Lab 06: Operational Amplifiers

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Lab Section A

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I hereby certify that this report is my own original work.

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Abstract

In this paper, the function of an op amp is explored. The op amp model uA741 was used to build a test circuit to analyze the voltage gain created by the operational Amplifier. The circuit was set up in as in inverting configuration with one voltage source and the waveforms at the input and output were analyzed. The phenomena of decreasing gain with increasing frequency were also discovered and analyzed. It was found that at some threshold frequency which depends on the internal structure of the op amp, the gain of the op amp begins to linearly decrease until the gain becomes 0. This showcases the importance of knowing the model op amp in use and the setting of max frequencies in practical settings.

Introduction

Op amps are a very useful circuit element that is widely use in today's world. They are one of the basic building blocks in almost every analog and mixed-signal electronic circuit. Historically, they were used in the first analog computers to compute operations such as addition , subtraction, multiplication, division, integration, and finding solutions to differential equations. While the op am seems small, on the inside it is made up of a fairly complicated circuit using diodes as well as a variety of passive and active circuit elements. For this lab, the op amp will be treated as an ideal op amp, for this purpose, there are two input voltages V_p and V_n and there is one output voltage V_0. The relationship of there three factors can be described using equation 1 [2].

$$V_0 = A(V_P - V_N) \tag{1}$$

The factor A can be taken as the gain factor, the magnitude of change made on the input voltage, A can be positive or negative depending on what input terminal is used. V_N is the inverting terminal and V_P is the non-inverting terminal. Pins 7 and 4 on the op amp are used as limits on the voltage, or positive or negative saturation levels respectively [1]. These properties of op amps make them perfect for use in many circuits that will be explored in this lab.

Procedure

Materials

- Breadboard
- Function Generator
- Oscilloscope
- Keithley Power Supply
- UA741 Op Amp
- 5kΩ, 100Ω, and 220Ω resistor.
- Jumper wires
- 3 banana leads
- Alligator clips

The first part of the lab involves assembling an inverting, negative feedback amplifier, shown in figure 1. The resistors R_i, R_f, and R_l will be set as a 100Ω, a 5kΩ, and a 220Ω resistor, respectively. The voltage source was a sinusoidal source. Specifically, the voltage source follows the equation:

$$V(t) = .03\, cos\, \omega t \text{ V}$$

The power supply, V_{cc}, was set to a 10 Volts, ensuring the op amp behaves ideally.

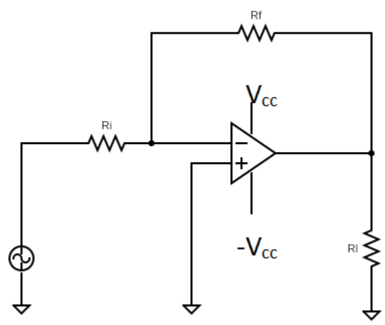

Figure 1: Standard Inverting Op Amp

The experimental input signal, V_i, and the output signal of the inverting op amp were recorded using various frequencies.

Analysis and Results

Inverting Negative Feedback

The resistors were measured so the exact value is known.

Table 1: Resistors for Inverted Op Amp

Resistor	Value (Ω)
R_L	216
R_i	98.73
R_f	5063

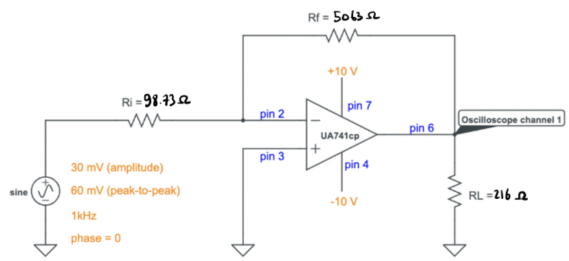

Figure 6.6a Inverting negative feedback amplifier circuit.

