COMPUTER ENGINEERING
MAHIDOL UNIVERSITY

EGCO334: Microprocessor and Interfacing

Pulse Width Modulation (PWM)

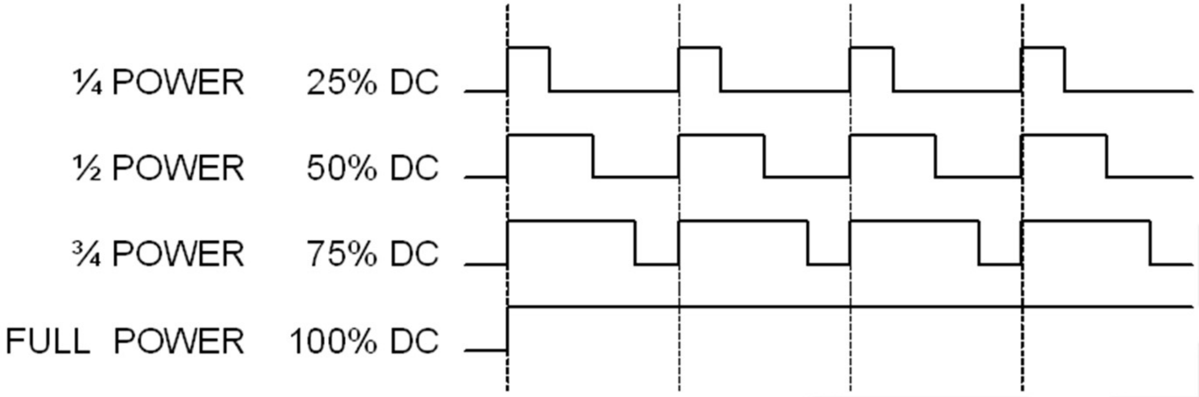
Outline

- Pulse Width Modulator (PWM)
- PWM Mode
  - Fast PWM
  - Phase Correct PWM
  - Phase and Frequency Correct PWM Mode

Pulse Width Modulator

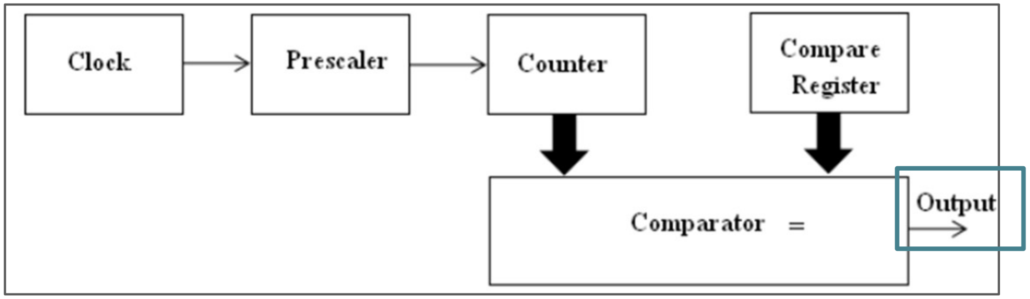
Pulse-width modulation (PWM) is a useful technique for controlling DC motor speeds, LED intensity and creating analog waveforms.

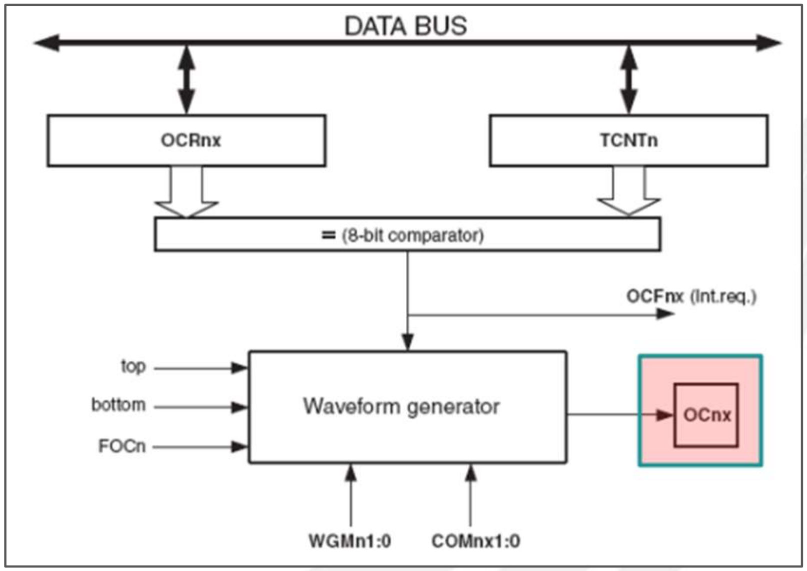
The idea is to modulate (or change) the width of a digital signal (a pulse) to deliver a varying amount of voltage



Pulse Width Modulator

Generating PWM Waveform by Arduino 328P

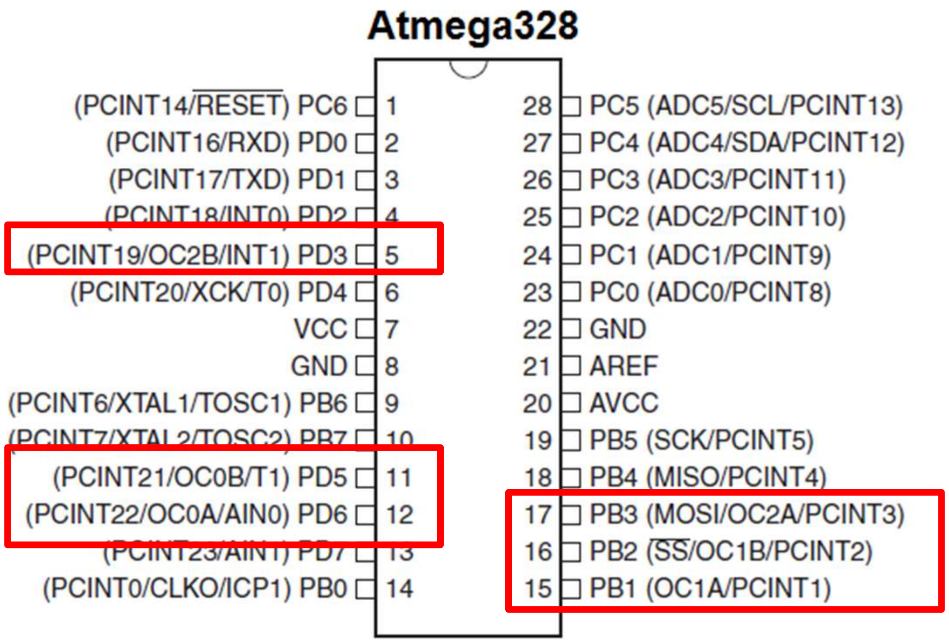




- OCRnx (OCR0A and OCR0B) = Output Compare Registers
- TCNTn (TCNT0) = Timer/Counter Register
- OCFnx (OCF0x) = Output Compare Flag
- Ocnx = Timer/Counter1 output compare match output

