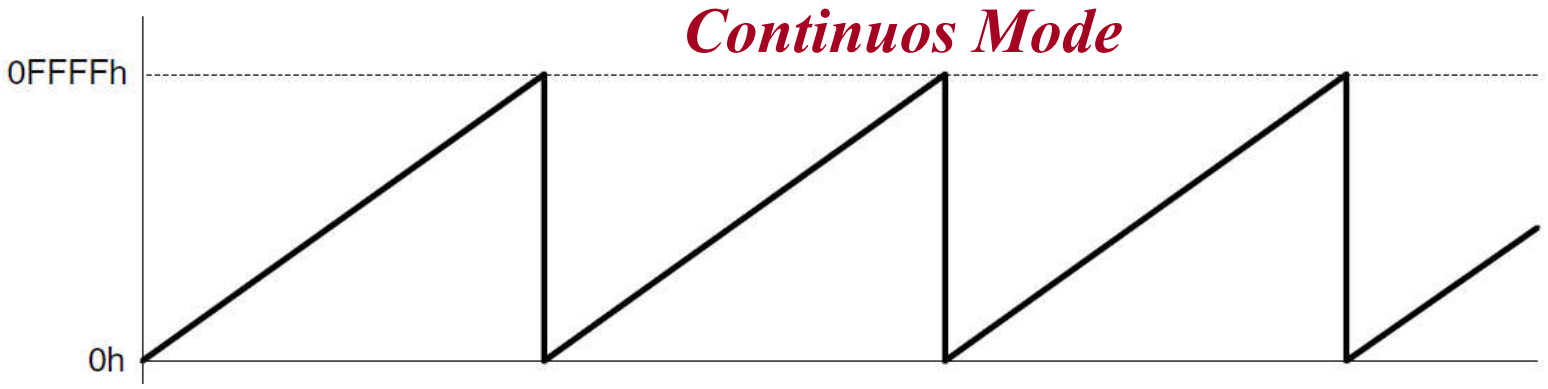
O *Timer* conta repetidamente até o valor armazenado no Registrador *TAxCCR0*.

Quando o *Timer* atinge o valor de comparação armazenado no Registrador *TAxCCR0*, a contagem é reiniciada a partir de zero.

A *flag* de interrupção *CCIFG* (registrador *TAxCCTL0*) é setada quando o *Timer* atinge o valor de comparação armazenado no Registrador *TAxCCR0*.

A *flag* de interrupção *TAIFG* (registrador *TAxCTL*) é setada quando o *Timer* passa do valor de comparação armazenado no Registrado *TAxCCR0* para zero.

