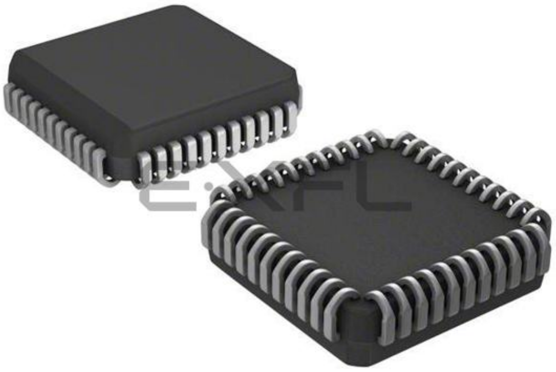

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What is "Embedded - Microcontrollers"?

"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	-40°C ~ 85°C (TA)
Mounting Type	Surface Mount
Package / Case	44-LCC (J-Lead)
Supplier Device Package	44-PLCC (16.59x16.59)
Purchase URL	https://www.e-xfl.com/product-detail/microchip-technology/pic16c65b-20i-l

TIP #3 Configuring Port Pins

All PIC MCUs have bidirectional I/O pins. Some of these pins have analog input capabilities. It is very important to pay attention to the signals applied to these pins so the least amount of power will be consumed.

Unused Port Pins

If a port pin is unused, it may be left unconnected but configured as an output pin driving to either state (high or low), or it may be configured as an input with an external resistor (about 10 kΩ) pulling it to V_{DD} or V_{SS}. If configured as an input, only the pin input leakage current will be drawn through the pin (the same current would flow if the pin was connected directly to V_{DD} or V_{SS}). Both options allow the pin to be used later for either input or output without significant hardware modifications.

Digital Inputs

A digital input pin consumes the least amount of power when the input voltage is near V_{DD} or V_{SS}. If the input voltage is near the midpoint between V_{DD} and V_{SS}, the transistors inside the digital input buffer are biased in a linear region and they will consume a significant amount of current. If such a pin can be configured as an analog input, the digital buffer is turned off, reducing both the pin current as well as the total controller current.

Analog Inputs

Analog inputs have a very high-impedance so they consume very little current. They will consume less current than a digital input if the applied voltage would normally be centered between V_{DD} and V_{SS}. Sometimes it is appropriate and possible to configure digital inputs as analog inputs when the digital input must go to a low power state.

Digital Outputs

There is no additional current consumed by a digital output pin other than the current going through the pin to power the external circuit. Pay close attention to the external circuits to minimize their current consumption.

TIP #4 Use High-Value Pull-Up Resistors

It is more power efficient to use larger pull-up resistors on I/O pins such as MCLR, I^2C™ signals, switches and for resistor dividers. For example, a typical I^2C pull-up is 4.7k. However, when the I^2C is transmitting and pulling a line low, this consumes nearly 700 uA of current for each bus at 3.3V. By increasing the size of the I^2C pull-ups to 10k, this current can be halved. The tradeoff is a lower maximum I^2C bus speed, but this can be a worthwhile trade in for many low power applications. This technique is especially useful in cases where the pull-up can be increased to a very high resistance such as 100k or 1M.

TIP #5 Reduce Operating Voltage

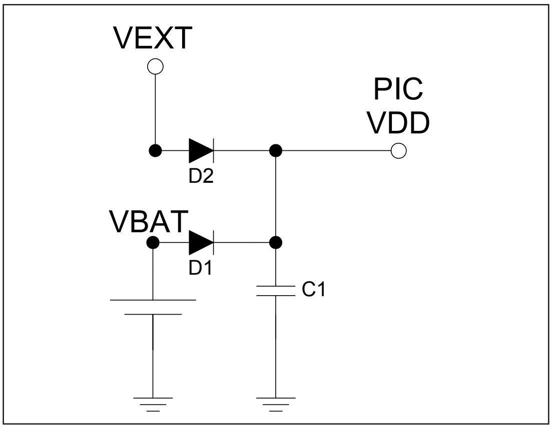
Reducing the operating voltage of the device, V_{DD}, is a useful step to reduce the overall power consumption. When running, power consumption is mainly influenced by the clock speed. When sleeping, the most significant factor is leakage in the transistors. At lower voltages, less charge is required to switch the system clocks and transistors leak less current.

It is important to pay attention to how reducing the operating voltage reduces the maximum allowed operating frequency. Select the optimum voltage that allows the application to run at its maximum speed. Refer to the device data sheet for the maximum operating frequency of the device at the given voltage.

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 #13 Deciding on PWM Frequency

In general, PWM frequency is application dependent although two general rules-of-thumb hold regarding frequency in all applications. They are:

1. As frequency increases, so does current requirement due to switching losses.
2. Capacitance and inductance of the load tend to limit the frequency response of a circuit.

In low-power applications, it is a good idea to use the minimum frequency possible to accomplish a task in order to limit switching losses. In circuits where capacitance and/or inductance are a factor, the PWM frequency should be chosen based on an analysis of the circuit.

Motor Control

PWM is used extensively in motor control due to the efficiency of switched drive systems as opposed to linear drives. An important consideration when choosing PWM frequency for a motor control application is the responsiveness of the motor to changes in PWM duty cycle. A motor will have a faster response to changes in duty cycle at higher frequencies. Another important consideration is the sound generated by the motor. Brushed DC motors will make an annoying whine when driven at frequencies within the audible frequency range (20 Hz-4 kHz.) In order to eliminate this whine, drive brushed DC motors at frequencies greater than 4 kHz. (Humans can hear frequencies at upwards of 20 kHz, however, the mechanics of the motor winding will typically attenuate motor whine above 4 kHz).

LED and Light Bulbs

PWM is also used in LED and light dimmer applications. Flicker may be noticeable with rates below 50 Hz. Therefore, it is generally a good rule to pulse-width modulate LEDs and light bulbs at 100 Hz or higher.

