

Capturing the Time of an External Event Input Capture Subsystem

- One way to determine the time of an external event is to wait for the event to occur, then read the TCNT register:

- For example, to determine the time a signal on Bit 0 of PORTB changes from a high to a low:

```
while ((PORTB & BIT0) != 0) ; /* Wait while Bit 0 high */  
time = TCNT; /* Read time after goes low */
```

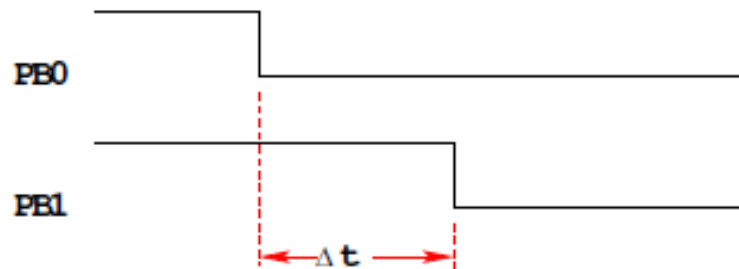
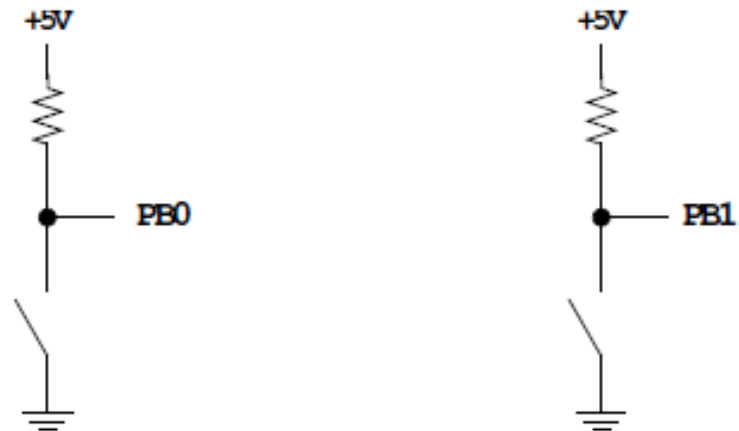
- Two problems with this:

1. Cannot do anything else while waiting
2. Do not get exact time because of delays in software

- To solve problems use hardware which latches TCNT when event occurs, and generates an interrupt.

- Such hardware is built into the MC9S12 — called the **Input Capture System**

Measure the time between two events



How to measure Δt ?

Wait until signal goes low, then measure TCNT

```
while ((PORTB & BIT0) == BIT0) ;  
start = TCNT;  
while ((PORTB & BIT1) == BIT1) ;  
end = TCNT;  
dt = end - start;
```

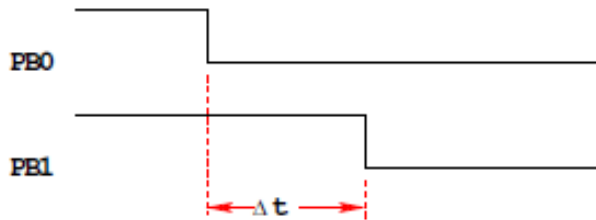
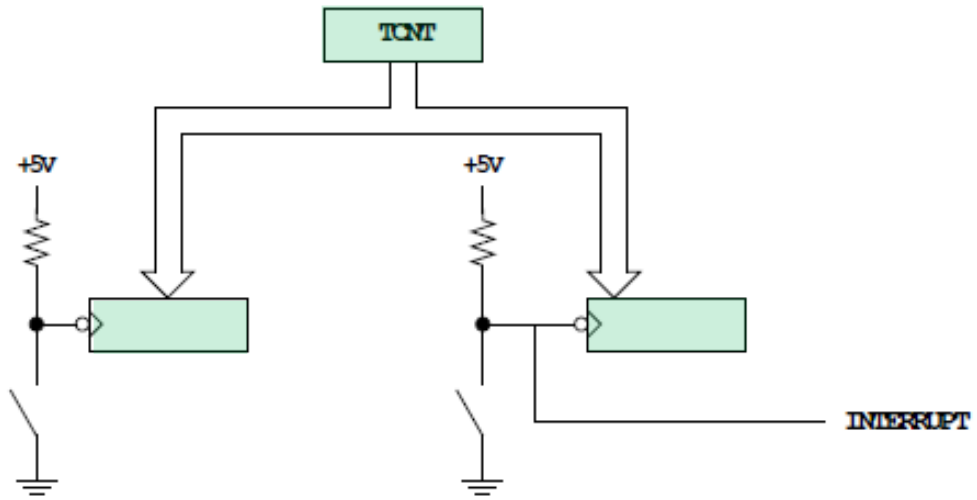
Problems: 1) May not get very accurate time
2) Can't do anything while waiting for signal level to change.

