ME 3300 Lab-09: Low Pass Filter Frequency Response

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Contents

1 Learning objective

The objectives of this experiment are to provide the student with an opportunity to:

- Design, build, and test an active inverting low-pass filter circuit using a generic operational amplifier chip
- Test the frequency response of the low-pass filter and compare to the theoretical equations.

2 Required Equipment

1. LM358AN Op-Amp
2. Powered breadboard
3. Digital Multi-meter
4. Wire kit and resistor kits
5. Screwdriver, pliers, wire stripper

3 Introduction

In this experiment, you will construct and test an active, inverting low-pass filter circuit. With the circuit complete and properly functioning, you will test the output from the circuit for various input frequencies using the function generator. At each test frequency, you will record the low-pass filter circuit's magnitude ratio and time delay. In your laboratory notebooks, draw the circuit for the experiment and record the steps involved for the experiment. Ensure you include all the details, as you will need them for the post-laboratory assignment. Figure 1 shows an active, inverting low-pass filter.

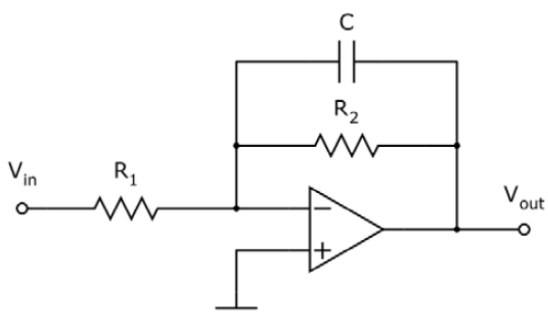

Figure 1: Schematic of an active inverting low-pass filter circuit

The magnitude ratio for a first-order system subjected to a simple period input is:

$$M(\omega) = \frac{B}{KA} = \frac{1}{\sqrt{1 + (\omega\tau)^2}}, \tag{1}$$

where τ is the time constant of your system(derived as R_2C). The phase shift is given by:

$$\phi(\omega) = \beta_1\omega = -tan^{-1}(\omega\tau), \tag{2}$$

where β_1 is the time delay in seconds. It is normal practice to design filters around -3dB ($M(\omega) = \frac{1}{\sqrt{2}}$ cutoff frequency, f_c, of the active low-pass filter circuit. In this experiment, we will use $R_1 = R_2 = 5M\Omega$ and $C = 0.05\mu F$:

$$f_c = \frac{1}{2\pi R_2 C} \tag{3}$$

4 Laboratory instruction

4.1 Part 1: Experimental circuit set up

1. Setup an active inverting low-pass filter circuit as shown in Fig. 1 with a gain of G=1 on the breadboard.
   - Use $R_1 = R_2 = 5M\Omega$ and $C = 0.05\mu F$.
   - Measure the resistances and capacitance with the digital multimeter.

- Reference figure 2 to create circuit.

2. Calculate and record the filter cut-off frequency.
3. Calculate and the record the actual static gain, K, of the system (Note: Your 2 resistors will not be exactly equal).
4. Reference the end of this document and the LM358 datasheet on how to connect the LM358 chip.
5. Use the powered breadboard to provide +15V and -15V to the chip at the V+ and GND pins (Note: the GND pin on the LM358 amplifier is not the signal ground), respectively.
6. The ground from the powered breadboard (or DC power supply) should be connected to both the input ground (from the DC power supply) and the output ground from the op-amp circuit (the GND pin on the LM358 amplifier is not the signal ground).
7. Construct your circuit on the breadboard in a neat and organized manner.

