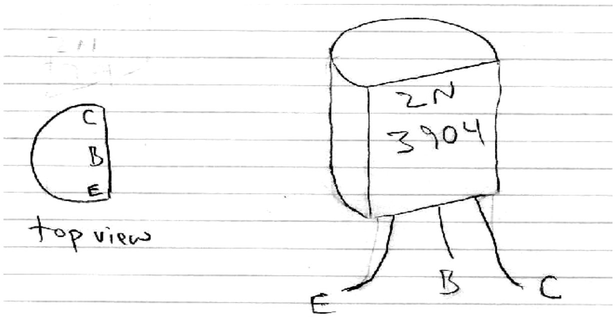
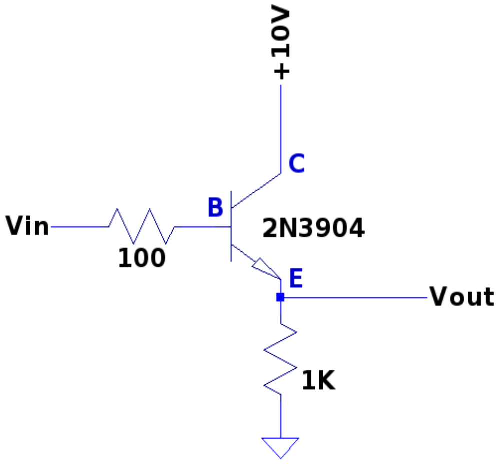
Physics 364 – fall 2010 – lab #5 – due by lecture, Monday 2010-10-18

Lab #5 is the first of two transistor labs. This week, we will look at several amplifier circuits built using Bipolar Junction Transistors. First, you'll build an emitter follower, pausing along the way to measure a few basic transistor properties. Then your emitter follower will gradually morph into a common-emitter amplifier. Finally, if you have time, you'll build a push-pull buffer to drive a speaker.

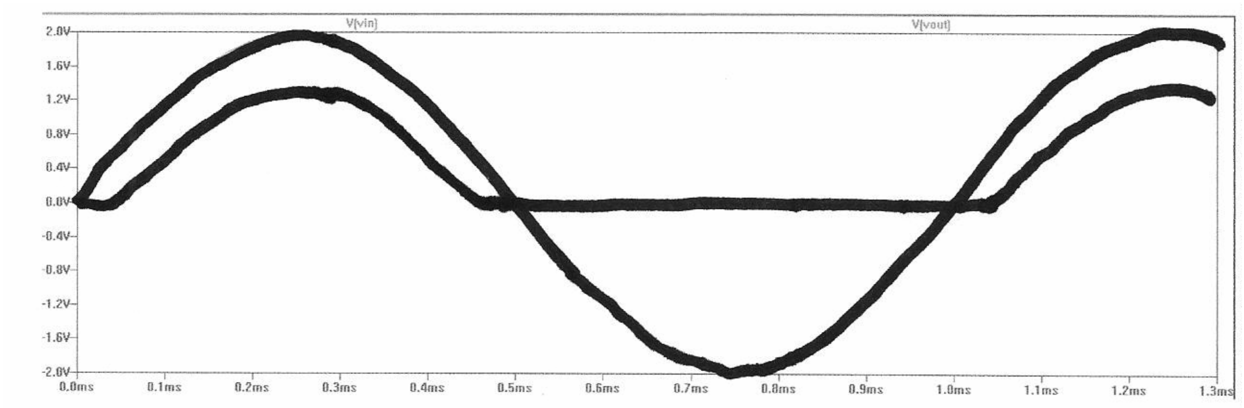


Part 1.

Build the (rather plain) emitter follower shown to the right. The 100Ω 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 (more than a few volts' reverse bias will cook the transistor), and (b) to make it easy for you to measure the base current I_B.

