IMPLEMENTING 16-BIT PWM USING THE PCA

Relevant Devices

This application note applies to the following devices:

C8051F000, C8051F001, C8051F002, C8051F005, C8051F006, C8051F010, C8051F011, and C8051F012.

Introduction

Pulse-width modulated (PWM) waveforms are often used in closed-loop feedback and control applications, such as controlling the on/off state of a heating element used to regulate the temperature of a laser in a DWDM (Dense Wavelength Division Multiplexing) application. In some applications, the built-in 8-bit PWM mode of the Programmable Counter Array (PCA) provides insufficient resolution for the task. This application note describes how to implement a PWM waveform achieving 16-bit resolution using the PCA in 'High-Speed Output' mode with minimal software overhead. Software examples in 'C' and assembly are provided at the end of this note.

Background

Figure 1 shows an example PWM waveform. The frequency of the PWM signal of the class used in feedback control applications is largely unimportant, as long as the waveform is 'fast enough', such that the step response of the control system is much slower than one period of the PWM signal. Signal information is encoded instead in the *duty cycle* of the waveform, the ratio of the time the waveform is high over one period of the PWM signal. The input to the PWM implementation is a number, usually an integer, that is proportional to the duty cycle desired at the output.

Implementation

There are many methods for implementing a PWM waveform in an 8051-based design: software loops, polled or interrupt-driven timers, etc. The examples in this note use the Programmable Counter Array (PCA). Using the PCA for this application results in a substantial reduction in CPU bandwidth requirements over any polled scheme (software or timer-based), and eliminates timing jitter caused by

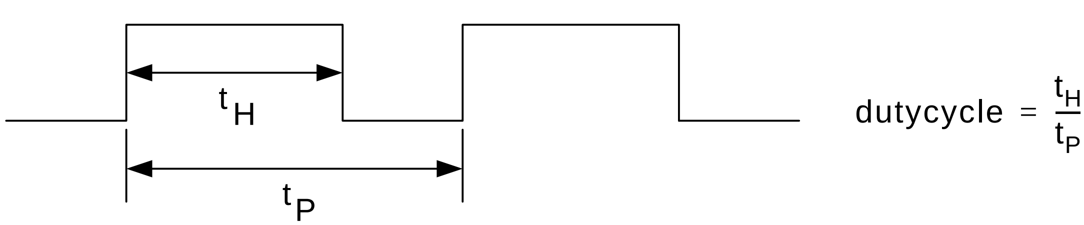


Figure 1. Example PWM Waveform

variable interrupt latency in interrupt-driven timer-based designs.

An Introduction to the PCA

The PCA consists of a single 16-bit counter/timer and five capture/compare modules, as shown in Figure 2. The counter/timer has a 16-bit timer/counter register (PCA0H:PCA0L), an associated mode register (PCA0MD), which selects the time base, and a control register (PCA0CN), which contains the timer/counter run control and the modules' capture/compare flags. Each capture/compare module has a configuration register (PCA0CPMx) which selects the module's mode (Edge-triggered Capture, Software Timer, High-Speed Output, or PWM) and a 16-bit capture/compare register (PCA0CPHn:PCA0CPLn).

Because the capture/compare modules share a common time base, they can operate in concert, to provide phase-locked excitation waveforms for motor control, for example. Or, because each module has its own control and capture/compare registers, it can operate independently of the other modules, as long as the routines for any module do not affect the shared time base (by stopping or resetting the counter/timer or by changing the counter/timer clock source).

The examples in this note configure the PCA modules to act independently; the routines for the allocated module affect only the configuration register and the capture/compare register for that module. The PCA Mode Register (PCA0MD) is configured once, then left alone, and the timer/counter register (PCA0H:PCA0L) is left free-running.

Selecting the PCA Time Base

The PCA time base can be derived from one of four sources: SYSCLK / 12, SYSCLK / 4, Timer0 overflows, or high-to-low transitions on an external pin, ECI. A block diagram of the PCA counter/timer is

