1. BASIC OP-AMP CIRCUITS

1.1 OBJECTIVE

1. To design the following basic op-amp circuits and explain the operation of each:

   a. Inverting amplifier
   b. Non-inverting amplifier
   c. Voltage follower

1.2 HARDWARE REQUIRED

S.No	Equipment/ Component name	Specifications/Value	Quantity
1	IC 741	Refer data sheet in appendix	1
2	Cathode Ray Oscilloscope	(0 – 20MHz) 1	1
3	Resistors	1.5K Ω	2
4	Dual Regulated power supply	(0 -30V), 1A	1
5	Function Generator	(0-2) MHz	1

1.3 THEORY

An op-amp is a high gain, direct coupled differential linear amplifier choose response characteristics are externally controlled by negative feedback from the output to input, op-amp has very high input impedance, typically a few mega ohms and low output impedance, less than 100 Ohm.

Op-amps can perform mathematical operations like summation integration, differentiation, logarithm, anti-logarithm, etc., and hence the name operational amplifier op amps are also used as video and audio amplifiers, oscillators and so on, in communication electronics, in instrumentation and control, in medical electronics, etc.

1.3.1 Circuit symbol and op-amp terminals

The circuit schematic of an op-amp is a triangle as shown below in Fig. 1-1 op-amp has two input terminal. The minus input, marked (-) is the inverting input. A signal applied to the minus terminal will be shifted in phase 180^o at the output. The plus input, marked (+) is the non-inverting input. A signal applied to the plus terminal will appear in the same phase at the output as at the input. $\underline{+}V_{CC}$ denotes the positive and negative power supplies. Most op-amps operate with a wide range of supply voltages. A dual power supply of $\underline{+}15V$ is quite common in practical op-amp circuits. The use of the positive and negative supply voltages allows the output of the op-amp to swing in both positive and negative directions.

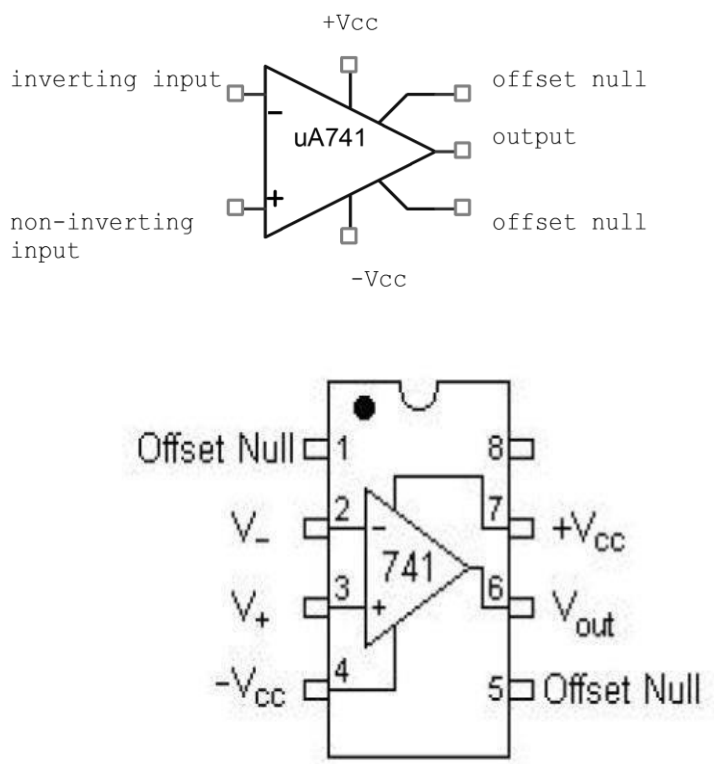


Fig-1-1 op-amp circuit symbol

1.3.2 Op amp internal circuit

Commercial integrated circuit OP-amps usually consists of your cascaded blocks as shown in figure 1-2shown below.

