Physics 120 Lab 8 (2018) Bipolar Junction Transistors

The bipolar junction transistor (BJT), conceived by William Shockley and first realized by Morry Tanenbaum (1955), predated the realization (although not the conception) of the FET and is one of the most profound technological achievements of the age of electronics. Let us study some basic BJT circuits. Compared with the FET, which functions as a voltage-controlled current source, the BJT operates as a current amplifier or a current-controlled current source.

8-1 Transistor junctions are diodes

Here is a method for spot-checking a suspected bad transistor: the transistor must look like a pair of diodes when you test each junction separately. Of course, the BJT does ***not*** behave like two back-to-back diodes when operating as the base is physically very thin and draws little current.

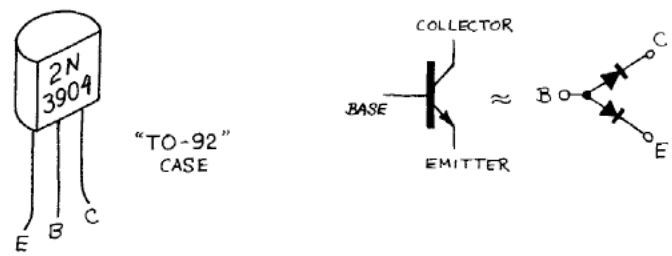

Figure 8.1: Transistor junctions (for testing, not to describe transistor operation).

Get a 2N3904 NPN transistor, identify its leads, and verify that it looks like the diagram of back-to-back diodes in Fugure 8.1. Use a DMM's *diode test* function (*Note:* indicated by a diode symbol on the function selector). The diode test apples a small current, *i.e.*, a few milliAmperes, that flows from the Red to Black lead and the meter reads the junction voltage. What voltages to you read for V_{BC} (**1 pt**) and V_{BE} (**1 pt**)? Document this.

8-2 Emitter follower

Wire up an NPN transistor as an emitter follower (Figure 8.2).

Drive the follower with a sine wave of about 1 V amplitude and 1 kHz that is symmetrical about zero volts and look with a scope at the poor replica that comes out. Show a **SCREENSHOT** (**1 pt**). Explain exactly why this happens (**1 pt**).

If you turn up the waveform amplitude you will begin to see bumps *below* ground. Show a **SCREENSHOT** (**1 pt**). How do you explain these (**2 pt**)? (*Hint*: see V_{BE} breakdown specification in the data sheet for the 2N3904 transistor).

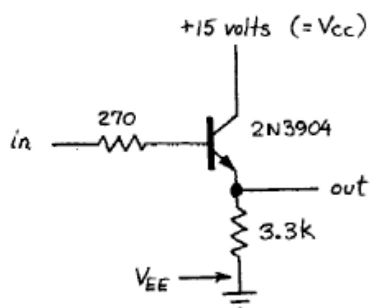

Figure 8.2: Emitter follower. The small base resistor is often necessary to prevent oscillations.

Now try connecting the emitter return, *i.e.*, the point marked V_{EE}, to -15 V instead of ground, and look at the output. Document with a **SCREENSHOT** (**1 pt**) and explain the improvement (**2 pt**).

8-3 Input and output impedance of emitter follower

Measure $\mathbf{R_{in}}$, the resistance looking into the base, and $\mathbf{R_{out}}$, the resistance looking back into the emitter, for the follower in Figure 8.3.

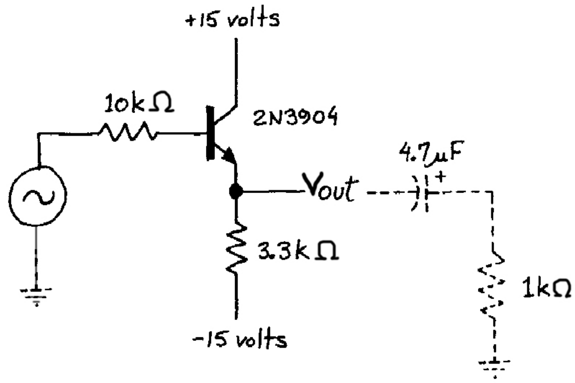

Figure 8.3: Follower: circuit for measuring $\mathbf{R_{in}}$ and $\mathbf{R_{out}}$

Using the circuit in Figure 8.2, replace the small base resistor with a 10 kΩ resistor to simulate a signal source of moderately high impedance, *i.e.*, low current capability (Figure 8.3).

Measure $\mathbf{R_{out}}$, the output impedance of the emitter follower, as follows. Connect a 1 kΩ load to the output and observe the drop in output signal amplitude. It is best to use a small input signal, less than a volt. Document with a **SCREENSHOT** (**1 pt**) and report $\mathbf{R_{out}}$ (**1 pt**). Explain why you should use a blocking capacitor (**1 pt**).

