(For Counsellor's use only)

Grade . . . . Name . . . .

Evaluated by . . . . Enrolment Number . . . . .

EXPERIMENT 4

STUDY OF OPAMP AS SUMMING AND INVERTING AMPLIFIER

4.1 INTRODUCTION

Given below is a list of some systems and equipment tbat I hope you have seen **and/or** used in your everyday life.

(a) A radio set
(b) A doctor's stethescope
(c) An electrocardiography **(ECG)** machine
(d) A microscope
(e) A public address system.

I am sure you will be surprised if I ask you what is common in **all the** above equipment? The answer is "Some sort of an amplifier". In a radio set, we have an amplifier which amplifies very **small** electrical signals (of the order of a few millivolts). **These signals are** received from distant radio stations. Not only that, you can even change the **amplification** by turning,tbe volume control. In a **doctor's** stethescope, sound of heartbeat is amplified. In an **ECG,** we have **amplification of small electrical signals** (a few **microvolt) given out by** the **heart. A** microscope **is an optical** instrument **to see** amplified **(magnified) images of very** small, **microscopic objects.** In a public address system, speech is given to the microphone by the person speaking. Speech is **converted** into electrical signals, amplified and fed to the loudspeaker. Thus, in all **above** examples, we have some **type** of amplifier.

Today you shall study a special type of amplifier, to amplify electrical signals, called an Operational Amplifier (Opamp).

Opamps may be treated as multipurpose devices which may be used as amplifiers, oscillators, differentiators, integrators, and can also performother mathematical operationals like addition, subtraction, multiplication etc. (and hence the name Opamp). They are very extensively used in present day electronics ranging from entertainment electronics to medical instrumentation and computers.

In this laboratory, we will carry out some simple experiments on an Opamp illustrating some of its elementary characteristics.

Objectives

After performing this experiment you will be able to use an Opamp as :

* Inverting amplifier.
* Summing amplifier.

4.2. APPARATUS

2 nos. - Variable power supplies of t15 V and -15 V.
2 nos. - Drycells of 1.5 V each.
1 no. - Digital multimeter for both a.c and d.c measurements.
2 nos. - Rheostats, or Potentiometer, Resistance, 10 K ohms each.
1 no. - Half-watt resistance of different values like 4.7 K ohm, 10 K ohm etc.
2 nos. - Switches.
1 no. - Oscilloscope.
1 no. - Opamp IC 741, with socket.

4.3 STUDY MATERIAL

4.3.1 Stages of OPAMP

The opamp is a high gain direct coupled amplifier, has high input impedance and low output impedance. Multiple applications of the opamp are made possible by the external control of the variable feedback employed in it. Feedback means that some or all of the output is connected to one of the inputs. Tbe connection may be simple or it may be through a complicated circuit. Fig.4.1.shows the symbol for an opamp. It has two inputs marked.

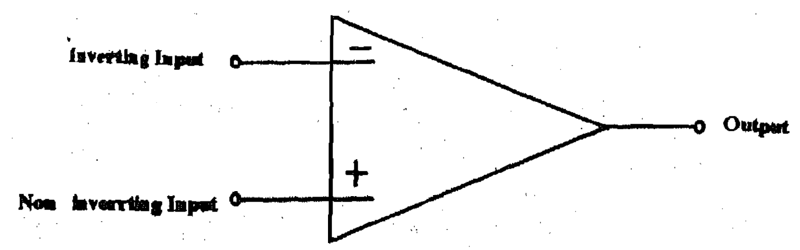

Fig. 4.1

The (-)input is called the "inverting input" The (+) input is called the "non-inverting input". A signal applied to the (-) input will be shifted in phase by 180° at the output. It means that if a -ve pulse is given at inverting input it will appear as a +ve pulse at the output. On the other hand a signal applied to the non-inverting (+) input will appear in the same phase at the output. This is shown in Figs.4.2 and 4.3, for inverting and non-inverting cases, respectively:

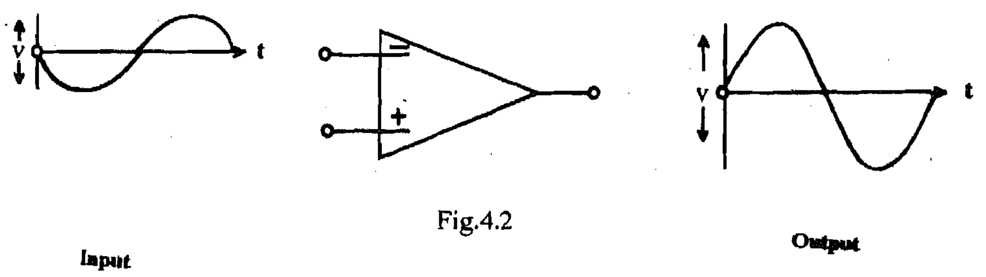

Fig.4.2

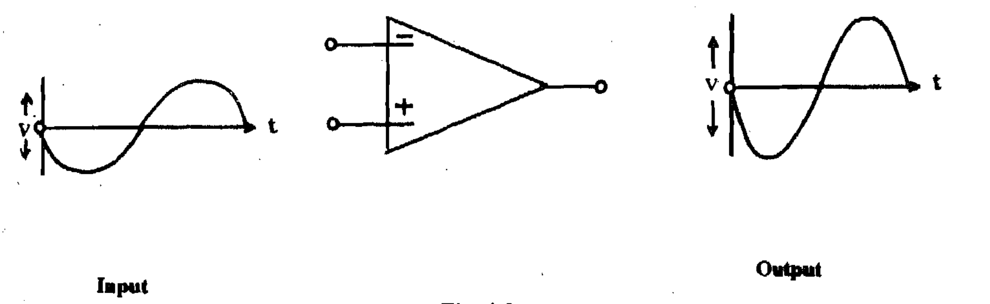

Fig.4.3

Though from the point of using the opamp it is not necessary to go into the details of the inside circuits of the opamp, but from the point of view of learning one may understand its working with reference to the block diagram sbown in Fig.4.4.

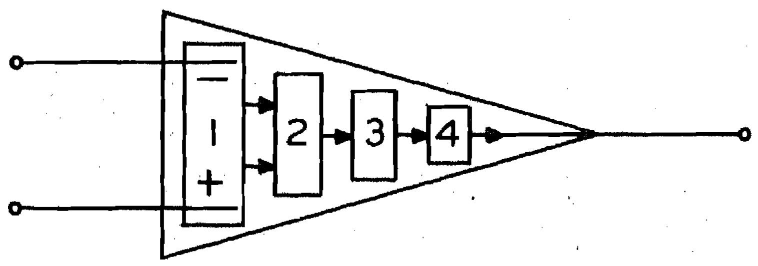

Fig.4.4

STAGE 1

The first stage of an opamp is a difference amplifier.
For most of the parameters like open loopgain, input impedence etc., we refer to the data sheet provided at the end of this experiment.

The difference amplifier amplifies the difference between the two input signals. It is an amplifier that could amplify a small difference in voltage between the inputs, even if the inputs themselves may be at a few volts above ground, For example, if the terminal marked -ve is at +2.01 volt DC and the otber at +2.00 volts DC, the difference 0.01 volt DC alone will be amplified. A well designed difference amplifier is not sensitive to environmental changes. The output signal from a difference amplifier is proportional to the difference between the two input signals. The mode of operation in which two different signals are applied at the inputs to get an output signal proportional to the difference of the two input signals is called "differential input differential output mode". The difference amplifier may also be used in a single ended output mode if one of the two inputs is grounded. When the +ve input (non-inverting) is grounded, a +ve input signal at the inverting input will appear as a -ve signal at the output (see Fig.4.5). This is referred to as "single ended input single ended output inverting mode". Similarly, if the inverting input is grounded and a signal is applied at the noninverting input it will appear at the output without any phase change. The operation will be termed as "single ended input single ended output non-inverting mode".

