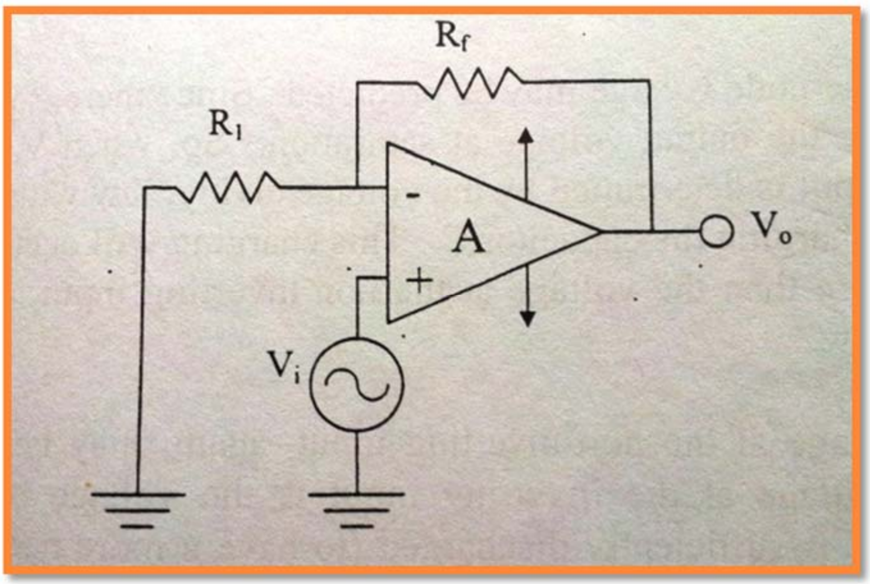
ELECTRICAL ENGINEERING 110L
CIRCUITS MEASUREMENTS LAB

LAB 7: OPERATIONAL AMPLIFIERS



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Objective

Op-Amps are one of the greatest electrical engineers breakthroughs that perform various analog mathematical functions such as differentiation and integration. Due to Op-Amps importance in every single technology today lab 7 will be focus on this topic. The goal of this lab was to observe the changes in voltage gain for inverting and non-inverting operational amplifiers when frequency is varied. The newer function generator is used to apply various frequencies and the oscilloscope is used to measure the values. Another part of the experiment was to measure the DC offset of the operational amplifier by finding an input voltage and resulting output voltages.

Theory

In this lab we were using the following governing equations to conduct experiments, collect data, and verify principles:

Table 1: Governing Equations for the experiments that follow.

Governing Equations	Equations Information
[1] $\frac{V_{out}}{V_{in}} = \frac{-R_F}{R_L}$	Inverting Amplifier R = Resistance (Ω), V = Voltage (V)
[2] $\frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R_L}$	Non-inverting Amplifier
[3] f=1/T	f = frequency (Hz) and T = period (s)
[4] dB = 20*log(V_{in}/V_{out})	Voltage ratio to dB conversion
[5] Gain = V_{out}/V_{in}	Gain of the circuit

OP-Amps –

Operational Amplifiers is basically a voltage controlled voltage source amplifier with a high gain. This means than an input voltage is amplified once outputted. The gain of an ideal OP-Amp is infinite. Another thing is the input current of the op-amp is zero meaning no current flow through the op-amp.

Kirchhoff's Current Law (KCL) –

Sum of all the current coming in equals the current going out. This law is useful when trying to setup a general equation for the circuit. This law may help with finding the impedance.

Kirchhoff's Voltage Law (KVL) –

Voltage in an enclosed loop adds up to zero. This law is useful when trying to setup a general equation for the circuit. This law may help with finding the impedance as well.

Procedure

Experiment 1:

In this first experiment we construct an inverting amplifier for a gain of -10. To do this we chose R_F = 100k Ω and R_L = 10k Ω. We need to make sure that the op-amp is operational by testing it on a machine the professor provided to see if the light flashed green and red. The initial step is to connect channel 1 and 2 to the input and output of the amplifier circuit. Next step is to make sure the op-amp is supplied at +/-15 V to its positive and negative terminal. With the setup finished, we can begin collecting various input voltages and output voltages at different frequencies. Make sure to run through all the frequencies so that the V_o/V_i goes from 10 to 1.2. The figure for the inverting amplifier is shown below.

