ELEG 309 Laboratory 4

BIPOLAR-TRANSISTOR BASICS

April 17, 2000

1 Objectives

Our overall objective is to familiarize you with the basic properties of Bipolar Junction Transistors (BJTs) in preparation for more detailed work on modelling and applications which your future holds. Concentration will be primarily on npn devices for several reasons: Primarily, it will reduce distraction and workload. By concentrating our attention (on only npn devices), other principles may be more easily seen, and comparisons made. As well, npn devices are somewhat special, being more common, having higher gain, and able to operate at higher speed.

2 Components and Instrumentation

Our explorations actually require only one transistor, a 2N3904, npn. However, a second transistor of the same type may be useful in allowing you to verify the relative sensitivity of some circuits to device-to-device variability. As well, a second device may be useful in trouble-shooting. Base diagrams of the transistors are provided in Fig. 1. As well, you require a DMM with dc voltage and ohms scales, two power supplies, a two-channel oscilloscope and a waveform generator. As usual, you will use resistors of various values, but primarily 10 kΩ. But since some of the resistors, the 10 kΩ ones in particular, will be used for the rapid evaluation of current amplitudes from voltage measurements, your task will be facilitated if, initially, you use your ohmmeter to measure (and record) values of your resistors.

Obviously, it would be particularly neat and tidy if all 10 kΩ resistors were exactly 10 kΩ. However, this is quite difficult to establish in practice. The best you can do is obtain 1% resistors, but even these are generally not identical. Next best is that they all are the same value, whether 10 kΩ or not, but which you can call 10 kΩ if you like (with an obvious but small error). Otherwise measure each, and label their values for more precise calculations.

3 Reading

Reading for this Experiment will be in Sections 4.2, 4.4, 4.5, 4.7, 4.8, 4.10, and 4.11 of the Text.

4 Preparation

As is the norm, Preparation is keyed to the Explorations to follow by the use of the section numbering employed there.

4.1 Component Familiarization and Identification

When examined with an ohmmeter, a device, thought to be a BJT, having pins x, y, z provides a set of readings as noted below. Using a labelled diode, the ohmmeter has been found to provide current flowing from its black lead.

Black Lead	Red Lead	Reading
x	y	open
x	z	open
y	x	300 Ω
y	z	open
z	x	400 Ω
z	y	open

Identify the transistor type, whether npn or pnp, and which connections are the emitter, collector and base.

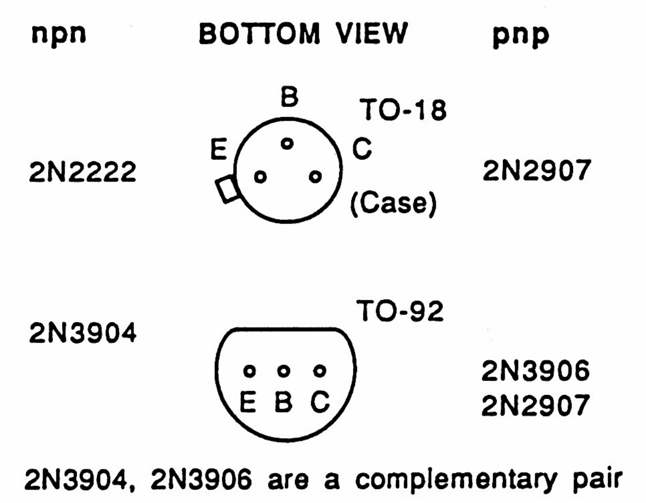

Figure 1: BJT Base Diagrams.

4.1.1 Transistor Characteristics

On a curve tracer it has been found that for a certain npn transistor 10 μA base current step setting yields 1.5 mA difference between consecutive i_C curves. What is the β_{ac} of the transistor? What is the α?

4.1.2 Establishing Device Currents

In the circuit of Fig. 2, using ±10 V supplies, V_B, V_E and V_C are found to be –0.042 V, –0.693 V and +0.697 V respectively. Calculate I_E and the corresponding V_{BE}. Find two estimates each of α and β. In which do you have most faith?

4.1.3 Identifying the Controlling Junction and Junction Current

In the circuit of Fig. 2, in which the transistor measured above is used, the negative supply is raised to -5 V. Estimate the new values of the 3 electrode voltages under the assumption that $n = 1$.

