EEL 4742 – Embedded Systems
Module 10 – Advanced Timers

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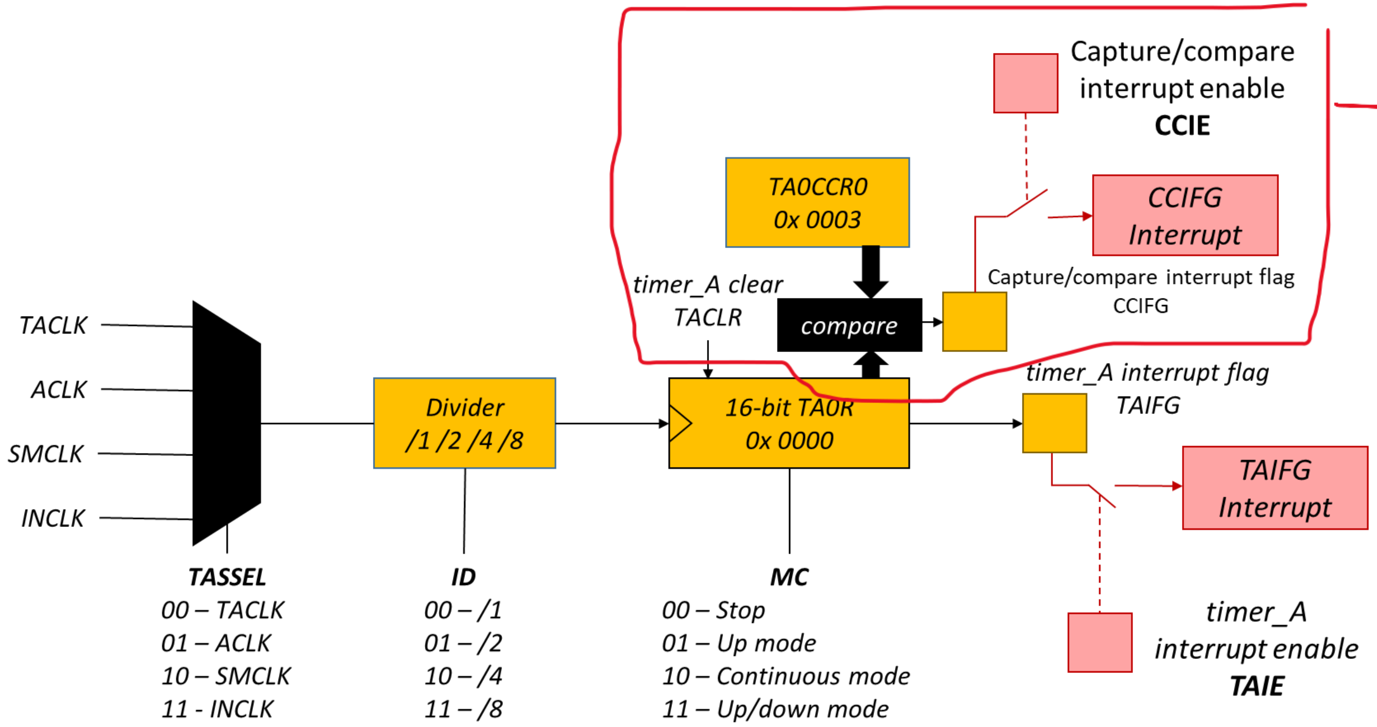
Multiple Channels of Timer_A

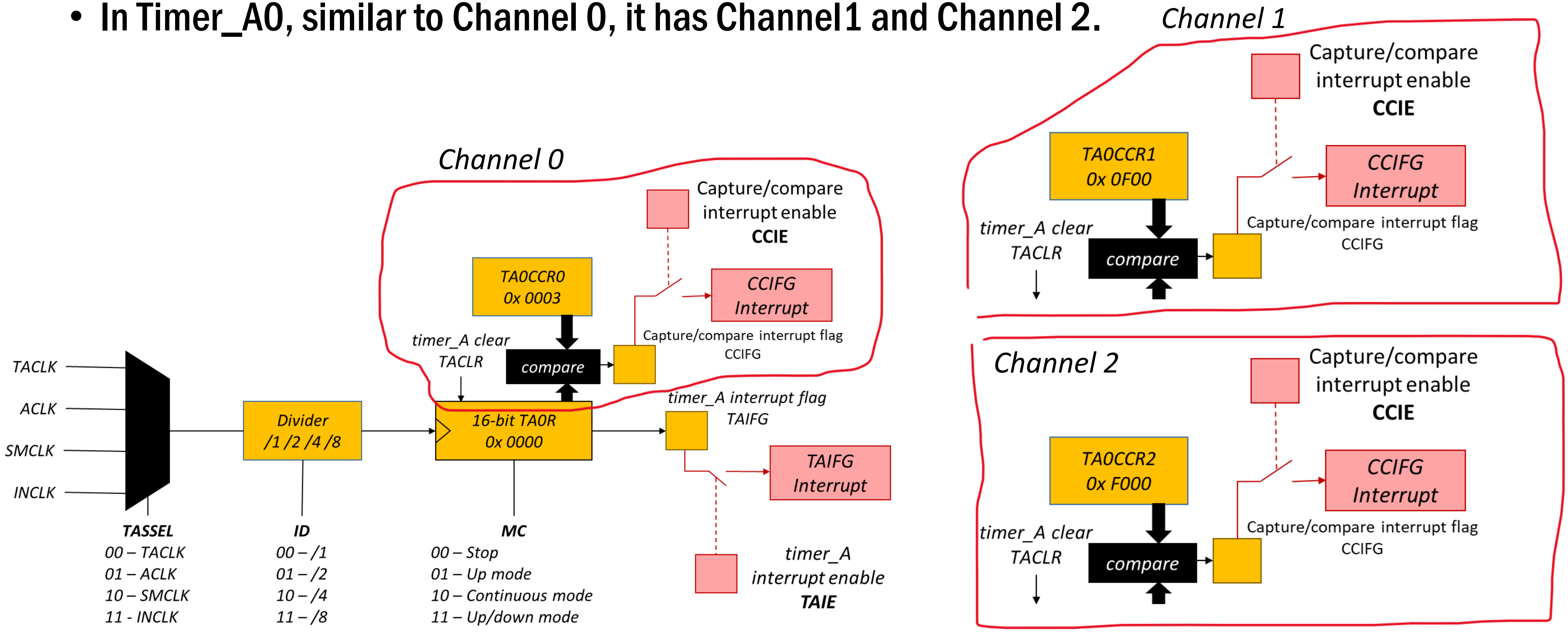
- For Timer_A
  - In Timer_A0, similar to Channel 0, it has Channel1 and Channel 2.



For the first channel of CCR0.