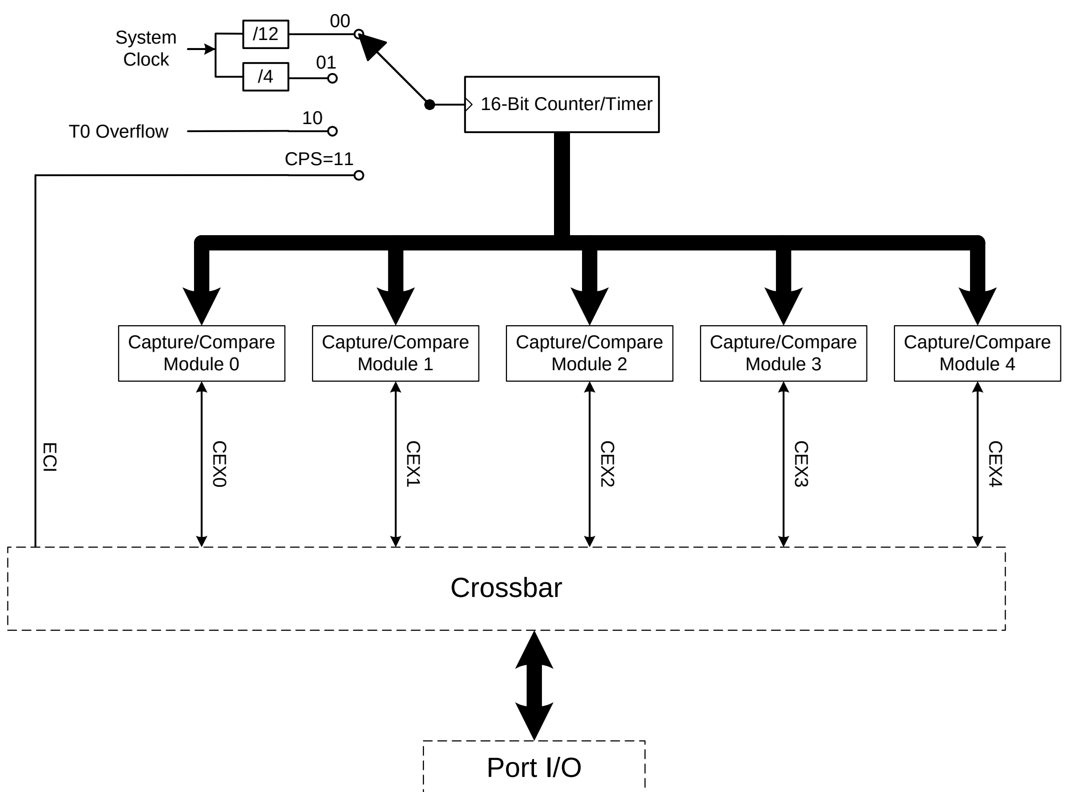


Figure 2. PCA Block Diagram

shown in Figure 3.

As will be shown in the following sections, the selection of the PCA time base determines the resulting frequency of the PWM waveform. As mentioned earlier, the frequency of the PWM waveform is generally not important, so long as it is ‘fast enough’.

One timing option that is not immediately obvious is that the PCA can be clocked at the SYSCLK rate by selecting Timer0 overflows as the PCA clock source, and setting Timer0 in 8-bit auto-reload mode with a reload value of ‘0xFF’.

The examples in this note all configure the PCA to use SYSCLK / 4 as the PCA clock source.

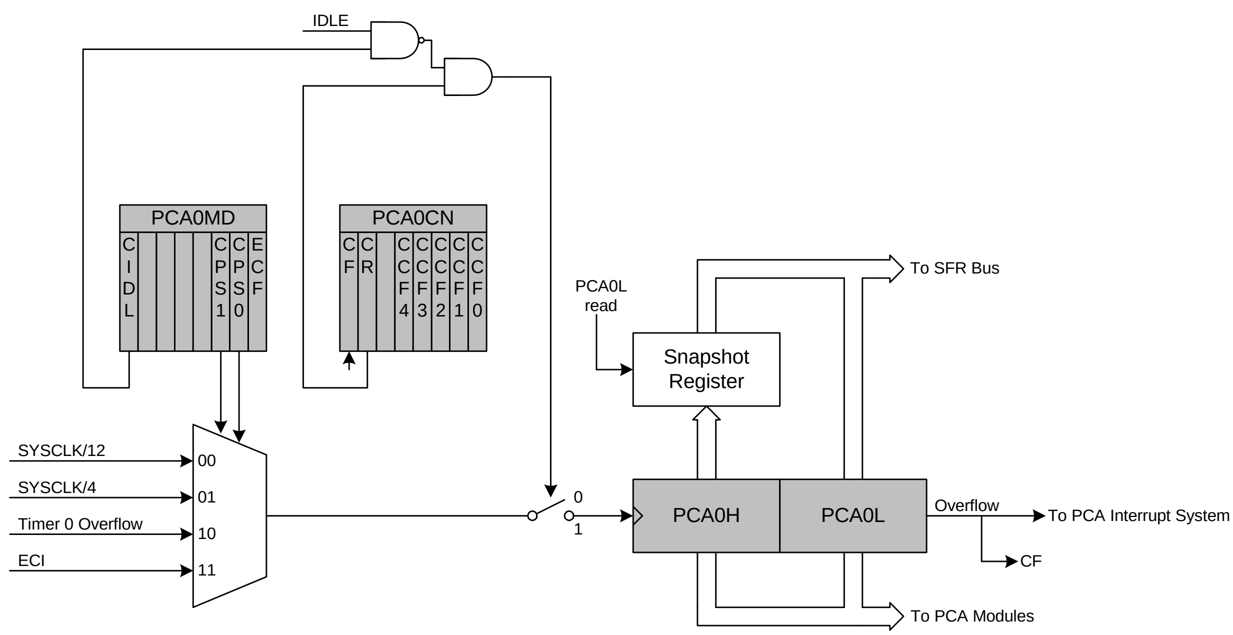


Figure 3. PCA Counter/Timer Block Diagram

8-Bit PWM Using the PCA

We first present a method for generating a PWM waveform with 8-bit precision, for completeness, and to introduce the PWM mode of the PCA.

In this mode, the capture/compare module is configured in PWM mode as shown in Figure 4. The period of the waveform at *CEXn* is equal to 256 PCA clocks. The low-time of the signal at *CEXn* is equal to the 8-bit value stored in the low-byte of the module's capture/compare register (PCA0CPLn). This relationship is shown in Figure 5.

At every overflow of the low-byte of the main PCA counter (PCA0L), the high-byte of the module's compare register is copied into the low-byte of the module's compare register (PCA0CPLn = PCA0CPHn). The duty cycle is changed by updating PCA0CPHn. The copying process ensures glitch-free transitions at the output.

The duty cycle of the output waveform (in %) is given by:

$$\text{dutycycle} = \frac{256 - \text{PCA0CPHn}}{256} \times 100$$

Because PCA0CPHn can contain a value between 0 and 255, the minimum and maximum programmable duty cycles are 0.38 % (PCA0CP0H = 0xFF) to 100 % (PCA0CP0H = 0x00). The resolution of the duty cycle selection is:

$$\text{resolution} = \frac{1}{256} \times 100 = 0.38$$

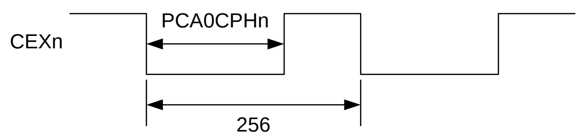


Figure 5. Output Waveform in 8-Bit PWM Mode

The key advantage of 8-bit PWM mode is that no CPU intervention is required to maintain an output waveform of a fixed duty cycle. In fact, if the CIDL bit (PCA0MD.7) is set to '0' (RESET state), the output waveform will be maintained even if the CPU is in IDLE mode.

