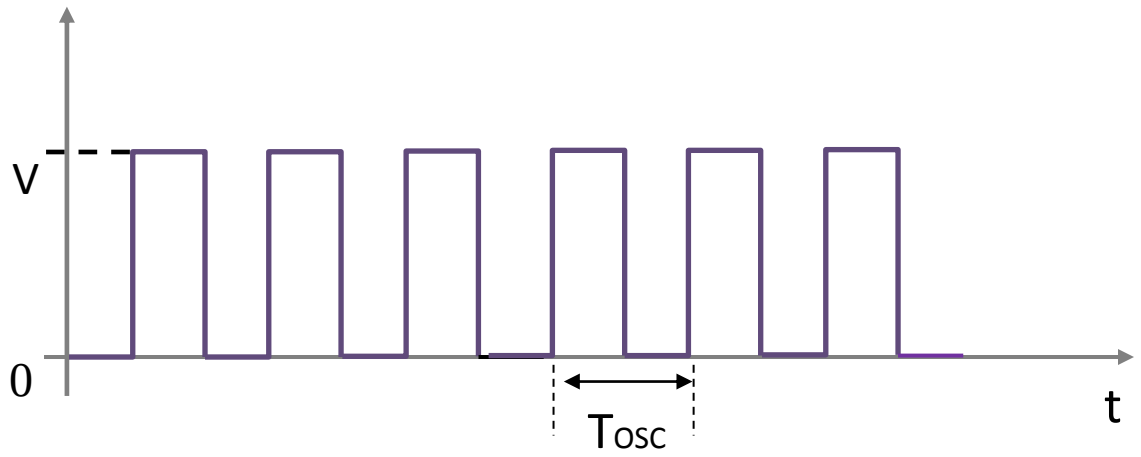
# The MCU's Pulse

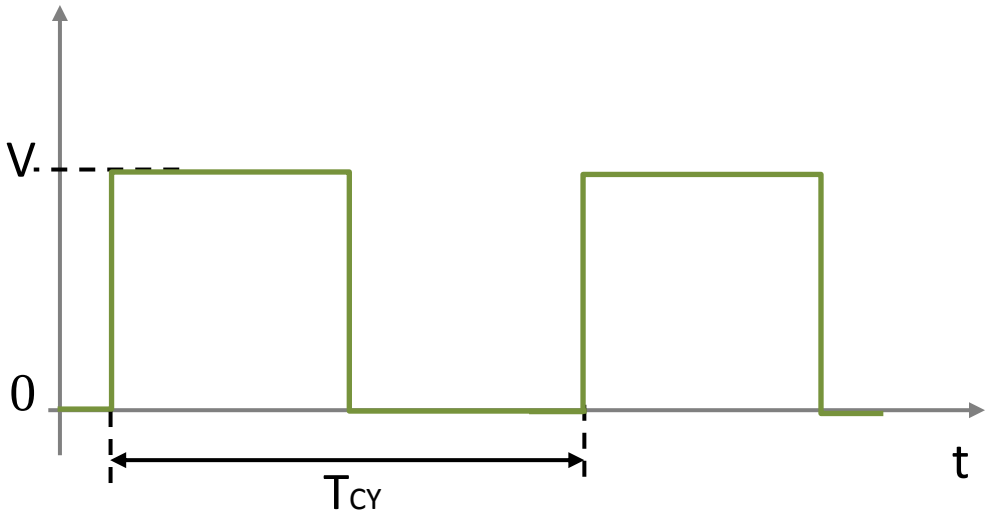
- Internal clock or oscillator to synchronize operation



