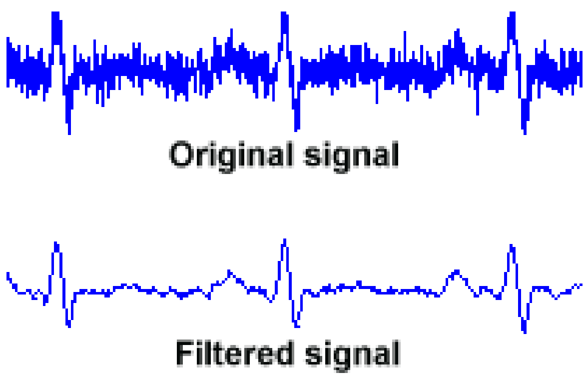
EE 2010 Circuit Analysis
Lab 12: Active Butterworth Filter

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

Learning Objectives:

- Demonstrate the utility and capability of an Op-Amp-driven active filter
- Understand the operation of Low Pass and High Pass filters
- Be aware of the variety of filter design approaches, e.g. Butterworth
- Be able to realize and validate active Low-Pass and High Pass Filters in a bench laboratory

Signal Filtering:
From WikipediA: In signal processing, a *filter* is a device or process that removes some unwanted components or features from a signal. Filtering is a class of signal processing, the defining feature of filters being the complete or partial suppression of some aspect of the signal. Most often, this means removing some frequencies or frequency bands.



A. Before coming to lab:

1. Background:

1.1 Read this WikipediA article on Filters in signal processing especially the purpose, terminology, technology, and types of filters commonly employed.

1.2 Read this WikipediA article on Low-Pass Filters

1.3 Finally, read this WikipediA article on Butterworth design approach with an understanding of why they are termed "maximally-flat"

2. The Butterworth Filter Family

2.1 Recall we have previously realized and verified a *passive filter* in a previous lab. A passive filter is inherently more limited in its design but seeks to provide similar functionality.

2.2 Read this Article on Active Low Pass Filters (up to "Non-Inverting and Inverting Amplifier Filter Circuit")

2.3 A 2nd-Order Low Pass Butterworth filter can be realized via the following OP-Amp circuit.

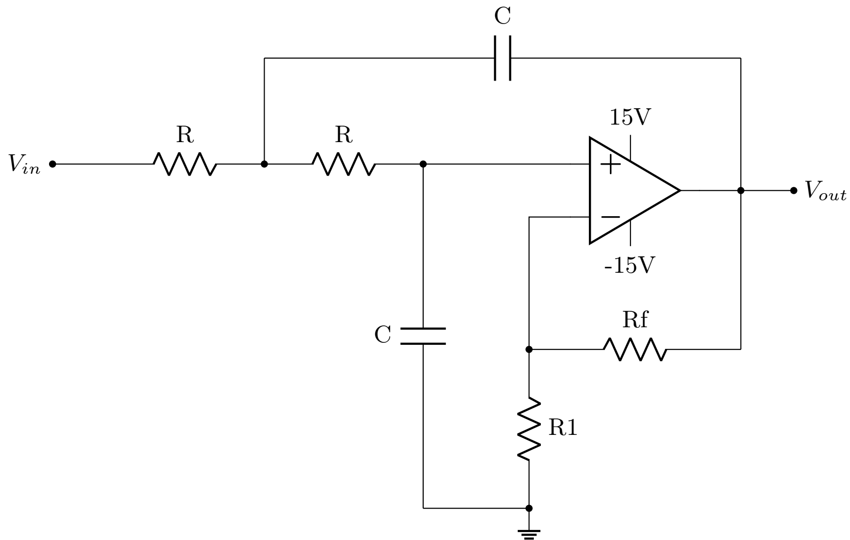


Figure 1: Low Pass Butterworth Filter

2.4 The most attractive advantage of a Butterworth design is that the pass band (the frequencies of interest) are maximally flat in magnitude.