TIP #14 Unidirectional Brushed DC Motor Control Using CCP

Figure 14-1: Brushed DC (BDC) Motor Control Circuit

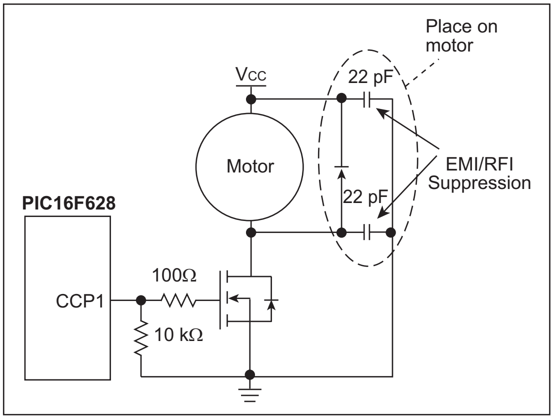


Figure 14-1 shows a unidirectional speed controller circuit for a brushed DC motor. Motor speed is proportional to the duty cycle of the PWM output on the CCP1 pin. The following steps show how to configure the PIC16F628 to generate a 20 kHz PWM with 50% duty cycle. The microcontroller is running on a 20 MHz crystal.

Step #1: Choose Timer2 Prescaler

a) F_{PWM} = Fosc/((PR2+1)*4*prescaler) = 19531 Hz for PR2 = 255 and prescaler of 1

b) This frequency is lower than 20 kHz, therefore a prescaler of 1 is adequate.

Step #2: Calculate PR2

PR2 = Fosc/(F_{PWM}*4*prescaler) – 1 = 249

Step #3: Determine CCPR1L and CCP1CON<5:4>

a) CCPR1L:CCP1CON<5:4> = DutyCycle*0x3FF = 0x1FF

b) CCPR1L = 0x1FF >> 2 = 0x7F, CCP1CON<5:4> = 3

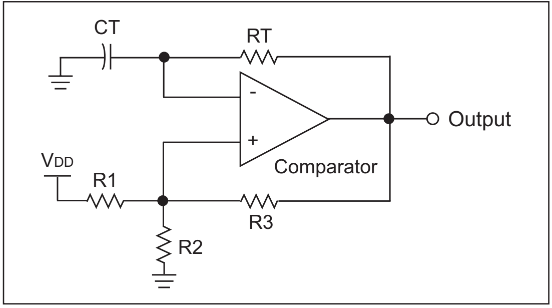
Step #4: Configure CCP1CON

The CCP module is configured in PWM mode with the Least Significant bits of the duty cycle set, therefore, CCP1CON = ‘`b001111000`’.

TIP #8 Multi-Vibrator (Square Wave Output)

A multi-vibrator is an oscillator designed around a voltage comparator or operational amplifier (see Figure 8-1). Resistors R1 through R3 form a hysteresis feedback path from the output to the non-inverting input. Resistor RT and capacitor CT form a time delay network between the output and the inverting input. At the start of the cycle, CT is discharged holding the non-inverting input at ground, forcing the output high. A high output forces the non-inverting input to the high threshold voltage (see Tip #3) and charges CT through RT. When the voltage across CT reaches the high threshold voltage, the output is forced low. A low output drops the non-inverting input to the low threshold voltage and discharges CT through RT. When the voltage across CT reaches the low threshold voltage, the output is forced high and the cycle starts over.

Figure 8-1: Multi-Vibrator Circuit



To design a multi-vibrator, first design the hysteresis feedback path using the procedure in Tip #3. Be careful to choose threshold voltages (V_{TH} and V_{TL}) that are evenly spaced within the common mode range of the comparator and centered on $V_{DD}/2$. Then use V_{DD} and V_{TL} to calculate values for RT and CT that will result in the desired oscillation frequency F_{OSC}. Equation 8-1 defines the relationship between RT, CT, V_{TH}, V_{TL} and F_{OSC}.

Equation 8-1

$$F_{OSC} = \frac{1}{2 * RT * CT * \ln(V_{TH}/V_{TL})}$$

Example:

- V_{DD} = 5V, V_{TH} = 3.333, V_{TL} = 1.666V
- R1, to R2, to R3 = 10k
- R_T = 15 kHz, C_T = .1 μF for F_{OSC} = 480 Hz

TIP #2 Brushless DC Motor Drive Circuits

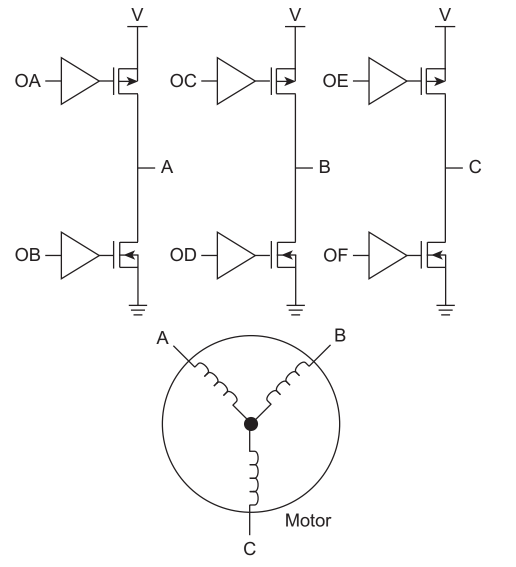
A Brushless DC motor is a good example of simplified hardware increasing the control complexity. The motor cannot commutate the windings (switch the current flow), so the control circuit and software must control the current flow correctly to keep the motor turning smoothly. The circuit is a simple half-bridge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