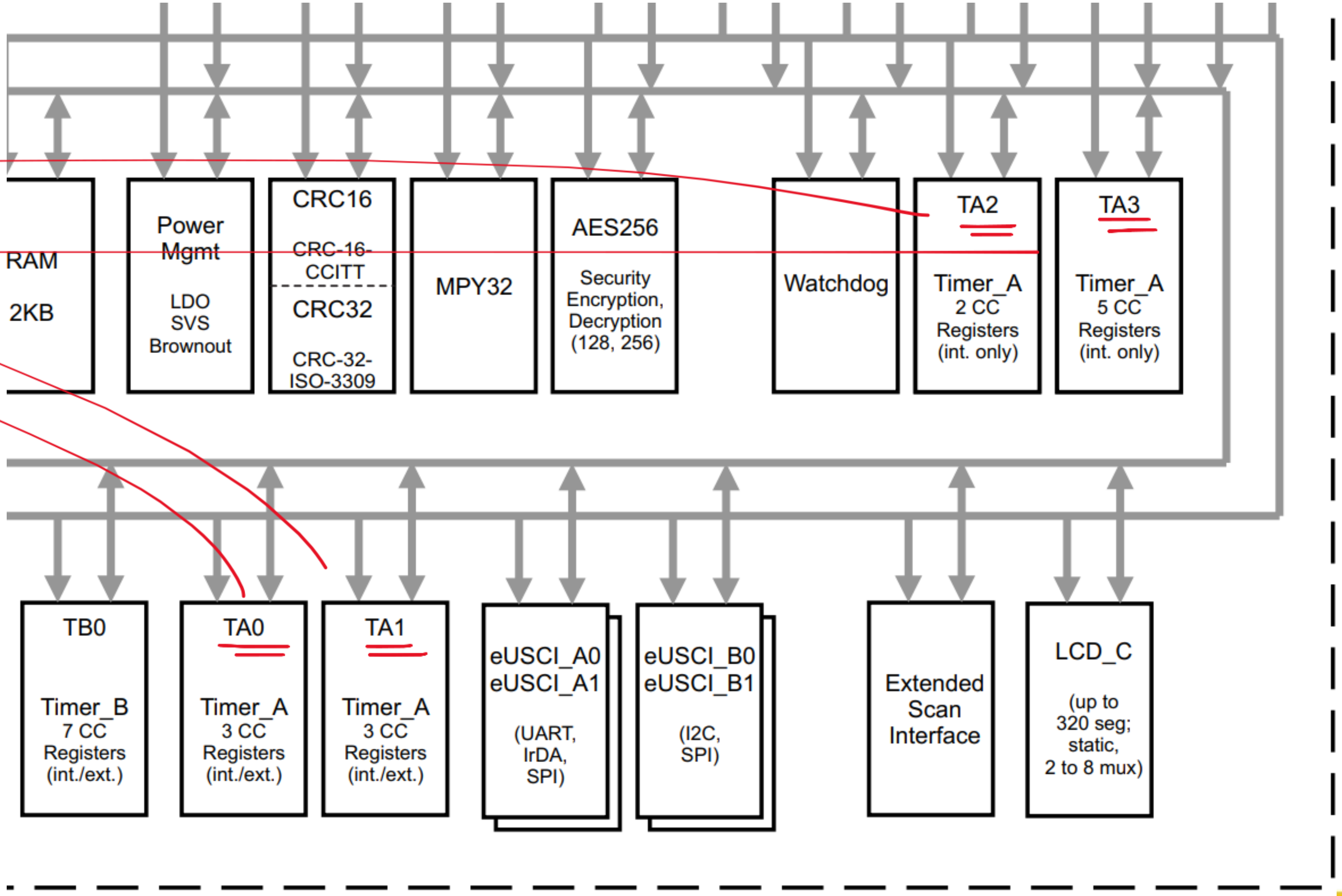
Multiple Channels of Timer_A

- For Timer_A
  - In Timer_A0, similar to Channel 0, it has Channel1 and Channel 2.



Multiple Channels of Timer_A

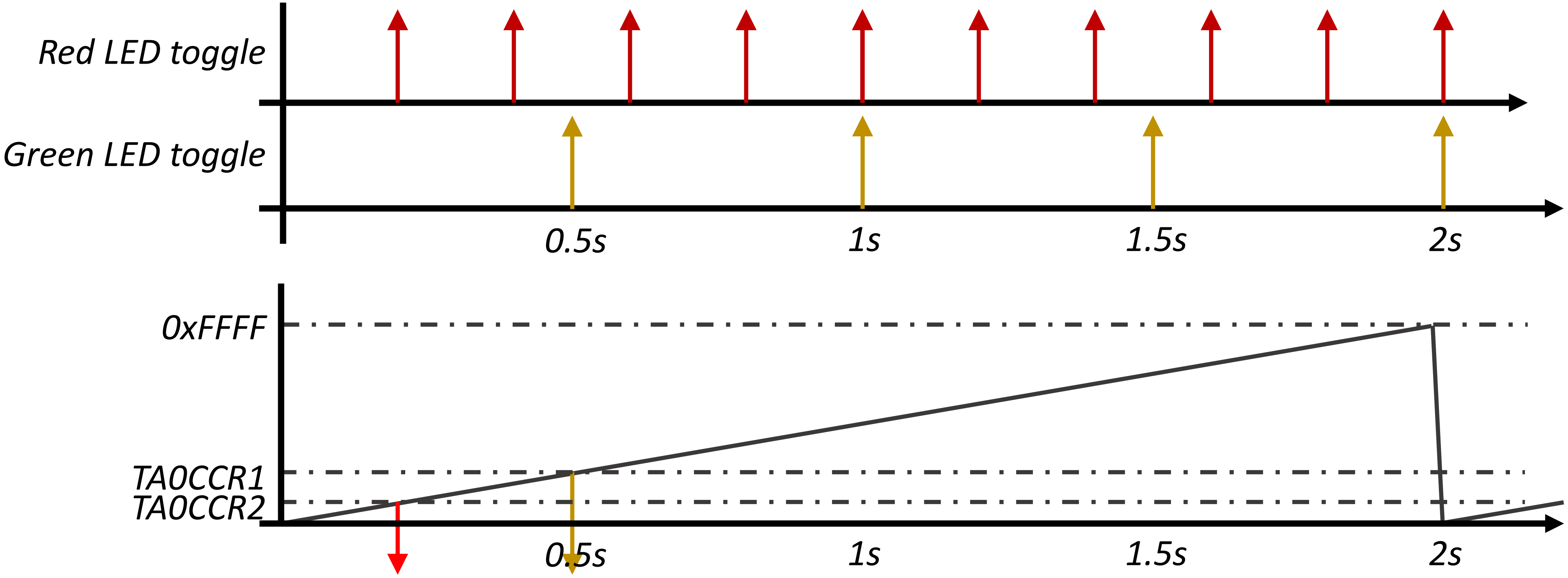
- **Four different timer modules in MSP430**
  - *TA0 (3 Channels)*
  - *TA1 (3 Channels)*
  - *TA2 (2 Channels)*
  - *TA3 (5 Channels)*



Multiple Channels of Timer_A

- Per each module → using multiple channels "simultaneously"

Application: *Toggle green LED every 0.5 second and*
Toggle red LED every 0.2 second



