Introduction to PIC Programming

Baseline Architecture and Assembly Language

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Lesson 5: Using Timer0

The lessons until now have covered the essentials of baseline PIC microcontroller operation: controlling digital outputs, timed via programmed delays, with program flow responding to digital inputs. That's all you really need to perform a great many tasks; such is the versatility of these devices. But PICs (and most other microcontrollers) offer a number of additional features that make many tasks much easier. Possibly the most useful of all are *timers*; so useful that at least one is included in every current 8-bit PIC.

A timer is simply a counter, which increments automatically. It can be driven by the processor's instruction clock, in which case it is referred to as a *timer*, incrementing at some predefined, steady rate. Or it can be driven by an external signal, where it acts as a *counter*, counting transitions on an input pin. Either way, the timer continues to count, independently, while the PIC performs other tasks.

And that is why timers are so very useful. Most programs need to perform a number of concurrent tasks; even something as simple as monitoring a switch while flashing an LED. The execution path taken within a program will generally depend on real-world inputs. So it is very difficult in practice to use programmed delay loops, as in lesson 2, as an accurate way to measure elapsed time. But a timer will just keep counting, steadily, while your program responds to various inputs, performs calculations, or whatever.

As we'll see when we look at midrange PICs, timers are commonly used to drive *interrupts* (routines which interrupt the normal program flow) to allow regularly timed "background" tasks to run. The baseline architecture doesn't support interrupts, but, as we'll see, timers are nevertheless very useful.

This lesson covers:

- Introduction to the Timer0 module
- Creating delays with Timer0
- Debouncing via Timer0
- Using Timer0 counter mode with an external clock
  (demonstrating the use of a crystal oscillator as a time reference)

Timer0 Module

The baseline PICs provide only a single timer, referred to these days as Timer0. It used to be called the Real Time Clock Counter (RTCC), and you will find it called RTCC in some older literature. When Microchip released more advanced PICs, with more than one timer, they started to refer to the RTCC as Timer0.

Timer0 is very simple. The visible part is a single 8-bit register, TMR0, which holds the current value of the timer. It is readable and writeable. If you write a value to it, the timer is reset to that value and then starts incrementing from there. When it has reached 255, it rolls over to 0, and then continues to increment.

In the baseline architecture, there is no "overflow flag" to indicate that TMR0 has rolled over from 255 to 0; the only way to check the status of the timer is to read TMR0.

As mentioned above, TMR0 can be driven by either the instruction clock (FOSC/4) or an external signal.

The configuration of Timer0 is set by a number of bits in the OPTION register:

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
OPTION	$\overline{\text{GPWU}}$	$\overline{\text{GPPU}}$	T0CS	T0SE	PSA	PS2	PS1	PS0

The clock source is selected by the T0CS bit:

T0CS = 0 selects timer mode, where TMR0 is incremented at a fixed rate by the instruction clock.

T0CS = 1 selects counter mode, where TMR0 is incremented by an external signal, on the T0CKI pin. On the PIC12F508/9, this is physically the same pin as GP2.

Note that if T0CS is set to '1', it overrides the TRIS setting for GP2. That is, GP2 cannot be used as an output until T0CS is cleared. All the OPTION bits are set to '1' at power on, so you must remember to clear T0CS before using GP2 as an output. Instances like this, where multiple functions are mapped to a single pin, can be a trap for beginners, so be careful!
These "traps" are often highlighted in the data sheets, so read them carefully!

T0CKI is a Schmitt Trigger input, meaning that it can be driven by and will respond cleanly to a smoothly varying input voltage (e.g. a sine wave), even with a low level of superimposed noise; it doesn't have to be a sharply defined TTL-level signal, as required by the GP inputs.

In counter mode, the T0SE bit selects whether Timer0 responds to rising or falling signals ("edges") on T0CKI. Clearing T0SE to '0' selects the rising edge; setting T0SE to '1' selects the falling edge.

Prescaler

By default, the timer increments by one for every instruction cycle (in timer mode) or transition on T0CKI (in counter mode). If timer mode is selected, and the processor is clocked at 4 MHz, the timer will increment at the instruction cycle rate of 1 MHz. That is, TMR0 will increment every 1 µs. Thus, with a 4 MHz clock, the maximum period that Timer0 can measure directly, by default, is 255 µs.

To measure longer periods, we need to use the *prescaler*.

The prescaler sits between the clock source and the timer. It is used to reduce the clock rate seen by the timer, by dividing it by a power of two: 2, 4, 8, 16, 32, 64, 128 or 256.

To use the prescaler with Timer0, clear the PSA bit to '0'.

[If PSA = 1, the prescaler is instead assigned to the watchdog timer – a topic covered in lesson 7.]

When assigned to Timer0, the prescale ratio is set by the PS<2:0> bits, as shown in the following table:

PS<2:0> bit value	Timer0 prescale ratio
000	1 : 2
001	1 : 4
010	1 : 8
011	1 : 16
100	1 : 32
101	1 : 64
110	1 : 128
111	1 : 256

If PSA = 0 (assigning the prescaler to Timer0) and PS<2:0> = '111' (selecting a ratio of 1:256), TMR0 will increment every 256 instruction cycles in timer mode. Given a 1 MHz instruction cycle rate, the timer would increment every 256 µs.

Thus, when using the prescaler with a 4 MHz processor clock, the maximum period that Timer0 can measure directly is 255 × 256 µs = 65.28ms.

Note that the prescaler can also be used in counter mode, in which case it divides the external signal on T0CKI by the prescale ratio.

If you don't want to use the prescaler with Timer0, set PSA to '1'.

