

Electric Circuits & Electronics Design Lab

EE 316-01

Lab 5: Basic Filters and Frequency Response

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Lab Section 316-01

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Introduction:

The purpose of this lab is to examine the frequency characteristics of a low and high pass filter. We look at the signal amplitude, signal phase, and how they relate to the input. We also introduce cutoff frequency and what that means. This report will have 5 main sections. First is the theoretical analysis which is done as the pre-lab and includes Multisim simulations and handwritten solutions to the circuit. Then we have the physical circuits which are constructed on breadboards in lab. Afterwards, we compare the results from those 3 sections and conclude with an analysis of the results.

Theoretical Analysis:

To begin, we consider a low pass filter shown in Figure 1. Low pass filters allow low frequencies to pass and blocks high frequencies. The cutoff frequency is what determines what frequencies below a certain point are allowed to pass. Ideally no frequencies above the cutoff frequency would be allowed to pass through. The equation used to find the gain is $\left| \frac{V_C}{E} \right| = \frac{1}{\sqrt{1+(2\pi fRC)^2}}$ and in order to put that in decibels you take $20\log$ of what you get from the gain equation. The phase angle for a low pass filter can be found using $\tan(\phi) = -2\pi fRC$. The phase angle should approach -180 degrees as the frequency increases.

Next, we look at high pass filters which does the opposite and lets high frequencies through and blocks low ones and is shown in Figure 2. The cutoff frequency still determines what frequencies are allowed to pass or not. The equation to find the gain is $\left| \frac{V_C}{E} \right| = \frac{2\pi fRC}{\sqrt{1+(2\pi fRC)^2}}$ and the phase angle is expressed as $\tan(\phi) = \frac{1}{2\pi fRC}$. The opposite occurs for it in that the phase angle will start to approach zero as the frequency increases. The cutoff frequency for both filters can be found with the same equation: $f_C = \frac{1}{2\pi RC}$.

The values calculated are shown in Table 1 and 2 for the low and high pass filters respectively with the accompanying handwritten work provided in Appendix 1. The cutoff frequency was found to be around 160 Hz. Figures 3 through 6 give the plots of gain and phase angle versus frequency for their respective filters.

