Title: Lab 2: Operational Amplifiers

Name: Robert Bara **Partner:** Dalton Hamilton, Mohamad Asaf, Abdulaziz Almersi

General Objective: The purpose of this lab is to explore how closed-loop Operational Amplifier configurations amplify an input signal. To observe this, three kinds of Operational Amplifiers will be simulated: a buffer, non-inverting operational amplifier, and inverting operational amplifier.

1.0 Background Activities:

Operational amplifiers are circuits that are wired using a closed-loop setup, so a portion of the output signal will be fed back into the input signal. Op-Amps contain incredibly high gain and can easily saturate their output, to combat this a feedback loop is created to manipulate the amount of gain needed. The addition of using a resistor within a feedback loop allows the op-amp's output signal, to be controlled, and through equations, calculated.

Since operational amplifiers may be wired in a variety of ways, below is a table taken from the textbook from used in ECE2332, Principles of Electric Circuits:

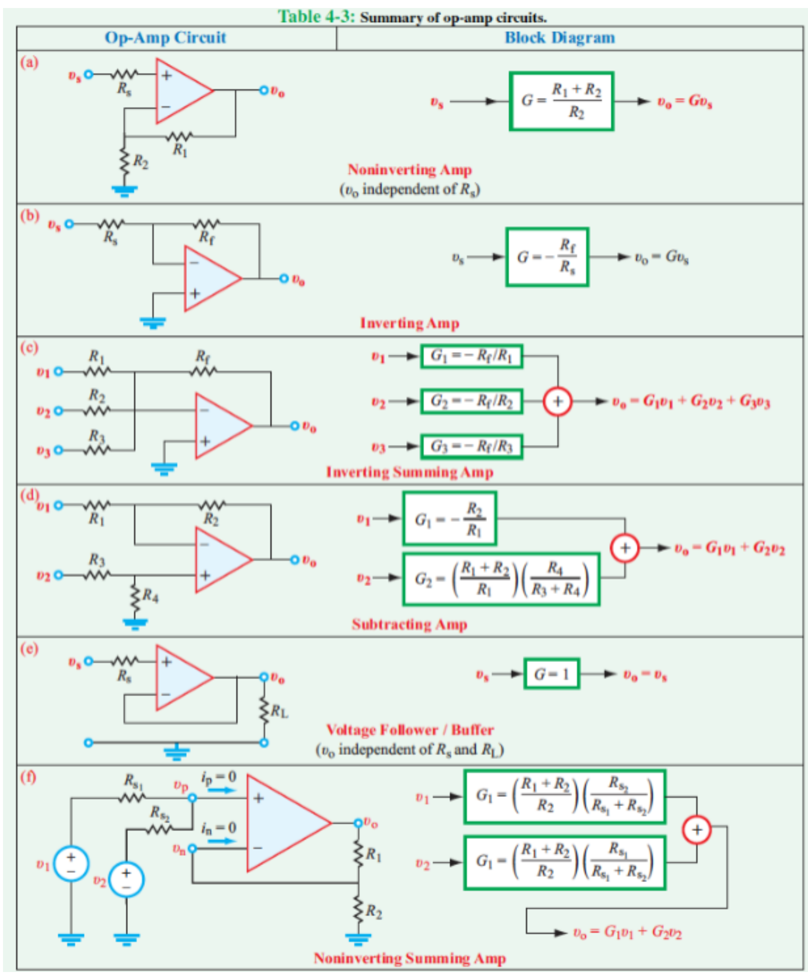


Figure 1. Summary of Op-Amp configurations and Vo Formulas

2.0 **Procedure**

Part I: Simulating an Op-Amp Follower

To simulate an op-amp follower, a buffer configuration will be set up in Multisim, which forces the output signal to be the same as the input signal. The circuit can be built using Multisim's 5T virtual Op-Amp. The power terminals are respectively wired to $+/-15V$, which can be simulated using two DC power sources. An AC signal will enter the op-amp and contain the following parameters: $2.5Vpp$, $60Hz$, $0\ \circ$ phase. A passive RC Lowpass filter will then be placed on the output, wired to ground, thus filtering out higher frequencies above $72\ Hz$, given $R = 220\Omega$, $C = 10uF$. The circuit should be built as follows:

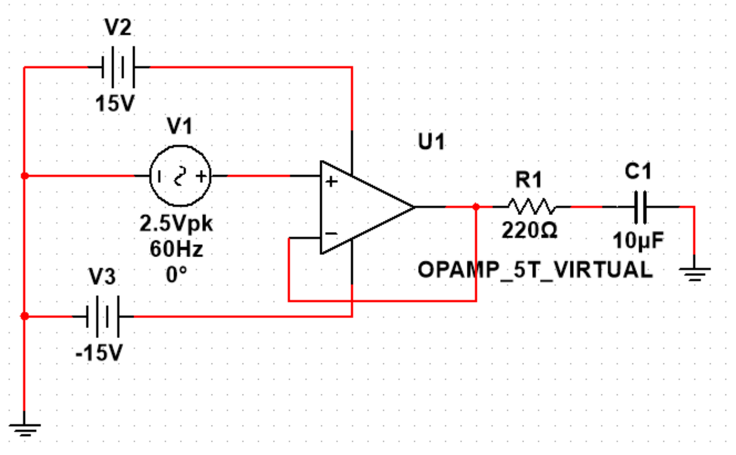


Figure 2. Voltage Follower Op-Amp

Two voltage probes should be added. One measuring the input signal, one measuring the output signal. Clicking run within interactive mode and then stopping the simulation will prove that the input and output signals should be equivalent, since the output travels through the feedback without a resistor. Furthermore, a graph in Multisim can be examined either by using an oscilloscope, or by examining the Multisim live version of the circuit.

<u>Part II: Simulating a Non-Inverting Op-Amp</u>

Using the same 5T Virtual Op-Amp from part I, change the power rails to $+/-12V$. Next replace the AC voltage source with a DC voltage source. Place two resistors in an inverting configuration so that $Rin = 1k\Omega$, which is connected to the ground and the negative feedback loop, while $Rf = 4k\Omega$, and is connected from the output of the op-amp, to the negative feedback loop. Place a voltage probe at the output of the circuit. The circuit should be built as seen below:

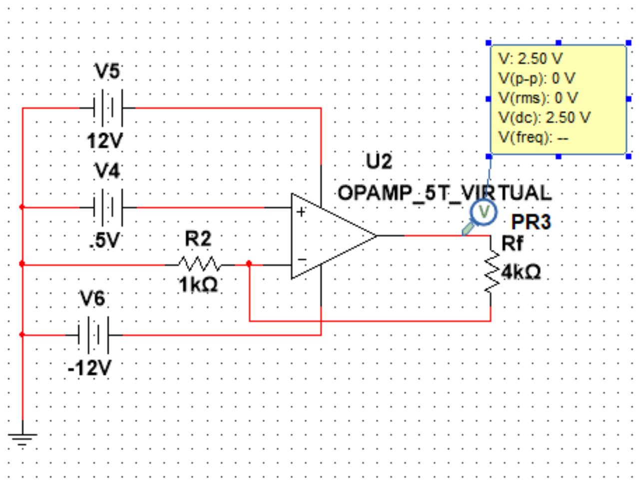


Figure 3. Simulation of Inverting Op-Amp

The measured voltage is amplified by a factor of $(1+\frac{Rf}{Rin})$, in this case the ratio of amplification, that is $\frac{Rf}{Ri}=4$. From this record what the measured voltage output is for the cases of the DC input voltage: $0.5V, 1V, 1.5V, 2V$.

Try changing the input voltage to $2.5V, 4V$, and $4.5V$ (any value above $2.4V$), notice that the output voltage is capped based upon the power supply to the op-amp.

Part III: Designing an Op-Amp

Take the circuit built in part II but modify the circuit by changing the ratio of resistors Rf and Rin. Record the output voltage for the same cases as you did in part II. Also calculate the resistor ratio Rf/Rin.

Examine the analysis questions for designing an op-amp with the following criteria:

1) An inverting amplifier with a gain of -15 and Rin is $33\ \Omega$. Find Rf?
2) A non-inverting amplifier with a gain of 45 and Rf is $2.2\ k\Omega$. Find Rin?

Answer each question by deriving the formula for Rf based upon the inverting and non-inverting op-amps.