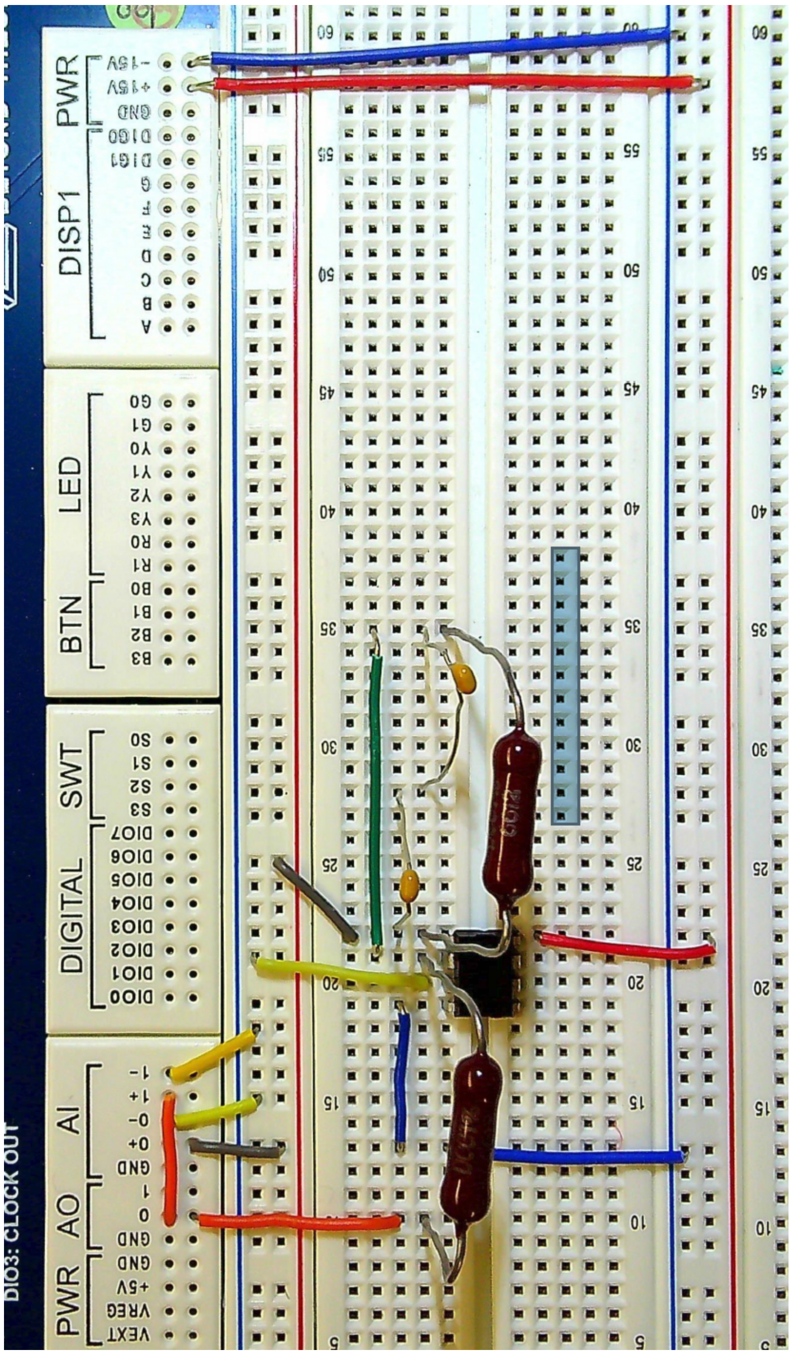

Figure 2: Active inverting low-pass circuit.

4.2 Part 2: Test the frequency response of the low pass filter

1. Connect the function generator to the input of the low-pass filter circuit and to the "AI0" of your data-acquisition.
2. Output from the low-pass filter circuit is connected to "AI1" of the DAQ.
3.
4. Set the function generator to these following settings:
   - Signal: Sine Wave
   - Offset: 2.5 VDC
   - Peak-to-Peak Voltage: 4 V
   - Frequency: 2000 mHz
5. Connect the input and output signal to oscilloscope and observe the behavior of the input and out put signal.
6. Make sure to observe 2-3 peak in the oscilloscope display.
7. Check this prior to collecting data through data acquisition device.
8. Collect the data for the following sine wave: frequency 2000 mHz, 2.5VDC offset and $4V_{pp}$. Make sure to capture 3-5 complete cycles by adjusting the time to acquire the data.
9. Save a data file using this naming convention: **XXmHz.csv** where
   - `XX` indicates the current frequency.
10. Collect the data for these following frequencies: 20, 40, 60, 80, 100, 200, 400, 600, 800, 1000, and 2000 mHz. Make sure to capture 3-5 complete cycles for each frequency. **Remember to save each data file as a different name!!**
11. NOTE: For 2000 mHz, ensure the input and output do not have the same input and output frequency.
12. NOTE: For lower frequency, if the DAQ times out before it finishes, check to see if you have enough peaks to get the peak-to-peak of the input and output. If not, redo the current frequency.

4.3 Part 3: Generate table for frequency response of the low pass filter)

1. Starting at a very low frequency data file (20 mHz), open the file and measure the following:
   - Peak-to-Peak Input Voltage (A). This is the difference between the maximum value of your input and the minimum value of your input.
   - Peak-to-Peak Output Voltage (B). This is the difference between the maximum value of your output and the minimum value of your output.
   - Period of the Input Signal. This will be used to calculate the input frequency. The signal period can be determined by measuring the time between two successive peaks of the input signal. You will need use the "Zoom" and "Data Cursor" tools in the figure in order to determine the location of consecutive peaks.
   - Time delay between input and output signals. This will used to calculate the phase lag between input and output signals. The time delay can be determined by measuring the time between the successive zero crossings of the input and output signals. You will need to use the "Zoom" tool in order to determine the location of each crossing.
2. Repeat step above for the remaining data files: 20, 40, 60, 80, 100, 200, 400, 600, 800, 1000, and 2000 mHz. Use Table 1 as a reference.
3. Evaluate your created plots and determine which additional data points(i.e. frequencies) to take to fill in your plots. Check with the lab proctor to see if you have enough data points.

