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EXPERIMENT : 07 Operational Amplifiers I

I. OBJECTIVE

To study the use of operational amplifier in inverting and summing amplifiers.

II. BASIC INFORMATION

II.1 Op-Amp 741

1. In instrumentation circuits, the difficulty often arises in determining how a small dc signal (a few millivolts or less) should be amplified to a more useful signal level. A possible solution is the use of an **operational amplifier (op amp)**. Pin details of op amp 741 are shown in Figure 1.
2. An op-amp is a two-input single-output device. It is a voltage amplifier with high gain, broad bandwidth, high input impedance and low output impedance. The two inputs are called **inverting** (−) and **noninverting** (+), as shown in Figure 1. Op amps require two power supplies of the same voltage magnitude but opposite polarities. Practical op amp has a finite open-loop gain and a low pass frequency response.
3. A few external components (resistors and capacitors) can be connected to an op amp to form a feedback network, which is capable of controlling the actual (closed-loop) **gain** of the amplification.

Caution: **An op-amp must be treated with special care**. They are powerful but can be easily damaged from wrong circuit wiring. In particular it is abusive to apply AC-signal voltages to the input terminals before providing the power supply (or fully powering up the device), or to exceed certain maximum limits. Therefore, for each section of this experiment, follow the following steps.

i. Set up the circuit with all signal sources turned off.
ii. Double-check your connection.
iii. Enable the power supply (i.e. power up the op amp device).
iv. Turn up the signal source.
v. Op amps can also be damaged if their outputs are shorted to ground or to the power supply. Please also be very careful with wiring.

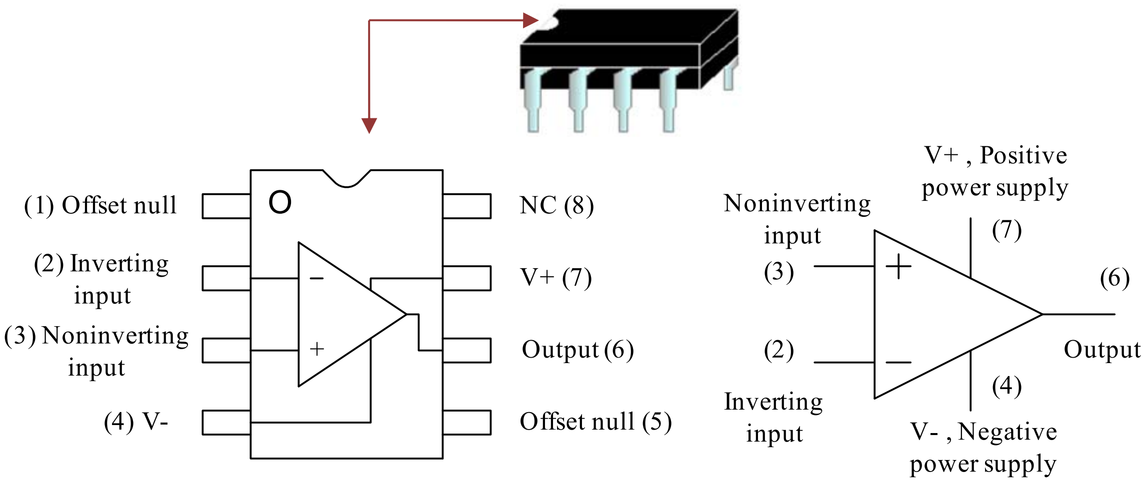


Figure 1: Pin details and configuration of IC 741.

4. Two important characteristics of the ideal op amp are

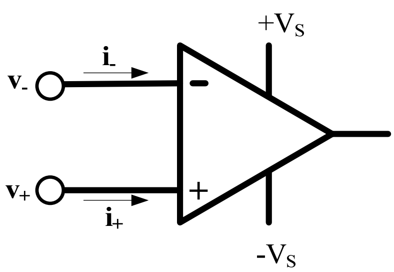
1) The currents into both input terminals are zero:

$$i_+ = i_- = 0\,.$$

2) The voltage across the input terminals is negligibly small:

$$v_+ \approx v_-\,.$$

Remark: Do not assume that $v_+ = v_- = 0$!