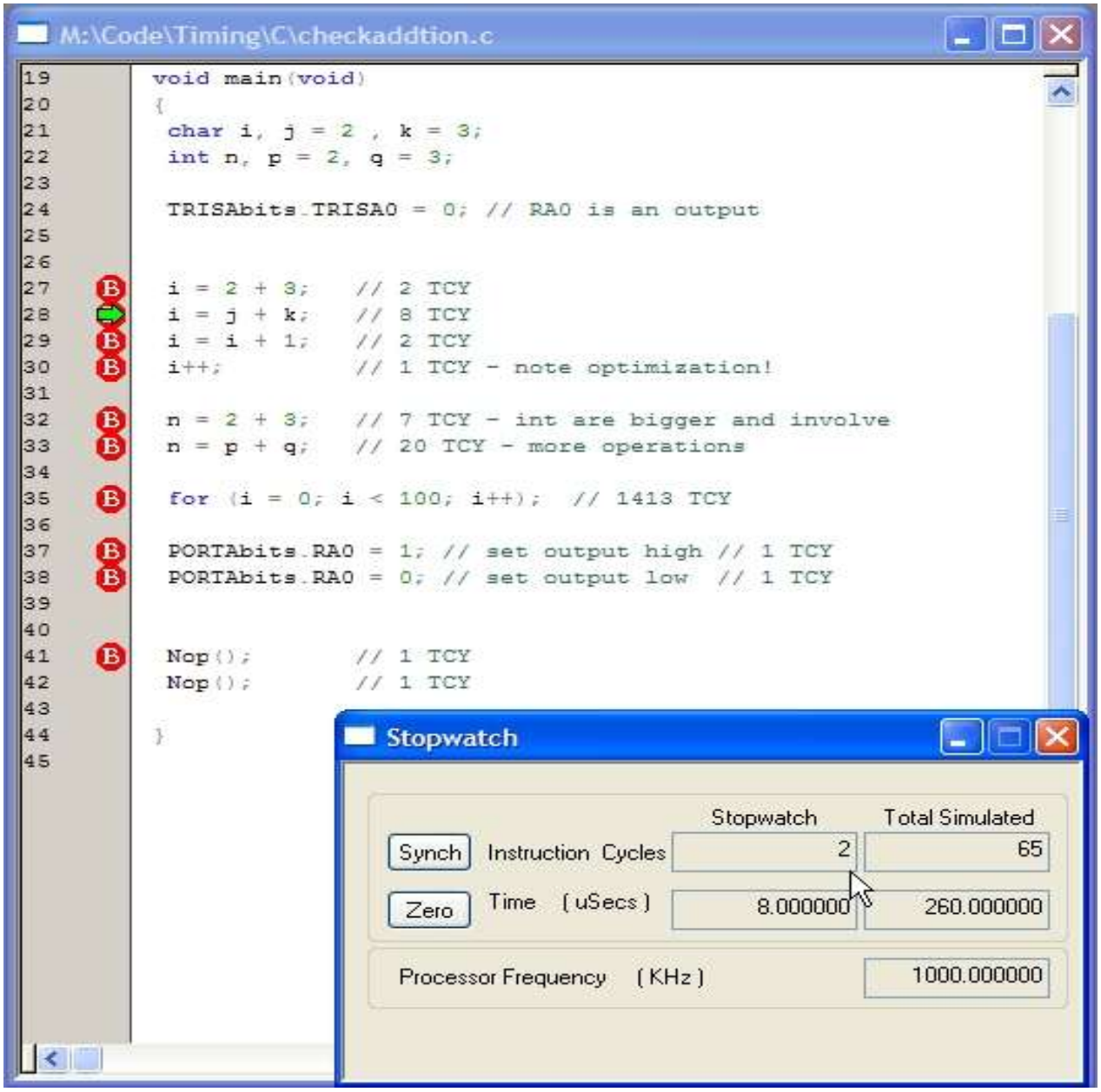

- One clock cycle = 1 $T_{osc}$ = 1/$f_{osc}$

# Clock Cycle

- The minimum time to perform any operation is one instruction cycle $T_{CY}$
- 1 $T_{CY}$ = 4 $T_{OSC}$




