Mixed Voltage Systems: Interfacing 5V and 3.3V Devices

by
Chris Savage
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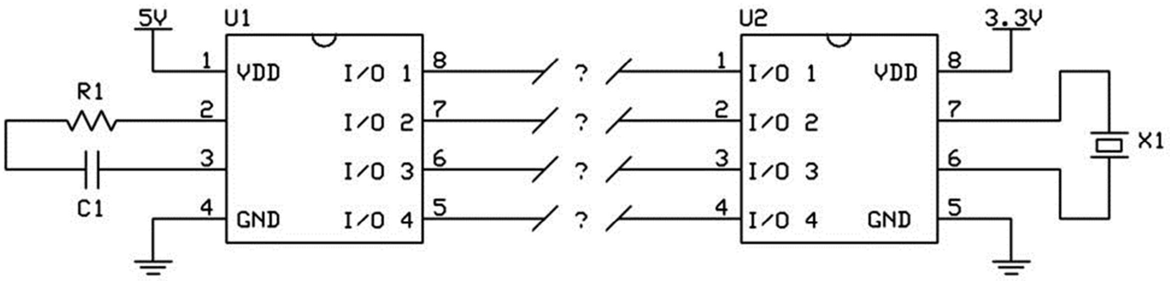


It is common today to find microcontrollers, interface chips, sensors and other devices in 5V or 3.3V flavors. But what happens when you need to interface a 5V sensor with your 3.3V microcontroller? Devices that operate at different voltages most often do not interface directly to one another. The goal of this article is to provide an understanding of the various options for interfacing signals at different voltages.

Introduction

Eight methods for interfacing 5V and 3.3V devices will be described. Not all methods can be used in all situations so it is important to read through all eight sections if this is your first experience with interfacing mixed voltage systems. It is not necessarily important which device in a system is 5V or 3.3V. For each interface method described the direction of the signals is more important, followed by any considerations of using that interface method in your system.

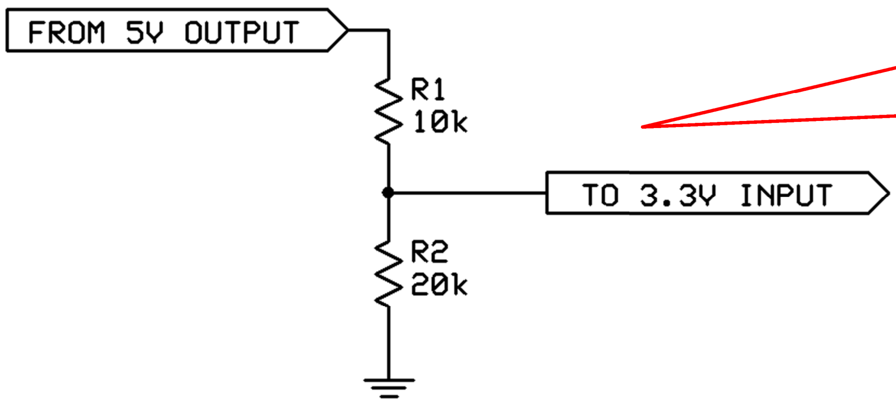
When interfacing mixed voltage systems it is helpful to understand that direction also determines the need for protection. For example, a 5V output going into a 3.3V input requires conditioning, however a 3.3V output going into a 5V input will usually not since the range of input voltages is within the accepted limits of the 5V device. A few exceptions are on some CMOS devices and when interfacing 3.3V to a 5V device with a Schmitt-Trigger input. Always be sure the 3.3V output will be detected as a high by checking the datasheet for the 5V device and verifying the voltage required to register a high input. On open-collector 3.3V outputs a pull-up resistor to 3.3V may be required. In the following interface methods it is assumed that the 5V and 3.3V devices share a common ground unless otherwise specified.

Remarque CPE importante : dans la majorité des cas, on peut piloter une entrée 5V avec un signal en logique 3V3

Voltage Divider

Also known as a potential divider, a voltage divider is probably the most common method of reducing voltage from one signal path to another and arguably the easiest. A voltage divider uses two resistors in series or a potentiometer to attenuate the voltage. This is commonly used to create a voltage reference but when used with a 3.3V device it allows a higher voltage output to be connected to the 3.3V device input.