3.0 Results:

3.1 Simulation Results:

PART I:

The figure below shows the setup for the operational amplifier for part I. The voltage follower is proven to be a buffer by placing two voltage probes: 1 at the input positive terminal, and another at the output terminal. Upon running the simulation in interactive mode, the voltages fluctuated because of the AC sinewave input, however upon stopping the simulation, it is clear that the simulation holds true to the equation that gain for an op-amp in buffer configuration is

$$G = 1, \qquad Vin = Vout$$

With Vin=2.25V and Vout=2.25V.

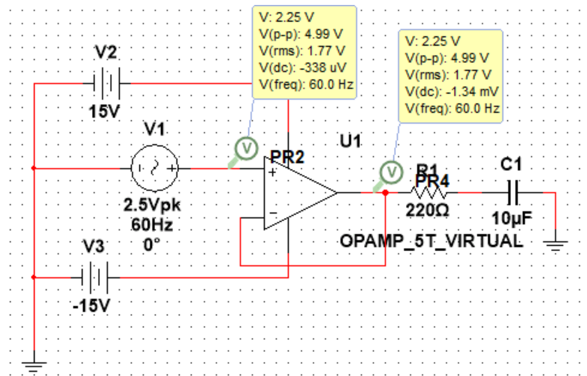


Figure 4. Multisim Simulation, V0=Vin

Furthermore, an oscilloscope reading can be taken, I decided to use the multisim live version of this for my report because the colors of the graph make it easier to observe that both probes for Vin and $Vout$ generate two identical graphs that overlap each other, as seen below:

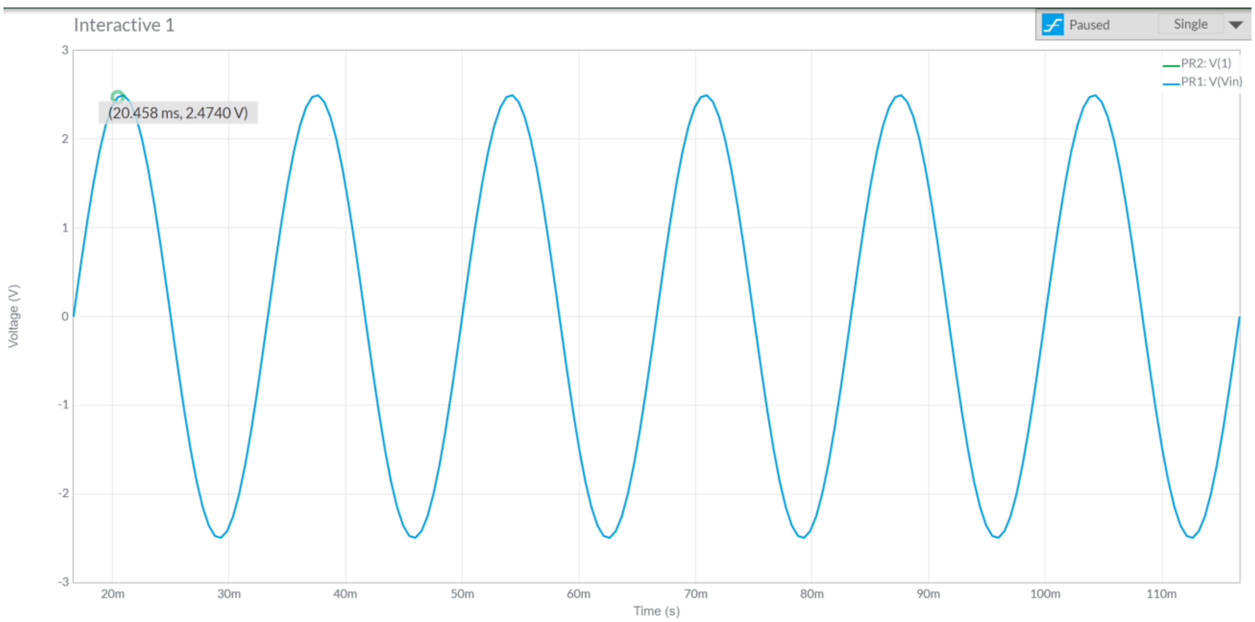


Figure 5. Interactive graph of V0=Vin from Multisim Live

<u>PART II:</u>

The non-inverting op-amp with $RL = 1k\Omega$ and $Rf = 4k\Omega$ circuit, is built for each case and shown below with the input voltages of: $0.5V, 1V, 1.5V, and\ 2V$.

