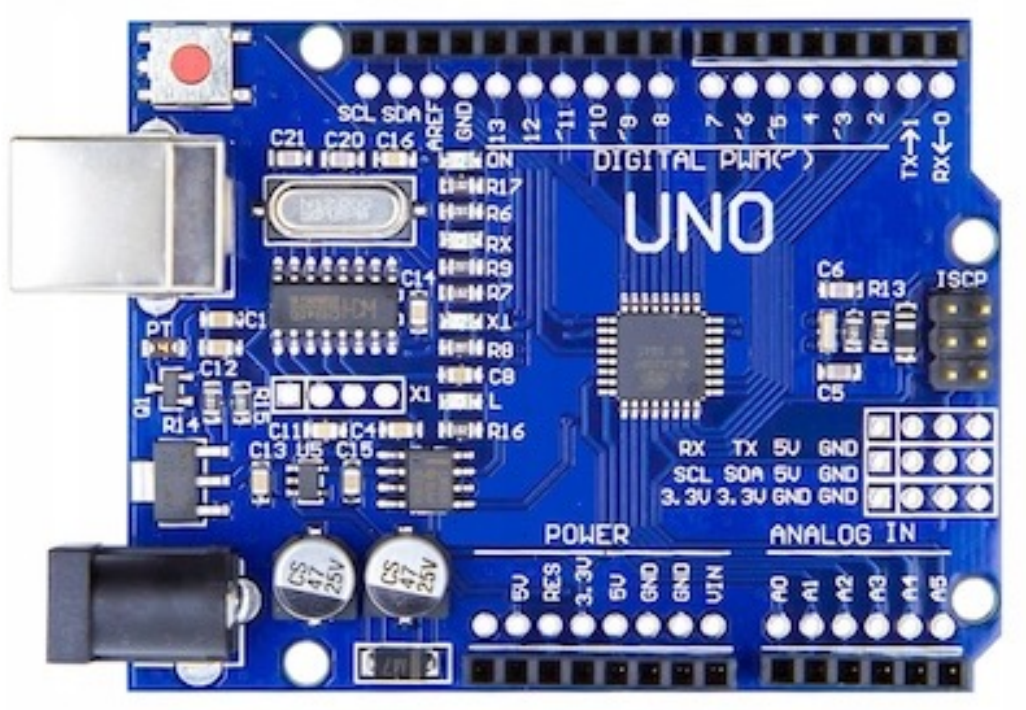
Embedded Systems Laboratory

Catedra de Calculatoare

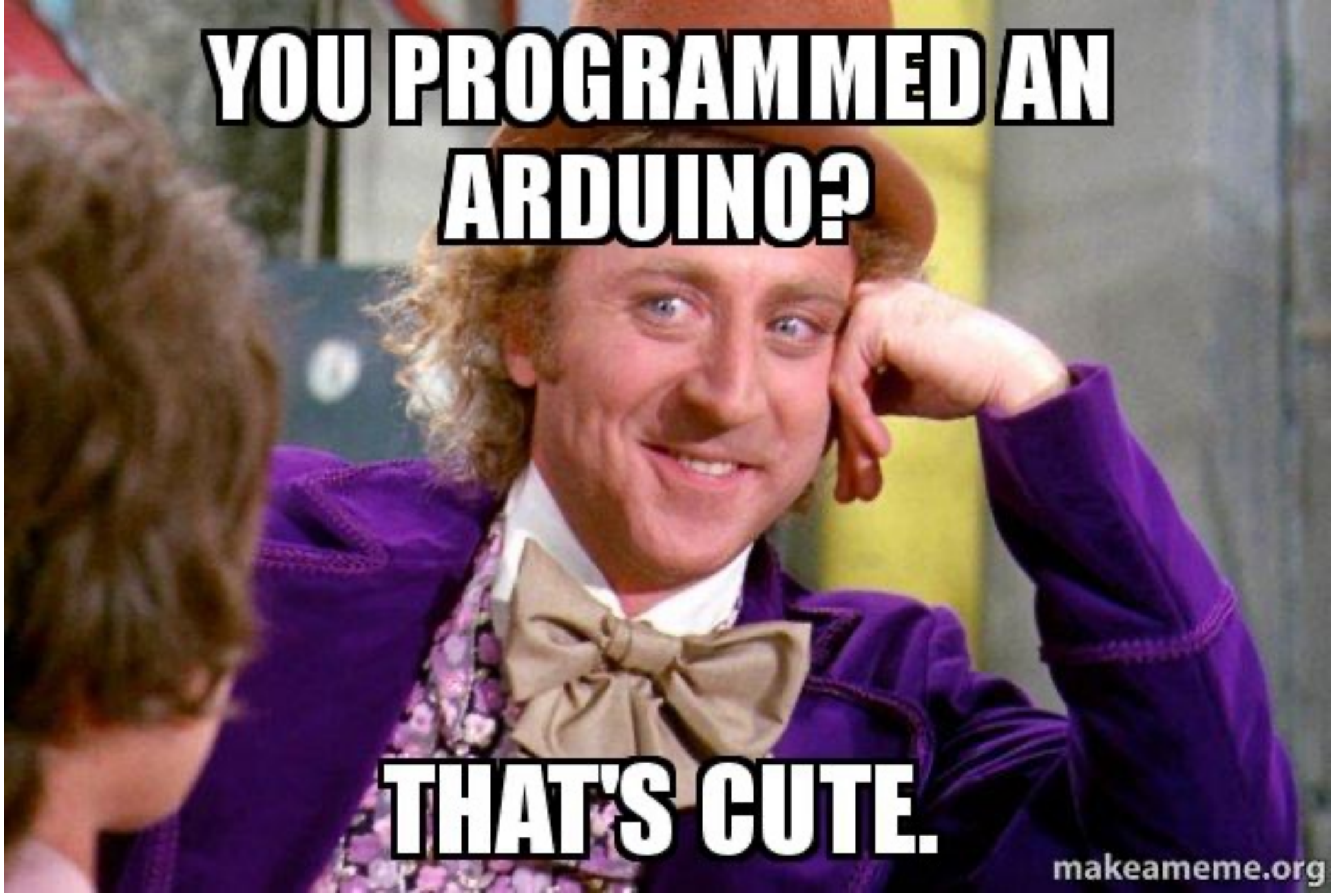
Facultatea de Automatica si Calculatoare

