Lab #5
Frequency Response & Bode Plots

Labs will be performed in groups of two or three students. Each person will turn in their own copy of the required work for the lab.

For this lab, one person from your group will need to check out the following from the EECS Shop.
- An analog probe kit with a breadboard (metal toolbox)
- AnalogDiscovery 2 kit (for Day 2 only)

Parts List
- 1 – 0.01 [μF] Capacitor
- 1 – 0.1 [μF] Capacitor
- 2 – 200 [Ω] Resistor
- 2 – 2 [kΩ] Resistor
- 1 – 100 [mH] Inductor

Experiment 1: Low Pass Filter (Day 1)

1. 1. Build the circuit as shown below in figure 1.

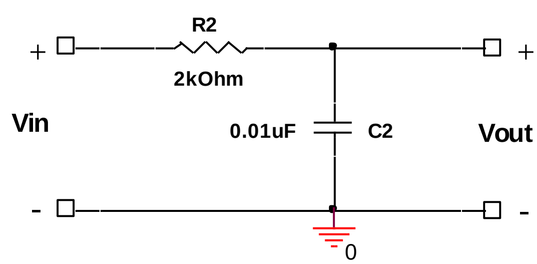


Figure 1

1. Place a "T" splitter on the output of the FG. Using a BNC to BNC cable, connect one of the outputs of the T splitter to Channel 2 of the oscilloscope and the other to V_{in} of your circuit. Trigger the oscilloscope off of Channel 2.

2. Connect the Channel 1 input of the oscilloscope to V_{out} of your circuit.

3. Set the DSO to average the waveform values to get better measurements. Push the “Acquire” key and select averaging with 16 bits. Note: Using averaging helps get more accurate measurements for steady state waveforms which aren’t very stable, but every time the waveform changes it takes a little while to stabilize.

4. Perform a manual frequency sweep to test the response of your circuit. To do this, start by setting the FG to produce a 1V ($2V_{pp}$) sine wave. Now record the magnitude (V_{pp}) of V_{out} and

V_{in} and the phase difference between V_{out} and V_i at the frequencies given in the table below. V_{in} will not change much (if any). The column is there for you to note changes if they do occur. The phase will sometimes be inverted. You will need to add 180 to the number on the DSO if this happened.

$$\boldsymbol{R}_2 = 2\boldsymbol{k}\Omega$$

$$\boldsymbol{R}_{\boldsymbol{FG}} = 50\Omega$$

$$\boldsymbol{R}_{\boldsymbol{T}} = \boldsymbol{R}_2 + \boldsymbol{R}_{\boldsymbol{FG}}$$

$$\boldsymbol{f}_{\boldsymbol{break}} = \frac{1}{2\pi \boldsymbol{R}_{\boldsymbol{T}}\boldsymbol{C}}$$

Note: This break frequency assumes that the V_{in} used to determine the gain is the set voltage of the function generator (which will always be constant over all frequencies). If the measured voltage at the input of the circuit (which may change for different frequencies) is used for the gain, then R_{FG} need not be included.

Frequency [Hz]	**V_{out} [V_{pp}]**	**V_{in} [V_{pp}]**	**ϕ[°]**
100			
200			
500			
1,000			
2,000			
Check out WHERE exactly the break frequency occurs. It may **NOT** be here !			
f_{break} = (you find it!)			
5,000			
10,000			
20,000			
50,000			
100,000			
200,000			
400,000			

Experiment 2: High Pass Filter (Day 1)

1. Build the circuit as shown below in figure 2.

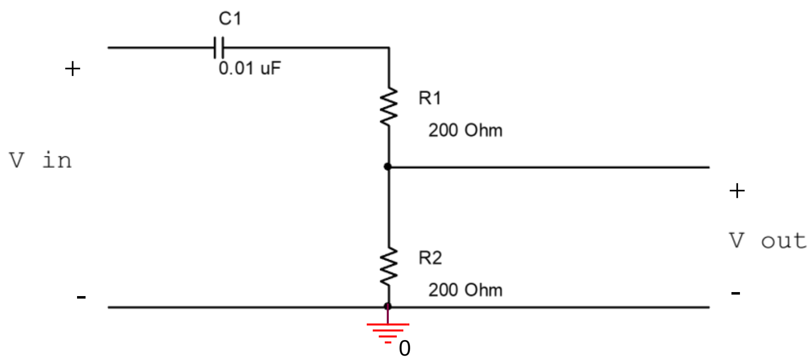


Figure 2

2. Connect the FG and oscilloscope as you did in Experiment 1.
3. Record your data in the table below.

$R_1 = 200\Omega$

$\boldsymbol{R_{FG}} = 50\Omega$

$R_T = 2R_1 + R_{FG}$

Frequency [Hz]	**V_{out} [V_{pp}]**	**V_{in} [V_{pp}]**	**ϕ[°]**
100			
200			
500			
1,000			
2,000			
5,000			
10,000			
20,000			
f_{break} = (you find it!)			
50,000			
100,000			
200,000			
400,000			

For your lab report your deliverables for Experiment 1 and Experiment 2 are:

- Find the break frequencies for the above 2 circuits in Experiment 1 and Experiment 2. (Theoretically and Practically).