2.5 The output of the Butterworth design and other common filter types are shown in Figure 2.

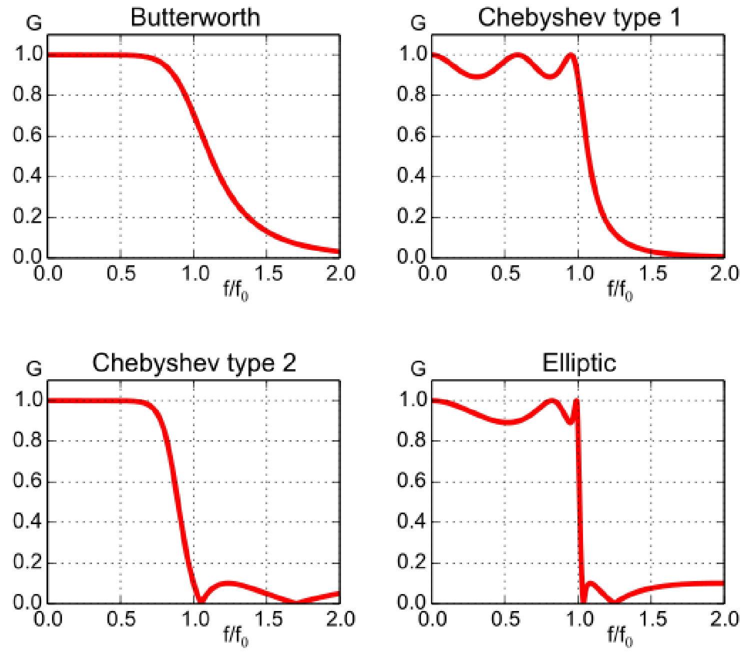


Figure 2: Frequency of the Signal vs. Signal Magnitude

2.6 Notice that while the Chebyshev and Elliptic designs have sharper cutoffs, they exhibit "ripple" in the pass band.

3. Multisim Simulation of a 2nd-Order Low Pass Butterworth Filter

3.1 You are to construct the Low-Pass Butterworth Filter from Figure 1 using the following component values:

- R = 10k Ω
- C = 0.015µF
- R1 = 56k Ω
- Rf = 33k Ω
- Sinusoidal Signal Generator Amplitude: 1V)
- Voltage Probes

