Timers: Timer0 Tutorial (Part 2)

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Preface

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INTRODUCTION

This chapter contains general information that will be useful to know before using the Timers Tutorial. Items discussed in this chapter include:

- Document Layout
- The Microchip Web Site
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document provides an introduction to Timer0.

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DOCUMENT REVISION HISTORY

Revision A (January 2008)

- Initial Release of this Document.

Timers: Timer0 Tutorial (Part 2)

OBJECTIVES

At the end of this lab you should be able to:

1. Develop application firmware to generate TMR0 overflow interrupts for specified time periods.
2. Develop application firmware using an external clock source with the Timer0 module.
3. Develop external Timer0 clock source applications that meet PIC16F690 Electrical Specifications.

PREREQUISITES

In order to successfully complete this lab you should:

1. Understand basic circuit theory.
2. Understand basic digital electronic components such as gates, multiplexers and memory registers.
3. Understand binary numbering systems and basic binary arithmetic.
4. Have some programming experience in the C Language.
5. Have completed the "*Introduction to MPLAB® IDE/PICC-Lite™ Compiler Tutorial*" (DS41322).
6. Have completed "*Timers: Timer0 Tutorial (Part1)"* (DS51682).

EQUIPMENT REQUIRED

This lab has been developed so that no hardware is required other than a PC. However, you will need the following:

1. You will need to download the free MPLAB Integrated Development Environment available at the following url:

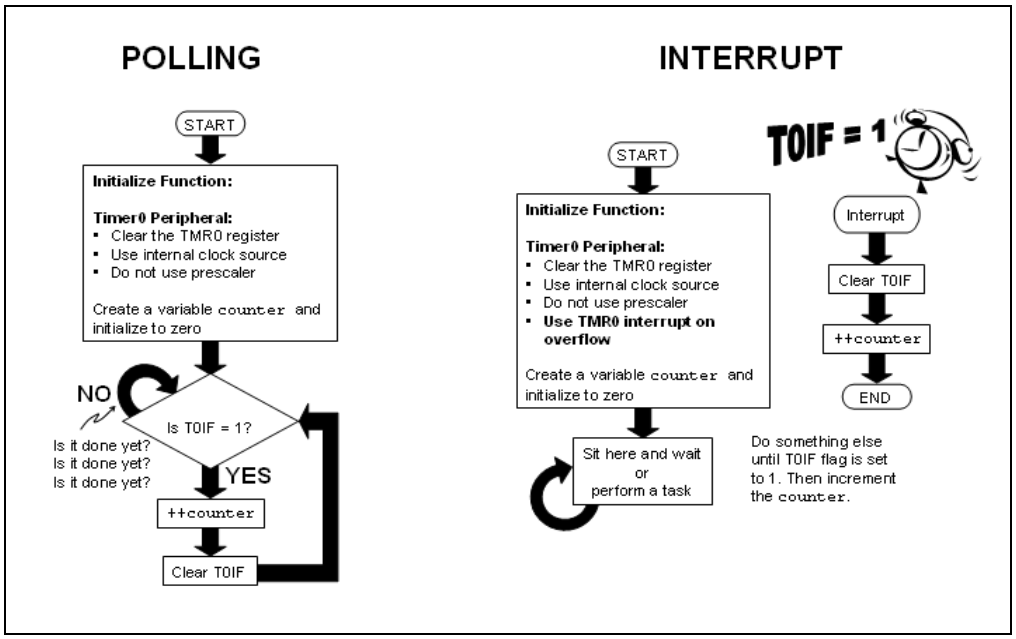
   http://www.microchip.com

   When prompted, unzip the contents of the file into a temporary folder on your desktop and then install.
2. Install the free HI-TECH PICC-Lite™ compiler (refer to the download instructions).
3. Once both programs are installed, complete the "*Introduction to MPLAB® IDE/PICC-Lite™ Compiler Tutorial*" (DS41322) if you haven't already. This lab assumes that you have done so and will expand on that knowledge.
4. It is also recommended that you download a copy of the PIC16F690 data sheet (DS41262) from www.microchip.com.

TIMER0 INTERRUPT

In the previous lab we incremented a variable, `counter`, whenever the Timer0 value register TMR0 overflowed from 255 to 0. To do this, a “Polling” algorithm was used where the Timer0 Interrupt Flag (T0IF) was checked periodically to see if it was set to ‘`1`’. This indicated that the TMR0 register had overflowed and that the `counter` variable should be incremented. Now, you may notice that this type of algorithm of periodically checking the T0IF ties up the processor for however long it takes to perform the check. This may be acceptable for some applications, however, there will be times when you would like the processor to devote its attention to a different task and only take care of, or “service”, incrementing the `counter` variable when the T0IF flag overflows without needing to constantly check its status. This is easily accomplished on mid-range PIC® microcontrollers, such as the PIC16F690, using interrupts which serve as an alarm, signaling that a particular event has occurred (such as when the T0IF flag is set). In Figure 1-1, the left-hand flowchart represents the polling algorithm used in the previous lab while the right-hand flowchart represents an alternative approach in the form of an interrupt routine.