Figure 1a illustrates a common voltage divider circuit. For equal values of R1 and R2 V_{OUT} will be ½ V_{IN}, however we are looking for V_{IN} = 5V and V_{OUT} = 3.3V.



Avis CPE : peu recommandé
--Consommation d'énergie
--Limitation de bande passante

Figure 1a

The formula for calculating the values of R1 and R2 is shown in **Figure 1b**.

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}}$$

Figure 1b

For V_{IN} = 5V and V_{OUT} = 3.3V and choosing a common value for R1 of 10K, we can solve for R2 using V_{OUT} = (20K / (10K + 20K)) * 5 so V_{OUT} = 3.33V.

Note that the tags show a unidirectional signal path because the voltage division (attenuation) occurs in one direction only. In this case the 5V is attenuated to 3.3V for the 3.3V device input.

Caveats: It is possible to send signals in the opposite direction, however the voltage will remain unchanged in that direction. If you send 3.3V from the attenuated side back through the divider to the 5V device, it will see only 3.3V, not 5V. Also, this explanation on voltage division does not take current draw into account. With a load on the output of the divider you will need to calculate for current separately (also covered at the above mentioned article).

Series Resistor Interface

A series resistor is sometimes used to interface 5V/3.3V devices, however it is important to understand that not all devices can be connected in this manner. This type of interface requires the 3.3V device to have protection from over-voltage on the I/O pins. This is done using clamping diodes which are designed to limit the input voltage to ~3.3V. These clamping diodes are pretty robust, however they are not meant to continuously sink large amounts of current. The series resistor limits the current across the clamping diode so that it is not permanently damaged.

Figure 2 shows a series resistor interfacing 5V and 3.3V devices. The value of R1 is based on the current capability of the clamping diodes.

Avis CPE : utilisable sur le 8051F020.
Fonctionnement Bi-directionnel sous certaines conditions

Figure 2

Not all 3.3V devices are able to be connected in this manner. If your device does not include clamping diodes you should not use a series resistor to interface to the 5V signal. While the 3.3V device may appear to function, it will eventually fail from electrical stress.

The Propeller chip does include protection, however the clamping diodes are rated at ±500 µA. These diodes also have a forward voltage drop of 0.4V. This means the diodes will conduct at 3.7V. To ensure the current limit of the diodes is not exceeded when providing 5V to an input pin we must use a minimum resistor value of 2600Ω.

5V input signal minus the point at which the diodes conduct (3.7V) gives a voltage difference of 1.3V. Solving using ohm's law; 1.3V divided by 500uA gives 2600 ohms.

(5V – 3.7V) / 0.0005A = 2600Ω

To allow for some safety margin due to tolerances and the fact that 2.6k is not a standard resistor value it is recommend to use a 3.3k (2.8k minimum) or 4.7k resistor. Both values are common. Remember, it is not necessary to use a resistor on a Propeller output going into a 5V input. The bidirectional port tags show that the signal can travel in each direction, but the resistor is only required when the signal is bidirectional or an output from the 5V device.

Caveats: Current is limited by the current rating of the clamping diodes. Larger resistors will reduce overall signal bandwidth. For example, you could use a 10K resistor in the example above, however less signal bandwidth would be available than using the minimum required resistor value.

Diode Interface

Using a diode to isolate the 5V signals from the 3.3V device can offer a safer method of interfacing and does not require the 3.3V device to have protection diodes. In this interface the diode prevents 5V signals from entering the 3.3V device but allows the 5V device to assert the signal low, ensuring that the 3.3V device only sees 3.3V or 0V (GND).

Figure 3 shows the diode circuit allowing a 5V device to control a 3.3V device. Note R1 which is used to ensure the 3.3V input is high when the 5V device is not asserting the line low. This resistor is needed if the 3.3V line is not already pulled high because the 5V device cannot assert the signal high through the diode.