- Different operations require different amounts of time to complete


M:\Code\Timing\C\checkaddtion.c
19 void main(void)
20 {
21 char i, j = 2 , k = 3;
22 int n, p = 2, q = 3;
23
24 TRISAbits.TRISA0 = 0; // RA0 is an output
25
26
27 i = 2 + 3; // 2 TCY
28 i = j + k; // 8 TCY
29 i = i + 1; // 2 TCY
30 i++; // 1 TCY - note optimization!
31
32 n = 2 + 3; // 7 TCY - int are bigger and involve
33 n = p + q; // 20 TCY - more operations
34
35 for (i = 0; i < 100; i++); // 1413 TCY
36
37 PORTAbits.RA0 = 1; // set output high // 1 TCY
38 PORTAbits.RA0 = 0; // set output low // 1 TCY
39
40
41 Nop(); // 1 TCY
42 Nop(); // 1 TCY
43
44 }
45
Stopwatch
Stopwatch
Total Simulated
Synch
Instruction Cycles
2
65
Zero
Time ( uSecs )
8.000000
260.000000
Processor Frequency ( KHz )
1000.000000

# Can Check $T_{CY}$ Physically

- If configured correctly, pin 14 outputs a continuous on/off signal or square wave with period of 1 $T_{CY}$
- To configure pin

```
#pragma config OSC = INTIO7     // puts fosc/4 on pin 14 to
                                // check freq
```

- Pin 14 not available for other purposes (no RA6)

# Can Control MCU Frequency

- SFRs: OSCCON and OSCTUNE
- Given osc.h and osc.c and set_osc_32MHz()
- OSCCON give speeds from 31KHz to 8 MHz
- OSCTUNE can multiply certain higher speeds (4 & 8 MHz) by 4 times to (16 & 32 MHz).

# OSC.C

```
#include “osc.h”

void set_osc_32MHz(void)
{
    int i;

    OSCCONbits.IRCF2 = 1;  // Set the OSCILLATOR Control Register to 8 MHz
    OSCCONbits.IRCF1 = 1;
    OSCCONbits.IRCF0 = 1;
    OSCTUNEbits.PLLEN = 1; // Enable PLL, boosts speed by 4x to 32 MHz
                           // NB available for  4 & 8 MHz base only
                           // no effect otherwise
    for(i=0;i<500;i++);    // delay to allow clock PLL to lock (stabilize)
}
```

**REGISTER 2-2: OSCCON: OSCILLATOR CONTROL REGISTER**

| R/W-0 | R/W-1 | R/W-0 | R/W-0 | R(1) | R-0 | R/W-0 | R/W-0 |
|---|---|---|---|---|---|---|---|
| IDLEN | IRCF2 | IRCF1 | IRCF0 | OSTS | IOFS | SCS1 | SCS0 |
| bit 7 | | | | | | | bit 0 |

bit 7 **IDLEN:** Idle Enable bit
1 = Device enters Idle mode on SLEEP instruction
0 = Device enters Sleep mode on SLEEP instruction

bit 6-4 **IRCF2:IRCF0:** Internal Oscillator Frequency Select bits
111 = 8 MHz (INTOSC drives clock directly)
110 = 4 MHz
101 = 2 MHz
100 = 1 MHz(3)
011 = 500 kHz
010 = 250 kHz
001 = 125 kHz
000 = 31 kHz (from either INTOSC/256 or INTRC directly)(2)

bit 3 **OSTS:** Oscillator Start-up Time-out Status bit(1)
1 = Oscillator start-up time-out timer has expired; primary oscillator is running
0 = Oscillator start-up time-out timer is running; primary oscillator is not ready

bit 2 **IOFS:** INTOSC Frequency Stable bit
1 = INTOSC frequency is stable
0 = INTOSC frequency is not stable

bit 1-0 **SCS1:SCS0:** System Clock Select bits
1x = Internal oscillator block
01 = Secondary (Timer1) oscillator
00 = Primary oscillator

**Note 1:** Reset state depends on state of the IESO configuration bit.
**2:** Source selected by the INTSRC bit (OSCTUNE<7>), see text.
**3:** Default output frequency of INTOSC on Reset.

| **Legend:** | | | |
|---|---|---|---|
| R = Readable bit | W = Writable bit | U = Unimplemented bit, read as '0' | |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared | x = Bit is unknown |

