Operational Amplifiers

Laboratory 3

EE 101 Winter 2016

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Section: 1, Monday 9:00am – 11:00am

Prof. Joel Kubby

2/15/2016

Introduction:

The purpose of this lab was to understand operational amplifiers and their use in circuits. And as I progressed through lab, I found theoretical calculations of voltage out, I was able to compare them with the experimental values found. Based upon these calculations, I was able to understand the differences of inverting and non-inverting amplifiers. This brings up the idea of the operational amp model. The “ideal” operational amp model has an infinite open-loop gain, an infinite input impedance Rin, and zero noise. The ideal operational amp tries to make the voltage difference between the inputs zeroes that the input draws no current. More specifically, inverting amplifiers have negative voltage gain; whereas the non-inverting amplifiers have positive voltage gain. But, before I got ahead of myself, I needed to know more about topics learned in class, such as an op amp circuit model. Here in this lab, I used the LM 741, an op amplifier, to demonstrate my understanding of the op amp circuit model. By following the steps: verifying negative feedback, assume the differential input voltage and input current of the op amp are forced to zero by summing-point constraint, and applying standard circuit-analysis principles, I was able to analyze a circuit with the LM 741. However, using negative feedback is only one portion of the lab; I also tested capacitors that created integrator circuits and differentiators. These integrator circuits I tested for were produce output voltages that were proportional to the integrated time of the input voltage. As for the differentiator, it produced a voltage output proportional to the input voltage’s rate of change.

Part 1: DC Amplification

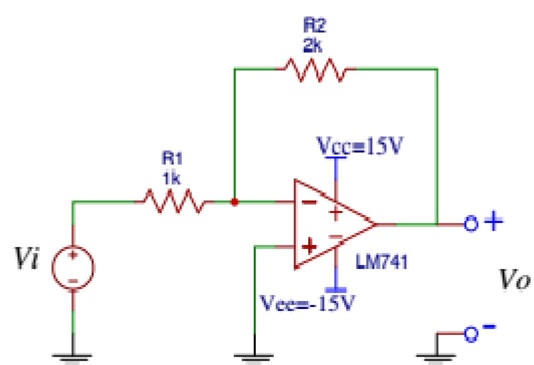


Figure 1: Our Amplifier circuit for Part 1

1. Applying the summing point constraint, theoretical I was able to force 0 voltage between the inputs, which allowed for the following equation: Vout / Vin = - R2/ R1. Thus, I was able to understand that this was an inverting amplifier, where it’s theoretical gain is –R2/ R1 or – (2k ohms/ 1k ohms) = -2.

2. I built the following circuit, Figure 2, neatly and clearly with the verification of the instructor Armando.

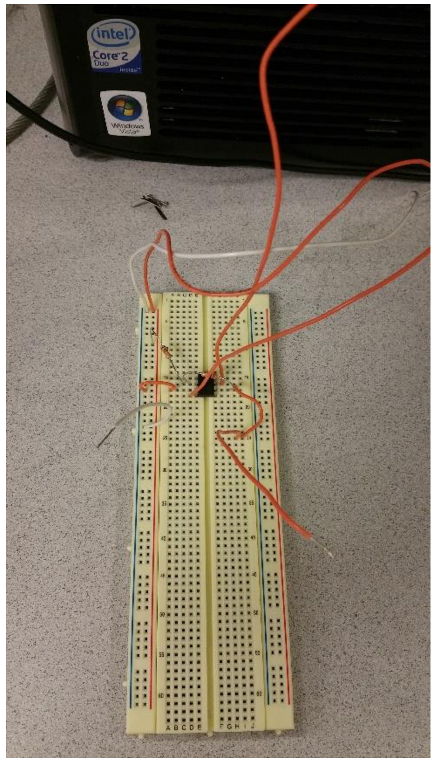


Figure 2: Inverted amplifier

3. After connecting and verifying that my circuit was correct, I connected the DC power supply to the circuit and recorded the input and output voltages on a table, Figure 3.

Vs (V)	Vo (V)
-5	10.499
-4	8.558
-3	6.46
-2	4.18
-1	2.004
0	0.00613
1	-1.996
2	-3.998
3	-6
4	-7.999
5	-9.997

Figure 3: Input, Vs, and Output, Vo

4. With the table intact, I was able to draw the best-fit straight line of Vo vs Vs, Figure 4, from my table. The slope of the graph was -2, which coincidently happens to be the theoretical gain.