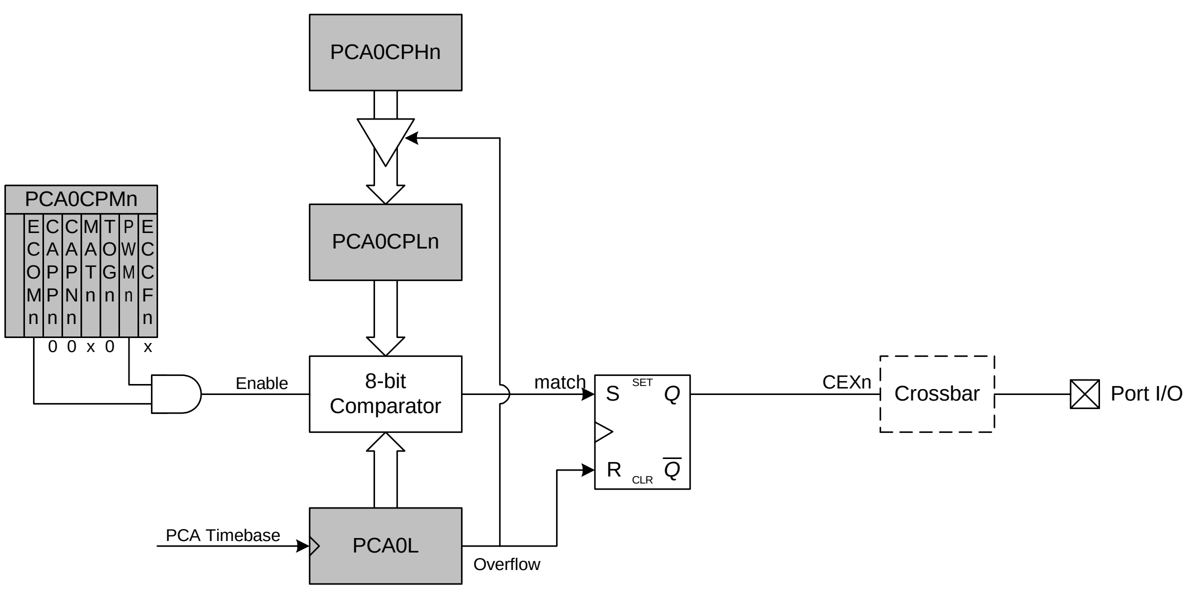


Figure 4. PCA Configuration in 8-Bit PWM Mode

Changing the duty cycle is implemented by a single 8-bit write to PCA0CPHn.

An example of 8-bit PWM mode is included in the file '`PWM8_1.c`' at the end of this note.

Additional notes on 8-bit PWM mode:

1. The output *CEXn* can be held low by clearing the ECOMn bit (PCA0CPMn.6) in the module configuration register. This allows a 0% duty cycle waveform to be generated. Normal PWM output can be resumed by writing a '1' to this bit OR by writing any value to PCA0CPHn.

2. Setting the MATn and ECCFn bits (PCA0CPMn.3 and PCA0CPMn.0 respectively) to '1' will cause an interrupt to be generated on the falling edge of *CEXn*.

16-Bit PWM Using the PCA

To implement a PWM waveform with 16-bit precision, we configure a PCA module in High-Speed Output mode, as shown in Figure 6. In this mode, the *CEXn* pin is toggled, and an optional interrupt is generated, each time a match occurs between the main timer/counter register (PCA0H:PCA0L) and the module's capture/compare register (PCA0CPHn:PCA0CPLn).

In the example code, the interrupt handler for the PCA module is implemented in two states: a rising-edge state and a falling-edge state, depending on which edge on *CEXn* initiated the interrupt. Note that the actual *CEXn* pin is decoded as the state variable.

During the rising-edge state, the module's capture/compare register is updated with the compare value for the next falling-edge (this value is called *PWM* in the attached example code). During the falling-edge state, the module's capture/compare register is

