EE 2010 Circuit Analysis
Lab 06: Frequency Response of Passive Circuits with dynamic Elements

Lab Section: **Printed Name (Last, First):**

Learning Objectives:

- Understand the frequency-dependent characteristics of circuits containing dynamic elements
- Be able to implement a "Frequency-Sweep" simulation
- Understand the concept of a frequency-dependent transfer function
- Understand the concept of frequency-selective "filtering"
- Be able to observe the dynamics of amplitude and phase changes in the frequency domain
- Be able to simulate and verify a simple RC low-pass and high-pass filter
- Understand how the frequency-dependent impedance of a capacitor can be utilized in filter design.
- Realize, observe, and measure the transfer-function characteristics of a first-order lowpass filter.

A. Before coming to lab:

1. Background

1.1 Read this overview of RC filters.

1.2 Read THIS WIKIPEDIA article on low-pass filters.

1.3 Watch this short demo video of an RC low-pass operation.

2. RC Low-Pass Circuit Simulation

For this lab, we employ the "AC-Sweep" function in a Multisim simulation to observe the frequency-dependent behavior of circuits with dynamic elements.

2.1 Construct a simulation of the circuit shown below:

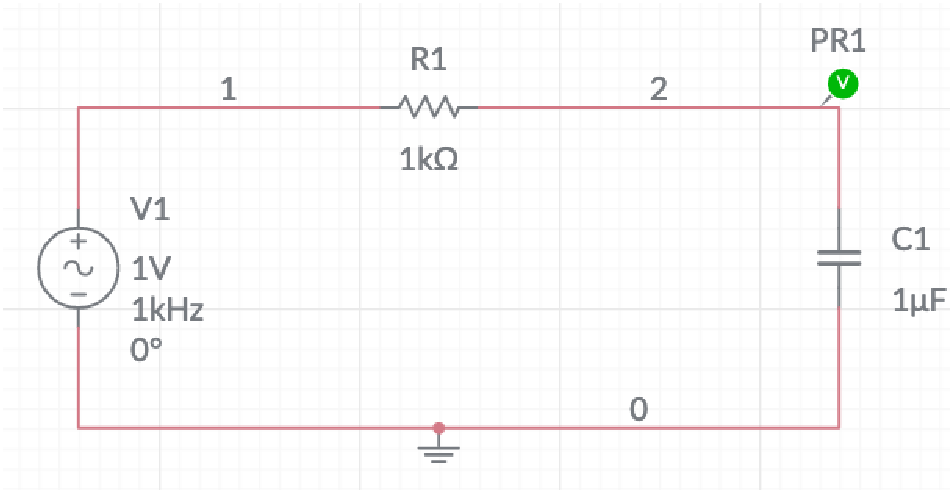


Figure 1: RC Low-Pass circuit schematic diagram

2.2 Notice the positions of the resistor and capacitor. Your intuition should predict the resulting transfer function to have a "low-pass" filter characteristic.

2.3 We have set the input waveform as a constant-amplitude sinusoid. We will observe the "output voltage" to gain insight to the operational transfer function of the circuit.

2.4 In the simulation control bar, select the "AC-Sweep" simulation mode as shown below:

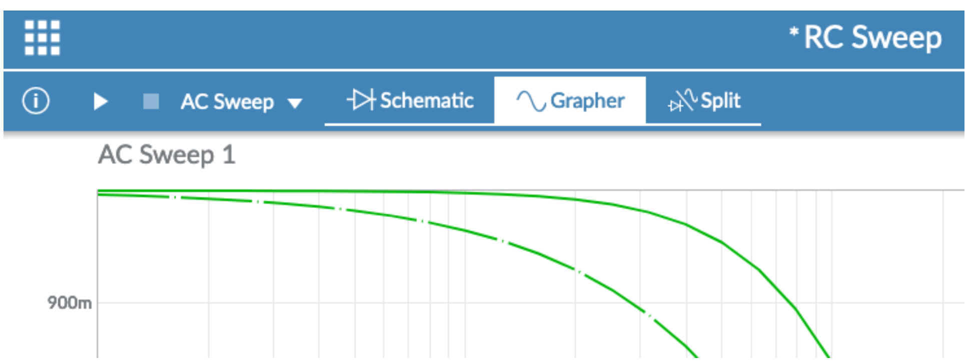


Figure 2: Frequency-Sweep Simulation mode

2.5 AC Sweep is an extremely useful simulation type in Multisim. The AC Sweep allows us to observe and characterize the frequency response of linear circuits. The frequency response indicates the behavior of the system over a range of frequencies. Using a logarithmic scale for the horizontal axis allows the consideration of a large range of frequencies.

