To: Professor Darish
From: *Trever Wagenhals*
Subject: *Op-Amps*

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Course &Section: 16.311-802
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SUMMARY

This experiment involved testing various op-amp designs, calculating and measuring output voltages of the configurations, understanding and explaining the operation of each op-amp, and understand the purpose of power supply capacitors.

EXPERIMENTAL APPROACH

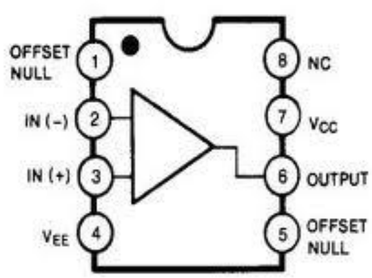
Equipment and Materials

- Signal Generator
- Oscilloscope
- Power Supply
- Op-amp
- Resistors : 1k ohm, 10k ohm

Procedure

The experiment was broken down into four different categories of op-amps: inverting amps, non-inverting amps, buffer amps, and inverting summing amps. With each amp, two power supplies of +15 VDC and -15 VDC were set up and attached to the rails of the op-amp, pin 4 and 7 respectively. From here, different designs were used to create various op-amps to test how their outputs varied based on similar inputs. Through these tests, it should have become clear the benefits of different op-amps and what situations they should be used in.

Figure 2.1: Pins of an op-amp



Steps 1-12 of this lab focused entirely on the inverting amplifier. Setting up the inverting amp involved connecting the input voltage to the negative pin (pin 2), placing a 1k Ohm resistor in to the negative input (pin 2) and a 10k Ohm resistor into the negative input (pin 2) and out to the Vout (pin 6).

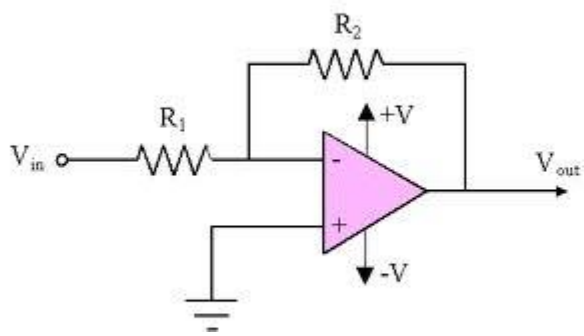
Steps 13-21 involved testing the design of a non-inverting amplifier. Setting up the amplifier involved connecting the input voltage to the positive pin this time (pin 3), and the resistors to the negative pin (pin 2).

Steps 22-28 dealt with a buffer amplifier. This setup involved supplying the power to the positive terminal (pin 3), and shorting the negative input with the output (pin 2 to pin 6).

Steps 29-41 was the inverting summing amplifier design and tested the idea of multiple voltage inputs. With each voltage input, a 10k Ohm resistor is put in series and attached to the negative pin (pin 2). Another 10k Ohm resistor is attached to the negative input (pin 2) and the output (pin 6)

DISCUSSION OF RESULTS

Figure 2.2: Inverting Op-Amp

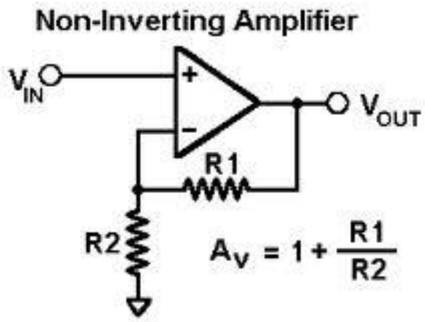


Through this setup, the voltage input was shown to have been changed from 2Vpp to 20.9Vpp with a phase shift of about 180 degrees. This data seems accurate because the gain, G, is equal to –R2/R1. So, the magnitude is amplified by 10 and the negative gain causes a phase shift of 180 degrees.