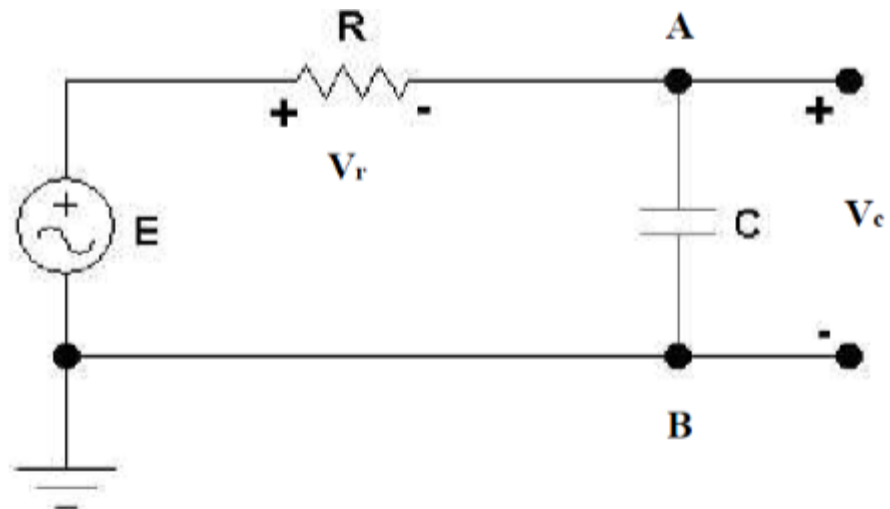


Figure 1. Low Pass Filter

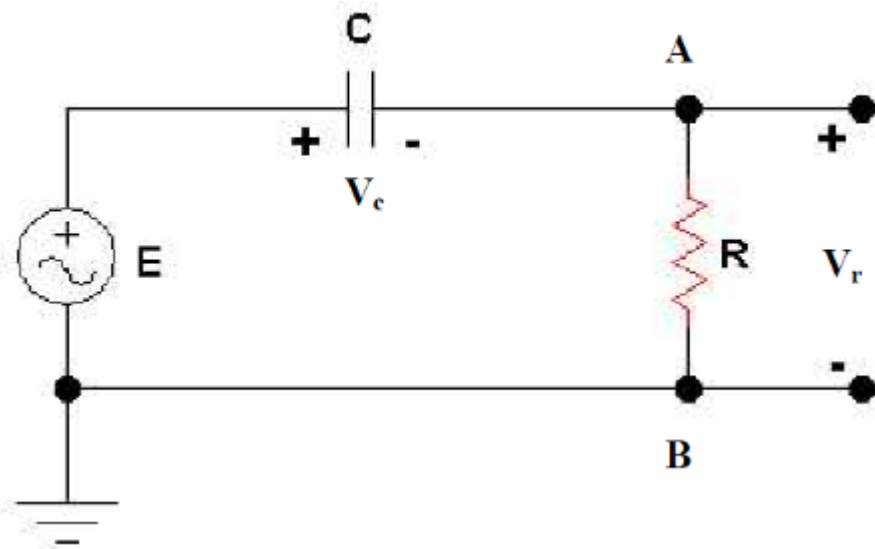
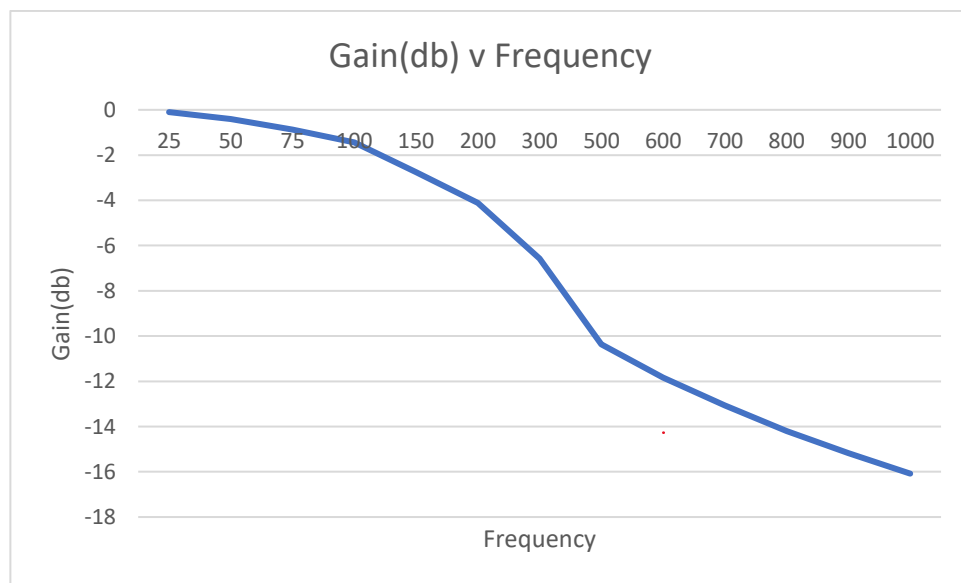


Figure 2. High Pass Filter

Table 1. Low Pass Filter Gain and phase angle

		Theoretical		
F(HZ)	V_C/E	Gain(db)	Phase Angle(rad)	Phase Angle(deg)
25	0.988	-0.10	-0.15708	-9
50	0.954	-0.41	-0.31416	-18
75	0.905	-0.87	-0.47124	-27
100	0.847	-1.44	-0.62832	-36
150	0.728	-2.76	-0.94248	-54
200	0.623	-4.11	-1.25664	-72
300	0.469	-6.58	-1.88496	-108
500	0.303	-10.37	-3.1416	-180
600	0.256	-11.84	-3.76992	-216
700	0.222	-13.07	-4.39824	-252
800	0.195	-14.2	-5.02656	-288
900	0.174	-15.18	-5.65488	-324
1000	0.157	-16.08	-6.2832	-360