- Use your experimentally measured values to plot the magnitude ($|H(j\omega)|(dB) = 20 * \log_{10}\left(\frac{Vout}{Vin}\right)$) of the frequency response (the Bode plot) with Excel. Plot the magnitude (on a linear scale) on the ordinate axis and angular frequency (on a log scale) on the abscissa axis.
- Use your experimentally measured values to plot the phase of the frequency response (the Bode plot) with Excel. Plot the phase (on a linear scale) on the ordinate axis and angular frequency (on a log scale) on the abscissa axis.
- Compare these plots with PSpice plots of the magnitude and phase of the frequency response. Plot the magnitude (on a log scale) or phase (on a linear scale) on the ordinate axis and angular frequency (on a log scale) on the abscissa axis.
- **Find the transfer functions from the Bode plots of the measured data (drawing asymptotes on the Bode plot is helpful to determine the transfer function) and compare them against the theoretical transfer functions.**

Experiment 3: Band-Pass Filter (Day 2)

1. Build the circuit as shown below in figure 3. Use two 2 [kΩ] resistors to create the 4 [kΩ] resistor.

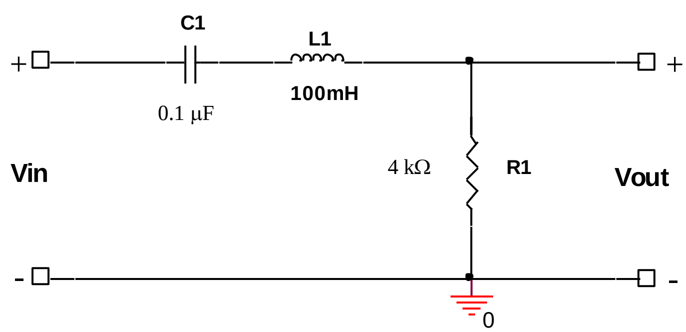


Figure 3

2. As in the previous experiments, record the response at the frequencies provided in the table below. You don't need to record the phase change for this experiment.

$$\omega_0 = \frac{1}{\sqrt{\boldsymbol{LC}}}$$

$$\omega_{\boldsymbol{LO}} = \frac{-(\boldsymbol{R_T}/\boldsymbol{L}) + \sqrt{(\boldsymbol{R_T}/\boldsymbol{L})^2 + 4\omega_0^2}}{2}$$

$$\omega_{\boldsymbol{HI}} = \frac{+(\boldsymbol{R_T}/\boldsymbol{L}) + \sqrt{(\boldsymbol{R_T}/\boldsymbol{L})^2 + 4\omega_0^2}}{2}$$

where

$$\boldsymbol{R_T} = \boldsymbol{R}_1 + \boldsymbol{R_{FG}}$$

$$R_1 = 4k\Omega$$

$$R_{FG} = 50\Omega$$

Note: These frequencies in the expressions above are in **radians/second.** Convert them to **Hz.**

Frequency [Hz]	**V_{out} [V_{pp}]**	**V_{in} [V_{pp}]**
100		
200		
f_{LO} =		
500		
1,000		
f_o =		
2,000		
5,000		
f_{HI} =		
10,000		
20,000		
50,000		

Experiment #4: What Circuit is this? (Day 2)

