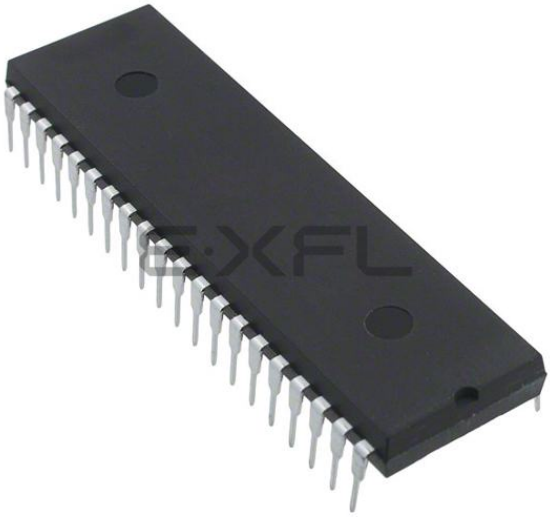

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What is "Embedded - Microcontrollers"?

"Embedded - Microcontrollers" refer to small, integrated circuits designed to perform specific tasks within larger systems. These microcontrollers are essentially compact computers on a single chip, containing a processor core, memory, and programmable input/output peripherals. They are called "embedded" because they are embedded within electronic devices to control various functions, rather than serving as standalone computers. Microcontrollers are crucial in modern electronics, providing the intelligence and control needed for a wide range of applications.

Applications of "Embedded - Microcontrollers"

Details	
Product Status	Active
Core Processor	PIC
Core Size	8-Bit
Speed	20MHz
Connectivity	I²C, SPI, UART/USART
Peripherals	Brown-out Detect/Reset, POR, PWM, WDT
Number of I/O	33
Program Memory Size	7KB (4K x 14)
Program Memory Type	OTP
EEPROM Size	-
RAM Size	192 x 8
Voltage - Supply (Vcc/Vdd)	4V ~ 5.5V
Data Converters	-
Oscillator Type	External
Operating Temperature	0°C ~ 70°C (TA)
Mounting Type	Through Hole
Package / Case	40-DIP (0.600", 15.24mm)
Supplier Device Package	40-PDIP
Purchase URL	https://www.e-xfl.com/product-detail/microchip-technology/pic16c65b-20-p

CHAPTER 1
8-Pin Flash PIC® Microcontrollers Tips ‘n Tricks

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TIPS ‘N TRICKS INTRODUCTION

Microchip continues to provide innovative products that are smaller, faster, easier to use and more reliable. The 8-pin Flash PIC® microcontrollers (MCU) are used in an wide range of everyday products, from toothbrushes, hair dryers and rice cookers to industrial, automotive and medical products.

The PIC12F629/675 MCUs merge all the advantages of the PIC MCU architecture and the flexibility of Flash program memory into an 8-pin package. They provide the features and intelligence not previously available due to cost and board space limitations. Features include a 14-bit instruction set, small footprint package, a wide operating voltage of 2.0 to 5.5 volts, an internal programmable 4 MHz oscillator, on-board EEPROM data memory, on-chip voltage reference and up to 4 channels of 10-bit A/D. The flexibility of Flash and an excellent development tool suite, including a low-cost In-Circuit Debugger, In-Circuit Serial Programming™ and MPLAB® ICE 2000 emulation, make these devices ideal for just about any embedded control application.

TIPS ‘N TRICKS WITH HARDWARE

The following series of Tips ’n Tricks can be applied to a variety of applications to help make the most of the 8-pin dynamics.

TIP #18 Swap File Register with W

Example 18-1

```
SWAPWF      MACRO   REG
            XORWF   REG,F
            XORWF   REG,W
            XORWF   REG,F
            ENDM
```

The following macro swaps the contents of W and REG without using a second register.

Needs: 0 TEMP registers
3 Instructions
3 TCY

An efficient way of swapping the contents of a register with the working register is to use three XORWF instructions. It requires no temporary registers and three instructions. Here’s an example:

W	REG	Instruction
10101100	01011100	XORWF REG,F
10101100	11110000	XORWF REG,W
01011100	11110000	XORWF REG,F
01011100	10101100	Result

TIP #19 Bit Shifting Using Carry Bit

Rotate a byte through carry without using RAM variable for loop count:

- Easily adapted to serial interface transmit routines.
- Carry bit is cleared (except last cycle) and the cycle repeats until the zero bit sets indicating the end.

Example 19-1

```
        LIST P=PIC12f629
        INCLUDE P12f629.INC
        buffer      equ   0x20

bsf     STATUS,C    ;Set 'end of loop' flag
rlf     buffer,f    ;Place first bit into C
bcf     GPIO,Dout   ;precondition output
btfsc   STATUS,C    ;Check data 0 or 1 ?
bsf     GPIO,Dout
bcf     STATUS,C    ;Clear data in C
rlf     buffer,f    ;Place next bit into C
movf    buffer,f    ;Force Z bit
btfss   STATUS,Z    ;Exit?
goto    Send_Loop
```

CHAPTER 2
PIC® Microcontroller Low Power Tips ‘n Tricks

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TIPS ‘N TRICKS INTRODUCTION

Microchip continues to provide innovative products that are smaller, faster, easier to use and more reliable. The Flash-based PIC® microcontrollers (MCUs) are used in an wide range of everyday products, from smoke detectors, hospital ID tags and pet containment systems, to industrial, automotive and medical products.

