# Microchip Technology - PIC16C716-04E/SS Datasheet

## 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 | 4MHz |
| Connectivity | - |
| Peripherals | Brown-out Detect/Reset, POR, PWM, WDT |
| Number of I/O | 13 |
| Program Memory Size | 3.5KB (2K x 14) |
| Program Memory Type | OTP |
| EEPROM Size | - |
| RAM Size | 128 x 8 |
| Voltage - Supply (Vcc/Vdd) | 4V ~ 5.5V |
| Data Converters | A/D 4x8b |
| Oscillator Type | External |
| Operating Temperature | -40°C ~ 125°C (TA) |
| Mounting Type | Surface Mount |
| Package / Case | 20-SSOP (0.209", 5.30mm Width) |
| Supplier Device Package | 20-SSOP |
| Purchase URL | https://www.e-xfl.com/product-detail/microchip-technology/pic16c716-04e-ss |

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

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TIPS ‘N TRICKS WITH HARDWARE

TIPS ‘N TRICKS WITH SOFTWARE

## 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.

# CHAPTER 2
# PIC® Microcontroller Low Power Tips ‘n Tricks

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### GENERAL LOW POWER TIPS ‘N TRICKS

### DYNAMIC OPERATION TIPS ‘N TRICKS

### STATIC POWER REDUCTION TIPS ‘N TRICKS

## 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.

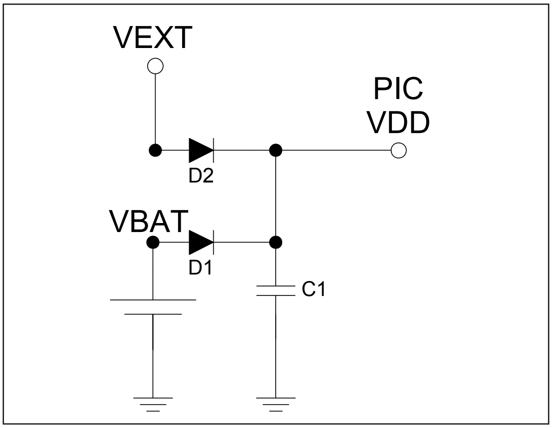
## GENERAL LOW POWER TIPS ‘N TRICKS

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

## TIP #7 Battery Backup for PIC MCUs

For an application that can operate from either an external supply or a battery backup, it is necessary to be able to switch from one to the other without user intervention. This can be accomplished with battery backup ICs, but it is also possible to implement with a simple diode OR circuit, shown in Figure 7-1. Diode D1 prevents current from flowing into the battery from VEXT when the external power is supplied. D2 prevents current from flowing into any external components from the battery if VEXT is removed. As long as the external source is present and higher voltage than the battery, no current from the battery will be used. When VEXT is removed and the voltage drops below VBAT, the battery will start powering the MCU. Low forward voltage Schottky diodes can be used in order to minimize the voltage dropout from the diodes. Additionally, inputs can be referenced to VEXT and VBAT in order to monitor the voltage levels of the battery and the external supply. This allows the micro to enter lower power modes when the supply is removed or the battery is running low. In order to avoid glitches on $V_{DD}$ caused by the diode turn-on delay when switching supplies, ensure enough decoupling capacitance is used on $V_{DD}$ (C1).

**Figure 7-1:**



## Dynamic Operation Tips n’ Tricks

The following tips and tricks apply to methods of improving the dynamic operating current consumption of an application. This allows an application to get processing done quicker which enables it to sleep more and will help reduce the current consumed while processing.

## TIP #8 Enhanced PIC16 Mid-Range Core

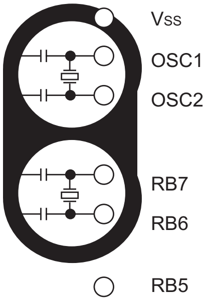
The Enhanced PIC16 mid-range core has a few features to assist in low power. New instructions allow many applications to execute in less time. This allows the application to spend more time asleep and less time processing and can provide considerable power savings. It is important not to overlook these new instructions when designing with devices that contain the new core. The Timer1 oscillator and WDT have also been improved, now meeting nanoWatt XLP requirements and drawing much less current than in previous devices.

## TIP #19 Low Power Timer1 Oscillator Layout

Applications requiring very low power Timer1/SOSC oscillators on nanoWatt and nanoWatt XLP devices must take PCB layout into consideration. The very low power Timer1/SOSC oscillators on nanoWatt and nanoWatt XLP devices consume very little current, and this sometimes makes the oscillator circuit sensitive to neighboring circuits. The oscillator circuit (crystal and capacitors) should be located as close as possible to the microcontroller.

No circuits should be passing through the oscillator circuit boundaries. If it is unavoidable to have high-speed circuits near the oscillator circuit, a guard ring should be placed around the oscillator circuit and microcontroller pins similar to the figure below. Placing a ground plane under the oscillator components also helps to prevent interaction with high speed circuits.

