Julia Laine

Partners: Devin Radzley, Geetika Chitturi

Section: 009

Lab: 07

AD2 #: 210321AA2E82

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Abstract

The purpose of this lab is to test the op-amp built in the previous labs and to demonstrate different measurements of the op-amp. The circuit uses the same ALD1105, ALD1106, and ALD1107 from the previous lab. The circuit is powered and measured by an AD2. First, the op-amp was made into a buffer circuit and the input and output signals were analyzed together with a sine wave. The buffer circuit's input and output was also measured with a square wave to show the slanted rising and falling edges. The slew rates for both sides were calculated. The circuit was changed to an open loop measurement circuit and the unity gain bandwidth was estimated and the -3dB points were found. Finally, a non-inverting amplifier circuit was built, and gain vs frequency plot and frequency response were found. Overall, the lab verified the op-amp was built correctly and demonstrated different uses of an op-amp.

Task 1

Objective

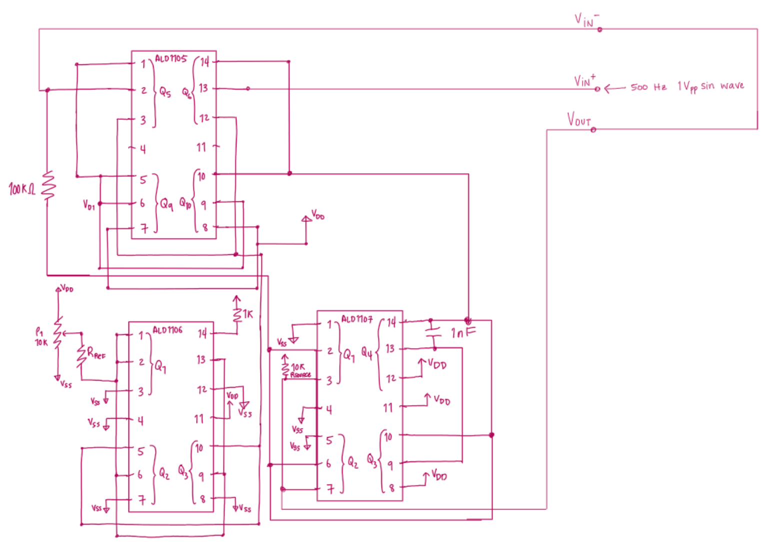
The objective of this task is to verify that the op-amp is built correctly. It also demonstrates that a buffer circuit and makes it easier to compare to an ideal op-amp.

Procedure

First, the op-amp circuit was built. It was adjusted from lab 6 since it got damaged in travel in its box. After the circuit was built, the I_{REF} current was set to 200μA. Next, a 500Hz $1V_{pp}$ sine wave signal was applied to v_{in}^{+}. The resulting v_{out} was compared to the v_{in}. The results were compared to an ideal op-amp.

Results

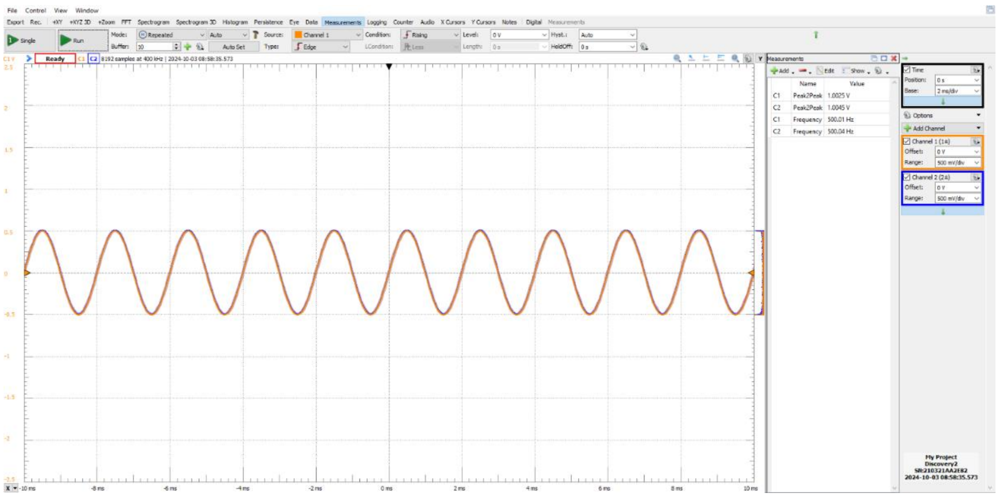
Circuit



I_{REF} value = 202 μA

V_{ref} = 202 mV

Oscilloscope screenshot comparing v_{out} and v_{in}



	C1 (v_{in}^{+})	C2 (v_{in}^{-})	Percent error
Frequency	500.01 Hz	500.04 Hz	0.0059%
Peak to Peak V	1.0025 V	1.0045 V	0.1995%

In an ideal op-amp, v_{in}^{+} and v_{in}^{-} would be the same. This op-amp appears to do a fine job of keeping v_{in}^{+} and v_{in}^{-} as close as possible.

Conclusions

This task was a success since the op-amp operated as ideally as it could and produced similar results to an ideal op-amp.

Task 2

Objective

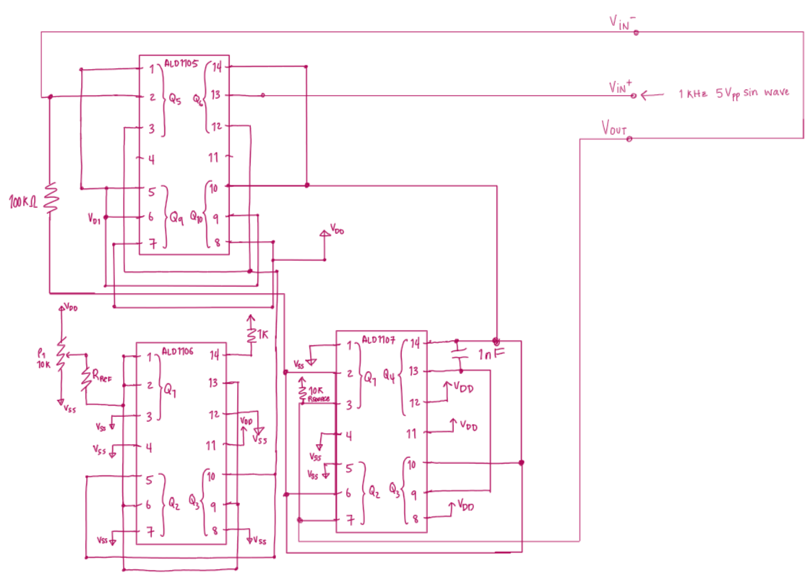
The objective of this task is to demonstrate the slew rate and how to measure it. It also demonstrates the slanted rising and falling edges of the output in comparison to the input wave.

