# UNIT - II

## Operational Amplifier and Applications

operational amplifier is having so many applications and it can be classified based on characteristics of operational Amplifier.

1. Linear op. Amplifier
2. Non-linear op Amplifier.

Linear
- → Adder
- → subtractor
- → Summing amp
- → Instrumentation amp
- → AC amplifier.

Non- linear
- Sample & hold ckt
- Multipliers & Divider
- V-I & I-V Converter.

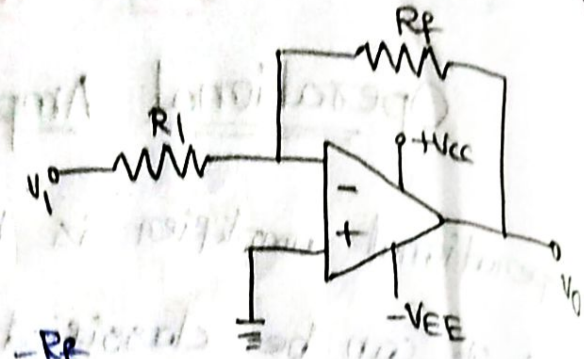
* **Basic Applications of op-Amplifier:-**

we are having 3types of basic op. Amplifier

1. scalar / Inverter
2. Summing Inverter
   - Inverting
   - Non-Inverting
3. Adder - subtractor.

1. Scalar / Inverter ckt :-

Scalar:-



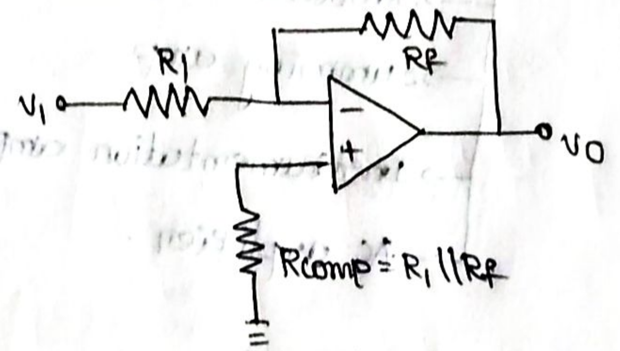

$A_{CL} = -\frac{R_f}{R_1}$

Let us Assume $K = \frac{-R_f}{R_1}$

When Rcomp is added to the non-inverting termi the 'K' is acts as scalar ckt.

i.e $A_{CL} = -K$ $\therefore (R_1 \neq R_f)$

$R_{comp} = R_1 \| R_f$




Inverter:-

if $R_1 = R_f$

$A_{CL} = -\frac{R_f}{R_1}$

$A_{CL} = -1$

$\frac{V_o}{V_i} = -1$

$\boxed{V_O = -V_i}$

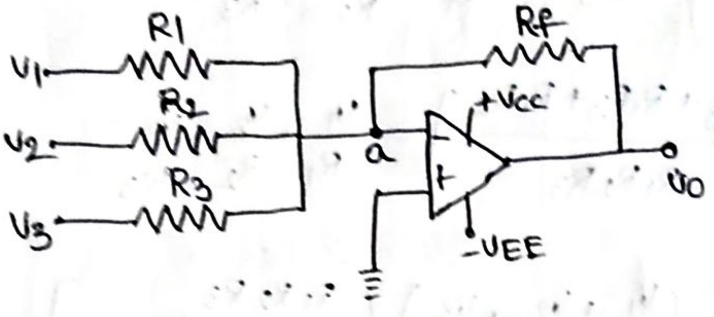
2. Summing Amplifier:-

This circuit is used to design the o/p signal is equals to summation of all the i/p signals.

$V_O = -(V_1 + V_2 + V_3 + \cdots)$ for inverting

$V_O = V_1 + V_2 + V_3 + \cdots$ for Non inverting.

i) Inverting summing amplifier:-




Apply KCL at node 'a'

$$\frac{V_a - V_1}{R_1} + \frac{V_a - V_2}{R_2} + \frac{V_a - V_3}{R_3} = \frac{V_0 - V_a}{R_f}$$

W.K.T => $V_a = 0$ [from virtual ground concept]

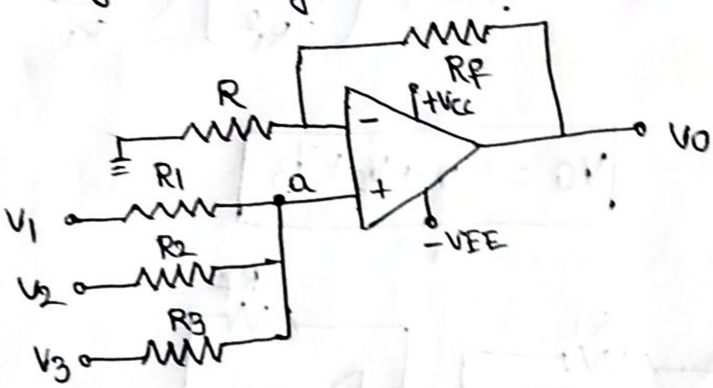
$$-\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right] = \frac{V_0}{R_f}$$

$$\boxed{-R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right] = V_0}$$

Assume $R_1 = R_2 = R_3 = R_f$

$$\therefore \boxed{V_0 = -(V_1 + V_2 + V_3)}$$

ii) Non-inverting summing Amplifier:-




Apply KCL at node 'a'

$$\frac{V_a - V_1}{R_1} + \frac{V_a - V_2}{R_2} + \frac{V_a - V_3}{R_3} = 0$$

$$\frac{V_a}{R_1} - \frac{V_1}{R_1} + \frac{V_a}{R_2} - \frac{V_2}{R_2} + \frac{V_a}{R_3} - \frac{V_3}{R_3} = 0$$

$$V_a\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right] = \frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}$$

$$V_a\left[\frac{R_2R_3+R_1R_3+R_1R_2}{R_1R_2R_3}\right] = \frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}$$

$$V_a = \left(\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right)\left(\frac{R_1R_2R_3}{R_2R_3+R_1R_3+R_1R_2}\right)$$

$$A_{CL} = 1+\frac{R_f}{R}$$

$$\frac{V_0}{V_i} = 1+\frac{R_f}{R}$$

$$V_0 = \left(1+\frac{R_f}{R}\right)V_a \quad [\because V_i = V_a]$$

$$\Rightarrow \boxed{V_0 = \left(1+\frac{R_f}{R}\right)\left[\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right]\left[\frac{R_1R_2R_3}{R_2R_3+R_1R_3+R_1R_2}\right]}$$

if $R_1 = R_2 = R_3$

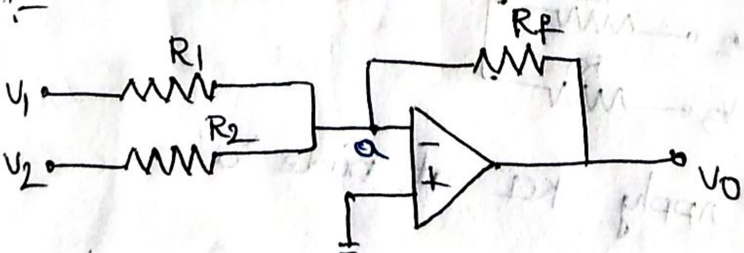
$$R_f = 2R$$

$$V_0 = \left(1+\frac{2\cancel{R}}{\cancel{R}}\right)\left(\frac{R_1^3}{R_1^2+R_1^2+R_1^2}\right)\left[\frac{V_1}{R_1}+\frac{V_2}{R_1}+\frac{V_3}{R_1}\right]$$

$$= (\cancel{1+2})\left(\frac{\cancel{R_1^3}}{\cancel{3}\cancel{R_1^2}}\right)\left(\frac{V_1+V_2+V_3}{\cancel{R_1}}\right)$$

$$\boxed{V_0 = V_1+V_2+V_3}$$

3. Adder :-




$$\frac{V_a-V_1}{R_1}+\frac{V_a-V_2}{R_2} = \frac{V_0-V_a}{R_f}$$

$$V_a = 0$$

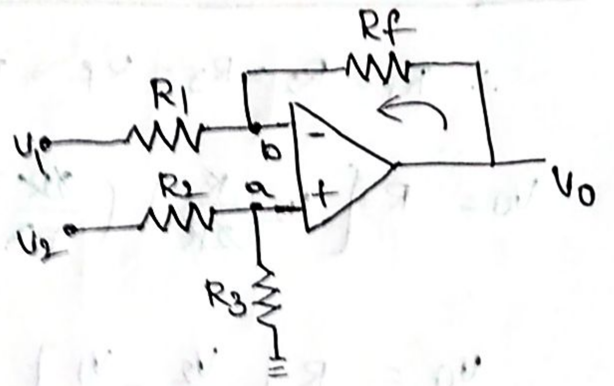
$$-\left[\frac{V_1}{R_1}+\frac{V_2}{R_2}\right]=\frac{V_0}{R_f}$$

$$-R_f\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right]=V_0$$

$$\because R_1=R_2=R_3=R_f$$

$$\therefore V_0=-(V_1+V_2)$$

<u>subtractor:-</u>




Apply KCL at node b

$$\frac{V_b-V_1}{R_1}+\frac{V_b-V_0}{R_f}=0 \quad -①$$

At node 'a'

$$\frac{V_a-V_2}{R_2}+\frac{V_a}{R_3}=0 \quad -②$$

From eq ①

$$\frac{V_b}{R_1}-\frac{V_1}{R_1}+\frac{V_b}{R_f}-\frac{V_0}{R_f}=0$$

$$V_b\left[\frac{1}{R_1}+\frac{1}{R_f}\right]=\frac{V_1}{R_1}+\frac{V_0}{R_f}$$

$$V_b=\left(\frac{V_1}{R_1}+\frac{V_0}{R_f}\right]\left(\frac{R_1R_f}{R_1+R_f}\right) -③$$

From eq ②

$$V_a\left[\frac{1}{R_2}+\frac{1}{R_3}\right)=\frac{V_2}{R_2} \quad -④$$

$$V_a=\frac{V_2}{R_2}\left[\frac{R_2R_3}{R_2+R_3}\right]=V_2\left(\frac{R_3}{R_2+R_3}\right]$$

From eq (3)

$$V_0 = R_f\left[V_b\left[\frac{1}{R_1}+\frac{1}{R_f}\right]-\frac{V_1}{R_1}\right]$$

$\therefore\ V_a = V_b$

$$\boxed{V_0 = R_f\left[V_2\cdot\left(\frac{R_3}{R_2+R_3}\right)\left(\frac{R_1+R_f}{R_1 R_f}\right)-\frac{V_1}{R_1}\right]}$$

$\therefore\ R_1 = R_2 = R_3 = R_f = R.$

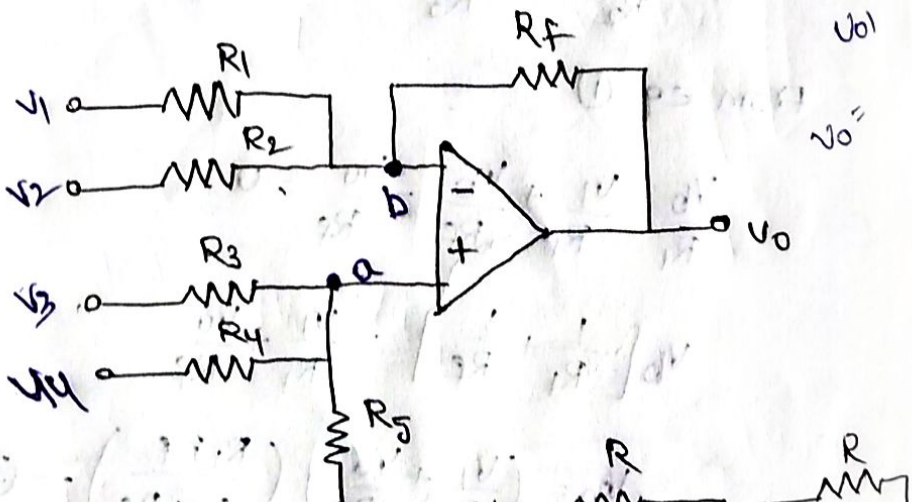
$$V_0 = R\left[V_2\left(\frac{\cancel{R}}{2R}\right)\left(\frac{2\cancel{R}}{R^2}\right)-\frac{V_1}{R}\right]$$

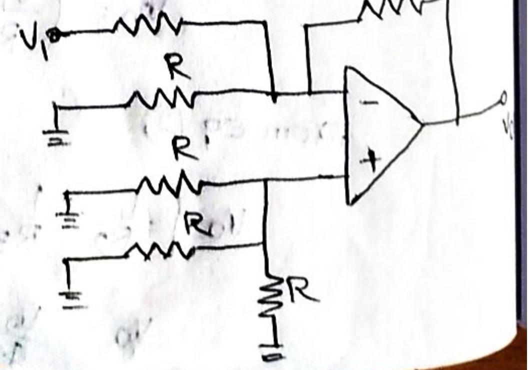
$$V_0 = R\left[\frac{V_2}{R}-\frac{V_1}{R}\right]$$

$$V_0 = \frac{\cancel{R}}{\cancel{R}}(V_2-V_1)$$

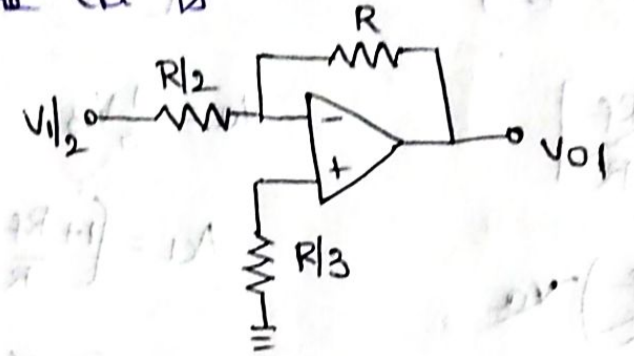
$$\boxed{V_0 = V_2 - V_1}$$

<u>Adder</u>- <u>subtractor</u> <u>using</u> <u>op-amplifier</u>:-



case.i):- when $v_1$ is active and remaining are inactive then the ckt is




$$A_{CL} = \frac{-R_f}{R_1}$$

$$\frac{V_O}{V_i} = -\frac{R_f}{R_1}$$

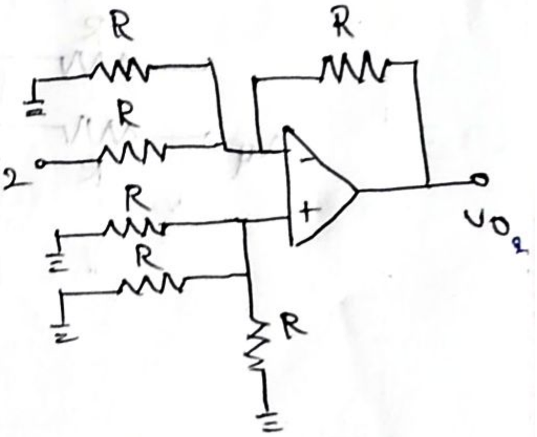
$$V_O = \left[-\frac{R_f}{R_1}\right] V_i \quad \text{—— ①}$$

$$\therefore \quad V_O = -\left[\frac{R}{R/2}\right]\left[\frac{V_1}{2}\right]$$

$$\boxed{V_{O1} = -V_1}$$

case-ii):- when $V_2$ is active.