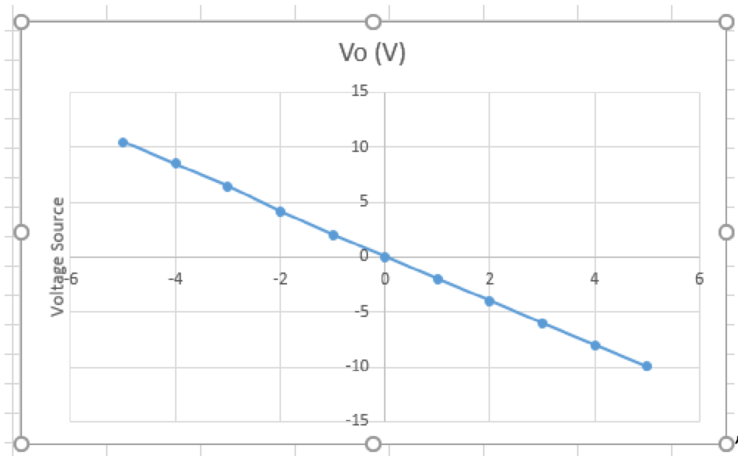


Figure 4: The best fight graph of Vo vs Vs

5. The slope from this best fit graph is that Vs/Vo = -2; this can be compared to my theoretical value where I applied the summing point constraint on the circuit given to us and found out the theoretical gain.

6. At this part, I expanded my input voltage from -10 Volts to 10 Volts and calculated the new graph of Vo vs Vs, as seen in Figure 5 with table and Figure 6 with the graph. This graph has a Plato around 13 voltages due to the constrains on the op amplifier set to -15 volts and 15 volts.

Vs (V)	Vo (V)
-10	13.963
-9	13.973
-8	13.984
-7	13.995
-6	12.23
-5	10.499
-4	8.558
-3	6.46
-2	4.18
-1	2.004
0	0.00613
1	-1.996
2	-3.998
3	-6
4	-7.999
5	-9.997
6	-11.992
7	-13.259
8	-13.243
9	-13.226
10	-13.209

Figure 5: Table for Voltage Source vs Voltage Out

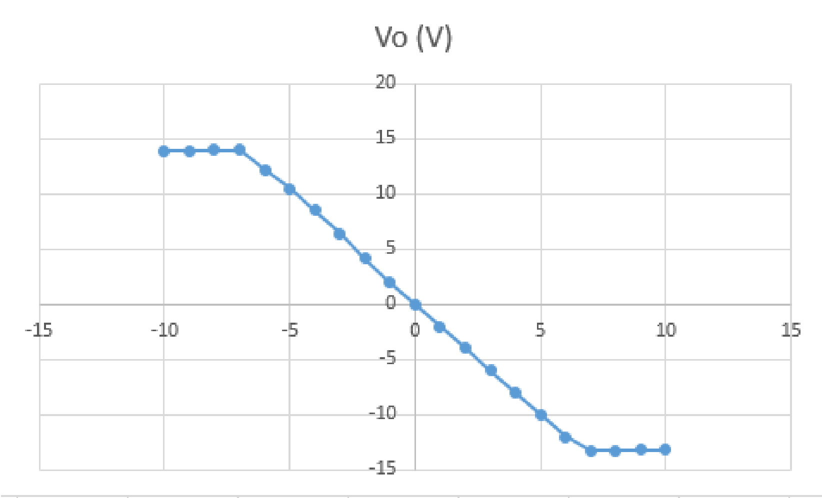


Figure 6: Graph Voltage Out (Y-axis) vs Voltage Source (X-Axis)

7. In Figure 6, one can clearly see that the slope of the operational amplifier was at a steady -2 until it closely reaches the positive supply voltage and negative supply voltage of our LM741H. This seems to determine that our voltage clearly reaches a point where the voltage is constant and is bounded.
8. For this part I set the Voltage Source to 3 Volts and measured the current through our R1 (experimentally 0.988 kohms resistor) and R2 (experimentally 1.975kohms) from Figure 1. We obtained that the current through R1 was 2.987 mA. We have Vs, I1 current and know that the summing point constraint forces the voltage drop to 0.

Therefore, with the Kirchhoff's Voltage Law, we have I1 = -VS / R1, solving for R1, R1 = -Vs / I1 = (3 Volts) / (0.002987A) = 1004 ohms or 1.004 kohms.

9. For this part I set the Voltage Source 0.5 Volts and measured the exact output voltage Vo to be -0.996 Volts. Then we connected an 82 ohms' resistor because the lab was out of 100-ohm resistor and measured the Vo to be -0.997 Volts. Now that we have Vo, we can use the voltage gain to theoretically calculate our output resistance of the op amp. R2 = R1*Vs / Vo = -((82ohms* 0.5Volts)/ (-0.997 Volts)) = 41.123 ohms.