Procedure

The buffer circuit from the last task was reused. A 5V_{pp} 1kHz square wave was applied at v_{in}^{+}. This was compared to a buffer circuit output. Screenshots and measurements of the rising and falling edges were taken.

Results

Circuit



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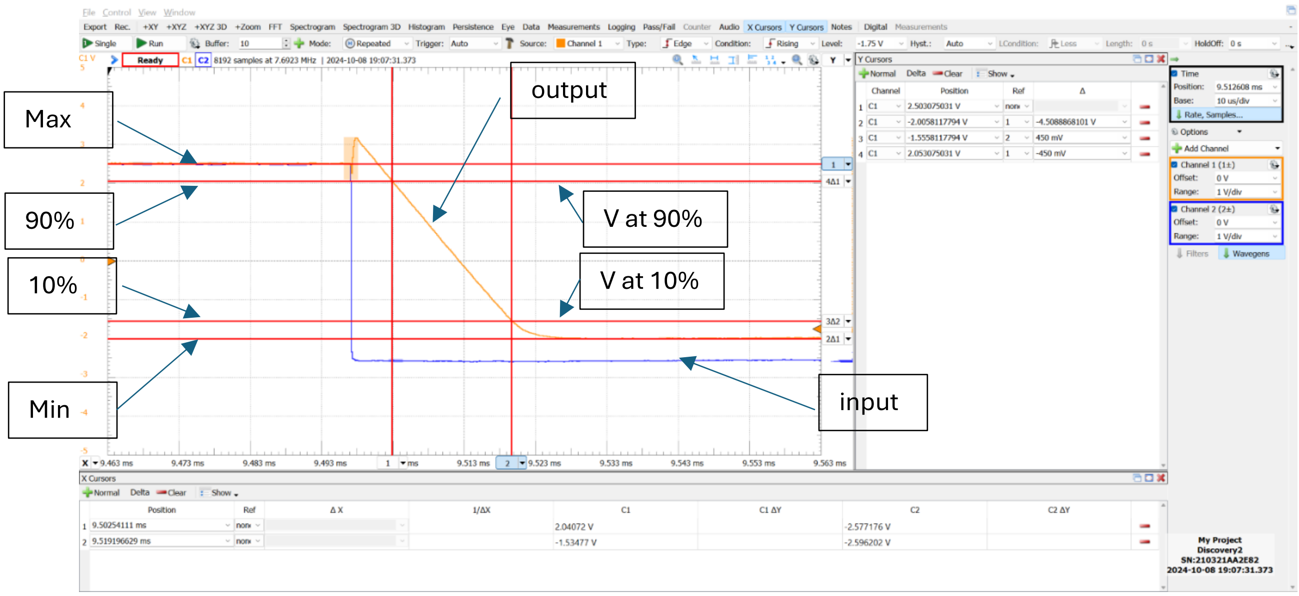
Falling Edge:



Position	C1 (output, V)	C2 (input, V)
9.50254 ms	2.04072	-2.577176
9.51919 ms	-1.53477	-2.596202

Δt : 16.65us

ΔV output: -3.57549 V

$$slew\ rate = \frac{\Delta V}{\Delta t} = -\frac{3.57549}{16.65} = 0.21474\,\frac{V}{\mu s}$$

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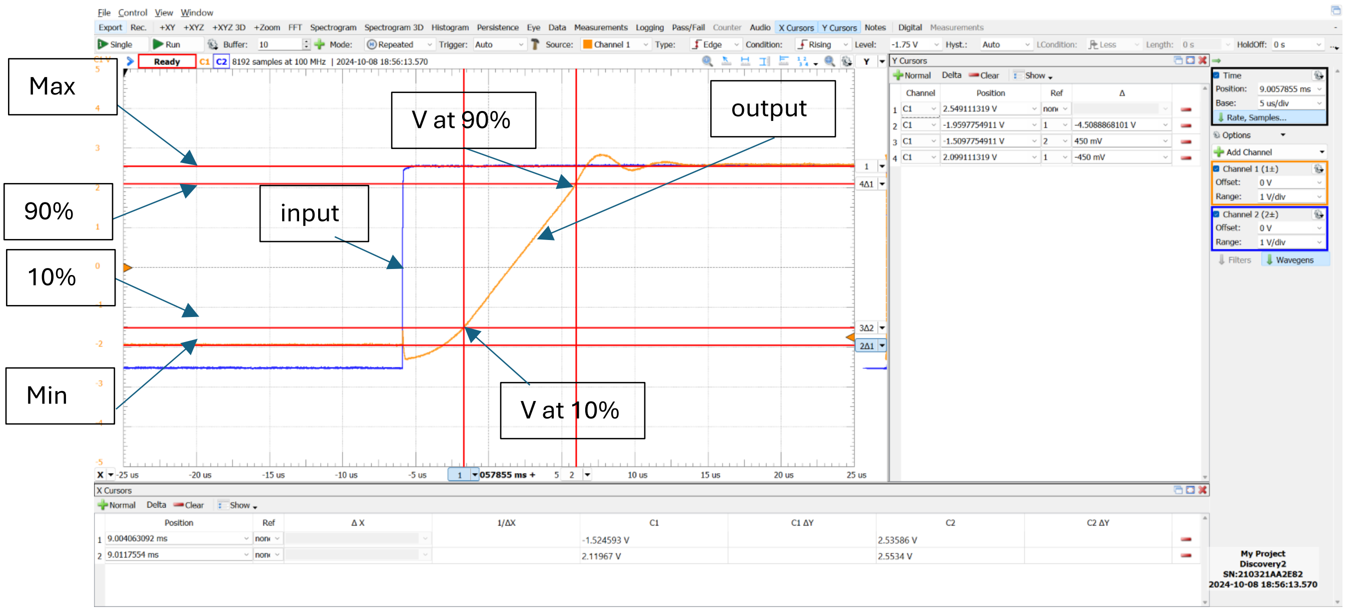
Rising Edge:



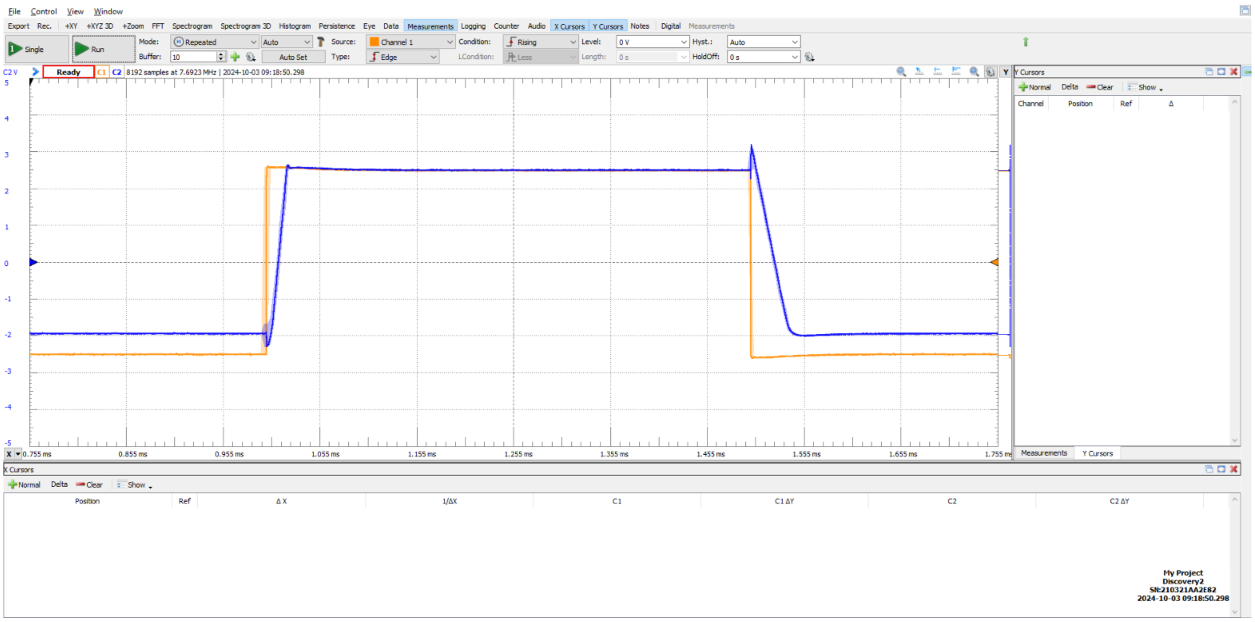
Position	C1 (output, V)	C2 (input, V)
9.004063 ms	-1.524593	2.53586
9.0117554 ms	2.11967	2.5534

Δt : 7.6924 us

ΔV output: 3.644263 V

$$slew\ rate = \frac{\Delta V}{\Delta t} = \frac{3.644263}{7.6924} = 0.473748\,\frac{V}{\mu s}$$

Overall Wave:



The output looks like a buffer circuit, given that it is not ideal. The output follows the input wave. It is angled due to the capacitor and the propagation delay within the circuit.

Conclusions

This task was successful because the slew rate was calculated successfully and the propagation delay of the input to the output was successfully demonstrated and measured.

Task 3

Objective

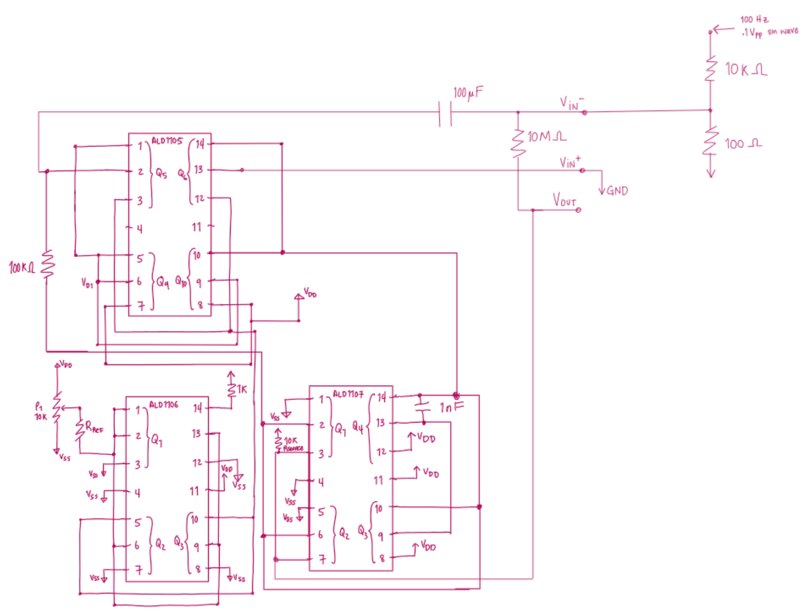
The objective of this task is to demonstrate the unity gain bandwidth of the op-amp. It also demonstrates how to analyze the gain and phase response of the op-amp.

Procedure

First, the circuit was edited to create an open loop measurement circuit. The oscilloscope circuit on the AD2 was configured to trigger in sync with the function generator. A sin wave at 100Hz and $.1V_{pp}$ was applied to v_{in}^{-}. A screenshot of the oscilloscope was taken and the gain was measured. Next, the phase response from 10Hz to 500kHz was measured. The -3dB point was measured. The unity gain bandwidth measured and phase at the point found.

