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Lab 5: Introduction To Op-Amps

Introduction:

During our time in the laboratory, we examined the fundamental principles of operational amplifiers. In the initial pre-lab, we calculated the output voltage expressions for four distinct amplifiers based on their respective input voltages. In the subsequent pre-lab, we utilized LTspice to simulate the behavior of both the inverting and non-inverting amplifiers and investigated how the value of resistor R_f affected the gain. We also simulated the summing and differential amplifiers, examining their ability to perform addition and subtraction with various inputs. During the actual lab, we constructed both inverting and non-inverting amplifiers, utilizing a 10kΩ potentiometer as the R_f component. By manipulating the potentiometer, we analyzed the relationship between R_f and the resulting output voltage.

Prelab 1: Closed-Loop Gain

Figure A: $$\frac{\cancel{v^-}^{0} - V_{in}}{R_i} + \frac{\cancel{v^-}^{0} - V_{out}}{R_f} = 0 \quad (v^- = v^+ = 0)$$

$$\frac{V_{out}}{R_f} = \frac{-V_{in}}{R_i}$$

$$\boxed{V_{out} = -V_{in}\frac{R_f}{R_i}}$$

Figure B: $$\frac{v^- - 0}{R_i} + \frac{v^- - V_{out}}{R_f} = 0 \quad (v^- = v^+ = V_{in})$$

$$\frac{V_{in}}{R_i} + \frac{V_{in} - V_{out}}{R_f} = 0$$

$$V_{out} = R_f\left(\frac{V_{in}}{R_i} + \frac{V_{in}}{R_f}\right)$$

$$V_{out} = V_{in}R_f\left(\frac{R_i + R_f}{R_iR_f}\right)$$

$$\boxed{V_{out} = V_{in}\left(1 + \frac{R_f}{R_i}\right)}$$

Figure C: $$\frac{\cancel{v^-}^{0} - V_{in1}}{R_{i1}} + \frac{\cancel{v^-}^{0} - V_{in2}}{R_{i2}} + \frac{\cancel{v^-}^{0} - V_{out}}{R_f} = 0 \quad (v^- = v^+ = 0)$$

$$\boxed{V_{out} = -R_f\left(\frac{V_{in1}}{R_{i1}} + \frac{V_{in2}}{R_{i2}}\right)}$$

Figure D: $$\frac{v^+ - V_{in2}}{R_1} + \frac{v^+}{R_2} = 0$$

$$v^+\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V_{in2}}{R_1}$$

$$v^+ = \frac{\cancel{R_1}R_2}{R_1 + R_2}\left(\frac{V_{in2}}{\cancel{R_1}}\right)$$

$$v^+ = \frac{R_2V_{in2}}{R_1 + R_2} = v^-$$

$$\frac{v^- - V_{in1}}{R_i} + \frac{v^- - V_{out}}{R_f} = 0$$

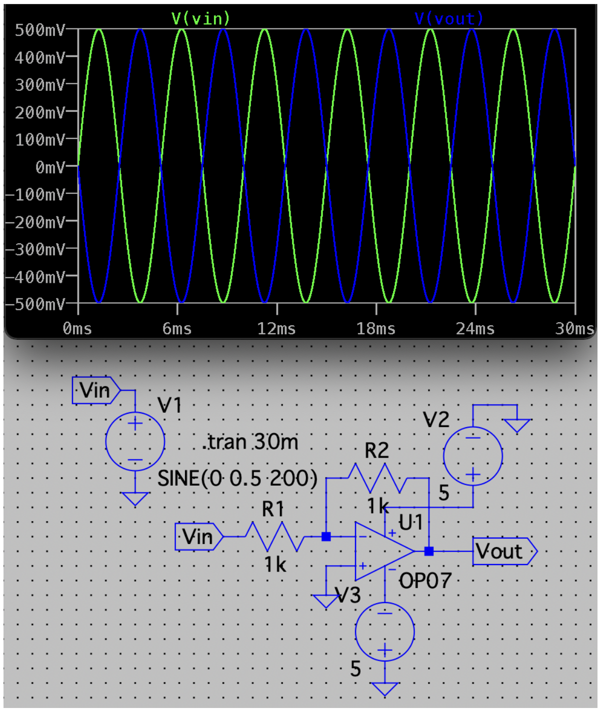
$$\frac{V_{out}}{R_f} = v^-\left(\frac{1}{R_i} + \frac{1}{R_f}\right) - \frac{V_{in1}}{R_i}$$

$$V_{out} = \frac{v^-R_f}{R_i} + v^- - \frac{R_fV_{in1}}{R_i}$$

$$\boxed{V_{out} = \frac{R_2V_{in2}}{R_1 + R_2}\left(\frac{R_f}{R_i} + 1\right) - \frac{R_fV_{in1}}{R_i}}$$

