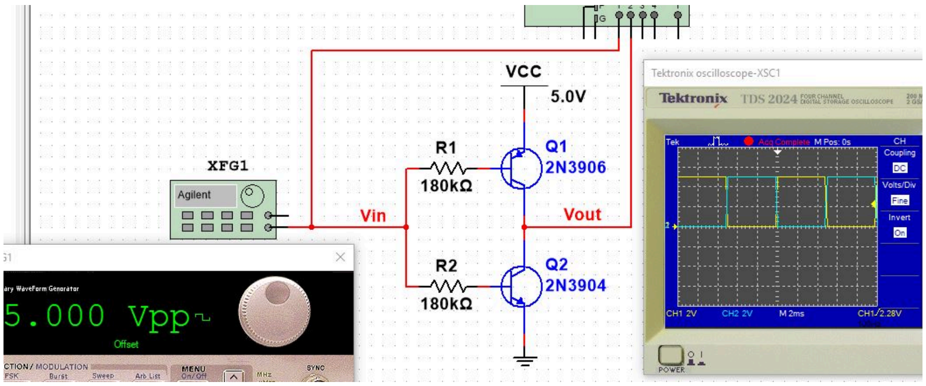
Totem Pole and H-Bridge Configurations

Up to this point, every circuit we've designed using semiconductor devices has had something to limit the current in series with the diode or transistor, since the resistance of a conducting semiconductor device is very low, and could allow a dangerous flow of current, usually resulting in thermal destruction of the semiconductor device.

The Totem Pole configuration, and the related H-Bridge bidirectional device driver, do not have resistors in series with the transistors. Instead, current is controlled by having one or the other of two series transistors turned off at any given time.

Totem Pole

Build the following circuit using Multisim, and verify its operation as indicated below.



Be very careful with the orientation of the two transistors -- the PNP transistor's Emitter is at the top!

Also, be careful with the setup of the function generator -- it's producing a square 0 to +5 V pulse, which, for the Agilent generator, requires an amplitude of 5 V_{p-p} and a DC offset of 2.5 V_{DC}.

1. When the input voltage (Channel 1) is at 0.0 V, what is the output voltage? 5 V

2. When the input voltage is at +5 V, what is the output voltage? 0 V

3. From a logic perspective, what is this circuit? NOT (inverter)

Remove the oscilloscope and the function generator, and instead connect V_{in} to ground and place a current and voltage (AV) probe on the wire between the Collectors of the two transistors.

4. How much current is flowing through the transistors, to the nearest microamp? 0 μA

Now, connect V_{in} to +5 V instead.

5. How much current is flowing through the transistors now, to the nearest microamp? 0 μA

Place a current probe on the wire to R_2.

6. How much Base current is flowing to the NPN transistor? 24.5 μA

Analysis

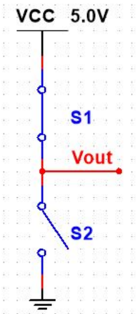
What we have built is a logic inverter (inverting transistor switch) that doesn't draw any current through what would normally be considered its main circuit path. Let's determine why.

7. When the input signal is at ground, how much Base current can flow through Q_1, the PNP transistor, assuming V_{BEon} is 0.7 V for both transistors? 23.9 μA

8. If current is flowing through Q_1's Base, it is likely to be in saturation , and can be pictured as a(n) closed switch

9. When the input signal is at ground, how much Base current can flow through Q_2, the NPN transistor? 0 μA. This means that Q_2 can be pictured as a(n) open switch

With the input signal at ground, we can model our transistors as in the following picture:



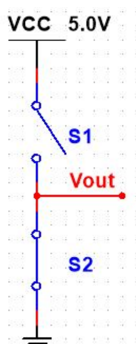
It should be fairly clear from this model that:

- V_{out} is directly connected to V_{CC}, so it will be +5 V
- No current can flow because Q_2 is in cutoff.

Let's investigate the opposite condition.