$$\boxed{V_{O2} = -V_2}$$

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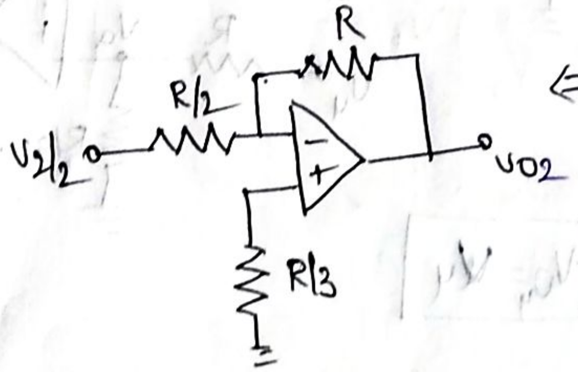
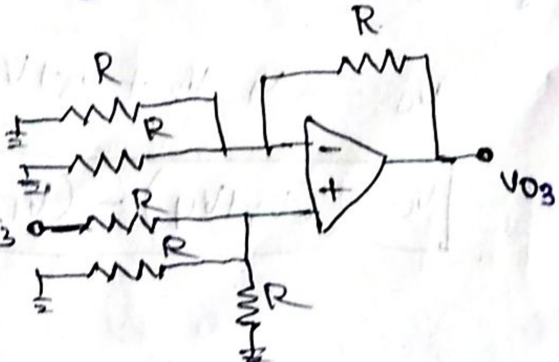
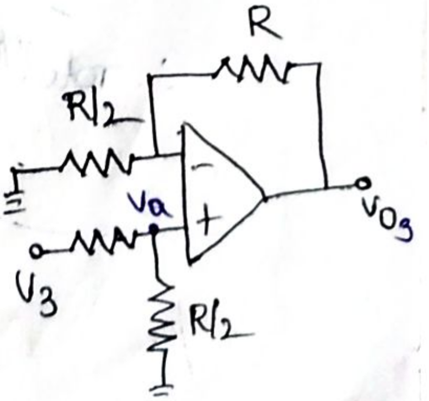



Case 3:- $V_3$ is active




⇒



$$V_3 = V_a\left[\frac{R}{R+R/2}\right] \Rightarrow V_a = V_3\left[\frac{R+R/2}{R}\right]$$

$$\cancel{\frac{V_0}{V_a} = \left[1+\frac{R_f}{R}\right]} \qquad V_a = \frac{1}{3}V_3$$

$$A_{CL} = \left(1+\frac{R_f}{R}\right) = \frac{V_0}{V_a}$$

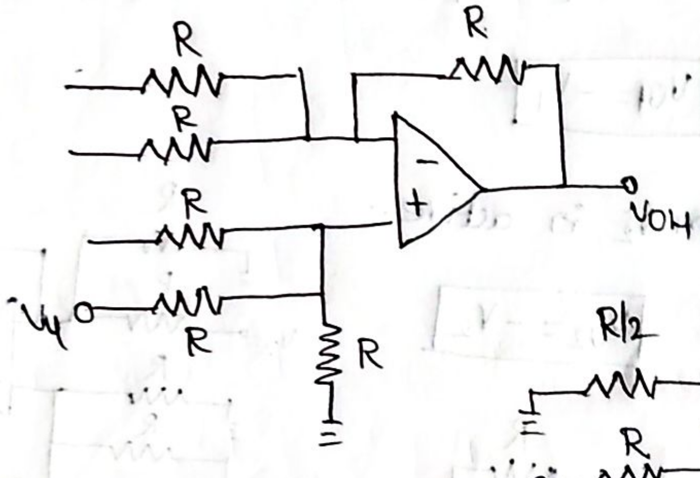
$$\cancel{V_0 = \left(1+\frac{R_f}{R}\right)V_a}$$

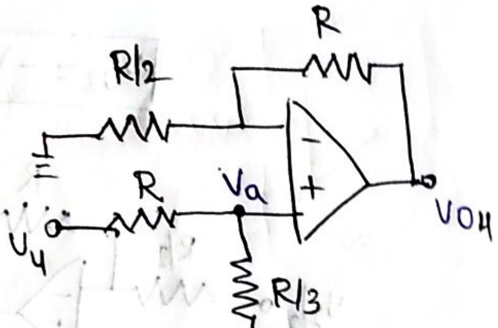
$$= \cancel{\left[1+\frac{R}{R}\right] \times V_3\left[\frac{R+R/2}{R}\right]} \qquad V_0 = \left[1+\frac{R}{R/2}\right]\frac{V_3}{3}$$

$$= \cancel{2\times V_3\left[\frac{2R+R}{2\times R}\right]} \qquad V_0 = (1+2)\times\frac{V_3}{3}$$

$$\boxed{V_{03} = V_3}$$

case 4:- $V_4$ is active.




similarly, $\boxed{V_{O4} = V_4}$

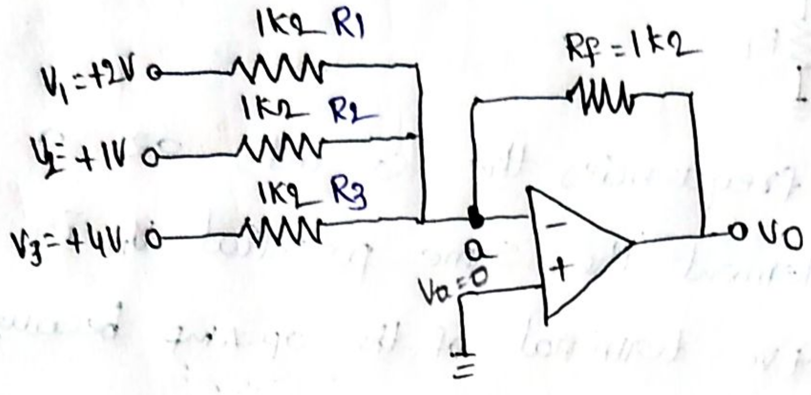
∴ Total o/p voltage $V_0 = V_{01} + V_{02} + V_{03} + V_{04}$

$$V_0 = -V_1 - V_2 + V_3 + V_4$$

$$\boxed{V_0 = (V_3+V_4) - (V_1+V_2)}$$

① Adder of Inverting op-Amp:-

Problem:- Find the $V_0$ of the given circuit.




Sol:- given that,

$V_1 = +2V$

$V_2 = +1V$

$V_3 = +4V$

$R_1 = R_2 = R_3 = R_f = 1k\Omega$

$V_0 = ?$

$$A_{CL} = -\frac{R_f}{R_{in}}$$

$$\frac{V_0}{V_{in}} = \frac{-R_f}{R_{in}}$$

$$V_0 = -R_f \times \frac{V_{in}}{R_{in}}$$

$$V_0 = -R_f \times \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]$$

Formula:-

$$\boxed{V_0 = -R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]} \quad \text{--- ①}$$

substitute the values in eq ①

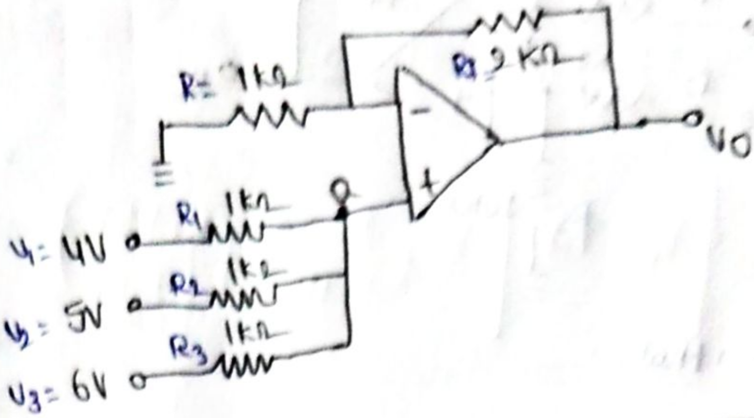
$$V_0 = -1\times10^3\left[\frac{2}{1\times10^3} + \frac{1}{1\times10^3} + \frac{4}{1\times10^3}\right]$$

$$= -\frac{\cancel{1\times10^3}}{\cancel{1\times10^3}}\left[2+1+4\right]$$

$$\therefore \boxed{V_0 = -7V}$$

② Adder of non-inverting op-amp:-

problem:- Find the $V_0$ of the given ckt.




sol:-

given that,

$V_1 = 4V$

$V_2 = 5V$

$V_3 = 6V$

$R_f = 2K\Omega$

$R = 1K\Omega$

$R_1 = R_2 = R_3 = 1K\Omega$

$V_0 = ?$

$A_{CL} = 1 + \frac{R_f}{R}$

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

$V_{in} = V_a$

$V_0 = \left(1 + \frac{R_f}{R}\right) V_a$

$V_a = \left[\frac{\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}\right]$

Formula:-

$$\boxed{V_0 = \left(1 + \frac{R_f}{R}\right)\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]\left[\frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2}\right]} \quad \text{—①}$$

Substitute the values in eq ①,

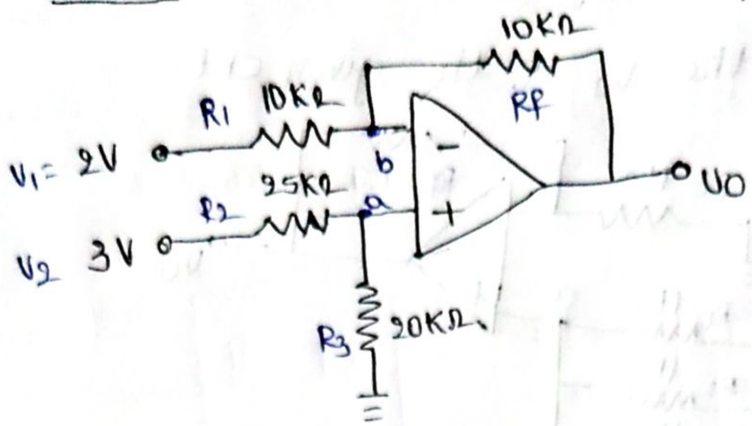
$V_0 = \left(1 + \frac{2}{1}\right)\left[\frac{4}{1} + \frac{5}{1} + \frac{6}{1}\right]\left[\frac{1 \times 1 \times 1}{1 + 1 + 1}\right]$

$= \cancel{3} \times [4 + 5 + 6] \times \frac{1}{\cancel{3}}$

$= 15V$

$\therefore \boxed{V_0 = 15V}$

③ Subtractor:- Find $V_0$ of the given ckt,




Sol:- Given that,

$V_1 = 2V$

$V_2 = 3V$

$R_1 = 10K\Omega$

$R_2 = 25K\Omega$

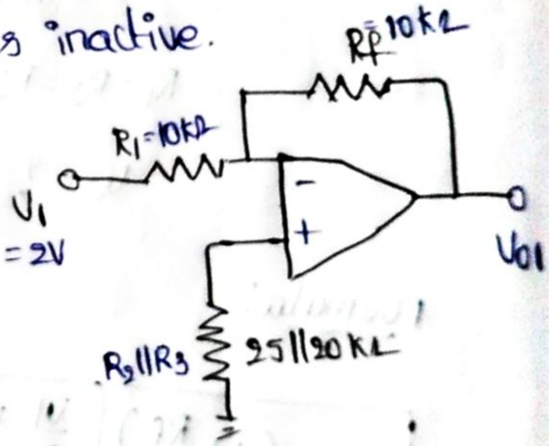
$R_3 = 20K\Omega$

$R_f = 10K\Omega$

$V_0 = ?$

Method 1:-

case (i): if $V_1$ is active, $V_2$ is inactive.




$$A_{CL} = \frac{-R_f}{R_{in}}$$

$$\frac{V_0}{V_{in}} = -\frac{R_f}{R_{in}}$$

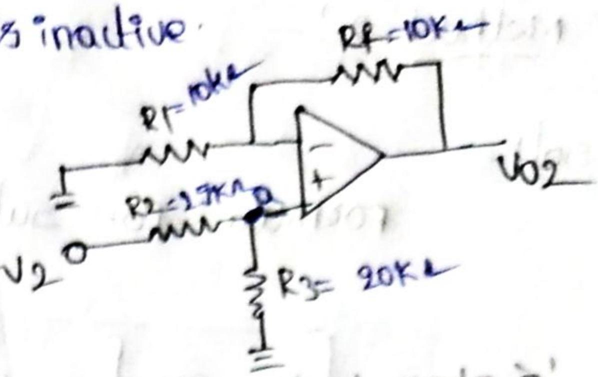
$$\boxed{V_{01} = -\frac{R_f}{R_1}(V_i)} \quad — ①$$

substitute the values in eq ①

$$V_{01} = \frac{-10\times10^3}{10\times10^3} \times 2$$

$$\boxed{V_{01} = -2V}$$

Case (ii):- if $V_2$ is active, $V_1$ is inactive.




$$A_{CL} = \left(1 + \frac{R_f}{R}\right)$$

$$\frac{V_{02}}{V_{in}} = \left[1 + \frac{R_f}{R}\right]$$

where $V_{in} = V_a$

$$V_{02} = \left(1 + \frac{R_f}{R}\right] V_a$$

At node 'a'

$$\frac{V_a - V_2}{R_2} - \frac{V_a}{R_3} = 0$$

$$V_a\left[\frac{1}{R_2} + \frac{1}{R_3}\right] = \frac{V_2}{R_2}$$

$$V_a = \frac{V_2}{R_2} \times \left[\frac{R_2 R_3}{R_2 + R_3}\right]$$

$$\therefore \boxed{V_{02} = \left(1 + \frac{R_f}{R}\right] \times \frac{V_2}{R_2} \times \left[\frac{R_2 R_3}{R_2 + R_3}\right]} \quad \text{--- (2)}$$

Sub. values in eq (2)

$$V_{02} = \left(1 + \frac{10\times10^3}{10\times10^3}\right] \times \left(\frac{3}{25\times10^3}\right)\left(\frac{25\times10^3 \times 20\times10^3}{(25+20)\times10^3}\right]$$

$$= (1+1) \times \frac{3}{1} \times \frac{20}{45}$$

$$= 2 \times 3 \times \frac{20}{45} = \frac{8}{3}$$

$$\therefore \boxed{V_{02} = \frac{8}{3}\,V}$$

Total voltage $\boxed{V_0 = V_{01} + V_{02}}$ --- (3)

sub values in eq (3)

$$V_0 = -2 + \frac{8}{3}$$

$$= \frac{-6+8}{3} = \frac{2}{3}$$

$$\boxed{V_0 = 0.66\,V}$$

Method 2:-

Sol:-

formula for subtractor,

$$\boxed{V_0 = R_f \left[ V_2 \times \left(\frac{R_3}{R_2+R_3}\right) \times \left(\frac{R_1+R_f}{R_1 R_f}\right) - \frac{V_1}{R_1} \right]} \quad \text{—} (1)$$

sub values in eq (1)

$$V_0 = 10\times10^3 \left[ 3\times \frac{20\times10^3}{25\times10^3+20\times10^3} \times \frac{10\times10^3+10\times10^3}{10\times10^3\times10\times10^3} - \frac{2}{10\times10^3} \right]$$

$$= 10\times10^3 \left[ \frac{3\times20\times\cancel{10^3}}{(25+20)\times\cancel{10^3}} \times \frac{(10+10)\cancel{10^3}}{10\times10^3\times10\times\cancel{10^3}} - \frac{2}{10\times10^3} \right]$$

$$= \frac{10\times\cancel{10^3}}{10\times\cancel{10^3}} \left[ \frac{3\times20\times20}{45\times10} - \frac{2}{1} \right]$$