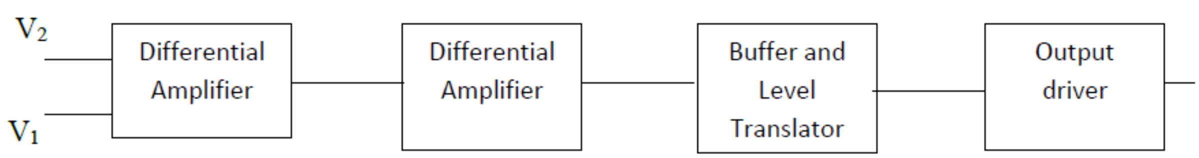


Fig 1-2Internal block schematic op-amp

The first two stages are cascaded difference amplifier used to provide high gain. The third stage is a buffer and the last stage is the output driver. The buffer is usually an emitter fallowing whose input impedance is very high so that it prevents loading of the high gain stage. The output stage is designed to provide low output impedance. The buffer stage along with the output stage also acts as a level shifter so that output voltage is zero for zero inputs.

In this laboratory experiment, you will learn several basic ways in which an op-amp can be connected using *negative feedback* to *stabilize the gain* and increase the *frequency response*. The extremely high *open-loop gain* of an op-amp creates an unstable situation because a small noise voltage on the input can be amplified to a point where the amplifier in driven out of its linear region. Also unwanted oscillations can occur. In addition, the open-loop gain parameter of an op-amp can vary greatly from one device to the next. Negative feedback takes a portion of output and applies it back out of phase with the input, creating an effective reduction in gain. This *closed-loop gain* is usually much less than the open-loop gain and independent of it.

1.3.3 Closed – loop voltage gain, A_{CL}

The closed-loop voltage gain is the voltage gain of an op-amp with external feedback. The amplifier configuration consists of the op-amp and an external negative feedback circuit that connects the output to the inverting input. The closed loop voltage gain is determined by the external component values and can be precisely controlled by them.

1.3.4 Non-inverting amplifier

An op-amp connected in a closed-loop configuration as a non-inverting amplifier with a controlled amount of voltage gain is shown in Fig 1-3.

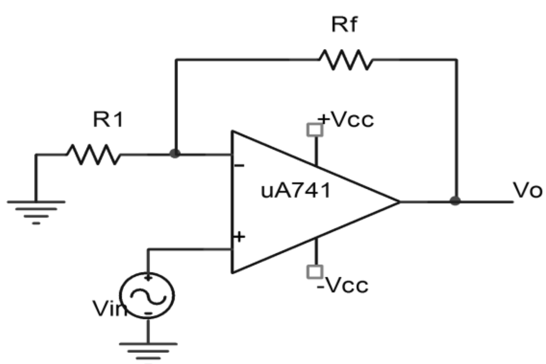


Fig. 1-3 Non-inverting amplifier configuration of op-amp

The input signal is applied to the noninverting (+) input. The output is applied back to the inverting(-) input through the feedback circuit (closed loop) formed by the input resistor R_1 and the feedback resistor R_f. This creates negative feedback as follows. Resistors R_1 and R_f form a voltage-divider circuit, which reduces V_O and connects the reduced voltage V_f to the inverting input. The feedback is expressed as :

$$V_f = \left(\frac{R_1}{R_1 + R_f}\right) V_0$$

The difference of the input voltage, V_{in} and the feedback voltage, $V_f$is the differential input of the op-amp. This differential voltage is amplified by the gain of the op-amp and produces an output voltage expressed as

$$V_0 = (1 + \frac{R_f}{R_1})\ V_{in}$$

The closed-loop gain of the non-inverting amplifier is, thus

$$A_{CL(NI)} = (1 + \frac{R_f}{R_1})$$

Notice that the closed loop gain is

- independent of open-loop gain of op-amp
- set by selecting values of R_1 and R_f

An expression for the input impedance of a non-inverting amplifier can be written as

$$Z_{in(NI)} = (1+A_{OL}\beta)Z_{in}$$

Where A_{OL} = open-loop voltage gain of op-amp

Z_{in} = internal input impedance of op-amp (without feedback)

β = attenuation of the feedback circuit

$$=\frac{V_f}{V_0} = \left(\frac{R_1}{R_1+R_f}\right)$$

Above equation shows that the input impedance of the non-inverting amplifier configuration with negative feedback is much greater than the internal output impedance of the op-amp itself.

The output impedance of a Non-Inverting amplifier can be written as

$$Z_{O(NI)} = \frac{Z_O}{1 + A_{OL}\beta}$$

This equation shows that the output impedance of non-inverting amplifier is much less than the internal output impedance, Z_o of the op-amp.