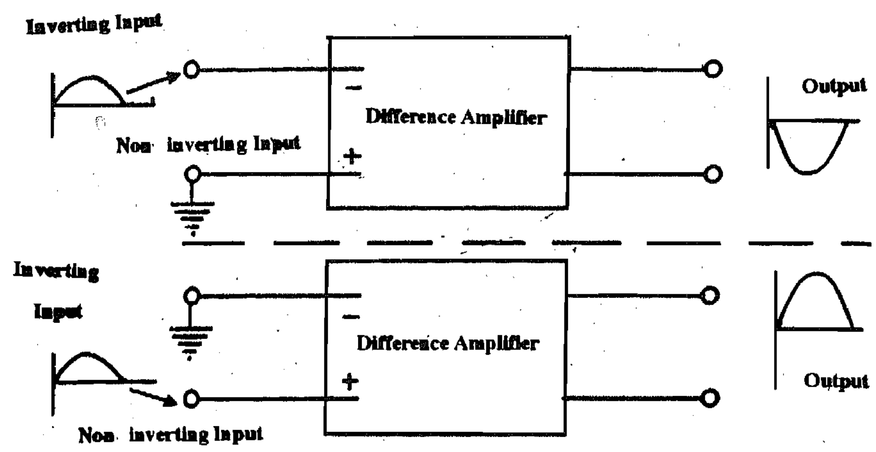

Fig.4.5

If in differential mode operation inputs V_1 and V_2 are applied respectively at the inverting and non-inverting inputs such that $V = -V_1 = V_2$ the differential gain A, is given by

$$A_d = \frac{V_{output}}{V_{input}} = \frac{V_{output}}{V_1-(+V_2)} \quad ...(1)$$

On the other hand under ideal conditions the output of the differential amplifier should be zero if identical signals (equal in amplitude and phase) are applied to the two inputs of the amplifier. In practice, however, this ideal condition of zero output signal is not achieved. One gets some output signal even when identical signals are applied at both inputs. The gain A_c in this condition is given by

$$A_c = \frac{2\,V_{output}}{(V_1+V_2)} \quad ......(2)$$

The ratio A_d/A_c is called the common mode rejection ratio **(CMRR)**. It is an index of the ability of the amplifier to reject signals common to both the inputs. In other words **CMRR** may be looked on as the quality factor of the amplifier to select proper signals out of a mass of noise common to both the inputs. The range of the common mode voltage ever which the difference amplifier works properly is called the common mode voltage range.

***STAGE* 2**

Stage 2 is the second amplifier and may be another difference amplifier with single ended input mode. It provides further gain.

STAGE 3

The third stage in the opamp is the "level shiher". Since each stage in the **opamp** is directly coupled to the next stage, the dc level increases from one stage to the next and ultimately approaches the power supply voltage. The level shifterstage provides compensation for this rise in the dc level.

STAGE 4

The last stage is the output power amplifier. It has high current gain, wide band width and low output impedance.

4.3.2 Use of negative feed back

The output of the **opamp is always** inverted with **respect** to' the **inverting input. If a** small amount of output is fed back (added) along with the inverting input, it will result in a feedback called negative feedback.

Multiple applications of the opamp are made possible by the external control of the negative feed back. The basic feedback circuit is shown in **Fig.4.6.a. As** shown, the output is fed back to the invertinginput through a resistance R_f. This provides **negative feed** back. **Suppose a** signal is applied at the inverting input as in Fig.4.6.a.