PIC MCUs featuring nanoWatt technology implement a variety of important features which have become standard in PIC microcontrollers. Since the release of nanoWatt technology, changes in MCU process technology and improvements in performance have resulted in new requirements for lower power. PIC MCUs with nanoWatt eXtreme Low Power (nanoWatt XLP™) improve upon the original nanoWatt technology by dramatically reducing static power consumption and providing new flexibility for dynamic power management.

The following series of Tips n’ Tricks can be applied to many applications to make the most of PIC MCU nanoWatt and nanoWatt XLP devices.

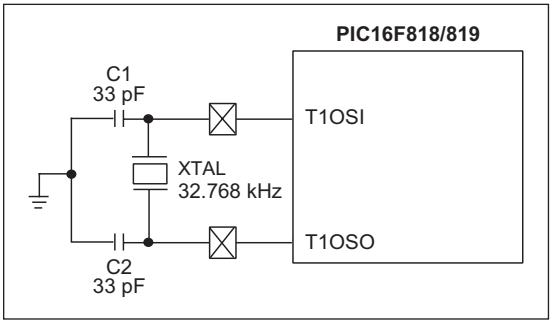
GENERAL LOW POWER TIPS ‘N TRICKS

The following tips can be used with all PIC MCUs to reduce the power consumption of almost any application.

TIP #12 Internal Oscillator Calibration

An internal RC oscillator calibrated from the factory may require further calibration as the temperature or V_{DD} change. Timer1/SOSC can be used to calibrate the internal oscillator by connecting a 32.768 kHz clock crystal. Refer to AN244, “*Internal RC Oscillator Calibration*” for the complete application details. Calibrating the internal oscillator can help save power by allowing for use of the internal RC oscillator in applications which normally require higher accuracy crystals

Figure 12-1: Timer1 Used to Calibrate an Internal Oscillator



The calibration is based on the measured frequency of the internal RC oscillator. For example, if the frequency selected is 4 MHz, we know that the instruction time is 1 µs (F_{OSC}/4) and Timer1 has a period of 30.5 µs (1/32.768 kHz). This means within one Timer1 period, the core can execute 30.5 instructions. If the Timer1 registers are preloaded with a known value, we can calculate the number of instructions that will be executed upon a Timer1 overflow.

This calculated number is then compared against the number of instructions executed by the core. With the result, we can determine if re-calibration is necessary, and if the frequency must be increased or decreased. Tuning uses the OSCTUNE register, which has a ±12% tuning range in 0.8% steps.

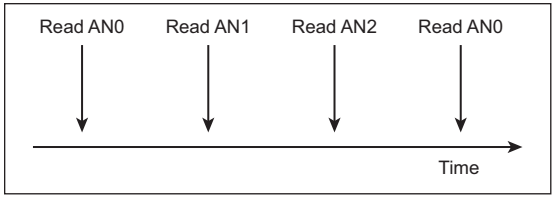
TIP #13 Idle and Doze Modes

nanoWatt and nanoWatt XLP devices have an Idle mode where the clock to the CPU is disconnected and only the peripherals are clocked. In PIC16 and PIC18 devices, Idle mode can be entered by setting the Idle bit in the OSCON register to ‘1’ and executing the `SLEEP` instruction. In PIC24, dsPIC® DSCs, and PIC32 devices, Idle mode can be entered by executing the instruction “`PWRSAV #1`”. Idle mode is best used whenever the CPU needs to wait for an event from a peripheral that cannot operate in Sleep mode. Idle mode can reduce power consumption by as much as 96% in many devices.

Doze mode is another low power mode available in PIC24, dsPIC DSCs, and PIC32 devices. In Doze mode, the system clock to the CPU is postscaled so that the CPU runs at a lower speed than the peripherals. If the CPU is not tasked heavily and peripherals need to run at high speed, then Doze mode can be used to scale down the CPU clock to a slower frequency. The CPU clock can be scaled down from 1:1 to 1:128. Doze mode is best used in similar situations to Idle mode, when peripheral operation is critical, but the CPU only requires minimal functionality.

TIP #11 Sequential ADC Reader

Figure 11-1: Timeline



Trigger Special Event mode (a sub-mode in Compare mode) generates a periodic interrupt in addition to automatically starting an A/D conversion when Timer1 matches CCPRxL and CCPRxH. The following example problem demonstrates how to sequentially read the A/D channels at a periodic interval.

Example

Given the PIC16F684 running on its 8 MHz internal oscillator, configure the microcontroller to sequentially read analog pins AN0, AN1 and AN2 at 30 ms intervals.

Step #1: Determine Timer1 Prescaler

a) Timer1 overflows at: Tosc*4*65536* prescaler.

b) For a prescaler of 1:1, the Timer1 overflow occurs in 32.8 ms.

c) This is greater than 30 ms, so a prescaler of 1 is adequate.

Step #2: Calculate CCPR1 (CCPR1L and CCPR1H)

a) CCPR1 = Interval Time/(Tosc*4*prescaler) = 0.030/(125 ns*4*1) = 6000 = 0xEA60

b) Therefore, CCPR1L = 0x60, and CCPR1H = 0xEA

Step #3: Configuring CCP1CON

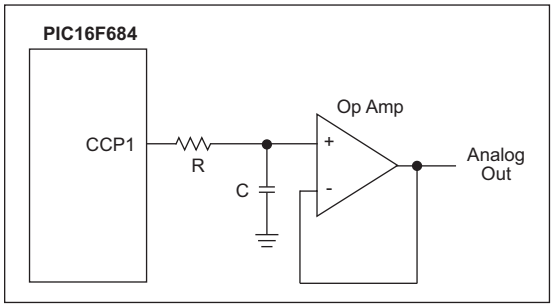
The ECCP module should be configured in Trigger Special Event mode. This mode generates an interrupt when Timer1 equals the value specified in CCPR1. Timer1 is automatically cleared and the GO bit in ADCON0 is automatically set. For this mode, CCP1CON = '`b00001011`'.

