Physics 364, Fall 2012, Lab #5

(Transistors I: emitter follower; common emitter amplifier)

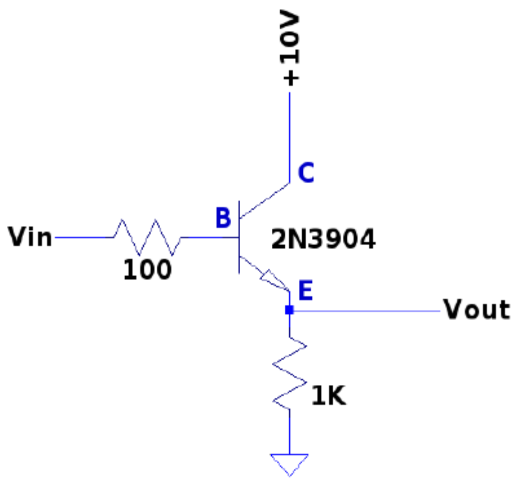
start Monday, October 8 — finish Friday, October 12.

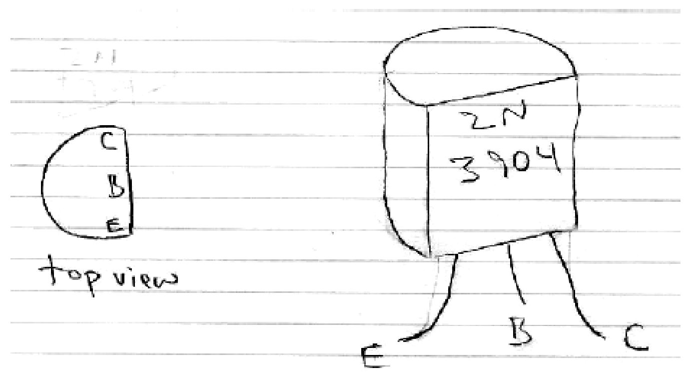
Course materials and schedule are at `positron.hep.upenn.edu/p364`

Lab #5 is the first of two labs covering Bipolar Junction Transistors. This week, we will study two of the most well-known types of transistor amplifier: the emitter folloer and the common emitter amplifier. These two transistor circuits are roughly analogous to the opamp follower and the opamp inverting amplifier.

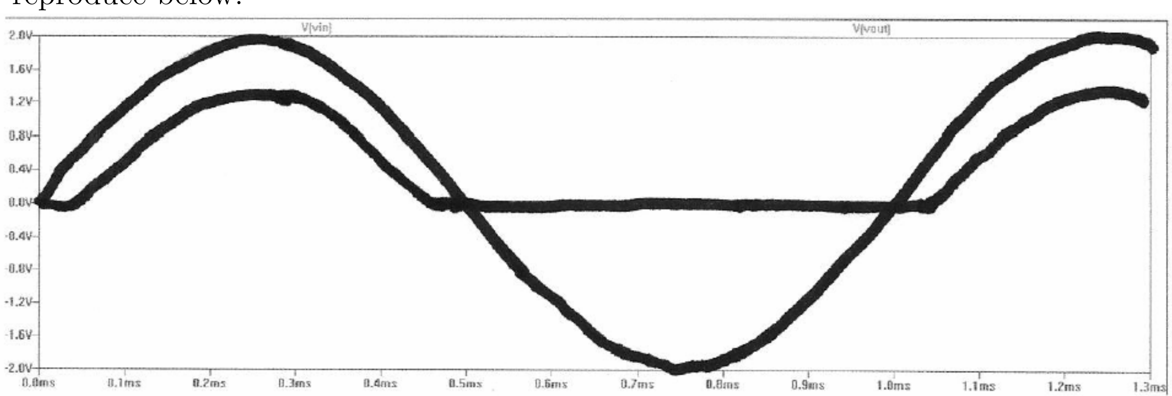
Part 1

Build the (rather plain) emitter follower shown in the left figure below. (The right figure below shows you how to identify the three terminals of the 2N3904 NPN transistor.) The 100 Ω resistor at the base is not strictly necessary, but we'll include it (a) to reduce the chances of applying too large a reverse bias to the base→emitter junction (letting V_{BE} go more than a few volts below zero will cook the transistor), and (b) to make it easy for you to measure the base current I_B.