Multiple Channels of Timer_A

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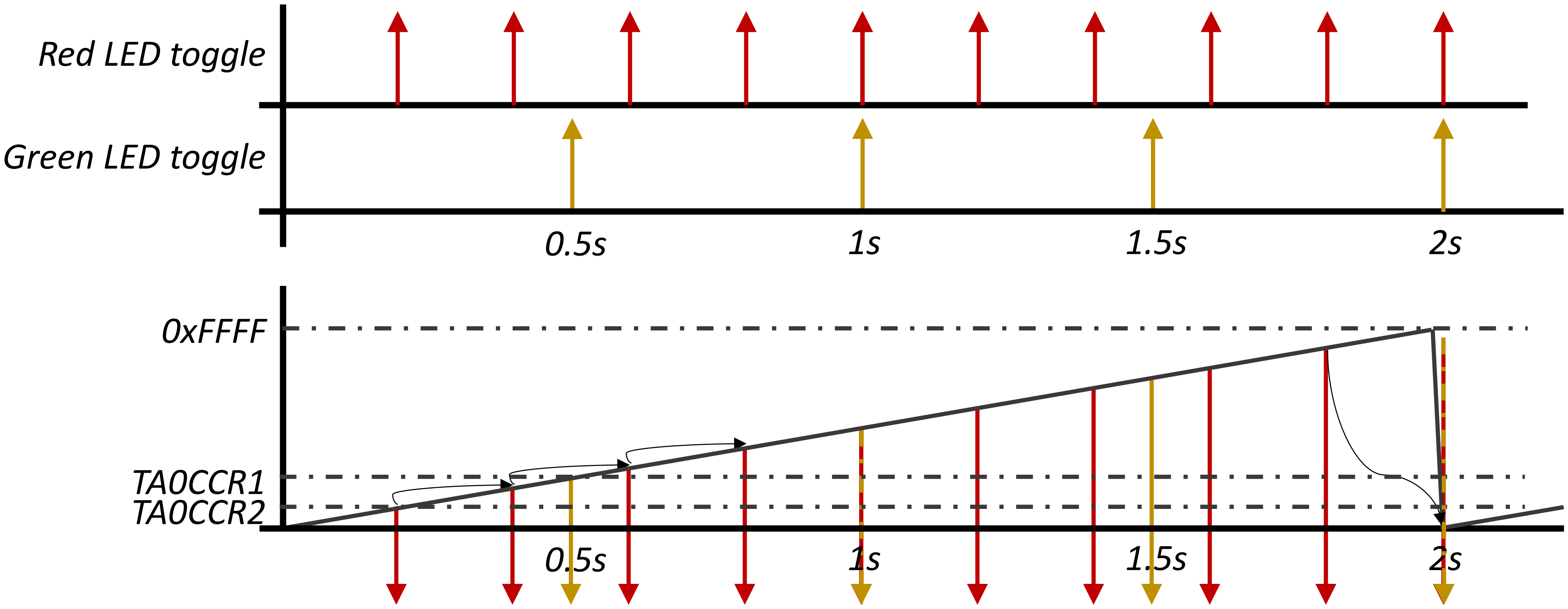

Multiple Channels of Timer_A

- Counting mode is <u>**continuous**</u>

Application: *Toggle <u>green LED every 0.5 second</u> and*
Toggle <u>red LED every 0.2 second</u>

To time simultaneous intervals with multiple channels, the timer module is operated in the ***continuous mode****, in which TAR counts from 0 up to 65,535 (64K).*

The channels schedule their interrupts by looking ahead from the current value of TAR

2 seconds = 65536
0.2 seconds = 65536/2 * 0.2 = 6553.6 ≈ 6554

```
main(){
    // Configure LED pins
    // Configure timer_A0

    TA0CCR1 = 6554 – 1;

    // Low power mode 3
    for(;;);
}
```

```
Channel_1_ISR(){
    // Clear flag
    // Toggle red LED
    TA0CCR1 = TA0R + (6554 – 1);
}
```

After the first overflow, the CCR is defined w.r.t. current TA0R.

rolls back to zero and counts up to desired value

Multiple Channels of Timer_A

- Counting mode is **<u>continuous</u>**

TA0R	TA0CCR1
0	*6553*
6553	*6553 + 6553 = 13106*
13106	*13106 + 6553 = 19659*
19659	*19659 + 6553 = 26212*
…	…
52424	*52424 + 6553 = 58977*
58977	*58977 + 6553 = 65530*
65530	*65530 + 6553 = 72083*
…	…

Application: *Toggle green LED every 0.5 second and*
Toggle red LED every 0.2 second

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counts from 0 up to 65,535 (64K).

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main(){
    // Configure LED pins
    // Configure timer_A0

    TA0CCR1 = 6554 – 1;

    // Low power mode 3
    for(;;);
}
```

```
Channel_1_ISR(){
    // Clear flag
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Multiple Channels of Timer_A

- Counting mode is <u>continuous</u>

TA0R	TA0CCR1
0	*6553*
6553	*6553 + 6553 = 13106*
13106	*13106 + 6553 = 19659*
19659	*19659 + 6553 = 26212*
…	…
52424	*52424 + 6553 = 58977*
58977	*58977 + 6553 = 65530*
65530	*65530 + 6553* *= (72083 % 65536) = 6547*
6547	*6547 + 6553 = 13100*
13100	*13100 + 6553 = 19653*
…	…

rolls back to zero and counts up to desired value

Application: *Toggle <u>green LED every 0.5 second</u> and*
Toggle <u>red LED every 0.2 second</u>

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counts from 0 up to 65,535 (64K).

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= 65536
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```
main(){
    // Configure LED pins
    // Configure timer_A0

    TA0CCR1 = 6554 – 1;

    // Low power mode 3
    for(;;);
}
```

```
Channel_1_ISR(){
    // Clear flag
    // Toggle red LED
    TA0CCR1 = TA0R + (6554 – 1);
}
```

After the first overflow, the CCR is defined w.r.t. current TA0R.

Multiple Channels of Timer_A

- Counting mode is <u>**continuous**</u>

Application: *Toggle green LED every 0.5 second and Toggle red LED every 0.2 second*

To time simultaneous intervals with multiple channels, the timer module is operated in the ***continuous mode****, in which TAR counts from 0 up to 65,535 (64K).*

The channels schedule their interrupts by looking ahead from the current value of TAR

2 seconds	***= 65536***
0.2 seconds	***= 65536/2 * 0.2 = 6553.6 ≈ 6554***
0.5 seconds	***= 65536/2 * 0.5 = 16384***

```
main(){
    // Configure LED pins
    // Configure timer_A0

    TA0CCR1 = 6554 – 1;
    TA0CCR2 = 16384 – 1;
    // Low power mode 3
    for(;;);
}
```

```
Channel_2_ISR(){
        // Clear flag
        // Toggle red LED
        TA0CCR2 = TA0R + (16384 – 1);
}
```

rolls back to zero and counts up to desired value

```
Channel_1_ISR(){
        // Clear flag
        // Toggle red LED
        TA0CCR1 = TA0R + (6554 – 1);
}
```

After the first overflow, the CCR is defined w.r.t. current TA0R.

Multiple Channels of Timer_A

- **Interrupts per channel**

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals **TA0CCR0**	CCIE in **TA0CCTL0**	CCIFG in **TA0CCTL0**	TIMER0_A0_VECTOR
TA0R register rolls back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	TIMER0_A1_VECTOR

For the #pragma used for defining ISR(). There are TWO different handler for each interrupt flag (One for TAIFG and one for CCIFG)!

Multiple Channels of Timer_A

- Interrupts per channel

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals TA0CCR0	CCIE in TA0CCTL0	CCIFG in TA0CCTL0	TIMER0_A0_VECTOR
TA0R register rolls back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	**TIMER0_A1_VECTOR**

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals TA0CCR1	CCIE in TA0CCTL1	CCIFG in TA0CCTL1	**TIMER0_A1_VECTOR**
TA0R register can roll back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	**TIMER0_A1_VECTOR**

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals TA0CCR2	CCIE in TA0CCTL2	CCIFG in TA0CCTL2	**TIMER0_A1_VECTOR**
TA0R register can roll back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	**TIMER0_A1_VECTOR**

Shared ISR (one function for all)

Multiple Channels of Timer_A

- Interrupts per channel

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals **TA0CCR0**	CCIE in **TA0CCTL0**	CCIFG in **TA0CCTL0**	TIMER0_A0_VECTOR
TA0R register rolls back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	**TIMER0_A1_VECTOR**

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals **TA0CCR1**	CCIE in **TA0CCTL1**	CCIFG in **TA0CCTL1**	**TIMER0_A1_VECTOR**
TA0R register can roll back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	**TIMER0_A1_VECTOR**

Event	Interrupt enable	Interrupt flag	Interrupt vector
TA0R equals **TA0CCR2**	CCIE in **TA0CCTL2**	CCIFG in **TA0CCTL2**	**TIMER0_A1_VECTOR**
TA0R register can roll back to 0x0000	TAIE in **TA0CTL**	TAIFG in **TA0CTL**	**TIMER0_A1_VECTOR**

The flag and enabler are separated. So, each can be used separately (but with the same ISR).

Shared ISR (one function for all)

Multiple Channels of Timer_A

- Example:
  - one LED (blinking) is based on channel 0 with periodic interrupt every 0.1 seconds
  - another LED (blinking) is based on channel 1 with periodic interrupt every 0.5 seconds.