Step #4: Add Interrupt Service Routine Logic

When the ECCP interrupt is generated, select the next A/D pin for reading by altering the ADCON0 register.

TIP #16 Generating an Analog Output

Figure 16-1: Low-Pass Filter



Pulse-width modulated signals can be used to create Digital-to-Analog (D/A) converters with only a few external components. Conversion of PWM waveforms to analog signals involves the use of an analog low-pass filter. In order to eliminate unwanted harmonics caused by a PWM signal to the greatest degree possible, the frequency of the PWM signal (F_{PWM}) should be significantly higher than the bandwidth (F_{BW}) of the desired analog signal. Equation 16-1 shows this relation.

Equation 16-1

$$F_{PWM} = K*F_{BW}$$

Where harmonics decrease as K increases

R and C are chosen based on the following equation:

Equation 16-2

$$RC = 1/(2\pi F_{BW})$$

Pick a value of C arbitrarily and then calculate R. The attenuation of the PWM frequency for a given RC filter is:

Equation 16-3

$$Att(dB = -10*\log[1+(2\pi F_{PWM}RC)2]$$

If the attenuation calculated in Equation 16-3 is not sufficient, then K must be increased in Equation 16-1. See Application Note AN538 "*Using PWM to Generate Analog Output in PIC17C42*" for more details on using PWM to generate an analog output.

Example 20-1: Transmit Routine

```
TxRountine
  MOVLW  8          ;preload bit counter
                    ;with 8
  MOVWF  counter
  BCF    TxLine     ;line initially high,
                    ;toggle low for START
                    ;bit
TxLoop
  CALL   DelayTb    ;wait Tb (bit period)
  RRF    RxByte,f   ;rotate LSB first into
                    ;the Carry flag
  BTFSS  STATUS,C   ;Tx line state equals
                    ;state of Carry flag
  BCF    TxLine
  BTFSC  STATUS,C
  BSF    TxLine
  DECFSZ Counter,f  ;Repeat 8 times
  GOTO   TxLoop
  CALL   Delay Tb   ;Delay Tb before
                    ;sending STOP bit
  BSF    TxLine     ;send STOP bit
```

Example 20-2: Receive Routine

```
RxRoutine
  BTFSC  RxLine       ;wait for receive
                      ;line to go low
  GOTO   RxRoutine
  MOVLW  8            ;initialize bit
                      ;counter to 8
  MOVWF  Counter
  CALL   Delay1HalfTb;delay 1/2 Tb here
                      ;plus Tb in RxLoop
                      ;in order to sample
                      ;at the right time
RxLoop
  CALL   DelayTb      ;wait Tb (bit
                      ;period)
  BTFSS  RxLine       ;Carry flag state
                      ;equals Rx line
                      ;state
  BCF    STATUS,C
  BTFSC  RxLine
  BSF    STATUS,C
  BTFSC  RxLine
  BSF    STATUS,C
  RRF    RxByte,f     ;Rotate LSB first
                      ;into receive type
  DECFSZ Counter,f    ;Repeat 8 times
  GOTO   RxLoop
```

NOTES:

CHAPTER 4
PIC® Microcontroller Comparator Tips ‘n Tricks

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TIPS ‘N TRICKS INTRODUCTION

Microchip continues to provide innovative products that are smaller, faster, easier to use and more reliable. The Flash-based PIC® microcontrollers (MCUs) are used in a wide range of everyday products from smoke detectors to industrial, automotive and medical products.

The PIC12F/16F Family of devices with on-chip voltage comparators merge all the advantages of the PIC MCU architecture and the flexibility of Flash program memory with the mixed signal nature of a voltage comparator. Together they form a low-cost hybrid digital/analog building block with the power and flexibility to work in an analog world.

The flexibility of Flash and an excellent development tool suite, including a low-cost In-Circuit Debugger, In-Circuit Serial Programming™ (ICSP™) and MPLAB® ICE 2000 emulation, make these devices ideal for just about any embedded control application.

The following series of Tips ‘n Tricks can be applied to a variety of applications to help make the most of discrete voltage comparators or microcontrollers with on-chip voltage comparators.

TIP #2 Faster Code for Detecting Change

When using a comparator to monitor a sensor, it is often just as important to know when a change occurs as it is to know what the change is. To detect a change in the output of a comparator, the traditional method has been to store a copy of the output and periodically compare the held value to the actual output to determine the change. An example of this type of routine is shown below.

Example 2-1

```
Test
   MOVF  hold,w     ;get old Cout
   XORWF CMCON,w    ;compare to new Cout
   ANDLW COUTMASK
   BTFSC STATUS,Z
   RETLW 0          ;if = return "no change"
   MOVF  CMCON,w    ;if not =, get new Cout
   ANDLW COUTMASK   ;remove all other bits
   MOVWF hold       ;store in holding var.
   IORLW CHNGBIT    ;add change flag
   RETURN
```

This routine requires 5 instructions for each test, 9 instructions if a change occurs, and 1 RAM location for storage of the old output state.