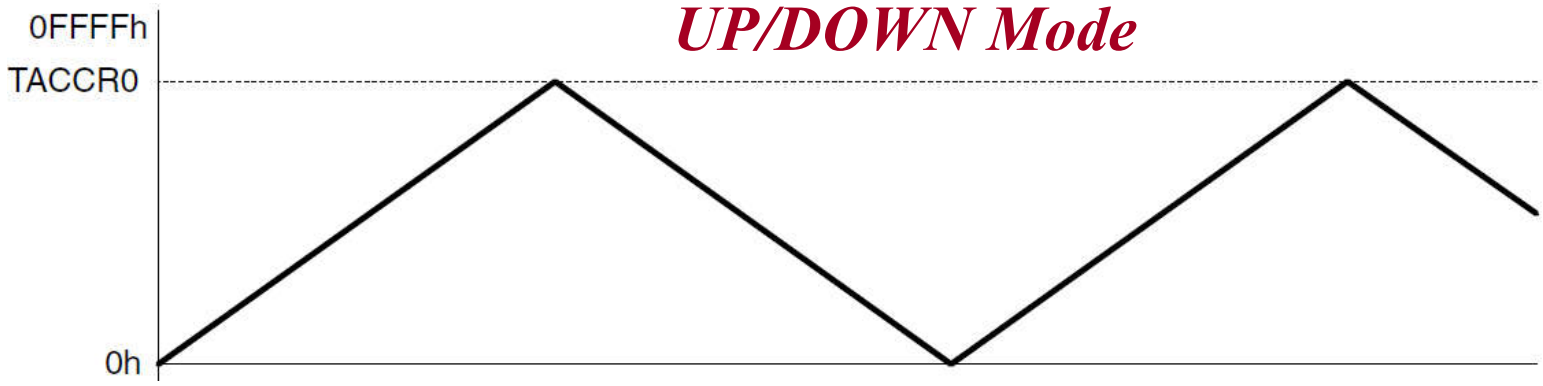
Modos de Contagem



O *Timer* conta repetidamente até 0xFFFF. Quando o *Timer* atinge 0xFFFF, a contagem é reiniciada a partir de zero.

A *flag* de interrupção *TAIFG* (registrador *TAxCTL*) é setada quando o *Timer* passa de 0xFFFF para zero.

Modos de Contagem



O *Timer* conta repetidamente de modo ascendente até o valor de comparação armazenado no Registrador *TAxCCR0* zero.

Quando atinge o valor de comparação (*TAxCCR0*) o *Timer* passa a contar de modo descendente até zero.

A *flag* de interrupção *CCIFG* é setada quando o *Timer* atinge o valor armazenado no Registrador de comparação *TAxCCR0*.

A *flag* de interrupção *TAIFG* é setada quando o *Timer* atinge o valor zero.

12.3.1 TACTL, Timer_A Control Register

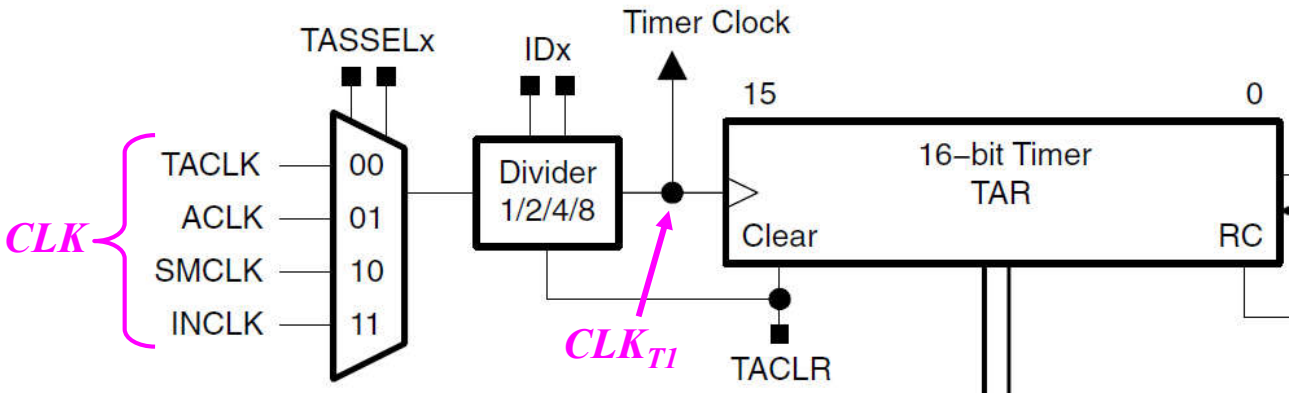
TA1CTL

15	14	13	12	11	10	9	8
Unused						TASSELx	
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)

7	6	5	4	3	2	1	0
IDx		MCx		Unused	TACLR	TAIE	TAIFG
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)

Unused	Bits 15-10	Unused
TASSELx	Bits 9-8	Timer_A clock source select
	00	TACLK
	01	ACLK
	10	SMCLK
	11	INCLK (INCLK is device-specific and is often assigned to the inverted TBCLK) (see the device-specific data sheet)
IDx	Bits 7-6	Input divider. These bits select the divider for the input clock.
	00	/1
	01	/2
	10	/4
	11	/8
MCx	Bits 5-4	Mode control. Setting MCx = 00h when Timer_A is not in use conserves power.
	00	Stop mode: the timer is halted.
	01	Up mode: the timer counts up to TACCR0.
	10	Continuous mode: the timer counts up to 0FFFFh.
	11	Up/down mode: the timer counts up to TACCR0 then down to 0000h.
Unused	Bit 3	Unused
TACLR	Bit 2	Timer_A clear. Setting this bit resets TAR, the clock divider, and the count direction. The TACLR bit is automatically reset and is always read as zero.
TAIE	Bit 1	Timer_A interrupt enable. This bit enables the TAIFG interrupt request.
	0	Interrupt disabled
	1	Interrupt enabled
TAIFG	Bit 0	Timer_A interrupt flag
	0	No interrupt pending
	1	Interrupt pending