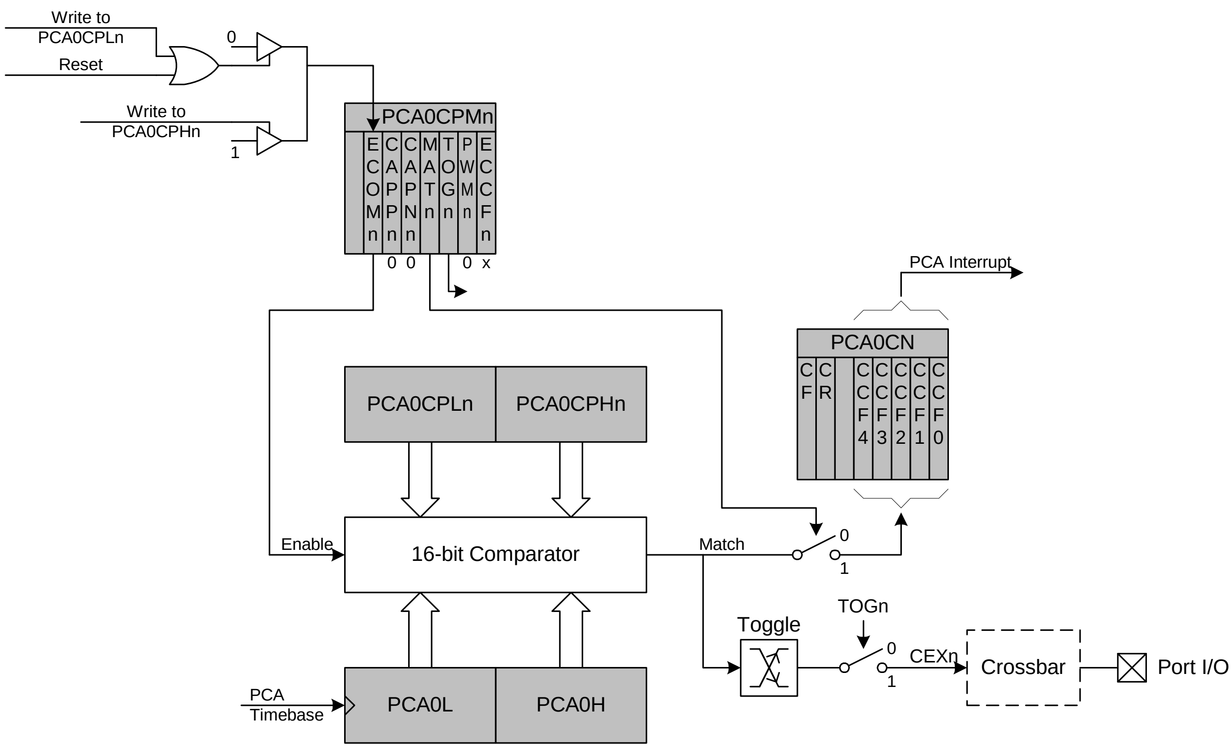


Figure 6. PCA Configuration in High-Speed Output Mode

loaded with the compare value for the next rising-edge, which is zero (0x0000). This is shown in Figure 7. Note that the period of the PWM waveform is 65536 PCA clocks.

The duty cycle (in %) is given by:

$$\text{dutycycle} = \frac{PWM}{65536} \times 100$$

The minimum and maximum allowed duty cycles are determined by the maximum time it takes to update the compare value after *CEXn* changes (which triggers the process interrupt). In both the 'C' example code and the assembly example code (`pwm16_1.c`' and '`pwm16_1.asm`' respectively), the minimum value for PWM is 7 PCA clocks (28 SYSCLK cycles in this case). This results in minimum and maximum duty cycle values of 0.01 % and 99.99 % respectively. The resolution of the duty cycle (in %) is:

$$\text{resolution} = \frac{1}{65536} \times 100 = 0.0015$$

or about 15 ppm (parts per million).

The CPU overhead required to process these interrupts is minimal. In the assembly example, processing both edges takes a total of 41 SYSCLK cycles, not counting the interrupt call and vector itself. Both edges must be processed every 65,536 PCA clocks, or 65,536 * 4 = 262,144 SYSCLKs, if the PCA clock is equal to SYSCLK / 4. CPU bandwidth consumed (in %) is equal to (41 / 262,144 * 100) = 0.015 %.

Also note that the CPU can be left in IDLE mode, as is done in the examples, since the PCA module interrupt will 'wake up' the core when required for processing.

The duty cycle can be changed by a single 16-bit write to the variable *PWM* in the examples.

n-Bit PWM Using the PCA

A generalized case of 16-bit PWM, we present n-Bit PWM for applications requiring more than 8-bits of precision but less than 16-bits of precision. One motivation for adopting the n-Bit approach is to achieve a higher output frequency from the PWM than can be obtained in the 16-bit implementation.

In this example ('`PWMn_1.c`'), two 16-bit variables are used: *PWM_HIGH*, which holds the number of PCA clocks for the output waveform to remain high, and *PWM_LOW*, which correspondingly holds the number of PCA clocks for the output waveform to remain low. The period of the

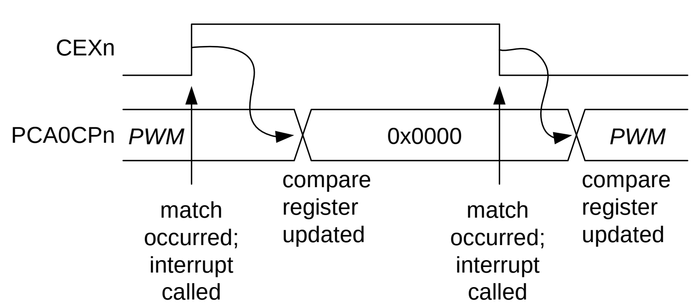


Figure 7. Capture/Compare Register Loading for 16-Bit PWM

output waveform is given by the sum of these two variables:

$$\text{period} = \text{PWMHIGH} + \text{PWMLOW}$$

The duty cycle (in %) is given by:

$$\text{dutycycle} = \frac{\text{PWMHIGH}}{\text{PWMHIGH} + \text{PWMLOW}} \times 100$$

The resolution of the duty cycle (in %) is:

$$\text{resolution} = \frac{1}{\text{PWMHIGH} + \text{PWMLOW}} \times 100$$

Similar to the 16-bit PWM case, the interrupt handler is implemented in two states, one for the rising-edge and one for the falling-edge. The primary difference is that in the 16-bit case, a constant (*PWM* or zero) was loaded into the PCA module's compare registers. In the n-Bit case, a constant (*PWM_HIGH* or *PWM_LOW*) is added to the current value in the module's compare register. The addition operation takes a few more cycles than loading a constant, which restricts the minimum high or low time of the output waveform a little more than the corresponding 16-bit solution.

