TIMER & Pulse-Width Modulation

Embedded System 2561, KU CSC

Adapted by Sorayut Glomglome

Outline

1. Basic Block Diagram
2. Advanced-control Timer
3. Pulse-width Modulation
4. General Purpose Timer
5. SysTick Timer
6. Watchdog Timer

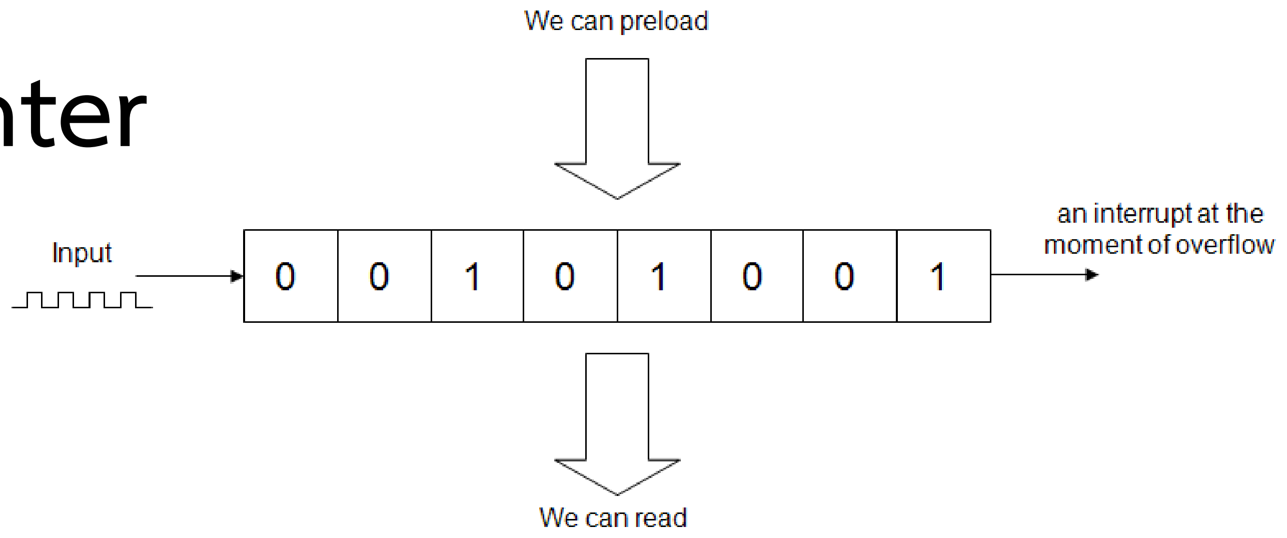
Learning Outcomes

1. Explain the use of timer
2. Config timing interrupt for specific period
3. Generate pulse-width modulation signal with specific duty cycle

Applications

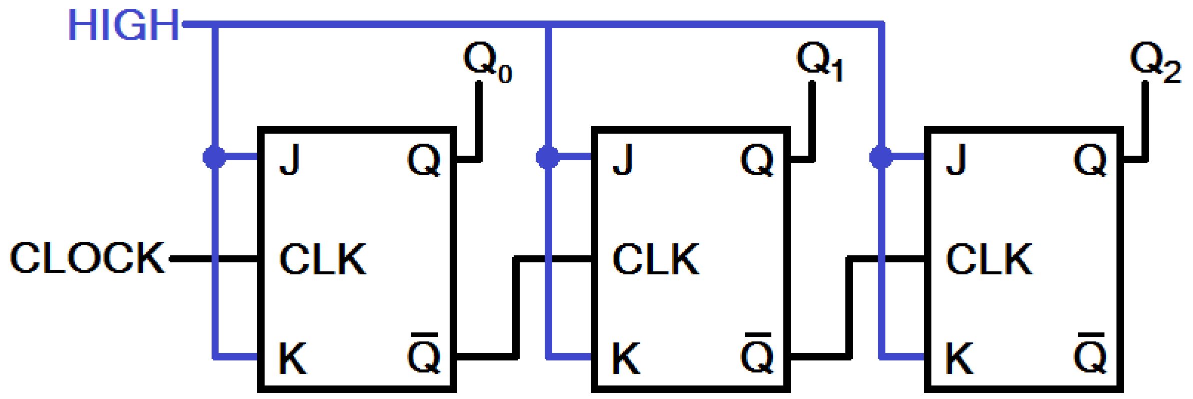
- Interval Timer for counting internal events.
- Pulse Width Demodulator via Capture inputs.
- Free running timer.

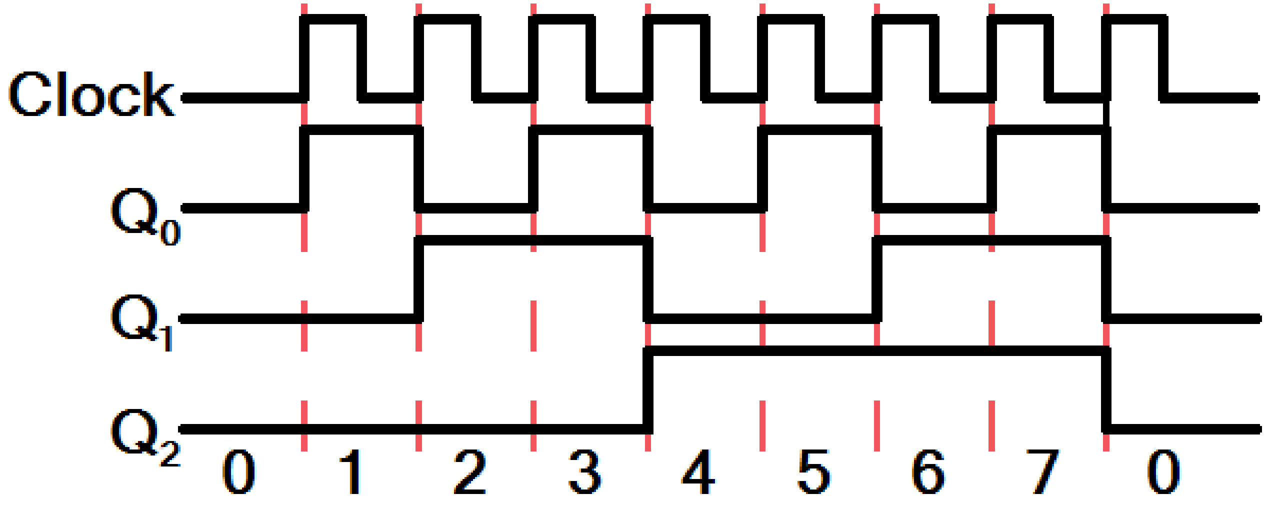
The Digital Counter



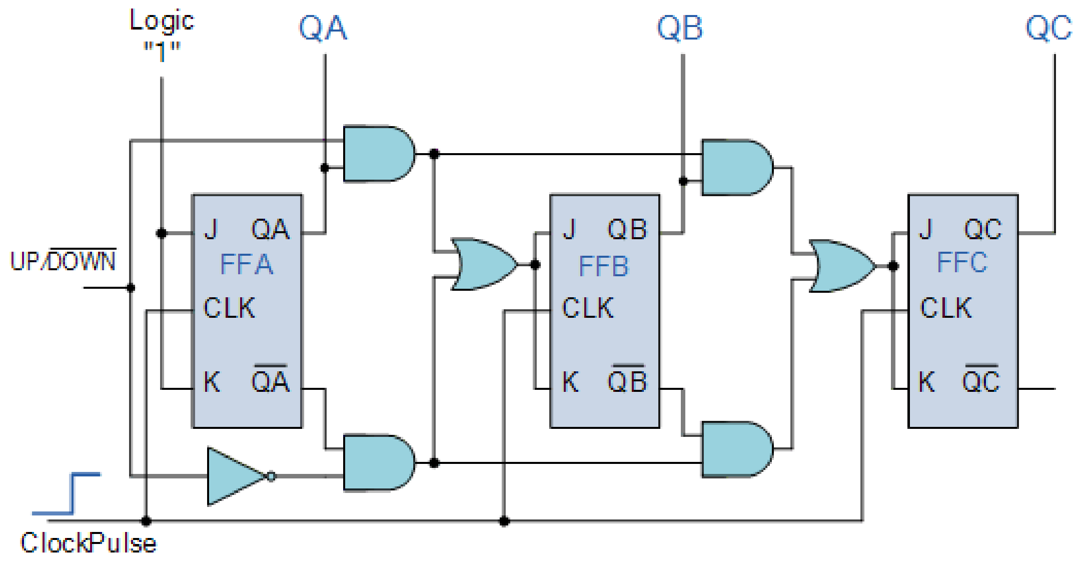
- n-bit counter can count from 0 to (2^n – 1)
- 8-bit counter can count from 0000 0000 to 1111 1111 or 0 to 255
- Overflow then start over; 0 → 255 →0
- Counting is according to clock pulses

3-bit Up Counter

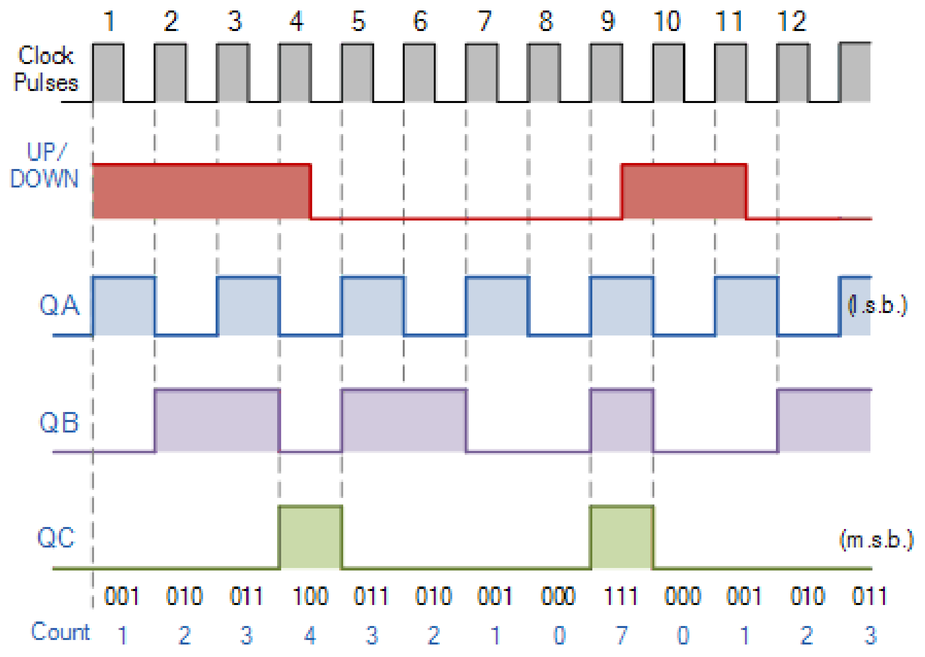




3-bit Synchronous Up/Down Counter

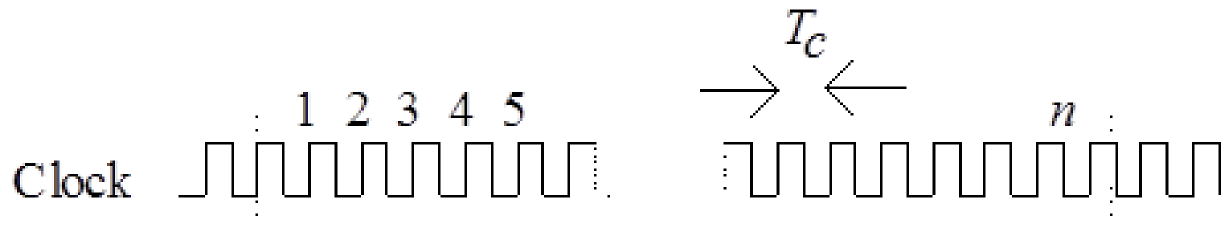


Logic "1"
QA
QB
QC
UP/$\overline{\text{DOWN}}$
J QA FFA CLK K $\overline{\text{QA}}$
J QB FFB CLK K $\overline{\text{QB}}$
J QC FFC CLK K $\overline{\text{QC}}$
ClockPulse



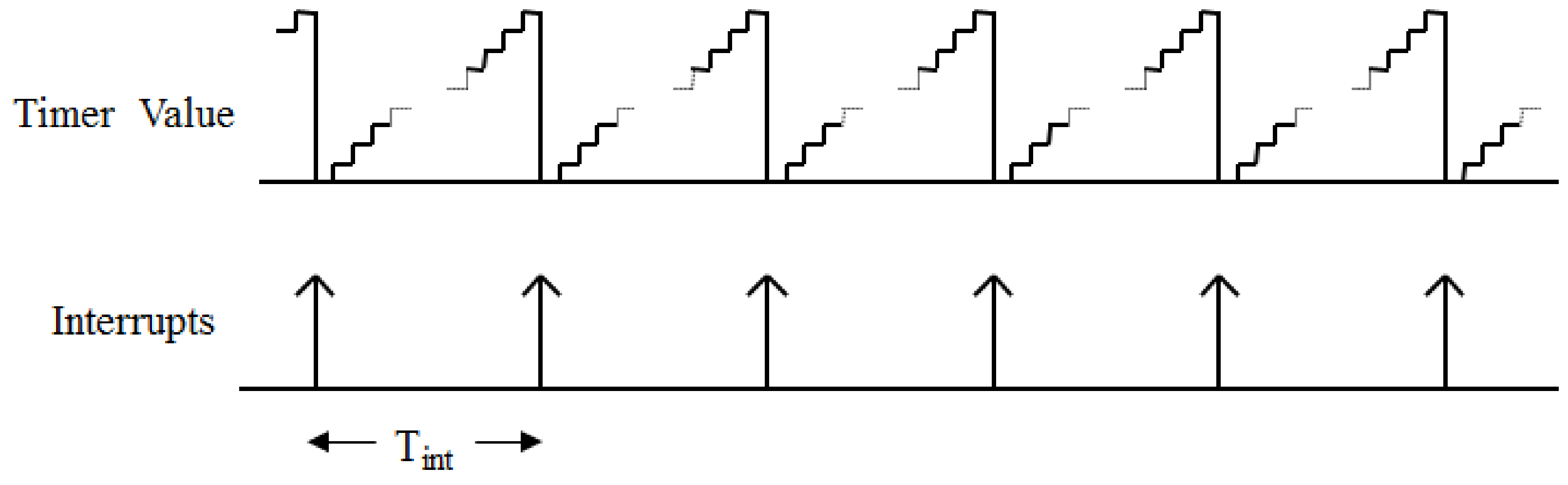
Counting and Timing

- An 8 bit counter with 1 MHz clock frequency.
- Clock period is 1 µs.
- Counting from 0➔255 ➔0 takes 256*1 µs

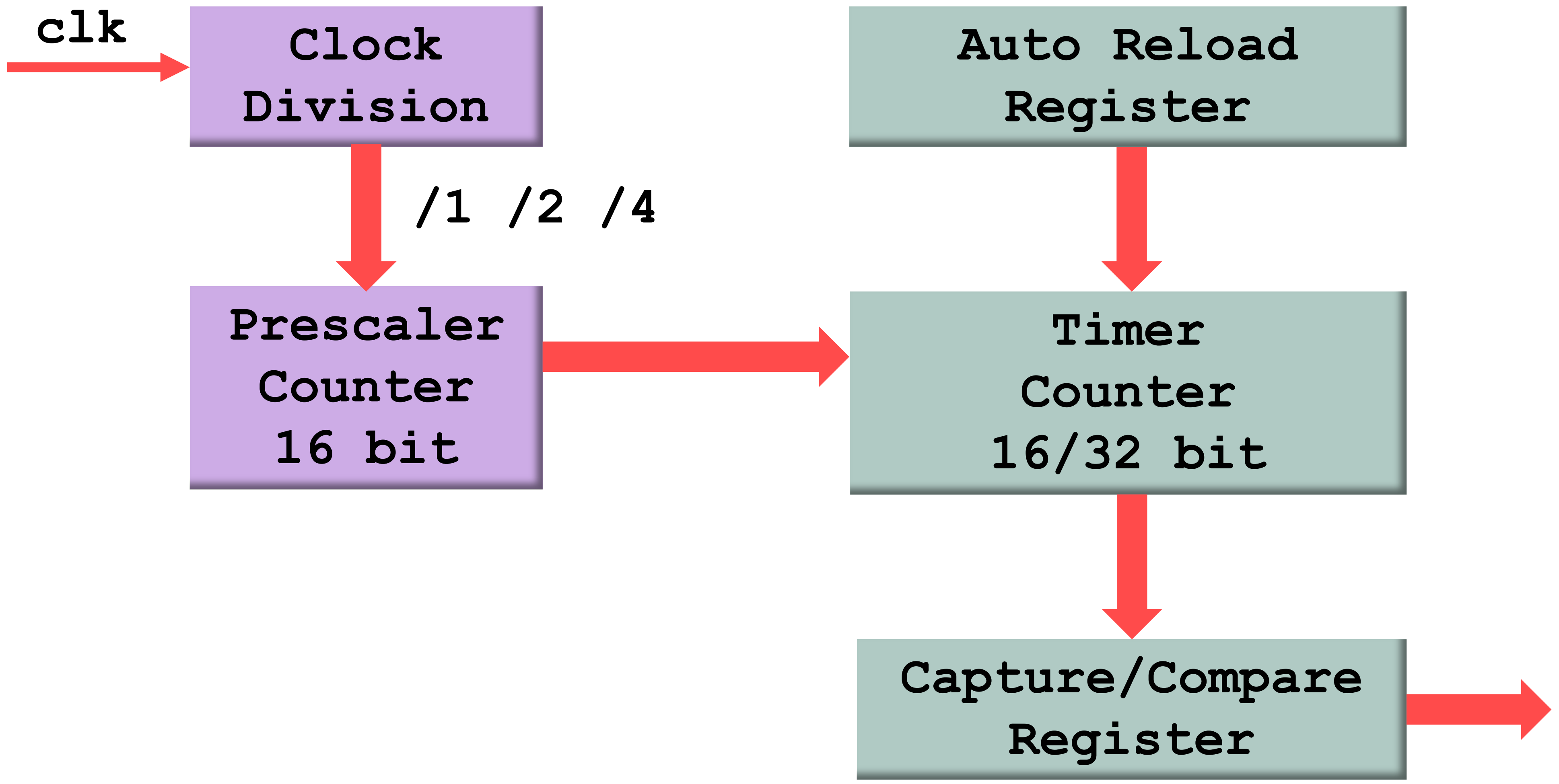


Counting and Timing – Interrupt on Overflow

- A counter overflow (0➔255 ➔0) can generate an interrupt signal.
- If a counter continues counting after an overflow, then interrupt signals will occur repeatedly.



