

NPN Transistor as a Digital Switch & Amplifier

Equipment

1	AC/DC Circuit board	EM-8656
1	Voltage Sensor	UI-5100
1	BNC-to-Banana Cord for 850 Output	UI-5119
1	Short Patch Cords (set of 8)	SE-7123
Required but not included:		
1	850 Universal Interface	UI-5000
1	PASCO Capstone	

Introduction

The purpose of this experiment is to investigate the operation of an NPN transistor.

Theory

A transistor is really two diodes arranged back to back as in Figure 1 where there is an np junction between the emitter and the base and a pn junction between the base and the collector. This is called an npn transistor. One can also have a pnp configuration. Note that in Figure 2, the schematic representation of the npn transistor shows the diode character of the np junction between the emitter and base explicitly as an arrow showing allowed current flow, but does not show the arrow for the base to collector. The base to collector arrow would also point away from the base. This is done as an easy way to identify the emitter on a schematic diagram without having to show the c, b, & e on the diagram. V_{supply} is always large enough so that the base/collector junction is forward biased, so current flows readily across this junction. Not shown in Figure 1, there is always a large resistance in series with the transistor base (as in Figure 2) to prevent much current through the base. However, any current through the emitter/base junction will flow freely through the base/collector junction. When V_{base} becomes positive by more than the bias voltage (the “turn-on” voltage from the Diode Properties lab), current flows through the emitter/base junction and thus through the base/collector junction and through the load resistor.

When current flows through the light emitting diode (LED), it will emit light, showing the use of the transistor as a digital switch. More commonly, the voltage across the load resistor will become the output voltage from the circuit used to drive the next stage of the overall circuit. A relatively small change in the base voltage can cause a large increase in the emitter current (as was shown in the Diode Properties lab). A large emitter current means a large collector current since the 22 k Ω resistor limits the base current. This means a large current flows through the load resistor and V_{Out} can be much larger the V_{In} (the voltage applied to the base). In this case, the circuit acts to amplify the signal.