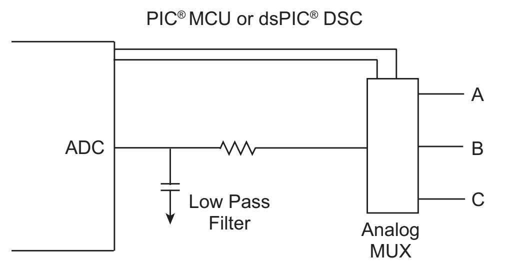
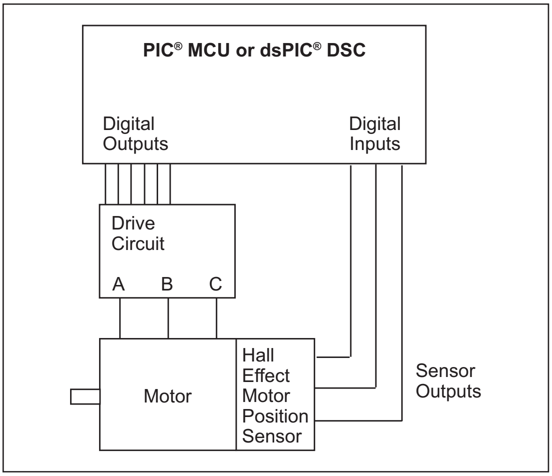


Figure 2-3: Quadrature Decoder (Sensor Motor)



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 #4 Drive Software

Pulse-Width Modulation (PWM) Algorithms

Pulse-Width Modulation is critical to modern digital motor controls. By adjusting the pulse width, the speed of a motor can be efficiently controlled without larger linear power stages. Some PIC devices and all dsPIC DSCs have hardware PWM modules on them. These modules are built into the Capture/Compare/PWM (CCP) peripheral. CCP peripherals are intended for a single PWM output, while the Enhanced CCP (ECCP) is designed to produce the complete H-Bridge output for bidirectional Brushed DC motor control. If cost is a critical design point, a PIC device with a CCP module may not be available, so software generated PWM is a good alternative.

The following algorithms are designed to efficiently produce an 8-bit PWM output on the Mid-Range family of PIC microcontrollers. These algorithms are implemented as macros. If you want these macros to be a subroutine in your program, simply remove the macro statements and replace them with a label and a return statement.

Example 4-1: 1 Output 8-Bit PWM

```
pwm_counter equ xxx ;variable
pwm         equ xxx ;variable

set_pwm macro A     ;sets the pwm
                    ;setpoint to the
                    ;value A
 MOVLW A
 MOVWF pwm
 endm

update_PWM macro    ;performs one update
                    ;of the PWM signal
                    ;place the PWM output
                    ;pin at bit 0 or 7 of
                    ;the port
 MOVF pwm_counter,w
 SUBWF pwm, w       ;if the output
                    ;is on bit 0
 RLF        PORTC,f ;replace PORTC with
                    ;the correct port if
                    ;the output is on bit
                    ;7 of the port
                    ;replace the rlf with
                    ;rrf incf
                    ;pwm_counter,f
```

Example 4-2: 8 Output 8-Bit PWM

```
pwm_counter equ xxx     ;variable
pwm0        equ xxx     ;
pwm1        equ pwm0+1
pwm2        equ pwm1+1
pwm3        equ pwm2+1
pwm4        equ pwm3+1
pwm5        equ pwm4+1
pwm6        equ pwm5+1
pwm7        equ pwm6+1
output      equ pwm7+1
set_pwm macro A,b       ;sets pwm b with
                        ;the value A
 MOVLW pwm0
 ADDLW b
 MOVWF fsr
 MOVLW a
 MOVWF indf
 endm

update_PWM macro        ;peforms one
                        ;update of all 8
                        ;PWM signals
                        ;all PWM signals
                        ;must be on the
                        ;same port
 MOVF       pwm_counter,w
 SUBWF      pwm0,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm1,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm2,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm3,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm4,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm5,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm6,w
 RLF        output,f
 MOVF       pwm_counter,w
 SUBWF      pwm7,w
 RLF        output,w
 MOVWF      PORTC
 INCF       pwm_counter,f
endm
```

TIP #5 Writing a PWM Value to the the CCP Registers With a Mid-Range PIC® Microcontroller

The two PWM LSb’s are located in the CCPCON register of the CCP. This can make changing the PWM period frustrating for a developer. Example 5-1 through Example 5-3 show three macros written for the mid-range product family that can be used to set the PWM period. The first macro takes a 16-bit value and uses the 10 MSb’s to set the PWM period. The second macro takes a 16-bit value and uses the 10 LSb’s to set the PWM period. The last macro takes 8 bits and sets the PWM period. This assumes that the CCP is configured for no more than 8 bits.

Example 5-1: Left Justified 16-Bit Macro

```
pwm_tmp    equ xxx  ;this variable must be
                    ;allocated someplace
setPeriod  macro a  ;a is 2 SFR’s in
                    ;Low:High arrangement
                    ;the 10 MSb’s are the
                    ;desired PWM value
 RRF       a,w      ;This macro will
                    ;change w
 MOVWF     pwm_tmp
 RRF       pwm_tmp,w
 ANDLW     0x30
 IORLW     0x0F
 MOVWF     CCP1CON
 MOVF      a+1,w
 MOVWF     CCPR1L
```

Example 5-2: Right Justified 16-Bit Macro

```
pwm_tmp    equ xxx  ;this variable must be
                    ;allocated someplace
setPeriod  macro a  ;a is 2 bytes in
                    ;Low:High arrangement
                    ;the 10 LSb’s are the
                    ;desired PWM value
 SWAPF     a,w      ;This macro will
                    ;change w
 ANDLW     0x30
 IORLW     0x0F
 MOVWF     CCP1CON
 RLF       a,w
 IORLW     0x0F
 MOVWF     pwm_tmp
 RRF       pwm_tmp,f
 RRF       pwm_tmp,w
 MOVWF     CCPR1L
```

Example 5-3: 8-Bit Macro

```
pwm_tmp    equ xxx  ;this variable must be
                    ;allocated someplace
setPeriod  macro a  ;a is 1 SFR
 SWAPF     a,w      ;This macro will
                    ;change w
 ANDLW     0x30
 IORLW     0x0F
 MOVWF     CCP1CON
 RRF       a,w
 MOVWF     pwm_tmp
 RRF       pwm_tmp,w
 MOVWF     CCPR1L
```

CHAPTER 6
LCD PIC® Microcontroller Tips ‘n Tricks

Table Of Contents

TIPS ‘N TRICKS INTRODUCTION

Using an LCD PIC® MCU for any embedded application can provide the benefits of system control and human interface via an LCD. Design practices for LCD applications can be further enhanced through the implementation of these suggested “Tips ‘n Tricks”.

