University of Utah

Electrical & Computer Engineering Department

ECE 2100

Experiment No. 9

Common-Emitter Amplifier

A. Stolp, 3/20/01
rev, 3/13/03

Minimum required points = 50 Grade base, 100% = 72 points
Recommend parts = 65 points (90%)

Objectives

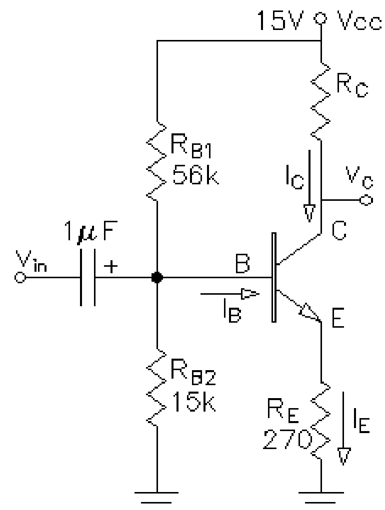
Explore the characteristics of a common-emitter amplifier with a bypass capacitor, including gain, distortion, input resistance, output resistance, and frequency response.

Check out from stockroom:

- Wire kit
- Two 10x scope probes (compensate before using)
- Speaker

Parts:

- 51, 270, 820, 1k, 1.5k, 15 k & 56 kΩ, resistors
- 1 - 10 µF, 10 -100 µF & 270 - 470 µF capacitors
- 2N3904 transistor



Experiment 1, Common-Emitter (32 pts, recomended)

Make the your circuit shown at right. If you want to do Experiment 3 later in the lab, leave your circuit from last lab alone and use a second transistor for this lab. Use a 270 Ω resistor for R_C.

Bias: Measure and record the DC bias voltages throughout the circuit (V_B, V_E, and V_C). Calculate I_E and V_C from your measured V_E and compare to your measured V_C.

Signals: Hook the signal generator up to this new circuit. Set both inputs of the scope to 2 V/div, DC coupling and adjust both ground levels to the bottom of the screen. Connect the scope probes to the base (v_B) and to the emitter (v_E). Does v_E still “follow” v_B the way it did in the common-collector amplifier from last lab? Make a sketch of these voltages in your notebook, showing AC signals riding on the DC bias voltages. This sketch will be very similar to the one you made before, only this time make your vertical (voltage) scale go to at least 15V. Show the DC value (V_{AVE}) of for both signals on your sketch. These should be the same as the DC bias voltages that you measured earlier.

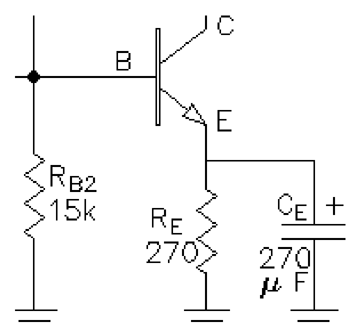
Move one scope probe from the emitter (v_E) to the collector (v_C). Now this *is* different. The signal at the collector is about the same size, but inverted (upside down). Add v_C to your sketch, show the DC value as well.

Move one scope probe from the base (v_B) to the emitter (v_E). It doesn't look much different than v_B, but it can help to explain why v_C is inverted with respect to v_B. The current through R_C and R_E are essentially the same. Since the top of R_C is held constant by Vcc and the bottom of R_E is held constant by ground, the signals at C and E must be inverted from one another. That's where the signal inversion comes from. Since R_C and R_E are equal in value, the signal sizes are also equal.

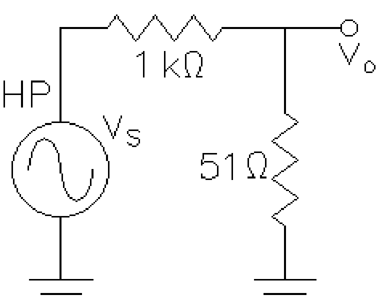
Clipping: Turn up the input signal level until you see clipping distortion in the output. Notice that both v_C and v_E clip at the same time and that v_C clips at Vcc and v_E clips at 0 V. What does this say about i_C and i_E at clipping? Turn the input level back down again.