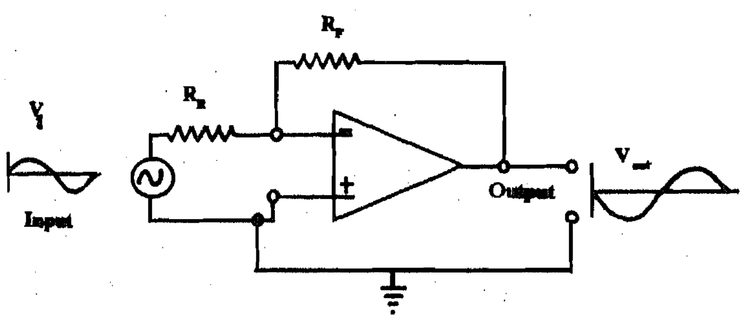

Fig.4.6.a

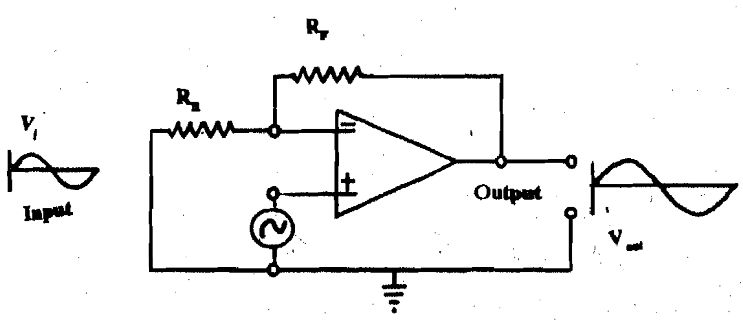

Fig.4.6.b

The output will be an amplified and inverted signal. Apart of this output signal **which** is 180° out of phase with the input is **fedback** at the inverting input through resistance R_F and **hence** negative feed back takes **place.** It is also possible to use the opamp as a non-inverting amplifier by applying signal to the (+) input (non-inverting), as shown in Fig.4.6.b. It may, however, be noted that the feed back network (resistance R_r) is still connected to the inverting input. **From** the detailed analysis which is beyond the scope of the present discussion it can be shown that for the arrangement of **Fig.4.6.a,** (inverting amplifier) the output voltage V_{output} is given **by**

$$V_{output} = (-) \frac{R_F}{R_R} * V_{input} \quad ....(4)$$

here V_{input} **is** the input voltage and the -ve sign represents the phase change of 180°

For the non-inverting amplifier circuit of fig. **4.6.b** the total output voltage V_{output} is given by

$$V_{output} = + \left(1 + \frac{R_F}{R_R}\right) * V_{input} \quad ....(5)$$

the **+ve** sign in the above equation indicates no phase change. **As** such the gains for the **inverting and** the non - inverting amplifier circuits are respectively G_{inv} and $G_{NON-INV}$ is given **by**

$$G_{inv} = (-) \frac{R_F}{R_R} \quad ....(6)$$

$$G_{non-inv} = 1 + \frac{R_F}{R_R} \quad ......(7)$$

It **may be** noted that apart from the ph ase term (-ve **or+ve)** the gain of the inverting and **non-inverting** configurations are different. A careful study of the circuits of **Fig.4.6.a** and Fig.4.6.b **for** inverting and non-inverting amplifier configurations will tell that the two circuits are **identical** except for the interchange of **input** terminals and the ground connections. The expressions **for** the gain differ because in **inverting** configuration resistances R_F and R_R form a voltage division network for both the input signal V_{input} and the signal fed back **from** output **to** the input **through** R_F. In the non-inverting configuration Fig.4.6.b the voltage division takes place only for the feedback signal and not for **the** input signal.

The following **numerical** examples will make **things** more clear.

(a) **Suppose** in Fig.4.6.a
R_R = 2.5 k **ohm** and R_F = 10 k ohm
then the gain is given by

$$G_{inv} = (-) \frac{R_F}{R_R} = (-) \frac{10}{2.5} \quad ....(8)$$

i.e.,the output signal will be amplified by a factor of 4 but will get out of phase by **180° w.r.t.** the input. One may use both **a.c.** and **d.c.** signals at **the** input.

(b) If $R_R = R_F$ **the gain** will be unity, and the signal in the output will be of the same magnitude but in opposite phase.

(c) if $R_R > R_F$, G_{inv} will be < 1.

Do you know why? Write a possible reason.

....

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....

