4) Operational Amplifier & Electronic Instruments.

Syllabus:-

Operational Amplifier:

Functional block diagram of operational amplifier, Ideal & practical values of performance parameter, op-amp application: Inverting & non-inverting amplifier.

Electronic Instruments:

Block diagram of digital multimeter, Function generator, Digital storage oscilloscope (DSO), DC power supply.

Op-amp - Operational Amplifier.

* Op-amp:

It is a electronic device which can be used to construct many electronic circuits such as amplifier, waveform generators, timers, various arithmetic circuit such as adder, substractor, multiplier, log antilog amplifier etc. is called op-amp.

It is basically multistage amplifier which uses a no. of amplifier stages interconnected to each other.

* Op-amp symbol & terminals.

The symbol of op-amp with it's terminal as show in below figure.

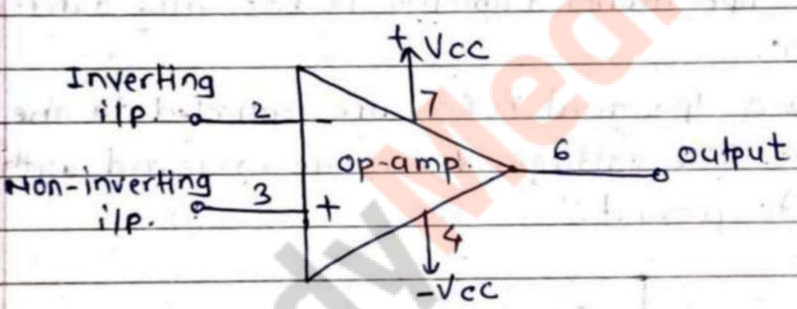
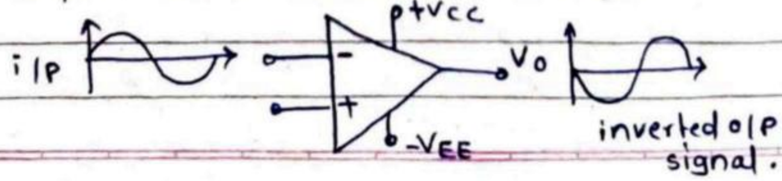


fig:- op-amp symbol & terminals.

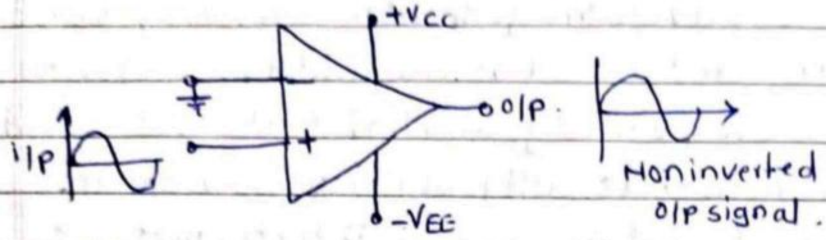
All op-amps have minimum following five terminals,

i) The +ve supply voltage terminal ⇒ $+V_{cc}$
ii) The -ve supply voltage terminal ⇒ $-V_{EE}$
iii) The o/p terminal
iv) The inverting i/p terminal marked as -ve.
v) The non inverting i/p terminal marked as +ve.

- If we connect the i/p signal to inverting i/p terminal then amplified output signal is 180° out of phase with respect to i/p as shown below,



If we connect input signal to non inverting terminal, then the applied output voltage is in phase with input signal as shown below fig.



* Differential Amplifier:- (Ideal Operational Amplifier).

An ideal operation amplifier is expected to amplify the differential signal present between its two input terminal.

As operational amplifier is basically a differential amplifier.

Two i/p signal v_1 & v_2 are connected to the i/p terminals. The voltages v_1 & v_2 are measured with respect to ground.

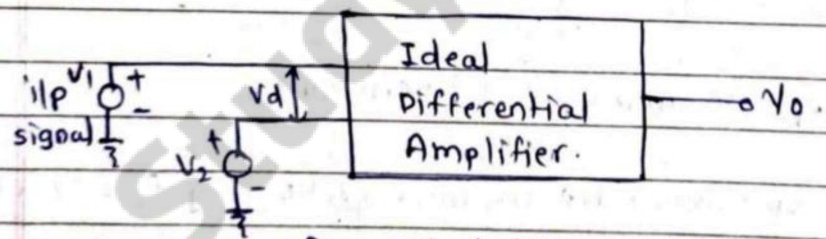


fig:- Ideal differential amplifier.

o/p vtg Vo is proportional to difference betn two i/p signal.

Vo is given by,

$$V_o \propto (v_1 - v_2).$$

$$V_o \propto V_d.$$

* Block Diagram of an op-amp:-

The op-amp is basically differential amplifier i.e. it will amplify the voltage which is differentially present between i/p terminals.

The block diagram of op-amp is as shown in below figure,

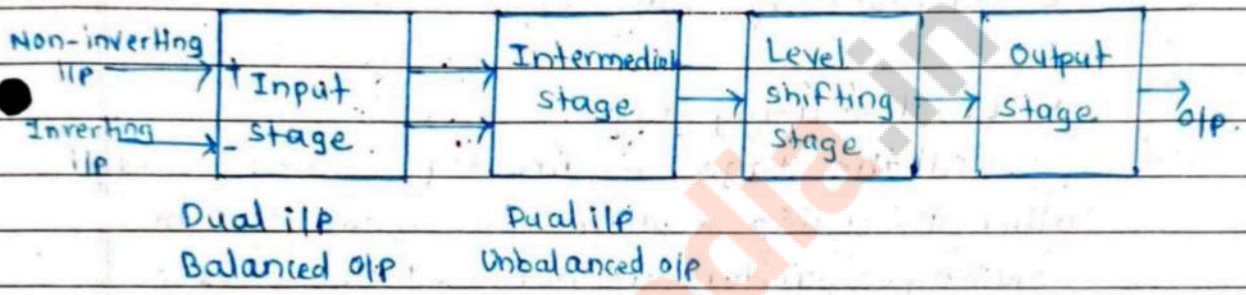


fig:- Block diagram of op-amp

The block diagram consist of four blocks as follows,

1. Input stage:-

The input stage is having dual i/p & balanced o/p differential amplifier.