2.6 Set the sweep parameters as opened by selecting the settings icon as shown below:

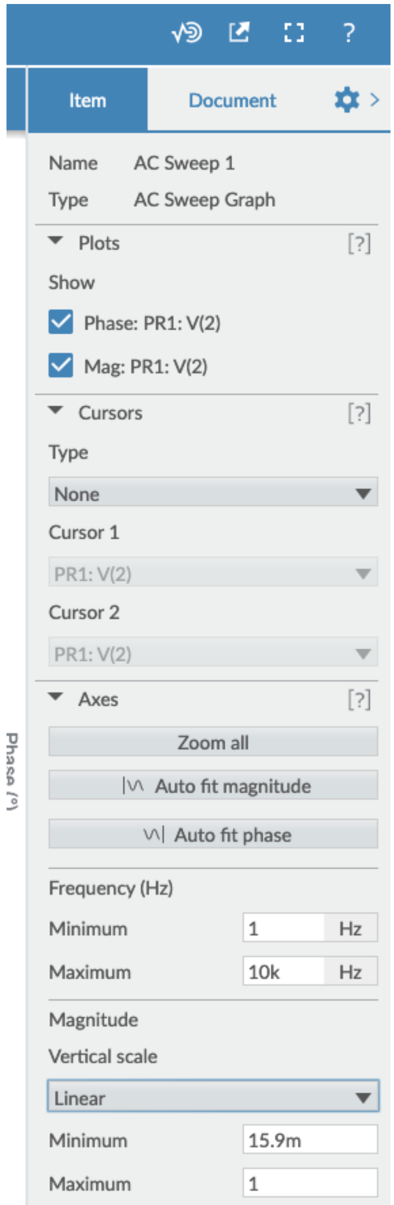


Figure 3: AC-Sweep Simulation mode

2.7 Notice especially the "Linear" sweep mode and the minimum and maximum frequencies of 1Hz and 10k Hz.

2.8 These settings determine the limits and appearance of the resulting simulation as shown below:

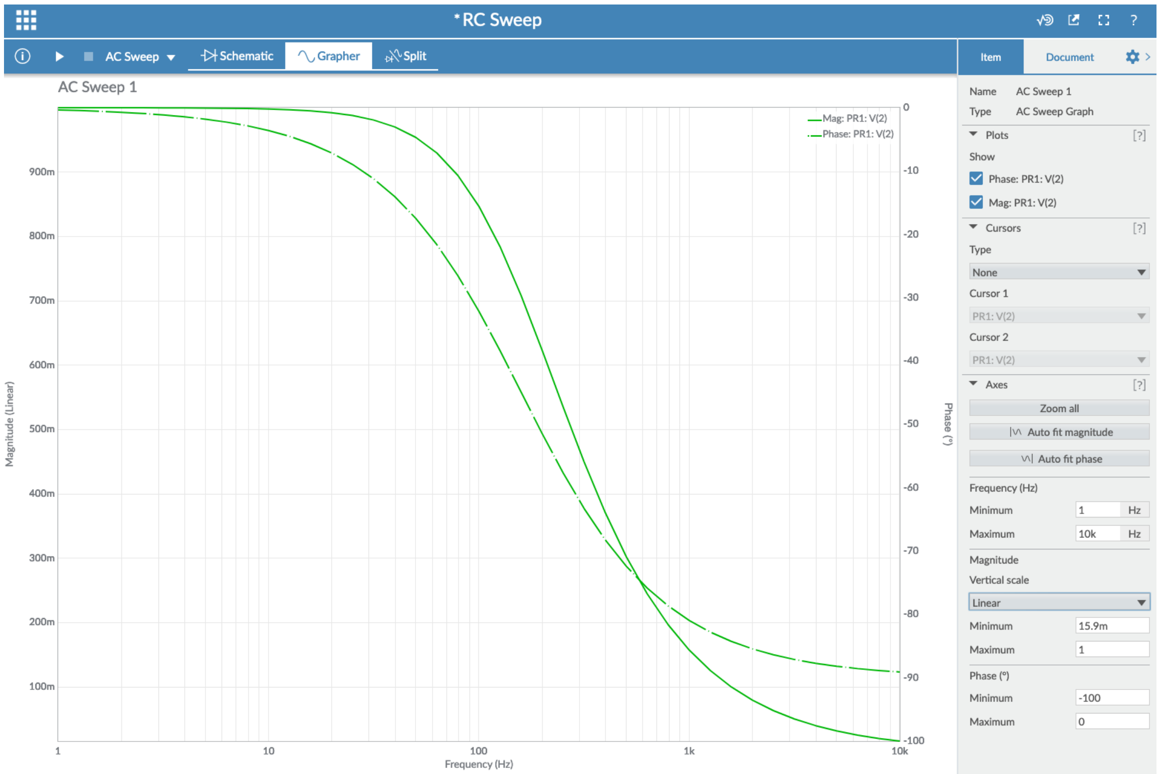


Figure 4: AC-Sweep Simulation for RC Low-Pass

2.9 This figure illustrates the magnitude and phase of the transfer function $H(s)$ for frequencies ranging from 1Hz to 10kHz.

2.10 Run the simulation and capture the results. Include the schematic and the AC-sweep figures in your lab report.

3. Observations

3.1 Notice that the amplitude curve (solid green) indicates no attenuation at low frequencies and begins to attenuate the signal significantly as the input frequencies increase. Hence the name "low-pass filter"

3.2 While we will not now dwell on the implications of the phase shift (dashed green), we note that the phase is also affected by the operation of the resistor-capacitor combination.

4. RC High-Pass Simulation

As before, we employ the "AC-Sweep" function in a Multisim simulation.