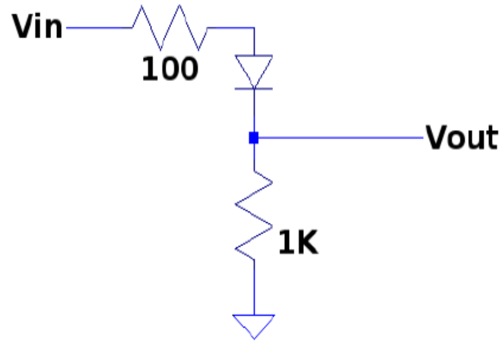




(a) First check your connections by trying out your follower with a 4 V_{pp} sine wave input. The output should resemble the graph on page 9 of the lecture notes, which I reproduce below.



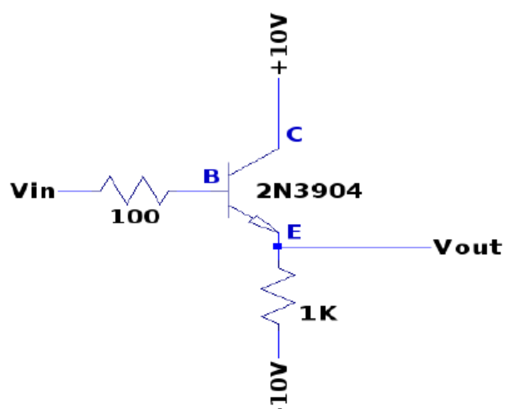
(b) (*Nothing to build here.*) Recalling that the base-emitter junction behaves as a diode, make sure that you understand the features of the input and output by considering the diode circuit at right, which closely resembles a circuit you built in Lab 1. (The output of this circuit looks just like the above graph.) Do you understand (from the diode I-V curve) why V_{out} is a diode drop (about 0.7 V) below V_{in} and is clipped at 0 V when $V_{\text{in}} < 0$?



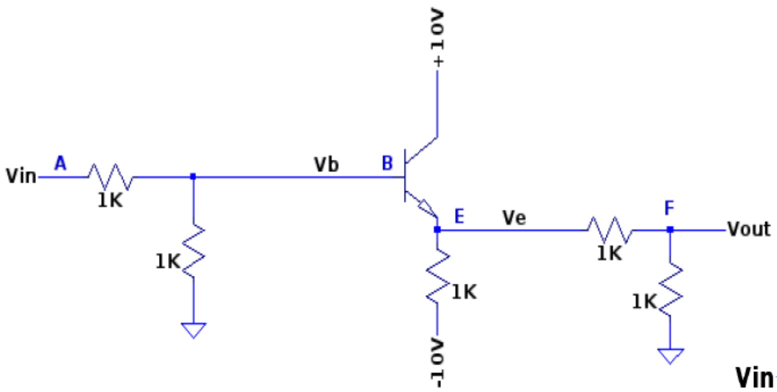
(c) Now let's measure β for your transistor by recording voltages and inferring currents for several DC input voltages. Fill in a table like the one below. Just program V_{in} and measure V_B and V_E. You should be able to infer all of the other values. See whether I_E vs. V_{BE} and I_E/I_B follow your expectation.