Results

Circuit



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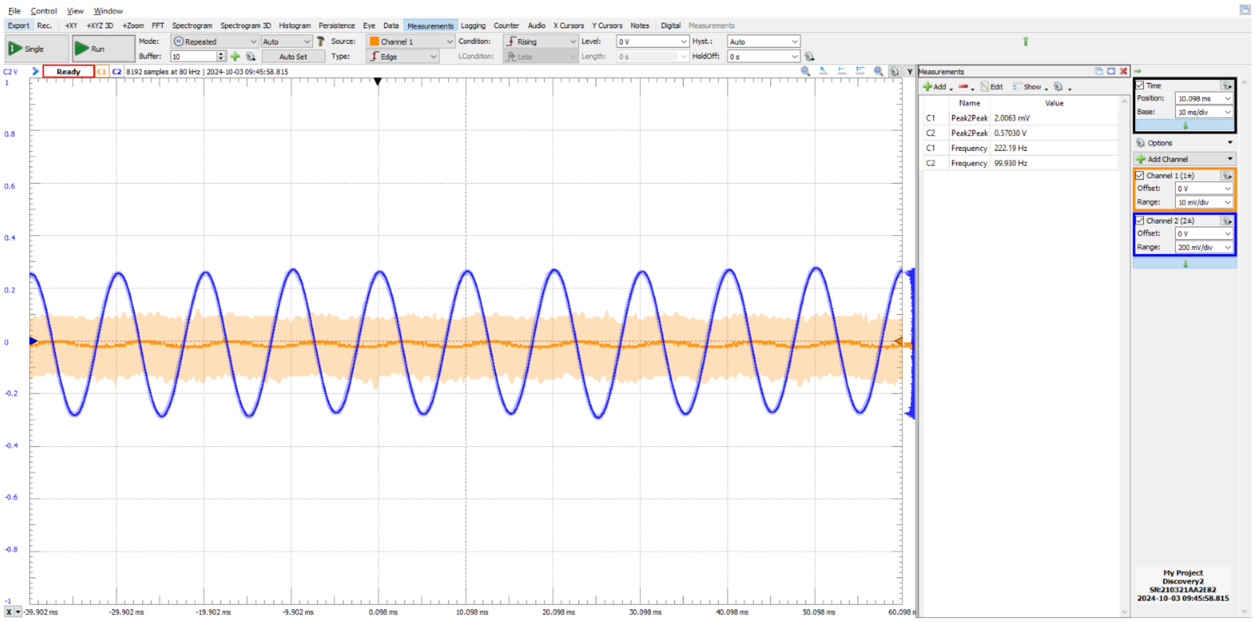
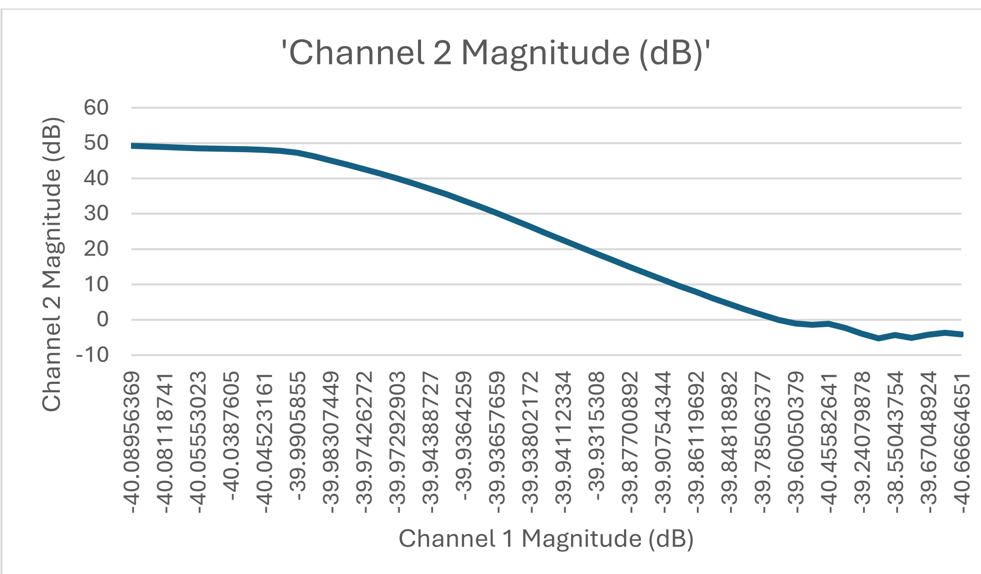
v_{out} *and* v_{in} screenshot (Ch1/orange – input, Ch2/blue – output)



Plot of gain and phase response



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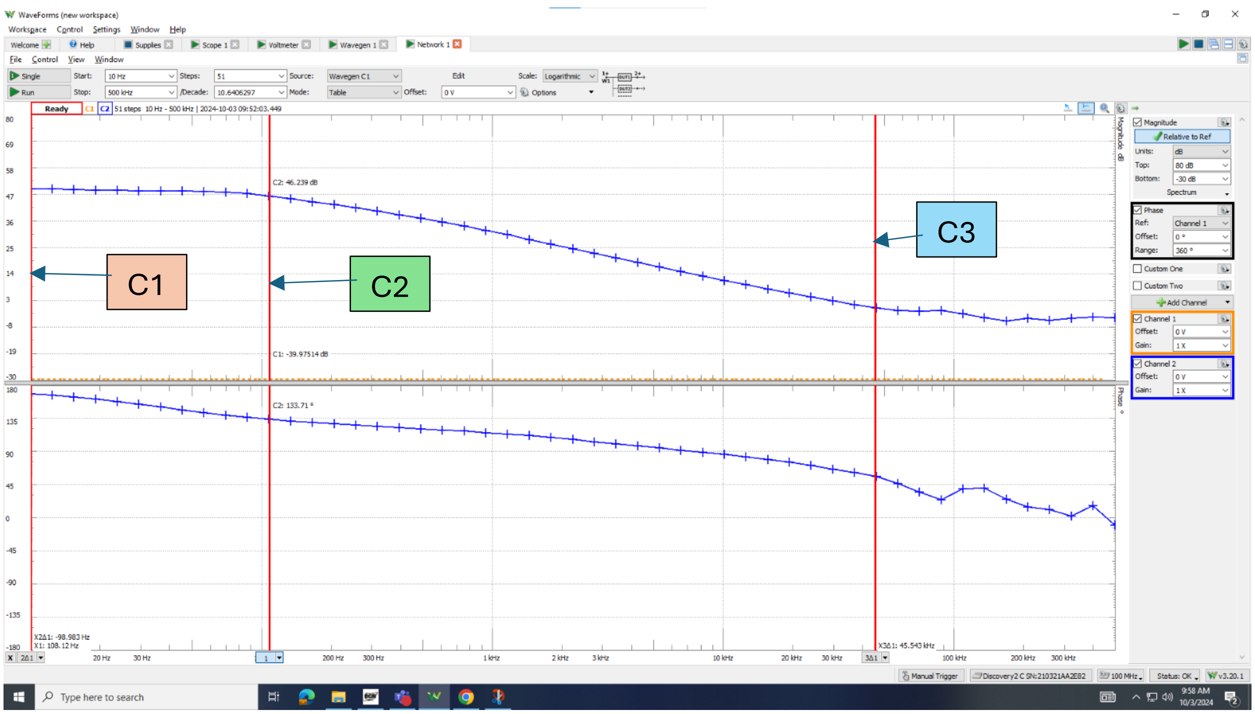
Gain response from 10Hz to 500kHz