Replace R_C with an 820 Ω resistor and adjust the input level so that the output shows clipping both top and bottom. The clipping on top looks pretty flat at 15 V, but the bottom clipping is weird. Notice that it tracks the emitter voltage when they get too close. That is saturation. In saturation all our precious assumptions based on β are in the dumpster. Notice also that v_C and v_E don't quite touch— they stay about 0.2 V apart. Make a sketch of these voltages in your notebook. Indicate the clipping due to cutoff and that due to saturation.

Gain: Turn down the input to avoid clipping and move the emitter scope probe back to the base. Measure the new signal gain ($v_c$pp/$v_b$pp). How does this compare to R_C/R_E? Try this again with R_C = 560 Ω. If you're still not sure about this gain = R_C/R_E concept, try some more R_C values or try changing R_E.



Emitter bypass capacitor: Now let's take this concept a step further. Put the 820 Ω resistor back in for R_C. Connect your big electrolytic capacitor from the emitter to ground. Now look what's happened to the gain. Turn down the input to just under clipping, if you can.

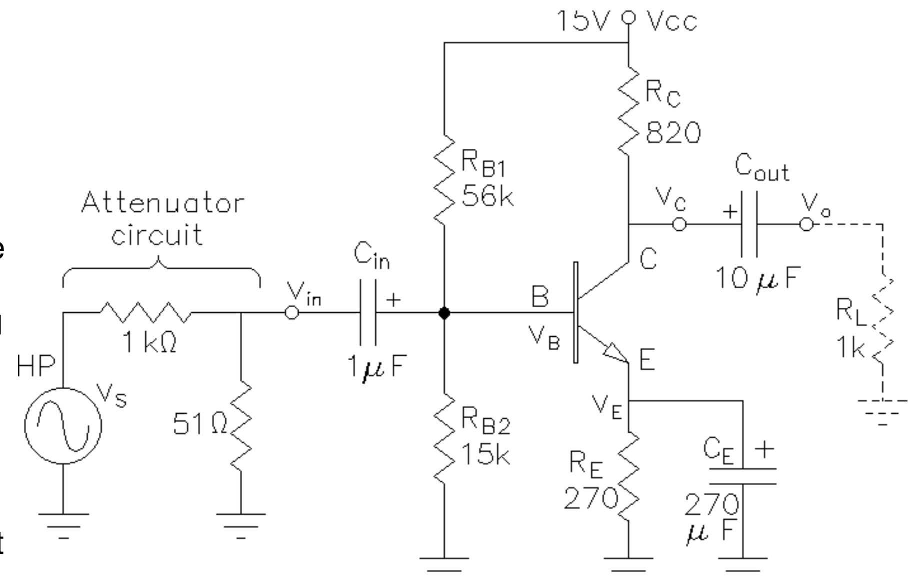


Signal source: For the remainder of this lab you will need a fairly small input signal. If you're using a Krone-Hite or Wavetek signal generator you can simply use the LO output, but if you're using the HP function generator you'll have to make a little attenuation circuit. The circuit shown divides the function generator signal by a factor of about 22 and has an output impedance of about 48 Ω. (If you have trouble seeing this, review Thévenin's theorem.) You will use the output of this circuit as your source voltage (v_{in}) for all the circuits that follow. The attenuator and amplifier circuits are shown hooked together on the next page.

Adjust the input so that the output is big, but not clipping. Notice again how big the gain is. Why does this capacitor increase the gain? Think in terms of the signal impedance from the emitter to ground. What did the capacitor do to our R_C/R_E? Essentially R_E is missing at signal frequencies, except for a little r_e that's inside the transistor. Unfortunately, r_e isn't very linear, resulting in output distortion.

Distortion: Adjust the input so that the output shows clipping and then turn it back down a little so that the clipping just disappears. Notice that when the collector signal voltage is big, like it is now, it is distorted. A sine wave will be fatter or wider at the top than at the bottom. Sketch this output waveform in your notebook showing the distortion. What causes this distortion? Remember that r_e is a function of i_C and that i_C is changing throughout the waveform. That means that the gain of this circuit is changing throughout the waveform. In the next lab you'll see how to trade some of the gain for a reduction in the distortion.