FIGURE 1-1: POLLING AND INTERRUPT ALGORITHMS TO INCREMENT `COUNTER` VARIABLE

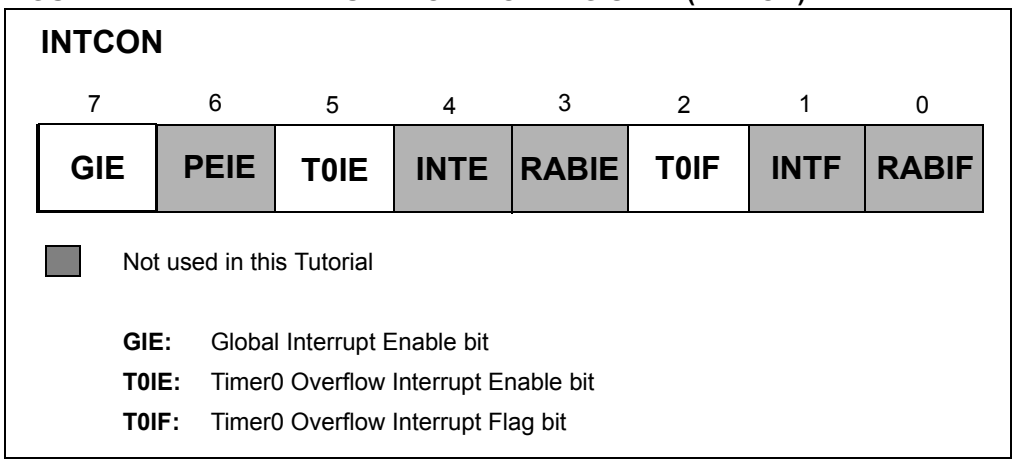


The PIC16F690 can be configured to perform a specific task when an interrupt occurs. This is called the Interrupt Service Routine or “ISR” for short. When any interrupt occurs, and there could be more than one, the processor will immediately stop what it is doing and jump to the ISR to service the interrupt. Once completed, the processor returns to what it was doing in code, prior to being interrupted. If multiple peripheral interrupts are used, a prioritization algorithm will need to be included in the ISR to determine which interrupt is serviced first. This lab will concentrate on Timer0 interrupts only and not introduce any others.

CONFIGURING TIMER0 INTERRUPTS

The PIC16F690, as with any other PIC mid-range microcontroller, can be configured to generate an interrupt when the TMR0 register overflows from 255 to 0 (11111111_2 to 00000000_2). To accomplish this, we must utilize the Interrupt Control (INTCON) register. Figure 1-3 shows the INTCON register with the bits used in this tutorial.

FIGURE 1-2: INTERRUPT CONTROL REGISTER (INTCON)



There are basically three primary Configuration bits used to configure any interrupt. First, the Global Interrupt Enable bit (GIE) acts as a sort of “Master Switch” that must be set to enable interrupt capability on the PIC mid-range microcontroller. The GIE will automatically clear to ‘0’ whenever an interrupt occurs, ensuring that no other interrupts can occur during execution of the ISR. Therefore, once the ISR is completed, the GIE must be set again to enable future interrupts. Next, each peripheral will have individual interrupt enable bits. These individual interrupt enable bits may be contained within a separate Peripheral Interrupt Register (PIRx). However, the Timer0 peripheral interrupt enable bit is contained within the INTCON register. The Timer0 Overflow Interrupt Flag bit (T0IF) is set, and remains set until cleared in software, when a Timer0 overflow has occurred. This bit needs to be cleared if further interrupts are required for this peripheral. The following recommended sequence should be used when configuring any interrupt and following any ISR:

1. Clear the interrupt flag (Timer0 Overflow Interrupt Flag).
2. Enable the individual peripheral interrupt (set the Timer0 Overflow Interrupt Enable bit).
3. Enable PIC mid-range MCU interrupt capability by setting the Global Interrupt Enable bit.

Interrupt configuration using these steps will ensure that interrupts do not occur during initialization, causing unexpected results.

HANDS-ON LAB 1: TIMER0 INTERRUPTS

Purpose:

In this lab, a counter variable will increment each time the TMR0 register overflows from 255 to 0. To accomplish this, we will configure INTCON so that an interrupt occurs whenever the T0IF (TMR0 Overflow Interrupt Flag) is set, indicating an overflow. To implement an interrupt using the PICC-Lite compiler, the interrupt function qualifier must be used followed by the chosen name of the Interrupt Service Routine (refer to Example 1-1).

EXAMPLE 1-1: TIMER0_ISR

```
void interrupt Timer0_ISR(void)
{
        if (T0IE && T0IF)  //are TMR0 interrupts enabled and
                           //is the TMR0 interrupt flag set?
        {
        T0IF=0;            //TMR0 interrupt flag must be cleared in software
                           //to allow subsequent interrupts
        ++counter;         //increment the counter variable by 1
        }
}
```

PROCEDURE

Part 1: Configuring Timer0 Interrupts

1. Create a new project in MPLAB IDE using the following:
   a) Select the PIC16F690 as the device.
   b) Select HI-TECH PICC-Lite™ as the Language Toolsuite.
   c) Create a folder on your C:\ drive and store the project there.
2. In the MPLAB IDE workspace, create a new file and copy the code in Example 1-2 into it.

EXAMPLE 1-2: HANDS-ON LAB CODE

```
#include   <pic.h>


 //Configure device
           __CONFIG(INTIO & WDTDIS & PWRTDIS & MCLRDIS &
                     UNPROTECT & BORDIS & IESODIS & FCMDIS);



//-----------------------DATA MEMORY

unsigned char counter;            //counter variable to count
                                  //the number of TMR0 overflows

//----------------------PROGRAM MEMORY

/*-------------------------------------------------------------
           Subroutine: Timer0_ISR
           Parameters: none
           Returns:     nothing
           Synopsys:    This is the Interrupt Service Routine for
                        Timer0 overflow interrupts. On TMR0 overflow
                        the counter variable is incremented by 1
-------------------------------------------------------------*/
void interrupt Timer0_ISR(void)
{
           if (T0IE && T0IF)      //are TMR0 interrupts enabled and
                                  //is the TMR0 interrupt flag set?
           {
           T0IF=0;                //TMR0 interrupt flag must be
                                  //cleared in software
                                  //to allow subsequent interrupts
           ++counter;             //increment the counter variable
                                  //by 1
           }
}
```

