Experiment 18: Transistor Lab 2 - Current Gain: The NPN Emitter-Follower Amplifier

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5100)

> **NOTE:** As with the previous lab, the 550 Universal Interface (UI-5101) may only be used if an external +5 V power supply is available.

- 2 Voltage Sensors, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
  - 2N3904 transistor
  - Resistors: 1 kΩ and 22 kΩ
  - Wire leads
- 2 banana plug patch cords (such as SE-9750)
- BNC Function Generator Output Cable, shrouded (UI-5129) or unshrouded (UI-5119)

Purpose

The purpose of this experiment is to investigate the DC transfer characteristics of the *npn* transistor, and to determine the current gain of the transistor.

Theory

Transistors are the basic elements in modern electronic amplifiers of all types. In a transistor circuit, the current through the collector "loop" is controlled by the current to the base, as seen in Figure 18.1 below.

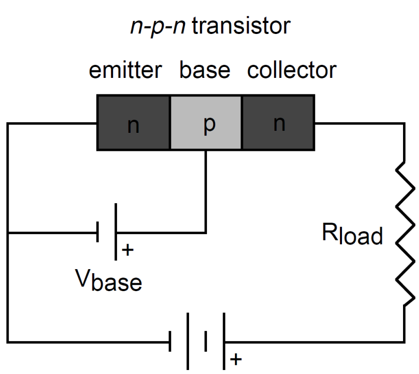


Figure 18.1

The voltage applied to the base is called the *base bias voltage*. If it is positive, electrons in the emitter are attracted onto the base. Since the base is very thin (approximately 1 micron), most of the electrons in the emitter flow across into the collector, which is maintained at a positive voltage. A relatively large current, I_C, flows between the collector and the emitter, while a much smaller current, I_B, flows through the base.

A small change in the base voltage due to an input signal causes a large change in the collector current and therefore a large voltage drop across the output resistor, R_{load}. The power dissipated by the resistor may be much larger than the power supplied to the base by its voltage source; thus, the device functions as a **power amplifier**. What is important for amplification (or *gain*) is the change in collector current for a given change in base current. *Gain* can be defined as the ratio of output current to input current.

A transistor circuit can amplify current or voltage.

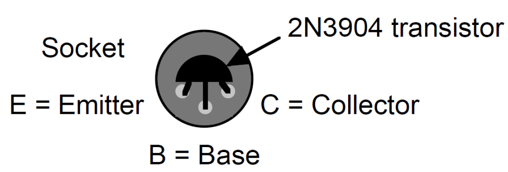
Procedure

Computer Setup

1. Connect your 850 Universal Interface to your computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the first Voltage Sensor to Analog Channel A of the Universal Interface, then connect the other Voltage Sensor to Analog Channel B. Check **Hardware Setup** to ensure both sensors have automatically connected. The system should automatically recognize them as Voltage Sensors; if it does not, select "Voltage Sensor" from the list of sensor options for each channel.
4. Enable monitoring of the Output Voltage from Output 1 by clicking the yellow circle on the Output 1 port and selecting "Output Voltage-Current Sensor" from the dropdown menu.
5. Set up the Signal Generator so that:
   - Output 1 outputs a sine wave with a frequency of 1 Hz and an amplitude of 4 V.
   - Output 2 outputs a DC voltage of 5 V.
   - Both Outputs are set to automatically start outputting the signals when you begin recording data.
6. Create a **Graph** display, with the voltage from Channel B on the y-axis, the voltage from Channel A on the x-axis, and a sample rate of 200 Hz.
7. Set up start and stop conditions such that Capstone automatically starts capturing data when the Output Voltage is greater than 0.01 V and ends data recording after 1 second.

Equipment Setup

1. Insert the 2N3904 transistor into the socket on the AC/DC Electronics Lab Board. The transistor has a half-cylinder shape with one flat side. The socket has three holes labeled "E" (emitter), "B" (base), and "C" (collector). When held so that the flat side faces you and the wire leads point down, the left lead is the emitter, the middle lead is the base, and the right lead is the collector.