4.1 Build the circuit shown below:

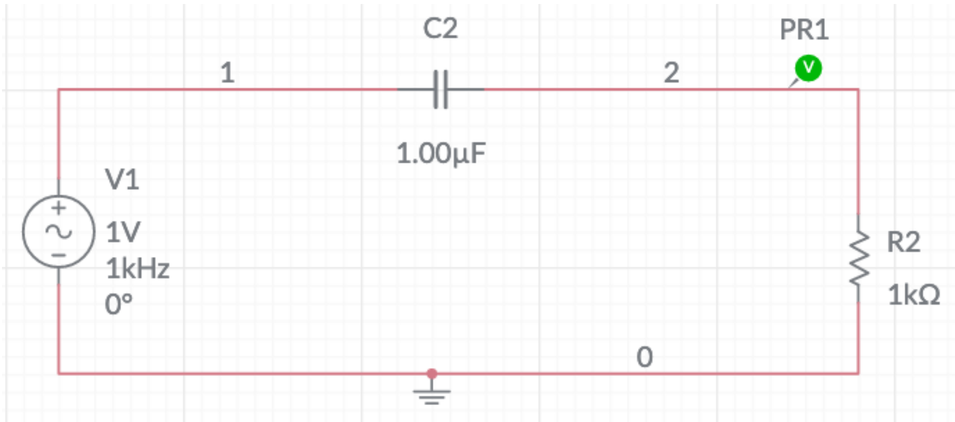


Figure 5: RC High-Pass circuit schematic diagram

4.2 Notice that we have merely switched the positions of the resistor and capacitor. Your intuition should predict the resulting transfer function to have a "high-pass" filter characteristic.