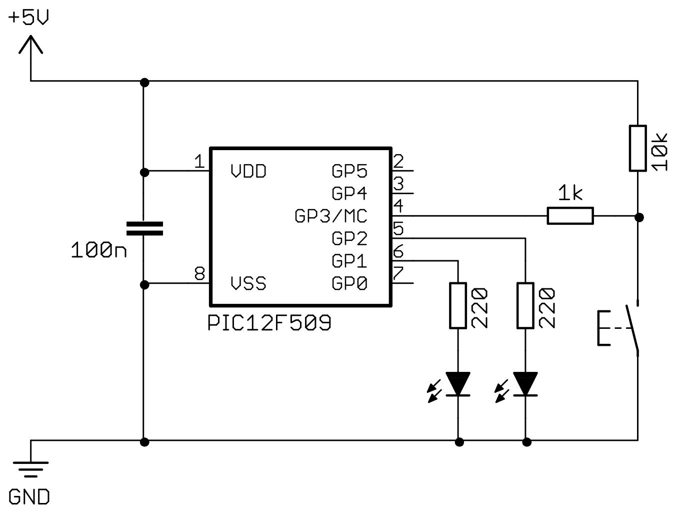
To make all this theory clearer (hopefully!), here are some practical examples…

Timer Mode

The examples in this section demonstrate the use of Timer0 in timer mode, to:

- Measure elapsed time
- Perform a regular task while responding to user input
- Debounce a switch

For each of these, we'll use the circuit shown on the right, which adds a LED to the circuit used in lesson 4. A second LED has been added to GP2, although any of the unused pins would have been suitable.



You may wish to make the two LEDs different colours, for example red on GP1 and green on GP2.

Example 1: Reaction Timer

To illustrate the use of Timer0 to measure elapsed time, we'll implement a very simple reaction time "game": light a LED to indicate 'start', and then if the button is pressed within a predefined time (say 200 ms) light the other LED to indicate 'success'. If the user is too slow, leave the 'success' LED unlit. Then reset and repeat.

There are many enhancements we could add, to make this a better game. For example, success/fail could be indicated by a bi-colour red/green LED. The delay prior to the 'start' indication should be random, so that it's difficult to cheat by predicting when it's going to turn on. The difficulty level could be made adjustable, and the measured reaction time in milliseconds could be displayed, using 7-segment displays. You can probably think of more – but the intent of here is to keep it as simple as possible, while providing a real-world example of using Timer0 to measure elapsed time.

We'll use the LED on GP2 as the 'start' signal and the LED on GP1 to indicate 'success'.

The program flow can be illustrated in pseudo-code as:

```
do forever
        clear both LEDs
        delay 2 sec
        indicate start
        clear timer
        wait up to 1 sec for button press
        if button pressed and elapsed time < 200ms
                indicate success
        delay 1 sec
end
```

A problem is immediately apparent: even with maximum prescaling, Timer0 can only measure up to 65 ms. To overcome this, we need to extend the range of the timer by adding a counter variable, which is incremented when the timer overflows. That means monitoring the value in TMR0 and incrementing the counter variable when TMR0 reaches a certain value.

This example utilises the (nominally) 4 MHz internal RC clock, giving an instruction cycle time of (approximately) 1 µs. Using the prescaler, with a ratio of 1:32, means that the timer increments every 32 µs.

If we clear TMR0 and then wait until TMR0 = 250, 8 ms (250 × 32 µs) will have elapsed. If we then reset TMR0 and increment a counter variable, we've implemented a counter which increments every 8 ms. Since 25 × 8 ms = 200 ms, 200 ms will have elapsed when the counter reaches 25. Hence, any counter value > 25 means the allowed time has been exceeded. And since 125 × 8 ms = 1 s, one second will have elapsed when the counter reaches 125, and we can stop waiting for the button press.

The following code sets Timer0 to timer mode (internal clock, freeing GP2 to be used as an output), with the prescaler assigned to Timer0, with a 1:32 prescale ratio by:

```
        movlw   b'11010100'     ; configure Timer0:
                ; --0-----          timer mode (T0CS = 0)
                ; ----0---          prescaler assigned to Timer0 (PSA = 0)
                ; -----100          prescale = 32 (PS = 100)
        option                  ;   -> increment every 32 us
```

Assuming a 4 MHz clock, such as the internal RC oscillator, TMR0 will begin incrementing every 32 µs.

To generate an 8 ms delay, we can clear TMR0 and then wait until it reaches 250, as follows:

```
        clrf    TMR0
w_tmr0  movf    TMR0,w          ; wait for 8ms (250x32us)
        xorlw   .250
        btfss   STATUS,Z
        goto    w_tmr0
```

Note that XOR is used to test for equality (TMR0 = 250), as we did in lesson 4.

In itself, that's an elegant way to create a delay; it's much shorter and simpler than "busy loops", such as the delay routines from lessons 2 and 3.

But the real advantage of using a timer is that it keeps ticking over, at the same rate, while other instructions are executed. That means that additional instructions can be inserted into this "timer wait" loop, without affecting the timing – within reason; if this extra code takes too long to run, the timer may increment more than once before it is checked at the end of the loop, and the loop may not finish when intended.