```
#include <msp430fr6989.h>
#define redLED BIT0 // Red at P1.0
#define greenLED BIT7 // Green at P9.7
void main(void) {
        WDTCTL = WDTPW | WDTHOLD; // Stop WDT
        PM5CTL0 &= ~LOCKLPM5; // Enable GPIO pins
        P1DIR |= redLED;
        P9DIR |= greenLED;
        P1OUT &= ~redLED;
        P9OUT &= ~greenLED;

        // Configure Channel 0
        TA0CCR0 = 3277
        TA0CCTL0 |= CCIE;
        TA0CCTL0 &= ~CCIFG;

        // Configure Channel 1
        TA0CCR1 = 16384
        TA0CCTL1 |= CCIE;
        TA0CCTL1 &= ~CCIFG;

        // Start the timer (any divider?)
        TA0CTL = TASSEL_1 | ID_0 | MC_2;
        // Enable the interrupts
        _enable_interrupts();
        return;
}
```

```
// ISR of Channel 0 (A0 vector)
#pragma vector = TIMER0_A0_VECTOR
__interrupt void T0A0_ISR() {
        P1OUT ^= redLED; // Toggle the red LED
        TA0CCR0 += 3277; // Schedule the next interrupt
        // Hardware clears Channel 0 flag (CCIFG in TA0CCTL0)
}

// ISR of Channel 1 (A1 vector)
#pragma vector = TIMER0_A1_VECTOR
__interrupt void T0A1_ISR() {
        P9OUT ^= greenLED; // Toggle the red LED
        TA0CCR1 += 16384; // Schedule the next interrupt
}
```

Multiple Channels of Timer_A

- **What is this code for?**

```
// ISR of Channel 0 (A0 vector)
#pragma vector = TIMER0_A0_VECTOR
__interrupt void T0A0_ISR() {
            P1OUT ˆ= redLED; // Toggle the red LED
            TA0CCR0 += 3277; // Schedule the next interrupt
            // Hardware clears Channel 0 flag (CCIFG in TA0CCTL0)
}

// ISR of Channel 1 (A1 vector)
#pragma vector = TIMER0_A1_VECTOR
__interrupt void T0A1_ISR() {
          switch (TA0IV) {
               case TA0IV_TACCR1: // Channel 1 interrupt (green LED)
                  if (flashEnable) { // Only toggle if flashing is enabled
                      P9OUT ^= greenLED; // Toggle the green LED
                  }
                  TA0CCR1 += 16384; // Schedule the next interrupt for green LED
                  break;
               case TA0IV_TACCR2: // Channel 2 interrupt (2-second interval)
                  toggleCounter++; // Increment counter every 2 seconds
                  if (toggleCounter >= 2) { // Toggle flash enable every 4 seconds
                      flashEnable ^= 1; // Toggle the flash enable flag
                      toggleCounter = 0; // Reset counter
                      if (!flashEnable) { // If flash is disabled
                          P1OUT &= ~redLED; // Ensure red LED is off
                          P9OUT &= ~greenLED; // Ensure green LED is off
                      }
                  }
                  TA0CCR2 += 65536; // Schedule the next 2-second interrupt
                  break;
          }
}
```

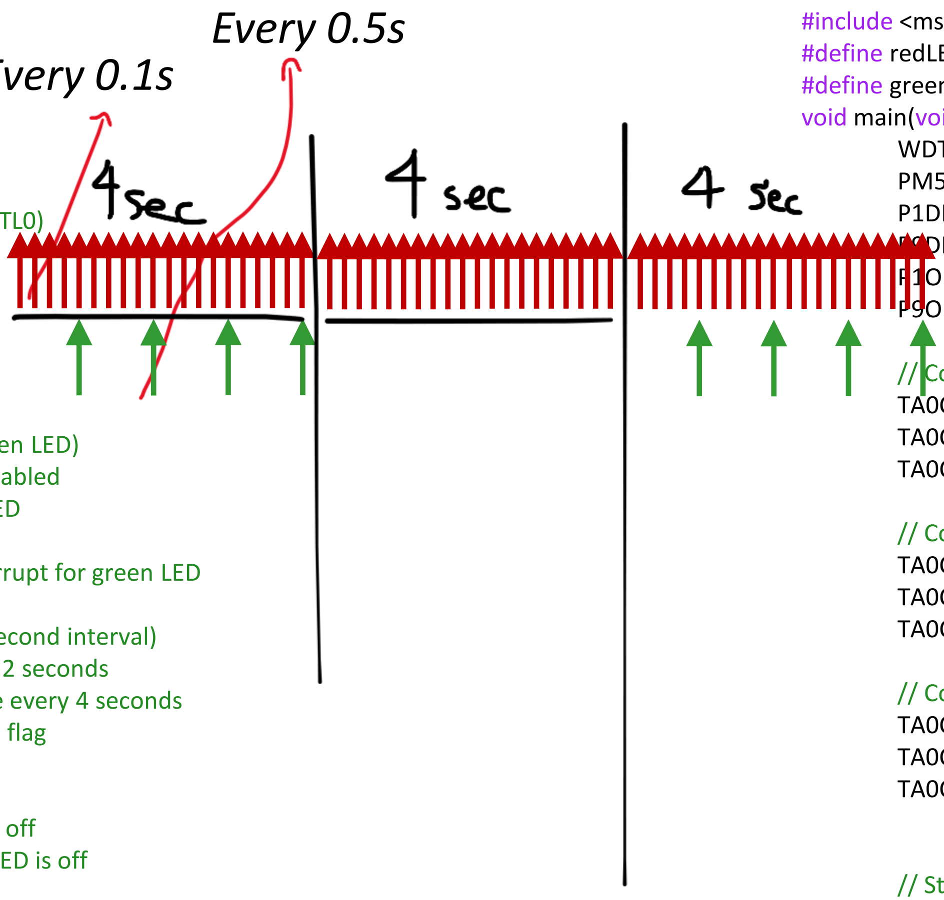
```
#include <msp430fr6989.h>
#define redLED BIT0 // Red at P1.0
#define greenLED BIT7 // Green at P9.7

volatile unsigned int flashEnable = 1; // Flag to control LED flashing volatile
unsigned int toggleCounter = 0; // Counter for 4-second timing

void main(void) {
            WDTCTL = WDTPW | WDTHOLD; // Stop WDT
            PM5CTL0 &= ˜LOCKLPM5; // Enable GPIO pins
            P1DIR |= redLED;
            P9DIR |= greenLED;
            P1OUT &= ˜redLED;
            P9OUT &= ˜greenLED;

            // Configure Channel 0
            TA0CCR0 = 3277;
            TA0CCTL0 |= CCIE;
            TA0CCTL0 &= ˜CCIFG;
            // Configure Channel 1
            TA0CCR1 = 16384;
            TA0CCTL1 |= CCIE;
            TA0CCTL1 &= ˜CCIFG;
            // Configure Channel 2
            TA0CCR2 = 65536;
            TA0CCTL2 |= CCIE;
            TA0CCTL2 &= ˜CCIFG;

            // Start the timer (any divider)
            TA0CTL = TASSEL_1 | ID_0 | MC_2;
            // Enbale the interrupts
            _enable_interrupts();
            return;
}
```

Multiple Channels of Timer_A

- **What is this code for?**

