ECE 100 - Linear Electronics Systems

Lab Report 5 - Nyquist Plots and Wien-Bridge Oscillator
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Abstract

The purpose of the lab is to first understand the process of finding the Nyquist plots of loop gain and then to understand the properties of the Wien-Bridge Oscillator circuit. The first part of the lab, we will find the loop gain of the circuits from previous labs and use that to plot the corresponding circuit's Nyquist plot. The Nyquist plot will help us understand whether the circuit is stable or not. In the second part of the lab, we will explore how the Wien-Bridge Oscillator circuit operates and amplifies the waveform continuously. We will also explore the stability of this system and how to use the properties of the op-amp and instability of the circuit to create a stable oscillator.

Experimental Procedures

Part 1: Nyquist Plots of the Op-Amp Circuits

- Problem 1: Unloaded Voltage Follower

1) Start with the Open Loop and Close Loop Equations to form our loop gain equation which is AB.
2) Using these equations we can start to draw our Nyquist Plots which can be obtained by finding the points 0, -90deg, -180deg from the bode plots.
3) Use those points to find the magnitude and then you can map those plots to a nyquist plot
4) Then mirror the plot to find the whole nyquist plot
5) Using MATLAB we transfer the transfer function to create the magnitude and phase bode plots as well as the Nyquist plot using "nyquistplot" and plot function.

- Problem 2: Voltage Follower Circuit with Capacitive Load

1) We start by using the values we are given for Ro and C and plug into our loop gain equations.
2) Since we are working with a unity gain we know that our DC gain will be 1
3) Using the loop gain equation you calculate you repeat steps 2-5 as in part 1

- Problem 3: Voltage Follower Circuit with a Capacitive Load and a Compensation Resistor

1) In this problem you are working with a second order circuit. The loop gain function will be different as in part 1 and 2 because the transfer function of the circuit will be different. It will be the second order equation.
2) Using this second order equation you multiply with A(s) and B(s) to find your loop gain equation.
3) Repeat steps 2-5 in part 1

- Problem 4: Differentiator Circuit with No Compensation

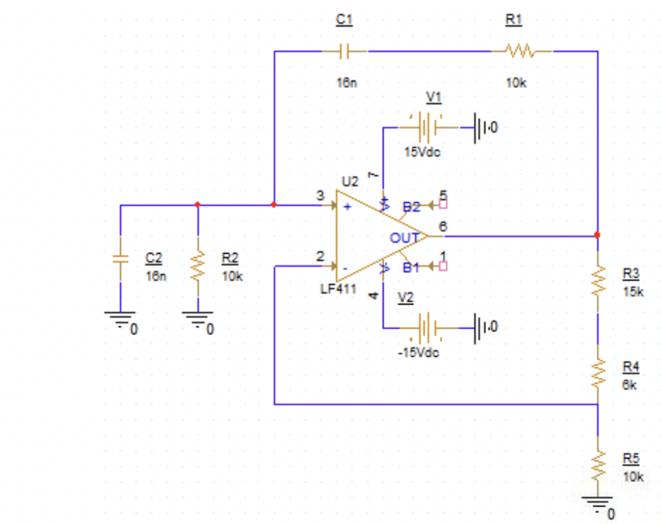
1) In this part you are working with a differentiator circuit and we have to calculate our loop gain. We find our A(s) and B(s) and multiply to find our loop gain equation
2) Repeat steps 2-5 in part 1

- Problem 5: Differentiator Circuit with Compensation Resistor

1) In this part we are adding a compensation resistor to our circuit in part 4.
2) We find that adding a compensation resistor change our loop gain equation because it adds another component Rc to our B(s) equation.
3) We find that it adds sRcC to our loop gain equation.
4) Then we just repeat steps 2-5 as in part 1

Part 2: Design of Wien-Bridge Oscillator

- Problem 1: System Level Design



a) Looking at our circuit we combine the impedances first to make solving the equation clear and quicker
   Calculating the loop gain function you find that B(s) = Z1/Z1+Z2
   We find that Z1 is C1 + R1 in series and that Z2 is C2 and R2 in parallel
   You use this equation and plug into MATLAB to find the nyquist plot to check for stability
b) In this part we create a block diagram using Simulink to simulate a feedback and graph the oscillation. We started by building the block diagram and then graphing the output waveform

- Problem 2 Circuit Level Simulation

a. We start by building our circuit in LTSpice. We then check to see our output voltage operating past the voltage of the power supply which we can check if there is an clipping
b. In LTSpice we use the fourier transform function and set our axis to log scale.We then calculate performance using the given equation. Which we calculate by finding Vout at different frequencies

c. Then to stop this clipping we add diodes to our circuit simulation. After simulating you should see a difference in the output waveform
d. Then we try to increase our frequency by a factor of 10 twice by changing values for your resistor and capacitor.

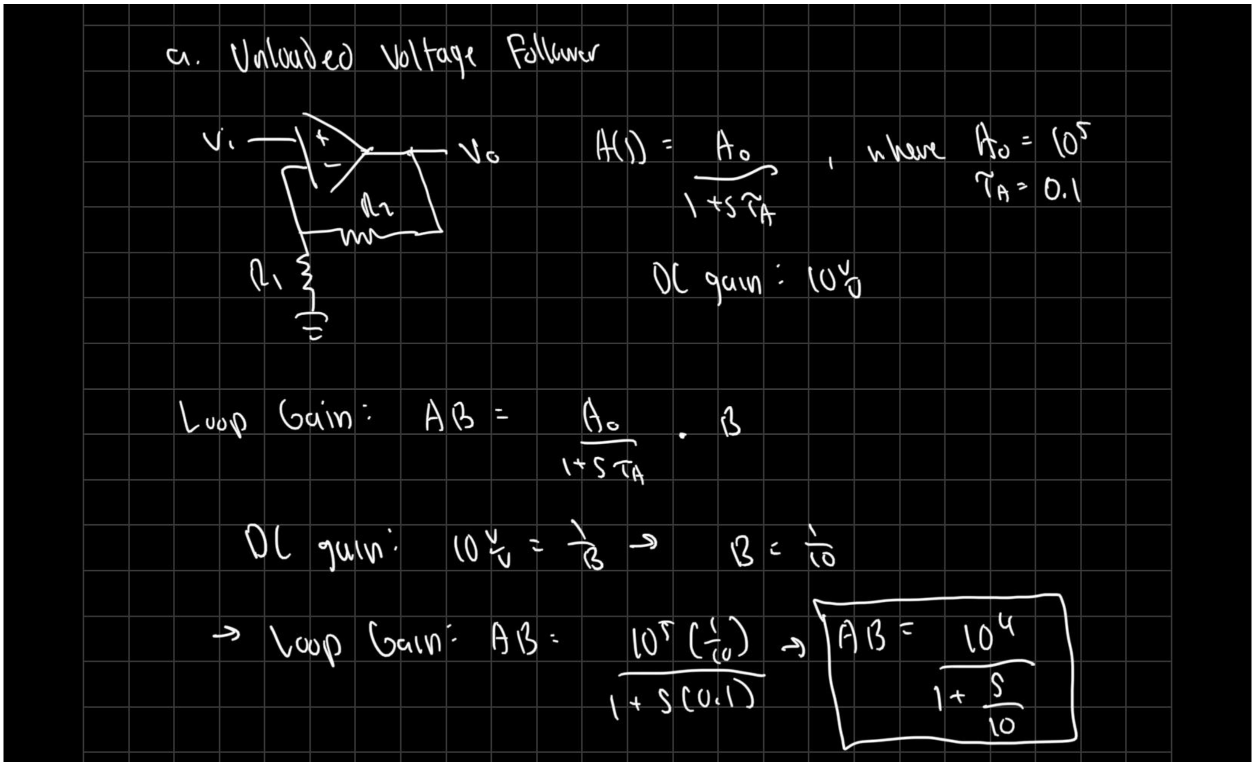
- <u>Problem 3: Measurement</u>

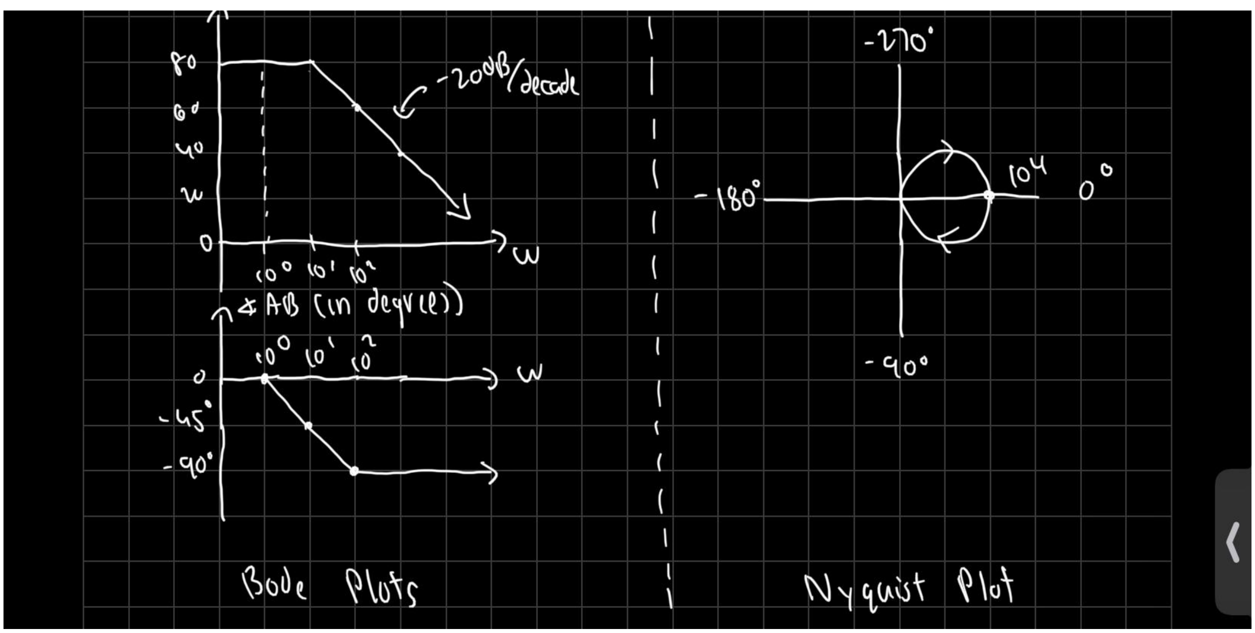
a. In this circuit you build the circuit in the schematic and measure the output waveform with an oscilloscope to view the noise produced by the circuit
b. In this next part you add two opposing diodes in parallel with the 6k resistor to check the limited voltage in the output
c. In this part you move the diodes in parallel with the 6k to the 15k to see how much of a change there is in the output
d. This part of the circuit you use different values of R and C to change the frequency of the graph. Using the equation 1/2pi*sqrt(R1C1R2C2) to find the expected value we should have for frequency. You might find that your frequency value isn't the same as this value. Therefore you will have to meet the 10% range from this frequency value. Using different values you try to change your frequency from 1kHz to 10kHz to 100kHz. After you have to minimize your frequency by trying to meet 1Hz and staying within 10% of our expected value.

Results

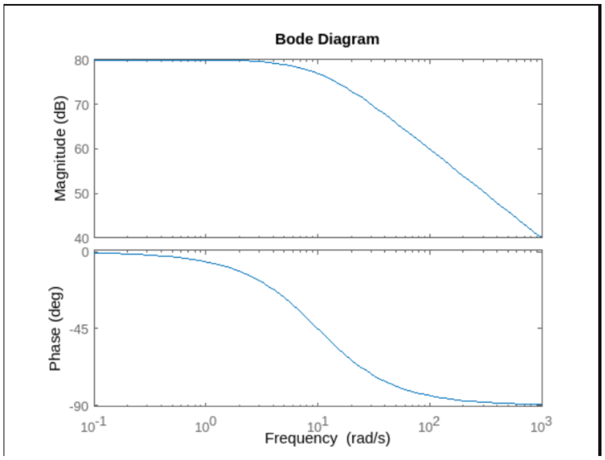
Part 1: Nyquist Plots of the Op-Amp Circuits

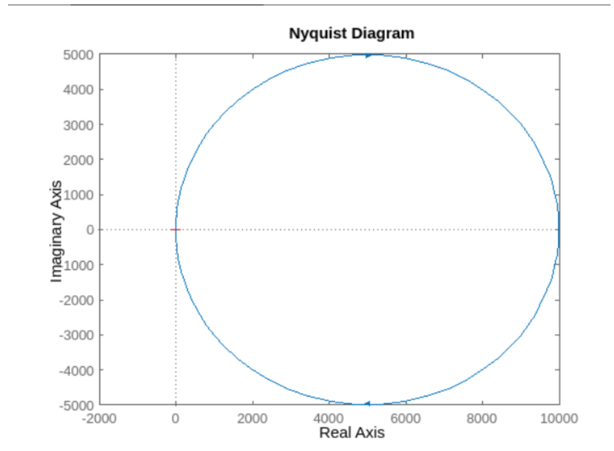
- Problem 1: Unloaded Voltage Follower

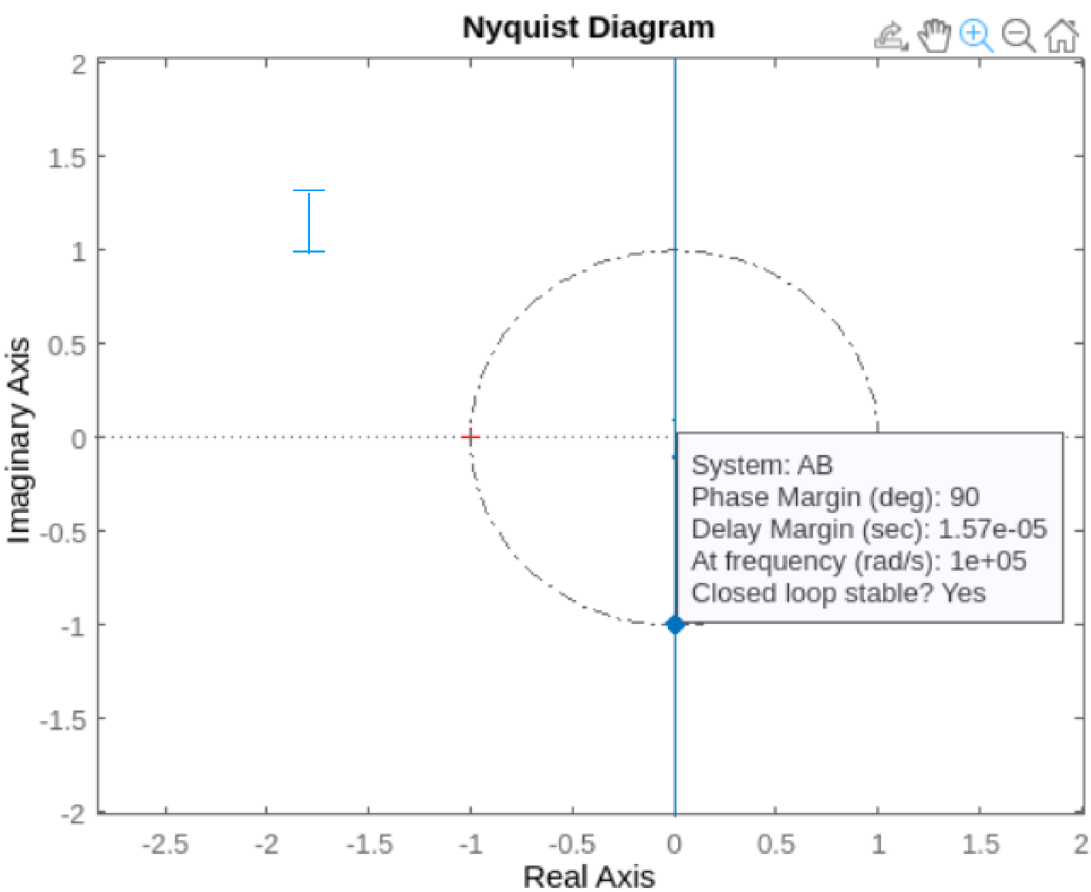




The figures above show the work to get the loop gain of the unloaded voltage follower and the corresponding Bode plots and Nyquist plots of the loop gain.

