EE321 – Lab 7

Bipolar Junction Transistors, Part I

In this lab we will investigate how a bipolar junction transistor (BJT) can be used to amplify signals.

1. First, use your multi meter to measure the base-emitter and base-collector junctions of your transistor (Figure 1 and 2). When you put your meter in "Diode" mode, the meter will indicate the voltage for 1 mA current through a forward-biased diode, and will indicate 0 if the diode is reversed biased. Test this on a diode then on a 2N3904 transistor. Record your readings. This is a useful way to check for bad transistors. This is better than using the Ohm-Meter for measuring the forward and reverse resistances of the junctions, as the measuring voltage and current are not known.

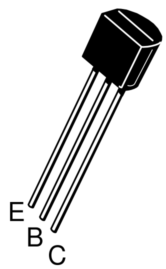

Figure 1.

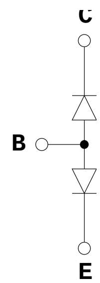

Figure 2.

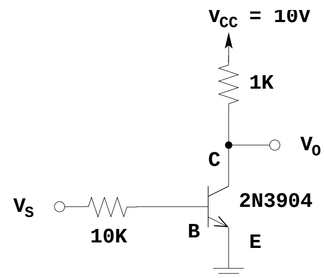

Figure 3.

2. The basic principle of a BJT is that the base-emitter voltage v_{BE} controls the collector current i_C when the transistor is biased in its 'active' mode (b-e junction forward biased, c-b junction reverse biased).

   - Construct the circuit (Figure 3). Lay your circuit out neatly, using the bus lines for V_{CC} and ground.
   - Connect a sine wave to v_S and display v_{BE} and v_C in on your oscilloscope.
   - Adjust input sine wave, v_S (the DC bias (offset) and amplitude) so that v_{BE} varies from about 0.0 to about 0.73 volts. Be sure to measure v_{BE} at the **base** of the transistor. Make v_{BE} large enough so that v_O goes from 10 V to 0 V.
   - Both v_{BE} and v_O will look like clipped sine waves. Where do they clip?

3. Note that $v_C = V_{CC} - i_C R_C$. Use this to determine where the transistor is in cutoff ($i_C = 0$) and where it is in saturation ($v_{CE} < 0.7$). (In between, the transistor is in its active region.)

   - Display v_C vs. v_{BE} using the x-y mode. Using this curve, plot i_C vs. v_{BE}. This curve should look like Figure 4.12 of Sedra and Smith. Note the three regions of the plot.
   - For what value of v_{BE} does the transistor start to turn 'on'? (Collector current start to flow?) Does this make sense?
   - When v_{BE} is too large, the collector current will drop v_C **below** v_B, thus forward-biasing the collector-base junction and driving the transistor into **saturation**. For what values of v_{BE} and i_C does this occur?

4. The transfer characteristic is linear if v_{BE} is restricted to small changes about a **bias point**, as in Figure 4.24 of Sedra and Smith.

   - Reduce the p-p signal amplitude and change the offset until only a small part of the transfer curve going from about 3.5 mA to 6.5 mA is left (fiddle with the signal generator until the output is a sine wave that goes between 6.5 V and 3.5 V. Start with an input amplitude of 0.1 V and offset of 0.5 V). Now you should find that v_C changes by 3 V p-p about the bias point at $I_C = 5$ mA.
   - Sketch the operating range on the plot of part 3 above.
   - In the time domain, display v_{BE} and v_C on your scope. What is the voltage gain v_c/v_{be} for the small signals? (Be sure to measure the 'input' vbe after the 10 kΩ resistor.)
   - How does the gain compare with theoretical value found in the prelab?
   - How could the gain be made larger? (There are two ways.)

5. Increase v_{BE} and note the distorted nature of v_C. Increase v_{BE} further until the output just "clips" on top and bottom. (Readjust the DC level so that the clipping is symmetrical).

   - Sketch a clipped waveform.
   - Note the DC levels of the clipping, and whether the clipping is due to saturation or cutoff.

6. The output voltage can be linearized over its entire range by using the input signal to control the base current rather than the base voltage. This is because the collector current is proportional to the base current, i.e. $i_C = \beta i_B$. We will show this in the following way:

   First we will bias the transistor in its active state by supplying a current to the base through R_B from $+V_{CC}$ (see Figure 4). This provides a DC base current $I_B = (V_{CC} - 0.7\text{V})/R_B$, which gets amplified by the transistor to give a DC collector current $I_C = \beta I_B$. Because β varies from transistor to transistor you will have to select the value of R_B to obtain the desired I_C.

   - The desired current for I_C is 5 mA
   - Begin by assuming $\beta = 100$ and calculate R_B.
   - Use this R_B in the circuit, measure I_C, and then get a better estimate of β.
   - Repeat this step until $I_C = 5$ mA $\pm$ 0.5 mA.
   - What value of R_B did you need, and what value of β does this imply?
   - Compare β to the value from the datasheet. datasheet. (In the datasheet, this DC β is called h_{FE}.)

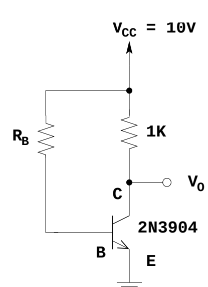

Figure 4.

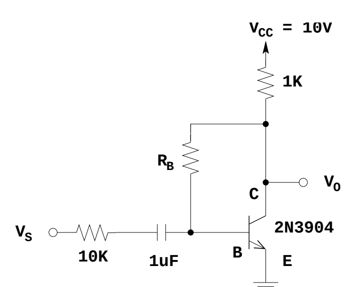

Figure 5.

7. Now add a signal component to the base current through a coupling capacitor, as shown in Figure 5, which does not affect the DC bias. Note that the input voltage has been converted to a current by resistor R_S.

   - Increase v_s until the output clips, and back off until the clipping just stops.
   - What is the maximum output voltage swing
   - Is the output linearly related to the input. v_s? (Adjust the scope — position, sensitivity, invert — until the input and output line up. If they line up and the output is a bigger copy of the input they are linearly related.)
   - What is the voltage gain, v_{out}/v_s?

Pre-Lab

1. From the datasheet for the 2N3904, find the following:

   - The maximum collector current.
   - The maximum voltage between the collector and emitter.
   - The DC current gain (H_{FE} or β) when $I_C = 10$ mA.
   - v_{CE} when the transistor is saturated.

2. Find the gain for the amplifier in Figure 3. The gain can be determined from these equations: $v_{out} = -i_c R_C$, $i_c = g_m v_{be}$, and $g_m = I_C/V_T$, with $I_C = 5$ mA.

3. In Figure 4 find R_B so that $I_C = 5$ mA (assume a β of 100). What would V_O be?

   For this same circuit, how would you find β if you were given R_B and V_O?