**Figure 19-1: Guard Ring Around Oscillator Circuit and MCU Pins**



## TIP #20 Use LVD to Detect Low Battery

The Low Voltage Detect (LVD) interrupt present in many PIC MCUs is critical in battery based systems. It is necessary for two reasons. First, many devices cannot run full speed at the minimum operating voltage. In this case, the LVD interrupt indicates when the battery voltage is dropping so that the CPU clock can be slowed down to an appropriate speed, preventing code misexecution. Second, it allows the MCU to detect when the battery is nearing the end of its life, so that a low battery indication can be provided and a lower power state can be entered to maximize battery lifetime. The LVD allows these functions to be implemented without requiring the use of extra analog channels to measure the battery level.

## TIP #21 Use Peripheral FIFO and DMA

Some devices have peripherals with DMA or FIFO buffers. These features are not just useful to improve performance; they can also be used to reduce power. Peripherals with just one buffer register require the CPU to stay operating in order to read from the buffer so it doesn’t overflow. However, with a FIFO or DMA, the CPU can go to sleep or idle until the FIFO fills or DMA transfer completes. This allows the device to consume a lot less average current over the life of the application.

## TIP #5 Measuring RPM Using an Encoder

Revolutions Per Minute (RPM), or how fast something turns, can be sensed in a variety of ways. Two of the most common sensors used to determine RPM are optical encoders and Hall effect sensors. Optical encoders detect the presence of light shining through a slotted wheel mounted to a turning shaft (see Figure 5-1.) As the shaft turns, the slots in the wheel pass by the eye of the optical encoder. Typically, an infrared source on the other side of the wheel emits light that is seen by the optical encoder through slots in the wheel. Hall effect sensors work by sensing the position of the magnets in an electric motor, or by sensing a permanent magnet mounted to a rotating object (see Figure 5-2). These sensors output one or more pulses per revolution (depending on the sensor).

**Figure 5-1: Optical Encoder**

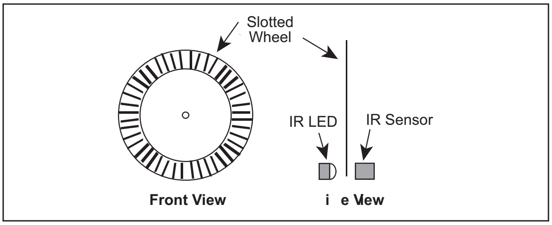
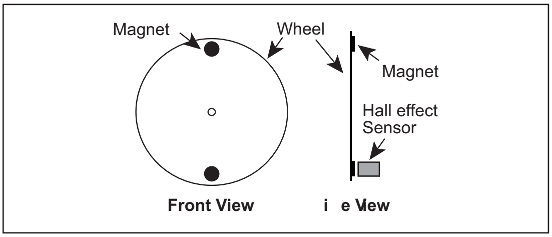


**Figure 5-2: Hall Effect Sensor**



In Figure 5-3 and Figure 5-4, the waveform is high when light is passing through a slot in the encoder wheel and shining on the optical sensor. In the case of a Hall effect sensor, the high corresponds to the time that the magnet is in front of the sensor. These figures show the difference in the waveforms for varying RPMs. Notice that as RPM increases, the period (T) and pulse width (W) becomes smaller. Both period and pulse width are proportional to RPM. However, since the period is the greater of the two intervals, it is good practice to measure the period so that the RPM reading from the sensor will have the best resolution. See Tip #1 for measuring period. The technique for measuring period with averaging described in Tip #2 is useful for measuring high RPMs.

**Figure 5-3: Low RPM**

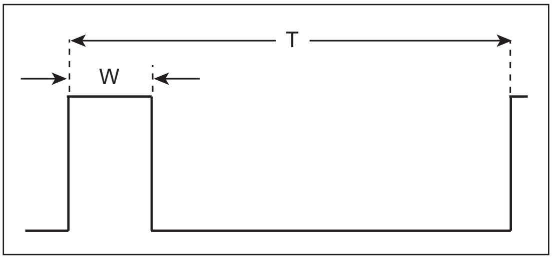
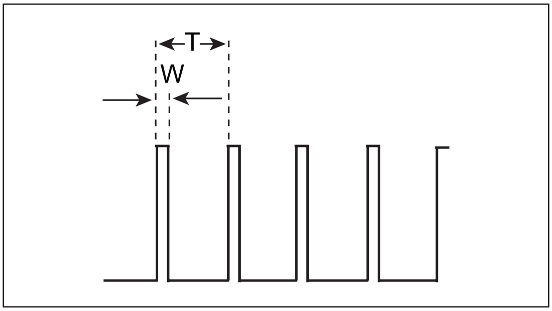


**Figure 5-4: High RPM**



## TIP #7 Periodic Interrupts

Generating interrupts at periodic intervals is a useful technique implemented in many applications. This technique allows the main loop code to run continuously, and then, at periodic intervals, jump to the interrupt service routine to execute specific tasks (i.e., read the ADC). Normally, a timer overflow interrupt is adequate for generating the periodic interrupt. However, sometimes it is necessary to interrupt at intervals that can not be achieved with a timer overflow interrupt. The CCP configured in Compare mode makes this possible by shortening the full 16-bit time period.