Table 2.1: Input and output of a -10 gain inverting op-amp

Input Vpp	Output Vpp
0.1Vpp	0.98Vpp
0.2Vpp	1.97Vpp
0.3Vpp	2.89Vpp
0.4Vpp	3.9Vpp
0.5Vpp	4.9Vpp
1.0Vpp	10.9Vpp
2.0Vpp	21.7Vpp

Figure 2.3: Non-inverting Amplifier

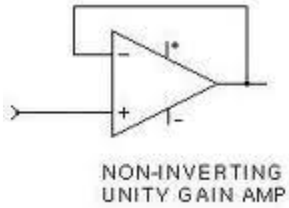


This design caused the input voltage of 2Vpp to become 24.9Vpp, showing a gain of about 11. The phases were also almost perfectly aligned. This data seems accurate because, based on the definition of a non-inverting amplifier, the gain should be 1 + R1/R2, which is 11 in this case.

Table 2.2: Input and Output of a 11 gain non-inverting op-amp

Input Vpp	Output Vpp
0.1Vpp	1.15Vpp
0.2Vpp	2.29Vpp
0.3Vpp	3.4Vpp
0.4Vpp	4.5Vpp
0.5Vpp	5.6Vpp
1.0Vpp	13.5Vpp
2.0Vpp	24.9Vpp

Figure 2.4: Buffer Amplifier



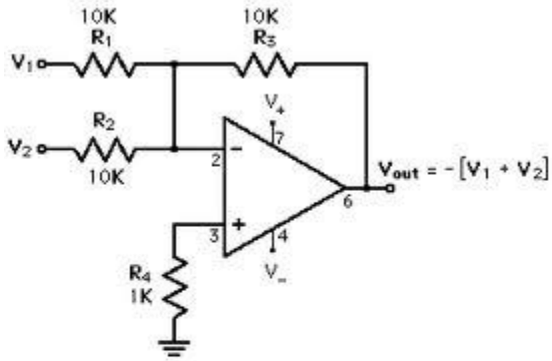
Setting up and testing the buffer amp, the input and output voltage were found to be identical, as well as the phase. This makes sense because the input voltage is to the positive terminal, and there is no resistance between the negative terminal and output. The benefits of this amp were not noted until the frequency was adjusted to a value much higher than the others without altering the input and output values.

Table 2.3: Input and Output of a Unit Gain Non-inverting amp

Input Vpp	Output Vpp
0.1Vpp	0.1Vpp
0.2Vpp	0.22Vpp
0.3Vpp	0.32Vpp
0.4Vpp	0.43Vpp
0.5Vpp	0.52Vpp
1.0Vpp	1.05Vpp
2.0Vpp	2.05Vpp

Also, it is important to note that while testing, the input voltages between 0.1Vpp and 0.3Vpp caused a ghosted image of a second wave behind the output voltage wave that would consistently flicker. This action was noted and had stopped at 0.4Vpp input, but the actual cause or explanation as to why this happened is unknown.

Figure 2.5: Inverting Summing Amplifier



When setting up a similar circuit as the one shown, and opening the voltage inputs so there is no voltage flowing through the circuit, the output voltage was expected to be 0V. In testing however, even without any input the output was getting a low reading of about 20mV.

Testing one input at a time, with an input of 1Vdc, the output was -1Vdc for each input. This result makes sense because the circuit looks identical to an inverting amplifier with one power supply connected a time. So, the gain for each power supply is –R2/R1, or -1. Connecting both voltages displayed a value of a -2Vdc on the output. This value also makes sense because this idea is using the concept of superposition, where Vout = V1 + V2 = -1 + -1 = -2

NOTE: Don't forget to label Figures and Tables

Questions and Answers:

Question 1: Comment on the magnitude and phase of the input and output signals in your lab notebook.
Because this is an inverting amp of -10 gain, the Vpp goes from 2.05Vpp to 20.9Vpp. The inverting amp also causes the two waves to become 176 degrees out of phase.

Repeat step 6 for the following frequencies: 10 Hz, 100 Hz, and 10 kHz.

