UNIVERSITY OF UTAH
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

ECE 3110 LABORATORY EXPERIMENT NO. 2

AMPLIFIER FREQUENCY RESPONSE

Objectives

This experiment will demonstrate the frequency and time domain response of a single-stage common emitter BJT amplifier. The measured data will be compared to SPICE simulations from SPICE assignment #1. To save a lot of time and possible frustration, read the section you are working on entirely before performing any measurements. There are often important hints or subtleties in following paragraphs.

Experiment

Build the amplifier shown in Fig. 1. You may use standard value components that are within 10% of the specified values, **but be sure to measure and record the actual values.**

During this experiment, you will be making measurements at frequencies in the 10 MHz range. At these higher frequencies, the parasitic capacitance of your breadboard, wires, and terminals of your discrete components can cause additional poles to appear in your circuit's measured transfer function. To minimize this effect, use the shortest possible wires and clip the terminal wires of your components to be as short as possible. Also, be sure the polarized electrolytic capacitors are connected with the proper polarity. NOTE: A common mistake in wiring this circuit is to get the emitter and collector reversed, so make sure you look at the data sheet.

R_1 = 45 KΩ
R_2 = 85 KΩ
R_C = 4.7 KΩ
R_E = 3.0 KΩ
R_L = 4.7 KΩ
C_B = 1 μF
C_C = 1 μF
C_E = 10 μF
Q = 2N3904

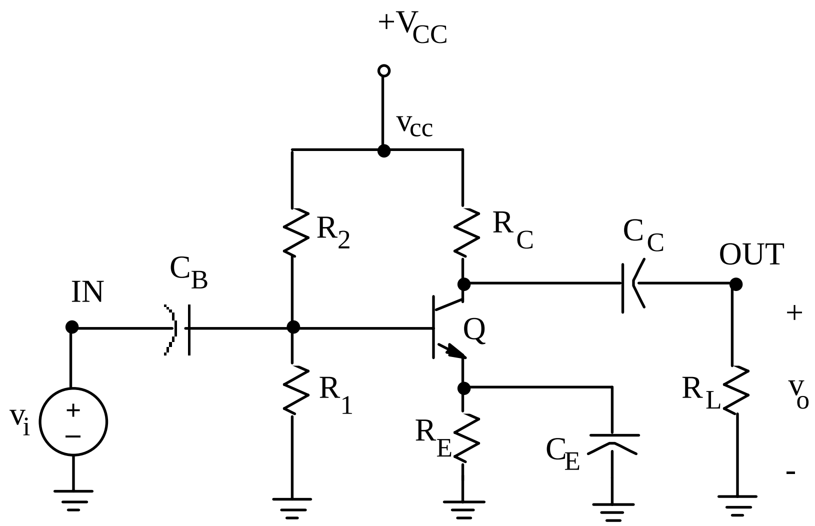

Fig. 1. Single stage bipolar voltage amplifier.

1. Calculate the expected DC voltages at all nodes of the circuit assuming a +10V power supply (ignore the base current also). With no AC signal applied to the circuit, set the DC supply to +10V. Measure and record the DC voltage at all nodes. Compare these measurements with calculations. Before proceeding, be sure that calculations and measurements are in reasonable agreement (to make sure the transistor is inserted properly).

2. Apply a small (less than 0.01-volt peak-to-peak) sinusoidal voltage to the input at a frequency of about 10 kHz. Use the bench-mounted signal generator with a voltage divider using a 1 kΩ and a 51Ω resistor to attenuate the signal generator output by a factor of approximately 20. **Use a 10X scope probe to avoid unnecessary loading of the amplifier output.** Observe the amplifier output and, if necessary, reduce the magnitude of the input until the output shows no distortion. Measure and record this input signal amplitude. Don't forget to take this voltage divider into account when calculating the gain.

   To get an idea of the overall transfer function, do a quick frequency sweep to locate approximately both the upper and lower corner frequencies of the amplifier gain (where the midband gain drops by 3 dB). Note the approximate corner frequencies.

Now, starting at a frequency two decades below the low corner frequency (f_L/100), measure the gain and the phase. **Adjust the phase response so that you have zero phase in the amplifier passband.** (This is necessary because a phase shift of 180 degrees and a negative sign in the gain are equivalent.)

Repeat the same measurements for the rest of the frequency range, up to around 20MHz. Take enough data so the measurements can be plotted and compared with SPICE results.

Keep in mind that Bode plots have logarithmic axes. In other words don't waste your time taking a lot of measurements, the points can be relatively spread out in frequency. Make sure you get many points near the corner frequencies though, since this is where you want to be the most accurate.

Another phase measurement issue is when the measurements are plotted and there are 180-degree discontinuities in the measurements. Don't worry, this is fairly normal. All this means is that the phase was measured relative to a different period. To fix this in MATLAB, use the `unwrap` function on your phase data, or adjust it manually. Make sure to look at the help file to get the syntax right. Keep in mind that unwrap works on data in *radians*, not degrees, so you will have to do a couple of conversions.

