Laboratory 4
Operational Amplifier

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MAE170

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Abstract:

The purpose of this lab is to explore the operating characteristics and frequency response for inverting configuration of an op-amp circuit and the non inverting configuration for the second stage opamp and the overall 2-stage amplifier circuit. The gain for the first stage (inverted) amplifier was -24.72 ± 0.50; the gain for the second stage (non-inverted) amplifier was 2.00 ± 0.01; and the gain for the overall system was -54.24± 0.65. The corner frequency for the inverted amplifier was 29,000 Hz. However the corner frequency for the 2-stage system was not able to be calculated due to a fire alarm. The clipping effect for the inverted amplifier started at 0.5V and peaked at 0.98V. The 2-stage system showed a phase change by a pi in the two graphs.

Introduction:

At Operational Amplifiers (OP-AMPs) is a DC-coupled high gain electronic voltage amplifier with a differential input and a single ended output. It usually comes with a non-inverting input and an inverting input. Op-Amps are important to amplify low voltage signals that might have been lost due to noise. Many processing systems also require voltages in the range 1-10V[1]. Amplifiers can distort signals by distortion of frequency and of phase along with source loading. The magnitude of the amplifier can be referred to "Gain," that is the ratio of the amplified output voltage over the input voltage. In order for the Op-Amp to achieve the amplifying effect it needs the configuration of capacitors and resistors. In this case, the voltage amplifier model, the circuit used two resistances, the input resistance and the output resistance[1]. The resistors resistance and configuration directly affects the "gain" of the system that is the voltage output over the voltage input. There are two kind of Op-Amps configuration: Inverting configuration and non-inverting configuration. The inverting amplifier is connected with a feedback that produces a closed loop operation, while the non-inverting amplifier where it is stabilized once a input resistor is placed in series to the feedback resistor[2].

Theory:

In this experiment, all of the calculations were made based on the "ideal Op-Amp characteristics," that is a series of assumptions to help effectively calculate the optimal values. These characteristics are the following: Infinite voltage gain; Infinite input impedance; zero output impedance; infinite bandwidth and zero input offset voltage. The Op-Amp in a circuit is usually presented with a non-inverting input (+) and an inverting input (-). According to the configuration and the resistors the voltage gain is calculated. Op-amps often use feedbacks on coupling the output back to stabilize the input by reinforcing it or canceling. This gives the system a better control, reduces the effect of noise or reduces output distortion***. In the case of the inverting amplifier the first golden rule states that no current flows into the input terminal and that voltage in the inverted input (-) will always be equal to the noninverting input(-) which helps us derive the first amplification equation (1) given the figure 1 configuration.

Vout/Vin= -Rf/Ri….(1)

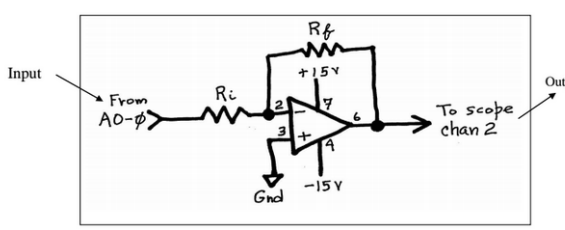


Figure 1***: Inverted OpAmp

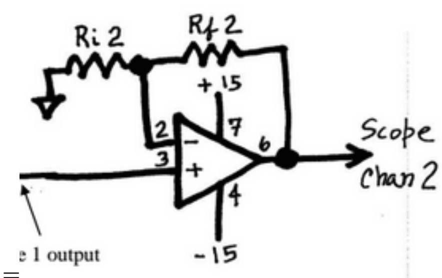


Figure 2*** non-inverting amplifier

Similarly using the same golden rules, the non-inverting amplification equation (2) is derived given the configuration of figure 2.