Equation 6.2: $V_o = (-R_f/R_i)V_i$ Equation 6.3: $G = V_o/V_i$

$w = 2\pi f$ $f = 1000$ hz $R_f = 5063\Omega$, $R_i = 98.73\Omega$ $V_o = \left(\frac{-5063\Omega}{98.73\Omega}\right)(0.03)\sin(2000\pi)$

$w = 2000\pi$ $V_i = 0.03\sin(2000\pi t)$

$V_i = 0.03\cos(2000\pi t + 90^\circ)$ $V_o = (-51.3)(0.03) = -1.54\text{ V}$

$G = \frac{V_o}{V_i} = \frac{-1.54}{0.03} = -51.3 = A$ $1.54 \times 2 = 3.08\ V_{pp}$

Figure 2: Shows the theoretical calculations for V_o and the gain

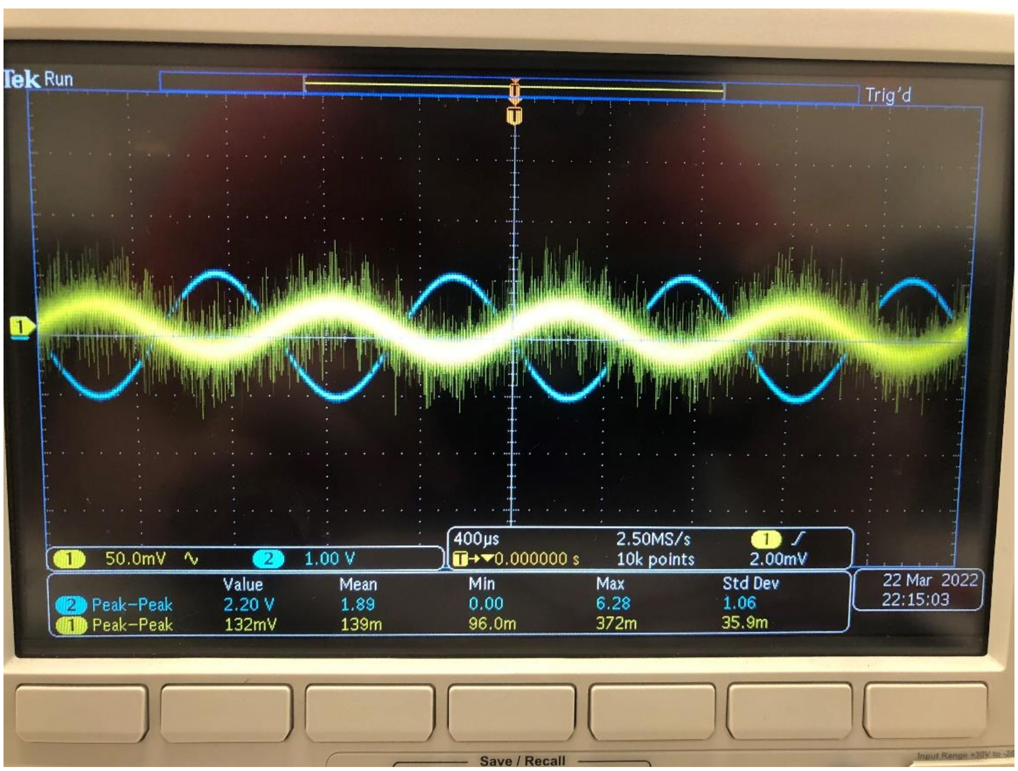

Figure 4: Shows the wavefrom of V_i (blue) and V_o Yellow

It can be seen that the waveform is indeed inverted from the input. It is also important to node that the equipment was malfunctioning, and the professor gave us permission to just take a picture of it and explain why there is an error in the voltage magnitude. The function generator said 60 mV peak to peak while the oscilloscope shows 130 mV. This is most likely due to some error within the oscilloscope. It can also be seen that there is a lot of noise on the output voltage.

Table 2: Closed Loop Voltage Gain of Inverted Op Amp

Frequency (Hz)	Vpp in (V)	Vpp out (V)	Closed Loop Gain
1	0.06	2.16	36
2	0.06	2.2	36.67
5	0.06	2.22	37
10	0.06	2.22	37
20	0.06	2.18	36.33
50	0.06	2.18	36.33
100	0.06	2.2	36.67
200	0.06	2.2	36.67
500	0.06	2.18	36.33
1000	0.06	2.2	36.67
2000	0.06	2.16	36
5000	0.06	2.14	35.67
10000	0.06	1.9	31.67
20000	0.06	1.44	24
50000	0.06	0.7	11.67
100000	0.06	0.4	6.67
200000	0.06	0.24	4
500000	0.06	0.14	2.33
1000000	0.06	0.12	2

Table 2 shows the collected data on the different frequencies. It can be seen that the closed loop gain is consistent until the 10000 Hz frequency is tested. At that point the closed loop gain continues to decrease until it is measured to be 2 at a frequency of 1 million Hz.