**Figure 3.** LPF Gain v Frequency

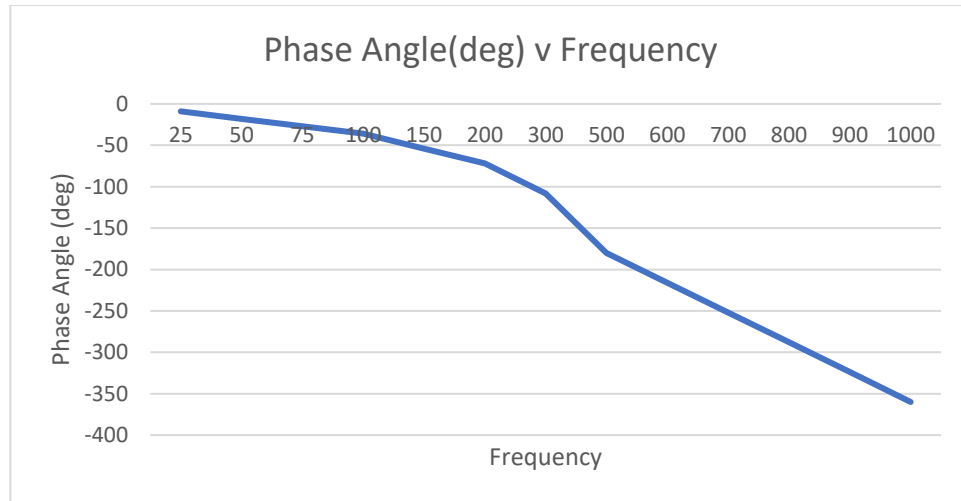


Figure 4. LPF Phase Angle v Frequency

Table 2. High Pass Filter Gain and Phase Angle

		Theoretical		
F(HZ)	V _C /E	Gain(db)	Phase Angle(rad)	Phase Angle(deg)
25	0.1551	-16.18	6.369427	365
50	0.299578	-10.4698	3.184713	182
75	0.426102	-7.40973	2.123142	121
100	0.531825	-5.48463	1.592357	91
150	0.685683	-3.27753	1.061571	61
200	0.782325	-2.13226	0.796178	46
300	0.883286	-1.07797	0.530786	30
500	0.952846	-0.41955	0.318471	18
600	0.966541	-0.29559	0.265393	15
700	0.975089	-0.21911	0.22748	13
800	0.98076	-0.16875	0.199045	11
900	0.984706	-0.13387	0.176929	10
1000	0.987558	-0.10875	0.159236	9

