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Phys 330 – Electronics

High and Low Pass Filters

Abstract:

During this lab, I experimented with Capacitors and resistors to create high and low-pass filters. I used Analog Discovery 2 to send sine, square, and triangle waves into various constructed circuits. I was given a random resistor and capacitor for part of the lab. Through testing, I was able to find my resistor value to be roughly 1k Ohm and the capacitor was 100 nF. After that, I used what I learned to experiment with a Differentiator and an Integrator circuit. For part 2 of the lab, I built a low-pass filter and attempted to find the -3dB frequency with a given resistor in series with a given capacitor. I found this frequency to be roughly 1.05 kHz. I then use the filter to clean a noisy signal. I generated a wave with a 10% voltage bounce outside the expected range. After running the wave through my filter, I got a 9% inconsistency in my wave. The last thing I tested in this lab was a high-pass filter and I calculated the cutoff frequency to be 1.1 kHz.

Background & Theory:

Filters are essential components in signal processing that are used to allow or suppress specific frequency ranges from a signal. Based on their function, filters can be categorized into different types, with high-pass and low-pass filters being two of the most used. A low-pass filter is designed to allow signals with frequencies lower than a certain cutoff frequency to pass through while reducing the amplitude of signals with frequencies higher than the cutoff frequency. This type of filter is commonly used in audio processing, electronics, and communication systems to remove high-frequency noise or to extract low-frequency components from a signal. A high-pass filter does the opposite: it allows signals with frequencies higher than the cutoff frequency to pass while signals with frequencies lower than the cutoff get suppressed. high-pass filters are used in applications where high-frequency components need to be preserved and lower frequencies removed. The key difference between high-pass and low-pass is the order of your capacitor and resistor. Both filters use the same equation when calculating the -3dB cutoff frequency which can be found below in equation 1.

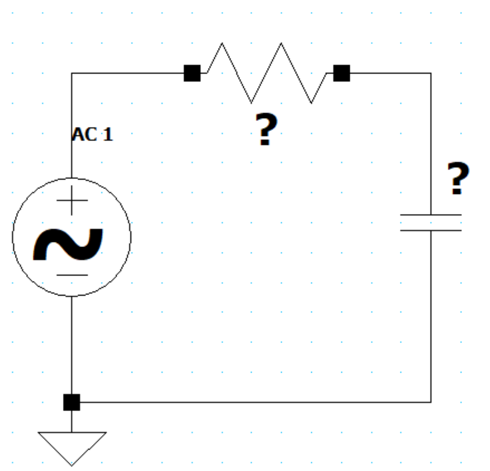
[EQ 1]

$$f_c = \frac{1}{2\pi RC}$$

Procedure & Analysis:

I worked through multiple processes in this lab and will demonstrate how I worked through them in my procedure. For this lab, because the circuits were so simple creating the systems proved easy while data acquisition was more difficult. My first task was finding an unknown resistance and capacitor in a RC circuit. The circuit construction can be found below in Figure 1.

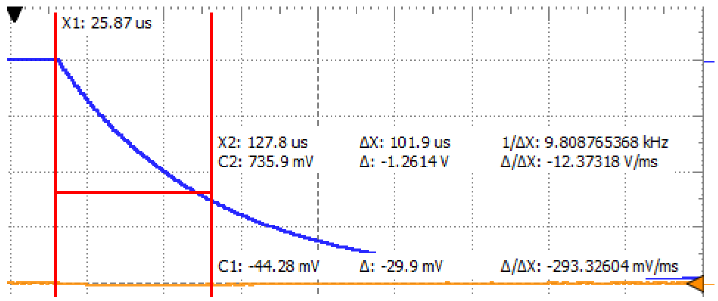
[Figure 1]