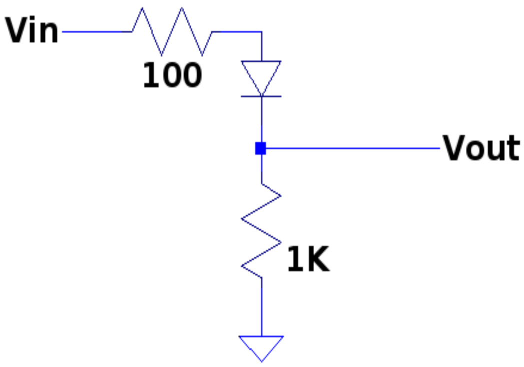


(a) First check your connections by trying out your follower with a 4Vpp sine wave input. The output should resemble the graph on page 3 of the lecture notes, which I reproduce below.



(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.)

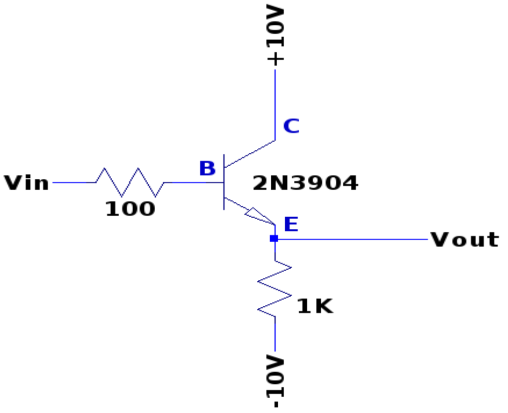
Do you understand (from the diode I-V curve) why V_{out} is a bit (a diode drop) below V_{in} and truncates when $V_{in}<0$?



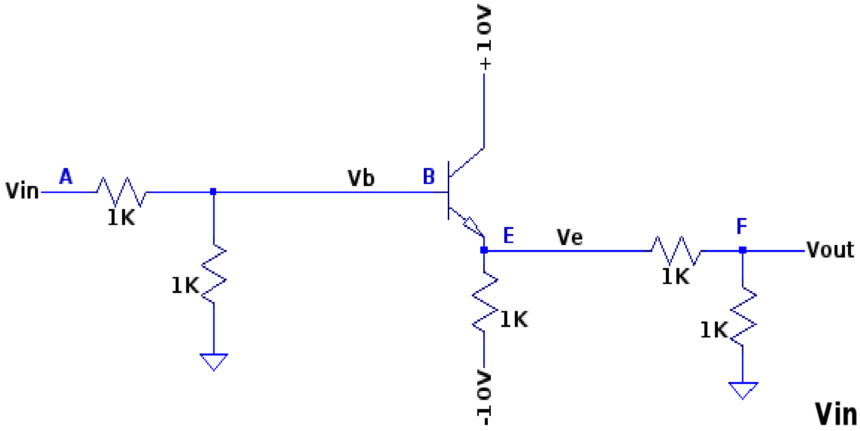
(c) Now let's measure β for your transistor by recording voltages and inferring currents for several DC input voltages. Fill in a table like the one below. Just program V_{in} and measure V_B and V_E. You should be able to infer all of the other values. See whether I_E vs. V_{BE} and I_E/I_B follow your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

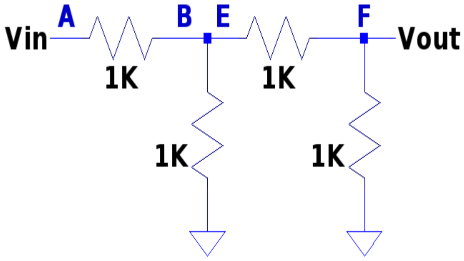
V_{in}	**V_B**	$V_{in}-V_B$	I_B	**V_E**	V_{BE}	I_E	I_C	I_C/I_B
-2V								
-1V								
+0V								
+1V								
+2V								
+4V								
+8V								

(d) Now move "V_{EE}" (beneath R_E) from 0V (ground) to -10V, so that we can follow a bipolar signal. Look at V_{in} and V_{out} now. Now remove the 100Ω resistor, just to assure yourself that it isn't doing anything important.