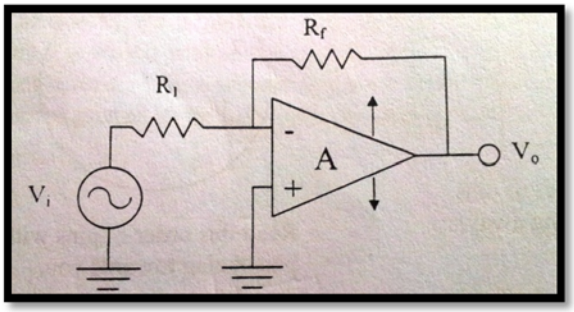

Figure 1: Inverting amplifier circuit design.

Experiment 2:

The second experiment uses the same procedure as the first experiment. The only difference is that this time we connect the non-inverting amplifier instead. Then we repeat the frequency and V_o/V_i measurement.

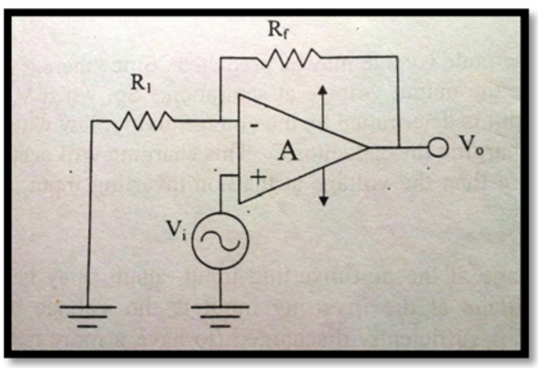

Figure 2: Non-Inverting amplifier circuit design.

Experiment 3:

In this third experiment we are going to build the circuit shown in the figure below. Try noticing where the DMM and function generator are placed. Connect and power the op-amp by connecting it to +/- 15V like in experiment 1. Now to begin the experiment we will find where the output voltage suddenly change from low to high and record the input voltage when the output suddenly changes (record it three times). We also perform the same task for high to low output voltage changes. Again record it three times.

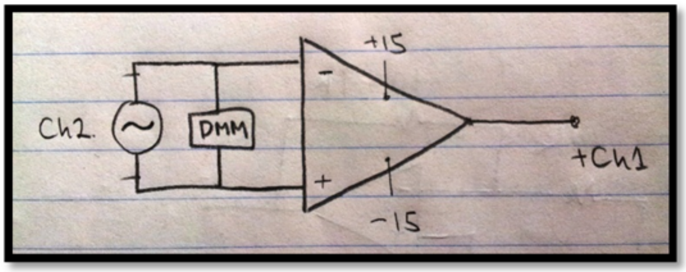

Figure 3: Circuit design for experiment 3.

Experiment 4:

This is our last experiment. This time we are going to construct a circuit where the function generator is directly hooked to the positive and negative terminal of the op-amp (note: this is not the location to make the op-amp operational). Again apply +/-15V to the op-amp to make it operational. Record the V_o and V_i. Basically set up the op-amp so that it is only connected to the function generator and the offset DC source.

DATA, DATA ANALYSIS, ERROR ANALYSIS, AND DISCUSSION

Error Analysis Equation

If the general equation is $F(x_1, x_2, \ldots, x_n)$ then the error for F (identified as σ_F) would be given by the following error propagation equation:

$$\sigma_F = \sqrt{(\frac{dF}{dx_1}\sigma_{x_1})^2 + (\frac{dF}{dx_2}\sigma_{x_2})^2 + \cdots + (\frac{dF}{dx_n}\sigma_{x_n})^2}$$

Experiment 1:

Data

Table 2: Data collected for the inverting amplifier circuit

f (kHz)	Vipp (V)±.005	Vopp (V)±.005	Vo/Vi ± uncertainty	
1	2.04	20.4	10	0.025
0.1	2.04	20.4	10	0.025
10	2.08	20.8	10	0.024
50	0.616	5.68	9.22077922	0.075
75	0.616	4.88	7.92207792	0.065
85	0.616	4.64	7.53246753	0.062
90	0.616	4.48	7.27272727	0.060
100	0.616	4.16	6.75324675	0.055
95	0.616	4.32	7.01298701	0.057
110	0.616	3.84	6.23376623	0.051