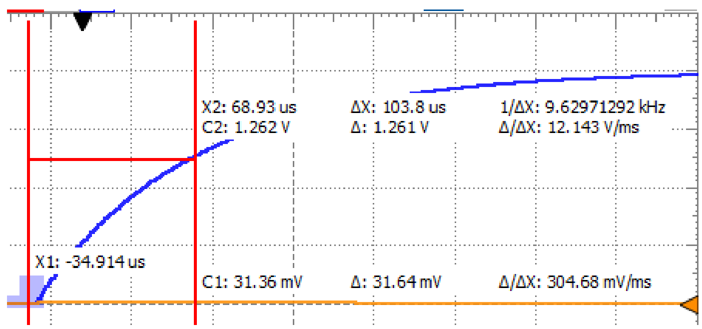
For this circuit, I set my waveform to measure
on each side of the capacitor and set up a voltage divider.

This circuit caused me many issues because I was getting strange variations in my measurements. At low amplitude, waveform seemed to struggle giving me consistent data. I set my waveform to measure the fall and rise of a square wave. I was looking for the time it would take to fall to 37% of the amplitude and rise to 63% of the amplitude. After 3 rounds of experimentation, I found the fall to be approximately 101.9 microseconds and the rise to be 103.8 microseconds. The other tests gave me different values but that was because Waveform didn't have high accuracy at 1 volt, and I wasn't starting my measurements from the absolute peak or minimum. The final graphs can be found below in Figures 2 and 3.

[Figure 2] This is the fall the only value I need is ΔX



[Figure 3] This is the rise the only value I need is ΔX



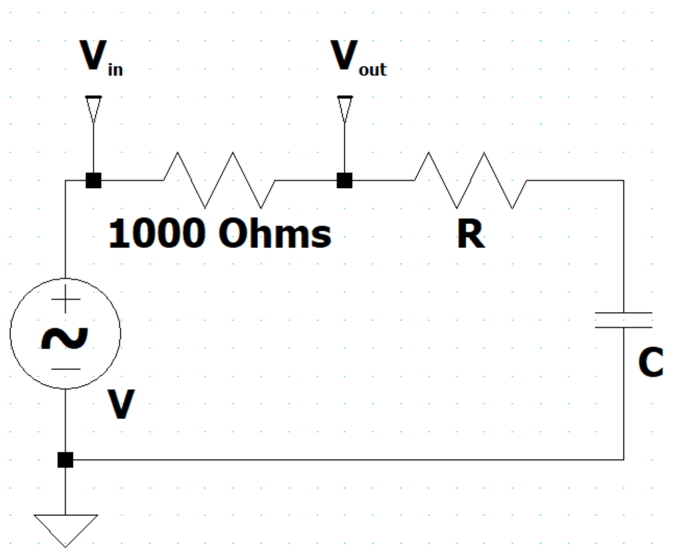
This gave me the time it took for my capacitor to charge and discharge. Because I had time, I could use an equation that relates resistance, capacitance, and time to circuit voltage. Luckily, I can find that below in equation 2.

[EQ 2]

$$V_{out} = V_{in}\left(1 - e^{-\frac{t}{RC}}\right)$$

With this equation I now only needed to find a way to either measure R or C then I could find one or the other. The good news is that because capacitance is 1 over the angular frequency if my frequency is super high capacitance will be negligible in my system. Then all I had to do was add another resistor this time with a calculated value and change my voltage divider to include my unknown resistor. This new circuit can be found in Figure 4 and shows the places where I will be reading my input and output voltage.

[Figure 4]



By using this circuit at high frequency, I could limit my variables to my known input voltage and resistance and my observed output voltage.

I constructed a new voltage divider and started to create my new equation. The new equation can be found below and the process I used to make it.