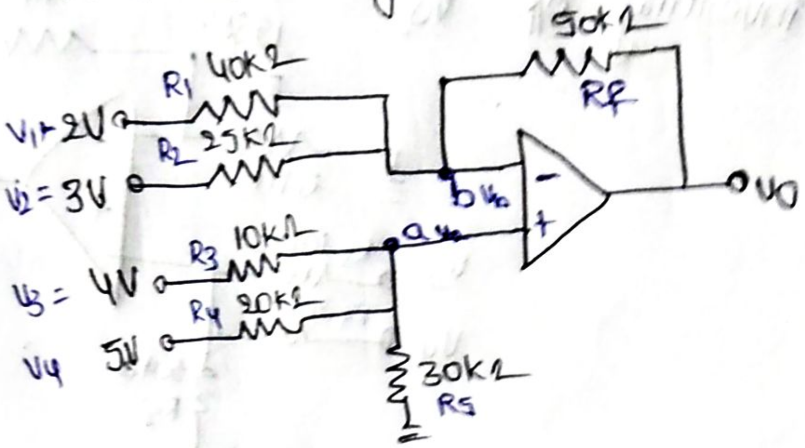
$$= \frac{\cancel{10}\times\cancel{3}\times\cancel{40}^{8}}{\cancel{10}\times\cancel{45}_{\cancel{9}\,3}} - 2 = \frac{8}{3} - 2 = \frac{8-6}{3}$$

$$= 0.66\text{V}$$

$$\therefore \boxed{V_0 = 0.66\text{ V}}$$

④ Adder-subtractor:-

problem:- Find $V_o$ of given ckt




sol:-

given that,

$V_1 = 2V$ $\quad R_1 = 40k\Omega$

$V_2 = 3V$ $\quad R_2 = 25k\Omega$

$V_3 = 4V$ $\quad R_3 = 10k\Omega$

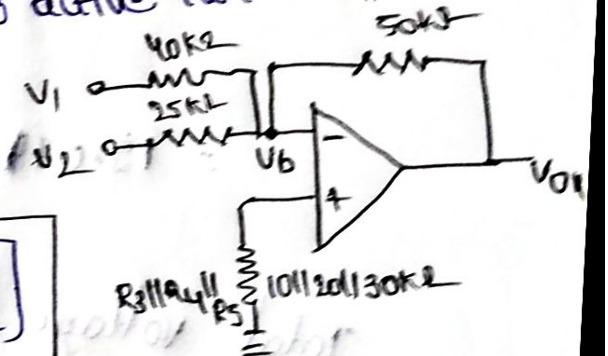
$V_4 = 5V$ $\quad R_4 = 20k\Omega$

$R_5 = 30k\Omega$

$R_f = 50k\Omega$

$\therefore V_0 = ?$

→ if $V_a$ is inactive $V_b$ is active then the o/p is inverting o/p $V_{01}$




$$\therefore \boxed{V_{01} = -R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2}\right]} \quad —①$$

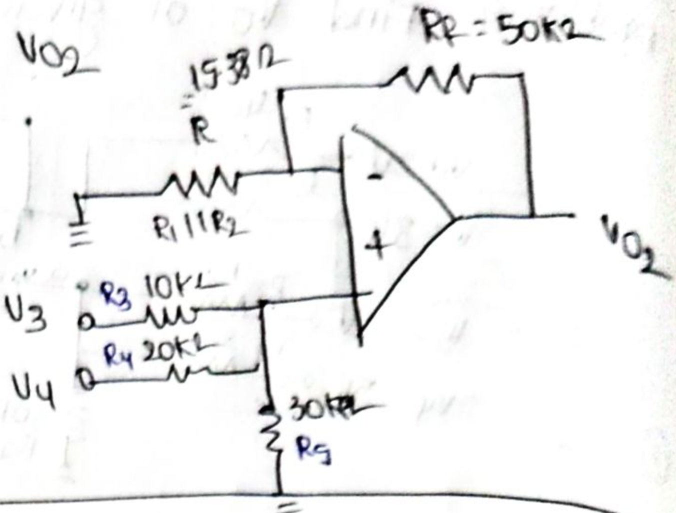
sub values in eq①

$$V_{01} = -50\times10^3\left[\frac{2}{40\times10^3} + \frac{3}{25\times10^3}\right]$$

$$= -\frac{50\times\cancel{10^3}}{\cancel{10^3}}\left[\frac{2}{40} + \frac{3}{25}\right] = -8.2V$$

$$\boxed{V_{01} = -8.2V}$$

→ if Va is active, Vb is inactive then the o/p is non-inverting o/p. $V_{o2}$




$$\boxed{V_{o2} = \left[1+\frac{R_f}{R}\right]\left[\frac{V_3}{R_3}+\frac{V_4}{R_4}\right]\left[\frac{R_3R_4R_5}{R_3R_4+R_4R_5+R_3R_5}\right]} \quad \text{—②}$$

sub values in eq ②

$$V_{o2} = \left[1+\frac{50}{15.38}\right] \times \left[\frac{4}{10\times10^3}+\frac{5}{20\times10^3}\right]\left[\frac{10\times20\times30\times10^{3}}{(10\times20)+(20\times30)+(10\times30)}\right]$$

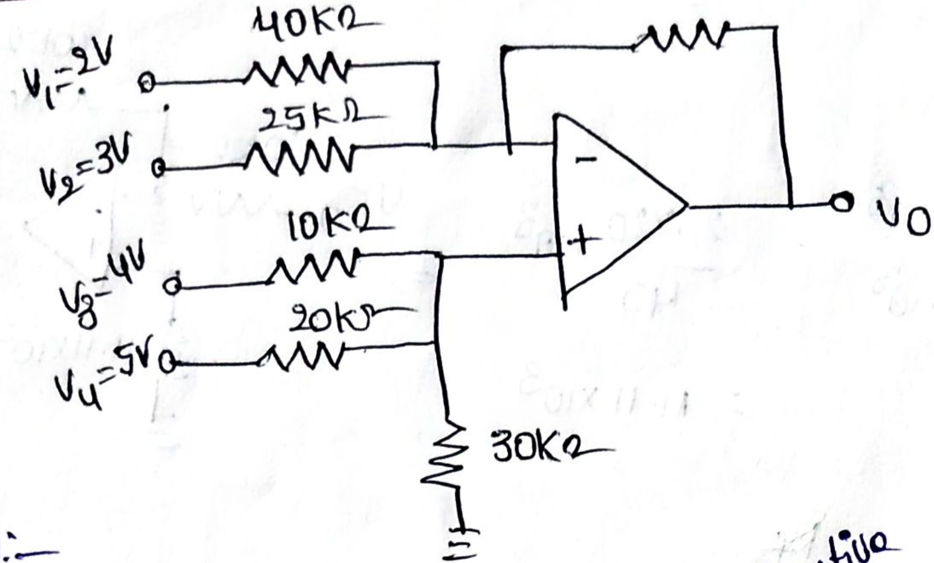
$= 15.071$

Total voltage, $\boxed{V_0 = V_{o1}+V_{o2}}$

$\therefore V_0 = -8.2 + 15.071$

$\therefore \boxed{V_0 = 6.87\,V}$

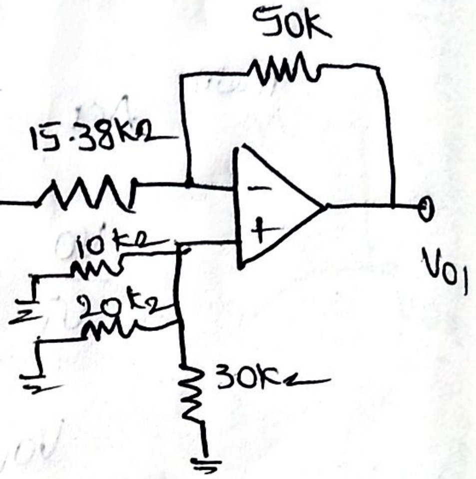
② Method 2:




Find Vo.

Sol:–

Case (i) :- $V_1$ is active, $V_2$, $V_3$, $V_4$ inactive

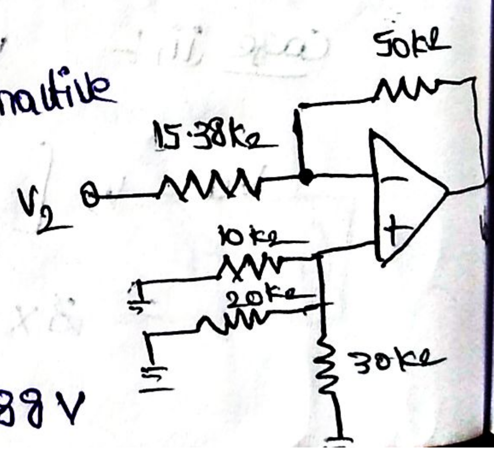



$$V_{01} = \left(-\frac{R_f}{R_1}\right) \times \frac{V_1}{2}$$

$$= -\frac{50 \times 10^3}{15.38 \times 10^3} \times \frac{2}{2}$$

$$V_{01} = -3.25\ V$$

Case (ii) :- $V_2$ is active, $V_1$, $V_3$, $V_4$ inactive



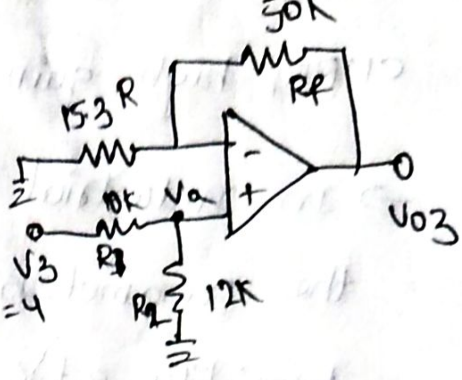

$$V_{02} = -\left[\frac{R_f}{R}\right] \times \frac{V_2}{2}$$

$$= -\frac{50}{15.38} \times \frac{3}{2} = -4.88\ V$$

$$\boxed{V_{o2} = -4.88\,V}$$

case iii): $V_3$ is active

$$V_a = \left(\frac{R_2}{R_1+R_2}\right) \times V_3$$




$$V_a = \left(\frac{12}{10+12}\right) \times 4$$

$$\boxed{V_a = 2.18\,V}$$

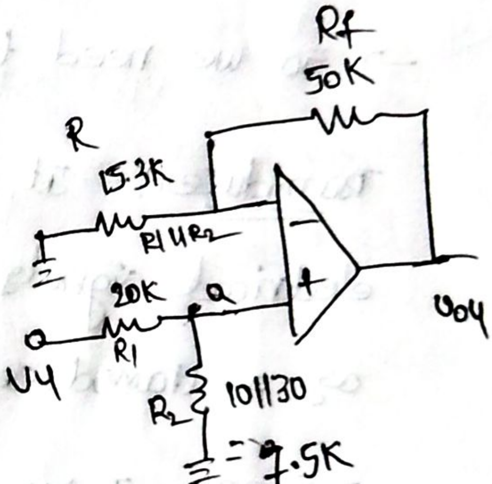
$$V_{o3} = \left(1+\frac{R_f}{R}\right) \times V_a$$

$$V_{o3} = \left[1+\frac{50}{15.3}\right] \times 2.18$$

$$\boxed{V_{o3} = 9.2\,V}$$

case iv):- $V_4$ is active.

$$V_a = \left(\frac{R_2}{R_1+R_2}\right) \times V_4$$




$$V_a = \left[\frac{7.5}{20+7.5}\right] \times 5$$

$$\boxed{V_a = 1.36\,V}$$

$$V_{o4} = \left(1+\frac{R_f}{R}\right) V_a$$

$$V_{o4} = \left[1+\frac{50}{15.3}\right] \times 1.36$$

$$\boxed{V_{o4} = 5.80\,V}$$

$$V_o = V_{o1} + V_{o2} + V_{o3} + V_{o4}$$

$$= -3.25 - 4.88 + 9.20 + 5.80$$

$$\boxed{V_o = 6.87\,V}$$

~~Method 2:~~

* **Instrumentation Amplifier:-**

In industrial applications we need high CMRR, high gain and high i/p impedence amplifier.

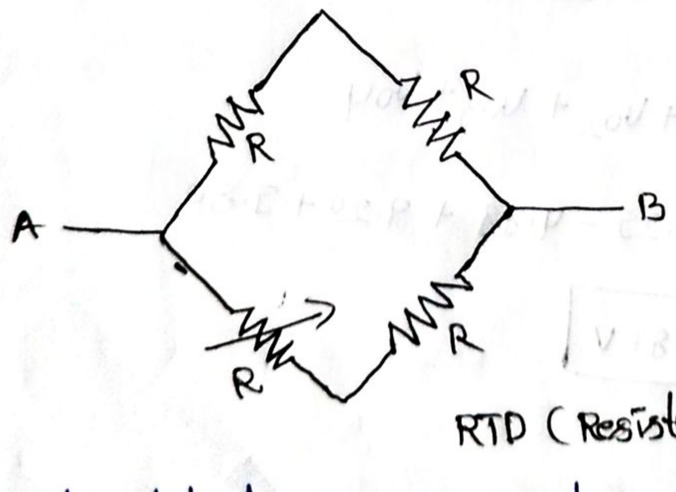
-> In Industrial application we are measuring the parameters like ~~tempr~~ temperature, humidity e.t.c.

-> These type of measurement parameters we can't directly apply to the i/p of the amplifiers.

-> So we need transducers.

Transducer:- It convert any parameter into the electrical signals. Normally we use bridge ckts as a transducer.

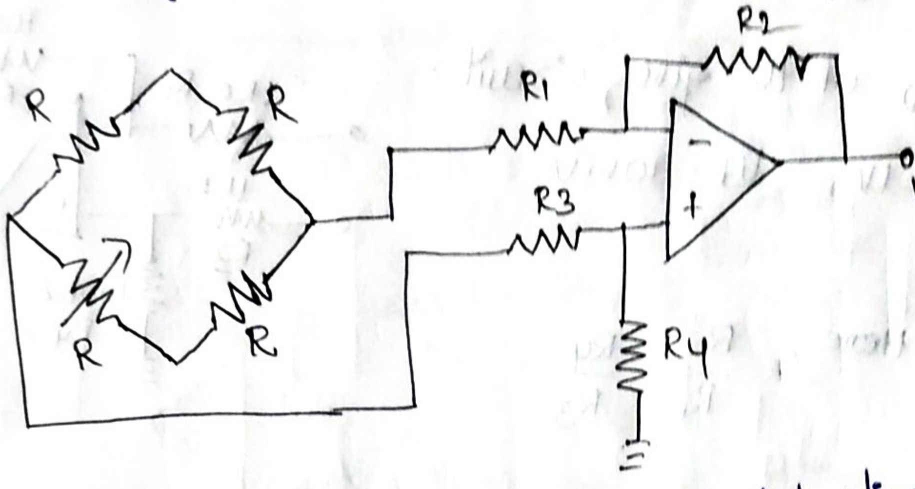
For eg:- I want to convert the temp into the electrical signals.




RTD (Resistance thermo Detector)

-> It detects the temperature and vary the resistance, the temperature also varies then we find the two voltages at A & B.

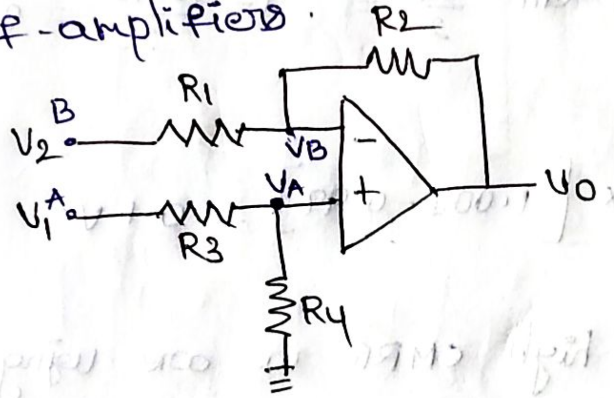
That voltages are 2 differential voltages.




1. To acheive high CMRR we need to elimate the common mode signals.

2. To acheive high i/p impedance check the resistance values in differential amp in the bridge ckt.

3. To acheive high gain we have to eliminate mismatching b/w the transistors that are used in diff-amplifiers.




$$V_O = \left(\frac{R_4}{R_3+R_4}\right) V_a \left[1+\frac{R_2}{R_1}\right] - \left(\frac{R_2}{R_1}\right) V_b$$

Assume $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

then $V_O = \frac{R_2}{R_1}\left\{V_a - V_b\right\}$

$V_d = V_a - V_b \Rightarrow V_O = \frac{R_2}{R_1} \times V_d$

$V_O = A_d V_d + A_{cm} V_{CM}$

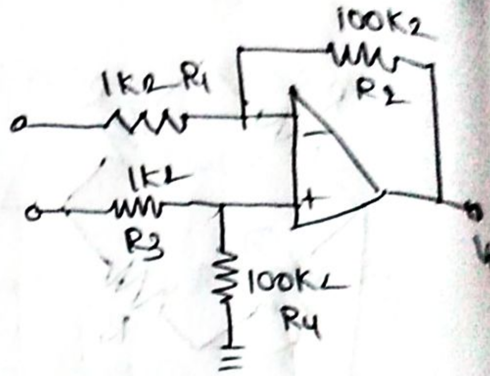
$V_A = V_{cm} + \frac{V_d}{2}$

$V_B = V_{CM} - \frac{V_d}{2}$

problem!