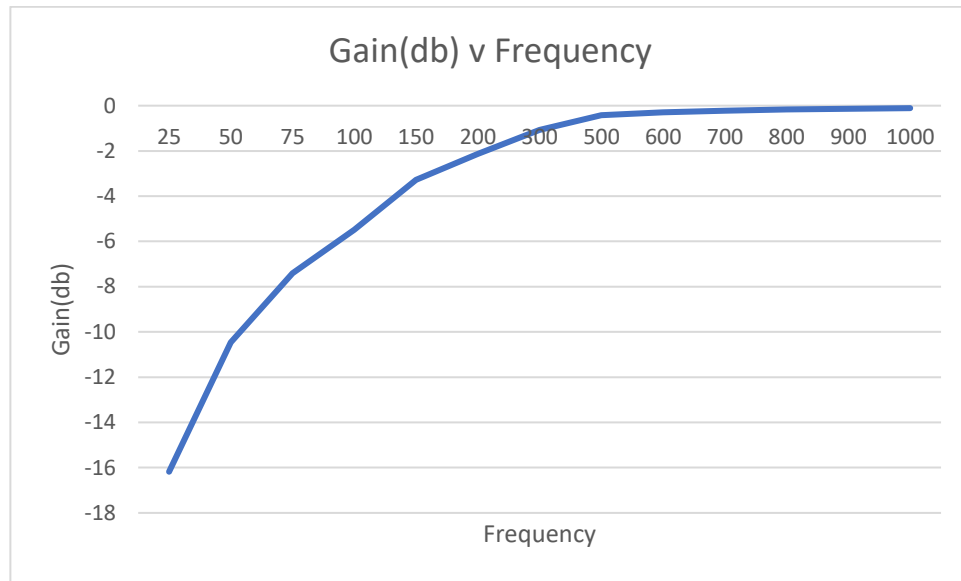


Figure 5. HPF Gain versus Frequency

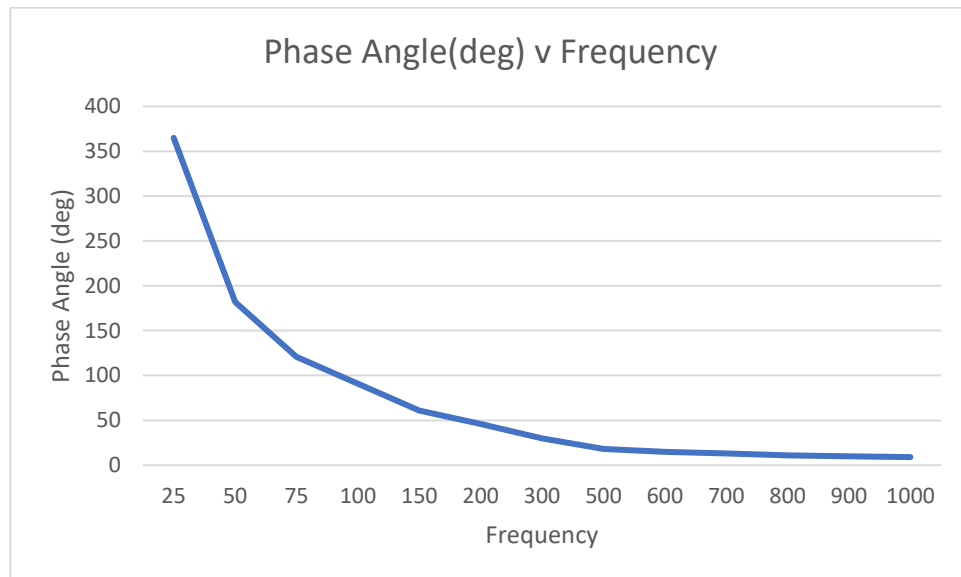


Figure 6. HPF Phase Angle versus Frequency

Simulations:

For the next phase of the lab, we built the circuits from Figure 1 and 2 in Multisim which are shown in Figure 7 and 8. We added the bode plotter so that we could get a plot of the frequency response. Using the bode plotter, we determined the cutoff frequency which occurs when the output is around -3 dB and got a printout of the phase angle. Those printouts are shown below. The cutoff frequency was very close to what we had calculated in the previous section. The high pass filter differs a little more from the calculated value because it wasn't exactly on -3 dB and was on -3.1 dB.