EXAMPLE 1-2: HANDS-ON LAB CODE (CONTINUED)

```
/*-------------------------------------------------------
           Subroutine: INIT
           Parameters: none
           Returns:     nothing
           Synopsys:    Initializes all registers
                        associated with the application
-------------------------------------------------------*/
Init(void)
{
           TMR0 = 0;              //Clear the TMR0 register

/*Configure Timer0 as follows:

           - Use the internal instruction clock
             as the source to the module
           - Assign the Prescaler to the Watchdog
             Timer so that TMR0 increments at a 1:1
             ratio with the internal instruction clock*/

           OPTION = 0B00001000;
           T0IE = 1;              //enable TMR0 overflow interrupts
           GIE = 1;               //enable Global interrupts

}

/*-------------------------------------------------------
           Subroutine: main
           Parameters: none
           Returns:     nothing
           Synopsys:    Main program function
-------------------------------------------------------*/
main(void)
{
           Init();                //Initialize the relevant registers

           while(1)               //Loop forever
           {
           }
}
```

Save as a .C file.

3. Build the project by pressing the Build Project icon . There should be no errors.
4. Select the MPLAB SIM as the debugger.
5. Open a Watch window and add the TMR0, INTCON and OPTION_REG Special Function Registers.
6. Add the `counter` symbol. Configure the Watch window to allow binary, hexadecimal and decimal values to be seen.
7. Press the Animate icon in the Debugger toolbar and confirm that the following occurs:
   a) On a TMR0 overflow (255 → 0) the T0IF flag is set (INTCON<2>).
   b) Using the Watch window, confirm that when the TMR0 flag sets, the Timer0_ISR() interrupt routine is executed and the `counter` variable is incremented by one.

Part 2: Timing Analysis

Next, we will check to see how fast the `counter` variable is actually incrementing.

1. Open the Stopwatch by selecting *Debugger > Stopwatch*.
2. The simulator Processor Frequency automatically defaults to 20 MHz. This will need to be changed to the oscillator frequency used on this particular PIC microcontroller. To change the Processor Frequency select *Debugger>Settings* and change the Processor Frequency to 8 MHz (max. internal oscillator frequency on the PIC16F690) under the Osc/Trace tab.
3. Setup a breakpoint next to the line in the `interrupt Timer0_ISR()` subroutine that increments the `counter` variable (see Figure 1-3).

FIGURE 1-3: INTERRUPT CONTROL REGISTER (INTCON)

```
19          Subroutine: Timer0_ISR
20          Parameters: none
21          Returns:    nothing
22          Synopsys:   This is the Interrupt Service Routine for
23                      Timer0 overflow interrupts. On TMR0 overflow
24                      the counter variable is incremented by 1
25      ------------------------------------------------------------*/
26      void interrupt Timer0_ISR(void)
27      {
28          if (T0IE && T0IF) //are TMR0 interrupts enabled and is
29                            //is the TMR0 interrupt flag set?
30          {
31          T0IF=0; //TMR0 interrupt flag must be cleared in software
32                  //to allow subsequent interrupts
33      B   ++counter;  //increment the counter variable by 1
34
35
36
```

Note: The specific line number in your code may differ from that shown.

Setting the breakpoint here will allow the Stopwatch to analyze the time interval between successive `counter` variable increments.

In the "*Timers: Timer0 Tutorial (Part1)*" (DS51682), an equation was introduced to determine the length of time for successive `counter` variable increments (see Equation 1-1).

EQUATION 1-1: DETERMINING INTERNAL INSTRUCTION CLOCK CYCLE PERIOD

$$Internal\ instruction\ cycle = 1 / [(Processor\ Frequency) / 4] = 1 / (8\ MHz / 4) = 500nS$$

Since the TMR0 register is 8-bits wide, it will take 256 internal instruction cycles for an overflow to happen (2^8 = 256). Since the PIC16F690 is configured to run off of the 8 MHz internal oscillator, we can use Equation 1-2 to determine TMR0 overflow.

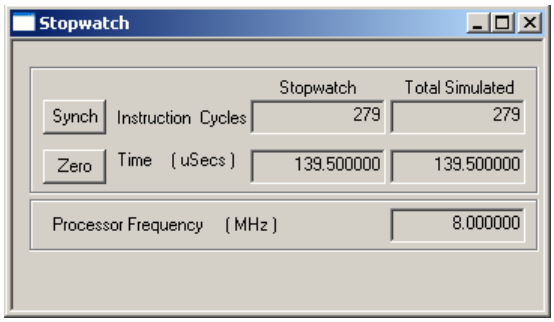
EQUATION 1-2: DETERMINING TMR0 OVERFLOW PERIOD

$$TMR0\ overflow = Internal\ instruction\ cycle \times 2^8\ (we\ must\ count\ the\ zero) = 500nS \times 256 = 128\mu S$$

On any TMR0 overflow, the Interrupt Service Routine (`Timer0_ISR()`) will execute by clearing T0IF and then increment the `counter` variable. Let's check to see if this is what happens.

4. Press the **Reset** button on the simulator toolbar.
5. Press the **Run** button to execute the program up until the breakpoint is encountered. The Stopwatch window should resemble Figure 1-4.

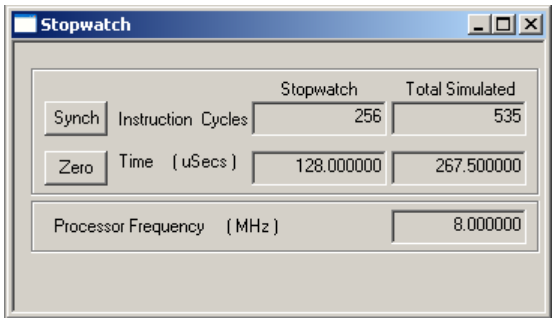
FIGURE 1-4: STOPWATCH WINDOW



Notice the Stopwatch indicates it took 139.5 µS to reach the breakpoint. This doesn't agree with Equation 1-2. However, don't forget that there is some extra code that the central processing unit (CPU) will need to execute before configuring the Timer0 peripheral such as device configuration, variable declarations and so on.