Note: the n-Bit PWM solution can be used to generate a waveform of an arbitrary frequency by programming the appropriate high and low values into *PWM_HIGH* and *PWM_LOW.*

Software Examples

PWM8_1.c

```
//-----------------------------------------------------------------------------
// PWM8_1.c
//-----------------------------------------------------------------------------
//
// AUTH: BW
//
// Target: C8051F000, F001, F002, F005, F006, F010, F011, or F012
// Tool chain: KEIL C51
//
// Description:
//                  Example source code for implementing 8-bit PWM.
//                  The PCA is configured in 8-bit PWM mode using
//                  SYSCLK/4 as its time base.  <PWM> holds the number of
//                  PCA cycles for the output waveform to remain low per 256-
//                  count period.  The waveform is high for (256 - PWM) cycles.
//                  The duty cycle of the output is equal to (256 - PWM) / 256.
//
//                  Because the 8-bit PWM is handled completely in hardware,
//                  no CPU cycles are expended in maintaining a fixed duty
//                  cycle.  Altering the duty cycle requires a single 8-bit
//                  write to the high byte of the module’s compare register,
//                  PCA0CP0H, in this example.
//
//                  Achievable duty cycle ranges are 0.38% (PCA0CP0H = 0xff)
//                  to 100% (PCA0CP0H = 0x00).
//

//-----------------------------------------------------------------------------
// Includes
//-----------------------------------------------------------------------------

#include <c8051f000.h>                        // SFR declarations

//-----------------------------------------------------------------------------
// Global CONSTANTS
//-----------------------------------------------------------------------------

#define PWM   0x80                            // Number of PCA clocks for
                                              // waveform to be low
                                              // duty cycle = (256 - PWM) / 256
                                              // Note: this is an 8-bit value

//-----------------------------------------------------------------------------
// Function PROTOTYPES
//-----------------------------------------------------------------------------

void main (void);

//-----------------------------------------------------------------------------
// MAIN Routine
//-----------------------------------------------------------------------------

void main (void) {
```

```
    WDTCN = 0xde;                           // Disable watchdog timer
    WDTCN = 0xad;

    OSCICN = 0x07;                          // set SYSCLK to 16MHz,
                                            // internal osc.

    XBR0 = 0x08;                            // enable CEX0 at P0.0
    XBR2 = 0x40;                            // enable crossbar and weak
                                            // pull-ups

    PRT0CF = 0x01;                          // set P0.0 output state to
                                            // push-pull
    PRT1CF = 0x20;                          // set P1.6 output to
                                            // push-pull (LED)


    // configure the PCA
    PCA0MD = 0x02;                          // disable CF interrupt
                                            // PCA time base = SYSCLK / 4
    PCA0CPL0 = PWM;                         // initialize PCA PWM value
    PCA0CPH0 = PWM;
    PCA0CPM0 = 0x42;                        // CCM0 in 8-bit PWM mode
    PCA0CN = 0x40;                          // enable PCA counter

    while (1) {
       PCON |= 0x01;                        // set IDLE mode
    }
}// *** END OF FILE ***
```

PWM16_1.c

```
//-----------------------------------------------------------------------------
// PWM16_1.c
//-----------------------------------------------------------------------------
//
// AUTH: BW
//
// Target: C8051F000, F001, F002, F005, F006, F010, F011, or F012
// Tool chain: KEIL C51
//
// Description:
//                  Example source code for implementing 16-bit PWM.
//                  The PCA is configured in high speed output mode using
//                  SYSCLK/4 as its time base.  <PWM> holds the number of
//                  PCA cycles for the output waveform to remain high.  The
//                  waveform is low for (65536 - PWM) cycles.  The duty
//                  cycle of the output is equal to PWM / 65536.
//
//                  Due to interrupt service times, there are minimum and
//                  maximum values for PWM, and therefore the duty cycle,
//                  depending on interrupt service times.  On the Keil C51
//                  compiler (Eval version), the minimum PWM value is 7
//                  PCA clocks; the maximum value is 65530.  This equates
//                  to a minimum duty cycle of 0.01% and a maximum duty
//                  cycle of 99.99%.  This assumes a PCA time base of SYSCLK/4
//                  and no other interrupts being serviced.
//
```

```
//-----------------------------------------------------------------------------
// Includes
//-----------------------------------------------------------------------------

#include <c8051f000.h>                       // SFR declarations

//-----------------------------------------------------------------------------
// Global CONSTANTS
//-----------------------------------------------------------------------------

#define PWM_START0x4000                      // starting value for the PWM
                                             // high time
sbit   PWM_OUT = P0^0;                       // define PWM output port pin

//-----------------------------------------------------------------------------
// Function PROTOTYPES
//-----------------------------------------------------------------------------

void main (void);
void PCA_ISR (void);                         // PCA Interrupt Service Routine

//-----------------------------------------------------------------------------
// Global VARIABLES
//-----------------------------------------------------------------------------
unsigned PWM = PWM_START;                    // Number of PCA clocks for
                                             // waveform to be high
                                             // duty cycle = PWM / 65536
                                             // Note: this is a 16-bit value

//-----------------------------------------------------------------------------
// MAIN Routine
//-----------------------------------------------------------------------------

void main (void) {

   WDTCN = 0xde;                             // Disable watchdog timer
   WDTCN = 0xad;

   OSCICN = 0x07;                            // set SYSCLK to 16MHz,
                                             // internal osc.

   XBR0 = 0x08;                              // enable CEX0 at P0.0
   XBR2 = 0x40;                              // enable crossbar and weak
                                             // pull-ups

   PRT0CF = 0x01;                            // set P0.0 output state to
                                             // push-pull
   PRT1CF = 0x20;                            // set P1.6 output to
                                             // push-pull (LED)


   // configure the PCA
   PCA0MD = 0x02;                            // disable CF interrupt
                                             // PCA time base = SYSCLK / 4
   PCA0CPL0 = (0xff & PWM);                  // initialize PCA compare value
   PCA0CPH0 = (0xff & (PWM >> 8));
   PCA0CPM0 = 0x4d;                          // CCM0 in High Speed output mode
```

```
    EIE1 |= 0x08;                               // enable PCA interrupt

    EA = 1;                                     // Enable global interrupts

    PCA0CN = 0x40;                              // enable PCA counter

    while (1) {
       PCON |= 0x01;                            // set IDLE mode
    }
}

//-----------------------------------------------------------------------------
// PCA_ISR
//-----------------------------------------------------------------------------
//
// This ISR is called when the PCA CCM0 obtains a match
// PWM_OUT is the CEX0 port pin that holds the state of the current edge:
//  1 = rising edge; 0 = falling edge
// On the rising edge, the compare registers are loaded with PWM_HIGH.
// On the falling edge, the compare registers are loaded with zero.
//
void PCA_ISR (void) interrupt 9
{
    if (CCF0) {
       CCF0 = 0;                                // clear compare indicator
       if (PWM_OUT) {                           // process rising edge

          PCA0CPL0 = (0xff & PWM);              // set next match to PWM
          PCA0CPH0 = (0xff & (PWM >> 8));

       } else {                                 // process falling edge

          PCA0CPL0 = 0;                         // set next match to zero
          PCA0CPH0 = 0;

       }
    } else if (CCF1) {                          // handle other PCA interrupt
       CCF1 = 0;                                // sources
    } else if (CCF2) {
       CCF2 = 0;
    } else if (CCF3) {
       CCF3 = 0;
    } else if (CCF4) {
       CCF4 = 0;
    } else if (CF) {
       CF = 0;
    }
}
// *** END OF FILE ***
```