Experiment 2, CE with bypass (33 pts, recommended)

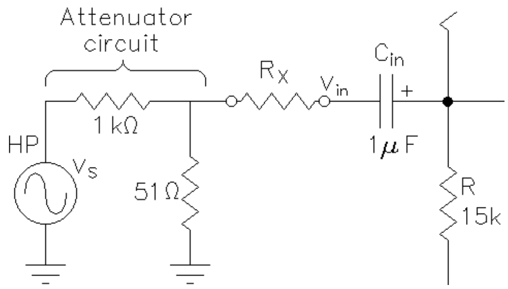


Add an output coupling capacitor to your circuit so that your full circuit looks like the one at right, just without R_L. (The attenuator is not needed with some signal generators.) Redraw the full circuit in your notebook. Make sure your lab book is very clear about what part of the circuit is the amplifier and what part is the attenuator. The attenuator circuit is **NOT** part of the amplifier. It is here only because the HP function generator can't be turned down enough for this amplifier.

Gain: Remove R_L if you added it already. Turn down the input enough so that the output of your transistor circuit looks undistorted (say 1-2 V_{pp} at v_o). Measure the signal gain of this amplifier ($A_V = v_c/v_b$, AC only, of course).

Using your earlier measurements of the DC bias voltages and currents, calculate $r_e = 25mV/I_C$. If you neglect the impedance of C_E, what signal gain do you expect from this amplifier? Compare the measured and theoretical gains. You'll probably find the your measured gain is a bit less than expected. Use the measured gain figure to calculate the actual r_e. The actual r_e may be higher than the theoretical r_e because the transistor is warmer than room temperature and because of bulk resistance and contact resistance within the transistor. Comment in your notebook. Later I'll refer back to this actual r_e as "the r_e you found from the gain measurement".

Input resistance: (3 pts + 3 possible extra) This paragraph is extra credit. The signals involved are small and difficult to measure accurately. Turn the input signal back down so the output is undistorted (say 1-2 V_{pp} at v_o). To find the input resistance, you'll have to add a resistor (R_x) between the source (with attenuator) and the amplifier input (see next drawing). Use a value about equal to the input resistance you expect to see (500 - 1 k Ω ought to do). Measure the signal voltage on both sides of this added resistor. Use these two measurements to calculate the input signal current. Divide the input voltage by the input current to get the input resistance (R_{in}). Remove R_x.

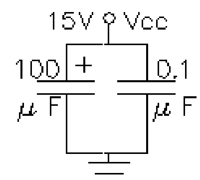


This paragraph is an alternate way to get the extra credit. you could add a potentiometer instead of a fixed resistor, adjust the pot until the input (and output) signals are halved, then take the pot out and measure it. The resistance of the pot would then be $R_S + R_{in}$. (Remember that R_s is about 48 Ω for the attenuator.) Remove the pot.

Circuit Noise Problems

Circuit noise can manifest itself in a variety of irritating ways. Sometimes it's just fuzz on the scope that does little more than mess up the scope's peak-to-peak voltage measurements, forcing you to take them manually. Sometimes noise problems can be so severe that even DC voltmeter readings become weird. Just connecting the meter's leads may cause the noise— check with the scope.

Usually capacitors are the solution to noise problems. In the op amp labs you placed some filter capacitors across the power supply right on the proto-board. That's actually a good idea for all the circuits that you build, especially those with high gain factors. A 100 μF electrolytic or tantalum in parallel with a 0.1 or 1 μF low-inductance ceramic disk is a good start.



Shorten or eliminate all the leads that you can. This may mean the removal of measuring leads or substitution boxes.

If you still have problems, you may have to place some small ceramic disk caps right in your circuit, from a noisy spot to ground. Be careful, though, this can seriously affect your circuit's frequency response.

Finally, there is yet another, less obvious way to measure the input resistance that I would like everyone to do. Measure the output signal voltage, call it v_{o1}. Add a resistor (R_x) between the source (with attenuator) and the amplifier input (see drawing above). Use a value about equal to the input resistance you expect to see (500 - 1 k Ω ought to do for this circuit). Measure the output signal voltage again, v_{o2}. If v_{o2} is not significantly lower than v_{o1}, use a bigger R_x.

Now: $$\frac{v_{01} - v_{02}}{v_{01}} = \frac{R_x}{R_s + R_x + R_{in}}$$

Solve this for R_{in}. (Remember that R_s is about 48 Ω for the attenuator.) Leave R_x in.

Calculate R_{in}: Assuming a reasonable β and using the r_e you found from the gain measurement, calculate the expected input resistance and compare. Note: you can make this and most other calculations later, if you want.