6. Press the **Zero** button in the Stopwatch window. This clears the Stopwatch to zero without resetting the CPU. Press the **Run** button once again in the simulator toolbar. The Stopwatch should now resemble Figure 1-5.

FIGURE 1-5: UPDATED STOPWATCH WINDOW



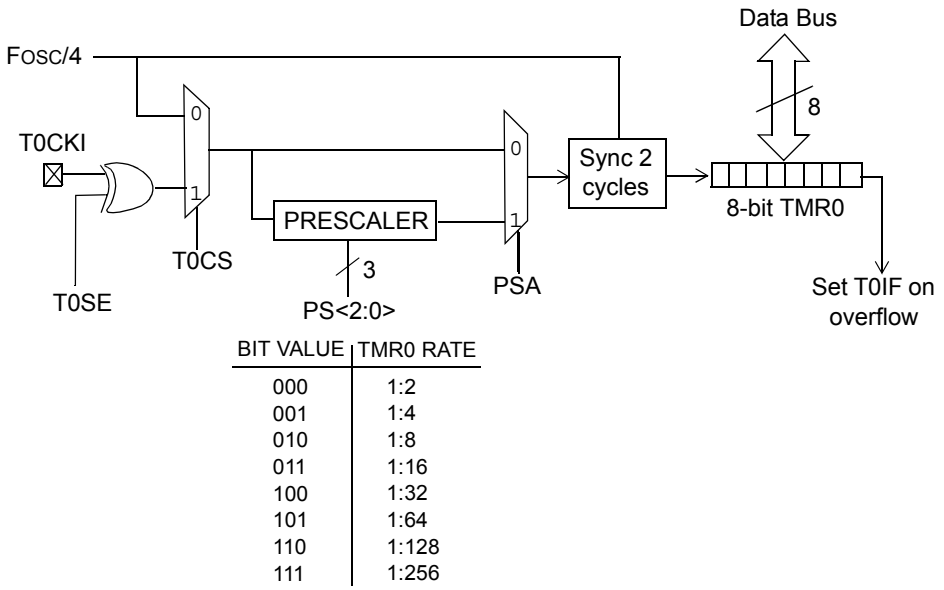
The Stopwatch should now indicate that it has taken precisely 128 µS to reach the breakpoint as per Equation 1-2. In *"Timers: Timer0 Tutorial (Part1)"* (DS51682), the time it took using polling instead of interrupts to increment the `counter` variable was close but not exactly what was calculated. Why do you think that is?

It can be concluded that in timing sensitive applications, it's a good idea to utilize TMR0 interrupts. In this way, if TMR0 overflows, the processor immediately stops whatever it is doing, services the interrupt (executes the interrupt subroutine) and then resumes its previous task.

USING AN EXTERNAL CLOCK SOURCE

When the topic of Timers was first introduced in "*Timers: Timer0 Tutorial (Part1)"* (DS51682), it was mentioned that these peripherals could be used as timers or counters. The only difference is how the module is used. Up until this point, the labs have focused on using Timer0 as a timer. In this section, Timer0 is used as a counter. PIC microcontrollers allow the use of an external source to drive the TMR0 register via connection to the Timer0 Clock Input pin (T0CKI) (refer to Figure 1-6 and Figure 1-7). This external source could be an oscillator or simply a pushbutton connected to the pin. Also notice in the block diagram that the T0CKI signal enters an XOR gate along with the Timer0 Source Edge Select bit (T0SE) from the OPTION register. This allows the TMR0 register value to increment on either the high-to-low (negative edge) or low-to-high (positive edge) transition of the signal on the T0CKI pin. Following the signal path through the block diagram, this signal can also be prescaled. Perhaps the application requires that the TMR0 register is incremented every 2nd negative edge of the input signal or every 256th edge of the positive going edge. Remember that in order to use this prescaler the PSA bit in the OPTION register needs to be cleared to zero. Also note that the input signal passes through a 2-cycle synchronization circuit to ensure synchronization with the PIC16F690 instruction clock.

FIGURE 1-6: SIMPLIFIED BLOCK DIAGRAM OF TIMER0 MODULE



BIT VALUE	TMR0 RATE
000	1:2
001	1:4
010	1:8
011	1:16
100	1:32
101	1:64
110	1:128
111	1:256

FIGURE 1-7: OPTION REGISTER SHOWING THE TIMER0 CLOCK SOURCE SELECT AND SOURCE EDGE SELECT BITS

OPTION

7	6	5	4	3	2	1	0
RABPU	INTEDG	**T0CS**	**T0SE**	**PSA**	**PS2**	**PS1**	**PS0**

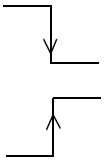
T0CS: Timer0 Clock Source Select bit

1 = Transition on T0CKI pin

0 = Internal instruction cycle clock (FOSC/4)

T0SE: Timer0 Source Edge Select bit

1 = Increment on high-to-low transition



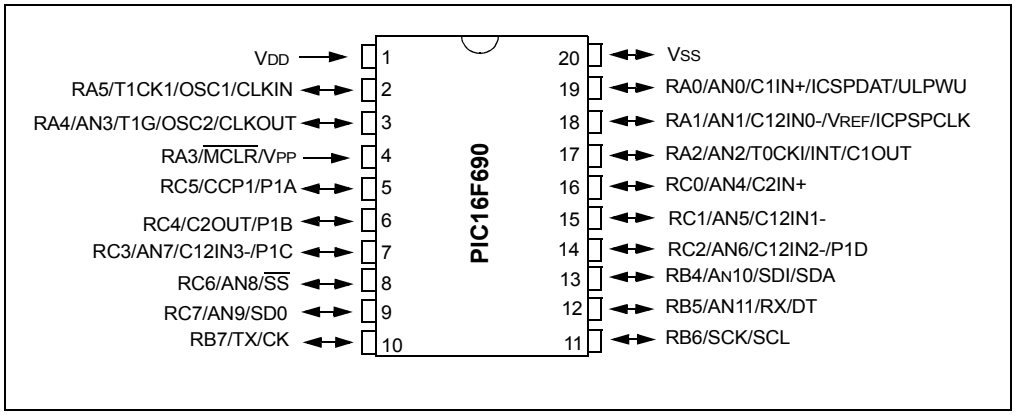
0 = Increment on high-to-low transition

Note: Configuring the Timer0 module using the OPTION register is discussed in greater detail in "*Timers: Timer0 Tutorial (Part1)*" (DS51682).