10. When the input signal is at +5 V, how much Base current can flow through Q_1, the PNP transistor, assuming V_{BEon} is 0.7 V for both transistors? 0 μA
11. With no current flowing through Q_1's Base, it will be in cutoff , and can be pictured as a(n) open switch
12. When the input signal is at +5 V, how much Base current can flow through Q_2, the NPN transistor? 23.9 μA. Assuming the transistor will be either saturated or cut off (not in the active region), this means that Q_2 can be pictured as a(n) closed switch

With the input signal at +5 V, we can model our transistors as in the following picture:



It should be fairly clear from this model that

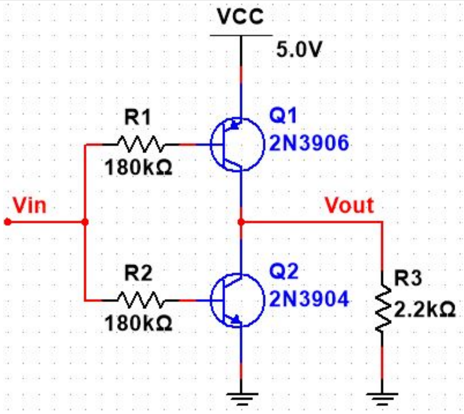
- V_{out} is connected directly to ground and is therefore at 0 V
- No current can flow because Q_1 is in cutoff

The Totem Pole arrangement therefore provides us with a clear voltage output, suitable for digital logic, without requiring any current through the main path of the transistors. Unfortunately, there is still some Base current required to saturate the "on" transistor in each case. When we study Field Effect Transistors, we'll discover that they also eliminate the need for any controlling current, and are therefore even more efficient than the BJT Totem Pole.

Totem Pole Device Driver

In and of itself, the Totem Pole configuration has no current path. However, when it is connected to a load, current will flow through that load when the Totem Pole creates a potential difference across the load. Since the transistors act as current sources, they can be designed to provide considerable current when required.

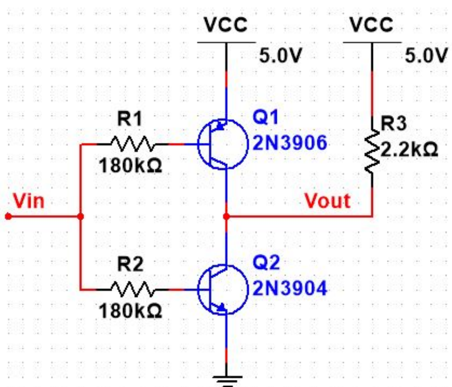
Let's go back to our original circuit, but this time with a load to ground.



In this case, current will flow through the load when V_{in} is LOW, because at that point V_{out} will be HIGH (at +5 V), so a potential difference will exist across the load resistor.

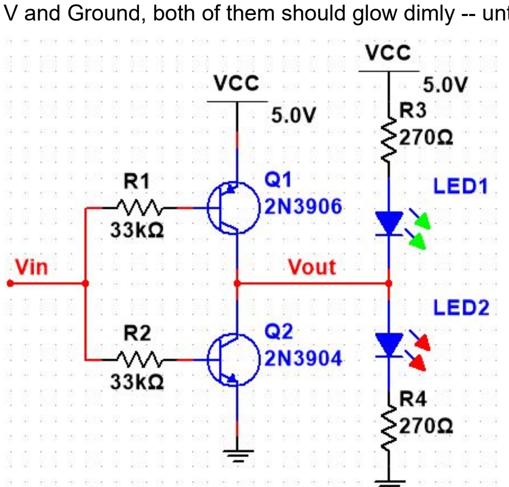
13. How much current will flow through the load when V_{out} is at +5 V? [2.27] mA
14. Given that the Base current for Q_1 is 23.9 μA from previous calculations, what current gain (β) would be required to produce this load current? [95] Since this is within the specified range of values for the 2N3904 and 2N3906, the transistors will still saturate when so needed.
15. When V_{in} is HIGH, how much current will flow through the load resistor? [0] mA

Now, consider the following arrangement:



16. This circuit will draw current through the load resistor when V_{in} is [HIGH] because V_{out} will be LOW, providing a potential difference from +5 V to ground across the load.