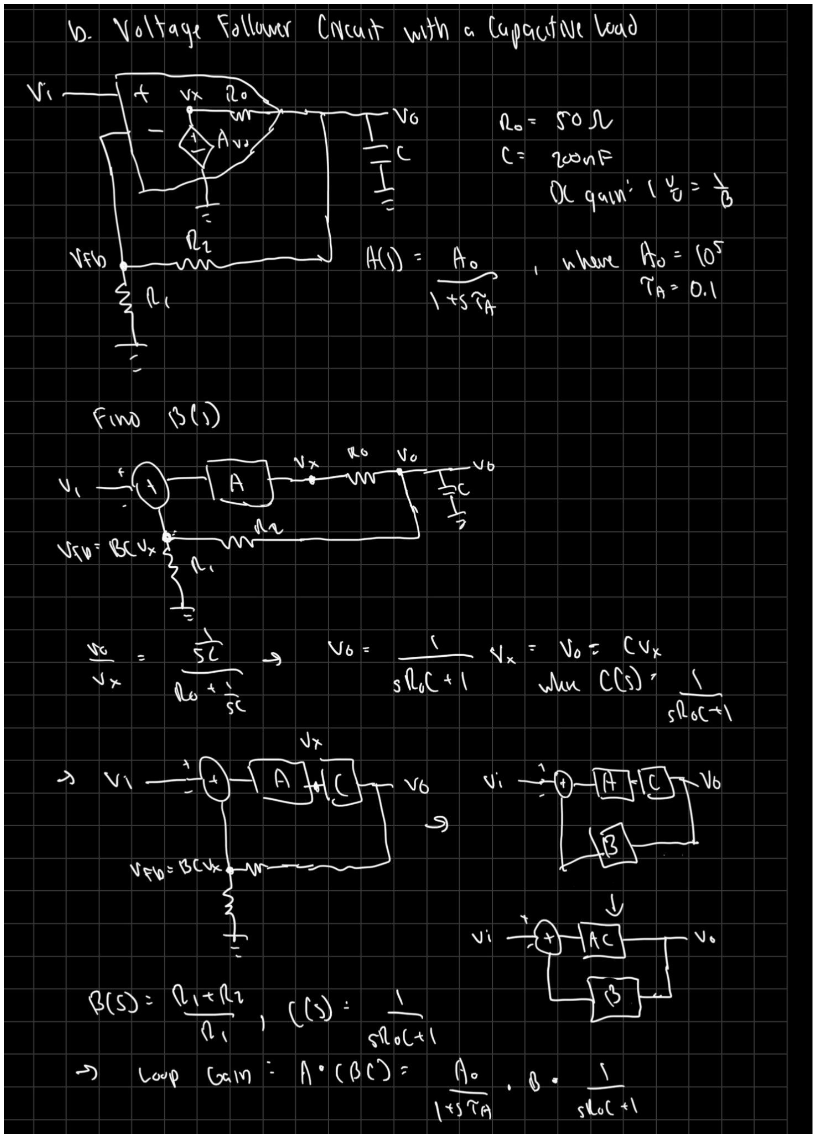


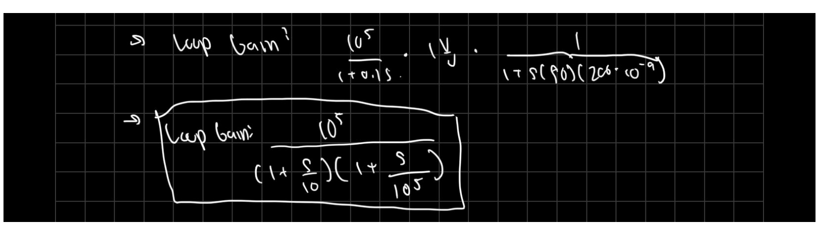




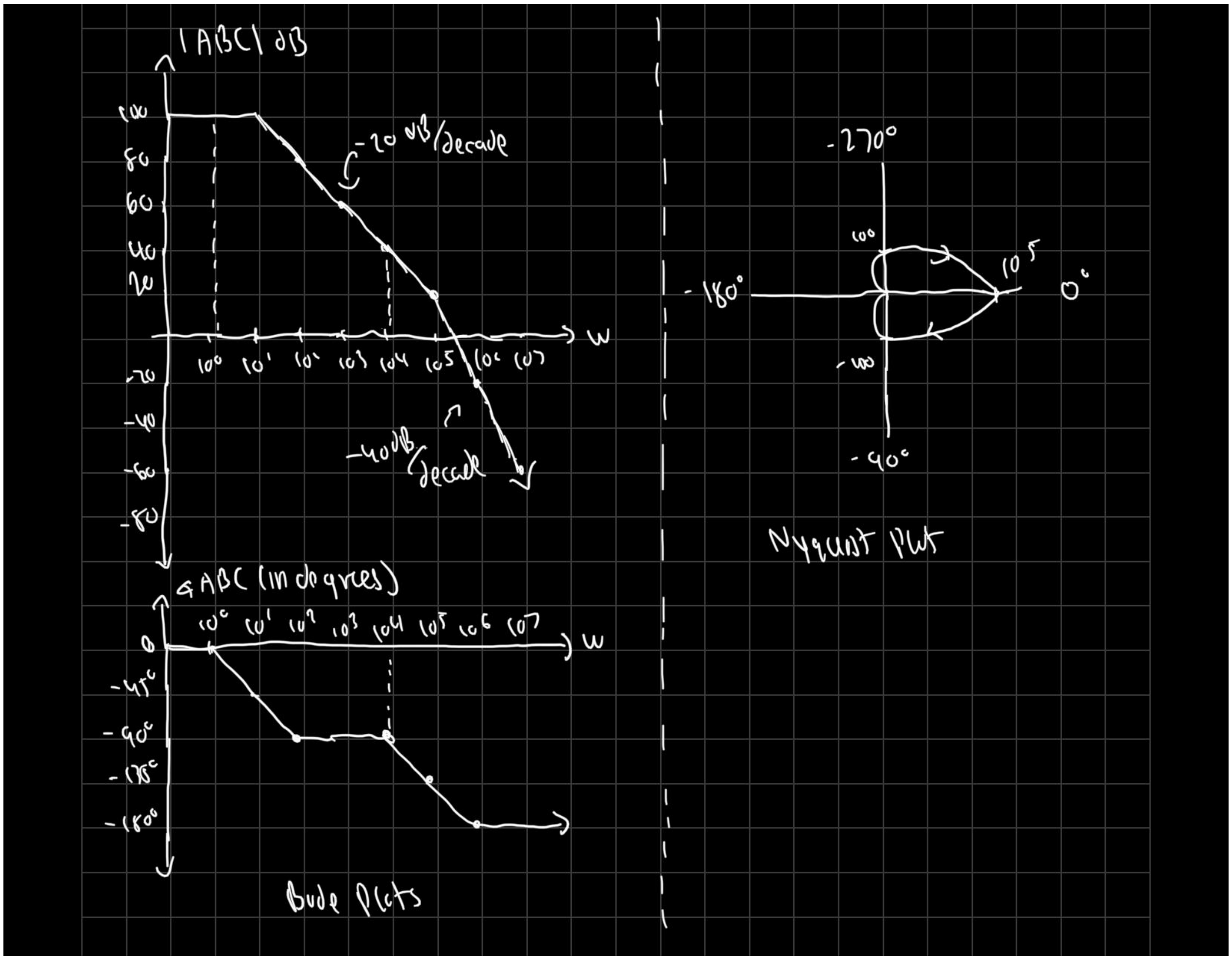
The figures above are the MatLab Bode plots and Nyquist plots of the loop gain of the unloaded voltage follower. We also have the zoomed in Nyquist plot showing a circle in the origin of a radius of 1 and the phase margin of this loop gain. The Nyquist plot shows that there is no value at -90°. The Nyquist plot also includes the origin and not the value of 1 at -180°, showing that this system is stable.

- <u>Problem 2: Voltage Follower Circuit with Capacitive Load</u>

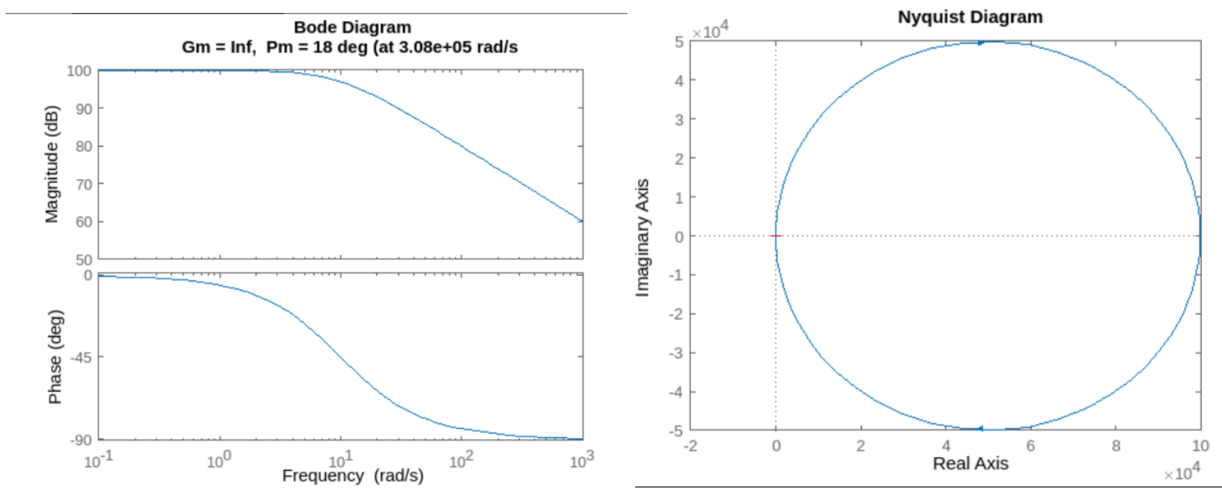




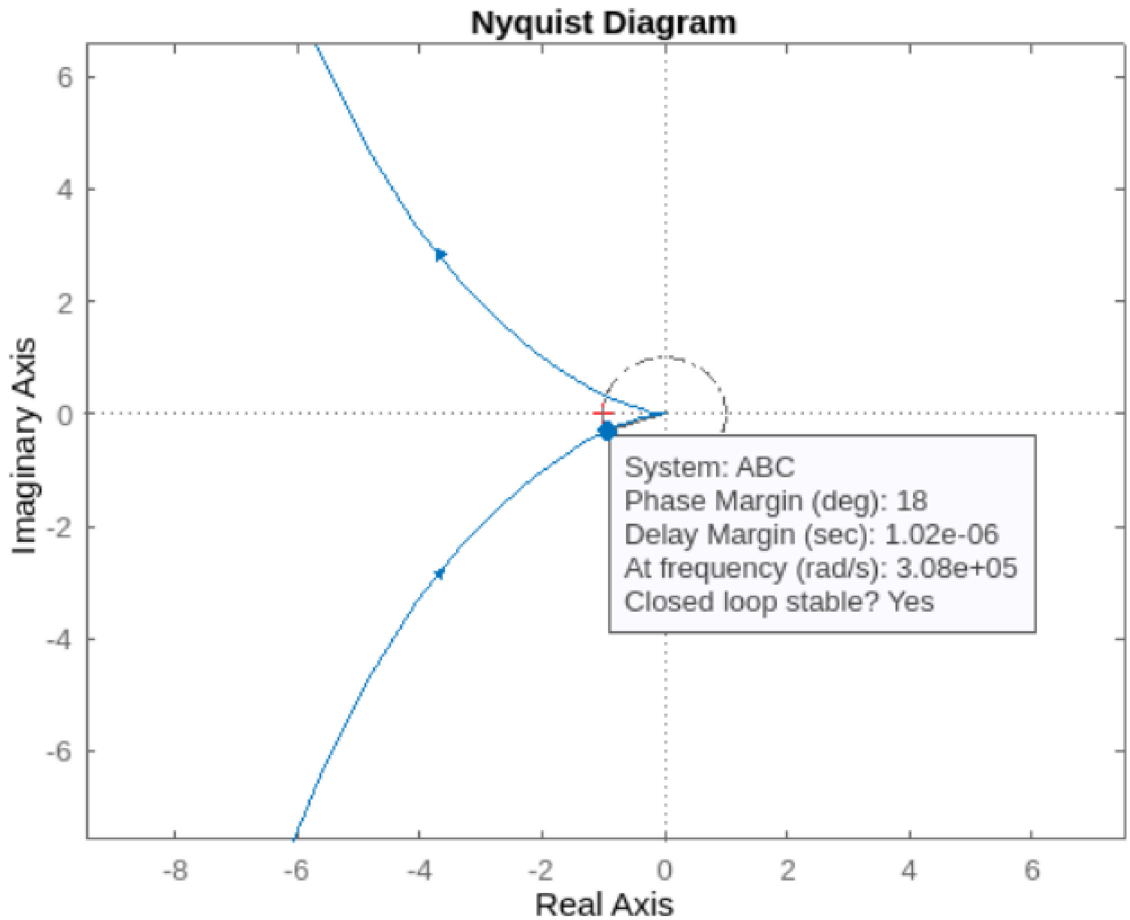
The figures above show the work of getting the loop gain of the voltage follower with a capacitive load.