4.3 Select the "AC-Sweep" simulation mode.

4.4 Set the sweep parameters to be the same as for the Low-Pass simulation study.

4.5 Notice especially the "Linear" sweep mode and the minimum and maximum frequencies of 1Hz and 10k Hz.

4.6 These settings determine the limits and appearance of the resulting simulation as shown below:

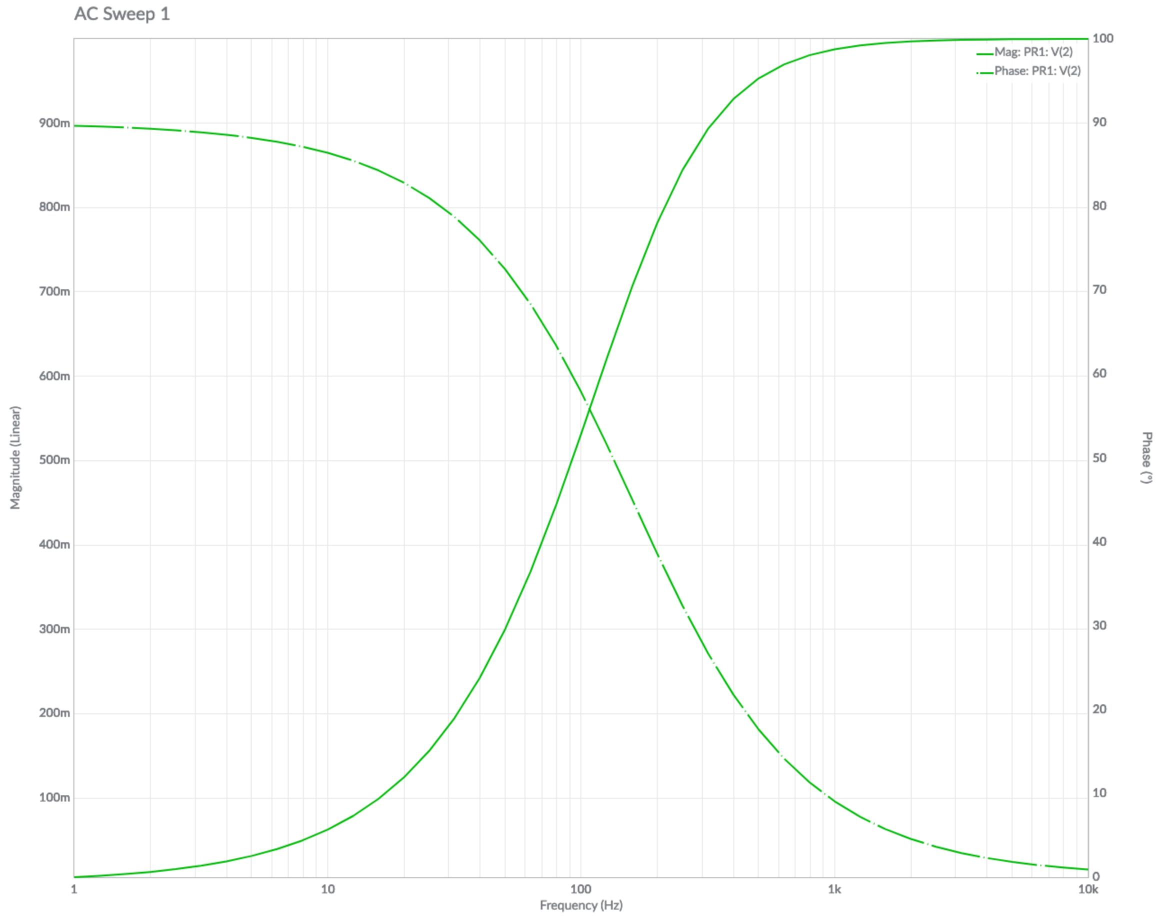


Figure 6: AC-Sweep Simulation for RC High-Pass

4.7 Run the simulation and capture the results. Include the schematic and the AC-sweep figures in your lab report.

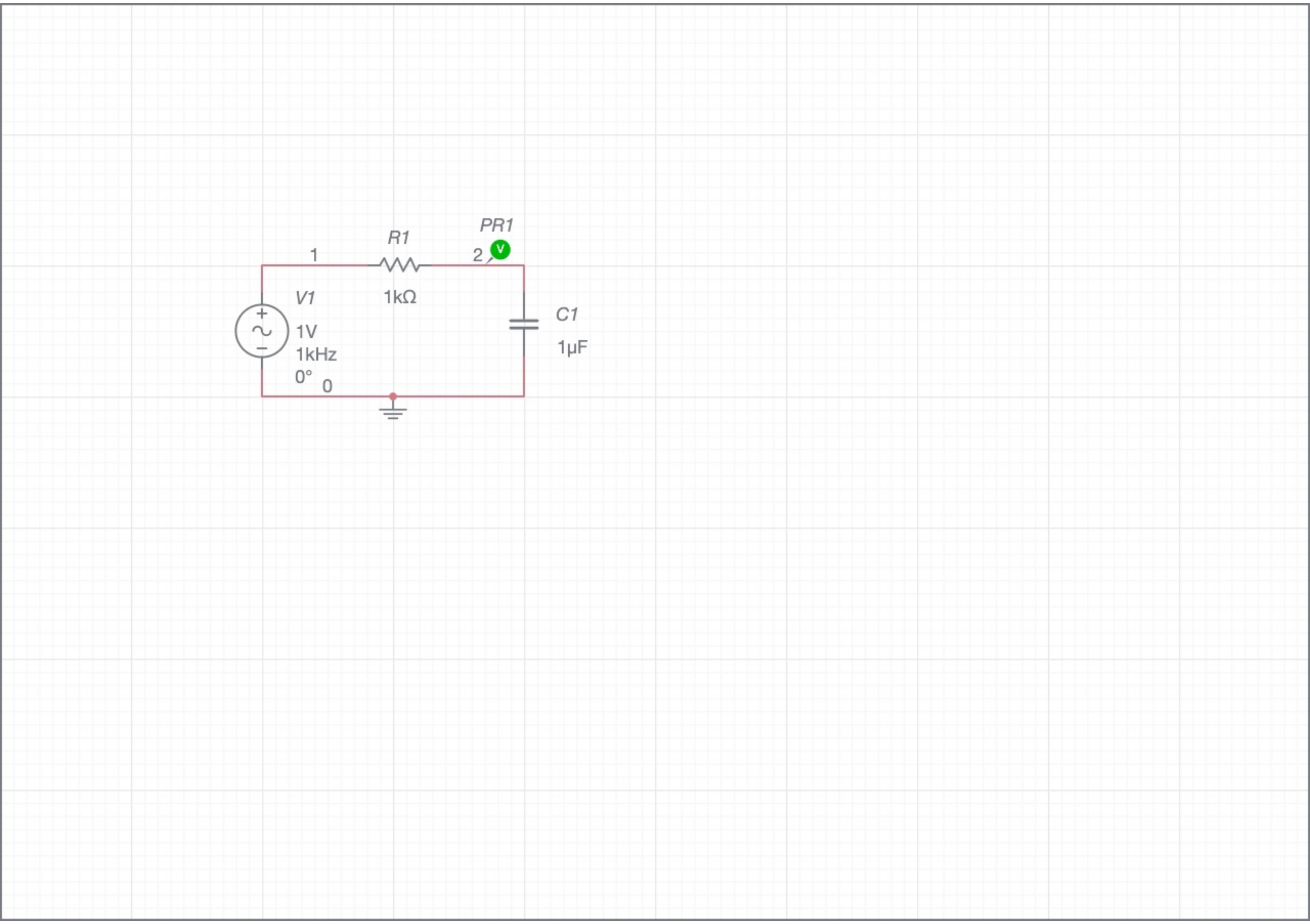
5. Observations

5.1 Notice that the amplitude curve (solid green) indicates high attenuation at low frequencies and less attenuation as the input frequencies increase. Hence the name "high-pass filter"