Find $V_0$ of the given circuit

$V_{CM} = 1V$, $V_d = 10mV$




sol:

Here, $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

then

$$V_0 = \frac{R_2}{R_1}\left[V_A - V_B\right] \quad \text{—— (1)}$$

where

$$V_A = V_{cm} + \frac{V_d}{2}$$

$$= 1 + \frac{10 \times 10^{-3}}{2} = 1.005$$

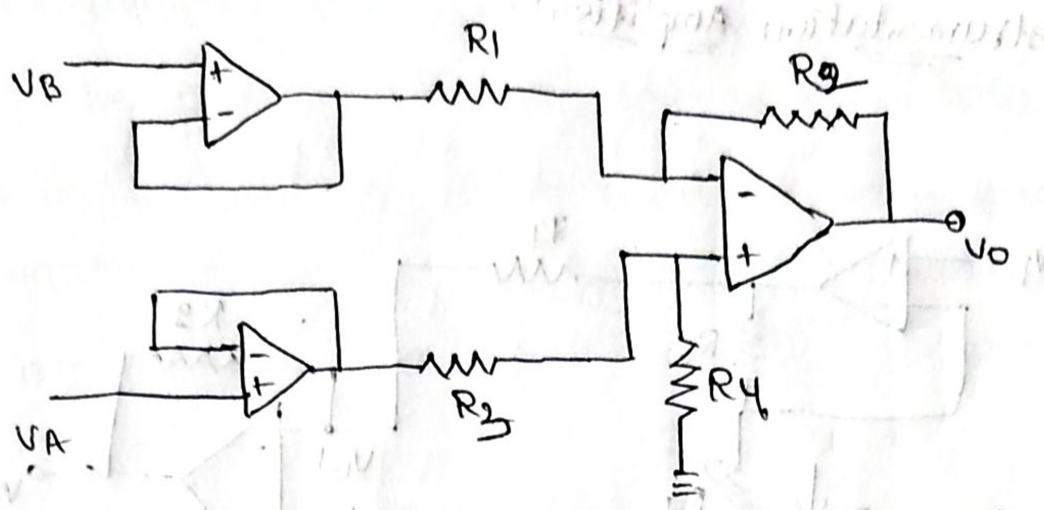
$$V_B = V_{cm} - \frac{V_d}{2} = 1 - \frac{10 \times 10^{-3}}{2} = 0.99V$$

$$V_0 = \frac{100}{1} \times \left[1.005 - 0.99\right] = 0.1V$$

→ To achieve high CMRR we are using monolithic IC's. In monolithic IC's all resistors are fabricated permanently but the i/p impedance is less by using Monolithic IC's.

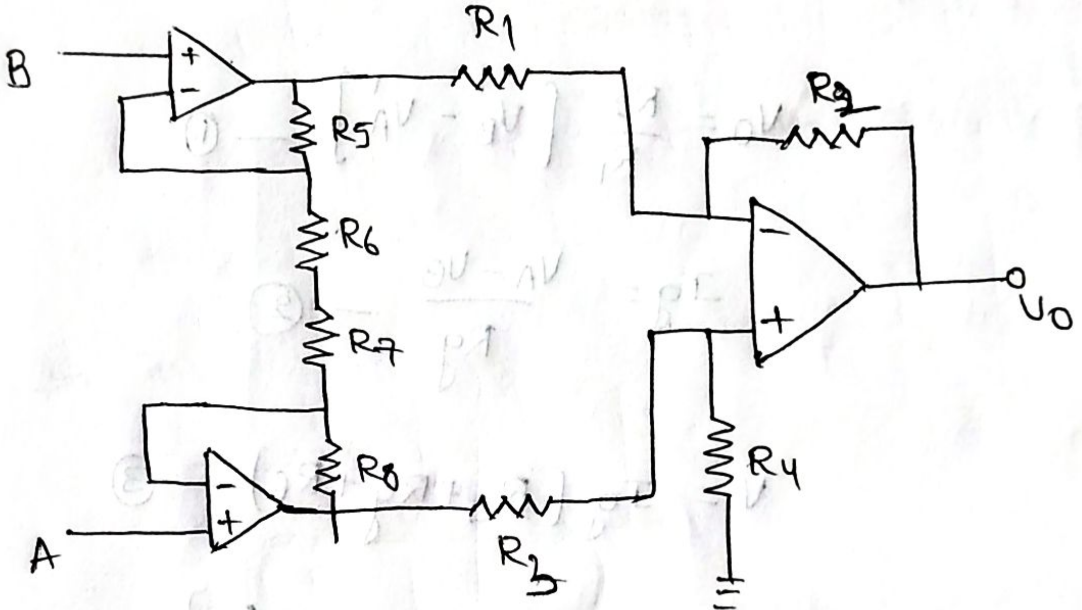
→ To acheive high i/p impedence we can use Buffer's Before the differential amplifier.

→ we are using Buffers along with the monolithic IC's




→ By using this above ckt we get fixed gain.

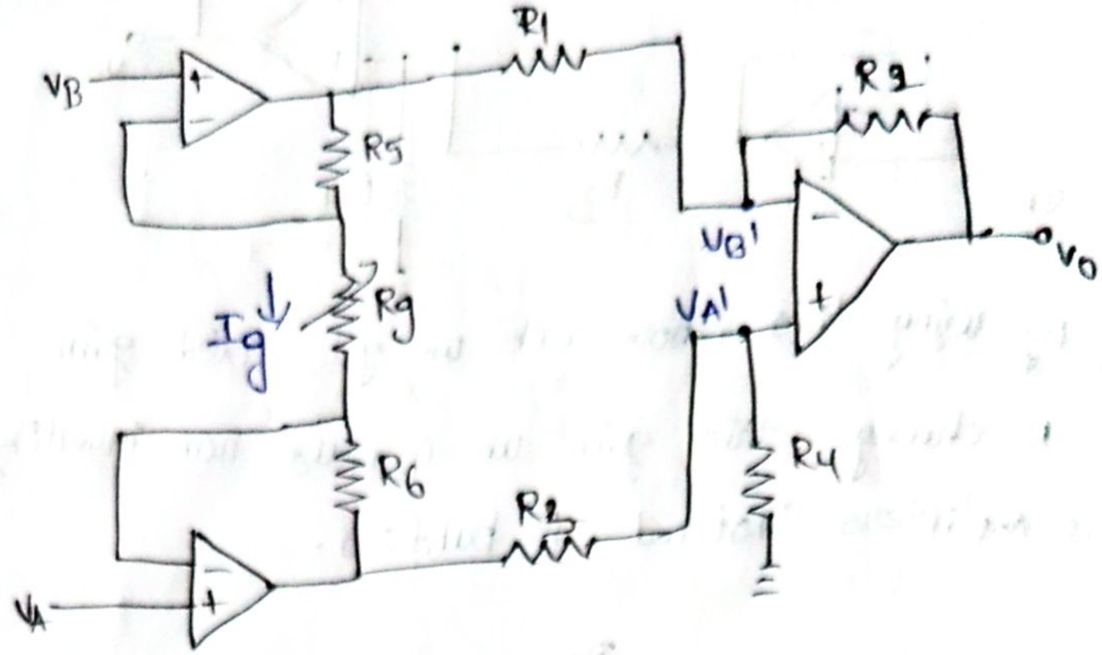
→ To change this gain we can use non-inverting op-Amplifiers instead of buffers.




→ The problem by using above ckt we have to match the $R_5, R_6, R_7, R_8$

→ To overcome this problem we are inserting a Resistor $R_g$.

## Instrumentation Amplifier:




$$\therefore V_0 = \frac{R_2}{R_1}\left[V_B' - V_A'\right] \quad \text{—— ①}$$

$$I_g = \frac{V_A - V_B}{R_g} \quad \text{—— ②}$$

$$V = I_g\left(R_5 + R_g + R_6\right) \quad \text{—— ③}$$

$$V_B' - V_A' = I_g\left(R_5 + R_g + R_6\right]$$

sub ②, ③

$$V_B' - V_A' = \left(\frac{V_A - V_B}{R_g}\right)\left(R_5 + R_g + R_6\right) \quad \text{—— ④}$$

sub ④ in ①

$$V_0 = \frac{R_2}{R_1}\left[\frac{V_A - V_B}{R_g}\right]\left[R_5 + R_g + R_6\right]$$

where $[R_5 = R_6 = R]$

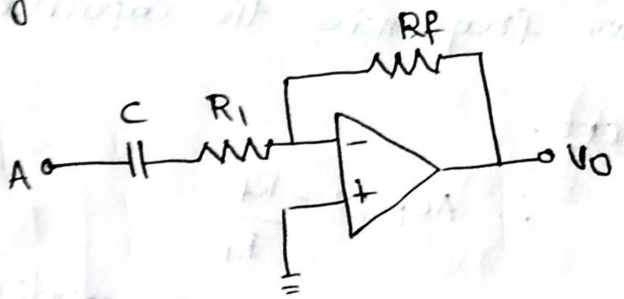
$$\therefore \boxed{V_0 = \frac{R_2}{R_1}\left[\frac{V_A - V_B}{R_g}\right]\left(2R + R_g\right]}$$

## AC Amplifier:-

The op Amplifier is designed for both AC & DC applications. if we want o/p as a frequency response we can use the AC amplifiers. In this AC amplifiers, we can use 1 capacitor to block the DC components.

1. Inverting AC amplifier.
2. Non-Inverting AC amplifier.

### 1. Inverting AC amplifier:-




In inverting op-amp,

$$ACL = \frac{V_o}{V_1} = -\frac{R_f}{R_1}$$

In inverting AC op-amp,

$$ACL = \frac{V_o}{V_i} = \frac{-R_f}{R_1 + X_C}$$

$$= \frac{-R_f}{R_1 + \frac{1}{j\omega C}} = \frac{-R_f}{R_1\left(1+\frac{1}{j\omega R_1 C}\right)}$$

$$= -\frac{R_f}{R_1} \times \frac{1}{1+\frac{1}{j\omega R_1 C}}$$

where, $\omega = 2\pi f$

$$\frac{V_0}{V_{in}} = \frac{-R_f}{R_1} \times \frac{1}{\left(1+\left(\frac{1}{j2\pi f R_1 C}\right)\right)}$$

assume, $f_1 = \frac{1}{2\pi R_1 C}$

$$\therefore \cancel{\frac{V_0}{V_{in}} = \frac{-R_f}{R_1} \times \frac{1}{1+j(f_1/f)}}$$

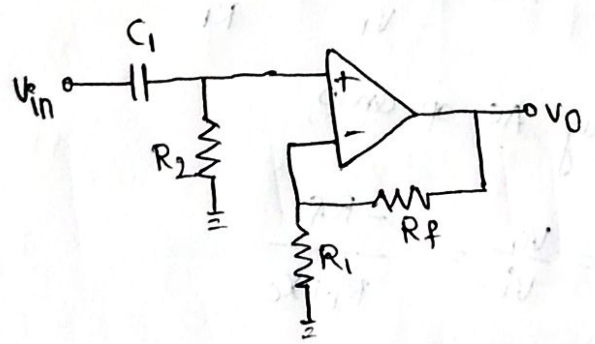
$$\frac{V_0}{V_{in}} = -\frac{R_f}{R_1} \times \left[\frac{1}{1+\frac{f_1}{jf}}\right] = -\frac{R_f}{R_1}\left[\frac{1}{1-\frac{jf_1}{f}}\right]$$

At higher frequencies the capacitor works as a short ckt.

$$\therefore A_{CL} \simeq -\frac{R_f}{R_1}$$

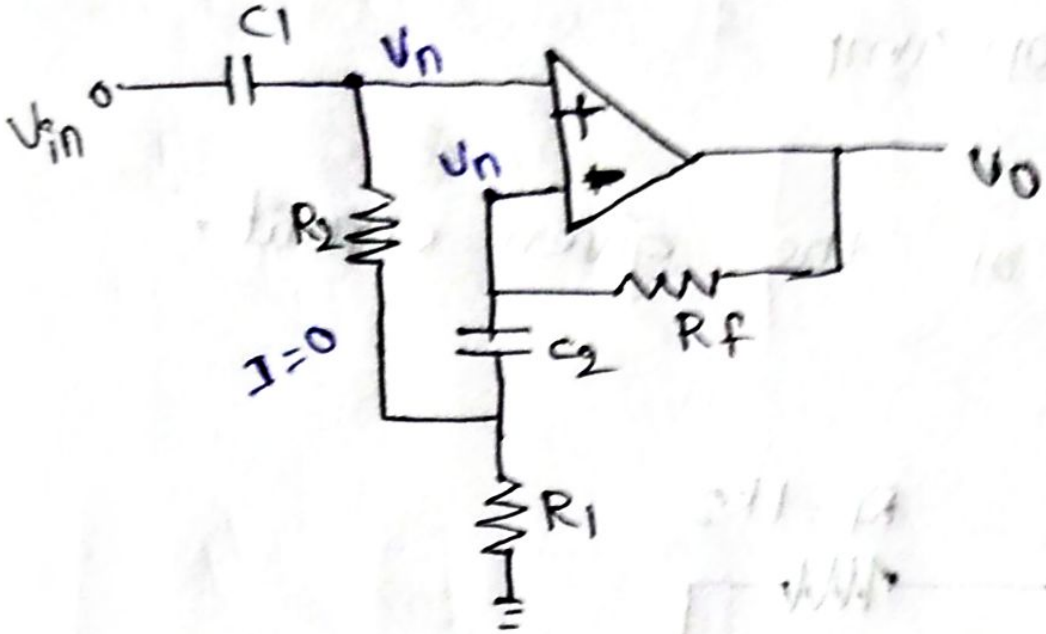
→ It is used for low frequency applications.

2. Non-inverting AC amplifier:-



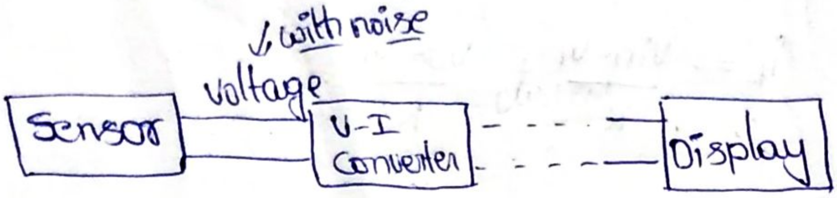

This $R_2$ is provided to eliminate the dc components by using this ckt i/p impedence of the op-Amp is decreased.

→ To achieve high i/p impedence place a capacitor b/w the resistors of $R_2$ & $R_f$.



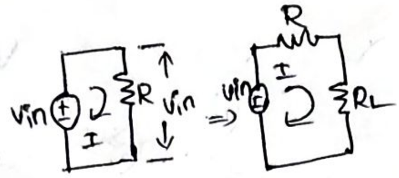

→ At higher frequencies the $C_2$ acts as a short ckt element the same potential $V_n$ is applied at +ve terminal of the op-Amp because of this no current flows through the $R_2$.

* V-I Converters (voltage - current)




with out distortion then the current will display.

There are 2 types.

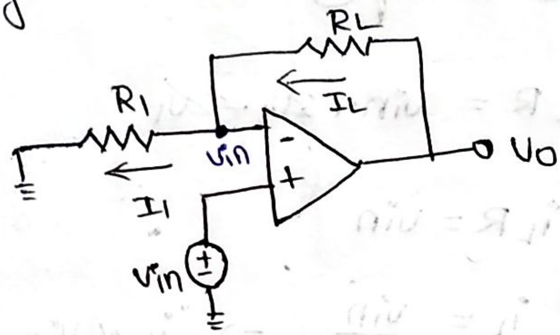



$I = \frac{Vin}{R}$ $\qquad$ $I = \frac{Vin}{R+RL}$

1) Floating node V-I Converter

2) Ground Load V-I Converter.