The figure above is the hand drawn Bode and Nyquist plots of the loop gain for the voltage follower with a capacitive load.

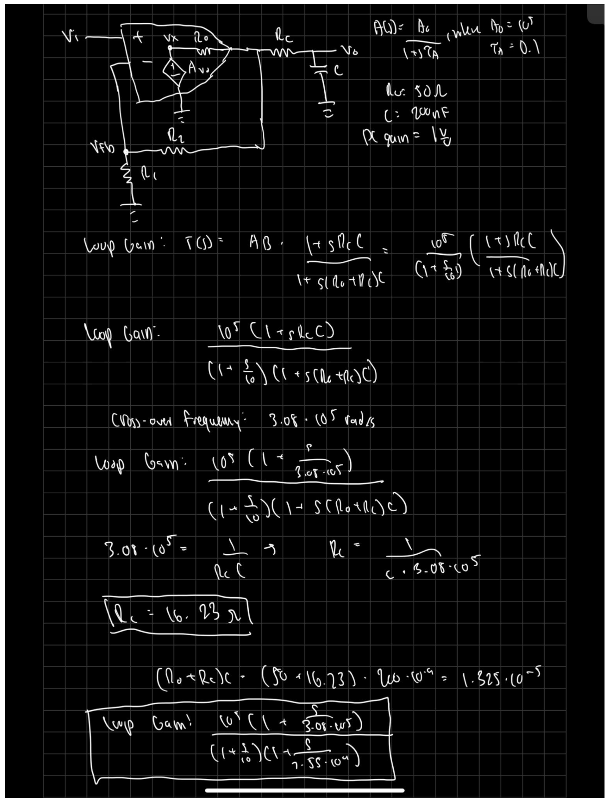


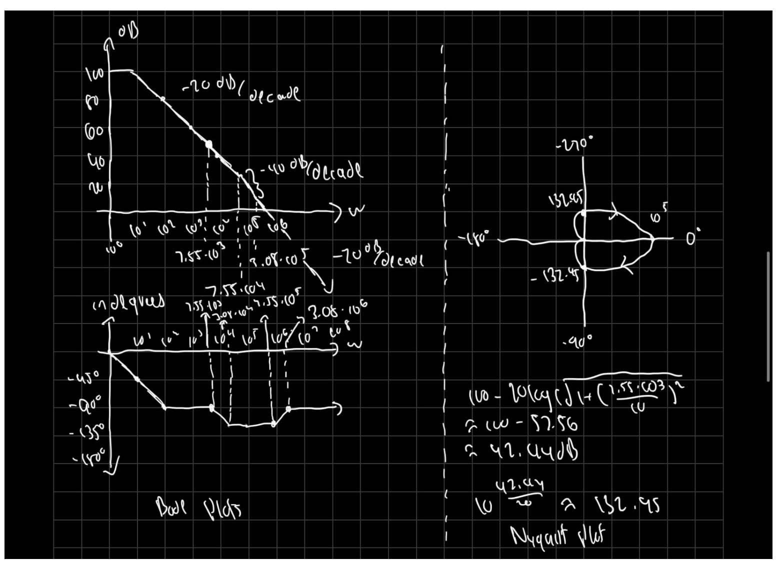
The figures above show the Matlab Bode and Nyquist plots for the voltage follower with a capacitive load.



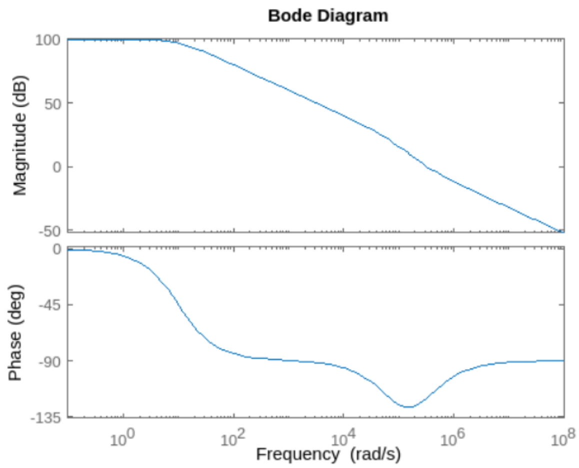
This figure is the zoomed in Nyquist plot of the voltage follower with a capacitive load. We see that the Nyquist plot encircles the origin, does not include the value of 1 at -180°, and has a positive phase margin, making this system stable.

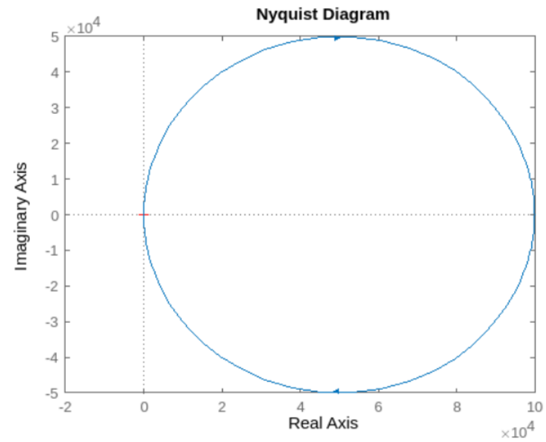
- <u>Problem 3: Voltage Follower Circuit with a Capacitive Load and a Compensation Resistor</u>

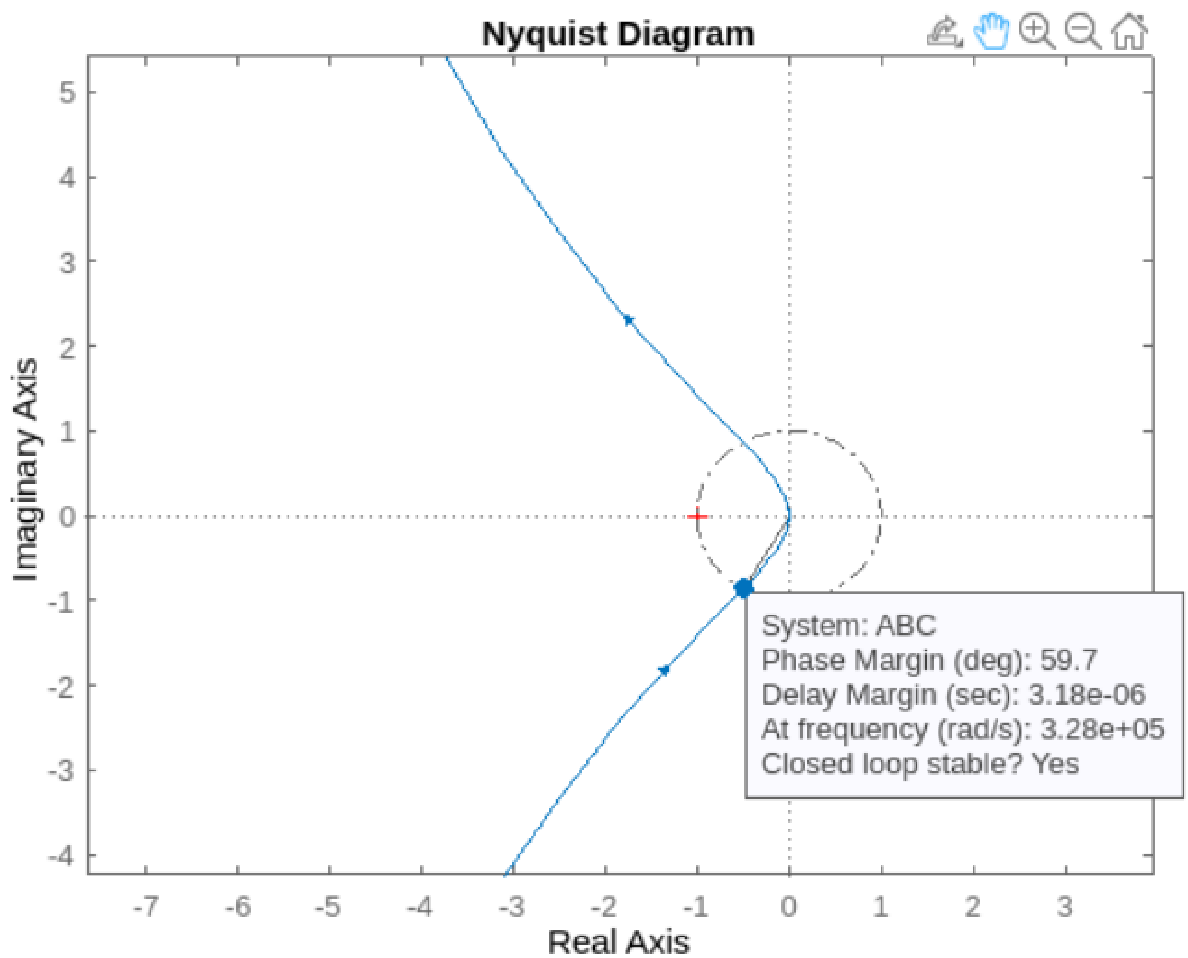




The figures above show the work of finding the loop gain of the voltage follower with a capacitive load and a compensation resistor and the hand drawn Bode and Nyquist plots of this loop gain. We also found the compensation resistance (16.23Ohms) where the zero of the loop gain is at the unity gain frequency of the uncompensated circuit.

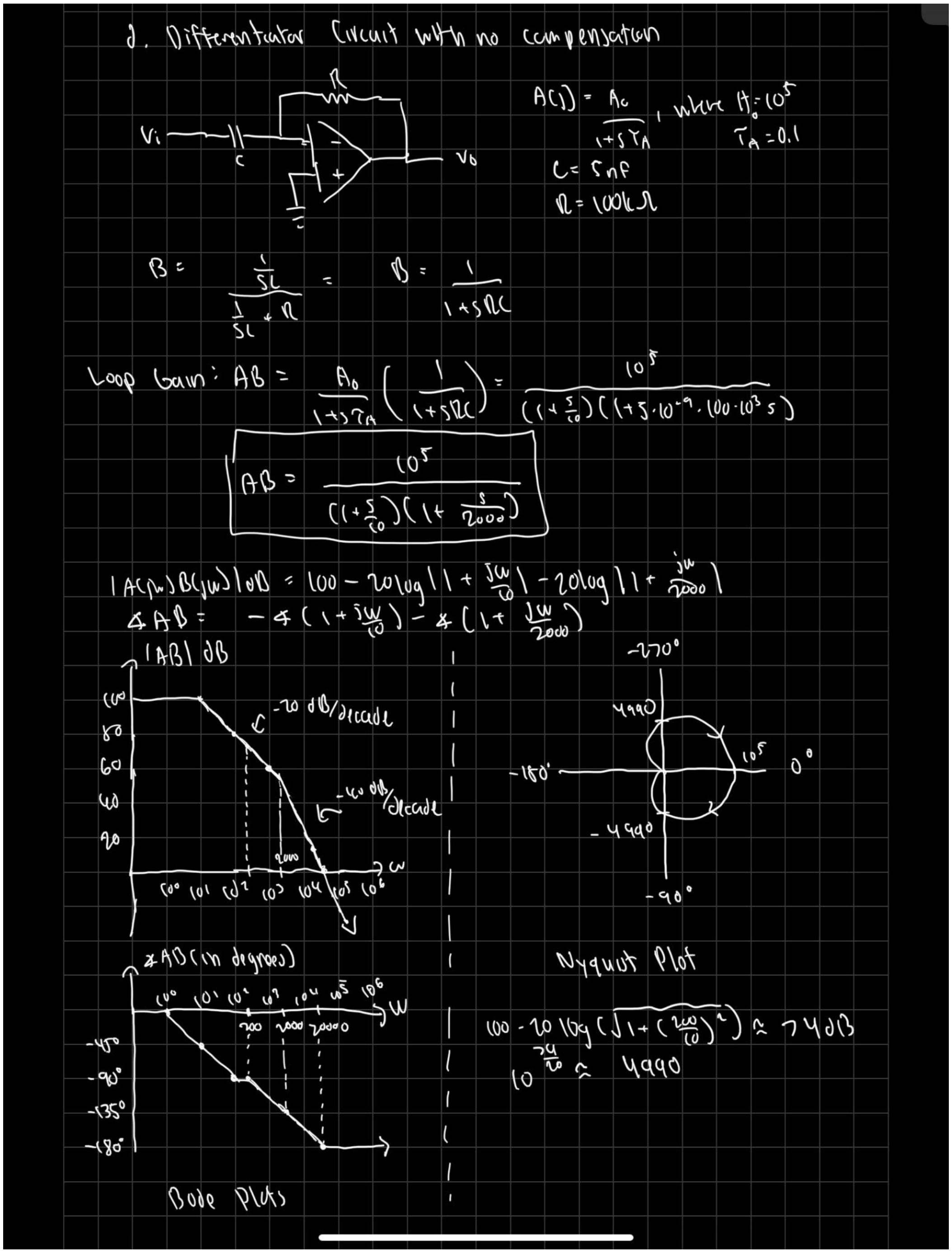




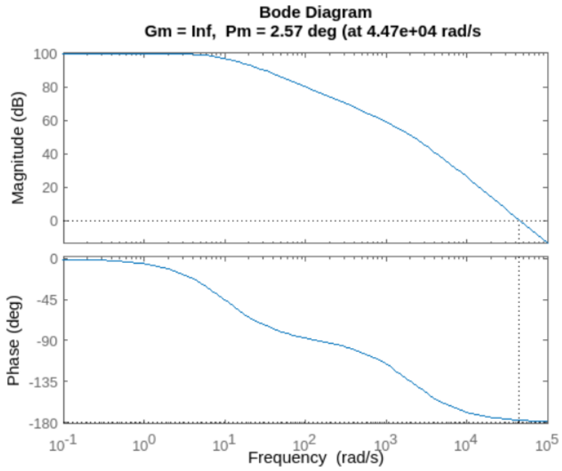


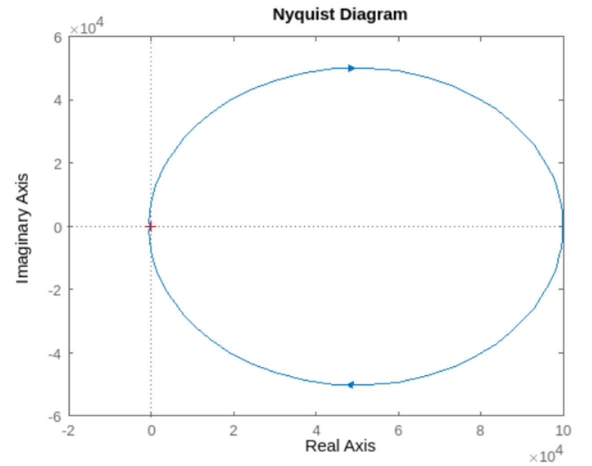
The figures above show the Matlab Bode and Nyquist plots of this loop gain. We also have the zoomed in Nyquist plot to show that the loop gain does not include the value of 1 at -180°, encircles the origin, and has a positive phase margin, resulting in this system to be stable.