This booklet describes many basic circuits and software building blocks commonly used for driving LCD displays. The booklet also provides references to Microchip application notes that describe many LCD concepts in more detail.

TIP #1 Typical Ordering Considerations and Procedures for Custom Liquid Displays

1. Consider what useful information needs to be displayed on the custom LCD and the combination of alphanumeric and custom icons that will be necessary.
2. Understand the environment in which the LCD will be required to operate. Operating voltage and temperature can heavily influence the contrast of the LCD and potentially limit the type of LCD that can be used.
3. Determine the number of segments necessary to achieve the desired display on the LCD and reference the PIC Microcontroller LCD matrix for the appropriate LCD PIC microcontroller.
4. Create a sketch/mechanical print and written description of the custom LCD and understand the pinout of the LCD. (Pinout definition is best left to the glass manufacturer due to the constraints of routing the common and segment electrodes in two dimensions.)
5. Send the proposed LCD sketch and description for a written quotation to at least 3 vendors to determine pricing, scheduling and quality concerns.
   a) Take into account total NRE cost, price per unit, as well as any setup fees.
   b) Allow a minimum of two weeks for formal mechanical drawings and pin assignments and revised counter drawings.
6. Request a minimal initial prototype LCD build to ensure proper LCD development and ensure proper functionality within the target application.
   a) Allow typically 4-6 weeks for initial LCD prototype delivery upon final approval of mechanical drawings and pin assignments.
7. Upon receipt of prototype LCD, confirm functionality before giving final approval and beginning production of LCD.

Note: Be sure to maintain good records by keeping copies of all materials transferred between both parties, such as initial sketches, drawings, pinouts, etc.

TIP #2 LCD PIC® MCU Segment/ Pixel Table

Table 2-1: Segment Matrix Table

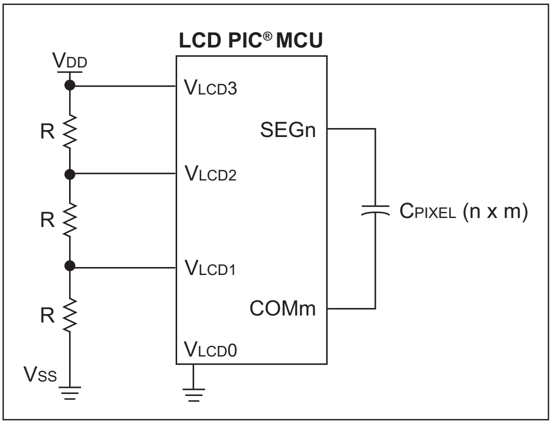
Multiplex Commons	Maximum Number of Segments/Pixels					Bias
	PIC16F913/ 916	PIC16F914/ 917	PIC16F946	PIC18F6X90 (PIC18F6XJ90)	PIC18F8X90 (PIC18F8XJ90)	
Static (COM0)	15	24	42	32/ (33)	48	Static
1/2 (COM1: COM0)	30	48	84	64/ (66)	96	1/2 or 1/3
1/3 (COM2: COM0)	45	72	126	96/ (99)	144	1/2 or 1/3
1/4 (COM3: COM0)	60	96	168	128/ (132)	192	1/3

This Segment Matrix table shows that Microchip's 80-pin LCD devices can drive up to 4 commons and 48 segments (192 pixels), 64-pin devices can drive up to 33 segments (132 pixels), 40/44 pin devices can drive up to 24 segments (96 pixels) and 28-pin devices can drive 15 segments (60 segments).

TIP #3 Resistor Ladder for Low Current

Bias voltages are generated by using an external resistor ladder. Since the resistor ladder is connected between V_{DD} and V_{SS}, there will be current flow through the resistor ladder in inverse proportion to the resistance. In other words, the higher the resistance, the less current will flow through the resistor ladder. If we use 10K resistors and V_{DD} = 5V, the resistor ladder will continuously draw 166 μA. That is a lot of current for some battery-powered applications.

Figure 3-1: Resistor Ladder

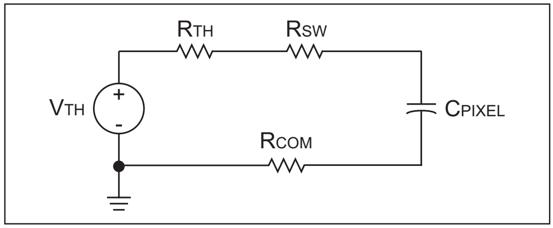


How do we maximize the resistance without adversely effecting the quality of the display? Some basic circuit analysis helps us determine how much we can increase the size of the resistors in the ladder.

The LCD module is basically an analog multiplexer that alternately connects the LCD voltages to the various segment and common pins that connect across the LCD pixels. The LCD pixels can be modeled as a capacitor. Each tap point on the resistor ladder can be modeled as a Thevenin equivalent circuit. The Thevenin resistance is 0 for $V_{LCD}3$ and $V_{LCD}0$, so we look at the two cases where it is non-zero, $V_{LCD}2$ and $V_{LCD}1$.

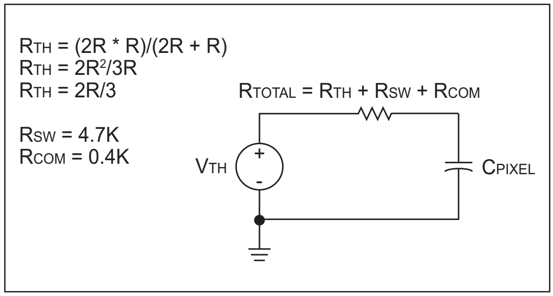
The circuit can be simplified as shown in Figure 3-2. R_{SW} is the resistance of the segment multiplex switch; R_{COM} is the resistance of the common multiplex switch.