> **IMPORTANT:** Connecting the transistor incorrectly can destroy the transistor.

2. Connect the 1 kΩ resistor (brown, black, red) vertically between the upper and lower component springs at the left edge of the component area.
3. Connect the 22 kΩ resistor (red, red, orange) vertically between the upper and lower component springs to the right of the 1 kΩ resistor.
4. Connect a wire lead between the component spring for the *emitter* terminal of the transistor and the component spring at the top end of the 1 kΩ resistor.
5. Connect another wire lead between the component spring for the *base* terminal of the transistor and the component spring at the top end of the 22 kΩ resistor.
6. Connect a third wire lead between the component spring for the *collector* terminal of the transistor and the component spring next to the top banana jack.
7. Connect banana plug patch cords to Output 1 of the 850 Universal Interface. Place alligator clips on the other ends of both cords.
8. Using the alligator clip on the banana plug patch cable, connect the positive (+) terminal of Output 1 to the component spring on the bottom of the 22 kΩ resistor.
9. Using the alligator clip on the banana plug patch cable, connect the negative (-) terminal of Output 1 to the component spring on the bottom of the 1 kΩ resistor.

10. Connect the red lead (+) of the BNC Function Generator Output Cable from Output 2 of the 850 Universal Interface to the top banana jack on the AC/DC Electronics Lab Board. (You do not need to connect the black lead (-), as the current from Output 2 will already go to ground through Output 1's negative terminal.)

The full circuit you construct should match that shown in Figure 18.2. A circuit diagram for the completed circuit is provided in Figure 18.3.

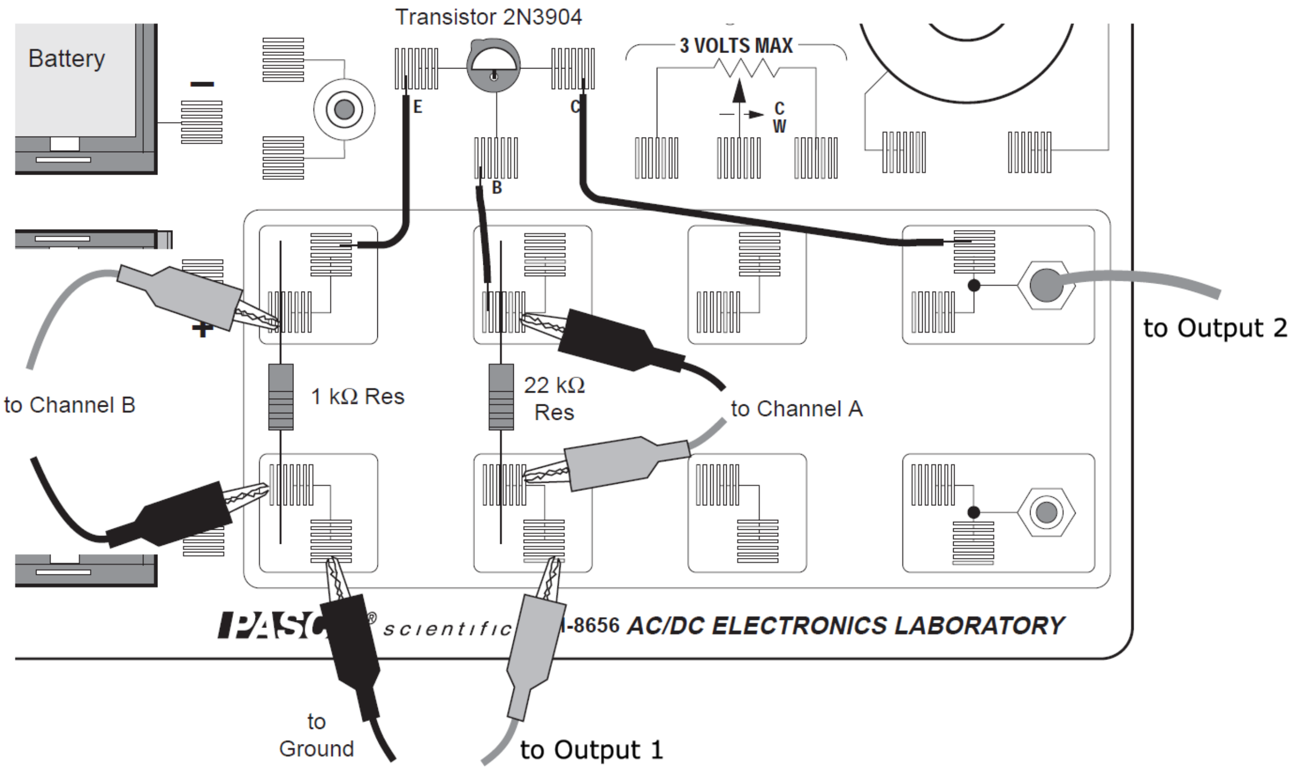
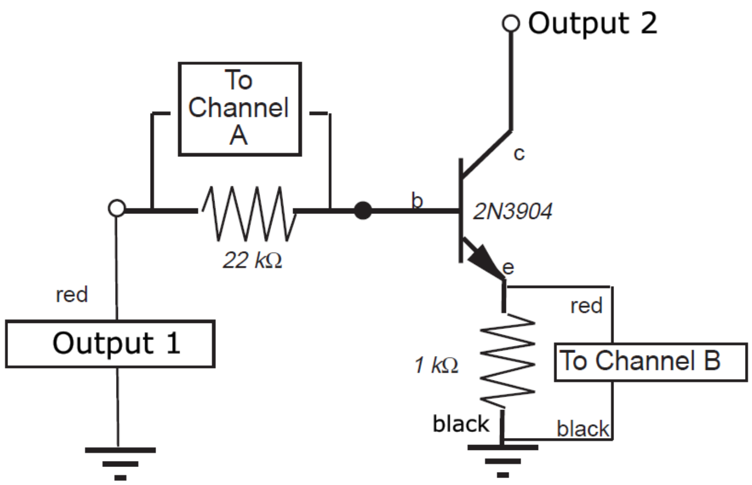