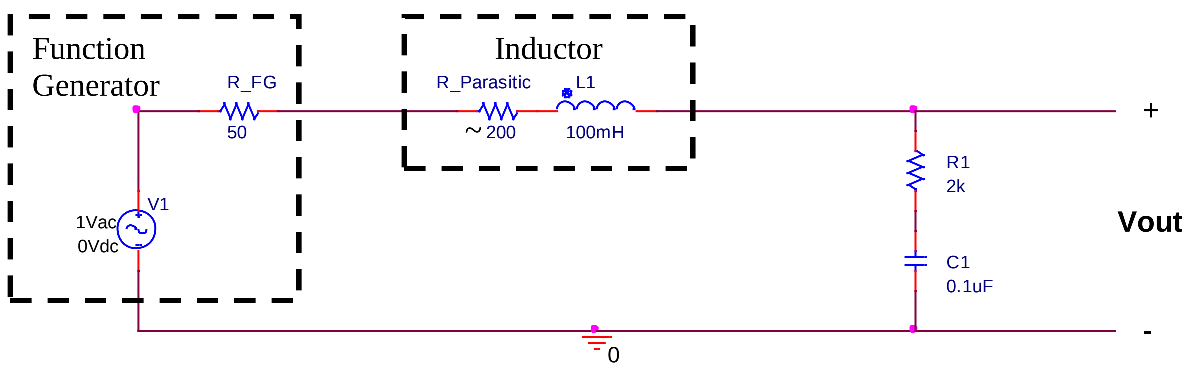


Figure 4

Construct the above circuit and take down reading as before for the frequency range between 100 Hz to 10 kHz (as you did in the previous circuit … phase change is NOT required). Choose an appropriate step size. Choose a maximum step size of 100 Hz between 1kHz and 4kHz. **The resistors R_Parasitic and R_FG are NOT physical resistors placed in the circuit.**

For your lab report your deliverables specific to Experiment 4 are:

- Find out the transfer function and infer the following theoretically:

1. What kind of a filter is this? (Is it a Filter?)
2. What are the break frequencies?
3. How many poles and zeros does this circuit have? What are they?
4. What's the Gain?

For your lab report your deliverables for Experiment 3 and Experiment 4 are:

- Use your experimentally measured values to plot the magnitude ($|H(j\omega)|(dB) = 20 * \log_{10}\left(\frac{Vout}{Vin}\right)$) of the frequency response (the Bode plot) with Microsoft Excel. Plot the magnitude (on a linear scale) on the ordinate axis and angular frequency (on a log scale) on the abscissa axis.
- Compare these plots with PSpice plots of the frequency response. Plot the magnitude (on a log scale) on the ordinate axis and angular frequency (on a log scale) on the abscissa axis. Make certain you take all of the circuit resistances into account in your analysis.
- **Find the transfer functions from the Bode plots of the measured data (drawing asymptotes on the Bode plot is helpful to determine the transfer function) and compare them against the theoretical transfer functions.**

Experiment 5: Using the Network Analyzer for the Frequency Response (Day 2)

Definition: A Network Analyzer (NA) is an instrument that measures different network parameters (s-, y-, z- and h-parameters) of electrical networks and circuits like filters, amplifiers, or any RF components or subsystems. The principle of operation is very simple: the NA sends a sinusoidal *stimulus* signal at a specific frequency to one port of the circuit, and measures the *output* sinusoidal at the same port or another port of the circuit (depending on the parameter being measured). The amplitude and phase differences between the sent and received signals are compared inside the NA and the results are saved. Then the same measurement is done at a different frequency point, and so on; sweeping over a specific frequency range determined by the desired measurement settings. The final result is a set of measurements representing the response of the circuit or device under test as a function of frequency.

Example: The frequency sweeping you have done in the experiments above was actually the job of a network analyzer when set to measure the S_{21} parameter of a two-port network. The S_{21} parameter is simply defined as the response of a circuit as the ratio of the voltage output at port 2 as a response to the signal applied at port 1 at the same frequency, i.e., $S_{21}(\omega) = V_{out2}(\omega)/V_{in1}(\omega)$. And this is simply the voltage gain (or response) of your circuit at frequency ω.

Experiment task: Use the AnalogDiscovery 2 device as a network analyzer to obtain the magnitude of the frequency response of the circuits of Experiments #3 and #4 shown above. Refer to the guide provided below about how to use the AnalogDiscovery 2 device as a network analyzer for this job.

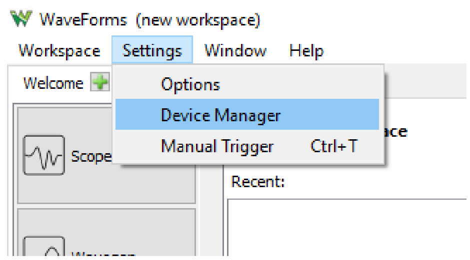
Using the AnalogDiscovery 2 as a Network Analyzer

Step 1: Connect the AnalogDiscovery 2 to your PC with the provided USB cable.

