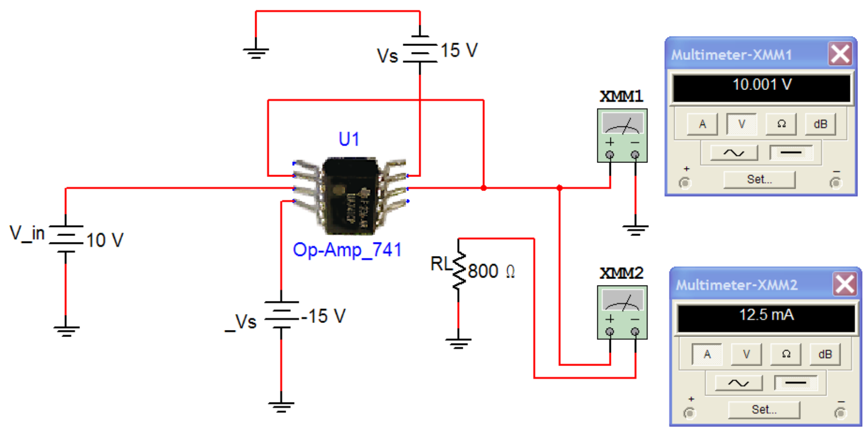
Experiment 7

Pre-Lab Activity

Read the Pre-reading materials, the laboratory activity and the post-lab before coming to the Laboratory. Solve the following problems and submit your solution to your instructor.

Problems

1. Use Multisim to build and simulate the following voltage follower circuit. The 741 op-amp can be inserted from the 3D VIRTUAL Family of components (under the Basic Components Group). Determine the saturation voltage v_{sat}. This can be done by changing v_{in} to a value equal to or above the bias voltage Vs.



2. Change v_{in} back to 10V in the above simulation. The ammeter XMM2 is measuring the load current. This is the output current supplied by the op-amp (note that no current flows back into the inverting input, pin 2 on the 741 op-amp, because of the high input resistance of the op-amp). The 741 op-amp output current can't increase beyond its saturation current $i_{sat} \cong 25$mA. What is the smallest value of R_L (with v_{in} = 10V) that prevents the op-amp form saturating its output current. Find v_o and i_o for $R_L = 400\Omega$.
3. Use Multisim to simulate the inverting amplifier shown in Figure 8. Set $R = 1k\Omega$, $R_f = 10k\Omega$, $R_L = 4.7k\Omega$, and $v_{in} = 1.2\sin(2000\pi t)$ Volts

(this is a 2.4V peak-to-peak signal with 1kHz frequency. Make sure to verify the signal amplitude using the virtual scope). Submit a printout of the virtual scope display showing (simultaneously) traces of v_{in} and v_o. Repeat your simulation by using R_f = 15kΩ.

4. Change the input to a triangular wave with peak-to-peak voltage of 4 volts and frequency of 1kHz. Verify the input amplitude using the scope. Keep the 15kΩ feedback resistor. Use the scope to generate an XY (or A/B) plot of v_o vs v_{in}. The plot should look like the one in Figure 7. Actually, the inverting property of the amplifier will make the plot look like the mirror image, w.r.t. the vertical, of the plot in Figure 7.
5. Use Multisim to simulate the non-inverting amplifier shown in Figure 9. Set R = 1kΩ, R_f = 10kΩ, R_L = 1kΩ, and $v_{in} = 1.2\sin(2000\pi t)$ Volts. Submit a printout of the virtual scope display showing (simultaneously) traces of v_{in} and v_o.
6. Use Multisim to find the output voltage of the three input summing amplifier (adder), shown in Figure 10. Set $R = R_f$ = 10kΩ and let v_1= 2V, v_2 = 4V and v_3 = - 9V. Compare your answer to the theoretical one obtained using Eq. (10).