Part 2: AC Amplification

1. For this part of the lab we continued the circuit used in Figure 1; however, we used a function generator to sinusoidal signal with 1V amplitude and 100 Hz frequency. Thus we obtained a signal observed in Figure 7, and can determine that the phase difference between the Vs and Vo was around 89° of the Voltage Source as a reference of time. Thus can lead us to the conclusion that the phase difference can be calculated Asin (wt – x) where x is any point on the graph. Thus, theoretically vo = AvVi = (-2) (1sin(100wt)) = -2sin(200pi); sin(z) = cos(z-90°) ~ estimate of 89° phase difference.

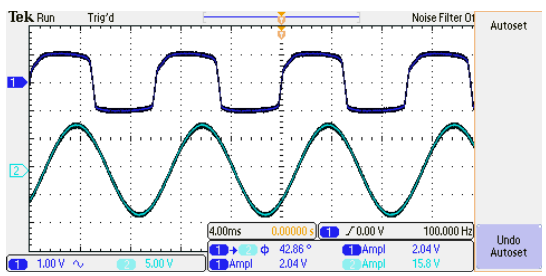


Figure 7: 1 V amplitude and 100 Hz Frequency on Figure 1 circuit

2. Next we set to increase the amplitude of Voltage source to 8 Volts and we observed the following in Figure 8, a voltage change; where the output voltage increased 8 times as if it were to be 1 voltage.

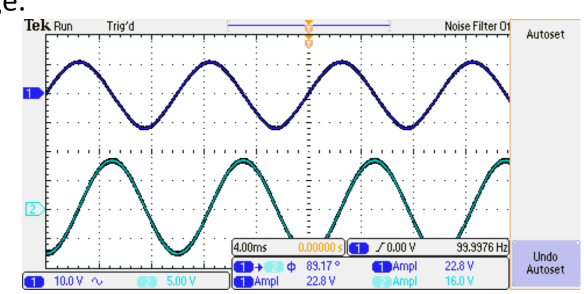


Figure 8: 8 V amplitude and 100 Hz Frequency on Figure 1 circuit

3. For this part we set R1 = 9.92kohms (theoretically 10kohms) and replaced R2 with a capacitor C1 = 0.1 microfarads as show in Figure 9.

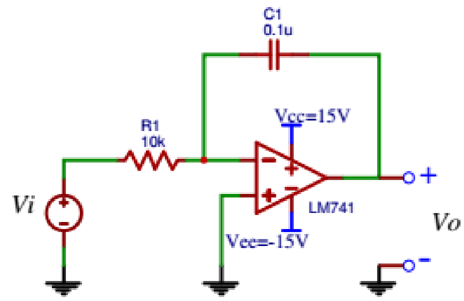
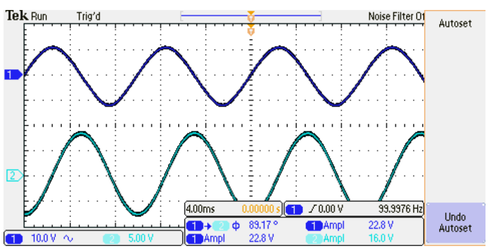


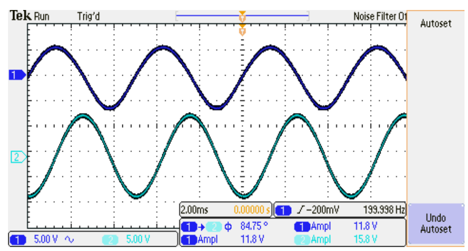
Figure 9: Circuit with a 0.1 microfarad

This is circuit can be described as an integrator, which produces an output voltage that are proportional to the running time integral of the input voltages. Theoretically if we summing point constraint, we can say that Iin = Vin / R1 and Vc = 1/C integral (t= 0 to t) Iin dt= 1/RC integral (t=0 to t) Vin dt and we get Vo = -1/ RC integral (t= 0 to t) Vin dt.

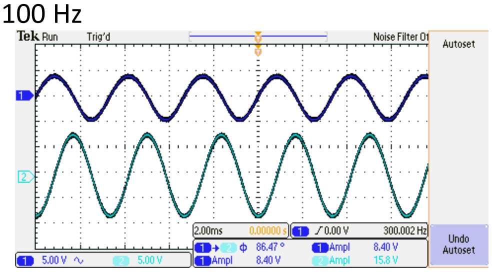
4. The next part was to start from 100 Hz and increase our frequency slowly to 10 kHz and back down; from Figure 10 we can observe that:



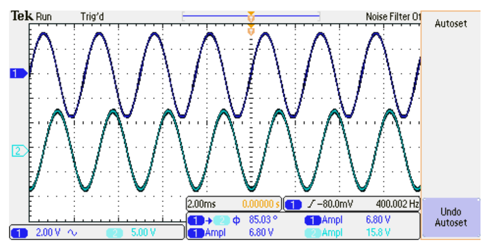
100 Hz



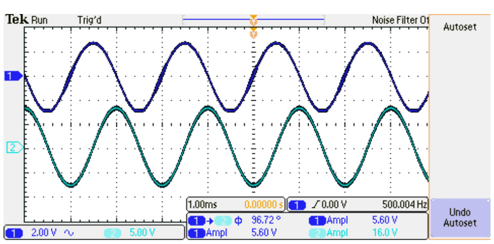
200 Hz



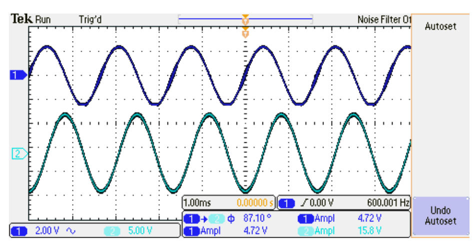
300 Hz



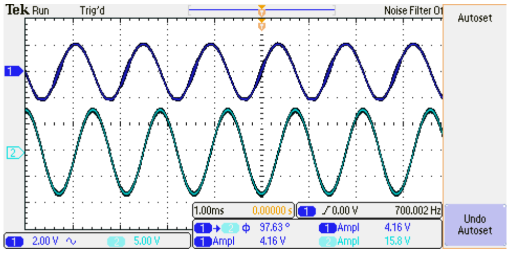
400 Hz



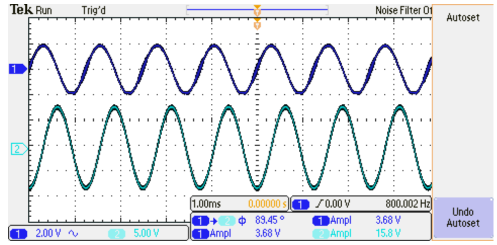
500 Hz



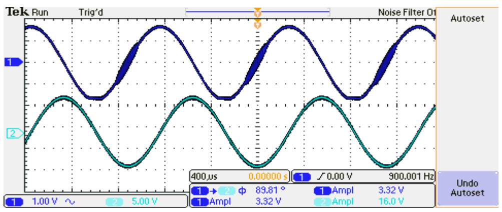
600 Hz



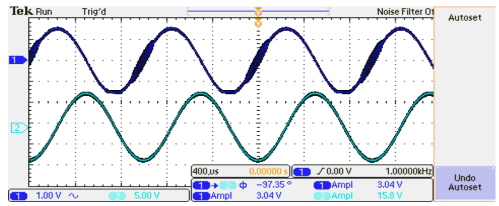
700 Hz



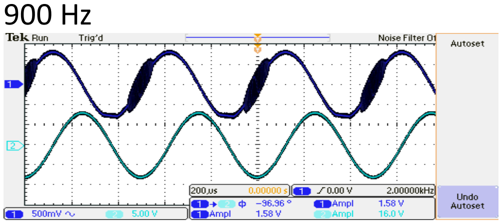
800 Hz



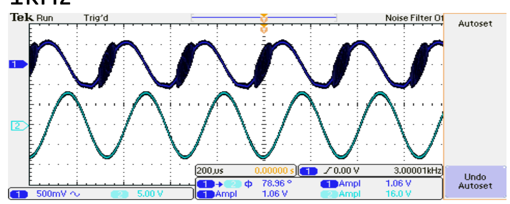
900 Hz



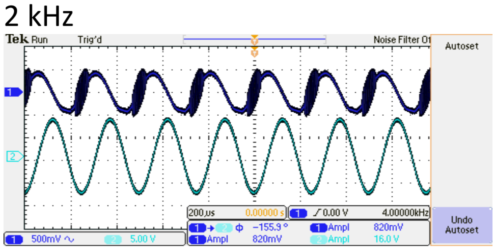
1kHz



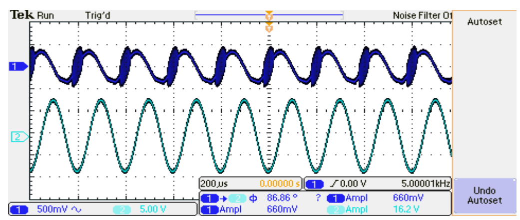
2 kHz



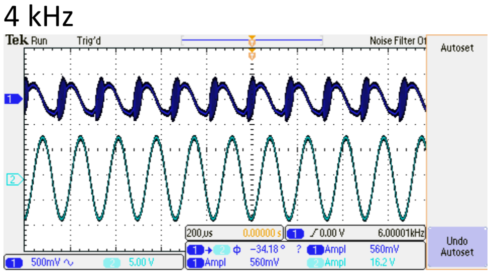
3 kHz



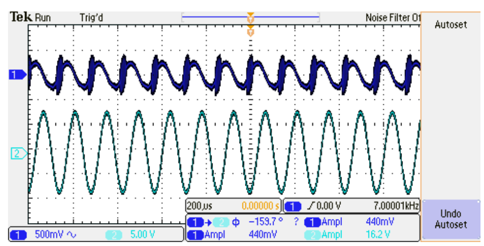
4 kHz



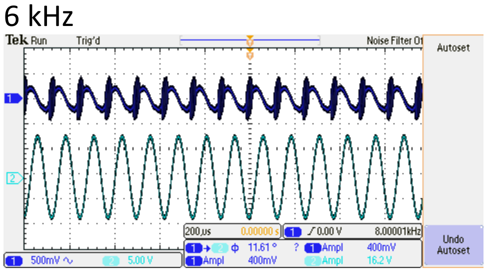
5 kHz



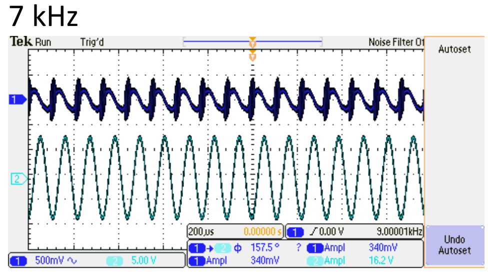
6 kHz



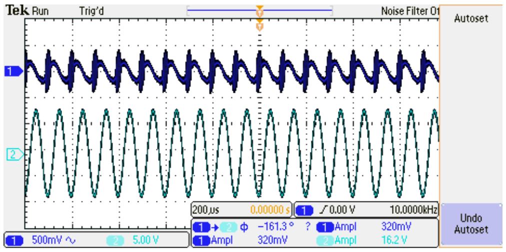
7 kHz



8kHz



9kHz



10kHz