The two inputs are inverting and non-inverting input terminals.

The i/p ~~te~~ stage requires high i/p impedance & low o/p impedance.

This stage provides most of the voltage gain of op-amp.

The function of a differential amplifier is to amplify the difference between two input signals.

2. Intermediate stage:

The output of the input stage is given to next stage which is intermediate stage.

- This is another differential amplifier with dual I/P, unbalanced output. i.e. single O/P.

- The overall gain requirement of the op-amp is very high. The Input stage alone cannot provide such a high gain.

- The main requirement of intermediate stage is to provide an additional voltage gain.

- Practically the intermediate stage is not a single amplifier but the chain of cascaded amplifiers called multistage amplifier.

3. Level shifting stage.

- All the stages are directly coupled to each other. As opamp amplifies d.c. signal also, the coupling capacitors are not used to casacade stages.

- Hence d.c. level shifts i.e. increases well above the ground.

- Due to increased dc level O/P voltage get distorted. It also limits the maximum O/P vtg swing.

- Hence before the O/P stage, it is necessary to bring such a high d.c. voltage level to zero volts with respect to ground.

- The level shifter stage brings d.c. level down to ground potential, when no signal is applied at I/P terminal.

4. Output stage.

The O/P stage must satisfy the following requirements:

1. Low O/P resistance.
2. Large current sourcing capacity.
3. Large O/P voltage swing.

* Ideal Operational Amplifier (op-amp):-

The ideal operational amplifier is basically an amplifier which amplifies the difference between two input signals. Hence it is called as differential amplifier.

Consider an ideal differential amplifier shown in below fig.

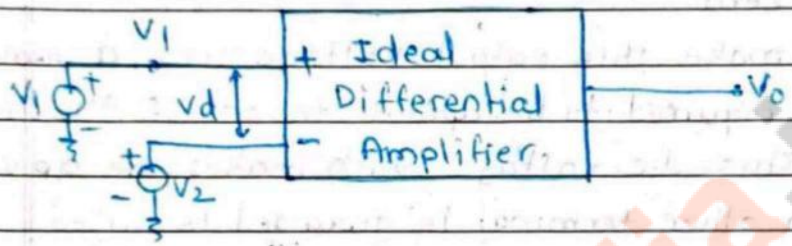


fig:- Ideal differential Amplifier.

V_1 & V_2 are two input signals while V_0 is single output signal.

Each signal is measured with respect to ground.

In an ideal differential amplifier, the o/p vtg V_0 is proportional to difference between two input signals. Hence we can write,

$$V_0 \propto (V_1 - V_2).$$

$$V_0 \propto V_d. \qquad \ldots V_d = V_1 - V_2.$$

* Ideal op-amp characteristics:

a) Open loop voltage gain: (A_v or A_{OL}) = ∞.

The gain of the op-amp in open loop condition is called open loop gain.

It is infinite for an ideal op-amp.

b) Input impedance ($R_{in} = \infty$)

The equivalent resistance measured at any i/p terminal with other terminal grounded is i/p impedance.

It is infinite for an ideal op-amp.

c) Output impedance ($R_0 = 0$).

The equivalent resistance measured between the o/p terminal of the op-amp and the ground.

It is zero for an ideal op-amp.

d) Input offset voltage ($V_{ios} = 0$).

When both the input terminals are grounded there exists a small voltage at o/p through it should be ideally zero.

To make this output voltage zero, a small voltage is required to be applied to one of the i/p terminal. This d.c. voltage which makes the o/p vtg zero, when other terminal is grounded is called input offset voltage.

It is zero for an ideal-opamp.

e) Input Bias current ($I_B = 0$).

For an ideal op-amp, no current flows into the i/p terminal.

Practically small currents flow into two i/p terminals of an op-amp. These are denoted as I_{b1} & I_{b2}.

The input bias current is average value of the magnitudes of two i/p currents I_{b1} & I_{b2} of an-opm. It is denoted as I_b.

∴ input bias current,

$$I_b = \frac{|I_{b1}| + |I_{b2}|}{2}.$$

f) Input offset current: ($I_{ios} = 0$).

The difference in magnitudes of I_{b1} & I_{b2} is called as input offset current.

$$I_{ios} = |I_{b1} - I_{b2}|.$$

It is zero for an ideal op-amp.

g) output offset voltage ($V_{oos} = 0$).

The voltage existing at output when inputs are zero due to input offset voltage & bias current is called output offset voltaage.

It is zero for an ideal op-amp.

h) slew rate ($S = \infty$).

The slew rate is defined as maximum rate of change of output voltage with time. It is denoted as S and expressed in V/μs.

This ensures that changes in the o/p voltage occur simultaneously with the change in i/p vtg.

$$\text{slew rate} = S = \left.\frac{dV_o}{dt}\right|_{\text{maximum}}.$$

It's ideal value is infinite for op-amp.

i) Power supply rejection ratio (PRSS=0).

The power supply rejection ratio of the change in input offset voltage due to change in supply voltage producing it, keeping other power supply voltage constant.

PRSS is measured in mV/V or μV/V.

$$\therefore PRSS = \left.\frac{\Delta V_{ios}}{\Delta V_{cc}}\right|_{\text{constant } V_{EE}}.$$

$$\text{or} \quad PRSS = \left.\frac{\Delta V_{ios}}{\Delta V_{EE}}\right|_{\text{constant } V_{cc}}.$$

j) CMRR:

The ratio of differential gain & common mode gain is defined as CMRR.

$$CMRR\ (\rho) = \frac{A_d}{A_{cm}}.$$

k) Bandwidth (BW) (BW = ∞).

The range of frequency over which the amplifier performance is satisfactory is called it's bandwidth.

It is measured in Hz.

It is infinite for an ideal op-amp.

* Open loop configuration of op-amp.

The following figure shows an op-amp in open loop condition.