However long the additional code is, it takes some time to run, so the timer increment will not be detected immediately. This means that the overall delay will be a little longer than intended. But with 32 instruction cycles per timer increment, it's safe to insert a short piece of code to check whether the pushbutton has been checked, for example:

```
        clrf    TMR0
w_tmr0  btfss   GPIO,3          ; check for button press (GP3 low)
        goto    btn_dn          ;   if pressed, jump to button down routine
        movf    TMR0,w
        xorlw   .250            ; while waiting 8ms (250x32us)
        btfss   STATUS,Z
        goto    w_tmr0
```

This timer loop code can then be embedded into an outer loop which increments a variable used to count the number of 8 ms periods, as follows:

```
        banksel cnt8ms          ; clear 8ms counter
        clrf    cnt8ms
wait1s  clrf    TMR0            ; clear timer0
w_tmr0  btfss   GPIO,3          ; check for button press (GP3 low)
        goto    btn_dn
        movf    TMR0,w
        xorlw   .250            ; wait for 8ms (250x32us)
        btfss   STATUS,Z
        goto    w_tmr0
        incf    cnt8ms,f        ; increment 8ms counter
        movlw   .125            ; continue to wait for 1s (125x8ms)
        xorwf   cnt8ms,w
        btfss   STATUS,Z
        goto    wait1s
```

The test at the end of the outer loop (`cnt8ms` = 125) ensures that the loop completes when 1 s has elapsed, if the button has not yet been pressed.

Finally, we need to check whether the user has pressed the button quickly enough (if at all). That means comparing the elapsed time, as measured by the 8 ms counter, with some threshold value – in this case 25, corresponding to a reaction time of 200 ms. The user has been successful if the 8 ms count is less than 25.

The easiest way to compare the magnitude of two values (is one larger or smaller than the other?) is to subtract them, and see if a *borrow* results.

If A ≥ B, A − B is positive or zero and no borrow is needed.

If A < B, A − B is negative, requiring a borrow.

The baseline PICs provide just a single instruction for subtraction: '`subwf f,d`' – "**sub**tract **W** from **f**ile register", where '`f`' is the register being subtracted from, and, '`d`' is the destination; '`,f`' to write the result back to the register, or '`,w`' to place the result in W.

The result of the subtraction is reflected in the Z (zero) and C (carry) bits in the STATUS register:

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
STATUS	GPWUF	-	PA0	$\overline{\text{TO}}$	$\overline{\text{PD}}$	Z	DC	C

The Z bit is set if and only if the result is zero (so subtraction is another way to test for equality).

Although the C bit is called "carry", in a subtraction it acts as a "not borrow". That is, it is set to '1' only if a borrow did *not* occur.

The table at the right shows the possible status flag outcomes from the subtraction A − B:

	Z	C
A > B	0	1
A = B	1	1
A < B	0	0

We can make use of this to test whether the elapsed time is less than 200 ms (`cnt8ms` < 25) as follows:

```
        ; check elapsed time
btn_dn  movlw   .25             ; if time < 200ms (25x8ms)
        subwf   cnt8ms,w
        btfss   STATUS,C
        bsf     GPIO,1          ;   turn on success LED
```

The subtraction being performed here is `cnt8ms` − 25, so C = 0 only if `cnt8ms` < 25 (see the table above). If C = 1, the elapsed time must be greater than the allowed 200 ms, and the instruction to turn on the success LED is skipped.

Complete program

Here's the complete code for the reaction timer, so you can see how the above code fragments fit together:

```
;************************************************************************
;                                                                       *
;   Description:    Lesson 5, example 1                                 *
;                   Reaction Timer game.                                *
;                                                                       *
;   Demonstrates use of timer0 to time real-world events                *
;                                                                       *
;   User must attempt to press button within 200ms of "start" LED       *
;   lighting.  If and only if successful, "success" LED is lit.         *
;                                                                       *
;       Starts with both LEDs unlit.                                    *
;       2 sec delay before lighting "start"                             *
;       Waits up to 1 sec for button press                              *
;       (only) on button press, lights "success"                        *
;       1 sec delay before repeating from start                         *
;                                                                       *
;************************************************************************
;                                                                       *
;   Pin assignments:                                                    *
;       GP1 - success LED                                               *
;       GP2 - start LED                                                 *
;       GP3 - pushbutton                                                *
;                                                                       *
;************************************************************************

    list        p=12F509        ; list directive to define processor
    #include    <p12F509.inc>

                ; int reset, no code protect, no watchdog, 4MHz int clock
    __CONFIG    _MCLRE_OFF & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** EXTERNAL LABELS
        EXTERN  delay10_R       ; W x 10ms delay


;***** VARIABLE DEFINITIONS
        UDATA
cnt8ms  res 1                   ; 8ms counter (incremented every 8ms)


;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value
        pagesel start
        goto    start           ; jump to main code

;***** Subroutine vectors
delay10                         ; delay W x 10ms
        pagesel delay10_R
        goto    delay10_R


;***** MAIN PROGRAM
MAIN    CODE

;***** Initialisation
start
        movlw   b'111001'       ; configure GP1 and GP2 (only) as outputs
        tris    GPIO
        movlw   b'11010100'     ; configure Timer0:
                ; --0-----          timer mode (T0CS = 0)
                ; ----0---          prescaler assigned to Timer0 (PSA = 0)
                ; -----100          prescale = 32 (PS = 100)
        option                  ;   -> increment every 32 us
```

```
;***** Main loop
loop    clrf    GPIO            ; start with all LEDs off
        ; delay 2s
        movlw   .200
        pagesel delay10
        call    delay10
        pagesel $
        bsf     GPIO,2          ; turn on start LED
        ; wait for button press
        banksel cnt8ms          ; clear 8ms counter
        clrf    cnt8ms
wait1s  clrf    TMR0            ; clear timer0
w_tmr0  btfss   GPIO,3          ; check for button press (GP3 low)
        goto    btn_dn
        movf    TMR0,w
        xorlw   .250            ; wait for 8ms (250x32us)
        btfss   STATUS,Z
        goto    w_tmr0
        incf    cnt8ms,f        ; increment 8ms counter
        movlw   .125            ; continue to wait for 1s (125x8ms)
        xorwf   cnt8ms,w
        btfss   STATUS,Z
        goto    wait1s
        ; check elapsed time
btn_dn  movlw   .25             ; if time < 200ms (25x8ms)
        subwf   cnt8ms,w
        btfss   STATUS,C
        bsf     GPIO,1          ;   turn on success LED
        ; delay 1s
        movlw   .100
        pagesel delay10
        call    delay10
        pagesel $

        ; repeat forever
        goto    loop


        END
```

