

FLOATING INPUTS and RESISTORS FOR PULL-UP, PULL-DOWN, and CURRENT LIMITING

EGR/CS 333 Digital Design and Interfacing
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Adapted from some of my previous lecture notes, plus references:

<http://www.seattlerobotics.org/encoder/mar97/basics.html> by Kevin Ross (**MOST OF THIS HANDOUT**)

<http://www.kpsec.freeuk.com/imped.htm> by John Hewes 2010

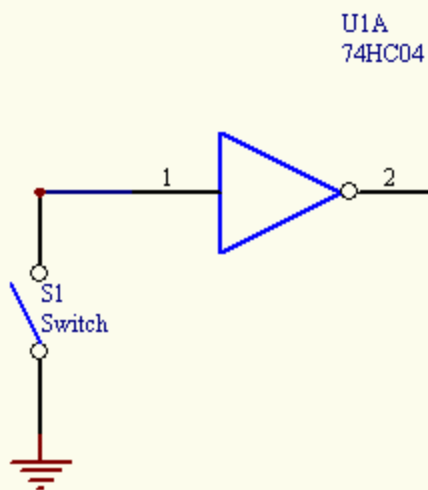
http://en.wikipedia.org/wiki/Input_impedance

PULL-UP RESISTOR

Is to insure that given no other input, a circuit assumes a default value (pulls the line high). A pull-down function is the same, to create a default value but pulls line low.

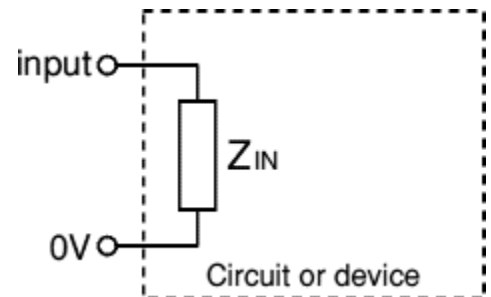
EXAMPLE: Gate U1A input (pin 1) and output (pin 2).

Input state of most logic gates is called **high impedance**. *The Input impedance of an electrical network is the equivalent impedance "seen" by a power source connected to that network. Usually input impedances should be high, at least ten times the output impedance of the circuit (or component) supplying a signal to the input. This ensures that the input will not 'overload' the source of the signal and reduce the strength (voltage) of the signal by a substantial amount.*



Input impedance (Z_{IN}) is the impedance 'seen' by anything connected to the input of a circuit or device

If nothing is connected to pin 1, the value of the input is considered to be **FLOATING**.



Most gates will float towards a high state for TTL BiPolar transistor circuits; This is a very weak condition, and any electrical noise could cause the input to go low.

For CMOS circuits, it may be low, but still unpredictable

When switch S1 is closed (on), the input state at pin1 goes low. Since there is a definite connection to an electrical potential (in this case ground), the state of the pin is stable.

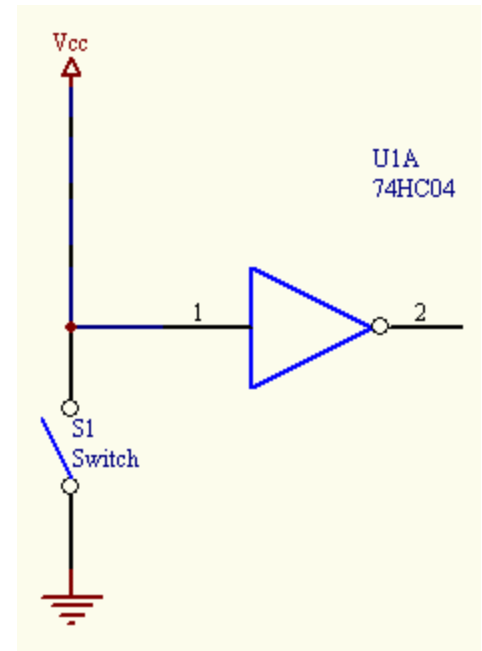
When switch S1 is open (off), input pin 1 is susceptible to a wide array of electrical problems. The traces or wires connected to pin 1 may very well allow enough electrical noise in (by acting as little antennas) to cause pin 1 to incorrectly switch states. What is needed here is a way to connect pin 1 to an electrical potential that can be removed when the switch is closed. This electrical potential will allow the pin to keep a steady state.

A floating input gate.
Not Good!

One thought is to tie the pin to Vcc (+5 volts) to insure pin 1 doesn't float. The line does not float, it has an ON state.

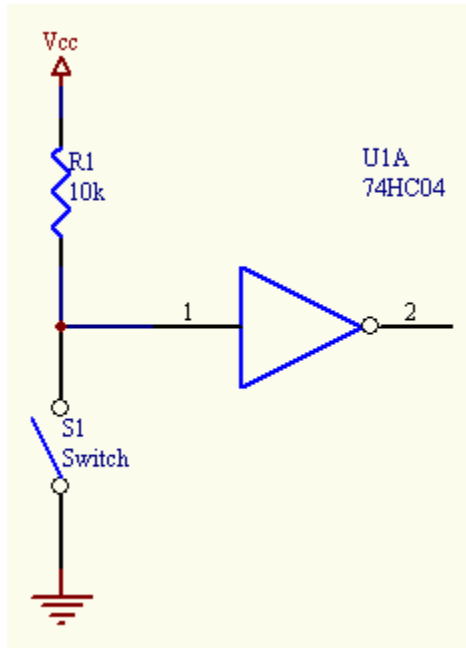
The problem is what happens when switch S1 is closed. This creates a direct electrical connection between Vcc and GND, it will short out the circuit. If you are lucky, it will just stop your entire system from working. If you are unlucky, it will burn up the wires!