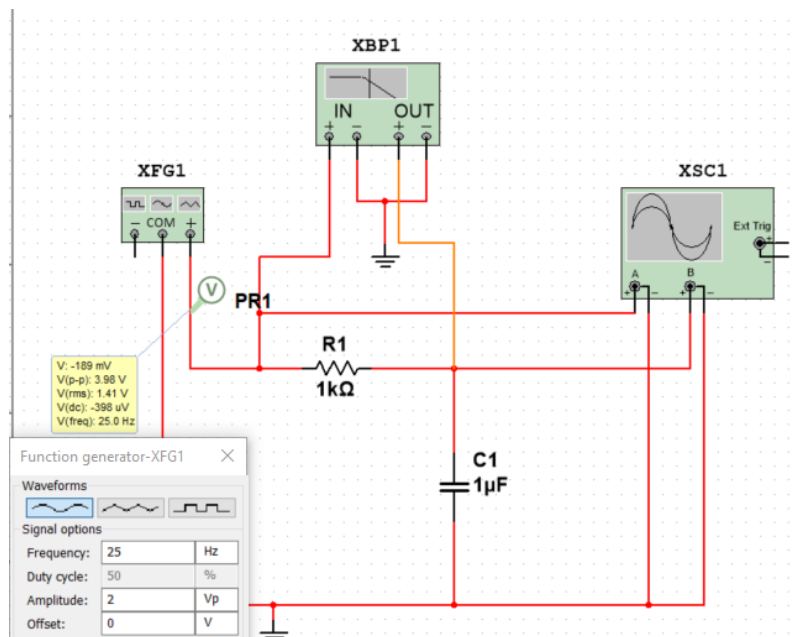


Figure 7: LPF in MultiSim

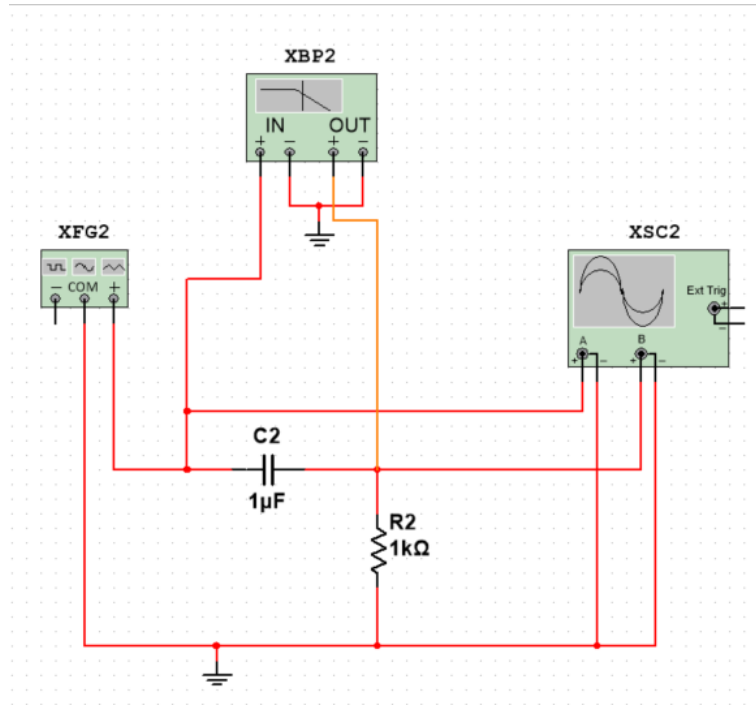


Figure 8. HPF in Multisim

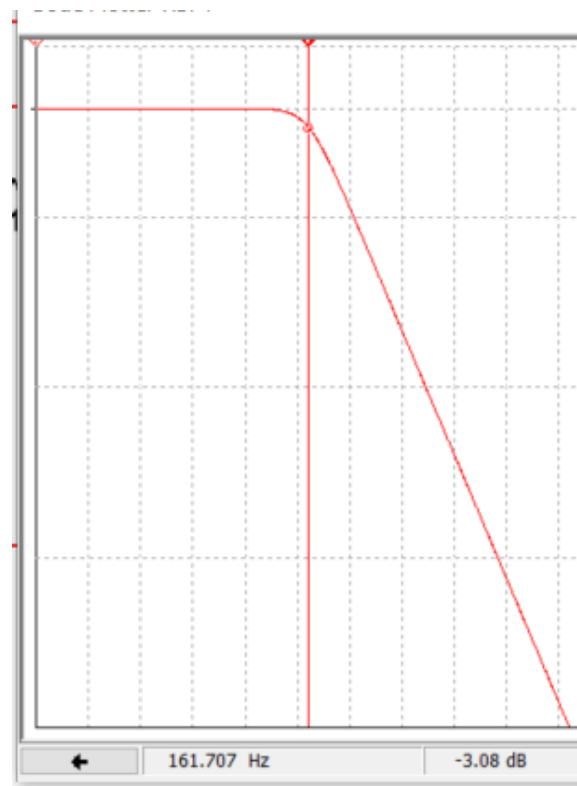


Figure 9. LPF Cutoff Frequency

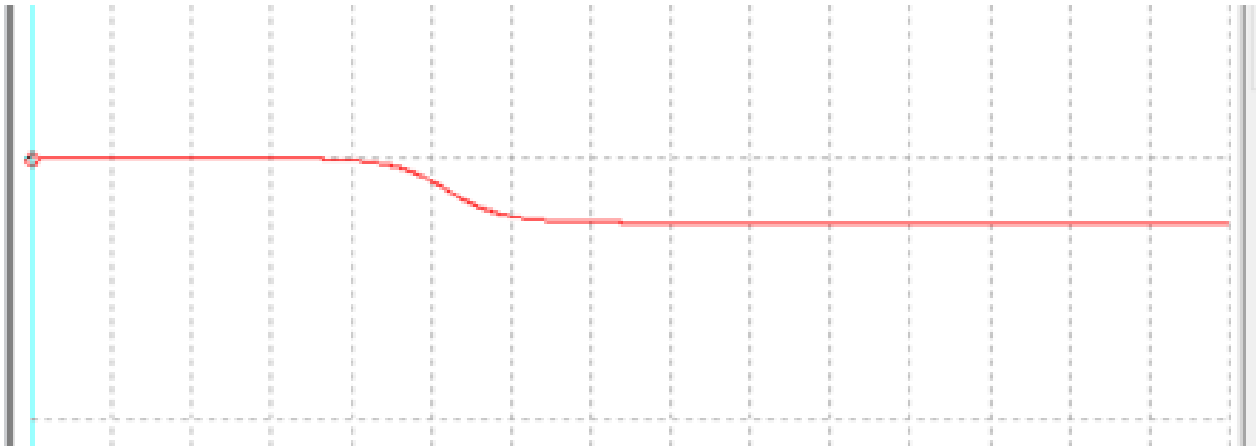


Figure 10. LPF Phase Angle Plot

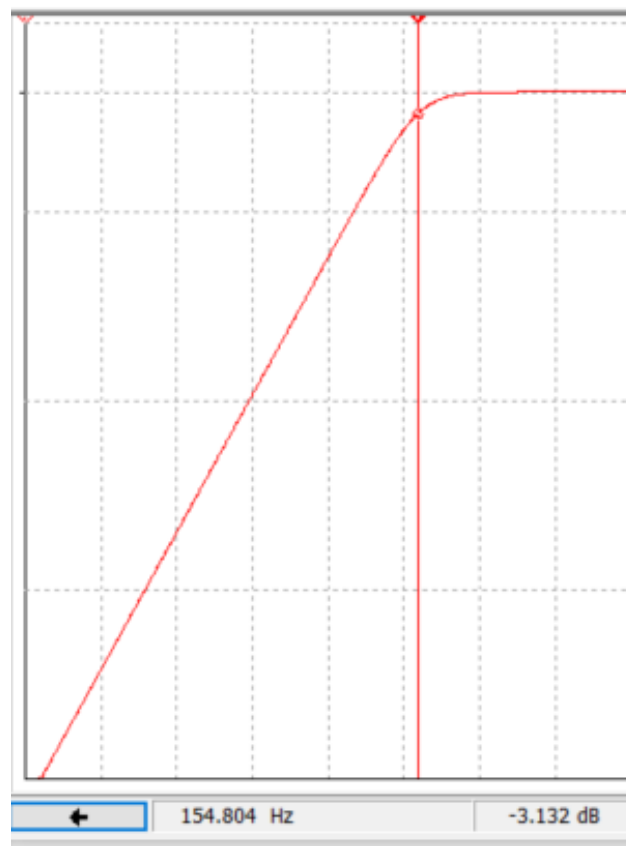


Figure 11. HPF Cutoff Frequency

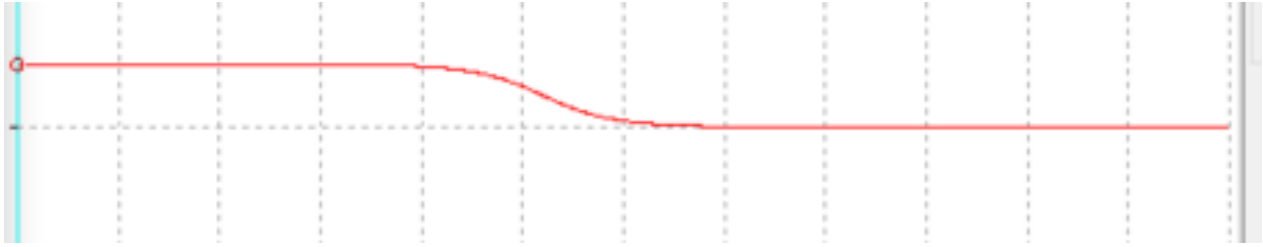


Figure 12. HPF Phase Angle Plot

Experimental:

For the last portion of the lab, we did the same things as prior but on a physical board to further validate the output results we obtained. We attached a function generator and oscilloscope to our circuit the same way as we did for the simulation. The oscilloscope gave us V_{OUT} so we then had to divide that by V_{IN} and take $20\log()$ of that in order to get the gain in dB. The results from are in Table 3 and 4 for the low and high pass filter respectively. The constructed circuit can be seen in Appendix 2.

Table 3. LPF Experimental Results

	Experimental		
F(HZ)	V_C/E	Gain(db)	Phase Angle(deg)