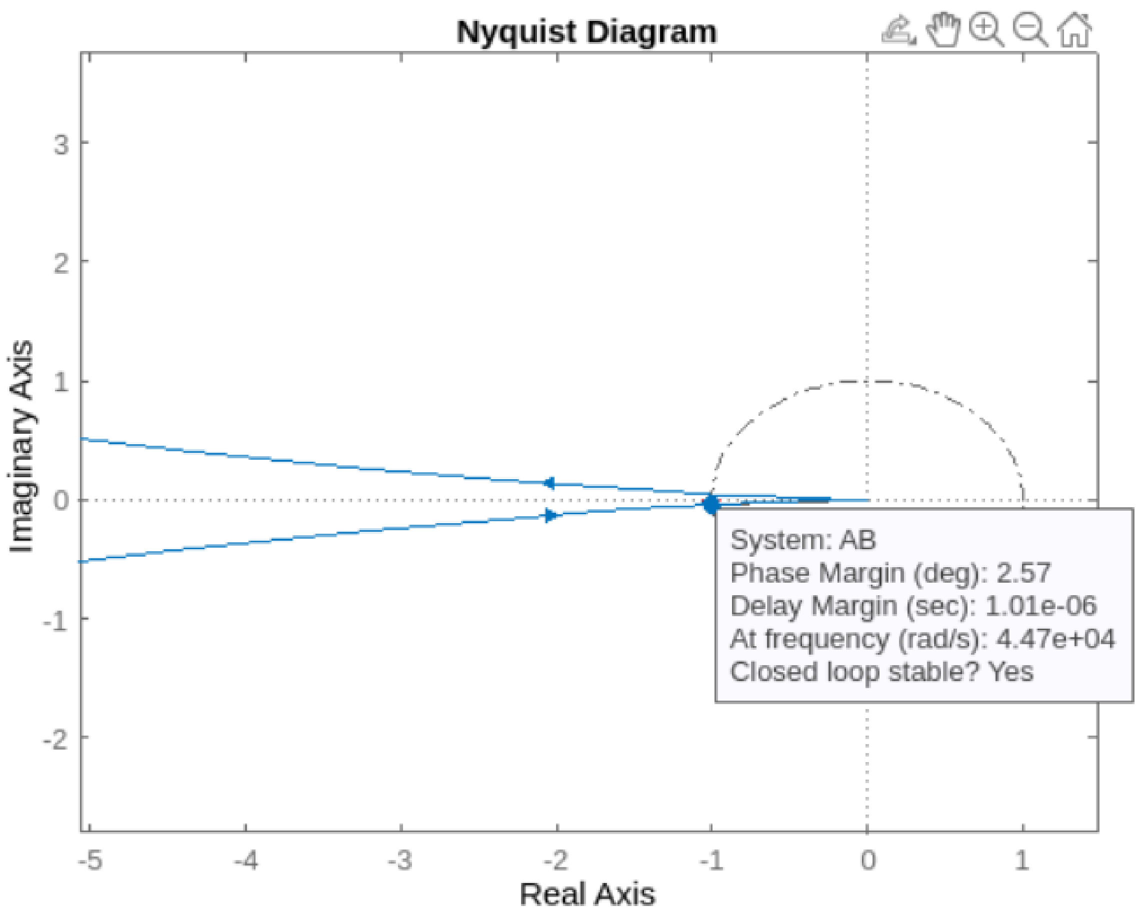
- <u>Problem 4:Differentiator Circuit with No Compensation</u>



The figure above is the work of getting the loop gain of the differentiator circuit without any compensation and the hand drawn Bode and Nyquist plots for this loop gain.

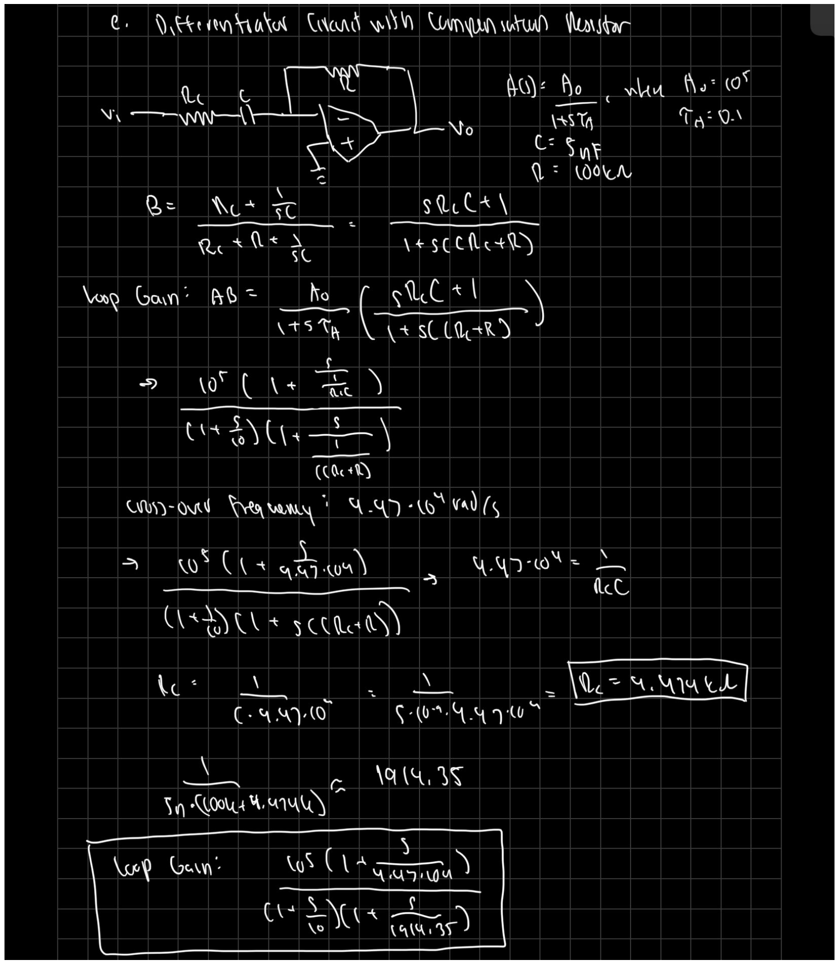


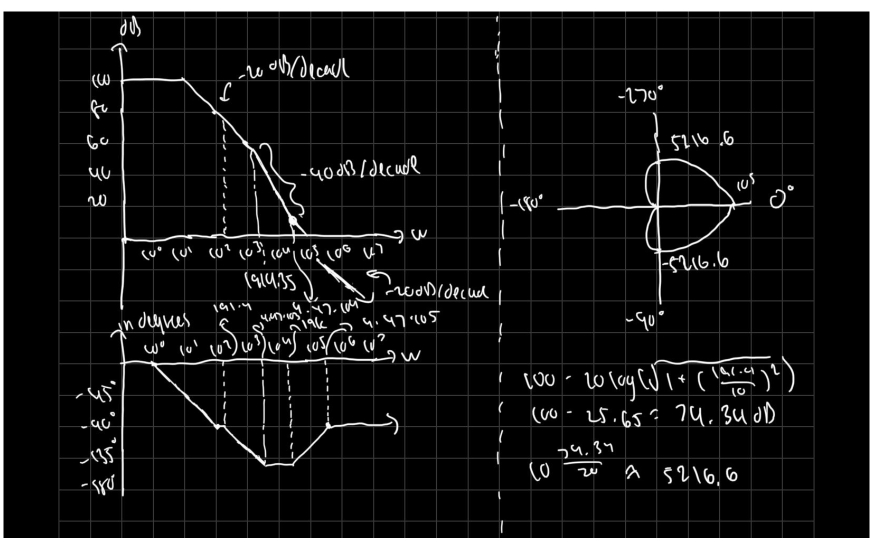




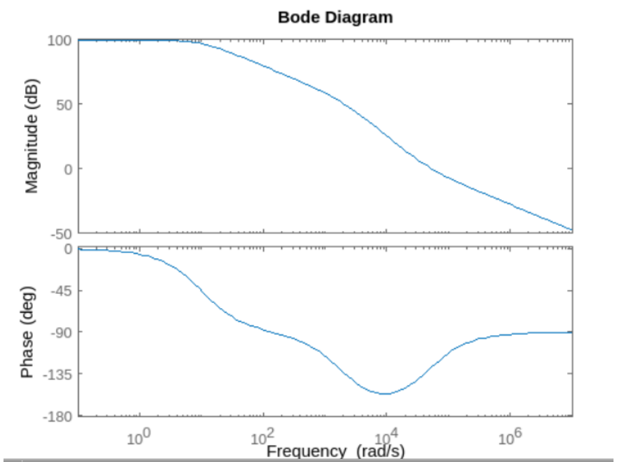
The figures above show the Matlab Bode and Nyquist plots of this loop gain. This also shows the zoomed in Nyquist plot of this loop gain. We can see that the plot encircles the origin, does not include the value of 1 at -180°, and has a positive phase margin, making this system stable.

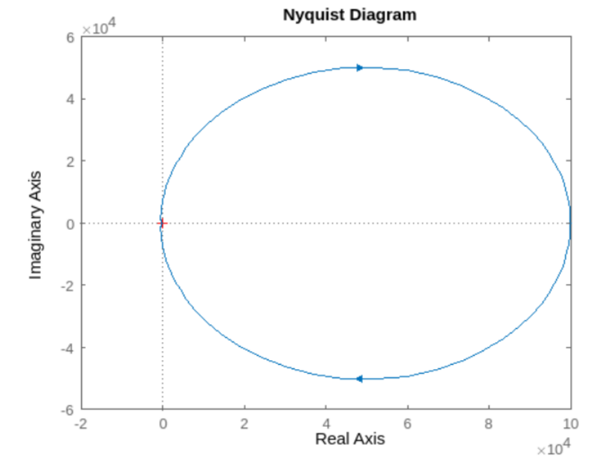
- <u>Problem 5: Differentiator Circuit with Compensation Resistor</u>

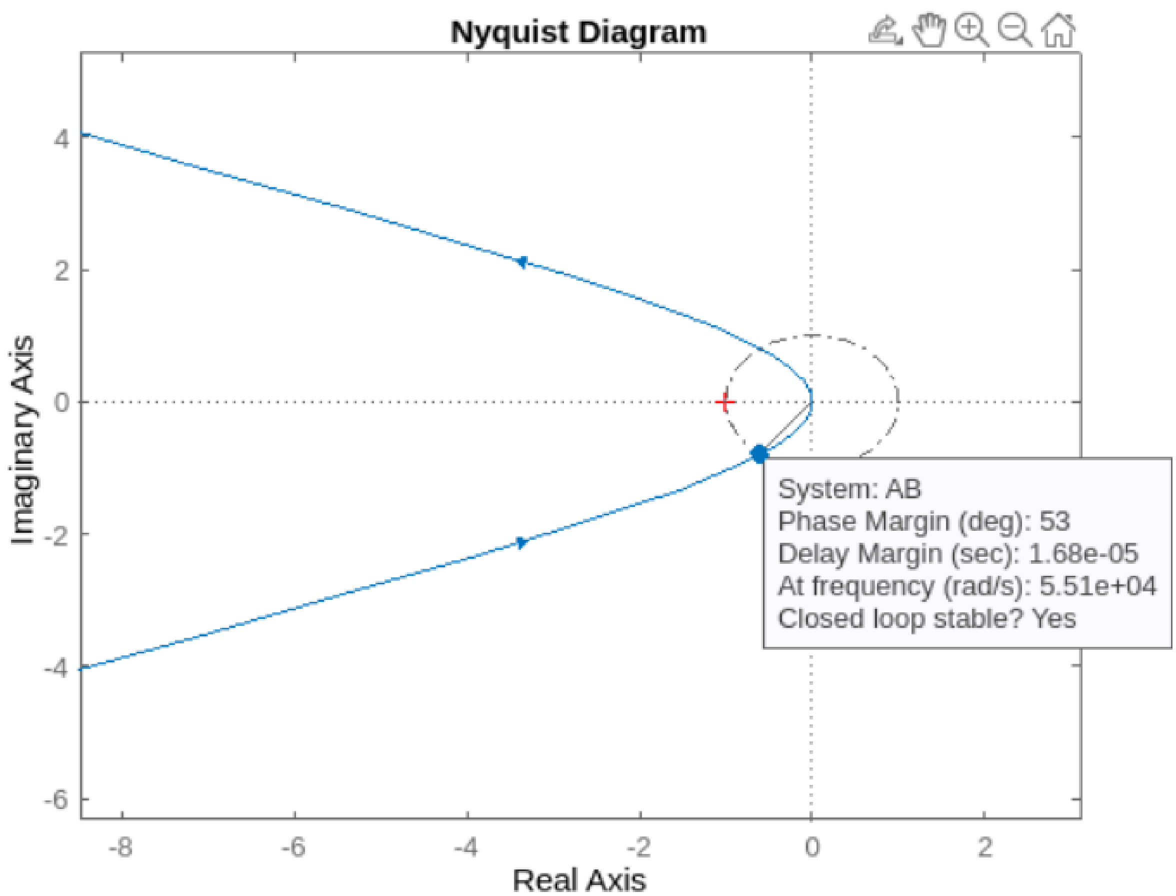




The figures above are the work to get the loop gain of the differentiator circuit with a compensation resistor and the hand drawn Bode and Nyquist plots of the loop gain. We also found the compensation resistance of this circuit which is about 4.47kOhms where the zero of the loop gain is at the unity gain frequency of the uncompensated circuit.