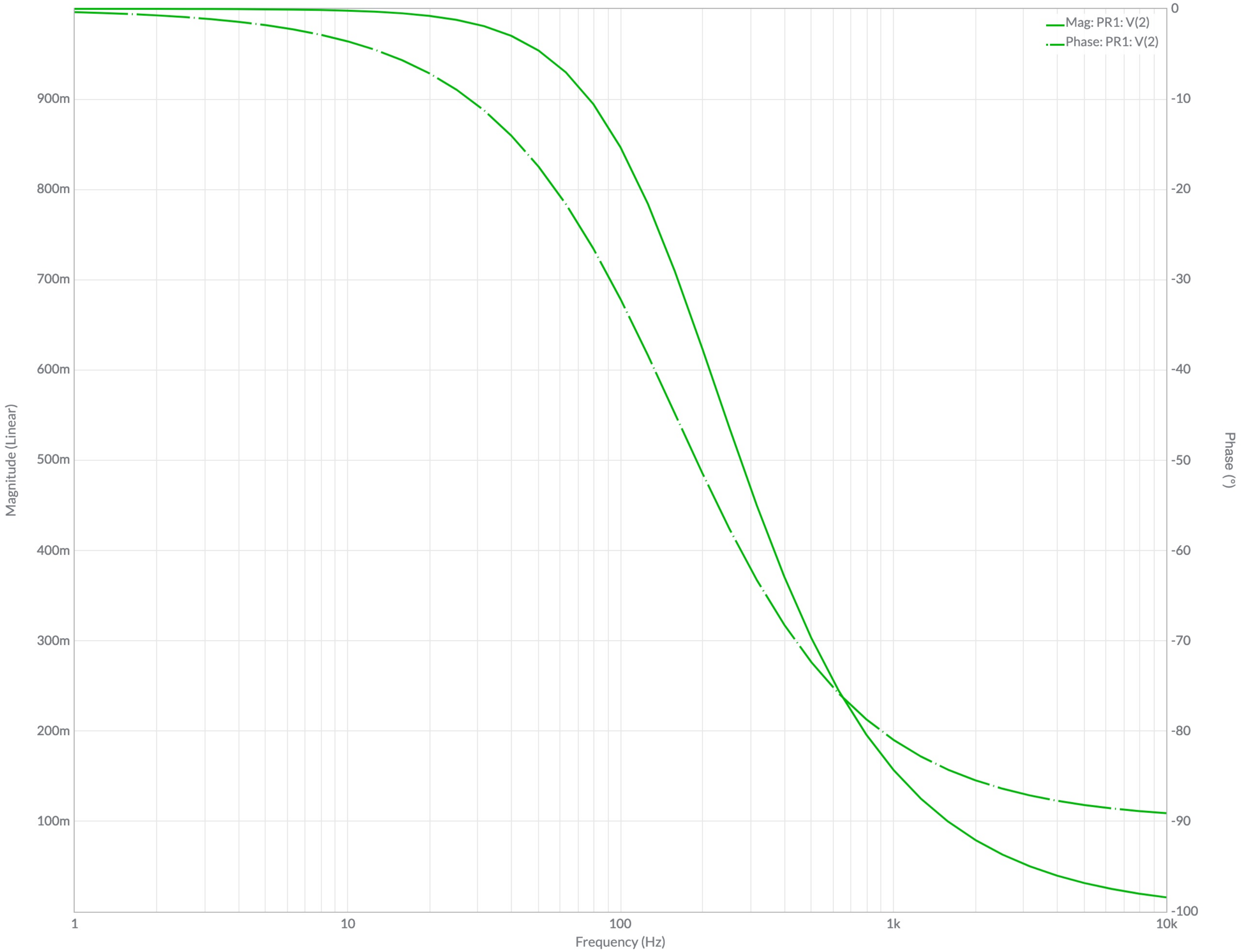
5.2 While we will not now dwell on the implications of the phase shift (dashed green), we note that the phase is also affected by the operation of the resistor-capacitor combination.

Explore "what ifs" by changing the values of R and C. Note that by simply adjusting these values, the "cutoff" frequency of the low-pass or high-pass filter can be realized as desired.

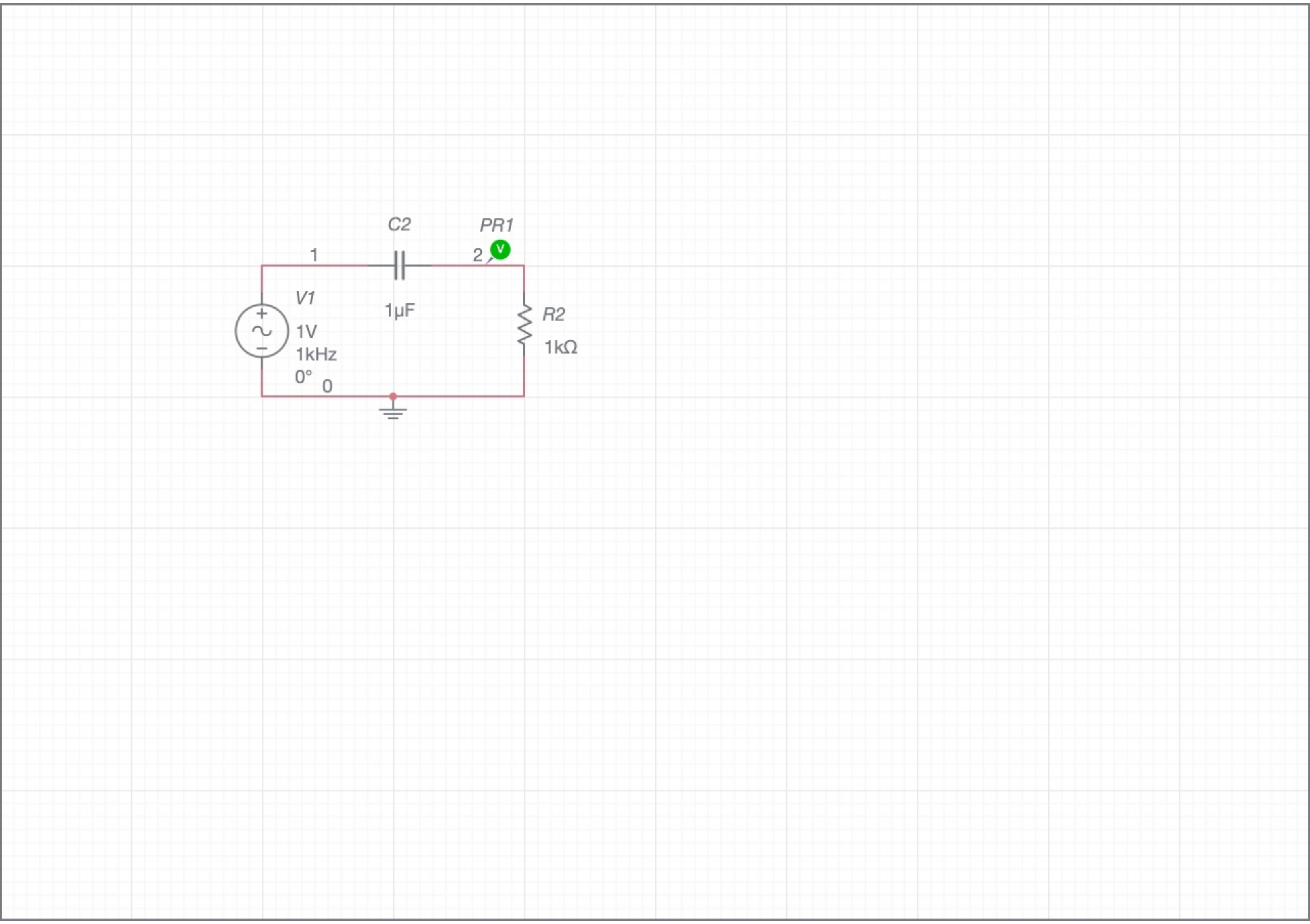
You will have the opportunity to experiment with this circuit configuration in the lab and see how this circuit behaves on the oscilloscope. You will be able to observe the change in magnitude of the signal as well as the phase change.