Measure the time between two events

Solution: Latch TCNT on falling edge of signal

Read latched values anytime later and get exact value

Can have MC9S12 generate interrupt when event occurs, so can do other things while waiting



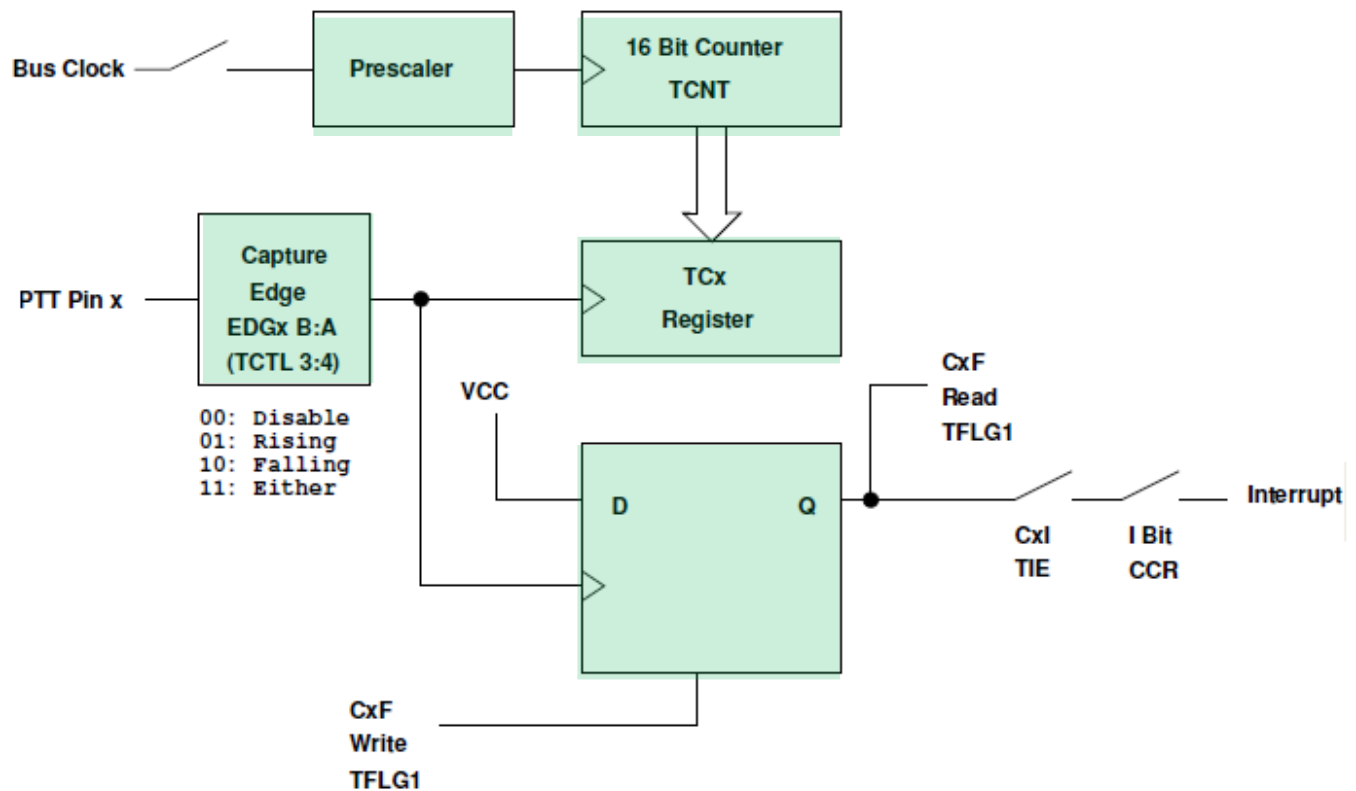
The MC9S12 Input Capture Function

- The MC9S12 allows you to capture the time an external event occurs on any of the eight Port T PTT pins
- An external event is either a rising edge or a falling edge
- To use the Input Capture Function:
 - Enable the timer subsystem (set TEN bit of TSCR1)
 - Set the prescaler
 - Tell the MC9S12 that you want to use a particular pin of PTT for input capture
 - Tell the MC9S12 which edge (rising, falling, or either) you want to capture
 - Tell the MC9S12 if you want an interrupt to be generated when the capture occurs

A Simplified Block Diagram of the MC9S12 Input Capture Subsystem

Input Capture

Port T Pin x set up as Input Capture ($IOSx = 0$ in TIOS)



Registers used to enable Input Capture Function

Write a 1 to Bit 7 of TSCR1 to turn on timer

TEN	TSWAI	TSBCK	TFPCA					0x0046 TSCR1
-----	-------	-------	-------	--	--	--	--	--------------

To turn on the timer subsystems: TSCR1 = BIT7;

Set the prescaler in TSCR2

Make sure the overflow time is greater than the time difference you want to measure

TOI	0	0	0	TCRE	PR2	PR1	PR0	0x004D TSCR2
-----	---	---	---	------	-----	-----	-----	--------------

PR2	PR1	PR0	Period (μs)	Overflow (ms)
0	0	0	0.0416	2.73
0	0	1	0.0833	5.46
0	1	0	0.1667	10.92
0	1	1	0.3333	21.84
1	0	0	0.6667	43.69
1	0	1	1.3333	86.38
1	1	0	2.6667	174.76
1	1	1	5.3333	349.53

To have overflow rate of 21.84 ms:

TSCR2 = 0x03;