```c
// ISR of Channel 0 (A0 vector)
#pragma vector = TIMER0_A0_VECTOR
__interrupt void T0A0_ISR() {
        P1OUT ^= redLED; // Toggle the red LED
        TA0CCR0 += 3277; // Schedule the next interrupt
        // Hardware clears Channel 0 flag (CCIFG in TA0CCTL0)
}

// ISR of Channel 1 (A1 vector)
#pragma vector = TIMER0_A1_VECTOR
__interrupt void T0A1_ISR() {
      switch (TA0IV) {
         case TA0IV_TACCR1: // Channel 1 interrupt (green LED)
           if (flashEnable) { // Only toggle if flashing is enabled
               P9OUT ^= greenLED; // Toggle the green LED
           }
           TA0CCR1 += 16384; // Schedule the next interrupt for green LED
           break;
         case TA0IV_TACCR2: // Channel 2 interrupt (2-second interval)
           toggleCounter++; // Increment counter every 2 seconds
           if (toggleCounter >= 2) { // Toggle flash enable every 4 seconds
               flashEnable ^= 1; // Toggle the flash enable flag
               toggleCounter = 0; // Reset counter
               if (!flashEnable) { // If flash is disabled
                   P1OUT &= ~redLED; // Ensure red LED is off
                   P9OUT &= ~greenLED; // Ensure green LED is off
               }
           }
           TA0CCR2 += 65536; // Schedule the next 2-second interrupt
           break;
      }
}
```

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        P1DIR |= redLED;
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        P1OUT &= ~redLED;
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        TA0CCTL0 |= CCIE;
        TA0CCTL0 &= ~CCIFG;

        // Configure Channel 1
        TA0CCR1 = 16384;
        TA0CCTL1 |= CCIE;
        TA0CCTL1 &= ~CCIFG;

        // Configure Channel 2
        TA0CCR2 = 65536;
        TA0CCTL2 |= CCIE;
        TA0CCTL2 &= ~CCIFG;


        // Start the timer (any divider)
        TA0CTL = TASSEL_1 | ID_0 | MC_2;
        // Engage a low-power mode
        _enable_interrupts();
        return;
}
```

Pulse Width Modulation (PWM)

- PWM is a specific (oscillating) signal
  - The period is fixed.

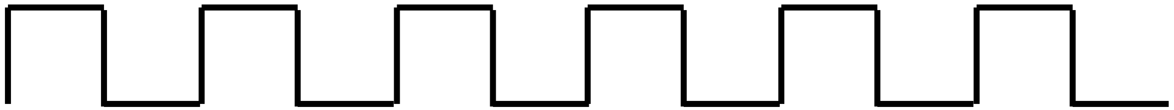
  - For each clock cycle
    - A specific period is high
    - A specific period is low

Here 50%

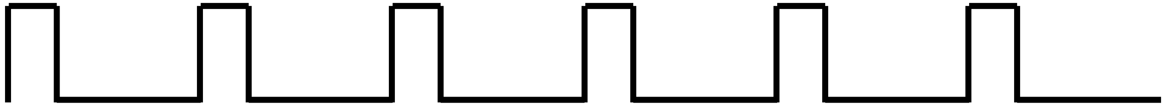
Here 50%

$$Duty\ cycle\ = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

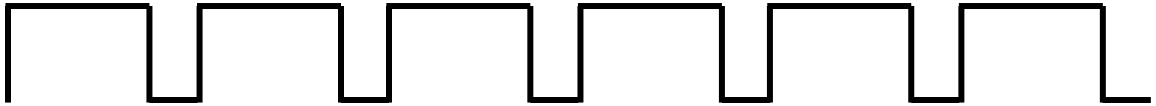
50% duty cycle



25% duty cycle



75% duty cycle



Pulse Width Modulation (PWM)

- PWM is a specific (oscillating) signal
  - The period is fixed.
  - For each clock cycle
    - A specific period is high
    - A specific period is low

Here 50%

Here 50%

We will be dimming the LED using ***pulse width modulation*** *(PWM).*

%50 ON

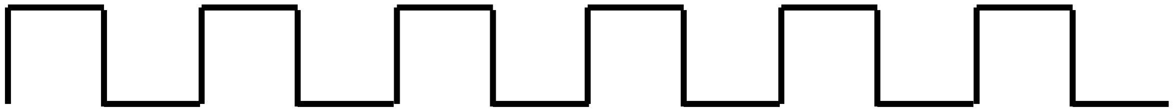
%25 ON

%75 ON

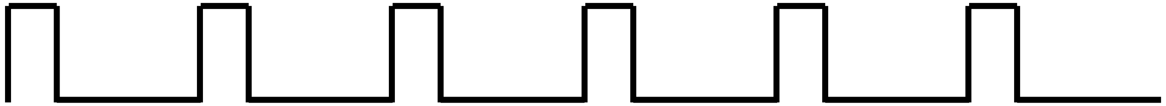
The higher the duty cycle is, The brighter the LED will be!

Connecting to LED

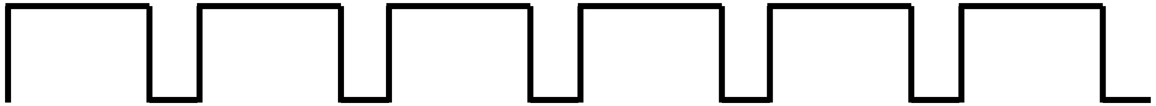
50% duty cycle



25% duty cycle

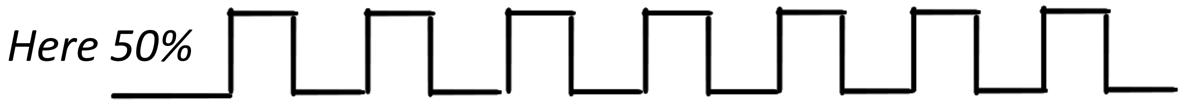


75% duty cycle



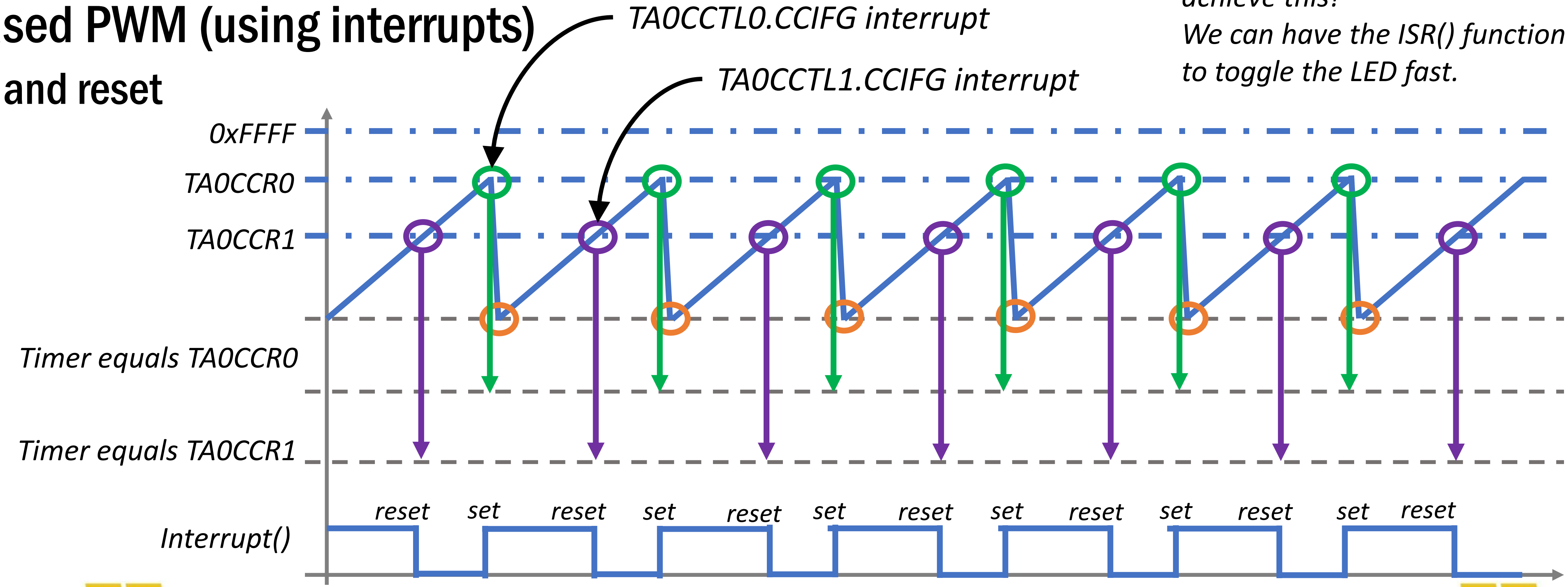
LED Dimming using PWM (based on Timer)