Figure 3-2: Simplified LCD Circuit



The Thevenin voltage is equal to either 2/3 V_{DD}, or 1/3 V_{DD}, for the cases where the Thevenin resistance is non-zero. The Thevenin resistance is equal to the parallel resistance of the upper and lower parts of the resistor ladder.

Figure 3-3: LCD Circuit Resistance Estimate



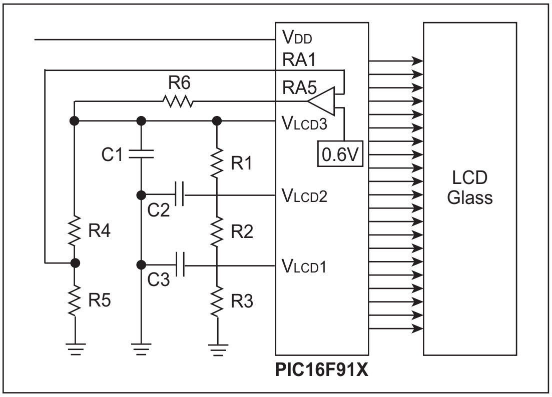
As you can see, we can model the drive of a single pixel as an RC circuit, where the voltage switches from 0V to $V_{LCD}2$, for example. For LCD PIC microcontrollers, we can estimate the resistance of the segment and common switching circuits as about 4.7K and 0.4K, respectively.

We can see that the time for the voltage across the pixel to change from 0 to V_{TH} will depend on the capacitance of the pixel and the total resistance, of which the resistor ladder Thevenin resistance forms the most significant part.

TIP #4: Contrast Control with a Buck Regulator

Contrast control in any of the LCD PIC MCUs is accomplished by controlling the voltages applied to the V_{LCD} voltage inputs. The simplest contrast voltage generator is to place a resistor divider across the three pins. This circuit is shown in the data sheet. The resistor ladder method is good for many applications, but the resistor ladder does not work in an application where the contrast must remain constant over a range of V_{DD}s. The solution is to use a voltage regulator. The voltage regulator can be external to the device, or it can be built using a comparator internal to the LCD PIC microcontroller.

Figure 4-1: Voltage Generator with Resistor Divider



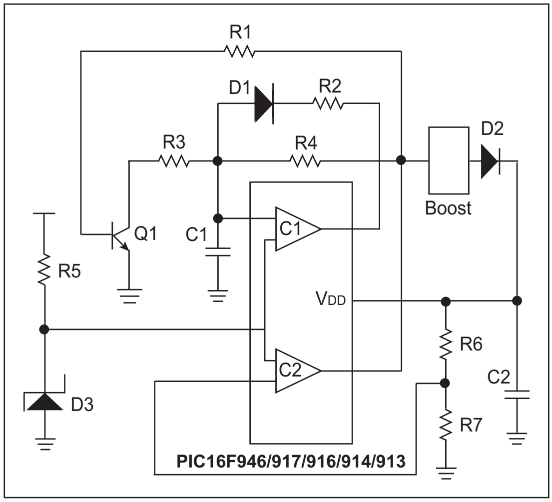
The PIC16F946/917/916/914/913 devices have a special Comparator mode that provides a fixed 0.6V reference. The circuit shown in Figure 4-1 makes use of this reference to provide a regulated contrast voltage. In this circuit, R1, R2 and R3 provide the contrast control voltages. The voltage on $V_{LCD}3$ is compared to the internal voltage reference by dividing the voltage at $V_{LCD}3$ at R4 and R5 and applying the reduced voltage to the internal comparator. When the voltage at $V_{LCD}3$ is close to the desired voltage, the output of the comparator will begin to oscillate. The oscillations are filtered into a DC voltage by R6 and C1. C2 and C3 are simply small bypass capacitors to ensure that the voltages at $V_{LCD}1$ and $V_{LCD}2$ are steady.

TIP #5: Contrast Control Using a Boost Regulator

In LCD Tip #4, a buck converter was created using a comparator. This circuit works great when V_{DD} is greater than the LCD voltage. The PIC microcontroller can operate all the way down to 2.0V, whereas most low-voltage LCD glass only operates down to 3V. In a battery application, it is important to stay operational as long as possible. Therefore, a boost converter is required to boost 2.0V up to 3.0V for the LCD.

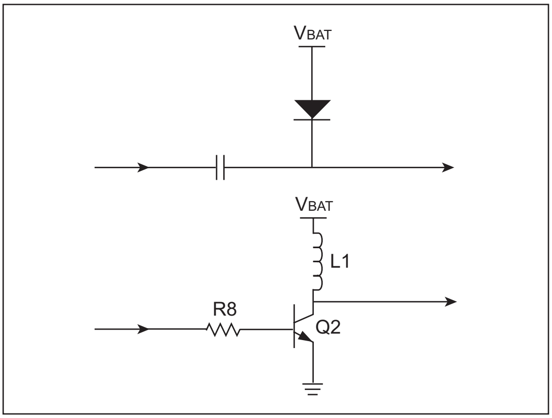
The figure below shows one circuit for doing this.

Figure 5-1: Boost Converter



In this circuit, both comparators are used. The voltage setpoint is determined by the value of Zenier diode D3 and the voltage at R6:R7. The rest of the circuit creates a simple multivibrator to stimulate a boost circuit. The boost circuit can be inductor or capacitor-based. When the output voltage is too low, the multivibrator oscillates and causes charge to build up in C2. As the voltage at C2 increases, the multivibrator will begin to operate sporadically to maintain the desired voltage at C2.

Figure 5-2: Two Types of Boost Converter



The two methods of producing a boost converter are shown above. The first circuit is simply a switched capacitor type circuit. The second circuit is a standard inductor boost circuit. These circuits work by raising V_{DD}. This allows the voltage at V_{LCD} to exceed V_{DD}.