Write a 0 to the bits of TIOS to make those pins input capture

IOS7	IOS6	IOS5	IOS4	IOS3	IOS2	IOS1	IOS0	0x0040	TIOS
------	------	------	------	------	------	------	------	--------	------

To make Pin 3 an input capture pin: $TIOS = TIOS \& \sim BIT3;$

Write to TCTL3 and TCTL4 to choose edge(s) to capture

EDG7B	EDG7A	EDG6B	EDG6A	EDG5B	EDG5A	EDG4B	EDG4A	0x004A	TCTL3
-------	-------	-------	-------	-------	-------	-------	-------	--------	-------

EDG3B	EDG3A	EDG2B	EDG2A	EDG1B	EDG1A	EDG0B	EDG0A	0x004B	TCTL4
-------	-------	-------	-------	-------	-------	-------	-------	--------	-------

EDGnB	EDGnA	Configuration
0	0	Disabled
0	1	Rising
1	0	Falling
1	1	Any

To have Pin 3 capture a rising edge:

$TCTL4 = (TCTL4 | BIT6) \& \sim BIT7;$

When specified edge occurs, the corresponding bit in TFLG1 will be set.

To clear the flag, write a 1 to the bit you want to clear (0 to all others)

CF7	CF6	CF5	CF4	CF3	CF2	CF1	CF0	0x008E	TFLG1
-----	-----	-----	-----	-----	-----	-----	-----	--------	-------

To wait until rising edge on Pin 3: `while ((TFLG1 & BIT3) == 0);`

To clear flag bit for Pin 3: `TFLG1 = BIT3;`

To enable interrupt when specified edge occurs, set corresponding bit in TIE register



To enable interrupt on Pin 3: `TIE = TIE | BIT3;`

To determine time of specified edge, read 16-bit result registers TC0 thru TC7

To read time of edge on Pin 3:

`unsigned int time;`
`time = TC3;`

Using Input Capture on the MC9S12

Input Capture: Connect a digital signal to a pin of Port T. Can capture the time of an edge (rising, falling or either) – the edge will latch the value of TCNT into TCx register. This is used to measure the difference between two times.