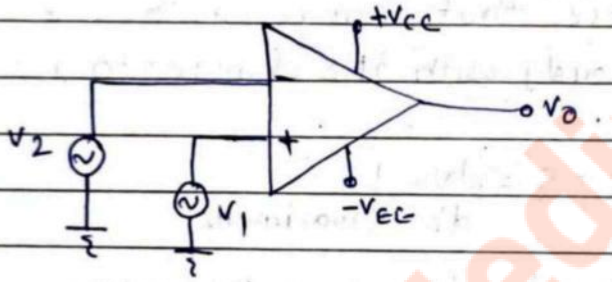


fig:- Open loop operation of an opamp.

- Very small noise voltage present at input are also sufficient to drive the op-amp into saturation due to high open loop gain.

- Such a small i/p voltage range is practically not useful for any linear application. Hence op-amp can not be used in open loop configuration for linear application.

* closed loop configuration of op-amp.

The closed loop mode of op-amp is possible using feedback.

The feedback allows to feed some part of output back to input.

The feedback ~~contro~~ helps to control gain which otherwise drives op-amp into saturation.

The -ve feedback is possible by adding a resistor as shown in below figure,

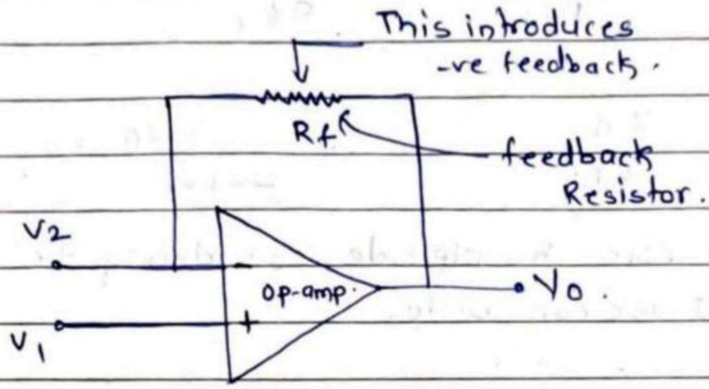


fig: op-amp with -ve feedback.

The gain resulting with feedback is called closed loop gain of op-amp.

* Op-amp as Inverting Amplifier :-

An op-amp which provides a phase shift of 180° between input and output is called inverting amplifier.

The basic circuit diagram of inverting amplifier using op-amp is shown in below fig.

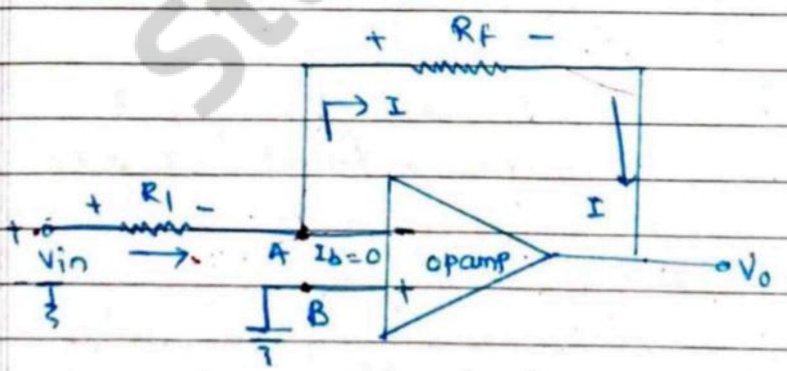


fig: Inverting amplifier.

By the concept of virtual ground two input terminals are always at the same potential.

As node B is grounded, node A is also at ground potential, from the concept of virtual ground,

$V_B = V_A = 0$.

$$\therefore I = \frac{V_{in} - V_A}{R_1} = \frac{V_{in} - V_A}{R_1}$$

$$I = \frac{V_{in}}{R_1} \quad \ldots \text{As } V_A = 0. \quad \text{——(1)}$$

Now from the o/p side, considering dirⁿ of current I we can write,

$$I = \frac{V_A - V_o}{R_f} = \frac{-V_o}{R_f} \quad (V_A = 0)$$

$$I = \frac{-V_o}{R_f} \quad \text{——(2).}$$

equating eqⁿ(1) & (2).

$$\frac{V_{in}}{R_1} = \frac{-V_o}{R_f}.$$

$$\boxed{\therefore A_V = \frac{V_o}{V_{in}} = \frac{-R_f}{R_1}}$$

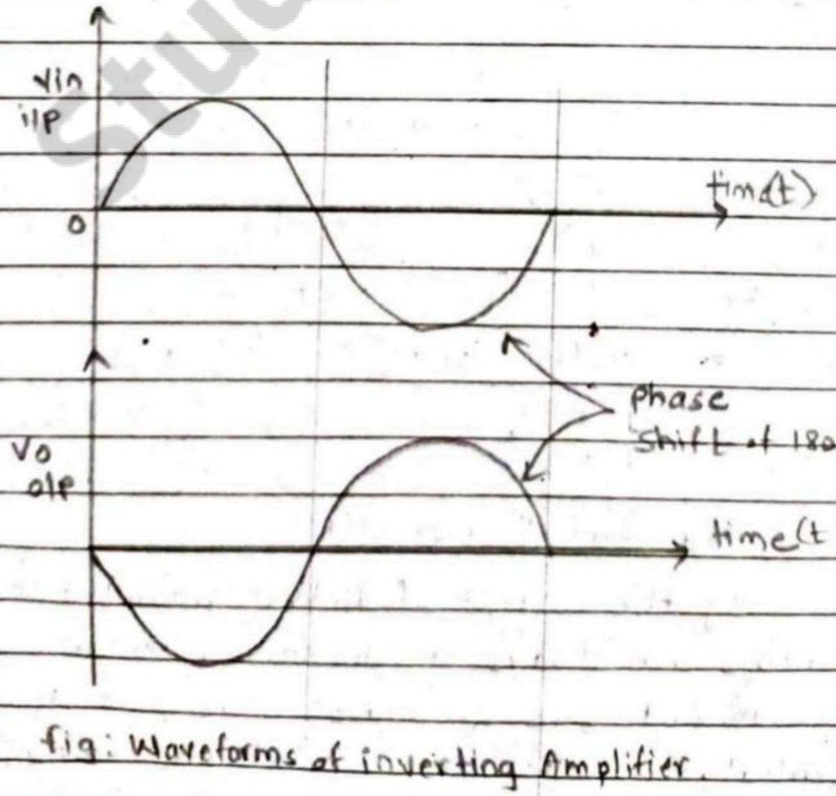


fig: Waveforms of inverting Amplifier.