The problem with short circuits is they allow too much current to flow from Vcc to GND. This causes heat to be generated, which can sometimes burn parts, wires, or even start fires. In addition, most circuits fail to function correctly because the voltage at the power supply drops to zero. In general, this is a bad situation!



A very bad idea!

Now add a pull-up resistor to limit the current that can flow through the circuit.



Pull-up resistor limits the current

When switch S1 is open (off), pin 1 is tied to Vcc through the resistor. Since pin1 is a high impedance input, a voltage meter or logic probe placed on pin 1 will show Vcc (+5v) if connected to pin 1.

When switch S1 is closed (on), pin 1 has a direct connection to GND, which takes it to the low state. The pin1 side of R1 also has a direct connection to ground. Current will flow from Vcc, through R1, and to ground. It isn't considered a short, however, because R1 will limit the amount of current that can flow to a very small amount. In fact, you can compute this using Ohms law.

$$I = V / R$$

$$I = 5v / 10,000ohms$$

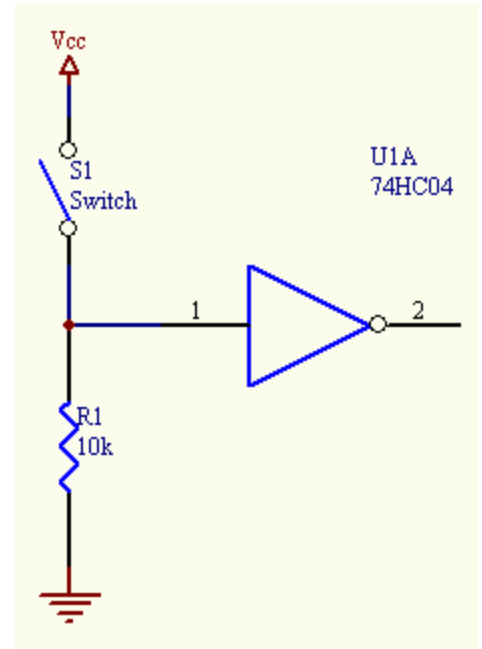
$$I = .0005A (.5mA)$$

Most digital circuits use a 10k or a 47k resistor for pullups. The exact value doesn't actually matter, as long as it is high enough to prevent too much current from flowing. 10k seems to be the most common, but if you are hoping to save as much power as possible, the a 47k resistor may be right for your application. In some cases, you can go higher, but then you are depending on characteristics of the pins on the chip.

You will find that pull-up resistors are extremely common in most digital circuits. The key function for a pull-up is to prevent input lines from floating. The key function for the resistor itself is to prevent too much current from flowing through the pull-up circuit.

PULL-DOWN RESISTOR

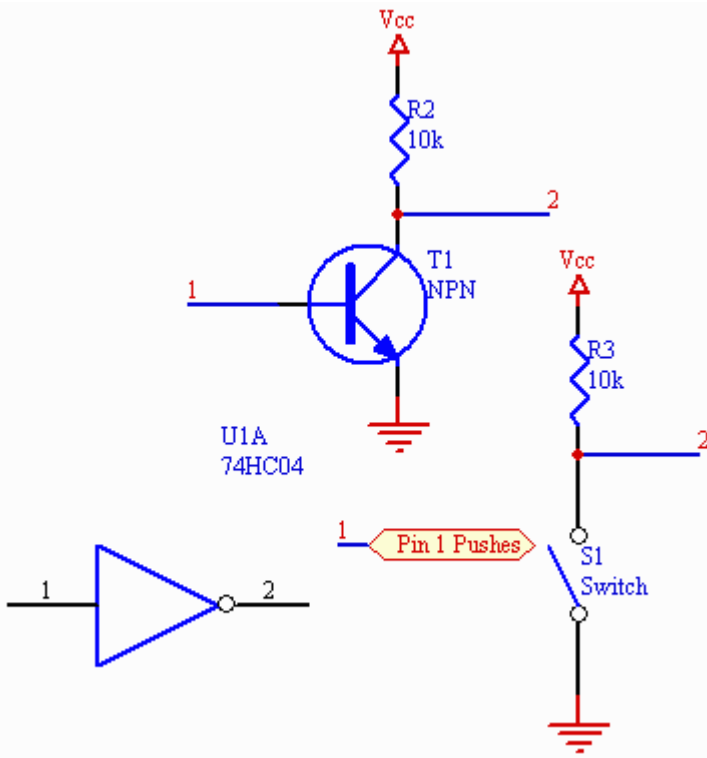
Just like the pull-up resistor, it is used to limit the current that can flow between Vcc and ground. Though less often used, it is still a valid thing to do.



