UNIVERSITY OF UTAH
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 2280

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1/08

Lab #1 {50 pts. Total}   Exploring Signals and Bode Plots

OBJECTIVES:

- Reacquaint yourself with the laboratory equipment and procedures.
- Compare experimental and derived Bode Plots.
- Understand Bode plots.

PARTS LIST:

- ❑ Wire kit
- ❑ 100k Ω resistor
- ❑ 500pF capacitor

PRE-LAB: (15 pts)

Procedure:

1. (3 pts) Derive the transfer function, Vo/Vs, for the circuit in **Fig. 1**.

2. (5 pts) Calculate and draw the Bode plots using the technique learned in class for the circuit in **Fig. 1**. (Use Semi-log graph paper.)

3. (5 pts) Use Matlab to plot the Bode plots. Print out both the magnitude and the phase plots. Example Matlab code can be found on the class website.

4. (2 pts) Mark the -3dB point on the Bode plots. This indicates the "break frequency". Above the "break frequency", the circuit does not work as expected. The "break frequency" can also be viewed as the bandwidth of the circuit.

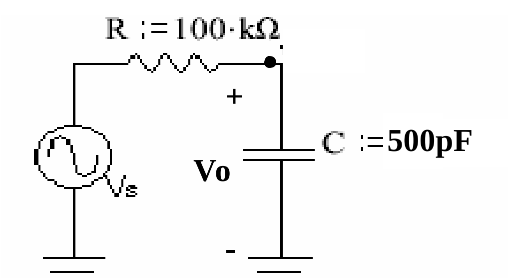


Fig. 1

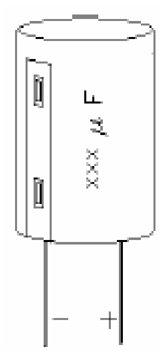
BACKGROUND INFORMATION:

Known capacitor and oscilloscope (o-scope) measurement issues are discussed.

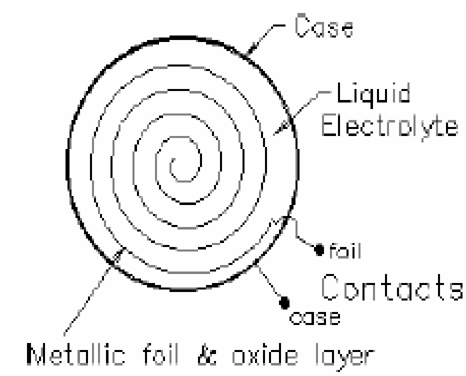
Capacitors:

CAPACITORS

Most small capacitors are marked with numbers and a letter like 104 (10 x 10^4 pF = 0.1 µF ±10%) or 471 (47 x 10^1 pF ±20%), These numbers are read like the bands on a resistor—two digits and a multiplier and indicate pico-farads. The letter indicates the part tolerance (how close should the actual value be to the marking).



Capacitors with values greater than 1 µF are usually constructed by immersing a roll of metal foil in a conducting liquid. A conducting liquid is called an electrolyte and these type of capacitors are called electrolytic capacitors. The foil is one plate and the liquid is the other. The dielectric is a very thin layer of oxide formed on the foil. Because the oxide layer is so thin, electrolytic capacitors can have very large values in relatively small packages.



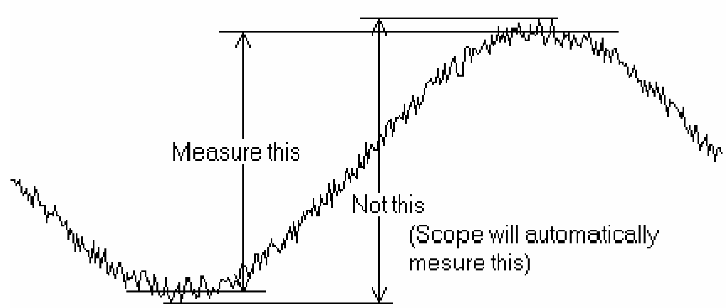
Unfortunately, the oxide dielectric also gives them some other, less desirable, characteristics. Most electrolytic capacitors can only be charged in one polarity. Voltage of the wrong polarity can damage the oxide layer and sometimes even cause the capacitor to explode. (I can personally vouch for this.) They are difficult to manufacture accurately and their actual value may differ from their claimed value by as much as a factor of two (-50%, +100%). The oxide is not the best of insulators so they can have significant leakage current. Finally, the oxide layer is so thin that electrolytic capacitors have relatively low voltage ratings.

HP/AGILENT FUNCTION GENERATOR WEIRDNESS

The designers of the HP/Agilent function generator assumed that you would always hook the output up to exactly a 50 Ω load, something that is practically never done. If you do hook it up to a 50Ω load, then you'll match the output impedance and the function generator will show the correct output voltage. Use any other load and it will read only half of the actual output voltage.

It's best just to learn to live with this little HP/Agilent annoyance. This is a good time to point out the difference between good and bad engineering design. Good design always considers the end user and how that end user will actually use the device or service. Bad engineering conforms to some internal standard of correctness with no regard for the real world. You be the judge of the case pointed out here.