Avis CPE : Si le « 3.3V Input » correspond à une entrée du 8051F020, il ne faut pas oublier que cette dernière contient une résistance de PullUp
Montage unidirectionnel.
Type de la diode : Schottky BAT41

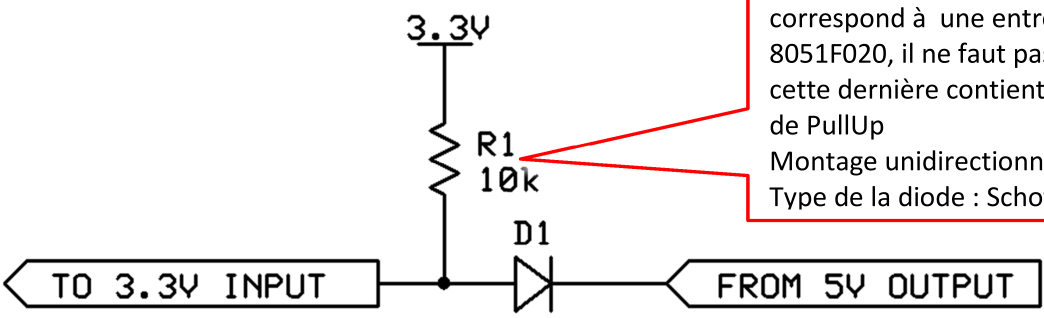


Figure 3

While the diode allows the 5V device to assert the 3.3V device low, the actual voltage of the low signal will be equal to the voltage drop of the diode. It is for this reason that a Schottky diode is typically used in this circuit, as it has a lower forward voltage (typically 0.2V). It is important to be sure the cathode of the diode is toward the 5V device.

Caveats: When the 3.3V signal line is pulled low it will not be at 0V, but instead at 0V + V_{FWD} of the diode.

Transistor (BJT) Interface

Transistors have long been used to control a larger voltage (or current) with a smaller voltage (or current), essentially acting as an amplifier or switch. When used to condition a signal a transistor inherently inverts the signal. Still a transistor provides yet another way to interface signals of different voltages. Within a microcontroller environment it is easy to compensate for inverted signals in code.

Figure 4 shows how to use a 2N3904 NPN transistor to safely interface to a 3.3V input from a 5V device. As you can see a pull-up resistor (R2) is required on the 3.3V side. A current limiting resistor (R1) is required on the 5V side. When the 5V output goes high, Q1 will bias pulling the 3.3V side to ground. When the 5V output is low, Q1 is not conducting and R2 pulls the 3.3V side to 3.3V.

Caveats: A single-transistor buffer such as the one shown inherently inverts the signal.

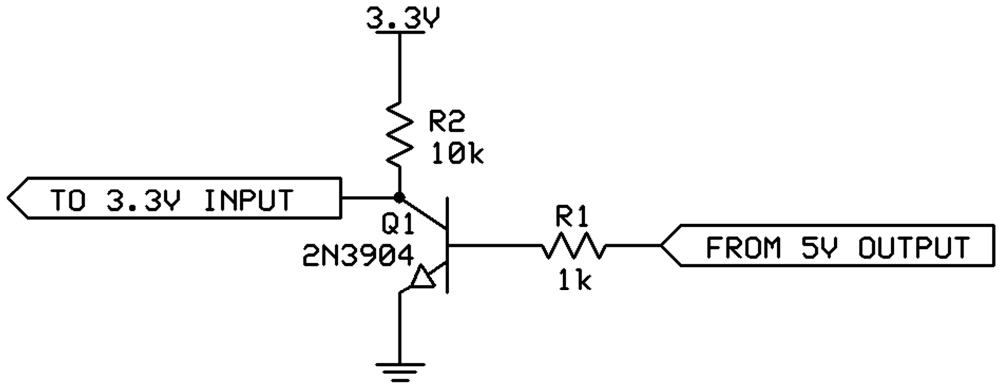


Figure 4

Figure 5 shows the same interface using a BS170 FET instead of a 2N3904 BJT. In this arrangement R2 is still required to pull up the 3.3V input, however R1 is now connected to ground to ensure Q1 is off when the 5V output is floating. This can happen on power-up if the control pin has not yet been initialized to an output.