II.2 Inverting, Non-Inverting, and Summing Amplifier

1. In **inverting amplifier**, the feedback resistor R_F is connected between the output and the inverting input as shown in Figure 2. The output of the inverting amplifier is

$$V_o = -\frac{R_F}{R_R} V_i.$$

The minus sign represents a 180° phase shift between the input and the output. The **closed-loop gain** of the inverting amplifier is $-(R_F / R_R)$.

2. Figure 3 shows a circuit of a **noninverting amplifier**. The input signal drives the noninverting input of the op amp. The external resistors R_1 and R_2 form the feedback voltage divider. The output of the noninverting amplifier is

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_i.$$

The closed-loop gain of the noninverting amplifier is equal to $1+(R_2/R_1)$.

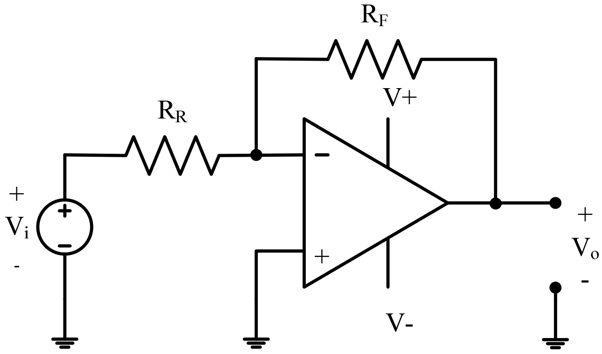


Figure 2: Inverting amplifier.

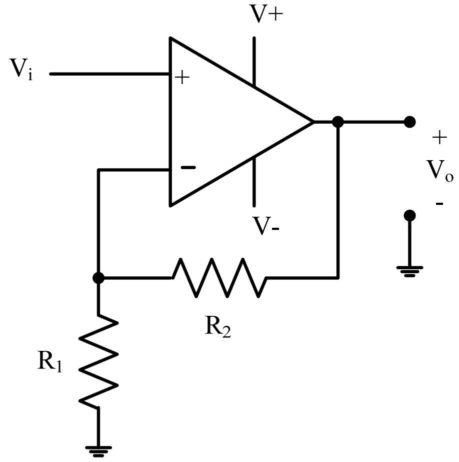


Figure 3: Noninverting amplifier.

3. An example of the **summing amplifier** is shown schematically in Figure 4. The output voltage is the sum of the input voltages with the sign inverted. The output voltage V_o in Figure 4 is given by

$$V_o = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 \right).$$

The summer provided in Figure 4 can be modified to provide three or more inputs.

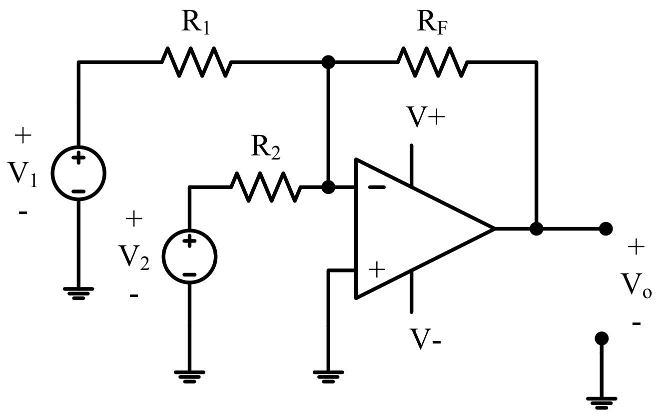


Figure 4**:** Op amp connected as a summing amplifier.

III. MATERIALS REQUIRED

Power supplies:

± 12V, DC, regulated

Variable 0-15 V

Equipment:

Oscilloscope

Function generator

Digital multi-meter

Resistors:

three 10-kΩ	one 5-kΩ	one 20-kΩ	one 30-kΩ
one 100-kΩ	one 12-kΩ		

Semiconductor:

Op amp 741

IV PROCEDIRE

Part A: Inverting amplifier

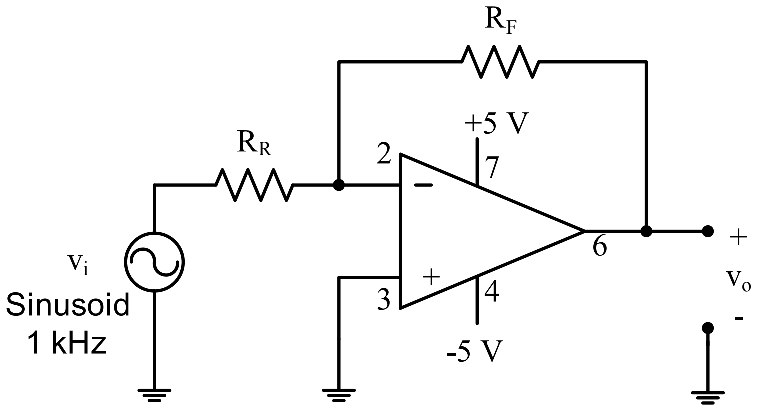


Figure 5: Experimental inverting amplifier.

1. Connect the circuit in Figure 5. Use $R_F = R_R = 10\ k\Omega$. Record the exact values of the resistance in Table 7-1.

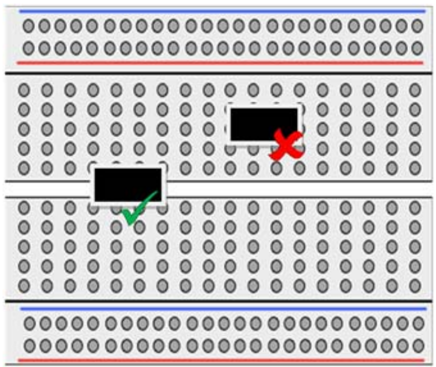
   Caution:

   (a) Do not connect the output (pin 6) of the op amp directly to the ground.

   (b) Connect ALL the ground nodes together.

   (c) As demonstrated in Figure 6b, plug in op amp chips so that they straddle the troughs on the proto board. In this way, each pin is connected to a different hole set.

2. The op amp must be powered by voltage supplies. These supplies are often ignored in op amp circuit diagrams for the sake of simplicity.
   Figure 6a shows how to power the op amp with $+V_{cc}$ and $-V_{cc}$.



(a) Powering the op amp (b) Plugging the 741 chip onto the proto-board

Figure 6: Connecting op-amp 741

Both power supplies in Figure 6a should be set to $V_{cc} = 5$ V which will make $V_7 = +5$ V and $V_4 = -5$ V.

3. Set the sine-wave generator output, v_i, to 1 kHz, and then adjust the output of the generator to its smallest value. Connect the Channel 1 of the oscilloscope to the input v_i whilst connect the Channel 2 of the oscillator to the output v_o.
4. When input v_i is sufficiently large, the output v_o will be distorted; that is v_o will not be perfect sinusoidal. Gradually increase the output v_i of the signal generator to just below the point where the waveform of v_o starts to get distorted. Measure the peak-to-peak output voltage $V_{o,p\text{-}p}$ and record the value in Table 7-1. This is the **maximum undistorted output signal**.
5. Use the oscilloscope to measure the peak-to-peak voltage $V_{i,p\text{-}p}$ of the input signal v_i, and record the results in Table 7-1.
6. Compute and record the gain of the amplifier.
7. Compare the phases of the input and output signal and indicate whether they are in phase or 180° out of phase in Table 7-1.
8. Reduce v_i to its smallest value. Repeat the above procedure but change the value of R_R to 5 kΩ, 20 kΩ, and 30 kΩ.

Part B: Operational amplifier as an inverting summer

1. Connect the experimental circuit as shown in Figure 7, where $R_F = R_1 = R_2 = 10$ kΩ, and V_1 and V_2 are 1.5 V each.
2. Adjust the power supply voltage to 12V.
3. Let connection S_1 close, i.e., V_1 is connected to R_1. Then open connection S_2, i.e., V_2 is not connected to R_2.
4. Measure V_1 and V_o, and record the results in Table 7-2.
5. Open S_1 and close S_2. Measure V_2 and V_o, and record the results in Table 7-2.
6. Both S_1 and S_2 are now closed. Measure and record V_o and V_i.
7. With S_1 and S_2 closed, reverse the polarity of V_1. Measure and record V_o and V_i.