Suggestions for measurement of $\boldsymbol{R_{out}}$*:*

- If you view the emitter follower's output as a signal source in series with $\boldsymbol{R_{out_{Thevenin}}}$, the 1 kΩ resistive load forms a voltage divider at signal frequencies, where the impedance of the blocking capacitor is negligibly small.
- The attenuations are likely to be small. To measure them we suggest that you *AC couple* the output signal to the scope, to ensure centering, then attach the load resistor and read the amplitude.

Remove the 1 kΩ load. Now measure $\mathbf{R_{in}}$, which is the impedance looking into the transistor's base, by looking alternately at both sides of the 10 kΩ input resistor. For this measurement the 3.3 kΩ emitter resistor is also the "load" resistor Again, use a small signal. Document with a **SCREENSHOT** (**1 pt**). Does the result make sense (**1 pt**)?

When you have measured $\mathbf{R_{in}}$ and $\mathbf{R_{out}}$, infer your transistor's β (**1 pt**) (*Hint:* see textbook or class handout on emitter follower for help). Does the result make sense (**1 pt**)?

8-4 Transistor current gain

You saw how the transistor's current gain, β, modified impedances in section 6.3. Now measure β directly at several values of I_C with the circuit shown in Figure 8.4. Use the DMM as an Ammeter. The 4.7 kΩ and 1 kΩ resistors limit the currents. Which currents do they limit, and to what values (**1 pt**)?

Try various values for **R**, using either the resistor substitution box or individual resistors. Try 1 MΩ, 500 kΩ, 200 kΩ, 100 kΩ, and 50 kΩ; note that when the resistor is too small the transistor will no longer be in the active state as I_C is too large. Estimate the collector current I_C for each different I_B (**5 pts;** one for each resistor) Don't bother to measure I_B directly; just assume V_{BE} = 0.6 V and calculate I_B as (5.0V - 0.6V) / (R + 4.7kΩ). Estimate β as an average across measurements; a plot of I_C versus I_B with a fitted line would be best (**2 pts**).

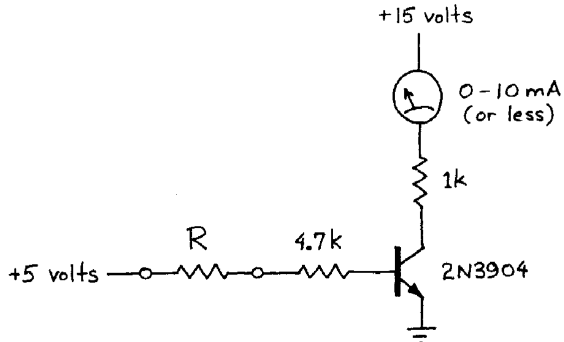

Figure 8.4: Circuit for measurement of β.

8-5 Common emitter amplifier

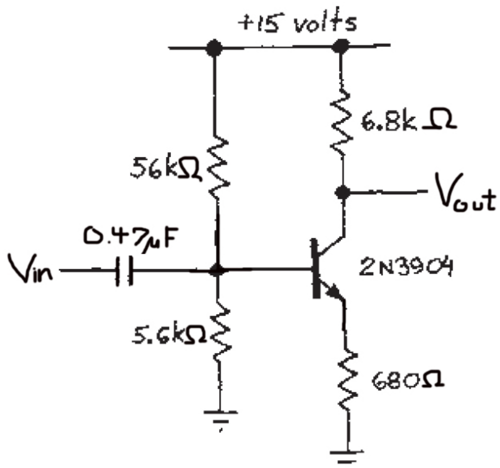

Figure 8.5: Common-emitter amplifier.

Wire up the common emitter amplifier shown in Figure 8.5 (*Note*: see design in lecture notes). What is the expected voltage gain (V_{out}/V_{in}) (**1 pt**)? Check it out using an input at ~ 1 kHz with an amplitude of a few hundred milliVolts. Is the signal's phase inverted? Document your work with **SCREENSHOTS** emphasizing the AC part and the DC offsets (**2 pts**).

Is the collector quiescent operating point at the expected values (*Note*: see design in lecture notes) (**1 pt**)? What should the output impedance be (**1 pt**)? Check it by connecting a resistive load as in section 8.3 (*Note:* you will need to estimate a good value for the load) through a blocking capacitor. The capacitor lets you test impedance at signal frequencies without altering the biasing scheme. Describe your results (**1 pt**) and document with a **SCREENSHOT**(**1 pt**).

32 point total