4.2 Other, Less-stable Biasing Schemes

4.2.1 Fixed Base-Emitter-Voltage Biasing

For the circuit shown in Fig. 4, with $V^+ = 10$ V, R_I, is adjusted until $V_C = 0.697$ V, in which case, $V_B = 0.693$ V. By what amount must the temperature of the transistor rise for saturation at $V_{CEsat} = 0.20$ V to occur? Assume a TC of - 2 mV/C and $n = 1$.

4.3 The BJT as an amplifier

4.3.1 Voltage Gain and Input Resistance

In the circuit of Fig. 5, with R_p adjusted so that $V_C = 5$ V with a 10 V supply, and v_i adjusted to make $v_c = 1$ V peak, estimate the signal v_b. If the signal at node A is three times larger than that at B, estimate R_{inb} and β.

4.3.2 Large-Signal Distortion

- For the situation described above, what is the voltage v_c for $v_b = 10$ mV peak? This would normally be the limit of small-signal operation, for which sinall-signal distortion is a few percent.
- For what peak signal values at v_c and v_b does the voltage at node C just reach the edge of saturation?

- For what value of peak input signal does the collector current reduce to 1% of its quiescent value?

5 Explorations

5.1 Component Familiarization and Identification

It may be instructive to familiarize yourself with your ohmmeter as a means of evaluating properties of junction devices: Use an ohmmeter range whose internal voltage source is high enough (>0.7 V) to allow a silicon diode junction to conduct. Some ohmmeters intentionally incorporate ranges (often marked with a diode symbol) whose voltages are low enough to allow conventional resistors to be measured even when shunted by diode junctions. Both to verify the ohmmeter polarity and its ability to cause a junction to conduct, check your ohmmeter range(s) using a diode whose banded end is the cathode (from which current flows during conduction). Otherwise, use a second voltmeter to verify the terminal-voltage polarity and magnitude. Finally, realize that larger junctions exhibit (slightly) lower resistances, and that the collector-base junction of a typical transistor is much larger than its emitter-base junction.

Now make ohmmeter measurements of your transistor(s), thereby checking the transistor type (npn vs pnp) and the pin connections. Note that the "resistance" between collector and emitter is ∞ for either polarity.

Consider the ease with which you can perform this piece of detective work.

5.1.1 Transistor Characteristics

- **Goal:** To familiarize yourself with the BJT family of chararacteristics.
- **Setup:** Connect your transistor to a curve tracer. Set-up the parameters of the instrument to obtain reasonable family of curves. Note: make sure the voltage between emitter and collector does not exceed 10 V and I_C does not exceed 1 mA.
- **Measurement:** Note the set-up of the curve tracer. Read currents and voltages from the display.
- **Tabulation:** Curve tracer set-up parameters, I_B, I_C.
- **Analysis:** Draw in your report the family of characteristics displayed on the curve tracer. What can you tell about the dependence of the collector current on V_{CE}? Draw the graph of I_C vs. I_B. What is the relationship between the two currents? Read β from your graph.

5.1.2 Establishing Device Currents (npn)

- **Goal:** To explore a simple but very effective approach to biasing.
- **Setup:**
  - Note that it will make your work much easier if all your "10 kΩ" resistors are the same value (near 10 kΩ), but well-matched (within a fraction of a percent for R_C and R_E, if possible).
  - Connect the circuit as shown in Fig. 2, with the supplies carefully adjusted to ±10.00 V.
- **Measurement:** Measure the voltages at B, E, C with respect to ground, using your DVM. Calculate $V_{BE}, I_E, I_C, I_B, \alpha, \beta$, immediately.
- **Tabulation:** $V_B, V_C, V_E, V_{BE}, I_E, I_C, I_B, \alpha, \beta$.
- **Analysis:** Consider the results of your measurements, particularly the values of β and α. Note that unless $R_E = R_C$ within a fraction of a percent, you may find α, calculated as I_C/I_E, to be in error, even appearing to exceed unity! A more appropriate approach to use when resistor values are uncertain is to calculate α as $\beta/(\beta+1)$. Do so, and compare.

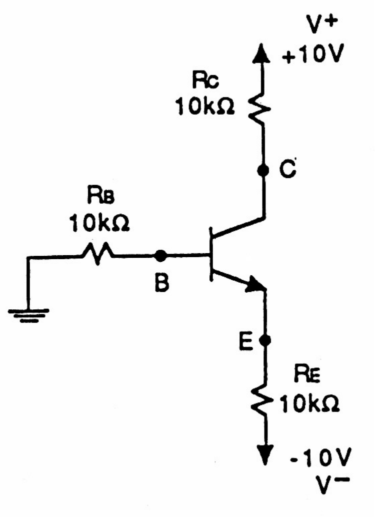

Figure 2: A Flexible Biasinig Circuit.