A faster method for microcontrollers with a single comparator is to use the comparator interrupt flag to determine when a change has occurred.

Example 2-2

```
Test
   BTFSS PIR1,CMIF  ;test comparator flag
   RETLW 0          ;if clear, return a 0
   BTFSS CMCON,COUT ;test Cout
   RETLW CHNGBIT    ;if clear return
                    ;CHNGFLAG
   RETLW COUTMASK + CHNGBIT;if set,
                    ;return both
```

This routine requires 2 instructions for each test, 3 instructions if a change occurs, and no RAM storage.

If the interrupt flag can not be used, or if two comparators share an interrupt flag, an alternate method that uses the comparator output polarity bit can be used.

Example 2-3

```
Test
   BTFSS CMCON,COUT ;test Cout
   RETLW 0          ;if clear, return 0
   MOVLW CINVBIT    ;if set, invert Cout
   XORWF CMCON,f    ;forces Cout to 0
   BTFSS CMCON,CINV ;test Cout polarity
   RETLW CHNGFLAG   ;if clear, return
                    ;CHNGFLAG
   RETLW COUTMASK + CHNGFLAG;if set,
                    ;return both
```

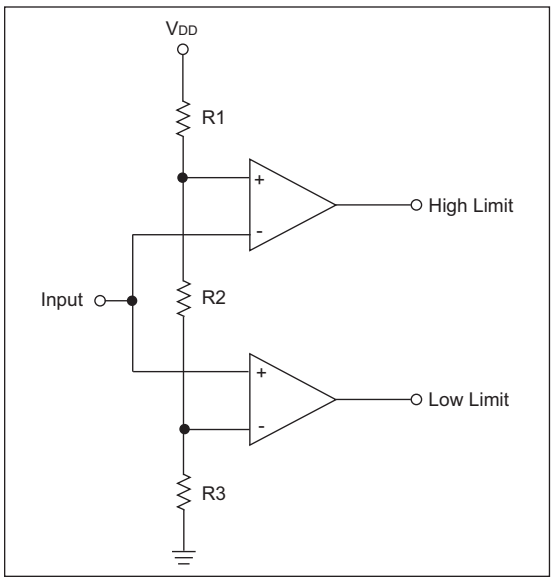
This routine requires 2 instructions for each test, 5 instructions if a change occurs, and no GPR storage.

TIP #5 Window Comparison

When monitoring an external sensor, it is often convenient to be able to determine when the signal has moved outside a pre-established safe operating range of values or window of operation. This windowing provides the circuit with an alarm when the signal moves above or below safety limits, ignoring minor fluctuations inside the safe operating range.

To implement a window comparator, two voltage comparators and 3 resistors are required (see Figure 5-1).

Figure 5-1: Window Comparator



Resistors R1, R2 and R3 form a voltage divider which generates the high and low threshold voltages. The outputs HIGH LIMIT and LOW LIMIT are both active high, generating a logic one on the HIGH LIMIT output when the input voltage rises above the high threshold, and a logic one on the LOW LIMIT output when the input voltage falls below the low threshold.

To calculate values for R1, R2 and R3, find values that satisfy Equation 5-1 and Equation 5-2.

Note: A continuous current will flow through R1, R2 and R3. To limit the power dissipation in the resistors, the total resistance of R1, R2 and R3 should be at least 1k. The total resistance of R1, R2 and R3 should also be kept less than 1 M to prevent offset voltages due to the input bias currents of the comparator.

Equation 5-1

$$V_{TH\text{-}HI} = \frac{V_{DD} * (R_3 + R_2)}{R1 + R2 + R3}$$

Equation 5-2

$$V_{TH\text{-}LO} = \frac{V_{DD} * R_3}{R1 + R2 + R3}$$

Example:

- V_{DD} = 5.0V, V_{TH} = 2.5V, V_{TL} = 2.0V
- R1 = 12k, R2 = 2.7k, R3 = 10k
- V_{TH} (actual) = 2.57V, V_{TL} (actual) = 2.02V

Adding Hysteresis:

To add hysteresis to the HIGH LIMIT comparator, follow the procedure outlined in Tip #3. Use the series combination of R2 and R3 as the resistor R2 in Tip #3.

To add hysteresis to the LOW LIMIT comparator, choose a suitable value for Req, 1k to 10 k , and place it between the circuit input and the non-inverting input of the LOW LIMIT comparator. Then calculate the needed feedback resistor using Equation 3-4 and Equation 3-5.

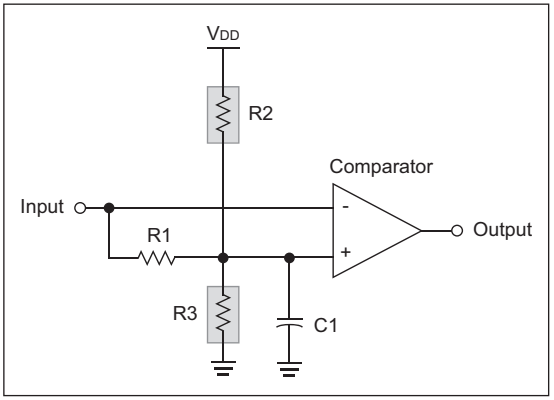
TIP #6 Data Slicer

In both wired and wireless data transmission, the data signal may be subject to DC offset shifts due to temperature shifts, ground currents or other factors in the system. When this happens, using a simple level comparison to recover the data is not possible because the DC offset may exceed the peak-to-peak amplitude of the signal. The circuit typically used to recover the signal in this situation is a data slicer.