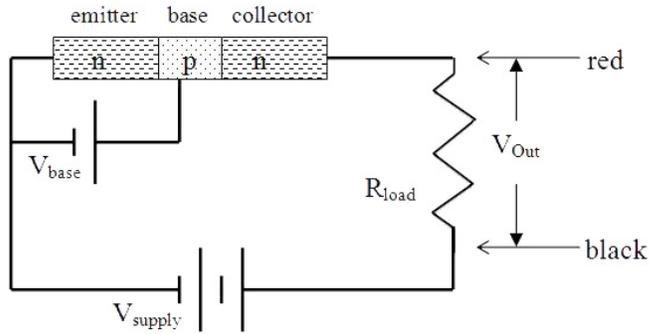


Figure 1: Transistor Theory

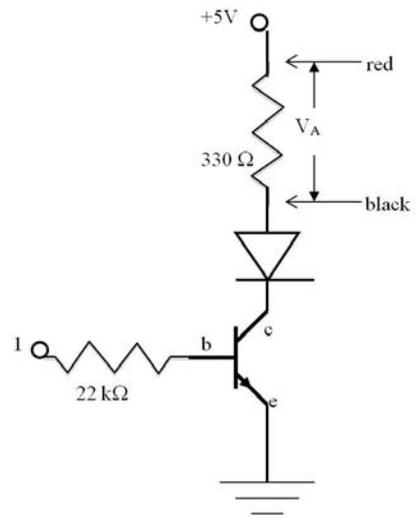


Figure 2: Transistor Switch Circuit

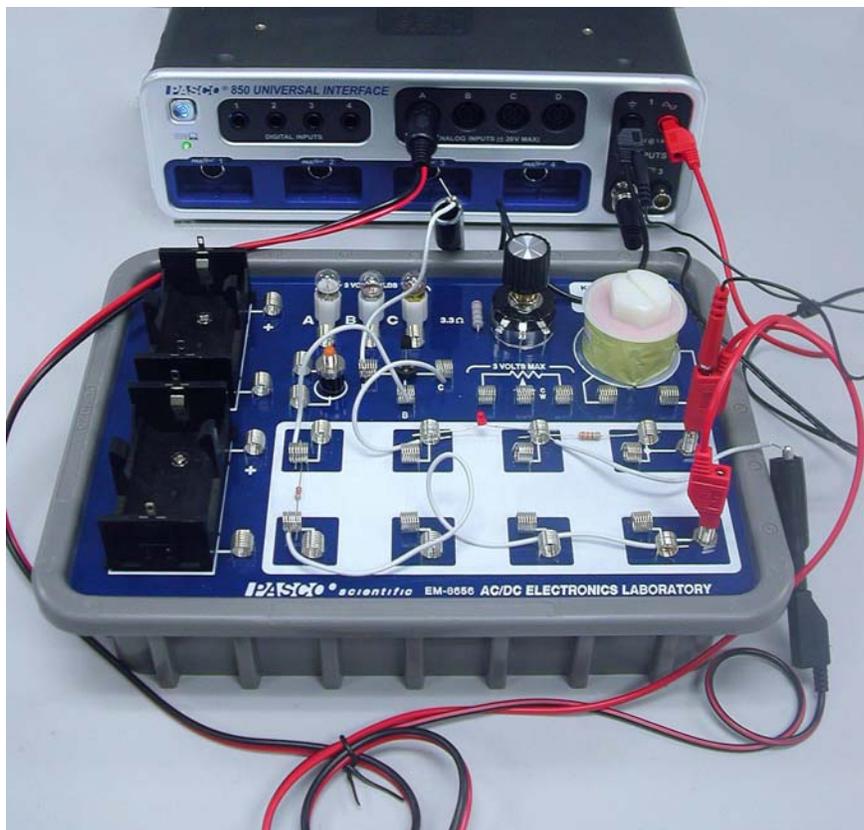


Figure 3: Setup

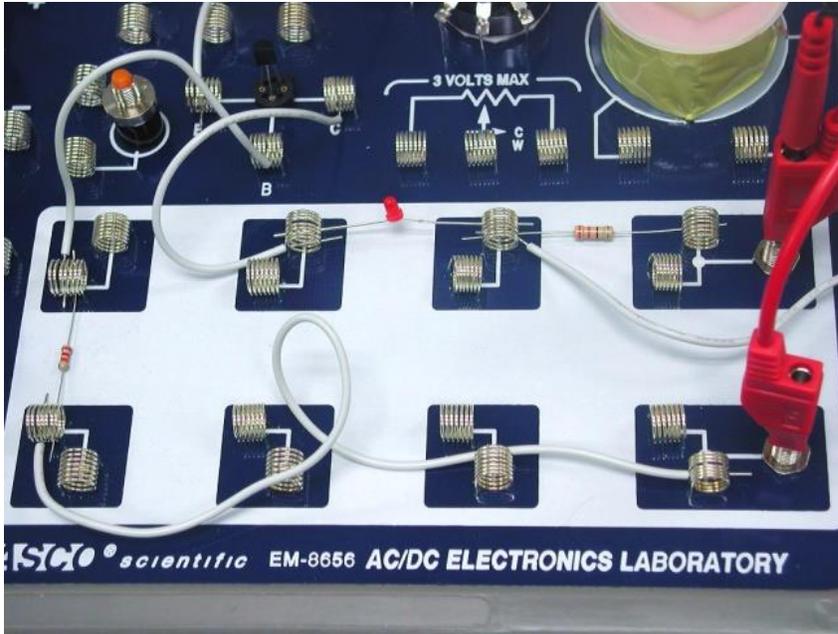


Figure 4: Close-up Setup

Setup

1. Locate the 2N-3904 transistor. Use Figure 5 to identify the base, emitter and collector. Bend the wires slightly to mount the transistor in the transistor mount as shown in Figure 6. Note that the flat side of the transistor is facing the base spring so the emitter is on the left.

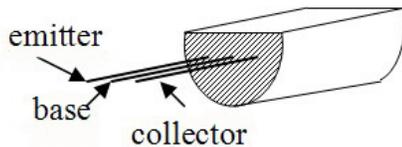


Figure 5: Emitter, Base, Collector

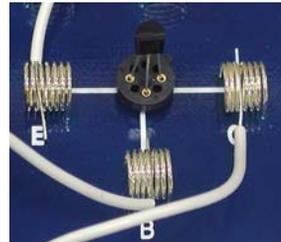


Figure 6: Mounting the Transistor

2. Find the red LED. If the wires have not already been bent so they will bridge between the two springs as in Figure 4, do so now. Be careful not to break the wires. When you are done, leave them bent, since repeatedly bending them will break them.