PR1
R1
1
2
1kΩ
V1
1V
1kHz
0°
0
C1
1µF

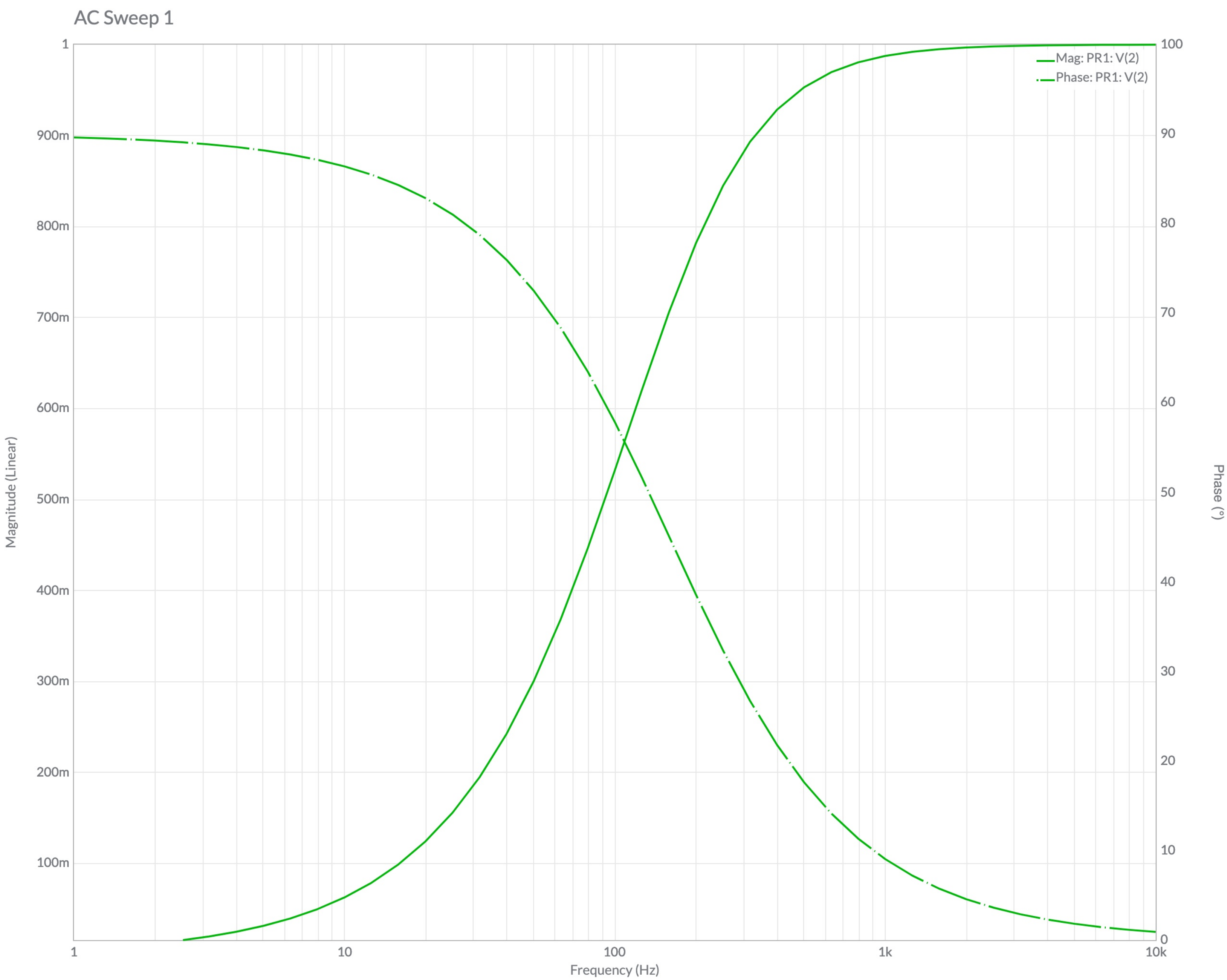
AC Sweep 1



Mag: PR1: V(2)
Phase: PR1: V(2)
900m
800m
700m
600m
500m
400m
300m
200m
100m
Magnitude (Linear)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Phase (°)
1
10
100
1k
10k
Frequency (Hz)