Vout/ Vin= (Ri2+Rf2)/(Ri2)....(2)

Experimental Procedure

First the inverting circuit was assembled as shown in figure 1. Channel 1 of the oscilloscope was attached to the input of the circuit and channel 2 to the output. A sine wave with frequency 1000 Hz and 100mV peak was then run through the circuit. The Vpp for channels 1 and 2 as well as the frequency for channel 2 were displayed on the oscilloscope. Next, the voltage amplitude was increased on the waveform generator until clipping was observed. Finally the -3dB corner frequency was determined by increasing the frequency on the waveform generator until:

$$Vout=Vin*Gain*1\sqrt{2} \ldots..(3)$$

Multiplying this value by 0.1, 0.2, 0.4, 0.6, 0.8, 1, 2, 4, 6, 8, and 10, these frequency were then used to take measurements of the output voltage. Using this data, a Bode plot was generated with the function "20*log (Vout/(Vin*Gain))" plotted on the y-axis and the function "fin/f-3dB" on the x-axis on a log scale.

Next the second stage of the circuit was added to create a non-inverting amplifier and the wave generator was run once again at 1000 Hz and 100mV peak. The circuit was analyzed at 3 places, once with channel 1 before the waveform generator and channel 2 at the output the inverting amplifier. The next analysis had channel 1 at the output of the inverting amplifier and channel 2 at the output of the noninverting amplifier. The final measurement was to determine the overall gain by clipping channel 1 to the input for the inverting amplifier and channel 2 to the output of the inverting amplifier, this allows the oscilloscope to measure over the entire circuit. The 3 different measurements can be seen in Figure 5 in the appendix, the blue displaying the first measurement, the green the second, and the red the final measurement. Finally, the -3dB frequency was determined once again until the Vout satisfied equation 3. Then the same method was used to create a second Bode plot.

Data and Results

Part 1

To properly determine the gain of the opamp, various measurements of the equipment being used had to be taken. The DMM reading of Ri, the 1kΩ resistor, was 1.001 ± 0.005 kΩ and the DMM reading of, Rf, the 27kΩ resistor was 27.220 ± 0.005 kΩ. When wave generator was run through the inverting amplifier, the Vpp of Channel 1 was 220 ± 4 mV and the Vpp of Channel 2 was 5.44 ± 0.05 V, as shown in Figure 3. When increasing the voltage, clipping began at 0.5 V and became clear at 0.7V as shown in Figure 4, eventually reaching its maximum at Vin 0.98 V. To determine the -3dB frequency the following calculations were done:

Gain using measured resistance and equation 1:

$$Vout/Vin=-27.220k\Omega/1.001k\Omega=-27.190 \pm 0.136$$

Gain using measured voltage output and input:

$$Vout/Vin=5.44V/0.220V=24.72 \pm 0.50$$

Insert for error propagation.

The gain measured voltage was measured with channel 1 and channel 2 set at 0, as shown in Figure 3, therefore it does no show the vertical displacement of both graphs. Therefore the actual value should be -24.72 ± 0.50.

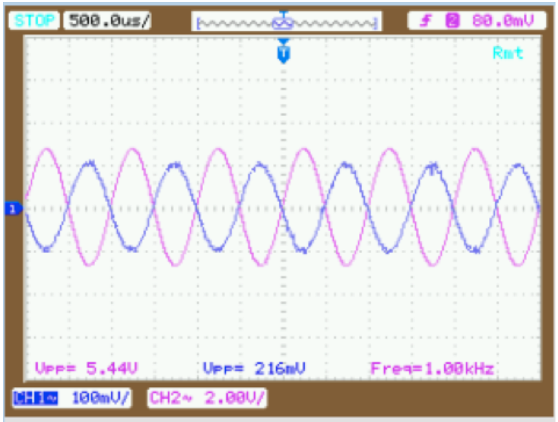


Figure 3: Input Voltage and Output Voltage.