Comparison to expected value:

There is a significant difference between the calculated value and the measured value. The calculated value was 3.08 Volts peak to peak and a gain of 51.3, while the calculated values were approximately 2.2 Volts peak to peak and a consistent gain of around 36.5. The difference between the theoretical and measured can come from the noise that is found in the practical setting as well as from failure in the measuring machinery. In the lab the oscilloscope was not working properly and was showing an incorrect V in different from what was clearly shown on the function generator. This shows that the huge error is most likely due to an incorrect internal setting in the oscilloscope. The professor also bore witness to this, and she told us to continue taking data and to explain the error in the report as is being done.

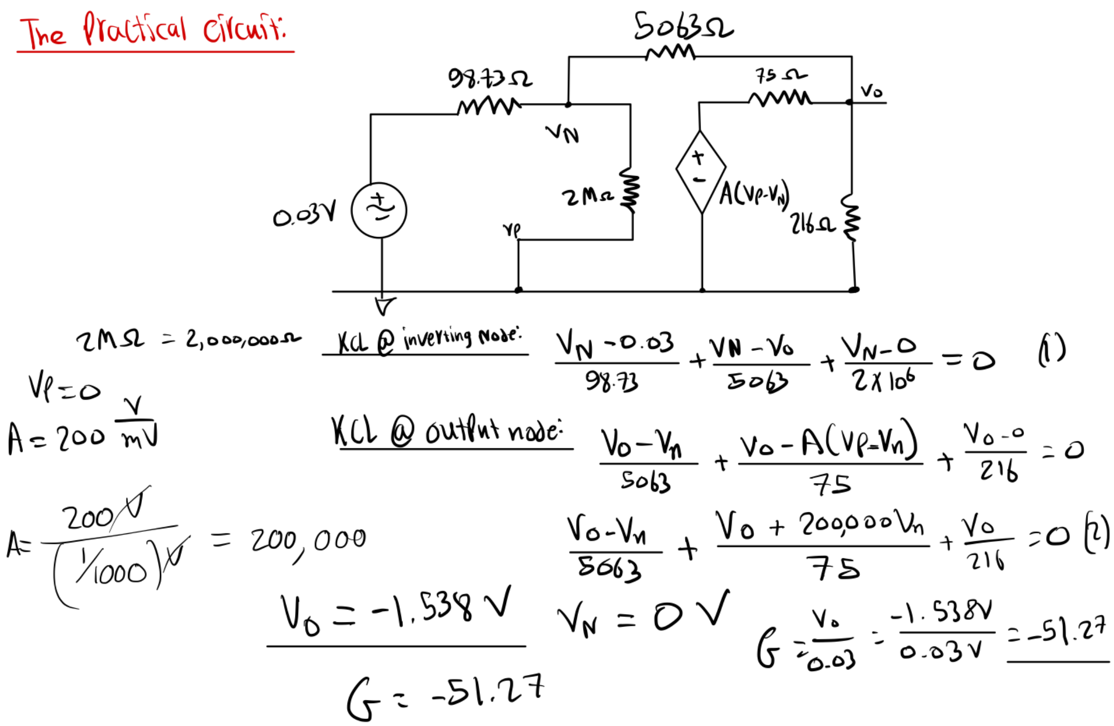

Figure 5: Shows the practical circuit being solved using the node voltage method

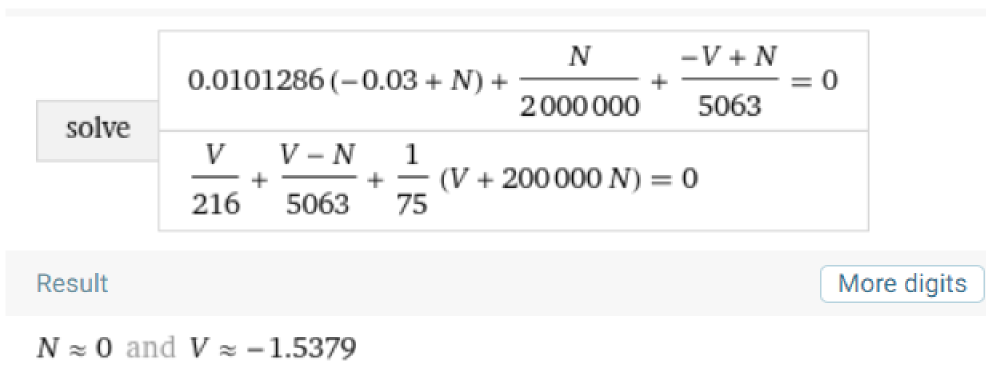

Figure 6: Shows the equation solver used for the node voltage equations

The calculations using the node voltage method on the non-inverting node also match the answers found using equations 6.2 and 6.3.

Why There Is Distortion at Higher Frequencies:

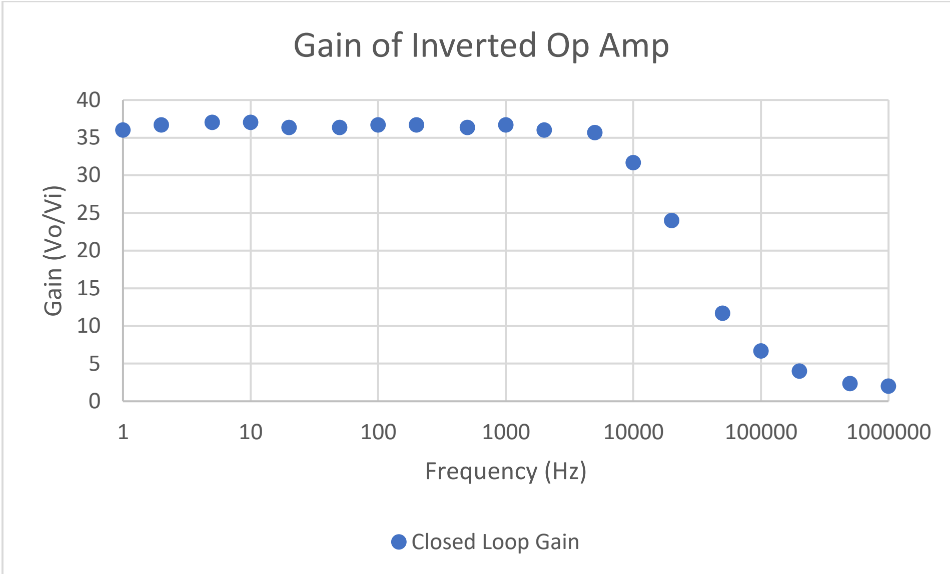

Figure 7: Shows where the gain relationship began deteriorating