Example 2: Flash LED while responding to input

As discussed above, timers can be used to maintain the accurate timing of regular ("background") events, while performing other actions in response to input signals. To illustrate this, we'll flash the LED on GP2 at 1 Hz (similar to lesson 2), while lighting the LED on GP1 whenever the pushbutton on GP3 is pressed (as was done in lesson 4). This example also shows how Timer0 can be used to provide a fixed delay.

When creating an application which performs a number of tasks, it is best, if practical, to implement and test each of those tasks separately. In other words, build the application a piece at a time, adding each new part to base that is known to be working. So we'll start by simply flashing the LED.

The delay needs to written in such a way that button scanning code can be added within it later. Calling a delay subroutine, as was done in lesson 3, wouldn't be appropriate; if the button press was only checked at the start and/or end of the delay, the button would seem unresponsive (a 0.5 s delay is very noticeable).

Since the maximum delay that Timer0 can produce directly from a 1 MHz instruction clock is 65 ms, we have to extend the timer by adding a counter variable, as was done in example 1.

To produce a given delay, various combinations of prescaler value, maximum timer count and number of repetitions will be possible. But noting that 125 × 125 × 32 µs = 500 ms, a delay of exactly 500 ms can be generated by:

- Using a 4 MHz processor clock, providing a 1 MHz instruction clock and a 1 µs instruction cycle
- Assigning a 1:32 prescaler to the instruction clock, incrementing Timer0 every 32 µs
- Resetting Timer0 to zero, as soon as it reaches 125 (i.e. every 125 × 32 µs = 4 ms)
- Repeating 125 times, creating a delay of 125 × 4 ms = 500 ms.

The following code implements the above steps:

```
;***** Initialisation
        movlw   b'111001'       ; configure GP1 and GP2 as outputs
        tris    GPIO
        movlw   b'11010100'     ; configure Timer0:
                ; --0-----        timer mode (T0CS = 0)
                ; ----0---        prescaler assigned to Timer0 (PSA = 0)
                ; -----100        prescale = 32 (PS = 100)
        option                  ;   -> increment every 32 us

        clrf    GPIO            ; start with all LEDs off
        clrf    sGPIO           ;   update shadow

;***** Main loop
start   ; delay 500ms
        banksel dlycnt
        movlw   .125            ; repeat 125 times
        movwf   dlycnt          ; -> 125 x 4ms = 500ms
dly500  clrf    TMR0            ; clear timer0
w_tmr0  movf    TMR0,w
        xorlw   .125            ; wait for 4ms (125x32us)
        btfss   STATUS,Z
        goto    w_tmr0
        decfsz  dlycnt,f        ; end 500ms delay loop
        goto    dly500

        ; toggle LED
        movf    sGPIO,w
        xorlw   b'000100'       ; toggle LED on GP2
        movwf   sGPIO           ;   using shadow register
        movwf   GPIO

        ; repeat forever
        goto    start
```

Here's the code developed in lesson 4, for turning on a LED when the pushbutton is pressed:

```
        clrf    sGPIO           ; assume button up -> LED off
        btfss   GPIO,3          ; if button pressed (GP3 low)
        bsf     sGPIO,1         ;   turn on LED

        movf    sGPIO,w         ; copy shadow to GPIO
        movwf   GPIO
```

It's quite straightforward to place some code similar to this (replacing the `clrf` with a `bcf` instruction, to avoid affecting any other bits in the shadow register) within the timer wait loop; since the timer increments every 32 instructions, there are plenty of cycles available to accommodate these additional instructions, without risk that the "TMR0 = 125" condition will be skipped (see discussion in example 1).

Here's how:

```
w_tmr0      ; check and respond to button press
        bcf     sGPIO,1         ; assume button up -> LED off
        btfss   GPIO,3          ; if button pressed (GP3 low)
        bsf     sGPIO,1         ;   turn on LED

        movf    sGPIO,w         ; copy shadow to GPIO
        movwf   GPIO
            ; check timer0 until 4ms elapsed
        movf    TMR0,w
        xorlw   .125            ; (4ms = 125 x 32us)
        btfss   STATUS,Z
        goto    w_tmr0
```

Complete program

Here's the complete code for the flash + pushbutton demo.