* Ideal Non inverting Amplifier:

An amplifier which amplifies the input without producing any phase shift between input and output is called non-inverting amplifier.

The block diagram of non-inverting amplifier is as shown below,

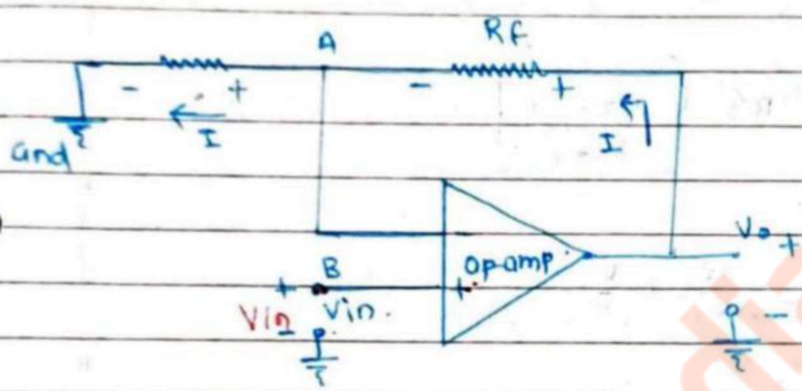


fig: Non-inverting amplifier.

The input is applied to non inverting i/p terminal of the op-amp.

The node B is at potential Vin, hence potential of point A is same as B which is Vin from concept of virtual ground.

$$\therefore V_A = V_B = V_{in}.$$

from o/p side we can write,

$$I = \frac{V_o - V_A}{R_f} = \frac{V_o - V_{in}}{R_f} \qquad \because V_A = V_{in} \qquad \text{---} (1)$$

At inverting terminal,

$$I = \frac{V_A - 0}{R_1} = \frac{V_{in}}{R_1} \qquad \text{---} (2)$$

equating eq^n (1) & (2).

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

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

$$\frac{V_o}{R_f} = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_f}.$$

$$\frac{V_o}{R_f} = V_{in}\left[\frac{1}{R_1} + \frac{1}{R_f}\right]$$

$$\frac{V_o}{V_{in}} = \cancel{R_f}\left[\frac{R_f + R_1}{R_1 \cancel{R_f}}\right]$$

$$\frac{V_o}{V_{in}} = \frac{R_f}{R_1} + \frac{R_1}{R_1}$$

$$\boxed{\therefore A_v = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}}$$

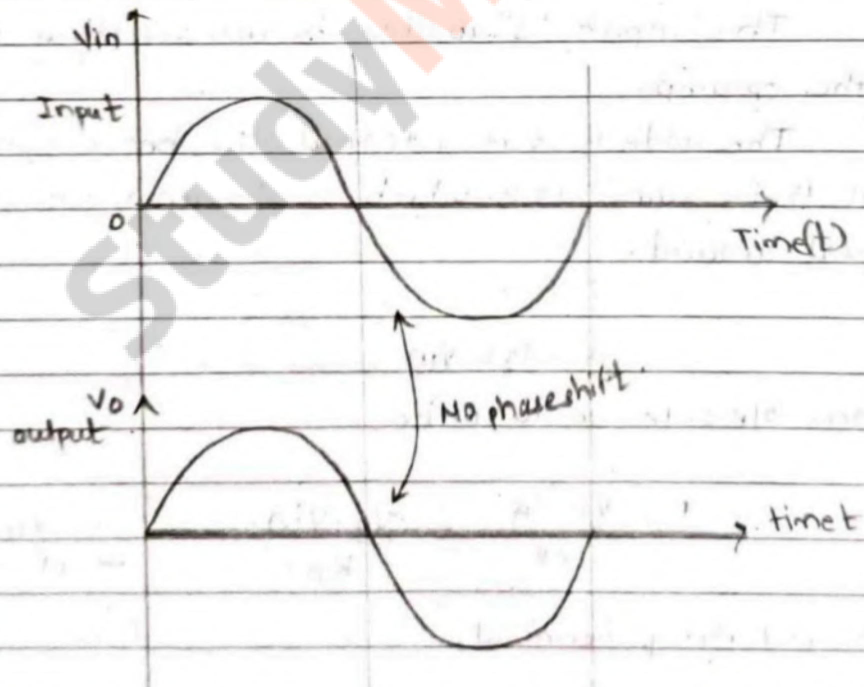


fig: Waveforms of non-inverting amplifier.

* Practical value & ideal value of opam parameter:-

Sr. No.	Performance Parameter	Value for IC 741.	Ideal Value
1.	Input Resistance (R_I)	$2M\Omega$	∞
2.	Output Resistance (R_o)	75Ω	0
3.	Voltage Gain (A_v)	2×10^5	∞
4.	Bandwidth (BW)	1MHz	∞
5.	CMRR	90dB	∞
6.	Slew Rate (S)	0.5 V/µs	∞
7.	Input offset voltage V_{ios}	2mV	0
8.	PSRR	150µV/V	0
9.	Input Bias Current I_B	50nA	0
10.	Input offset current I_{ios}	6nA	0

Problems on Op-amp.