1) Floating node V-I Converter :-



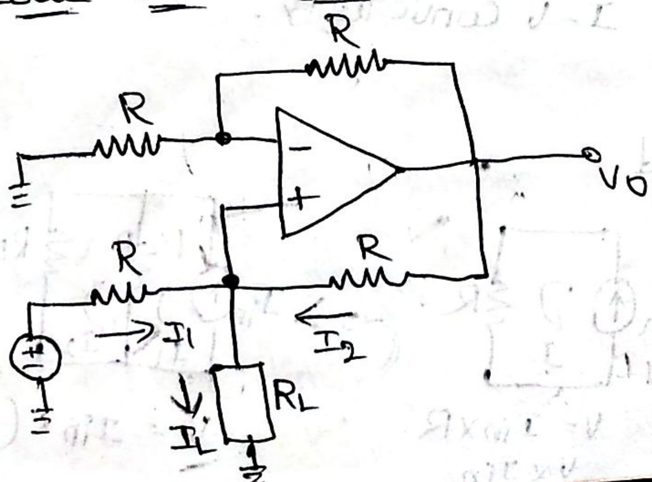

where $I_1 = I_L$

$$\boxed{\frac{Vin}{R_1} = I_L}$$

$Vin \propto I_L$

when $R_1$ is fixed this circuit will acts as V-I Converter.

2) Ground Load V-I Converter :-



$$i_L = i_1 + i_2$$

$$i_L = \frac{V_{in} - V_1}{R} + \frac{V_0 - V_1}{R}$$

$$i_L R = V_{in} + V_0 - 2V_1 \quad \text{--- (1)}$$

$$V_0 = \left(1 + \frac{R_f}{R_1}\right) V_1$$

diode
LED
ZENER DIODE

$$V_0 = \left(1 + \frac{\cancel{R}}{\cancel{R}}\right) V_1$$

$$V_0 = 2V_1 \quad \text{--- (2)}$$

Sub (2) in eq (1)

$$i_L R = V_{in} + \cancel{2V_1} - \cancel{2V_1}$$

$$i_L R = V_{in}$$

$$i_L = \frac{V_{in}}{R} \Rightarrow i_L \propto V_{in}$$

when 'R' is fixed this ckt acts V-I Converter.

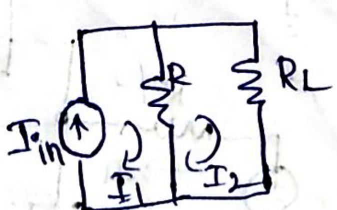
→ <u>I to V Converters</u>:-

when we want to store the data then the o/p should interms of voltage. but the data storage should take the voltages to store the o/p. we use the I-V Converters.

Normal method

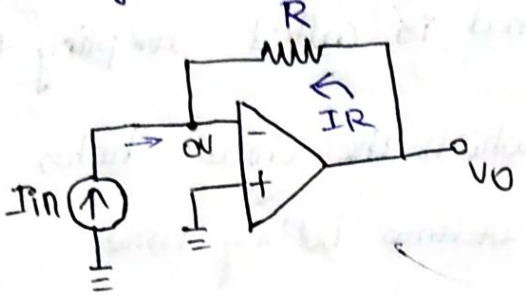

$V = I_{in} \times R$

$V \propto I_{in}$




$V = I_{in} \times (R \| R_L)$

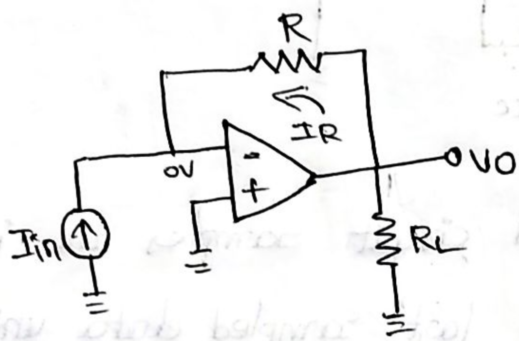
By using Op-Amp




$$I_{in} = I_R$$

$$I_{in} = \frac{V_O}{R}$$

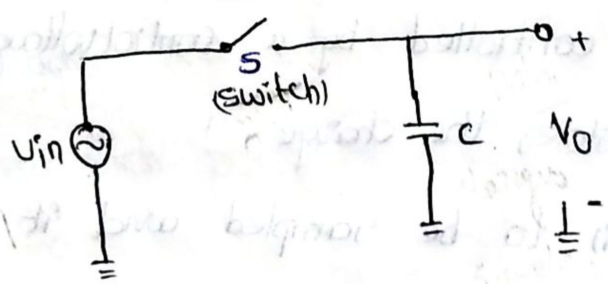
$$\boxed{V_O = I_{in} \times R}$$




→ For Ideal op-amplifier $R_L$ does not effect.

So. $\boxed{V_O = 0}$

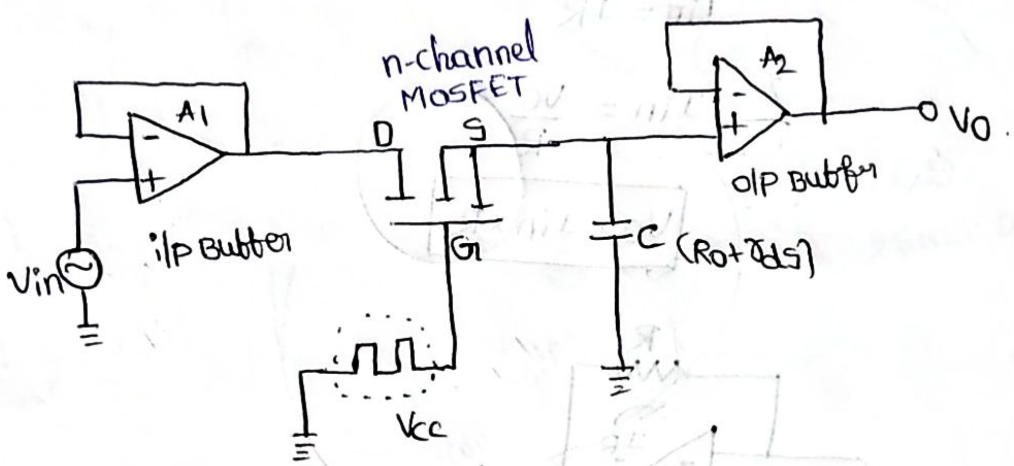
* sample & hold circuits:-




The sample and hold circuit is an electronic circuit which creates the samples of voltage given to it as input and after these, it holds these samples for definite time.

→ The time during which the circuit generates the sample of the input signal is called sampling time.

→ The time during which the circuit holds the sampled value is called ~~holdtime~~ holding time.



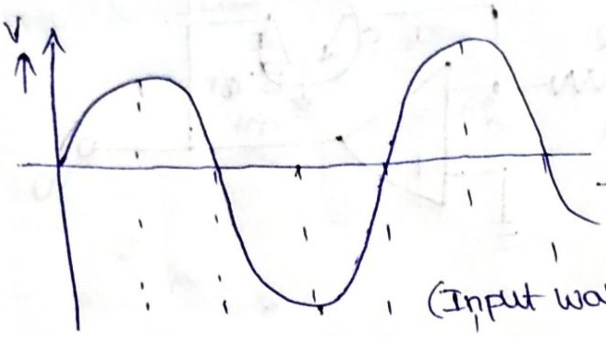

→ A sample and hold circuit samples the i/p signal and holds on to its last sampled data untill the i/p is sampled again.

→ This type of circuits used in A→D Converters and PCM system (pulse code Modulated).

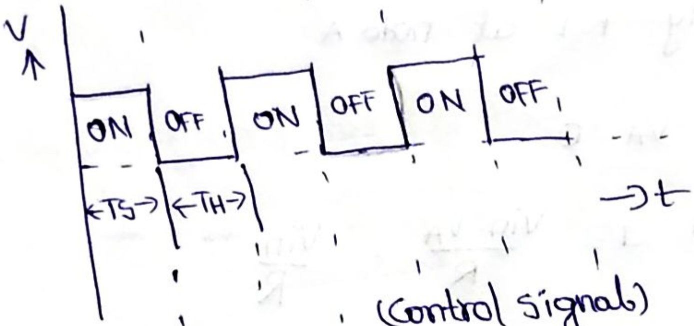
→ In this circuit n-channel MOSFET works as a switch and it is controlled by a control voltage (Vc). The capacitor 'c' stores the charge.

→ The i/p voltage (Vi) to be sampled and it is apply to the drain of the MOSFET and Vc is applied at the Gate terminal of MOSFET.

→ when Vc is +ve the FET turns 'ON' and the capacitor charges to the instantanious value of i/p (Vi) with (Ro+rds) where Ro → o/p Resistance of A1
rds → on Resistance of MOSFET



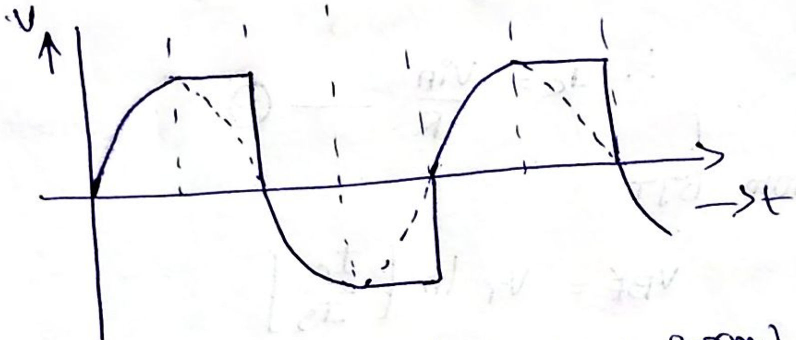

(Input wave form)




$T_S \rightarrow$ Sampling time

$T_H \rightarrow$ Holding time

(Control signal)




(output wave form)

## * log Amplifiers:-

→ In log Amplifiers, BJT is used as a diode with base and collector shorted. i.e $V_{CB} = 0$.

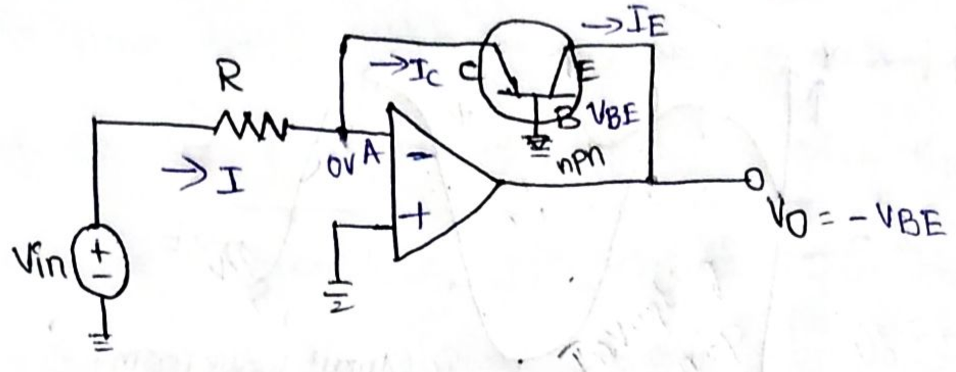
→ For such BJT, the base-emitter voltage $V_{BE}$ is

$$V_{BE} = V_T \ln\left[\frac{I_C}{I_S}\right]$$

where $I_C$ = Collector current

$I_S$ = Emitter saturation current.

$$I_C = I_S \left[e^{\frac{V_{BE}}{V_T}}\right]$$




Apply KCL at node A

where $V_A = 0$

then $I = \frac{V_{in} - V_A}{R} = \frac{V_{in}}{R}$

$I = I_C$ (At node A)

$\therefore I_C = \frac{V_{in}}{R}$ —— ①

From BJT

$V_{BE} = V_T \ln\left[\frac{I_C}{I_S}\right]$

where $V_O = -V_{BE}$

$= -V_T \ln\left[\frac{I_C}{I_S}\right]$

From eq ①

$V_O = -V_T \ln\left[\frac{V_{in}/R}{I_S}\right]$

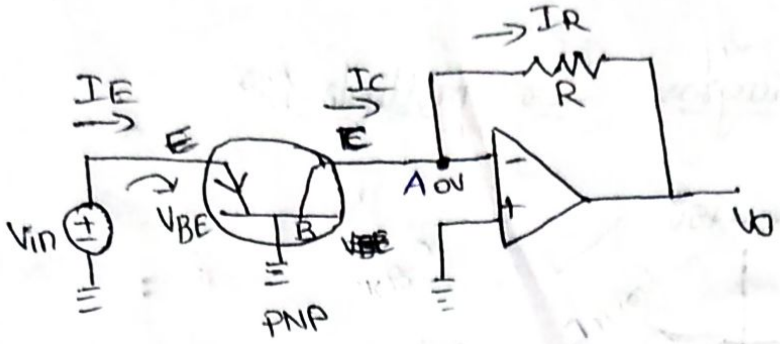
$= -V_T \ln\left[\frac{V_{in}}{R I_S}\right]$

where $R I_S = V_{ref}$

$$\therefore \boxed{V_O = -V_T \ln\left[\frac{V_{in}}{V_{ref}}\right]}$$

$\therefore V_O \propto \ln(V_{in})$

Anti-log amplifiers:-




From virtual ground method, $V_A = 0V$

$$\therefore \quad V_{CB} = 0V$$

From node A,

$$I_C = I_R \implies I_R = \frac{V_A - V_o}{R} = -\frac{V_o}{R}$$

where, $I_C = I_S\left(e^{\frac{V_{BE}}{V_T}}\right)$

$$\therefore \quad -\frac{V_o}{R} = I_S \times e^{\frac{V_{BE}}{V_T}}$$

$$V_o = -RI_S \times e^{\frac{V_{BE}}{V_T}} \quad \text{where } V_{BE} = V_{in}$$

$$\therefore \boxed{V_o = -RI_S \times e^{\frac{V_{in}}{V_T}}}$$

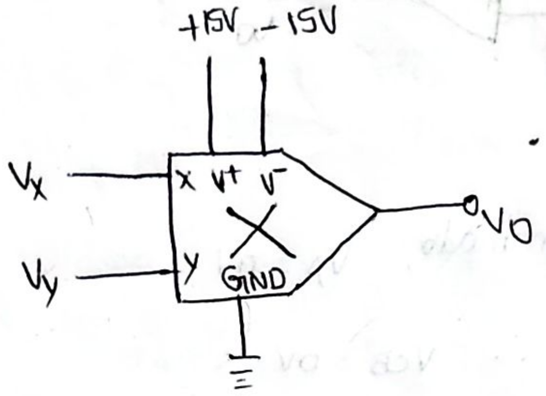
where $RI_S = V_{ref}$

$$\therefore \boxed{V_o = -V_{ref} \times e^{\frac{V_{in}}{V_T}}}$$

$$V_o \propto e^{V_{in}}$$

# * Multiplier:-

Schematic diagram for multiplier:-




$V_O \propto V_x V_y$

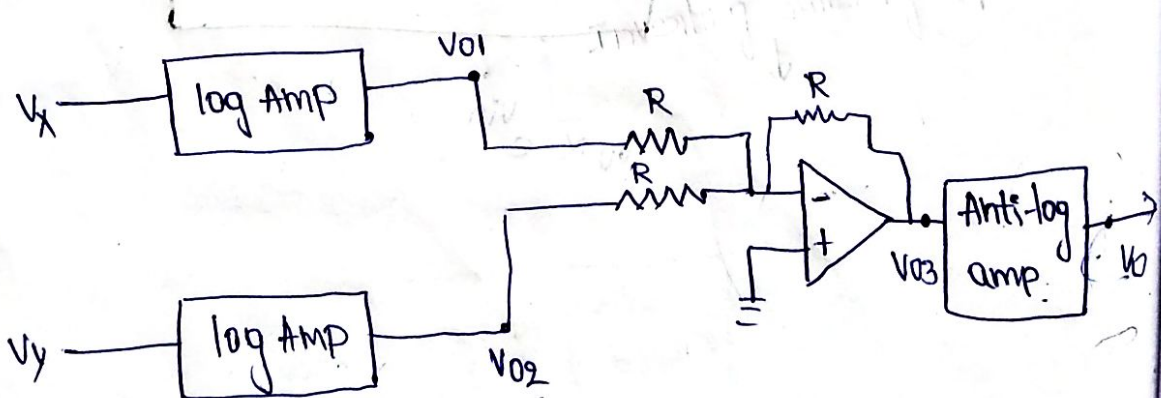
where, $V_O = \frac{V_x V_y}{V_{ref}}$

For practical $V_{ref} = 10V$

classification:-

1. One quadrant Multiplier, both i/ps are +ve or, -ve
2. Two quadrant Multiplier, one i/p is +ve, other +ve or -ve
3. Four quadrant Multiplier, i/ps are ±ve, ±ve