3. Now replace the 10X scope probe with a short section of co-ax cable. (Note that standard coax cable has a capacitance of around 30 pF/foot.) Repeat the gain and phase measurements over the same frequency range as above. Do you notice a difference in the corner frequencies? What was the difference and what do you think caused it?

5. Measure the input impedance of the amplifier at about 10 kHz using the circuit shown in Fig. 2. This circuit has a 1-kΩ resistor inserted between the signal source and the input. Set the input voltage to a value that produces no distortion

in the output (you will probably need the attenuator again). Carefully measure and record V_1 and V_2 and the value of R, but make sure to use two probes for this. One probe will measure V_1 relative to ground, and the second will measure V_2 relative to ground. If you connect one probe directly across the resistor you short out the scope and may blow a fuse and possibly destroy your circuit as well. This is because the negative input of the scope probe is connected to *earth ground*. You can also use a multimeter in AC mode to measure the RMS voltage, but only do this if the other measurement is too noisy. From the measurements, calculate the value of R_{in}. Measurements of V_1 and V_2 must be as accurate as possible because both values will be only a few millivolts.

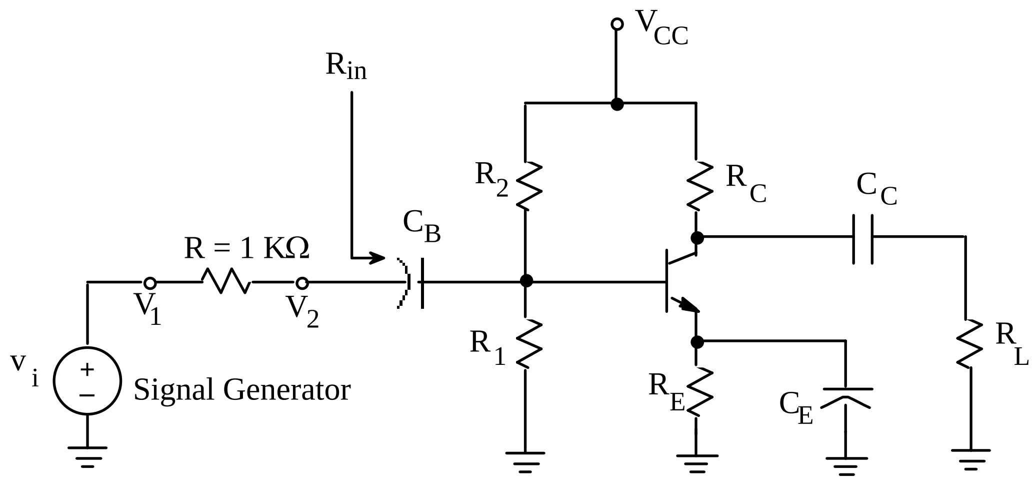

Fig. 2. Input impedance measurement.

6. Measure the response of this amplifier to a square-wave input. Because the amplifier gain is dependent on frequency, an input square wave will not result in a perfect square wave at the output. For a discussion of the shape of the output pulse, see Appendix D, pp. 12-15. First use a low-amplitude, high frequency square wave on the input. The amplitude of the input should be about 0.01 volt. Measure the rise time (see Fig. D-13 in the book) and fall time (which should be very close to the rise time). Now decrease the frequency of the square wave by several orders of magnitude and measure the "percentage sag" (see Fig. D-14 in the book). The cursors feature of the scope make these measurements easier.

Report

1. Calculate the mid-band gain of the amplifier A_M, the input impedance R_{in}, and the lowest corner frequency (use equations developed in the textbook). Using the simulated results from SPICE assignment #1, make a table that compares the mid-band gain, input resistance, and lowest corner frequency. How do they compare? Why are they different?

2. Compare, in table form, your simulated DC node voltages, measured DC node voltages, and the values calculated by hand. How do they compare? Why are they different?

3. Prepare a Bode plot of magnitude and phase both measured data with the 10x probe and measured data with the coax cable on the same set of axes using MATLAB.

   Make sure the phase starts at zero, and use *unwrap* on the phase if there are any 180-degree jumps in the measured data. Also, don't plot the measurements as a continuous line, use a * and ^ to plot the measured points (i.e. *plot(x,y,'*-')*).

   How do the plots compare with the simulated SPICE results? What causes the simulated to vary from the measured? Which type of probe is better for measurements? Is the SPICE model accurate?

4. Compute the upper and lower corner frequencies, i.e. the 3-dB frequencies, of your amplifier from your low-amplitude square-wave measurements. Compare these values with those obtained from your transfer function measurements. Refer to Appendix D in the text for the relationship between corner frequencies and time constants.