* Formula :-

1. Voltage gain (A_{OL} or A_L).

$$A_{OL} = \frac{V_o}{V_d} \quad \text{.... } V_o \text{ is o/p vtg .}$$

where, $V_d = V_1 - V_2$ .... V_1 & V_2 are i/p vtgs

2. Op-amp as Inverting Amplifier.

$$A_V = \frac{V_o}{V_{in}} = \frac{-R_f}{R_1} .$$

3. Op-amp as Non inverting Amplifier.

$$A_V = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1} .$$

Que.1) An op-amp is used in inverting mode with $R_1 = 1K\Omega$, $R_f = 15K\Omega$, $V_{cc} = \pm 15V$. calculate o/p voltage for following inputs i) $V_{in} = 150mV$ ii) $V_{in} = 2V$.

⟹ Given,

$R_1 = 1K\Omega$, $R_f = 15K\Omega$

i) $V_{in} = 150mV = 150 \times 10^{-3} V$.

$$A_V = \frac{V_o}{V_{in}} = \frac{-R_f}{R_1}$$

$$\frac{V_o}{150mV} = \frac{-15}{1} .$$

$$V_o = -15 \times 150 \times 10^{-3} V .$$

$$\boxed{\begin{aligned} V_o &= -0.225V \\ V_o &= -225mV . \end{aligned}}$$

ii) $V_{in} = 2V$.

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

$$\frac{V_o}{2} = \frac{-15}{1}$$

$$V_o = -15 \times 2$$

$$\boxed{V_o = -30V.}$$

Que. 2) for a noninverting amplifier, calculate Av, if $R_f = 100K\Omega$ & $R_1 = 4.7K\Omega$.

⟹

Given.

$R_f = 100K\Omega$

$R_1 = 4.7K\Omega$

$A_v = ?$

for Noninverting amplifier.

$$A_v = 1 + \frac{R_f}{R_1}$$

$$= 1 + \frac{100}{4.7}$$

$$= \frac{4.7+100}{4.7}$$

$$= \frac{104.7}{\cancel{100}\ 4.7}$$

$$\boxed{\therefore A_v = 22.2766}$$

Que. For a non-inverting amplifier using op-amp if $R_f = 20K\Omega$ and $R_1 = 1K\Omega$, $V_{cc} = \pm 15V$. calculate o/p voltage for $V_{in} = 3V$.

⟹ Given,

$R_f = 20K\Omega$

$R_1 = 1K\Omega$

$V_{in} = 3V$.

for non inverting amplifier,

$$A_v = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}$$

$$= 1 + \frac{20}{1}$$

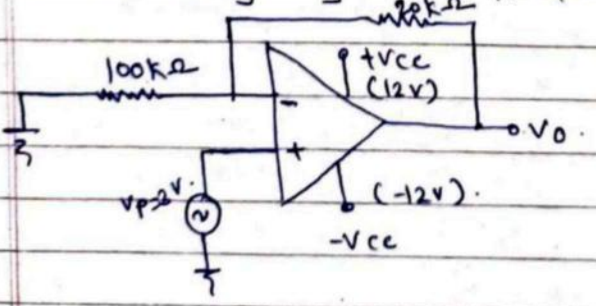
$$\frac{V_o}{V_{in}} = 20.$$

$$V_o = 20 \times V_{in}$$

$$V_o = 20 \times 3$$

$$\boxed{V_{in} = 60V}$$

Que. Calculate o/p voltage 'V_o' of op-amp circuit shown in following fig. Draw i/p & o/p waveforms.



⟹ from figure it is non inverting amplifier.

$R_f = 20K\Omega$

$R_1 = 10K\Omega$

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

$$= \left(1 + \frac{20}{10}\right) 3.$$

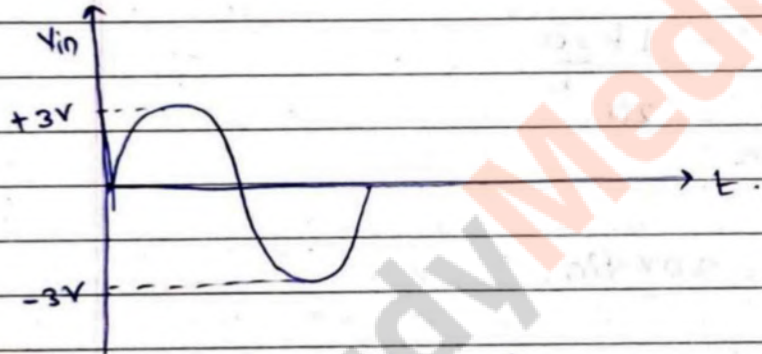
$$= (1+2)3$$

$$\boxed{V_0 = 9V.}$$

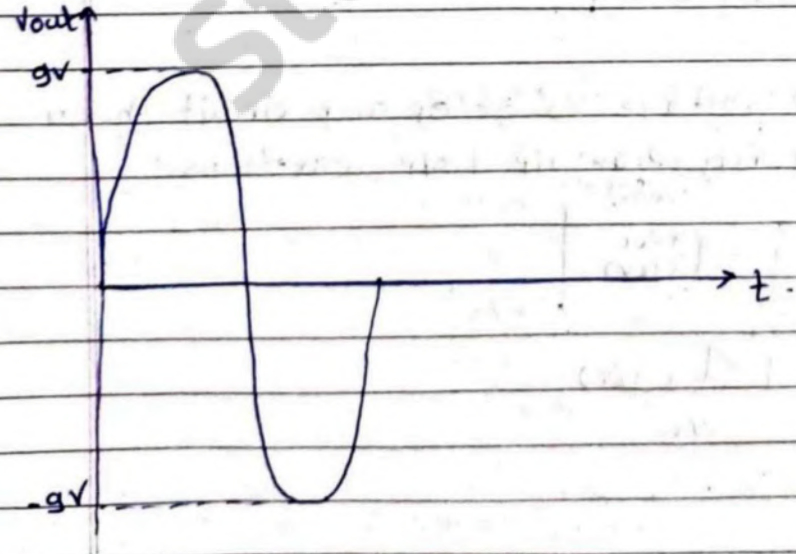
$V_{in} = 3\sin\omega t.$

$V_{out} = 9\sin\omega t.$

$\therefore$ so waveforms will be as follows.



(a) : Input waveform.



(b) : output waveform.

Unit 04: Electronic Instrumentation.