Figure 18.2



Current gain: *npn* Transistor Emitter-Follower Amplifier

Figure 18.3

Data Recording

1. When you are ready, begin data collection. Capstone will automatically stop recording data after 1 second.
2. Use the **Scale to Fit** tool to view the collected data.

Analysis

1. In the **Calculator**, create a new variable called "I_c" which is equal to the voltage from Channel B divided by the resistance of the 1 kΩ resistor (either using the printed value or measuring the resistance with a multimeter); this variable should be measured in (A). This measures the current which passes through the collector, also known as the **output current**.
2. Create another new variable called "I_b" which is also measured in amps and is equal to the voltage from Channel A divided by the resistance of the 22 kΩ resistor (either using the printed value or measuring the resistance with a multimeter). This measures the current which passes through the base, also known as the **input current**.

TIP: If desired, multiply the values from I_c and I_b by 1000 to convert from amps to milliamps (mA).

3. Create a new plot area or Graph display; plot I_c versus I_b in this area. Draw a sketch or take a screenshot of the results.
4. Using the **Highlight** and **Curve Fit** tools, create a linear fit of the diagonal portion of the I_c versus I_b data.
5. The "*m*" value of the Linear Fit line is the slope of that linear region. Record the value of the slope.
6. The slope of this region can be interpreted as:

$$\text{slope} = \frac{\Delta I_c}{\Delta I_b} = \beta$$

   where β is called the *current gain* of the transistor. Record the current gain of the 2N3904 transistor you used in the space below.

   Current gain = ____________________

Discussion

1. Create a new graph showing I_C versus the voltage measured by Channel A. How does the general shape of this plot compare to the plot of current versus voltage for a diode?
2. What is the current gain of the 2N3904 transistor? Does it make sense with what you learned about current gain in the previous experiment?