# OSC.C

```
#include “osc.h”

void set_osc_32MHz(void)
{
    int i;

    OSCCONbits.IRCF2 = 1;  // Set the OSCILLATOR Control Register to 8 MHz
    OSCCONbits.IRCF1 = 1;
    OSCCONbits.IRCF0 = 1;
    OSCTUNEbits.PLLEN = 1; // Enable PLL, boosts speed by 4x to 32 MHz
                           // NB available for 4 & 8 MHz base only
                           // no effect otherwise
    for(i=0;i<500;i++);    // delay to allow clock PLL to lock (stabilize)
}
```

| fosc (MHz) | Tosc (ns) | TCY (ns) |
|---|---|---|
| 32 | | |
| 16 | | |
| 8 | | |
| 4 | | |
| 2 | | |
| 1 | | |
| 0.500 | | |
| 0.250 | | |
| 0.125 | | |

| fosc (MHz) | Tosc (ns) | Tcy (ns) |
|---|---|---|
| 32 | 31.25 | 125 |
| 16 | 62.50 | 250 |
| 8 | 125 | 500 |
| 4 | 250 | 1 000 |
| 2 | 500 | 2 000 |
| 1 | 1 000 | 4 000 |
| 0.500 | 2 000 | 8 000 |
| 0.250 | 4 000 | 16 000 |
| 0.125 | 8 000 | 32 000 |

# Note

Although you can change the operating frequency of the MCU, $f_{OSC}$, (almost) every operation takes the same number to $T_{CY}$ to complete.

For this reason operation times are always given in $T_{CY}$ and time graphs are plotted against time in $T_{CY}$.

# Delays

- delays.h

```
void Delay1TCY(void)                        // 1 TCY delay – same as Nop();
void Delay10TCYx(unsigned char unit)   // delay = 10 * unit * TCY
void Delay100TCYx(unsigned char unit) // delay = 100 * unit * TCY
void Delay1KTCYx(unsigned char unit)  // delay = 1000 * unit * TCY
void Delay10KTCYx(unsigned char unit) // delay = 10,000 * unit * TCY
```

- unit  1 to 255 (0 = 256)
- See C18 C Compiler Libraries PDF for details

| fosc (MHz) | Delay10KTCYx(0) |
| --- | --- |
| 32 | |
| 16 | |
| 8 | |
| 4 | |
| 2 | |
| 1 | |
| 0.500 | |
| 0.250 | |
| 0.125 | |

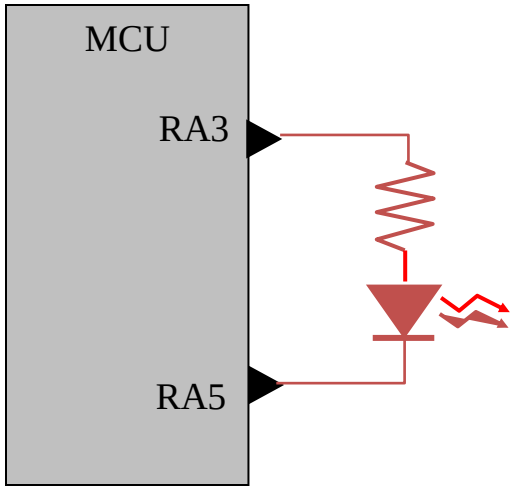
| fosc (MHz) | Delay10KTCYx(0) |
|---|---|
| 32 | 256 x 10 000 x 125 ns = 0.32 s |
| 16 | 256 x 10 000 x 250 ns = 0.64 s |
| 8 | 256 x 10 000 x 500 ns = 1.28 s |
| 4 | 256 x 10 000 x 1 000 ns = 2.56 s |
| 2 | 256 x 10 000 x 2 000 ns = 5.12 s |
| 1 | 256 x 10 000 x 4 000 ns = 10.24 |
| 0.500 | 256 x 10 000 x 8 000 ns = 20.48 s |
| 0.250 | 256 x 10 000 x 16 000 ns = 40.96 s |
| 0.125 | 256 x 10 000 x 32 000 ns = 81.92 s |