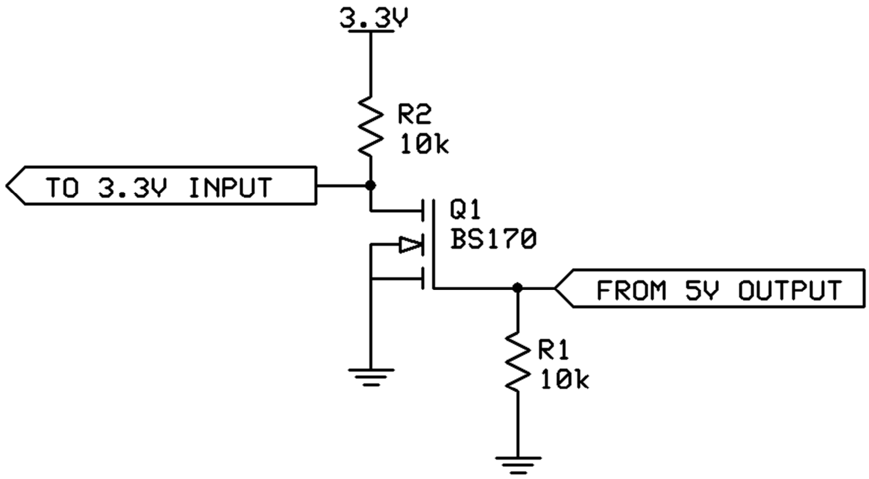


Figure 5

While inversion is easily handled in software on a microcontroller, if for some reason you cannot have the signal inverted in your design and want to use the FET design you can also create a 2-stage buffer as shown in **Figure 6**.

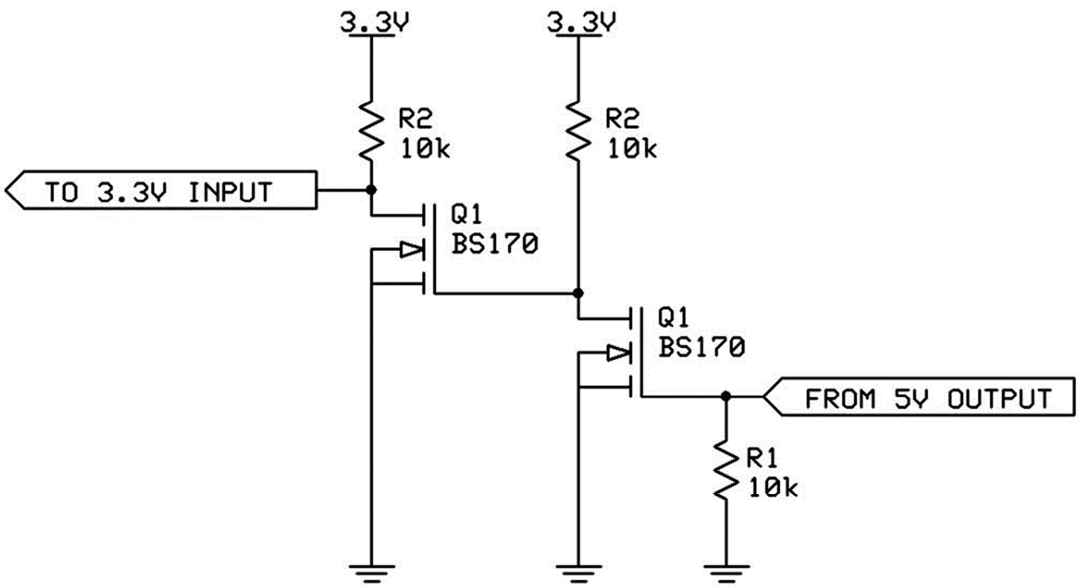


Figure 6

In this circuit the signal is double inverted making the output signal follow the input relative to the voltage supply levels.