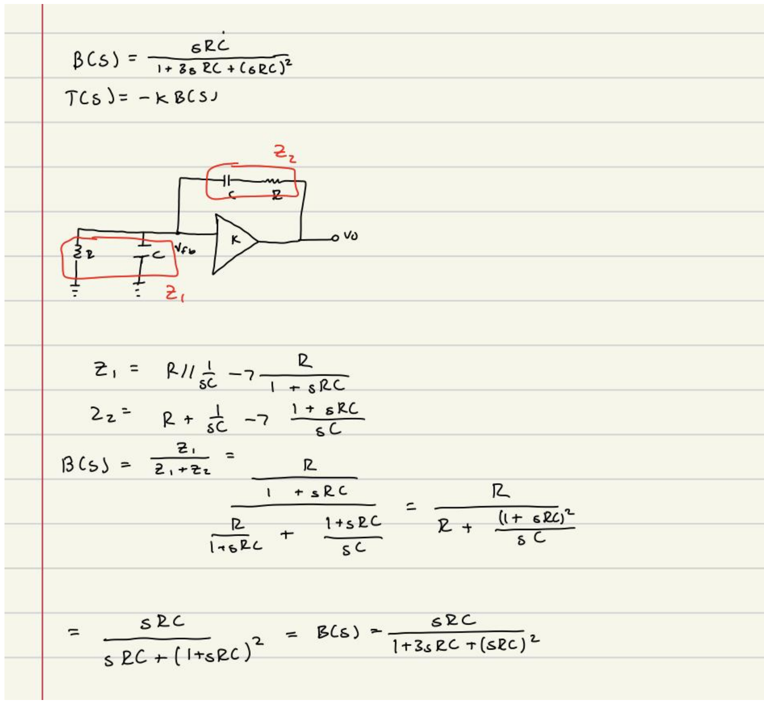


The figures above show the Matlab Bode and Nyquist plots of this loop gain. This also shows the zoomed in Nyquist plot of this loop gain. We can see that the plot encircles the origin, does not include the value of 1 at -180º, and has a positive phase margin, making this system stable.

Part 2: Design of Wien-Bridge Oscillator

- Problem 1: System Level Design

a.



$$B(s) = \frac{sRC}{1 + 3sRC + (sRC)^2}$$

$$T(s) = -k\,B(s)$$

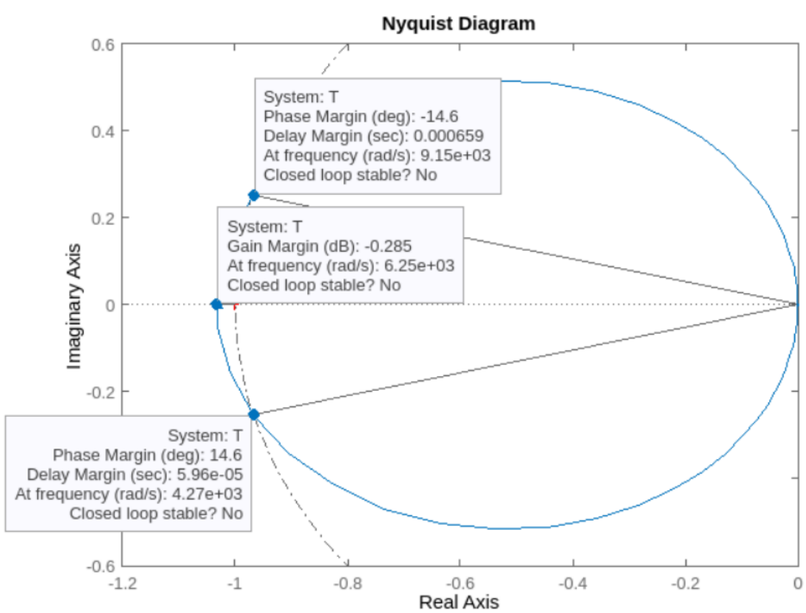
$$Z_1 = R \,//\, \frac{1}{sC} \rightarrow \frac{R}{1 + sRC}$$

$$Z_2 = R + \frac{1}{sC} \rightarrow \frac{1 + sRC}{sC}$$

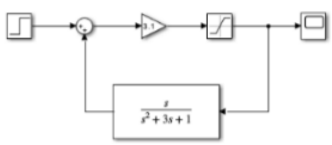
$$B(s) = \frac{Z_1}{Z_1 + Z_2} = \frac{\frac{R}{1 + sRC}}{\frac{R}{1+sRC} + \frac{1+sRC}{sC}} = \frac{R}{R + \frac{(1+sRC)^2}{sC}}$$

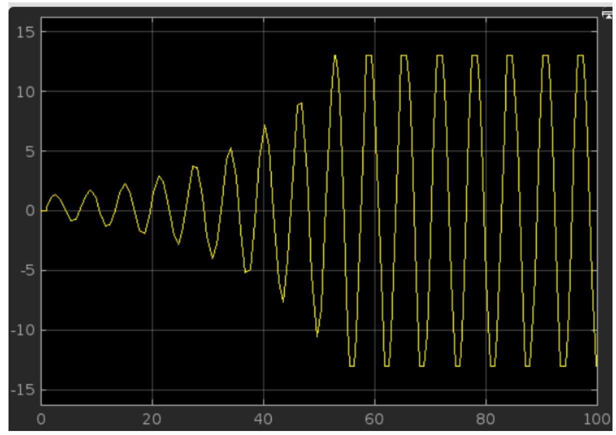
$$= \frac{sRC}{sRC + (1+sRC)^2} = B(s) = \frac{sRC}{1 + 3sRC + (sRC)^2}$$

The figure above is the work for the loop gain of the Wien-Bridge Oscillator circuit.



The figure above is the Nyquist plot of the Wien-Bridge Oscillator circuit plotted in Matlab. Because the plot goes over the value of 1 at -180° and has a negative phase margin, the system is unstable.

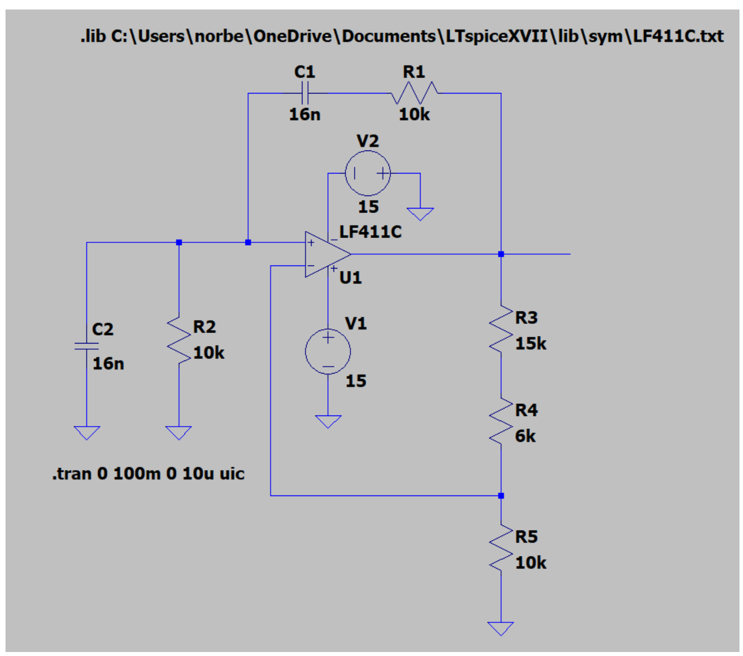
a. 



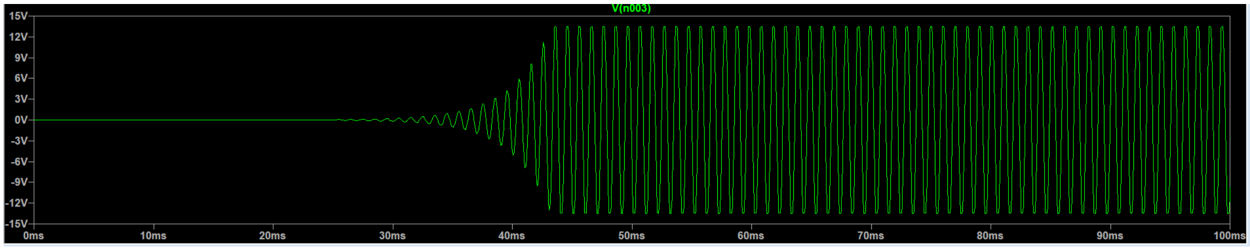
The figures above show the Matlab Simulink block diagram of the closed loop gain of the Wien-Bridge Oscillator circuit and the corresponding output voltage of this.

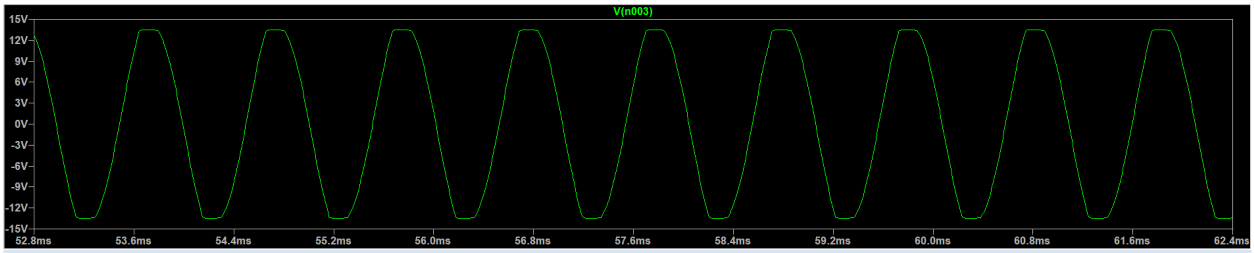
- <u>Problem 2 Circuit Level Simulation</u>

a.



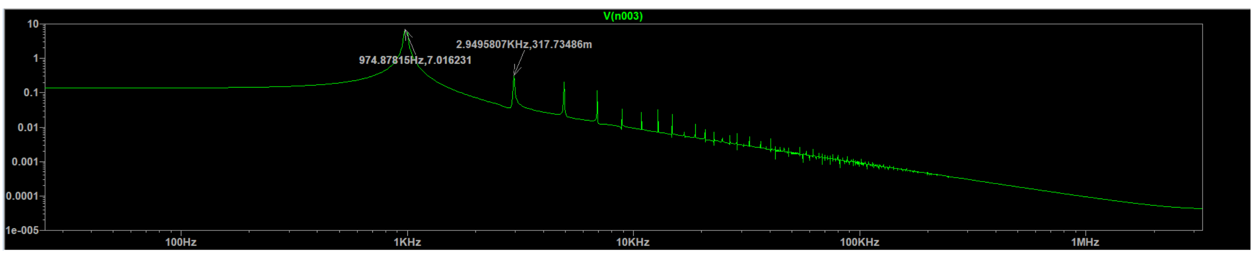
The figure above shows the circuit of the Wien-Bridge Oscillator.





The figures above are the output voltage waveform of the Wien-Bridge Oscillator circuit. The top picture shows the continuous amplification of the output voltage until the saturation voltage of the op-amp. And the bottom picture shows the expanded clipped output, showing that the output clips to where the saturation voltage lies.

e.

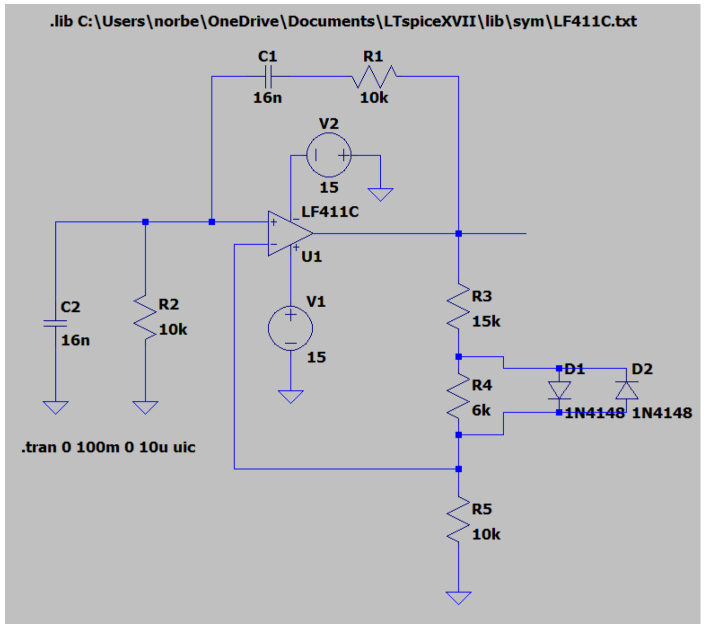


b. $P = 20\log\left(\dfrac{V_{out}(j(1kHz))}{V_{out}(j(3kHz))}\right) = \dfrac{7.016}{317.73 \cdot 10^{-3}}$

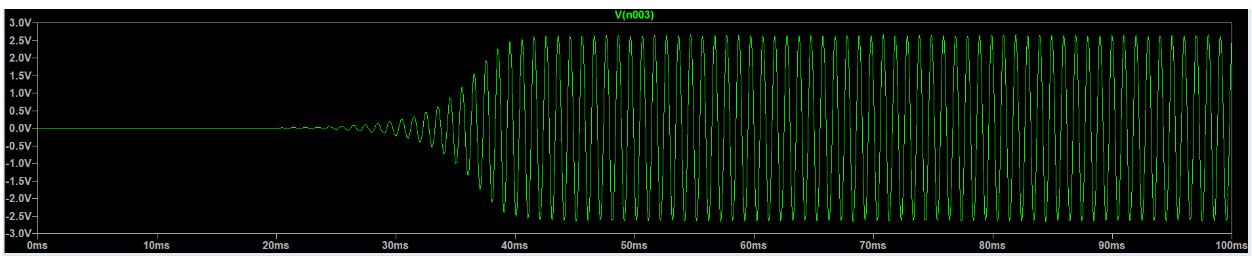
$\boxed{P \approx 22.08}$

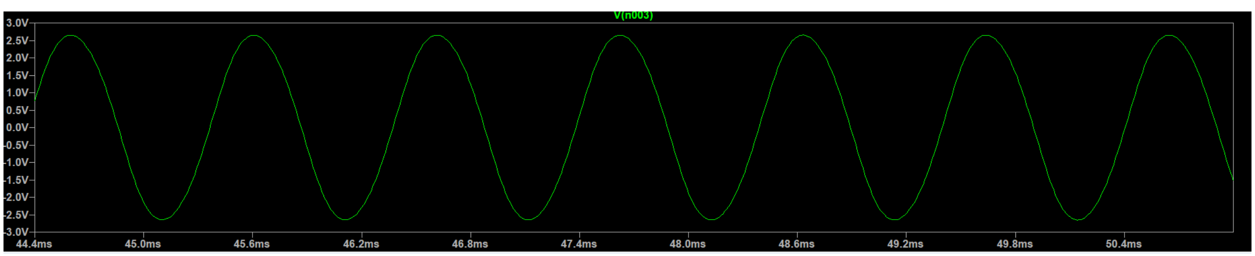
The figures above show the output voltage in the view of FFT. This displays the frequencies of the output voltage and shows what frequencies are incorporated in the output waveform. We also found the performance of this oscillator by measuring the points at 1kHZ and 3kHz. The performance of this oscillator is about 22.

f.