3.2 Apply a sinusoidal signal to the input of the filter with an amplitude of 1 V.

3.3 Measure the input and output voltages of the filter using voltage probes.

3.4 The resulting schematic should approximate the figure below.

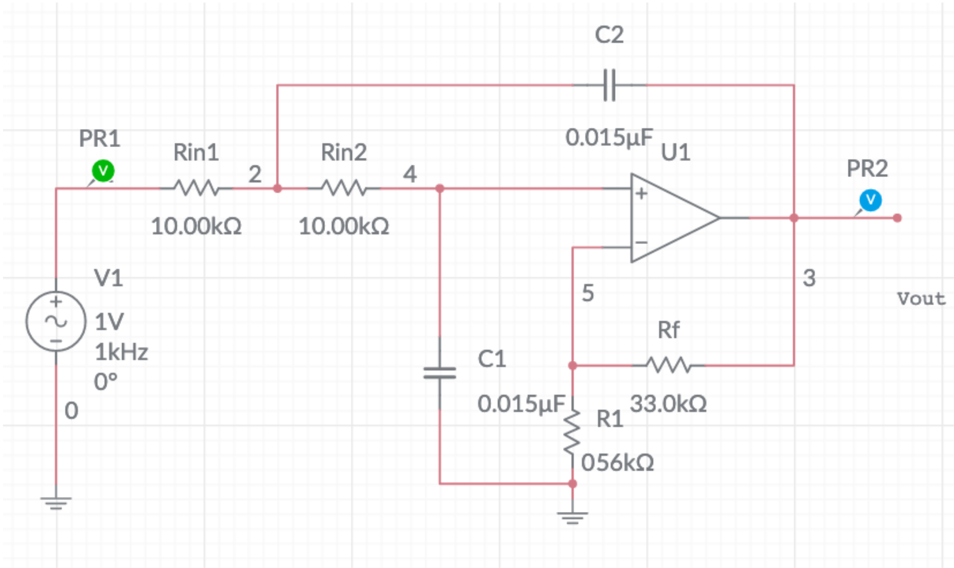


Figure 3: Multisim Schematic of a 2nd-Order Butterworth LPF

3.5 Implement a simulation using the “Frequency-Sweep” option.

3.6 The Frequency-Sweep should produce a grapher result like the figure below.

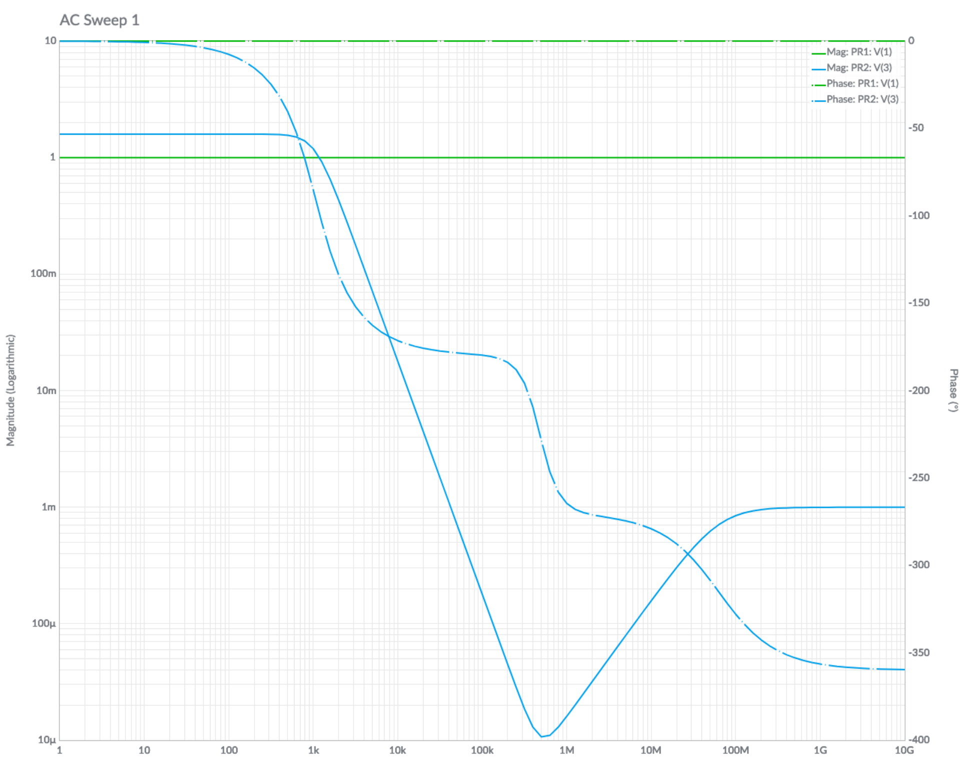


Figure 4: Multisim Frequency Sweep of a 2nd-Order Butterworth LPF

3.7 Note the trend observed in the magnitude of the output as the frequency of the input signal increases.

4. Realization of a 2nd-Order High Pass Butterworth Filter

Interestingly, a low-pass filter may be transformed to a high-pass filter by interchanging the positions of resistors R and capacitors C as is shown in Figure 5.