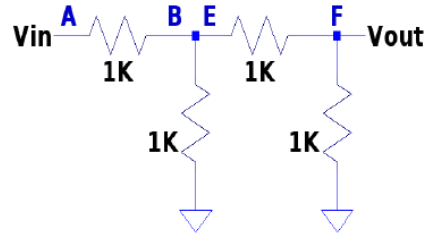
V_{in}	V_B	$V_{\text{in}} - V_B$	I_B	V_E	V_{BE}	I_E	I_C	I_C/I_B
-2 V								
-1 V								
0 V								
$+1$ V								
$+2$ V								
$+4$ V								
$+8$ V								

(d) Now move "V_{EE}" (beneath R_E) from 0 V (ground) to -10 V, so that we can follow a bipolar signal. (You might also want to replace the 1 kΩ resistor with 5 kΩ, to keep your transistor from getting too warm. Can you see why (if V_{in} is 0 V on average) a small value of R_E makes the transistor dissipate enough power to warm it up?) Now remove the 100 Ω resistor from the base, just to assure yourself that it isn't doing anything important. Check, of course, that you can now follow a bipolar signal!



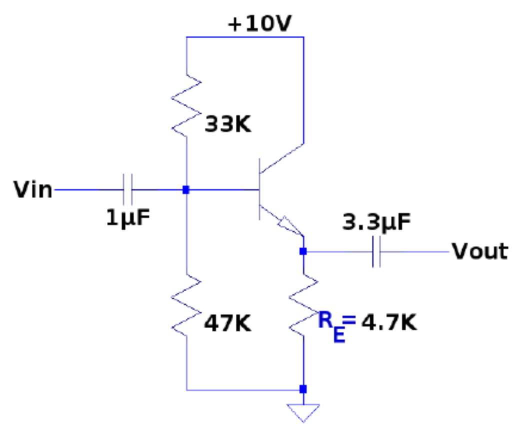
(e) Let's build our favorite (most dreaded?) "voltage divider loads voltage divider" circuit, as shown below — though this time we'll change the resistances to keep the math even simpler than usual. What do you see at points A, B, E, and F? (I didn't want to confuse anyone by writing A, B, C, D.) What would you expect from your opamp follower? What would you expect with no follower at all, e.g. by imagining (don't bother to build) the small figure to the right?





Part 2

Now build the AC-coupled follower from page 12 of the lecture notes (shown at right).



Does the follower follow? At what amplitude V_{in} does V_{out} begin to show clipping? Look at V_E when V_{out} is clipping, to understand what is happening.

What are $f_{3\text{dB}}$ for the input and output filters? First calculate (estimate) what you expect for each filter before you start to measure.

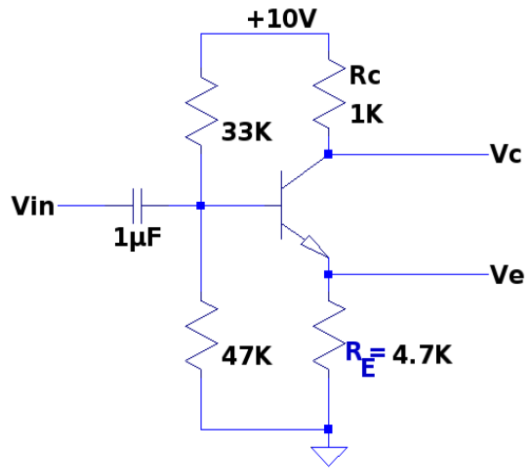
What are the quiescent (i.e. DC) values of V_B, V_E, V_{BE}, I_E, and I_C? (Most of these you can infer by measuring V_B and V_E.)

What is the quiescent current through the biasing network (the voltage divider to the left of the base)? What quiescent I_B do you estimate from your measured β from Part 1? An equivalent way of saying that the voltage divider is not too heavily loaded (does not droop) is to say that the current drawn by the base is much less than the current that flows through the two resistors of the voltage divider.

Don't take apart your follower yet!

Part 3

(a) First make a minor modification to your emitter follower from Part 2: Add a 1 kΩ resistor in place of the direct connection from the collector to +10 V. Also, remove the 3.3 μF output capacitor.