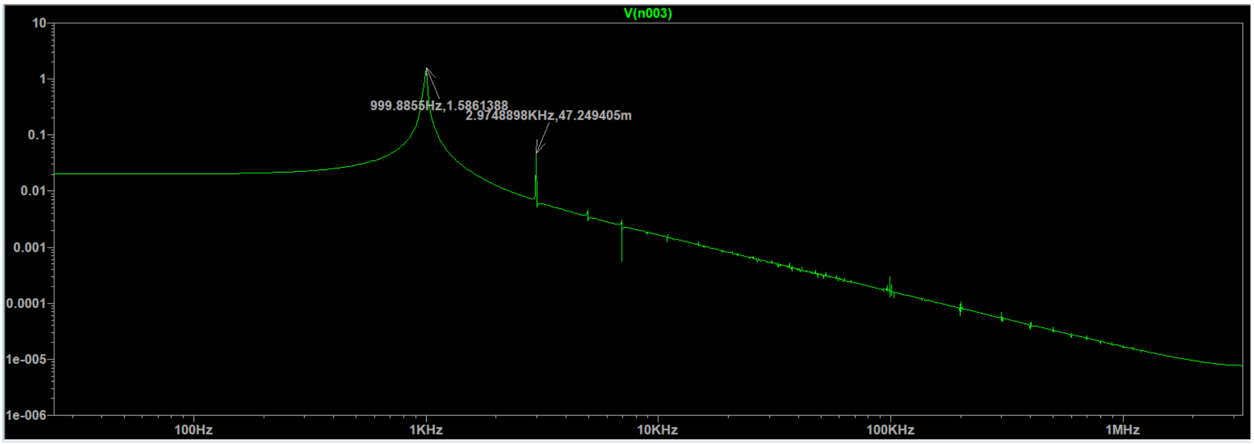


The figure shown above is the Wien-Bridge Oscillator circuit with two diodes in opposite directions in parallel with the R4 resistor.





The figure above shows the output waveform of the oscillator. The diodes decrease the amplitude of the saturated oscillations resulting in a smoother waveform and no clipping. The estimated amplitude resulting from adding two diodes went from about 13V to about 3V.

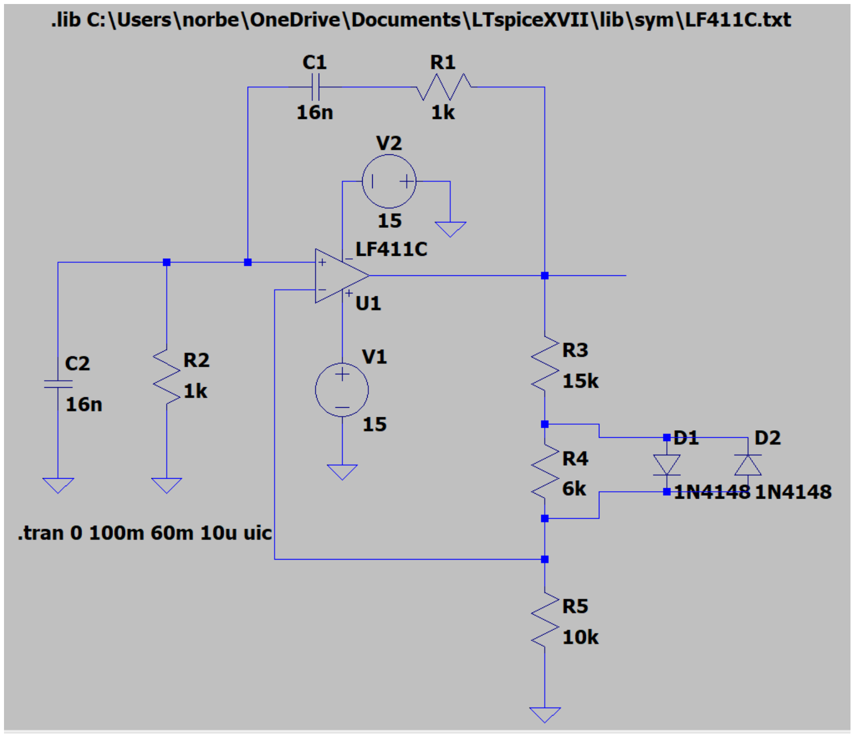


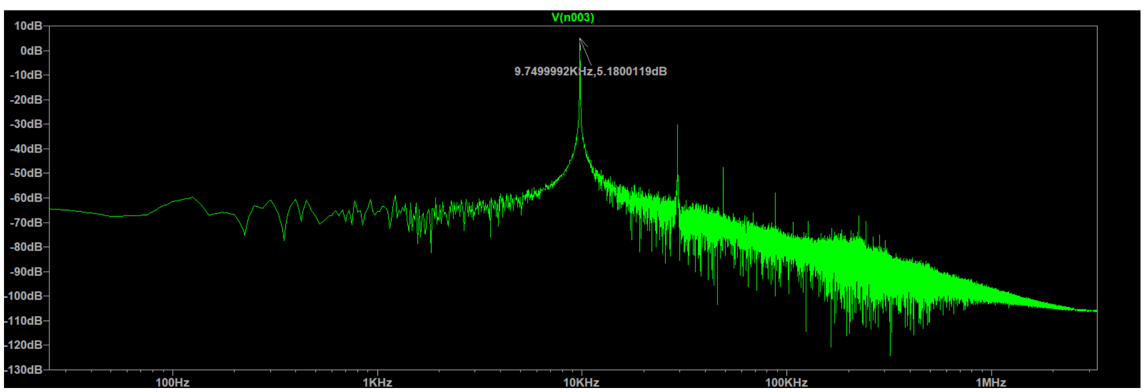
c. $P = 20\log\left(\dfrac{V_{out}(j(1kHz))}{V_{out}(j(3kHz))}\right) = \dfrac{1.586}{47.25\cdot 10^{-3}}$

$\boxed{P \approx 33.57}$

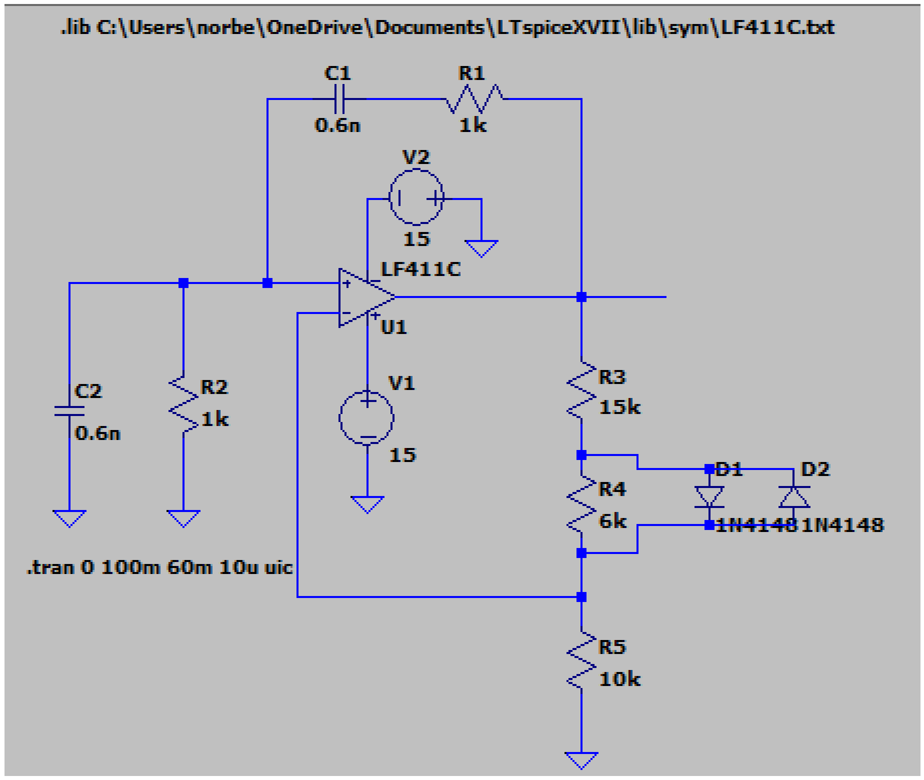
The figure shown above is the output in the FFT view. We found that using the two diodes in parallel with the R4 resistor increases the performance of the oscillator with a performance of about 33.

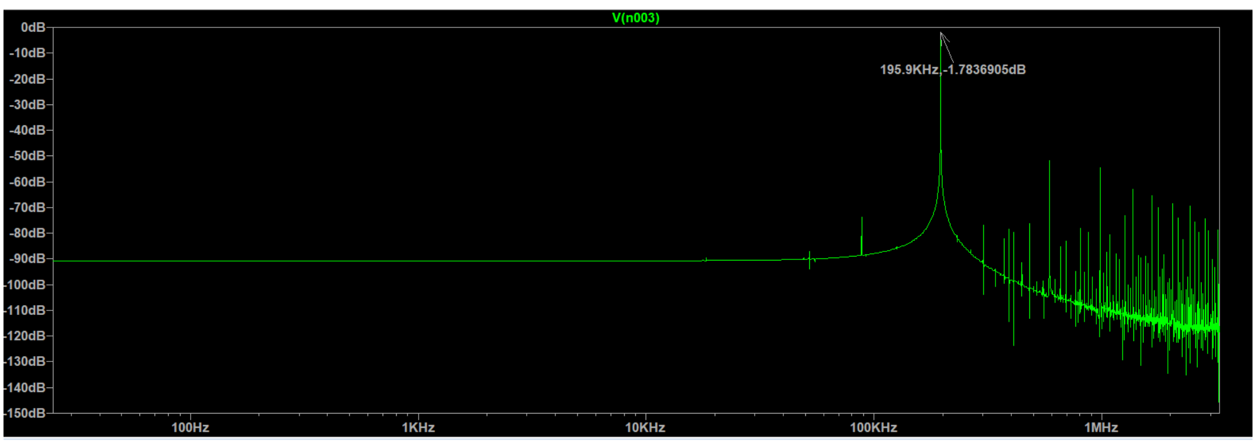
g.





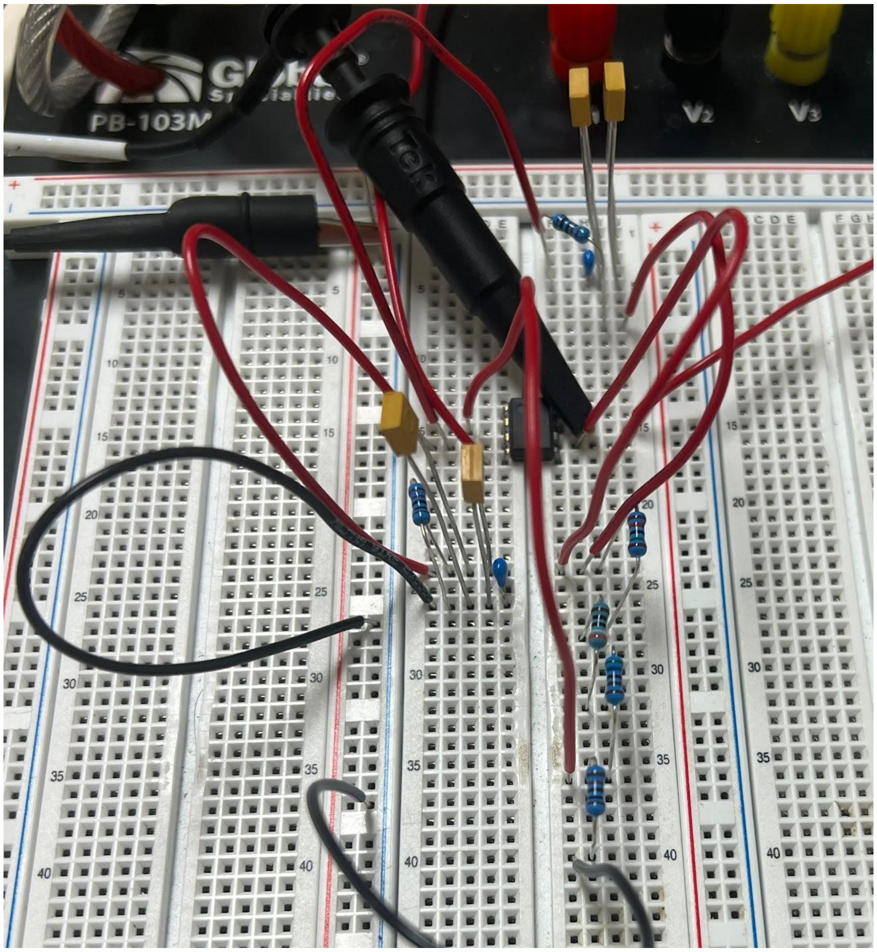
The figures above show the circuit of the oscillator to get a frequency of about 10kHz. To increase the frequency of the oscillator by a factor of 10 we decreased the resistance by a factor of 10, resulting in the resistance to be 1kOhms. We cannot decrease the resistance to further increase the frequency but we can decrease the capacitance to further increase the frequency. Therefore, we can increase the frequency by another factor of 10.