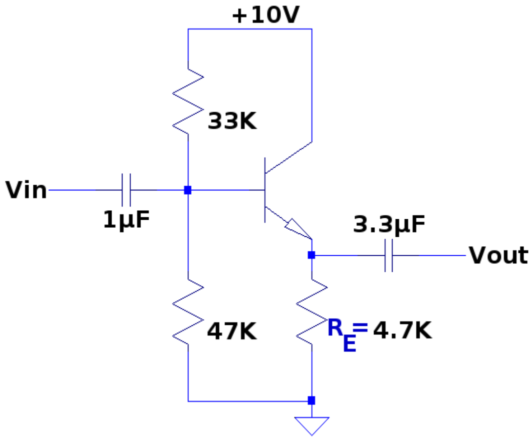
(e) Let's build our favorite "voltage divider loads voltage divider" circuit, though this time we'll change the resistances to keep the math even simpler than usual. What do you see at points A, B, E, and F? (I didn't want to confuse anyone by writing A, B, C, D.) What would you expect from your opamp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





Part 2.

(a) Now build the AC-coupled follower from page 5 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_{3dB} for the input and output filters? (Measure and calculate.)

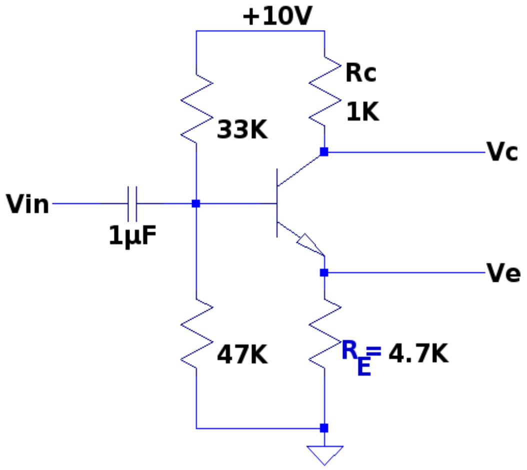
What are the quiescent values of V_B, V_E, V_{BE}, I_E, and I_C? (Most of these you can infer by measuring V_B and V_E.)

What is the quiescent current through the biasing network (the voltage divider at the base)? What quiescent I_B do you estimate from your measured β from Part 1?

Don't take apart your follower yet!

Part 3.

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



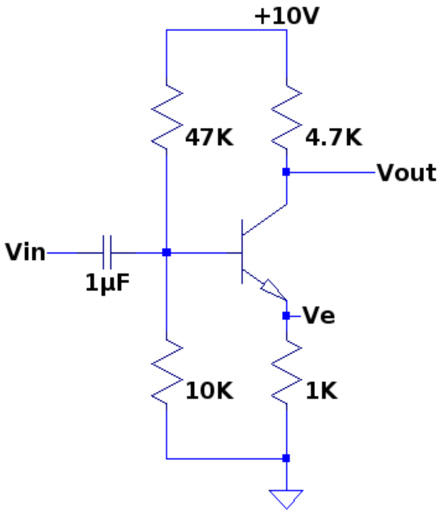
Drive your circuit with a 2Vpp sine wave and look at the signals at both the emitter and the collector. What are the DC levels at collector and emitter? Why? What are the signal amplitudes (and relative signs)? Why?

(b) Now replace the 4.7K emitter resistor with 1K. 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. 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 Vcc from +10V to about +8V. If you do this and it works for you, explain why it works.)

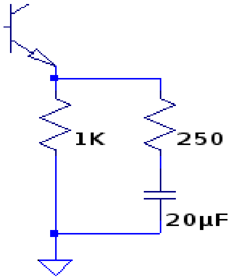
(c) Modify the biasing network (the divider at the base) so that the quiescent current through the collector is about 2.5mA. To do that, figure out where the emitter should rest, then the base. Now re-measure quiescent V_B, V_E, V_C. Now what is the largest signal you can apply to the input without clipping?