TIP #6: Software Controlled Contrast with PWM for LCD Contrast Control

In the previous contrast control circuits, the voltage output was set by a fixed reference. In some cases, the contrast must be variable to account for different operating conditions. The CCP module, available in the LCD controller devices, allows a PWM signal to be used for contrast control. In Figure 6-1, you see the buck contrast circuit modified by connecting the input to RA6 to a CCP pin. The resistor divider created by R4 and R5 in the previous design are no longer required. An input to the ADC is used to provide feedback but this can be considered optional. If the ADC feedback is used, notice that it is used to monitor the V_{DD} supply. The PWM will then be used to compensate for variations in the supply voltage.

Figure 6-1: Software Controlled Voltage Generator

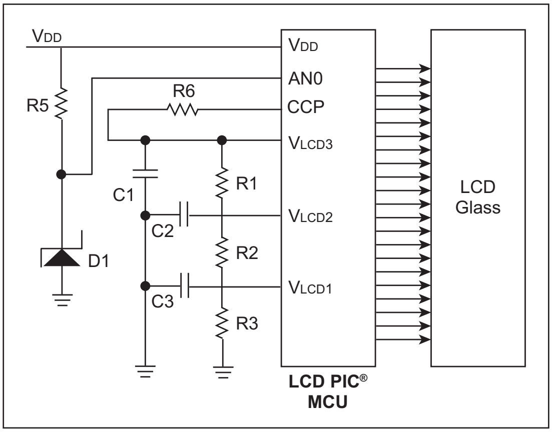
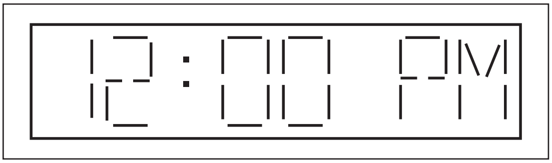
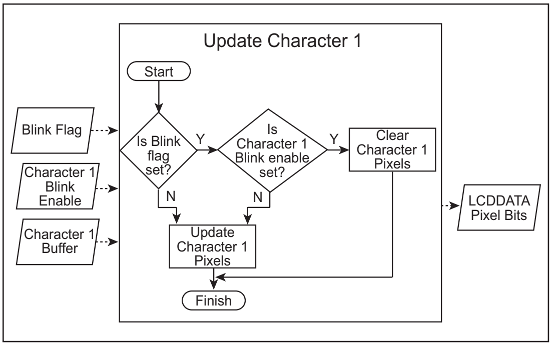


Figure 11-1: Common Clock Application



Fortunately, blinking is quite easy to implement. There are many ways to implement a blinking effect in software. Any regular event can be used to update a blink period counter. A blink flag can be toggled each time the blink period elapses. Each character or display element that you want to blink can be assigned a corresponding blink enable flag. The flowchart for updating the display would look like:

Figure 11-2: Updating Display Flowchart



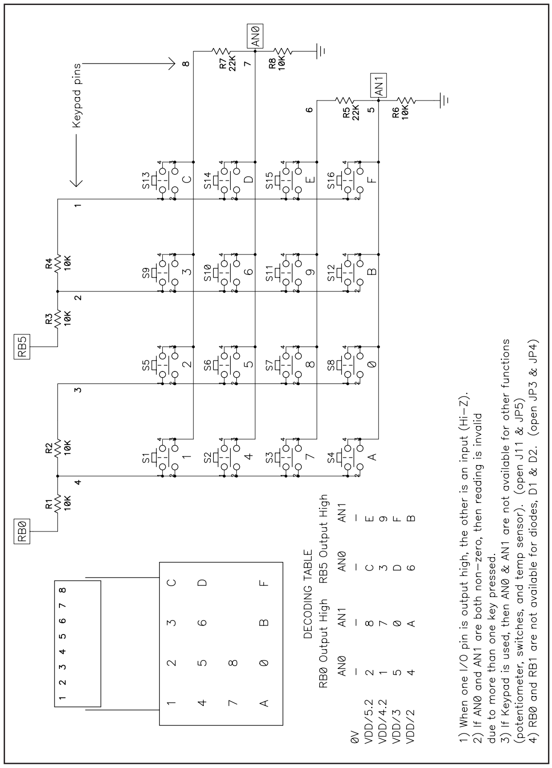
TIP #12 4 x 4 Keypad Interface that Conserves Pins for LCD Segment Drivers

A typical digital interface to a 4 x 4 keypad uses 8 digital I/O pins. But using eight pins as digital I/Os can take away from the number of segment driver pins available to interface to an LCD.

By using 2 digital I/O pins and 2 analog input pins, it is possible to add a 4 x 4 keypad to the PIC microcontroller without sacrificing any of its LCD segment driver pins.

The schematic for keypad hook-up is shown in Figure 12-1. This example uses the PIC18F8490, but the technique could be used on any of the LCD PIC MCUs.

Figure 12-1: Keypad Hook-up Schematic



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

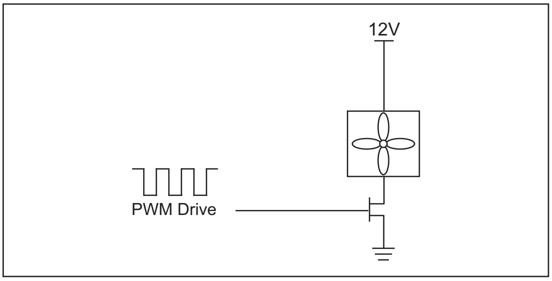
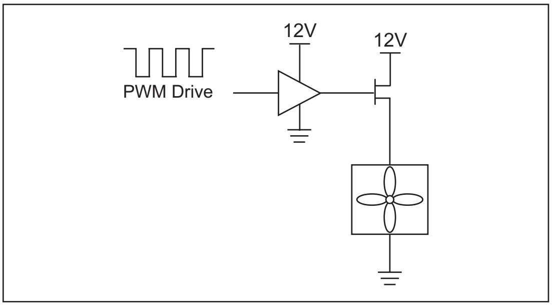


Figure 14-2: High-Side PWM Drive



Method 1 – Pulse-Width Modulation

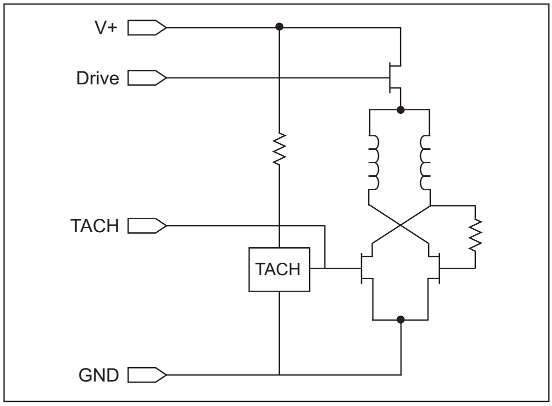
As shown in Figure 14-1 and Figure 14-2, a simple PWM drive may be used to switch a two-wire fan on and off. While it is possible to use the circuit in Figure 14-1 without a high-side MOSFET driver, some manufacturers state that switching on the low side of the fan will void the warranty.