To use Port T Pin x as an input capture pin:

1. Turn on timer subsystem (1 -> Bit 7 of TSCR1 reg)
2. Set prescaler (TSCR2 reg). To get most accuracy set overflow rate as small as possible, but larger than the maximum time difference you need to measure.
3. Set up PTx as IC (0 -> bit x of TIOS reg)
4. Set edge to capture (EDGxB EDGxA of TCTL 3-4 regs)

EDGxB	EDGxA	
0	0	Disabled
0	1	Rising Edge
1	0	Falling Edge
1	1	Either Edge

5. Clear flag (1 -> bit x of TFLG1 reg, 0 -> all other bits of TFLG1)

6. If using interrupts

- (a) Enable interrupt on channel x (1 -> bit x of TIE reg)
- (b) Clear I bit of CCR (**cli** or **enable()**)
- (c) In interrupt service routine,
 - i. Read time of edge from TCx
 - ii. Clear flag (1 -> bit x of TFLG1 reg, 0 -> all other bits of TFLG1)

7. If polling in main program

- (a) Wait for Bit x of TFLG1 to become set
- (b) Read time of edge from TCx
- (c) Clear flag (1 -> bit x of TFLG1 reg, 0 -> all other bits of TFLG1)

/* Program to determine the time between two rising edges using
the MC9S12 Input Capture subsystem */

```
#include <hidef.h>           /* common defines and macros */
#include "derivative.h"      /* derivative-specific definitions */
#include <stdio.h>
#include <termio.h>

unsigned int first, second, time;

void main(void)
{
    TSCR1 = 0x80;           /* Turn on timer subsystem */
    TSCR2 = 0x05;           /* Set prescaler for divide by 32 */
                               /* 87.38 ms overflow time */

    /* Setup for IC1 */
    TIOS = TIOS & ~0x02;    /* IOC1 set for Input Capture */
    TCTL4 = (TCTL4 | 0x04) & ~0x08; /* Capture Rising Edge */
    TFLG1 = 0x02;          /* Clear IC1 Flag */

    /* Setup for IC2 */
    TIOS = TIOS & ~0x04;    /* IOC2 set for Input Capture */
    TCTL4 = (TCTL4 | 0x10) & ~0x20; /* Capture Rising Edge */
    TFLG1 = 0x04;          /* Clear IC2 Flag */

    while ((TFLG1 & 0x02) == 0) ; /* Wait for 1st rising edge; */
    first = TC1;                /* Read time of 1st edge; */

    while ((TFLG1 & 0x04) == 0) ; /* Wait for 2nd rising edge; */
    second = TC2;              /* Read time of 2nd edge; */

    time = second - first;     /* Calculate total time */
    printf("time = %d cycles\n",time);
    __asm(swi);
}
```

Using the Keyword **volatile** in C

- Consider the following code fragment, which waits until an event occurs on Pin 2 of PTT:

```
#define TRUE 1
#define FALSE 0

#include <hidef.h>      /* common defines and macros */
#include "derivative.h" /* derivative-specific definitions */
#include "vectors12.h"

#define enable() __asm(cli)
#define disable() __asm(sei)

interrupt void tic2_isr(void);
unsigned int time, done;

void main(void) {
    disable();

    /* Code to set up Input Capture 2 */
    TFLG1 = 0x04;          /* Clear CF2 */
    UserTimerCh2 = (short) &tic2_isr; /* Set interrupt vector */
    enable();             /* Enable Interrupts */
    done = FALSE;
    while (!done) ;
    __asm(swi);
}

interrupt void tic2_isr(void) {
    time = TC2;
    TFLG1 = 0x04;
    done = TRUE;
}
```

- An optimizing compiler knows that `done` will not change in the `main()` function. It may decide that, since `done` is `FALSE` in the `main()` function, and nothing in the `main()` function changes the value of `done`, then `done` will always be `FALSE`, so there is no need to check if it will ever become `TRUE`.

- An optimizing compiler might change the line

`while (!done) ;`

to

`while (TRUE) ;`

and the program will never get beyond that line.

- By declaring `done` to be volatile, you tell the compiler that the value of `done` might change somewhere else other than in the `main()` function (such as in an interrupt service routine), and the compiler should not optimize on the `done` variable.

`volatile unsigned int time, done;`

- If a variable can change its value outside the normal flow of the program (i.e., inside an interrupt service routine), declare the variable to be of type volatile.