Part 4.

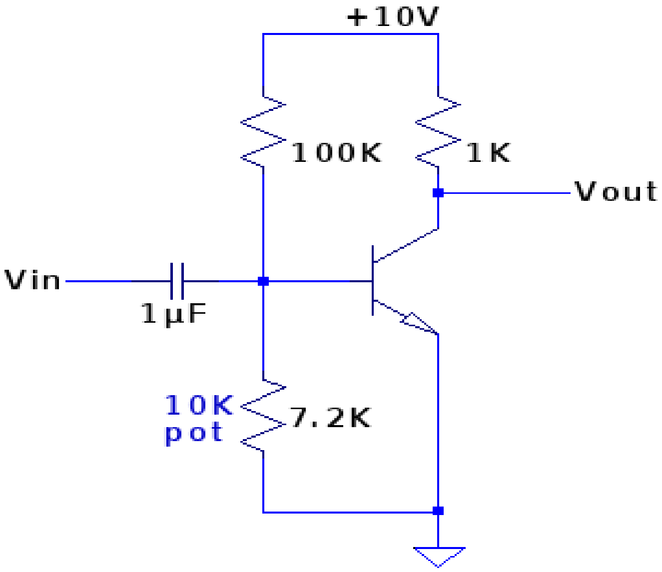
(a) Build the common emitter amplifier drawn to the right. Look at the quiescent state first. Predict, then measure V_B, then V_E, then V_C. What do you expect the gain to be? Now inject a 1Vpp sine wave and check.



(b) Now let's raise the AC gain a bit. In parallel with the 1K emitter resistor add a 250Ω resistor with a 20µF bypass 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.

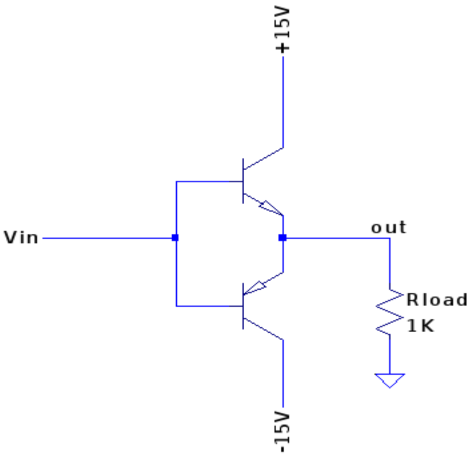


(c) *Optional, but should be quite informative. If you run out of time, I encourage you to try it in LTspice.* Now try the grounded emitter amplifier, to see its limitations. Build the circuit shown below. Use a 100K resistor and a 10K pot for the bias network, so that you can easily move V_B around in the range of approximately 0—1 volt. Aim for about 0.7 volt, 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 1mA. 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 9 of the lecture notes. Explain how this shape comes about. Try a range of emitter resistors (or better yet a 1K pot, 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=25mV/I_C) at the signal peaks vs. valleys?



Part 5. – *optional, but fun!*

(a) Build the push-pull buffer shown to the right (use one npn 2N3904 and one pnp 2N3906). Drive it with a 10Vpp sine wave. Do you see the crossover distortion on the scope, when the output crosses zero? Why does this happen? If you can find a speaker (just a speaker this time, not an amplified one!), try driving the speaker to hear the distortion.



(b) Now put an op-amp follower between the signal source and the push-pull. This should do exactly the same thing as the circuit in part (a), but testing it this way gives you a chance to check that you wired it up correctly.

(c) Now move the feedback to the output of the push-pull, as shown below. You should see the crossover distortion magically disappear! Why does this happen? Try both to see the distortion disappear (with the scope) and to hear it (with the speaker).