Timer Basic Block Diagram



Time Interval

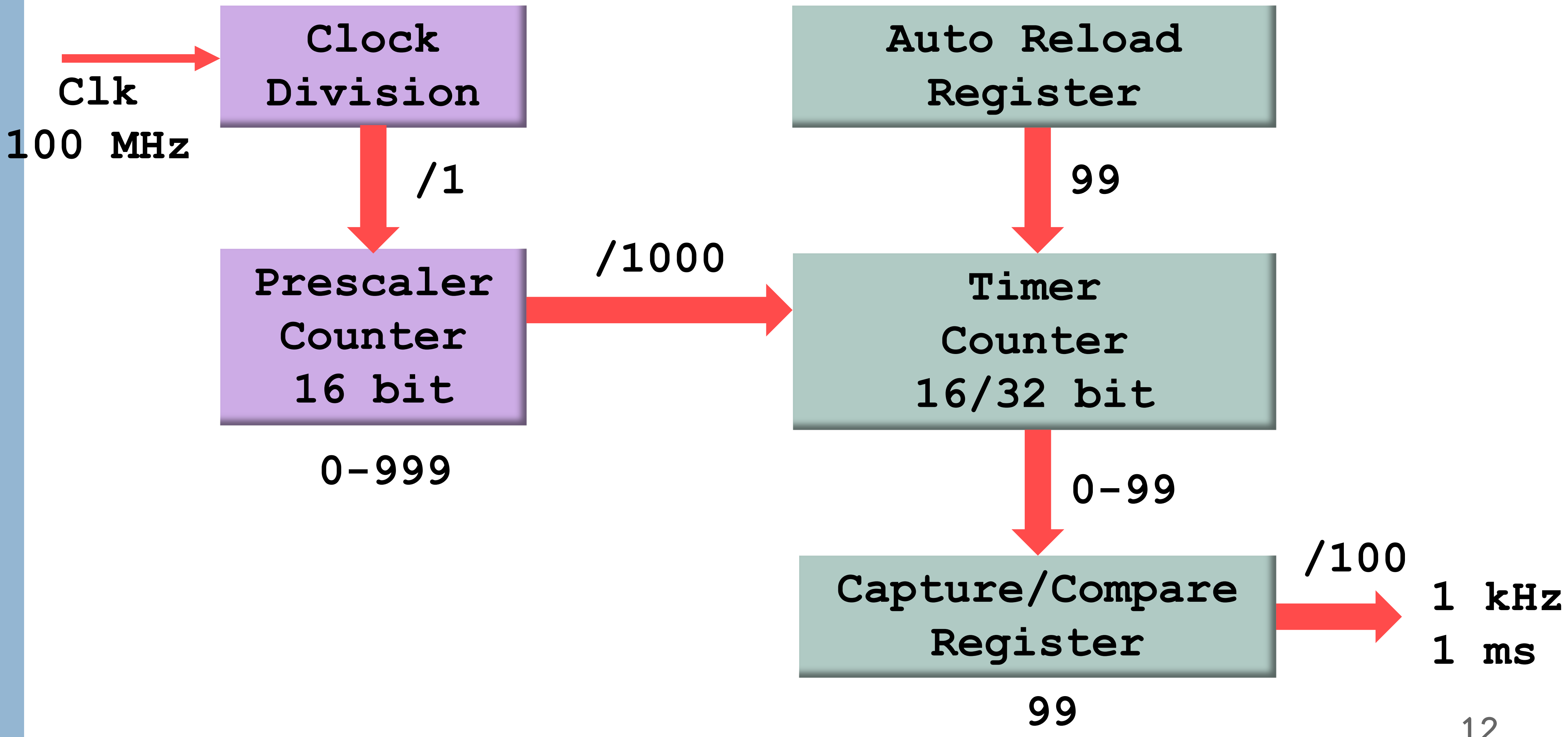
$$\frac{Timer\ Clock\ Speed\ (Hz)}{Clock\ Division \times Prescaler \times Period} = Interrupt\ Frequency\ (Hz)$$

1, 2, 4 16 bit 16/32 bit

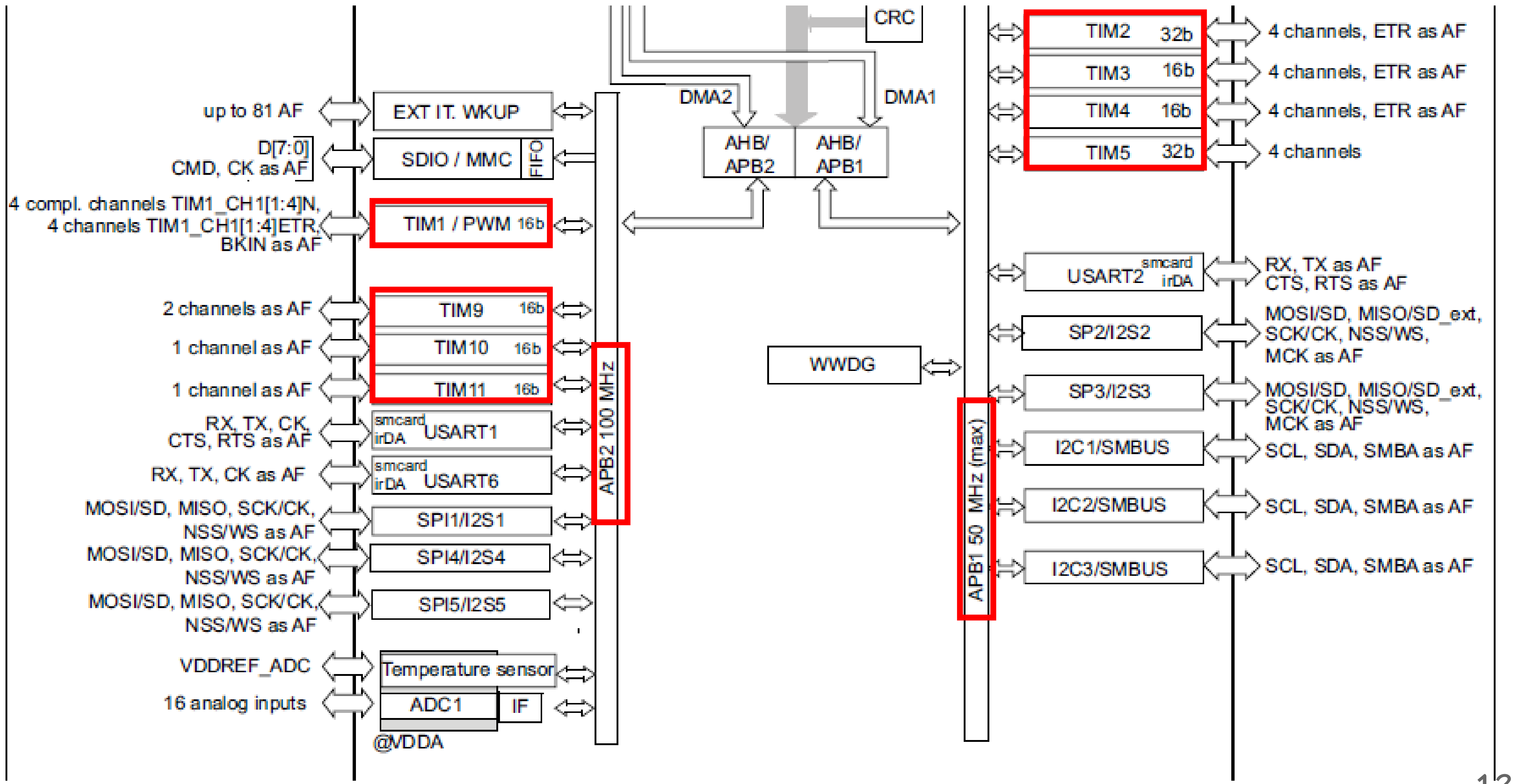
$$\frac{100\ MHz}{1 \times 100 \times 1000} = 1\ kHz$$