PWM16_1.asm

```
;-----------------------------------------------------------------------------
;   CYGNAL, INC.
;
;
;   FILE NAME  :     pwm16_1.ASM
;   TARGET MCU:      C8051F000, F001, F002, F005, F006, F010, F011, or F012
```

```
;   DESCRIPTION:     Example source code for implementing 16-bit PWM.
;                    The PCA is configured in high speed output mode using
;                    SYSCLK/4 as its time base.  PWM holds the number of
;                    PCA cycles for the output waveform to remain high.  The
;                    waveform is low for (65536 - PWM) cycles.  The duty
;                    cycle of the output is equal to PWM / 65536.
;
;                    Due to interrupt service times, the minimum value for
;                    PWM is 7 PCA cycles, and the maximum value is 65529.
;                    This equates to a minimum duty cycle of 0.01068% and a
;                    maximum duty cycle of 99.9893%.
;
;                    If the PCA time base is changed to SYSCLK / 12, the min and
;                    max values for PWM change to 3 and 65533 respectively,
;                    for min and max duty cycles of 0.0046% and 99.9954%
;                    respectively.
;
;                    Processing the rising edge interrupt handler takes 18 cycles.
;                    Processing the falling edge interrupt handler takes 19 cycles.
;
;                    One interrupt handler is called for each edge, and there are
;                    2 edges for every 65536 PCA clocks.  Using SYSCLK / 4 as the
;                    PCA time base, that means that 37 cycles are consumed for
;                    edge maintenance for every (65536 * 4) = 262,144 SYSCLK
;                    cycles, not counting vectoring the interrupt.
;                    CPU utilization is (37 / 262,144)*100% = 0.0141%
;
;                    Using SYSCLK / 12 as the PCA timebase, 37 cycles are
;                    consumed for edge maintenance for every (65536 * 12) =
;                    786,432 SYSCLK cycles.  CPU utilization is (37 / 786,432)
;                    = 0.0047%.
;
;                    The period of the waveform is 65536 PCA clocks.  Using
;                    SYSCLK / 4 as the PCA time base, the period is 262,144 SYSCLK
;                    cycles.  Using the default internal oscillator at 2MHz, the
;                    period is 131ms (7.6Hz).  Using the 16MHz internal
;                    oscillator (as in this example), the period is 16.4us
;                    (61 Hz).
;
;                    Using SYSCLK / 12 as the PCA time base, the period is
;                    65536 * 12 = 786,432 SYSCLK cycles.  Using the default
;                    internal oscillator at 2MHz, the period is 393ms (2.5Hz).
;                    Using the 16MHz internal oscillator, the period is 49.2ms
;                    (20Hz).
;
;                    In this example, the output is routed to P0.0, which is
;                    also labeled 'PWM_OUT'.
;
;-----------------------------------------------------------------------------

;-----------------------------------------------------------------------------
; EQUATES
;-----------------------------------------------------------------------------

$MOD8F000

PWM    EQU    32768                          ; Number of PCA clocks for waveform
                                             ;  to be high
                                             ; duty cycle = PWM / 65536
```

```
                                        ; max = 65529 (99.9893% duty cycle)
                                        ; min = 7 (0.01068% duty cycle)
                                        ; Note: this is a 16-bit constant

PWM_OUT   EQU    P0.0                   ; define PWM output port pin

;-----------------------------------------------------------------------------
; RESET AND INTERRUPT VECTOR TABLE
;-----------------------------------------------------------------------------

CSEG
      org    00h
      ljmp   Main

      org    04bh
      ljmp   PCA_ISR                    ; PCA Interrupt Service Routine

;-----------------------------------------------------------------------------
; MAIN PROGRAM CODE
;-----------------------------------------------------------------------------
      org    0b3h                       ; start at end of interrupt handler
                                        ; space
Main:
      ; Disable watchdog timer
      mov    WDTCN, #0deh
      mov    WDTCN, #0adh

      ;  Enable the Internal Oscillator at 16 MHz
      mov    OSCICN, #07h

      ; Enable the Crossbar, weak pull-ups enabled
      mov    XBR0, #08h                 ; route CEX0 to P0.0
      mov    XBR2, #40h

      orl    PRT0CF, #01h               ; Configure Port 0.0 as Push-Pull

      ; Configure the PCA
      mov    PCA0MD, #02h               ; disable cf interrupt,
                                        ; PCA time base = SYSCLK/4
      mov    PCA0CPL0, #LOW(PWM)        ; initialize the PCA compare value
      mov    PCA0CPH0, #HIGH(PWM)
      mov    PCA0CPM0, #4dh             ; CCM0 in High Speed output mode

      ; Enable interrupts
      orl    EIE1,#08h                  ; Enable PCA interrupt
      setb   EA                         ; Enable global interrupts

      mov    PCA0CN, #40h               ; enable PCA counter

      jmp    $

;-----------------------------------------------------------------------------
;  CCF0 Interrupt Vector
;
;
; This ISR is called when the PCA CCM0 obtains a match
; PWM_OUT is the CEX0 port pin that holds the state of the current edge:
;  1 = rising edge; 0 = falling edge
; On the rising edge, the compare registers are loaded with PWM_HIGH.
```

```
; On the falling edge, the compare registers are loaded with zero.

PCA_ISR:
       jbc    CCF0, CCF0_HNDL              ; handle CCF0 comparison
       jbc    CCF1, PCA_STUB               ; stub routines
       jbc    CCF2, PCA_STUB
       jbc    CCF3, PCA_STUB
       jbc    CCF4, PCA_STUB
       jbc    CF,   PCA_STUB

PCA_STUB:
PCA_ISR_END:
       reti

CCF0_HNDL:
       jnb    PWM_OUT, CCF0_FALL
                                           ; handle rising edge
CCF0_RISE:
       mov    PCA0CPL0, #LOW(PWM)
       mov    PCA0CPH0, #HIGH(PWM)

       reti

CCF0_FALL:                                 ; handle falling edge
       mov    PCA0CPL0, #00
       mov    PCA0CPH0, #00

       reti

; rising edge takes 4+3+11 = 18 cycles
; falling edge takes 4+4+11 = 19 cycles

;-----------------------------------------------------------------------------
; END
;-----------------------------------------------------------------------------

END
; *** END OF FILE ***
```