In all above three cases one can see that by controlling the ratio of R, and R, an output signal of increased amplitude, same amplitude or of diminished amplitude may be obtained, but the phase change is always 180^0.

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In a similar way for the non-inverting amplifier configuration if

(a) R_F = 10 K ohm, R, = 2.5 K ohm

$$G_{non\text{-}inv} = 1 + \frac{10}{2.5} = 5 \quad ....(9)$$

(b) for the case

$R_F = R_R$ = 10 K ohm (say)

$G_{non\text{-}inv} = 2$, and for

(c) $R_R > R_F$, $G_{non\text{-}inv}$ will always be greater than unity.

(d) In the extreme case when in non-inverting configuration

R, = 0 and $R_R = \infty$ (see Fig.4.7)

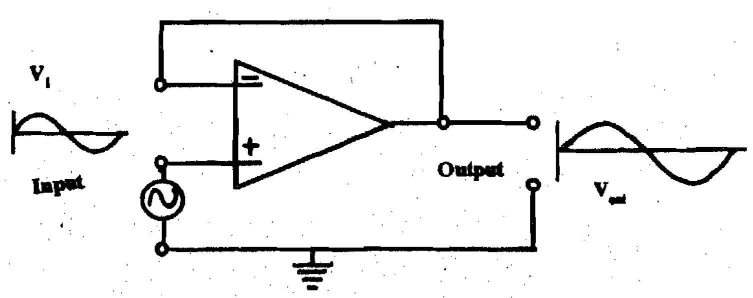
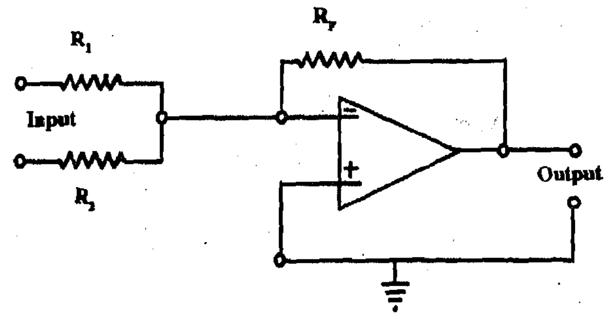


Fig. 4.7

$$G_{non\text{-}inv} = 1 + 0 = 1 \qquad ....(10)$$

so in this configuration the output voltage is equal in amplitude and in phase with the input. This is called the voltage follower circuit.

Mathematical operation of summing may also be performed by the opamp, using the connection shown in Fig.4.8.



. Fig. 4.8

The gain of the above circuit is given by

$$G = \frac{-\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right)}{(V_1 + V_2)} \qquad ......(11)$$

If $R_F = R_1 = R_2$, then the gain $G = -1$ and therefore $V_{output} = -(V_1 + V_2)$ which is the sum of input voltage
signal This will be true even if V^1 and V^2 are of opposite sign, so this is really an algebraic summing circuit.

The output voltage may be made equal to the sum of input voltages V_1 and V_2, each scaled by some multiplying constant, by choosing the values of R_F, R_1 and R_2. For instance $R_F = 2R_1 = 3R_2$.

$$V_{output} = (2V_1 + 3V_2)$$

4.3.3. OPAMP as a Half-Wave rectifier and as an Electronic Ammeter:

Opamp half-wave rectifier circuit is shown in Fig.4.9

This is a modified version of **Fig.4.7,** with diode inserted in the output. When the output is positive, the diode conducts and the circuit acts exactly as Fig.4.7. The gain is **1,** and the positive part of the signal is faithfully given to the output.

When the output is negative the diode does not conduct. The output is effectivcly disconnected from the opamp, and only connected to ground through the resistor.

Thus the circuit acts as an amplifier for only positive signals. It acts as a half-wave rectifier. So does a diode by itself! But **in the** opamp circuit the signal source always faces a **high-**impedance amplifier input. With a simple diode the source **is short-circuited** on **positive** inputs.