Configuração do *clock* para o *TIMER1_A*



$$CLK_{T1} = CLK / div$$

Tempo para incrementar o *Timer1* (Período):

$$T_{T1} = 1 / CLK_{T1} = 1 / (CLK / div) = div / CLK$$

Considerando *CLK* = *SMCLK* e DCO = 1 MHz:

$$T_{T1} = div / 1.10^6 = div \times 10^{-6} = div\ \mu s$$

- $div = 1$ ➔ $T_{T1} = 1\ \mu s$
- $div = 2$ ➔ $T_{T1} = 2\ \mu s$
- $div = 4$ ➔ $T_{T1} = 4\ \mu s$
- $div = 8$ ➔ $T_{T1} = 8\ \mu s$

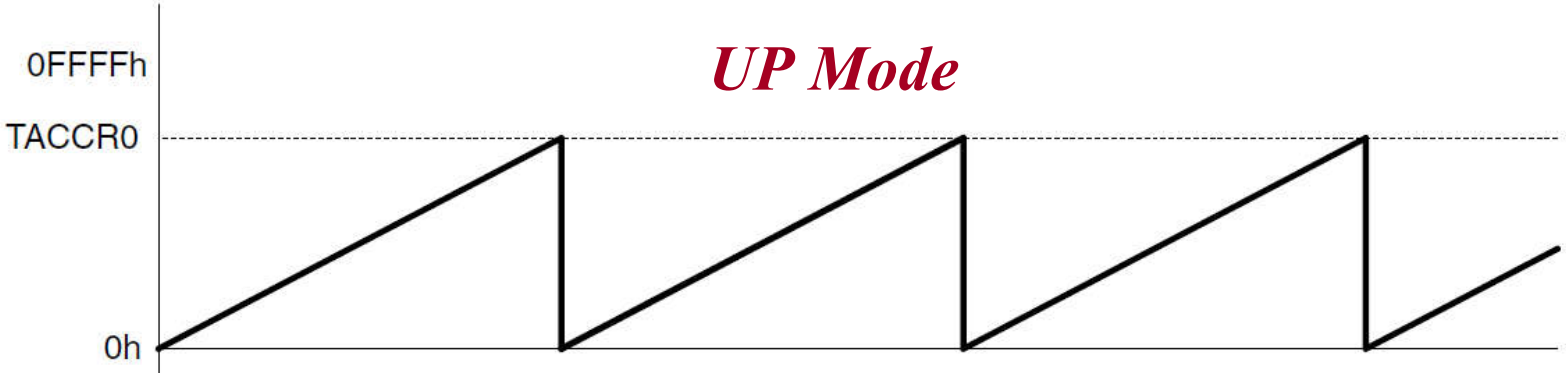
Número de incrementos do *Timer* necessários para temporizar 250*ms*

Considerando $div = 4$ ➔ $T_{T0} = 4\ \mu s$

Para temporizar t µs ➔ $4 \times N$ µs:

N: número de incrementos do *Timer*

$250000 = 4 \times N \longrightarrow N = 62500$



UP Mode

$TA1CCR0 = 62.500$

12.3.2 TAR, Timer_A Register

TAR1

15	14	13	12	11	10	9	8
TARx							
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)
7	6	5	4	3	2	1	0
TARx							
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)

TARx Bits 15-0 Timer_A register. The TAR register is the count of Timer_A.