Here's an interesting variation on the circuit. Try this in Multisim. It seems that, having two properly-biased LEDs connected together between +5 V and Ground, both of them should glow dimly -- until you consider the action of the Totem Pole transistors.



17. Assume that the forward barrier potential of each of the LEDs is 2.0 V. When V_{in} is LOW, V_{out} is HIGH. How much current will flow through the Green LED, LED1? [0] mA

18. When V_{in} is LOW, how much current will flow through the Red LED, LED2? [11.1] mA

19. So, when V_{in} is LOW, [the Red LED will gl…]

20. When V_{in} is HIGH, V_{out} is LOW. How much current will flow through the Green LED? [11.1] mA

21. When V_{in} is HIGH, how much current will flow through the Red LED? [0] mA

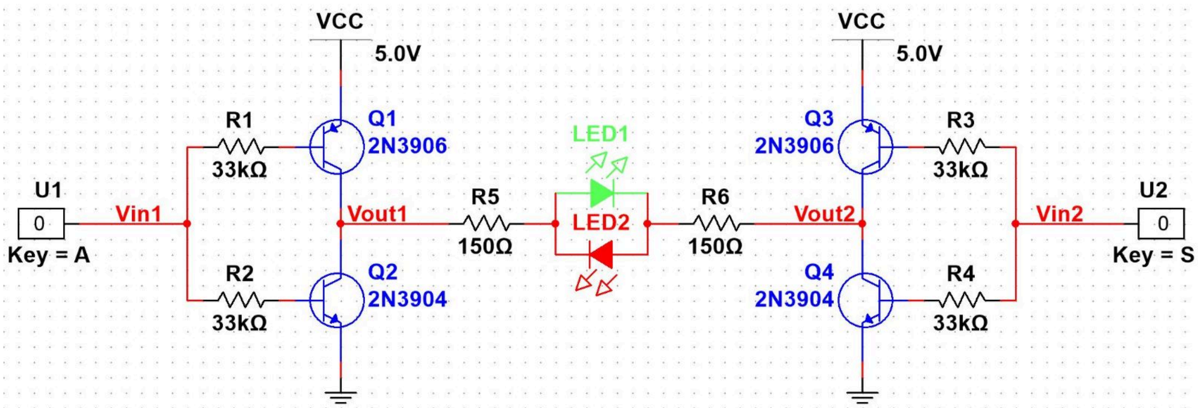
22. So, when V_{in} is HIGH, [the Green LED will…]

Notice that the Base resistors are considerably smaller in this example, in order to provide sufficient current to drive the LEDs. If you want, you can double-check to see if they provide sufficient Base current to saturate the transistors.

From this example, we've discovered that the Totem Pole configuration can selectively activate one of two connected circuits. The H-Bridge takes this control one step further.

H-Bridge Bidirectional Device Driver

The H-Bridge is made of two Totem Poles with a load between them, often a reversible DC motor. In the circuit below, two LEDs, mounted in opposite directions, will be used instead to show the direction of current flow.



Again, you can build this circuit in Multisim to verify its operation. If you want, you can use an "INTERACTIVE_DIGITAL_CONSTANT" for each of V_{in1} and V_{in2}.

23. From what we learned about this device before, we should be able to fill in the following table.

V_{in1}	V_{in2}	V_{out1}, V	V_{out2}, V	V_{out2} - V_{out1}, V	LED1	LED2
LOW	LOW	5	5	0	OFF	OFF
LOW	HIGH	5	0	-5	ON	OFF
HIGH	LOW	0	5	5	OFF	ON
HIGH	HIGH	0	0	0	OFF	OFF

Note that there are two possible combinations for turning off both the LEDs, or in a motor H-Bridge, to turn off the motor: 00 and 11. This mirrors the operation of an Exclusive OR, with the exception that the two "True" output conditions are electrically opposite to each other.