[RP1]

Part 2: Simulations
A: Inverting Configuration



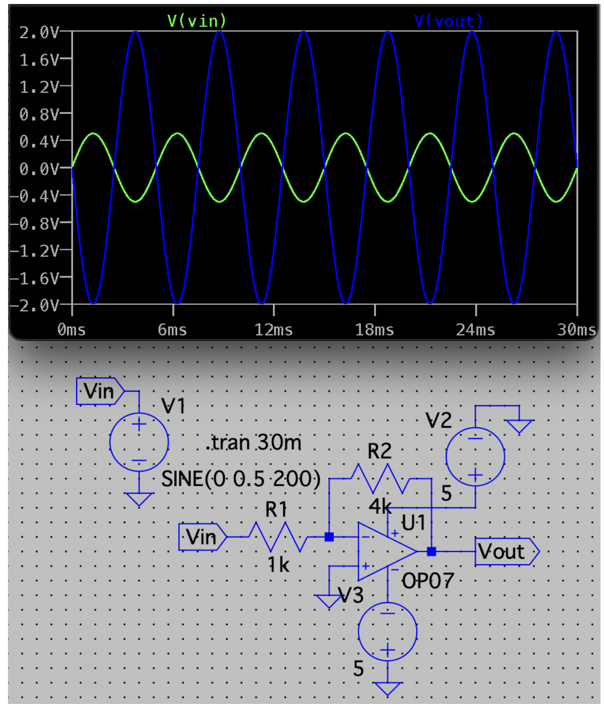
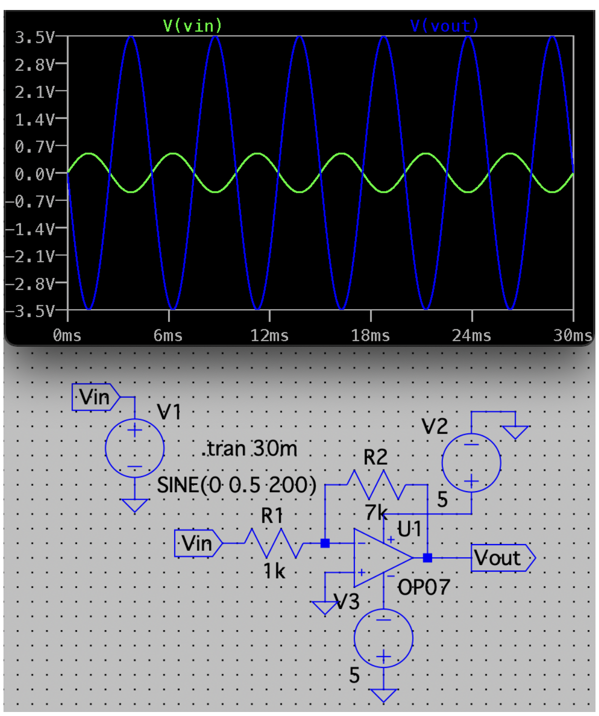


Figure 1. Inverting Op-Amp with Gain of 1. Figure 2. Inverting Op-Amp with Gain of 4.