12.3.3 TACCRx, Timer_A Capture/Compare Register x

TA1CCR0

15	14	13	12	11	10	9	8
TACCRx							
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)
7	6	5	4	3	2	1	0
TACCRx							
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)

TACCRx Bits 15-0 Timer_A capture/compare register.

Compare mode: TACCRx holds the data for the comparison to the timer value in the Timer_A Register, TAR.

Capture mode: The Timer_A Register, TAR, is copied into the TACCRx register when a capture is performed.

12.3.4 TACCTLx, Capture/Compare Control Register *TA1CCTL0*

15	14	13	12	11	10	9	8
CMx		**CCISx**		**SCS**	**SCCI**	**Unused**	**CAP**
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	r	r0	rw-(0)
7	6	5	4	3	2	1	0
OUTMODx			**CCIE**	**CCI**	**OUT**	**COV**	**CCIFG**

CMx Bit 15-14 Capture mode
- 00 No capture
- 01 Capture on rising edge
- 10 Capture on falling edge
- 11 Capture on both rising and falling edges

CCISx Bit 13-12 Capture/compare input select. These bits select the TACCRx input signal. See the device-specific data sheet for specific signal connections.
- 00 CCIxA
- 01 CCIxB
- 10 GND
- 11 V_{CC}

SCS Bit 11 Synchronize capture source. This bit is used to synchronize the capture input signal with the timer clock.
- 0 Asynchronous capture
- 1 Synchronous capture

SCCI Bit 10 Synchronized capture/compare input. The selected CCI input signal is latched with the EQUx signal and can be read via this bit

Unused Bit 9 Unused. Read only. Always read as 0.

CAP Bit 8 Capture mode
- 0 Compare mode
- 1 Capture mode

12.3.4 TACCTLx, Capture/Compare Control Register

TA1CCTL0

15	14	13	12	11	10	9	8
CMx		CCISx		SCS	SCCI	Unused	CAP
rw-(0)	rw-(0)	rw-(0)	rw-(0)	rw-(0)	r	r0	rw-(0)
7	6	5	4	3	2	1	0
OUTMODx			CCIE	CCI	OUT	COV	CCIFG

OUTMODx Bits 7-5 Output mode. Modes 2, 3, 6, and 7 are not useful for TACCR0, because EQUx = EQU0.

- 000 OUT bit value
- 001 Set
- 010 Toggle/reset
- 011 Set/reset
- 100 Toggle
- 101 Reset
- 110 Toggle/set
- 111 Reset/set

CCIE Bit 4 Capture/compare interrupt enable. This bit enables the interrupt request of the corresponding CCIFG flag.

- 0 Interrupt disabled
- 1 Interrupt enabled

CCI Bit 3 Capture/compare input. The selected input signal can be read by this bit.

OUT Bit 2 Output. For output mode 0, this bit directly controls the state of the output.

- 0 Output low
- 1 Output high

COV Bit 1 Capture overflow. This bit indicates a capture overflow occurred. COV must be reset with software.