Note that, because GPIO is being updated from the shadow copy, every "spin" of the timer wait loop, there is no need to update GPIO when the LED on GP2 is toggled; the change will be picked up next time through the loop.

```
;************************************************************************
;   Description:    Lesson 5, example 2                                 *
;                                                                       *
;   Demonstrates use of Timer0 to maintain timing of background actions *
;   while performing other actions in response to changing inputs       *
;                                                                       *
;   One LED simply flashes at 1 Hz (50% duty cycle).                    *
;   The other LED is only lit when the pushbutton is pressed            *
;                                                                       *
;************************************************************************
;                                                                       *
;   Pin assignments:                                                    *
;       GP1 - "button pressed" indicator LED                            *
;       GP2 - flashing LED                                              *
;       GP3 - pushbutton                                                *
;                                                                       *
;************************************************************************

    list        p=12F509
    #include    <p12F509.inc>

                ; int reset, no code protect, no watchdog, 4MHz int clock
    __CONFIG    _MCLRE_OFF & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** VARIABLE DEFINITIONS
        UDATA_SHR
sGPIO   res 1                   ; shadow copy of GPIO

        UDATA
dlycnt  res 1                   ; delay counter


;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value
```

```
;***** MAIN PROGRAM

;***** Initialisation
start
        movlw   b'111001'       ; configure GP1 and GP2 (only) as outputs
        tris    GPIO
        movlw   b'11010100'     ; configure Timer0:
                ; --0-----         timer mode (T0CS = 0)
                ; ----0---         prescaler assigned to Timer0 (PSA = 0)
                ; -----100         prescale = 32 (PS = 100)
        option                  ;   -> increment every 32 us

        clrf    GPIO            ; start with all LEDs off
        clrf    sGPIO           ;   update shadow


;***** Main loop
loop    ; delay 500ms
        banksel dlycnt
        movlw   .125            ; repeat 125 times
        movwf   dlycnt          ; -> 125 x 4ms = 500ms
dly500  ; (begin 500ms delay loop)
        clrf    TMR0            ; clear timer0
w_tmr0      ; check and respond to button press
        bcf     sGPIO,1         ; assume button up -> LED off
        btfss   GPIO,3          ; if button pressed (GP3 low)
        bsf     sGPIO,1         ;   turn on LED

        movf    sGPIO,w         ; copy shadow to GPIO
        movwf   GPIO
            ; check timer0 until 4ms elapsed
        movf    TMR0,w
        xorlw   .125            ; (4ms = 125 x 32us)
        btfss   STATUS,Z
        goto    w_tmr0
        ; (end 500ms delay loop)
        decfsz  dlycnt,f
        goto    dly500

        ; toggle LED
        movf    sGPIO,w
        xorlw   b'000100'       ; toggle LED on GP2
        movwf   sGPIO           ;   using shadow register

        ; repeat forever
        goto    loop

        END
```

Example 3: Switch debouncing

Lesson 4 explored the topic of switch bounce, and described a counting algorithm to address it, which was expressed as:

```
count = 0
while count < max_samples
      delay sample_time
      if input = required_state
            count = count + 1
      else
            count = 0
end
```

The switch is deemed to have changed when it has been continuously in the new state for some minimum period, for example 10 ms. This is determined by continuing to increment a count while checking the state of the switch. "Continuing to increment a count" while something else occurs, such as checking a switch, is exactly what a timer does. Since a timer increments automatically, using a timer can simplify the logic, as follows:

```
reset timer
while timer < debounce time
      if input ≠ required_state
            reset timer
end
```

On completion, the input will have been in the required state (changed) for the minimum debounce time.

Assuming a 1 MHz instruction clock and a 1:64 prescaler, a 10 ms debounce time will be reached when the timer reaches 10 ms ÷ 64 µs = 156.3; taking the next highest integer gives 157.

The following code demonstrates how Timer0 can be used to debounce a "button down" event:

```
wait_dn clrf    TMR0            ; reset timer
chk_dn  btfsc   GPIO,3          ; check for button press (GP3 low)
        goto    wait_dn         ;   continue to reset timer until button down
        movf    TMR0,w          ; has 10ms debounce time elapsed?
        xorlw   .157            ;   (157=10ms/64us)
        btfss   STATUS,Z        ; if not, continue checking button
        goto    chk_dn
```

That's shorter than the equivalent routine presented in lesson 4, and it avoids the need to use two data registers as counters. But – it uses Timer0, and on baseline PICs, there is only one timer. It's a scarce resource! If you're using it to time a regular background process, as we did in example 2, you won't be able to use it for debouncing. You must be careful, as you build a library of routines that use Timer0, that if you use more than one routine which uses Timer0 in a program, the way they use or setup Timer0 doesn't clash.

But if you're not using Timer0 for anything else, using it for switch debouncing is perfectly sensible.

Complete program

The following program is equivalent to that presented in lesson 4, except that internal pull-ups are not enabled (if you want to enable them, simply load OPTION with '10010101' instead of '11010101').

By using Timer0 for debouncing, it's shorter and uses less data memory:

```
;************************************************************************
;   Description:    Lesson 5, example 3                                 *
;                                                                       *
;   Demonstrates use of Timer0 to implement debounce counting algorithm *
;                                                                       *
;   Toggles LED on GP1                                                  *
;   when pushbutton on GP3 is pressed (low) then released (high)        *
```

```
;************************************************************************
;                                                                       *
;   Pin assignments:                                                    *
;       GP1 - indicator LED                                             *
;       GP3 - pushbutton                                                *
;                                                                       *
;************************************************************************

    list        p=12F509
    #include    <p12F509.inc>

                ; int reset, no code protect, no watchdog, 4MHz int clock
    __CONFIG    _MCLRE_OFF & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** VARIABLE DEFINITIONS
        UDATA_SHR
sGPIO   res 1                   ; shadow copy of GPIO


;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value


;***** MAIN PROGRAM

;***** Initialisation
start
        movlw   b'111101'       ; configure GP1 (only) as an output
        tris    GPIO
        movlw   b'11010101'     ; configure Timer0:
                ; --0-----          timer mode (T0CS = 0)
                ; ----0---          prescaler assigned to Timer0 (PSA = 0)
                ; -----101          prescale = 64 (PS = 101)
        option                  ;   -> increment every 64 us

        clrf    GPIO            ; start with LED off
        clrf    sGPIO           ;   update shadow


;***** Main loop
loop
        ; wait until button pressed, debounce using timer0:
wait_dn clrf    TMR0            ; reset timer
chk_dn  btfsc   GPIO,3          ; check for button press (GP3 low)
        goto    wait_dn         ;   continue to reset timer until button down
        movf    TMR0,w          ; has 10ms debounce time elapsed?
        xorlw   .157            ;   (157=10ms/64us)
        btfss   STATUS,Z        ; if not, continue checking button
        goto    chk_dn

        ; toggle LED on GP1
        movf    sGPIO,w
        xorlw   b'000010'       ; toggle shadow register
        movwf   sGPIO
        movwf   GPIO            ; write to port

        ; wait until button released, debounce using timer0:
wait_up clrf    TMR0            ; reset timer
```

```
chk_up  btfss   GPIO,3          ; check for button release (GP3 high)
        goto    wait_up         ;   continue to reset timer until button up
        movf    TMR0,w          ; has 10ms debounce time elapsed?
        xorlw   .157            ;   (157=10ms/64us)
        btfss   STATUS,Z        ; if not, continue checking button
        goto    chk_up

        ; repeat forever
        goto    loop


        END
```