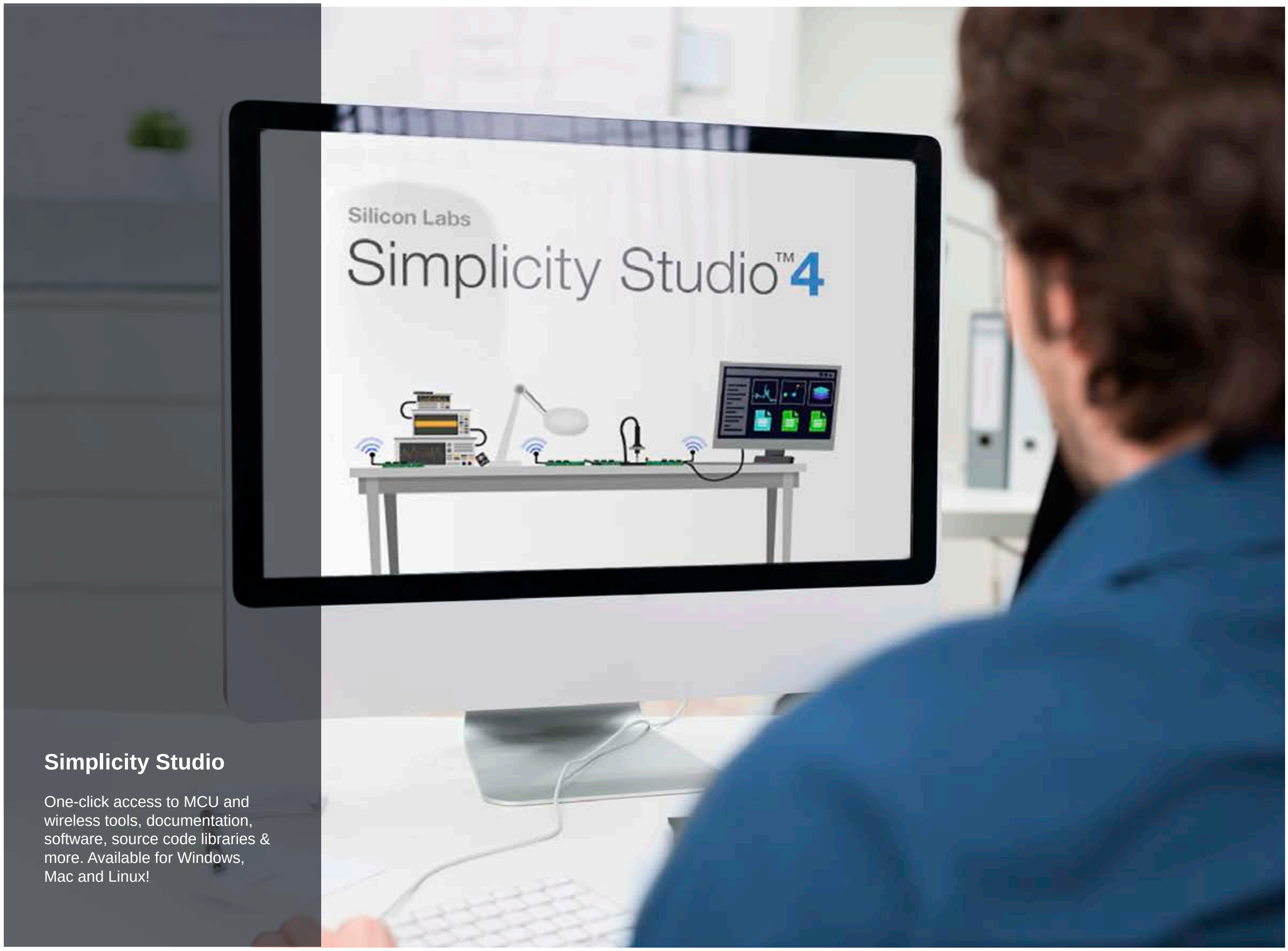
PWMn_1.c

```
//-----------------------------------------------------------------------------
// PWMn_1.c
//-----------------------------------------------------------------------------
//
// AUTH: BW
//
// Target: C8051F000, F001, F002, F005, F006, F010, F011, or F012
// Tool chain: KEIL C51
//
// Description:
//                  Example source code for implementing an n-bit PWM.
//                  The PCA is configured in high speed output mode using
//                  SYSCLK/4 as its time base.  <PWM_HIGH> holds the number of
//                  PCA cycles for the output waveform to remain high.
//                  <PWM_LOW> holds the number of PCA cycles for the output
//                  waveform to remain low.  The duty cycle of the output
//                  is equal to PWM_HIGH / (PWM_HIGH + PWM_LOW).
```

```
//
//                  Due to interrupt service times, there are minimum and
//                  maximum values for PWM_HIGH and PWM_LOW, and therefore
//                  the duty cycle, depending on interrupt service times.
//                  Regardless ofthe efficiency of the compiler, duty
//                  cycles between1% and 99% should be very easy to achieve.
//
//                  With the eval version of the Keil compiler, the minimum
//                  high and low counts are 20 PCA cycles each (max frequency
//                  is about 100kHz w/ 16MHz internal SYSCLK).  This assumes
//                  no other interrupts being serviced, and PCA time base is
//                  SYSCLK / 4.
//

//-----------------------------------------------------------------------------
// Includes
//-----------------------------------------------------------------------------

#include <c8051f000.h>                    // SFR declarations

//-----------------------------------------------------------------------------
// Global CONSTANTS
//-----------------------------------------------------------------------------

#define PWM_START   0x8000                // starting value for the
                                          // PWM_HIGH time and PWM_LOW time
sbit   PWM_OUT = P0^0;                    // define PWM output port pin

//-----------------------------------------------------------------------------
// Function PROTOTYPES
//-----------------------------------------------------------------------------

void main (void);
void PCA_ISR (void);                      // PCA Interrupt Service Routine

//-----------------------------------------------------------------------------
// Global VARIABLES
//-----------------------------------------------------------------------------
unsigned PWM_HIGH = PWM_START;            // Number of PCA clocks for
                                          // waveform to be high
unsigned PWM_LOW = ~PWM_START;            // Number of PCA clocks for
                                          // waveform to be low
                                          // duty cycle =
                                          // PWM_HIGH / (PWM_HIGH + PWM_LOW)

//-----------------------------------------------------------------------------
// MAIN Routine
//-----------------------------------------------------------------------------