**Program to measure the time between two rising edges, and
print out the result**

```
#include <hidef.h> /* common defines and macros */
#include "derivative.h" /* derivative-specific definitions */
#include <stdio.h>
#include <termio.h>
#include "vectors12.h"

#define enable() __asm(cli)
#define disable() __asm(sei)

#define TRUE 1
#define FALSE 0

/* Function Prototypes */
interrupt void tic1_isr(void);
interrupt void tic2_isr(void);

/* Declare things changed inside ISRs as volatile */
volatile unsigned int first, second, time, done;

void main(void)
{
    disable();
    done = FALSE;

    /* Turn on timer subsystem */
    TSCR1 = 0x80;

    /* Set prescaler to 32 (87.38 ms), no TOF interrupt */
    TSCR2 = 0x05;
```

```
/* Setup for IC1 */
TIOS = TIOS & ~0x02;          /* Configure PT1 as IC */
TCTL4 = (TCTL4 | 0x04) & ~0x08; /* Capture Rising Edge */
TFLG1 = 0x02;                /* Clear IC1 Flag */

/* Set interrupt vector for Timer Channel 1 */
UserTimerCh1 = (short) &tic1_isr;
TIE = TIE | 0x02;           /* Enable IC1 Interrupt */

/* Setup for IC2 */
TIOS = TIOS & ~0x04;          /* Configure PT2 as IC */
TCTL4 = (TCTL4 | 0x10) & ~0x20; /* Capture Rising Edge */
TFLG1 = 0x04;                /* Clear IC2 Flag */

/* Set interrupt vector for Timer Channel 2 */
UserTimerCh2 = (short) &tic2_isr;
TIE = TIE | 0x04;           /* Enable IC2 Interrupt */

/* Enable interrupts by clearing I bit of CCR */
enable();
while (!done)
{
    __asm(wai);                /* Low power mode while waiting */
}
time = second - first;        /* Calculate total time */
printf("time = %d cycles\r\n",time); /* print */
}

interrupt void tic1_isr(void)
{
    first = TC1;
    TFLG1 = 0x02;
}
```



```
interrupt void tic2_isr(void)
{
    second = TC2;
    done = TRUE;
    TFLG1 = 0x04;
}
```

Ways to implement delays Output Compare Subsystem

- Want event to happen at a certain time?
- Want to produce pulse with width T?

Could use software delay

```
void delay (unsigned int ms) {  
    unsigned int i;  
    while (ms > 0) {  
        i = D_1MS;  
        while (i > 0) {  
            i = i - 1;  
        }  
        ms = ms - 1;  
    }  
}
```

Cannot do anything while waiting

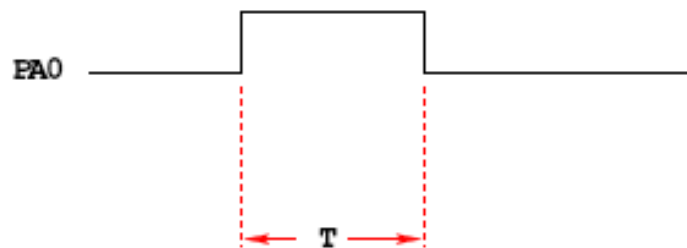
- Timer Overflow or Real Time Interrupt:

Only limited number of fixed delays

The MC9S12 Output Compare Function

Want event to happen at a certain time

Want to produce pulse with width T



Wait until TCNT == 0x0000, then bring PA0 high

Wait until TCNT == T, then bring PA0 low

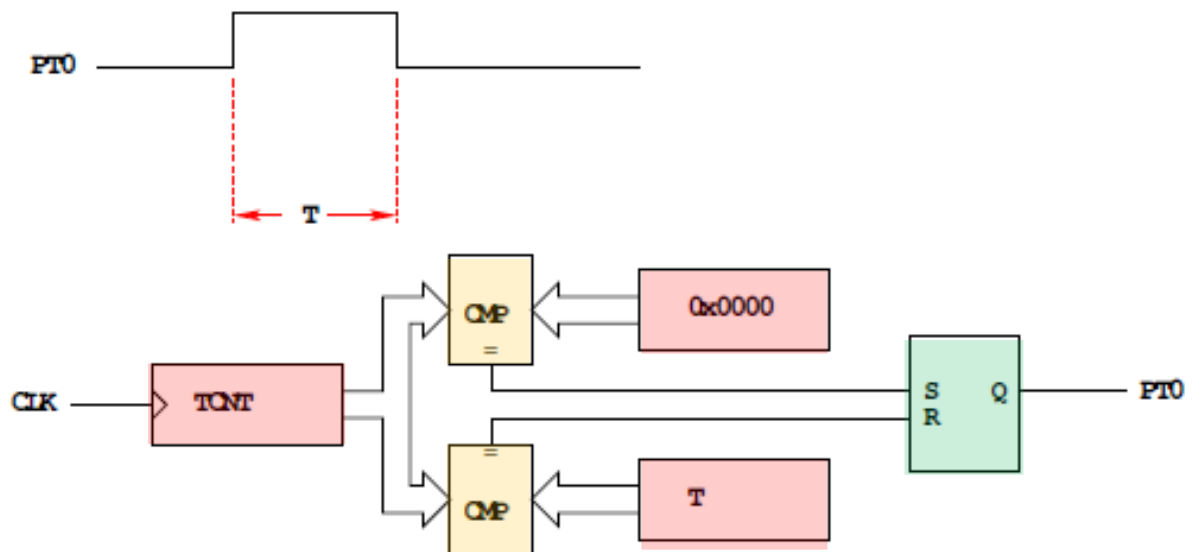
```
while (TCNT != 0x0000) ;  
PORTA = PORTA | 0x01;  
while (TCNT != T) ;  
PORTA = PORTA & ~0x01;
```

Problems:

- 1) May miss TCNT == 0x0000 or TCNT == T
- 2) Time not exact -- software delays
- 3) Cannot do anything else while waiting

Want event to happen at a certain time

Want to produce pulse with width T



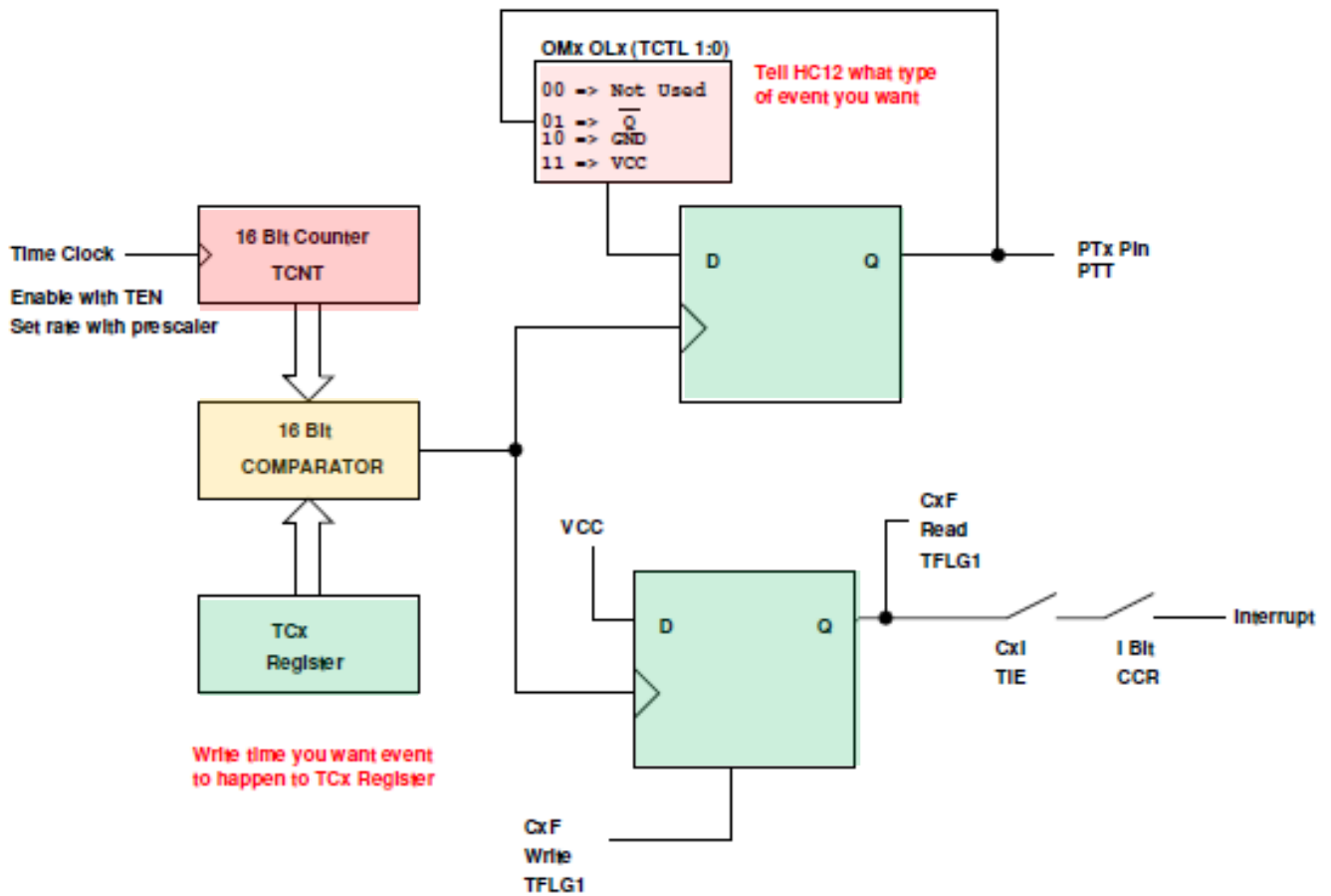
Wait until $TCNT == 0x0000$, then bring PT0 high, since PT is connected to Output Compare

