

LAB 6

BIPOLAR TRANSISTORS AND AMPLIFIERS

Objective

In this experiment you will study the i - v characteristics of an npn bipolar junction transistor. You will bias the transistor at an appropriate point for use as an amplifier and can try it as a microphone preamplifier. Steps 1-4 **duplicate** Lab 5; you should skip those steps and begin your lab with step 5. Steps 1-4 are listed here only for your reference.

BACKGROUND

The bipolar junction transistor (BJT) is a three-terminal device often used in amplifiers and other electronic circuits. In this experiment we will work with a version of the device known as the *n*pn transistor (the other version, which we will not consider here, is the pnp transistor). We will consider only the external i - v characteristics of the device; its physics and operation are studied in semiconductor device classes.

The symbol for a npn transistor is shown in Fig. 1. Assume that a positive voltage v_{CE} of at least several tenths of 1 V is applied between the collector and emitter. A collector current i_C can flow, depending on the voltage v_{BE} between the base and emitter. In other words, v_{BE} controls the value of i_C . The dependence of i_C on v_{BE} is exponential. Thus, the collector current can vary drastically as the base-emitter voltage is varied, and this makes possible the realization of high-gain amplifiers, as we will see in this Lab.

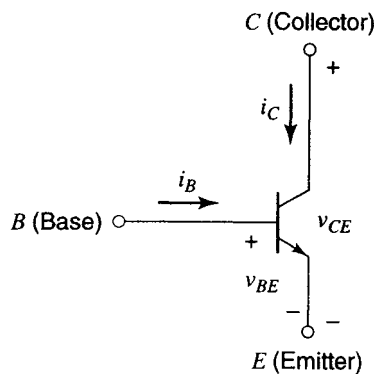


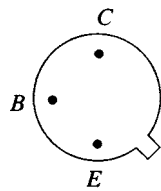
Figure 1. npn transistor

In addition, the presence of v_{BE} causes a small current i_B to flow into the base. This is usually a small fraction of the collector current i_C . The ratio i_C/i_B is called the current gain of the transistor, and it is often denoted by β_F . A typical value of this quantity is 100. It should be kept in mind, though, that this parameter is not reliable; it varies significantly with

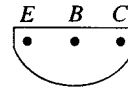
temperature, and can even be significantly different between two transistors of supposedly the same type.

In the first part of this experiment, we will view i_B as the controlling variable for i_C , to provide some familiarity with a common way of showing the transistor characteristics. We should note, however, that when designing circuits it is more appropriate to view v_{BE} as the controlling variable; this view is more directly connected to the way transistors are (or should be) used in most circuits. We will switch to this latter point of view when using the transistor as an amplifier.

The BJT we will be using in this experiment is the 2N2222A. The lead assignments for two common packages for this device are shown in the bottom views of Fig. 2. In the package you are using, the lead assignment may be different; check with your instructor to make sure you know which lead is which in your transistor. **IMPORTANT:** Some 2N2222's will not have this lead assignment. When in doubt use the transistor tester in the instrument room to verify the lead assignment.



Bottom View



Bottom View

Figure 2. Typical lead assignments for 2N2222A transistor

BIPOLAR TRANSISTOR I-V CHARACTERISTICS

1. You will measure the transistor characteristics, using the setup in Fig. 3. The part labeled "Measuring setup" is a piece of instrumentation designed for making transistor measurements. The voltage of PS#1 is used for varying the base current, i_B . The resistor is used for limiting this current (connecting PS#1 directly across the base-emitter would be risky since the base current depends exponentially on the base-emitter voltage; thus a slight increase in the latter could cause a huge change in the base current). The circles labeled A are ammeters, used to monitor the base and collector currents. Hook up the circuit, using connections as short as possible. To avoid some problems associated with nonidealities of digital ammeters, connect them as shown in the figure. Note that when hooked up in this way, the ammeter will not show the base and collector currents but, rather, their opposite. Thus, you should change the sign of these readings to obtain the two currents.