## * Designing a multiplier by using a log & antilog Amplifier:-




$V_O = \frac{V_x V_y}{V_{ref}}$

From the ckt.

$$V_{O1} = -V_T \ln\left[\frac{V_x}{V_{ref}}\right] \quad \text{①}$$ [from log amplifier]

$$V_{O2} = -V_T \ln\left(\frac{V_y}{V_{ref}}\right] \quad \text{②}$$

$$V_{O3} = -\left[V_{O1} + V_{O2}\right]$$

$$= -\left[-V_T \ln\left[\frac{V_x}{V_{ref}}\right] - V_T \ln\left(\frac{V_y}{V_{ref}}\right]\right]$$

$$= V_T \ln\left[\frac{V_x}{V_{ref}}\right] + V_T \ln\left[\frac{V_y}{V_{ref}}\right]$$

$$= V_T \left[\ln\left(\frac{V_x}{V_{ref}}\right) + \ln\left[\frac{V_y}{V_{ref}}\right]\right]$$ [log a + log b = log ab]

$$= V_T \ln\left[\frac{V_x}{V_{ref}} \times \frac{V_y}{V_{ref}}\right]$$

$$V_{O3} = V_T \ln\left[\frac{V_x V_y}{V_{ref}^2}\right] \quad \text{③}$$

$$V_O = -V_{ref} \times e^{\frac{V_{O3}}{V_T}} \quad \text{④}$$ [from Anti log amp]

$$= -V_{ref} \times \cancel{e}^{\frac{\cancel{V_T}\,\cancel{\ln}\,\frac{V_x V_y}{V_{ref}^2}}{\cancel{V_T}}}$$

$$= -\cancel{V_{ref}} \times \frac{V_x V_y}{V_{ref}^{\cancel{2}}}$$

$$V_O = \frac{-V_x V_y}{V_{ref}}$$

we want to change the sign then voltage follower is used at the output terminal then, $\boxed{V_O = \frac{V_x V_y}{V_{ref}}}$

* Applications of Multiplier:-

1. frequency doubling
2. Squaring a signal
3. Detecting phase angle difference b/w 2 signals
4. Multipling 2 signals

* frequency doubling:-

$V_x = V_x \sin wt$ $\qquad V_0 = \dfrac{V_x V_y}{V_{ref}}$ —— (1)

$V_y = V_y \sin(wt+\theta)$

$V_0 = \dfrac{V_x V_y}{V_{ref}} \sin wt \cdot \sin(wt+\theta)$

$= \dfrac{V_x V_y}{V_{ref}} \sin wt \left[\sin wt \cos\theta + \cos wt * \sin\theta\right]$

$= \dfrac{V_x V_y}{V_{ref}} \left[\sin^2 wt \cos\theta + \cos wt \sin wt \sin\theta\right]$

$\left[\sin^2 a = 1-\cos^2 a\right]$

$\cos 2a = 2\cos^2 a - 1$

$\cos^2 a = \frac{1}{2} + \frac{1}{2}\cos 2a$

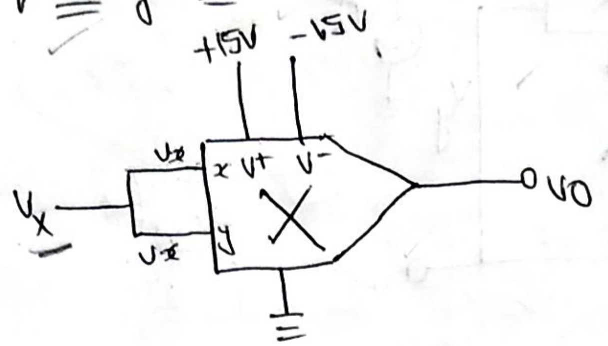
$\sin^2 a = 1 - \frac{1}{2} - \frac{1}{2}\cos 2a$

$= \frac{1}{2}\left[1-\cos 2a\right]$

$\therefore V_0 = \dfrac{V_x V_y}{V_{ref}} \left[\dfrac{\cos\theta}{2}(1-\cos 2wt) + \dfrac{\sin\theta \sin 2wt}{2}\right]$

$V_0 = \left(\dfrac{V_x V_y}{V_{ref}} \dfrac{\cos\theta}{2}\right) - \dfrac{V_x V_y}{V_{ref}} \cos\theta \cos 2wt + \dfrac{V_x V_y}{2V_{ref}} \sin\theta \sin 2wt$

* Squaring ckt:-




$$\therefore V_O = \frac{V_x V_y}{V_{ref}} \quad \text{where } V_y = V_x$$

$$V_O = \frac{V_x \times V_x}{V_{ref}}$$

$$V_O = \frac{V_x^2}{V_{ref}}$$

* phase angle detection:-

$$V_x = V_{mx} \sin \omega t$$

$$V_y = V_{my} \sin(\omega t + \theta)$$

$$V_O = \frac{V_{mx} V_{my}}{V_{ref}} \times \sin \omega t \times \sin(\omega t + \theta)$$

From Frequency doubling,

$$V_O = \underbrace{\frac{V_{mx} V_{my}}{2V_{ref}} \cos\theta}_{\text{DC term}} - \frac{V_{mx} V_{my}}{V_{ref}} \cos\theta \cos 2\omega t + \frac{V_{mx} V_{my}}{2V_{ref}} \sin\theta \sin 2\omega t$$

↓

phase angle detection

* **Divider:-**

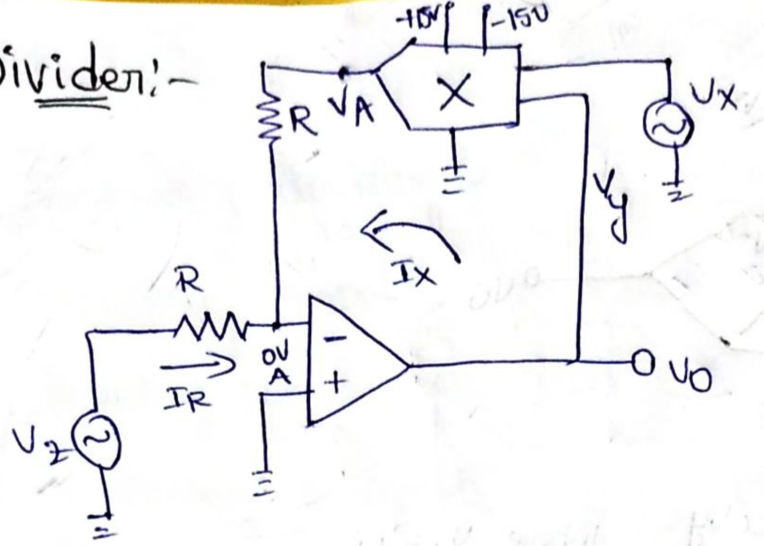



fig:- Divider ckt using multiplier and op-Amp

$$i_R = -i_x \quad \text{---} \ (1)$$

$$V_A = \frac{-V_x V_y}{V_{ref}}$$

$$I_x = \frac{-V_A}{R} = +\frac{V_x V_y}{V_{ref}} \times \frac{1}{R} \quad \text{---} \ (2) \quad (V_y = V_O)$$

$$I_R = \frac{V_z}{R} \quad \text{---} \ (3)$$

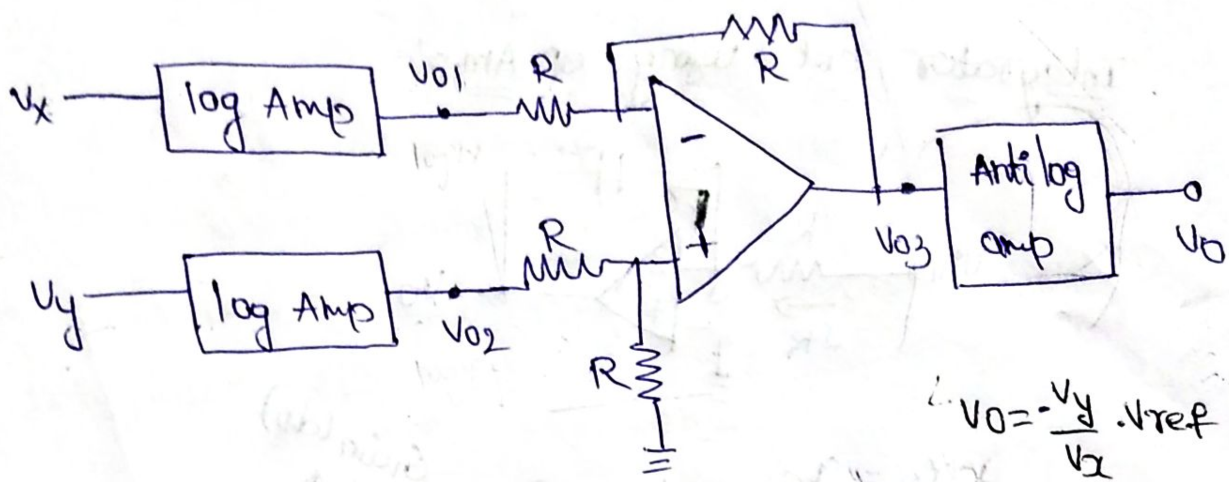
From (1)

$$-\frac{V_x V_O}{V_{ref}} \times \frac{1}{\cancel{R}} = \frac{V_z}{\cancel{R}}$$

$$\boxed{V_O = -\frac{V_z}{V_x} \times V_{ref}}$$

where $V_z$, $V_x$ are i/ps

* Designing a divider by using log & anti-log Amplifier:-




$$\therefore V_0 = -\frac{V_y}{V_x} \cdot V_{ref}$$

$$V_{01} = (\ln V_x) \cdot V_{ref}$$

$$V_{02} = (\ln V_y) \cdot V_{ref}$$

$$V_{03} = V_{02} - V_{01}$$

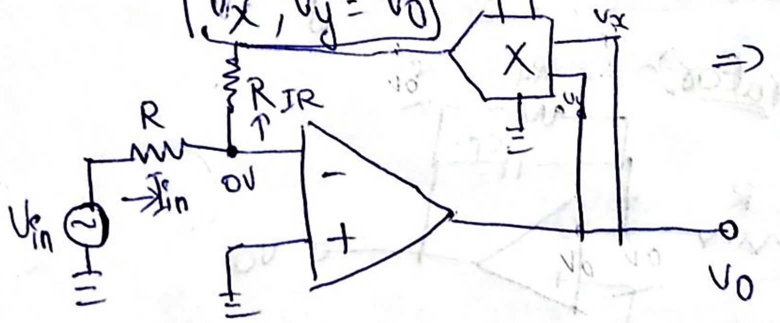
$$= (\ln V_y - \ln V_x)^{V_{ref}} \Rightarrow \left(\ln\left[\frac{V_y}{V_x}\right]\right) V_{ref}$$

$$V_{03} = V_{ref} \ln\left[\frac{V_y}{V_x}\right]$$

apply anti-log

$$V_0 = -V_{ref} \cdot \frac{V_y}{V_x}$$

Finding square root:




$\Rightarrow$

$$I_{in} = -I_R$$

$$\frac{V_{in}}{R} = -\frac{V_x V_y}{V_{ref} \cdot R}$$

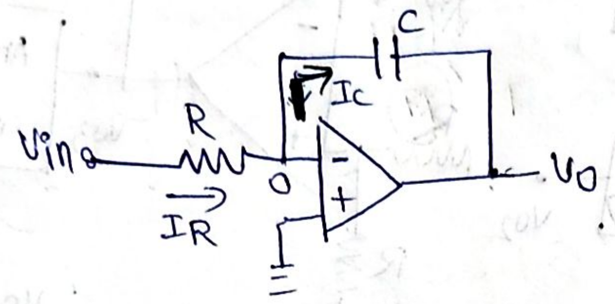
$$\frac{V_{in}}{R} = -\frac{V_0^2}{V_{ref} \cdot \cancel{R}}$$

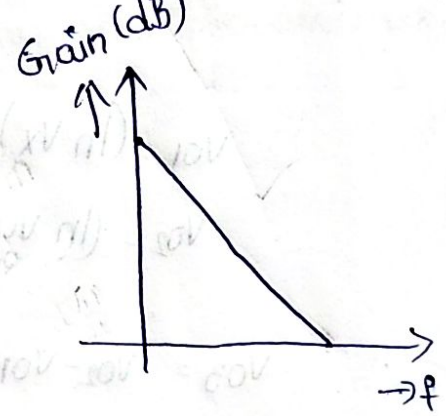
$$V_0^2 = -V_{in} \cdot V_{ref}$$

$$V_0 = \sqrt{|V_{in}| \cdot V_{ref}}$$

## * Integrator and Differentiator using op Amplifier:-

Integrator ckt using op Amp:-




$I_R = I_C$

$$\frac{V_{in}}{R} = C \cdot \frac{dV_o}{dt}$$

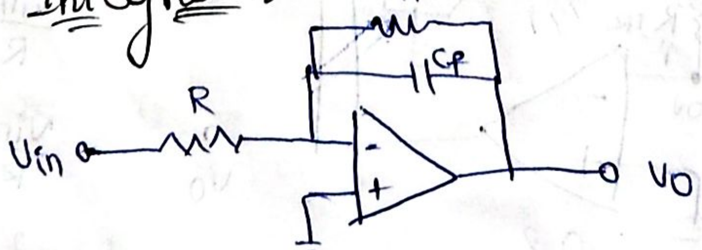
$$\frac{dV_o}{dt} = \frac{1}{RC} \cdot V_{in}$$

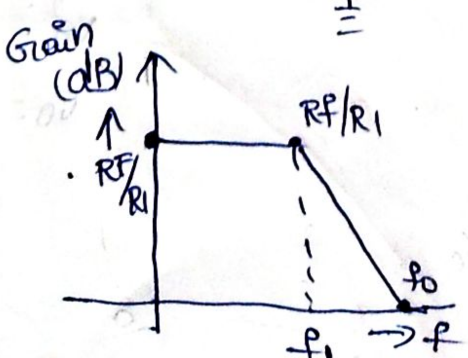
$$\boxed{V_o = \frac{1}{RC} \int V_{in}\, dt}$$

→ operational amplifier it maintains some input offset voltage (Vios) but due to this Vios, the gain of this integrator is affected.

→ To eliminate this effect we can add a feed back resistor Rf along with the Cf

practical Integrator:-




$$f_1 = \frac{1}{2\pi R_f C_f}$$

$$f_o = \frac{1}{2\pi R C_f}$$

for proper Integration.

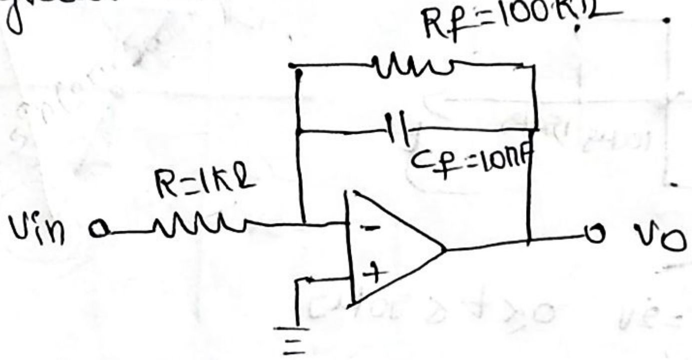
$f_1 < f_a < f_0$

$f_1 \rightarrow$ Lower cut of frequency

$f_a \rightarrow$ i/p frequency

$f_0 \rightarrow$ zero dB frequency.

① Find lower cut off frequency for the given Integrator ckt.