The data slicer shown in Figure 6-1 operates by comparing the incoming signal with a sliding reference derived from the average DC value of the incoming signal. The DC average value is found using a simple RC low-pass filter (R1 and C1). The corner frequency of the RC filter should be high enough to ignore the shifts in the DC level while low enough to pass the data being transferred.

Resistors R2 and R3 are optional. They provide a slight bias to the reference, either high or low, to give a preference to the state of the output when no data is being received. R2 will bias the output low and R3 will bias the output high. Only one resistor should be used at a time, and its value should be at least 50 to 100 times larger than R1.

Figure 6-1: Data Slicer



Example:

Data rate of 10 kbits/second. A low pass filter frequency of 500 Hz: R1 = 10k, C1 = 33 μF. R2 or R3 should be 500k to 1 MB.

TIP #6 Current Sensing

The torque of an electric motor can be monitored and controlled by keeping track of the current flowing through the motor. Torque is directly proportional to the current. Current can be sensed by measuring the voltage drop through a known value resistor or by measuring the magnetic field strength of a known value inductor. Current is generally sensed at one of two places, the supply side of the drive circuit (high side current sense) or the sink side of the drive circuit (low side current sense). Low side sensing is much simpler but the motor will no longer be grounded, causing a safety issue in some applications. High side current sensing generally requires a differential amplifier with a common mode voltage range within the voltage of the supply.

Figure 6-1: Resistive High Side Current Sensing

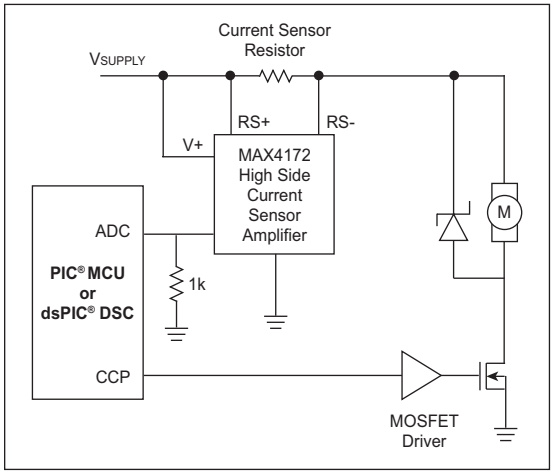
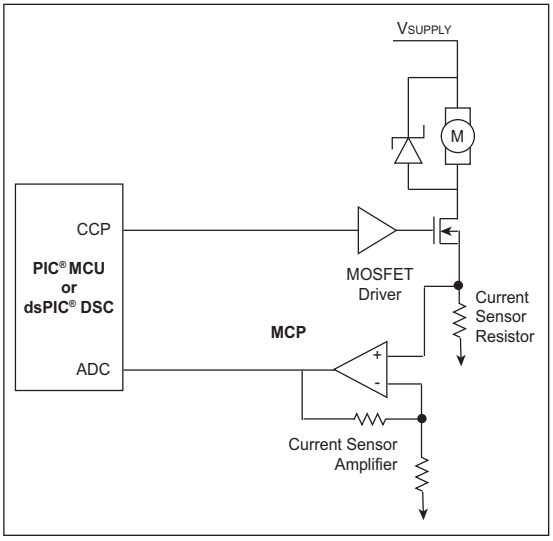
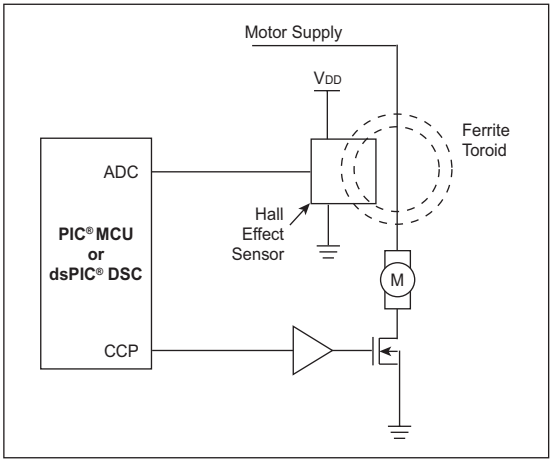


Figure 6-2: Resistive Low Side Current Sensing



Current measurement can also be accomplished using a Hall effect sensor to measure the magnetic field surrounding a current carrying wire. Naturally, this Hall effect sensor can be located on the high side or the low side of the load. The actual location of the sensor does not matter because the sensor does not rely upon the voltage on the wire. This is a non-intrusive method that can be used to measure motor current.

Figure 6-3: Magnetic Current Sensing



CHAPTER 7
Intelligent Power Supply Design Tips ‘n Tricks

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TIPS ‘N TRICKS INTRODUCTION

Microchip continues to provide innovative products that are smaller, faster, easier-to-use and more reliable. PIC® microcontrollers (MCUs) are used in a wide range of everyday products from washing machines, garage door openers and television remotes to industrial, automotive and medical products.

While some designs such as Switch Mode Power Supplies (SMPS) are traditionally implemented using a purely analog control scheme, these designs can benefit from the configurability and intelligence that can only be realized by adding a microcontroller.

This document showcases several examples in which a PIC microcontroller may be used to increase the functionality of a design with a minimal increase in cost.