**Example Problem:**

A PIC16F684 running on its 8 MHz internal oscillator needs to be configured so that it updates a LCD exactly 5 times every second.

**Step #1: Determine a Timer1 prescaler that allows an overflow at greater than 0.2 seconds**

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

b) For a prescaler of 1:1, Timer1 overflows in 32.8 ms.

c) A prescaler of 8 will cause an overflow at a time greater than 0.2 seconds.
8 x 32.8 ms = 0.25s

**Step #2: Calculate CCPR1 (CCPR1L and CCPR1H) to shorten the time-out to exactly 0.2 seconds**

a) CCPR1 = Interval Time/(TOSC*4*prescaler) = 0.2/(125 ns*4*8) = 5000 = 0xC350

b) Therefore, CCPR1L = 0x50, and CCPR1H = 0xC3

**Step #3: Configuring CCP1CON**

The CCP module should be configured in Trigger Special Event mode. This mode generates an interrupt when the Timer1 equals the value specified in CCPR1L and Timer1 is automatically cleared[1]. For this mode, CCP1CON = ‘`b00001011`’.

**Note 1:** Trigger Special Event mode also starts an A/D conversion if the A/D module is enabled. If this functionality is not desired, the CCP module should be configured in “generate software interrupt-on-match only” mode (i.e., CCP1CON = `b`‘`00001010`’). Timer 1 must also be cleared manually during the CCP interrupt.

## TIP #9 Generating the Time Tick for a RTOS

Real Time Operating Systems (RTOS) require a periodic interrupt to operate. This periodic interrupt, or “tick rate”, is the basis for the scheduling system that RTOS’s employ. For instance, if a 2 ms tick is used, the RTOS will schedule its tasks to be executed at multiples of the 2 ms. A RTOS also assigns a priority to each task, ensuring that the most critical tasks are executed first. Table 9-1 shows an example list of tasks, the priority of each task and the time interval that the tasks need to be executed.

**Table 9-1: Tasks**

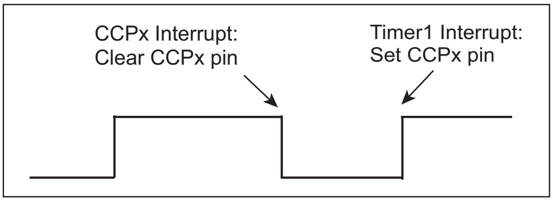
| Task | Interval | Priority |
|---|---|---|
| Read ADC Input 1 | 20 ms | 2 |
| Read ADC Input 2 | 60 ms | 1 |
| Update LCD | 24 ms | 2 |
| Update LED Array | 36 ms | 3 |
| Read Switch | 10 ms | 1 |
| Dump Data to Serial Port | 240 ms | 1 |

The techniques described in Tip #7 can be used to generate the 2 ms periodic interrupt using the CCP module configured in Compare mode.

> **Note:** For more information on RTOSs and their use, see Application Note AN777 “*Multitasking on the PIC16F877 with the Salvo™ RTOS*”.

## TIP #10 16-Bit Resolution PWM

**Figure 10-1: 16-Bit Resolution PWM**



1. Configure CCPx to clear output (CCPx pin) on match in Compare mode (CCPxCON <CCPSM3:CCPxM0>).
2. Enable the Timer1 interrupt.
3. Set the period of the waveform via Timer1 prescaler (T1CON <5:4>).
4. Set the duty cycle of the waveform using CCPRxL and CCPRxH.
5. Set CCPx pin when servicing the Timer1 overflow interrupt[1].

> **Note 1:** One hundred percent duty cycle is not achievable with this implementation due to the interrupt latency in servicing Timer1. The period is not affected because the interrupt latency will be the same from period to period as long as the Timer1 interrupt is serviced first in the ISR.

Timer1 has four configurable prescaler values. These are 1:1, 1:2, 1:4 and 1:8. The frequency possibilities of the PWM described above are determined by Equation 10-1.

**Equation 10-1**

$$F_{PWM} = F_{OSC}/(65536*4*prescaler)$$

For a microcontroller running on a 20 MHz oscillator (Fosc) this equates to frequencies of 76.3 Hz, 38.1 Hz, 19.1 Hz and 9.5 Hz for increasing prescaler values.

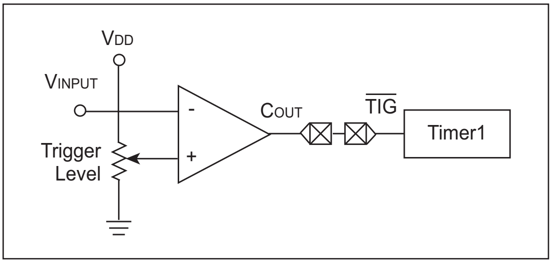
## TIP #4 Pulse Width Measurement

To measure the high or low pulse width of an incoming analog signal, the comparator can be combined with Timer1 and the Timer1 Gate input option (see Figure 4-1). Timer1 Gate acts as a count enable for Timer1. If the input is low, Timer1 will count. If the $\overline{\text{T1G}}$ input is high, Timer1 does not count. Combining $\overline{\text{T1G}}$ with the comparator allows the designer to measure the time between a high-to-low output change and a low-to-high output change.

