Embedded Systems Laboratory
## Fangning Hu

Output Compare Unit

In this lab, we are going to blink LEDs and control the brightness of LEDs by Output compare Unit with CTC mode.

Introduction:

Output Compare Unit belongs to the Timer Module. The unit uses a 16-bits comparator continuously compare the Timer1 register TCTN1 with a pre-stored value in the Output Compare Register (**OCR1A**). When the counter TCTN1 matches (is equal to) OCR1A, the comparator signals a **Compare Match**. An Output Compare Interrupt (**TIMER1_COMPA_vect**) will be triggered. Please check the Timer Interrupt Mask Register (**TIMSK1**) to enable this interrupt. Inside the Output Compare Interrupt Service Routine, you can write program to set the pins of PORTD to be on (logic high) or off (logic low). By setting the proper value in OCR1A, you can make LED blinking.

There are different operation Mode for Output Compare Unit. In CTC mode, the Counter (TCTN1) is increased by one in each clock cycle and will be automatically clear to zero when it matches OCR1A (TCTN1 = OCR1A) as shown in Fiture 16-6.

Figure 16-6. CTC Mode, Timing Diagram
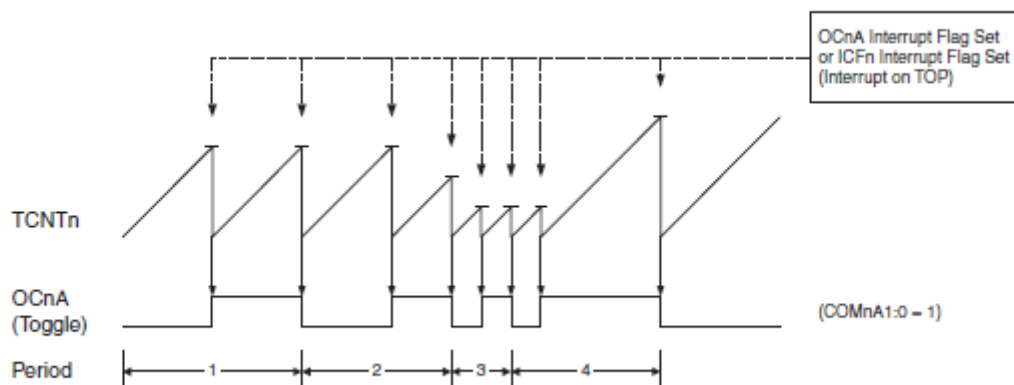
Please have a look at table 16-4 to check how to set to CTC mode. You need to set bits in the register TCCR1A and TCCR1B.

Table 16-4. Waveform Generation Mode Bit Description[1]

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

There is also a special output pin associated to the output compare unit, called **OC1A (PORTB1, please check the Pin Layout diagram)**. This pin will change its state each time when the Compare Match happens (TCNT1=OCR1A). Please check Table 16-1 to toggle this pin.

Table 16-1. Compare Output Mode, non-PWM

COM1A1/COM1B1	COM1A0/COM1B0	Description
0	0	Normal port operation, OC1A/OC1B disconnected.
0	1	Toggle OC1A/OC1B on Compare Match.
1	0	Clear OC1A/OC1B on Compare Match (Set output to low level).
1	1	Set OC1A/OC1B on Compare Match (Set output to high level).

Table 16-2 shows the COM1x1:0 bit functionality when the WGM13:0 bits are set to the fast PWM mode.

Apart from generating equal on-off-time waveforms by fixed OCR1A, one can dynamically change the value in OCR1A to control the ratio of the on-time of the output waveform. When you have an LED blinking with a very high frequency (prescaler = 1), human can hardly perceive its off-time. But the brightness of the LED is determined by the average of the on-time current, i.e., the logic high period of the waveform. By adjusting the on-time ratio, one can control the brightness of the LED. This type of digital-to-analog converting (convert a digital 16-bits value to an analog on-time ratio) is called **Pulse Width Modulation (PWM)**.

PreLab Tasks:

1. Read the corresponding content in the datasheet **Chapter 16.8 Output Compare Unit** to **Chapter 16.9.2 Clear Timer on Compare Match (CTC) Mode**. Study the functions of necessary registers in order to enable the Output Compare Interrupt.

2. Calculate a proper combination of the value in OCR1A and counting frequency to have an Output Compare Match every 1 second.

3. Design a program that you can generate PWM signal on the pins of PORTD and on the pin OC1A.

Lab Assignments:

1. Write a proper program to blink the LED on the pins of PORTD and on the pin OC1A by output compare interrupt with CTC mode.

2. Modify your counting frequency higher and higher such that you can not perceive the LED off. Try to have different brightness of your LED.

Lab Report: The requirements are the same as the previous lab.