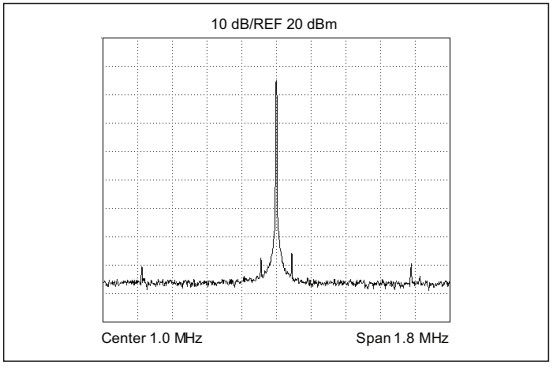
Several of the tips provide working software examples or reference other documents for more information. The software and referenced documents can be found on the Microchip web site at www.microchip.com/tipsntricks.

TIP #4 Creating a Dithered PWM Clock

In order to meet emissions requirements as mandated by the FCC and other regulatory organizations, the switching frequency of a power supply can be varied. Switching at a fixed frequency produces energy at that frequency. By varying the switching frequency, the energy is spread out over a wider range and the resulting magnitude of the emitted energy at each individual frequency is lower.

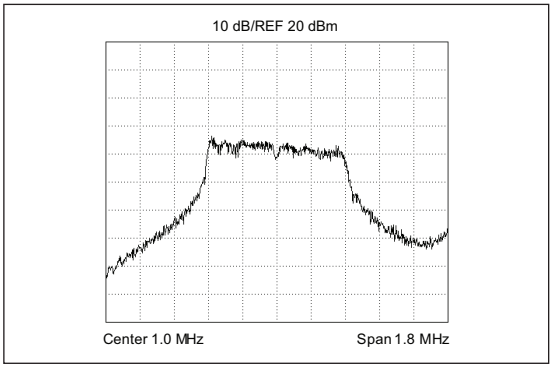
The PIC10F200 has an internal 4 MHz oscillator. A scaled version of oscillator can be output on a pin (Fosc/4). The scaled output is 1/4 of the oscillator frequency (1 MHz) and will always have a 50% duty cycle. Figure 4-1 shows a spectrum analyzer shot of the output of the Fosc/4 output.

Figure 4-1: Spectrum of Clock Output Before Dithering



The PIC10F200 provides an Oscillator Calibration (OSCCAL) register that is used to calibrate the frequency of the oscillator. By varying the value of the OSCCAL setting, the frequency of the clock output can be varied. A pseudo-random sequence was used to vary the OSCCAL setting, allowing frequencies from approximately 600 kHz to 1.2 MHz. The resulting spectrum is shown in Figure 4-2.

Figure 4-2: Spectrum of Clock Output After Dithering



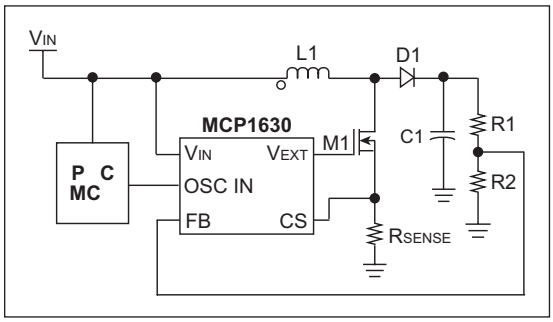
By spreading the energy over a wider range of frequencies, a drop of more than 20 dB is achieved.

Example software is provided for the PIC10F200 that performs the pseudo-random sequence generation and loads the OSCCAL register.

TIP #5 Using a PIC® Microcontroller as a Clock Source for a SMPS PWM Generator

A PIC MCU can be used as the clock source for a PWM generator, such as the MCP1630.

Figure 5-1: PIC MCU and MCP1630 Example Boost Application



The MCP1630 begins its cycle when its clock/oscillator source transitions from high-to-low, causing its PWM output to go high state. The PWM pulse can be terminated in any of three ways:

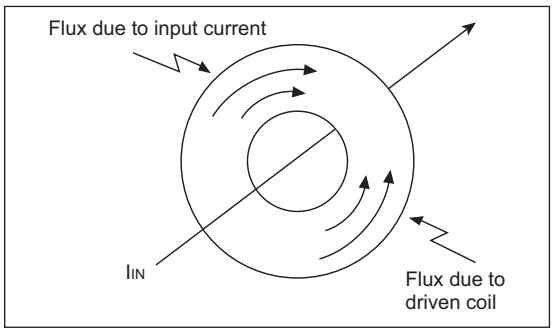
1. The sensed current in the magnetic device reaches 1/3 of the error amplifier output.
2. The voltage at the Feedback (FB) pin is higher than the reference voltage (V_{REF}).
3. The clock/oscillator source transitions from low-to-high.

The switching frequency of the MCP1630 can be adjusted by changing the frequency of the clock source. The maximum on-timer of the MCP1630 PWM can be adjusted by changing the duty cycle of the clock source.

The PIC MCU has several options for providing this clock source:

- The Fosc/4 pin can be enabled. This will produce a 50% duty cycle square wave that is 1/4th of the oscillator frequency. Tip #4 provides both example software and information on clock dithering using the $F_{OSC}/4$ output.
- For PIC MCUs equipped with a Capture/Compare/PWM (CCP) or Enhanced CCP (ECCP) module, a variable frequency, variable duty cycle signal can be created with little software overhead. This PWM signal is entirely under software control and allows advanced features, such as soft-start, to be implemented using software.
- For smaller parts that do not have a CCP or ECCP module, a software PWM can be created. Tips #1 and #2 use software PWM for soft-start and provide software examples.