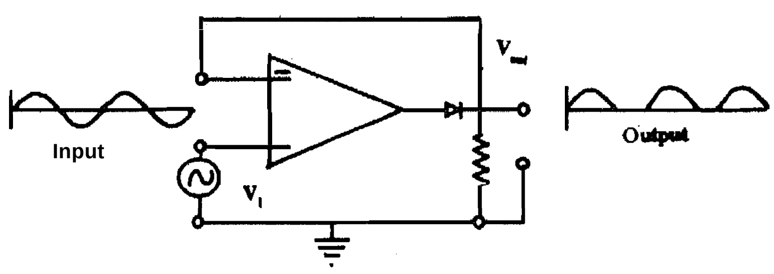


Fig.4.9

In the following circuit diagram **(Fig.4.10)** an opamp works as an electronic ammeter.

The input voltage V_i applied to the left end **of** R causes a current A, to flow in the input circuit. It is this **current** which is to **be** measured. The output voltage of the opamp is V_0.

$$V_0 = - R_F * V_i /R_R = R_F * R_R A_i /R_R = R_f A_i$$

Thus the output voltage is proportional to the **current** A_i and does not depend **on** R_R. This is the action for which the circuit is called an "electronic ammeter".

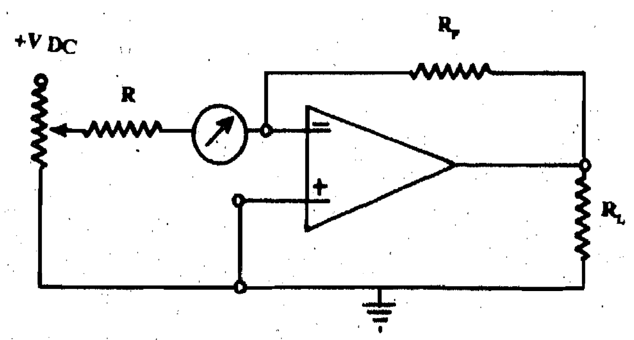


Fig.4.10

4.3.4 OPAMP Specification:

The manufacturer provides a circuit diagram, a basediagram andspecifications for each opamp type including performance graphs. These specifications are also available in opamp manuals. Opamp specifications can be divided into two types.

Data Sheet Specifications give maximum ratings or limits which if exceeded may permanently damage the device. They are,

(Please refer the data sheet attached)

(a) Supply Voltage: In most of the opamp two power supplies such as +15 V and -15 V are required. However some opamps require only a single supply.

(b) Power Dissipation: The maximum power that the opamp IC can dissipate without being damaged is always specified. A typical value is 0.5 watt.

(c) Bandwidth : Roughly, this indicates the maximum frequency at which a signal will experience the other characteristic values.

(d) Input and output impedances: The input and output impedances in normal operation are specified.

4.3.5 Types of OPAMP:

In general opamp can be classified into four types.

a. General purpose type, examples 709, 101, 741, 747 etc.

b. High frequency, high slew rate type. eg. LH 0063

c. High voltage, high power type. eg. LH 0004, LH 0021

d. programmable type or micropower opamp. eg. 4250

Most of the opamps are manufactrued in three types of the base packages having different number of pins in their bases namely (i) Metal can Package (ii) flat packages and (iii) Dual in-line pakage.

4.4 PRECAUTIONS

1. Never exceed V+, V- potentials +9 V. These are the maximum values to avoid electrical damage.

2. Never apply potentials at input more than + 5 V.

4.5. THE EXPERIMENT

To study the inverting amplifier configuration of the opamp 741 and to find the gain of the amplifier for different combinations of the feed back resistances R_F and R_1.

Procedure- 1. Make the connections as shown in Fig.4.11 and follow the steps given below.