Wait until $TCNT == T$, then bring PT0 low, since PT is connected to Output Compare

Now pulse is exactly T cycles long

Output Compare PORT T 0-7

To use Output Compare, you must set IOSx to 1 in TIOS



The MC9S12 Output Compare Function

- The MC9S12 allows you to force an event to happen on any of the eight PORTT pins
- An external event is a rising edge, a falling edge, or a toggle
- To use the Output Compare Function:
 - Enable the timer subsystem (set TEN bit of TSCR1)
 - Set the prescaler
 - Tell the MC9S12 that you want to use Bit x of PTT for output compare
 - Tell the MC9S12 what you want to do on Bit x of PTT (generate rising edge, falling edge, or toggle)
 - Tell the MC9S12 what time you want the event to occur
 - Tell the MC9S12 if you want an interrupt to be generated when the event is forced to occur
- There are some more complicated features of the output compare subsystem which are activated using registers CFORC, OC7M, OC7D and TTOV.
 - Writing a 1 to the corresponding bit of CFORC forces an output compare event to occur, the same as if a successful comparison has taken place (Section 8.6.5 of Huang).

- Using OC7M and OC7D allow Timer Channel 7 to control multiple output compare functions (Section 8.6.4 of Huang).
- Using TTOV allows you to toggle an output compare pin when TCNT overflows. This allows you to use the output compare system to generate pulse width modulated signals.
- We will not discuss these advanced features in this class.

Write a 1 to Bit 7 of TSCR1 to turn on timer



To turn on the timer subsystem: TSCR1 = 0x80;

Set the prescaler in TSCR2

Make sure the overflow time is greater than the width of the pulse you want to generate



PR2	PR1	PR0	Period (μs)	Overflow (ms)
0	0	0	0.0416	2.73
0	0	1	0.0833	5.46
0	1	0	0.1667	10.92
0	1	1	0.3333	21.84
1	0	0	0.6667	43.69
1	0	1	1.3333	86.38
1	1	0	2.6667	174.76
1	1	1	5.3333	349.53

To have overflow rate of 21.84 ms:

TSCR2 = 0x03;

Write a 1 to the bits of TIOS to make those pins output compare

IOS7	IOS6	IOS5	IOS4	IOS3	IOS2	IOS1	IOS0	0x0080	TIOS
------	------	------	------	------	------	------	------	--------	------

To make Pin 4 an output compare pin: $TIOS = TIOS | 0X10;$

Write to TCTL1 and TCTL2 to choose action to take

OM7	OL7	OM6	OL6	OM5	OL5	OM4	OL4	0x0048	TCTL1
-----	-----	-----	-----	-----	-----	-----	-----	--------	-------

OM3	OL3	OM2	OL2	OM1	OL1	OM0	OL0	0x0049	TCTL2
-----	-----	-----	-----	-----	-----	-----	-----	--------	-------

OMn	OLn	Configuration
0	0	Disconnected
0	1	Toggle
1	0	Clear
1	1	Set

To have Pin 4 toggle on compare:

$TCTL1 = (TCTL1 | BIT0) \& \sim BIT1;$

Write time you want event to occur to TCn register.