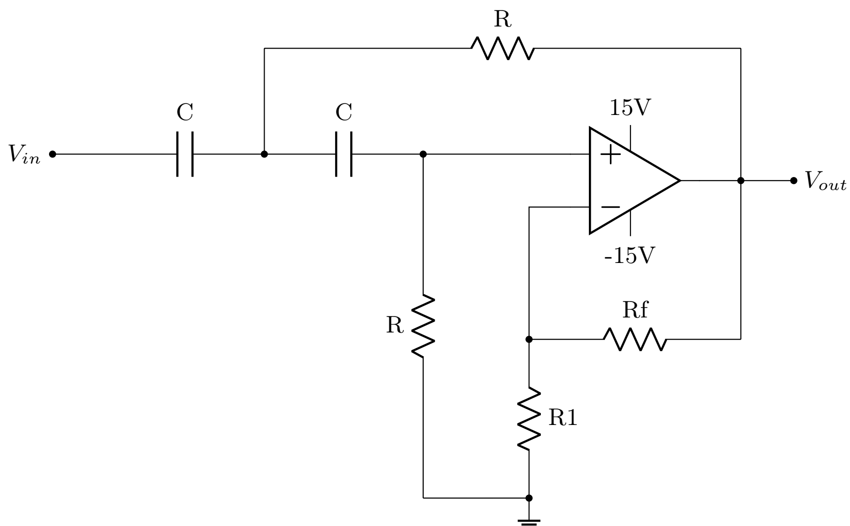


Figure 5: High Pass Butterworth Filter

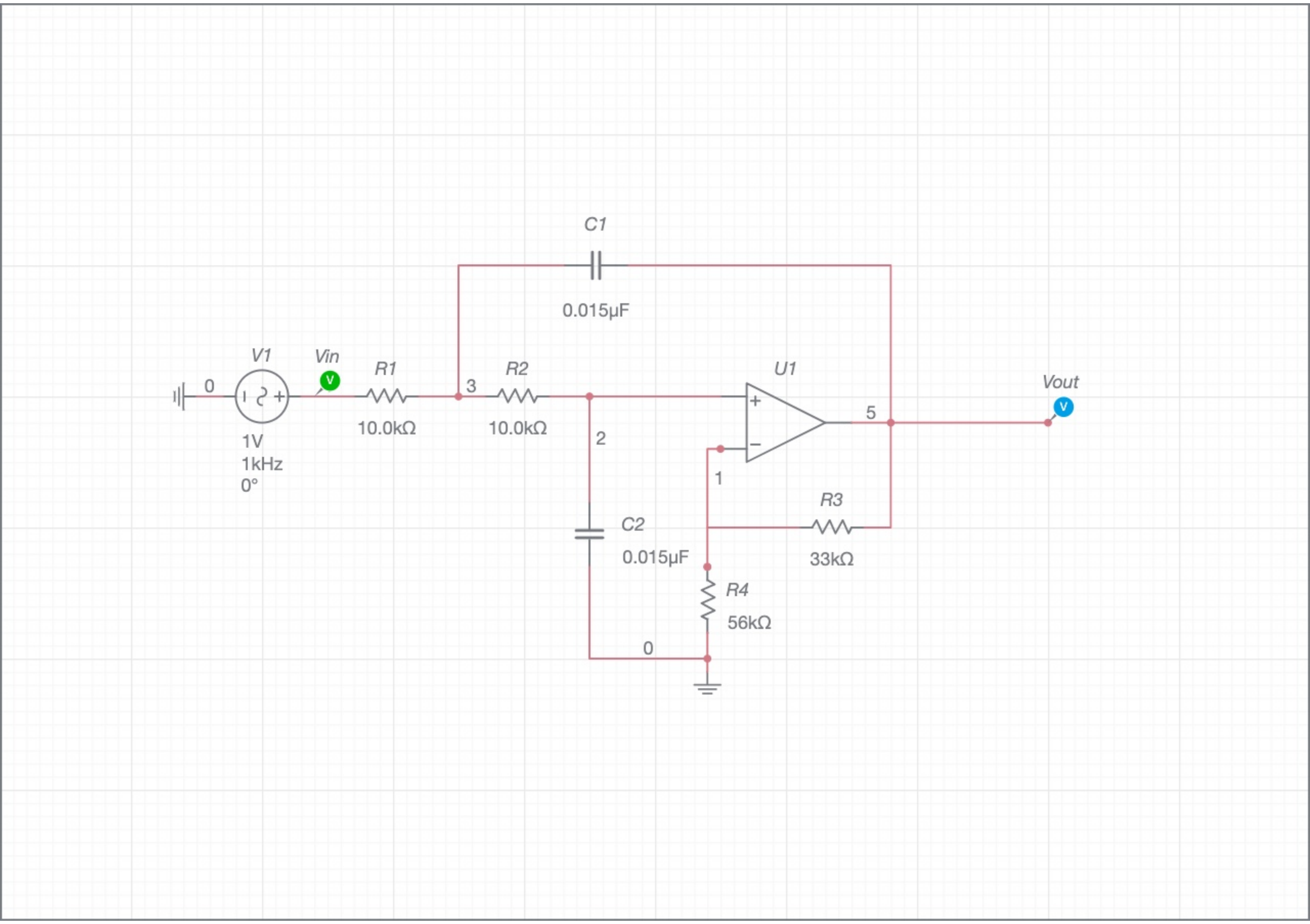
4.1 Implement a simulation using the "Frequency-Sweep" option.