1.3.5 Voltage follower

The voltage follower configuration is a special case of the non-inverting amplifier where all the output voltage is feedback to the inverting input by straight connection, as shown in fig. 1.4

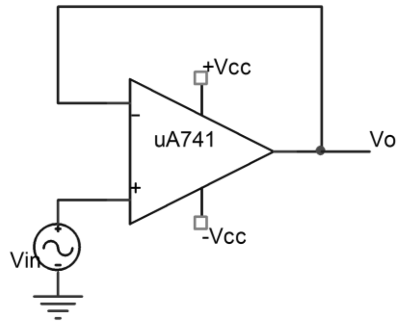


Fig. 1.4 Voltage follower configuration of op-amp

As you can see, the straight feedback connection has a voltage gain of (which means there is no gain).

$$A_{CL\,(VF)} = 1$$

The most important features of the voltage follower configuration are its very high input impedance and its very low output impedance. These features make it a nearly ideal buffer amplifier for interfacing high-impedance sources and low-impedance loads.

$$Z_{IN(VF)} = (1+A_{OL})Z_{in}$$

$$Z_{O(VF)} = \frac{Z_O}{1 + A_{OL}}$$

As you can see, the voltage follower input impedance is greater for a given A_{OL} and Z_{in} than for the non-inverting amplifier. Also, its output impedance is much smaller.

1.3.6. Inverting amplifier

An op-amp connected as an inverting amplifier with a controlled amount of voltage gain is shown in fig. 1.5

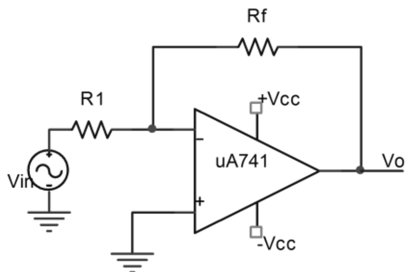


Fig.**1.5** inverting amplifier

The input signal is applied through a series input resistor R_1 to the inverting input. Also, the output is fed back through R_f to the same input. The non-inverting input is grounded. An expression for the output voltage of the inverting amplifier is written as R_f

$$V_O == -\frac{R_f}{R_1} V_{in}$$

The –ve sign indicates inversion. The closed-loop gain of the inverting amplifier is, thus R_f

$$A_{CL(I)} =-\frac{R_f}{R_1}$$

The input & output impedances of an inverting amplifier are

$$Z_{in(I)} = R_1$$

$$Z_{O(I)} =\frac{Z_O}{1+A_{OL}\beta}$$

The output impedance of both the non-inverting and inverting amplifier configurations is very low; in fact, it is almost zero in practical cases. Because of this near zero output impedance, any load impedance connected to the op-amp output can vary greatly and not change the output voltage at all.

1.3.7. Design Constraints

• The output signal is limited by the IC's power sources: the output signal cannot be greater than +15V.

1.5 EXPERIMENT

(1) Non-Inverting amplifier

1.1 Design a non-inverting amplifier for the gain of 10. Let R_1=1.5k Assemble the circuit.

1.2 Feed sinusoidal input of amplitude 1V and frequency 1KHz

1.3 Observe the input voltage and output voltage on a CRO. Tabulate the reading in Table

(2) Voltage follower

2.1 Assemble a voltage follower circuit.

2.2 Feed sinusoidal input of amplitude 10V and frequency 1KHz.

2.3 Observe the input and output voltages on a CRO. Tabulate the readings in Table.

(3) Inverting amplifier

3.1 Design an inverting amplifier for the gain of 10. Let R_1=1.5kΩ. Assemble the circuit.

3.2 Feed sinusoidal input of amplitude 1V and frequency 1KHz.

3.3 Observe the input and output voltages on a CRO. Tabulate the readings in Table

op-amp configuration / circuit	**Input signal**		**Output signal**		**Voltage gain**	
	Amplitude	**Frequency**	**Amplitude**	**Frequency**	**Designed value**	**Observed value**
Non-inverting amplifier						
Voltage follower						
Inverting amplifier						