Cursor	dB	Phase (degrees)	Frequency (Hz)
C1	49.233	168.38	108.12
C2	46.239	133.71	207.103
C3	.04807	56.151	45,641.983

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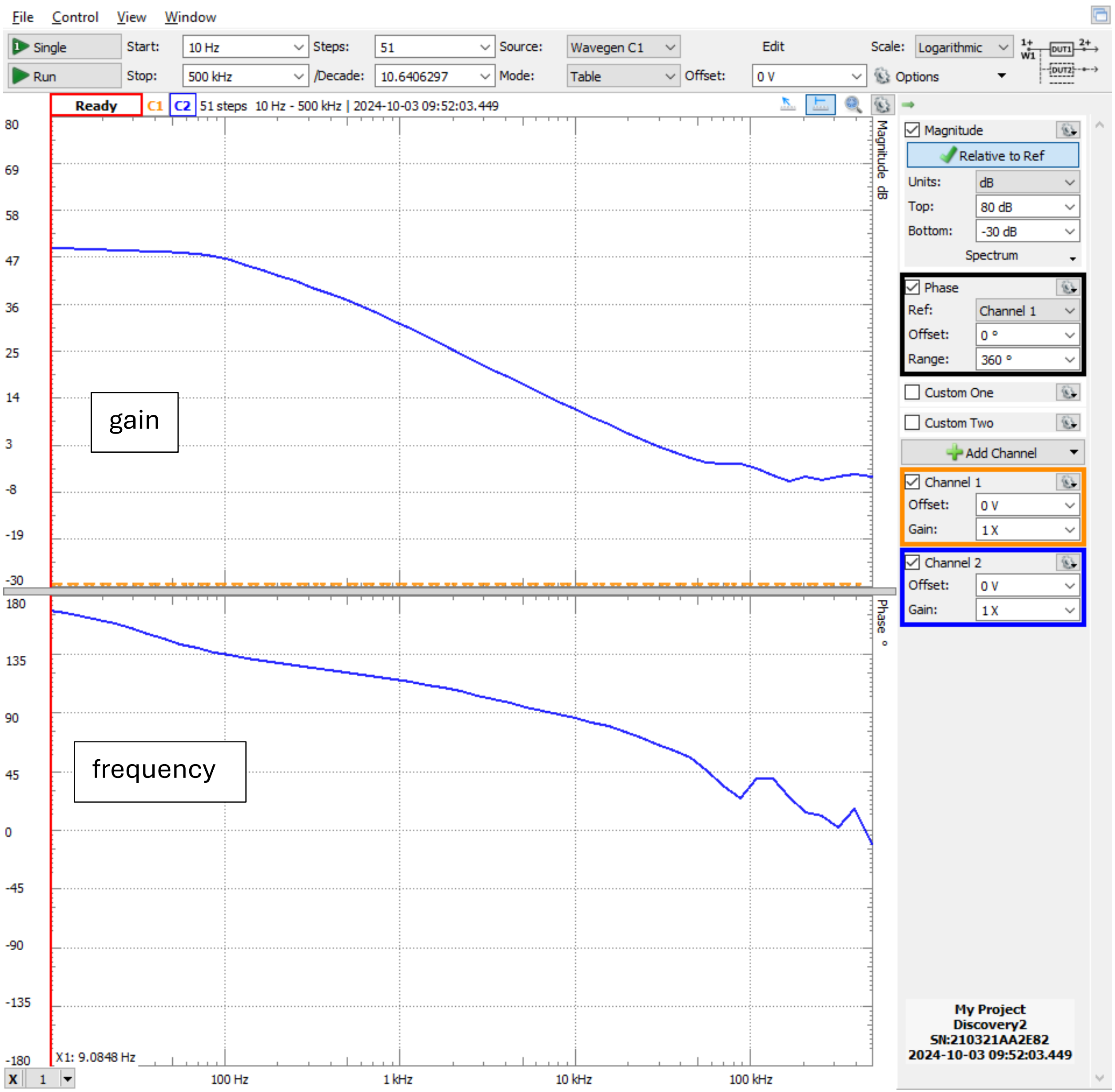


Conclusions

This task was a success since the gain and phase responses were successfully plotted and the -3dB points were measured. The unity gain bandwidth was successfully measured and the phase at the point was found.