PROIECTAREA CU MICROPROCESOARE



Arduino Digital and Analog I/O Pins

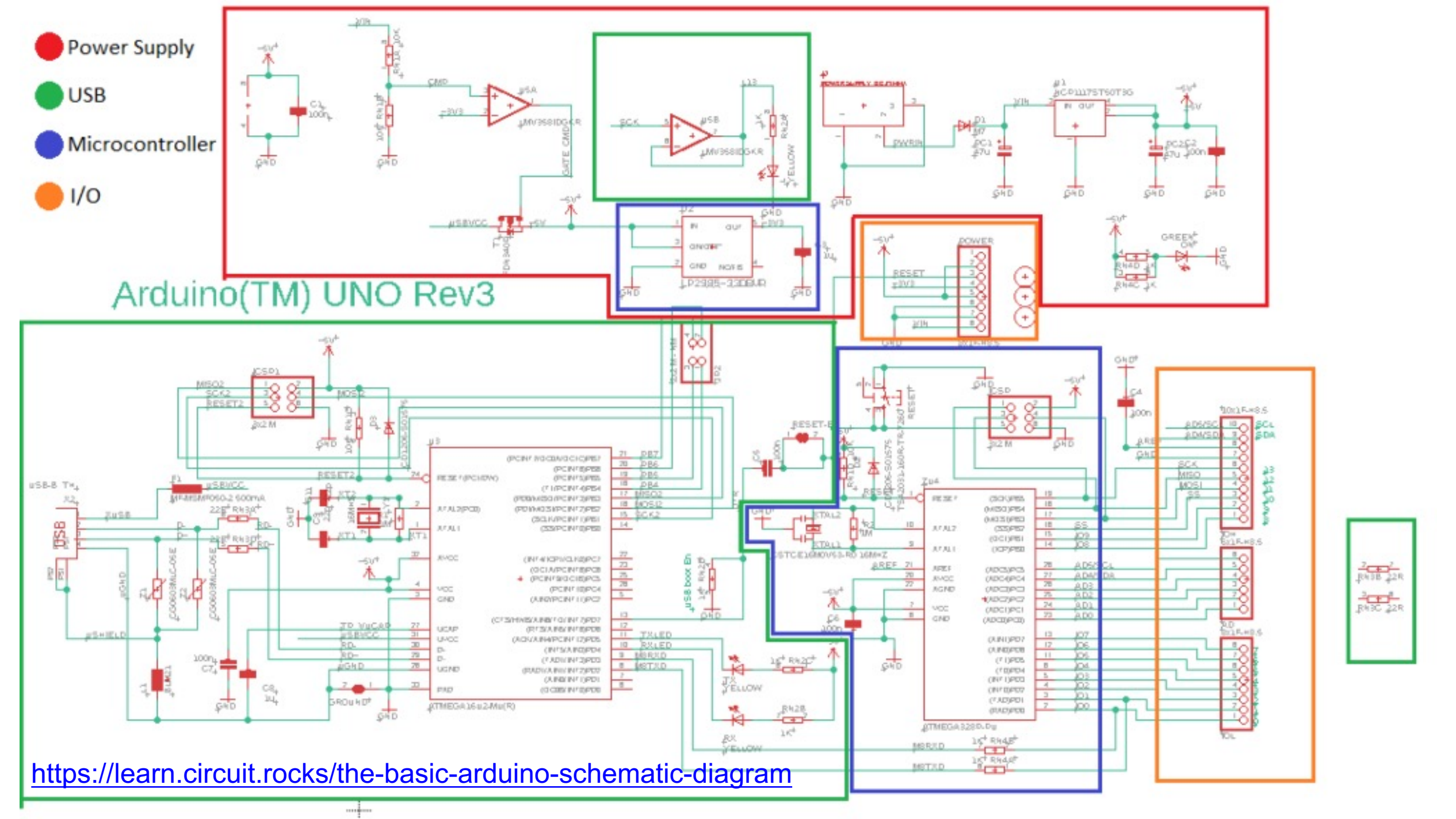
- Digital pins:
  - Pins 0 – 7: PORT D [0:7]
  - Pins 8 – 13: PORT B [0:5]
  - Pins 14 – 19: PORT C [0:5] (Arduino analog pins 0 – 5)
  - digital pins 0 and 1 are RX and TX for serial communication
  - digital pin 13 connected to the base board LED
- Digital Pin I/O Functions
  - pinMode(*pin*, *mode*)
    - Sets pin to INPUT or OUTPUT mode
    - Writes 1 bit in the DDRx register
  - digitalWrite(pin, value)
    - Sets pin value to LOW or HIGH (0 or 1)
    - Writes 1 bit in the PORTx register
  - int value = digitalRead(pin)
    - Reads back pin value (0 or 1)
    - Read 1 bit in the PINx register


YOU PROGRAMMED AN ARDUINO?
THAT'S CUTE.
makeameme.org

Port Pin Definitions

```
#define PINB _SFR_IO8(0x03)
#define PINB0 0
...
#define PINB7 7

#define DDRB _SFR_IO8(0x04)
#define DDB0 0
...
#define DDB7 7

#define PORTB _SFR_IO8(0x05)
#define PORTB0 0
...
#define PORTB7 7

#define PINC _SFR_IO8(0x06)
#define PINC0 0
...
#define PINC6 6

#define DDRC _SFR_IO8(0x07)
#define DDC0 0
...
#define DDC6 6
```

```
#define PORTC _SFR_IO8(0x08)
#define PORTC0 0
...
#define PORTC6 6

#define PIND _SFR_IO8(0x09)
#define PIND0 0
...
#define PIND7 7

#define DDRD _SFR_IO8(0x0A)
#define DDD0 0
...
#define DDD7 7

#define PORTD _SFR_IO8(0x0B)
#define PORTD0 0
...
#define PORTD7 7
```


Power Supply
USB
Microcontroller
I/O
Arduino(TM) UNO Rev3
https://learn.circuit.rocks/the-basic-arduino-schematic-diagram

Interrupts

- Allow program to respond to events when they occur
- Allow program to ignore events until the occur
- External events e.g.:
  - UART ready with/for next character
  - Signal change on pin
    - Action depends on context
  - # of edges arrived on pin
- Internal events e.g.:
  - Power failure
  - Arithmetic exception
  - Timer “tick”

ATmega328 Interrupts

VectorNo.	Program Address[2]	Source	Interrupt Definition
1	0x0000[1]	RESET	External Pin, Power-on Reset, Brown-out Reset and Watchdog System Reset
2	0x0002	INT0	External Interrupt Request 0
3	0x0004	INT1	External Interrupt Request 1
4	0x0006	PCINT0	Pin Change Interrupt Request 0
5	0x0008	PCINT1	Pin Change Interrupt Request 1
6	0x000A	PCINT2	Pin Change Interrupt Request 2
7	0x000C	WDT	Watchdog Time-out Interrupt
8	0x000E	TIMER2 COMPA	Timer/Counter2 Compare Match A
9	0x0010	TIMER2 COMPB	Timer/Counter2 Compare Match B
10	0x0012	TIMER2 OVF	Timer/Counter2 Overflow
11	0x0014	TIMER1 CAPT	Timer/Counter1 Capture Event
12	0x0016	TIMER1 COMPA	Timer/Counter1 Compare Match A
13	0x0018	TIMER1 COMPB	Timer/Coutner1 Compare Match B
14	0x001A	TIMER1 OVF	Timer/Counter1 Overflow
15	0x001C	TIMER0 COMPA	Timer/Counter0 Compare Match A
16	0x001E	TIMER0 COMPB	Timer/Counter0 Compare Match B

ATmega328 Interrupts (cont.)

VectorNo.	Program Address(2)	Source	Interrupt Definition
17	0x0020	TIMER0 OVF	Timer/Counter0 Overflow
18	0x0022	SPI, STC	SPI Serial Transfer Complete
19	0x0024	USART, RX	USART Rx Complete
20	0x0026	USART, UDRE	USART, Data Register Empty
21	0x0028	USART, TX	USART, Tx Complete
22	0x002A	ADC	ADC Conversion Complete
23	0x002C	EE READY	EEPROM Ready
24	0x002E	ANALOG COMP	Analog Comparator
25	0x0030	TWI	2-wire Serial Interface
26	0x0032	SPM READY	Store Program Memory Ready

Interrupt Model

- When an interrupt event occurs:
  - Processor does an automatic procedure call
  - CALL automatically done to address for that interrupt
    - Push current PC, Jump to interrupt address
  - Each event has its own interrupt address
  - The global interrupt enable bit (in SREG) is automatically cleared
    - i.e. nested interrupts are disabled
    - SREG bit can be set to enable nested interrupts if desired
- Interrupt procedure, aka "interrupt handler"
  - Does whatever it needs to, then returns via RETI
  - The global interrupt enable bit is automatically set on RETI
  - One program instruction is always executed after RETI

Interrupts

- Type 1 – Event is remembered when interrupt is disabled
  - If interrupt is not enabled, flag is set
    - When interrupt is enabled again, interrupt takes place, and flag is reset
- Type 2 – Event is not remembered when interrupt is disabled
  - Signal level causes interrupt
  - If level occurs when interrupt is enabled, interrupt takes place
  - If interrupt is not enabled, and level goes away before the interrupt is enabled, nothing happens

Interrupt Model

- Interrupt hander is invisible to program
  - Except through side-effects, e. g. via flags or variables
  - Changes program timing
    - Can't rely on "dead-reckoning" using instruction timing
- Must be written so they are invisible
  - Cannot stomp on program state, e. g. registers
  - Save and restore any registers used
    - Including SREG

Interrupt Vectors

- Table in memory containing the first instruction of each interrupt handler
- Typically at program address 0

```
Address  Labels Code                    Comments
0x0000          jmp    RESET           ; Reset Handler
0x0002          jmp    EXT_INT0        ; IRQ0 Handler
0x0004          jmp    EXT_INT1        ; IRQ1 Handler
0x0006          jmp    PCINT0          ; PCINT0 Handler
0x0008          jmp    PCINT1          ; PCINT1 Handler
0x000A          jmp    PCINT2          ; PCINT2 Handler
0x000C          jmp    WDT             ; Watchdog Timer Handler
0x000E          jmp    TIM2_COMPA      ; Timer2 Compare A Handler
0x0010          jmp    TIM2_COMPB      ; Timer2 Compare B Handler
0x0012          jmp    TIM2_OVF        ; Timer2 Overflow Handler
0x0014          jmp    TIM1_CAPT       ; Timer1 Capture Handler
0x0016          jmp    TIM1_COMPA      ; Timer1 Compare A Handler
0x0018          jmp    TIM1_COMPB      ; Timer1 Compare B Handler
0x001A          jmp    TIM1_OVF        ; Timer1 Overflow Handler
0x001C          jmp    TIM0_COMPA      ; Timer0 Compare A Handler
0x001E          jmp    TIM0_COMPB      ; Timer0 Compare B Handler
```