$$Time\ Interval = 1\ ms$$

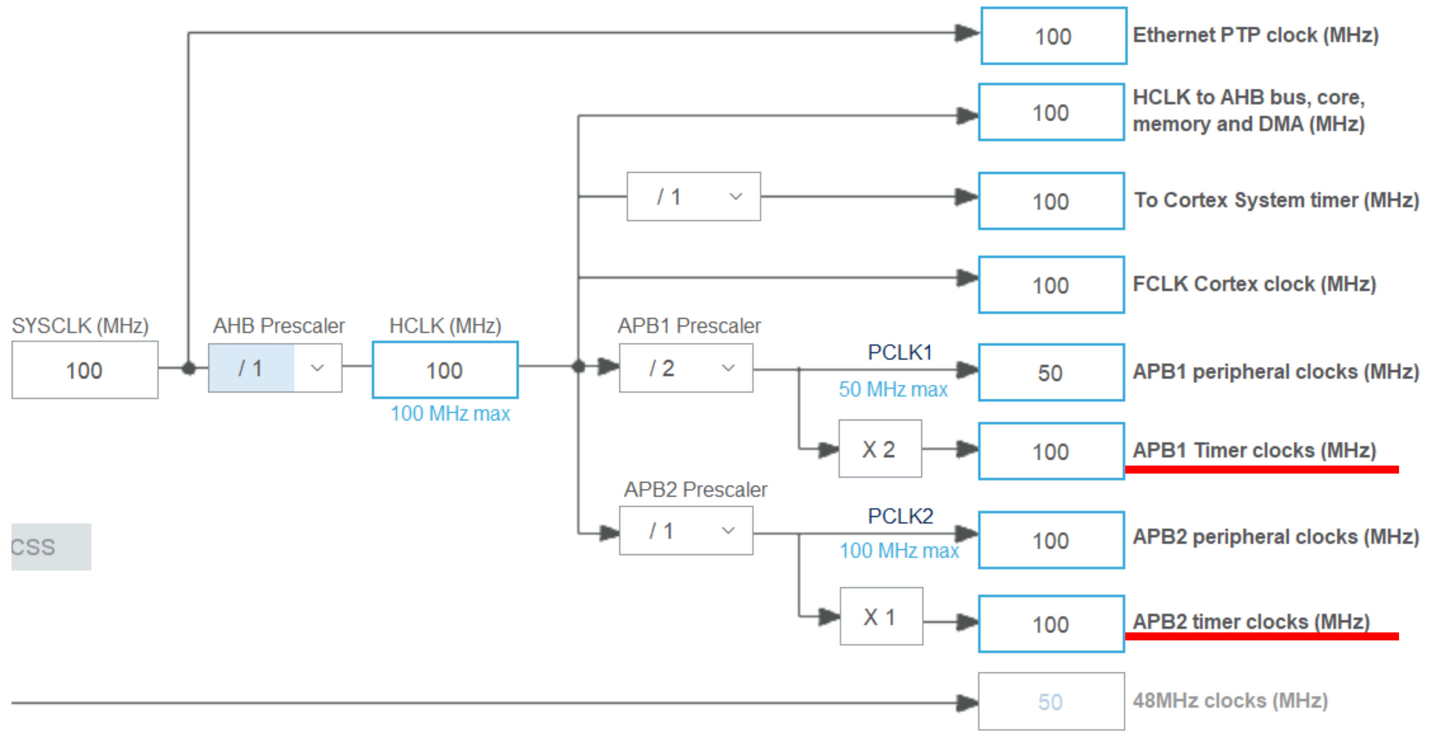
Timer Basic Block Diagram

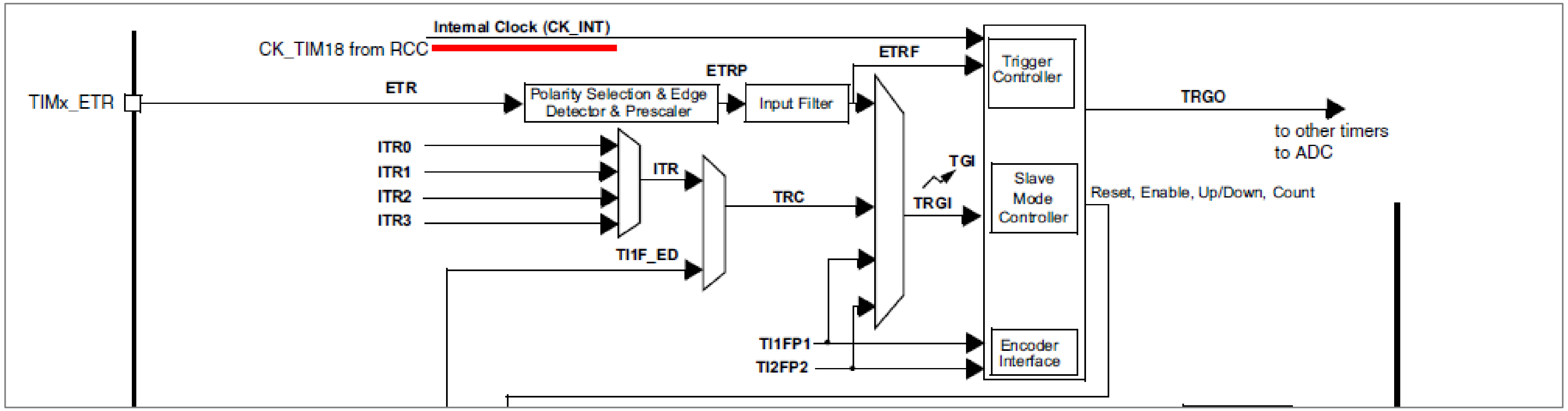


STM32F411 Timers

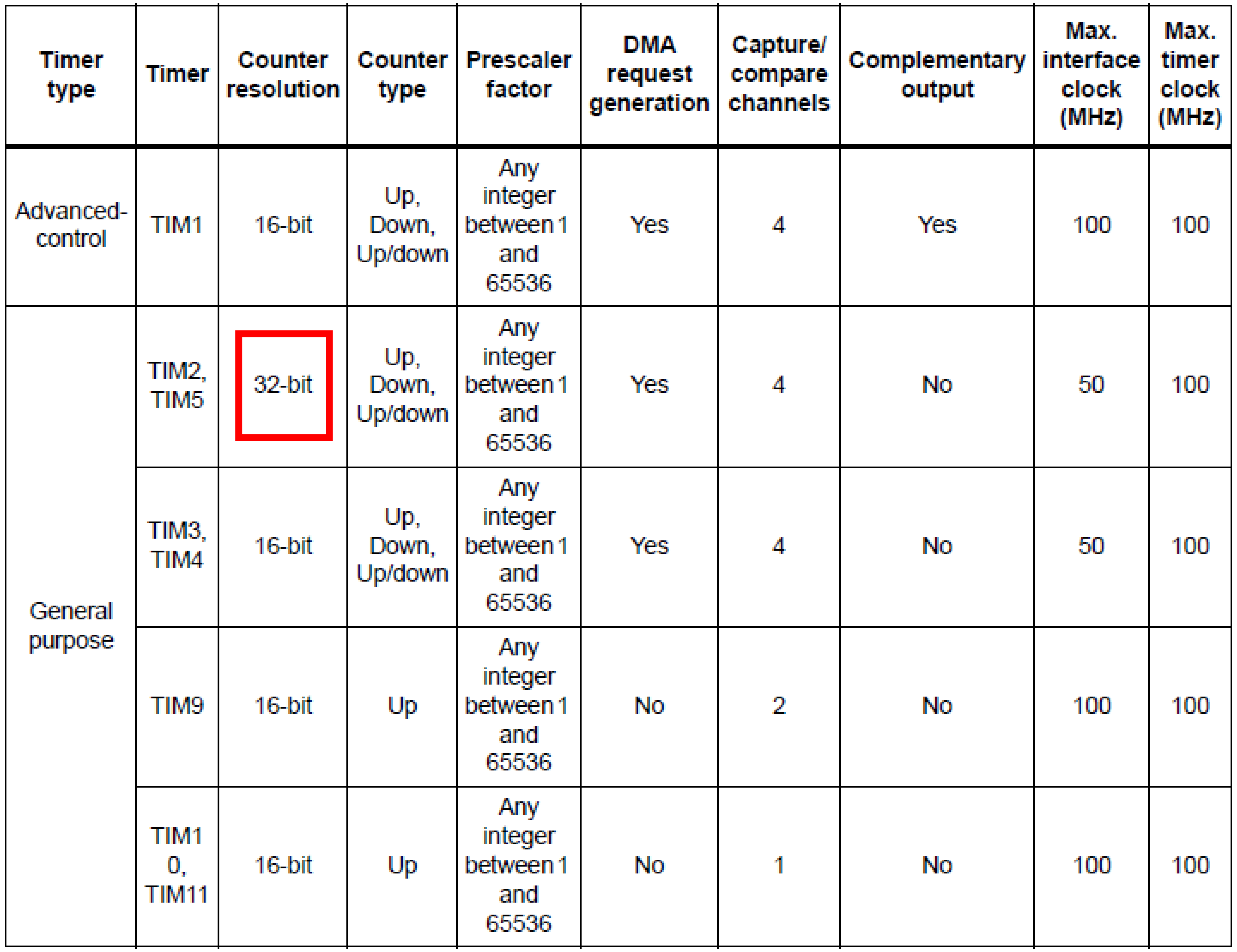


Clock Signal





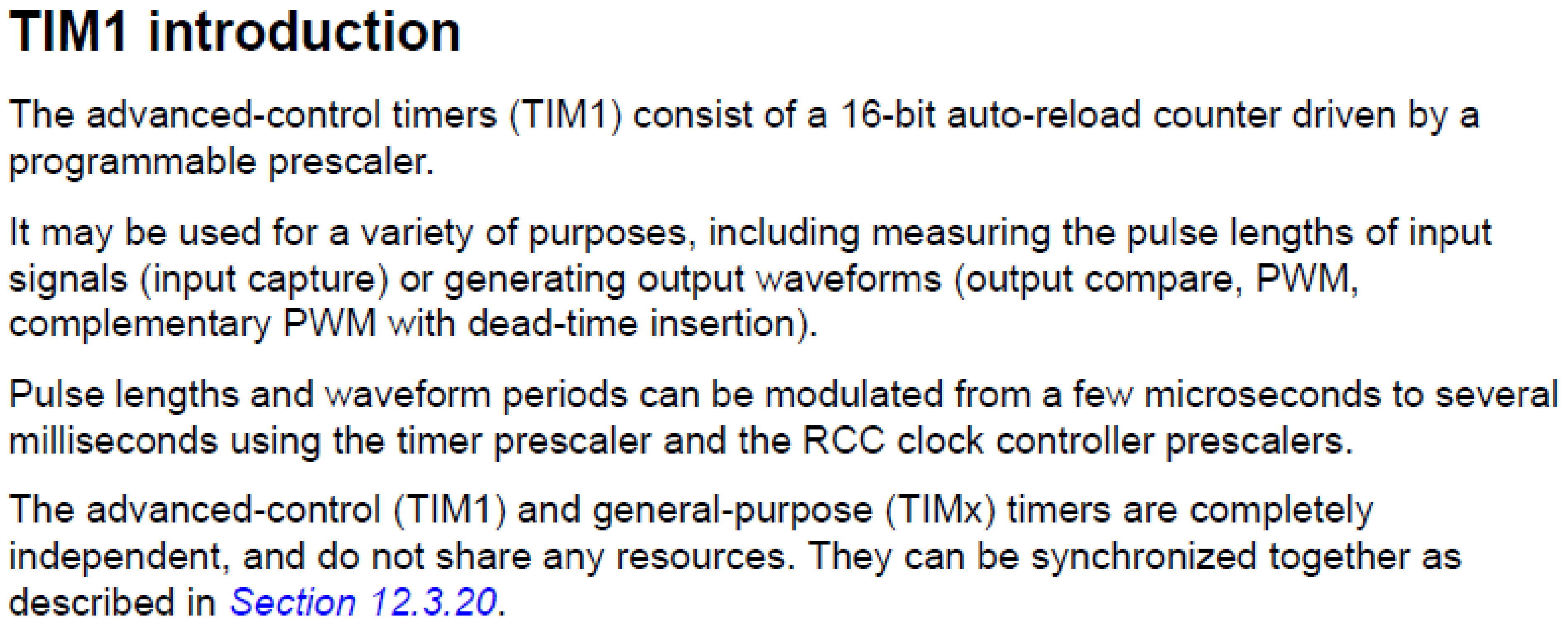
STM32F411 Timers



Timer type	Timer	Counter resolution	Counter type	Prescaler factor	DMA request generation	Capture/ compare channels	Complementary output	Max. interface clock (MHz)	Max. timer clock (MHz)
Advanced-control	TIM1	16-bit	Up, Down, Up/down	Any integer between 1 and 65536	Yes	4	Yes	100	100
General purpose	TIM2, TIM5	32-bit	Up, Down, Up/down	Any integer between 1 and 65536	Yes	4	No	50	100
	TIM3, TIM4	16-bit	Up, Down, Up/down	Any integer between 1 and 65536	Yes	4	No	50	100
	TIM9	16-bit	Up	Any integer between 1 and 65536	No	2	No	100	100
	TIM10, TIM11	16-bit	Up	Any integer between 1 and 65536	No	1	No	100	100

- 1 Advanced-control timer
- 7 General-purpose timers
- 2 Watchdog timers
- 1 System Timer

Advanced-control timer – TIM1



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.

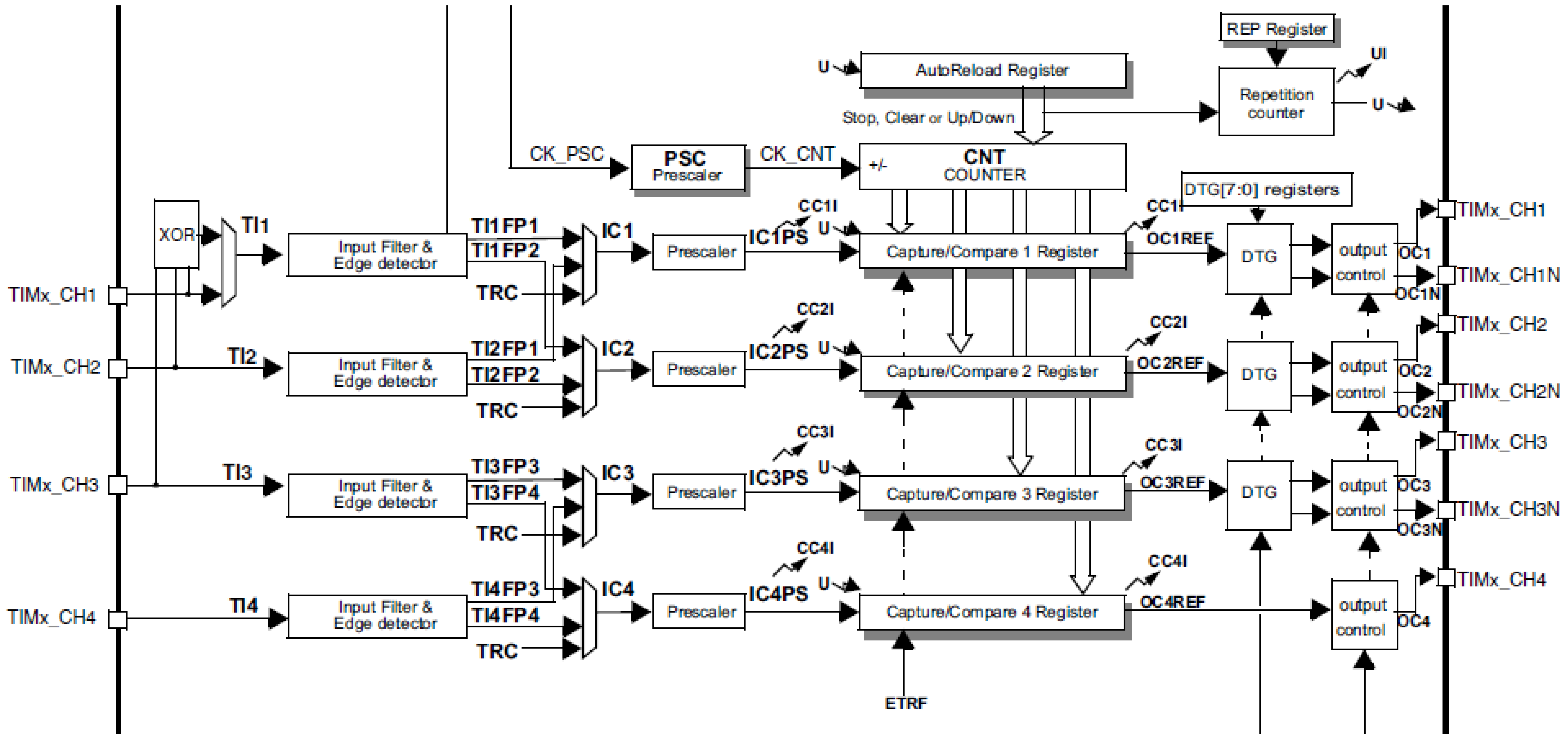
The advanced-control (TIM1) and general-purpose (TIMx) timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 12.3.20*.

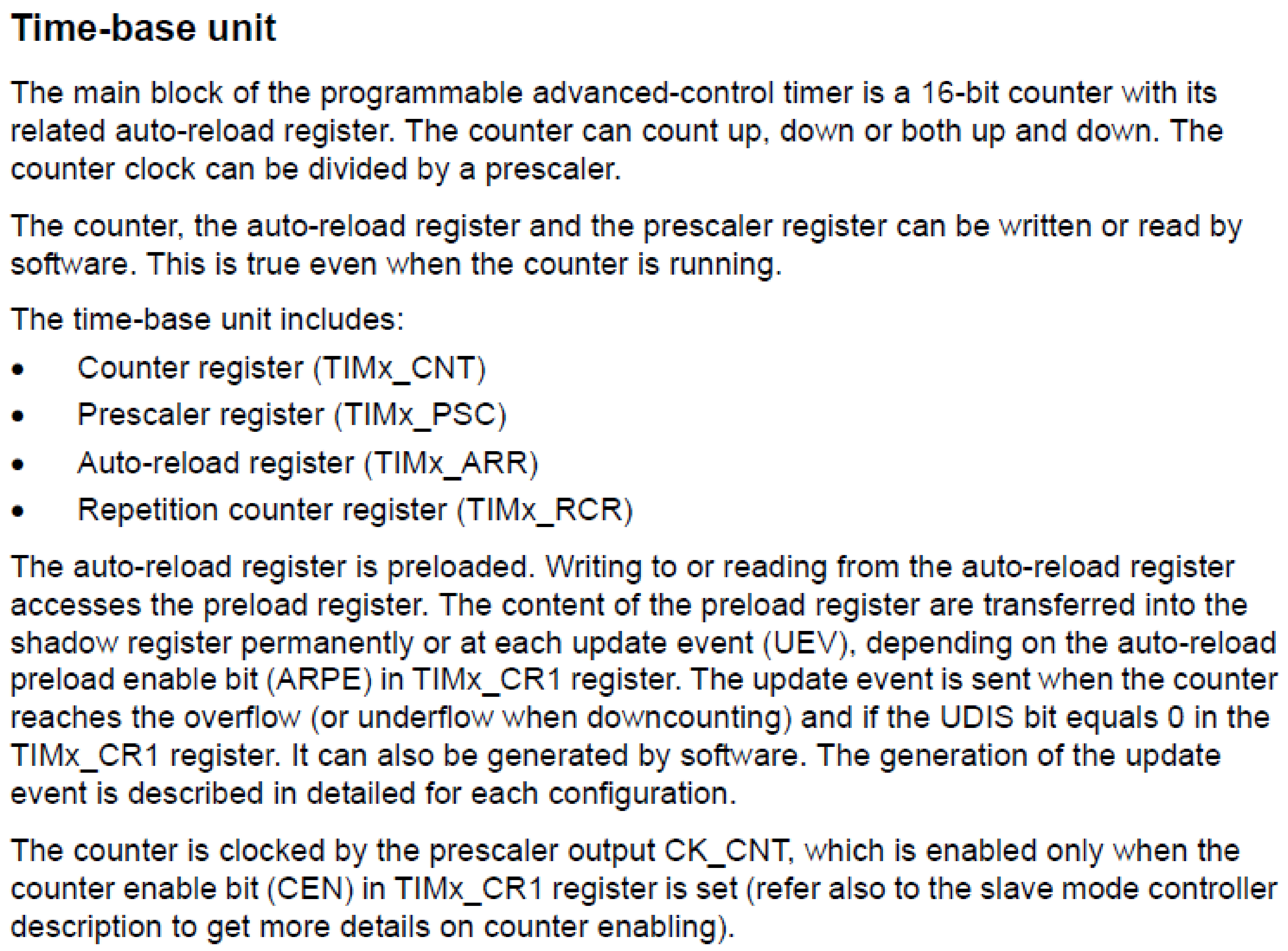
TIM1 main features

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.

Timer Block Diagram – Advanced Timer





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)

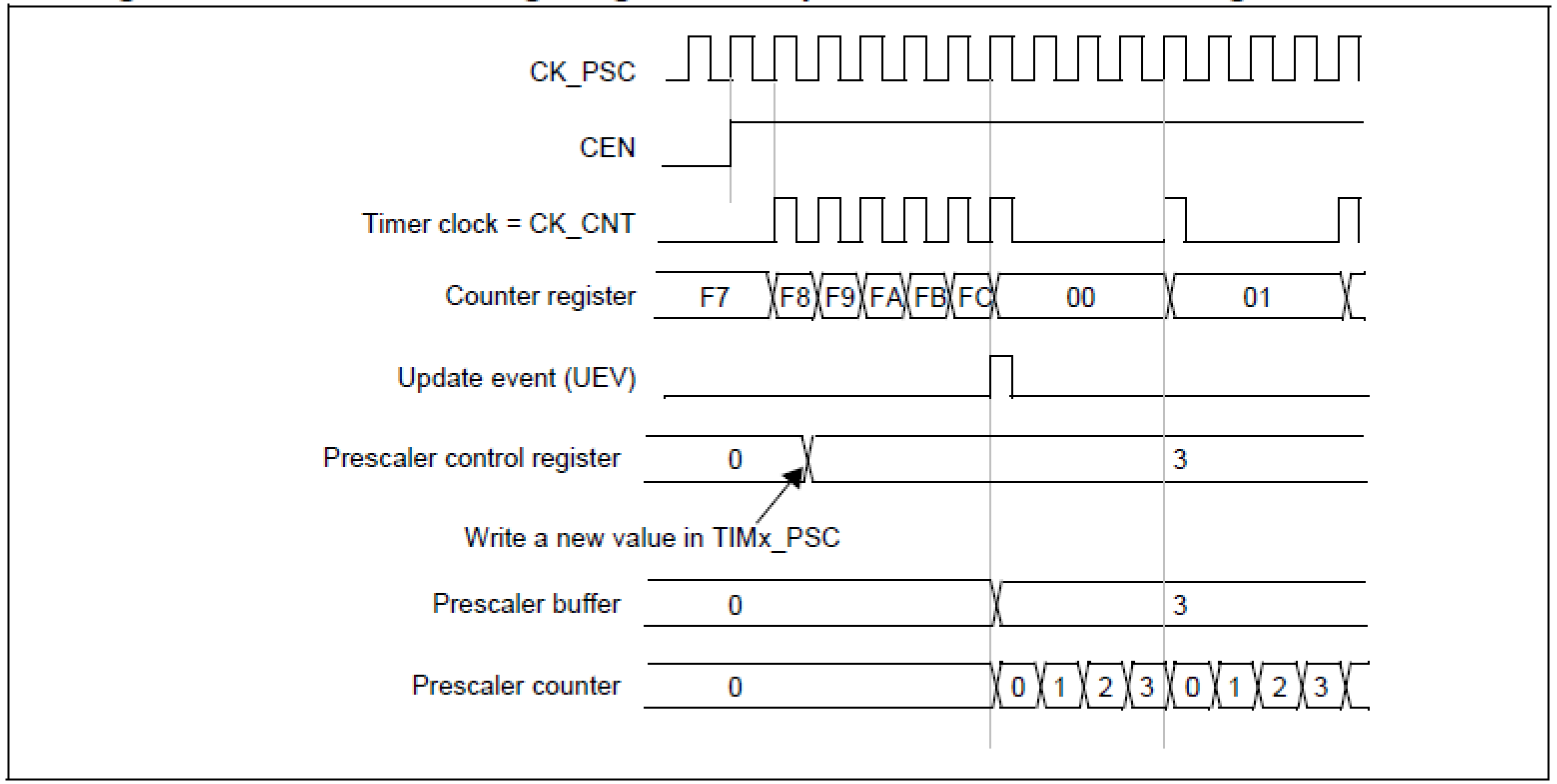
The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx_CR1 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).

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 41. Counter timing diagram with prescaler division change from 1 to 4



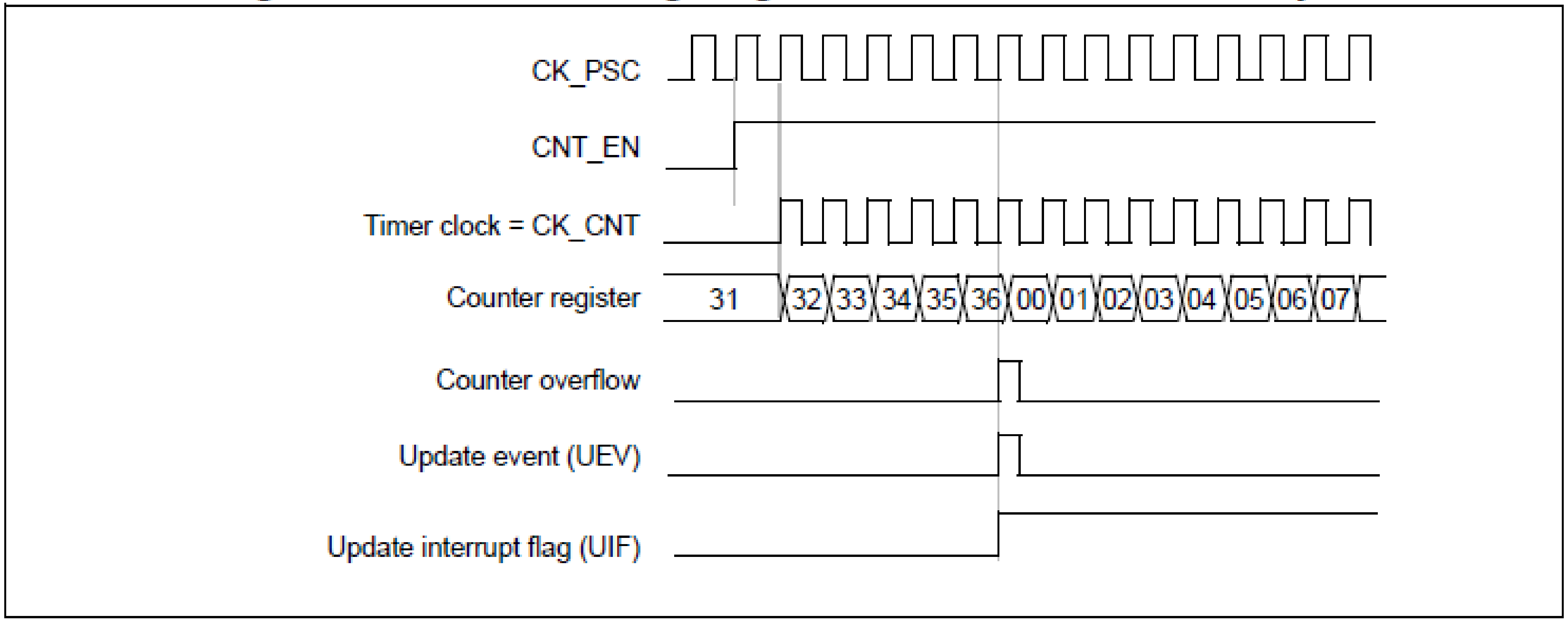
Up Counting Mode

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.