Task 4

Objective

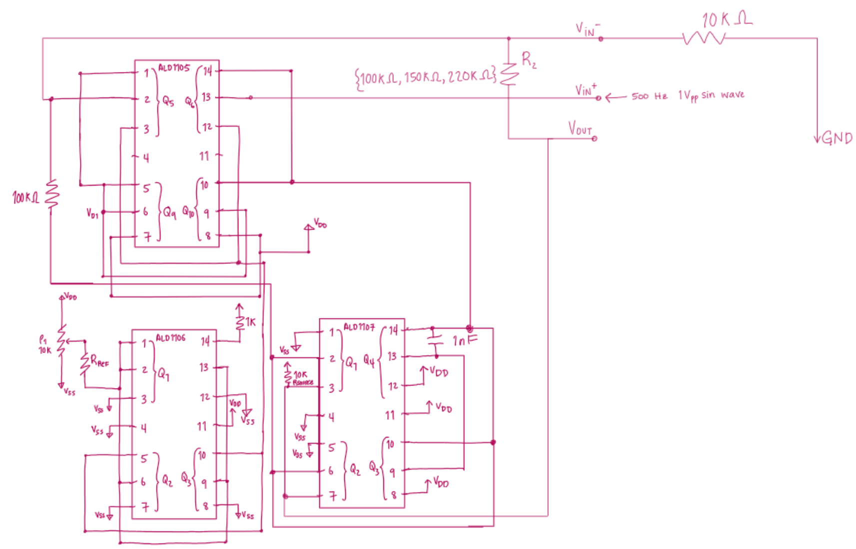
The purpose of this task is to demonstrate how the gain can be changed using different resistors outside of the op-amp. This task demonstrates a non-inverting amplifier circuit.

Procedure

The circuit was built and then tested with various resistor values. For each resistor (100 kΩ, 150 kΩ, and 220 kΩ), the expected gain was found. Next, a sin wave was applied to find the actual gain. Afterwards, a gain vs. frequency plot was created and the -3dB point was estimated. The phase at the point was measured and the GBW was measured from the plot also. Finally, the relationship of gain bandwidth over different gains was analyzed.

Results

Circuit



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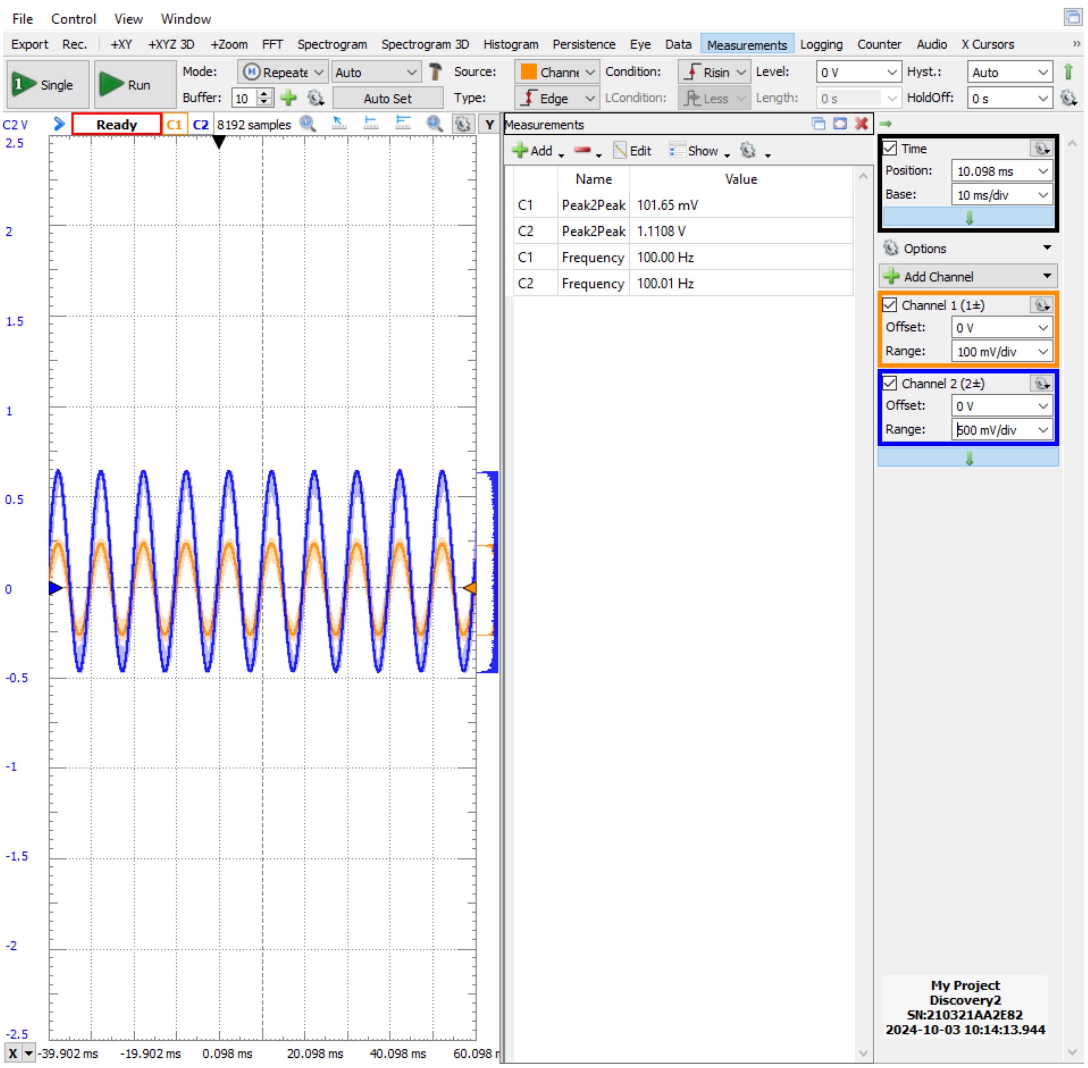
100k results