Caveats: The Double-Inverted circuit can be done easier and cheaper these days with specialized 1-bit ICs designed for this task, however this circuit shows the underlying concept.

Optical Isolation Interface

Optical Isolators work just like transistors as far as the output is concerned, but with two important benefits. First, optical isolators can provide complete electrical isolation between two different devices, which can be useful if there is a lot of electrical noise present. The other benefit when using optical isolators is that it is possible to prevent the signal from being inverted depending on how the input to the opto is wired. This is because the input to the opto is essentially an LED. This LED controls the base of the transistor providing isolation while biasing the internal photo-transistor. **Figure 7** shows how a 4N25 opto-coupler could be connected to send a 5V signal safely to a 3.3V input.

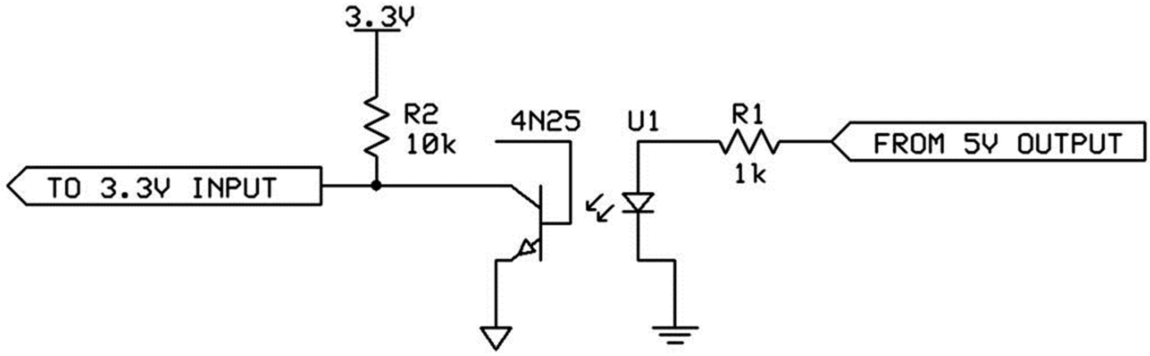


Figure 7
(3.3V/5V GND are NOT common)

Note that this circuit still inverts the signal, however this effect can easily be changed by connecting the input as active-low rather than active-high as shown in **Figure 8**.

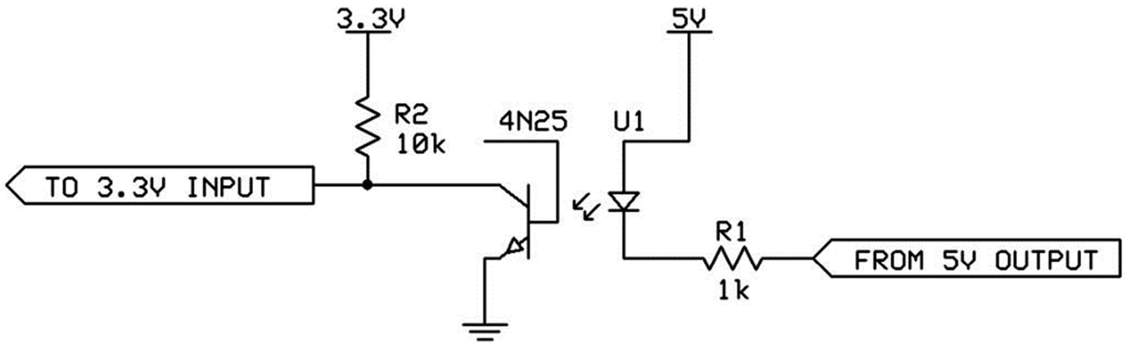


Figure 8

By keeping the signals optically isolated, noise and voltage issues are non-existant. In this manner optocouplers have several advantages over previous methods demonstrated for interfacing 5V and 3.3V signals. Optocouplers are also very useful for interfacing 5V or 3.3V microcontrollers to devices that operate at much higher voltages such as 12V automotive systems or 24V industrial applications.

Caveats: While an optically isolated interface can be a benefit in certain situations it can cause issues in circuits where a common ground is required between systems. This type of interface is usually only used in highly noisy environments, such as industrial or automotive interfacing or where isolation is desired.