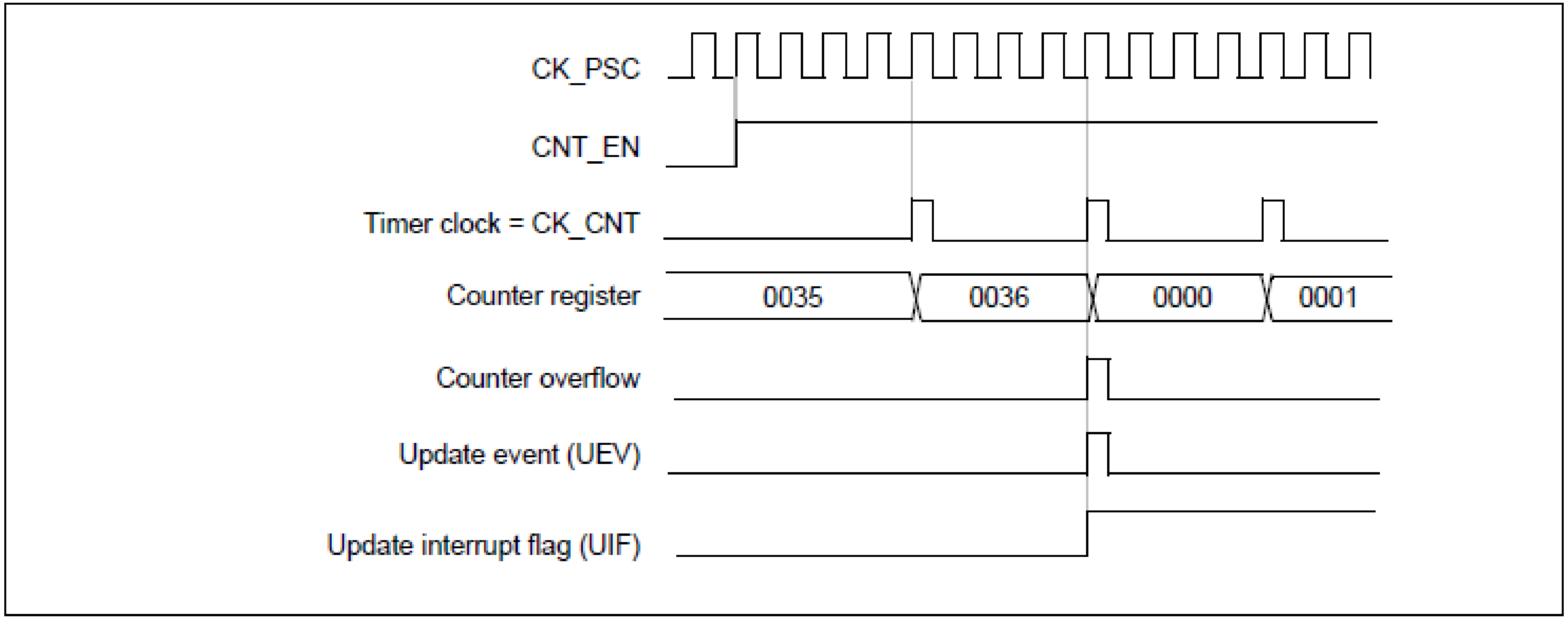
Up counting Mode, TIMx_ARR = 0x36

Figure 42. Counter timing diagram, internal clock divided by 1



Up counting Mode, TIMx_ARR = 0x36

Figure 44. Counter timing diagram, internal clock divided by 4



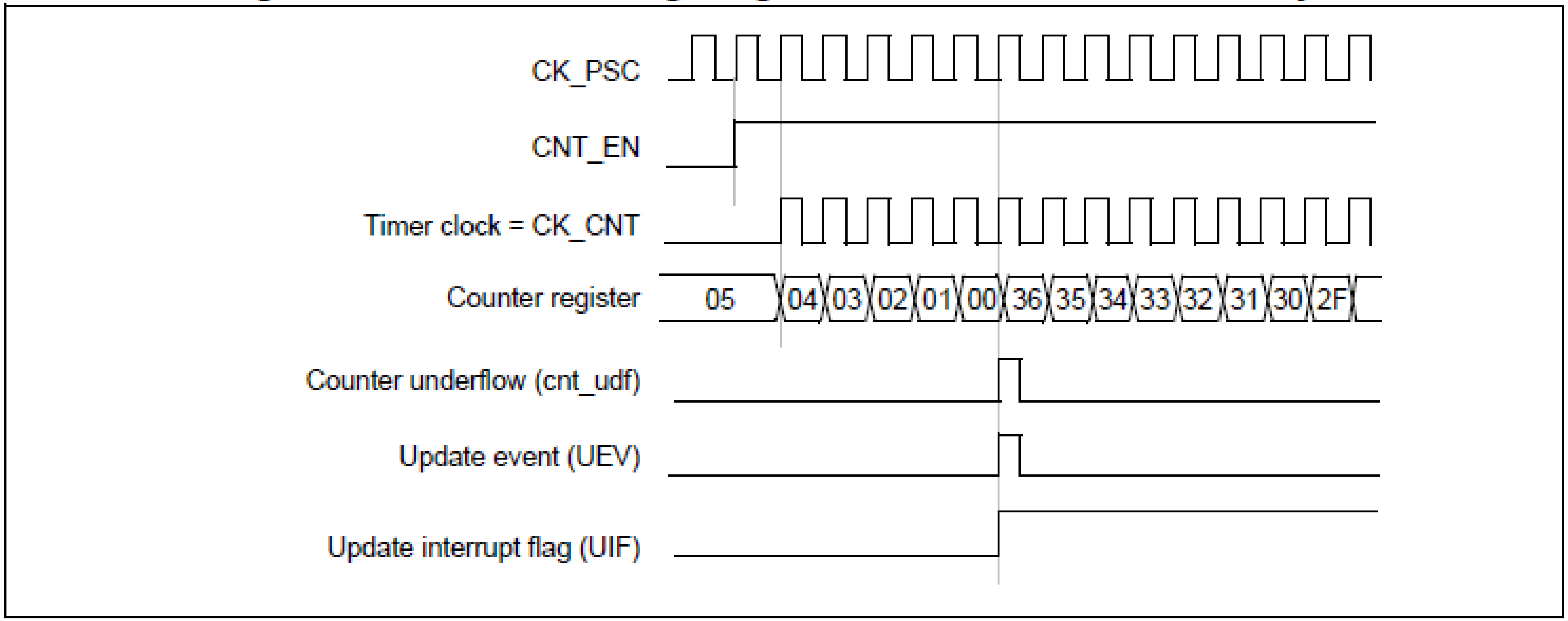
Down Counting Mode

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.