* Principles and block diagram of digital multimeter (DMM):-

The name of the instrument itself suggests that a multimeter is used to ~~convert~~ measure more than one quantities. Usually multimeters measure the following quantities,

1. a.c or d.c current
2. a.c or d.c voltage.
3. Resistance.

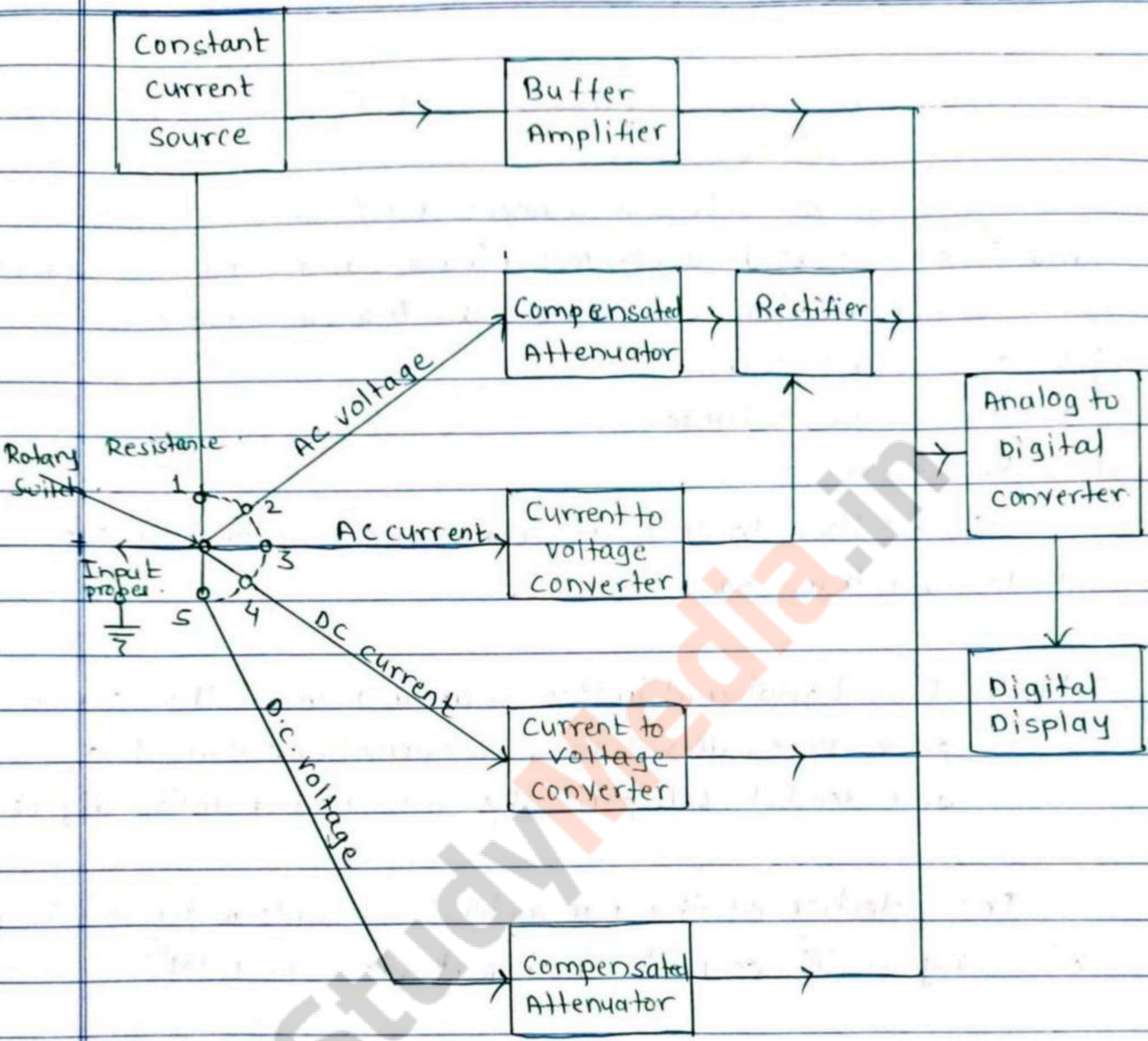
In addition to this, it can also be used to test capacitors, diodes and transistors.

Def^n: The digital multimeter is an instrument that can measure dc voltage, ac voltage, dc current, ac current, resistance and decibels & displays the measured quantity digitally.

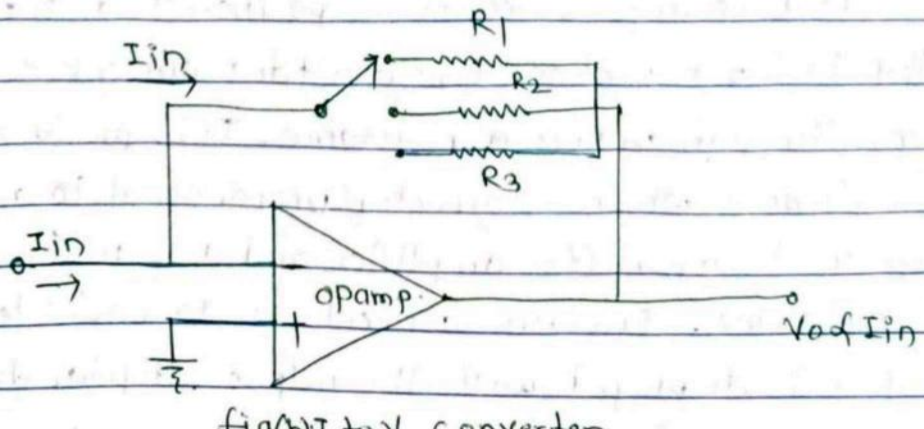
The selection of the parameter is possible with the help of rotary switch connected to input probes of DMM.