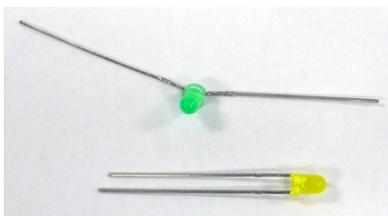


Figure 7: LED Cathode Is Shorter

4. Identify the cathode (negative) side of the red LED. There are four ways to identify the cathode (refer to Figure 7): 1) the wire on the cathode side is shorter, 2) there is a flat spot on the plastic by the cathode (shows clearly on the right of the green LED in Figure 7), 3) if you hold the diode up in front of a light, you will see a triangle...the wide side is attached to the cathode, and 4) if the diode doesn't flash when you do the experiment, it is probably backwards. Attach the diode to the spring clips so its cathode is to the left, toward the transistor.
5. Setup the circuit shown in Figures 2, 3 & 4 using the 330 Ω (orange-orange-brown- gold) resistor between the spring clips at top right, and a 22 k Ω (red-red-orange-gold) resistor at the left.
6. Attach the white jumper wires as shown in Figure 4.
7. Attach a Voltage Sensor to Analog Input A on the 850 Universal Interface. Its red end should attach to the upper jack on the circuit board by the 330 Ω resistor (see Figure 3). Attach an alligator clip to the black end, clip it to a white wire and attach the white wire to a spring clip at the right end of the diode. *Caution: if you attach the alligator clip directly to the spring clip, you will tend to pull the spring loose from the circuit board.*
8. Attach a red patch cord from red jack on Output 1 on the 850 Universal Interface, to the lower banana jack on the circuit board. Attach a black patch cord to the Output 1 black jack. Attach an alligator clip to the black end, clip it to a white wire and attach the white wire to a spring clip by the transistor emitter (E).
9. Attach the BNC connector to Output 2 on the 850 Universal Interface. Its red end should attach to the red patch cord in the upper jack on the circuit board (see Figures 3 & 4). The black plugs into the black patch cord already in the black jack from Output 1 so both output power supplies have a common ground.
10. In PASCO Capstone, open the Hardware Setup and click on Output 1 on the 850 interface and select the Output Voltage/Current sensor. Then click on Output 2 on the interface and select the Output Voltage sensor.
11. Create a graph of Voltage (Ch A) vs. time. Then click on the vertical axis measurement selector and choose "Add Similar Measurement" and select the Output Voltage (Ch 01).

Procedure: Digital Switch

1. Click open the Signal Generator at the left of the screen.
2. Set Output 1 for a Sine Waveform with a Frequency of 1 Hz and an amplitude of 2.0 V. Voltage Offset should be 0 V. Click Auto.
3. Set Output 2 for a DC Waveform. Set the DC Voltage to 5 V. Click Auto.
4. Click the Signal Generator again to close the panel.
5. Set the common sample rate to 200 Hz.
6. Open the Recording Conditions at the bottom of the screen. Set the Stop Condition to Time Based and set the time to 5 seconds.
7. Click RECORD. Observe the diode. Data collection will stop automatically after 5 s.
8. Click on the Selection icon in the graph toolbar. Adjust the handles on the selection box to select the data around the region where V_{out} first rises above 0 V.
9. Click on the Scale-to-Fit icon on the graph toolbar.
10. Determine the bias voltage (the value of V_{base}) required to allow the transistor to conduct. Enter the value in the box below to the nearest 0.1 V.

Analysis

1. How does the behavior of the LED correlate to the V_{out} graph?
2. Explain the relationship between the V_{out} and V_{base} curves.

Procedure: Amplifier

1. Replace the red LED with a white jumper wire.
2. Click open the Signal Generator at the left of the screen.
3. Set Output 1 for a Sine Waveform with a Frequency of 1 Hz and an amplitude of 2.0 V. Set the Voltage Offset to 0 V. Click Auto. Note: same as Digital Switch run.
4. Set Output 2 for a DC Waveform. Set the DC Voltage to 5 V. Click Auto.
5. Click the Signal Generator again to close the panel.
6. Change the Stop Condition to 2 seconds.
7. Click RECORD. Data collection will stop automatically after 2 s.
8. Click on the Data Summary icon. Re-label run #1 as “LED” and run #2 as “no LED”. Close the Data Summary box.
9. Click on the Run Select (multi-color) icon in the graph toolbar to allow display of multiple data sets. Click on the black triangle and select the “LED” and “no LED” runs. Answer Questions 1 & 2 under Amplifier Analysis.
10. Click on the Run Select icon so only one run shows.

11. Click open the Signal Generator. Decrease the Output 1 Amplitude to 0.7 V. Increase the Voltage Offset to 0.5 V.
12. Click Record.
13. Increase the Voltage Offset to 1.0 V. Click Record.
14. Increase the Voltage Offset to 1.5 V. Click Record.

Analysis

1. You may have thought that the LED was important in determining the behavior of the circuit. Was the LED important?
2. Why was the peak voltage for V_{out} different for the two cases?
3. Explain the difference in V_{out} between the last three runs.
4. For the last case, how does the output waveform compare to the input waveform?
5. For the last run, what is the gain = V_{out}/V_{base} ?