Figure 10: 100Hz – 1kHz, 1kHz – 10kHz of Figure 9

The oscillators we used were pretty bad, we got noisy around 2kHz as one can observe; however, the point was that the frequency became higher we increased the frequency. It seems that an over shot of with less resistance can cause a waveform to not be as stable; therefore, by adding a Mega ohm resistor, we try to normalize the frequency.

5. Using the circuit with the 9.8Mohm (Theoretically 10Mohms) resistor, one can observe with the chart on Figure 12. Comparing this with our theoretical gain using the formula vo = -1/(10000kohms) (0.1microfarad) integral (0 to 9) vin dt = -1.69, we can see that at that rate the Vo should be decreasing at -1.69 per ms, which is near the slope of our graph.

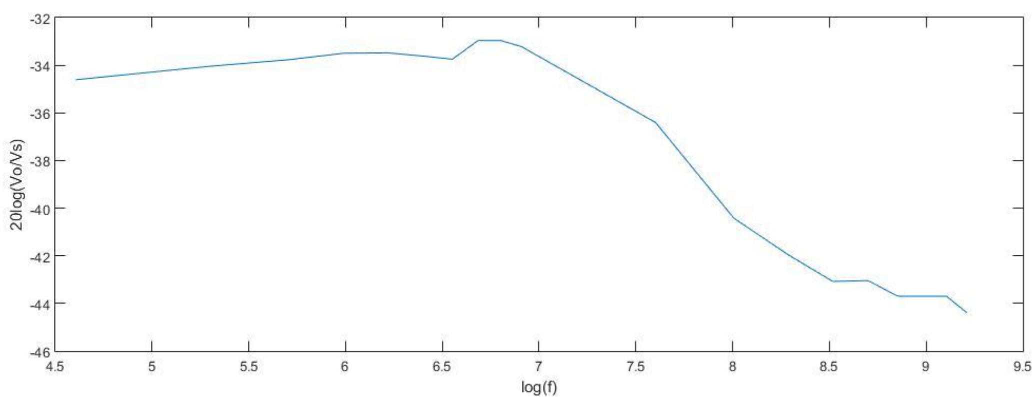
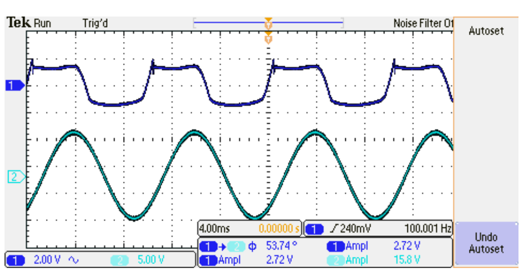
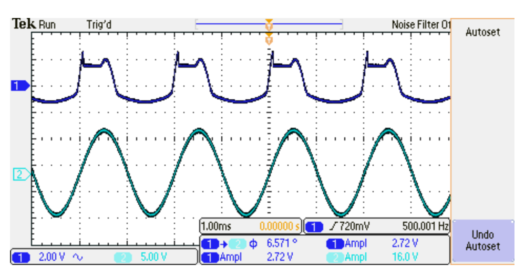