[EQ 3]

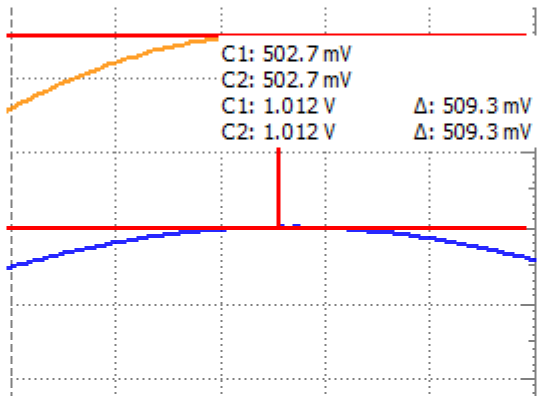
$$V_{out} = V_{in}\frac{R}{1000 + R}$$

$$R = \left(\frac{1000 * V_{out}}{V_{in} - V_{out}}\right)$$

At high frequency only

After making my equation I set up my waveform to send a 1-volt wave to measure the drop for the output voltage. This can be found below in Figure 5.

[Figure 5]



This figure shows a zoomed-in section of the two sine waves with an amplitude difference of approximately half a volt.

The resistor I was using wasn't exactly 1000 Ohms, it was 985 Ohms so after using Equation 3 I found the resistance to be 972 Ohms. This made me believe I was given a 1k Ohm resistor. The last part I needed was to find my capacitance and to do this I used equation 2 to find the capacitance necessary to get my time for 37% output. This led to a new equation I constructed found below in equation 4.

[EQ 4]

$$-1 = -\frac{t}{RC}$$

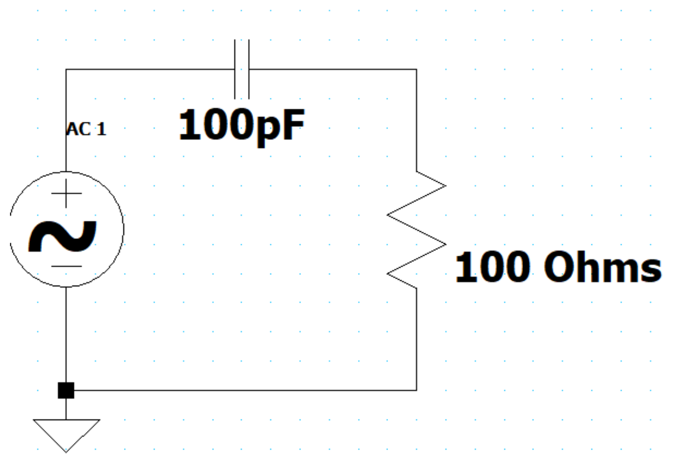
$$C = \frac{t}{R}$$

$$C = \frac{103 \, microseconds}{972 \, \Omega}$$

This was able to find me a capacitance of 102 nF

After this I built a Differentiator and attempted to verify what I built was a Differentiator. The circuit I built can be found below in Figure 6.

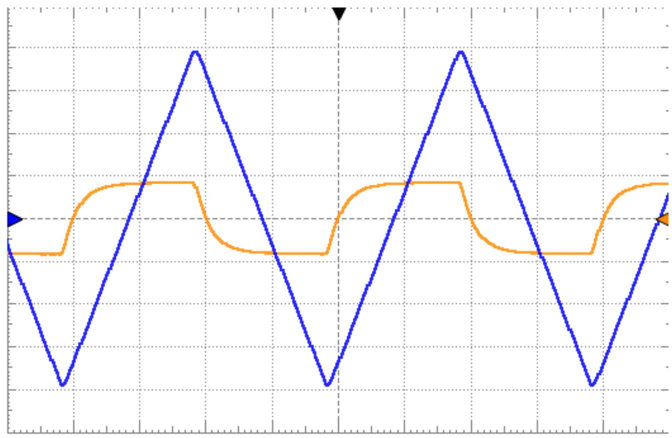
[Figure 6]



For all the testing, I used waveform and connected channels 1 and 2 on each side of the resistor