To make a measurement between a low-to-high and a high-to-low transition, the only change required is to set the CINV bit in the comparator CMCON register which inverts the comparator output.

Because the output of the comparator can change asynchronously with the Timer1 clock, only comparators with the ability to synchronize their output with the Timer1 clock should be used and their C2SYNC bits should be set.

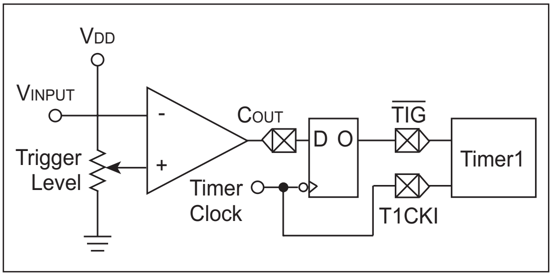
**Figure 4-1: Comparator with Timer1 and $\overline{\text{T1G}}$**



If the on-chip comparator does not have the ability to synchronize its output to the Timer1 clock, the output can be synchronized externally using a discrete D flip-flop (see Figure 4-2).

> **Note:** The flip-flop must be falling edge triggered to prevent a race condition.

**Figure 4-2: Externally Synchronized Comparator**

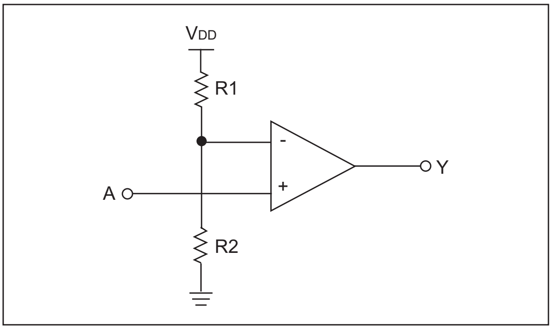


## TIP #15 Level Shifter

This tip shows the use of the comparator as a digital logic level shifter. The inverting input is biased to the center of the input voltage range ($V_{IN}/2$). The non-inverting input is then used for the circuit input. When the input is below the $V_{IN}/2$ threshold, the output is low. When the input is above $V_{IN}/2$, then the output is high. Values for R1 and R2 are not critical, though their ratio should result in a threshold voltage $V_{IN}/2$ at the mid-point of the input signal voltage range. Some microcontrollers have the option to connect the inverting input to an internal voltage reference. To use the reference in place of R1 and R2, simply select the internal reference and configure it for one half the input voltage range.

**Note:** Typical propagation delay for the circuit is 250-350 ns using the typical on-chip comparator peripheral of a microcontroller.

**Figure 15-1: Level Shifter**



**Example:**

- $V_{IN}$ = 0 - 2V, $V_{IN}/2$ = 1V, $V_{DD}$ = 5V
- R2 = 10k, R3 = 3.9k

## TIP #16 Logic: Inverter

When designing embedded control applications, there is often the need for an external gate. Using the comparator, several simple gates can be implemented. This tip shows the use of the comparator as an inverter.

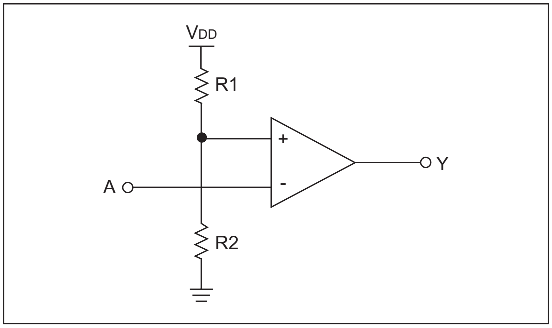
The non-inverting input is biased to the center of the input voltage range, typically $V_{DD}/2$. The inverting input is then used for the circuit input. When the input is below $V_{DD}/2$, the output is high. When the input is above $V_{DD}/2$, then the output is low.

Values for R1 and R2 are not critical, though they must be equal to set the threshold at $V_{DD}/2$.

Some microcontrollers have the option to connect the inverting input to an internal voltage reference. To use the reference in place of R1 and R2, move the input to the non-inverting input and set the output polarity bit in the comparator control register to invert the comparator output.

**Note:** Typical propagation delay for the circuit is 250-350 ns using the typical on-chip comparator peripheral of a microcontroller.