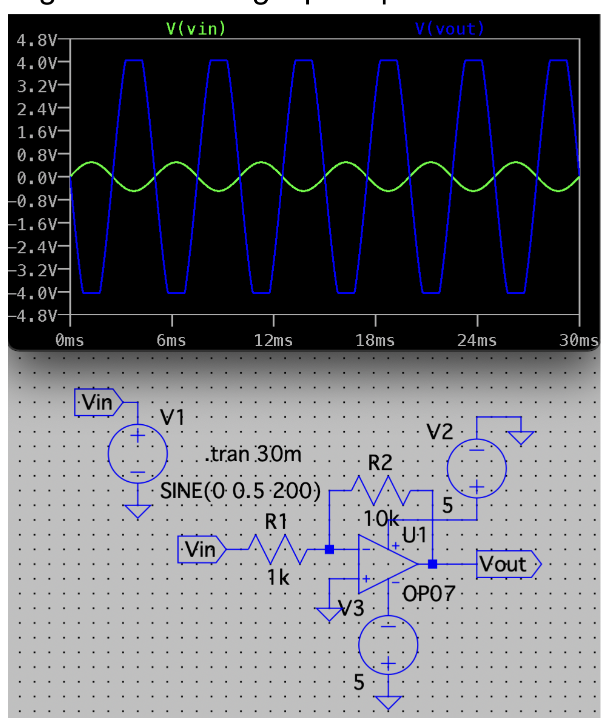


Figure 3. Inverting Op-Amp with Gain of 7. Figure 4. Inverting Op-Amp with Gain of 10.
[RP2][RP3]

$$G = \frac{v_{out}}{v_{in}} = \frac{-R_f}{R_i}$$

Expected |Gain|	1	4	7	10
R_f	1kΩ	4kΩ	7kΩ	10kΩ
|Gain| from LTspice	1	4	7	8

Table 1. Values of R_f and calculated gain for different theoretical gain. **[RP4]**

No. The v_{out} signal got clipped, and the calculated gain from LTSpice was 8. **[RP5]**

B: Non-inverting Configuration

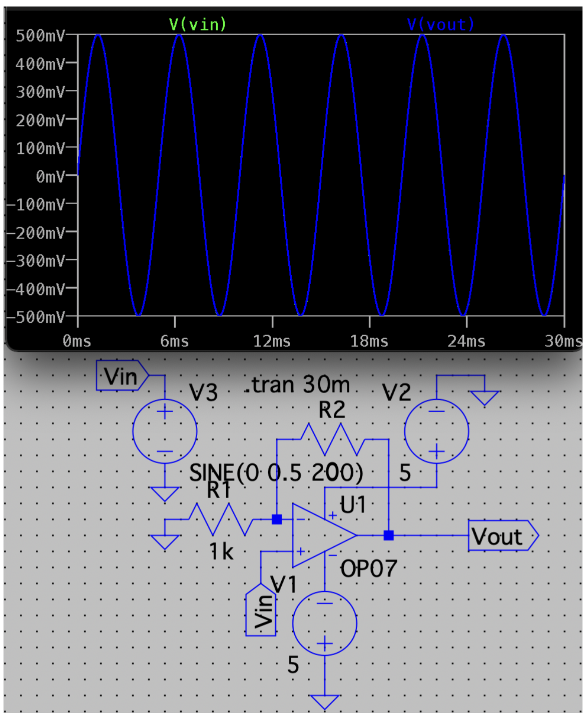


Figure 5. Inverting Op-Amp with Gain of 1.

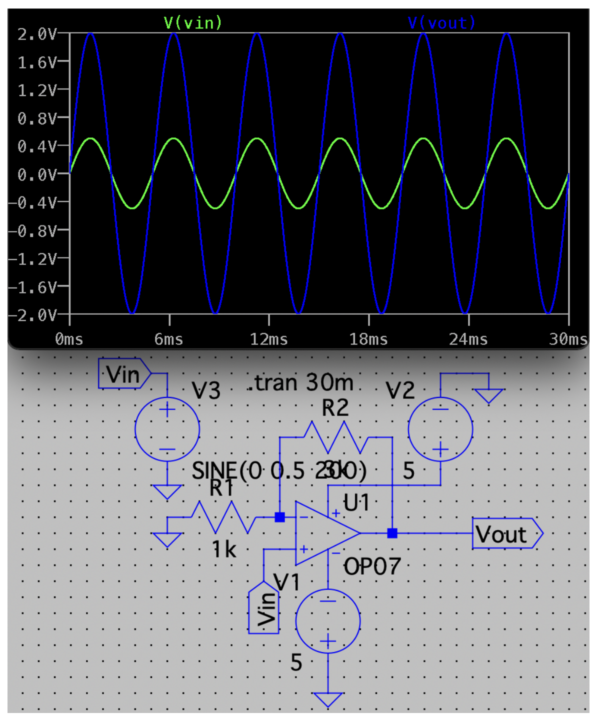


Figure 6. Inverting Op-Amp with Gain of 4.