# What is the total delay in sec?

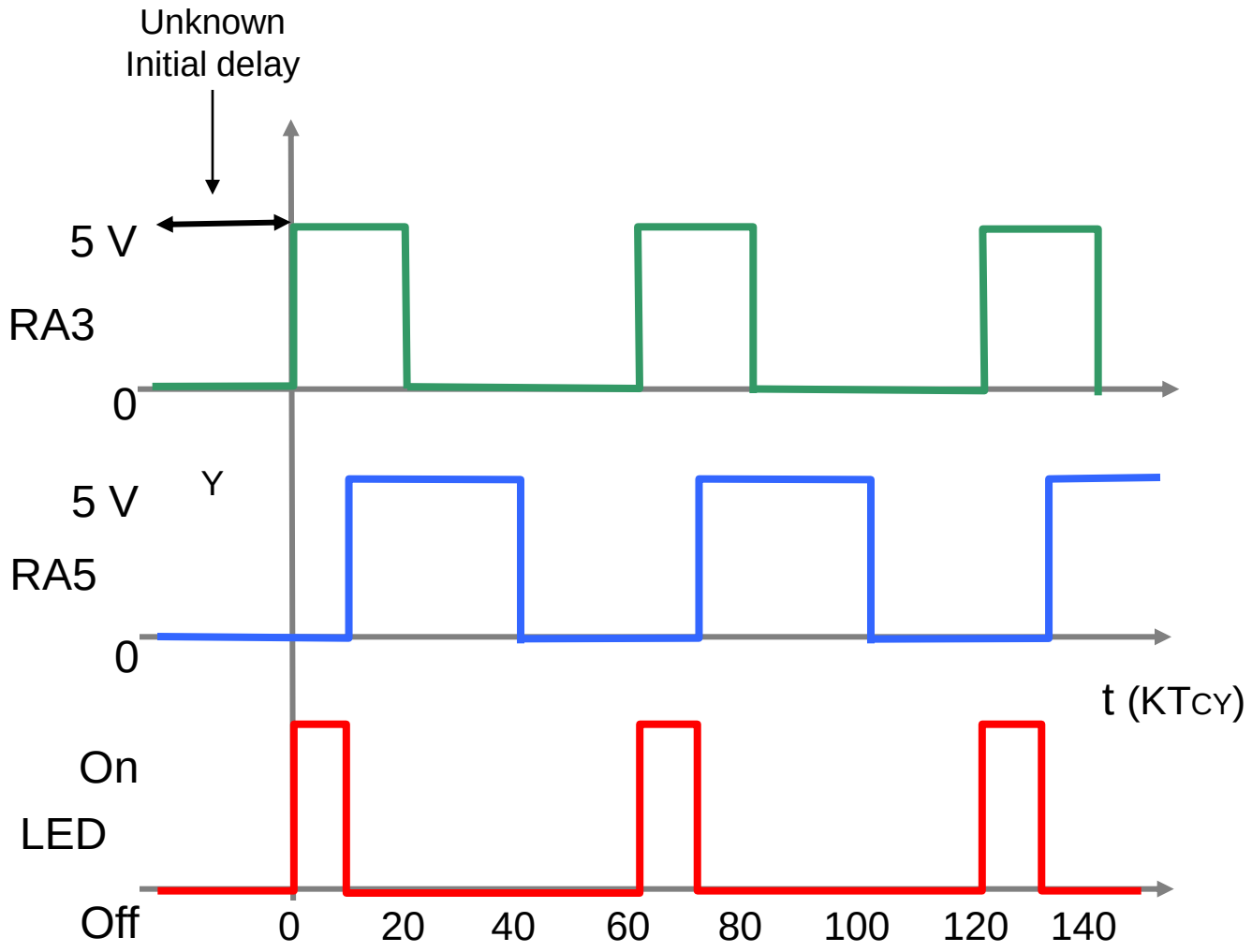
```
main()
{
set_osc_8MHz();
Delay1KTCYx(250);
Delay10TCYx(300);
while(1);
}
```