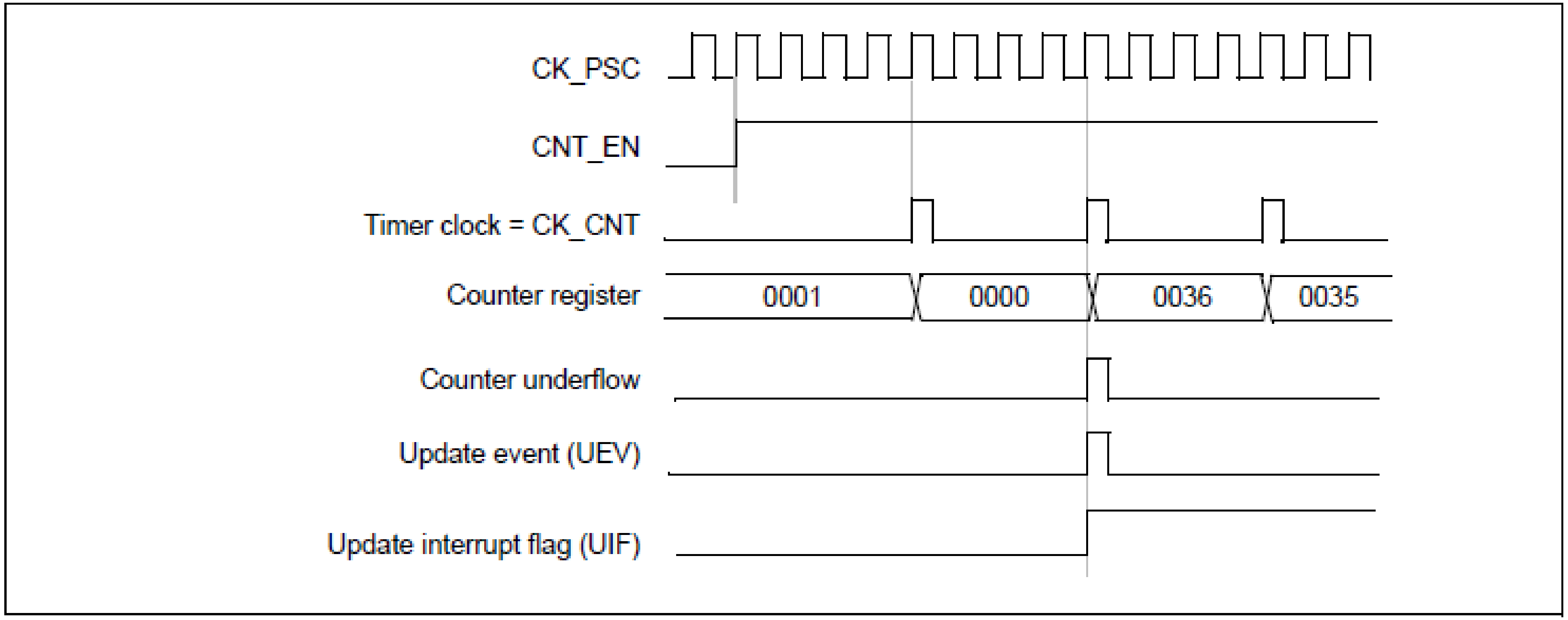
Down Counting Mode, TIMx_ARR = 0x36

Figure 48. Counter timing diagram, internal clock divided by 1



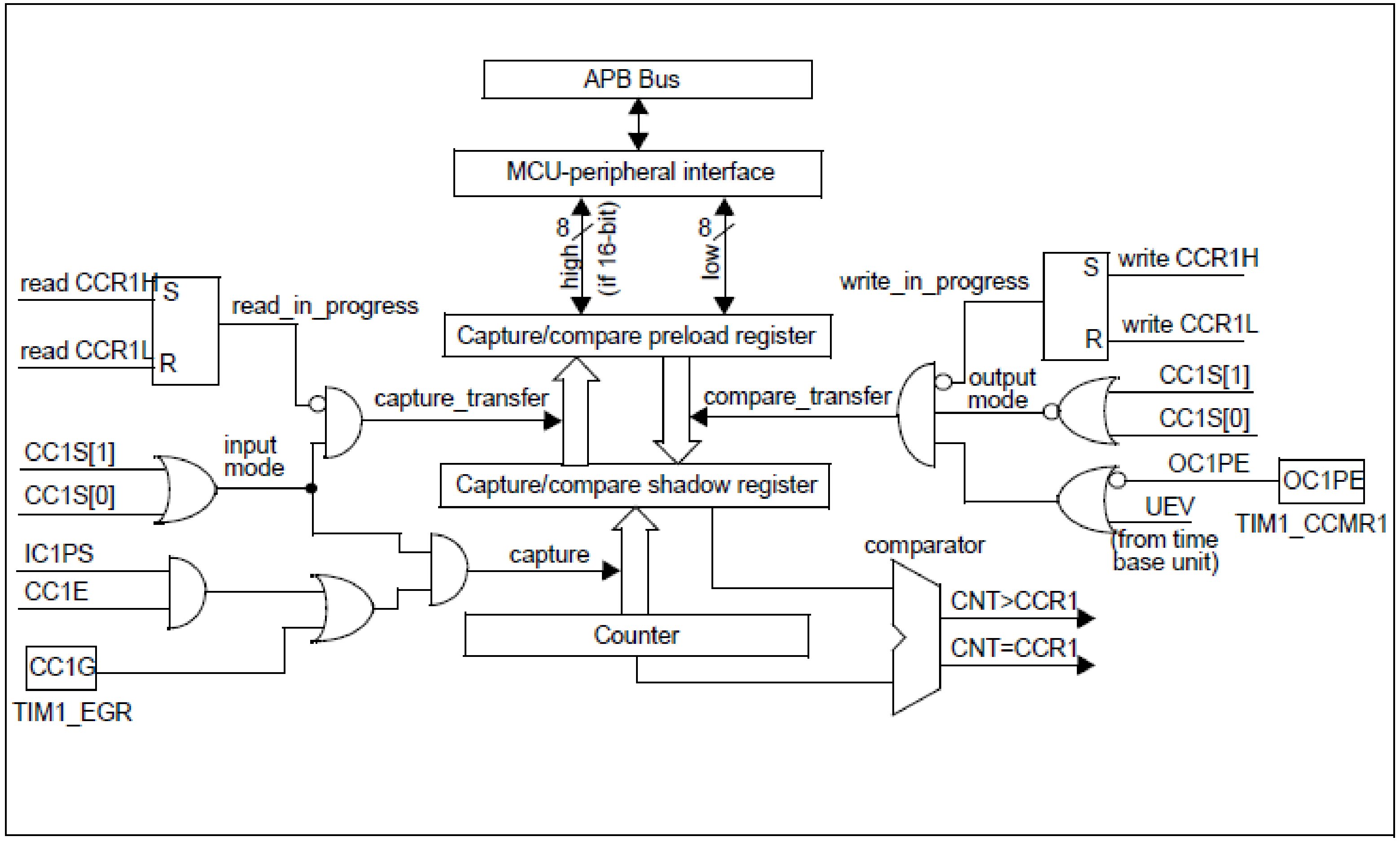
Down Counting Mode, TIMx_ARR = 0x36

Figure 50. Counter timing diagram, internal clock divided by 4



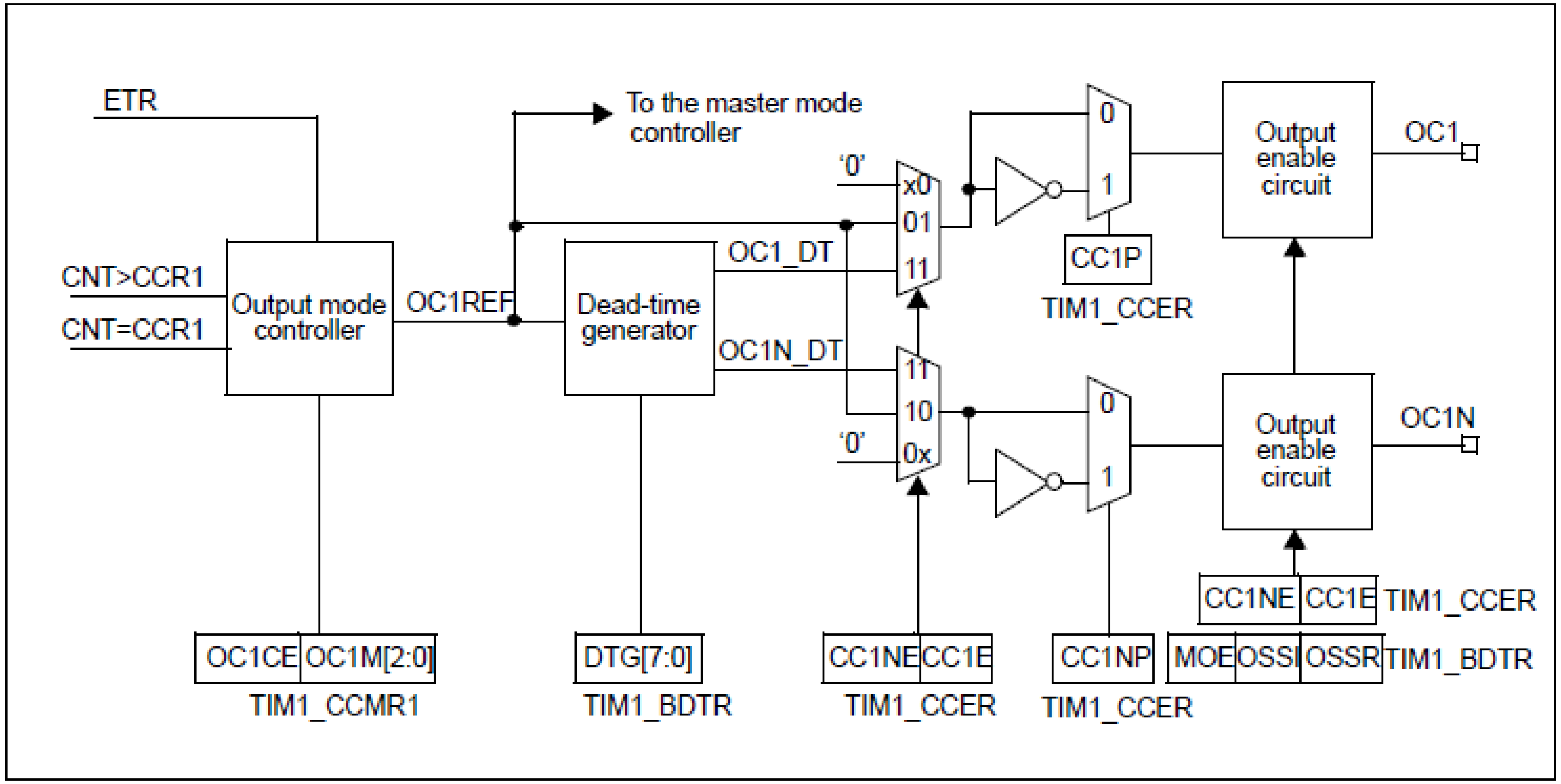
Capture/Compare Circuit

Figure 66. Capture/compare channel 1 main circuit



Capture/Compare Channel

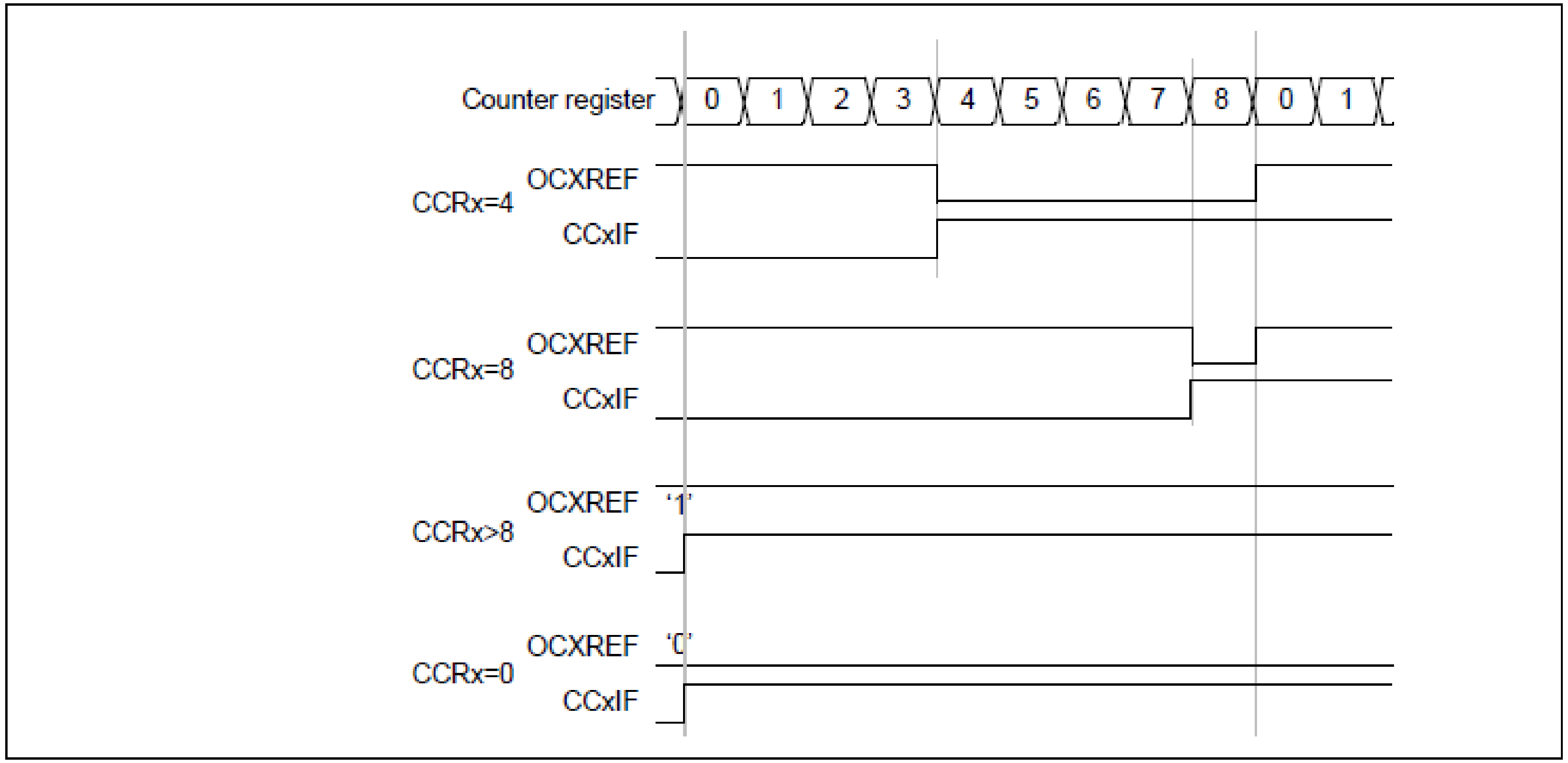
Figure 67. Output stage of capture/compare channel (channel 1 to 3)



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.

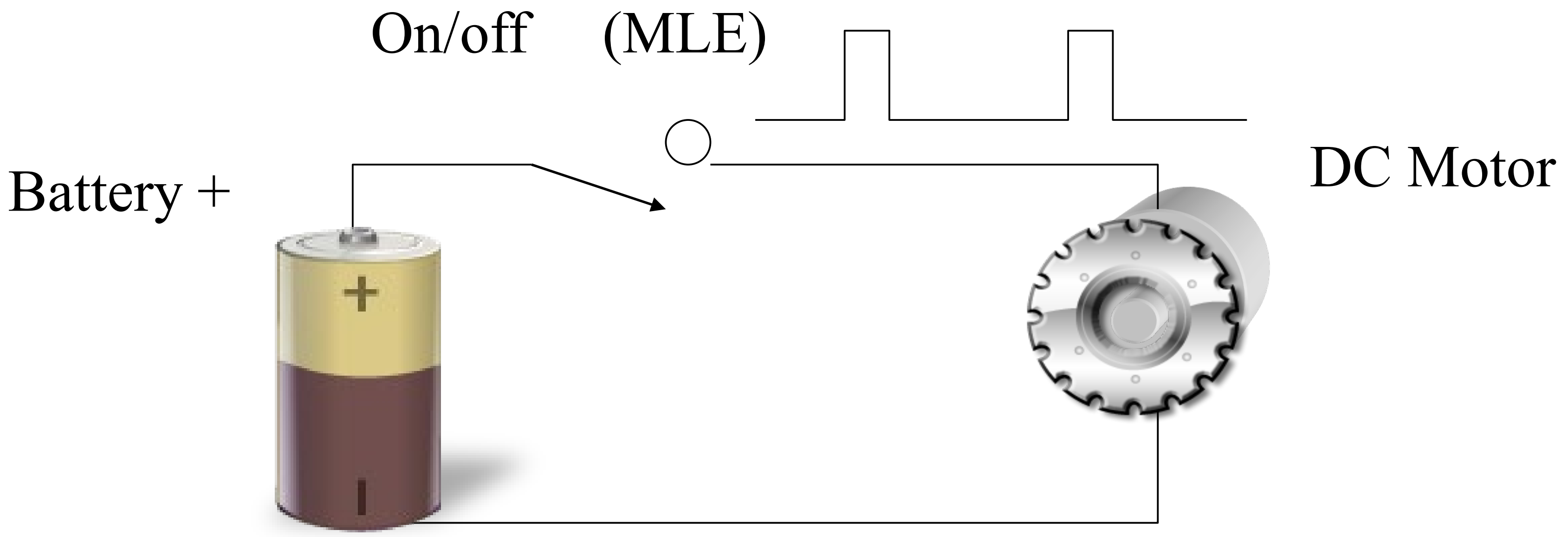
Figure 71. Edge-aligned PWM waveforms (ARR=8)



Pulse Width Modulation PWM unit

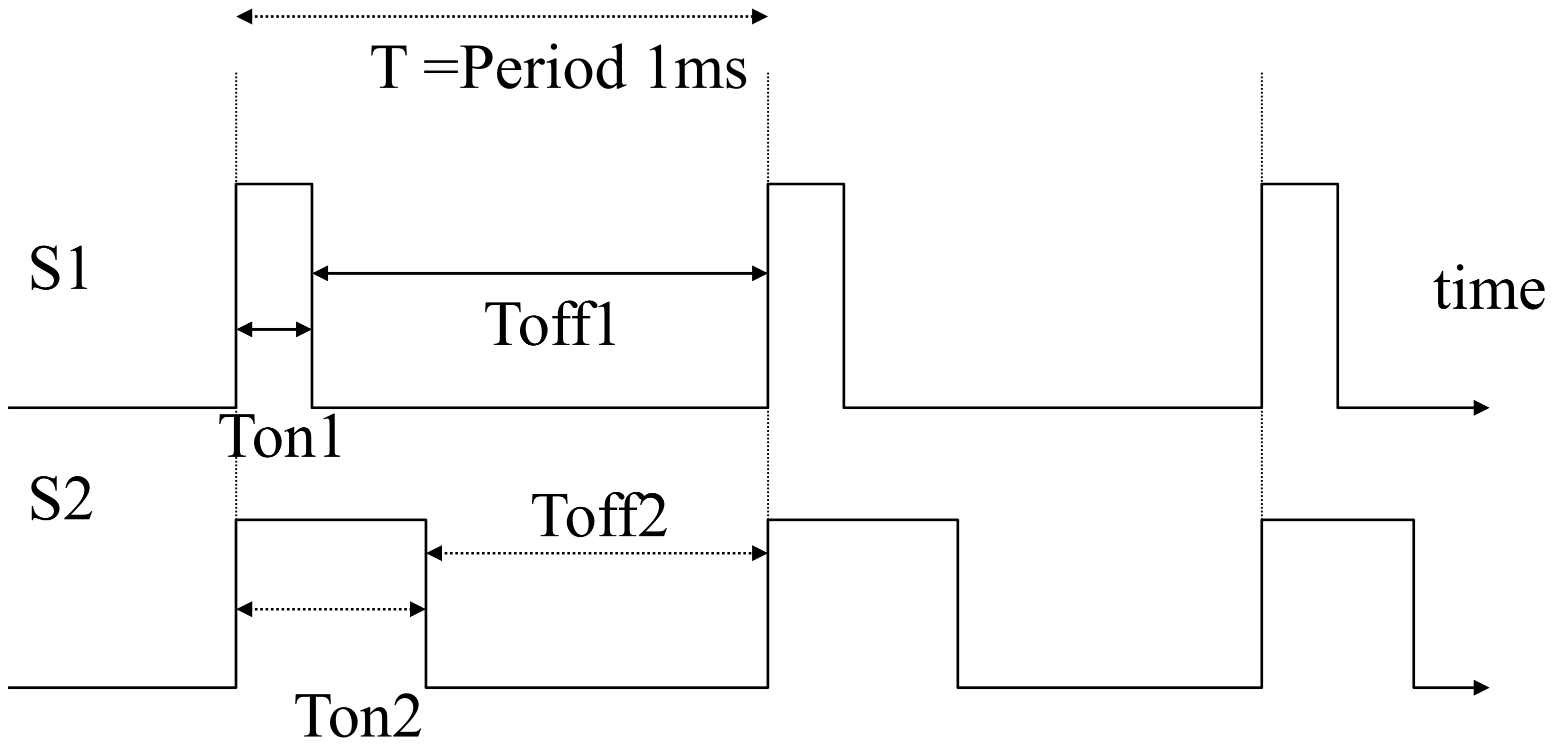
Use on-off time to control energy delivery

- The DC motor speed is determined by the on/off time of the motor enable signal MLE



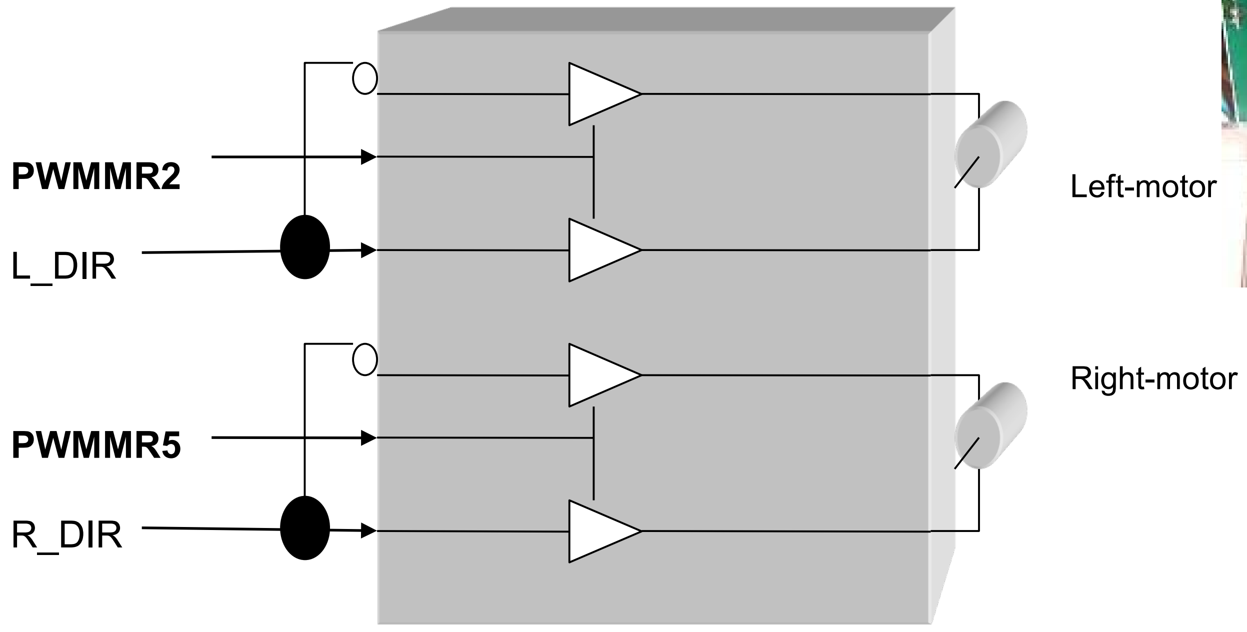
Timing diagrams of pulse width modulation

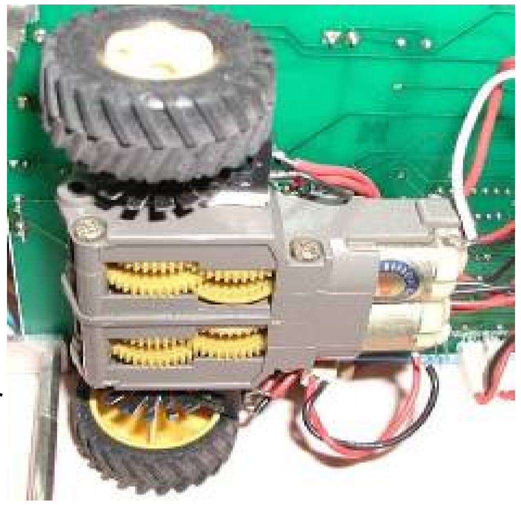
- Comparing two pulse modulated signals S1,S2



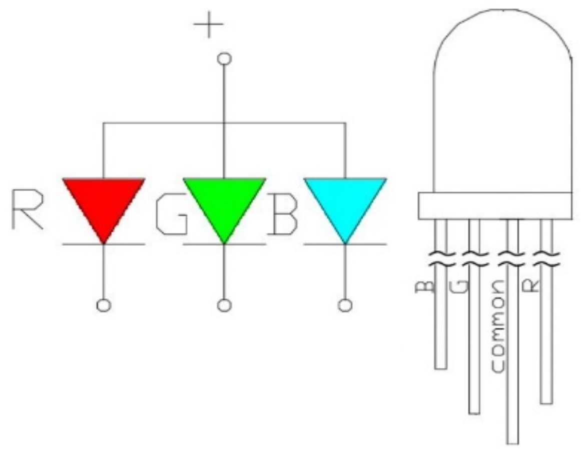
Use L293 H bridge circuit

- A chip for generating enough current to drive 2 motors controlled by 4 signals



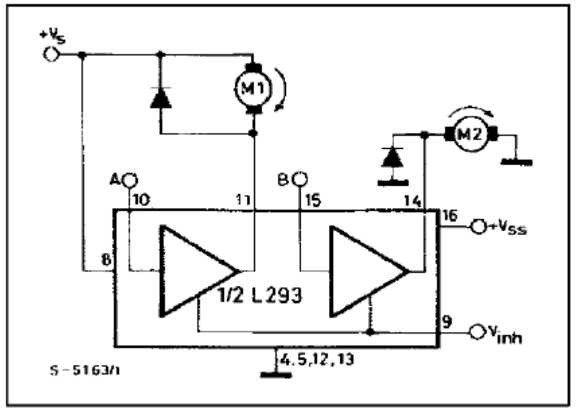


L293D & RGB LED



APPLICATION INFORMATION

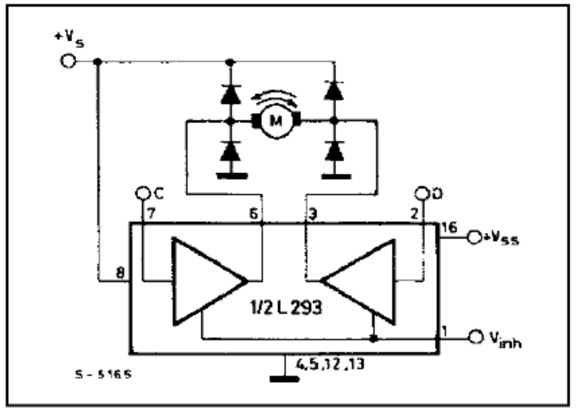
Figure 8 : DC Motor Controls (with connection to ground and to the supply voltage)



V_{inh}	A	M1	B	M2
H	H	Fast Motor Stop	H	Run
H	L	Run	L	Fast Motor Stop
L	X	Free Running Motor Stop	X	Free Running Motor Stop

