ENEE 307 Laboratory #4 (2n3904 npn bipolar transistor, 2n3906 pnp bipolar transistor, and current mirror)


A. Laboratory description

A bipolar transistor has three leads and they are named as the **emitter** (which emits the current-carrying carriers), the **collector** (of carriers), and the **base**. First, we are to experiment with 2n3904, an npn bipolar transistor. The electrical characteristic of a typical bipolar transistor is shown in Fig. 5.19.

![Figure 5.19](image)

**FIGURE 5.19** (a) Conceptual circuit for measuring the $i_C-v_{CE}$ characteristics of the BJT. (b) The $i_C-v_{CE}$ characteristics of a practical BJT.

Read the text and understand the transistor circuit symbol. The curves shown in Fig. 5.19 is called **“the current versus current characteristics measured in the common emitter configuration.”** In this typical representation, the collector current $i_C$ is shown as a function of $v_{CE}$, at a fixed $v_{BE}$. The characteristics are nonlinear. As $v_{BE}$ is changed to another value, we measure $i_C$ versus $v_{CE}$ and obtain a curve again. We repeat this process several times and the resulting data is a record of the behavior of this transistor. The inset in Fig. 5.19 shows the measurement circuit for the transistor characteristics. In this circuit, we “step” the voltage between the base and the emitter; as this voltage is stepped, so is the current flowing into the base. Within one “step,” we “sweep” the voltage between the collector and the emitter.

On the other hand, we can also use a small base current $i_B$ to control a large collector current ($i_C$). The several key equations are summarized in Table 5.2, shown below. As we see in Table 5.2, $i_C$ is proportion to $i_B$, and the proportionality constant $\beta$ is called the common emitter current gain. For a transistor to be useful, the current gain should be large enough, i.e., $\beta > 100$.

Note that there $i_B$ is exponentially dependent on $v_{BE}$ --- see Table 5.2.

Because of the nearly linear relation between $i_C$ and $i_B$, we usually measure and represent **“the current versus current characteristics measured in the common emitter configuration.”**
configuration” like that shown in Fig. 5.21.

<table>
<thead>
<tr>
<th>TABLE 5.2</th>
<th>Summary of the SJT Current-Voltage Relationships in the Active Mode</th>
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<tbody>
<tr>
<td>$i_C = I_S e^{v_{BE}/V_T}$</td>
<td></td>
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<tr>
<td>$i_E = I_S \beta e^{v_{BE}/V_T}$</td>
<td></td>
</tr>
<tr>
<td>$i_C = I_S \alpha e^{v_{BE}/V_T}$</td>
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</table>

*Note:* For the PNP transistor, replace $v_{BE}$ with $v_{EB}$.

- $i_C = \alpha i_E$
- $i_E = (1 - \alpha) i_I = \frac{i_E}{\beta + 1}$
- $i_C = \beta i_E$
- $i_E = (\beta + 1) i_I$
- $\beta = \frac{\alpha}{1 - \alpha}$
- $\alpha = \frac{\beta}{\beta + 1}$
- $V_T =$ thermal voltage $= \frac{kT}{q} \approx 25 \text{ mV}$ at room temperature

![Common-emitter characteristics. Note that the horizontal scale is expanded around the origin to show the saturation region in some detail.](image)

The characteristic in Fig. 5.21 is taken by fixing the dc base current $i_B$, and measure the $i_C$ versus $v_{CE}$. The circuit that is used to measure this I-V curve is shown in the inset of Fig. 5.21.

The general idea is for the transistor to amplify a small signal. But, does the small signal refer to a voltage change or current variation? For a MOSFET, the input signal is definitely voltage, because there is supposed to be zero input current. However, for a bipolar transistor, both voltage and current will be present at the input. The input terminal
of a bipolar transistor is a pn junction and thus nonlinear in its I-V characteristic. To apply a signal to the input of a bipolar transistor, we have to understand how to properly control both the current and voltage.

Another type of bipolar transistor is the pnp type. The circuit symbol and the directions of current flow are shown clearly in Table 5.3, part of which is copied below in the box for reference.