120	0.616	3.6	5.84415584	0.048
130	0.216	1.5	6.94444444	0.162
140	0.216	1.44	6.66666667	0.156
150	0.236	1.48	6.27118644	0.135
175	0.236	1.36	5.76271186	0.124
200	0.236	1.22	5.16949153	0.112
225	0.232	1.12	4.82758621	0.106
250	0.236	1.04	4.40677966	0.096
275	0.236	0.96	4.06779661	0.089
300	0.232	0.88	3.79310345	0.085
325	0.232	0.8	3.44827586	0.077
350	0.232	0.76	3.27586207	0.074
400	0.232	0.66	2.84482759	0.065
500	0.232	0.54	2.32758621	0.055
600	0.232	0.44	1.89655172	0.046
700	0.232	0.328	1.4137931	0.037
800	0.232	0.284	1.22413793	0.034
900	0.232	0.24	1.03448276	0.031
1000	0.228	0.208	0.9122807	0.030
10000	0.228	0.032	0.14035088	0.022

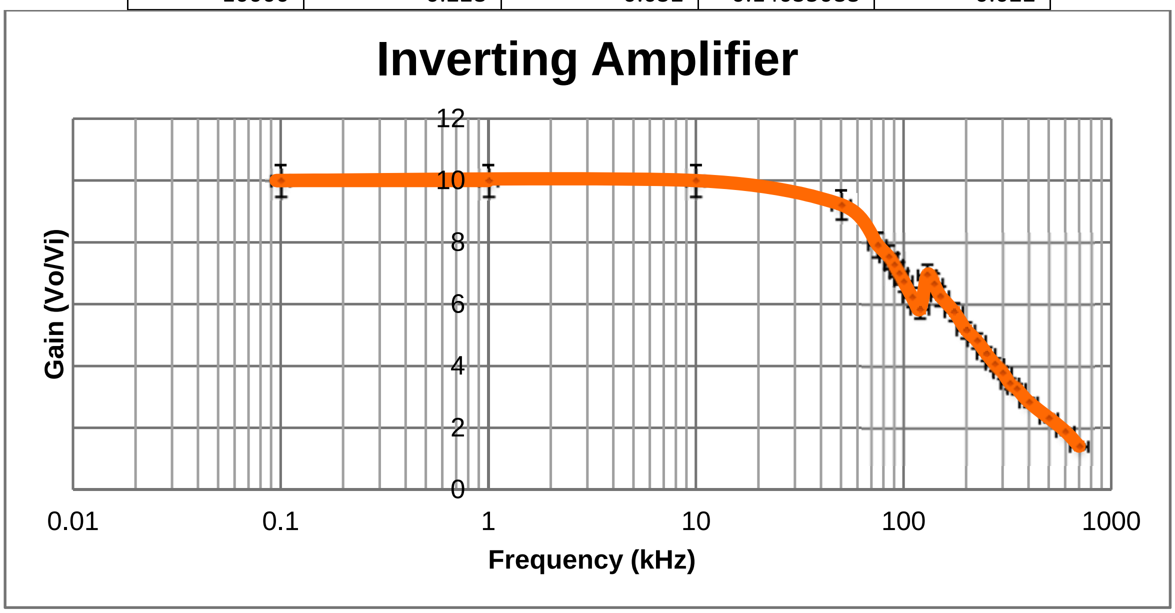

Figure 4: Inverting amplifier circuit Gain (V_o/V_i) vs. Frequency graph

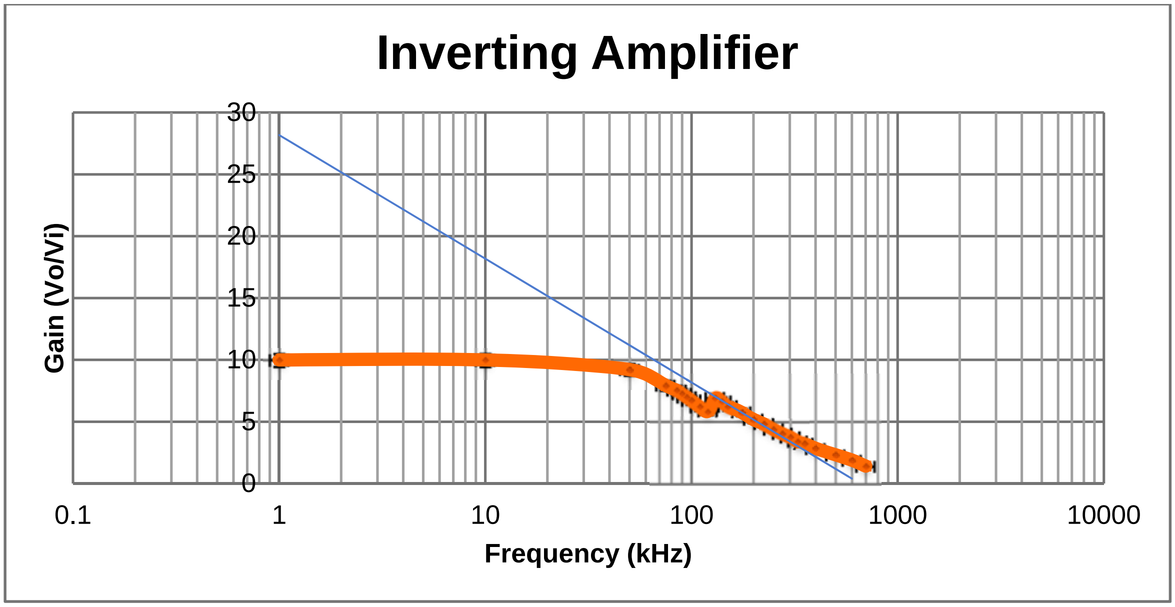

Figure 5: Inverting amplifier circuit Gain (V_o/V_i) vs. Frequency graph with linear line

Data Analysis & Error Analysis

From the table above we were able to calculate for the error and present it in the graphs. Notice that the graph has error bar based on percent error. The following errors are calculated from the error propagation equation. In the graph it should be noted that the slight jump at about 120 kHz is because we change the peak to peak voltage and frequency while measuring for the voltage. To fix this we left the peak to peak voltage constant afterward.

R_F = 100.7+/-.05 kΩ

R_L = 10.0+/-.05 kΩ

Theoretical:

$$G = \frac{V_o}{V_i} = -\frac{R_2}{R_1} = -\frac{100.7k\Omega}{10.00k\Omega} = -10.07 +/-.051\ \text{k}\Omega$$

Measured is 10 from the table above

$$\%\ error = \frac{|-10.07 - 10|}{|10.07|} \times 100\% = .65\%$$

Discussion