Sol:- given that,

$R = 1k\Omega$

$R_f = 100k\Omega$

$C_f = 10nf$

Lower cut off frequency $f_1 = ?$

Formula:- $\boxed{f_1 = \frac{1}{2\pi R_f C_f}}$

$$f_1 = \frac{1}{2\pi \times 100\times10^3 \times 10\times10^{-9}} = 159.23 Hz$$

$$f_0 = \frac{1}{2\pi R C_f} = \frac{1}{2\pi\times 10^3 \times 10\times10^{-9}} = 15.92 KHz$$

ii) $v_{in} = \sin(2\pi \times 5000t)$

$$V_0 = -\frac{1}{R\times C_f}\int v_{in}(t)\,dt$$

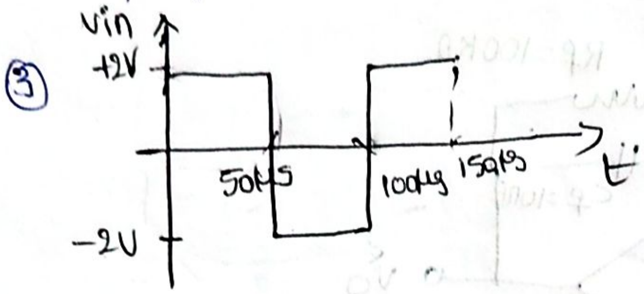
$$= -\frac{1}{10^3\times 10\times10^{-9}}\int \sin(2\pi\times 5000t)\,dt$$

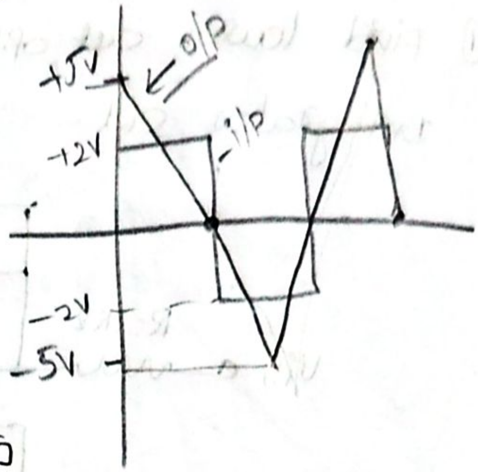
$$= -10^5 \left[ - \frac{\cos(2\pi \times 5000t)}{2\pi \times 5000} \right]$$

$$V_0 = 3.183 \cos(2\pi \times 5000t)$$

The amplitude of o/p signal depends upon R, Cf & Vin also.

(3)




$v_1(t) = 2V \quad 0 \leq t \leq 50\mu s$

$v_2(t) = -2V \quad 50\mu s \leq t \leq 100\mu s$

Total time period = 100µs.

$$f = \frac{1}{T} = \frac{1}{100 \times 10^{-6}} = 10KHz$$

$$V_{01} = -\frac{1}{RC_f} \int V_{in}(t)\, dt \qquad V_{02} = -\frac{1}{RC_f} \int V_{in}(t)\, dt$$

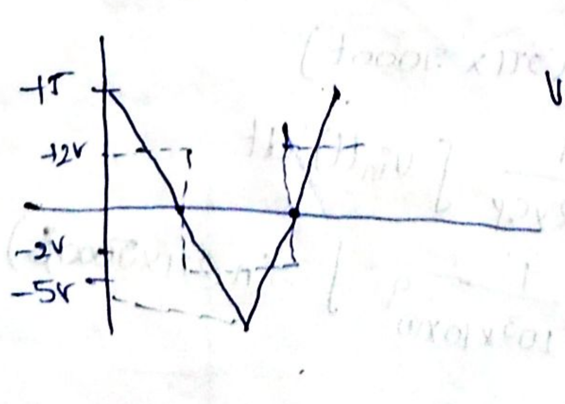
$$= -10^5 \int_0^{50\mu s} 2V dt \qquad = -10^5 \int_{50}^{100} -2V dt$$

$$= -10^5 \left[2 [t]_0^{50\mu s}\right] \qquad = +10^5 \times 2 [100-50] \times 10^{-6}$$

$$= +10V$$

$$= -10^5 \times 2 [50 - 0] = -10^5 \times 100 \times 10^{-6}$$

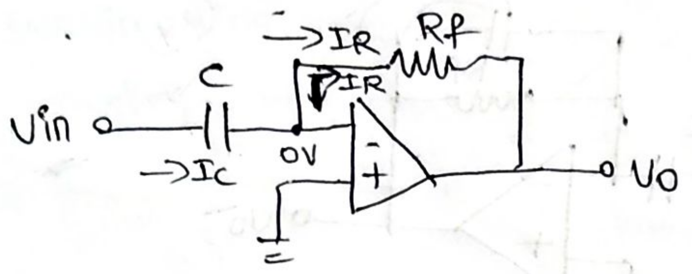
$$= -10V$$




$$V_0 = V_{01} + V_{02}$$

$$= -10 + (+10) = \underline{0V}$$

* Differentiator ckt using op-amplifier:




$$I_C = I_R$$

$$C \frac{dv_{in}}{dt} = \frac{V_o}{R_f}$$

$$R_f C \frac{dv_{in}}{dt} = V_o$$

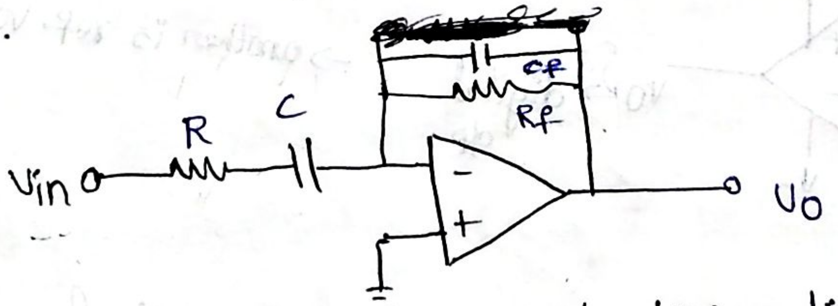
$$\boxed{V_o = R_f C \frac{dv_{in}}{dt}}$$

$$\therefore A = -\frac{X_C}{R}$$

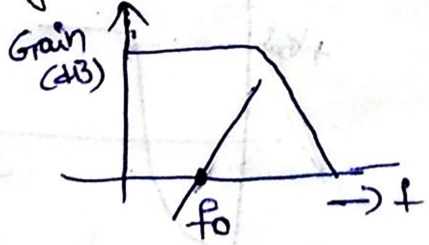
Drawbacks:

* high sensitive to frequency
* Low i/p impedance because of frequency is high.

To overcome this we are connecting i/p Resistance R, feedback capacitance Cf to the Ideal differentiator.

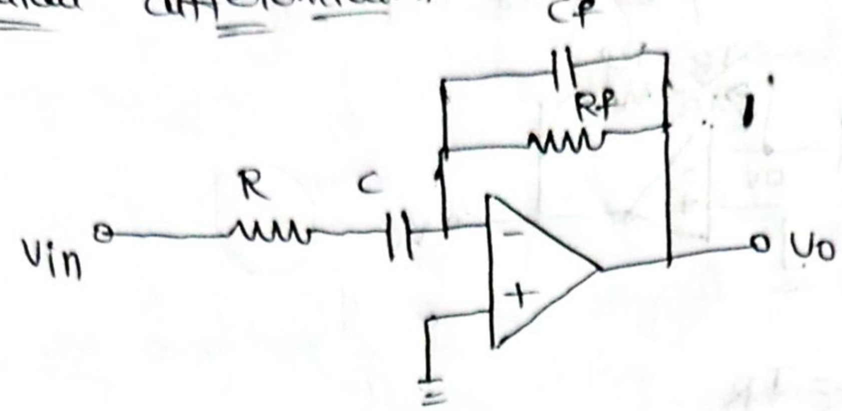



Frequency response of Ideal differentiator



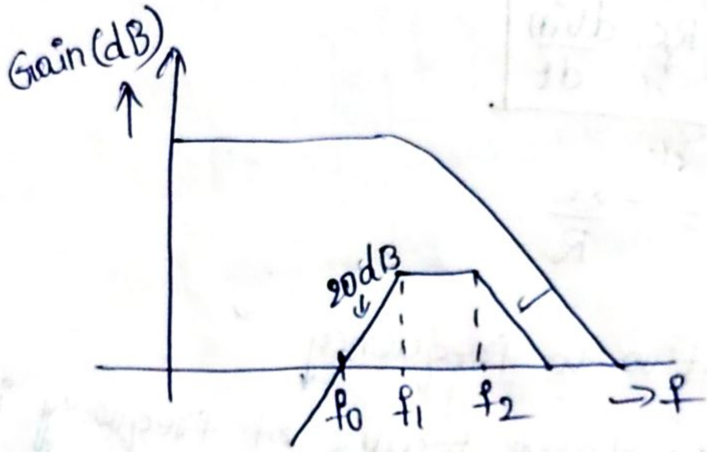

The Ideal differentiator frequency response limited by the open loop gain.

Practical differentiator:

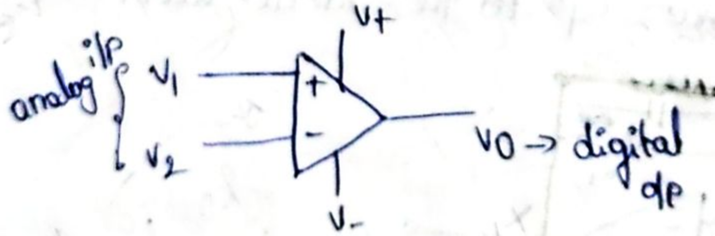



$$f_1 = \frac{1}{2\pi RC} \quad , \quad f_2 = \frac{1}{2\pi R_f C_f}$$

Frequency response for practical differentiator.

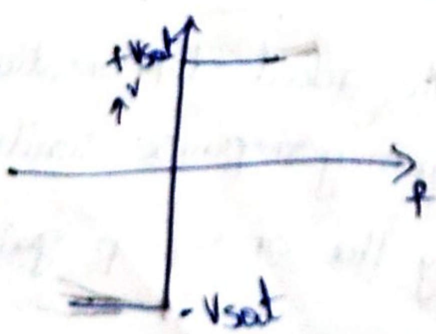



* Comparator

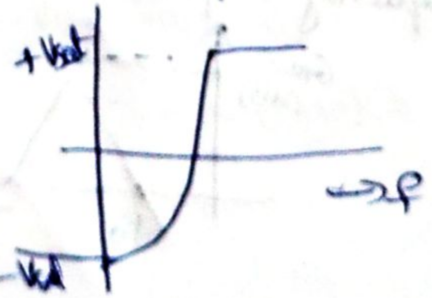



→ one is i/p voltage
→ another is ref. voltage

Ideal



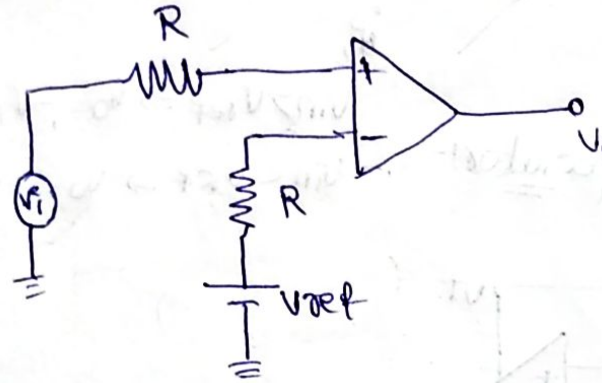

practical



There are basically two types of comparators:-

1. Non-inverting comparator.
2. Inverting comparator.

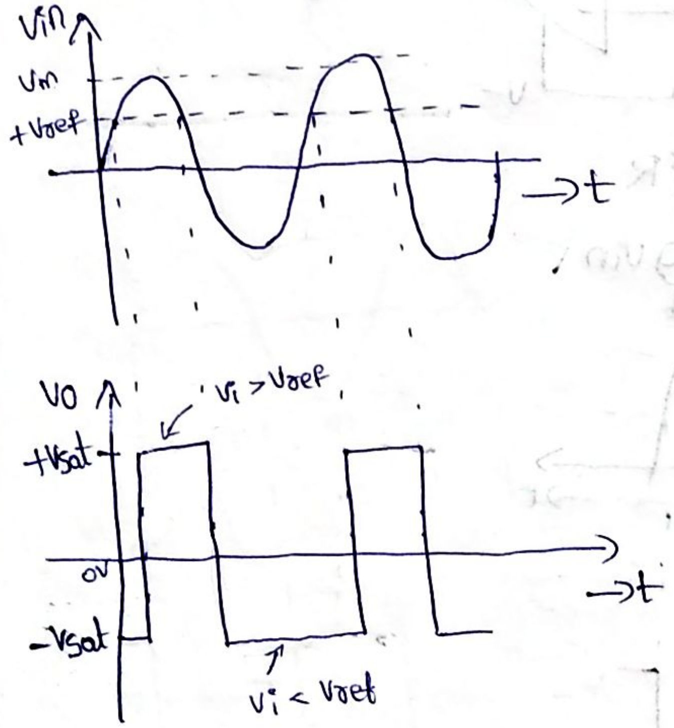
* **Non-inverting comparator:-**

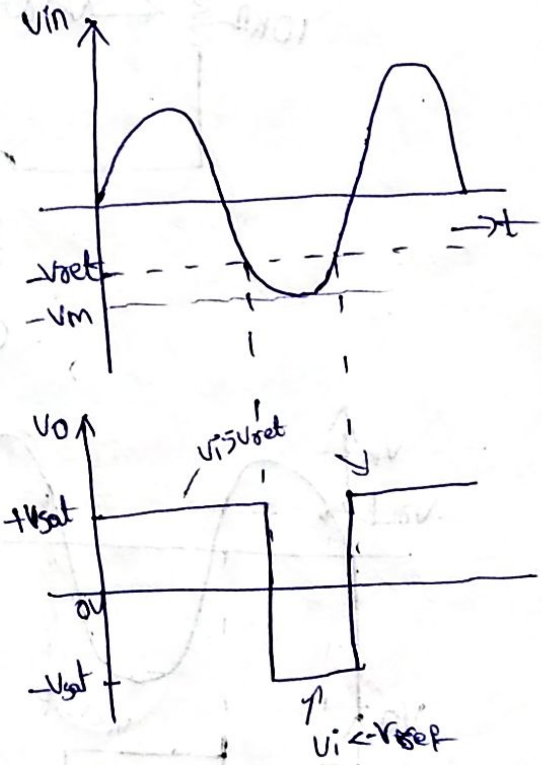



if,

$V_{in} > V_{ref} \Rightarrow V_0 = +V_{sat}$

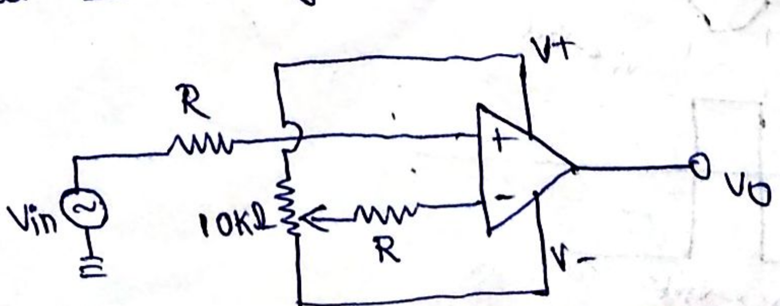
$V_{in} < V_{ref} \Rightarrow V_0 = -V_{sat}$



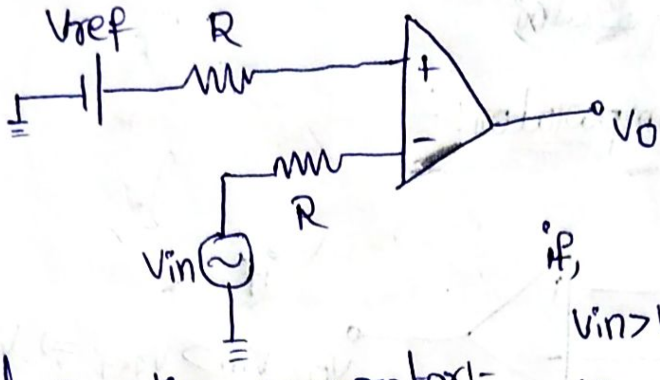




For some applications instead of Vref, we are using a potentiometer of 10 KΩ is added to the inverting terminal.