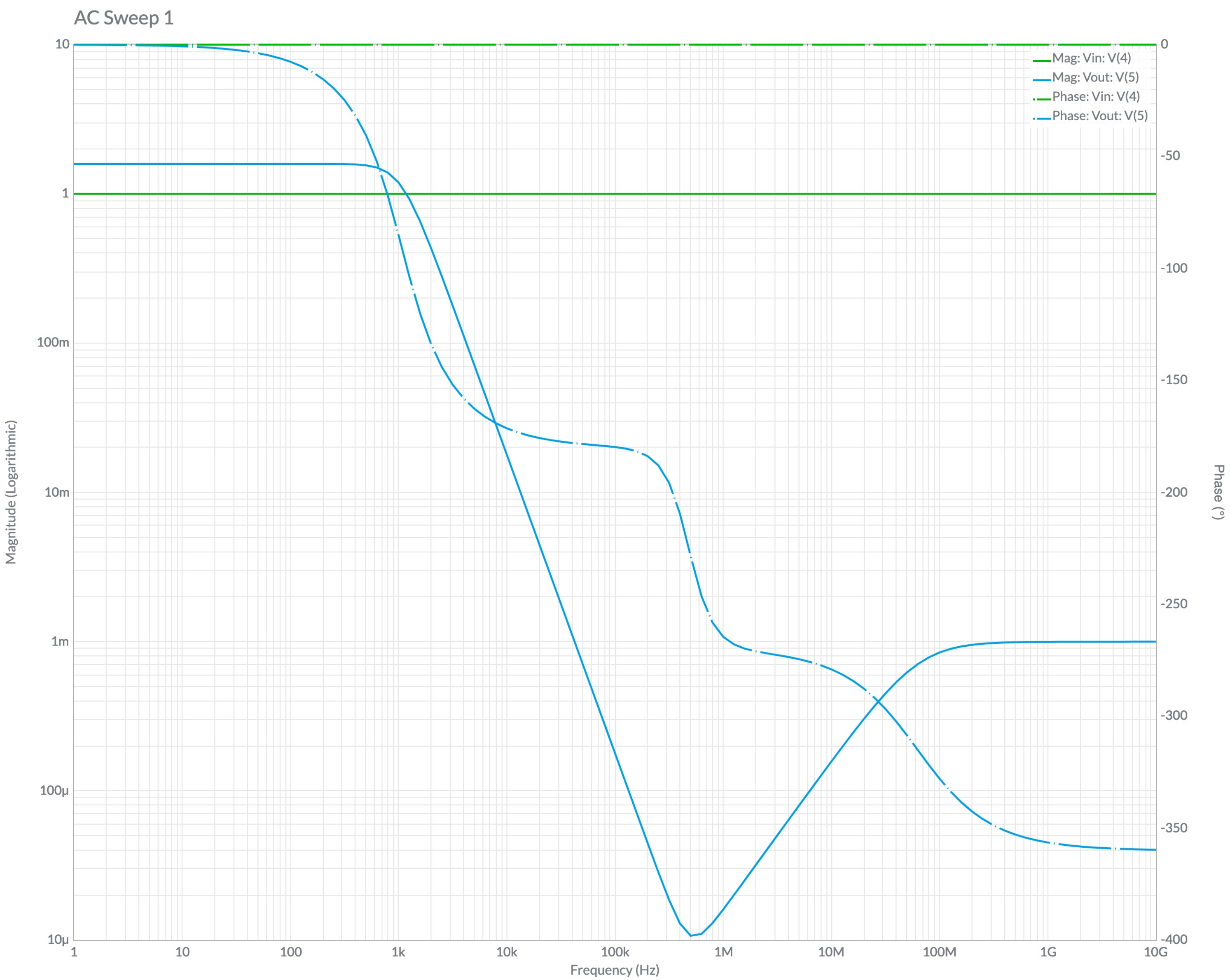
4.2 Observe and record the Frequency-Sweep of the HPF.

