Types of Level-Shifting

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How it works

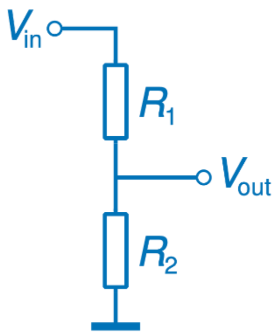
A level shifter (level translator), in digital electronics, also called logic-level shifter or voltage level translation, is a circuit used to translate signals from one logic level or voltage domain to another (usually between 5V and 3.3V), allowing compatibility between ICs with different voltage requirements.

This document is a guide on how to level shift from 5V to 3.3V and vice versa.

METHOD#1: The Voltage Divider

- **This is probably the most common method of level shifting. It uses 2 resistors and an input voltage to create an output voltage that is a fraction of the input.**
- **Below you can see the formula that you need to use to calculate the resistors that you need in your circuit:**

$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2} \quad <=>$$



$Figure\ 1.0$

<u>Advantages:</u>
- Easy and quick to set up.
- Good for prototyping.
- Cheap.

<u>Disadvantages:</u>
- This method works for slow signals.
- Works only from 5V to 3.3V (unidirectional).
- Not reliable at high frequencies.
- Can add a lot of slew and cause havoc that is tough to debug.

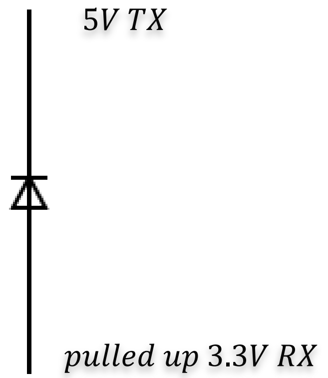
<u>Note:</u> A voltage divider (also known as a potential divider) is a passive linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}). Voltage division is the result of distributing the input voltage among the components of the divider.

METHOD#2: The Diode

Part example: 1N4148

- **Using a reverse biased diode is another simple method of level shifting.**
- **Reverse bias usually refers to how a diode is used in a circuit, so that if a diode is reverse biased, the voltage at the cathode is higher than that at the anode, therefore, no current will flow until the electric field is so high that the diode breaks down.**

Scenario: Imagine we want to send data from the 5V driven TX pin of a controller to the 3.3V capable RX pin of another controller. What we can do is to put a reverse biased diode in series from one transmission point to the other like in the Figure 2.0.



$Figure\ 2.0$

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Note: It is important to understand that for this to work we need a pull-up across the diode that connects RX to TX. A solution would be enabling the internal pull-up resistor on the RX pin.

METHOD#3: Bi-Directional Logic Level Converters

Part example: TXB0108

- **If you are looking for a dedicated solution then a Bi-Directional Logic Level Converter (LLC) is the way to go! It reduces the voltage from a signal This is the recommended method to level shift signals that require high speed communication (serial at a high baud rate, I2C, etc…).**
- **You simply connect the signal with the High Voltage to the HV pins and it outputs the signal with the lower voltage on the other side (LV).**

Advantages: Easy and quick to set up.
Good at high frequencies.
Some can auto-detect the direction.

Disadvantages: Can struggle to drive high current applications such as LED's.
You need to research a bit to see if it fits your application.
Expensive.

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METHOD#4: Bi-Directional Level Shifting with Transistors

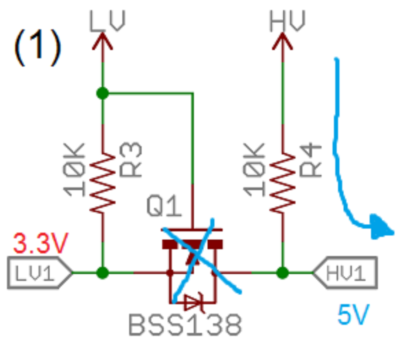
Part example: MMBT2222LT1G

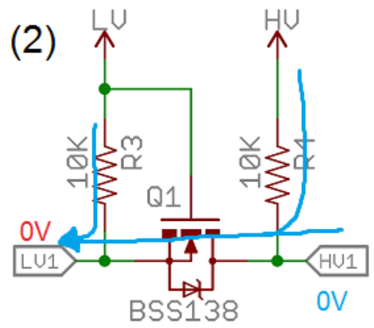
- **Here things get a bit more complicated. There obviously are two modes of operation, up-shifting (LV1 is input, HV1 is output), and down-shifting (HV1 is input, LV1 is output).**
- **Let's assume that LV is 3.3V and HV is 5V. Here are the possible scenarios:**

Up-Shifting (LV1 = Input, HV1 = Output)

1. When the input pin is high, then the V_{gs} of the MOSFET will be zero. Both the gate and the source are at 3.3V. As such the MOSFET is turned off, and the output pin will be pulled up to 5V by R4.

2. When the input is pulled low, the source will be at 0V, but the gate will remain at 3.3V. As such V_{gs} is now 3.3V and the MOSFET turns on. The MOSFET will pull the drain down to te source voltage (0V), which means the output pin will now be low. (The input pin is sinking current from both R3 and R4).





METHOD#4: Bi-Directional Level Shifting with Transistors

Part example: MMBT2222LT1G

Down-Shifting (LV1 = Output, HV1 = Input)

3. When the input pin is high, there is nothing in the circuit pulling the output down. As such it will be pulled up to 3.3V by R3. This will make the V_{gs} of the MOSFET zero, preventing any current flowing from input to output. As such the output voltage cannot exceed 3.3V, even though the input is 5V.

4. When the input is pulled low, the body diode of the MOSFET which goes from source to drain will start conducting and pull the output down. As the output is pulled down, the source voltage moves towards V_{sd} (body diode forward voltage).

5. As this happens, V_{gs} will now be 3.3V - V_{sd}, which must be sufficient to turn the MOSFET on. Once the MOSFET turns on, the output voltage will then drop towards zero as current trough R3 flows through the channel rather than the body diode.