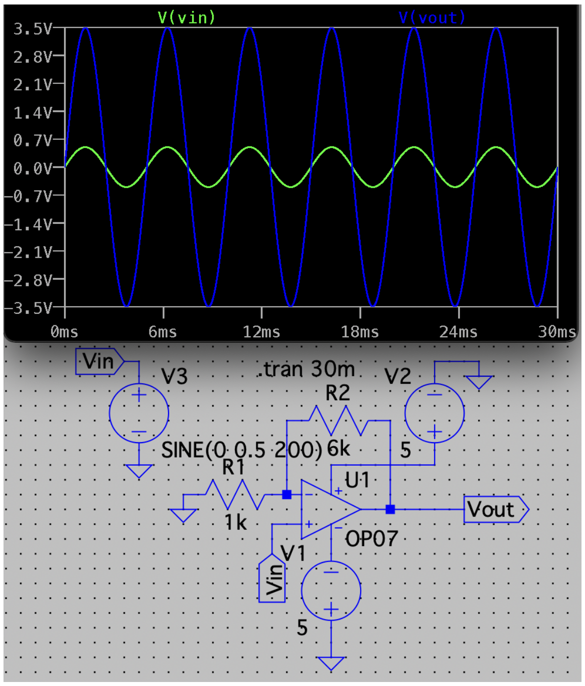


Figure 7. Inverting Op-Amp with Gain of 7.

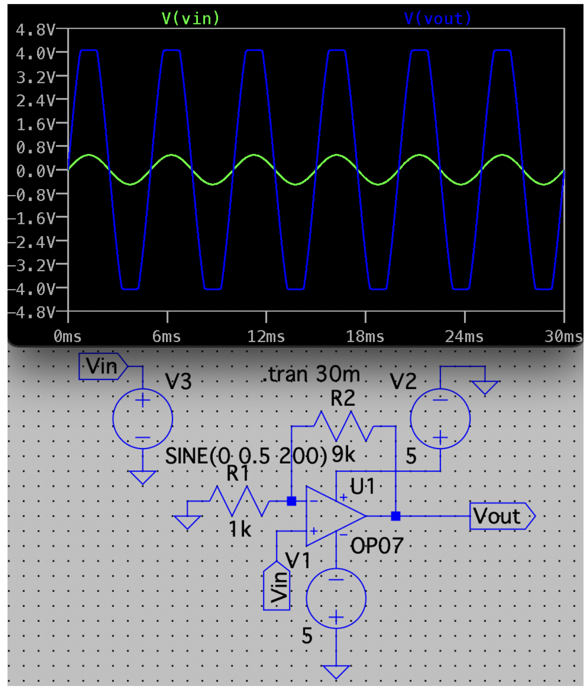


Figure 8. Inverting Op-Amp with Gain of 10.

[RP6][RP7]

$$G = \frac{v_{out}}{v_{in}} = 1 + \frac{R_f}{R_i}$$

Expected |Gain|	1	4	7	10
R_f	0kΩ	3kΩ	6kΩ	9kΩ
|Gain| from LTspice	0	4	7	8

Table 2. Values of R_f and calculated gain for different theoretical gain. **[RP8]**

No. The v_{out} signal got clipped, and the calculated gain from LTSpice was 8. **[RP9]**