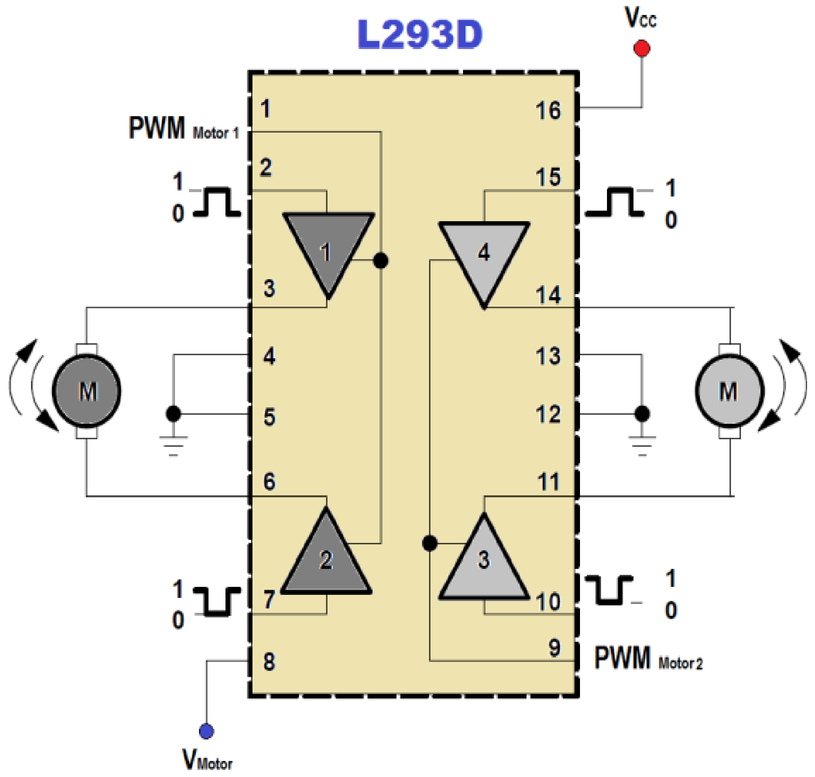
L = Low H = High X = Don't Care

Figure 9 : Bidirectional DC Motor Control

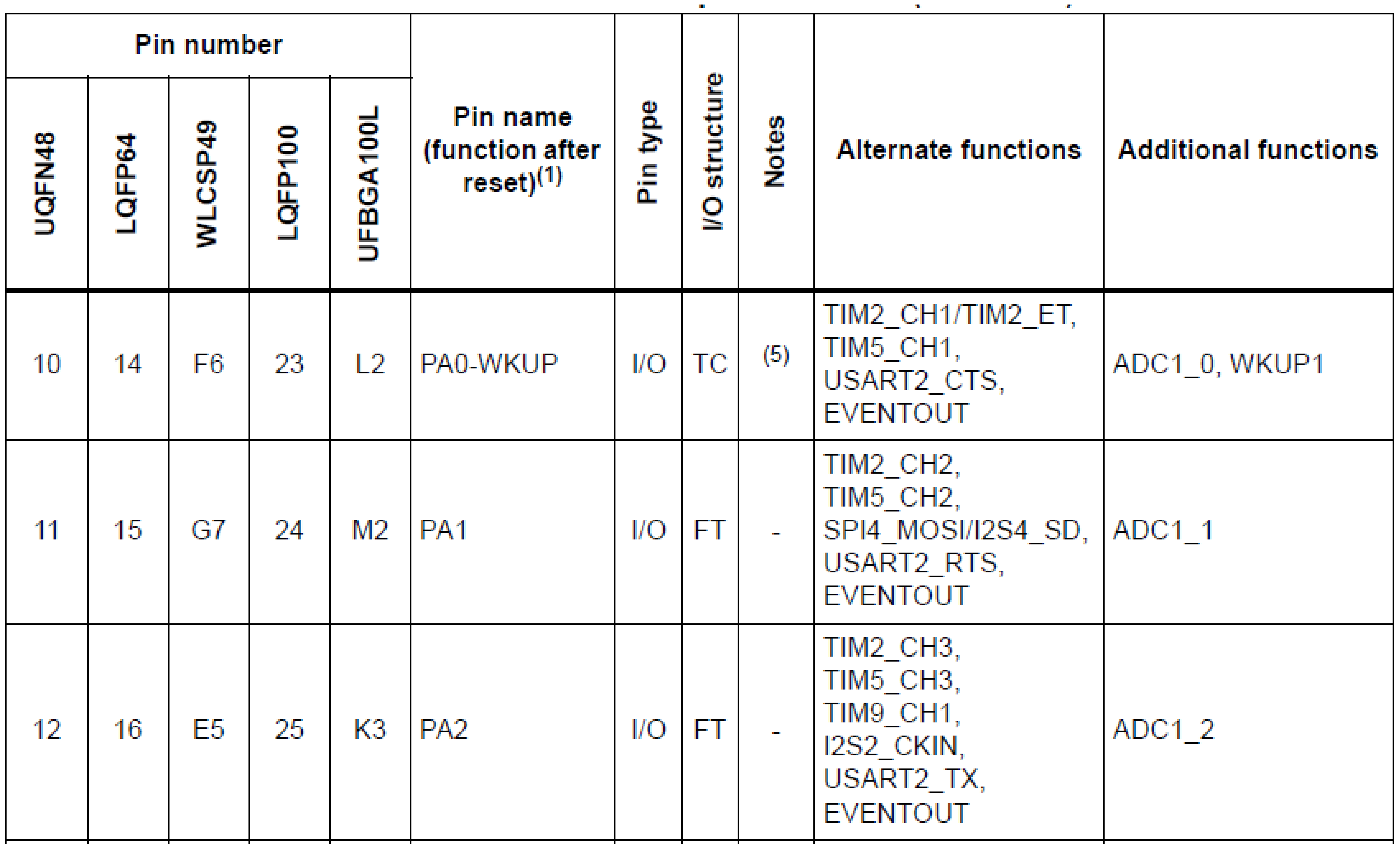


Inputs	Function	
V_{inh} = H	C = H ; D = L	Turn Right
	C = L ; D = H	Turn Left
	C = D	Fast Motor Stop
V_{inh} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't Care

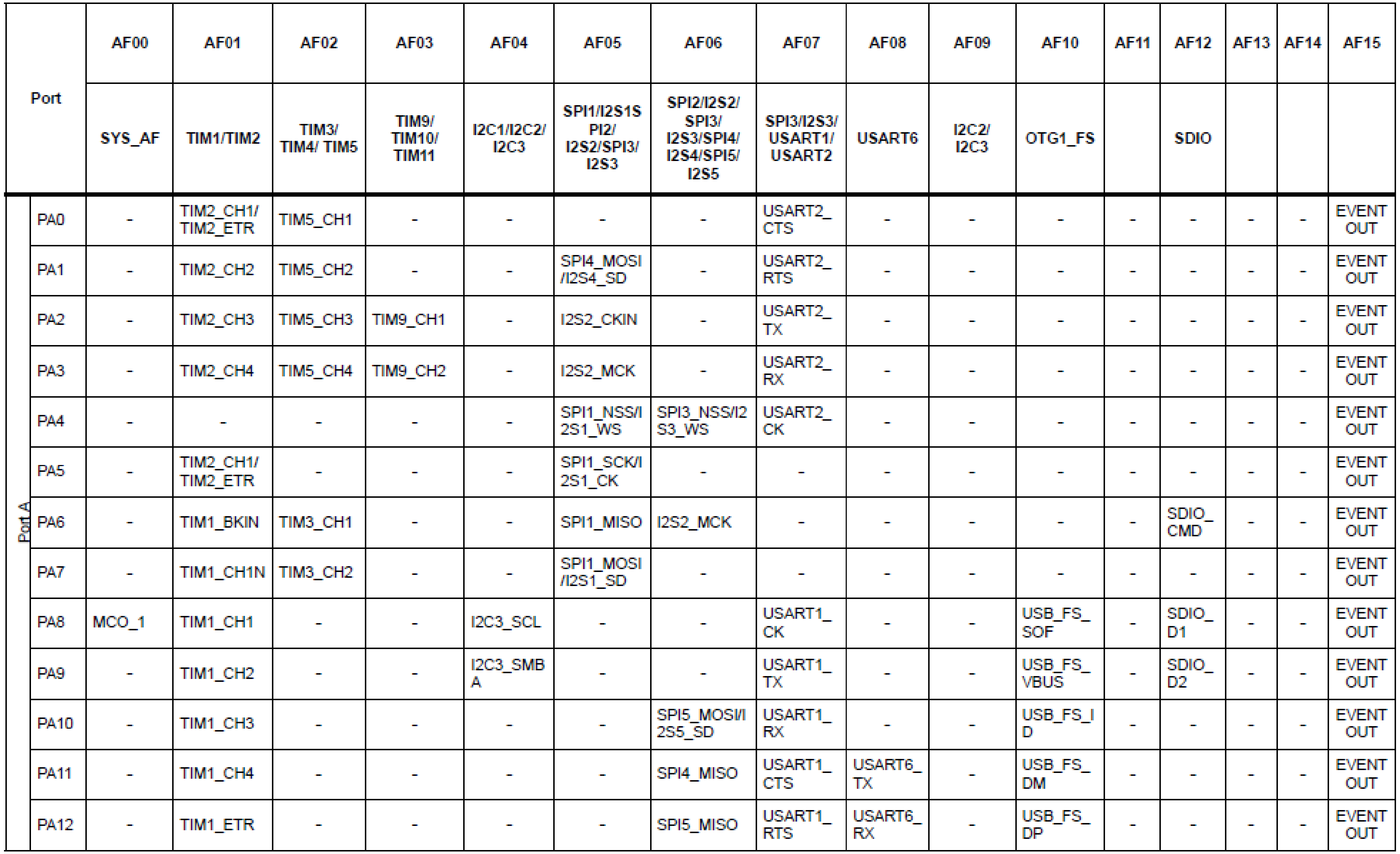


Timer Pin Definitions



Pin number					Pin name (function after reset)[1]	Pin type	I/O structure	Notes	Alternate functions	Additional functions
UQFN48	LQFP64	WLCSP49	LQFP100	UFBGA100L						
10	14	F6	23	L2	PA0-WKUP	I/O	TC	(5)	TIM2_CH1/TIM2_ET, TIM5_CH1, USART2_CTS, EVENTOUT	ADC1_0, WKUP1
11	15	G7	24	M2	PA1	I/O	FT	-	TIM2_CH2, TIM5_CH2, SPI4_MOSI/I2S4_SD, USART2_RTS, EVENTOUT	ADC1_1
12	16	E5	25	K3	PA2	I/O	FT	-	TIM2_CH3, TIM5_CH3, TIM9_CH1, I2S2_CKIN, USART2_TX, EVENTOUT	ADC1_2

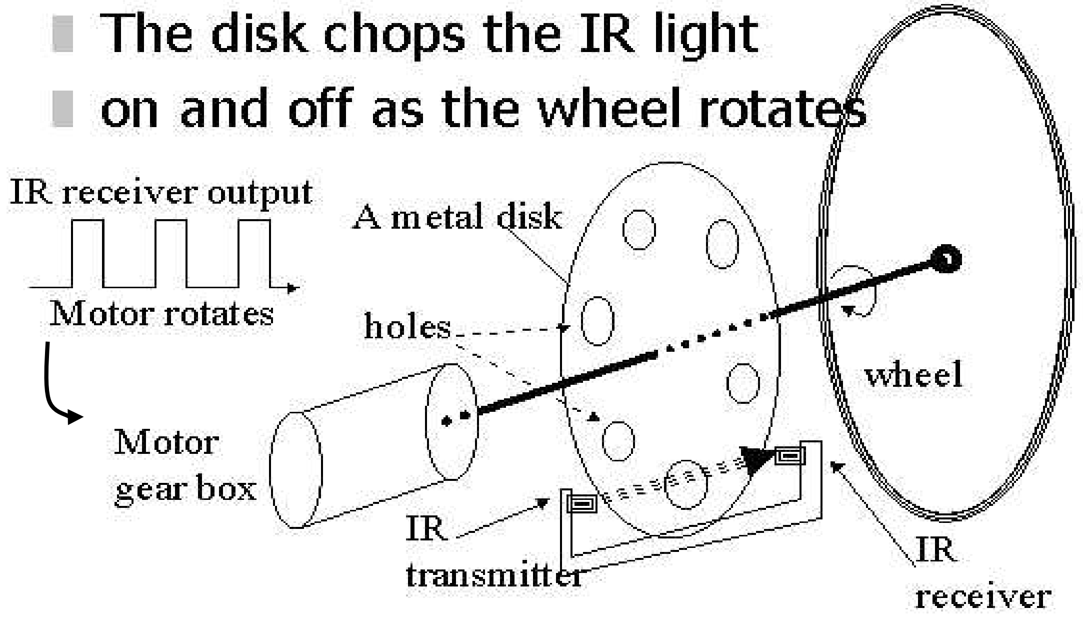
Alternate Function Mapping



Port		AF00	AF01	AF02	AF03	AF04	AF05	AF06	AF07	AF08	AF09	AF10	AF11	AF12	AF13	AF14	AF15
		SYS_AF	TIM1/TIM2	TIM3/ TIM4/ TIM5	TIM9/ TIM10/ TIM11	I2C1/I2C2/ I2C3	SPI1/I2S1SPI2/ I2S2/SPI3/ I2S3	SPI2/I2S2/ SPI3/ I2S3/SPI4/ I2S4/SPI5/ I2S5	SPI3/I2S3/ USART1/ USART2	USART6	I2C2/ I2C3	OTG1_FS		SDIO			
Port A	PA0	-	TIM2_CH1/ TIM2_ETR	TIM5_CH1	-	-	-	-	USART2_ CTS	-	-	-	-	-	-	-	EVENT OUT
	PA1	-	TIM2_CH2	TIM5_CH2	-	-	SPI4_MOSI /I2S4_SD	-	USART2_ RTS	-	-	-	-	-	-	-	EVENT OUT
	PA2	-	TIM2_CH3	TIM5_CH3	TIM9_CH1	-	I2S2_CKIN	-	USART2_ TX	-	-	-	-	-	-	-	EVENT OUT
	PA3	-	TIM2_CH4	TIM5_CH4	TIM9_CH2	-	I2S2_MCK	-	USART2_ RX	-	-	-	-	-	-	-	EVENT OUT
	PA4	-	-	-	-	-	SPI1_NSS/I 2S1_WS	SPI3_NSS/I2 S3_WS	USART2_ CK	-	-	-	-	-	-	-	EVENT OUT
	PA5	-	TIM2_CH1/ TIM2_ETR	-	-	-	SPI1_SCK/I 2S1_CK	-	-	-	-	-	-	-	-	-	EVENT OUT
	PA6	-	TIM1_BKIN	TIM3_CH1	-	-	SPI1_MISO	I2S2_MCK	-	-	-	-	-	SDIO_ CMD	-	-	EVENT OUT
	PA7	-	TIM1_CH1N	TIM3_CH2	-	-	SPI1_MOSI /I2S1_SD	-	-	-	-	-	-	-	-	-	EVENT OUT
	PA8	MCO_1	TIM1_CH1	-	-	I2C3_SCL	-	-	USART1_ CK	-	-	USB_FS_ SOF	-	SDIO_ D1	-	-	EVENT OUT
	PA9	-	TIM1_CH2	-	-	I2C3_SMB A	-	-	USART1_ TX	-	-	USB_FS_ VBUS	-	SDIO_ D2	-	-	EVENT OUT
	PA10	-	TIM1_CH3	-	-	-	-	SPI5_MOSI/I 2S5_SD	USART1_ RX	-	-	USB_FS_I D	-	-	-	-	EVENT OUT
	PA11	-	TIM1_CH4	-	-	-	-	SPI4_MISO	USART1_ CTS	USART6_ TX	-	USB_FS_ DM	-	-	-	-	EVENT OUT
	PA12	-	TIM1_ETR	-	-	-	-	SPI5_MISO	USART1_ RTS	USART6_ RX	-	USB_FS_ DP	-	-	-	-	EVENT OUT

Left Wheel sensor – LWheelsen
(same for Right wheel sensor RWheelsen)

- The disk chops the IR light
- on and off as the wheel rotates

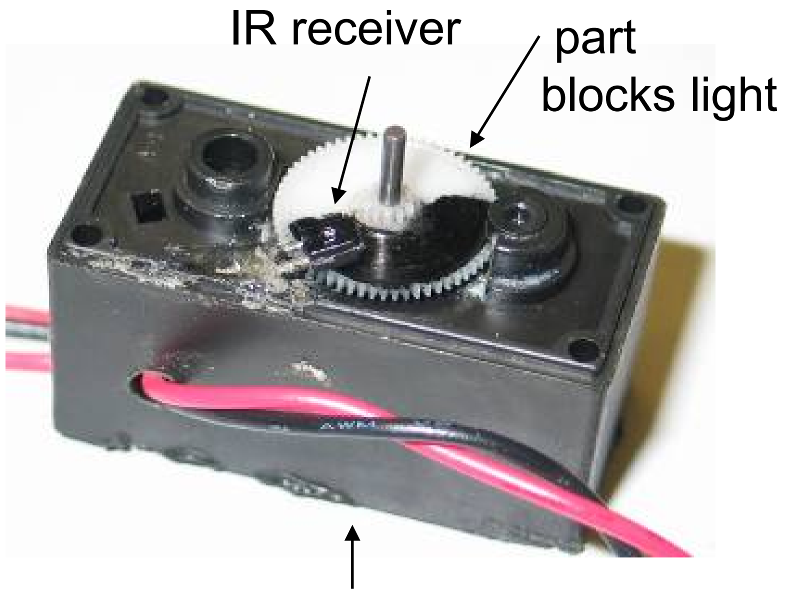


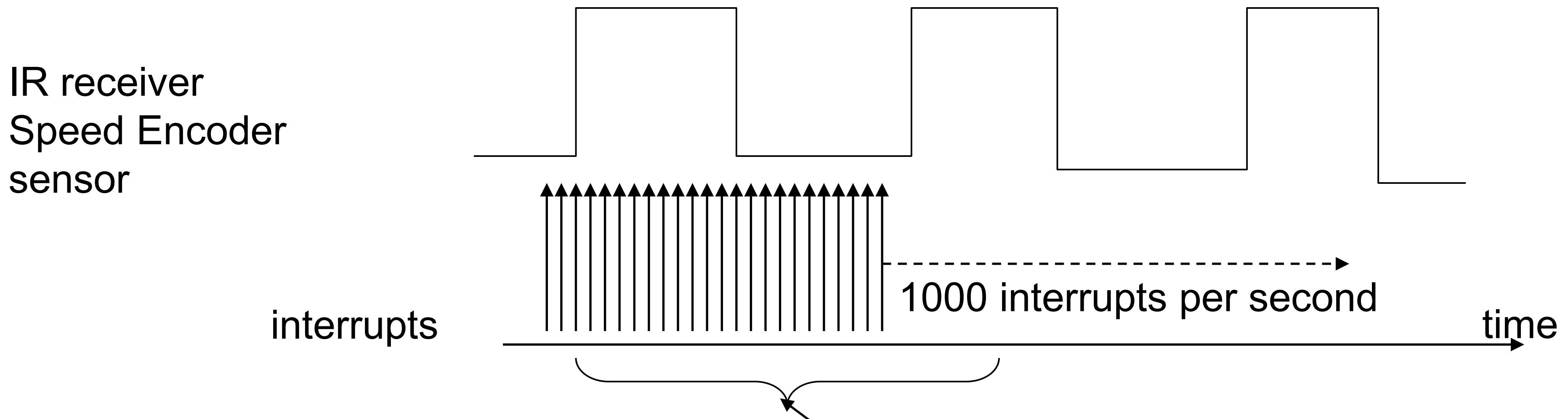
 LWSensor

 RWSensor

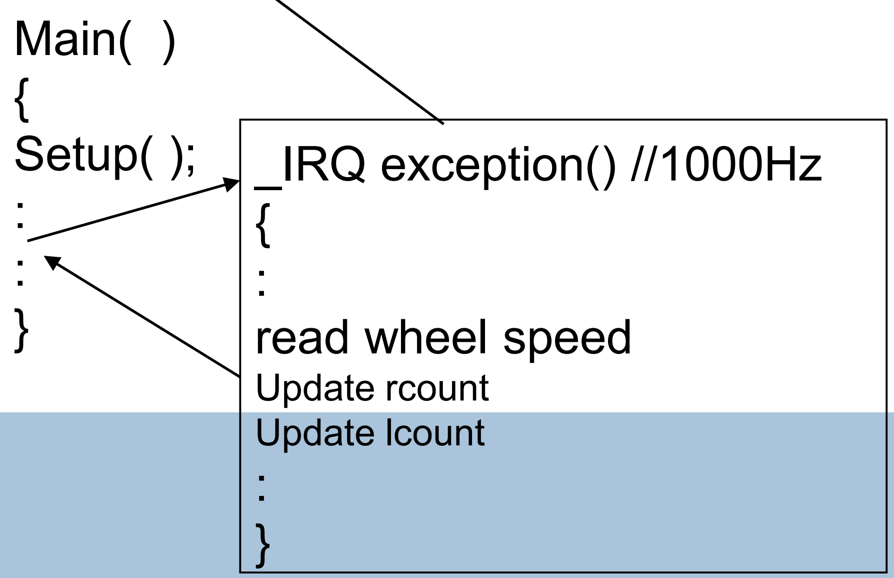
Our motor and speed encoder

Each wheel rotation= 88 on/off changes





Read wheel count (lcount, rcount) using interrupts



```
Main( )
{
Setup( );
:
:
}
```