Figure 15-2: Flux Directions



The net flux in the core should be approximately zero. Because the flux will always be very near zero, the core will be very linear over the small operating range.

When I_{IN} = 0, the output of the comparator will have an approximate 50% duty cycle. As the current moves one direction, the duty cycle will increase. As the current moves the other direction, the duty cycle will decrease. By measuring the duty cycle of the resulting comparator output, we can determine the value of I_{IN}.

Finally, a Delta-Sigma ADC can be used to perform the actual measurement. Features such as comparator sync and Timer1 gate allow the Delta-Sigma conversion to be taken care of entirely in hardware. By taking 65,536 (2^16) samples and counting the number of samples that the comparator output is low or high, we can obtain a 16-bit A/D result.

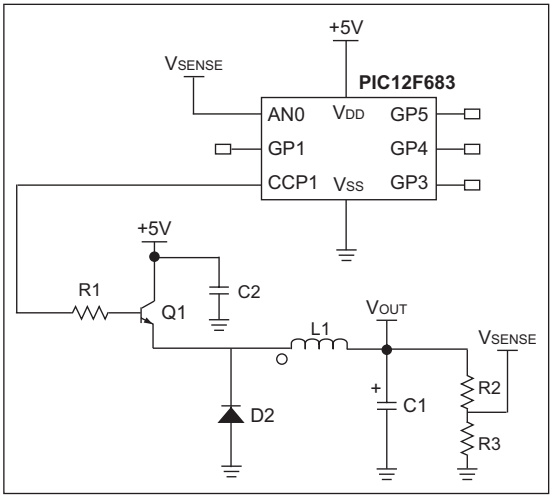
Example schematic and software are provided for the PIC12F683 in both C and Assembly.

For more information on using a PIC MCU to implement a Delta-Sigma converter, please refer to AN700, “*Make a Delta-Sigma Converter Using a Microcontroller’s Analog Comparator Module*” (DS00700), which includes example software.

TIP #16 Implementing a PID Feedback Control in a PIC12F683-Based SMPS Design

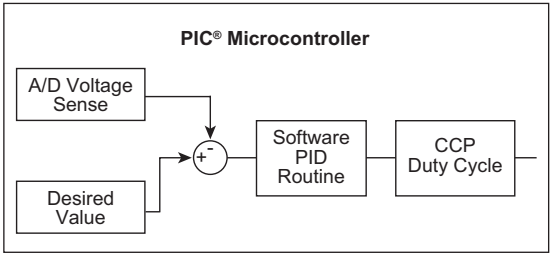
Simple switching power supplies can be controlled digitally using a Proportional Integral Derivative (PID) algorithm in place of an analog error amplifier and sensing the voltage using the Analog-to-Digital Converter (ADC).

Figure 16-1: Simple PID Power Supply



The design in Figure 16-1 utilizes an 8-pin PIC12F683 PIC MCU in a buck topology. The PIC12F683 has the basic building blocks needed to implement this type of power supply: an A/D converter and a CCP module.

Figure 16-2: PID Block Diagram



TIP #19 Execution-Indexed Software State Machine

Another common type of state machine is the execution-indexed state machine. This type of state machine uses a state variable in order to determine what is executed. In C, this can be thought of as the switch statement structure as shown in Example 19-1.

Example 19-1: Example Using Switch Statement

```
SWITCH (State)
{
  CASE 0: IF (in_key()==5)  THEN state = 1;
          Break;
  CASE 1: IF (in_key()==8)  THEN State = 2;
                            Else State = 0;
          Break;
  CASE 2: IF (in_key()==3)  THEN State = 3;
                            Else State = 0;
          Break;
  CASE 3: IF (in_key()==2)  THEN UNLOCK();
                            Else State = 0;
          Break;
}
```

Each time the software runs through the loop, the action taken by the state machine changes with the value in the state variable. By allowing the state machine to control its own state variable, it adds memory, or history, because the current state will be based on previous states. The microcontroller is able to make current decisions based on previous inputs and data.

In assembly, an execution-indexed state machine can be implemented using a jump table.

Example 19-2: Example Using a Jump Table

```
  MOVFW   state      ;load state into w
  ADDWF   PCL,f      ;jump to state
                     ;number
  GOTO    state0     ;state 0
  GOTO    state1     ;state 1
  GOTO    state2     ;state 2
  GOTO    state3     ;state 3
  GOTO    state4     ;state 4
  GOTO    state5     ;state 5
```

In Example 19-2, the program will jump to a GOTO statement based on the state variable. The GOTO statement will send the program to the proper branch. Caution must be taken to ensure that the variable will never be larger than intended. For example, six states (000 to 101) require a three-bit state variable. Should the state variable be set to an undefined state (110 to 111), program behavior would become unpredictable.

Means for safeguarding this problem include:

- Mask off any unused bits of the variable. In the above example, ANDLW b’00000111’ will ensure that only the lower 3 bits of the number contain a value.
- Add extra cases to ensure that there will always be a known jump. For example in this case, two extra states must be added and used as error or Reset states.

TIP #4 Powering 3.3V Systems From 5V Using Switching Regulators

A buck switching regulator, shown in Figure 4-1, is an inductor-based converter used to step-down an input voltage source to a lower magnitude output voltage. The regulation of the output is achieved by controlling the ON time of MOSFET Q1. Since the MOSFET is either in a lower or high resistive state (ON or OFF, respectively), a high source voltage can be converted to a lower output voltage very efficiently.