Expected gain (for non-inverting amplifier):

$$A_v = \frac{R_2}{R_1} + 1 = \frac{100k}{10k} + 1 = 11$$

Input and output graph



C1 = input, C2 = output

Channel	Voltage
C1 (in)	101.65 mV
C2 (out)	1.1108 V

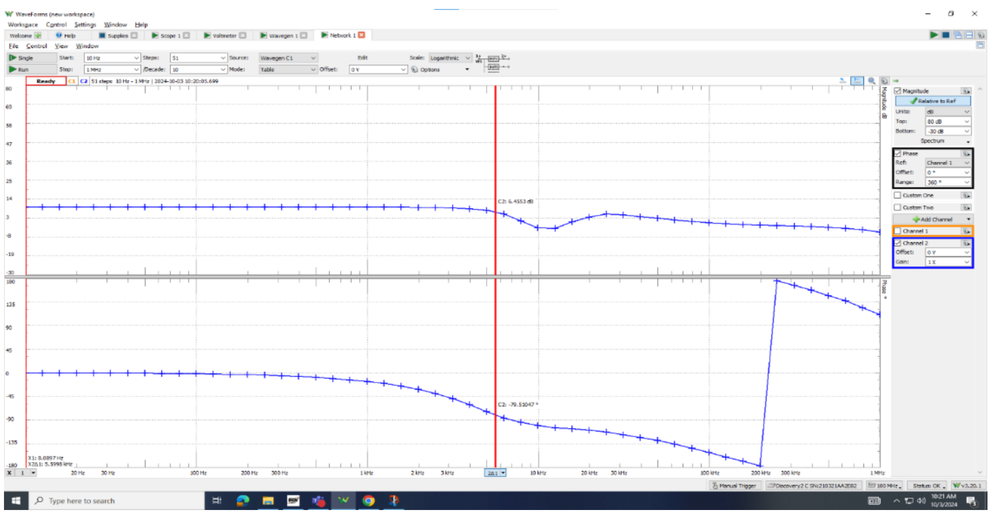
Gain:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{1.1108}{.10165} = 10.92769$$

Percent error:

$$\%Error = \frac{|Actual - Expected|}{Expected} \times 100 = .65734\%$$

Gain vs. frequency graph (10Hz – 1MHz)



-3dB point: 6.3733 dB

Phase at -3dB: -80.04386°

Max gain: 9.3733 dB

Conversion to Linear Scale

$$Gain = 20\log_{10}\mathrm{A_v}$$

$$A_v \ = \ 10^{\left(\frac{\max gain}{20}\right)} = 10^{\frac{9.3733}{20}} = 2.942151$$

GBW Calculation

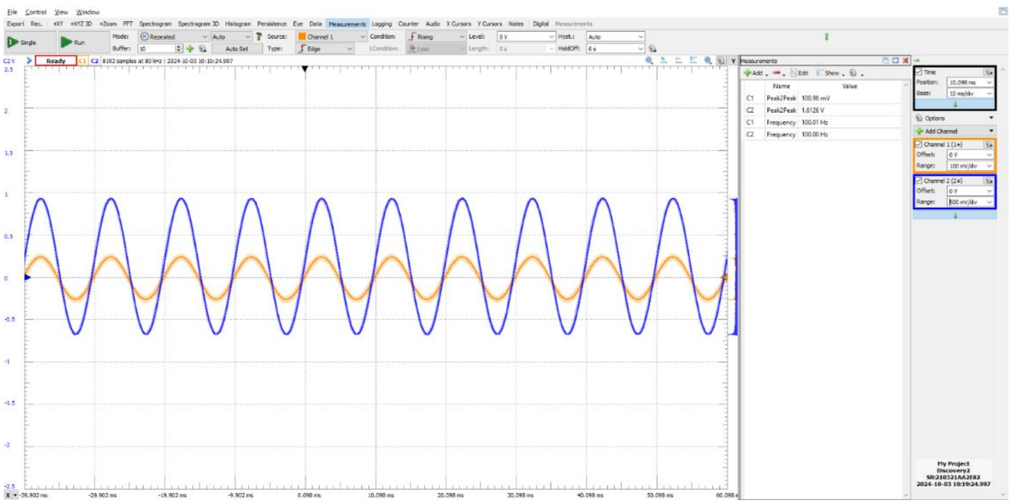
$$GBW = Max\ Gain_{linear} * Bandwidth = 2.942151 * 6.1263kHz = 18024.50\ Hz$$

150k results

Expected gain (for non-inverting amplifier):

$$A_v = \frac{R_2}{R_1} + 1 = \frac{150k}{10k} + 1 = 16$$

Input and output graph



C1 = input, C2 = output

Channel	Voltage
C1 (in)	100.98 mV
C2 (out)	1.6126 V

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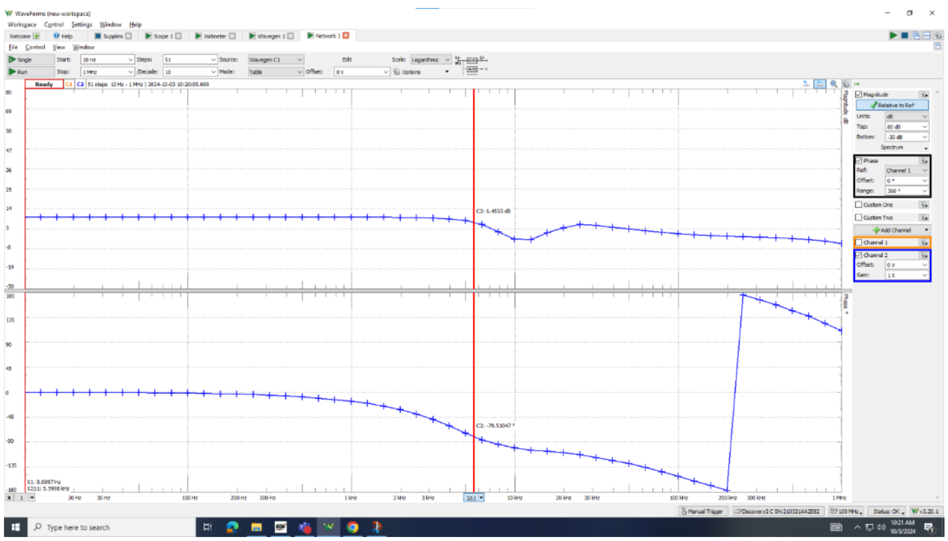
Gain:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{1.6126}{.10098} = 16.10539$$

Percent error:

$$\%Error = \frac{|Actual - Expected|}{Expected} \times 100 = .658125\%$$

Gain vs. frequency graph (10Hz – 1MHz)



