ECE 300 Lab 1: Frequency Response of a Filter

## Objective

This laboratory project has the following goals:

* To measure the frequency response of a simple passive audio filter,
* To determine the insertion loss of the filter,
* To compare the measured results with those predicted by calculation,
* To present the measured and predicted results graphically using MATLAB.

## Background

Figure 1 shows a function generator connected to a load resistor. The value of load resistance has been chosen for maximum power transfer. Also shown is a filter inserted between the generator and the load. The *insertion loss* of the filter is a measure of the power lost when the filter is inserted. Insertion loss is defined as the ratio of power that the generator can deliver directly to the matched load to the power that is delivered to the same load when the filter is inserted between the generator and the load.



Figure 1. Inserting a Filter

Insertion loss is usually expressed in decibels according to the formula



Referring to Fig. 1, a simple voltage divider shows that  when the filter is not present. Using

 ,

we can write the insertion loss as



Filters are usually designed so that the insertion loss is a function of frequency. A well-designed filter will provide a low insertion loss at frequencies in the passband of the filter, and a high insertion loss at frequencies in the stopband of the filter.

In this lab project we will investigate a passive fifth-order Butterworth lowpass filter designed for a passband bandwidth of about 3 kHz. Figure 2 shows a schematic diagram of the filter.



Figure 2. Schematic Diagram of the Orange Filter

These filters are called “orange” filters because they are built in orange boxes. Note that a  load resistor that matches the function generator’s  source resistance is included in the box. The load resistor can be engaged by a switch.

A straightforward but tedious circuit analysis shows that the system function  of the orange filter is given by



To find the insertion loss, substitute , find the magnitude as a funciton of , and convert to decibels as in Eq. . You can also find the phase response by substituting and computing the angle as a function of . (In this lab project it is convenient to use  rather than  because the function generator is calibrated in hertz.)

## Prelab

1. Using MATLAB, create a plot of insertion loss in dB vs. frequency in Hz. Use Eq. with and then Eq. to calculate insertion loss. Your plot should use a linear frequency scale from 0 to 4000 Hz. Plot your insertion loss as a smooth, continuous curve.

Hints:

* Use linspace or the colon operator to create a frequency array f containing enough points between 0 and 4000 Hz to produce a smooth insertion loss curve.
* MATLAB understands that .
* Use .\* for multiplication when you want to multiply arrays point by point. Similarly use ./ for division and .^ for exponentiation.
* Use abs in MATLAB to take the magnitude of a complex number. Use angle to compute the angle (in radians). Be sure to take the magnitude before you take the logarithm, or you will get surprising results.
* The command to take a logarithm to base 10 in MATLAB is log10.
* Use the xlabel and ylabel commands to label the axes. Use title to put a title on your graph.

1. Using MATLAB, create a plot of phase response in degrees vs. frequency in Hz. Use a linear scale for frequency from 0 to 4000 Hz. Use subplot to plot the insertion loss and phase response on the same page.
2. Suppose when no filter is present the load voltage is

.

Find the load voltage  when the filter is inserted. Show your work. Do not use Maple.

# Settings and Parts Used

Function Generator: Set Ch 1 to sine at 100 Hz

Other Equipment:

50 Ω coaxial terminating resistor

Orange filter

Memory stick to get data from scope

Laptop with MATLAB running

Coax: 1 BNC-BNC and 2 BNC to alligator

# Part 1: Preparation for Measurement

1. Record in the data memo the identification number of your filter. This number will come in handy if you have to return to the laboratory to gather additional data or to investigate suspicious results.
2. Place the 50 Ω coaxial terminating resistor directly across the output of the function generator. Measure the voltage across the resistor using the oscilloscope. Figure 3 is a schematic diagram of the terminating resistor. The voltage displayed on the oscilloscope will be  and its amplitude (i.e., peak value, *not* peak-to-peak value) will be  .



Figure 3. Schematic Diagram of Coaxial Terminating Resistor

The value of  should remain constant as you vary the frequency, provided you do not alter the function generator’s amplitude setting. Record the value of .

1. Devise an experiment to verify that . Describe your experiment and its result in the data memo.
2. Set the switch on the orange filter to engage the built-in 50 Ω resistor. Use the ohmmeter function on the lab bench DMM to determine which way the switch should be set. Once you have the switch set, do not change the setting for the remainder of the lab. Connect the orange filter to the function generator in place of the terminating resistor. Connect the oscilloscope to the output of the orange filter. Verify that the amplitude of the waveform you see on the oscilloscope is close to the value of  you obtained in Step b. Do not proceed unless this is the case. Note that we are not going to observe the voltage at the input of the filter!