Interrupt Vectors

- If interrupts are not used, this memory can be used as part of the program
  - i.e. nothing special about this part of memory
- Example interrupt routine
  - RESET: Sets up the stack pointer

```
0x0033RESET:   ldi    r16, high(RAMEND); Main program start
0x0034         out    SPH,r16         ; Set Stack Pointer to top of RAM
0x0035         ldi    r16, low(RAMEND)
0x0036         out    SPL,r16
0x0037         sei                    ; Enable interrupts
0x0038         <instr>  xxx
```

Defined ISRs

```
#define INT0_vect            _VECTOR(1)      /*    External Interrupt Request 0    */
#define INT1_vect            _VECTOR(2)      /*    External Interrupt Request 1    */
#define PCINT0_vect          _VECTOR(3)      /*    Pin Change Interrupt Request    0  */
#define PCINT1_vect          _VECTOR(4)      /*    Pin Change Interrupt Request    0  */
#define PCINT2_vect          _VECTOR(5)      /*    Pin Change Interrupt Request    1  */
#define WDT_vect             _VECTOR(6)      /* Watchdog Time-out Interrupt */
#define TIMER2_COMPA_vect    _VECTOR(7)      /* Timer/Counter2 Compare Match A */
#define TIMER2_COMPB_vect    _VECTOR(8)      /* Timer/Counter2 Compare Match A */
#define TIMER2_OVF_vect      _VECTOR(9)      /* Timer/Counter2 Overflow */
#define TIMER1_CAPT_vect     _VECTOR(10)     /* Timer/Counter1 Capture Event */
#define TIMER1_COMPA_vect    _VECTOR(11)     /* Timer/Counter1 Compare Match A */
#define TIMER1_COMPB_vect    _VECTOR(12)     /* Timer/Counter1 Compare Match B */
#define TIMER1_OVF_vect      _VECTOR(13)     /* Timer/Counter1 Overflow */
#define TIMER0_COMPA_vect    _VECTOR(14)     /* TimerCounter0 Compare Match A */
#define TIMER0_COMPB_vect    _VECTOR(15)     /* TimerCounter0 Compare Match B */
#define TIMER0_OVF_vect      _VECTOR(16)     /* Timer/Couner0 Overflow */
#define SPI_STC_vect         _VECTOR(17)     /* SPI Serial Transfer Complete */
#define USART_RX_vect        _VECTOR(18)     /* USART Rx Complete */
#define USART_UDRE_vect      _VECTOR(19)     /* USART, Data Register Empty */
#define USART_TX_vect        _VECTOR(20)     /* USART Tx Complete */
#define ADC_vect             _VECTOR(21)     /* ADC Conversion Complete */
#define EE_READY_vect        _VECTOR(22)     /* EEPROM Ready */
#define ANALOG_COMP_vect     _VECTOR(23)     /* Analog Comparator */
#define TWI_vect             _VECTOR(24)     /* Two-wire Serial Interface */
#define SPM_READY_vect       _VECTOR(25)     /* Store Program Memory Read */
```

Interrupts

- Global interrupt enable
  - Bit in SREG
  - Allows all interrupts to be disabled with one bit
  - sei() – set the bit
  - cli() – clear the bit
- Interrupt priority is determined by order in table
  - Lower addresses have higher priority
- ISR(vector) – Interrupt routine definition
- reti() – return from interrupt
  - automatically generated for ISR

External Interrupts

- Monitors changes in signals on pins
- What causes an interrupt can be configured
  - by setting control registers appropriately
- Pins:
  - INT0 and INT1 – range of event options
    - INT0 – PORT D [2]
    - INT1 – PORT D [3]
  - PCINT[23:0] – any signal change (toggle)
    - PCINT[7:0] – PORT B [7:0]
    - PCINT[14:8] – PORT C [6:0]
    - PCINT[23:16] – PORT D [7:0]
- Pulses on inputs must be slower than I/O clock rate

INT0 and INT1

- External Interrupt Control Register:

Bit	7	6	5	4	3	2	1	0	
(0x69)	–	–	–	–	ISC11	ISC10	ISC01	ISC00	EICRA
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- Sense Control (INT0 is the same)

Table 12-1. Interrupt 1 Sense Control

ISC11	ISC10	Description
0	0	The low level of INT1 generates an interrupt request.
0	1	Any logical change on INT1 generates an interrupt request.
1	0	The falling edge of INT1 generates an interrupt request.
1	1	The rising edge of INT1 generates an interrupt request.

INT0 and INT1

- External Interrupt Mask Register

Bit	7	6	5	4	3	2	1	0	
0x1D (0x3D)	–	–	–	–	–	–	INT1	INT0	EIMSK
Read/Write	R	R	R	R	R	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

  - If INT# bit is set (and the SREG I-bit is set), then interrupts are enabled on pin INT#

- External Interrupt Flag Register

Bit	7	6	5	4	3	2	1	0	
0x1C (0x3C)	–	–	–	–	–	–	INTF1	INTF0	EIFR
Read/Write	R	R	R	R	R	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

  - Interrupt flag bit is set when a change triggers an interrupt request
  - Flag is cleared automatically when interrupt routine is executed
  - Flag can be cleared by writing a 1 to it

Arduino Language Support for External Interrupts

- attachInterrupt(interrupt, function, mode)
  - interrupt: 0 or 1
  - function: interrupt function to call
  - mode: LOW, CHANGE, RISING, FALLING
- detachInterrupt(interrupt)
- interrupts( ) – Enable interrupts : sei( )
- noInterrupts( ) – Disable interrupts : cli( )

PCINT[23:0]

- Pin Change Interrupt Control Register

Bit	7	6	5	4	3	2	1	0	
(0x68)	–	–	–	–	–	PCIE2	PCIE1	PCIE0	PCICR
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

  - PCIE2 enables interrupts for PCINT[23:16]
  - PCIE1 enables interrupts for PCINT[14:8]
  - PCIE0 enables interrupts for PCINT[7:0]

- Pin Change Interrupt Flag Register

Bit	7	6	5	4	3	2	1	0	
0x1B (0x3B)	–	–	–	–	–	PCIF2	PCIF1	PCIF0	PCIFR
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

  - PCIF# set if corresponding pins generate an interrupt request
  - Cleared automatically when interrupt routine is executed

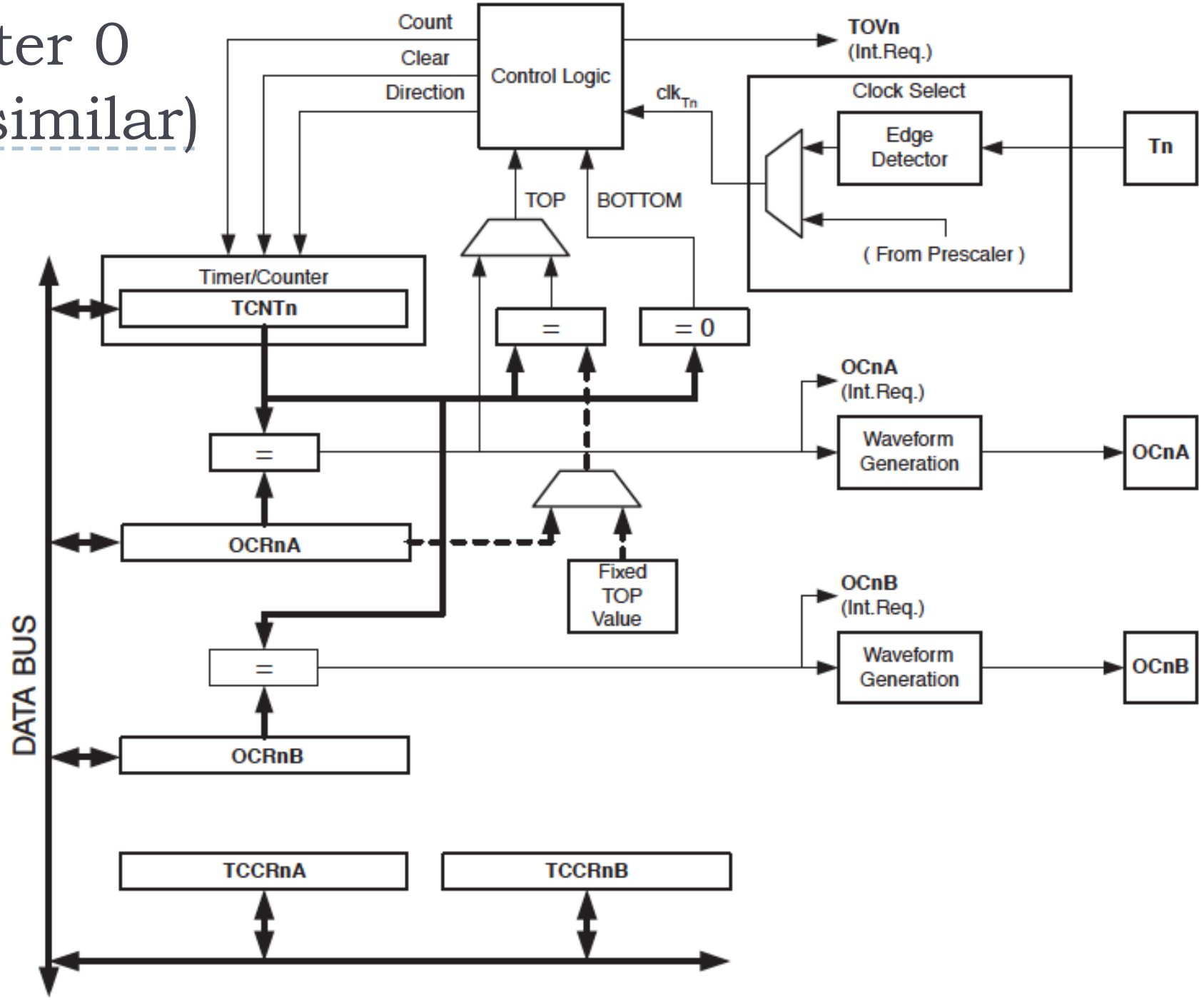
PCINT[23:0]

