**Signature**

**Name (print, please)**

**Lab section #**

**Lab partner’s name (if any)**

**Date(s) lab was performed**

**ECE 3155**

**Experiment I**

**AC Circuits and Bode Plots**

Revised dps jan 2025

In this lab we will demonstrate basic principles of simple time-dependent passive circuits. Toward that goal, we will test theoretical circuit solutions by making measurements of the response of RC circuits. Specifically, square wave inputs will be used to illustrate the time domain response, and sinusoidal inputs to illustrate frequency domain response. Try to understand not only how these circuits work, but why they work the way they do. In particular, think about the frequency response of capacitors in part B.

We will be generating Bode plots as part of the lab. There are three major reasons why Bode plots are so widespread in Electrical Engineering. First, they are useful because the Bode plots represent, in graphical form, all the information needed to be able to predict the response of a circuit to any input, since Fourier’s Theorem tells us that any signal can be thought of as a sum of sinusoidal components. Second, because of the mathematics behind linear circuit responses, Bode plots are remarkably easy to approximate. Third, since they are primarily plots on logarithmic scales, they present information in a way that is proportional to its importance. In this lab, we will produce Bode plots for two circuits to become familiar with their forms.

***Notes on Reporting Results***

In this lab you will be making several plots. Be sure your plots are neat and large enough to be read easily. In addition, be sure that axes are clearly labeled and that they include units and “tick marks” spaced appropriately. You may use appropriate semilog graph paper and make your plots by hand, or you may produce plots from your measurements with a computer graphing program. For example, Microsoft Excel can be used to produce the plots. On the web site for the course (<https://courses.egr.uh.edu/ECE/ECE3355/ECE3155_Materials/>), you will find an Excel spreadsheet that can be used to print out semilog graph paper. In addition, you will probably be able to find several free applications on the web for this purpose.

***Notes on the Lab Equipment***

You will find that your Bode Plot magnitude measurements go much more quickly if you make good use of the multimeter. The digital multimeter has a “relative” measurement feature that allows all measurements to be made relative to one initial measurement. This can be done on a dB scale as well. The procedure for the use of this technique can be found in the multimeter manuals, which are available from the lab TAs, or on the web at <https://www.keysight.com/us/en/assets/9018-05456/user-manuals/9018-05456.pdf>.

**Components Required**

2.7[k] resistor (1) – used for both Circuit 1 and Circuit 2

470[] resistor (1)

0.033[F] capacitor (1)

0.1[F] capacitor (1) – used for both Circuit 1 and Circuit 2

741 op amp (1)

**Procedure**

**Part A: Time Domain Analysis**

1. Build the circuit shown in Figure 1 on your prototyping board. Apply a 250[Hz] square wave, going from 0[V] to 5[V], to the input, *vIN(t)*. You will need to use the “Offset” capability of your signal generator. Use the oscilloscope to determine that the signal source is set appropriately to produce this waveform. Using one probe to monitor the input and another to monitor the output, sketch the waveforms *vIN(t)* and *vOUT(t)* on graph paper. Line up the two plots so that they have same ordinate (vertical axis). In other words, the two plots should be aligned vertically so that the relationship between input and output is clear. As always, show units on all scales.



**Figure 1 – Circuit 1.**

2. Measure the time constant for the case where the input makes a transition from 0[V] to 5[V], and again for a transition from 5[V] to 0[V]. Calculate the time constants that would be expected. Use the nominal values of your components. Are the results reasonable? Explain.

**Part B: Frequency Domain Analysis**

1. Calculate the transfer function *T()* or *H()* for Circuit 1. Use impedances for all components, and solve for the complex ratio of the output phasor voltage to the input phasor voltage; this complex ratio is called the transfer function. Then, find *T(**f)* or *H(f),* using the relationship *w* = 2p*f*. Record the results below.

2. Using the sinusoidal signal source at 5[Vpp] (or any other convenient voltage), measure the frequency response of your circuit from 10[Hz] to 100[kHz]. The frequency response is made up of two parts; the gain, or magnitude response, and the phase response, which is the phase shift between the output and input sinusoids. Pick several frequencies, and plot the magnitude and the phase of the frequency response as a function of log(*f*). Plot the magnitude in deciBels(dB). Plot the phase as a linear function, but again as a function of log(*f*). These two plots are the magnitude and phase Bode plots for the circuit.