MOSFET (Pass Transistor) Interface

In open-collector systems such as 1-Wire®, I2C or even non-inverted serial interfaces a Pass Transistor interface such as the one shown in **Figure 9** is an ideal method for bi-directional level translation and can be achieved with an N-Channel MOSFET such as the BS170. If neither device (5V or 3.3V) pulls the data line low, V_{GS} of Q1 is 0V and the 5V device sees 5V while the 3.3V device remains at 3.3V.

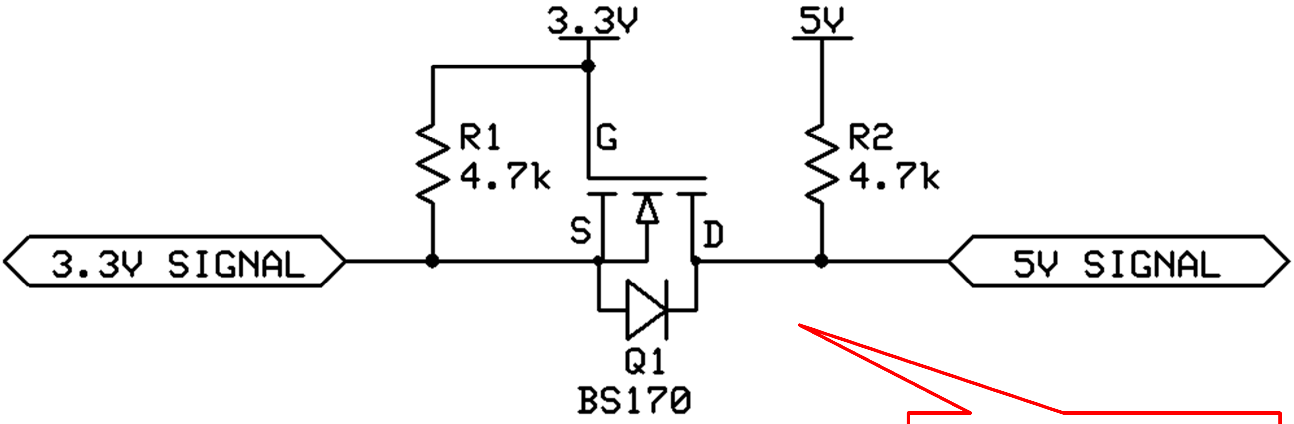


Figure 9

Avis CPE : Un vrai Montage Bi-directionnel

If the 3.3V device pulls the data line low the V_{GS} of Q1 is 3.3V and will turn on Q1, pulling the 5V data line low. If the 5V device pulls the data line low, the body diode of Q1 will be forward biased, pulling the source to 0.6V. V_{GS} will be 2.7V and Q1 will turn on, pulling the 3.3V data line low. In this manner logic levels are translated in both directions.

Ideally the 3.3V device will have zero resistance at ground, however in a real-world application this is likely not the case. If you factor in the resistance of the sinking driver you can calculate that V_{GS} will not necessarily be at 3.3V, but lower depending on the value of R1 and the R_{DS} of Q1.

Caveats: In this design slew rate is directly dependant on the values of R1/R2 and affected by the devices sharing the bus, which can affect capacitance. Lower resistor values will increase the maximum transmission rate, however power consumption will be increased.

Buffer Interface

Buffer arrays are typically used to buffer current on a signal bus, however they can be used to interface 5V devices to 3.3V devices by using a family of buffer known as LVC (Low-Voltage CMOS). This particular family is suited to 3.3V devices while providing 5V tolerant inputs. A common 74LVCxxx buffer for interfacing 5V devices to 3.3V devices is the 74LVC244A, which is an octal buffer, enabled in two groups of four ports.

The 74LVC244A provides a non-inverting 3.3V buffered output which can accept both 5V and 3.3V input signals. The outputs are capable of sourcing/sinking up to 50 mA and the supply range is typically 1.65V to 3.6V making 1.8V operation possible. The signal is unidirectional.