void main (void) {

   WDTCN = 0xde;                          // Disable watchdog timer
   WDTCN = 0xad;

   OSCICN = 0x07;                         // set SYSCLK to 16MHz,
                                          // internal osc.

   XBR0 = 0x08;                           // enable CEX0 at P0.0
   XBR2 = 0x40;                           // enable crossbar and weak
```

```
                                          // pull-ups

   PRT0CF = 0x01;                         // set P0.0 output mode to
                                          // push-pull
   PRT1CF = 0x20;                         // set P1.6 output to
                                          // push-pull (LED)


   // configure the PCA
   PCA0MD = 0x02;                         // disable CF interrupt
                                          // PCA time base = SYSCLK / 4
   PCA0CPL0 = (0xff & PWM_HIGH);          // initialize PCA compare value
   PCA0CPH0 = (0xff & (PWM_HIGH >> 8));
   PCA0CPM0 = 0x4d;                       // CCM0 in High Speed output mode

   EIE1 |= 0x08;                          // enable PCA interrupt

   EA = 1;                                // Enable global interrupts

   PCA0CN = 0x40;                         // enable PCA counter

   while (1) {
      PCON |= 0x01;                       // set IDLE mode
   }
}

//-----------------------------------------------------------------------------
// PCA_ISR
//-----------------------------------------------------------------------------
//
// This ISR is called when the PCA CCM0 obtains a match
// PWM_OUT is the CEX0 port pin that holds the state of the current edge:
//  1 = rising edge; 0 = falling edge
// On the rising edge, the compare registers are updated to trigger for the
// next falling edge.
// On the falling edge, the compare registers are updated to trigger for the
// next rising edge.
//
void PCA_ISR (void) interrupt 9
{
   unsigned temp;                         // holding value for 16-bit math

   if (CCF0) {
      CCF0 = 0;                           // clear compare indicator
      if (PWM_OUT) {                      // process rising edge

         // update compare match for next falling edge
         temp = (PCA0CPH0 << 8) | PCA0CPL0;   // get current compare value
         temp += PWM_HIGH;                // add appropriate offset

         PCA0CPL0 = (0xff & temp);        // replace compare value
         PCA0CPH0 = (0xff & (temp >> 8));

      } else {                            // process falling edge

         // update compare match for next rising edge
         temp = (PCA0CPH0 << 8) | PCA0CPL0;   // get current compare value
         temp += PWM_LOW;                 // add appropriate offset
```

```
          PCA0CPL0 = (0xff & temp);           // replace compare value
          PCA0CPH0 = (0xff & (temp >> 8));

       }
    } else if (CCF1) {                        // handle other PCA interrupt
       CCF1 = 0;                              // sources
    } else if (CCF2) {
       CCF2 = 0;
    } else if (CCF3) {
       CCF3 = 0;
    } else if (CCF4) {
       CCF4 = 0;
    } else if (CF) {
       CF = 0;
    }
}
// *** END OF FILE ***
```



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