# Solving Timing problems

What is the On and Off times for the LED using this circuit and code?




```
#include <delays.h>
#include “osc.h”
void main(void)
{
    Set_OSC_32MHz();
    TRISAbits.TRISA3 = 0; // set RA3 as output
    TRISAbits.TRISA5 = 0; // set RA5 as output
    PORTAbits.RA3 = 0;    // initialize to low
    PORTAbits.RA5 = 0;    // initialize to low
    while(1)              // anything in here repeats
     forever
      {
       PORTAbits.RA3 = 1;    // set RA3 high
       Delay1KTCYx(10);      // wait 1,000 * 10 TCY
       PORTAbits.RA5 = 1;    // set RA5 high
       Delay1KTCYx(10);      // wait 1,000 * 10 TCY
       PORTAbits.RA3 = 0;    // clear RA3 (low)
       Delay1KTCYx(20);      // wait 1,000 * 30 TCY
       PORTAbits.RA5 = 0;    // clear RA5 (low)
       Delay1KTCYx(20);      // wait 1,000 * 30 TCY
      }
}
```


Unknown
Initial delay
5 V
RA3
0
Y
5 V
RA5
0
t (KTCY)
On
LED
Off
0
20
40
60
80
100
120
140

# Timer Modules

- delay functions keep anything from happening.
- would like to multitask

  e.g. give 10 sec to press button

- timers are like egg timers with alarms
  - set
  - do something else
  - come back when alarm goes off

# How timers work

- Two slightly different ways to use an egg timer to get a 3 minute egg
  - Set timer to 3 minutes and listen for alarm
  - Set timer to more than 3 minutes and check time every so often until 3 minutes pass
- No auditory alarm. Instead a “flag”, a one bit of memory, is set to 1

```
if ( flag == 1 ) // timer finished
```

- Counts up not down

# Timer Software

- PIC has 4 timers, will only use Timer0

  #include <timers.h>

  OpenTimer0(unsigned char *config*) ****

  WriteTimer0(unsigned int *timer*)

  ReadTimer0(void)

  CloseTimer0(void)

  INTCONbit.TR0IF (flag = 0 or 1)

- See C18 C Compiler Libraries PDF for details

## OpenTimer0

**Function:** Configure and enable timer0.

**Include:** `timers.h`

**Prototype:** `void OpenTimer0( unsigned char config );`

**Arguments:** ***config***

A bitmask that is created by performing a bitwise AND operation ('&') with a value from each of the categories listed below. These values are defined in the file `timers.h`.

**Enable Timer0 Interrupt:**

| | |
|---|---|
| `TIMER_INT_ON` | Interrupt enabled |
| `TIMER_INT_OFF` | Interrupt disabled |

**Timer Width:**

| | |
|---|---|
| `T0_8BIT` | 8-bit mode |
| `T0_16BIT` | 16-bit mode |

**Clock Source:**

| | |
|---|---|
| `T0_SOURCE_EXT` | External clock source (I/O pin) |
| `T0_SOURCE_INT` | Internal clock source (TOSC) |

**External Clock Trigger (for `T0_SOURCE_EXT`):**

| | |
|---|---|
| `T0_EDGE_FALL` | External clock on falling edge |
| `T0_EDGE_RISE` | External clock on rising edge |

**Prescale Value:**

| | |
|---|---|
| `T0_PS_1_1` | 1:1 prescale |
| `T0_PS_1_2` | 1:2 prescale |
| `T0_PS_1_4` | 1:4 prescale |
| `T0_PS_1_8` | 1:8 prescale |
| `T0_PS_1_16` | 1:16 prescale |
| `T0_PS_1_32` | 1:32 prescale |
| `T0_PS_1_64` | 1:64 prescale |
| `T0_PS_1_128` | 1:128 prescale |
| `T0_PS_1_256` | 1:256 prescale |

# config bitmask

Always use

TIMER_INT_OFF, T0_SOURCE_INT

Choices

T0_EDGE_FALL or T0_EDGE_RISE (doesn't matter)