- Creating the duty cycle as needed
  - To determine dimming



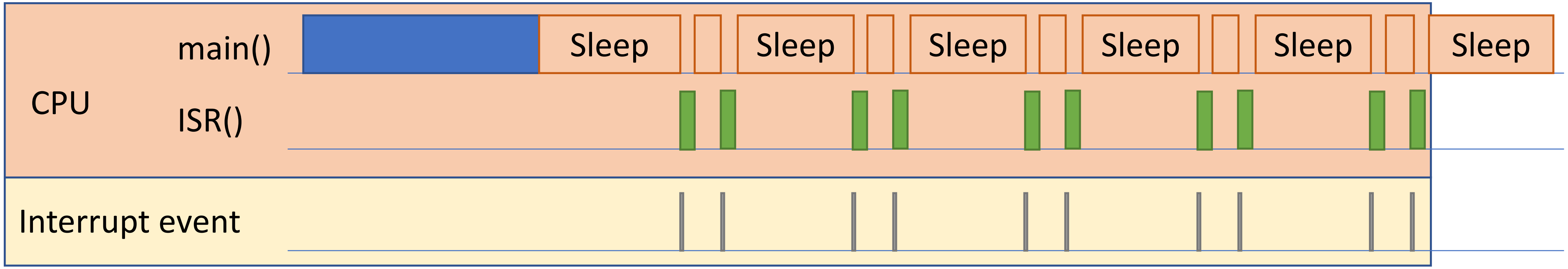
We can use timer interrupts to achieve this!
We can have the ISR() function to toggle the LED fast.

- Timer-based PWM (using interrupts)
  - To set and reset



LED Dimming using PWM (based on Timer)

- The use of ISR for blinking LED and checking CCRs



- Delay calculation by timer module
- Interrupt service routines to handle interrupts
- Low power mode to turn off CPU

We don’t need to keep CPU/ISR busy for such recurring flags!

*Timer_A0 peripheral in MSP430 has a **“timer output”** feature, which can be used to generate simple signals, including PWM signals.*

Timer Output for PWM

- Timer output is a feature of the capture/compare block of timer_A

The TA0CCTL1 register to configure channel 1's output mode.

TA0CCTL1

								OUTMOD			*CCIE*		*OUT*		*CCIFG*
15	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*

OUTMOD	***Description***	***Value at timer out when***	
		TA0R equals TA0CCR1	***TA0R equals TA0CCR0***
000b	OUT bit	-	-
001b	Set	Set	-
010b	Toggle/Reset	Toggle	Reset
011b	Set/Reset	Set	Reset
100b	Toggle	Toggle	-
101b	Reset	Reset	-
110b	Toggle/Set	Toggle	Set
111b	Reset/Set	Reset	Set

How to access this timer output signal?

Similar to using ISR() as seen earlier

Timer Output for PWM

- Timer output is a feature of the capture/compare block of timer_A

The TA0CCTL1 register to configure channel 1's output mode.

TA0CCTL1

								OUTMOD			CCIE		OUT		CCIFG
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

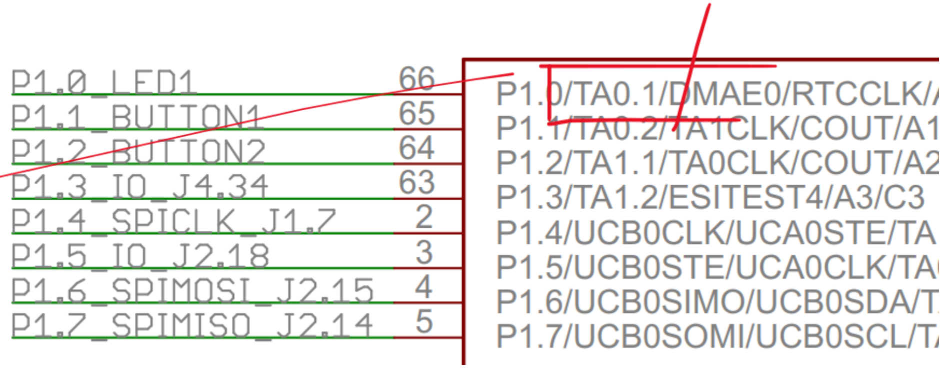
OUTMOD	Description	Value at timer out when	
		TA0R equals TA0CCR1	TA0R equals TA0CCR0
000b	OUT bit	-	-
001b	Set	Set	-
010b	Toggle/Reset	Toggle	Reset
011b	Set/Reset	Set	Reset
100b	Toggle	Toggle	-
101b	Reset	Reset	-
110b	Toggle/Set	Toggle	Set
111b	Reset/Set	Reset	Set

Different timer output modes, in combination with continuous (or up) mode, plus the value of CCRs, can be used to generate a wide variety of signals.

Timer Output for PWM

- Timer output is a feature of the capture/compare block of timer_A

Default value



PIN NAME (P1.x)	x	FUNCTION	CONTROL BITS AND SIGNALS (1)		
			P1DIR.x	P1SEL1.x	P1SEL0.x
P1.0/TA0.1/DMAE0/RTCCLK/A0/C0/VREF-/VeREF-	0	P1.0 (I/O)	I: 0; O: 1	0	0
		TA0.CCI1A	0	0	1
		TA0.1	1		
		DMAE0	0	1	0
		RTCCLK (2)	1		
		A0, C0, VREF-, VeREF- (3) (4)	X	1	1
P1.1/TA0.2/TA1CLK/COUT/A1/C1/VREF+/VeREF+	1	P1.1 (I/O)	I: 0; O: 1	0	0
		TA0.CCI2A	0	0	1
		TA0.2	1		
		TA1CLK	0	1	0
		COUT (5)	1		
		A1, C1, VREF+, VeREF+ (3) (4)	X	1	1