As you can see from **Figure 10**, the pins are grouped into two ports with four outputs each. There is a separate output enable pin for each group of pins.

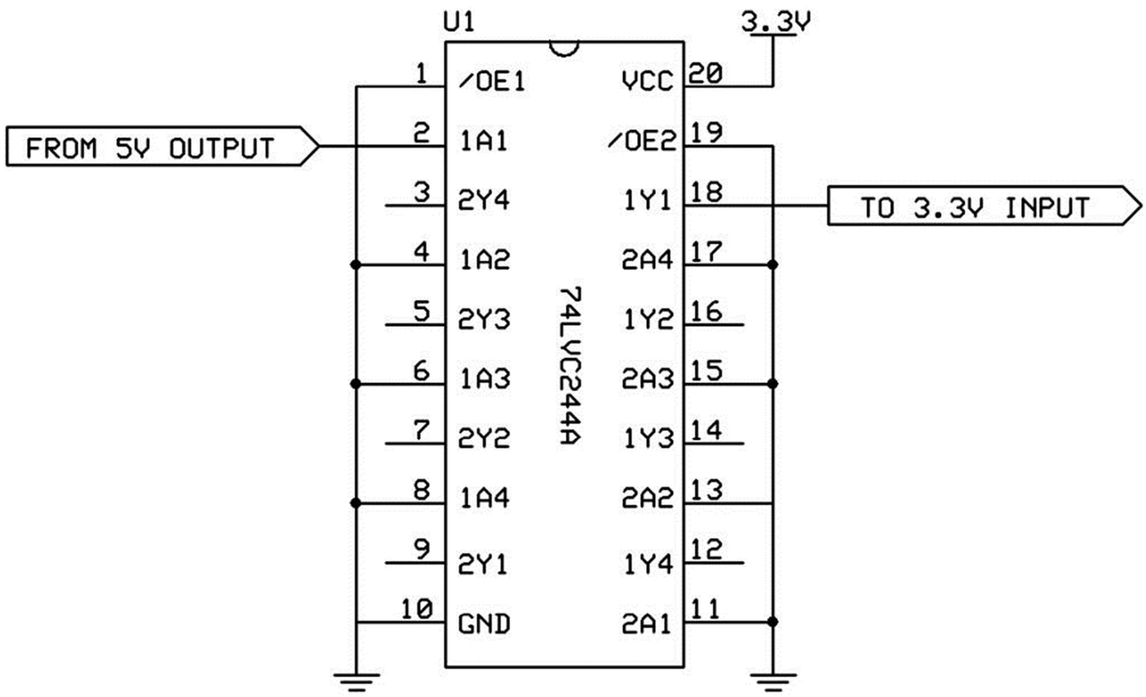


Figure 10

When an /OE pin is high, the outputs for that group are high-impedance. When an /OE pin is low data is passed from an A input to the Y output at a level equal to V_{CC}. Unused inputs are commonly tied to ground to reduce noise and power consumption.

Other LVC-family devices are available with 1, 2, 4 or more drivers.

Caveats: Although the buffer accepts 5V signals on the inputs, the device is powered by 3.3V and therefore uses a single 3.3V supply. The 5V signals coming in must have their own 5V source.

Voltage Translator Interface

Voltage Translators are specialized devices designed to overcome traditional problems associated with bi-directional mixed voltage interfaces. As specialized devices these voltage translators are not typically to be used in a design without verifying the electrical requirements of the circuit against those required by the translator.

The TXB0108PW is a non-inverting, bi-directional eight port voltage translator with individual V_{CCA} and V_{CCB} supply inputs and an active high output enable. Port A can operate from 1.2V to 3.6V and Port B can operate from 1.65V to 5.5V, however Port A voltage supply must always be less than or equal to Port B voltage supply.

