Lab 7: Bipolar Junction Transistors

U.C. Davis Physics 116A

INTRODUCTION

The purpose of this lab is to measure some DC and AC characteristics of a transistor (a bipolar junction transistor, or BJT) in two useful circuit configurations, the emitter follower amplifier and the common emitter amplifier. Background material for this lab can be found in the text, *Bobrow,* sections 7.1-7.3 and 9.1.

1. DC properties of BJT in the Common Collector Configuration

In this section, you will see what the transistor does in a common collector (emitter follower) circuit and what the entire circuit does. Construct the emitter follower circuit shown in figure 1.

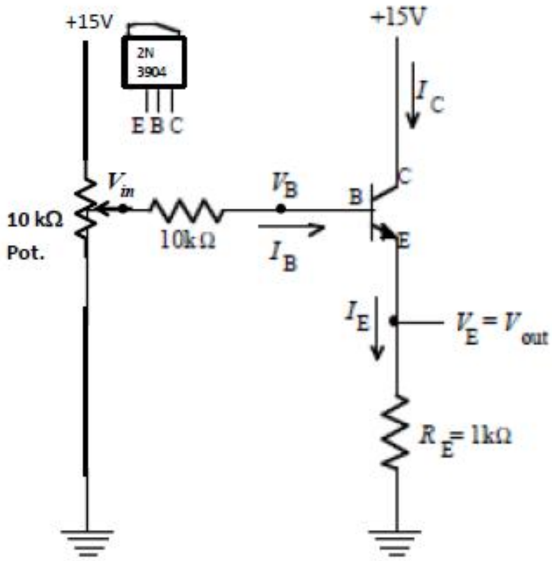

Figure 1: An emitter follower amplifier

First we will examine the base-emitter junction. Use the potentiometer to set V_B to approximately 0.25, 0.5, 0.7, 1.0, 2, 4, 8, and 14 volts. For each setting measure V_B, V_{in}, and V_E. From these data, calculate $V_{BE} = V_B - V_E$, I_B and I_E from Ohm's law, $I_C = I_E - I_B$, and $h_{fe} = \beta = I_C / I_B$. Put all of this in one data table.

To analyze these data, plot I_B *vs.* V_{BE}. This will look like a nearly vertical line, but since the base-emitter junction is a forward biased diode, it is actually part of diode exponential curve. On the same graph, plot a calculated diode curve that approximately fits your data. Also on the same graph, indicate how a straight line can fit these data points fairly well. This line represents an "effective resistance" r_{pi} for the base of the transistor. From the slope of this line, calculate r_{pi} using Ohm's law.

Now plot $\ln(I_B)$ *vs.* V_{BE}. In Lab 6, we made similar plots for diodes. We noted that:

$$\ln(I) = \ln[I_0 \exp(V / nV_T)] = \ln(I_0) + V / nV_T$$

Do the data for the base-emitter junction fall on a straight line in your log-lin plot? If so, do the slope and intercept has the values that you would expect?

Now, looking at the data and both of the graphs, answer these questions: What is the range of V_{BE}? Does V_{BE} stay at approximately 0.7V? What does it mean for a transistor to be in its "active region"? Does the transistor stay in its active region? Is $I_C \approx I_E$? Is $\beta \approx 200$ (within a factor of 2)? A BJT in common-collector configuration is often described as a "current amplifier". How is this transistor functioning as a current amplifier in this circuit?

For your lab report, include the data table, the two I_B *vs.* V_{BE} graphs with data points and calculated curves, and a discussion which includes answers to the questions in the previous paragraph.

2. DC properties of the Common Emitter Amplifier

In this section, you will build and analyze a common emitter amplifier, a popular transistor amplifier circuit. Use 1 kΩ resistors for R_C and R_E. Use a 10 kΩ resistor for R_B. Build the amplifier as shown in figure 2.

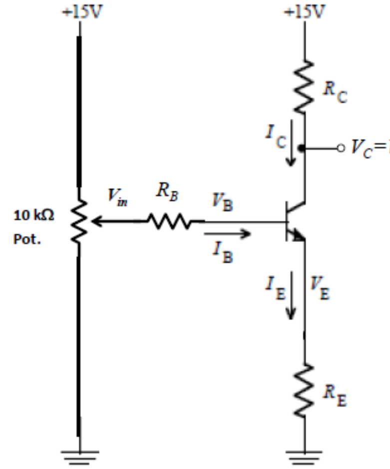

Figure 2: A common emitter amplifier (DC config.)

First, set V_B to 5.75 V. Now, find the bias conditions of the transistor. That is, find the voltages and currents in the circuit with no AC input signal. This is also called the "quiescent point", the "operating point", or the "DC" conditions for the circuit. To do this, measure V_{in}, V_B, V_E, and V_C. Then use Ohm's law to calculate I_B, I_E and I_{CQ}. Compare the I_B you get using Ohm's law to $I_B = I_C / \beta$ using the β you found in section 1. What value do you get for V_{BE}? Is the transistor in the active region?