To have event occur on Pin 4 when $TCNT == 0x0000:$

$TC4 = 0x0000;$

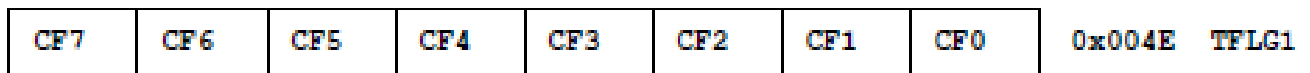
To have next event occur T cycles after last event, add T to TCn.

To have next event occur on Pin 4, 500 cycles later:

TC4 = TC4 + 500;

When $TCNT == TCn$, the specified action will occur, and flag CnF will be set.

To clear the flag, write a 1 to the bit you want to clear (0 to all others)



To wait until $TCNT == TC4$: **while ((TFLG1 & BIT4) == 0) ;**

To clear flag bit for Pin 4: **TFLG1 = BIT4;**

To enable interrupt when compare occurs, set corresponding bit in TIE register



To enable interrupt when $TCNT == TC4$: **TIE = TIE | BIT4;**

Using Output Compare on the MC9S12

1. In the main program:

- (a) Turn on timer subsystem (TSCR1 reg)
- (b) Set prescaler (TSCR2 reg)
- (c) Set up PTx as OC (TIOS reg)
- (d) Set action on compare (TCTL 1-2 regs, OMx OLx bits)

OMx	OLx	Action
0	0	Disconnected
0	1	Toggle
1	0	Clear
1	1	Set

- (d) Clear Flag (TFLG1 reg)
- (f) To use interrupts: Enable int (TIE reg)

2. In interrupt service routine

- (a) Set time for next action to occur (write TCx reg)
 - For periodic events add time to TCx register
- (b) Clear flag (TFLG1 reg)

Program to implement a 100 Hz square wave on output pin PT2:
Make output toggle ever 5 ms, for a 10 ms period: $5 \text{ ms} * 24 \times 10^6$
cycles/s = 120, 000 cycles. TCNT can only count up to 65,536
cycles. Need to use prescaler to get correct frequency. A prescaler
of 4 divides the clock by 16, so: $5 \text{ ms} * (24 \times 10^6 \text{ cycles/s} / 16) = 7,$
500 cycles.

```
#include <hidef.h>                /* common defines and macros */
#include "derivative.h"          /* derivative-specific definitions */
#include "vectors12.h"

/* Need 10 ms period. Set prescaler to 4, to divide 24 MHz clock by 16. So
10 ms * (24,000,000 cycles/sec / 16) = 15,000 */

#define PERIOD 15000
#define HALF_PERIOD (PERIOD/2)

#define disable() __asm(sei)
#define enable() __asm(cli)

interrupt void toc2_isr(void);

void main(void)
{
    disable();
    TSCR1 = 0x80;                /* Turn on timer subsystem */
    TSCR2 = 0x04;                /* Set prescaler to 0.666 us */

    TIOS = TIOS | 0x04;          /* Configure PT2 as Output */
                                /* Compare */
    TCTL2 = (TCTL2 | 0x10) & ~0x20; /* Set up PT2 */
                                /* to toggle on compare */
    TFLG1 = 0x04;                /* Clear Channel 2 flag */
}
```

```
/* Set interrupt vector for Timer Channel 2 */
UserTimerCh2 = (unsigned short) &toc2_isr;

TIE = TIE | 0x04; /* Enable interrupt on Channel 2 (local enable)*/
enable();        /* global enable */

while (1)
{
    __asm(wai);
}

interrupt void toc2_isr(void)
{
    TC2 = TC2 + HALF_PERIOD;
    TFLG1 = 0x04;
}
```