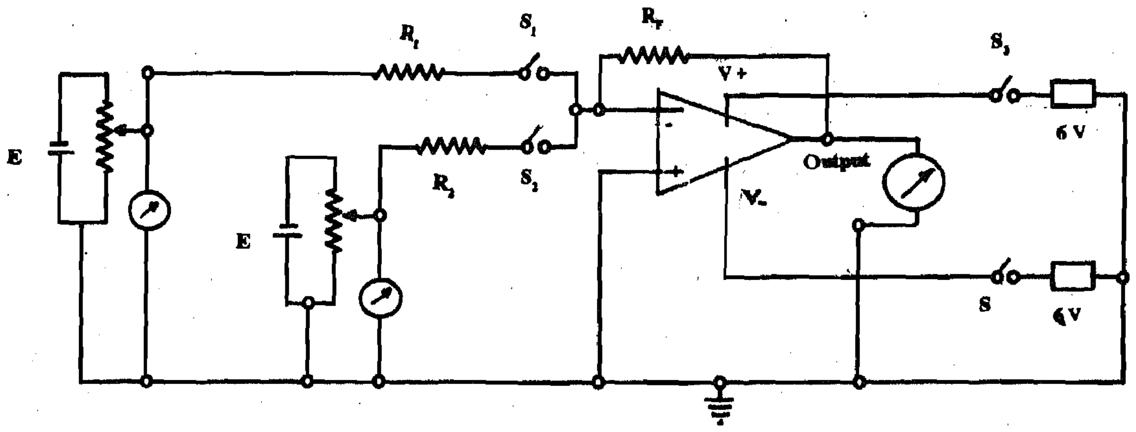


Fig.4.11

Step 1. Keep $R_1 = R_2 = R_F$ = 4.7 K ohm

Step 2. Open switch S_1, S_2, S_3 & S_4.

Step 3. Switch on power and adjust power supplies to +6 V and - 6 V. Switch on S_3 and S_4.

Step 4. Adjust rheostats Rh_1 and Rh_2 so that voltage readings of V_1 and V_2 are zero.

Step 5. Switch on S_1 and S_2 and read V_3. If it gives some value of voltage at the output (V_3) note it. It may be treated as **zero error.**

Step 6. Switch off S_2.

Step 7. By varying rheostat Rh_1 change V_1. This will also change the output voltage V_3. Take reading of V_1 and V_3 for different settings of V_1.

Step 8. Switch off S_1 and switch on S_2 vary rheostat Rh_2 to change V_2. **Take readings** of V_3 for different setting of V_2.

Step 9. Tabulate your data in Table 1.

TABLE - 1

TABLE FOR THE OPAMP INVERTING CONFIGURATION

R_F = 4.7 K ohm

R_R = (R_1 = R_2) = **4.7 K ohm**

SWITCH	SWITCH	INPUT	OUTPUT	GAIN	PHASE
ON	OFF	+0.25			180°
"	"	+0.50			"
"	"	+0.75			"
"	"	+1.00			"
"	"	+1.25			"
"	"	+1.50			"
OFF	ON	-0.25			"
"	"	-0.50			"
"	"	-0.75			"
"	"	-1.00			"
"	"	-1.25			"
"	"	-1.50			"

MEAN GAIN =

Step 10. Switch off S_1 & S_2

Step 11. Set $R_1 = R_2 = 9.5$ K ohm and keep $R_F = 4.7$K ohm.

Step 12. Repeat steps 4 to 10, using Table 2.

TABLE - 2
TABLE FOR THE OPAMP INVERTING CONFIGURATION
R_F = 4.7 K ohm
$R_R = (R_1 = R_2) = 9.5$ K ohm

SWITCH	SWITCH	INPUT	OUTPUT	GAIN	PHASE
ON	OFF	+0.25			180°
"	"	+0.50			"
"	"	+0.75			"
"	"	+1.00			"
"	"	+1.25			"
"	"	+1.50			"
OFF	ON	-0.25			"
"	"	-0.50			"
"	"	-0.75			"
"	"	-1.00			"
"	"	-1.25			"
"	"	-1.50			"

MEAN GAIN =

Step 13. Set $R_1 = R_2$ = 2.5 K ohm

Step 14. Repeat steps 4 to 10, using Table 3.