The relationship between the input and output voltage can be established by balancing the volt-time of the inductor during both states of Q1.

Equation 4-1

$$(V_S - V_O) * t_{on} = Vo * (T - t_{on})$$
$$\text{Where: } T \equiv t_{on}/\text{Duty\_Cycle}$$

It therefore follows that for MOSFET Q1:

Equation 4-2

$$\text{Duty\_Cycle}_{Q1} = V_O/Vs$$

When choosing an inductor value, a good starting point is to select a value to produce a maximum peak-to-peak ripple current in the inductor equal to ten percent of the maximum load current.

Equation 4-3

$$V = L * (di/dt)$$
$$L = (V_S - V_O) * (t_{on}/I_o * 0.10)$$

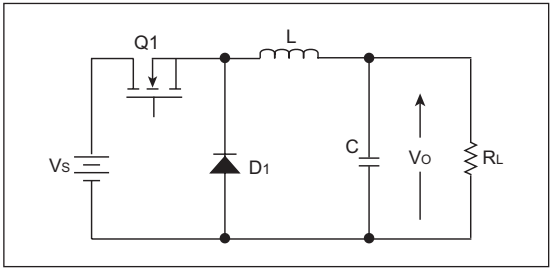
When choosing an output capacitor value, a good starting point is to set the LC filter characteristic impedance equal to the load resistance. This produces an acceptable voltage overshoot when operating at full load and having the load abruptly removed.

Equation 4-4

$$Z_o \equiv \sqrt{L/C}$$
$$C = L/R^2 = (I_O^2 * L)/V_O^2$$

When choosing a diode for D1, choose a device with a sufficient current rating to handle the inductor current during the discharge part of the pulse cycle (I_L).

Figure 4-1: Buck Regulator



Digital Interfacing

When interfacing two devices that operate at different voltages, it is imperative to know the output and input thresholds of both devices. Once these values are known, a technique can be selected for interfacing the devices based on the other requirements of your application. Table 4-1 contains the output and input thresholds that will be used throughout this document. When designing an interface, make sure to reference your manufacturers data sheet for the actual threshold levels.

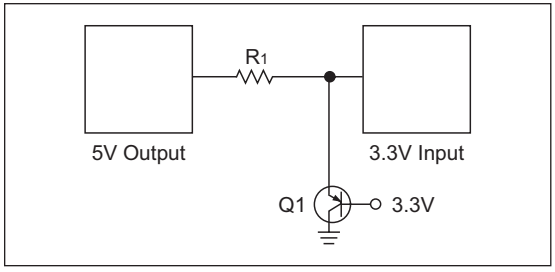
Table 4-1: Input/Output Thresholds

	V_{OH} min	V_{OL} max	V_{IH} min	V_{IL} max
5V TTL	2.4V	0.5V	2.0V	0.8V
3.3V LVTTL	2.4V	0.4V	2.0V	0.8V
5V CMOS	4.7V (Vcc-0.3V)	0.5V	3.5V (0.7xVcc)	1.5V (0.3xVcc)
3.3V LVCMOS	3.0V (Vcc-0.3V)	0.5V	2.3V (0.7xVcc)	1.0V (0.3xVcc)

TIP #11 5V → 3.3V Active Clamp

One problem with using a diode clamp is that it injects current onto the 3.3V power supply. In designs with a high current 5V outputs, and lightly loaded 3.3V power supply rails, this injected current can float the 3.3V supply voltage above 3.3V. To prevent this problem, a transistor can be substituted which routes the excess output drive current to ground instead of the 3.3V supply. Figure 11-1 shows the resulting circuit.

Figure 11-1: Transistor Clamp

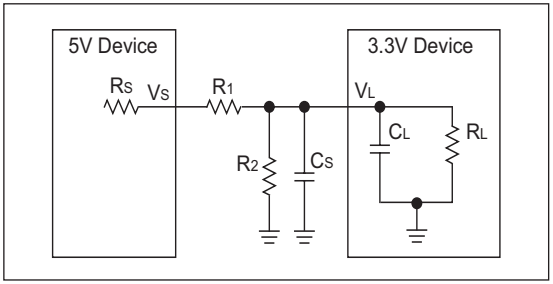


The base-emitter junction of Q1 performs the same function as the diode in a diode clamp circuit. The difference is that only a small percentage of the emitter current flows out of the base of the transistor to the 3.3V rail, the bulk of the current is routed to the collector where it passes harmlessly to ground. The ratio of base current to collector current is dictated by the current gain of the transistor, typically 10-400, depending upon which transistor is used.

TIP #12 5V → 3.3V Resistor Divider

A simple resistor divider can be used to reduce the output of a 5V device to levels appropriate for a 3.3V device input. An equivalent circuit of this interface is shown in Figure 12-1.

Figure 12-1: Resistive Interface Equivalent Circuit



Typically, the source resistance, Rs, is very small (less than 10Ω) so its affect on R1 will be negligible provided that R1 is chosen to be much larger than Rs. At the receive end, the load resistance, R_L, is very large (greater than 500 kΩ) so its affect on R2 will be negligible provided that R2 is chosen to be much less than R_L.

There is a trade-off between power dissipation and transition times. To keep the power requirements of the interface circuit at a minimum, the series resistance of R1 and R2 should be as large as possible. However, the load capacitance, which is the combination of the stray capacitance, Cs, and the 3.3V device input capacitance, C_L, can adversely affect the rise and fall times of the input signal. Rise and fall times can be unacceptably long if R1 and R2 are too large.