Laboratory #7

Frequency Response of First and Second Order Passive Circuits.

I. Pre-Laboratory Assignments

1. Copy and paste this entire laboratory assignment into your laboratory notebook. Do all of your pre-lab and laboratory work in your lab book in ink. Do not bring any loose paper to the lab.

2. Three circuits will be analyzed to determine their frequency response. These are shown in Figs. 1-3 below. To begin, the transfer function of each circuit will be calculated and used to plot both the magnitude and phase versus frequency on a Bode plot by hand, and then using Matlab. These calculations will be compared to the frequency response of the circuit simulated by a circuit simulation program.

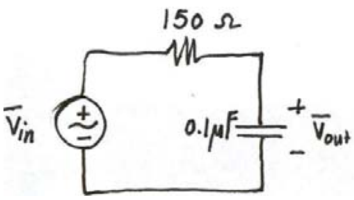


Fig. 1

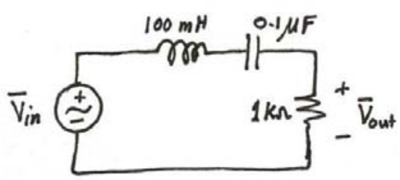


Fig. 2

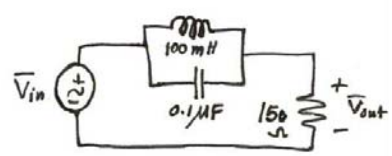


Fig. 3

3. For each of the circuits above, perform the following:
   a. Based on the layout of the circuit and the frequency dependent impedances of some of the circuit elements, describe what you think the frequency response will be and why.
   b. Determine the transfer function for the circuit $\mathbf{H}(\omega)=|\mathbf{V}_{out}/\mathbf{V}_{in}|$ in the form of $\mathbf{N}(\omega)/\mathbf{D}(\omega)$, where $\mathbf{N}(\omega)$ and $\mathbf{D}(\omega)$ are polynomials in ω.
   c. Construct the approximate Bode magnitude and phase plots for $\mathbf{H}(\omega)$ by hand.
   d. Construct the Bode magnitude and phase plots for $\mathbf{H}(s)$**,** where $s=j\omega$, using Matlab (see below for more information).
   e. Construct the exact magnitude and phase vs. frequency plots for $\mathbf{H}(f)$ using a circuit simulation program.
   f. Determine the cutoff frequency (f_c) for the circuit of Fig.1, and the resonance frequencies (f_0) for the circuits of Figs. 2 and 3 for parts 3.c, 3.d, and 3.e. Compare the results obtained from each of these three methods.

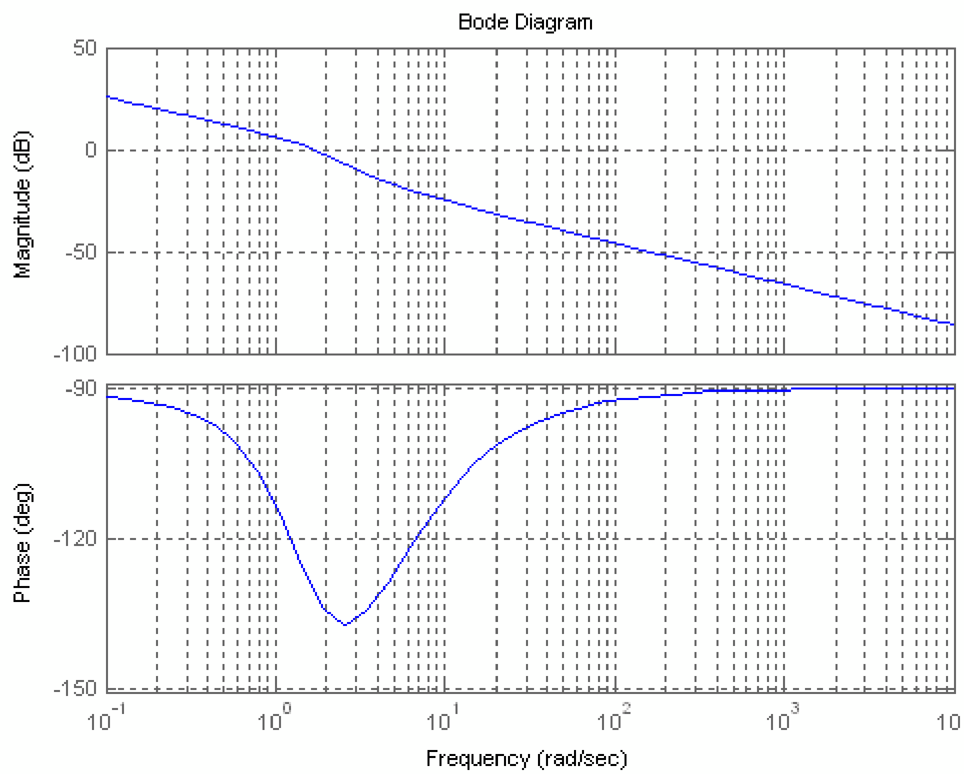
Quick Bode plots using MATLAB: Matlab can be used to quickly plot the magnitude and phase versus frequency for a transfer function using the built in command **bode**. To do so, this transfer function must be in the form of a ratio of polynomials. Take, for example, this transfer function