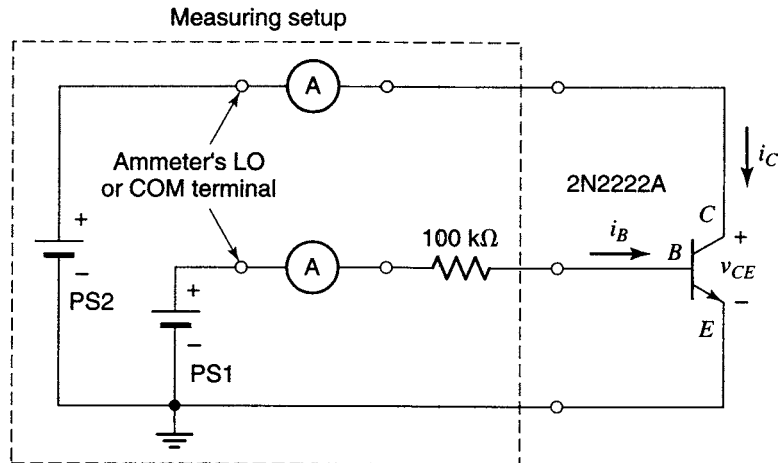


Figure 3. Setup for measuring transistor I-v characteristics

2. Measure the collector current, i_C , versus the collector-emitter voltage, v_{CE} , from 0 to 10 V, for a fixed value of i_B , equal to 10 mA, using the following procedure:
 - Set PS#1 for a desired value of v_{CE} .
 - If necessary, readjust PS#1 so that $i_B = 10$ mA.
 - Read the corresponding value of i_C .

By repeating this procedure for several v_{CE} values, you can form a table of i_C versus v_{CE} , which you can use to generate a plot later on. In the region where i_C is almost constant with respect to v_{CE} , you will need only a very few points. However, be sure you take a sufficient number of readings in the region where i_C is a strong function of v_{CE} ; you will need these later to produce a smooth plot.

3. Repeat step 2 for i_B values of 20 mA, 30 mA, and 40 mA.
4. Using the data you have collected in the previous two steps, plot a family of curves for the collector current, i_C , versus the collector-emitter voltage, v_{CE} , from 0 to 10 V, with i_B as a parameter. Use a single set of axes for this plot. There should be a total of four curves on this plot (one for each of the four values of i_B). Label the plot properly. What is the approximate value of the current gain, $\beta_F = i_C/i_B$? We emphasize that this is not a value one can rely on. If the temperature changes, so will β_F .

A BJT-RESISTOR INVERTER

5. You will next use the circuit of Fig. 4, but do not hook it up yet. This circuit is an example of a setup that is very sensitive because, as you will see, the transistor can amplify the effect of voltage variations present between its base and emitter. Thus, if interference finds its way to the base or emitter, it will be amplified and can produce a large error, or

puzzling readings, in the collector-emitter voltage. To minimize this possibility, follow these guidelines:¹

- Use connections as short as possible.
- Use only a single ground point, as indicated in the figure. (If you use multiple ground points, the currents flowing from one such point to the next can cause minute voltage drops across the wires, which are not perfect short circuits. These minute voltage drops can appear as variations in the base or emitter voltage; when amplified by the circuit, they may not be so minute anymore, and they can interfere with proper measurements.)

Following these guidelines, set up the circuit of Fig. 4, but do not turn on the power supplies yet.

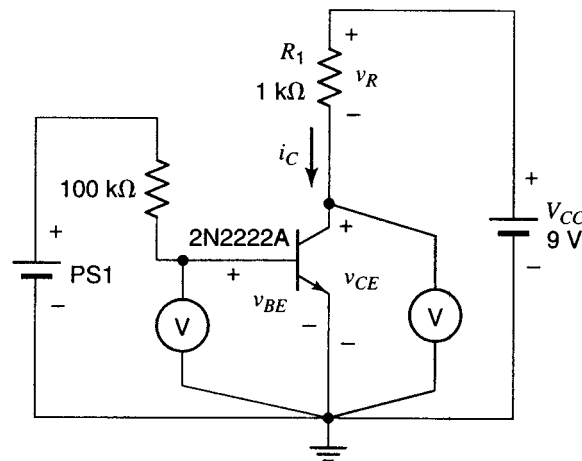


Figure 4. Transistor amplifier

- By varying PS#1, v_{BE} can be varied. When this voltage is raised sufficiently (e.g., to roughly 0.7 V for silicon transistors, such as the one we are using), the collector current i_C of the transistor will become significant for our purposes. This current will cause a voltage drop $v_R = R i_C$ across the load resistor R . Using KVL you can see that the collector-emitter voltage v_{CE} will be equal to $V_{CC} - v_R$ and will thus be less than V_{CC} . As v_{BE} is increased, i_C and thus v_R will also increase, and v_{CE} will decrease. Given that i_C is exponentially related to v_{BE} , a very slight increase of the latter can cause a drastic decrease in v_{CE} . Eventually, v_{CE} can become so small that it will limit further increases in i_C and thus in v_R . Based on this description, answer the following question without doing the experiment: What do you think the plot of v_{CE} versus v_{BE} would look like?
- Turn on the power supplies. Take measurements and produce a plot of v_{CE} versus v_{BE} (the latter should be varied by varying PS#1, and the corresponding values of v_{BE} and v_{CE} should be recorded). Be sure that you take enough measurements to adequately reproduce the steep part of the plot. Does the plot agree with your prediction in step 6?

¹ If, after following these guidelines, you still encounter interference, consider the use of power supply bypassing. This will be discussed in class.