5.1.3 Identifying the Controlling Junction and Junction Current

- **Goal:** To verify the dominant role of the V_{BE} junction in establishing device currents, and to emphasize emitter-current control.
- **Setup:** Same as in Fig. 2, with $V^+ = 10$ V and $V^- = -10$ V.
- **Measurement:**
  - Raise V^- to –5 V, and measure V_B, V_E, V_C and V_{BE}. Calculate all terminal currents, β and α.
  - With $V^- = -5$ V, lower V^+ to +5 V, and remeasure and recalculate above quantities.
- **Tabulation:** $V_B, V_C, V_E, V_{BE}, I_B, I_C, I_E$
- **Analysis:** Consider what you have learned about the independent and dependent variables involved in transistor current control. Clearly, for active-mode operation (as arranged above), transistor currents depend on conditions in the emitter circuit, and are essentially independent of conditions in the collector. Use Eq. 4.3 in the Text and the data above to calculate n and I_S.

5.2 Other, Less-stable Biasing Schemes

5.2.1 Base-Current Bias

- **Goal:** To demonstrate the inadequacy of a bad, (unfortunately) but common, bias design.
- **Setup:**
  - Connect the circuit as shown in Fig. 3.
  - Note that the circuit in Fig. 3 is not a recommended bias design.
- **Measurement:**
  - Measure the voltage at node C, adjusting potentiometer R_p until $V_C = +5$ V.
  - Measure the voltages at nodes A and B with your DVM.
  - While measuring V_C, heat the transistor, perhaps by blowing through a straw.
  - Remove the transistor (carefully). Insert another one in its place; measure V_C.
- **Tabulation:** V_A, V_B, and values of V_C for two temperatures and two transistors.

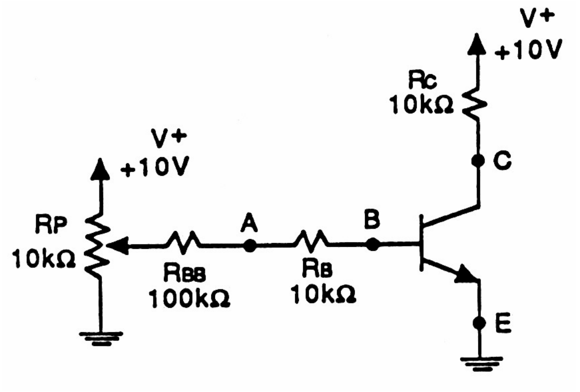

Figure 3: A Bad Base-Current-Biasing Circuit.

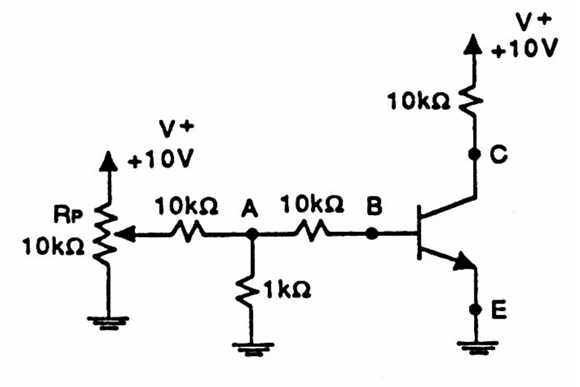

Figure 4: A Bad Base-Voltage-Biasinig Circuit.

- **Analysis:** Consider the fact that satisfactory operation of this circuit depends critically on β. As β varies from device to device or with temperature, the voltage V_{CE} will vary greatly, with saturation easily possible for high β. In fact, the very best transistor you can get, one with $\beta = \infty$ does not work at all! This is a clear sign of bad design!

5.2.2 Fixed Base-Emitter-Voltage Biasing

Note, this is clearly the worst bias design of all, unless the desire is to create an electronic thermometer.

