

BIPOLAR TRANSISTOR CHARACTERISTICS AND AMPLIFICATION**OBJECTIVE**

To characterize an npn bipolar transistor, and measure the dc operating point and the ac performance of a single transistor amplifier.

THEORY

Bipolar transistors are semiconductor devices that contain two pn junctions, similar to the junctions in diodes. For the npn transistor the p type material is common to both junctions, so that there is first an np junction and then a pn junction. However, a transistor is a lot more than two diodes in series, because it has a current gain, as discussed below.

PROCEDURE

1) Connect the circuit in Fig. 1, and use the potentiometer to vary the voltage at the input in 1 volt steps from 0 to 10 volts. Record the voltage V_B at point B. In addition, record the voltage at point C, which is the "collector" of the transistor.

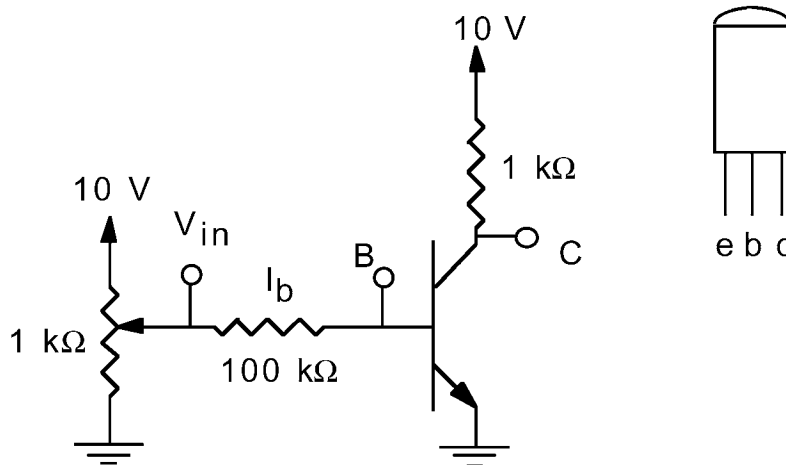


Figure 1 – Transistor Bias Circuit

“TYPICAL” T0-92 transistor leads

The current I_b which flows into the base of the transistor also flows through the 100 kW resistor, so it can be computed from

$$I_b = \frac{V_{in} - V_B}{100kW} \quad (5-1)$$

One can then compute the differential resistance of the emitter to base junction of the transistor, also called the "base impedance" of the transistor. However, it is more interesting to look at the voltage at point C, which is the collector of the transistor. With the input at zero volts, no current flows either to the base or to the collector of the transistor. The transistor is said to be "cut off." The voltage at point C is 10 volts, the

same as the supply voltage. This is because no current flows through the 1 kW collector resistor. However, as the base current increases, the collector current also increases, causing a voltage drop across the 1 kW resistor. The collector current is roughly proportional to the base current:

$$I_c = bI_b \quad (5-2)$$

where b is the current gain of the transistor. Increase the input voltage in 1 volt steps and measure the collector voltage V_c and the base voltage V_b .

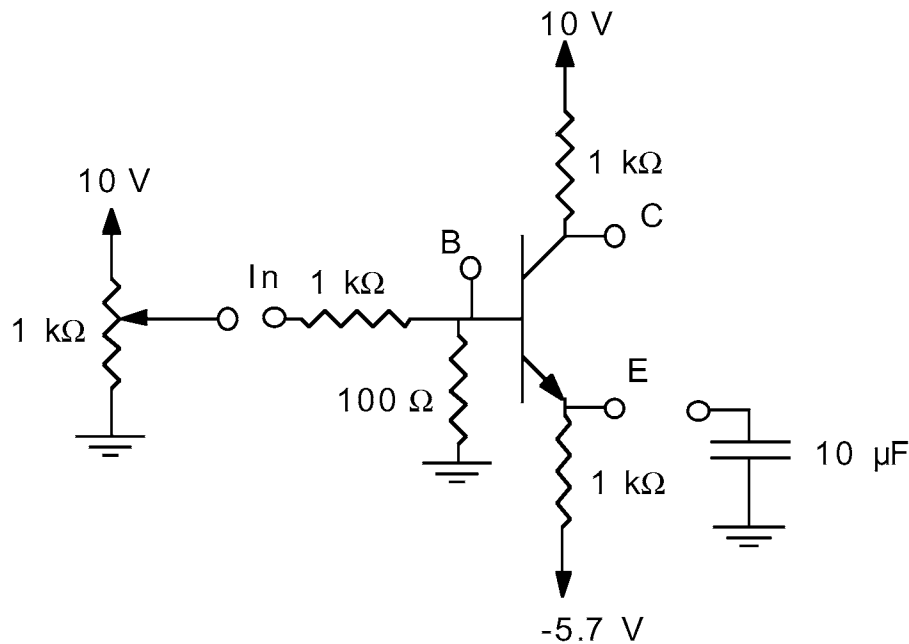


Figure 2 – Transistor “amplifier”

2) Connect the circuit in Figure 2, without connecting the potentiometer. Note that the base is held near ground (by the 100 W resistor), and the emitter is attached to a 1 kW resistor to -5.7 volts. Therefore, the emitter-base junction is forward biased, and the emitter is at a potential of -0.7 volts, approximately 0.7 volts more negative than the base. (If the 1 kW emitter resistor were returned to some positive potential, +V, the emitter-base junction would be reverse biased and the emitter would go to +V. However, the emitter can't go more than about 0.7 volts negative with respect to the base because the emitter-base junction conducts. If you ever see a larger voltage (in a silicon transistor) throw the transistor away - it's burned out. The emitter current is the same as the current through the 1 kW emitter resistor; since there are 5 volts across this resistor (5.7V-0.7V), from Ohm's law the emitter current is 5 mA.