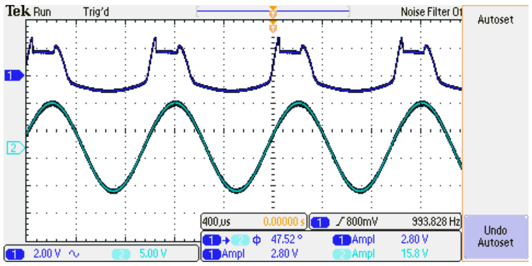
Figure 12: Integrator plot 20log(G) vs log(F)

6. Next we were to take one screen shot for the outputs f= 100, 500, 1000, 3000, 5000, 7000, 10000 Hz,

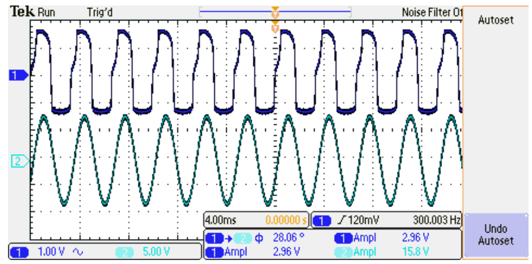




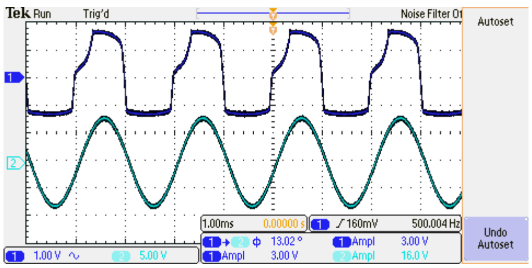
100 Hz



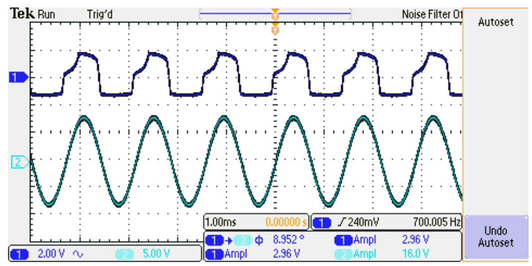
500 Hz



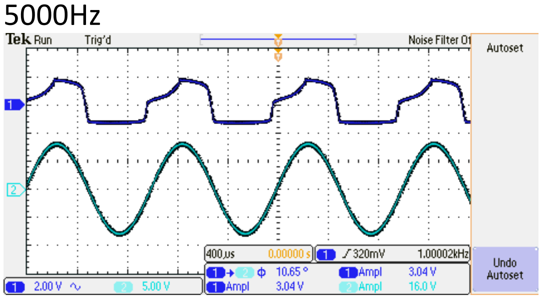
1000 Hz



3000Hz



5000Hz



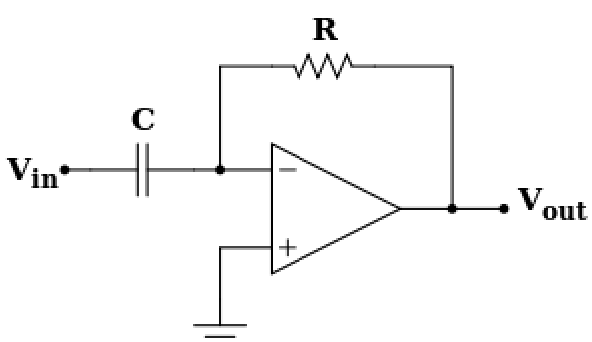
7000Hz

10000Hz

Figure 13: The outputs for F = 100, 500, etc.

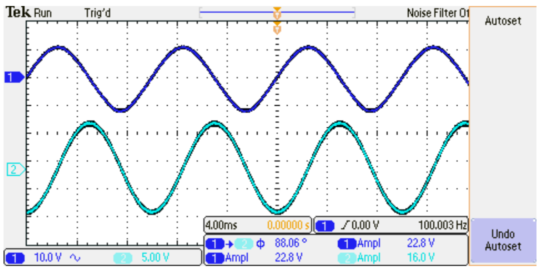
Thus we used sin waves; however, we notice that the phase is inverted compared to the input signal and with respect to Voltage source in, there is a 180-degree phase shift because the input signal is connected directly to the inverting input terminal of the op-amp.