change it from the default setting of P1.0 to Timer_A0 channel 1

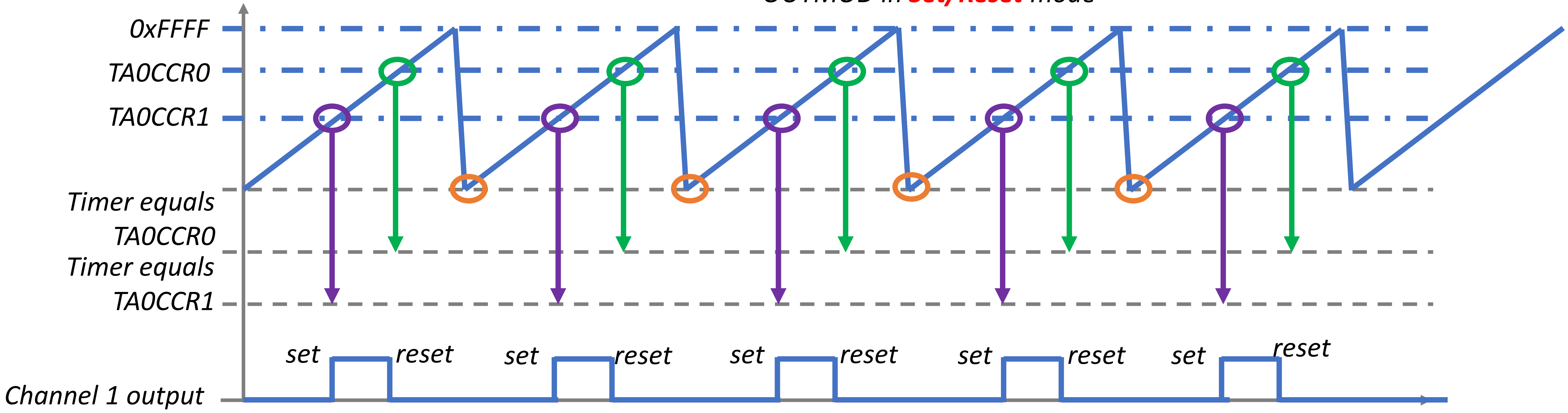
Similarly, TA0.2 is for timer_A0 channel 2 and so on.

LED Dimming using PWM (based on Timer)

- Creating the duty cycle as needed
  - To determine dimming

- Timer-based PWM (using interrupts)
  - To set and reset

For channel 1
with timer in ***continuous*** *mode*
OUTMOD in ***Set/Reset*** *mode*



LED Dimming using PWM (based on Timer)

- Creating the duty cycle as needed
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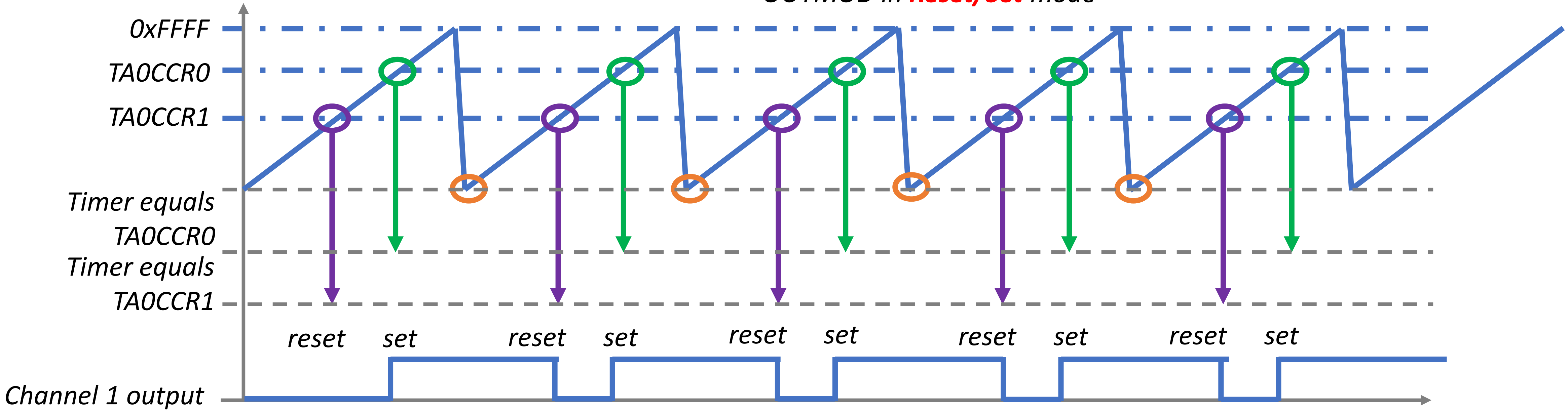
- Timer-based PWM (using interrupts)
  - To set and reset

For channel 1
with timer in ***continuous*** *mode*
OUTMOD in ***Reset/Set*** *mode*

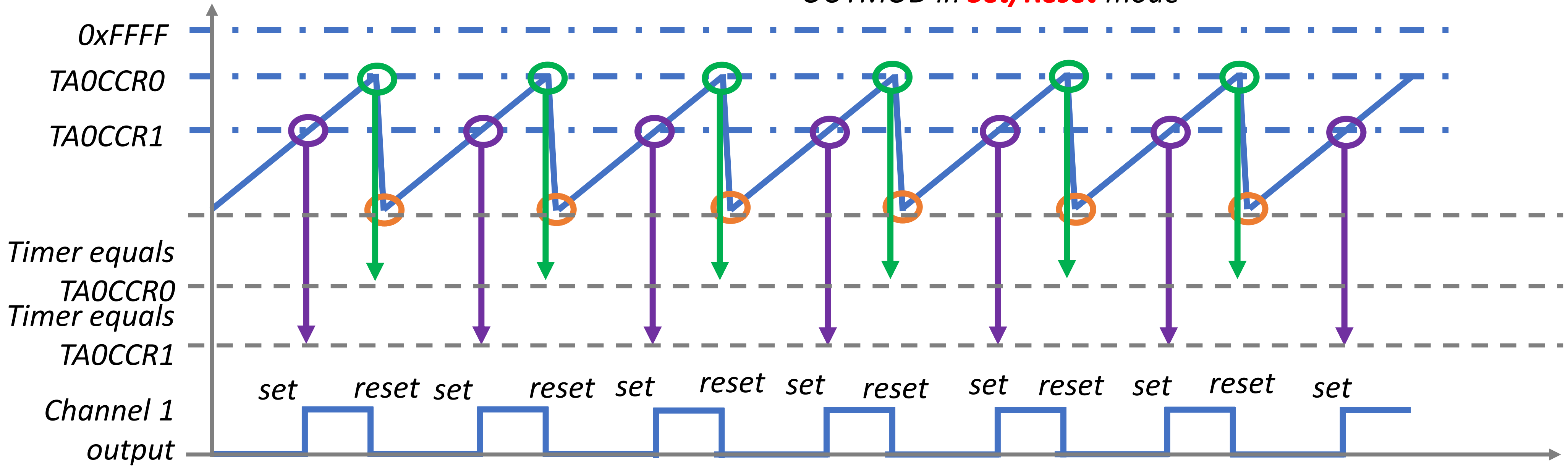


LED Dimming using PWM (based on Timer)

- Creating the duty cycle as needed
  - To determine dimming

- Timer-based PWM (using interrupts)
  - To set and reset

For channel 1
with timer in ***up*** *mode*
OUTMOD in ***Set/Reset*** *mode*



LED Dimming using PWM (based on Timer)