- Pin Change Mask Register 2

Bit	7	6	5	4	3	2	1	0	
(0x6D)	PCINT23	PCINT22	PCINT21	PCINT20	PCINT19	PCINT18	PCINT17	PCINT16	PCMSK2
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

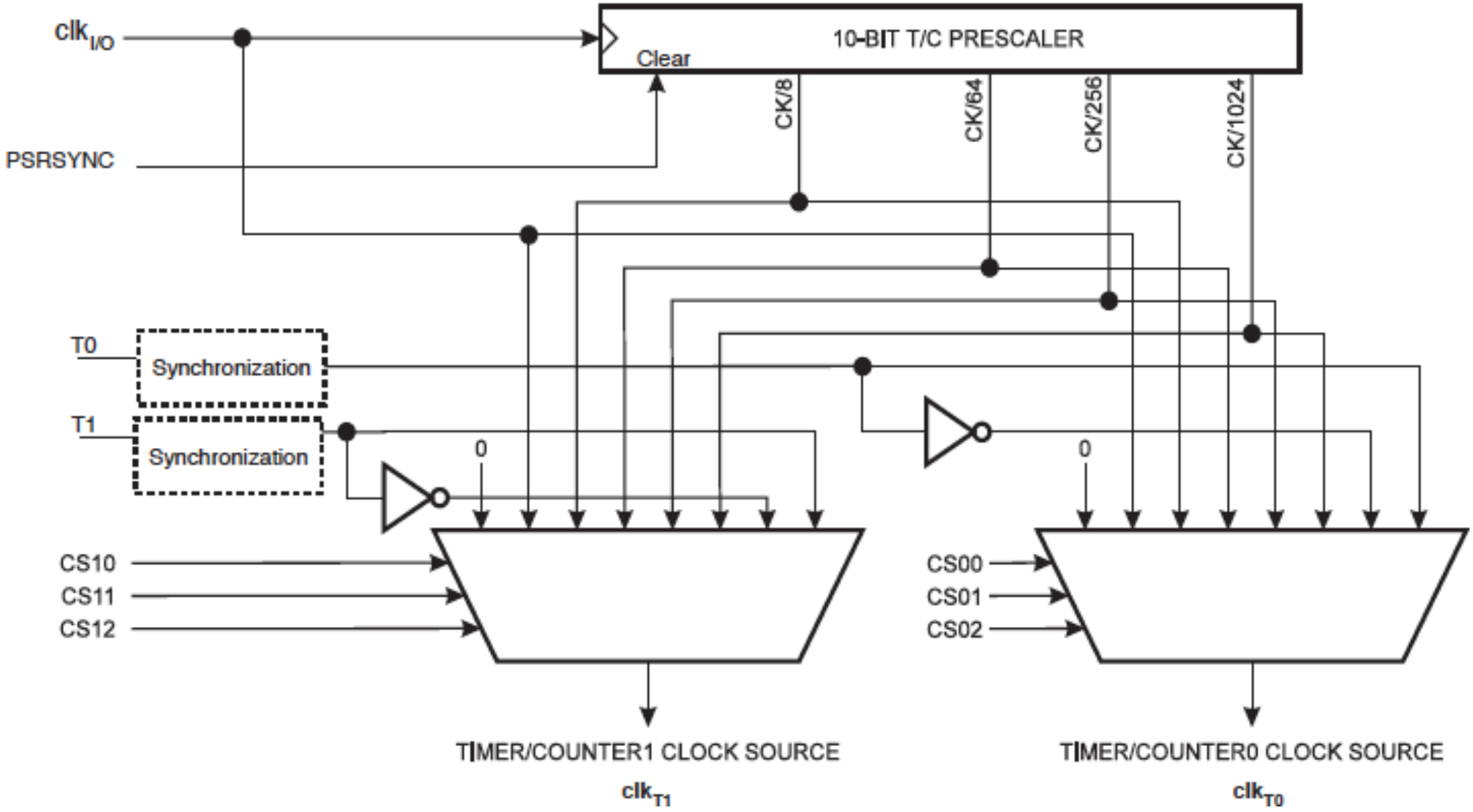
- Each bit controls whether interrupts are enabled for the corresponding pin
- Change on any enabled pin causes an interrupt
- (Mask registers 1 and 0 are similar)

8-bit Timer/Counter 0 (1 and 2 are very similar)



Prescaler for Timer/Counter 0 & 1

Figure 16-2. Prescaler for Timer/Counter0 and Timer/Counter1 (1)



Clock Source Select (CS0[2:0])

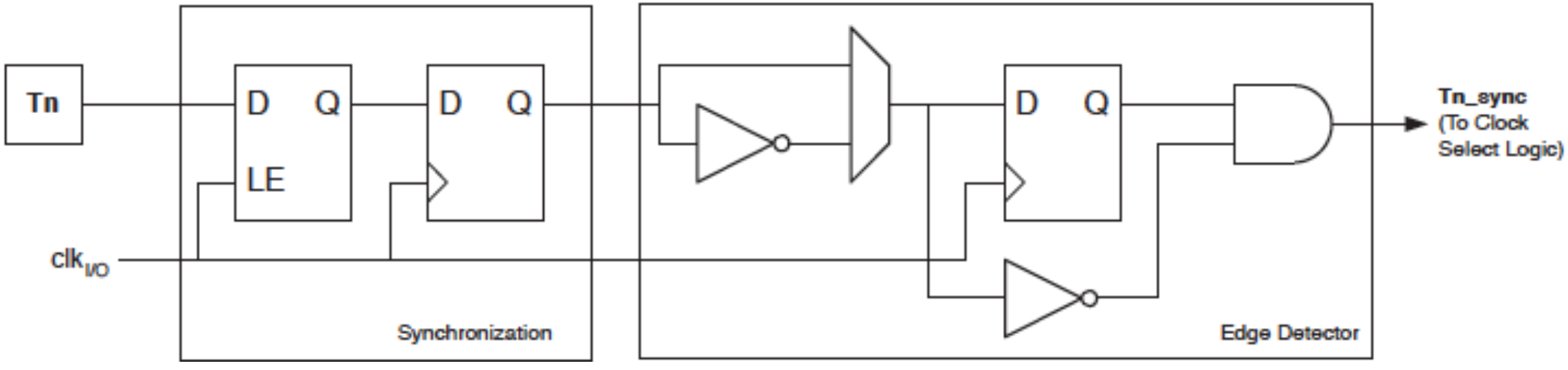
CS02	CS01	CS00	Description
0	0	0	No clock source (Timer/Counter stopped)
0	0	1	$clk_{I/O}$/(No prescaling)
0	1	0	$clk_{I/O}$/8 (From prescaler)
0	1	1	$clk_{I/O}$/64 (From prescaler)
1	0	0	$clk_{I/O}$/256 (From prescaler)
1	0	1	$clk_{I/O}$/1024 (From prescaler)
1	1	0	External clock source on T0 pin. Clock on falling edge.
1	1	1	External clock source on T0 pin. Clock on rising edge.