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

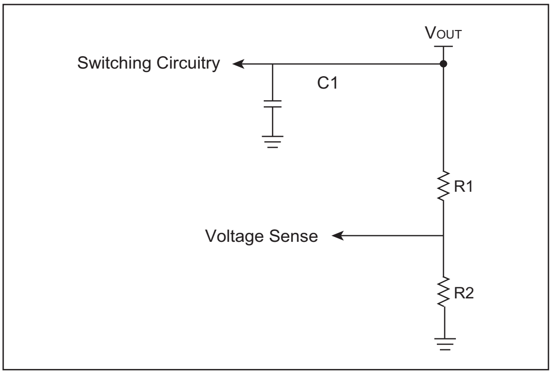


A 4-wire fan allows speed to be controlled using PWM via the Drive line. Since power to the tachometer sensor is not interrupted, it will continue to output the correct speed.

TIP #21 Using Output Voltage Monitoring to Create a Self-Calibration Function

A PIC microcontroller can be used to create a switching power supply controlled by a PID loop (as described in Tip #16). This type of power supply senses its output voltage digitally, compares that voltage to the desired reference voltage and makes duty cycle changes accordingly. Without calibration, it is sensitive to component tolerances.

Figure 21-1: Typical Power Supply Output Stage



The output stage of many power supplies is similar to Figure 21-1. R1 and R2 are used to set the ratio of the voltage that is sensed and compared to the reference.

A simple means of calibrating this type of power supply is as follows:

1. Supply a known reference voltage to the output of the supply.
2. Place the supply in Calibration mode and allow it to sense that reference voltage.

By providing the supply with the output voltage that it is to produce, it can then sense the voltage across the resistor divider and store the sensed value. Regardless of resistor tolerances, the sensed value will always correspond to the proper output value for that particular supply.

Futhermore, this setup could be combined with Tip #20 to calibrate at several temperatures.

This setup could also be used to create a programmable power supply by changing the supplied reference and the resistor divider for voltage feedback.

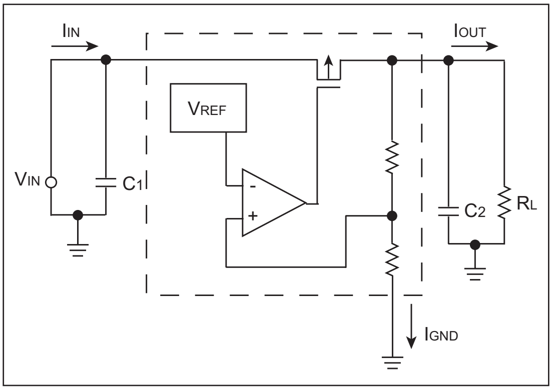
TIP #1 Powering 3.3V Systems From 5V Using an LDO Regulator

The dropout voltage of standard three-terminal linear regulators is typically 2.0-3.0V. This precludes them from being used to convert 5V to 3.3V reliably. Low Dropout (LDO) regulators, with a dropout voltage in the few hundred milli-volt range, are perfectly suited for this type of application. Figure 1-1 contains a block diagram of a basic LDO system with appropriate current elements labeled. From this figure it can be seen that an LDO consists of four main elements:

1. Pass transistor
2. Bandgap reference
3. Operational amplifier
4. Feedback resistor divider

When selecting an LDO, it is important to know what distinguishes one LDO from another. Device quiescent current, package size and type are important device parameters. Evaluating for each parameter for the specific application yields an optimal design.

Figure 1-1: LDO Voltage Regulator



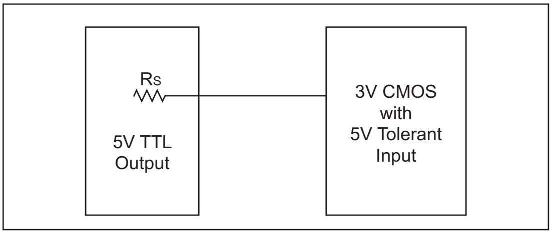
An LDOs quiescent current, I_Q, is the device ground current, I_{GND}, while the device is operating at no load. I_{GND} is the current used by the LDO to perform the regulating operation. The efficiency of an LDO can be approximated as the output voltage divided by the input voltage when $I_{OUT} >> I_Q$. However, at light loads, the I_Q must be taken into account when calculating the efficiency. An LDO with lower I_Q will have a higher light load efficiency. This increase in light load efficiency has a negative effect on the LDO performance. Higher quiescent current LDOs are able to respond quicker to sudden line and load transitions.

TIP #9 5V → 3.3V Direct Connect

5V outputs have a typical V_{OH} of 4.7 volts and a V_{OL} of 0.4 volts and a 3.3V LVCMOS input will have a typical V_{IH} of 0.7 x V_{DD} and a V_{IL} of 0.2 x V_{DD}.

When the 5V output is driving low, there are no problems because the 0.4 volt output is less than in the input threshold of 0.8 volts. When the 5V output is high, the V_{OH} of 4.7 volts is greater than 2.1 volt V_{IH}, therefore, we can directly connect the 2 pins with no conflicts if the 3.3V CMOS input is 5 volt tolerant.