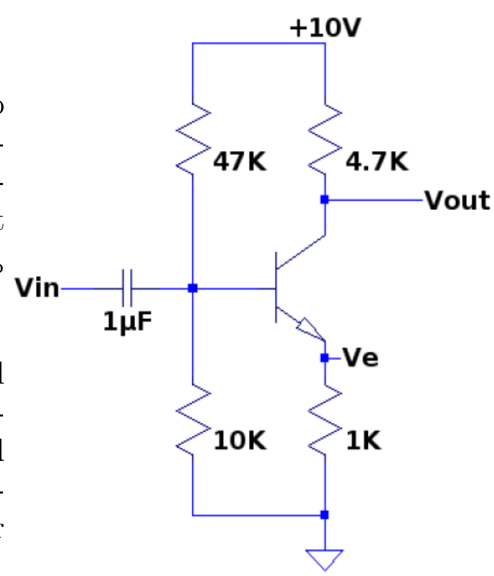
Drive your circuit with a 2 V_{pp} sine wave and look at the signals at both the emitter and the collector. What are the DC levels at emitter and collector? Why? (This is really important to understand!) What are the signal amplitudes (and relative signs)? Why?

(b) Now replace the 4.7 kΩ emitter resistor with 1 kΩ. What is the largest signal you can apply to the input before one of the outputs clips? Which one clips first? Why? Predict, then measure the quiescent voltage, V_B, at the base. (Quiescent means in the absence of any AC signal.) Now predict, then measure V_E. What is I_E? Now predict, then measure V_C. (*Note:* If your transistor saturates at DC, so that you can't get even a very small signal through without distortion, try lowering V_{CC} from +10 V to about +8 V. If you do this and it works for you, try to explain why it works!)

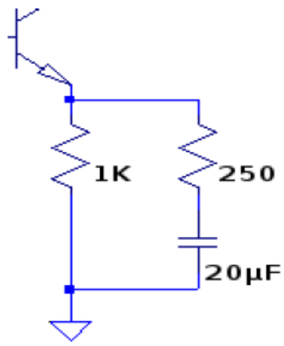
(c) Modify the biasing network (the voltage divider to the left of the base) so that the quiescent current through the collector is about 2.5 mA. To do that, figure out where the emitter should rest, then the base. Now remeasure the quiescent values of V_B, V_E, and V_C. Now what is the largest signal that you can apply to the input without clipping?

Part 4

(a) Build the common emitter amplifier drawn to the right. Look at the quiescent state first. Predict, then measure V_B. Then predict, then measure V_E. Then predict, then measure V_C. What do you expect the gain to be? Now inject a 1 V_{pp} sine wave and check.



(b) Now let's raise the AC gain a bit. In parallel with the 1 kΩ emitter resistor add a 250 Ω resistor in series with a 20 μF capacitor, as sketched below. What gain do you predict at signal frequencies? Measure it. What do you expect for the largest signal you can amplify? Try it.



(c) Now try the *grounded emitter amplifier* (so called by Horowitz & Hill), to see its limitations. Build the circuit shown below. Use a 100 kΩ resistor and a 10 kΩ potentiometer for the bias network, so that you can easily move V_B around in the range of approximately 0–1 V. Aim for about 0.7 V, and adjust if you need to. (You can use the quiescent value of V_C to measure I_C, and adjust V_B to keep I_C around 1 mA. I_C will creep upward as your transistor grows warmer.) Drive the input with the largest sine wave that doesn't cause the output to clip. You should see the "barn roof" distortion illustrated on page 16 of the lecture notes. You can make the effect even more impressive with a triangle wave instead of a square wave input. Explain how this "barn roof" shape comes about. Try a range of emitter resistors (or better yet, use a 1 kΩ potentiometer, if you can find one) to see at what point the distortion becomes less noticeable. Can you explain the appearing / disappearing distortion by considering $R_E + r_e$ (where $r_e = 25\text{ mV}/I_C$) at the signal peaks vs. valleys?