Pulse Width Modulator

Generating PWM Waveform by Arduino 328P



Output	AVR pin	Arduino Pin
OC2B	= PD3	= D3
OC0B	= PD5	= D5
OC0A	= PD6	= D6
OC1A	= PB1	= D9
OC1B	= PB2	= D10
OC2A	= PB3	= D11

Pulse Width Modulator

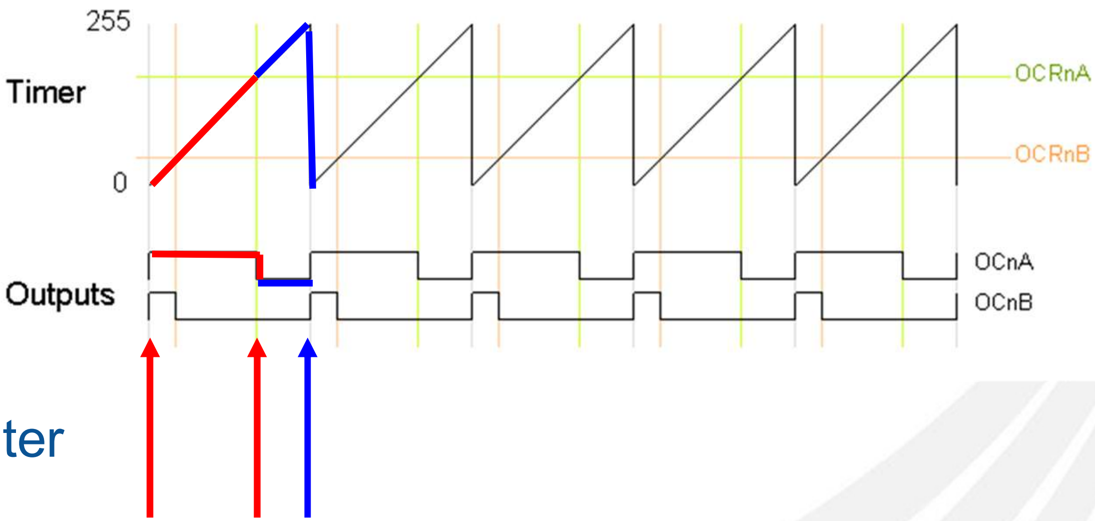
Timer/Counter Modes of Operation

- Normal
- CTC (Clear Timer on Compare Match)
- **Fast PWM (Single Slope PWM)**
- **Phase Correct PWM (Double Slope PWM)**
- **Phase and Frequency Correct PWM Mode (Timer/Counter 1 Only)**

Pulse Width Modulator

Fast PWM

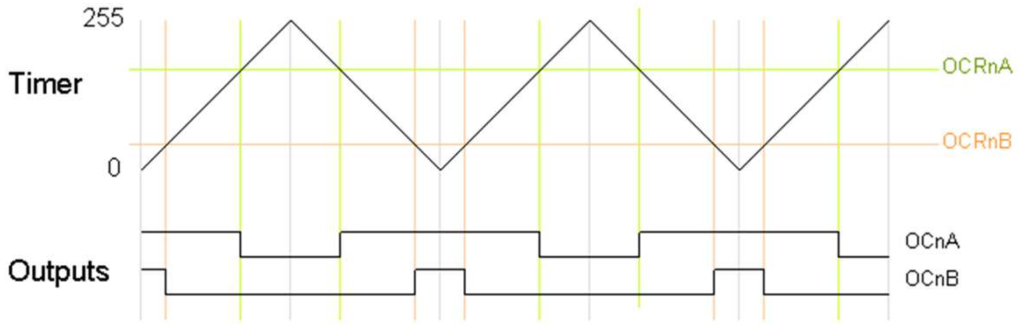
- Timer repeatedly counts from 0 to 255
- The output turns on when the timer is at 0
- The output turns off when the timer matches the output compare register



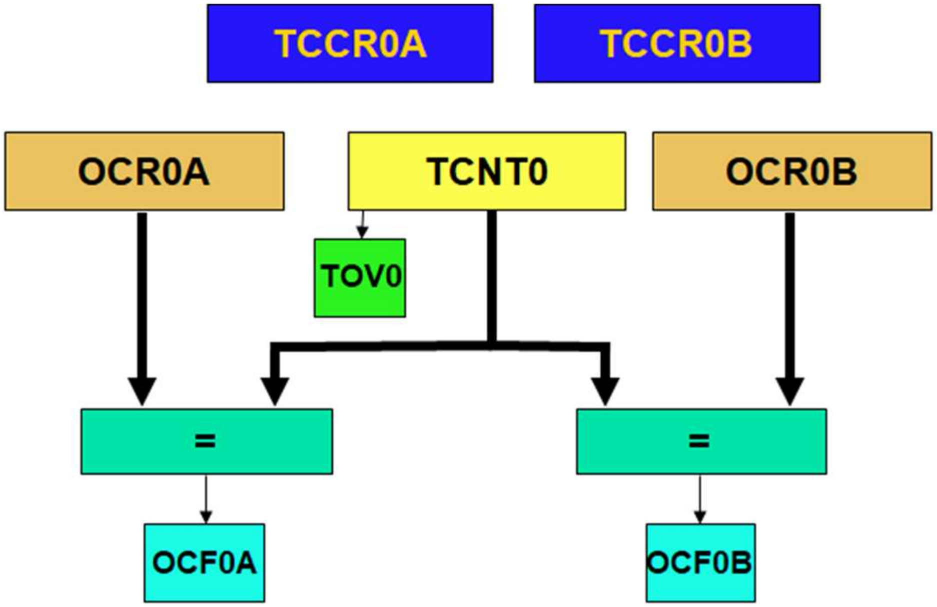
Pulse Width Modulator

Phase-Correct PWM

- The timer counts from 0 to 255 and then back down to 0
- The output is cleared when timer hits the output compare while up-counting
- The output is set when timer hits the output compare while down-counting
- Output frequency will be approximately half of the value for fast PWM mode