Effect of C_E on R_{in}: Use the scope to observe the input signal on the transistor side of R_x (v_{in} or v_b). Remove the bypass capacitor (C_E) and look at what happens to that input voltage. What happened to the input resistance when you removed C_E? What does the bypass capacitor do to the input resistance?

Output resistance R_O: Undo any changes to your circuit so it's back to that shown at the beginning of experiment 2, except still without R_L. Measure the open-circuit output signal voltage (v_o). Add a 1 kΩ load resistor (R_L) and measure the output signal voltage again. Use these two measurements to calculate the output resistance of this amplifier (think Thévenin again).

Alternatively, you could add a potentiometer or the resistor decade box instead of a fixed load resistor, and adjust the load until the output voltage is halved. The value of the load would then be equal to R_O.

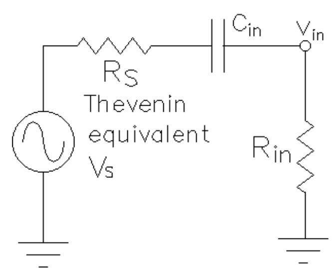
What is your theoretically expected output resistance? (Theoretically, $R_O \approx R_C$). Compare your measured R_O to your expected R_O . Remove the load.

Probe Compensation

Remember to compensate your 10x probes before using them to make frequency dependant measurements. This can actually become an issue in this lab.

Frequency response: For an amplifier like this, three points will adequately define the frequency response curve; the low corner frequency (f_{CL}), the midband gain, and the high corner frequency (f_{CH}). You've already measured the midband gain, so all you've got to do is vary the input frequency to find the low and high corner frequencies of the output signal. (Make sure the scope is set to DC coupling or it may effect the low frequency measurement).

Calculate frequency response: Calculate the corner frequency due to the input coupling capacitor (C_{in}). Look at the model showing the source, C_{in} and R_{in}. Use the R_{in} that you just measured and remember that R_S is about 48 Ω for the attenuator.. Is this a high-pass or a low-pass filter? Now think back to Bode plots and calculate the corner frequency of this circuit.



Calculate the corner frequency due to the emitter bypass capacitor (C_E). Roughly, this will be the frequency at which the impedance of the capacitor is equal to r_e. (Note: this approximation only works in this circuit because R_S is so small.) Use the r_e you found from the gain measurement.

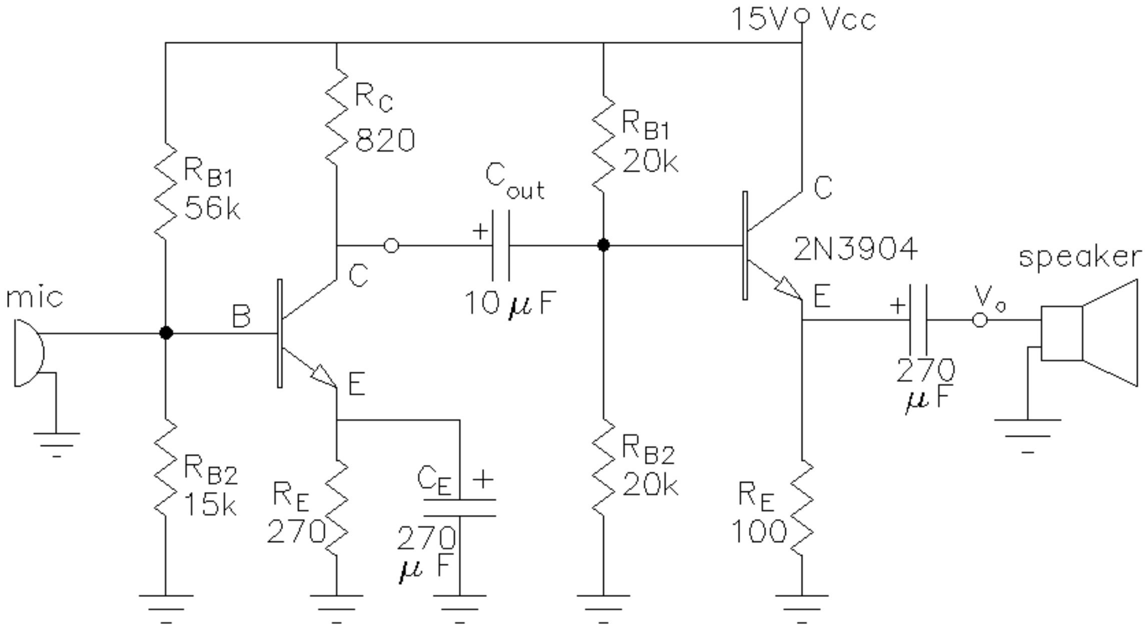
Unless the two corner frequencies are very close, the actual corner frequency will be the highest of the two. The highest f_{CL} dominates to become f_{CL} for the amplifier and is called the dominant low-frequency pole. Compare to your measured f_{CL}. Calculating f_{CH} is beyond the scope of this lab. You'll learn how to do that later.