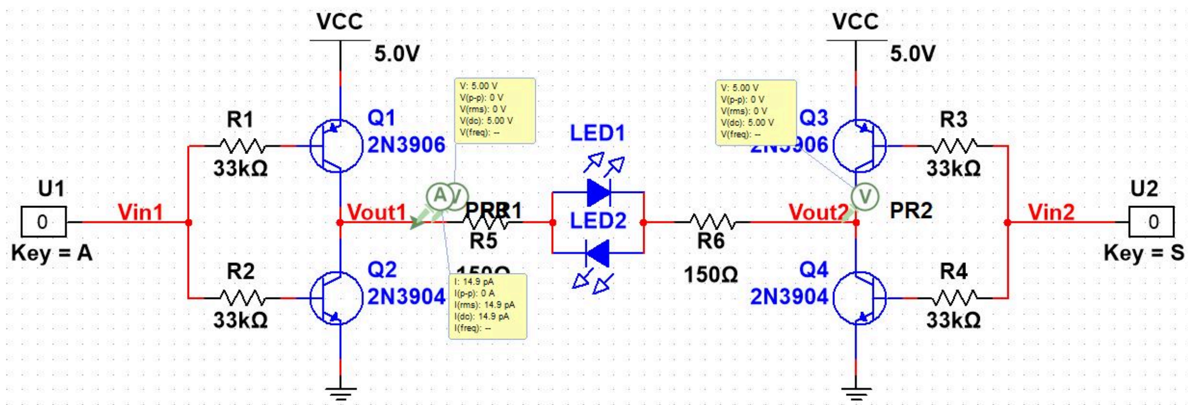
In an H-Bridge used to drive a bidirectional motor, there would need to be protection for the transistors against the inductive currents generated by the motor when the transistors attempt to turn the motor off. In this case, unlike in the case of the relay driver, we can't simply put a diode across the motor, because in one direction it would conduct, taking all of the current away from the motor and likely burning out. Instead, either of three techniques are employed:

- a ***Snubber Capacitor*** is typically placed across the motor to prevent the voltage from rising instantly by temporarily storing the charge and restoring it to the motor coils where the energy can be dissipated as heat.
- ***two zener diodes***, in series back to back, allow for the normal operating voltage, as the zener breakdown is chosen to be greater than the power supply voltage; however, the inductive spike will cause the reverse-biased zener to break over, thereby conducting through the forward-biased zener, effectively holding the spike voltage to $V_Z + V_D$ in either direction.
- ***protection diodes*** mounted in reverse-bias across all four of the transistors will also provide paths for the inductive current, although the path will vary depending upon which way the motor was turning when the transistors were turned off and which transistors were turned off.

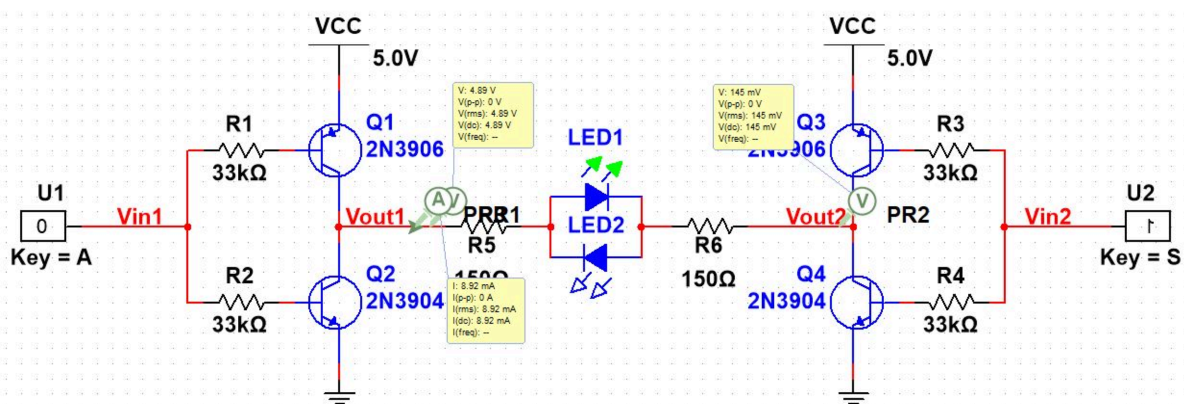
The following images are screenshots showing the voltages and currents for the circuit above, for the four possible logic combinations. Look particularly at:

- Voltage levels in combination with the input levels
- Current flow and direction
- Which LEDs are glowing