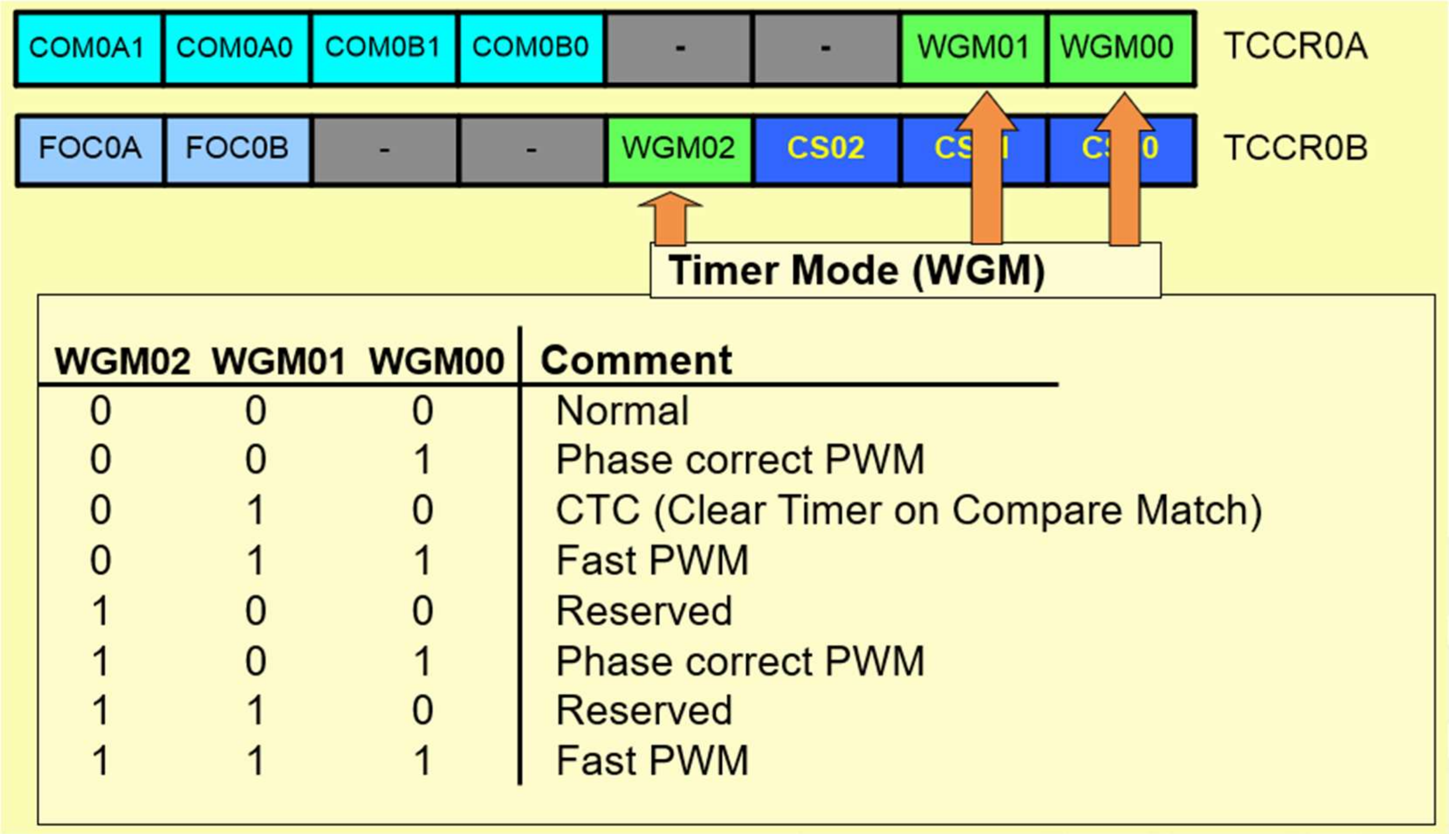


Timer0 PWM



COM0A1	COM0A0	COM0B1	COM0B0	-	-	WGM01	WGM00	TCCR0A
FOC0A	FOC0B	-	-	WGM02	CS02	CS01	CS00	TCCR0B

Timer0 PWM

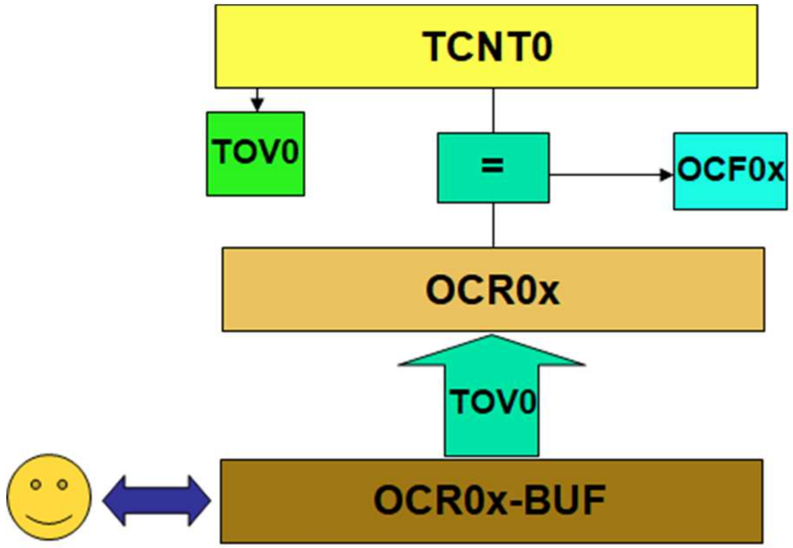


COM0A1	COM0A0	COM0B1	COM0B0	-	-	WGM01	WGM00	TCCR0A
FOC0A	FOC0B	-	-	WGM02	CS02	CS01	CS00	TCCR0B

Timer Mode (WGM)

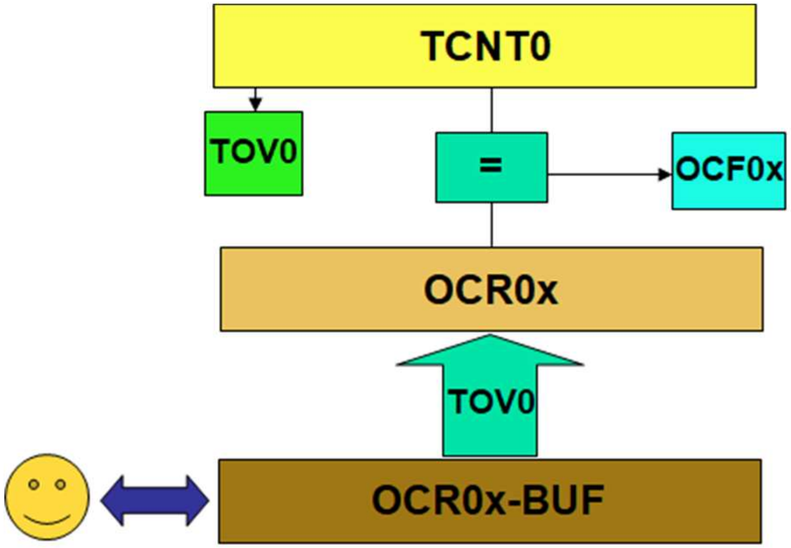
WGM02	WGM01	WGM00	Comment
0	0	0	Normal
0	0	1	Phase correct PWM
0	1	0	CTC (Clear Timer on Compare Match)
0	1	1	Fast PWM
1	0	0	Reserved
1	0	1	Phase correct PWM
1	1	0	Reserved
1	1	1	Fast PWM