Counter Mode

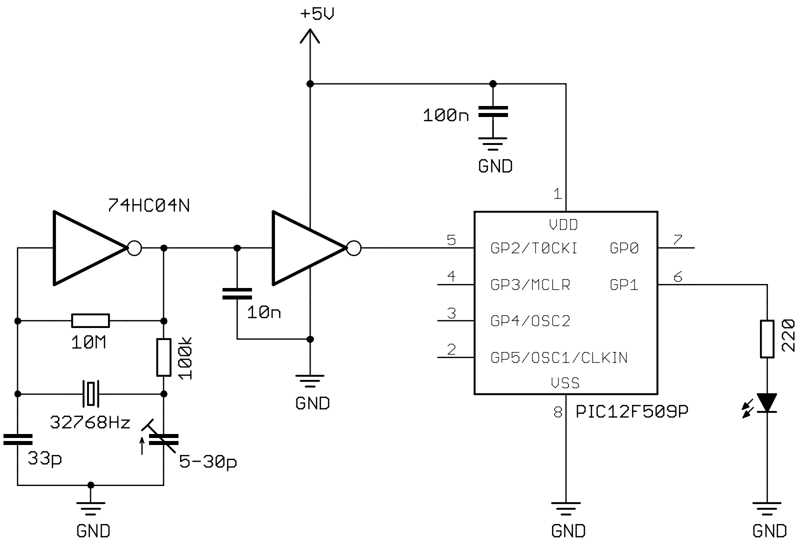
As discussed above, Timer0 can also be used to count external events, consisting of a transition (rising or falling) on the T0CKI input.

This is useful in a number of ways, such as performing an action after some number of input transitions, or measuring the frequency of an input signal, for example from a sensor triggered by the rotation of an axle. The frequency in Hertz of the signal is simply the number of transitions counted in 1 s.

However, it's not really practical to build a frequency counter, using only the techniques (and microcontrollers) we've covered so far!

To illustrate the use of Timer0 as a counter, we'll go back to LED flashing, but driving the counter with a crystal-based external clock, providing a much more accurate time base.

The circuit used for this is as shown on the right.



A 32.768 kHz "watch crystal" is used with a CMOS inverter to generate a 32.768 kHz clock signal.

In theory, the crystal should be loaded by 12.5 pF, equivalent to two 25 pF capacitors in series. Typically, in published circuits you'll see a pair of 22 pF capacitors between each side of the crystal and ground, since 22 pF is a close enough "standard value" and the circuit wiring will probably add a few picofarads of stray capacitance in any case.

But crystal oscillators are notoriously fiddly things, and can be something of a "black art" to get right. You'll find a number of detailed discussions of their ins and outs in applications notes on the Microchip web site. So to get a prototype working, it's a good idea to use a variable capacitor, as shown above, and then use an oscilloscope to monitor the output while adjusting the capacitance until the output (at the output of the inverter) is stable. If you don't own an oscilloscope (you should! They're invaluable!), you can use a multimeter if it has a frequency range. If it reports close to 32.768 kHz, the oscillator is running ok.