$$\mathbf{H}(s)=\frac{s^2+6s+8}{2s^3+4s^2+4s}$$

In terms of the Matlab **bode** command, the numerator vector is [1, 6, 8] while the denominator vector is [2, 4, 4, 0]. Note the 0 term at the end of the denominator vector. The Matlab **bode** command can be used to generate the Bode magnitude and phase plots for the given transfer function by typing its numerator and denominator vectors, as follows:

bode([1, 6, 8], [2, 4, 4, 0], {.1, 10000});
grid on;

where the frequency range is controlled by entering the minimum and maximum frequency values after the denominator vector. The Bode plots generated by Matlab for this specific **H**(s) are:



There are other ways to construct Bode plots in Matlab, or any mathematics package, of course. This just illustrates the use of the **bode** command in Matlab.

II. Laboratory Experiments

All three of the circuits in Figs. 1-3 above will be constructed in the lab using the peg board and associated components located in the center drawer of your lab station, plus the large toroidal inductor used in previous labs.

For each of the circuits shown above in Figs. 1-3, perform the following:

1. Setup the circuit using the function generator as your sinusoidal input (10 V_{pp}) with zero average value and measure the input voltage $v_{in}(t)$ using channel 1 of the oscilloscope and measure the output voltage $v_{out}(t)$ using channel 2.

2. Vary the frequency of the input voltage from at least two decades below the cutoff or resonance frequency to at least two decades above. Measure the input and output voltage amplitudes at many frequency points. Record a sufficient number of strategically located data points so that you can construct a meaningful and well established amplitude versus frequency plot on a semi-log scale. You will probably need to record more data points near the cutoff or resonance frequency.

3. Make a table listing the frequency in Hz, input voltage amplitude, output voltage amplitude, and the transfer function magnitude $H(f) \equiv \left| \mathbf{V}_{\text{out}}(f) / \mathbf{V}_{\text{in}}(f) \right|$ as a linear ratio and also in dB.

4. Accurately plot the $H(f)$ versus frequency response using a computer plotting package.

5. What is the measured cutoff or resonance frequency, as appropriate for the circuit?

6. Lastly, you'll use the frequency sweep capabilities of the function generator to quickly gauge the frequency response of this last circuit shown in Fig. 3. Keeping the same connections of the function generator and oscilloscope described in part 1 of the lab, now set the function to perform a frequency sweep of a sinusoidal input voltage. Keeping a sinusoidal waveform with 10 V_{pp}, now press the Sweep button on the function generator, select Log, select Start frequency of 200 Hz, a Stop frequency of 5,000 Hz, and Time (to sweep) of 1s. Appropriately change the time scale so that the screen captures approximately one complete sweep of this change in input frequency. The output voltage amplitude changes as the input voltage frequency changes, as expected. Take a screen capture of this response.

III. Analysis and Conclusions

a) Compare the results of your hand analysis in the preliminary and your data from simulations. Create a table to organize your data comparisons.
b) Explain notable differences.
c) Do these circuit simulation Bode plots in pre-lab part 3.e match the approximate Bode plots found in parts 3.c and 3.d? State your explanations very clearly and concisely.
d) Explain very clearly and concisely why the input voltage amplitude in lab part 2 varied with frequency.
e) Describe why the output voltage envelope measured in part 6 of the lab is a rough gauge of the frequency response of the circuit. Of particular importance in this previous sentence is why the "envelope" is important and why this is only an approximation.
f) When you are finished with your lab, make a photocopy of all the right side pages and print them out. Turn in your lab at the beginning of lecture on the due date. If you don't have easy

access to a photocopier machine, the app GeniusScan works with your smartphone and allows you to easily create a pdf that can be printed.

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† Portions of this lab were adapted from D. Anagnostou, “Lab Experiment – 7,” 2015. We would also like to acknowledge Mr. Sam Coffin for suggesting part 6 in the lab section.