Timer0 PWM



- Output Compare Registers (Double Buffer Register)
  - OCR0x
  - OCR0x-BUF
- TCNT0 = Timer/Counter Register
- OCF0x = Output Compare Flag
- Oc0x = Timer/Counter1 output compare match output

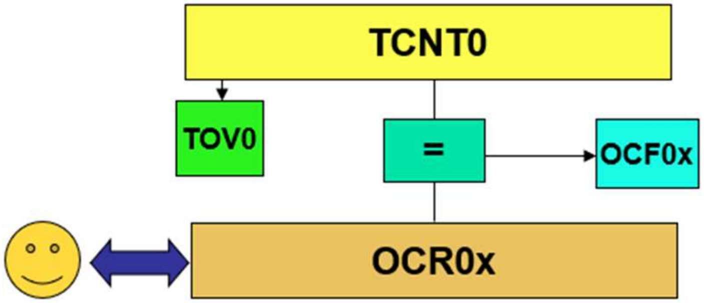
Timer0 PWM

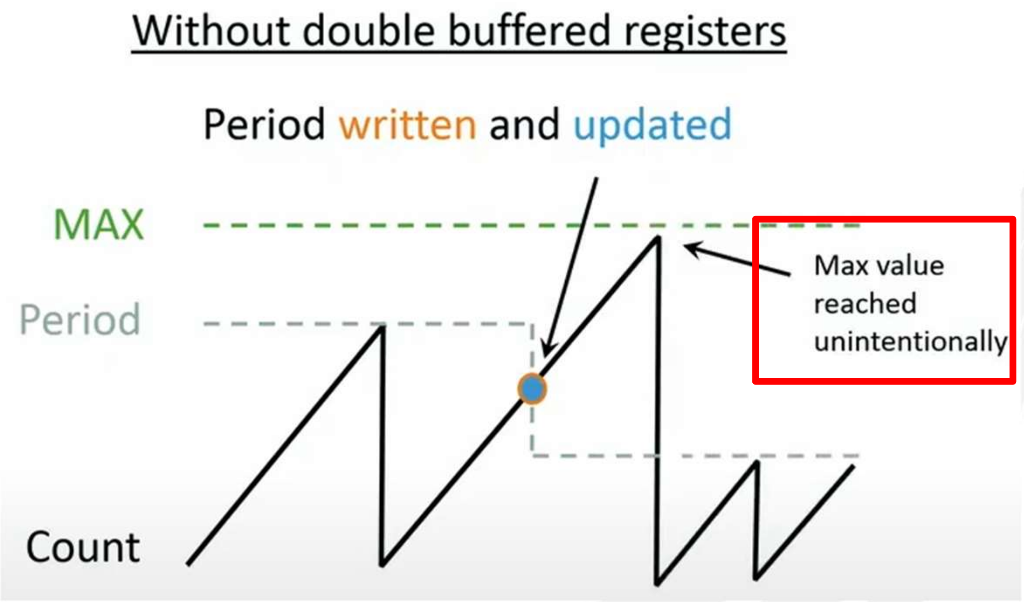


- Output Compare Registers (Double Buffer Register)
  - OCR0x
  - OCR0x-BUF

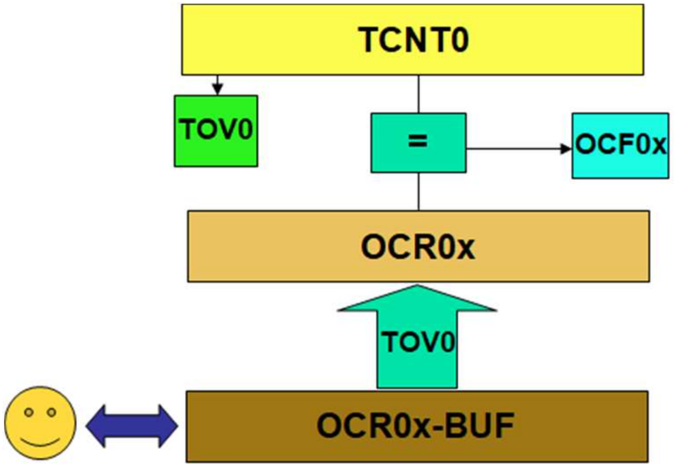
OCR0x-BUF will be update by user and the value will be passed to OCR0X when TOV0 is set