From the graph we can tell that this is a -20dB/decade slope decrease or -10/decade depending on the scale of graph we are using. Since this is a -10/decade type of graph we can determine the gain at 4Hz by assuming that it is linear on a log scale.

This means that at 200 kHz gain is 5.17. Using the equation y = 10*log(x)+c we can find 4Hz.

y = -10*log(x) +c → 5.17 = -10*1og(200)+c → c = 28.1803 → -10*1og(4)+28.1803 = 22.16 when at 4kHz.

This time the error fit within the expected range. This means that the experiment was done quite well as the gain is close to the expected gain.

Changing the voltage of the power supply will change the gain on the graph. Apparently as we increase the input voltage our graph becomes more triangular an less of a sine wave.

Experiment 2:

Data

Table 3: Data collected for the non-inverting amplifier circuit

f (kHz)	Vipp (V)±.005	Vopp (V)±.005	Vo/Vi ± uncertainty	
0.1	0.232	2.4	10.3448276	0.224
0.05	0.232	2.4	10.3448276	0.224
1	0.232	2.4	10.3448276	0.224
10	0.232	2.4	10.3448276	0.224
50	0.232	2.32	10	0.217
75	0.232	2.2	9.48275862	0.206
100	0.232	2.04	8.79310345	0.191
125	0.232	1.88	8.10344828	0.176
150	0.232	1.68	7.24137931	0.158
175	0.232	1.52	6.55172414	0.143
200	0.232	1.44	6.20689655	0.135
225	0.232	1.28	5.51724138	0.121
250	0.232	1.2	5.17241379	0.114
275	0.232	1.12	4.82758621	0.106
300	0.232	1.04	4.48275862	0.099
325	0.232	0.96	4.13793103	0.092
350	0.232	0.92	3.96551724	0.088
375	0.232	0.88	3.79310345	0.085
425	0.232	0.8	3.44827586	0.077
475	0.232	0.72	3.10344828	0.070
550	0.232	0.64	2.75862069	0.063
600	0.232	0.56	2.4137931	0.056
700	0.232	0.52	2.24137931	0.053
800	0.232	0.48	2.06896552	0.050
900	0.232	0.44	1.89655172	0.046
1000	0.232	0.4	1.72413793	0.043
3000	0.232	0.24	1.03448276	0.031
5000	0.232	0.2	0.86206897	0.028
10000	0.232	0.16	0.68965517	0.026