Almost all the 5 mA flows into the collector (only a little, $1/b$, which is on the order of 1%, flows into the base). Therefore there is approximately a 5 volt drop across the 1 kW

collector resistor, and since the supply end of the resistor is at +10 volts, the collector end is at 5 volts. The circuit is said to bias the transistor in the middle of its operating range, since the collector can both increase and decrease in voltage by 5 volts without becoming either more positive than the supply voltage or more negative than the base. This is often a desirable way to bias a transistor in an analog circuit. Note that small changes in component values or voltages will only result in small changes in the operating point - it will always be pretty close to 5 volts.

Connect the potentiometer and use it to apply 0 to 1 volts to the base of the transistor (point B) in Figure 2, in 0.1 volt steps, and measure the voltages at the collector, point C, and the emitter, point E.

Gain is defined as the change in output voltage (V_{out}) divided by the change in input voltage (V_{in}). (A) Use your DC measurements to calculate the gain of the circuit from the input to the output at point E, and from the input to the output at point C.

Disconnect the potentiometer, and apply a 0.2 volt p-p signal at about 1 kHz to the base (point B), and observe the collector (point C) and the emitter (point E) with the scope. Because the series 1 k Ω resistor attenuates the signal, about 2 volts p-p is required at the input. (B) Based on these waveforms, what is the gain of the circuit from the input to point E? What is the gain of the circuit from the input to point C?

This circuit biases the transistor right in the middle of its range, which is desirable, but its gain is quite low.

TRICK: Connect a 10 μ F capacitor from point E to ground. This has two consequences:

- 1) For dc the capacitor is an open circuit (infinite impedance) so nothing happens. The transistor remains biased as before.
- 2) For a high enough ac frequency the capacitor is a short circuit (almost zero impedance) so the emitter is grounded. The gain therefore becomes as large as in part 1.

Apply a small signal (much less than 0.1 volt p-p) to the input, and observe the signal at the collector, point C. (C) How large is the gain from the input to point C?

Careful: you will probably have to reduce the input signal still further to prevent the output from "clipping," or being limited at its high and low voltage limits. Note that because the transistor is biased in the middle of its active range the clipping is symmetrical.

(D) How high in frequency does the ac signal have to be in order for the capacitor to look like a short circuit? Vary the input frequency to find a lower frequency where the gain drops to 0.71 of its high frequency value. This frequency is called the break point frequency (the full analysis of this is called a Bode plot).

Another way of studying the frequency response is to apply a (small) square wave to the input at about 100 Hz. For **short** times, corresponding to **high** frequencies, the capacitor acts as a short circuit and the gain is very high. For **long** times, corresponding to **low**

frequencies, the gain is low. (E) *Sketch the output waveform with the square wave input.*

LAB REPORT

In addition to your responses for (A), (B), (C), (D) and (E) above include the following in your lab report.

1. Use your voltage measurements from Part 1 to compute the base current and the collector current. Plot the **collector current** (Y axis) as a function of the **base current** (X axis). This plot should be nearly linear; the ratio of collector current to base current is called the dc β . What this plot shows is that the transistor is a good current amplifier, since a relatively small base current (the input current) controls a much larger collector current (the output current).
2. Using the same data, plot the **collector voltage** (Y axis) as a function of the **base current** (X axis). Note that as the collector current *increases* the voltage at the collector *decreases* because there is a larger voltage drop across the 1 k Ω collector resistor.
3. Now plot the **voltage at the collector**, point C, (Y axis) as a function of the **voltage at the input** (X axis). This shows that the circuit is a voltage amplifier, since the voltage at the collector (the output voltage) is controlled by the voltage at the input (the input voltage). Unfortunately it's not a very good amplifier: the gain, or the change in output voltage divided by the corresponding change in input voltage, is not very high. However, suppose the circuit is redefined, so that the input is considered to be at the base, point B? In that case your measurements would show that the circuit has a very high voltage gain, since the input, point B, hardly changes in voltage at all while the collector changes from 10 volts to almost zero. However, it's still not a very good amplifier, for two reasons:
 - 1) It has a very low input impedance, because the base-emitter junction is a forward biased diode. Usually an amplifier should have a high input impedance.
 - 2) The gain occurs for an input voltage of about 0.7 volts. Usually an amplifier should work best when its input is near zero. Worse yet, the 0.7 varies, from transistor to transistor, even for the same transistor at different temperatures.
4. Using your measurements in Part 2, plot the **collector voltage** (Y axis) and the **emitter voltage** (Y axis) as a function of the **input voltage** (X axis). *What is the ac voltage gain of the circuit from the input to the collector (point C)? What is the ac voltage gain of the circuit from the input to the emitter (point E)?*