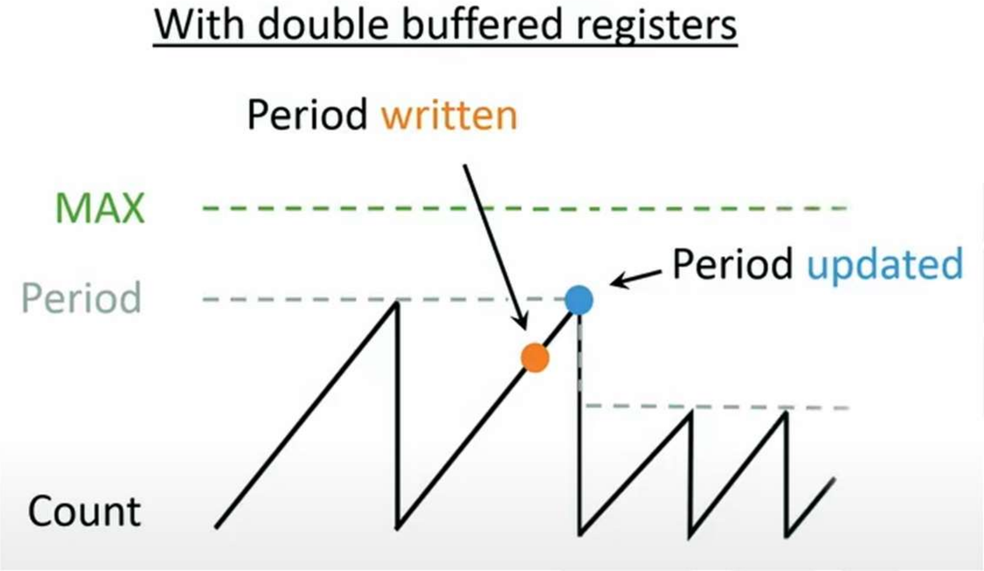
Timer0 PWM


TCNT0
TOV0
=
OCF0x
OCR0x

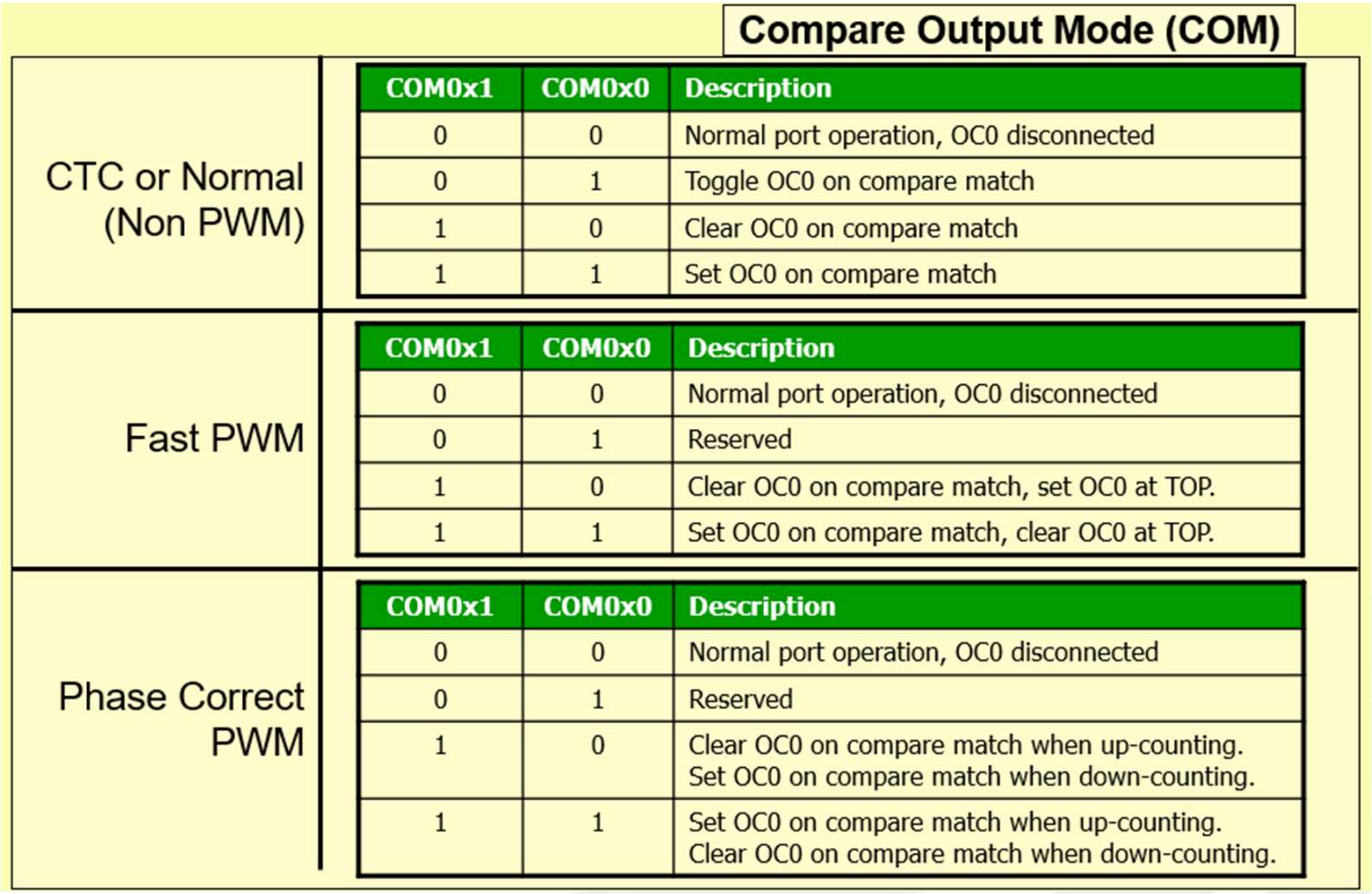

Without double buffered registers
Period written and updated
MAX
Period
Count
Max value reached unintentionally