Question 2: Comment about the voltage gain and phase shift in your lab notebook.
Even when the frequency is adjust down to 10Hz and up to 10kHz, there is no difference in the phase or the gain to be noted.

Repeat step 6 for a frequency of 100 kHz.
Question 3: Explain what is happening and why in your lab notebook?
At this high of a frequency, the op-amp does not function properly, affecting the phase, shape of the wave, and gain. The Vpp goes from 2.05 up to 3.05, much less than a gain of 10. The phase drops from almost 180 degrees out of phase down to about 20 degrees. The wave does not appear sinusoidal either, looking more like a sawtooth wave.

Shut the power supply output off, replace R2 with a 22k Ω resistor, then turn the power supply output on.
Question 4: Explain what the output looks like and why it does in your lab notebook.
Because the new inverting op amp is -22k/1k ohms, the gain is going to be -22. So, multiplying the 2 Vpp in by 22, the expected wave would be 44Vpp. But, because the rails only go from +15VDC to -15VDC, the wave is clipped at the rails and cannot exceed them, limiting the wave to 30Vpp.

Question 5: Comment on the magnitude and phase of the input and output signals in your lab notebook.
With non-inverting amps, the gain is equal to 1 + R2/R1, so in this case 11. So, with Vpp in, the output appears as 24.9Vpp. The two waves were in phase because it is non inverting.

Repeat step 17 for the following frequencies: 10 Hz, 100 Hz, and 10 kHz.
Question 6: Comment about the voltage gain and phase shift in your lab notebook.
Similar to before, the wave's magnitude or phase is not affected within these ranges of frequencies.

Repeat step 17 for a frequency of 100 kHz.
Question 7: Explain what is happening and why?
Once again, the op amp is not designed to run at frequencies this high, so the gain is diminished, the waves end up being out of phase, and the wave becomes a sawtooth wave.

Question 8: Comment on the magnitude and phase of the input and output signals in your lab notebook.
In a buffer amp, the input and output are going to remain identical, having the same Vpp and frequencies. The gain is then set to 1 because of this.

Repeat step 24 for the following frequencies: 10 Hz, 100 Hz, and 10 kHz.
Question 9: Comment about the voltage gain and phase shift in your lab notebook.
Once again, the wave is not affected by the range of frequencies and remain identical to the first result.

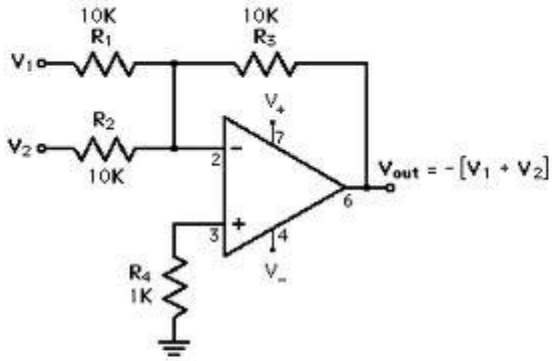
Repeat step 24 for a frequency of 100 kHz.

Question 10: Explain what is happening and why?

This time, the design allows for the op amp to operate at even high frequencies. Buffer amps are designed to compensate for the difference in the high input impedance and low output impedance. The wave will appear just as it did in the previous attempts, unlike the sawtooth wave, loss of gain, and phase shift shown in other tests. From additional testing, it was noted that this buffer amp did not see loss of performance until about 10 times this value of 1MHz.

Question 11: Show your voltage divider design in your lab notebook.

Figure 2.5: Summing Inverting Amplifier



Question 12: Explain what is happening and why?

If one power supply is examined at a time, it can be noted that this circuit is identical to an inverting op-amp. So, testing at V1 and then at V2, the voltage gain for each is -1. With an input of 1Vdc, the gain is negative for each power supply, which causes an output equal to the additional of each power supply output. So, Vout = V1 + V2 = -1 + -1 = -2Vdc