C2
PR1
1
2
V
V1
1µF
R2
1V
1kHz
1kΩ
0°
0


AC Sweep 1
Mag: PR1: V(2)
Phase: PR1: V(2)
1
900m
800m
700m
600m
500m
400m
300m
200m
100m
Magnitude (Linear)
100
90
80
70
60
50
40
30
20
10
0
Phase (°)
1
10
100
1k
10k
Frequency (Hz)

B. In Lab Procedures

In this lab session you will realize and validate the RC filter from the Pre-Lab simulations.

For the In-Lab experience, it is necessary to watch **this video** on measuring phase with a two-channel oscilloscope.

1. Construct the RC filter

1.1 Obtain an **8.2kΩ Resistor** and a **0.01µF Capacitor**. Assemble the circuit to resemble the simulated R-C lowpass circuit above.

1.2 When connecting the source using the BNC-to-Alligator cable (shown below), the red alligator clip will be used as the input lead and the black alligator clip as the ground lead.

1.3 Connect the input to the resistor and the ground to the capacitor, like in the Pre-Lab. Be careful to connect the BNC connector to the **OUTPUT** terminal on the front panel of the signal generator and not the **SYNC** terminal. This is a common error.
Note: Do not energuize the circuit yet.

1.4 Connect the oscilloscope probes (shown below) across the capacitor, with the black alligator clip connected to ground. It does not matter if the BNC connector on the probes is connected to Input 1/X or Input 2/Y. If there are no oscilloscope probes available, the BNC-to-Alligator cables can also be used.

1.5 Your circuit should resemble the protoboard realization below.

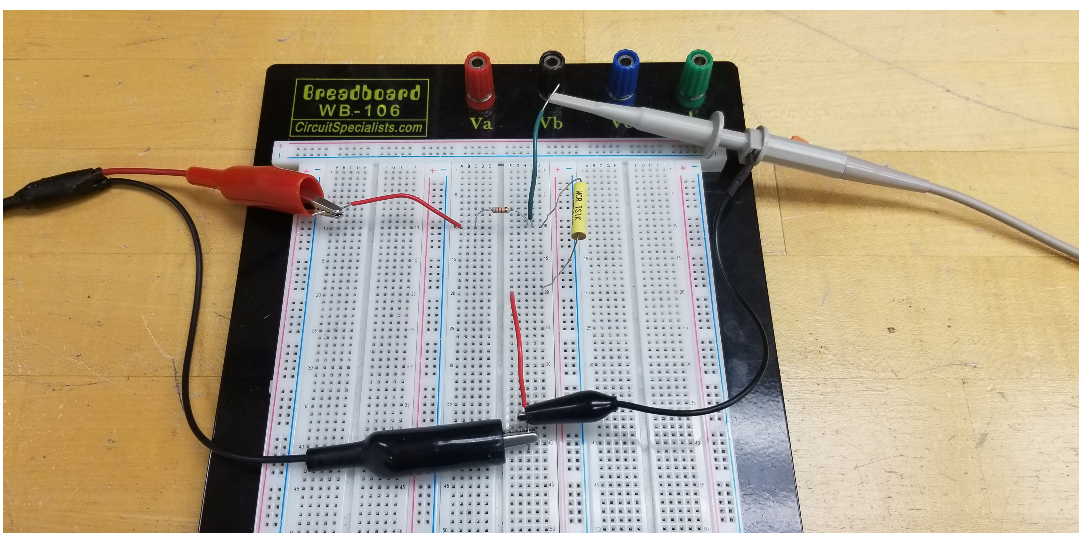


Figure 7: RC Low-Pass Filter Example

2. Oscilloscope Frequency Measurements of an RC filter

In this section we'll operate the function generator and the oscilloscope to determine the frequency response of a linear circuit.

2.1 Turn on the function generator. Set the wave type to a sine wave, the amplitude to 5V, and the frequency to 100Hz.

2.2 Turn on the oscilloscope. Press the **Auto-scale** button to get the waveform in to view on the oscilloscope.

Note: The Auto-scale function is a very useful feature on the oscilloscope. However, it won't produce the desired result, particularly if the amplitude or frequency of the input is low. In these cases the Volts/div dial can be used to adjust vertical scale, and the Time/div dial can be used to adjust the horizontal scale.

2.3 The three *Measure* buttons can be used to obtain amplitude, frequency, and time measurements.

2.4 Press the **Voltage** button to open up the Voltage Measurement Softkey Options at the bottom of the display. Make sure that the **Source** is set to whichever source the oscilloscope are probes connected to. Select the V_{p-p} option to measure the peak-to-peak voltage.

Note: There is a difference between the peak-to-peak voltage and amplitude of a wave. Peak-to-peak voltage is exactly as the name describes, the difference between the highest point of the wave and the lowest point of the wave. We know that the amplitude of a wave is the difference between the inflection point of a wave and its highest point. So, the peak-to-peak voltage will, in most cases, be twice the amplitude of the wave.