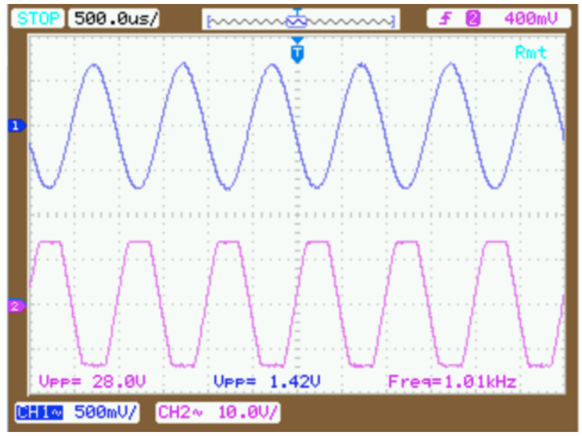


Figure 4: Clipping Effect

Percent error

[(27.19-24.72)/27.19] x 100 = 9.08%

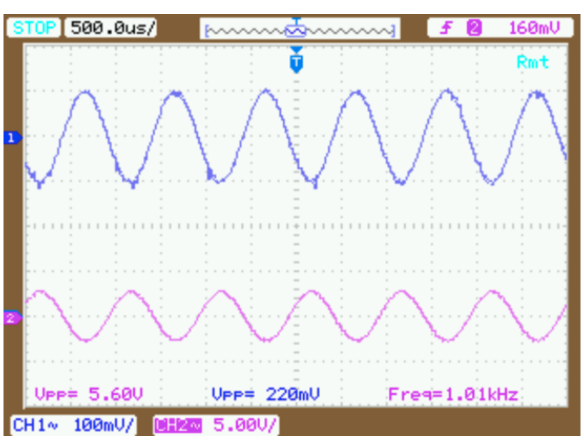
Vout using equation 3, where Channel 1 Vpp is 1.42 ± 0.05 V, and Channel 2 Vpp is 28.0 ± 0.5 V.

Vout=(0.2)(24.72)(0.702)=3.50 ± 0.28 V

Using the calculate value of Vout, the -3dB frequency was determined to be 39000 Hz with Channel 1 Vpp= 220 ± 4mV and Channel 2 Vpp=3.48 ± 0.04 V. Using the -3dB frequency, Table 1 in the Appendix was created which then resulted in Figure 6 in Appendix.

<u>Part 2</u>

To determine the gain in the non-inverting amplifier, the resistance of the additional resistors were measured. The DMM reading of Ri2, a 10kΩ resistor, was 9.98 ± 0.05 kΩ. And the DMM reading of Rf2, another 10kΩ resistor, was 9.99 ± 0.05 kΩ. Using these values along with equation 2, the calculated gain for the non-inverting stage 2 Op-amp was 2.00 ± 0.01. The overall 2-stage gain of the circuit displayed Channel 1 Vpp= 0.424 ± 0.005V and Channel 2 Vpp=22.40 ± 0.05 V as seen in Figure 8. This data gives us a gain of -52.83 ± 0.63. The Vgain for the overall 2-stage amplifier is calculated by multiplying the Vgain at Stage 1 by the Vgain at Stage 2, this results a V total gain of -54.24± 0.65, giving us a error. The overall phase shift from state 1 input to stage 2 output was **π** as can be seen in figure 7 in the appendix. Further data and observations could not be taken due to a fire alarm in the lab.



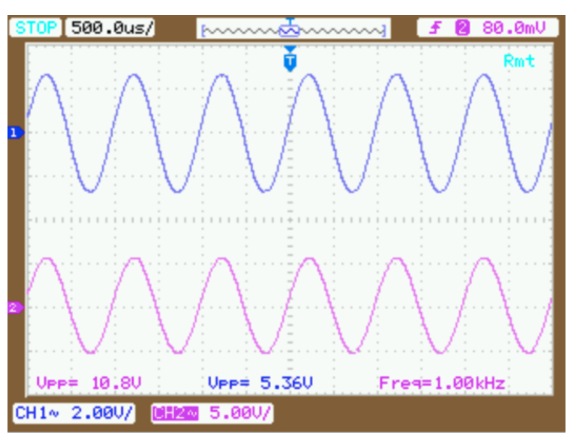


Figure 8: Stage1 inverting amplifier, Figure 9: Stage 1 output, Stage 2 output.