1. Resistance Measurement:

The rotary switch is in position '1' and resistance is connected to input probes. The constant current source drives a current through unknown resistance. This produces voltage across resistance which is directly proportional to resistance. It is given to the buffer amplifier and then to analog to digital convertor. The ADC converts it to equivalent digital signal & it is displayed with the help of digital display.



fig(a): Block diagram of digital multimeter.



fig(b): I to V converter

2. A.C. voltage measurement:

The rotary switch is in position '2' and input a.c voltage is applied to probes. If it is above the selected range, it is attenuated with the help of compensated attenuator. It is rectified to produce proportional dc voltage. Then it is given to ADC which displays it in volts.

3. AC current measurement:

The rotary switch is in position '3' and unknown current is applied across input probes. It is converted to proportional voltage using current to voltage converter.

The I-V converter is op-amp circuit as shown in fig(b). The op-amp input current is zero hence I_{in} flows through R_1 is V_o hence o/p voltage $V_o \propto I_{in}$.

The resistances R_1, R_2 & R_3 are used for proper range selection. This voltage is rectified and then given to ADC which displays current in amperes.

4. D.C. Current measurement:

The rotary switch is in position '4' and unknown dc current is applied across input probes. This is converted to proportional voltage with the help of current to voltage converter. This voltage is given to ADC without rectification. As this is proportional to d.c current, ADC displays it in amperes on digital display.

5. D.C. voltage measurement:

The rotary switch is in position '5' and unknown voltage is applied across input probes. It is attenuated & directly given to ADC without rectification. The ADC displays it in volts.

Applications:

1. AC/DC voltage measurement.
2. AC/DC current measurement.
3. Resistance Measurement.
4. Diode & transistor testing.

* Function Generator:-

The function generator is an instrument which generates different types of waveforms.

The most required common waveforms are sine wave, sawtooth wave, triangular wave, square wave etc.

In function generator, the o/p waveforms can be generated at a desired frequency in a range from few hertz to several kilohertz.

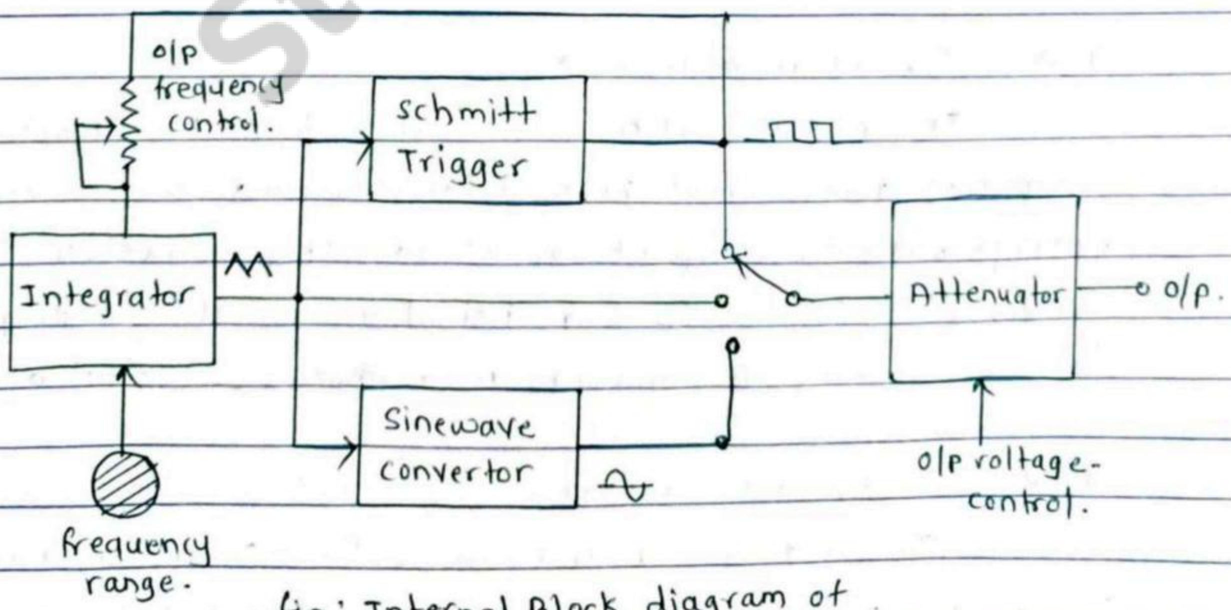


fig: Internal Block diagram of functional Generator.

The internal block diagram of a basic function generator is as shown in figure.

It shows that the output of an integrator is connected to the inputs of schmitt trigger as well as a sine wave generator.

The square wave o/p of schmitt trigger is connected to the inputs of the integrator which produces a triangular wave as its output.

A rotary switch SW is used for selecting one of the functions (square, sine or triangular) to the o/p stage which is generally an attenuator.

The sine wave converter is a wave shaping circuit using diodes which converts the triangular wave to a sine wave. The schmitt trigger converts the triangular wave from the integrator into a square wave.

The attenuator provides the output voltage control in steps as well as fine controls. It provides various ranges of o/p voltage & smooth variation of voltage within selected range.

Applications:

1. In the electronic laboratories for generating various signals
2. On the areas of product design, training & production.
3. In the fields of research & education.

* Digital storage oscilloscope (DSO).

The conventional CRO cannot store waveforms. Therefore a special type of CRO that can store waveform in digital form has been designed. It is known as digital storage oscilloscope.

The digital storage oscilloscope replaces unreliable storage method used in analog storage scopes with the digital storage with the help of memory.

The memory can store data as long as required without degradation. It also allows complex processing of the signal by the high speed digital processing circuits.

The convential cathode ray tube is used in this oscilloscope hence cost is less.

In this DSO, once the waveform is digitised then it can be farther loaded into the computer & can be analysed in detail.

Block diagram:-

The input signal is applied to attenuator & amplifier section.

The attenuated signal is then applied to the vertical amplifier.