We are now going to map out the i_C vs. v_{CE} characteristic of this transistor. First draw in the DC load line and identify the Q point. You will now make a series of measurements. For each setting, you will measure V_C, V_E, V_{in}, and V_B. You will use those data to calculate i_B, i_E, i_C, and v_{CE}. You will use four different collector resistors, R_C = 470 Ω, 1 kΩ, 1.5 kΩ, and 2.2 kΩ. For each R_C, you will set the potentiometer to generate four different base currents, i_B = 10, 20, 30, 40 μA. Once you have made all of these measurements, draw a family of four i_C vs. v_{CE} characteristic curves, and draw the four corresponding load lines.

3. AC properties of the CE amplifier

Now we will study the AC performance of this amplifier. First consider the bias resistors, R_1 and R_2. Remember the design parameter for the bias resistors is that $R_B < (0.1)(\beta)(R_{EAC})$, where R_{EAC} is the AC resistance on the emitter ($R_E \| R_{E2}$ from fig. 3), and $R_B = R_1 \| R_2$. Select a combination of resistors that will give a V_{BB} = 5.75 V. Recall that $R_1 = R_B/(1 - V_{BB}/V_{CC})$, and $R_2 = R_B V_{CC}/V_{BB}$. Try to select single resistors for R_1 and R_2. Pick values close to your design rather than using combinations of multiple resistors. Remember resistors have a 5% variation, so you do need to more accurate than 5% (otherwise you would be using more expensive 1% resistors).

Replace the potentiometer from the Fig. 2 circuit with bias resistors R_1 and R_2 as shown in Fig. 3. These bias resistors set the Q point of the amplifier. Then connect the function generator as v_{in}. Use a 0.1 μF capacitor for C_{in}. Set the function generator to generate a 0.5V peak-to-peak 10kHz sine wave as the input signal. (Note: the emitter bypass capacitor and the load capacitors not yet connected. These are still open circuits). Monitor v_{in} and v_{out} simultaneously with the oscilloscope (Channels 1 and 2, be sure to AC couple channel 2) and sketch them on the same set of axes. Measure the gain of this amplifier. Compare it to the calculated gain, R_C/R_E. Why should the gain of this amplifier be R_C/R_E and not β? Note the phase difference from input to output. Many amplifiers invert the signals they amplify.

Explore the behavior of the amplifier a little more by using different frequencies (100 Hz, 1 kHz, 10 kHz, 100 kHz – Keep v_{in} at 0.5 V), and amplitudes for v_{in} (0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0 – Keep v_{in} at 10 kHz). The output of an ideal amplifier should always look just like the input multiplied by the gain. However, real amplifiers only work correctly over a limited range of output voltages and frequencies. Determining these ranges is an important part of 116A's classroom work. See if you can determine approximately the minimum and maximum frequencies for which the gain is constant. Also, see if you can determine the range of acceptable output voltages. Try to determine what causes each of these limits.

Measure the DC output level at V_C. (Make sure to take the AC coupling off channel 2 to make this measurement). Next connect a 0.1 μF load capacitor and a 1 kΩ load resistor, now measure the DC level of V_{out} at the load resistor. Why is this different? Has the gain changed with the load resistor connected? Next connect a 4.7 μF emitter bypass capacitor and a 100 Ω R_{E2}. What is the gain now? Is it what you expected? Draw the AC load line for these three configurations. Explore the limits to the output voltage swing for each configuration.

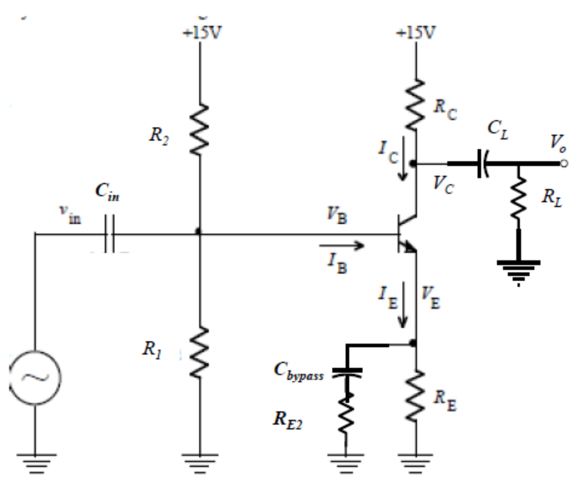

Figure 3: A common emitter amplifier (AC config.)

4. Properties of pnp transistors

How would you modify your circuit to use a 2N3906 pnp transistor? Try it. Do you get the gain that you expect?