25	4.02	0.043321	-8
50	3.9	-0.21991	-18
75	3.58	-0.96354	-25
100	3.34	-1.56627	-32
150	2.81	-3.06707	-44
200	2.37	-4.54623	-52
300	1.81	-6.88763	-62
500	1.21	-10.3855	-72
600	1.01	-11.9548	-73
700	0.880	-13.1515	-74

800	0.780	-14.1993	-75
900	0.720	-14.8945	-75
1000	0.630	-16.0544	-79

Table 4. HPF Experimental Results

	Experimental		
F(HZ)	V_C/E	Gain(db)	Phase Angle(deg)
25	0.7	-15.1392	80
50	1.29	-9.82941	70
75	1.77	-7.08173	64
100	2.17	-5.31201	56
150	2.71	-3.38181	46
200	3.04	-2.38373	37
300	3.42	-1.36068	27
500	3.66	-0.77158	20
600	3.66	-0.77158	17
700	3.74	-0.58377	15
800	3.74	-0.58377	14
900	3.74	-0.58377	10
1000	3.74	-15.1392	9

Results and Discussion:

The results for the high pass filter for all three types of observations seem to match pretty well. You can see from the experimental results that after passing the cutoff frequency the gain starts to become constant and the phase angle starts to approach 0 as the frequency gets closer to

1kHz and above. Most of the discrepancies in the gain and phase angle are due to rounding errors.