8. In the plot produced in the previous step, consider the point at which $v_{CE} = 4$ V. What is the corresponding value of v_{BE} ?
9. Your plot should be steep around the point defined in the previous step. If v_{BE} varies around this point, the corresponding variation of v_{CE} should be much larger. What is, approximately, the value of the slope $(Dv_{CE})/(Dv_{BE})$ around this point? Is it positive or negative? Why? The behavior you see is often said to be inverting. Why this name?
10. Set PS#1 so that $v_{CE} = 4$ V. This will be the bias value of v_{CE} . Similarly, the corresponding value of v_{BE} is the bias value of that quantity. According to what you found in the previous step, if you can couple a small signal across base-emitter, so that it changes v_{BE} *around* its bias value, you will obtain an amplified version of this signal as a variation in v_{CE} . This is what you will do in the following step.

OBTAINING AC AMPLIFICATION WITH A BJT

11. To couple the small signal across base-emitter and to couple the resulting v_{CE} variation to an external device without disturbing the DC bias values set in step 10, use two coupling capacitors² as shown in Fig. 5. **If a polarity is indicated on the capacitors, make sure you connect them as indicated.** The load indicated as a resistor by a broken line is anything connected to the output, for example, a scope probe (the latter has a very large resistance value, so it will not appreciably affect the operation of the circuit). Measure the base-emitter and collector-emitter voltages again to make sure that they were not inadvertently changed.

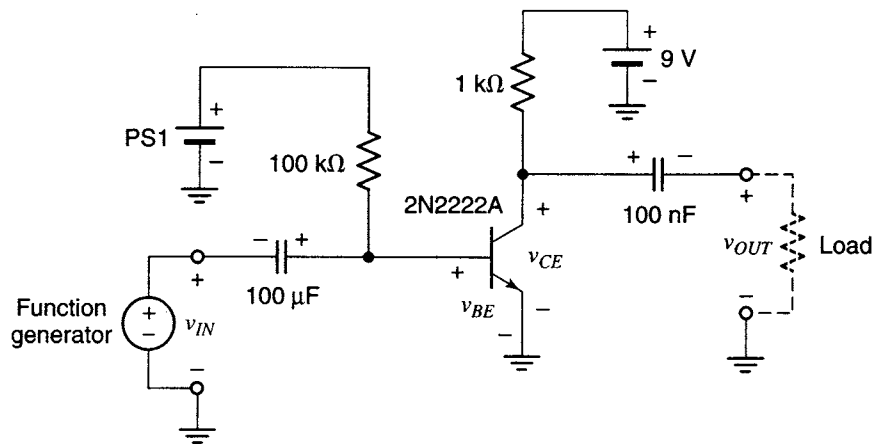


Figure 5. AC transistor amplifier

12. Try the circuit as an amplifier by connecting the function generator with a 1 kHz, 5 mV peak signal at the input. Use the scope to study the waveforms of v_{IN} , v_{BE} , v_{CE} , and v_{OUT} , as well as how these are related to one another. To see the total voltage across base-emitter and across collector-emitter, you need to use DC coupling for the scope inputs; to see only the AC variation of these voltages, you need to use AC coupling instead. If everything is

² If you need more explanations about signal coupling through capacitors please contact the TAs.

working correctly, the variation of all these waveforms should be approximately sinusoidal.

13. Sketch the above waveforms. Make sure you understand the reason for their form.
14. Does the relation between the input and output waveforms justify the name inverter for this circuit?
15. Verify that the input signal is amplified at the output. What is the amplification factor?
16. Is the amplification factor approximately equal to the slope obtained in part 9? It should be. Why?
17. Vary the input signal amplitude slowly, and observe v_{CE} with the scope. At what output amplitudes does the output waveform get visibly distorted? Why do you think it gets distorted? Try to answer this question by referring to the plot you obtained in step 7.
18. Try various other bias points while observing v_{CE} . Each time, turn down the input signal amplitude and adjust PS#1 so that v_{CE} attains a desired DC (bias) value. Then, increase the input amplitude and determine how large the sinusoidal variation in v_{CE} can be before significant distortion sets in.
19. How should one select the bias point so that the maximum possible output amplitude, without significant distortion, is obtained from this circuit? Leave the circuit biased at such a point.

OPTIONAL FROM THIS POINT ON

20. Replace the function generator by a microphone, and observe the input and output waveforms.
21. If you still have time, you can try this transistor amplifier in a complete sound system. How does this preamplifier sound?

NOTE: The circuits in this experiment were kept as simple as possible in order to explain some basic principles. Although the method, used above to bias the transistor is sometimes employed, the resulting circuit turns out to be sensitive to temperature variations and device tolerances. You will learn how to design better biasing circuits.