- **Goal:** To demonstrate the total folly of fixed-voltage bias design.
- **Setup:** Connect the circuit as shown in Fig. 4.
- **Measurement:**
  - Adjust potentiometer R_p until the voltage at node C is $V_C = 5$ V.
  - Measure V_A, V_B with your DVM.
  - While measuring V_C, heat the transistor by blowing on it through a straw.
- **Tabulation:** V_A, V_B, and values of V_C at two temperatures.
- **Analysis:** Consider the fact that the base-emitter voltage at a fixed emitter current, drops by 2 mV for each °C rise in temperature. Use your measurement to estimate the rise in temperature you have induced in a burst of expiration!

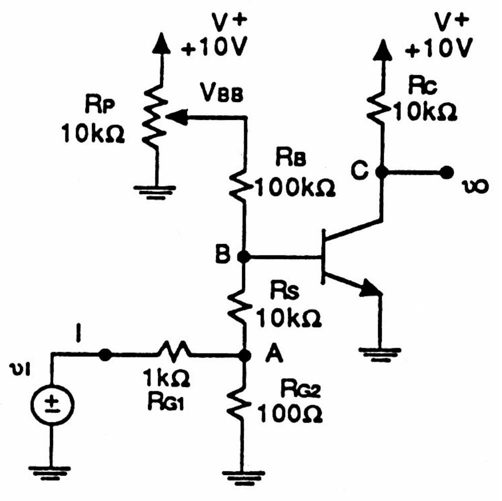

Figure 5: A Badly-Biased but Otherwise-Interestitig Amplifier.

5.3 The BJT as Amplifier

While the circuit shown in Fig. 5 uses a rather bad bias design, being a combination of base-current and base-voltage biasing, it is relatively convenient for the measurement of gain of a particular transistor under stable environmental conditions. Incidentally, the presence of the potentiometer R_p is, generally speaking, a sure sign of less-than-ideal design.

5.3.1 Voltage Gain and Input Resistance

- **Goal:** To investigate important basic properties of a BJT amplifier.
- **Setup:** Connect the circuit as shown in Fig. 5. (Note the earlier comment on the suitability of this bias design.)
- **Measurement:**
  - With v_i set to zero (or open), adjust R_P so that the dc voltage at C is 5 V.
  - With v_i a sine wave at 1000 Hz, measure at nodes I and C, adjusting the input-signal amplitude so that v_c, is a sine wave of 1 V peak amplitude.
  - Measure the peak signals at I, A, and B, the latter being quite small.
- **Tabulation:** $v_c, v_b, v_a, v_i, v_o/v_b, v_o/v_a, v_o/v_i$
- **Analysis:** Consider the overall operation of the BJT circuit as an amplifier. Calculate the voltage gains $v_o/v_b, v_o/v_a, v_o/v_i$, and the current into the base i_b (through RS) and, thereby, R_{inb}. Note that v_o/v_b is the basic BJT gain while v_o/v_a is the gain which might result from a source whose internal resistance is $R_s = 10\,\mathrm{k}\Omega$. As usual, some signal is lost in the bias network (R_B) although, here, this loss is small, since $R_B \gg R_{inb}$

5.3.2 Large-Signal Distortion

- **Goal:** To demonstrate that BJT amplifier operation is relatively linear over only a very limited signal range.
- **Setup:**
  - Connect the circuit as in Fig. 5.
  - Adjust for Vc = 5 V as directed above.
- **Measurement:**

  - Measure the voltages at nodes C and I with your dual-channel oscilloscope. Adjust the input voltage so the output is a 1 V peak-to-peak sine wave.
  - Adjust the oscilloscope channel gain, polarity and dc position controls on the channel connected to node I so that the signals at nodes C and I exactly overlap. You may find it necessary to set the node-C channel on ac coupling, although it is best left on dc coupling, as we shall see.
  - Raise the input voltage slowly, while observing the voltages at nodes I and C. Note that the output voltage begins to deviate from that at I at the peaks. Note finally (and assuing dc coupling for the channel connected to node C), that the peaks of the output flatten, going no higher than 10 V, nor lower than a few tenths volts above ground. Measure v_b for the output just noticeably deviating from v_i and then when it is at its positive peak limit, and then at its negative peak limit.

- **Tabulation:** Values of v_C, v_i, v_b at which distortion in v_c, is noticed, and then positive and negative peak clipping occur.

- **Analysis:** Consider the effects you have observed as evidence of non-linear signal distortion, at first relatively minor, and then seen as very serious clipping as the transistor cuts off and/or saturates (in an order which depends on biasing detail). One normally minimizes distortion by keeping v_b less than 10 mV peak. How do your results compare with this value? (Use your earlier calculation of the gain v_o/v_i.)