TABLE - 3
TABLE FOR THE OPAMP INVERTING CONFIGURATION
R_F = 4.7 K ohm
$R_1 = R_2$ = 2.5 K ohm

SWITCH	SWITCH	INPUT	OUTPUT	GAIN	PHASE
ON	OFF	+0.25			1800
"	"	+0.50			"
"	"	+0.75			"
"	"	+1.00			"
"	"	+1.25			"
"	"	+1.50			"
OFF	ON	-0.25			"
"	"	-0.50			"
"	"	-0.75			"
"	"	-1.00			"
"	"	-1.25			"
"	"	-1.50			"

MEAN GAIN =

Procedure-2

Using the same circuit connections you can investigate the summing operation of an opamp.

Step 1. Adjust the power supplies to +6 V and -6 V and turn ON S_3 and S_4.

Step 2. Make $R_F = R_1 = R_2 = 4.7$ K ohm

Step 3. Make $V_1 = V_2 = 1$ Volt, and note the measured values of V_1, V_2 and V_3 in Table 4.

Step 4. Make $R_F = R_1 = 4.7$ K ohm
$R_2 = 9.4$ K ohm

Repeat Step 3.

Step 5. Make $R_F = 4.7$ K ohm
$R_1 = 2.3$ K ohm
$R_2 = 9.4$ K ohm

Repeat Step 3.

TABLE 4

R_1	R_2	R_Q	V_1	V_2	V_3	Expected V_3

Calculations: For each set of R_F and R_R calculate gain using Equation (6), Equation (7) or Equation (11).

Compare the mean gain obtained by doing the experiment with the one calculated.

Result & Discussion: Discuss the variation of gain with R_F and R_R. Also estimate the likely error in your measurements discuss possible reasons for these.

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4.6 CONCLUSIONS

You have found out how to amplify signal voltages and perform the summing operations upon two voltage signals.

(a) Write down 3 situations where you can use this type of amplifier.

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(b) What output will you get if you give zero volt to both inputs?

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(c) Do you find any change in gain when you change supply voltages?

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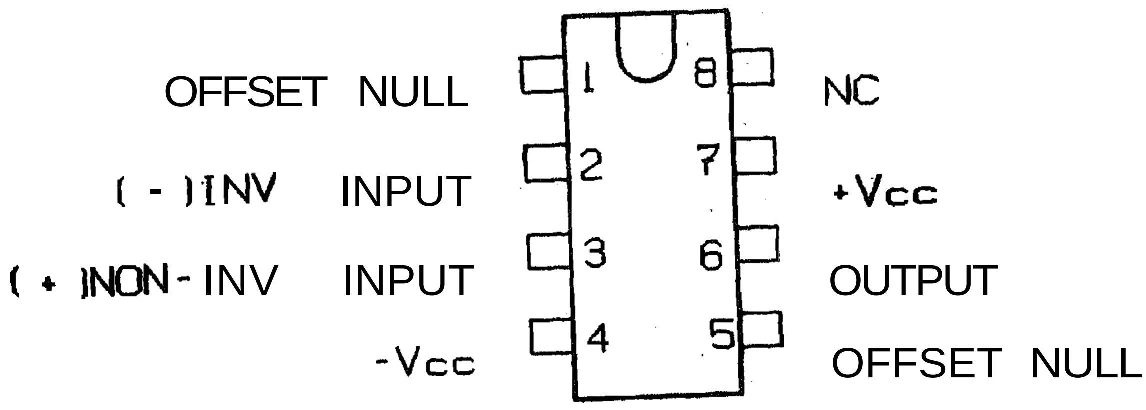

Top View

SUPPLY VOLTAGE + 15 V

POWER DISSIPATION 500 mw

OPEN LOOP GAIN 106

BANDWIDTH 1 KHz

INPUT BIAS CURRENT 1 microampere

INPUT IMPEDANCE 1 megohm

OUTPUT IMPEDANCE 100 Ohm.

INPUT OFFSET VOLTAGE

INPUT BIAS CURRENT

LARGE SIGNAL GAIN

C M M R

SLEW RATE & SETTLING TIME