Discussion

As mentioned before, the calculated gain for the inverted amplifier was -27.19 ± 0.136, whereas the measured gain was -24.7± 0.50. The percentage error was about 9.08%, this is considered a relatively accurate result. This minor deviance might be due to the noise coming from the noise of the system and the wires from all of the instruments. When the voltage amplitude was increased Channel 2 started to show a planar shape on the peaks of the graph, which is the clipping effect. The clipping starts forming when the voltage is increased to 0.5 V and slowly becomes more prominent, as seen in Figure 4, eventually reaching its maximum at Vin 0.98 V. Clipping occurs in order to keep the sine waveform within the range of the voltage. Although when observed, the clipping effect did not particularly showed positive and negative clipping at different voltages; it may occur. This may happen when a diode is included in the system. Positive clipping happens when the diode is kept in series with the load and negative clipping happens when the diode is kept in parallel with the load. The corner frequency, -3dB, was found to be 29,000 Hz. Given the data result from table 1, the decibels and frequency ratio, as shown in Figure 6 is shown to have a decreasing trend. It first slowly decreases up to the -4.18 and afterwards, it decreases exponentially until its multiple of 7.98 and further results were not been able to take because of the maximum capacity of the waveform generator.

The calculated gain for the non-inverting stage 2 opamp was 2.00 ± 0.01. Using this result combined to the calculated gain for stage 1 inverting opamp, the overall gain for the both stages was -54.24± 0.65. The measured overall gain was 52.83 ± 0.63, hence the percent error is 2.6%. This is an accurate result and its slight deviation might be due to the system noise mentioned before, however it is so small that it is negligible. As seen in Figure 7, the phase shift for the overall system was $\boldsymbol{\pi}$ in the sine waves. Although there is lack of data points to compare the frequency and decibel relationship for the 2-stage amplifier, once the frequency is found using the method of the first part of the experiment, the data points can be found by plugging in different multipliers of the frequency. The resulting graph should be similar to the Bode plot for the inverting amplifier. First decreasing slowly and then decreasing exponentially after it hits the corner frequency.

Error Propagation:

Error propagation for theoretical gain for inverted amplifier, where SRi, Ri and SRf and Rf are expected values:

$$\partial G_t = Gain_t * \sqrt{\left(\frac{SR_i}{R_i}\right)^2 + \left(\frac{SR_f}{R_f}\right)^2} = 0.136$$

Error propagation for measured gain for inverted amplifier where SRi, Ri and SRf and Rf are measured from the DMM:

$$\partial G_m = Gain_m * \sqrt{\left(\frac{SR_i}{R_i}\right)^2 + \left(\frac{SR_f}{R_f}\right)^2} = 0.50$$

Error propagation for the calculation of Vout to determine the corner frequency for inverted amplifier.

$$\partial V_{out} = V_{out} * \sqrt{\left(\frac{SVpp1}{Vpp1}\right)^2 + \left(\frac{SVpp2}{Vpp2}\right)^2} = 0.28$$

Error propagation for theoretical gain for non-inverting amplifier, where SRi, Ri and SRf and Rf are expected values:

$$\partial G_t = Gain_t * \sqrt{\left(\frac{SR_i}{R_i}\right)^2 + \left(\frac{SR_f}{R_f}\right)^2} = 0.01$$

Error propagation for measured gain for overall amplifier where G1 and G2 are the respective gains for both amplifiers

$$\partial G_m = Gain_m * \sqrt{\left(\frac{SG1}{G1}\right)^2 + \left(\frac{SG2}{G2}\right)^2} = 0.65$$

Conclusion

Using 2 know resistor values as well as a wave generator, the gain of the inverting amplifier could be calculated 2 ways. First using the measured resistance and equation 1, the gain was 27.19. Using the measured output and input voltage the gain was 24.72V. The difference gave an error of 9.08%. The -3dB frequency was determined to be 39000 Hz. Additionally knowing 2 more resistors, the calculated gain for the non-inverting was 2.00V. Using the oscilloscope to measure the voltage difference, the gain was 2.02V, a 1.1% error difference.

Acknowledgements

We would like to thank Professor Farhat Beg, Professor Robert Cattolica and Rich Inman.