1.4 PRE LAB QUESTIONS

1. Identify each of the op-amp configurations

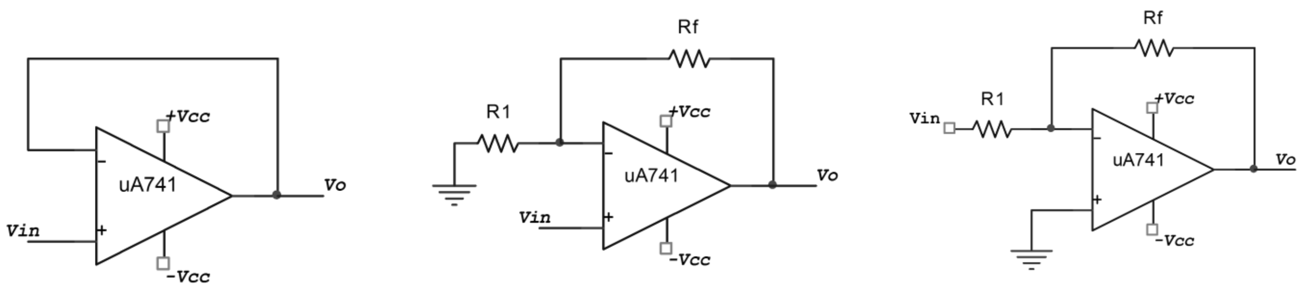


Fig.(a)

2. A non-inverting amplifier has R_1 of 2KΩ & R_f of 200KΩ. Determine V_f and β (Feedback voltage and feedback fraction), if V_O = 5V

3. For the amplifier in Fig.(b) determine the following: (a) $A_{CL(NI)}$ (b) V_O (c) V_f

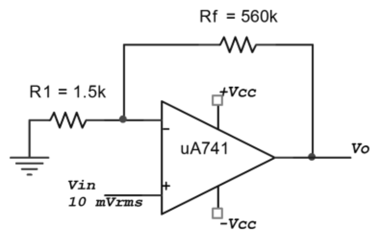


Fig.(b)

4. An inverting amplifier with gain 1 have different input voltage: 1.2v,3.2v and 4.2v. Find the output voltage?
5. Give an expression for output voltage of non-inverting summing amplifier with five input voltage?
6. An inverting scaling amplifier has three input voltages V_a, V_b and V_c. Find it output voltage?
7. 3v, 5v and 7v are the three input voltage applied to the inverting input terminal of averaging amplifier. Determine the output voltage?
8. If the gain of a non-inverting averaging amplifier is one, determine the input voltages if the output voltage, if the output voltage is 3v?

1.5. POST LAB QUESTIONS

1. What is the relationship, if any, between the polarity of the output and input voltages in your experimental op-amp? Refer to your data.
2. Find the value of R_f that will produce closed-loop gain of 300 in each amplifier in fig.(i)

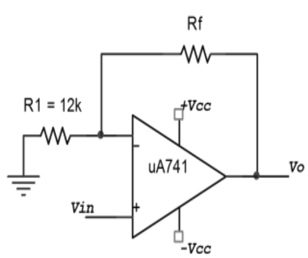
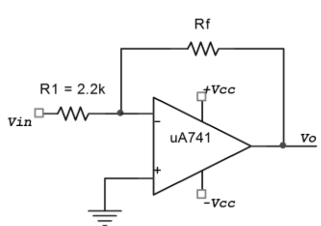


Fig.(i)

3. Determine the approximate values for each of the following quantities in Fig.(j).



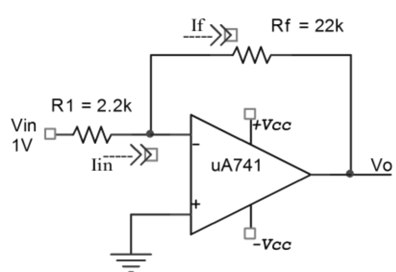


Fig.(j)