Laboratory Activity

Required components:

One 47Ω resistor (±5%, ½ W)

One 470Ω resistor (±5%, ½ W)

One 1kΩ resistor (±5%, ½ W)

One 4.7kΩ resistor (±5%, ½ W)

One 10kΩ resistor (±5%, ½ W)

One 15kΩ resistor (±5%, ½ W)

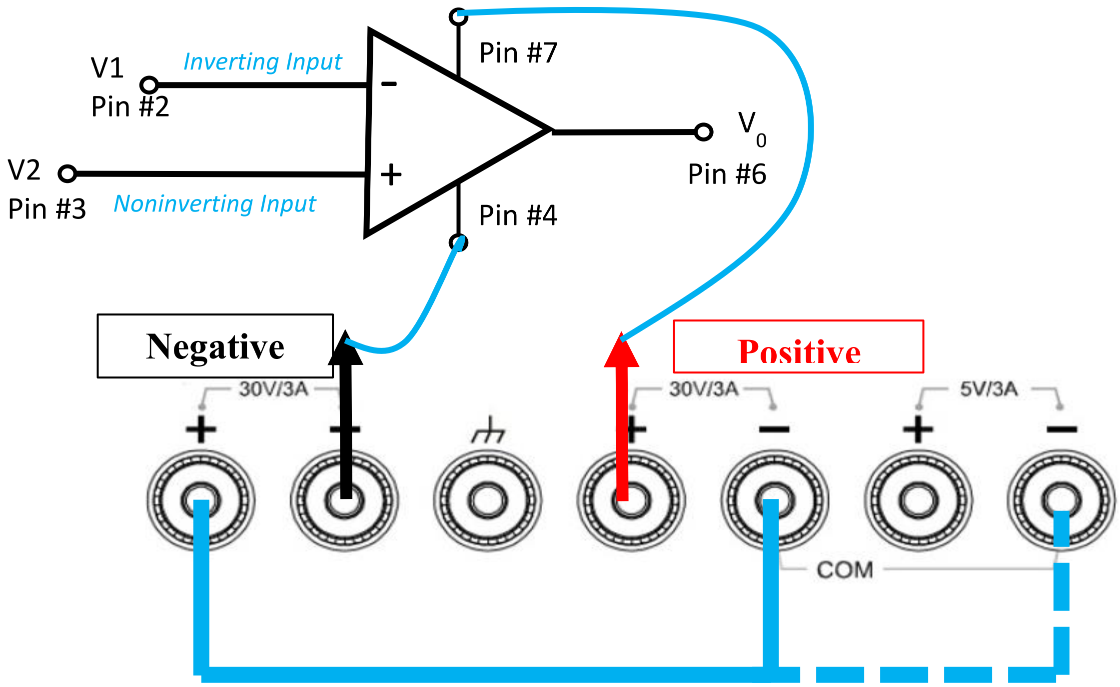
One 10kΩ potentiometer (±10%, ½ W)

One LM741 op-amp.

Note:

- All circuits in this experiment (and in all future experiments) should be constructed on the protoboard.
- When making current measurements, set the ammeter to display the reading in mA. Record your measurement with two significant digits to the right of the decimal point (employ rounding).
- When making voltage measurements, set the voltmeter to display the reading in Volts. Record your measurement with two significant digits to the right of the decimal point (employ rounding).
- When measuring resistance, set the Ohmmeter to record the displayed reading accurate to two significant digits to the right of the decimal point.

1. Obtain the above resistors from your lab instructor and measure and record their actual resistance.
2. Attach the LM741 op-amp to the protoboard. Refer to the Protoboard Unit for proper positioning and placement of the op-amp chip.
3. Use the DC power supply to generate the $\pm$15V bias voltages (use the 25V supply port with the output tracking feature enabled). Connect the power supply to the op-amp pins 4 and 7, as shown in the figure below.



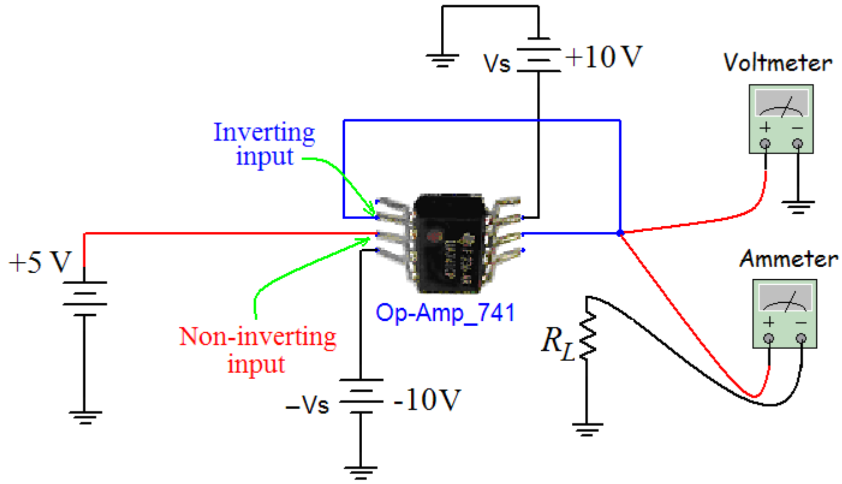
4. Have your instructor check your circuit before you continue.