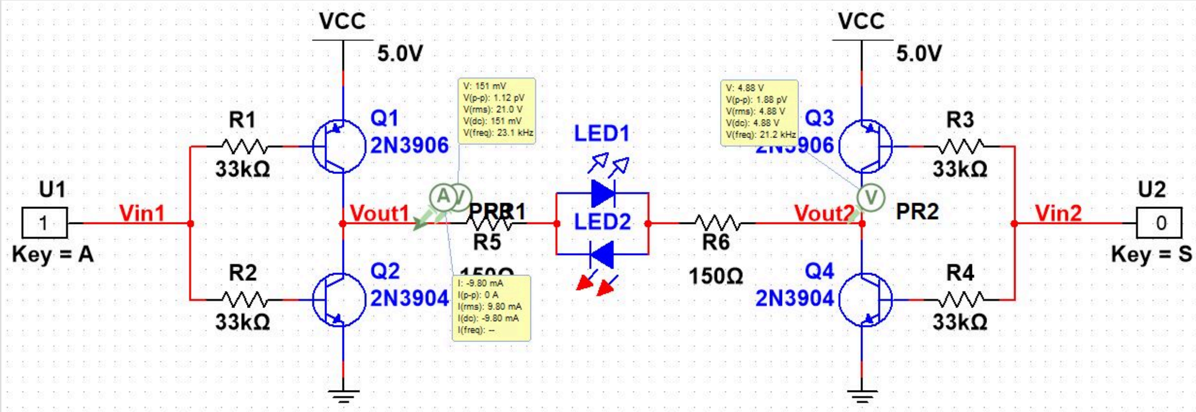
Inputs 00



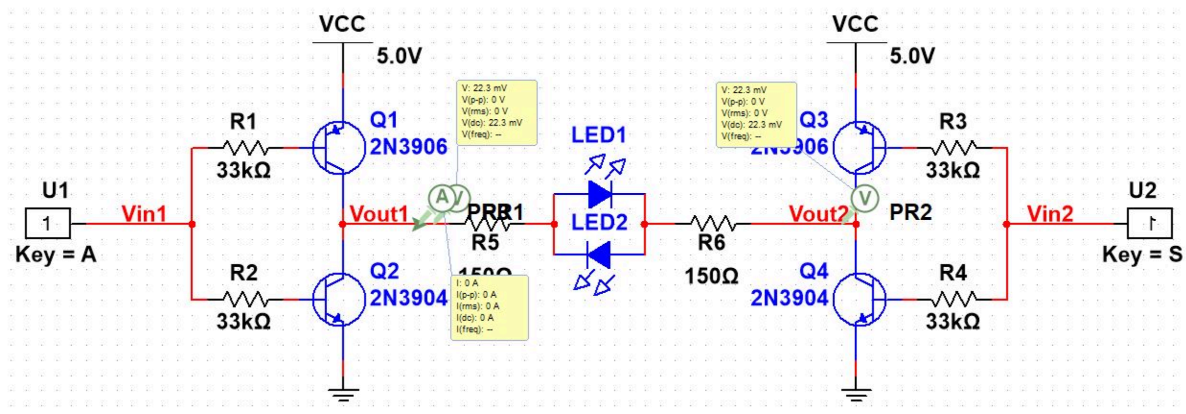
Inputs 01



Inputs 10


VCC
5.0V
VCC
5.0V
R1
33kΩ
Q1
2N3906
LED1
LED2
Q3
R3
33kΩ
U1
1
Key = A
Vin1
Vout1
R5
R6
150Ω
Vout2
PR2
Vin2
U2
0
Key = S
R2
33kΩ
Q2
2N3904
Q4
2N3904
R4
33kΩ

Inputs 11


VCC
5.0V
VCC
5.0V
R1
33kΩ
Q1
2N3906
LED1
LED2
Q3
R3
33kΩ
U1
1
Key = A
Vin1
Vout1
R5
R6
150Ω
Vout2
PR2
Vin2
U2
Key = S
R2
33kΩ
Q2
2N3904
Q4
2N3904
R4
33kΩ