Taking measurements using the oscilloscope:



Make sure that you are not measuring noise (see the graph). If you let the o-scope "quick measure" the peak-to-peak voltage it will show the difference between highest noise peak on the highest peak of your waveform and the lowest noise peak on the lowest peak of your waveform. That is not a very accurate measurement of the size of your waveform. A better way to measure is using the manual cursors from the average of the top fuzz to the average of the bottom fuzz. That is, try your best to measure the signal voltage as though the noise was not present.

If you want the o-scope voltage measurements to make sense, be sure to let the o-scope know that our probes are both 1x (Hit A1 and use the rightmost button under the screen; repeat for A2). It will not detect the probe automatically.

> **Noise problems:**
> Turn the BW limit "on" for each of the analog channels (A1 and A2). This limits the bandwidth of the scope somewhat, cleans up the signal, and will not seriously affect our measurements. Also, trigger the scope off Vout rather than Vin and do whatever is needed to make the signal stable (Reject HF, Noise Reject, etc. under Mode /Coupling).

Finally, be on the lookout for bad probes— I found several, but not before wasting quite a bit of time wondering why all I could get on the scope was noise. Noise can be a problem with these scopes, especially with all the computers in close proximity. The noise will usually manifest itself as a high frequency fuzz that "rides" your signal waveform.

<u>EXPERIMENT 1 Bode Plots:</u> (35 pts)

Procedure:

1. Connect the circuit in Fig. 1 (page 1) on your protoboard. As discussed in class, as the frequency changes, the output value (or response) of a circuit may change. To create the Bode magnitude plot, watch the output as you change the frequency. The Bode magnitude plot can be created using a brute-force method or an advanced, clever way. The brute-force method will be fully explained in **step 3**.

2. To facilitate utilizing the brute-force method, make a table with about 17 rows and 4 columns. Label the columns: frequency (Hz), Vin(Vpp), Vo (Vpp) and Vo/Vin(dB).

- To convert Vo/Vin to dB use **Formula 1.0**.

Formula 1.0 $20\log_{10}(Vo/Vin)$ Conversion of Vo/Vin to dB (decibels)

(2a) Record your measurements. Your table should look something like **Table 1.**

Table 1

f (Hz)	Vin (vpp)	Vo (vpp)	Vo/Vin (dB)
50			
100			
200			
500			
1k			
2k			
5k			
10k			

3. **(**10 pts) The brute-force way to experimentally create a Bode magnitude plot is to apply an input voltage at a certain frequency and measure the output voltage.

(3a) Record the frequency, input voltage, and output voltage in your table.

(**3b)** Repeat this procedure for 50 Hz, 100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, 10 kHz, and so on until it is too hard to read the output voltage.

(3c) Plot the results of the transfer function (dB) vs frequency. (Use a log scale for the frequency. If you do not have log paper, equally space the frequencies from **step (3b)** above along the x-axis. (This will work as an approximate log scale.)

4. (8 pts) Having done the brute-force way once, I am sure you will never want to do it again. Now let's try a more clever way.

(4a) First, scan through a large range of frequencies while keeping an eye on the input and output waveforms. Form a mental picture of the approximate frequency response curve– flat out to some frequency and then down (low pass filter).

The important features for the circuit in **Fig. 1** are:

- low-frequency value in the flat section
- "corner" frequency (f_C)
- downward slope

(4b) Take one measurement of each important feature listed above.

- Measure the low-frequency value like you did before (or just copy a representative measurement from the last set).

(4c) Calculate the output voltage that you will see at f_C (0.707 times the low-frequency value). This is known as the -3 dB point (calculate 20log10(0.707) to see why).

(4d) Turn up the frequency until you see that value. Assuming that the input signal stays constant at all frequencies, that will be where the output voltage drops to about 71% of its low-frequency value. Record the frequency as f_C.

(4e) Now measure the value at about 2 times f_C and again at 4 times f_C to confirm that the value decreases by about a factor of two for a two-fold increase in frequency (the gain is inversely proportional to the frequency). That is an -8 dB per octave or a 20 dB per decade slope. (An octave is a factor of two and a decade is a factor of ten).

With a little knowledge of Bode plots, you can very nearly duplicate the first frequency response curve with just these few measurements. That is the smart way to take a magnitude frequency response.

5. (10 pts.) You can also use the same clever method above to create the Bode phase plot. You will need to look at the same frequency pts as those determined in **step 4** above. Look at the *phase* change of the output compared to the input. You should see that the output phase stays the same compared to the input phase at the start. As you increase frequency, the output phase will start to shift compared to the input signal.

(5a) Measure these changes and plot the values. The o-scopes do not measure phase directly, so first measure a change in time, Δt. The phase (degrees) can be found by **Formula 2.0**

Formula 2.0 $\Delta t / T = q / 360^{\circ}$ where T is the time period, 2 is the phase (degrees)

6. (5 pts) Compare the measurements in **steps 4 and 5** with your hand calculations and the Matlab printout for both phase and magnitude. Note the differences between your hand drawn Bode plots and the Matlab Bode plots.

7. (2 pts) Why is it important to understand where the -3dB (break frequency) point on the graph is located for magnitude?

8. Write a short conclusion. The conclusion should be a line or two. State your observations and conclusions.

9. Call your Lab TA over for check-off. Be prepared to discuss your measurements, calculations, and conclusions and to show your notebook.

10. **(Optional)** Perform any other experiments you think would help you understand Bode plots and/or signals.