5. If a signal voltage of 10mV is applied to each amplifier in Fig.(k), what are the output voltages?

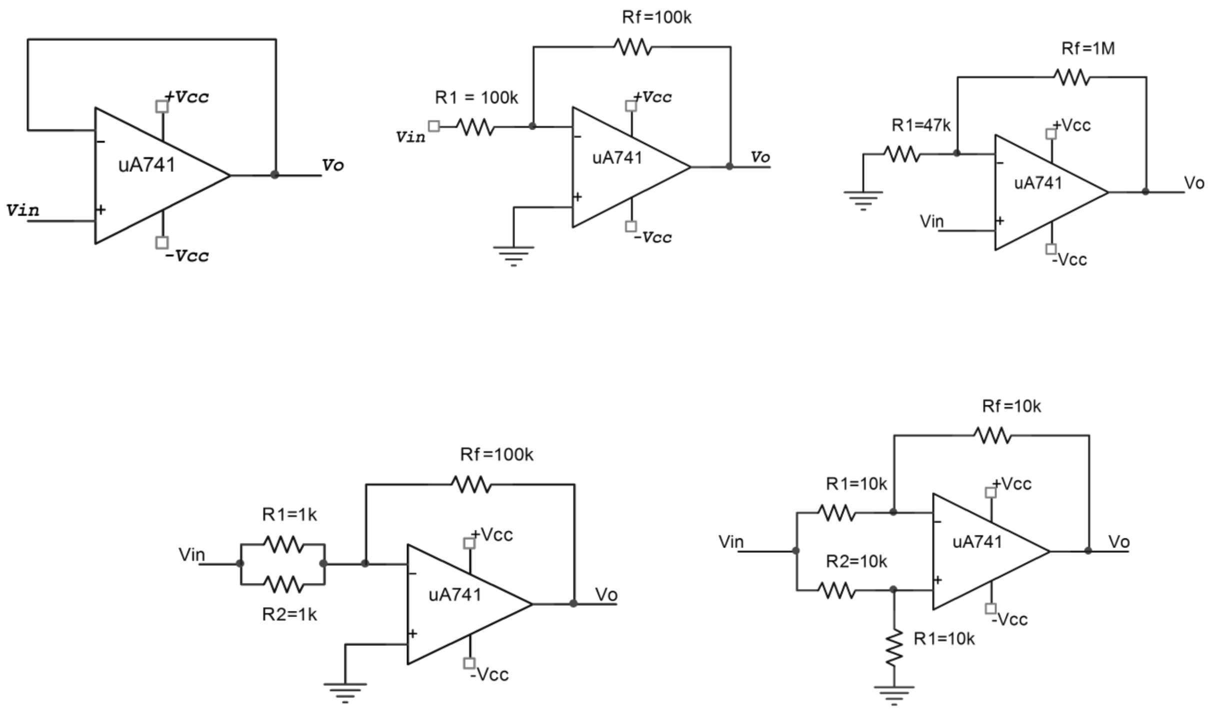
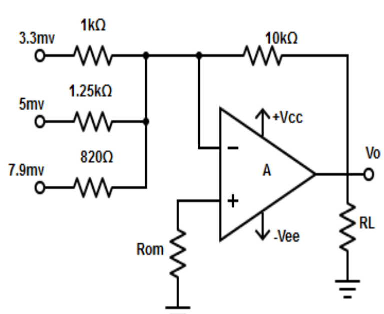


Fig. (k)

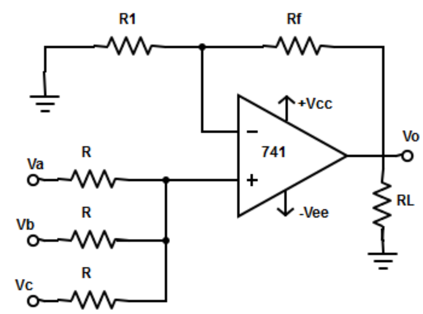
6. The following circuit represents an inverting scaling amplifier. Compute the value of R_{oM} and V_O?



7. If the gain of a non-inverting averaging amplifier is one, determine the input voltages if the output voltage, if the output voltage is 3v?

8. Calculate the output voltage, when a voltage of 12mv is applied to the non-inverting terminal and 7mv is applied to inverting terminal of a subtractor.

9. In the circuit shown, supply voltage = ±15v, V_a= +3v , V_b= -4v , V_c= +5v, R= R_1= 1kΩ and R_F= 2kΩ. 741 op-amp has A= 2×10^5 and R_1= 10kΩ. Determine the output voltage internal resistance of the circuit?



10. Calculate the output voltage for the summing amplifier given below, where R=2kΩ and RL =10kΩ