The less common pull-down

The Current Limiting Resistor

If you have just read the above article, you hopefully understand how a resistor limits the amount of current that can flow through a circuit. In the above example, we were dealing with input pins. Expanding on that idea, consider a simple circuit that use limiting resistors with output pins and also with an LED.



Unlike an input pin, which has only high impedance, an output pin is designed to have two states: Drive (on, or high logic) and Sink (off, or low logic).

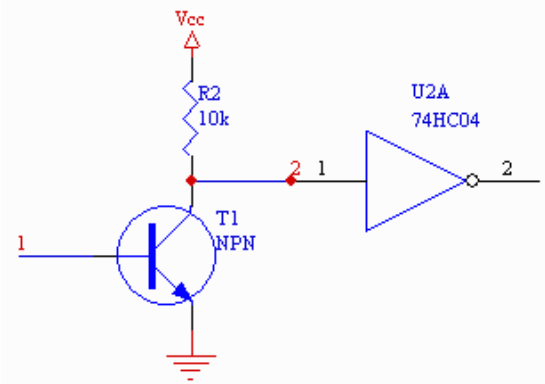
Let us look at a simple digital circuit, the 74HC04 Inverter. The picture on the right shows the symbol for the 74HC04. Internally, this chip is constructed using transistors. I have taken great liberty by reducing the circuit to a single transistor version, T1. Digital circuits use transistors as switches. When a current is supplied at pin 1, the transistor allows current to flow from pin 2 to GND.

Closing the switch allows current to flow from pin 2 to GND. These are functionally equivalent circuits. The actual implementation of the 74HC04 is much more complex, but the basic ideas presented are still valid.

In digital circuits, output gates are switches.

In the above drawing, you can see that the equivalent circuit using the switch demonstrates that the internals of an output gate use a pull-up resistor. By replacing the original push button switch by the equivalent transistor circuit, it looks like the schematic on the right.

A quick analysis shows that when T1 is off, R2 pulls the output pin high, which is good for U2A's input pin. When T1 is on, T1 ties U2A's input pin to GND, which brings the input pin low. R2 allows a little bit of current to flow.



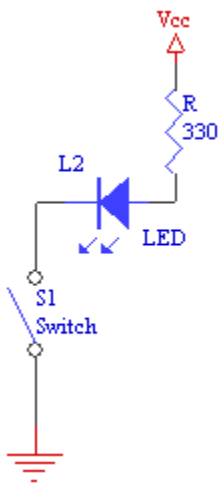
Note that on the real 74HC04, the pull-up resistor R2 is internal to the chip. Therefore, you can directly connect the output of most integrated circuits directly to the input of others without an external pull-up resistor.

There are times when you connect the output of a gate to a device that isn't the input of another device. For example, driving an LED, is an example.

An important consideration when connecting anything to an output gate is what will happen when the gate drops to logic zero. This basically creates a direct line to GND, just like the switch example. Before you connect anything to an output gate, you should consider how much current will flow through the gate in the zero state. Quite often, you will need to add a current limiting resistor to insure that you don't burn up the part.

Most logic parts are capable of handling around 20mA of current per pin. This means that you need to consider carefully the device being attached.

How to make an LED work



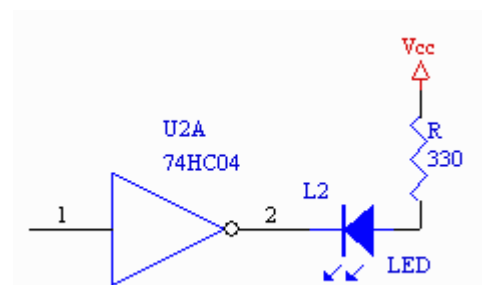
An LED (Light Emitting Diode) is a semiconductor that emits light energy when a current flows through it. Current will only flow one direction, just like a regular diode. There are a few things you need to know about an LED before you use one. First, and most importantly, is that an LED has very low internal resistance. This means that left to itself, an LED will pass so much current that it will burn up. They require an external resistor to limit the current.

Most LED's have a current rating, which determines the size of the resistor you will need. The current rating tells you what the maximum allowable current for the part is. In general, the higher the current, the brighter the LED.

Most LED's seem to handle at least 15mA. If you are using a 5 volt circuit, then Ohms law tells you what resistor value to use. $R = V / I$, so $R = 5v / .015A = 333$ ohms.

Now let us consider what happens when using the output of a chip, such as the 74HC04, to operate an external device. For example, the circuit on the right drives an LED. When the gate is HIGH, then there is no path to GND for cathode of the LED L1. When the gate is LOW, then output pin 2 is connected to ground, and current flows.

Since R3 only allows 15mA of current to pass, the gate is safe from being overloaded. Remember that most gates can handle 20mA of current. The same holds true for most microcontrollers.



In Summary: The output from gates acts very much like a switch. When the gate is logic low, it goes to ground. Most gates can only handle about 20mA of current without burning up. You should always understand how much current will flow when the device is connected to a logic low gate.