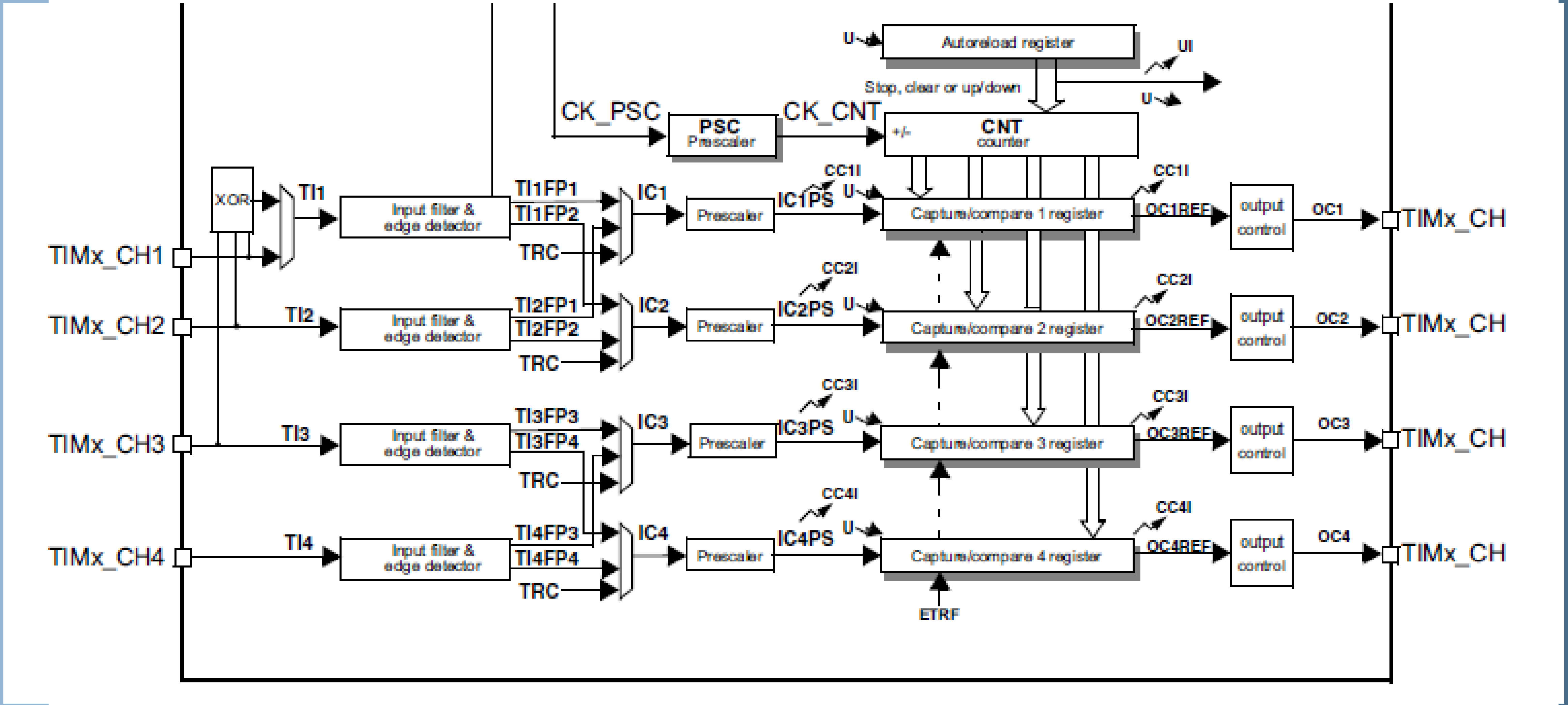
```
_IRQ exception() //1000Hz
{
:
read wheel speed
Update rcount
Update lcount
:
}
```

TIM2 to TIM5 main features

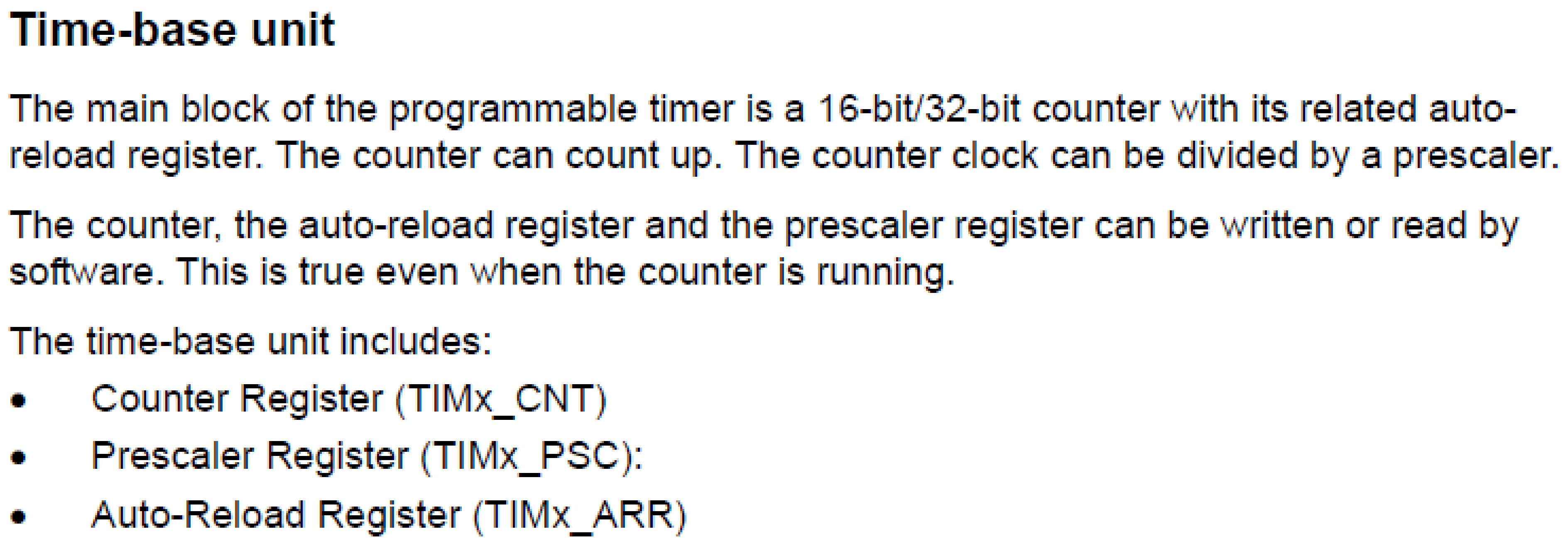
General-purpose TIMx timer features include:

- 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

TIM2-TIM5 Block Diagram



TIM2-TIM5 Time-base unit



Time-base unit

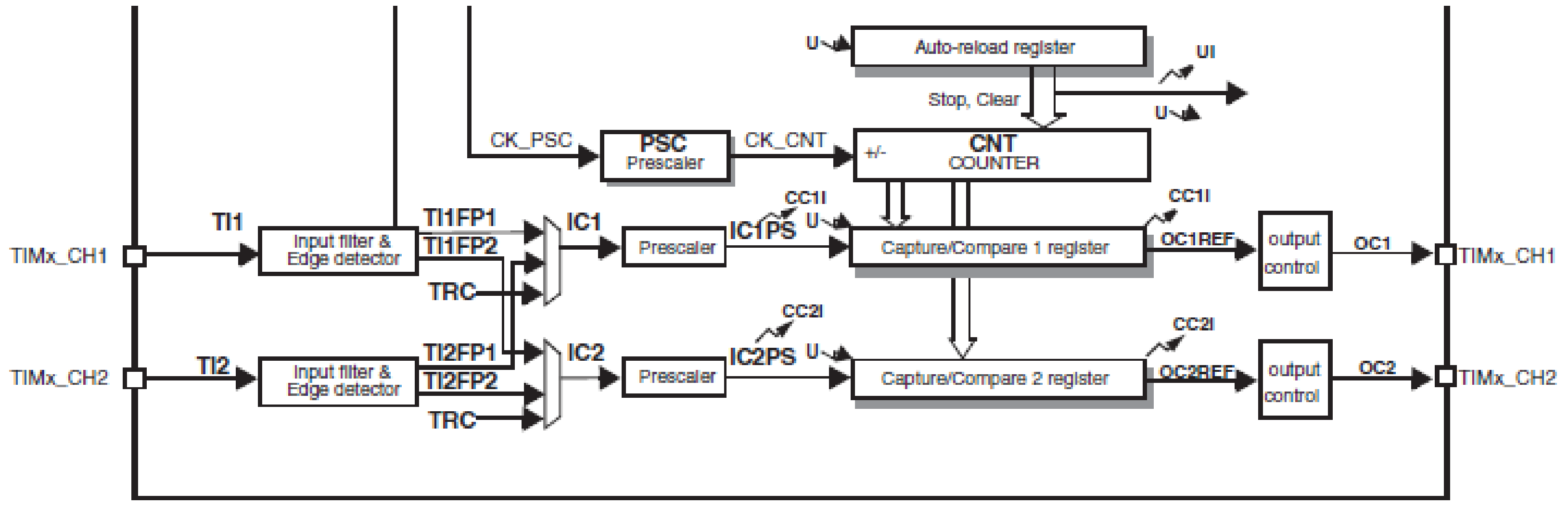
The main block of the programmable timer is a 16-bit/32-bit counter with its related auto-reload register. The counter can count up. The counter clock can be divided by a prescaler.

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)

TIM9

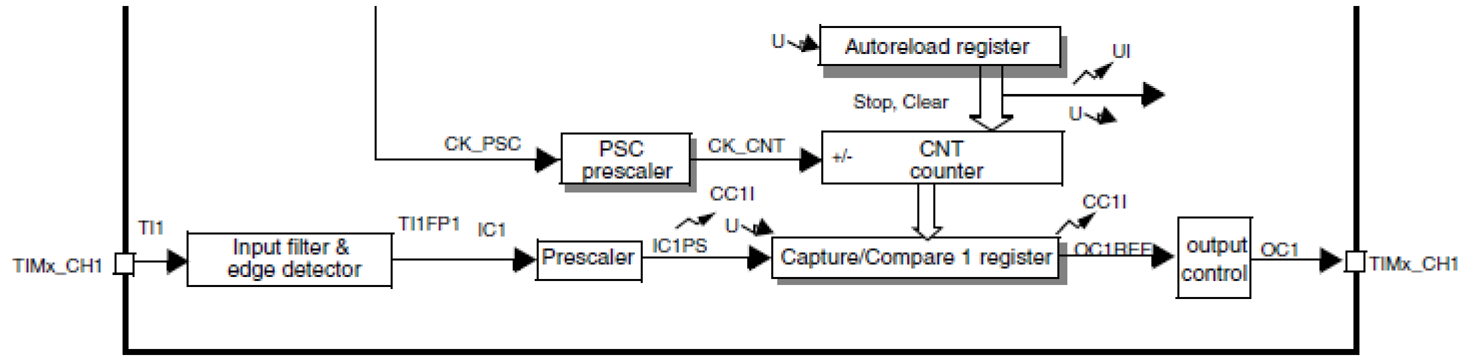


TIM9 main features

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

TIM10/TIM11

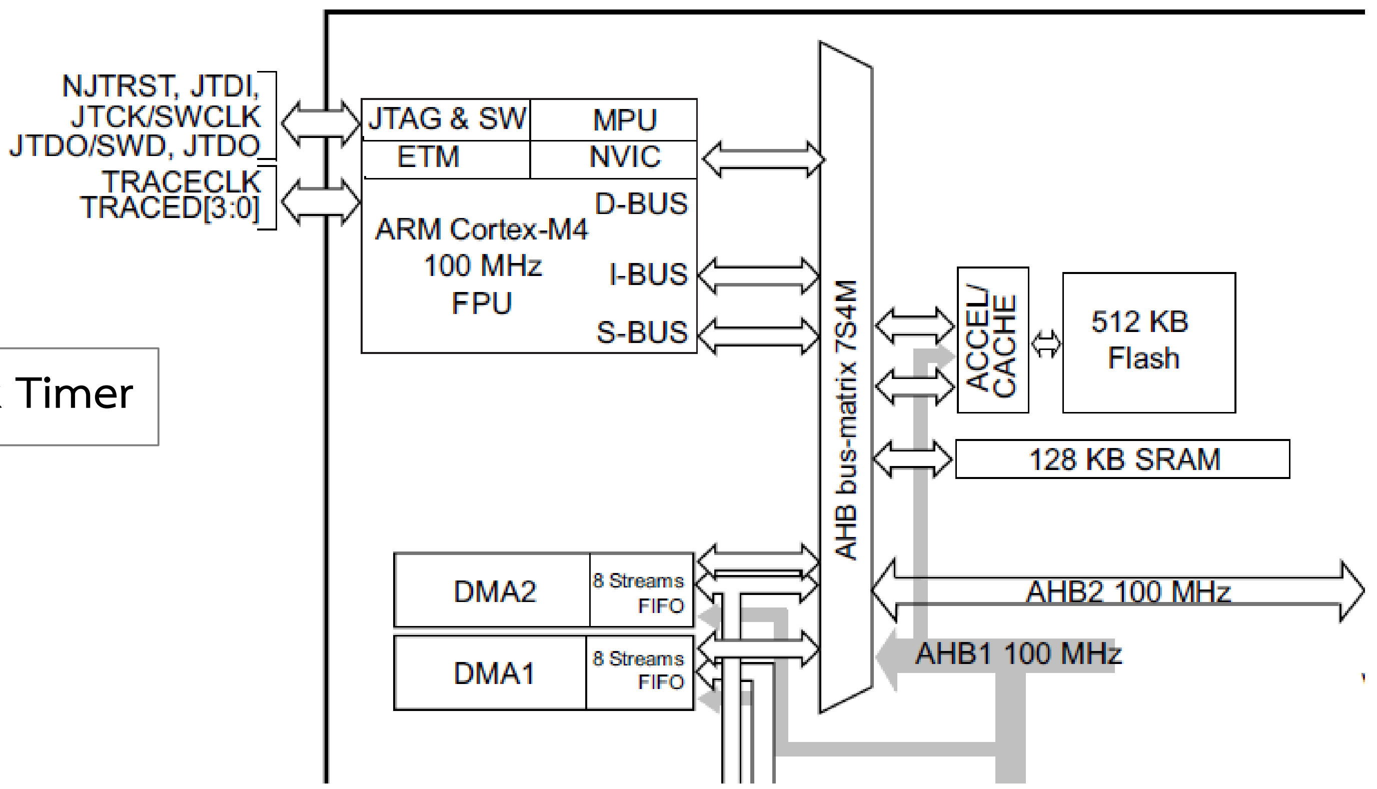


TIM10/TIM11 main features

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

SysTick timer



HAL_Delay function uses Systick Timer

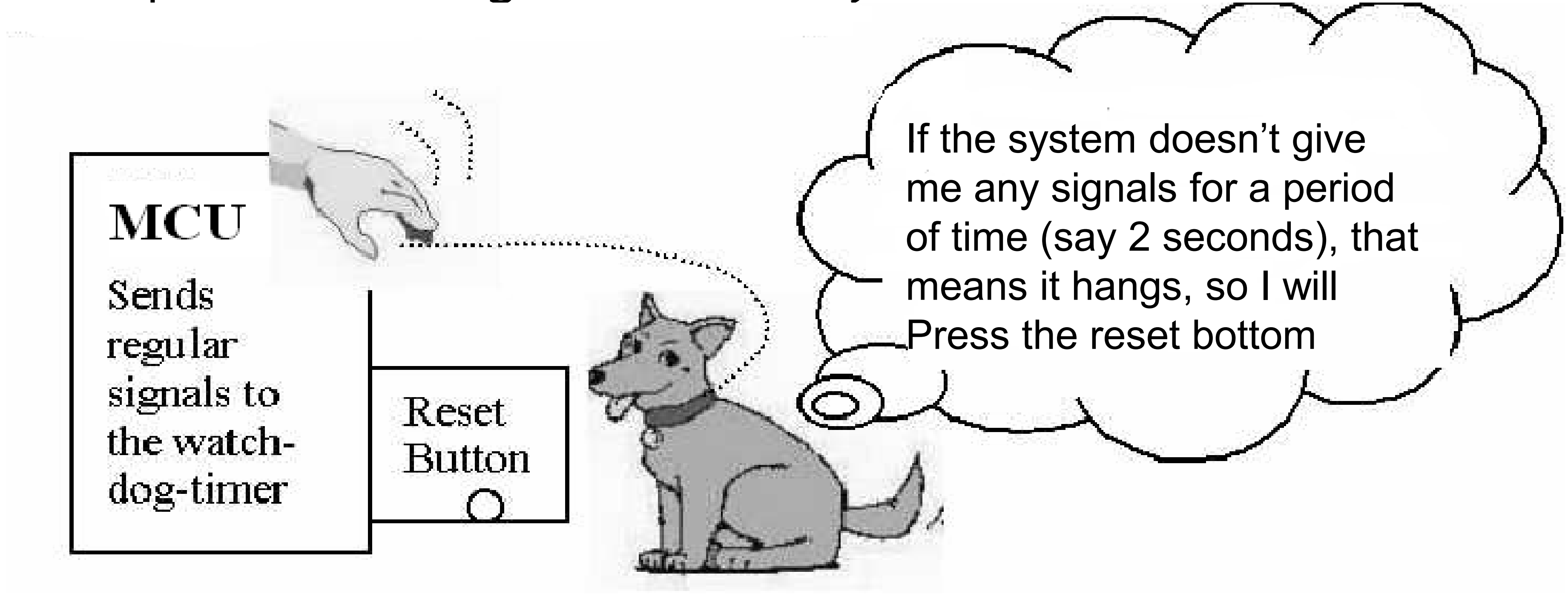
SysTick timer

This timer is dedicated to real-time operating systems, but could also be used as a standard downcounter. It features:

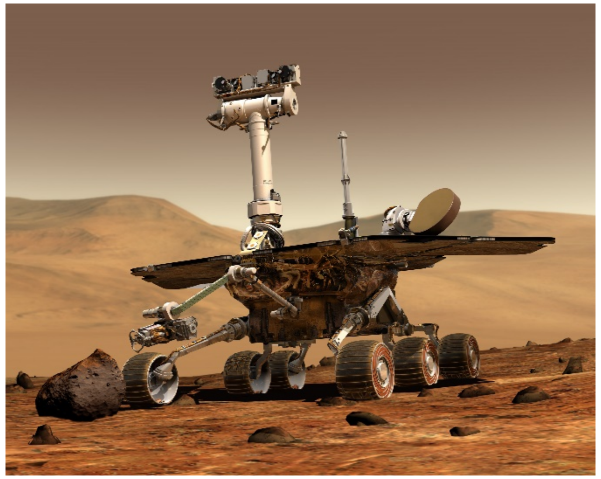
- A 24-bit downcounter
- Autoreload capability
- Maskable system interrupt generation when the counter reaches 0
- Programmable clock source.

Watchdog timer

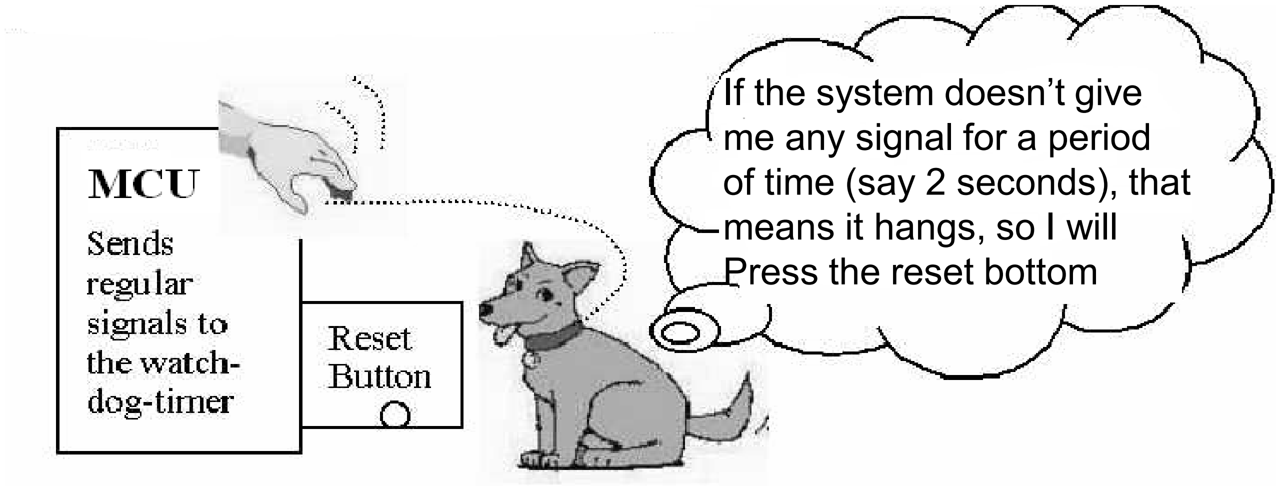
- For implementing fail safe systems


MCU
Sends regular signals to the watch-dog-timer
Reset Button
If the system doesn't give me any signals for a period of time (say 2 seconds), that means it hangs, so I will Press the reset bottom

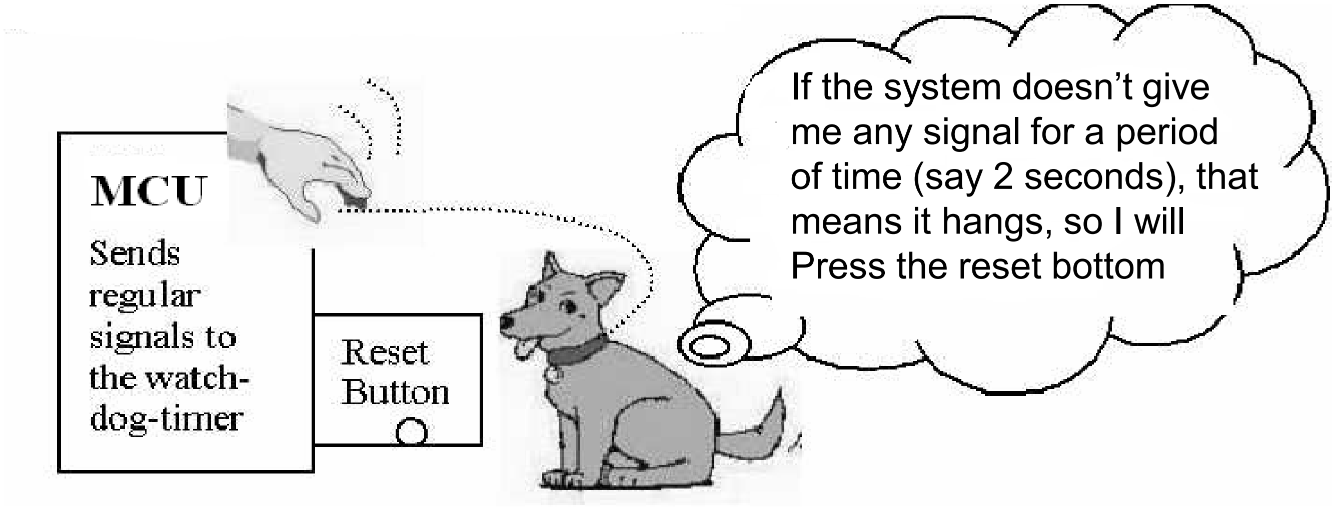
Example, solar power wireless telephone (register setting , see appendix)



- At remote area, maintenance is difficult
- If the software does not operate properly (hangs)
  - That means it sends no regular signals to the watch dog sensor
- Then
  - the watch-dog resets the system


MCU
Sends regular signals to the watch-dog-timer
Reset Button
If the system doesn't give me any signal for a period of time (say 2 seconds), that means it hangs, so I will Press the reset bottom

Software

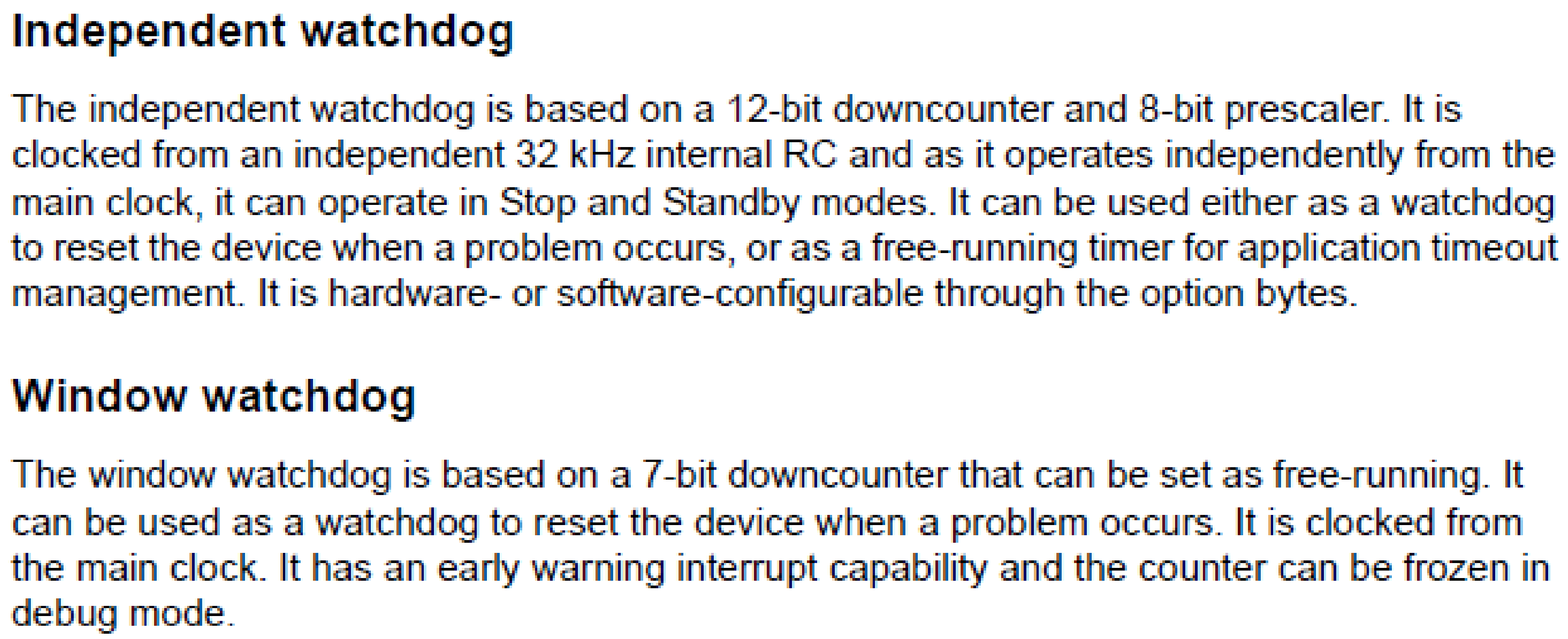

MCU
Sends regular signals to the watch-dog-timer
Reset Button
If the system doesn't give me any signal for a period of time (say 2 seconds), that means it hangs, so I will Press the reset bottom

- ➢Main

```
{
    While(1)
    { Do_the _neccessary();
      Send_a_pulse_to_watch_dog();
    }
}
```

- ➢If the software hangs, it will not **Send_a_pulse_to_watch_dog()**;
- ➢so the system is reset by the watch_dog_hardware

STM32F411 Watchdog Timer



Independent watchdog

The independent watchdog is based on a 12-bit downcounter and 8-bit prescaler. It is clocked from an independent 32 kHz internal RC and as it operates independently from the main clock, it can operate in Stop and Standby modes. It can be used either as a watchdog to reset the device when a problem occurs, or as a free-running timer for application timeout management. It is hardware- or software-configurable through the option bytes.

Window watchdog

The window watchdog is based on a 7-bit downcounter that can be set as free-running. It can be used as a watchdog to reset the device when a problem occurs. It is clocked from the main clock. It has an early warning interrupt capability and the counter can be frozen in debug mode.

Independent Watchdog

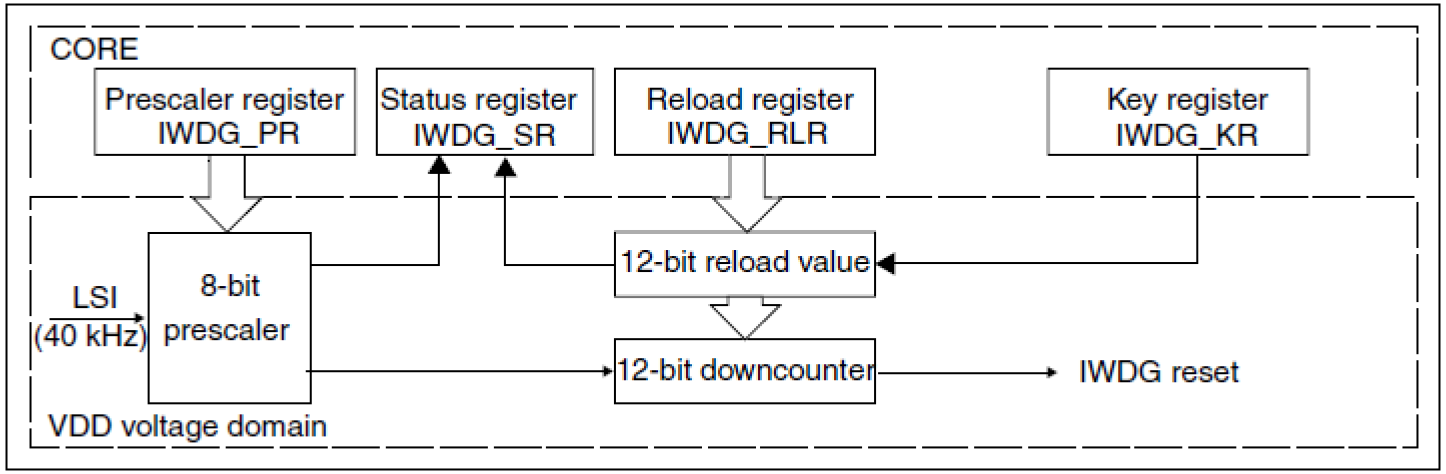
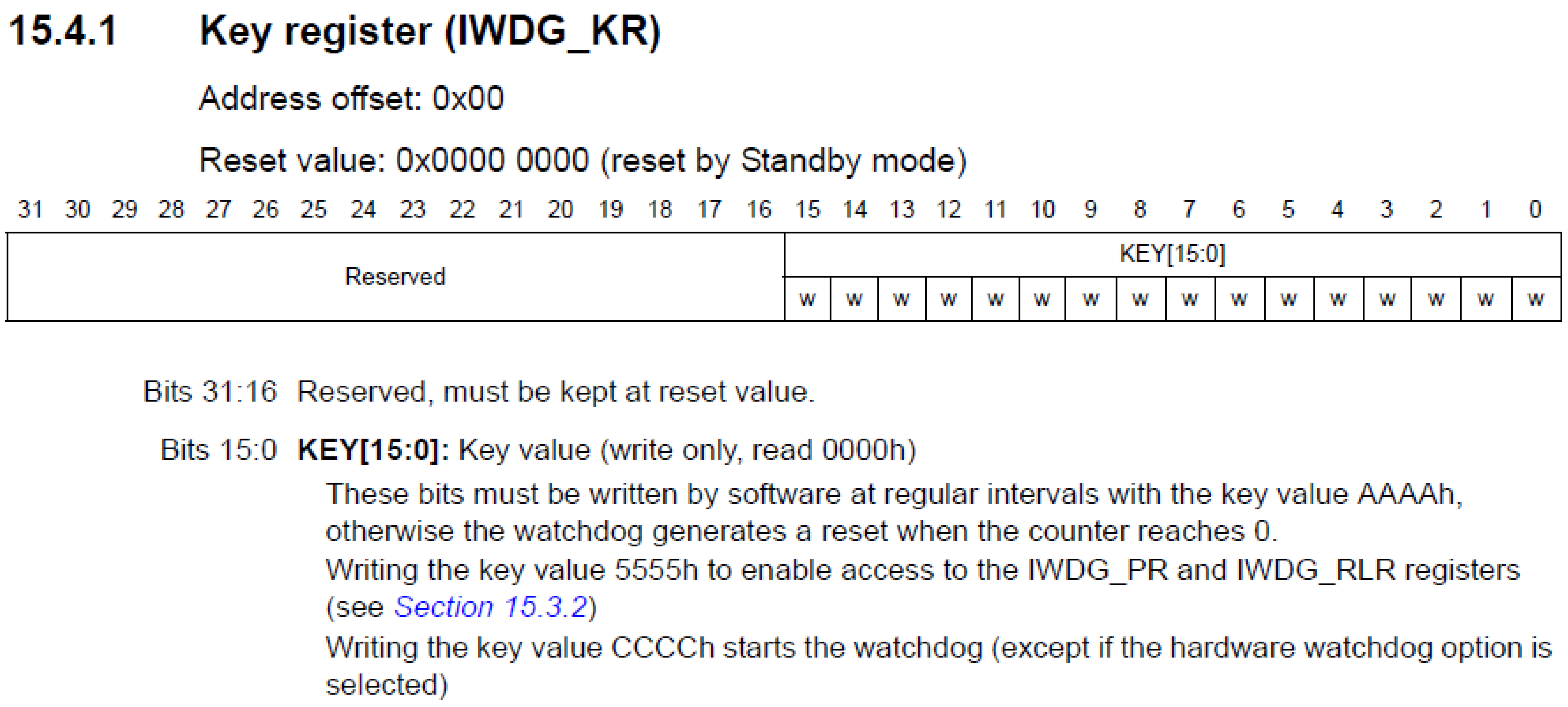


Table 61. Min/max IWDG timeout period at 32 kHz (LSI)(1)

Prescaler divider	PR[2:0] bits	Min timeout (ms) RL[11:0]= 0x000	Max timeout (ms) RL[11:0]= 0xFFF
/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

Start and Reset Independent Watch



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]															
																w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

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)

Summary

- Need to know clock speed and bit length for timer to operate correctly.
- Overflow/Underflow event can generate timing interrupt.
- Timers may connect to different APB buses and have different bit length.
- PWM signal generated from timer can drive LED and help drive motor.
- System timer is close to processor core.