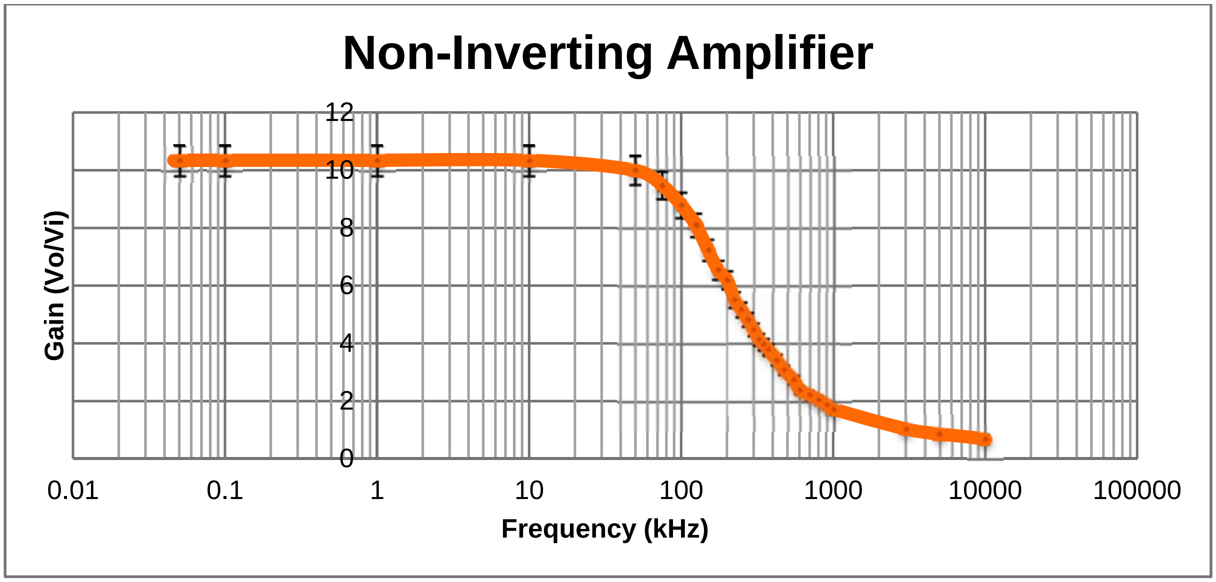

Figure 6: Non-inverting amplifier circuit Gain (V_o/V_i) vs. Frequency graph

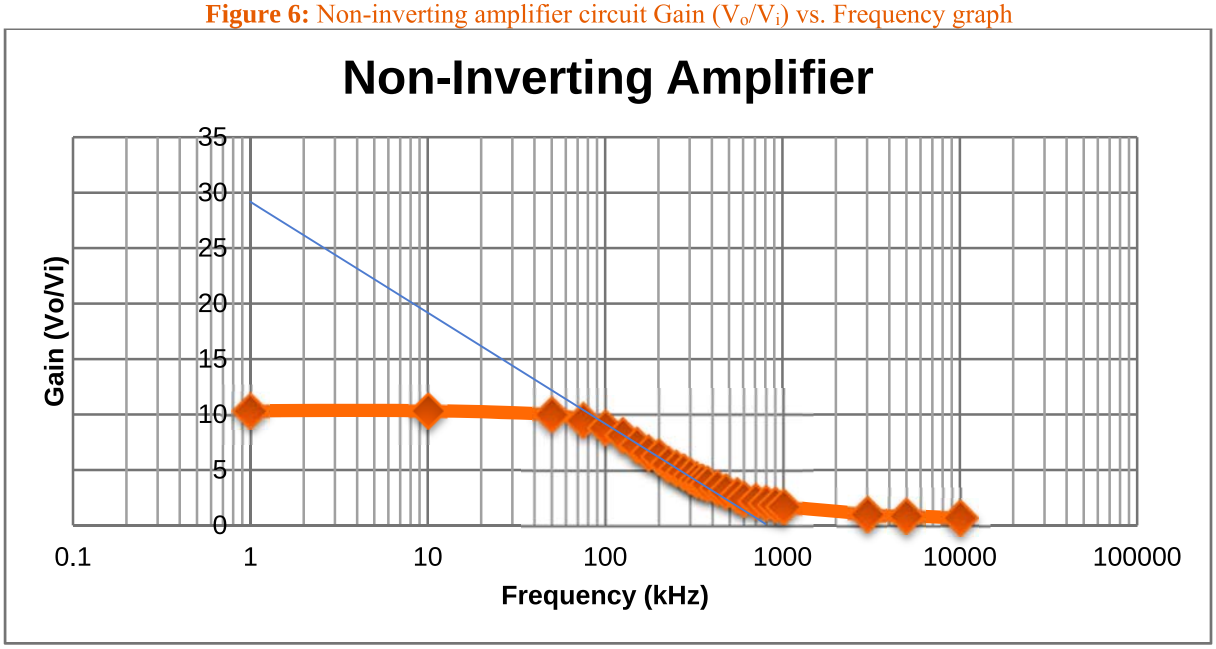

Figure 7: Non-inverting amplifier circuit Gain (V_o/V_i) vs. Frequency graph with linear line

Data Analysis & Error Analysis

From the table above we were able to calculate for the error and present it in the graphs. Notice that the graph has error bar based on percent error. The following errors are calculated from the error propagation equation. In the graph it should be noted that there is no jump this time and is much smoother. This is because from the first experiment we realized the issues we were having so we stick with one peak to peak voltage and vary the frequency. This remove the jump that appeared earlier in experiment 1. Again we used the same resistors.

R_F = 100.7+/-.05 kΩ

R_L = 10.0+/-.05 kΩ

Theoretical:

$$G = \frac{V_o}{V_i} = 1 + \frac{R_2}{R_1} = 1 + \frac{100.7k\Omega}{10.00k\Omega} = 11.07 +/-.051 \text{ k}\Omega$$

Measured is 10.34 from the table above

$$\%\, error = \frac{|11.07 - 10.34|}{|11.07|} \times 100\% = 7.1\%$$

Surprising this experiment the % error is higher than what we normally would obtain. This mean it is quite different from the expected value. There could have been some slight error when we are reading and recording the voltage peak to peak since the values were jumping by a few tens of mV but we have to take the average of them anyway.

Discussion

In this part of the experiment we were quite surprised by the value we got for our percent error. They were almost never that high in our previous experiment. Their values were all quite close in the range when we look at the values only. The problem is that the uncertainty does not account for the error in the discrepancy. The other problem is that calculating for the error when using the cursor function cannot easily be quantified so this will be adding further uncertainty that is currently not accounted for. In the case of the graph it is actually really nice. It has the obvious -10/decade.