**Figure 16-1: Inverter**



## TIP #2 Brushless DC Motor Drive Circuits

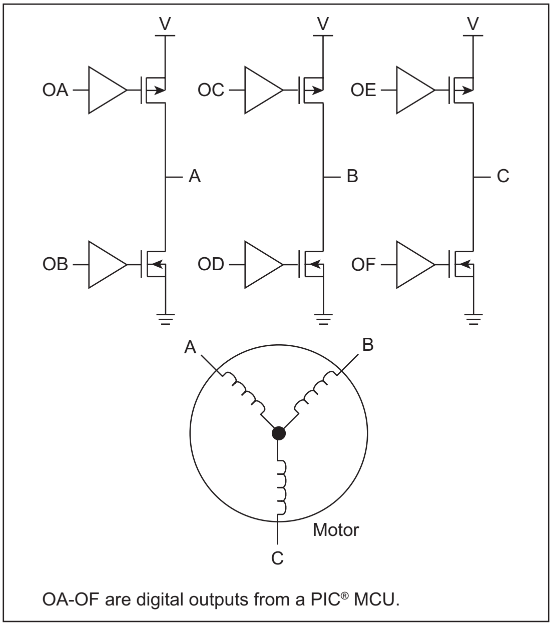
A Brushless DC motor is a good example of simplified hardware increasing the control complexity. The motor cannot commutate the windings (switch the current flow), so the control circuit and software must control the current flow correctly to keep the motor turning smoothly. The circuit is a simple half-bridge on each of the three motor windings.

There are two basic commutation methods for Brushless DC motors; sensored and sensorless. Because it is critical to know the position of the motor so the correct winding can be energized, some method of detecting the rotor position is required. A motor with sensors will directly report the current position to the controller. Driving a sensored motor requires a look-up table. The current sensor position directly correlates to a commutation pattern for the bridge circuits.

Without sensors, another property of the motor must be sensed to find the position. A popular method for sensorless applications is to measure the back EMF voltage that is naturally generated by the motor magnets and windings. The induced voltage in the un-driven winding can be sensed and used to determine the current speed of the motor. Then, the next commutation pattern can be determined by a time delay from the previous pattern.

Sensorless motors are lower cost due to the lack of the sensors, but they are more complicated to drive. A sensorless motor performs very well in applications that don’t require the motor to start and stop. A sensor motor would be a better choice in applications that must periodically stop the motor.

**Figure 2-1: 3 Phase Brushless DC Motor Control**



OA-OF are digital outputs from a PIC® MCU.

**Figure 2-2: Back EMF Sensing (Sensorless Motor)**

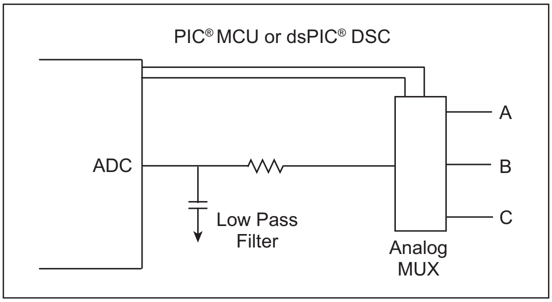
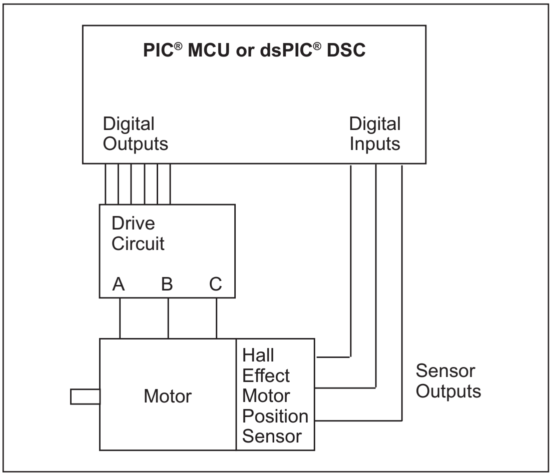


**Figure 2-3: Quadrature Decoder (Sensor Motor)**



Application notes describing Brushless DC Motor Control are listed below and can be found on the Microchip web site at: www.microchip.com.

- AN857, “*Brushless DC Motor Control Made Easy*” (DS00857)
- AN885, “*Brushless DC Motor Fundamentals*” (DS00885)
- AN899, “*Brushless DC Motor Control Using PIC18FXX31*” (DS00899)
- AN901, “*Using the dsPIC30F for Sensorless BLDC Control*” (DS00901)
- AN957, “*Sensored BLDC Motor Control Using dsPIC30F2010*” (DS00957)
- AN992, “*Sensorless BLDC Motor Control Using dsPIC30F2010*” (DS00992)
- AN1017, “*Sinusoidal Control of PMSM with dsPIC30F DSC*” (DS01017)
- GS005, “*Using the dsPIC30F Sensorless Motor Tuning Interface*” (DS93005)

## TIP #3 Stepper Motor Drive Circuits

Stepper motors are similar to Brushless DC motors in that the control system must commutate the motor through the entire rotation cycle. Unlike the brushless motor, the position and speed of a stepping motor is predictable and does not require the use of sensors.