- T0 pin – PORT D[4]
- T1 pin – PORT D[5]
- Pin can be configured as output pin

  Program can generate clock

External Clock Source

Figure 16-1. T1/T0 Pin Sampling



Timer/Counter Registers

- TCNT0 – Timer/Counter Register (8-bit)
- OCR0A – Output Compare Register A
- OCR0B – Output Compare Register B
- TCCR0A/B – Timer/Counter Control Registers
- TIMSK0 – Timer/Counter Interrupt Mask Register
  - TOV interrupt
  - Compare A&B interrupts
- TIFR0 – Timer/Counter Interrupt Flag Register
  - TOV interrupt
  - Compare A&B interrupts

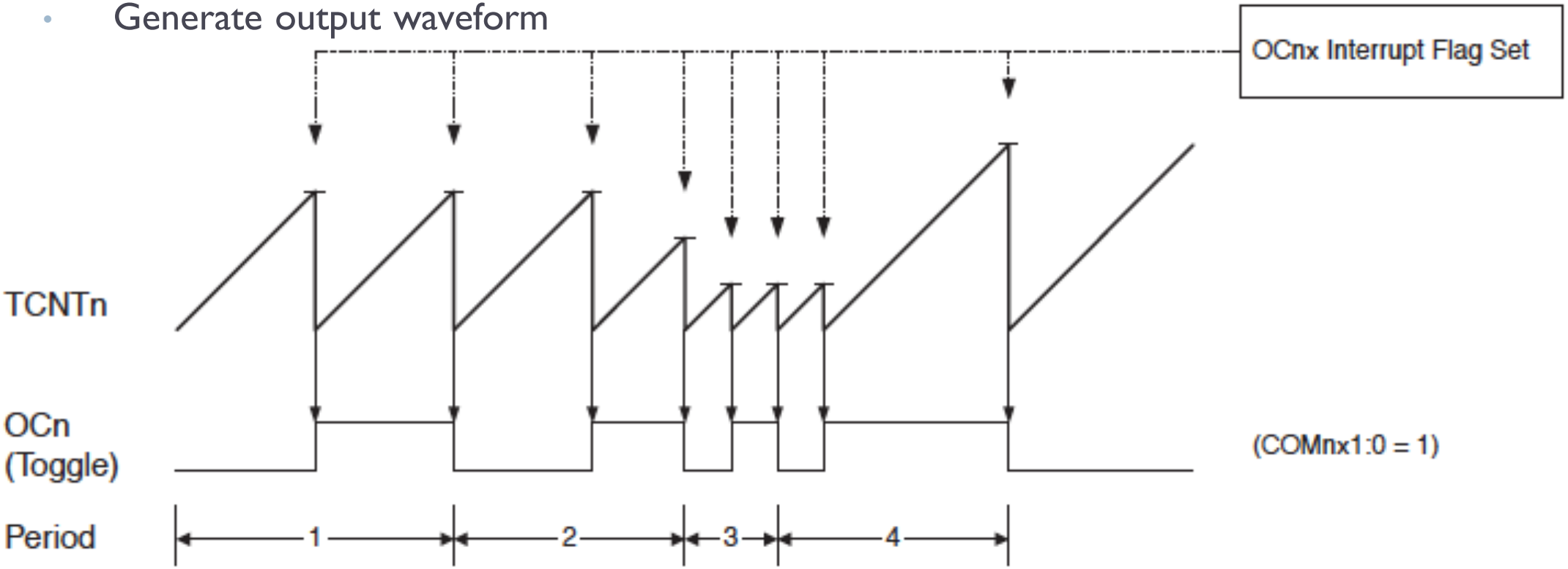
Normal Mode (0)

- Timer increments
- Wraps around at TOP = 0xFF
- Starts again at 0
- TOV0 interrupt flag set when TCNT0 reset to 0

- Useful for generating interrupts every N time units
- Useful for generating an interrupt in N time units
  - Set TCNT0 to an initial value (255 – N)

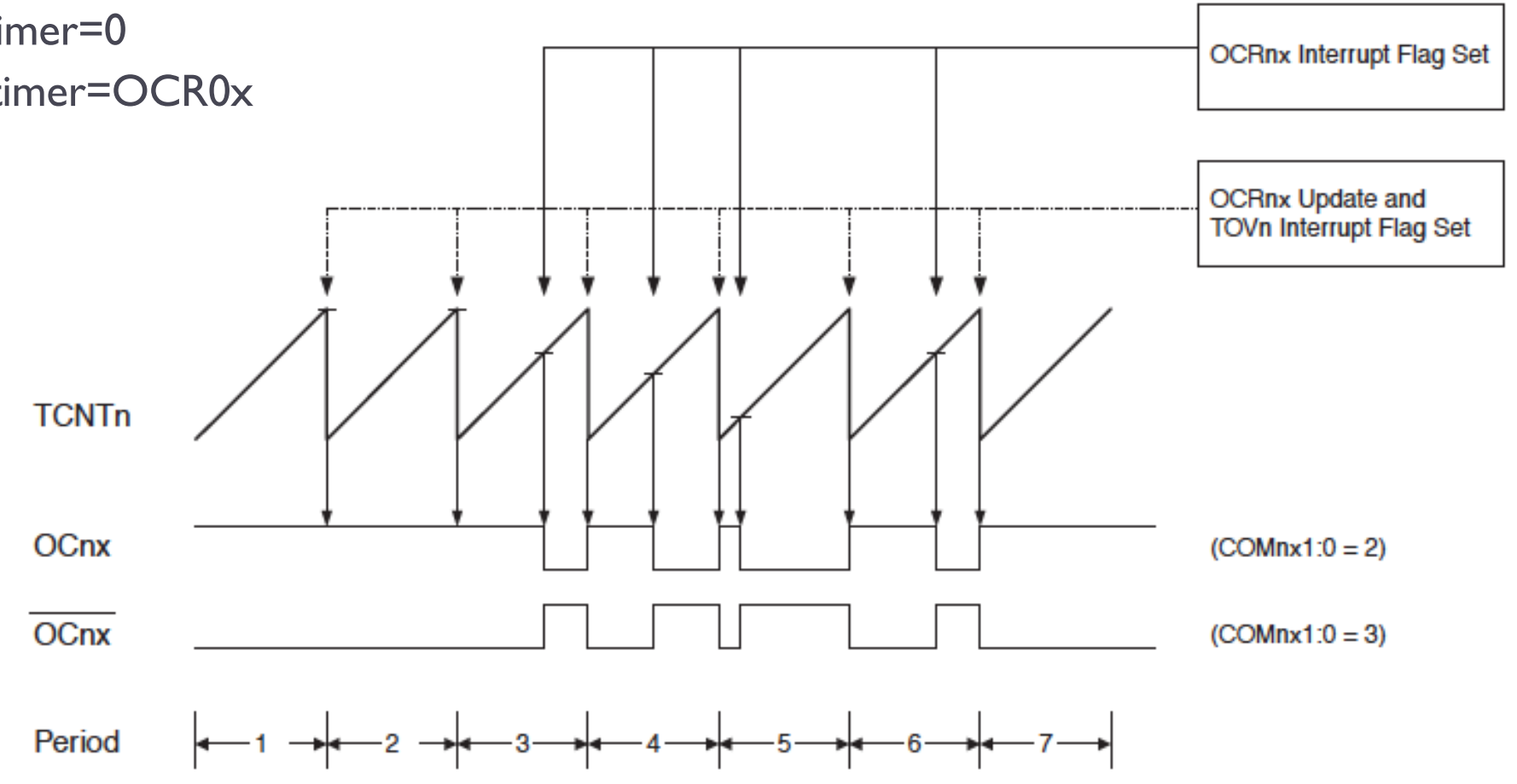
CTC (Clear Timer on Compare) Mode (2)

- Timer increments
- Wraps around at OCR0A
  - OCR0A defines top value of counter
- Starts again at 0
- OCF0A interrupt flag set when TCNT0 reset to 0
- Pin OC0A can be made to toggle when counter resets
  - Generate output waveform



