Current Gain of an NPN Transistor

Equipment

1	AC/DC Electronics Laboratory	EM-8656
2	Voltage Sensors	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 measure the current gain 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.

The current that flows through the 22 kΩ resistor and into the base is very small but the voltage it develops across the 22 kΩ resistor controls the much larger current through the emitter (which is nearly equal to the current through the collector). More importantly, the collector current is directly proportional to the base current, so the transistor acts as a linear current amplifier. The output signal is exactly the same as the input signal except larger. This remains true as long as the voltage on the base does not drop below the bias voltage and the current does not become so large that it begins to overdrive the system. The current gain is defined as

$$\text{Current gain} = \text{collector current/base current} \approx \text{emitter current/base current} \quad (1)$$

Written by Chuck Hunt

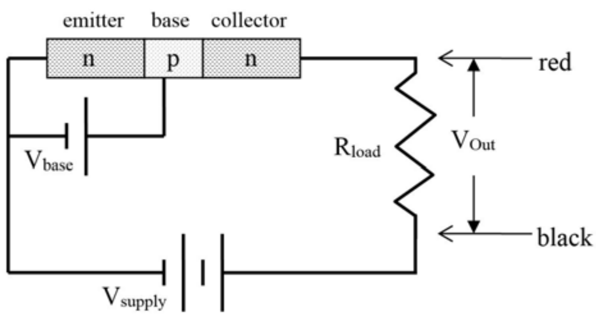

Figure 1: Transistor Theory

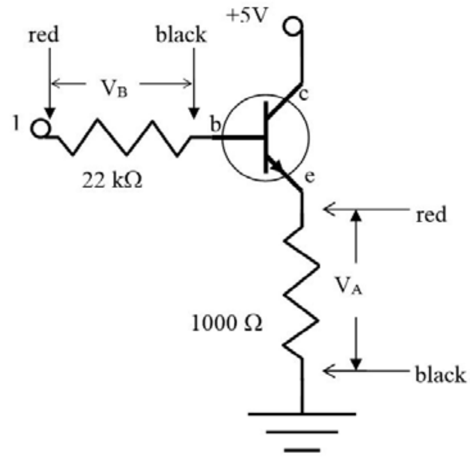

Figure 2: Gain Measurement Circuit

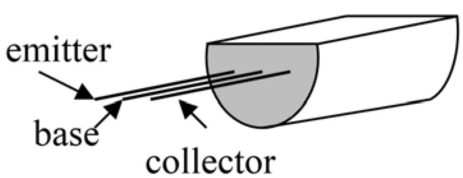

Figure 3: Physical Transistor

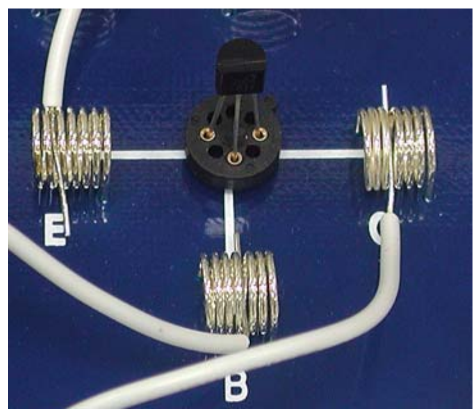

Figure 4: Transistor Mount

Setup

1. Locate the 2N-3904 transistor. Use Figure 3 to identify the base, emitter and collector. Bend the wires slightly to mount the transistor in the transistor mount as shown in Figure 4. Note that the flat side of the transistor is facing the base spring so the emitter is on the left.
2. Setup the circuit shown in Figures 2 & 5 using a 1000 Ω (brown-black-red- gold) resistor between the spring clips at far left in series with the transistor emitter (E). A 22 kΩ (red-red-orange-gold) resistor is in the middle left in series with the transistor base.
3. The red output of Output 1 on the 850 Universal Interface is connected to the lower jack on the Electronics Laboratory (point 1 in Figure 2) which is connected to the end of the 22 kΩ resistor away from the transistor base. The black output from Output 1 is connected to the end of the 1000 Ω resistor away from the transistor emitter.
4. The BNC connector is attached to Output 2 on the 850. The black banana from the BNC is

attached to the black output of Output 1 making the ground common for both power supplies. The red banana from the BNC is attached to the upper jack on the Electronics Laboratory which is attached to the transistor collector with a white wire.

5. Attach a Voltage Sensor to Analog Input B on the 850 Universal Interface as shown in Figure 6. Its red end should attach to the lower jack on the Electronics. Attach an alligator clip to the black end, clip it to a white wire and attach the white wire to a spring clip between the transistor base and the 22 kΩ resistor. *Caution: if you attach the alligator clip directly to the spring clip, you will tend to pull the spring loose from the circuit board.* This Voltage Sensor will measure the voltage across the 22 kΩ resistor. The current through the resistor will be calculated by dividing the voltage (V_B) by 22 kΩ.
6. Attach a Voltage Sensor to Analog Input A on the 850 as shown in Figure 7. Its black end should attach to the common ground coming from the 850 Output 1 black jack. Attach an alligator clip to the red end, clip it to a white wire and attach the white wire to a spring clip between the transistor emitter and the 1000 Ω resistor. This Voltage Sensor will measure the voltage across the 1000 Ω resistor. The current through the resistor will be calculated by dividing the voltage (V_A) by 1000 Ω.
7. In PASCO Capstone, open the calculator and make the following calculations:

   i base = [Voltage, Ch B]/22   Units of mA

   i emitter = [V out, Ch A]/1   Units of mA
8. Make a graph of “i emitter” vs. “i base”.
9. Set the Common Sample Rate to 200 Hz.

Procedure

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. 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. Click RECORD. Data collection will stop automatically after 2 s.
6. Click on the Selection icon in the graph toolbar. Adjust the handles on the selection box to select the data where the current is not zero and the relationship appears linear.
7. Click on the black triangle by the curve Fit icon and select Linear.
8. Record the slope. Note that it is unitless.

Analysis

1. Why is there a bend in the curve?
2. Why is Equation 1 from Theory defining current gain not very satisfactory?
3. A better definition is to define the current gain as

   Current gain = $\Delta I_c/\Delta I_b \approx \Delta I_e/\Delta I_b$ (for the linear region where $I_c > 0$)

   Why is this a more useful definition?
4. Using this definition, what is the current gain for this circuit?
5. How linear is the linear portion? Why is this important?