C: Adder Configuration

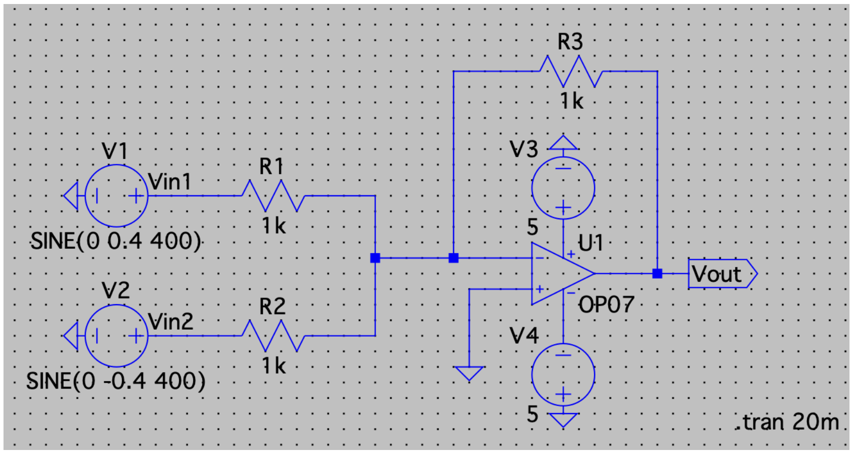


Figure 9. Adder configuration schematic. **[RP10]**

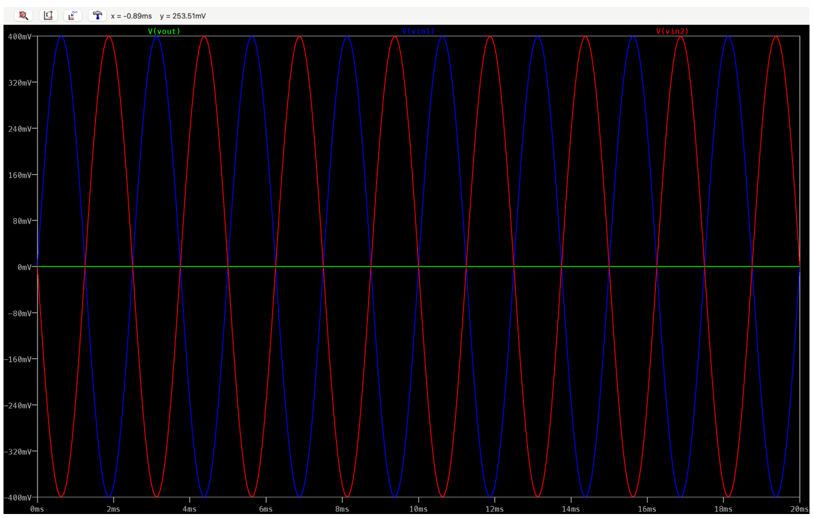


Figure 10. Simulation Results of Adder Configuration (V_{in1}= $-V_{in2}$). **[RP11]**

An adder outputs the sum of two input signals, and since our input signals are the opposite of each other, the sum gives us 0. **[RP12]**

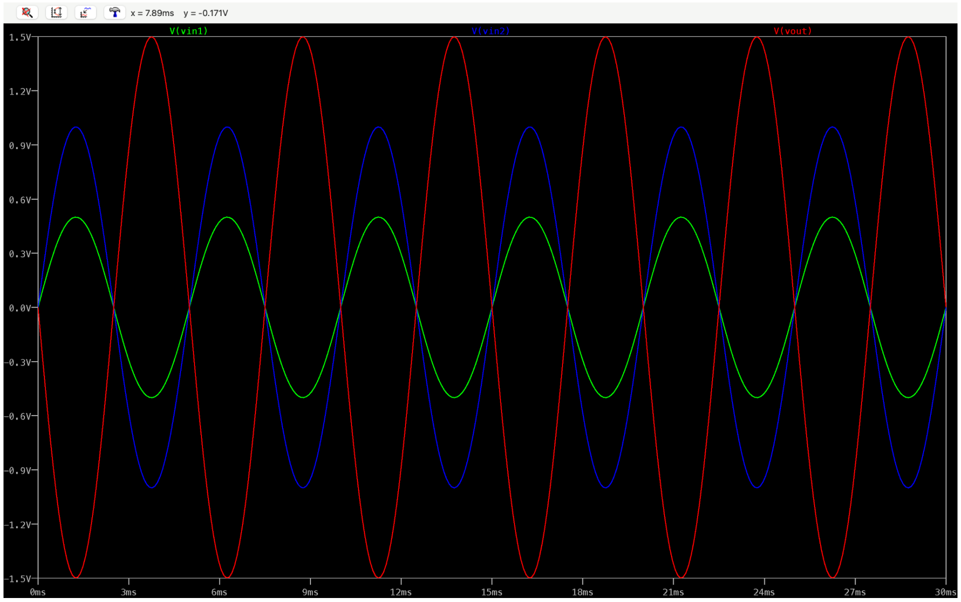


Figure 11. Simulation Results of Adder Configuration with 0.5V and 1V amplitudes. **[RP13]**