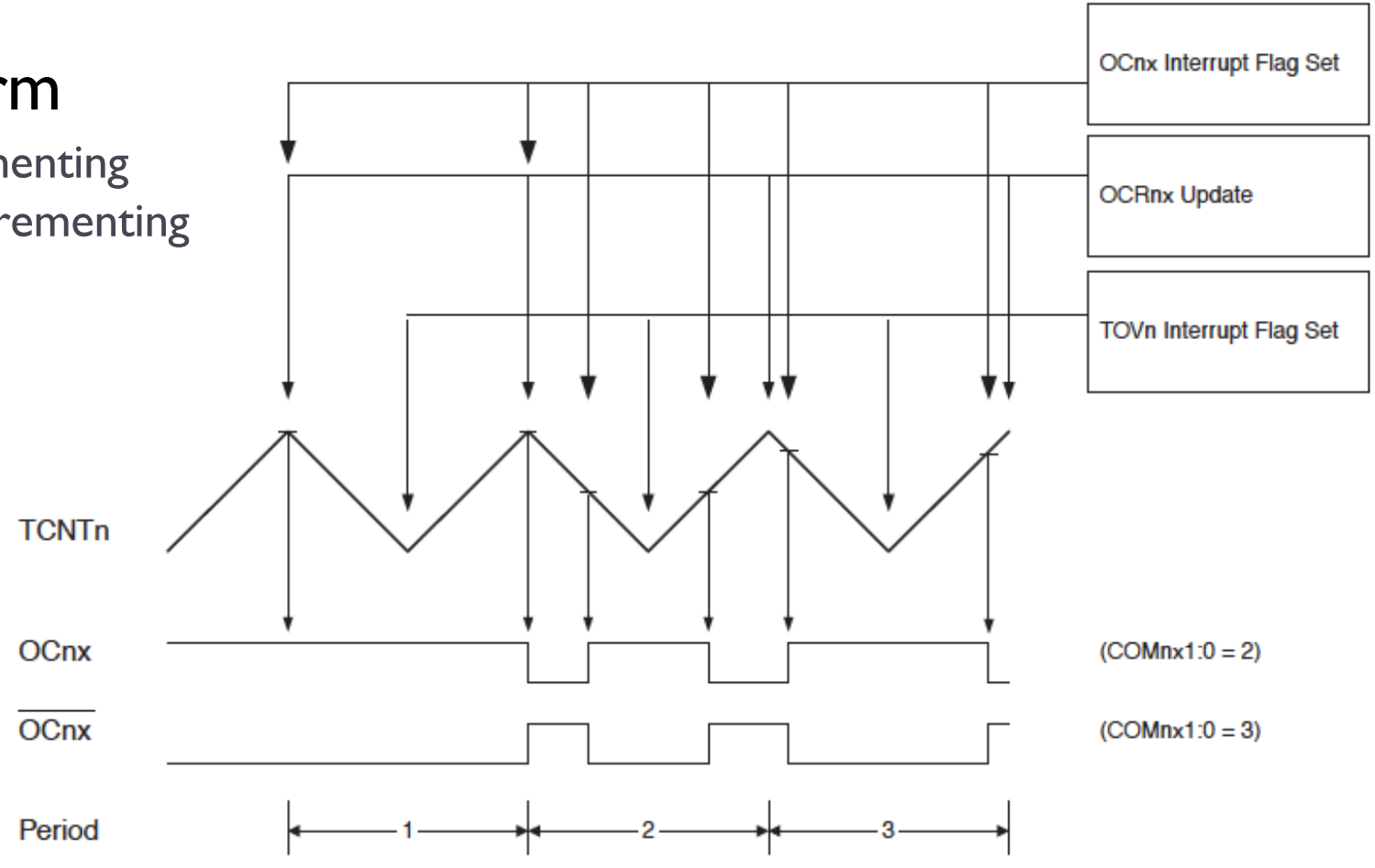
Fast PWM Mode (3&7)

- Timer increments
- Wraps around at 0xFF (3) or OCR0A (7)
- Start again at 0
- Pin OC0x generates waveform
  - Set (reset) when timer=0
  - Reset (set) when timer=OCR0x



Phase-Correct PWM Mode (1&5)

- Timer increments then decrements
- Increments from 0
- Up to 0xFF (1) or OCR0A (5)
- Than back down to 0
- Pin OC0x generates waveform
  - Set when timer=OCR0x while incrementing
  - Reset when timer=OCR0x while decrementing



Timer/Counter Control Registers

- Timer/Counter Control Register A

Bit	7	6	5	4	3	2	1	0	
0x24 (0x44)	COM0A1	COM0A0	COM0B1	COM0B0	–	–	WGM01	WGM00	TCCR0A
Read/Write	R/W	R/W	R/W	R/W	R	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- Timer/Counter Control Register B

Bit	7	6	5	4	3	2	1	0	
0x25 (0x45)	FOC0A	FOC0B	–	–	WGM02	CS02	CS01	CS00	TCCR0B
Read/Write	W	W	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Mode Summary

Table 14-8. Waveform Generation Mode Bit Description

Mode	WGM02	WGM01	WGM00	Timer/Counter Mode of Operation	TOP	Update of OCRx at	TOV Flag Set on[(1)(2)]
0	0	0	0	Normal	0xFF	Immediate	MAX
1	0	0	1	PWM, Phase Correct	0xFF	TOP	BOTTOM
2	0	1	0	CTC	OCRA	Immediate	MAX
3	0	1	1	Fast PWM	0xFF	BOTTOM	MAX
4	1	0	0	Reserved	–	–	–
5	1	0	1	PWM, Phase Correct	OCRA	TOP	BOTTOM
6	1	1	0	Reserved	–	–	–
7	1	1	1	Fast PWM	OCRA	BOTTOM	TOP

Notes: 1. MAX = 0xFF
2. BOTTOM = 0x00

COM0A[1:0] (COM0B[1:0] similar)

Table 14-2. Compare Output Mode, non-PWM Mode

COM0A1	COM0A0	Description
0	0	Normal port operation, OC0A disconnected.
0	1	Toggle OC0A on Compare Match
1	0	Clear OC0A on Compare Match
1	1	Set OC0A on Compare Match

Table 14-3. Compare Output Mode, Fast PWM Mode(1)

0	0	Normal port operation, OC0A disconnected.
0	1	WGM02 = 0: Normal Port Operation, OC0A Disconnected. WGM02 = 1: Toggle OC0A on Compare Match.
1	0	Clear OC0A on Compare Match, set OC0A at BOTTOM, (non-inverting mode).
1	1	Set OC0A on Compare Match, clear OC0A at BOTTOM, (inverting mode).

Table 14-4. Compare Output Mode, Phase Correct PWM Mode(1)

0	0	Normal port operation, OC0A disconnected.
0	1	WGM02 = 0: Normal Port Operation, OC0A Disconnected. WGM02 = 1: Toggle OC0A on Compare Match.
1	0	Clear OC0A on Compare Match when up-counting. Set OC0A on Compare Match when down-counting.
1	1	Set OC0A on Compare Match when up-counting. Clear OC0A on Compare Match when down-counting.

Timer/Counter 0 Interrupts

- Timer/Counter 0 Interrupt Mask

Bit	7	6	5	4	3	2	1	0	
(0x6E)	–	–	–	–	–	OCIE0B	OCIE0A	TOIE0	TIMSK0
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

  - TOIE0 – Timer Overflow interrupt
  - OCIE0A/B – Compare A/B interrupt

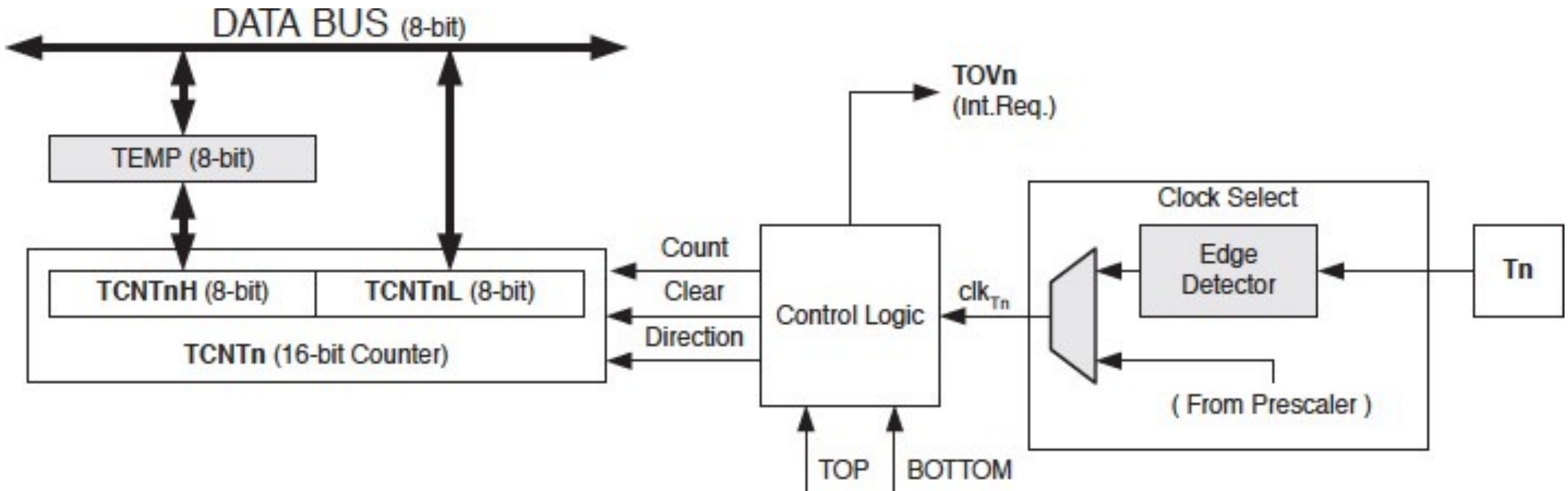
- Timer/Counter 1 Interrupt Flags

Bit	7	6	5	4	3	2	1	0	
0x15 (0x35)	–	–	–	–	–	OCF0B	OCF0A	TOV0	TIFR0
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