Comparator Circuit:

5. Set the inverting input voltage to +5V (use the 6V DC power supply port) and the non-inverting input to 0V (by connecting it to ground). Measure and record the op-amp output voltage for the following bias voltage values $\pm V_S = \pm 15$V, $\pm V_S = \pm 10$V and $\pm V_S = \pm 5$V.
6. Repeat Step 5 for the case where the non-inverting input voltage is set to +5V and the inverting input to 0V.

Voltage Follower:

7. Disconnect the op-amp input pins from any DC source or ground connection. Set the bias voltage to $\pm V_S = \pm 10$V. Modify your op-amp circuit to get a voltage follower (i.e., add a wire between the output pin and the inverting input). Connect a 5V DC source to the non-inverting input of the op-amp. Connect 4.7kΩ load resistor R_L between the output of the op-amp and ground. Connect a voltmeter to monitor the voltage across R_L and an ammeter to monitor the current through R_L. The circuit should look like the one shown below. Record the load resistor voltage and current. Repeat for R_L = 470Ω, and R_L = 47Ω.

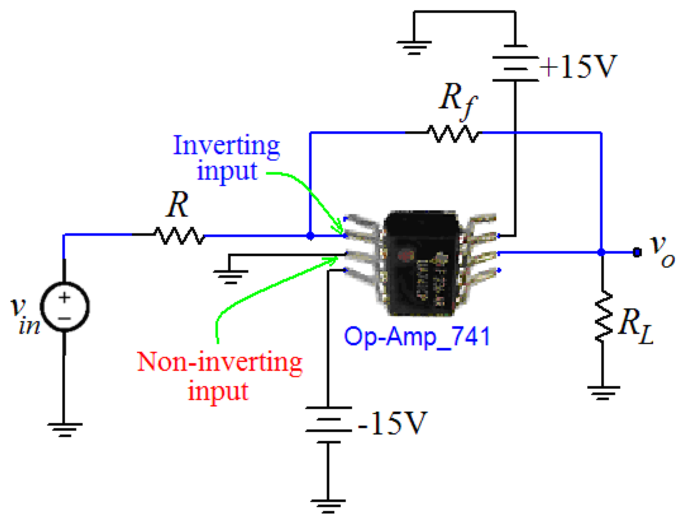


Inverting Amplifier:

8. *a.* Modify the previous circuit into an inverting amplifier as shown in the figure below. Set the bias voltages to $\pm$15V. Set R = 1kΩ, R_f = 10kΩ, R_L = 4.7kΩ, and v_{in} = 1.2sin(2000πt) Volts. v_{in} is a 2.4V peak-to-peak sine signal with 1kHz frequency. Make sure to verify the signal amplitude using the scope; do not rely on the function generator's amplitude indicator. Use the scope to display (apply *autoscale*) the input and output voltages on Channels 1 and 2, respectively. Use the *Quick Measure* key to find the peak-to-peak value of v_o. Save the scope's display as an image file.

b. Press the *square wave* key on the function generator. You might need to calibrate the probe if the displayed input square wave is distorted. Save the scope display into an image file.

c. Set the scope's time axis scale to 10μs/Division. Use the scope's *cursor system* to measure the slope (ΔY/ΔX) of the rising (or falling) edge of the output signal.



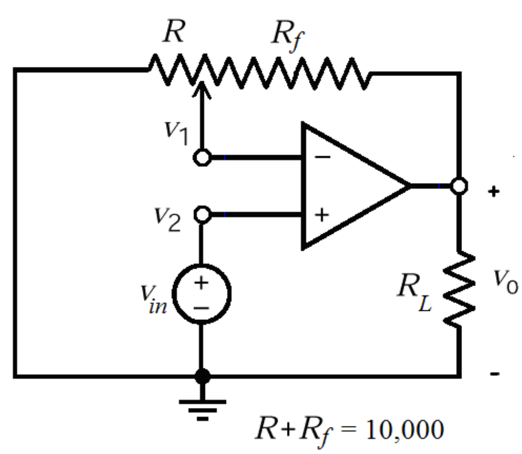
9. Repeat Step 8*a* using R_f = 15kΩ.
10. *a*. Change the input signal to a triangular wave with peak-to-peak voltage of 4V and a frequency of 1kHz. Verify the input signal peak-to-peak value using the scope. Keep the 15kΩ feedback resistor. Use the scope to generate an XY plot of v_o vs v_{in}. Use Channel 1 and 2 *Vertical Shift* knobs to center the plot at middle point of the display. Set Channel 1 scale to 1V/Div and Channel 2 to 5V/Div. The plot should look like the one in Figure 7. Actually, the inverting property of the amplifier will make the plot look like the mirror image, with respect to the vertical, of the plot in Figure 7. Save the plot to an image file.
    b. Employ the cursor system to measure the slope of the displayed plot in the neighborhood of the origin.