4.3 Note the trend observed in the magnitude of the output as the frequency of the input signal increases.

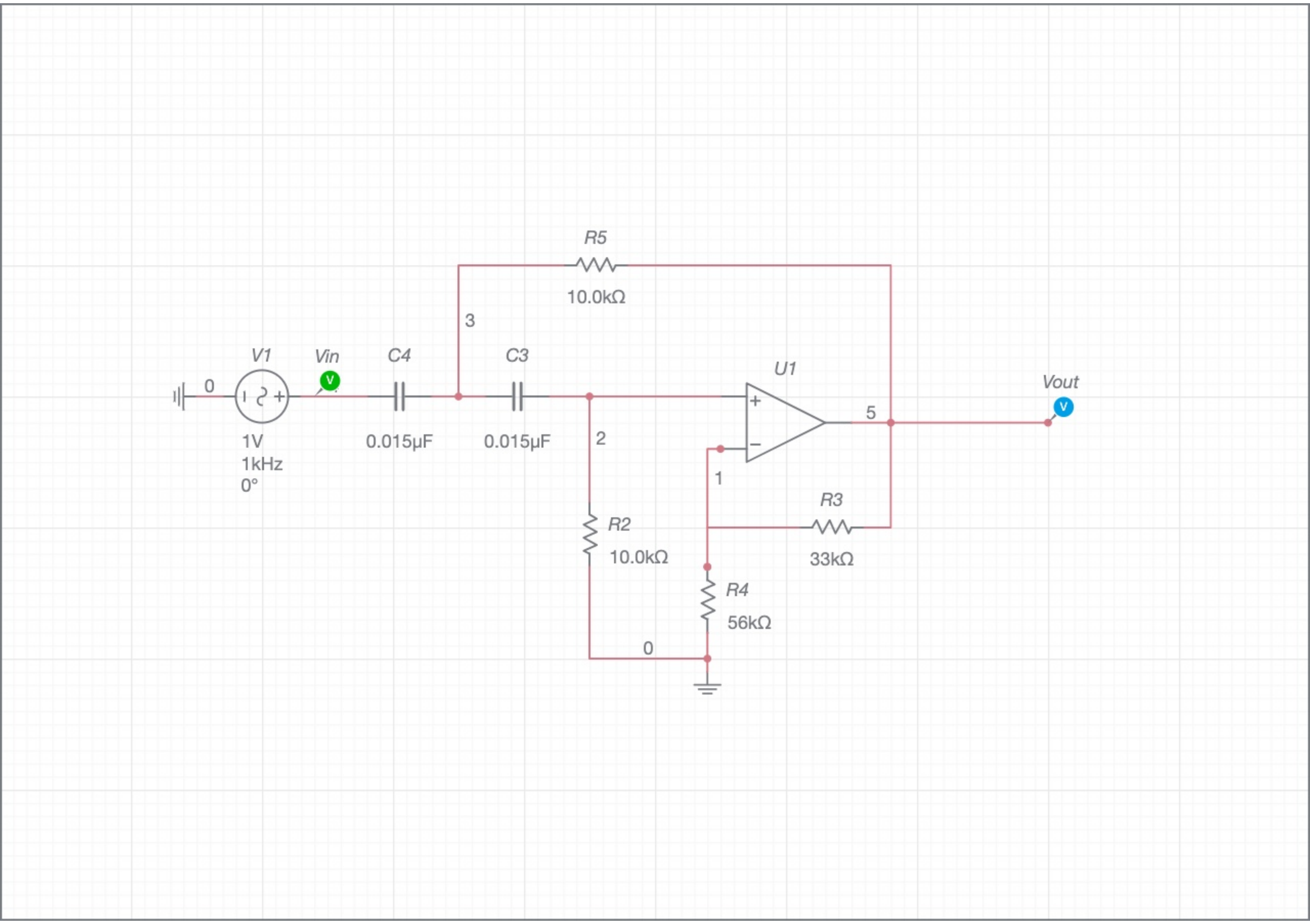
Challenge: How might one use these results to design a 4-th order band-pass or band-reject filter?