The results for the low pass filter seem to differ until you reach the cutoff frequency and then the discrepancies seem to be rounding errors. The phase angles don't seem to match up at all. In the experimental results they reach -80, and they should be somewhere around -180 and in the theoretical results the phase angles seemed to make a full circle and made it back to -360 degree one it reached 1kHz. I'm unsure of the exact reason there are such huge discrepancies, it is either from miscalculation or the experimental setup up being wrong. It does seem to at least follow the expected behavior of being a constant value before the cutoff frequency; however, it's behavior is not as clear as the high pass filter

Conclusion

Overall, the results of lab followed the behavior we expected and observed from our calculations. It gave us an understanding of how low and high pass filters work and what to look for to find the cutoff frequency. We can now spot the difference between the two if given a plot of their frequency behavior. All together the lab helped further our understanding of commonly used circuits.

Appendix 1:

Used excel to generate the numbers

Theoretical Lab 5

$$\tan(\phi) = -2\pi fRC$$

$-2\pi RC$ constant only need to change f
 $-2\pi(1k)(1\mu F)$
 $\approx -6.2832 \times 10^{-3}$
 $-6.2832 \times 10^{-3} f = \tan(\phi)$

Prelab has results

* Note 1000 f has the phase angle equal to $-2\pi RC$

$$\left| \frac{V_C}{E} \right| = \frac{1}{\sqrt{1 + (2\pi fRC)^2}}$$

phase angle #

$$\frac{V_C}{E} = \frac{1}{\sqrt{1 + (\text{phase})^2}}$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{6.2832 \times 10^{-3}} = 159.15 \approx 160$$

$$\tan(\phi) = \frac{1}{2\pi fRC}$$

$\frac{1}{(6.2832 \times 10^{-3}) f}$

6.207×10^{-18}
 1.988

$$\frac{V_C}{E} = \frac{(6.2832 \times 10^{-3}) f}{\sqrt{1 + (6.2832 \times 10^{-3})^2 f^2}}$$

0.9528

* Note used excel on this one and 3.14 as pi whereas
 Low Pass was calculator and pi button

x-axis

db vs freq
 phase vs freq

$$20 \log \left(\frac{V_{out}}{V_{in}} \right)$$

Appendix 2:

Signed lab results

	High		Low	
	Gain	Phase	Gain	Phase
25	0.7	80°	4.02	-8°
50	1.29	70°	3.9	-18°
75	1.77	60°	3.58	-25°
100	2.17	50°	3.34	-32°
150	2.71	40°	2.81	-44°
200	3.04	37°	2.37	-52°
300	3.42	27°	1.81	-62°
500	3.66	20°	1.26	-71°
600	3.66	17°	1.01	-73°
700	3.74	15°	0.88	-74°
800	3.74	14°	0.780	-75°
900	3.74	10°	0.720	-75°
1000	3.74	9°	0.630	-79°