2.5 With the initial frequency at 100 Hz, fill out the following table adjusting the frequency of the input accordingly. As you change the frequency you will likely have to rescale the oscilloscope display.

Frequency (Hz)	V_{p-p} (V)	Amplitude (V)
100	10.2	5.12
1000	8.8	4.48
2000	6.64	3.32
5000	3.4	1.7
15000	1.22	0.62

2.6 Were these the results that you expected from the RC Low-Pass Filter that we constructed? Describe the results. Compare to the results of the Pre-Lab.

yes. as frequency increased, voltage decreased. same as in prelab graph

2.7 Use the V_{p-p} measurement tool on the oscilloscope, and the fact that the voltage at the cutoff frequency is $0.707 * V_{max}$ to determine the exact cutoff frequency for your filter (or as close as you can get). Write your result in the space below. (Remember, V_{p-p} measures peak-to-peak voltage while $0.707 * V_{max}$ calculates amplitude.)

(0.707*5.2) = 3.676V -> 1.94kHz (from theoretical calculation for fc)

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3. RC High-Pass Measurements

3.1 Turn off the function generator and disconnect the alligator clips. Disconnect the oscilloscope probes, you may leave the oscilloscope on.

3.2 Switch the positioning of the resistor and the capacitor so that while still in series, the resistor is now the output element.

3.3 Connect the function generator input to the capacitor and the ground to the resistor. And connect the oscilloscope probes across the resistor to measure the output.

Everything that you do here for setting up the circuit will be a "mirror" of what you did in the Pre-Lab and the first part of the Lab Procedures. An example of what your circuit should look like can be seen below.

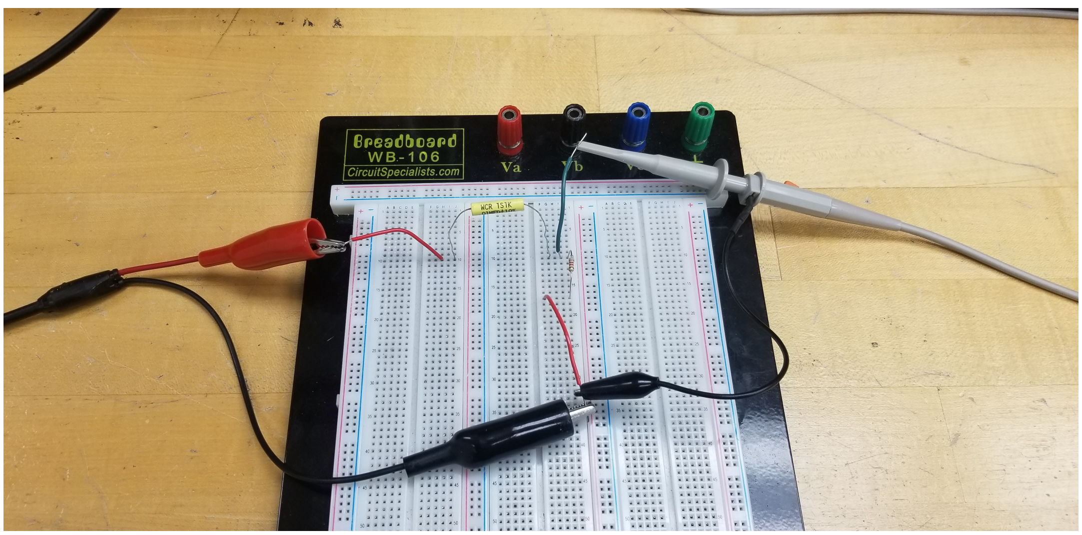

Figure 8: Example of the New Filter Construction

3.4 Turn on the function generator and configure it with the same wave type and amplitude as before. If you turned the oscilloscope off, you should once again configure it to measure peak-to-peak voltage.

3.5 With the initial frequency at 100 Hz, fill out the following table adjusting the frequency of the input accordingly. As you change the frequency you will likely have to rescale the oscilloscope display.

Frequency (Hz)	V_{p-p} (V)	Amplitude (V)
100	0.540	0.28
1000	4.56	2.28
2000	6.88	3.44
5000	8.56	4.28
15000	9.04	4.52

3.6 What behavior did you observe as you increased the frequency of the input signal? What kind of filter is this? Think about how we described the previous filter and its corresponding behavior.

as frequency increased, voltage increased. high pass filter. it matches

3.7 Use the V_{p-p} measurement tool on the oscilloscope, and the fact that the voltage at the cutoff frequency is $0.707 * V_{max}$ to determine the exact cutoff frequency for your filter (or as close as you can get). Write your result in the space below. (Remember, V_{p-p} measures peak-to-peak voltage while $0.707 * V_{max}$ calculates amplitude.)

3.8 Compare the cutoff frequency of the low-pass filter to the cutoff frequency of this filter.

Same

C. Takeaways:

- The steady-state sinusoidal response of dynamic circuits is frequency-dependent.
- The frequency response of a dynamic circuit is characterized by both amplitude and phase.
- Both amplitude and phase responses can be measured by an Oscilloscope.
- The amplitude and phase responses are distinctive of the class of dynamic circuit under consideration.
- Frequency-selective filters are an essential part of all signal processing applications.
- Frequency-selective filters are easily designed and constructed from readily-available components.