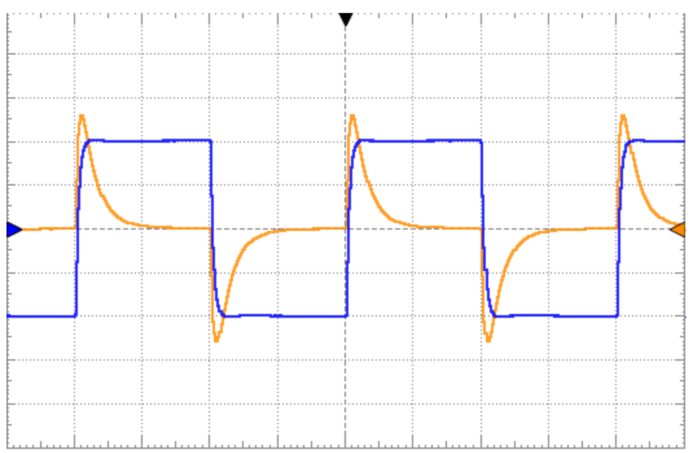
For this to be a differentiator I needed to use a wave that I could tell was the derivative of the other. To do this I generated a triangle wave and square wave then checked to see if I was getting the differential wave out. The outputs that verified these relationships can be found below in Figure 7 and 8.

[Figure 7]



As you can see above though the wave has a slight bend to the front and back it is a square wave.

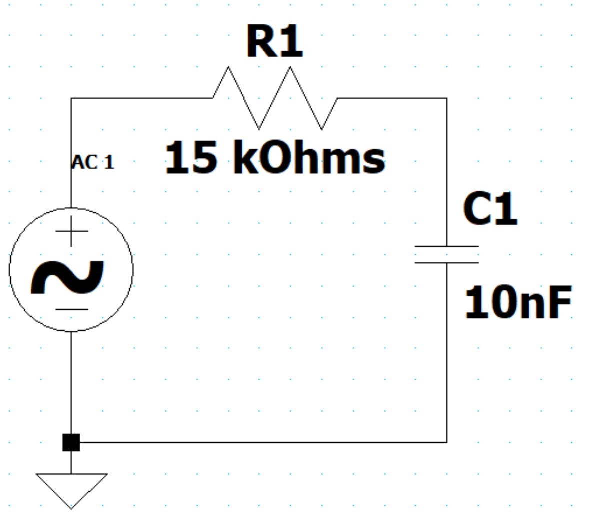
[Figure 8]



The generated square wave produces a spike wave that perfectly matches its differential

The integrator led right into part two of the lab Low-pass filters. In my notebook, I started by using the incorrect equation but humorously enough it was so close to the actual equation it didn't change anything. The circuit I would be building can be found below in Figure 9 and I would be sending a sine wave across a range of frequencies to find the -3dB cutoff frequency. This is an equation we found in our background above in equation 1.

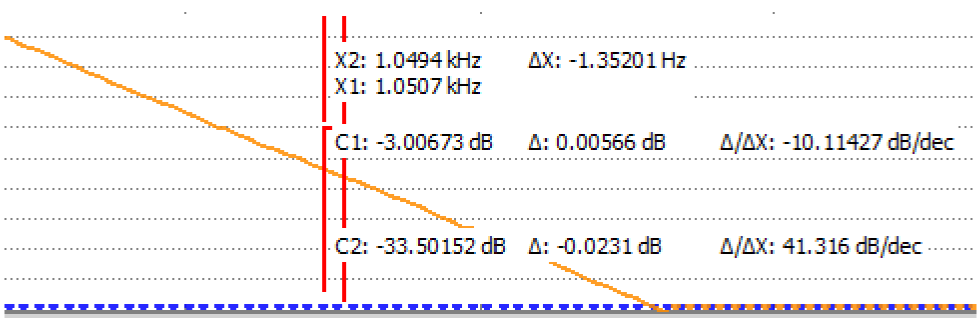
[Figure 9]



For this circuit, I would be checking decibel drop over the capacitor over a range of frequencies.