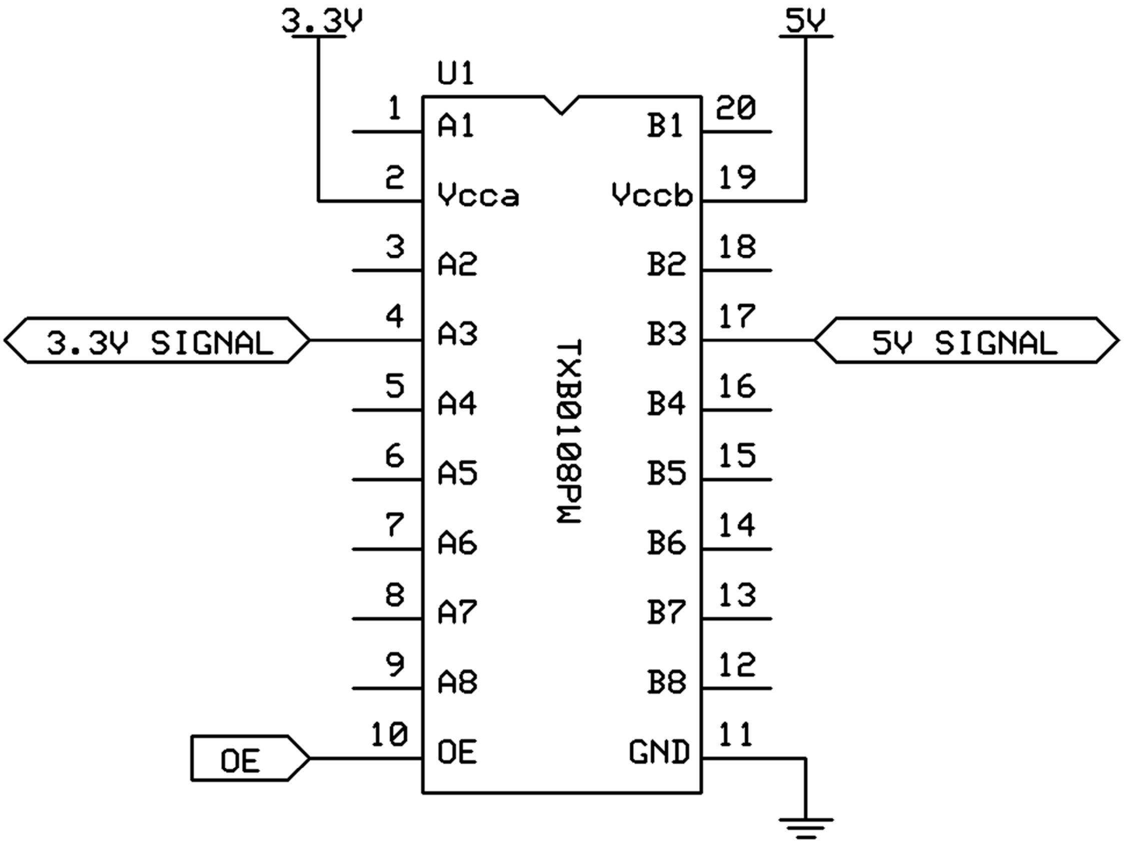


Figure 11

Devices such as the TXB0108PW implement protection features such as disabling the outputs when either Port VCC is at ground. This device also contains one-shots to detect rising and falling edges on Ports A & B. This speeds up low-to-high and high-to-low transitions. The TXB0108PW, like other similar devices will have specific requirements for the input/output circuits to ensure proper operation.

For example, the TXB0108PW requires an input drive strength of at least ±2 mA. The device is also designed to drive capacitive loads of up to 70 pF.

Caveats: Output loads must have an impedance of >50 kΩ so as not to contend with the output drivers. This excludes the TXB0108PW from use in I2C or 1-Wire interfaces or anywhere there is an open-drain driver connected to the bi-directional data line.

Conclusion

This article demonstrated many (8) ways of interfacing 5V and 3.3V technology. If you find that you still have questions when facing this type of interface please feel free to join us on the Savage Circuits forums. Savage Circuits is a project website devoted to microcontrollers and electronics and the projects we create with them.

This project was published in the April 2011 issue of Nuts and Volts Magazine.
Updated on 6-14-2011.

PERMALINK: http://www.savagecircuits.com/mixedvoltage