The typical data of 2n3906 (pnp) and 2n3904 (npn) are shown below. Note that for pnp transistors, the (current carrying charge) carrier is hole, the emitter “emits” carriers, and the collector “collects” carriers. So, to bias the pnp transistors correctly, the collector is more negative than the emitter, or, \( V_{CE} < 0 \). The convention for the collector current direction defined in Table 5.3 above is the author’s choice. Label your circuit’s current direction clearly to avoid confusion.

![Fig. 1: Circuit symbol and typical characteristics of 2n3904 and 2n3906, respectively.](image)

A current mirror is a popular scheme in generating a constant dc current source, useful in circuits that need a dc current source and also used as an ac load. Example 6.14(a) shows a current-mirror circuit using two npn transistors. The current-mirror circuit has many applications; see discussions in section 6.3 and 6.12.
A. Pre-laboratory work

1. Use Q2N3904 and PSPICE simulate the “current-voltage characteristics of 2n3904 in the common-emitter configuration.” Compare your result with that shown “Fig. 1” above in the box. Plot your simulated I-V curves as that shown in Fig. 1 above --- put down the scale, unit, tick mark, etc. Choose a base current in a range that properly describes the characteristics of this bipolar transistor.

2. Use Q2N3906 and repeat the simulation described above for its characteristics.

3. Follow the analysis in EXAMPLE 6.14, do PSPICE simulation. The goal is to generate 2mA dc current through “Q2.” That is, use this circuit shown in Fig. 6.63, with 2n3904 as the bipolar transistor. The seemingly open end is for you to add a load (such as a resistor) and a dc voltage source. Once the dc voltage and the load resistance are properly designed, the resistive load will sense a dc current, defined by your current mirror circuit. The design element of the pre-laboratory here is for you to understand and apply the knowledge that you have learned. You can read the textbook, search the internet, and combine with common (electronic) sense to design a circuit that works. One starting point is to follow the examples discussed in the textbook.

4. PSPICE simulate this circuit shown in Fig. P6.33 using 2n3906. The collector of Q2 is not open in the real circuit. You need to finish the design by using first a load resistor and a dc voltage source --- in this very case, zero volt is one convenient option. The goal is to generate 2mA dc current through the collector branch of “Q2.”
B. What to do in the laboratory

1. Measure the “current-voltage characteristics of 2N3904 in the common-emitter configuration.” Record and plot the current-voltage characteristics in your post-lab report. The method is the same as what you used for the MOSFET: use the load line concept, like that shown in Fig. 5.32 (on top of next page). The $R_C$ at the collector branch helps measure the collector current, while the voltage across $R_B$ at the base branch measures the base current.

Wire up the circuit, choose a $V_I$ (the dc voltage at the input), fix the $V_{CC}$, and measure the voltages across $R_B$ and $R_C$ to determine $I_B$ and $I_C$ (both dc currents), respectively. This measurement gives you one data point; $I_C$ versus $V_{CE}$ under a fixed $I_B$. Next, increase $V_{CC}$ and repeat the measurements. Note that you may have to adjust $V_I$ slightly in order to maintain a constant $I_B$. After you finish one curve, change $V_I$ and repeat. Get a few curves that can show a span of current-voltage curves like the characteristics shown in Fig. 1.

2. Measure “current-voltage characteristics of 2N3906 in the common-emitter configuration.” Use a similar circuit and method as stated in step 1 above. Be certain of the polarity of the biases.

3. Wire the circuit shown in Fig. 6.63(a) and generate a constant current of 2mA. Record the voltages and currents everywhere. Compare the data with your design.

4. Wire the circuit shown in Fig. P6.33 and generate a constant current of 2mA. Record the voltages and currents everywhere. Compare the data with your design.

5. For current sources, you must think of a way to verify that the output current is indeed constant --- controlled by $I_{REF}$ of course. For one example, use a resistor as the load, measure the output current first. Then, increase the resistance value by as much as 50% and see if the current remains the same.

6. The current mirrors will be used in the next laboratory: differential amplifier. One mirror will provide constant current to the differential pair, while the other is used as an active load.

C. Post-laboratory report questions, in addition to your report on data and your additional observation

1. Present your data. Label the figures clearly.
2. Add observation and discussion with the simulated results.
3. Conclusion and other comments you may have.