After plugging in the resistor and capacitor value I was given I found my cutoff frequency should be roughly 1.06 kHz. I was able to use a waveform network to verify this in figure 10.

[Figure 10]



The actual -3dB number Is -3.0105dB but I was only looking to verify my math.

My next assignment was to smooth a signal using this same circuit by sending a wave with a lot of noise. I generated a sine wave that would have 10% noise and checked to see the voltage at the capacitor for an array of times. I then exported these values to a CSV and compared them to a perfect sine wave. I got 8000+ values and calculated the percent error for each but a screenshot can be found in Figure 11 that shows my percent error for my average noise.

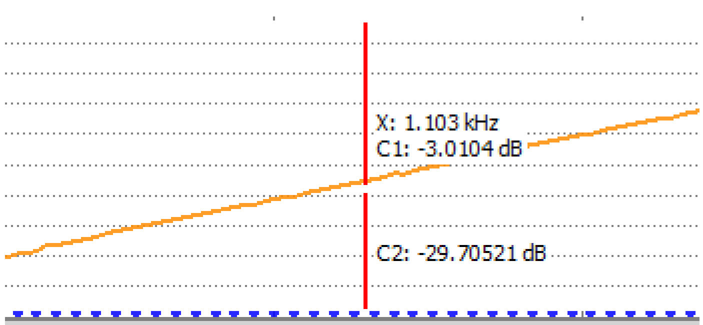
[Figure 11]

#Frequency: 200 Hz							
#Period: 5 ms							
#Amplitude: 1 V							
#Offset: 0 V							
#Phase: 0 °							
Time (s)	Channel 1	Channel 2 (V)					Average Noise%Err
-0.00512	-0.13614	0.002425		-0.14971	9.063293		9.421974887
-0.00512	-0.13479	0.003429		-0.14815	9.017976		
-0.00512	-0.13311	0.003764		-0.1466	9.200899		
-0.00512	-0.13177	0.003094		-0.14505	9.15563		
-0.00511	-0.13009	0.002425		-0.14349	9.343549		
-0.00511	-0.12874	0.003094		-0.14194	9.298396		
-0.00511	-0.1284	0.00209		-0.14038	8.533252		
-0.00511	-0.12672	0.00276		-0.13883	8.719826		
-0.00511	-0.12571	0.00276		-0.13727	8.420365		
-0.00511	-0.12403	0.002425		-0.13572	8.609463		
-0.00511	-0.12235	0.002425		-0.13416	8.80272		
-0.00511	-0.12134	0.00276		-0.1326	8.492996		
-0.0051	-0.11966	0.00276		-0.13105	8.689002		

This file was able to show me I reduced noise to ~10% of a perfect sine wave

Finally, just to round things off I needed to build a high-pass filter and check to see if the cutoff frequency was the same. For the high-pass filter, I used the same resistor and capacitor I used in the low-pass filter found in Figure 9. The only difference is I swapped their respective positions in other words I measured across the resistor. This was able to give me my cutoff frequency found below in Figure 12.

[Figure 12]



This shows the difference between high-pass and low-pass cutoff was 40 Hz

All the data I found in this lab was supported by one another, however some of my data had large ranges. Many of the times I was reading Hertz just 10 data points could range by 5 to 20 Hertz. When I wanted to check the resistances, I had none of them were the actual numbers I was working with. Almost every resistor was 10% lower than the assumed resistance. This lab is all about getting close enough to be confident in your understanding and knowing that I feel my data is very good.

Conclusion:

This lab taught me a lot about the nature of high-pass and low-pass filters. It also taught me I don’t need to fuss over a couple of Hz differences and to pay more attention to percentage error rather than statistical error. The common problems I ran into during this lab were maneuvering around waveforms and algebraically breaking down equations.

Sources

Lab3 Notebook