Differentiator:

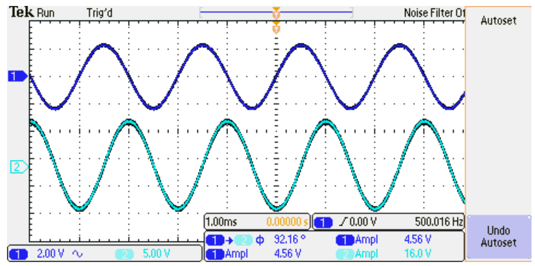


3. We do the same set up from the Integrator; except switch the capacitor and resistor 1 of the Figure 9. This would make it a differentiator because the Voltage output is directly proportional to the input voltage rate of change with respect to time.

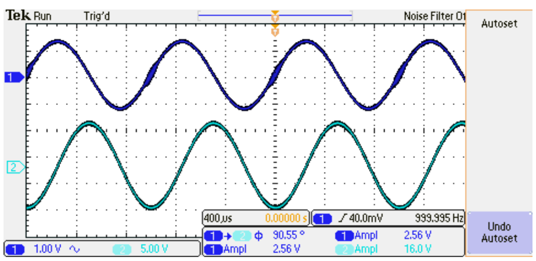
4. For this part we start from 100 Hz and increase the frequency slowly to 10 kHz. We observed a similar waveform as Integrator except that it was instable at high frequencies and the capacitive input make it create random noise to the signals. See the graphs and the noise.



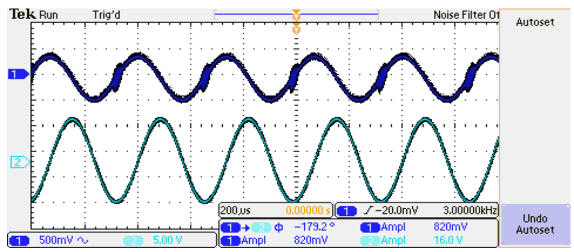
100 Hz



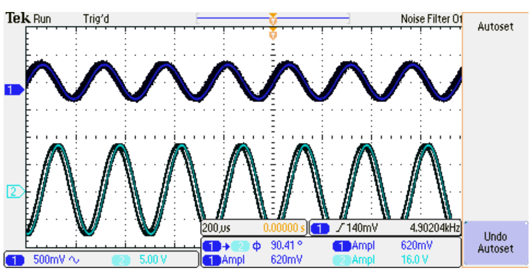
500 Hz



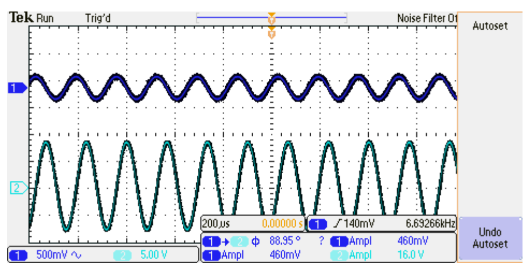
1000Hz



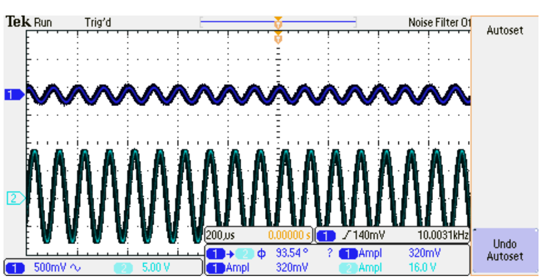
3000Hz



5000Hz



7000Hz



10000Hz

The reason we need to put a 10Megaohm is because of the noise and signal that is created because of the differentiator. Therefore, we will use the resistor in parallel with the capacitor to stabilize the waveform.

5. Using the circuit with the 9.8Mohm (Theoretically 10Mohms) resistor, one can observe from with the chart on Figure 15. Here, I derived another formula which is set to –Rc (dvin)/dt. Plugging in the values we get that the slope near -7.54, which is close to the voltage/frequency.