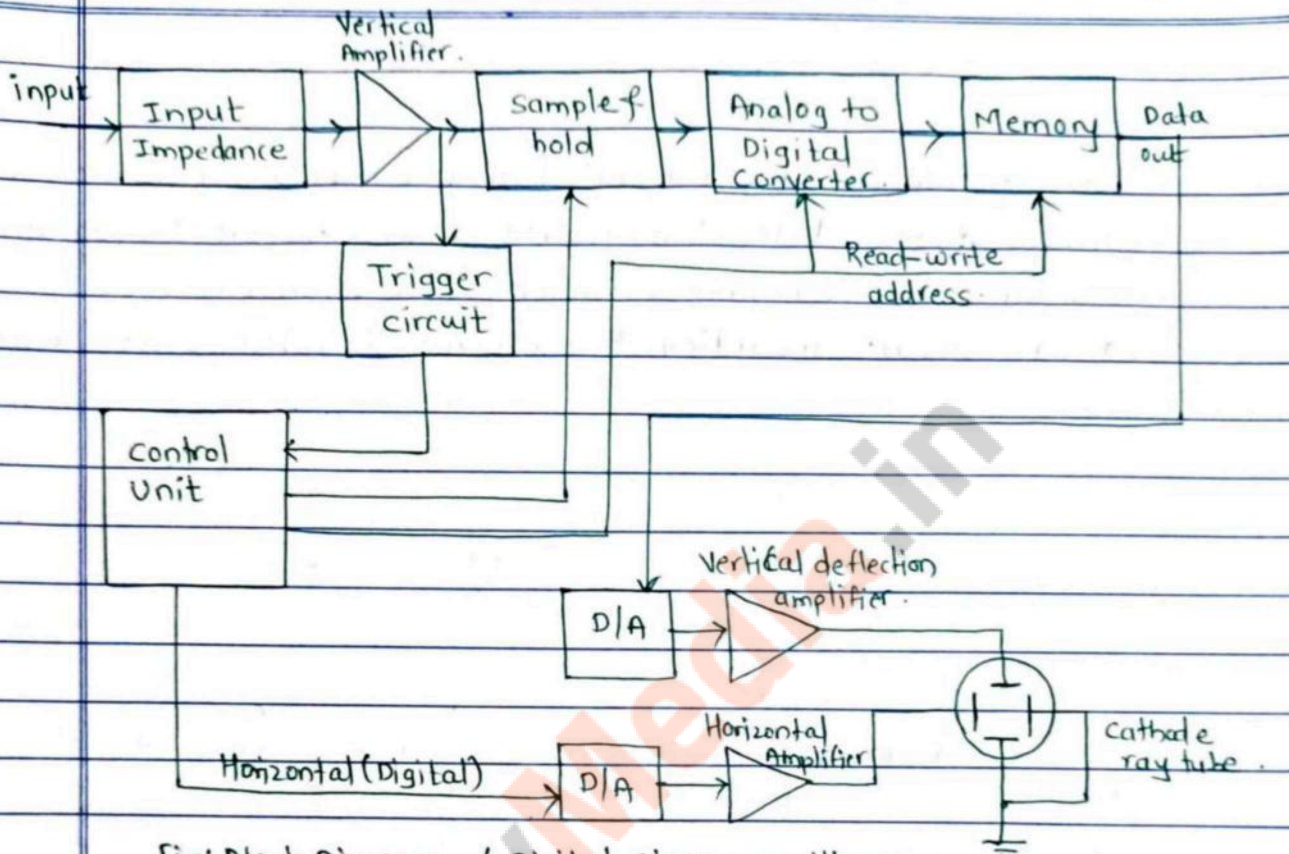


fig: Block Diagram of Digital storage oscilloscope

The vertical input, after passing through vertical amplifier is digitised by an analog to digital converter (A/D converter) to create a data set that is stored in memory.

* AC to DC power supply :-

A typical d.c regulated power supply consist of various stages. Following figure shows the block diagram of a typical d.c. regulated power supply, consisting of various circuits including the nature of voltages at various points.

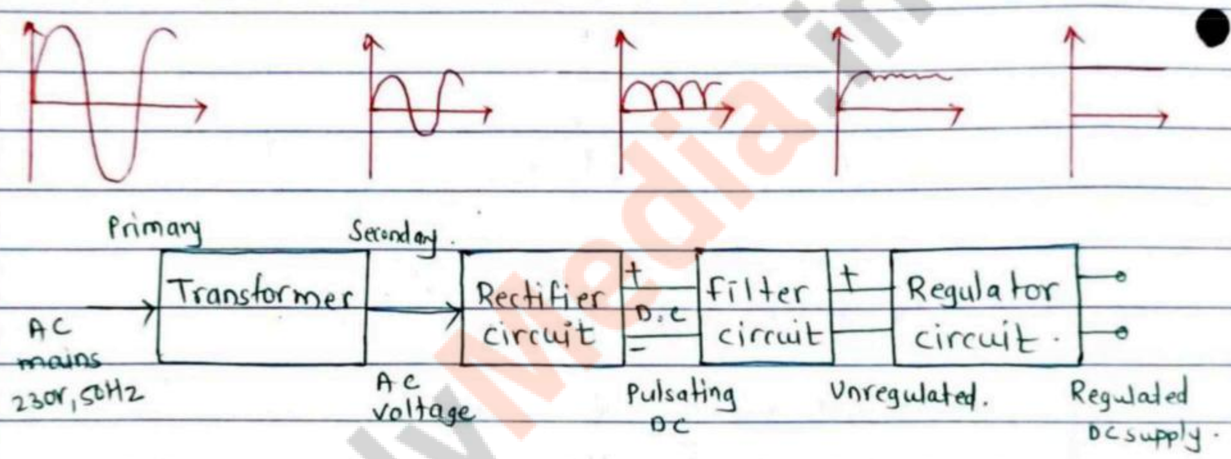


fig:- Block diagram of regulated power supply.

The AC main voltage (230V, 50Hz) is applied to a step down transformer. It reduces the amplitude of ac voltage and applies it to a rectifier.

The rectifier is usually bridge type full wave rectifier. It converts ac voltage into pulsating DC voltage.

The filter circuit is used after rectifier circuit, which reduces the ripple content in the pulsating d.c and tries to make it smoother. still then filter output contains some ripple. This voltage is called unregulated d.c. ~~vo~~ voltage.