Experiment 3:

Data

Table 4: Table for the notch frequency

	Low to High	**High to Low**
Voltage (V)	13.7+/-.05	13.9+/-.05
Voltage (V)	13.7+/-.05	13.8+/-.05
Voltage (V)	13.7+/-.05	13.8+/-.05

Data Analysis & Error Analysis & Discussion

In this experiment we measure the changes in voltage as we tune it to a certain voltage. At this specific voltage of around 13.7 to 13.9 V the voltage for the output alternate between negative and positive. There was not much data recording here since we only recorded the function generator voltage when the DMM changes sign.

Experiment 4:

The measured values for this experiment are:

V_o = 164 mV

V_i = 20.4 V

Apparently we were unable to get to 0V like we wanted. We were only able to get close to the value. Apparently in the lab manual the DC offset stated is supposed to be about 5mV our value is totally off not sure what went wrong here. This could be that we did not actually record the values for the DC offset and assume that this was actually the DC offset value.

CONCLUSION

In conclusion this experiment was a decent. We were able to get kind of small percent error for the first experiment. The second experiment we didn't run into problems at all when we were experimenting especially after we notice that changing the peak to peak voltage changes our graph. But for some reason the percent error were around 7% which is quite high. Though it is true that equipment and our ability to use the cursor function does affect our measurement.

Even with this problem we were able to still complete the op-amp circuit and understand their gain vs. frequency graph. Our other problem was the last two experiment as things becomes confusing.

To improve in our future experiment we need a better method of measuring the voltage using the cursor function. Since our voltages were at the mV it begins to jump quite a lot and our measurement was only within +/-10mV accuracy. Because this was hard to estimate we were unable to do error propagation that well. Beside that the overall experiment was a decent.