As shown in Figure 1-8, which shows the pin-out diagram for the PIC16F690, the T0CKI pin shares functionality as follows:

- RA2 represents the bit 2 position of the PORTA register
- INT represents an external interrupt pin
- C1OUT represents the output of the Comparator 1 module
- AN2 represents an input to the Analog-to-Digital converter module.

FIGURE 1-8: PIC16F690 PIN-OUT DIAGRAM



The AN2 feature of this pin means it can be used for either digital or analog signals. The PIC16F690, has been designed so that the analog pins (i.e., ANx) will default to analog when the PIC MCU powers up. Since this pin will be used for a digital signal, analog functionality is disabled using a Special Function Register called the Analog Select Register (ANSEL) as shown in Figure 1-9.

FIGURE 1-9: ANALOG SELECT REGISTER

ANSEL: ANALOG SELECT REGISTER

7	6	5	4	3	2	1	0
ANS7	**ANS6**	**ANS5**	**ANS4**	**ANS3**	**ANS2**	**ANS1**	**ANS0**

ANS<7:0>: Analog Select bits

Analog select between analog or digital function on pins AN<7:0> respectively

1 = Pin is configured as Analog input

0 = Pin is configured as Digital input

Referring to the pin-out diagram for the PIC16F690 in Figure 1-8, notice that there are actually 12 analog configurable pins (i.e., AN0 → AN11). The Analog Select High (ANSELH) register can be configured as well if needed for these pins. However, in this application, the only pin of interest is the T0CKI/AN2 pin. These other pins will be discussed in greater detail in other labs and as always, for more information on this or any other feature of this product, refer to the data sheet.

When using an external input signal of any kind, it is important to pay particular attention to electrical specifications and timing parameters listed in the data sheet. The 2-cycle synchronization block shown in Figure 1-6 samples the input signal on the T0CKI pin and synchronizes it with the clock used by PIC16F690. Therefore, there are some important equations to know when not using the prescaler for Timer0 (see Equation 1-3 and Equation 1-4):

EQUATION 1-3: MINIMUM HIGH PULSE WIDTH OF T0CKI SOURCE SIGNAL WITH NO PRESCALER

$$T_{T0H} = \left(\frac{2}{\text{PIC MCU OscillatorFrequency}}\right) + 20\text{nS} = \text{minimum HIGH T0CK1 signal pulse width}$$

Example:

If using the 8 MHz internal oscillator, use Equation 1-4 and Equation 1-5.

EQUATION 1-4: MINIMUM LOW PULSE WIDTH OF T0CKI SOURCE SIGNAL

$$T_{T0H} = \left(\frac{2}{8MHz}\right) + 20nS = \textit{a minimum HIGH pulse of 270nS}$$

EQUATION 1-5: MINIMUM LOW PULSE WIDTH OF T0CKI SOURCE SIGNAL WITH NO PRESCALER

$$T_{T0H} = \left(\frac{2}{\text{PIC MCU OscillatorFrequency}}\right) + 20\text{nS} = \text{minimum LOW T0CK1 signal pulse width}$$

Example:

If using the 8 MHz internal oscillator, the minimum low pulse width can be calculated as shown in Equation 1-6.

EQUATION 1-6: MINIMUM LOW PULSE WIDTH OF T0CKI SOURCE SIGNAL WITH 8 MHz INTERNAL OSCILLATOR

$$T_{T0H} = \left(\frac{2}{8MHz}\right) + 20nS = \textit{a minimum} \text{ LOW } \textit{pulse} \text{ width } \textit{of 270nS}$$

The internal sampling that occurs on the T0CKI signal takes two clock cycles of the PIC microcontrollers oscillator. Divide 2 by the oscillator frequency in Hz to obtain an answer in seconds (same as multiplying the oscillator frequency in seconds by 0.5). The 20 nS added at the end of the equations represents a small 20 nS RC delay present within the device. In this lab, the 8 MHz internal oscillator is used. Therefore, it is necessary to ensure that the incoming signal stays High and/or Low for a minimum of 270 nS when not using the prescaler. If the incoming signal is a TTL square wave, this means the period can be no less than 270nS + 270nS = 540nS or a frequency of (1/540nS) = 1.8 MHz

To use the prescaler on the T0CKI source signal, Equation 1-7 is used.

EQUATION 1-7: T0CKI SOURCE SIGNAL MINIMUM PERIOD

$$T_{T0H} = 20\text{nS OR } \frac{\left(\frac{4}{\textit{PIC MCU OSCILLATORFREQUENCY (Hz)}}\right) + 40nS}{\textit{Prescale value (i.e. 2,4...256)}} \quad \textit{whichever is greater}$$

$$= \textit{minimum T0CKI signal period}$$

Example:

If using the 8 MHz internal oscillator and a Timer0 prescale value of 64, the minimum T0CKI signal period is calculated as shown in Equation 1-8.