The two input signals are in phase sine waves with 0.5V and 1V amplitudes, and the resulting output signal is an inverting sine wave of amplitude 1.5V. The amplitude of V_{out} is the sum of the amplitudes of the two input signals. **[RP14]**

One way to get rid of the negative sign of V_{out} is by feeding the output of the adder into an inverting amplifier (Figure A). **[RP15]**

Connect n inputs in parallel and feed into the negative terminal of the amplifier. **[RP16]**

D: Subtracter Configuration

$$V_{out} = \frac{R_2 V_{in2}}{R_1 + R_2}\left(\frac{\cancel{R_f}^{\,1}}{\cancel{R_i}_{\,1}} + 1\right) - \frac{\cancel{R_f}^{\,1} V_{in1}}{\cancel{R_i}_{\,1}}$$

$$V_{out} = 2V_{in2}\left(\frac{R_2}{R_1 + R_2}\right) - V_{in1} = V_{in2} - V_{in1}$$

$$\frac{R_2}{R_1 + R_2} = \frac{1}{2}$$

$$R_1 = R_2 = 1k\Omega$$

[RP17]

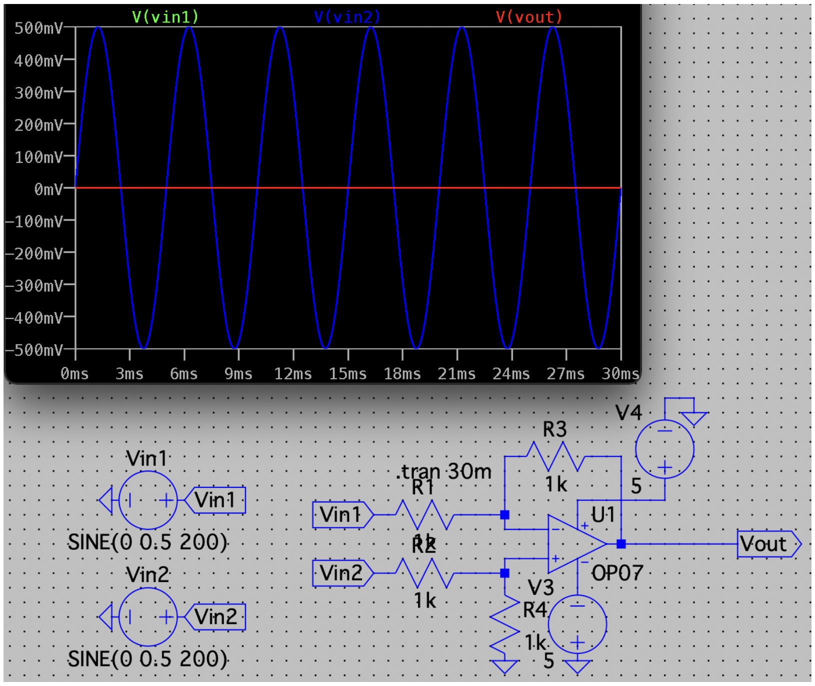


Figure 12. Schematic & Simulation of Subtractor Configuration ($Vin_1 = Vin_2$). **[RP18][RP19]**

The result is zero because the two input signals of the subtractor are the same, so the difference is zero. **[RP20]**