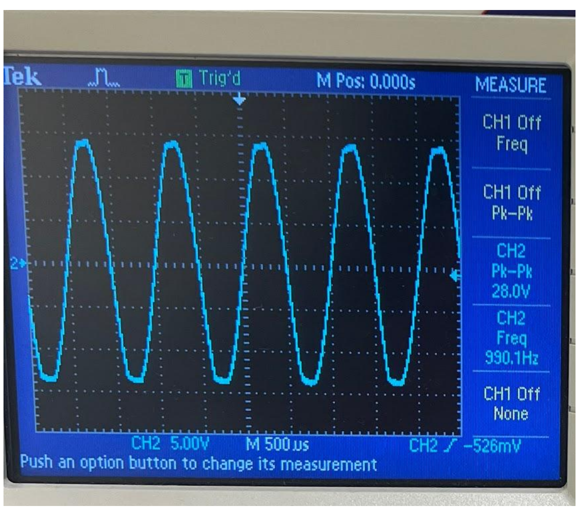




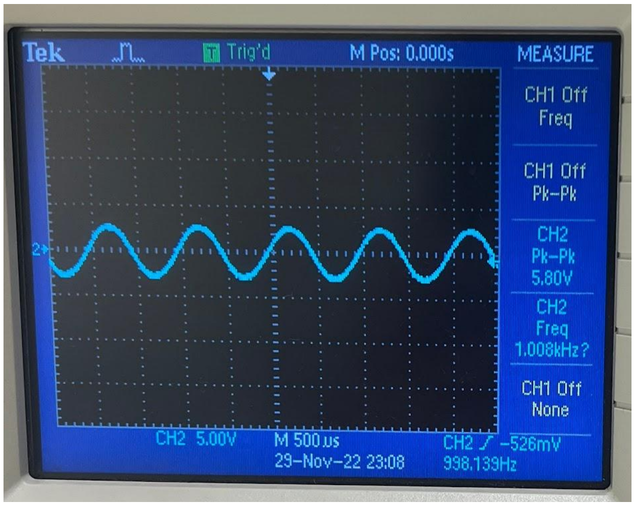
The figures above show the oscillator with the maximum frequency in the simulation. We found that to get the maximum frequency, we need a capacitance of C1 and C2 to be equal to 0.6nF and the resistance of R1 and R2 to be 1kOhms. We got the maximum frequency to be about 195kHz.

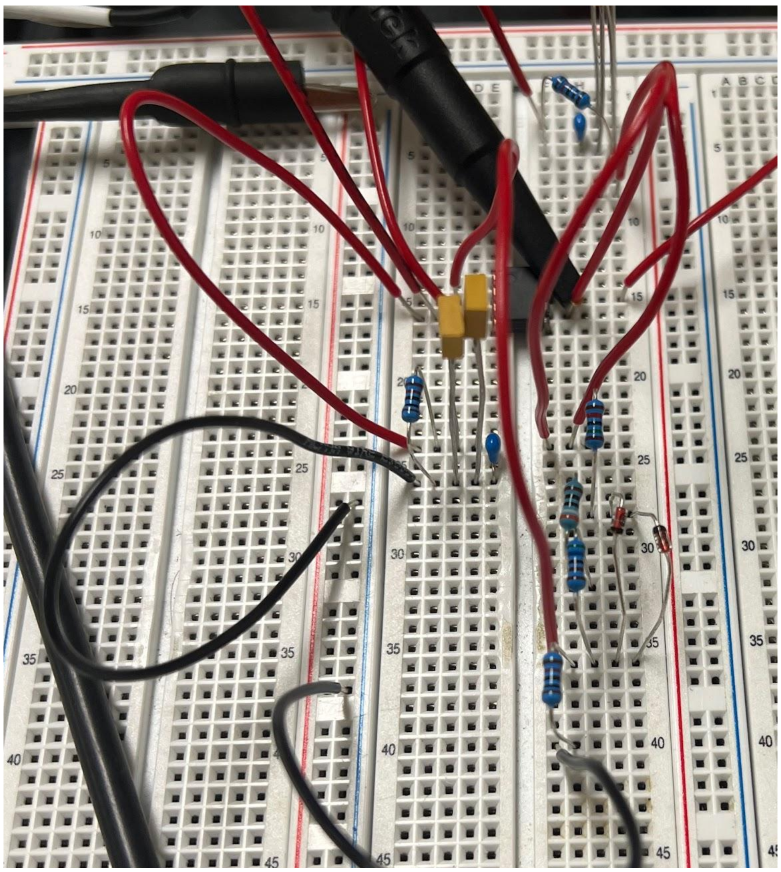
- <u>Problem 3: Measurement</u>

a) 

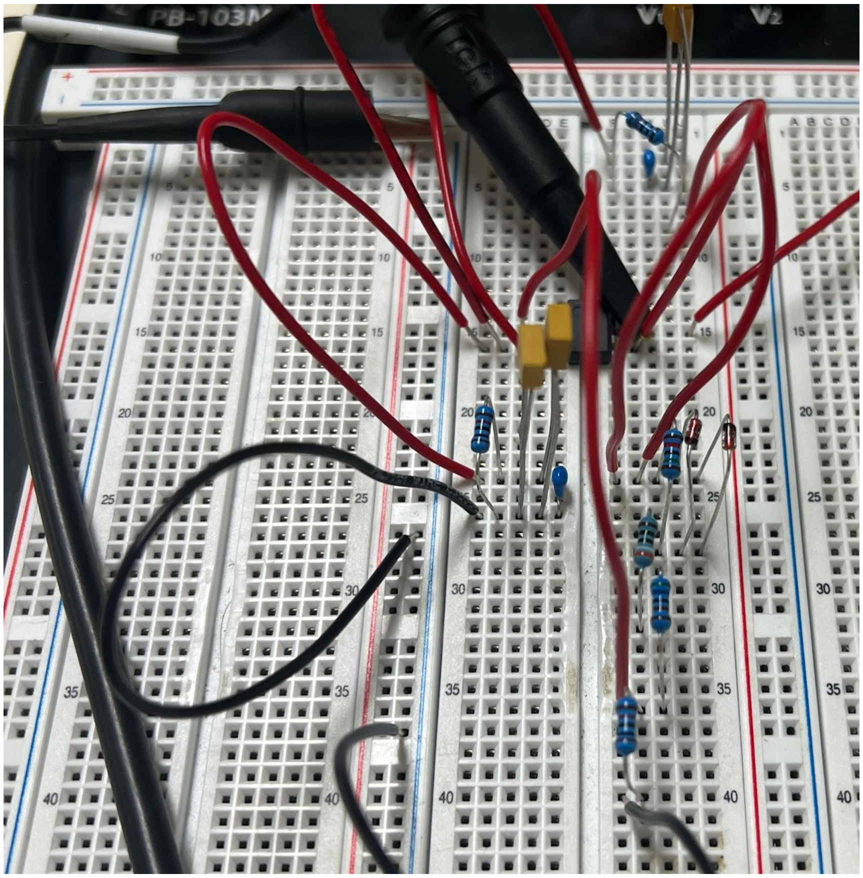


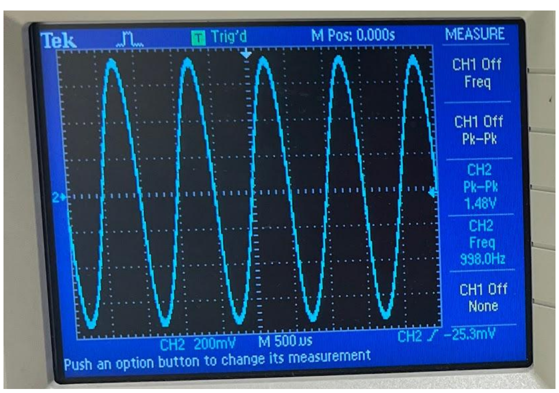
This is the circuit without any diodes placed on the resistors

b) 

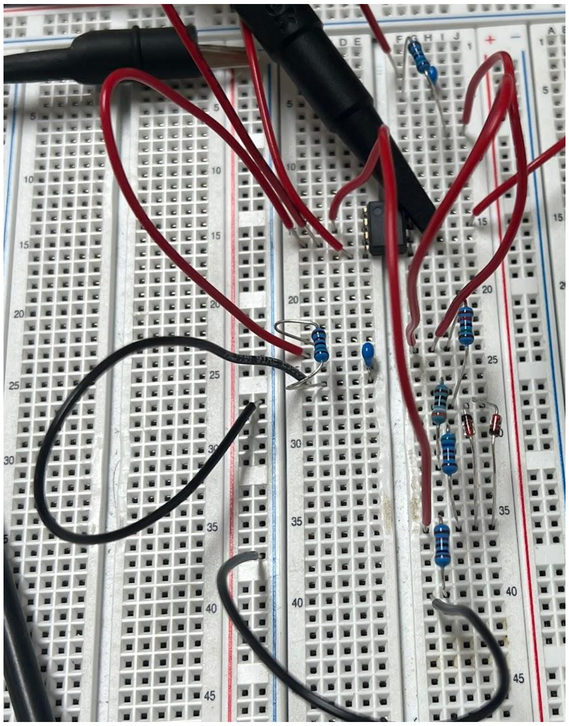


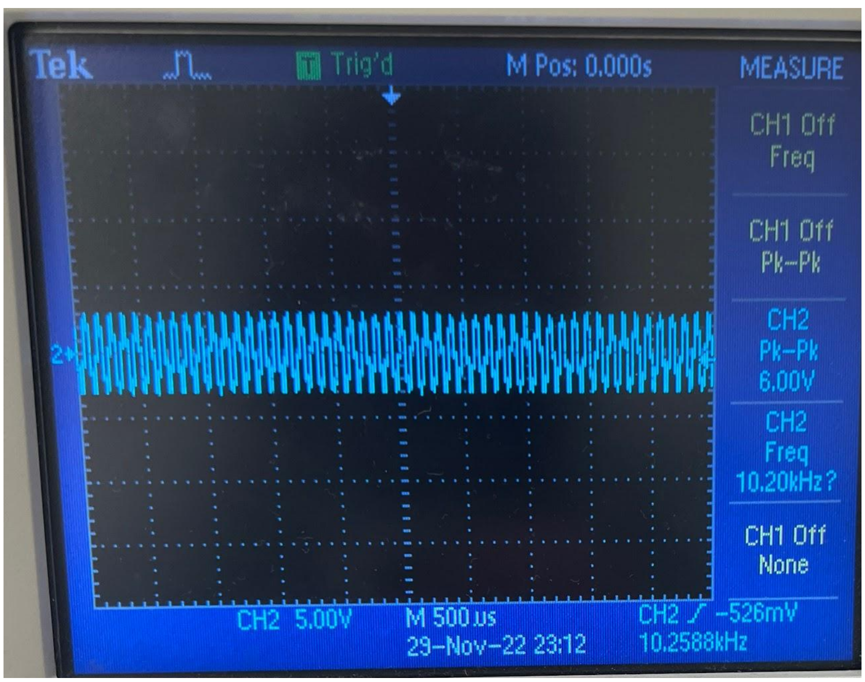
This circuit is the diodes added to the 6k resistor. We find that by adding these two diodes in parallel with the 6k resistor we see that our output voltage is limited by almost 4 times the amount of voltage.

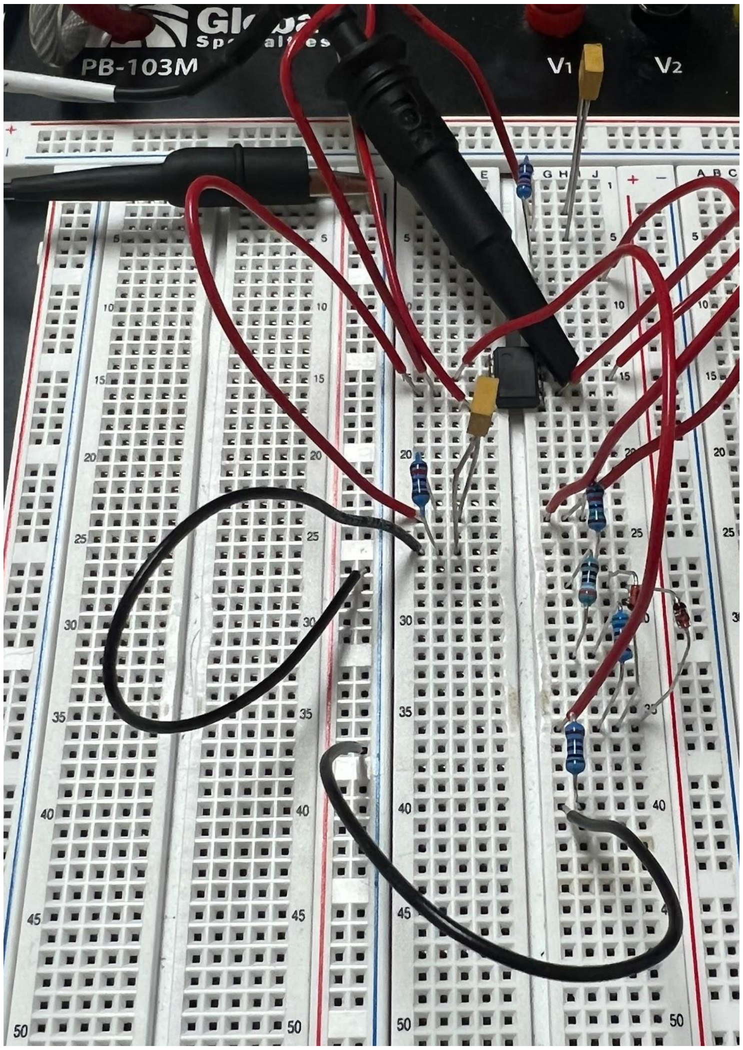
c) 