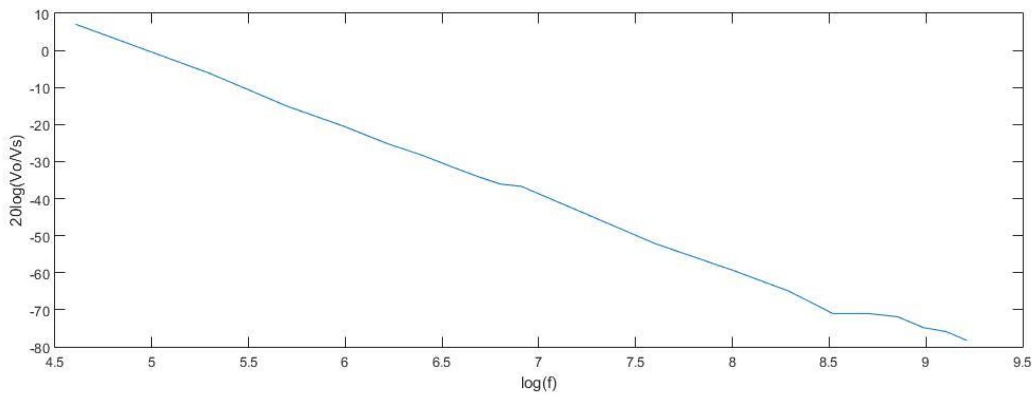
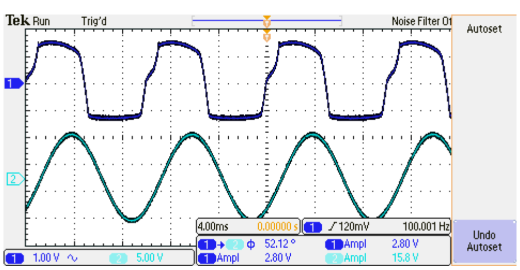
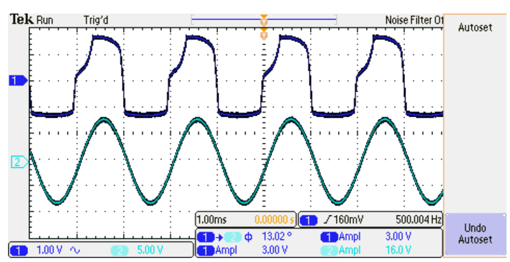


Figure 15: The graph 20log(G) vs log(f)

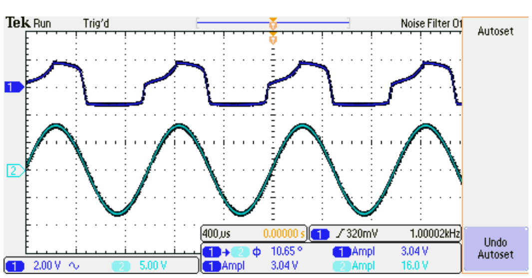
6. The following are the screen shots of the output for f =100, 500, etc. and this is a differentiator because the input resistor limits the increase gain and the circuit then acts like a differentiator amplifier at low frequencies with good resistive feedback at high frequencies to cancel the noise:



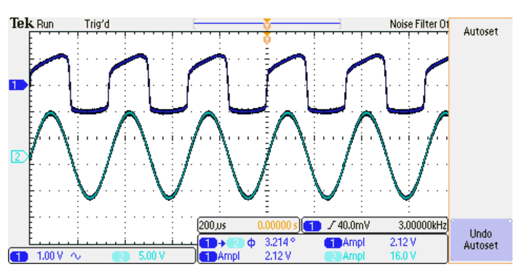
100 Hz



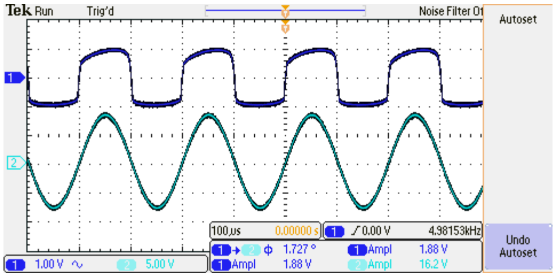
500 Hz



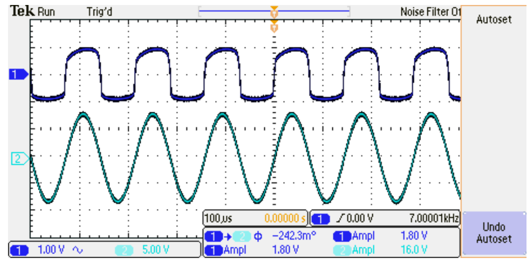
1000 Hz



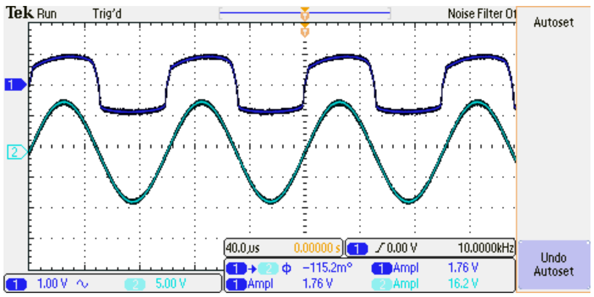
3000 Hz



5000 Hz



7000 Hz



10000 Hz

Conclusion: This lab may have been the most tedious; however, I learned a lot about waveforms and phase differences based upon how to set up circuits in correlation to amplifiers. I wish we were assisted better during lab times; however, the lab was decent enough to be done. As well the equipment was terrible this time around and had to go all around to check which oscilloscopes were working. In this lab, I was able to compare my theoretical voltage gains, as well as build the circuits that corresponded to the teachings in class. From my tables and graphs, one can observe that the calculations were a little off; however that is human error, with some connections or likewise the oscilloscope not properly working.