EQUATION 1-8: T0CKI SOURCE SIGNAL USING 8 MHz INTERNAL OSCILLATOR AND TIMER0 PRESCALE VALUE OF 0

$$T_{T0H} = \frac{\left(\frac{4}{8MHz}\right) + 40nS}{64} = 8.4\text{nS}$$ *which is less than 20nS. Therefore, use a minimum period of 20 nS*

In Equation 1-5, if the calculated value is less than 20 nS, a minimum period of 20 nS must be maintained. Otherwise, maintain a minimum period at the calculated value.

HANDS-ON LAB 2: USING AN EXTERNAL CLOCK SOURCE

Purpose:

In this lab, the counter variable will still increment each time the TMR0 register overflows from 255 to 0. This time, an external signal will be used as the Timer0 clock source and the TMR0 register configured to increment on the low-to-high transition of the signal. To simulate an external clock source the Stimulus feature of MPLAB SIM is used.

Procedure:

Part 1: Using MPLAB SIM Stimulus

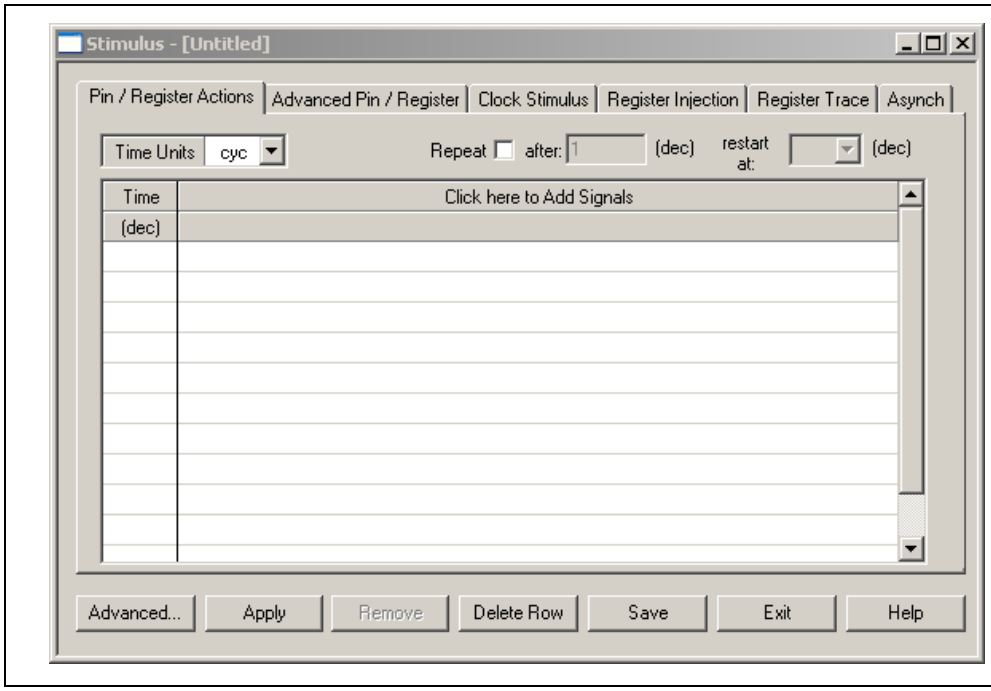
1. Using either the project created in the previous lab or a new project, change the OPTION register configuration value in the `Init()` to allow for the use of an external clock source and configure the ANSEL register so that the T0CKI pin is a digital input as shown in code Example 1-3.

EXAMPLE 1-3: CHANGES TO `INIT()`

```
Init(void)
{

    ANSEL = 0B111111011;//Configure T0CKI/AN2 as a digital I/O

    TMR0 = 0;//Clear the TMR0 register


/*Configure Timer0 as follows:

    -   Use the T0CKI pin and external source
        as the source to the module
    -   Increment the TMR0 register on the low-to-high
        transition of the external source
    -   Assign the Prescaler to the Watchdog
        Timer so that TMR0 increments at a 1:1
        ratio with the internal instruction clock*/

    OPTION = 0B00101000;
    T0IE = 1;//enable TMR0 overflow interrupts
    GIE = 1; //enable Global interrupts

}
```

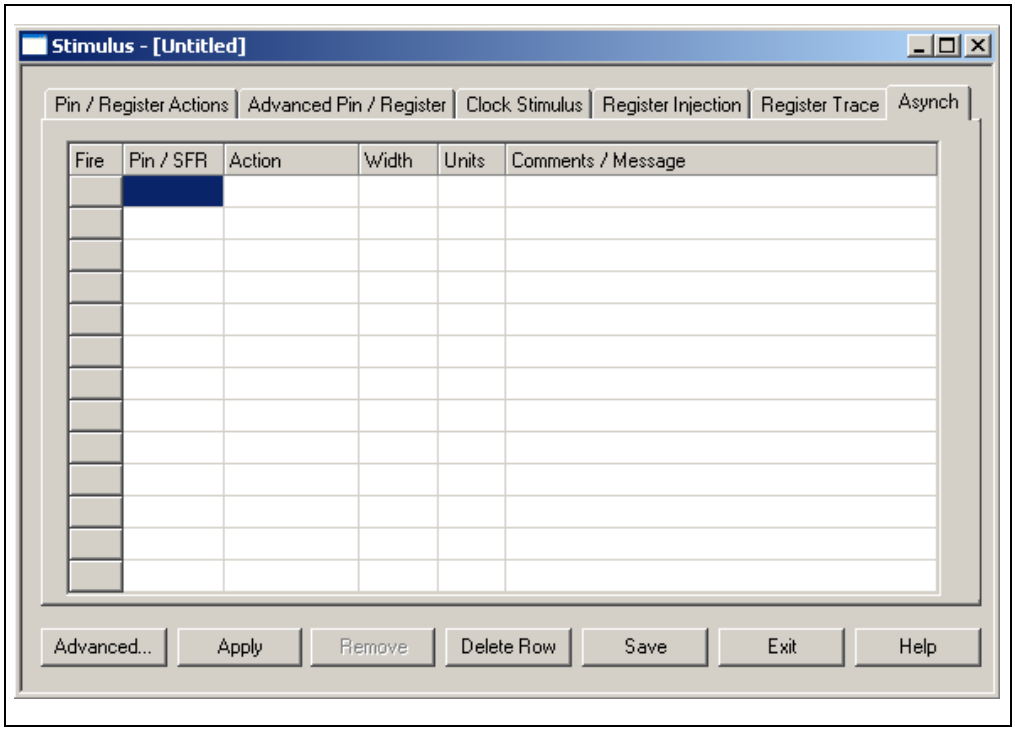
2. Re-compile the code and ensure that there are no errors.
3. Make sure that the MPLAB SIM simulator is selected as the debugger. Open the Stimulus Tool by selecting *Debugger>Stimulus>New Workbook*. The window in Figure 1-10 should now appear.