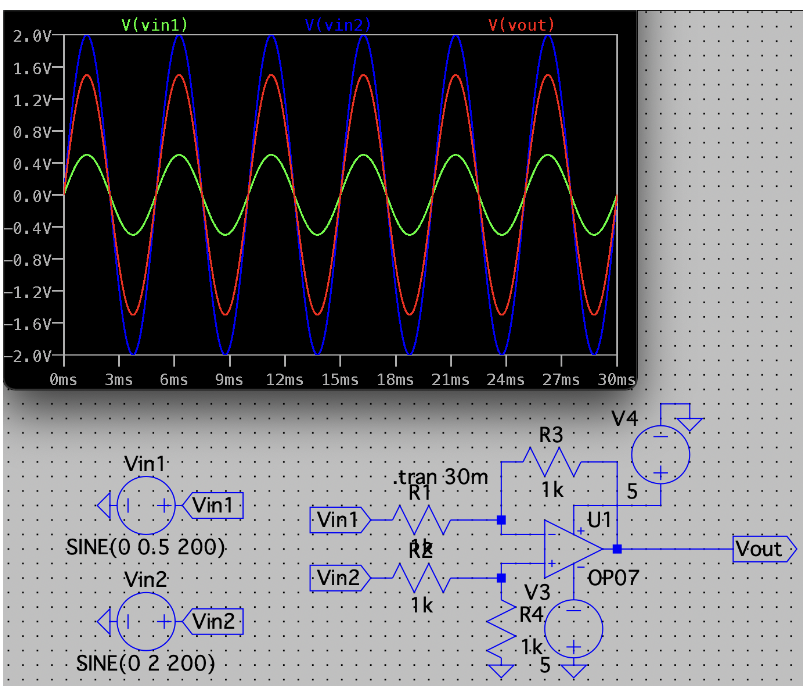


Figure 13. Schematic & Simulation of Subtractor Configuration ($Vin_1 \neq Vin_2$). **[RP21]**

The two input signals are sine waves that are in sync with each other and have amplitudes of 0.5V and 2V respectively. The output signal that results from combining these two input signals is also a sine wave, with an amplitude of 1.5V. Alternatively, the output signal can be thought of as the difference between the two input signals. **[RP22]**

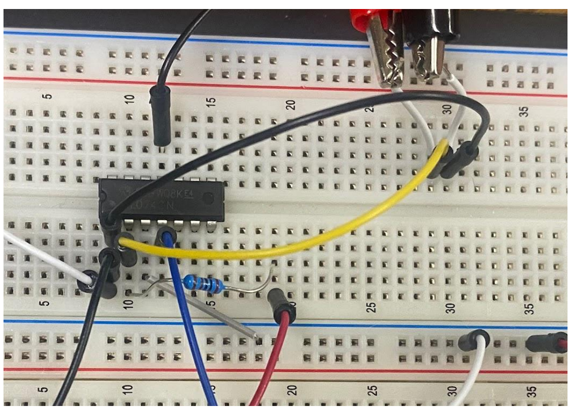
Lab: Circuit Construction
Maximum dual supply voltage: 6V
Minimum dual supply voltage: 36V

The typical differential voltage gain is 2.0 x 10^5 V/V

Unity gain bandwidth (frequency at which the gain of the amplifier is equal to 1): 100kHz

The typical input offset voltage is 3mV. When the input offset voltage is multiplied by the gain, it will result in a deviation in output voltage. **[RP23]**

Open-loop gain: the gain of an op-amp without feedback
Closed-loop gain: the gain of an op-amp with a feedback circuit **[RP24]**



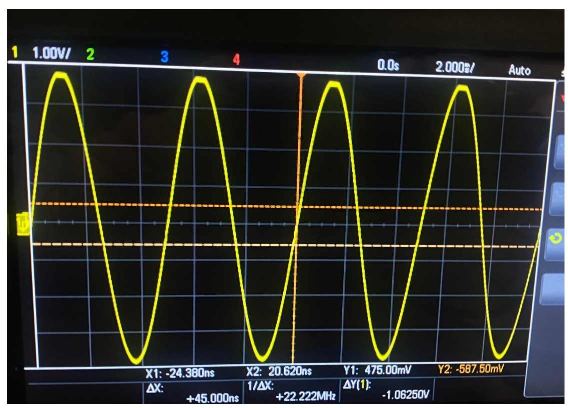


Figure 14. Inverting Amplifier Circuit.   Figure 15. Inverting Amplifier Waveform **[RP25]**

R_f = 8k **[RP26]**

R_f = 1k such that $V_{out} = -V_{in}$ **[RP27]**

Forgot to take pictures of circuit and waveform in the lab. **[RP28]**

R_f = 6.4k **[RP29]**

R_f = 0 such that $V_{out} = V_{in}$ **[RP30]**

Conclusion:

In conclusion, our laboratory exploration of operational amplifiers allowed us to gain a deeper understanding of their fundamental concepts. Through the use of LTspice simulations and practical circuit construction, we were able to observe how the gain of both inverting and non-inverting amplifiers varied with changes in resistor values. Our results showed that the gain of the inverting amplifier was 1 when the initial and final resistance were both equal to 1kΩ, and that the gain of the non-inverting amplifier was 1 when the final resistance was approximately 0Ω. These results matched with our initial expression of V_{out}.