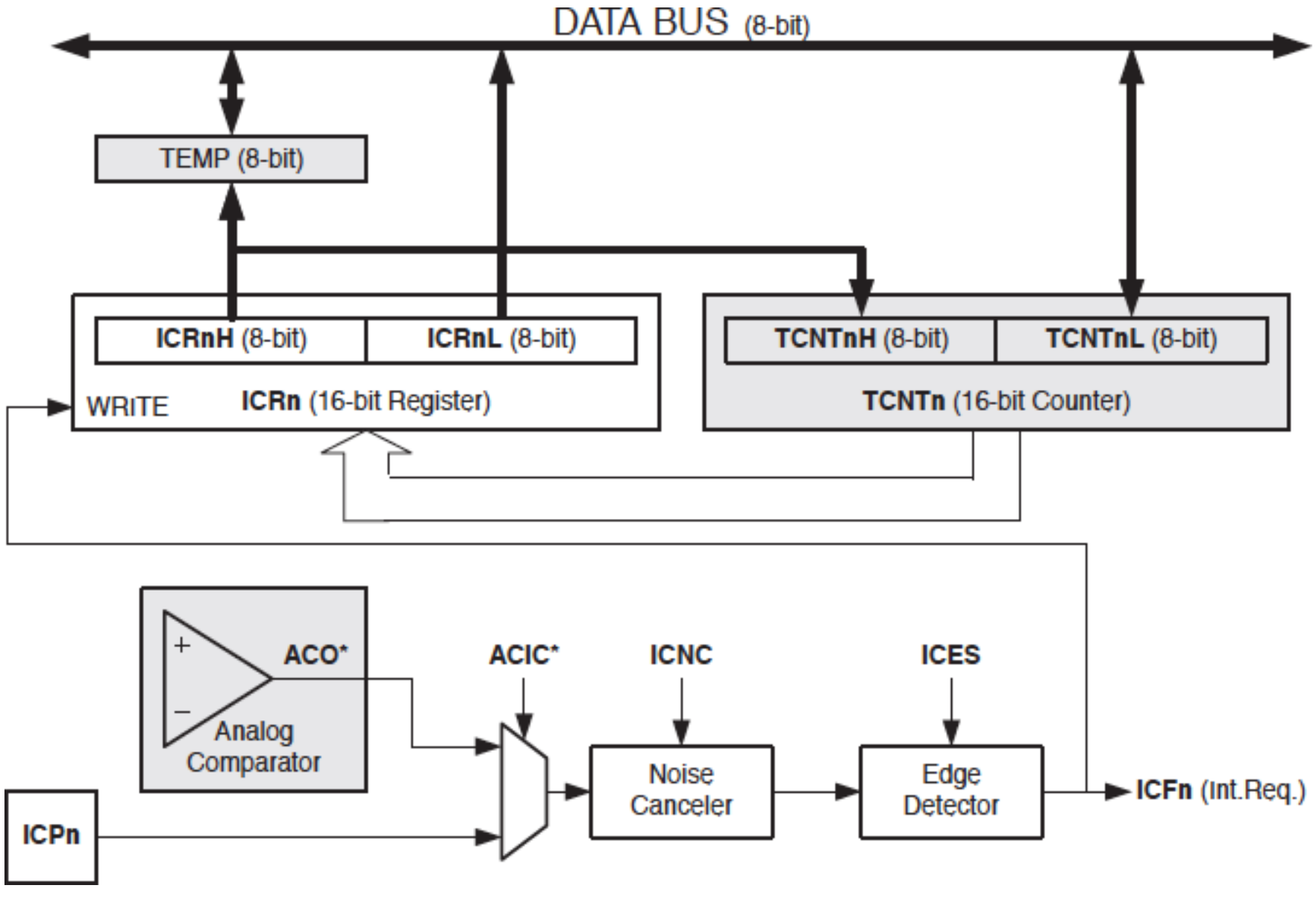
  - TOV0 – Timer Overflow flag
  - OCF0A/B – Compare A/B interrupt flag

Timer/Counter 2 (16-bit)

- Similar to Timer/Counter 1
  - 16-bit counter vs. 8-bit counter
  - 16-bit registers
    - Uses shared temporary 8-bit register to enable 16-bit read/write
  - Input capture register



Input Capture Unit



Input Capture Unit

- Event on input causes:
  - Counter value (TCNT1) to be written to ICR1
    - Time-stamp
  - Interrupt flag ICF1 to be set
    - Causing an interrupt, if enabled
- Pin ICP1 – Port B [0]
- Noise Canceller
  - Pulses less than 4 clock cycles long are filtered
- Useful for measuring frequency and duty cycle
  - PWM inputs

Timer/Counter 1

- ICR can also be used as the TOP value
  - Allows OCR1A to be used for PWM generation

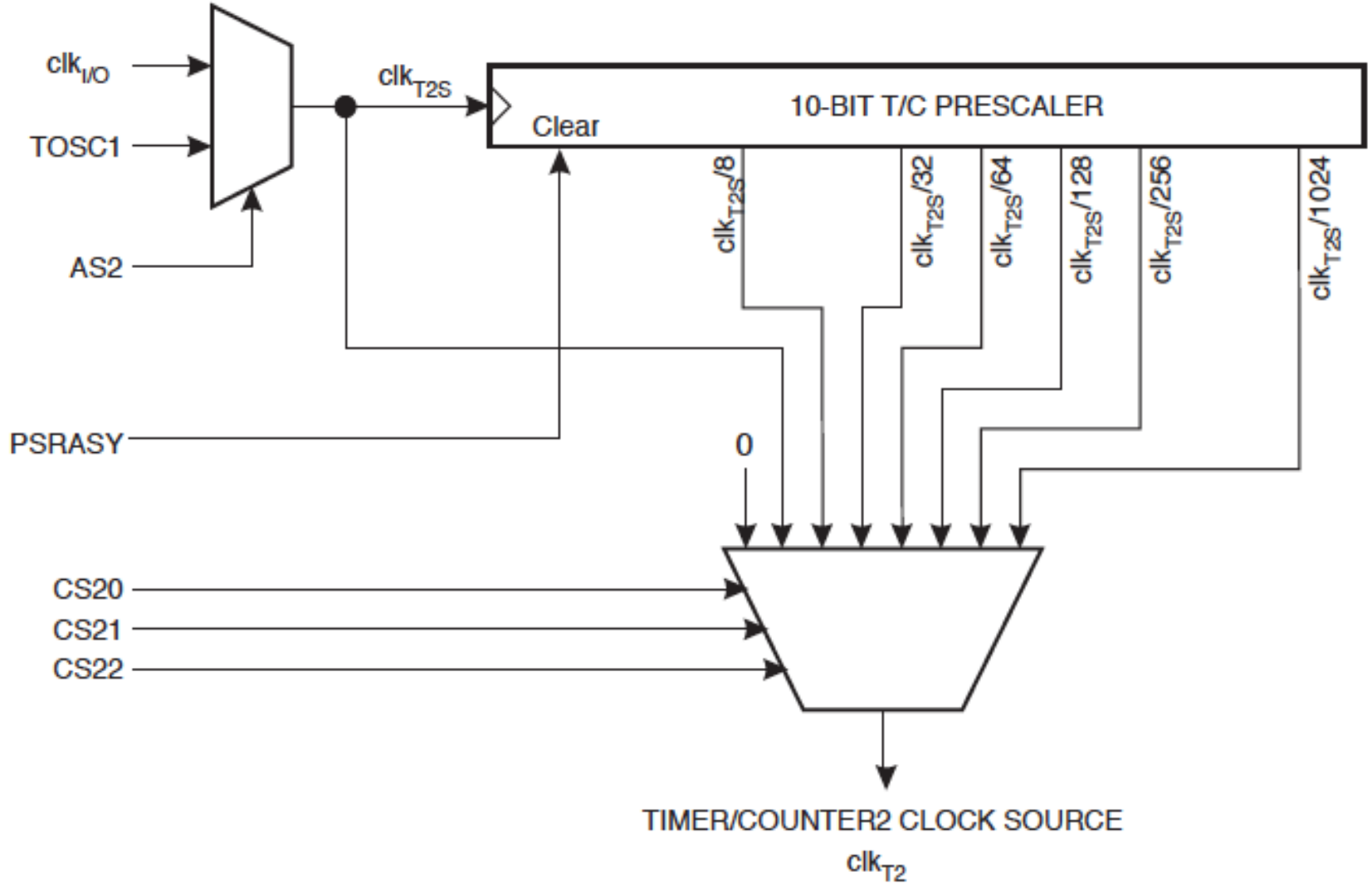
Timer/Counter 1 Modes

Mode	WGM13	WGM12 (CTC1)	WGM11 (PWM11)	WGM10 (PWM10)	Timer/Counter Mode of Operation	TOP	Update of OCR1x at	TOV1 Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCR1A	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICR1	BOTTOM	BOTTOM
9	1	0	0	1	PWM, Phase and Frequency Correct	OCR1A	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICR1	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCR1A	TOP	BOTTOM
12	1	1	0	0	CTC	ICR1	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICR1	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCR1A	BOTTOM	TOP