connect 2 of each to each other in series

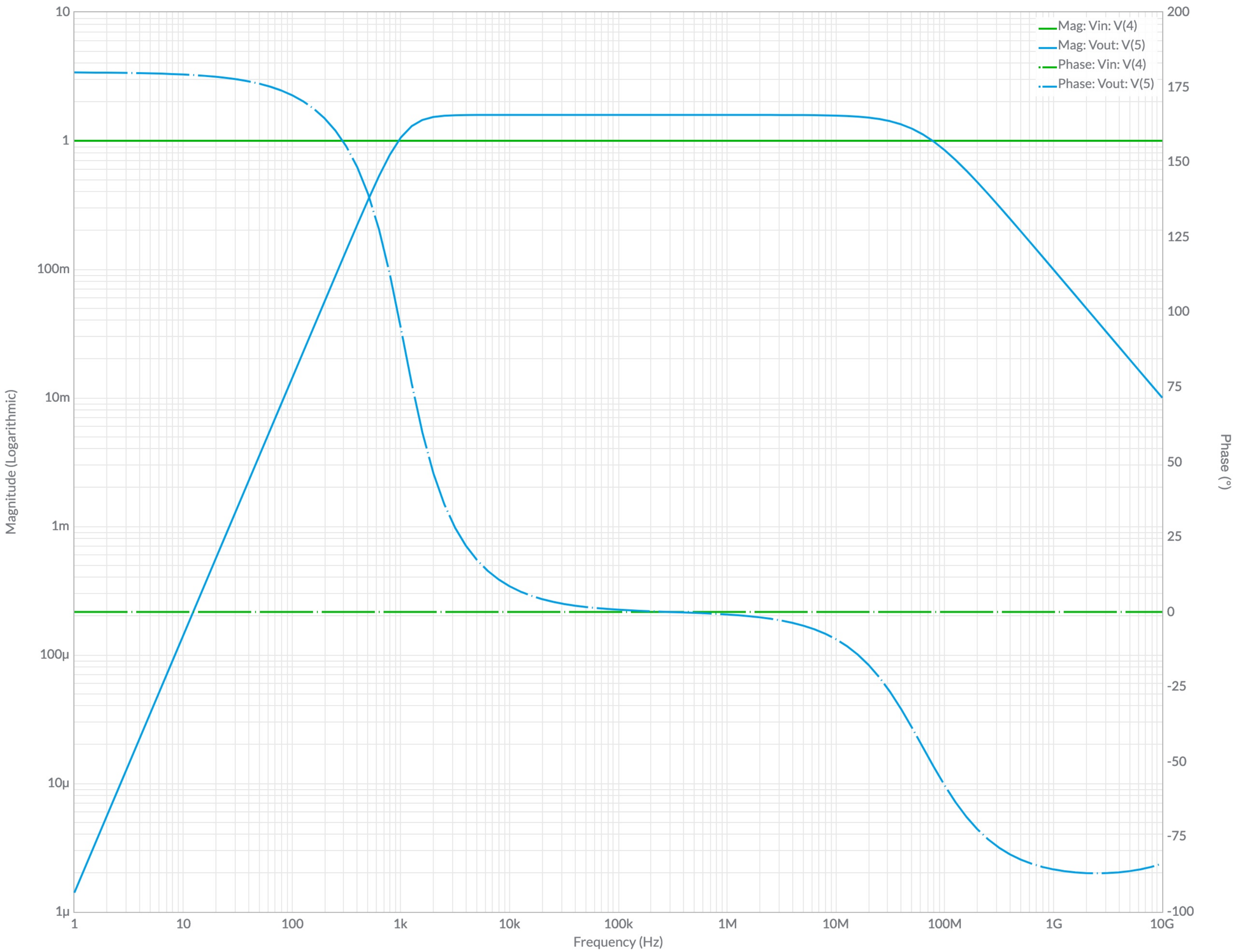

C1
0.015µF
V1
Vin
R1
R2
U1
Vout
0
3
10.0kΩ
10.0kΩ
5
2
1V
1kHz
0°
1
R3
C2
0.015µF
33kΩ
R4
56kΩ
0