# Part 2: Insertion Loss

1. Step the function generator frequency from 100 Hz to 4 kHz in 100 Hz steps. At each step, use the oscilloscope to measure the amplitude of the filter output waveform. Set up two arrays in MATLAB. In array fmeas list the function generator frequencies. In array VLmeas list the filter output amplitudes. Make sure that when you are finished, the two arrays are of the same length.
2. Use Eq. in MATLAB to produce another array ILmeas of insertion loss values.
3. Plot measured insertion loss vs. frequency on the same graph you created for the prelab. The measured points should be plotted as “x’s”, and not joined with a line. You can create the required plot with plot(f,IL,’-’,fmeas,ILmeas,’x’); where f and IL are the arrays you produced in the prelab. Add a legend (using legend) so that you can tell which curve is which. Your graph should show two curves: an analytic curve plotted as a continuous line and a curve of measured data plotted with x’s.
4. Determine the frequency at which the insertion loss is 3 dB. Record the 3 dB frequency in your data memo.

# Part 3: Phase Response

1. Connect Channel 1 of the oscilloscope to the TTL Output connector on the function generator. Connect Channel 2 of the oscilloscope to the output of the filter. The TTL Output connector on the function generator produces a square wave (TTL levels) that is in phase with . You will use this square wave a a phase reference for phase measurements.
2. Set the function generator frequency to 100 Hz. Set the measurement function on the oscilloscope to measure the phase of Channel 2 with respect to Channel 1. Step the frequency from 100 Hz to 4 kHz in 100 Hz steps. Record the phase measurements in a MATLAB array Pmeas.
3. Plot measured phase vs. frequency on the same graph you created for the prelab. The measured points should be plotted as “x’s”, and not joined with a line. Add a legend (using legend) so that you can tell which curve is which. Your graph should show two curves: an analytic curve plotted as a continuous line and a curve of measured data plotted with x’s.

# Part 4: Swept-Frequency Measurements

1. Connect oscilloscope Channel 1 to the filter output. Turn off Channel 2.
2. Set the function generator for sweep. Set the start frequency to 100 Hz and the stop frequency to 5 kHz. Set the sweep speed to 1 second.
3. Observe the filter output on the oscilloscope. You should see the function generator automatically sweep through the set of measurements you made in Part 1.
4. Now reduce the sweep speed to 0.1 second. The amplitude of the waveform on the oscilloscope will trace out the frequency response of the filter. **Obtain a screen capture for your data memo.**
5. If you continue to reduce the sweep speed, the output will eventually produce a distorted version of the filter’s frequency response. Explain why the distortion occurs.

# Part 5: Single-Frequency Measurement

1. Disconnect the filter from the function generator and replace it with the terminating resistor. Set the function generator to produce



across the terminating resistor. Then disconnect the terminating resistor and restore the filter.

1. Use your measured insertion loss and phase response data to predict the filter output voltage. Enter the predicted output amplitude and phase in the table in the data memo.
2. Measure the amplitude and phase of the waveform at the filter output. Enter the measured values in the data table in the data memo.
3. Calculate the percentage error in the amplitude ( ) and the number of degrees of error in the phase. (Do not show a percentage error for phase. What would you get if the predicted phase were zero?) Enter these values in the data table.

Data Memo for Lab 1

Names:

Date:

Section:

### Part 1: Preparation

1. Provide the identification number of your filter:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. 
3. Describe how you verified that :

### Part 2: Insertion Loss

c) Place your plot of insertion loss vs. frequency here:

d) The frequency at which the insertion loss is 3 dB is:

### Part 3: Phase Response

c) Place your plot of phase vs. frequency here:

### Part 4: Swept-Frequency Measurements

d) Place your swept-frequency screen capture here:

e) Explain why distortion occurs if the sweep duration is too short:

### Part 5: Single-Frequency Measurement

Fill in the table below showing predicted and measured amplitude and phase at 3 kHz:

|  |  |  |  |
| --- | --- | --- | --- |
|  | Predicted | Measured | Error |
| Amplitude (V) |  |  | % |
| Phase (degrees) |  |  | degrees |