FIGURE 1-10: STIMULUS WORKBOOK WINDOW



4. Next, select the Asych tab in the Stimulus window. The Stimulus window should resemble Figure 1-11.

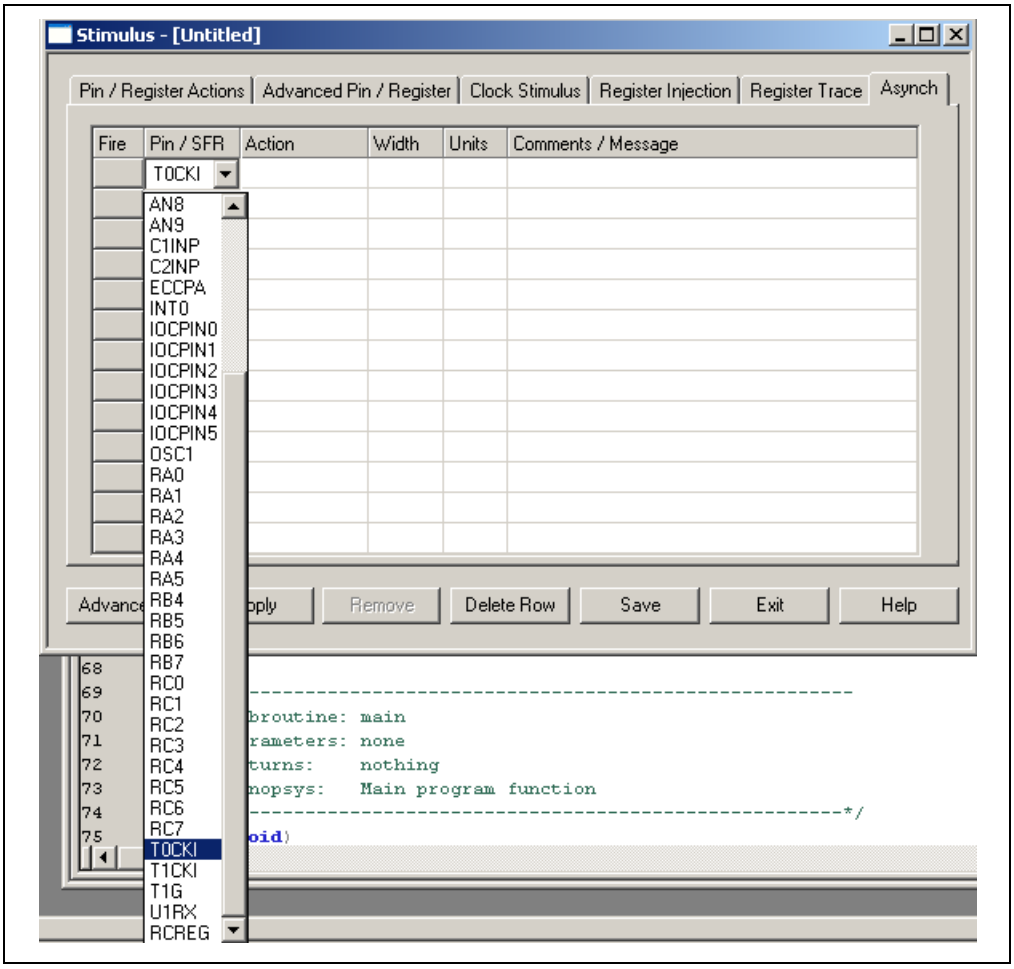
FIGURE 1-11: ASYNCH TAB IN STIMULUS WORKBOOK



Stimulus is a tool used to simulate a signal on a pin external to the PIC MCU or to actually generate a change to a bit in a peripheral's Special Function Register. This can be accomplished either synchronously by applying a predefined series of signal changes to an I/O pin, or asynchronously as we will use in this lab. Synchronous applications of the Stimulus feature will be discussed in other labs.