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Pictures of Circuits

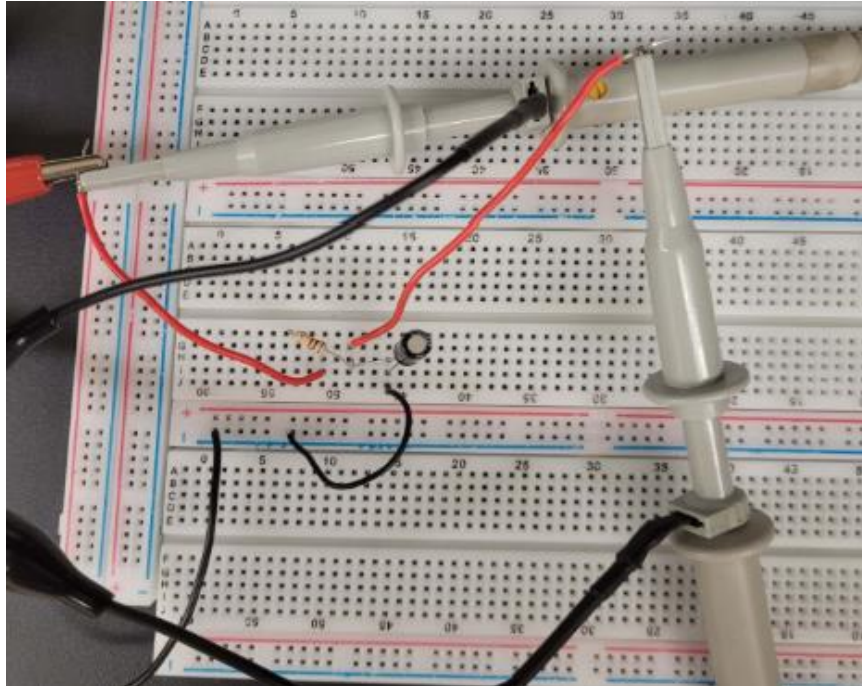


Figure 1. LPF

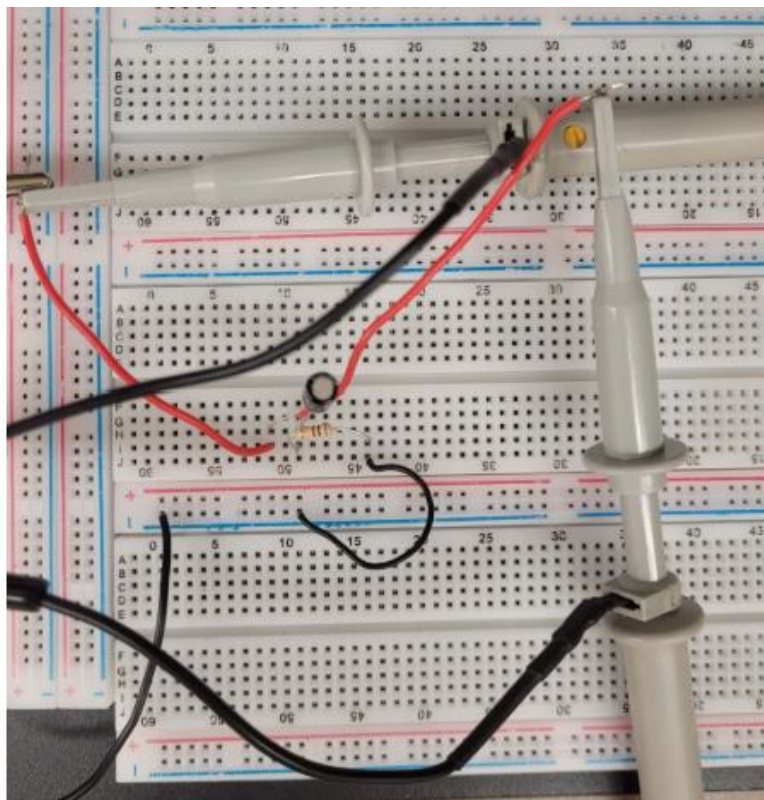


Figure 2. HPF

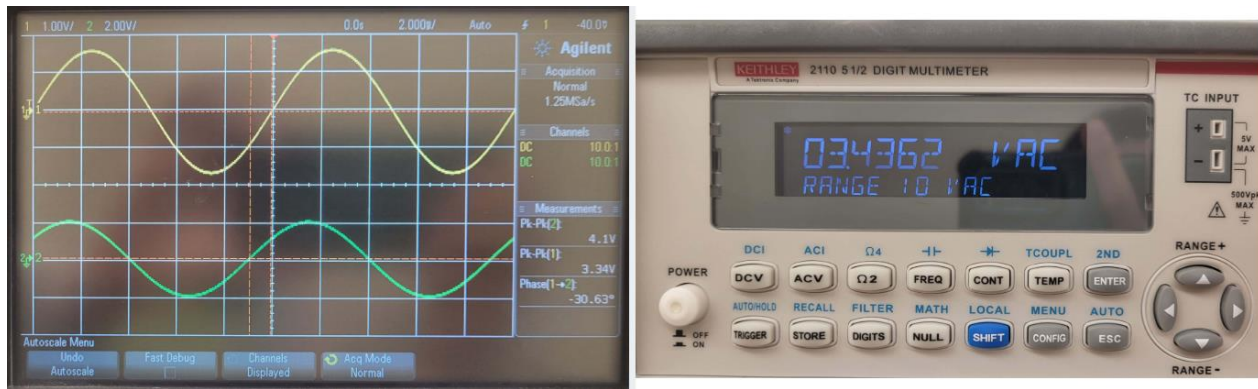


Figure 3. Example Output from LPF 100Hz