There are two basic types of stepper motors, although some motors are built to be used in either mode. The simplest stepper motor is the unipolar motor. This motor has four drive connections and one or two center tap wires that are tied to ground or Vsupply, depending on the implementation. Other motor types are the bipolar stepper and various combinations of unipolar and bipolar, as shown in Figure 3-1 and Figure 3-2. When each drive connection is energized, one coil is driven and the motor rotates one step. The process is repeated until all the windings have been energized. To increase the step rate, often the voltage is increased beyond the motors rated voltage. If the voltage is increased, some method of preventing an over current situation is required.

There are many ways to control the winding current, but the most popular is a chopper system that turns off current when it reaches an upper limit and enables the current flow a short time later. Current sensor systems are discussed in Tip #6. Some systems are built with a current chopper, but they do not detect the current, rather the system is designed to begin a fixed period chopping cycle after the motor has stepped to the next position. These are simpler systems to build, as they only require a change in the software.

## TIP #8 In-Circuit Debug (ICD)

There are two potential issues with using the ICD to debug LCD applications. First, the LCD controller can freeze while the device is Halted. Second, the ICD pins are shared with segments on the PIC16F946/917/916/914/913 MCUs.

When debugging, the device is Halted at breakpoints and by the user pressing the pause button. If the ICD is configured to Halt the peripherals with the device, the LCD controller will Halt and apply DC voltages to the LCD glass. Over time, these DC levels can cause damage to the glass; however, for most debugging situations, this will not be a consideration. The PIC18F LCD MCUs have a feature that allows the LCD module to continue operating while the device has been Halted during debugging. This is useful for checking the image of the display while the device is Halted and for preventing glass damage if the device will be Halted for a long period of time.

The PIC16F946/917/916/914/913 multiplex the ICSP™ and ICD pins onto pins shared with LCD segments 6 and 7. If an LCD is attached to these pins, the device can be debugged with ICD; however, all the segments driven by those two pins will flicker and be uncontrolled. As soon as debugging is finished and the device is programmed with Debug mode disabled, these segments will be controlled correctly.

## TIP #9 LCD in Sleep Mode

If you have a power-sensitive application that must display data continuously, the LCD PIC microcontroller can be put to Sleep while the LCD driver module continues to drive the display.

To operate the LCD in Sleep, only two steps are required. First, a time source other than the main oscillator must be selected as the LCD clock source, because during Sleep, the main oscillator is Halted. Options are shown for the various LCD PIC MCUs.

**Table 9-1: Options for LCD in Sleep Mode**

| Part | LCD Clock Source | Use in Sleep? |
|---|---|---|
| PIC16C925/926 | FOSC/256 | No |
| | T1OSC | Yes |
| | Internal RC Oscillator | Yes |
| PIC16F946/917/ 916/914/913 | FOSC/8192 | No |
| | T1OSC/32 | Yes |
| | LFINTOSC/32 | Yes |
| PIC18F6X90 | (FOSC/4)/8192 | No |
| PIC18F8X90 | T1OSC | Yes |
| PIC18F6XJ90 | INTRC/32 | Yes |
| PIC18F8XJ90 | | |

Second, the Sleep Enable bit (SLPEN) must be cleared. The LCD will then continue to display data while the part is in Sleep. It’s that easy!

When should you select the internal RC oscillator (or LFINTOSC) over the Timer1 oscillator? It depends on whether your application is time-sensitive enough to require the accuracy of a crystal on the Timer1 oscillator or not. If you have a timekeeping application, then you will probably have a 32 kHz crystal oscillator connected to Timer1.

Since Timer1 continues to operate during Sleep, there is no penalty in using Timer1 as the LCD clock source. If you don’t need to use an external oscillator on Timer1, then the internal RC oscillator (INTRC or LFINTOSC) is more than sufficient to use as the clock source for the LCD and it requires no external components.

# CHAPTER 7
# Intelligent Power Supply Design Tips ‘n Tricks

## Table Of Contents

## 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 #3 A Tracking and Proportional Soft-Start of Two Power Supplies

Expanding on the previous tip, we can also use a PIC MCU to ensure that two voltages in a system rise together or rise proportionally to one another, as shown in Figure 3-1. This type of start-up is often used in applications with devices that require multiple voltages (such as I/O and core voltages).

Like the previous two, this tip is designed to control the shutdown pin of the SMPS controller and will only work with controllers that respond quickly to changes on the shutdown pin.

**Figure 3-1: Timing Diagram**

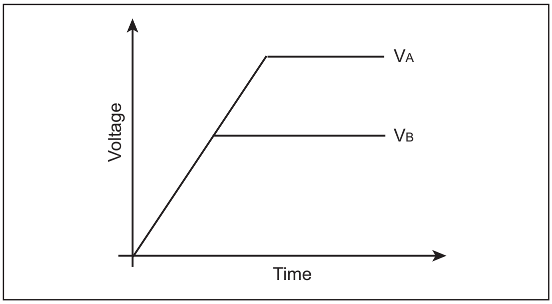
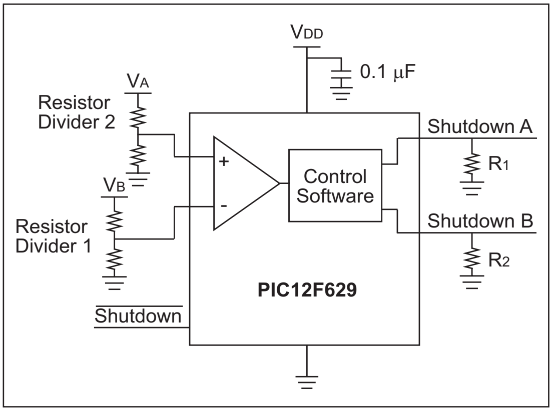