Figure 9-1: 5V Tolerant Input



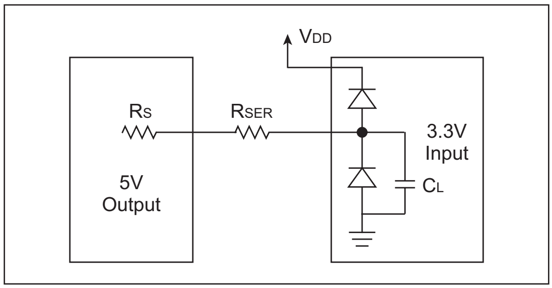
If the 3.3V CMOS input is not 5 volt tolerant, then there will be an issue because the maximum volt specification of the input will be exceeded.

See Tips 10-13 for possible solutions.

TIP #10 5V → 3.3V With Diode Clamp

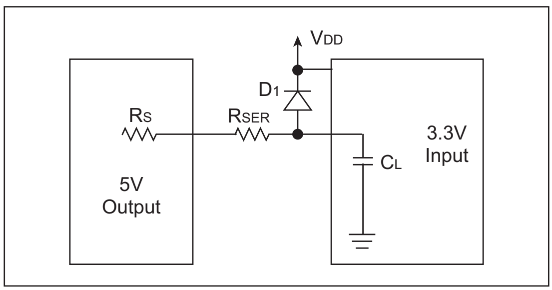
Many manufacturers protect their I/O pins from exceeding the maximum allowable voltage specification by using clamping diodes. These clamping diodes keep the pin from going more than a diode drop below V_{SS} and a diode drop above V_{DD}. To use the clamping diode to protect the input, you still need to look at the current through the clamping diode. The current through the clamp diodes should be kept small (in the micro amp range). If the current through the clamping diodes gets too large, then you risk the part latching up. Since the source resistance of a 5V output is typically around 10Ω, an additional series resistor is still needed to limit the current through the clamping diode as shown Figure 10-1. The consequence of using the series resistor is it will reduce the speed at which we can switch the input because the RC time constant formed the capacitance of the pin (C_L).

Figure 10-1: Clamping Diodes on the Input



If the clamping diodes are not present, a single external diode can be added to the circuit as shown in Figure 10-2.

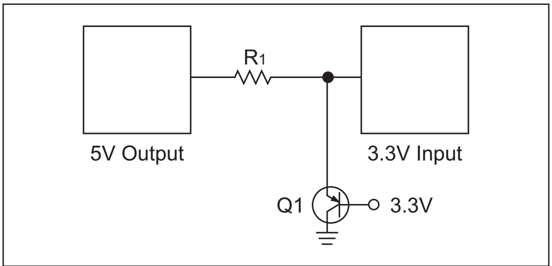
Figure 10-2: Without Clamping Diodes



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

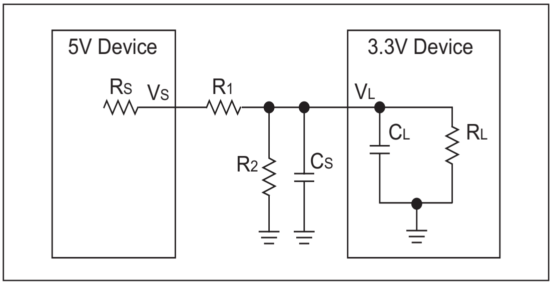


The base-emitter junction of Q1 performs the same function as the diode in a diode clamp circuit. The difference is that only a small percentage of the emitter current flows out of the base of the transistor to the 3.3V rail, the bulk of the current is routed to the collector where it passes harmlessly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

Neglecting the affects of R_S and R_L, the formula for determining the values for R1 and R2 is given by Equation 12-1.

Equation 12-1: Divider Values

$$\frac{V_S}{R_1 + R_2} = \frac{V_L}{R_2} \quad \text{; General relationship}$$

$$R_1 = \frac{(V_S - V_L) \cdot R_2}{V_L} \quad \text{; Solving for } R_1$$

$$R_1 = 0.515 \cdot R_2 \quad \text{; Substituting voltages}$$

The formula for determining the rise and fall times is given in Equation 12-2. For circuit analysis, the Thevenin equivalent is used to determine the applied voltage, V_A, and the series resistance, R. The Thevenin equivalent is defined as the open circuit voltage divided by the short circuit current. The Thevenin equivalent, R, is determined to be 0.66*R1 and the Thevenin equivalent, V_A, is determined to be 0.66*V_S for the circuit shown in Figure 12-2 according to the limitations imposed by Equation 12-2.

Equation 12-2: Rise/Fall Time

$$t = -\left[R \cdot C \cdot \ln\left(\frac{V_F - V_A}{V_I - V_A}\right)\right]$$

Where:

- t = Rise or Fall time
- R = 0.66*R_1
- C = C_S+C_L
- V_I = Initial voltage on C (V_L)
- V_F = Final voltage on C (V_L)
- V_A = Applied voltage (0.66*V_S)

As an example, suppose the following conditions exist:

- Stray capacitance = 30 pF
- Load capacitance = 5 pF
- Maximum rise time from 0.3V to 3V ≤ 1 µS
- Applied source voltage Vs = 5V

The calculation to determine the *maximum* resistances is shown in Equation 12-3.

Equation 12-3: Example Calculation

Solve Equation 12-2 for *R*:

$$R = -\left[\frac{t}{C \cdot \ln\left(\frac{V_F - V_A}{V_I - V_A}\right)}\right]$$

Substitute values:

$$R = -\left[\frac{10 \cdot 10^{-7}}{35 \cdot 10^{-12} \cdot \ln\left(\frac{3 - (0.66 \cdot 5)}{0.3 - (0.66 \cdot 5)}\right)}\right]$$

Thevenin equivalent maximum R:

R = 12408

Solve for maximum R1 and R2:

$R1 = 0.66 \cdot R$ $\qquad$ $R2 = \dfrac{R1}{0.515}$

$R1 = 8190$ $\qquad$ $R2 = 15902$