- Creating the duty cycle as needed
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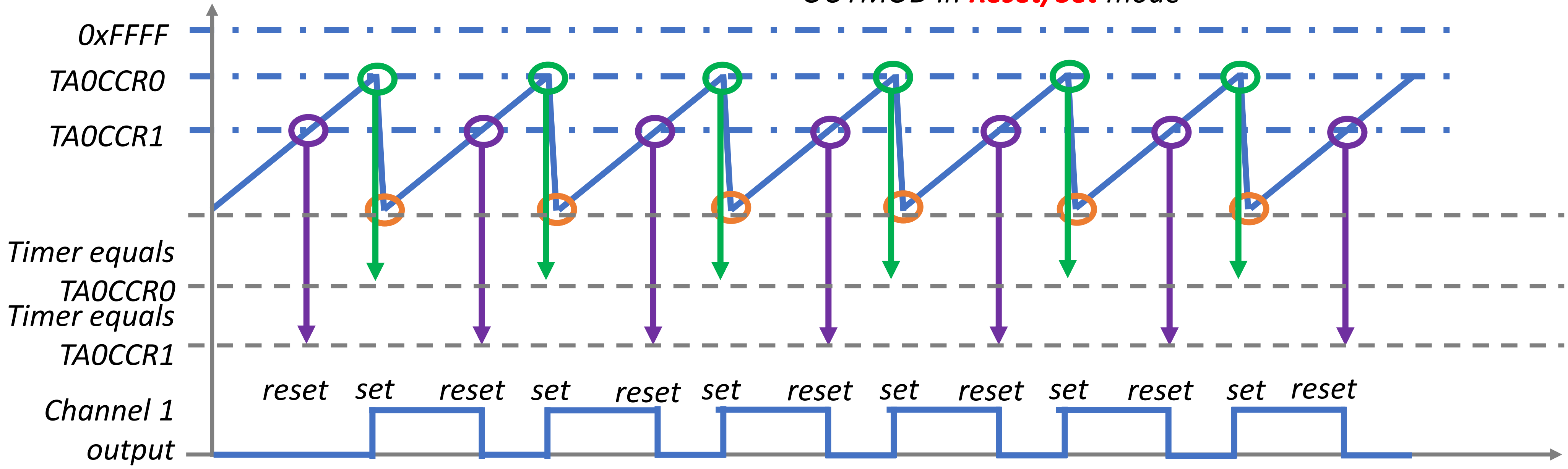
- Timer-based PWM (using interrupts)
  - To set and reset

For channel 1
with timer in **up** *mode*
OUTMOD in **Reset/Set** *mode*



LED Dimming using PWM (based on Timer)

- **Duty cycle calculation**

$$Duty\ cycle\ = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

TA0CCR0 controls the frame size.

Say, frame rate = $50Hz$*.*

frame size = $1/50$ *=* $20ms$

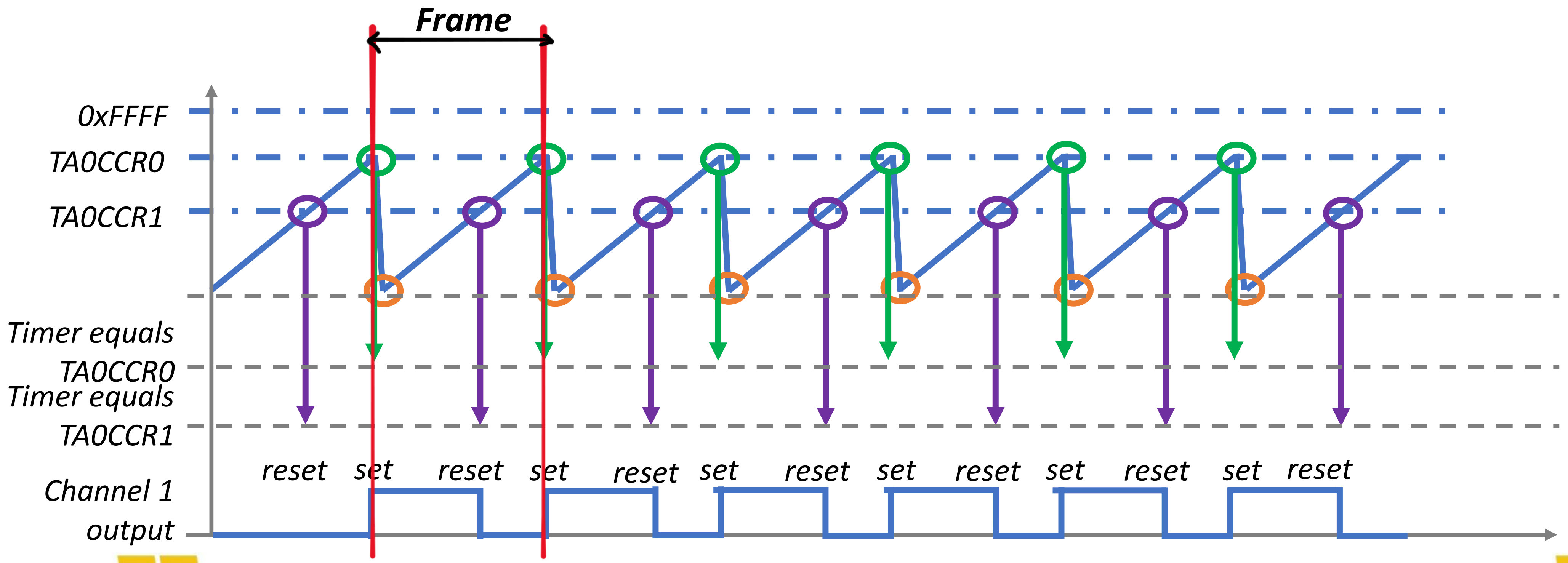
TA0CCR0 *= 32768 x 0.02 ≈* ***655***

Duty cycle = 40%

$t_{ON}\ =\ 20ms \times 40\%\ = 8ms$

TA0CCR1 *= TA0CCR0 x 40%*

= 655 x 40% = ***262***



LED Dimming using PWM (based on Timer)

- **Duty cycle calculation**

```
// Code that dimming an LED using timer_A0 channel 1
#include <msp430fr6989.h>
#define redLED BIT0                                     // Red LED at P1.0
void main(void)
{
        WDTCLTC = WDTPW | WDTHOLD;                      // stop watchdog timer

        P1DIR |= redLED;                                // Direct pin as output
        P1SEL1 &= ~LED;                                 // Primary function, P1.0
        P1OUT &= ˜redLED;                               // Turn LED Off

        TA0CTL = TASSEL_1 | ID_0 | MC_1 | TACLR;        // ACLK, up mode, clear TAR, no divider

        TA0CCR0 = 655;                                  // Set frame rate for PWM
         TA0CCR1 = 262;                                 // Set duty cycle (40% of 655)
         TA0CCTL1 = OUTMOD_7;                           // OUTMOD_7 is set/reset mode for PWM

         _low_power_mode_3();                           // Enter low power mode 3

return;
}
```

$$\frac{32{,}768}{x} = \frac{1s}{20\,ms}$$

TA0CCR0 controls the frame size.

Say, frame rate = $50Hz.$

frame size = $1/50 = 20ms$

TA0CCR0** = 32768 x 0.02 ≈ **655

Duty cycle = 40%

$t_{ON} = 20ms \times 40\% = 8ms$

***TA0CCR1** = TA0CCR0 x 40%*

*= 655 x 40% = **262***

$$Duty\ cycle = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

LED Dimming using PWM (based on Timer)

- **Duty cycle calculation**

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(Q) Do we need µc or/and interrupt here for controlling the process?

[redacted]

LED Dimming using PWM (based on Timer)

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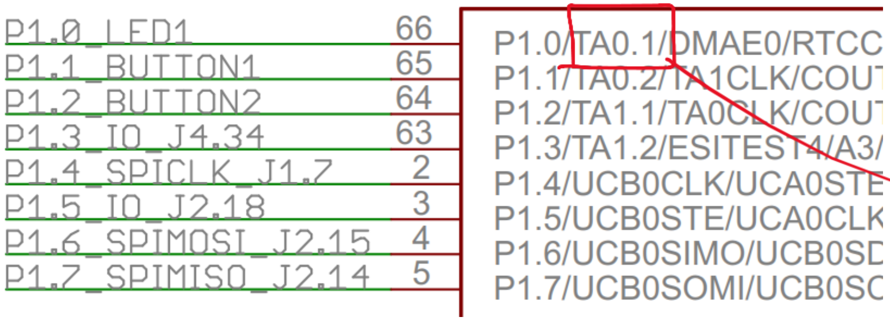

(Q) Do we need µc or/and interrupt here for controlling the process?

PWM available on the pin

(A) There is no need for any ISR(). Because we are not using any interrupts.

Thank You!

Questions?

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