T0_8BIT or T0_16BIT (usually use 16 bit counter)

prescalers (count every $2^n$ edges)

| | | Time Limit ($T_{CY}$) | |
|---|---|---|---|
| prescaler | Value | 8 Bit (255) | 16 Bit (65535) |
| T0_PS_1_1 | 1 | 0 – 255 | 0 – 65535 |
| T0_PS_1_2 | 2 | 0 – 510 | 0 – 131070 |
| T0_PS_1_4 | 4 | 0 – 1020 | 0 – 262140 |
| T0_PS_1_8 | 8 | 0 – 2040 | 0 – 524280 |
| T0_PS_1_16 | 16 | 0 – 4080 | 0 – 1048560 |
| T0_PS_1_32 | 32 | 0 – 8160 | 0 – 2097120 |
| T0_PS_1_64 | 64 | 0 – 16320 | 0 – 4194220 |
| T0_PS_1_128 | 128 | 0 – 32640 | 0 – 8388480 |
| T0_PS_1_256 | 256 | 0 – 65280 | 0 – 16776960 |

# Precision ($T_{CY}$)

| prescaler | $\Delta T$ |
|---|---|
| T0_PS_1_1 | 1 |
| T0_PS_1_2 | 2 |
| T0_PS_1_4 | 4 |
| T0_PS_1_8 | 8 |
| T0_PS_1_16 | 16 |
| T0_PS_1_32 | 32 |
| T0_PS_1_64 | 64 |
| T0_PS_1_128 | 128 |
| T0_PS_1_256 | 256 |

# On a 32 MHz setting, what is the longer time available? Precision?

1 TCY = 4 x 1/32 MHz = 125 ns ($125 \times 10^{-9}$ s)

Largest time

256 x 65535 x 125 ns = 2.097 s

Precision

256 x 125 ns = 0.000032 s

# Wait for Alarm

```
#include <timers.h>

OpenTimer0(TIMER_INT_OFF & T0_SOURCE_INT &
   T0_16BIT & T0_PS_1_1);
INTCONbits.TMR0IF = 0;   // reset
WriteTimer0(15536);     // allow (65536-15536)x1 = 50K TCY
while(!INTCONbits.TMR0IF)
        { // do other things – check button or use LCD etc}
INTCONbits.TMR0IF = 0;   // reset
CloseTimer0();
```

# Check Time Occasionally

```
#include <timers.h>

OpenTimer0(TIMER_INT_OFF & T0_SOURCE_INT &
   T0_16BIT & T0_PS_1_1);

WriteTimer0(0);     // allow at most 65536x1 TCY
while(ReadTimer0() <= 50000u) // only 50 000x1 TCY
        { // do other things – check button or use LCD etc}

CloseTimer0();
```

# How long do you wait?

```
#include <timers.h>

OpenTimer0(TIMER_INT_OFF & T0_SOURCE_INT &
   T0_16BIT & T0_PS_1_4);
INTCONbits.TMR0IF = 0;   // reset
WriteTimer0(33555);     // ??? TCY
while(!INTCONbits.TMR0IF)
        { // do other things – check button or use LCD etc}
INTCONbits.TMR0IF = 0;   // reset
CloseTimer0();
```

- Note need prescaler for > 65536 $T_{CY}$

What is minimum prescaler and precision for

| $T_{CY}$ | prescaler | Counter | $\Delta T$ |
|---|---|---|---|
| 1 000 215 | | | |
| 5 250 450 | | | |
| 21 000 100 004 | | | |

# Blink LED 0.5s on, 0.15s off until button pressed

```
main()
{
// Configure output LED and input button pins
set_osc_32MHz();
OpenTimer0(TIMER_INT_OFF & T0_SOURCE_INT & T0_16BIT  & T0_PS_1_64);
// 0.5 s/125 ns = 4E6 TCY. 4E6/65536 = 61 – use 64
while(1)
      {
        WriteTimer0(0);
        // LED on
       while(ReadTimer0() <=  62500u && button == OFF)
            { //monitor button}
       WriteTimer0(0);
        // LED off
      while(ReadTimer0() <= 18750u && button == OFF)
            { //monitor button}
      }
}
```