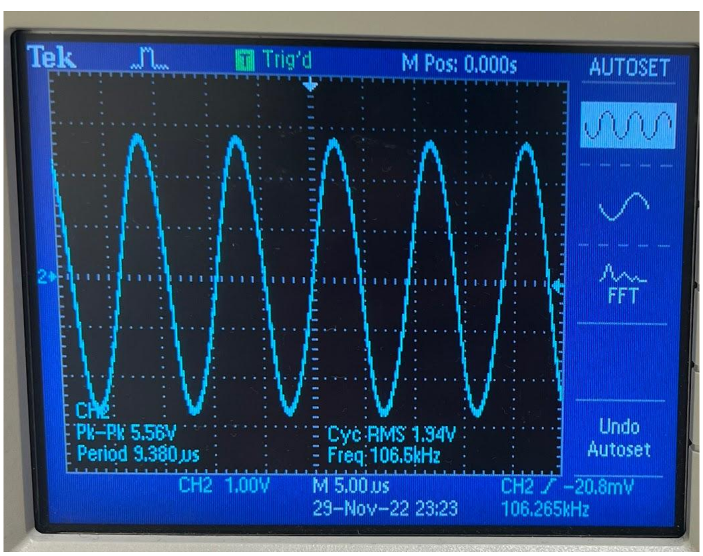


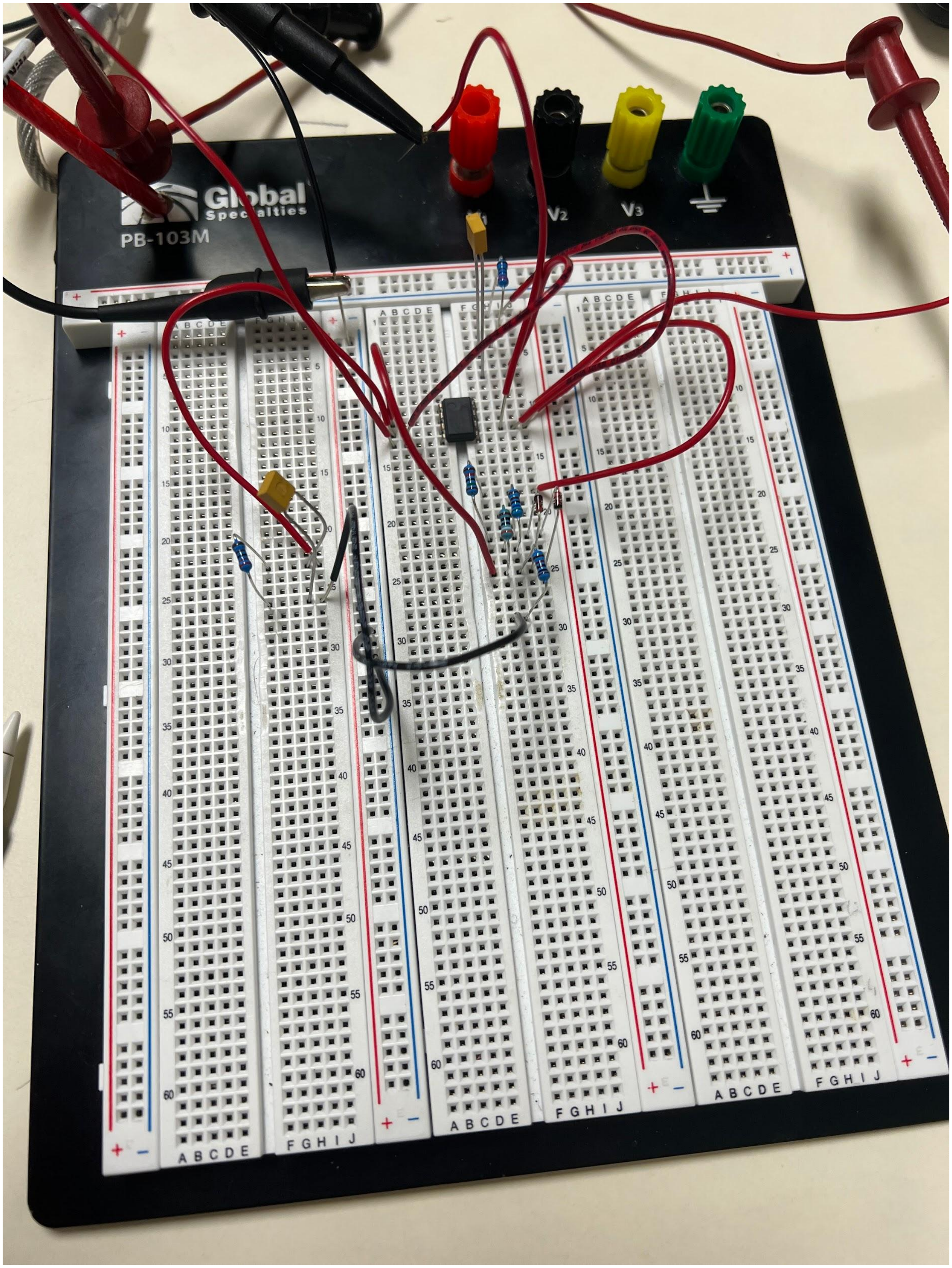
Voltage gain is further limited when the diodes are moved to the 15kOhm resistor. This graph has a different scale but we can see that voltage output was limited more than at the 6kOhm resistor as the voltage pk-pk is a lot less than the previous one.

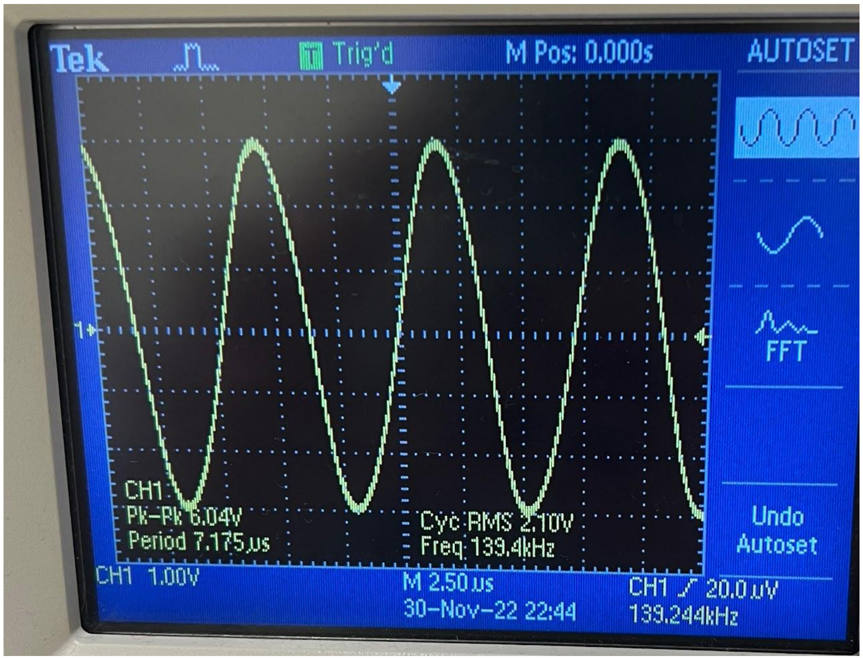
d) 

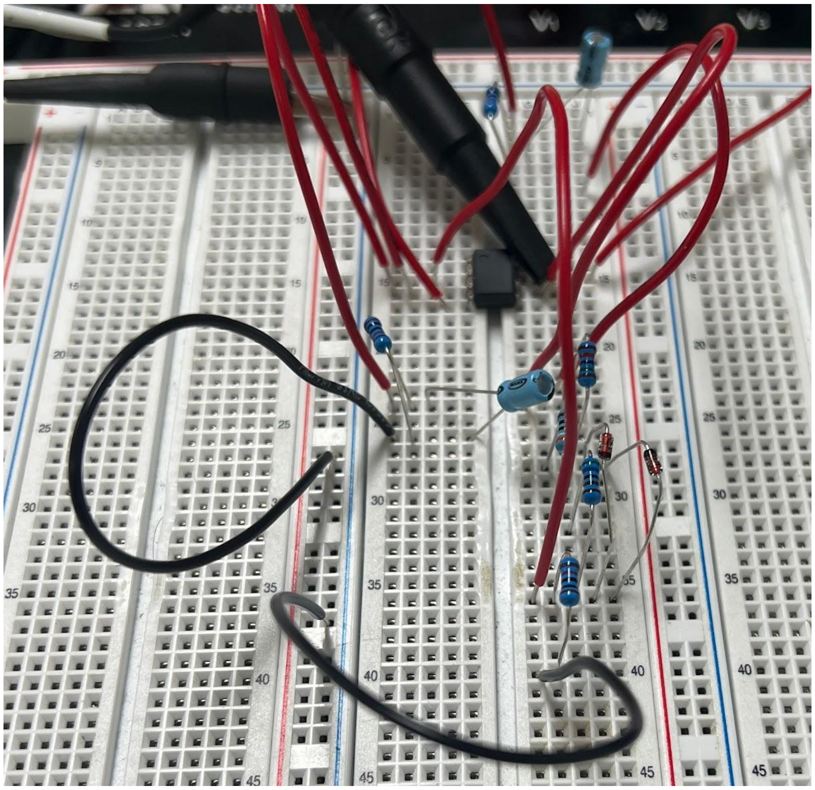

Tek
Trig'd
M Pos: 0.000s
MEASURE
CH1 Off
Freq
CH1 Off
Pk-Pk
CH2
Pk-Pk
6.00V
CH2
Freq
10.20kHz ?
CH1 Off
None
CH2 5.00V
M 500 us
29-Nov-22 23:12
CH2 -526mV
10.2588kHz

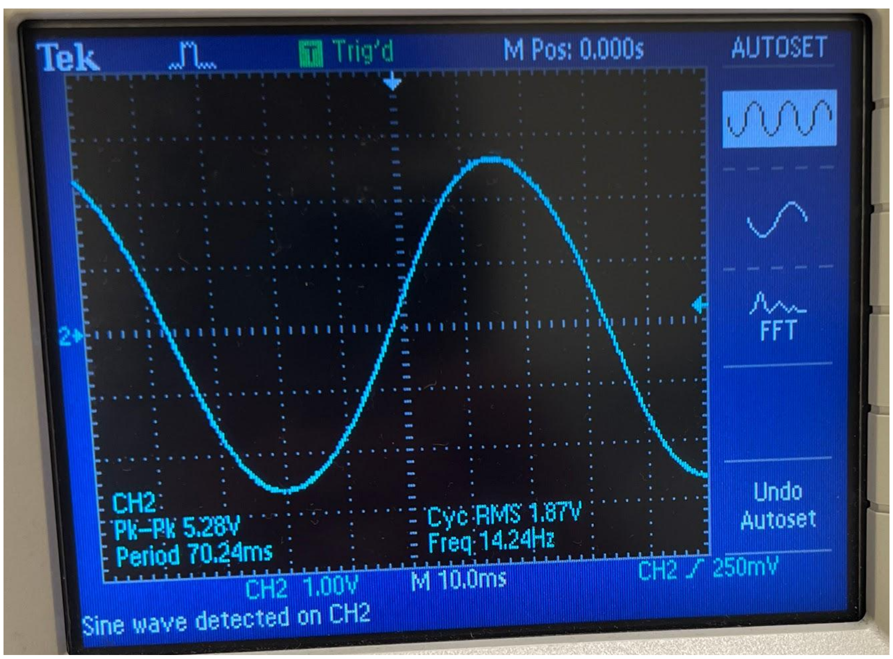

PB-103M
V1
V2


Tek
Trig'd
M Pos: 0.000s
AUTOSET
FFT
CH2
Pk-Pk 5.56V
Period 9.380μs
Cyc RMS 1.94V
Freq 106.5kHz
Undo
Autoset
CH2 1.00V
M 5.00μs
29-Nov-22 23:23
CH2 ∕ -20.8mV
106.265kHz


Global
Specialties
PB-103M
V2
V3


Tek
Trig'd
M Pos: 0.000s
AUTOSET
FFT
CH1
Pk-Pk 6.04V
Period 7.175us
Cyc RMS 2.10V
Freq 139.4kHz
Undo
Autoset
CH1 1.00V
M 2.50us
30-Nov-22 22:44
CH1 20.0uV
139.244kHz





1kHz to 10kHz (I used R = 1.5kOhms and C = 10nF)
10kHz to 100kHz (I used R = 1.2kOhms and C = 1.18nF)
HIghest (139kHz (I used R = 2kOhms and C = 520pF)
14Hz (I used R = 51kOhms and C = 220nF)
For <10Hz (I used R = 100kOhms and C = 220nF)

The highest frequency I was able to reach was 139kHz before missing the 10% mark. For higher frequencies I found that lower resistor and capacitors increased frequencies and the opposite to lower it. I wasn't able to get it as low as 1Hz exactly because the oscilloscope only measures for above 10Hz of frequencies but I was able to get it to 14Hz.

Conclusion

In the first part of the lab, we found many different Nyquist plot for different configurations of op-amp circuits. We calculated many different loop gain equations using A and B as well as different transfer functions. Many of these circuits were previous circuits we had already made calculations for so finding loop gains were easy as we were able to look back for equations we derived. We were able to put together the hand drawn plots by using the bode plots for phase and magnitude and mapping it into a Nyquist plot.

In the second part of the lab, we calculated our loop gain equation for the circuit schematic by calculating the loop gain equation of the op-amp. We found that equation by calculating the impedances and equating B(s) to Z1/Z1+Z2. We then used simulink to create a block diagram of the transfer function and was able to create the output oscillation.

In the third part of the lab, we simulated our circuit using LTSpice. We were able to get out graphs correct and simulate the circuit with the high peak to peak voltage. We then added the diodes to the circuit and were able to confirm that it did minimize the peak to peak voltage to around 2.8. Which ended up the same as our circuit. We found that the diodes didn't clip our circuit. We were able to get a peak frequency of 196kHz in our simulations which did differ from out circuit that we built.

In the last part of the lab, we build the circuit and measured the different outputs for different configurations of this circuit. With the regular circuit in the schematic we found that there was a high voltage output from pk-pk. We then added diodes at opposite directions to the 6kOhm resistor and 15kOhm resistor and found that our output voltage was limited because of the diodes. Then using the expected frequency equation we tried different values for R and C and while staying within the 10% range. We first tried to increase our frequency by a factor of 10 twice so from 1kHz to 10kHz and then 10kHz to 100kHz. We were able to meet the 10% and then found our highest frequency of 139kHz. Any other values we tried it would be above the 10%. We found the low R and C values would increase our frequency and vice versa. We were able to lower our frequency but found that our oscilloscope could not measure below 10Hz of frequency so we got it down to as low as 14Hz.