Timer0 PWM


TCNT0
TOV0
=
OCF0x
OCR0x
TOV0
OCR0x-BUF


With double buffered registers
Period written
MAX
Period
Period updated
Count

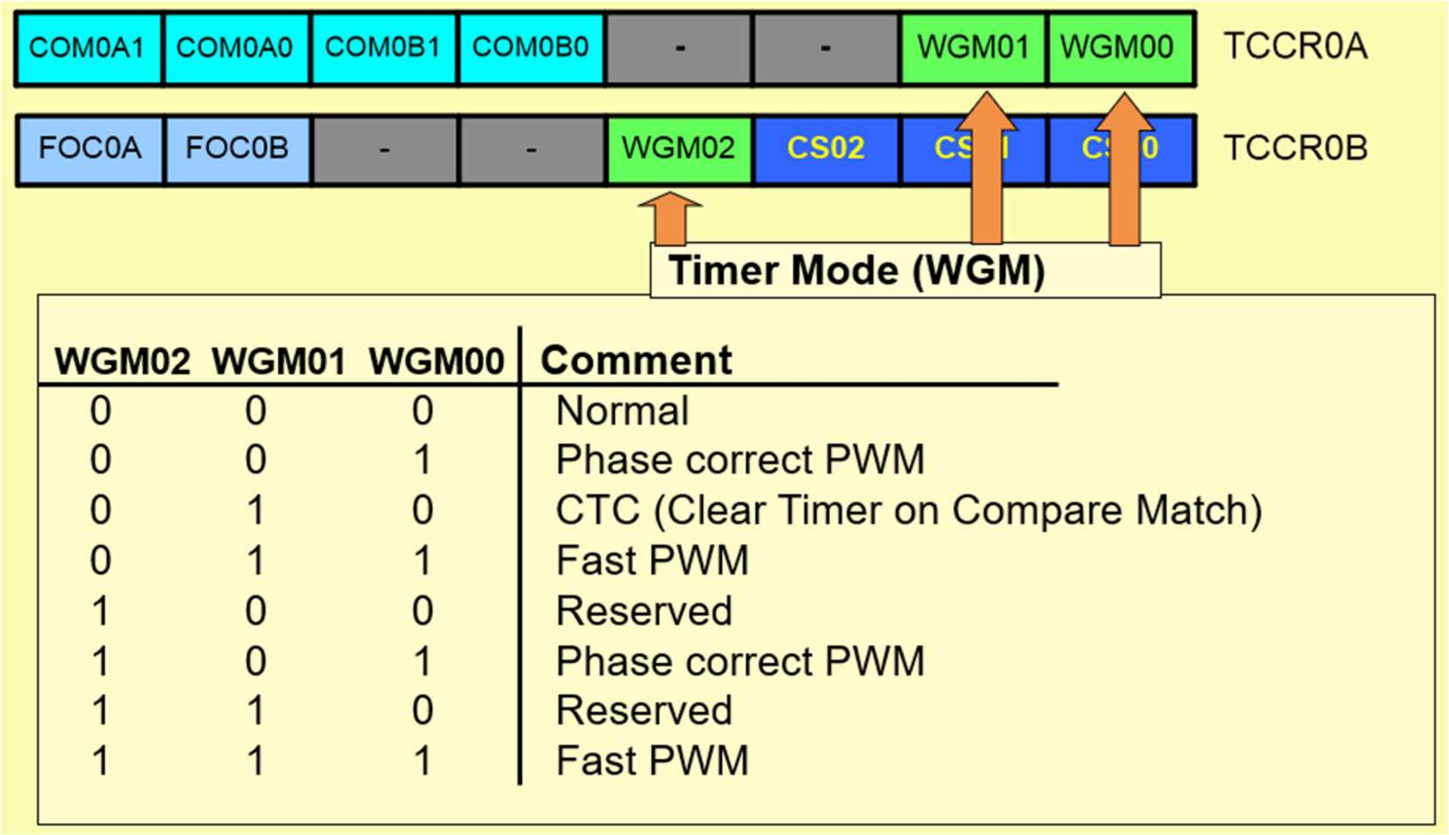
Timer0 PWM



Compare Output Mode (COM)

	COM0x1	COM0x0	Description
CTC or Normal (Non PWM)	0	0	Normal port operation, OC0 disconnected
	0	1	Toggle OC0 on compare match
	1	0	Clear OC0 on compare match
	1	1	Set OC0 on compare match
Fast PWM	0	0	Normal port operation, OC0 disconnected
	0	1	Reserved
	1	0	Clear OC0 on compare match, set OC0 at TOP.
	1	1	Set OC0 on compare match, clear OC0 at TOP.
Phase Correct PWM	0	0	Normal port operation, OC0 disconnected
	0	1	Reserved
	1	0	Clear OC0 on compare match when up-counting. Set OC0 on compare match when down-counting.
	1	1	Set OC0 on compare match when up-counting. Clear OC0 on compare match when down-counting.

Timer0 PWM



COM0A1	COM0A0	COM0B1	COM0B0	-	-	WGM01	WGM00	TCCR0A
FOC0A	FOC0B	-	-	WGM02	CS02	CS01	CS00	TCCR0B

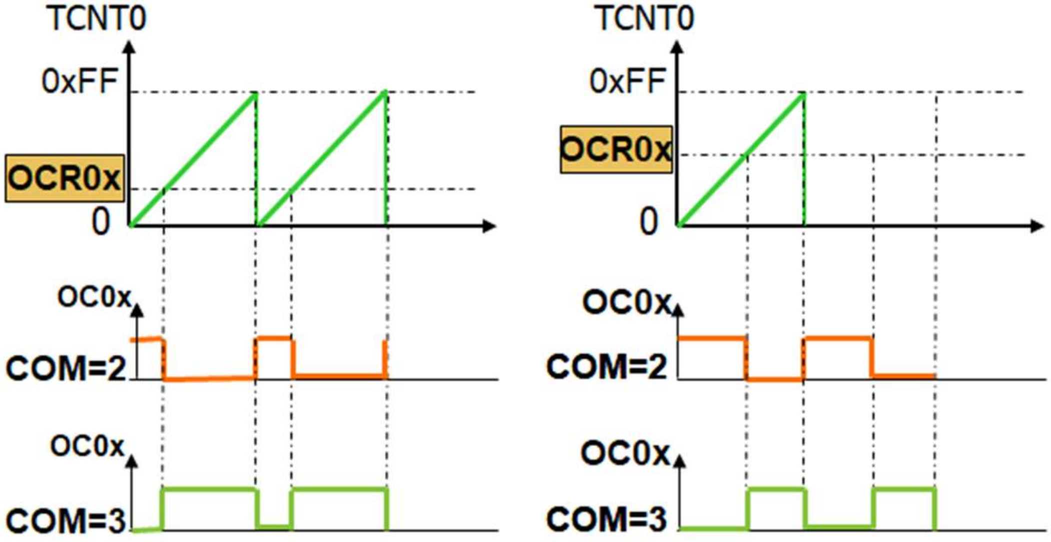
Timer Mode (WGM)

WGM02	WGM01	WGM00	Comment
0	0	0	Normal
0	0	1	Phase correct PWM
0	1	0	CTC (Clear Timer on Compare Match)
0	1	1	Fast PWM
1	0	0	Reserved
1	0	1	Phase correct PWM
1	1	0	Reserved
1	1	1	Fast PWM

Timer0 PWM

Fast PWM Calculations

Fast PWM
Duty cycle = changeable (0% to 100%)
Frequency = selectable between limited choices



$$F_{OC0} = \frac{f_{clk}}{N(256)}$$

(N = prescaler)

$$\text{duty cycle}_{\text{non-invert}} = \frac{\text{OCR0}}{256} \times 100$$

$$\text{duty cycle}_{\text{invert}} = 1 - \text{duty cycle}_{\text{non-invert}}$$