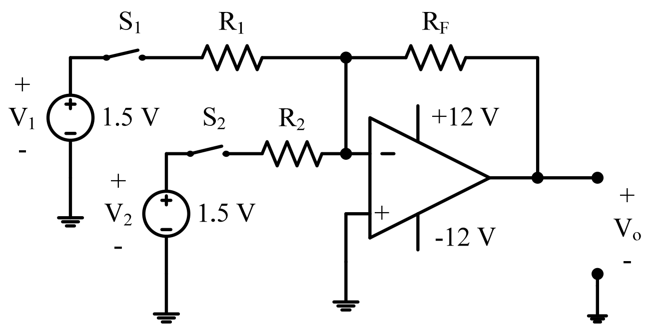


Figure 7: A summing amplifier circuit.

TABLE 7-1: Inverting amplifier

R_F (Ω)	R_R (Ω)		V_{p-p}		Gain		Phase difference
		Measured	$V_{i,p-p}$	$V_{o,p-p}$	R_F/R_R	$V_{o,p-p}/V_{i,p-p}$	
	10 k						
	5 k						
	20 k						
	30 k						

TA's Signature: ________________________

TABLE 7-2: Op amp as a summer

R_F = ____________________ R_1 = ____________________ R_2 = ____________________

Condition		Input Polarity		V_i (V)		V_o (V)
S_1	S_2	V_1	V_2	V_1	V_2	
Close	Open	+	N/A		N/A	
Open	Close	N/A	+	N/A		
Close	Close	+	+			
Close	Close	-	+			

TA's Signature: ________________________

QUESTIONS

1. The two input terminals of an op amp are labeled as

   (a) high and low. (b) positive and negative.

   (c) active and inactive. (d) inverting and non-inverting.

   (e) differential and non-differential.

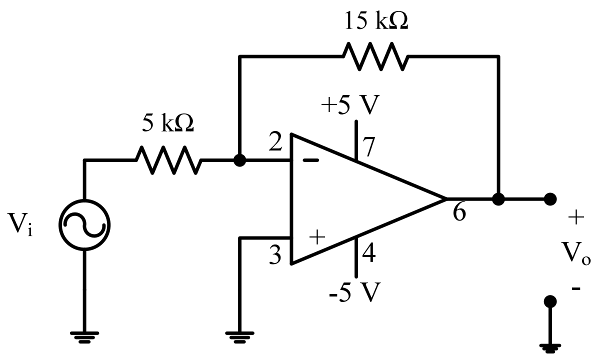


Figure 8: An inverting amplifier

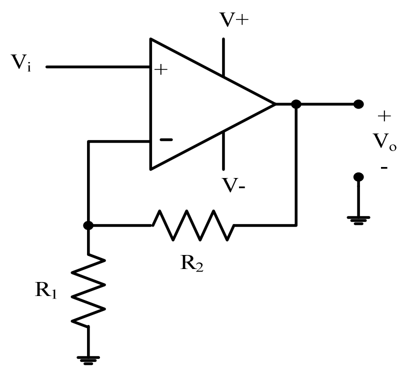


Figure 9: A noninverting amplifier

2. Find the voltage output of the op amp circuit in Figure 8 when $V_i = 40$ mV.

   (a) -40 mV (b) -60 mV (c) -80 mV (d) -100 mV (e) -120 mV

3. From Figure 8, calculate the current through the feedback resistor.

   (a) 4 μA (b) 6 μA (c) 8 μA (d) 10 μA (e) 12 μA

4. Design a noninverting amplifier in Figure 9 with gain 3.5.

   (a) $R_1 = 2$ kΩ $R_2 =$ 10 kΩ (b) $R_1 = 4$ kΩ $R_2 =$ 12 kΩ

   (c) $R_1 = 4$ kΩ $R_2 =$ 10 kΩ (d) $R_1 = 6$ kΩ $R_2 =$ 12 kΩ

   (e) $R_1 = 6$ kΩ $R_2 =$ 10 kΩ

5. From the results in Question 4, find V_o when $V_i = 4$ V.

   (a) 8 V (b) 10 V (c) 12 V (d) 14 V (e) 16 V

6. Design a circuit with an output $V_o = -(3V_1 + 4V_2 + 5V_3)$, where V_1, V_2, and V_3 are the three inputs of the circuit.