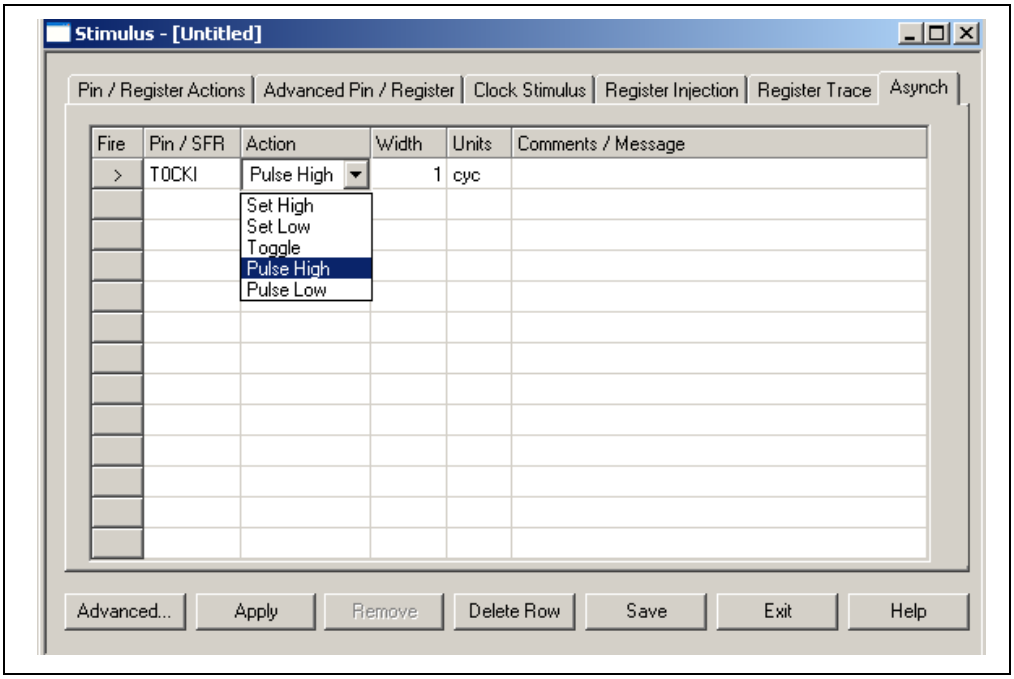
5. Click on the cell immediately below the Pin/SFR heading and select the T0CKI pin (see Figure 1-12).

FIGURE 1-12: SELECTING THE T0CKI PIN



6. Click the cell immediately under the Action Tab and select Pulse High (see Figure 1-13).

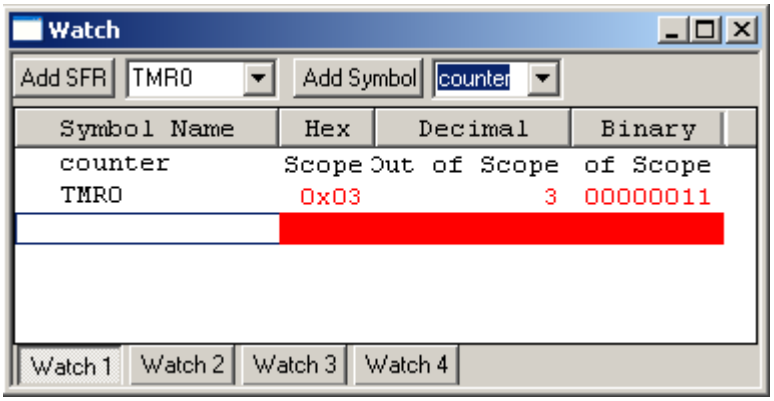
FIGURE 1-13: SELECT PULSE HIGH ACTION



The Stimulus tool is now configured so that during a simulation Run, pressing the **Fire** button [›] next to the T0CKI cell will pulse that pin input High.

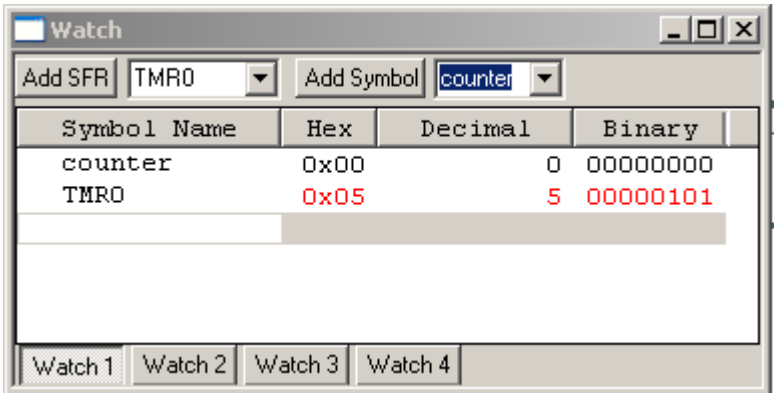
7. Open the Watch window and add the TMR0 Special Function Register as well as the `counter` symbol (see Figure 1-14).

FIGURE 1-14: WATCH WINDOW WITH TMR0 AND COUNTER REGISTERS



8. Click **Reset** then **Run** buttons in the debugger toolbar.
9. While the simulation is running, press the **Fire** button in Stimulus next to the T0CKI cell 5 times.
10. Next, stop the simulation and observe the changes to the TMR0 register. The Watch window should resemble Figure 1-15.

FIGURE 1-15: UPDATED WATCH WINDOW



Note that the TMR0 register has a value of 5 corresponding to the number of **Fire** button presses.

Try pressing the **Fire** button enough times to generate a TMR0 overflow interrupt that will increment the `counter` variable.

EXERCISES

1. Using the code and `Init()` function from Lab 1, configure the prescaler to generate a TMR0 interrupt that will increment the counter variable for each of the following periods **exactly** assuming that the PIC16F690 internal 8 MHz oscillator is used:
   a. 8.192 mS
   b. 1.024 mS
   c. 15.616 mS
2. Using Equation 1-2, develop a new equation that determines the prescaler value based off the required overflow period. Develop the equation further to determine a value to preload into TMR0 to generate an interrupt that doesn't fit neatly into a specific prescaler value.
3. Configure the application code used in question 1 to increment the `counter` variable every 1 second.
4. Calculate the minimum external clock source periods on the T0CKI pin for the following (these assume you are using the PIC16F690):
   a. Using an external crystal oscillator of 20 MHz and a Timer0 prescaler value of:
      i. 32
      ii. 64
   b. Using an external crystal oscillator of 20 MHz with the Timer0 prescaler disabled.
   c. Using the internal 32 kHz oscillator with the Timer0 prescaler set to 128.
5. Refer to the PIC16F690 data sheet (DS41262), Table 17-5 in the Electrical Specifications section. Suppose that all equations have been performed correctly. What is an external condition that could affect the synchronous operation of the application using an external source on the T0CKI pin?

NOTES:

NOTES:

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