AC Sweep 1
Mag: Vin: V(4)
Mag: Vout: V(5)
Phase: Vin: V(4)
Phase: Vout: V(5)
10
1
100m
10m
1m
100µ
10µ
Magnitude (Logarithmic)
0
-50
-100
-150
-200
-250
-300
-350
-400
Phase (°)
1
10
100
1k
10k
100k
1M
10M
100M
1G
10G
Frequency (Hz)


R5
10.0kΩ
3
V1
Vin
C4
C3
U1
Vout
0
1V
1kHz
0°
0.015µF
0.015µF
2
5
1
R3
33kΩ
R2
10.0kΩ
R4
56kΩ
0

AC Sweep 1



Mag: Vin: V(4)
Mag: Vout: V(5)
Phase: Vin: V(4)
Phase: Vout: V(5)
Magnitude (Logarithmic)
10
1
100m
10m
1m
100µ
10µ
1µ
Phase (°)
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Frequency (Hz)
1
10
100
1k
10k
100k
1M
10M
100M
1G
10G

B. In-Lab Procedures

It is extremely important to follow the pinout specs carefully, especially when applying power to the LM741. Refer to the datasheet before energizing. Have the data sheet available during construction.

1. Construction of a 2nd-Order Low Pass Butterworth Filter

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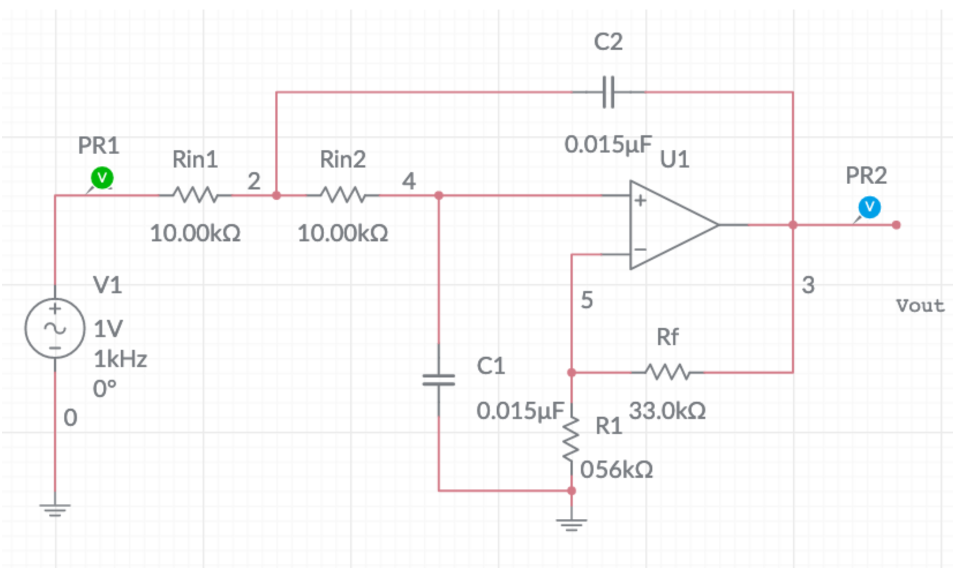

Figure 6: Multisim Schematic of a 2nd-Order Butterworth LPF

1.5 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	3.29	1.62
1000	3.16	1.58
10000	.312	.158
100000	.046	.023
1000000	.027	.0135

1.6 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, voltage decreased linearly, similar to pre-lab

C. Takeaways:

- Filtering is a very useful and frequently-utilized signal processing operation.
- Active filters offer significant flexibility in filter design and implementation.
- Low-pass and high-pass filters can be viewed as mathematical "duals."
- A 4th-order band-pass or band-reject filter can be realized as a concatenation of a 2nd-order low-pass and a 2nd-order high-pass.