Copy R_{in}, f_{CL}, and f_{CH} measurements and calculations on a separate paper for use with SPICE project #S2.

Extra: (2 pts) If the circuit had a load resistor (R_L), how would you find the corner frequency due to C_{out}? Use the R_O that you found earlier and the C_{out} that you have in your circuit and find the value of R_L (if any) would make the corner frequency due to C_{out} dominant? (If your calculation says that R_L would have to be negative, then C_{out} is so big that no available (+) value of R_L will make this the dominant corner frequency.)

Experiment 3, 2 Stage Amplifier (5 to 15 pts.)

Put your two circuits together to get the circuit shown below.



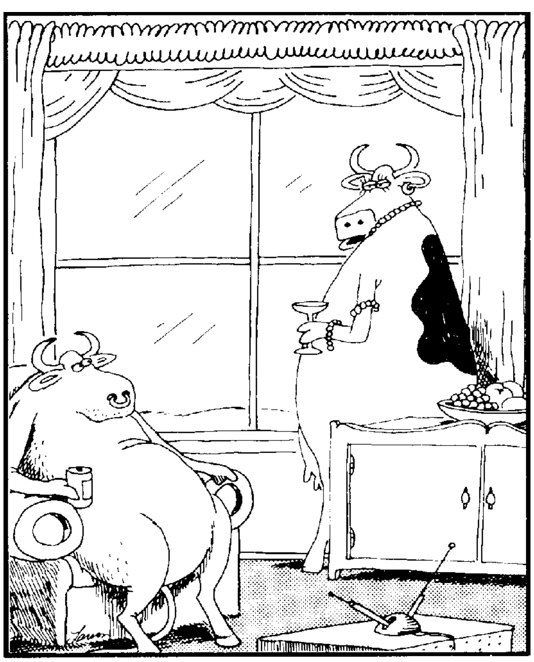
Test this circuit as you see fit. The more you do, the more points you'll get.

Main points of this lab:

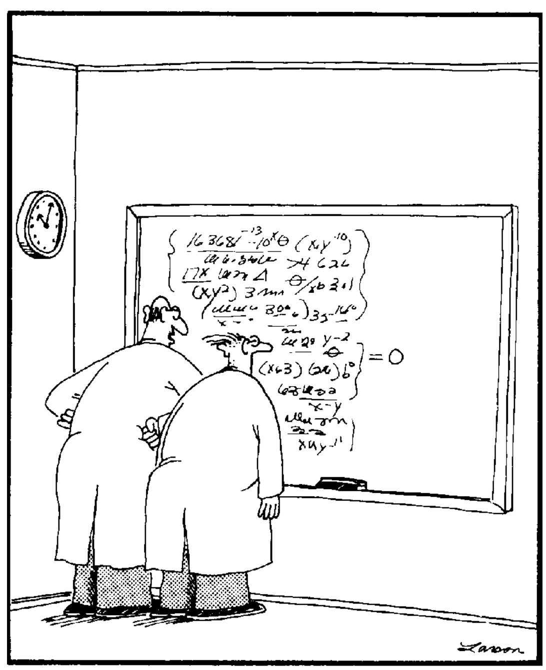
1) If R_E is bypassed gain goes up but so does distortion.
2) The bypass capacitor lowers the Input impedance.
3) Each capacitor in the circuit may be the cause of the low corner frequency.

Conclusion

As always, check off & conclude. Note: The common-emitter circuit will be used again in the next lab, so you may not want to tear it apart.



"Wendell . . . I'm not content."



"No doubt about it, Ellington—we've mathematically expressed the purpose of the universe. Gad, how I love the thrill of scientific discovery!"