Timer0 PWM

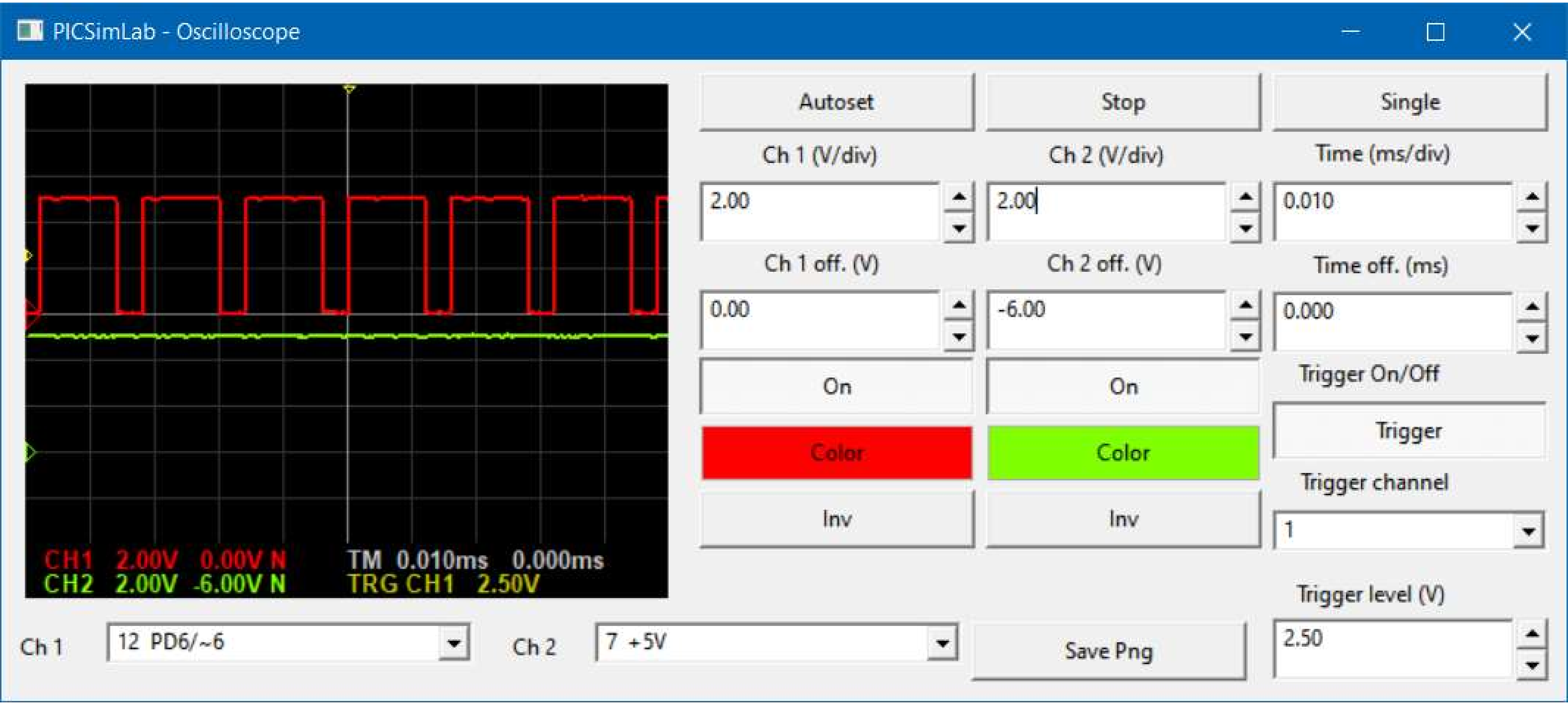
Fast PWM Calculations

Assuming XTAL = 16 MHz, make the following pulse duty cycle = 75% and frequency = 62.500KHz

$$F_{OC0} = \frac{f_{clk}}{N(256)} \Rightarrow 62.500\text{KHz} = \frac{16\text{MHz}}{N(256)} \Rightarrow N = \frac{16\text{MHz}}{62.500\text{K}*256} = 1$$

$$0.75 = \frac{\text{OCR0}}{256}$$

$$\text{OCR0} = 192$$



PICSimLab - Oscilloscope

```
CH1   2.00V   0.00V N      TM  0.010ms   0.000ms
CH2   2.00V  -6.00V N      TRG CH1   2.50V
```

Ch 1 (V/div): 2.00

Ch 2 (V/div): 2.00

Time (ms/div): 0.010

Ch 1 off. (V): 0.00

Ch 2 off. (V): -6.00

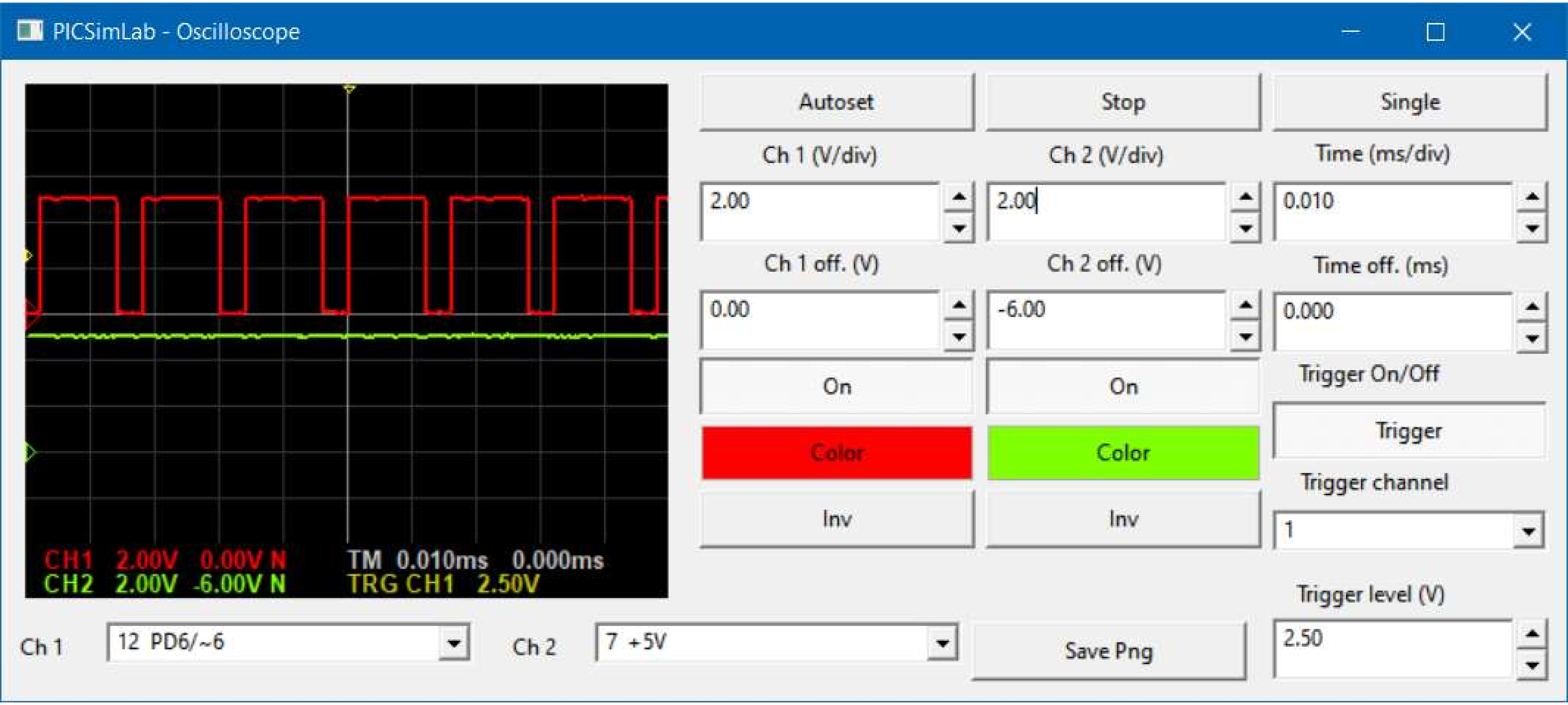
Time off. (ms): 0.000

Trigger channel: 1

Trigger level (V): 2.50

Ch 1: 12 PD6/~6

Ch 2: 7 +5V



PICSimLab - Oscilloscope

Ch 1 (V/div) 2.00

Ch 2 (V/div) 2.00

Time (ms/div) 0.010

Ch 1 off. (V) 0.00

Ch 2 off. (V) -6.00

Time off. (ms) 0.000

Trigger channel 1

Trigger level (V) 2.50

Ch 1 12 PD6/~6

Ch 2 7 +5V

```
CH1  2.00V  0.00V N    TM  0.010ms   0.000ms
CH2  2.00V -6.00V N    TRG CH1   2.50V
```