Reference

[1] N. Busan, S. Roberts, and R. Kapadia. “Operational Amplifiers”

[2] “Difference between Inverting and Non Inverting Amplifier”
http://www.differencebetween.com/difference-between-inverting-and-vs-non-inverting-amplifier

[3] R. Narayan “Lecture 4: Operational Amplifiers”

Appendix

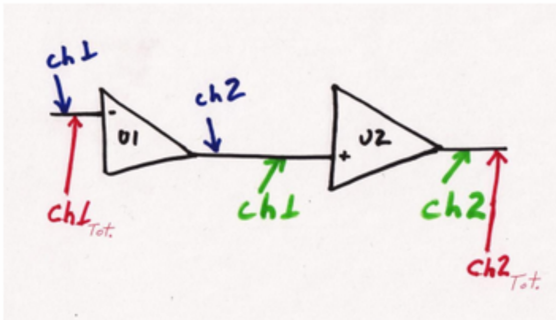


Figure 5: Visual display of measurement inputs and outputs for noninverting amplifier

Hz	fin/f-3dB (x-axis)	Vout	Vin	20*log (Vout/(Vin*Gain)) (y-axis)
3900	0.1	5.28	0.208	0.237472686
7800	0.2	5.28	0.228	-0.559957555
15600	0.4	5	0.228	-1.033235918
23400	0.6	4.4	0.228	-2.143582475
31200	0.8	3.96	0.228	-3.058732287
39000	1	3.48	0.228	-4.181051126
78000	2	2.04	0.228	-8.820032657
156000	4	1.04	0.228	-14.67196922
234000	6	0.72	0.2	-16.72788905
312000	7.69	0.5	0.19	-19.449611

Table 1: Frequency Ratio and Frequency Ratio Data points for inverting amplifier

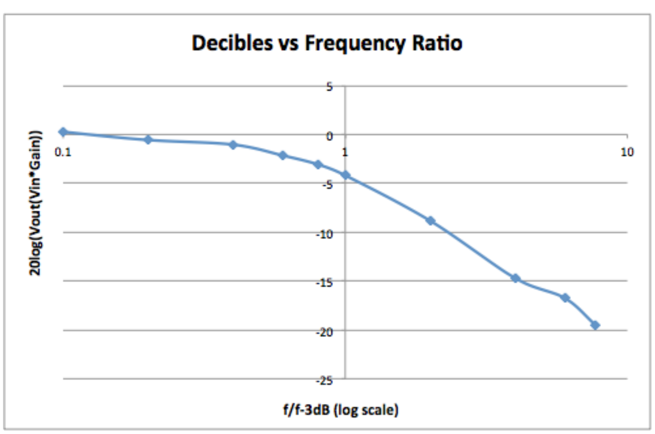


Figure 6: Frequency response plot for inverting amplifier

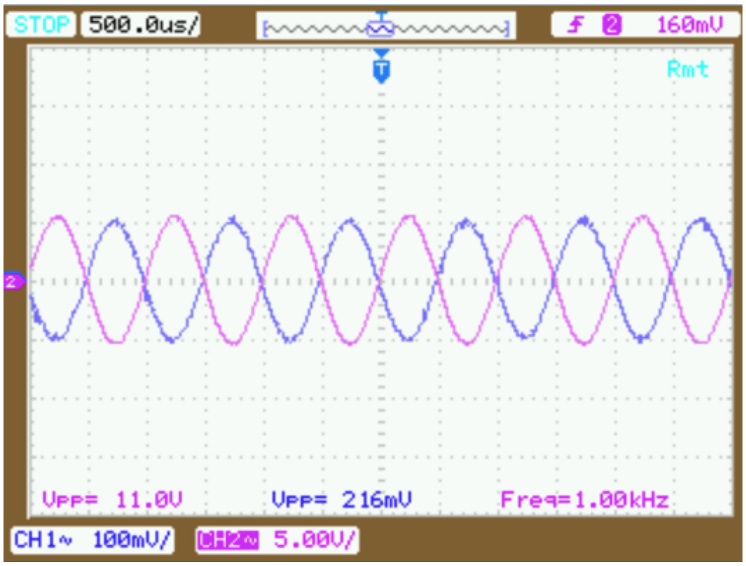


Figure 7: Stage 1 input and Stage 2 output phase shift

*****http://www.circuitstoday.com/diode-clippers