From this graph it can clearly be seen that the closed loop gain relationship quickly deteriorates at a certain threshold, in this case at around 10,000 Hertz. This caused because at high frequencies the open loop gain starts to become too small and thus the differential voltage needed to get the correct voltage is too small. This makes it so you need more input differential voltage to produce the same output voltage and the gain begins to decrease [3].

Conclusion

It was shown with empirical evidence that the uA741 operational amplifier does indeed succeed in creating gain across its terminals. Furthermore, different methods of solving the practical circuit proved to conclude with the same solution. The fact and reason for why the gain decreases at high frequencies was also proven empirically and explored using research and mathematical analysis. Although the data shows the correct trend, there were many errors with operating the oscilloscopes, and it seems like there is an incorrect setting on the oscilloscope that the professor validated. This lab can be improved by finding the problems in the oscilloscope or by using another tool instead of the oscilloscope.

References

[1] Nilsson, J. W., & Riedel, S. A. (2019). *Electric Circuits* (10th ed.). Pearson Education, Inc.

[2] Nussinov, T., Lab 6B Handout, Spring 2021, "Operational Amplifiers"

[3] *Op-Amp Practical Considerations: Operational Amplifiers: Electronics Textbook*. All About Circuits. (n.d.). Retrieved April 10, 2022, from https://www.allaboutcircuits.com/textbook/semiconductors/chpt-8/op-amp-practical considerations/

Partner Contributions:

Seif Elkhashab:

- Abstract
- Intro
- Conclusion
- Analysis
- Circuit Calculations
- References

Lucas Alcantara:

- Tables
- Procedure
- Lab 06 A
- Graph