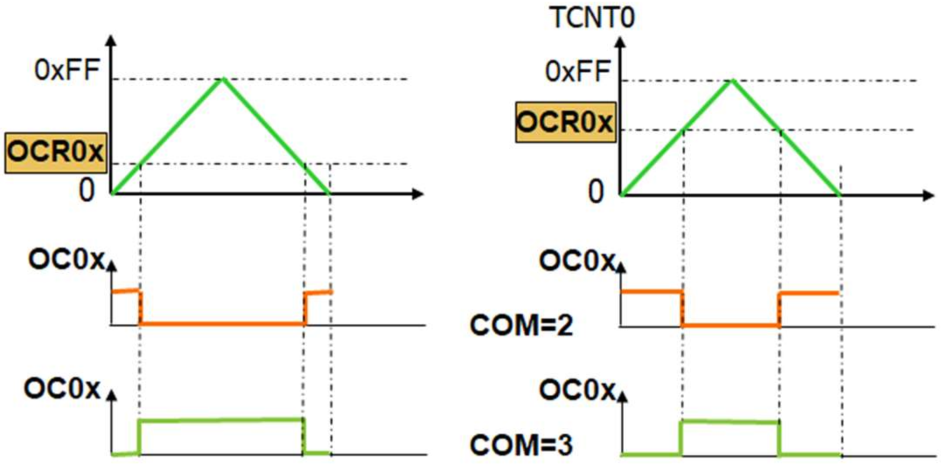
$$\left(1\frac{2}{3}\times 0.01\times 10^{-3}\right)^{-1} = 60,000$$

Timer0 PWM

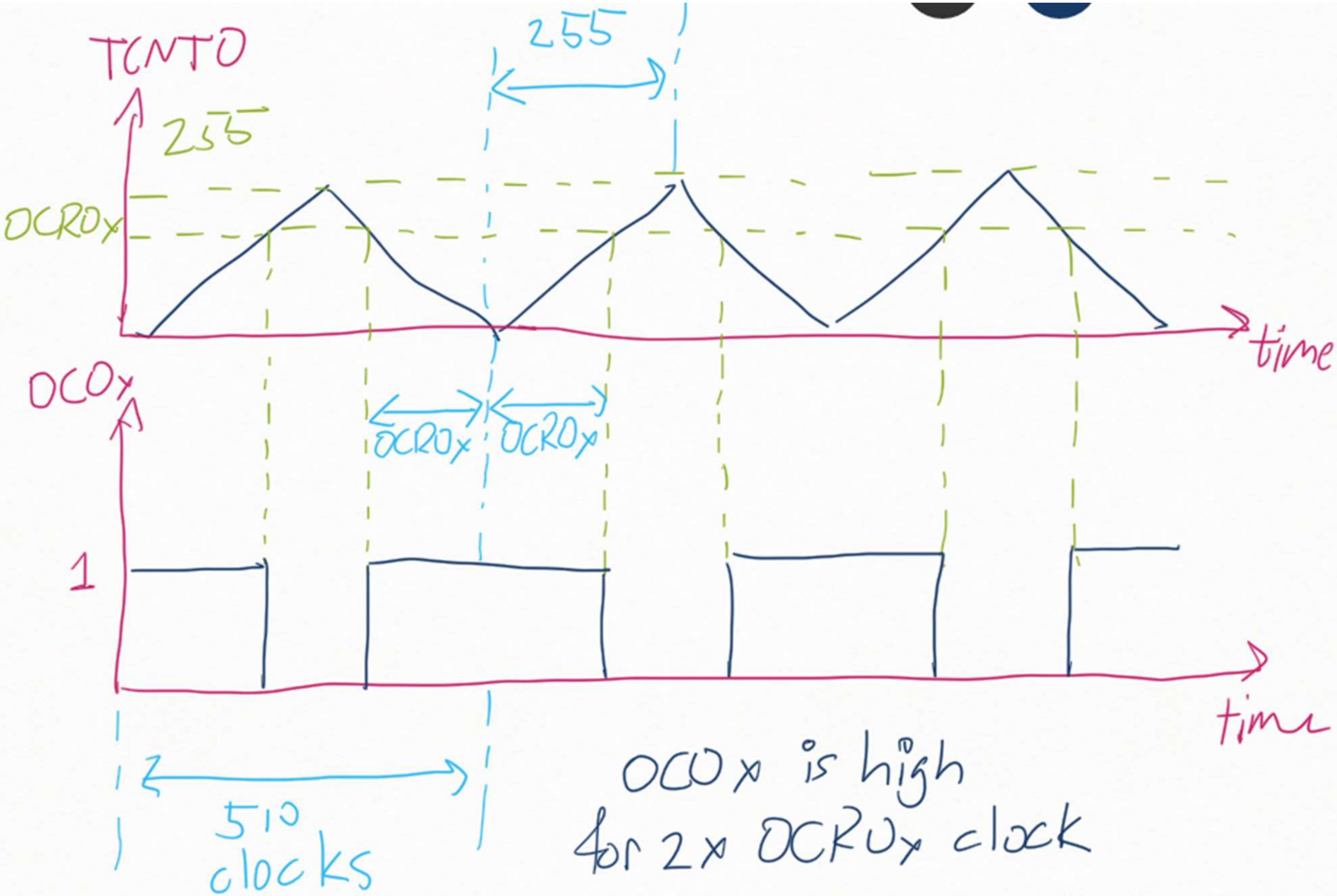
Phase correct PWM Calculations

Phase Correct PWM
Duty cycle = changeable (0% to 100%)
Frequency = selectable between limited choices

$$F_{OC0} = \frac{f_{clk}}{N(510)}$$



$$\text{Duty Cycle} = \frac{\cancel{2} \times OCR0x}{\cancel{2} \times 255} = \frac{OCR0x}{255} \times 100$$



OC0x is high
for 2x OCR0x clock

Timer0 PWM

Phase correct PWM Calculations

Assuming XTAL = 16 MHz, make the following wave:
duty cycle = 75% and frequency = 31.372KHz

$$F_{OC0} = \frac{f_{clk}}{N(510)} \Rightarrow 31.372\text{KHz} = \frac{16\text{MHz}}{N(510)} \Rightarrow N = \frac{16\text{MHz}}{31.372\text{K}*510} = 1$$

$$0.75 = \frac{\text{OCR0}}{255}$$

$$\text{OCR0} = 191$$

Exercise 10

1. Write a program that use fast PWM, and generate a waveform with frequency 7812 Hz and duty cycle 20%.