**Figure 3-2: Example Schematic**



The comparator of the PIC MCU is used to determine which voltage is higher and increases the on-time of the other output accordingly. The logic for the shutdown pins is as shown in Table 3-1.

**Table 3-1: Shutdown Pin Logic**

| Case | Shutdown A | Shutdown B |
|---|---|---|
| $V_A > V_B$ | Low | High |
| $V_B > V_A$ | High | Low |
| $V_B$ > Internal Reference | High | High |

To determine if it has reached full voltage, $V_B$ is compared to the internal voltage reference. If $V_B$ is higher, both shutdown outputs are held high.

Resistor Divider 1 should be designed so that the potentiometer output is slightly higher than the comparator voltage reference when $V_B$ is at full voltage.

The ratio of resistors in Resistor Divider 2 can be varied to change the slope at which $V_A$ rises.

Pull-down resistors ensure the power supplies will not operate unexpectedly when the PIC MCU is being reset.

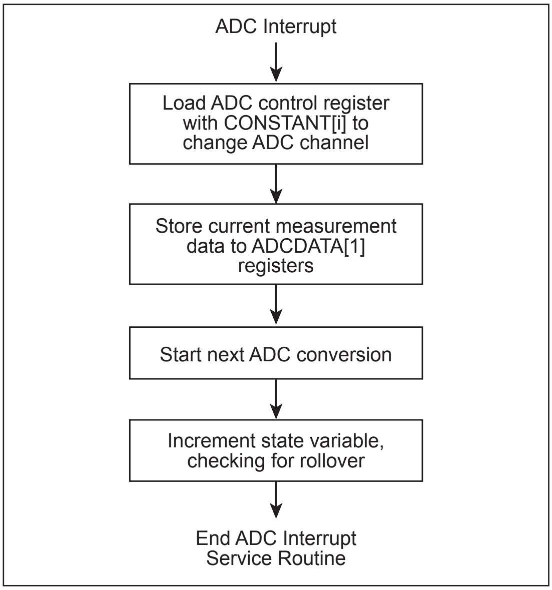
## TIP #18 Data-Indexed Software State Machine

A state machine can be used to simplify a task by breaking the task up into smaller segments. Based on a state variable, the task performed or the data used by the state machine can be changed. There are three basic types of state machines: data-indexed, execution indexed and a hybrid of the two. This tip will focus on a data-indexed state machine.

The data-indexed state machine is ideal for monitoring multiple analog inputs with the Analog-to-Digital Converter (ADC). The state variable in these state machines determines which data is acted upon. In this case, the tasks of changing the ADC channel, storing the current result and starting a new conversion are always the same.

$ YHU\ VLPSOH ÀRZ GLDJUDP IRU D GDWD LQGH[HG state machine is shown in Figure 18-1.

Figure 18-1: Data-Indexed State Machine Flowchart


ADC Interrupt
Load ADC control register with CONSTANT[i] to change ADC channel
Store current measurement data to ADCDATA[1] registers
Start next ADC conversion
Increment state variable, checking for rollover
End ADC Interrupt Service Routine

As shown in Figure 18-1, a constant array &2167$17>L@ FDQ EH FUHDWHG values to be loaded into the ADC control register to change the ADC channel. )XUWKHUPRUH D GDWD DUUD\ $ used to store the results of the ADC conversion. Finally, the next conversion is started and the logic required to increment and bind the state variable is executed.

This particular example used the ADC interrupt to signal when a conversion has completed, and will attempt to take measurements as quickly as possible. A subroutine could also be built to perform the same task, allowing the user to call the subroutine when needed.

Example software is provided using the PIC16F676 and RS-232 to monitor several ADC channels.

## TIP #14 Brushless DC Fan Speed Control

There are several methods to control the speed of a DC brushless fan. The type of fan, allowable power consumption and the type of control desired are all factors in choosing the appropriate type.