When you pick the frequencies to measure, pick several in each decade, and a couple of extra points near to where the magnitude response is varying rapidly. Typically, for the magnitude plot this occurs near the breakpoints of the response, i.e. where the slope of the magnitude plot changes. The breakpoint frequency is often called the 3[dB] frequency for reasons that will not be discussed here. For the purposes of this experiment, we will define a breakpoint frequency as the point of change of slope in the magnitude Bode plot.

3. On the same Bode plots you constructed from your measurements, plot the transfer function that you calculated in part 1. You may use either the exact values, or use the straight-line approximations. Compare the Bode plots you measured and theoretical Bode plots. Do the locations of the breakpoints on the magnitude plots agree? Does the phase plot run as expected? They should be close, within the tolerances of your components and equipment. Explain any significant differences, or repeat measurements where significant deviations occur. *Be careful to plot the frequency response as a function of log(f)*. In general, a Bode plot can be made either as a function of *f* or *w*, but using log(*f*) facilities the comparison with the measured transfer function.

4. The slope of the magnitude plot, where it is increasing at a constant rate, should be 20[dB/dec] for circuits such as the one in Figure 1. Measure the slope at this point and state its value below.

5. Compare the breakpoint angular frequency from your Bode plot, expressed in [radians/sec], with the inverse of the time constant that you measured and calculated in Part 2. Discuss your results.

6. Repeat steps 1 through 5 for the circuit shown in Figure 2. Note that this is not a single time constant circuit. This circuit incorporates a 741 op amp used in the follower configuration to obtain two distinct and relatively easy to calculate breakpoint frequencies. Use the equivalent circuit in Figure 2 for your calculations, and use Figure 3 to assist in hooking up the circuit. It is not necessary for you to know anything about the op amp to do this lab. Report your results on a separate page.



**Figure 2** – Circuit 2. This second circuit uses a 741 op amp. Connect the pins as shown, with a wire connecting pins 2 and 6. Connect pin 4 to -15[V], and pin 7 to +15[V]. The pin numbering scheme is shown in Figure 3. No direct connection from the op amp to ground is needed.



**Figure 3** Pin Numbering Scheme for 741 Op Amp viewed from the top of the chip. The little circle, or the indented section, whichever is present, indicates the location of pin 1.

**Questions**

1. Is Circuit 1 high pass, a low pass, or a band pass filter?
2. For Circuit 1 with the square wave input as you used in Part A, what was the peak-to-peak voltage at the input? What was the peak-to-peak voltage at the output? Do these results mean that this circuit is an amplifier?
3. Is Circuit 2 a high pass, a low pass, or a band pass filter?
4. In Circuit 2 we expect two breakpoint frequencies. How do these breakpoint frequencies relate to the values of the components in the circuit?
5. How would the output of Circuit 2 have been different if the op amp had not been used? In other words, if the op amp had been replaced by a wire connecting pin 3 to pin 6, how would your response have been different? This question involves some fairly complicated mathematics, and so will be considered as a Bonus question in the grading.

**To the Student: We are no longer using Pre-laboratory exercises as a tool for guiding student work. This page is left here, in case a return to pre-laboratory exercises is considered. You may ignore this page.**

**Pre-Lab**

The Pre-Lab should be done before you get to the lab. Turn it in to your ECE 3355 instructor on the due date indicated for the pre-lab in the class schedule. If you use separate sheets of paper to do this work, attach it to the end of this lab handout.

1. Part B.1: Calculate the transfer function for the circuit of Figure 1.

2. Part B.3: Plot the transfer function for the circuit of Figure 1. Use the actual function for your plot, not the straight-line approximation. Use appropriate log paper for this. You will be plotting measured values on the same graph when you get to the lab.

3. Part B.6: Calculate and plot the transfer function for the circuit of Figure 2, as you did for Figure 1.