Table 1: Response of the low pass filter at different frequencies.

Frequency (mHz)	Peak-to-Peak Voltage (A)	Peak-to-Peak Voltage (B)	Period of Input Signal (s)	Time Delay (s)	M(f)
10					
20					
40					
60					
80					
100					
200					
400					
600					
800					
1000					
2000					

4.4 Part 4: Plot Magnitude Ratio and Phase Shift response of the low pass filter)

1. Calculate the experimental magnitude ratio. The magnitude ratio can be determined by measuring the input the output voltages (A and B in Part 3) of each signal and knowing the static gain, K, of the system.
2. Plot magnitude ratio vs. frequency on a log-log graph using Matlab. Plot these on the same figure as the theoretical relationship (you will need to create the data using the theoretical equation). See Eq 1.
3. Plot phase lag (you will need to convert time delay to phase lag) vs. frequency on a semi-log graph using Matlab. Plot these on the same figure as the theoretical relationship(you will need to create the data using the theoretical equation). See Eq. 2
4. As needed, add additional data points in order to fill in the experimental vs. theoretical graphs for the Magnitude Ratio and Phase Lag plots. These will be the main outcome for your post laboratory assignment. Be sure to acquire enough data to be able to make strong statements about the relationship between theory and experimental results.

5 Post-Laboratory

For this experiment, submit the following items on Canvas for your post-laboratory assignment.

1. **Magnitude Ratio Plot.**
   - Submit a single figure with both theoretical and experimental magnitude ratio plotted vs. frequency using a log-log scale.
   - The plot should be 3.5” tall and 6.5” wide.
   - Properly annotate your plot: axis labels, title, legend, etc.
   - Include legend of all different sampling types.
     - Use title: “FirstName LastName’s Magitude Ratio Plot”.
   - Use Fig. 3 as a reference

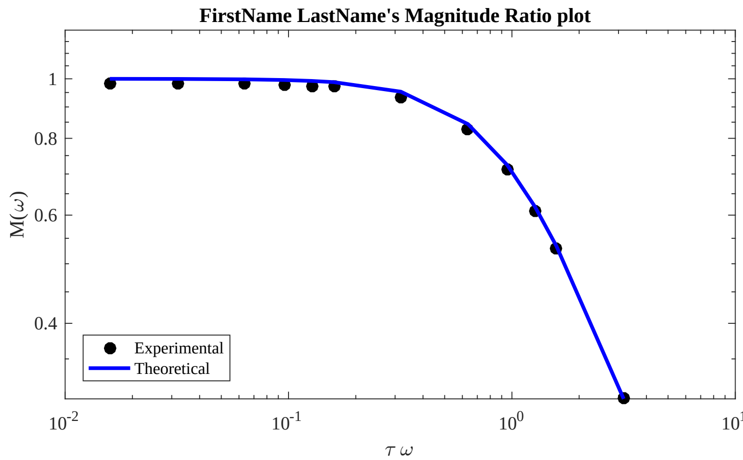

Figure 3: Sample magnitude ratio plot

2. **Phase Shift Ratio Plot.**
   - Submit a single figure with both theoretical and experimental phase lag plotted vs. frequency using a semi-log scale.
   - The plot should be 3.5" tall and 6.5" wide.
   - Properly annotate your plot: axis labels, title, legend, etc.
   - Include legend of all different sampling types.
     - Use title: "FirstName LastName's Phase Shift Plot".
   - Use Fig. 4 as a reference.

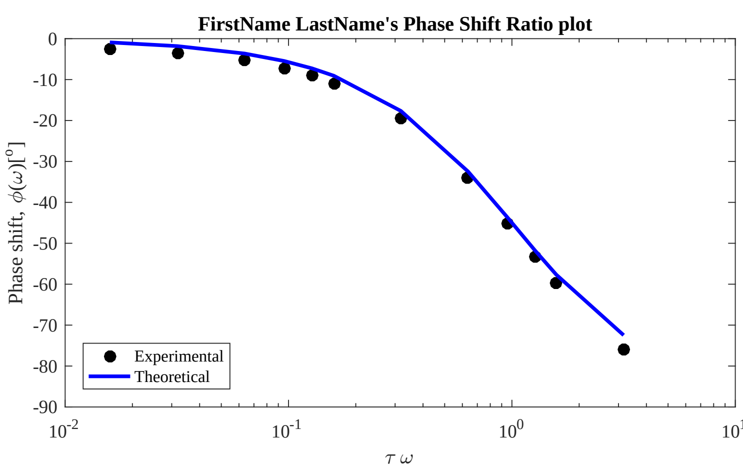

Figure 4: Sample phase lag plot

3. Answer all questions in the post-lab assessment on Canvas.