**Figure 14-1: Low-Side PWM Drive**

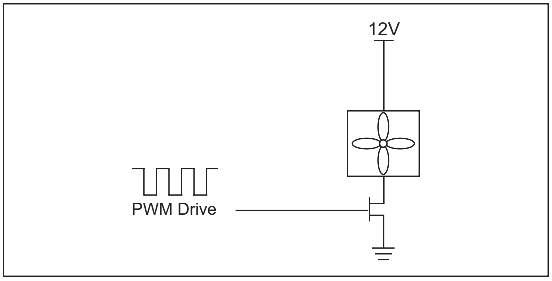
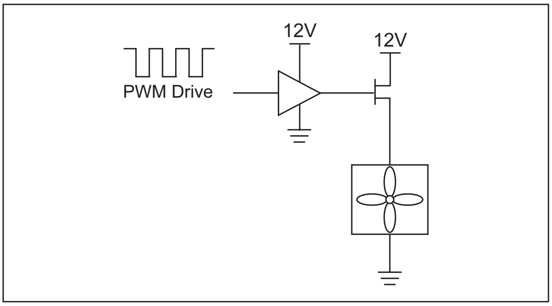


**Figure 14-2: High-Side PWM Drive**



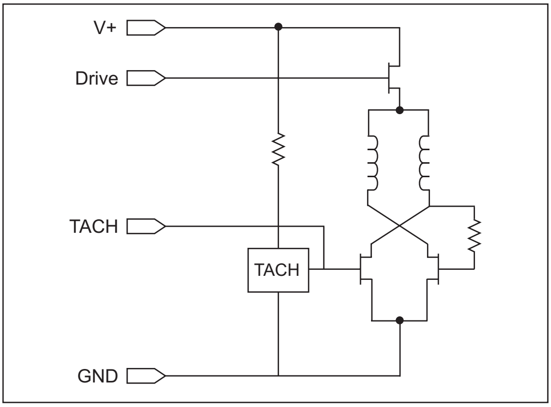
### Method 1 – Pulse-Width Modulation

As shown in Figure 14-1 and Figure 14-2, a simple PWM drive may be used to switch a two-wire fan on and off. While it is possible to use the circuit in Figure 14-1 without a high-side MOSFET driver, some manufacturers state that switching on the low side of the fan will void the warranty. Because of this, it is necessary to switch the high side of the fan in order to control the speed. The simplest type of speed control is ‘on’ or ‘off’. However, if a higher degree of control is desired, PWM can be used to vary the speed of the fan.

For 3-wire fans, the tachometer output will not be accurate if PWM is used. The sensor providing the tachometer output on 3-wire fans is powered from the same supply as the fan coils, thus using a PWM to control fan speed will render the fan’s tachometer inaccurate.

One solution is to use a 4-wire fan which includes both the tachometer output and a drive input. Figure 14-3 shows a diagram of a 4-wire fan.

**Figure 14-3: Typical 4-Wire Fan**



A 4-wire fan allows speed to be controlled using PWM via the Drive line. Since power to the tachometer sensor is not interrupted, it will continue to output the correct speed.

## 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

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

It therefore follows that for MOSFET Q1:

### Equation 4-2

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

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

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

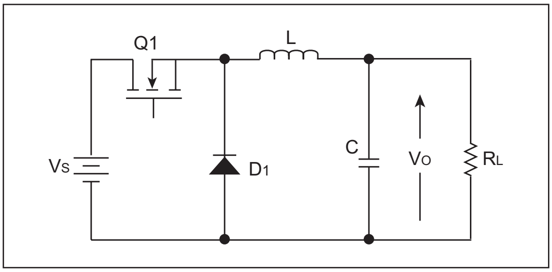
When choosing an output capacitor value, a good starting point is to set the LC filter characteristic impedance equal to the load resistance. This produces an acceptable voltage overshoot when operating at full load and having the load abruptly removed.

### 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.

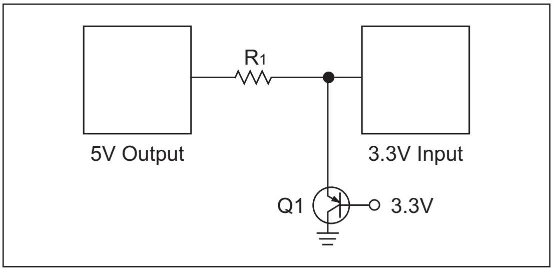
### Table 4-1: Input/Output Thresholds

| | $V_{OH}$ 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<br>(Vcc-0.3V) | 0.5V | 3.5V<br>(0.7xVcc) | 1.5V<br>(0.3xVcc) |
| 3.3V LVCMOS | 3.0V<br>(Vcc-0.3V) | 0.5V | 2.3V<br>(0.7xVcc) | 1.0V<br>(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**

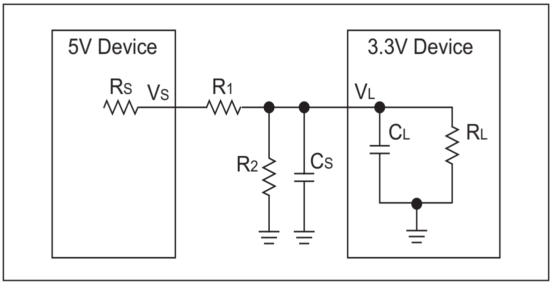


The base-emitter junction of Q1 performs the same function as the diode in a diode clamp circuit. The difference is that only a small percentage of the emitter current flows out of the base of the transistor to the 3.3V rail, the bulk of the current is routed to the collector where it passes harmlessly 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.

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