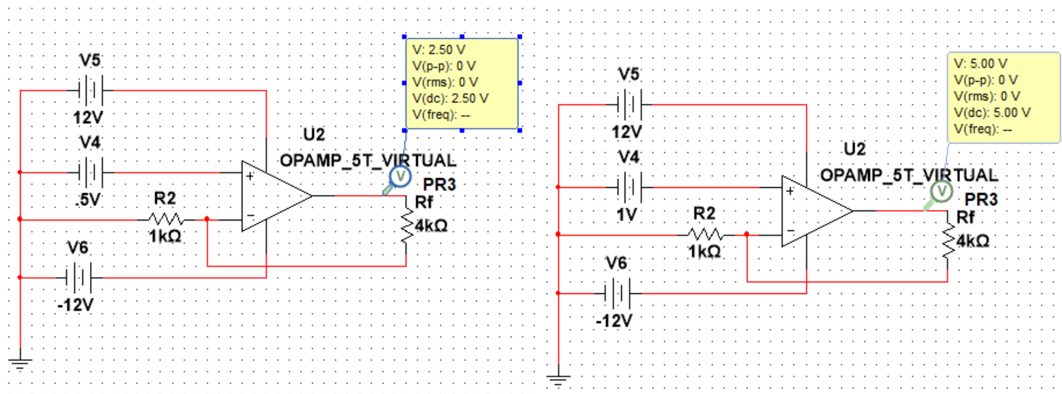


Figure 6A. Case: 0.5V, Figure 6B. Case 1V

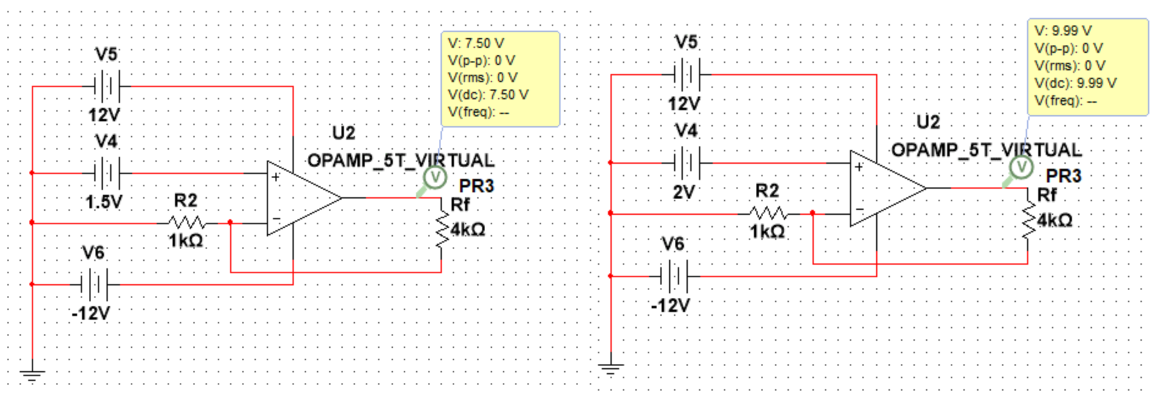


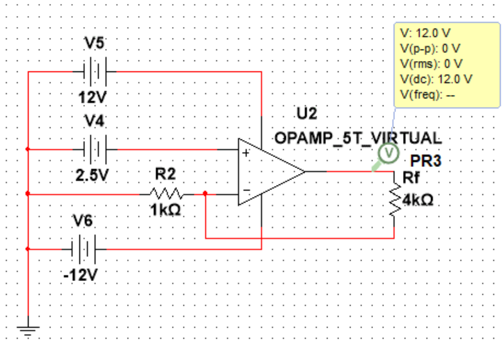
Figure 7C. Case: 1V, Figure 6D. Case 2V

For each circuit, the relationship between the input voltage (Vs), measured output voltage (V probe), and resistor ratio (Rf/Rin) can be witnessed in the follow Table:

Table 1-1

Input Voltage (Vs)	**Measured Output Voltage (V probe)**	**Ratio (Rf/Rin)**
0.5 [V]	2.5 [V]	4
1 [V]	5 [V]	4
1.5 [V]	7.5 [V]	4
2 [V]	9.99 [V]	4

At higher voltages, the output is capped because to the amplification cannot exceed the source voltage unless a larger voltage source is given:



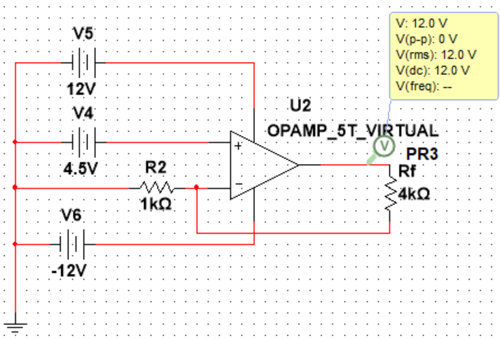


Figure 8E. Case: 2.5V, *Figure 6F. Case 4.5V*

PART III:

Changing the values of Rin and Rf, I decided to pick two commonly used values of $Rin = 3.3k\Omega$ and $Rf = 10k\Omega$. Using MATLAB, I calculated the following ratio and gain factor for a non-inverting op-amp configuration.

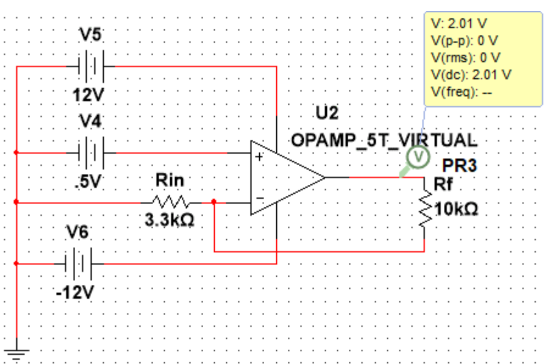
```
Rf=10e3; %[kohms]
Ri=3.3e3; %[kohms]
G=1+(Rf/Ri) %Gain

Ratio=Rf/Ri
```

```
G = 4.0303
Ratio = 3.0303
```

Figure 9. Calculations for my Resistor choices

Modifying the design built in PART II, I changed each respective resistor to my choices and recorded a measured output voltage for the same input cases detailed in PARTII.



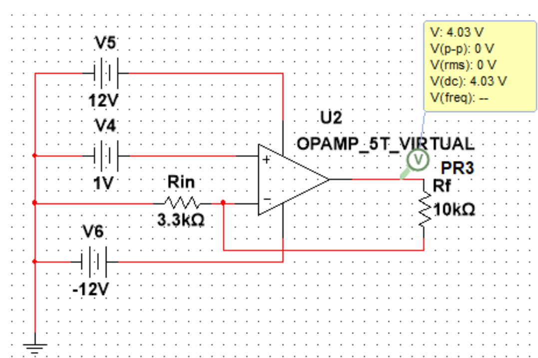


Figure 8A. Case: 0.5V, *Figure 8B. Case 1V*

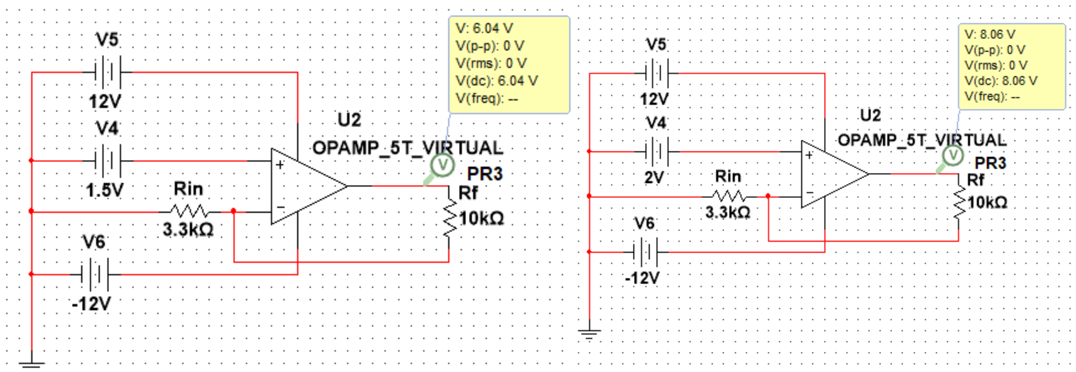


Figure 8C. Case: 1V, Figure 8D. Case 2V

Furthermore, for each circuit, the relationship between the input voltage (Vs), measured output voltage (V probe), and resistor ratio (Rf/Rin) can be witnessed in the follow Table:

Table 2-2

Input Voltage (Vs)	Measured Output Voltage (V probe)	Ratio (Rf/Rin)
0.5 [V]	2.01 [V]	3.0303
1 [V]	4.03 [V]	3.0303
1.5 [V]	6.04 [V]	3.0303
2 [V]	8.06 [V]	3.0303

3.2 Analysis

To answer the question about designing a non-inverting op amp and inverting op amp, I observed the formulas from the Op-Amp summary table found in figure 1, and I rearranged the equations using simple algebra done in OneNote to solve for Rf:

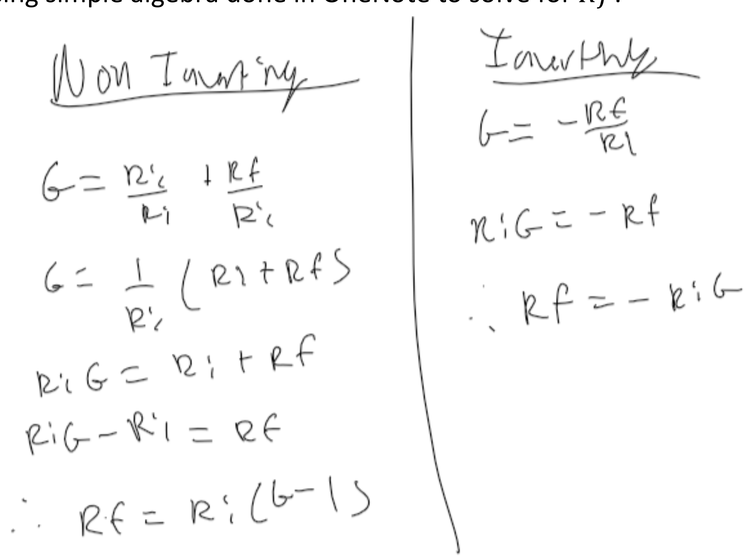


Figure 10. Algebra in OneNote

From this I created a simple MATLAB script to calculate what Rf should have been for each case:

```
%Analysis Questions
%Ri=33 ohms     G=-15   Rf=?
%Gain for Inverting Amp,    G=-Rf/Ri
Ri=33;
G=-15;
Rf=-G*Ri

%Checking work
Gain=-Rf/Ri
```

```
Rf = 495

Gain = -15
```

```
%Ri=2.2 kohms G=45   Rf=?
Ri=2.2e3;
G=45;
Rf=Ri*(G-1)
%checking work
G=1+(Rf/Ri) %Gain
```

```
Rf = 96800

G = 45
```

Figure 11. MATLAB Design Calculations

4.0 Conclusion:

This lab's purpose was to solidify my knowledge and understanding of operational amplifiers. Operational amplifiers can be used in a variety of ways depending on how they are wired. In the closed loop configuration, the gain of an op-amp is manipulated through the feedback loop of the IC. By manipulating the feedback loop, an op-amp can be used to add/subtract or isolate parts of a circuit by using a buffer. This lab explored using a buffer, which is when an op-amp does not use a resistor to control the negative feedback, and the output terminal get's fed back into the negative input terminal. By measuring the voltage coming into the positive terminal and the node voltage coming out of the output terminal, it is apparent that these voltages are the same since current travels back through the negative feedback loop. Creating a buffer could be useful in a circuit such as a bandpass filter, which could be comprised of two filters: a lowpass and a high pass, and implementing a buffer in between each filter will eliminate filter bleeding. The lab also examined non-inverting and inverting op-amps by proving how an op-amp can amplify an input voltage based upon the feedback resistor ratio and source voltage coming into it. The op-amp can only amplify until it reaches a capped voltage which can not amplify further than the amount of voltage that is being used to power the op-amp, through the +/- power rail terminals.