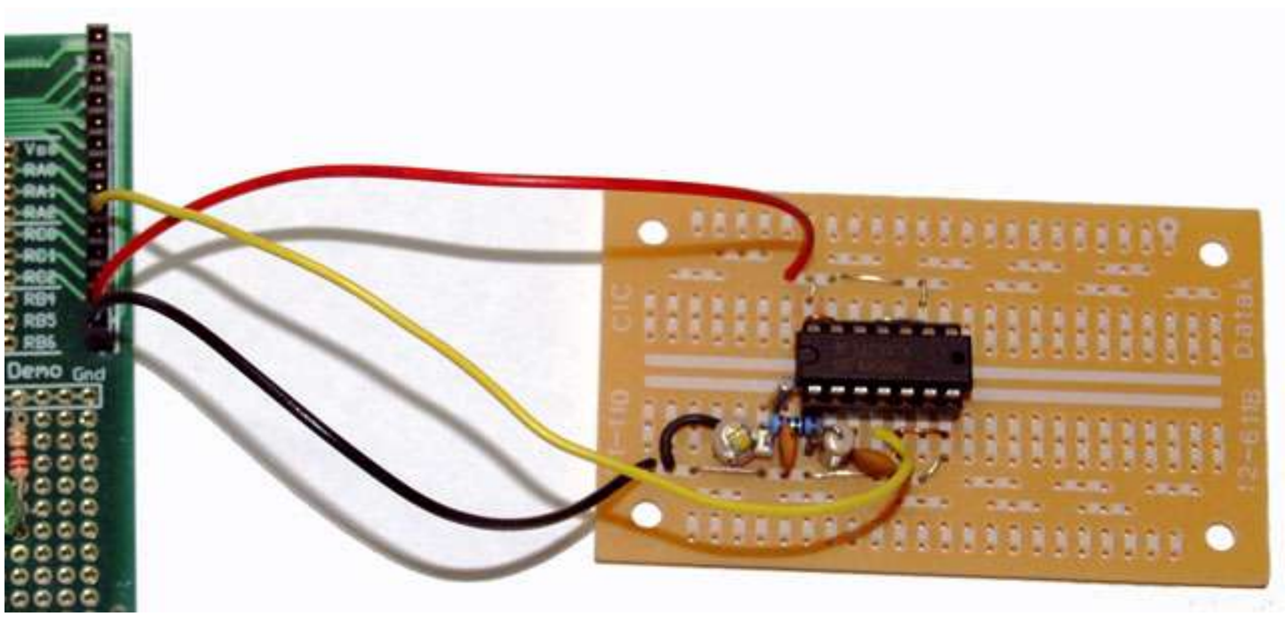
The second inverter in the circuit above, between the oscillator and the PIC, shouldn't be necessary. I included it in the prototype because, to avoid the stray capacitance problems inherent in breadboard, I built the clock module on a prototyping PCB, as shown in the photograph below. My intention was to build a stand-alone module, providing a 32.768 kHz signal, able to drive a wide range of circuits. The second inverter acts as a buffer, isolating the oscillator stage from whatever circuitry it is attached to, to avoid overloading the oscillator, which would stop it oscillating.

Here's where the "black art" aspect appears. When I first built the prototype, I hadn't connected the second inverter stage, and an oscilloscope connected to the output of the first inverter showed correct oscillation. Simply connecting a buffer to this should not stop the oscillator from working. And yet, when the second stage was connected, the output of the second inverter showed no oscillation. Odd! But it gets stranger. Checking the input to the second inverter showed a nicely defined waveform, so why nothing at the output? A dead inverter perhaps? I replaced it with another 74HC04 chip, but the behaviour was the same. No output from the second inverter, but the input to it, from the first inverter, was ok. Two chips with inverter 1 working and inverter 2 not, would be too much coincidence! Then I happened to check the output of the second inverter again, and found a nice 32.768 kHz waveform.

To cut the story short, it turned out that the oscillator stage wasn't starting, until touched at its output by the oscilloscope probe! No oscillation was occurring, until the junction between the two inverters was probed… Stranger still was that it was not necessary for the oscilloscope probe to be in place, for the oscillation to continue correctly. It only needed to be there for start-up.

And that, finally, is why there is a 10 nF capacitor loading the input to the buffer stage. It adds the capacitance which appears to be necessary for the crystal oscillator to start up. 10 nF is of course greater than the capacitative load the oscillator probe would have presented, but I have found that this value provides for reliable oscillator start-up and continued operation.

The output signal from the buffer is fed directly to the T0CKI (GP2) input on the PIC. If using the Low Pin Count Demo Board, this can be done by connecting the 32.768 kHz clock module to the 14-pin header on the demo board (GP2 is brought out as pin 9 on the header, while power and ground are pins 13 and 14), as illustrated in the photograph on the next page:



We'll use this clock input to generate the timing needed to flash the LED on GP1 at almost exactly 1 Hz (the accuracy being set by the accuracy of the crystal oscillator, which can be expected to be much better than that of the PIC's internal RC oscillator).

Those familiar with binary numbers will have noticed that 32768 = 2^{15}, making it very straightforward to divide the 32768Hz input down to 1 Hz.

Since 32768 = 128 × 256, if we apply a 1:128 prescale ratio to the 32768 Hz signal on T0CKI, TMR0 will be incremented 256 times per second. The most significant bit of TMR0 (TMR0<7>) will therefore be cycling at a rate of exactly 1 Hz; it will be '0' for 0.5 s, followed by '1' for 0.5 s.

So if we clock TMR0 with the 32768 Hz signal on T0CKI, prescaled by 128, the task is simply to light the LED (GP1 high) when TMR0<7> = 1, and turn off the LED (GP1 low) when TMR0<7> = 0.

To configure Timer0 for counter mode (external clock on T0CKI) with a 1:128 prescale ratio, set the T0CS bit to '1', PSA to '0' and PS<2:0> to '110':

```
        movlw   b'11110110'     ; configure Timer0:
                ; --1-----          counter mode (T0CS = 1)
                ; ----0---          prescaler assigned to Timer0 (PSA = 0)
                ; -----110          prescale = 128 (PS = 110)
        option                  ;   -> increment at 256 Hz with 32.768 kHz input
```

Note that the value of T0SE bit is irrelevant; we don't care if the counter increments on the rising or falling edge of the signal on T0CKI – only the frequency is important. Either edge will do.

Next we need to continually set GP1 high whenever TMR0<7> = 1, and low whenever TMR0<7> = 0.

In other words, continually update GP1 with the current value or TMR0<7>.

Unfortunately, there is no simple "copy a single bit" instruction in baseline PIC assembler!