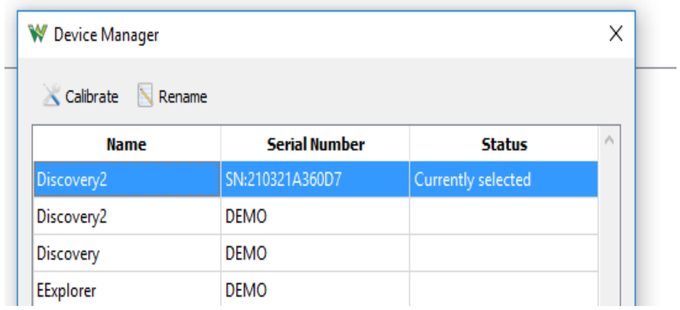
Step 2: Open **WaveForms** software from the programs list in your PC. You may find this in the **Digilent** folder

Step 3: Go to **Settings** > **Device Manager** to add your connected device, as shown below:

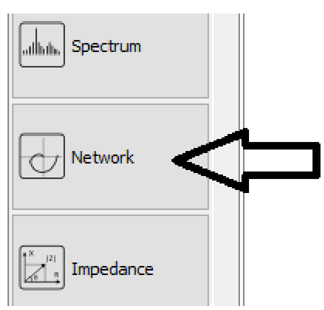
a) Open the Devices Manager



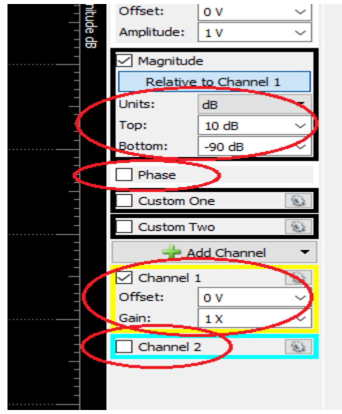
b) Left-click on the device and click the **Select** button at the bottom of the window.



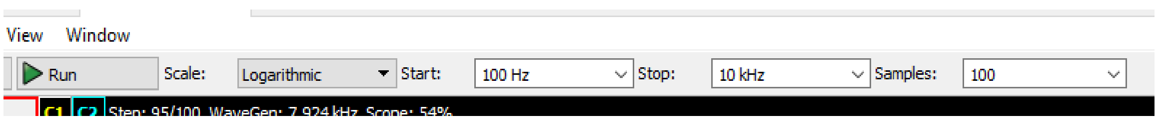
Step 4: Open the network analyzer application window by selecting the **Network** button from the device list at the left of the main window, as shown below:



Step 5: Uncheck the **Phase** option from the control panel at the right of the window, and uncheck **Channel2**. Set the magnitude unit to dB, as shown below:

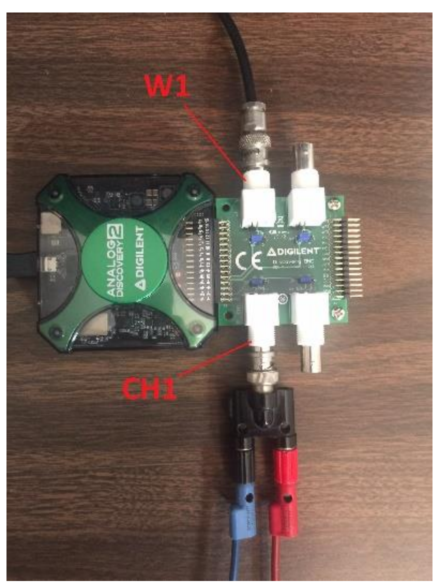


Step 6: Select the start and stop frequency over which the NA will sweep and select the number of frequency points to be visited during this sweeping, as shown below:

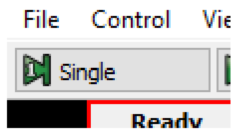


Step 7: *Carefully and gently* connect a BNC-to-EZ Hook Cable to the "W1" port on the Discovery BNC adapter. This will provide the stimulus signal to your circuit under test.

Step 8: *Carefully and gently* connect the BNC-to-Female Banana adapter to "Ch1" port on the Discovery BNC adapter. And then connect two Banana wires to the adapter, terminated with EZ hooks at the other ends to connect to your circuit under test. This will be taking the output from the circuit back to the network analyzer to complete measurement. The connections at the Discovery BNC adapter will look like the picture shown below:



Step 9: Connect the W1 EZ hooks to the input of your circuit, and Ch1 hooks to the output, then select the "**Single"** button, shown below, to start sweeping over the frequency range that was set above.



Step 10: Save the measurement data as a CSV file by selecting **File**>**Export**. In the Export window, select **Bode** as a source and check the **Label** checkbox, then click on **Save**. The first column in the saved file will contain the frequency points, and the second column will contain the measured values in dB scale.