-3dB point: 6.4553 dB

Phase at -3dB: -79.5104°

Max Gain: 9.4553 dB

Conversion to Linear Scale

$$Gain = 20\log_{10}\mathrm{A_v}$$

$$A_v \ = \ 10^{(\frac{\max gain}{20})} = 10^{\frac{9.4553}{20}} = 2.970058$$

GBW Calculation

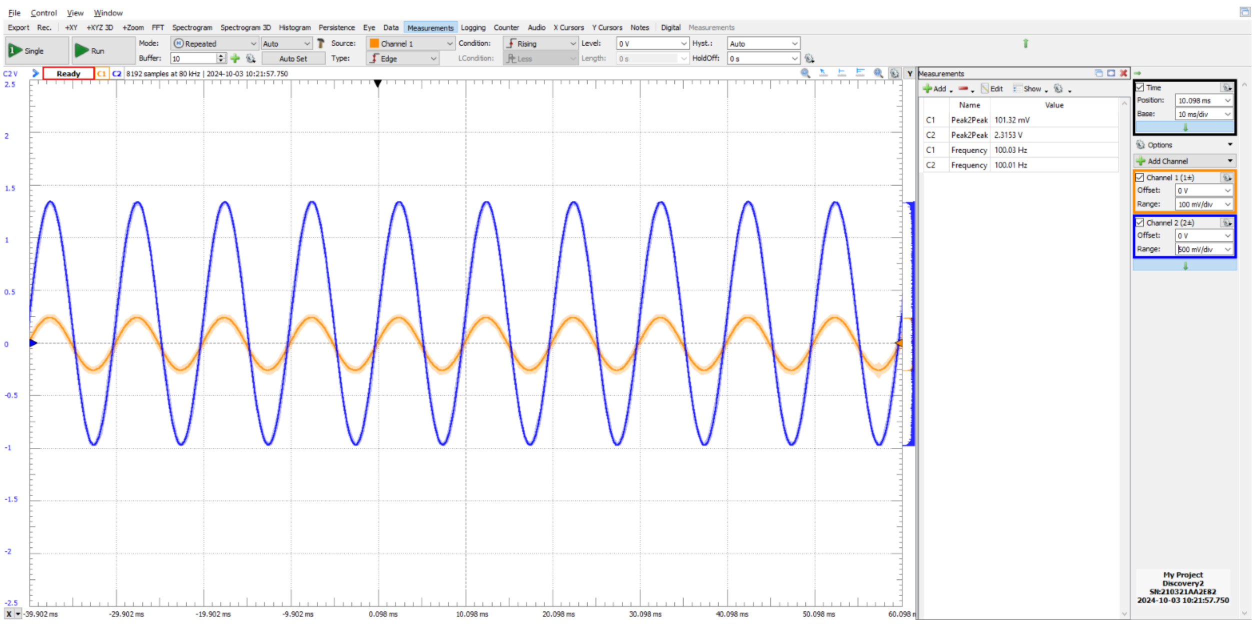
$$GBW = Max\ Gain_{linear} * Bandwidth = 2.970058 * 5.5998kHz = 16631.7335\ Hz$$

220k results

Expected gain (for non-inverting amplifier):

$$A_v = \frac{R_2}{R_1} + 1 = \frac{220k}{10k} + 1 = 23$$

Input and output graph



C1 = input, C2 = output

Channel	Voltage
C1 (in)	101.32 mV
C2 (out)	2.3153 V

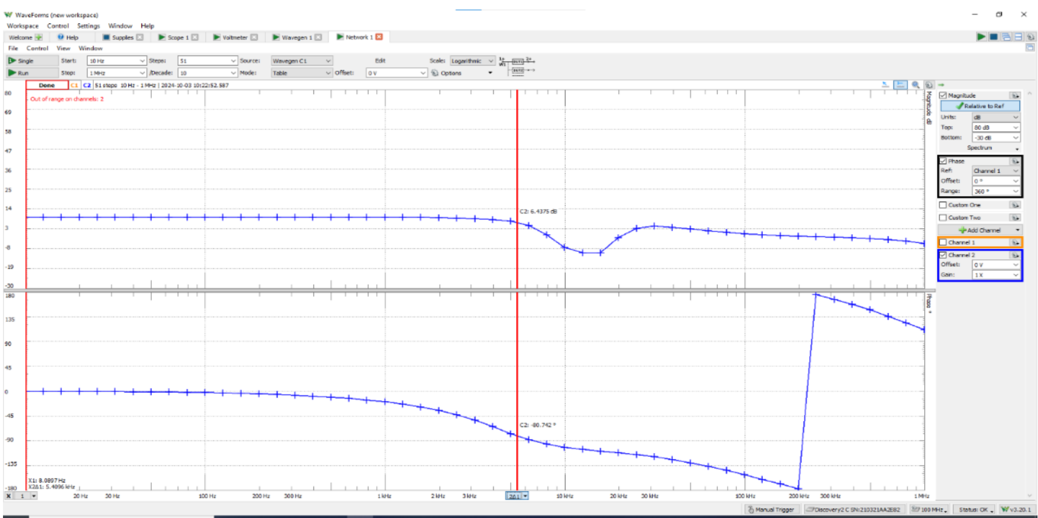
Gain:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{2.3153}{.101} = 22.92$$

Percent error:

$$\%Error = \frac{|Actual - Expected|}{Expected} \times 100 = .331\%$$

Gain vs. frequency graph (10Hz – 1MHz)



-3dB point: 6.4375 dB

Phase at -3dB: -80.742°

Max gain: 9.4375 dB

Conversion to Linear Scale

$$Gain = 20\log_{10}\mathrm{A_v}$$

$$A_v = 10^{\left(\frac{max\,gain}{20}\right)} = 10^{\frac{9.4375}{20}} = 2.96398$$

GBW Calculation

$$GBW = Max\ Gain_{linear} * Bandwidth = 2.96398 * 6.1263kHz = 18158.23\ Hz$$

Conclusions

This task was successful because the GBW was successfully found for each resistor value. The percent error on each resistor value's gain vs predicted was very small, so the op-amp worked as expected.