If you're not using a shadow register for GPIO, the following "direct approach" is effective, if a little inelegant:

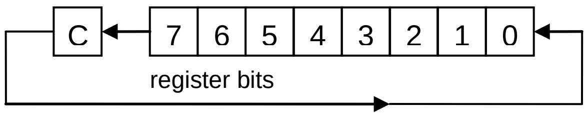
```
start   ; transfer TMR0<7> to GP1
        btfsc   TMR0,7          ; if TMR0<7>=1
        bsf     GPIO,1          ;   set GP1
        btfss   TMR0,7          ; if TMR0<7>=0
        bcf     GPIO,1          ;   clear GP1

        ; repeat forever
        goto    start
```

As described in lesson 4, if you are using a shadow register (as previously discussed, it's generally a good idea to do so, to avoid potential, and difficult to debug, problems), this can be implemented as:

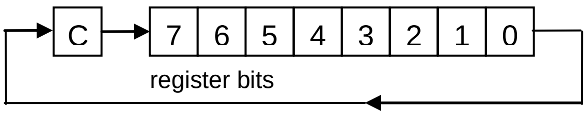
```
start   ; transfer TMR0<7> to GP1
        clrf    sGPIO           ; assume TMR0<7>=0 -> LED off
        btfsc   TMR0,7          ; if TMR0<7>=1
        bsf     sGPIO,1         ;   turn on LED

        movf    sGPIO,w         ; copy shadow to GPIO
        movwf   GPIO

        ; repeat forever
        goto    start
```

But since this is actually an instruction longer, it's only really simpler if you were going to use a shadow register anyway.

Another approach is to use the PIC's rotate instructions. These instructions move every bit in a register to the left or right, as illustrated:



'`rlf f,d`' – "**r**otate **l**eft **f**ile register through carry"



'`rrf f,d`' – "**r**otate **r**ight **f**ile register through carry"

In both cases, the bit being rotated out of bit 7 (for `rlf`) or bit 0 (for `rrf`) is copied into the carry bit in the STATUS register, and the previous value of carry is rotated into bit 0 (for `rlf`) or bit 7 (for `rrf`).

As usual, '`f`' is the register being rotated, and '`d`' is the destination: '`,f`' to write the result back to the register, or '`,w`' to place the result in W.

The ability to place the result in W is useful, since it means that we can "left rotate" TMR0, to copy the current value to TMR0<7> into C, without affecting the value in TMR0.

There are no instructions for rotating W, only the addressable special-function and general purpose registers. That's a pity, since such an instruction would be useful here. Instead, we'll need to rotate the bit copied from TMR0<7> into bit 0 of a temporary register, then rotate again to move the copied bit into bit 1, and then copy the result to GPIO, as follows:

```
        rlf     TMR0,w          ; copy TMR0<7> to C
        clrf    temp
        rlf     temp,f          ; rotate C into temp
        rlf     temp,w          ; rotate once more into W (-> W<1> = TMR0<7>)
        movwf   GPIO            ; update GPIO with result (-> GP1 = TMR0<7>)
```

Note that '`temp`' is cleared before being used. That's not strictly necessary in this example; since only GP1 is being used as an output, it doesn't actually matter what the other bits in GPIO are set to. Of course, if any other bits in GPIO were being used as outputs, you couldn't use this method anyway, since this code will clear every bit other than GP1! In that case, you're better off using the bit test and set/clear instructions, which are generally the most practical way to "copy a bit". But it's worth remembering that the rotate instructions are also available, and using them may lead to shorter code.

Complete program

Here's the complete "flash a LED at 1 Hz using a crystal oscillator" program, using the "copy a bit via rotation" method:

```
;************************************************************************
;                                                                       *
;   Description:    Lesson 5, example 4b                                *
;                                                                       *
;   Demonstrates use of Timer0 in counter mode and rotate instructions  *
;                                                                       *
;   LED flashes at 1Hz (50% duty cycle),                                *
;   with timing derived from 32.768KHz input on T0CKI                   *
;                                                                       *
;   Uses rotate instructions to copy MSB from Timer0 to GP1             *
;                                                                       *
;************************************************************************
;                                                                       *
;   Pin assignments:                                                    *
;       GP1 - flashing LED                                              *
;       T0CKI - 32.768kHz signal                                        *
;                                                                       *
;************************************************************************

    list        p=12F509
    #include    <p12F509.inc>

                ; ext reset, no code protect, no watchdog, 4MHz int clock
    __CONFIG    _MCLRE_ON & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** VARIABLE DEFINITIONS
        UDATA_SHR
temp    res 1                   ; temp register used for rotates
```

```
;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value


;***** MAIN PROGRAM

;***** Initialisation
start
        movlw   b'111101'       ; configure GP1 (only) as output
        tris    GPIO
        movlw   b'11110110'     ; configure Timer0:
                ; --1-----          counter mode (T0CS = 1)
                ; ----0---          prescaler assigned to Timer0 (PSA = 0)
                ; -----110          prescale = 128 (PS = 110)
        option                  ;   -> increment at 256 Hz with 32.768 kHz input

;***** Main loop
loop    ; TMR0<7> cycles at 1Hz
        ; so continually copy to GP1
        rlf     TMR0,w          ; copy TMR0<7> to C
        clrf    temp
        rlf     temp,f          ; rotate C into temp
        rlf     temp,w          ; rotate once more into W (-> W<1> = TMR0<7>)
        movwf   GPIO            ; update GPIO with result (-> GP1 = TMR0<7>)

        ; repeat forever
        goto    loop

        END
```

Hopefully the examples in this lesson have given you an idea of the flexibility and usefulness of the Timer0 peripheral. We'll revisit it later, and introduce other timers when we move onto the midrange architecture, but in the next lesson we'll take a quick look at how some of the MPASM assembler directives can be used to make our code easier to read and maintain.