Non-Inverting Amplifier:

11. Construct the non-inverting amplifier shown in Figure 9. Set the bias voltages to ±15V. Set R = 1kΩ, R_f = 10kΩ, R_L = 4.7kΩ, and v_{in} = 1.2sin(2000π*t*) Volts (set the amplitude of v_{in} using the scope). Use the scope (apply *autoscale*) to display the input and output voltages on Channels 1 and 2, respectively. Record the measured peak-to-peak values of v_{in} and v_o. Save the scope's display as an image file.
12. *a*. Increase the amplitude of v_{in} from 1.2V to 2.5V (i.e., to 5Vpp); verify using the scope. In some cases, the output from the function

generator might have a slight undesirable DC bias (offset). This DC bias can be measured with the scope: Employ signal averaging, with #AVG = 8 to help sharpen the signal, and use the *Quick Measure* feature of the scope to compute the signal average. This average represents the amount of undesirable DC bias in the input signal. Let the signal average be equal to *ave*. This undesired value can be subtracted by offsetting (using the *offset* feature of the function generator) the generated signal by +*ave* if *ave* is negative and –*ave* if *ave* is positive.

b. Replace R_f and R by a 10kΩ potentiometer as shown in the figure below. Here, R_f and R change as the potentiometer is adjusted, with the constraint: R = 10,000 - R_f . As you monitor the output voltage with the scope, turn the knob of the potentiometer until the maximum value of v_o reaches v_{sat}. Record the value of v_{sat}. Disconnect the potentiometer. Do not touch the knob in order not to change the potentiometer setting. Measure R_f and R.



13. **Sort all components and give them back to your instructor.**

Post-Lab Activity

Write a technical report that discusses your observations and includes analysis and justifications of all steps in this activity. Tabulate and/or plot experimental data whenever possible. More specifically, your report should address the following points:

Note:

- Use the actual (measured) resistor values in all theoretical calculations and in Multisim simulations.
- When you are asked to "compare" measured values to theoretical values, always compute the error in percent.

- Discuss the effect of the bias voltage and input voltage on the linear operation of the voltage follower in Steps 5 and 6. Compare your results to those obtained using Equation (5). Tabulate the bias voltages and their corresponding saturation voltages.
- Why does the voltage follower fail (Step 7) when a 47Ω load resistor is used? What is the value of the op-amp saturation current?
- How does the op-amp output in Step 8*a* compare to the theoretical expected output?
- Is the op-amp operation affected by the functional form of the input signal? Explain by comparing the results of Steps 8*a* and 8*b*. What op-amp parameter does the slope you obtained in Step 8*c* represent?
- Why does the inverting amplifier output voltage saturate (Step 9)? What is the largest possible gain for this amplifier (assuming linear op-amp operation)?
- What does the slope you that you have determined in Step 10*b* represent?
- Compare the result of Step 11 to the theoretical value obtained using Equation (9).
- Use the expression (v_o peak-to-peak)/(v_{in} peak-to-peak) to determine the experimental gain for the non-inverting amplifier in Step 11. Compare this gain to the theoretical value $G = 1+\frac{R_f}{R}$ (use actual resistor values).

- Show that the non-inverting amplifier gain (Step 12*b*) is $G = R_{pot}/(R_{pot} - R_f)$, where R_{pot} is the overall potentiometer resistance (10kΩ nominal value in this case). Compare the value of R_f that you obtained in Step 12*b* to the theoretical upper bound for R_f obtained from the expression: $1+\frac{R_f}{R} < \frac{|v_{sat}|}{\max|v_{in}(t)|}$ (employ the measured values for $|v_{sat}|$ and R).