- 0 No capture overflow occurred
- 1 Capture overflow occurred

CCIFG Bit 0 Capture/compare interrupt flag

- 0 No interrupt pending
- 1 Interrupt pending

Vetores de Interrupções do MSP430G2553

INTERRUPT SOURCE	INTERRUPT FLAG	SYSTEM INTERRUPT	WORD ADDRESS	PRIORITY
Power-Up External Reset Watchdog Timer+ Flash key violation PC out-of-range(1)	PORIFG RSTIFG WDTIFG KEYV(2)	Reset	0FFFEh	31, highest
NMI Oscillator fault Flash memory access violation	NMIIFG OFIFG ACCVIFG(2)(3)	(non)-maskable (non)-maskable (non)-maskable	0FFFCh	30
Timer1_A3	TA1CCR0 CCIFG(4)	maskable	0FFFAh	29
Timer1_A3	TA1CCR2 TA1CCR1 CCIFG, TAIFG(2)(4)	maskable	0FFF8h	28
Comparator_A+	CAIFG(4)	maskable	0FFF6h	27
Watchdog Timer+	WDTIFG	maskable	0FFF4h	26
Timer0_A3	TA0CCR0 CCIFG(4)	maskable	0FFF2h	25
Timer0_A3	TA0CCR2 TA0CCR1 CCIFG, TAIFG (5)(4)	maskable	0FFF0h	24
USCI_A0/USCI_B0 receive USCI_B0 I2C status	UCA0RXIFG, UCB0RXIFG(2)(5)	maskable	0FFEEh	23
USCI_A0/USCI_B0 transmit USCI_B0 I2C receive/transmit	UCA0TXIFG, UCB0TXIFG(2)(6)	maskable	0FFECh	22
ADC10 (MSP430G2x53 only)	ADC10IFG(4)	maskable	0FFEAh	21
			0FFE8h	20
I/O Port P2 (up to eight flags)	P2IFG.0 to P2IFG.7(2)(4)	maskable	0FFE6h	19
I/O Port P1 (up to eight flags)	P1IFG.0 to P1IFG.7(2)(4)	maskable	0FFE4h	18

Vetores de Interrupção:

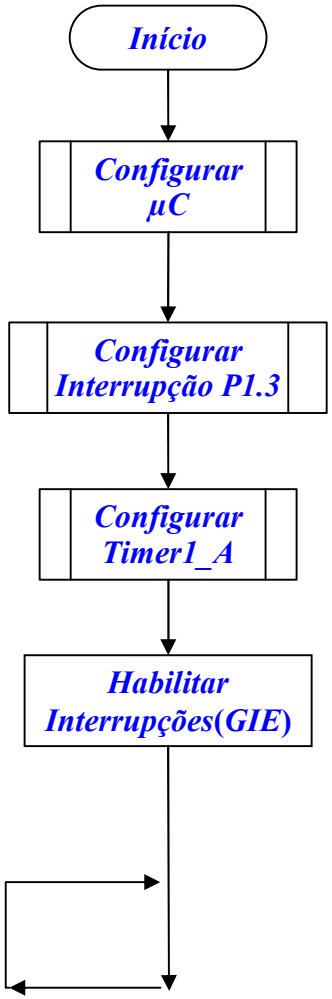
```
ORG    0xFFE4    (ASEG  0xFFE4)
DC16   interrupcao_P1

ORG    0xFFFA    (ASEG  0xFFFA)
DC16   interrupcao_TA1
```

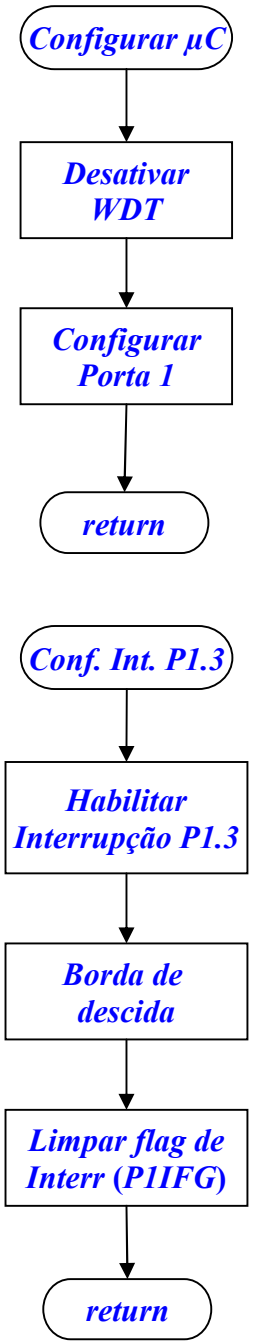
Rotina de Interrupção da Porta 1:

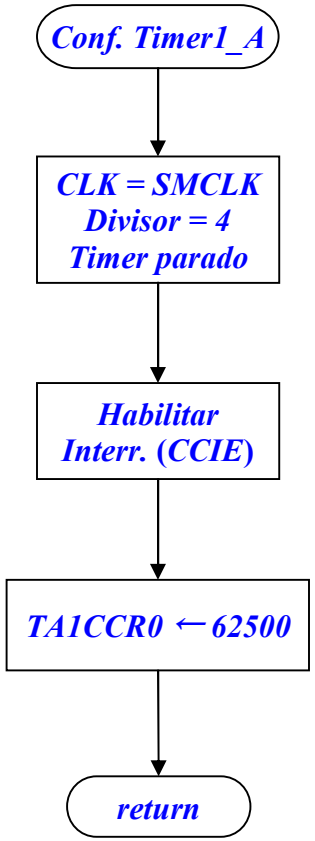
```
interrupcao_P1:
        . . .
        . . .
        bic.b  #BIT3, &P1IFG    ; Limpar flag de interrupção
        reti
```

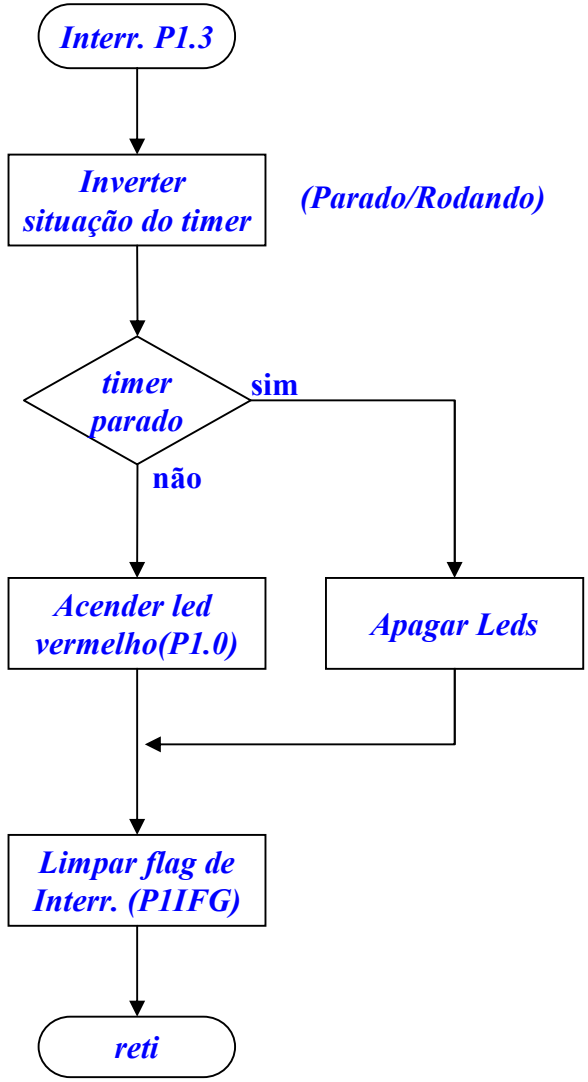
Rotina de Interrupção do Timer1_A:

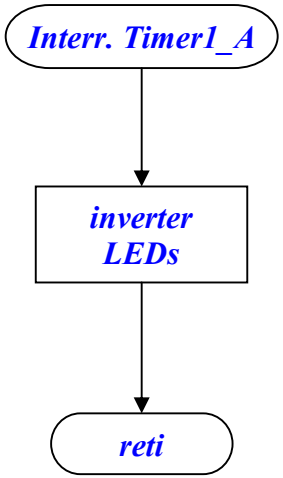
```
interrupcao_TA1:
        . . .
        . . .
        reti
```


Início
Configurar µC
Configurar Interrupção P1.3
Configurar Timer1_A
Habilitar Interrupções(GIE)


Configurar µC
Desativar WDT
Configurar Porta 1
return
Conf. Int. P1.3
Habilitar Interrupção P1.3
Borda de descida
Limpar flag de Interr (P1IFG)
return


Conf. Timer1_A
CLK = SMCLK
Divisor = 4
Timer parado
Habilitar Interr. (CCIE)
TA1CCR0 ← 62500
return


Interr. P1.3
Inverter situação do timer
(Parado/Rodando)
timer parado
sim
não
Acender led vermelho(P1.0)
Apagar Leds
Limpar flag de Interr. (P1IFG)
reti


Interr. Timer1_A
inverter LEDs
reti