Timer/Counter 2 (8-bit)

- Identical to Timer/Counter 1
- Except for clock sources

Figure 17-12. Prescaler for Timer/Counter2



External and Pin Change Interrupts

```
#define  PCIFR  _SFR_IO8(0x1B)
#define  PCIF0  0
 #define PCIF1  1
 #define PCIF2  2


 #define EIFR  _SFR_IO8(0x1C)
 #define INTF0  0
 #define INTF1  1

 #define EIMSK  _SFR_IO8(0x1D)
 #define INT0  0
 #define INT1  1

 #define PCICR  _SFR_MEM8(0x68)
 #define PCIE0  0
 #define PCIE1  1
 #define PCIE2  2

 #define EICRA  _SFR_MEM8(0x69)
 #define ISC00  0
 #define ISC01  1
 #define ISC10  2
 #define ISC11  3
```

```
#define  PCMSK0  _SFR_MEM8(0x6B)  0
#define  PCINT0
...
#define  PCINT7  7


#define  PCMSK1  _SFR_MEM8(0x6C)
#define  PCINT8  0
...
#define  PCINT14  6

#define  PCMSK2  _SFR_MEM8(0x6D)
#define  PCINT16  0
...
#define
         PCINT23  7
```

Timer/Counter 0 Registers

```
#define TCCR0A _SFR_IO8(0x24)
#define WGM00 0
#define WGM01 1
#define COM0B0 4
#define COM0B1 5
#define COM0A0 6
#define COM0A1 7

#define TCCR0B _SFR_IO8(0x25)
#define CS00 0
#define CS01 1
#define CS02 2
#define WGM02 3
#define FOC0B 6
#define FOC0A 7

#define TCNT0 _SFR_IO8(0x26)
#define TCNT0_0 0
...
#define TCNT0_7 7
```

```
#define OCR0A _SFR_IO8(0x27)
#define OCROA_0 0
...
#define OCROA_7 7

#define OCR0B _SFR_IO8(0x28)
#define OCR0B_0 0
...
#define OCR0B_7 7
```

Timer/Counter Interrupts

```
#define TIFR0 _SFR_IO8(0x15)
#define TOV0 0
#define OCF0A 1
#define OCF0B 2

#define TIFR1 _SFR_IO8(0x16)
#define TOV1 0
#define OCF1A 1
#define OCF1B 2
#define ICF1 5

#define TIFR2 _SFR_IO8(0x17)
#define TOV2 0
#define OCF2A 1
#define OCF2B 2
```

```
#define TIMSK0 _SFR_MEM8(0x6E)
#define TOIE0 0
#define OCIE0A 1
#define OCIE0B 2

#define TIMSK1 _SFR_MEM8(0x6F)
#define TOIE1 0
#define OCIE1A 1
#define OCIE1B 2
#define ICIE1 5

#define TIMSK2 _SFR_MEM8(0x70)
#define TOIE2 0
#define OCIE2A 1
#define OCIE2B 2
```

Timer/Counter 1

```
#define TCCR1A _SFR_MEM8(0x80)
#define WGM10 0
#define WGM11 1
#define COM1B0 4
#define COM1B1 5
#define COM1A0 6
#define COM1A1 7

#define TCCR1B _SFR_MEM8(0x81)
#define CS10 0
#define CS11 1
#define CS12 2
#define WGM12 3
#define WGM13 4
#define ICES1 6
#define ICNC1 7

#define TCCR1C _SFR_MEM8(0x82)
#define FOC1B 6
#define FOC1A 7
```

```
#define  TCNT1 _SFR_MEM16(0x84)

#define  TCNT1L _SFR_MEM8(0x84)
#define  TCNT1L0 0
...
#define  TCNT1L7 7

#define  TCNT1H _SFR_MEM8(0x85)
#define  TCNT1H0 0
...
#define  TCNT1H7 7

#define  ICR1 _SFR_MEM16(0x86)

#define  ICR1L _SFR_MEM8(0x86)
#define  ICR1L0 0
...
#define  ICR1L7 7

#define  ICR1H _SFR_MEM8(0x87)
#define  ICR1H0 0
...
#define  ICR1H7 7
```

Timer/Counter 1 (cont)

```
#define OCR1A _SFR_MEM16(0x88)

#define OCR1AL _SFR_MEM8(0x88)
#define OCR1AL0 0
...
#define OCR1AL7 7

#define OCR1AH _SFR_MEM8(0x89)
#define OCR1AH0 0
...
#define OCR1AH7 7

#define OCR1B _SFR_MEM16(0x8A)

#define OCR1BL _SFR_MEM8(0x8A)
#define OCR1BL0 0
...
#define OCR1BL7 7

#define OCR1BH _SFR_MEM8(0x8B)
#define OCR1BH0 0
...
#define OCR1BH7 7
```

Timer/Counter 2

```
#define TCCR2A _SFR_MEM8(0xB0)
#define WGM20 0
#define WGM21 1
#define COM2B0 4
#define COM2B1 5
#define COM2A0 6
#define COM2A1 7

#define TCCR2B _SFR_MEM8(0xB1)
#define CS20 0
#define CS21 1
#define CS22 2
#define WGM22 3
#define FOC2B 6
#define FOC2A 7

#define TCNT2 _SFR_MEM8(0xB2)
#define TCNT2_0 0
...
#define TCNT2_7 7

#define OCR2A _SFR_MEM8(0xB3)
#define OCR2_0 0
...
#define OCR2_7 7

#define OCR2B _SFR_MEM8(0xB4)
#define OCR2_0 0
...
#define OCR2_7 7

#define ASSR _SFR_MEM8(0xB6)
#define TCR2BUB 0
#define TCR2AUB 1
#define OCR2BUB 2
#define OCR2AUB 3
#define TCN2UB 4
#define AS2 5
#define EXCLK 6
```

Timer Interrupt Program Example

```
void setup()    {
  DDRB =          ;    // Pin 13 as output
  // Using timer 2
  // Set to Normal mode, Pin OC0A disconnected
  TCCR2A =          ;
  // Prescale clock by 1024
  // Interrupt every 256K/16M sec = 1/64 sec TCCR2B =
            ;
  // Turn on timer overflow interrupt flag
  TIMSK2 =          ;
  // Turn on global interrupts sei();
}
uint8_t timer = 0;
// ISR to be called at Timer2 overflow
ISR(          _vect) {
  timer++;
  PORTB =          ;
}
void loop(){
  // Nothing to do
}
```

Timer Example #2

```
void setup()    {
  DDRB =            ;  // Pin 13 OUTPUT
  // Set to CTC mode, Pin OC0A disconnected
  TCCR2A =          ;
  // Prescale clock by 1 (no prescale)
  TCCR2B =          ;
  // Set compare register
  OCR2A =           ;
  // Turn on timer compare A interrupt flag
  TIMSK2 =          ;
  // Turn on global interrupts
  sei();
}
char timer = 0;
ISR(              _vect) {
  timer++;
  PORTB =           ;
}
void loop(){
  // Nothing to do
}
```

External Interrupt Example

```
#define pinint0
#define pinint1
void setup()    {
  pinMode(pinint0,          );
  pinMode(pinint1,          );
  Serial.begin(9600);
  // External interrupts 0 and 1
  // Interrupt on rising edge
  EICRA =           ;
  // Enable both interrupts
  EIMSK =           ;
  // Turn on global interrupts
  sei();
}
ISR(      _vect)  {


}
ISR(      _vect)  {


}
```

```
// Print out the information
void loop()
{

  Serial.print("X:  ");
  Serial.print(percent0);
  Serial.print("   Y: ");
  Serial.println(percent1);
}
```