**Practical Non-inverting comparator:-**



## * Inverting comparator:-

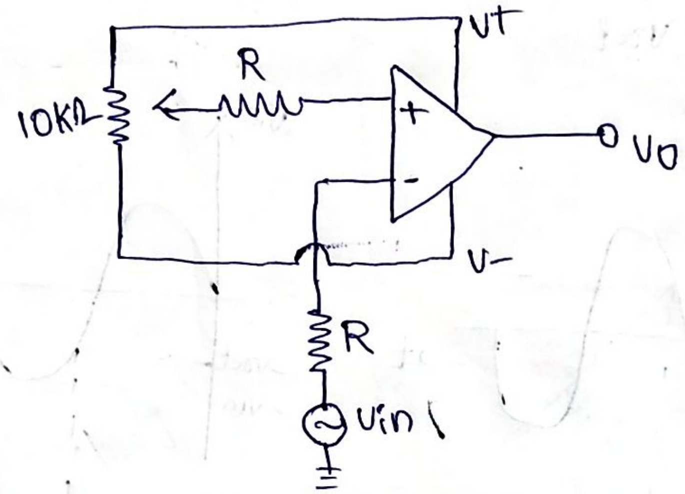


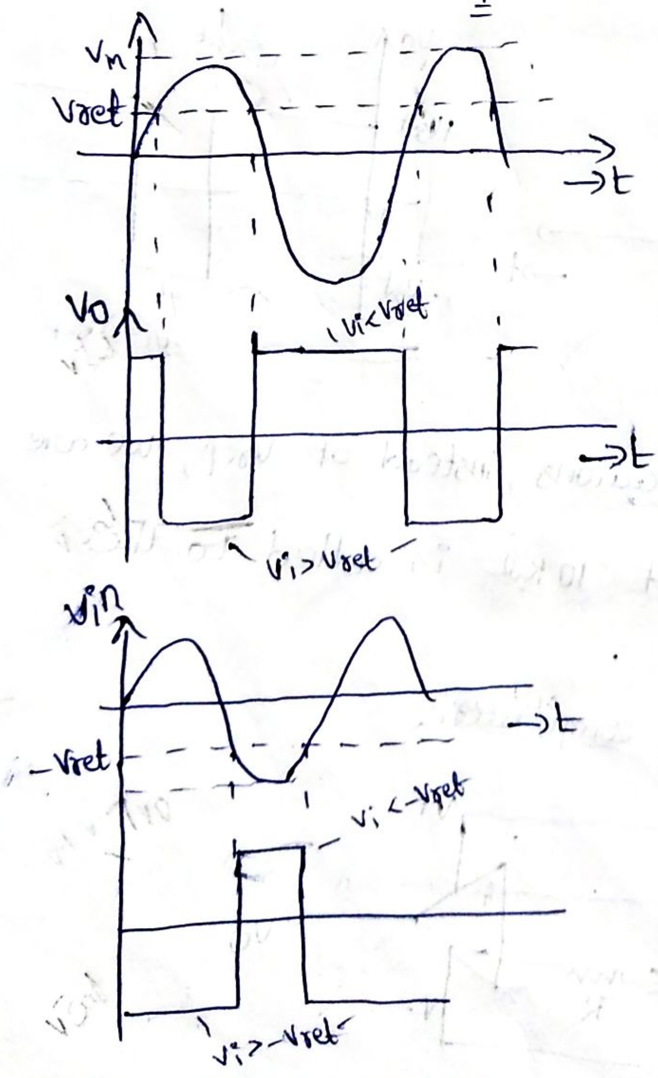

if,

$V_{in} > V_{ref} \Rightarrow V_0 = -V_{sat}$

$V_{in} < V_{ref} \Rightarrow V_0 = +V_{sat}$

### practical Inverting comparator:-



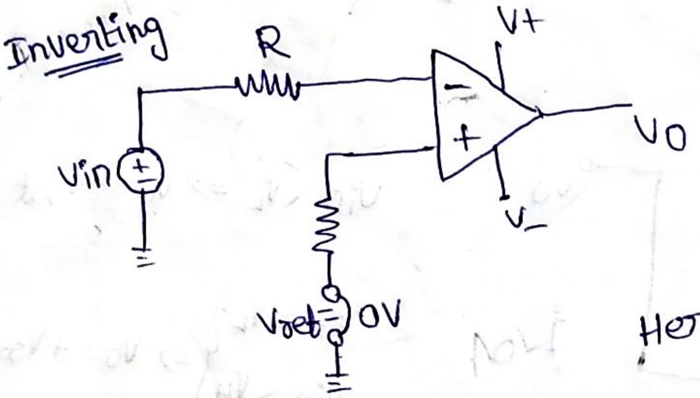



* Applications of Comparator:-

1. zero frequency detector
2. window Detector
3. Time marker generator
4. phase meter.

① zero frequency detector:-

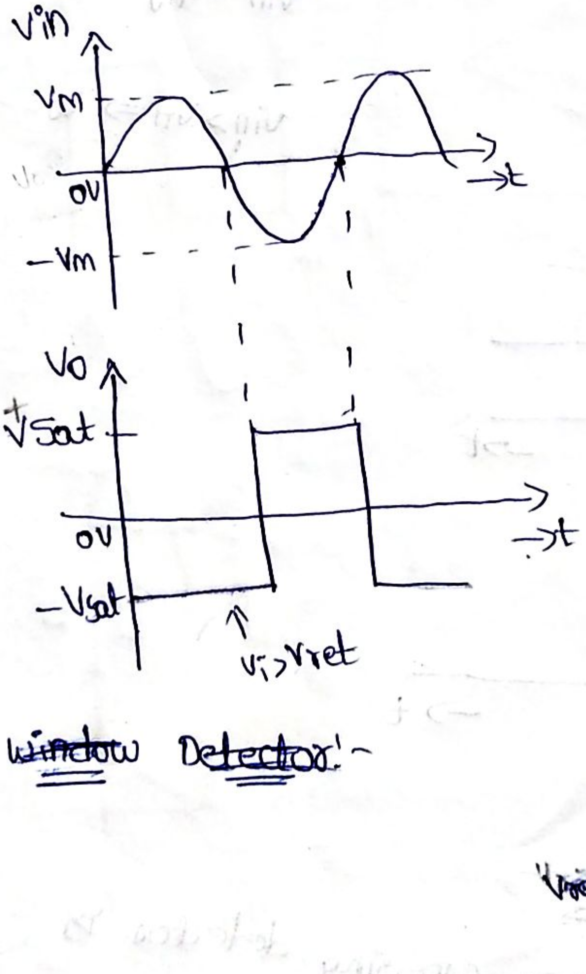
Inverting



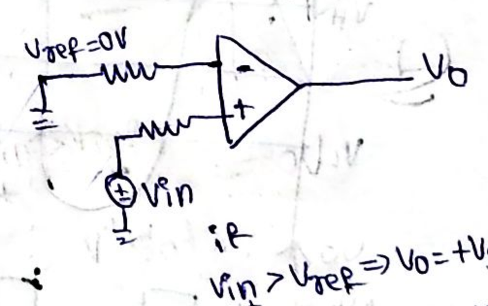

Here $V_{ref} = 0V$

$V_{in} > V_{ref} \Rightarrow V_o = -V_{sat}$

$V_{in} < V_{ref} \Rightarrow V_o = +V_{sat}$




Non-Inverting

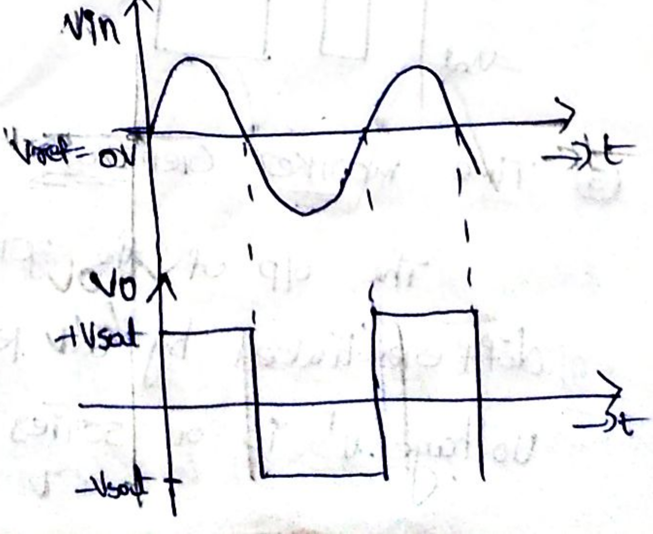



if

$V_{in} > V_{ref} \Rightarrow V_o = +V_{sat}$

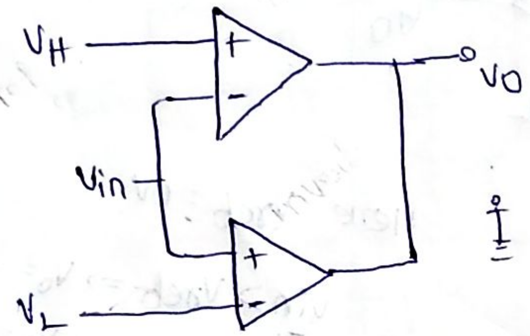
$V_{in} < V_{ref} \Rightarrow V_o = -V_{sat}$

② window Detector:-



② Window Detector:- In this comparator, we are using two comparators. In some applications, when it is required to have a high to low o/p when the input is specific band. It can be designed by combination of Inverting and non-Inverting comparator.

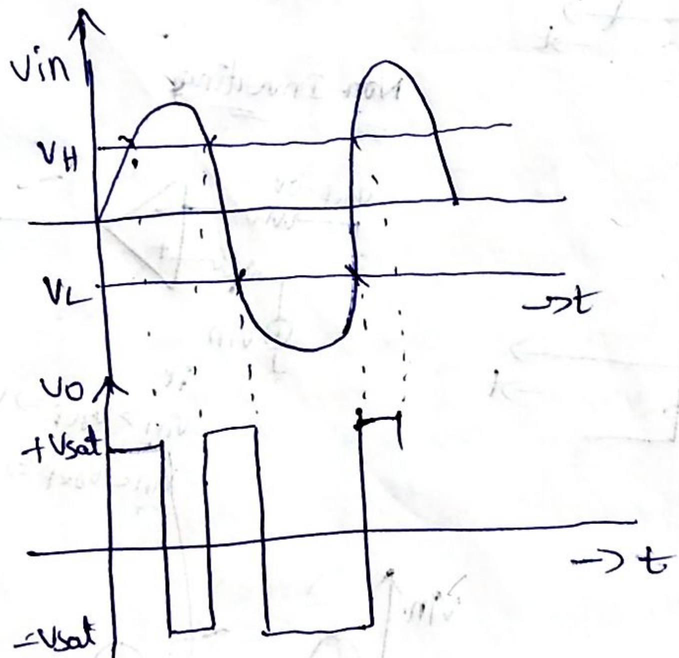
$V_L < V_{in} < V_H \Rightarrow V_0 = \pm V_{sat}$




$V_{in} < V_L \Rightarrow V_0 = -V_{sat}$

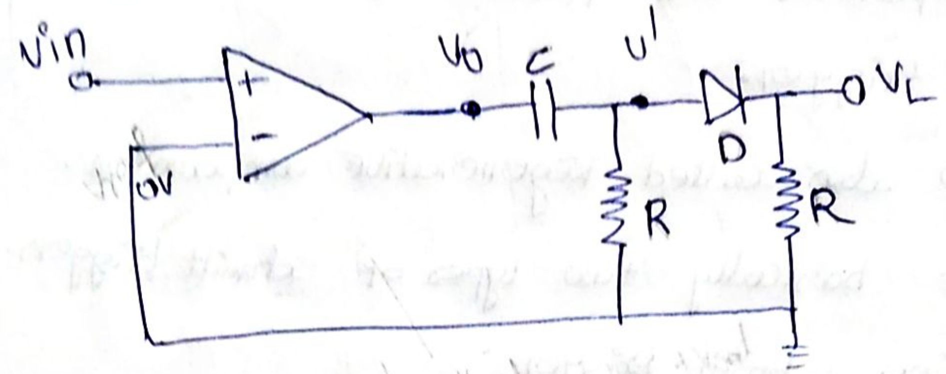
$\left.\begin{matrix} V_{in} > V_L \\ V_{in} < V_H \end{matrix}\right\} \Rightarrow V_0 = +V_{sat}$

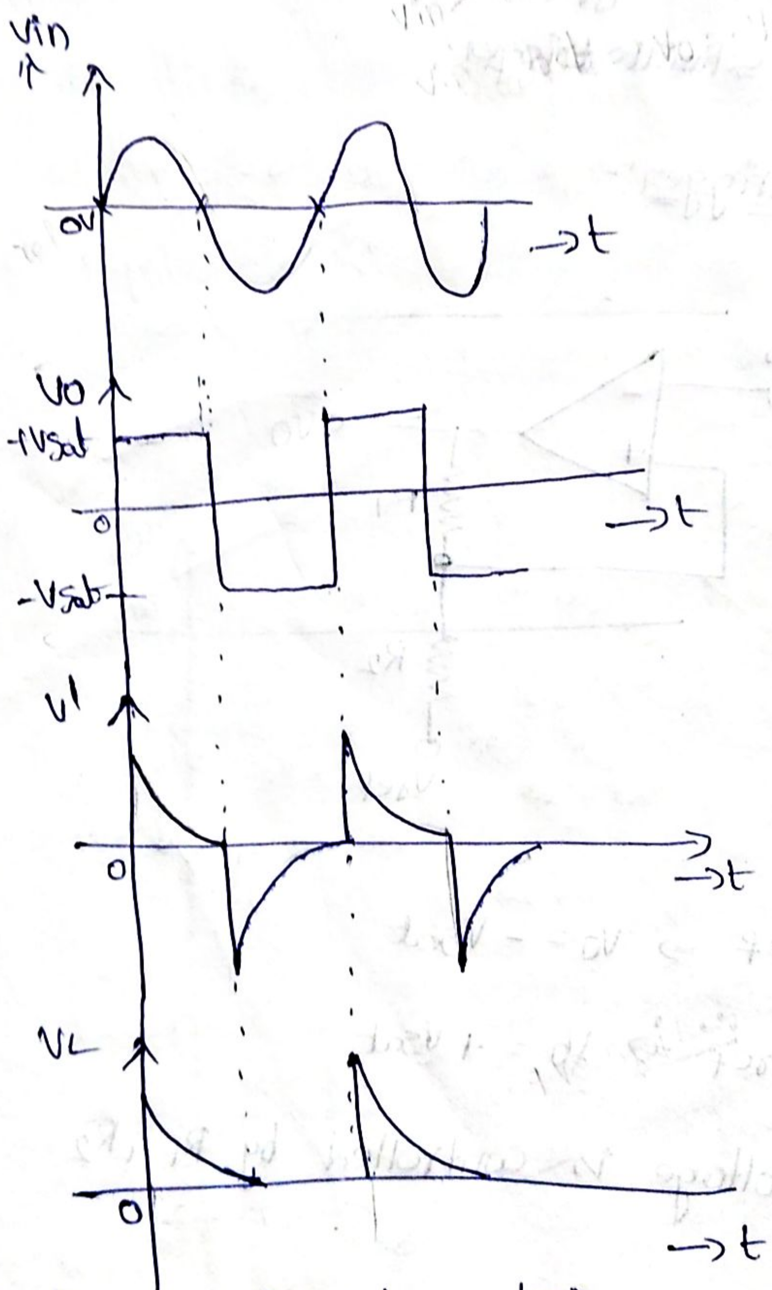
$V_{in} > V_H \Rightarrow V_0 = -V_{sat}$




③ Time marker Generator:-

The o/p of the zero-crossing detector is differentiated by an RC circuit, so that the voltage $v'$ is a series of positive and negative pulses. The negative portion is clipped off after passing through the diode D the o/p is $V_L$.




(4) <u>phase Detector (phase meter)</u> :- By using time marker Generator. Both voltages are converted into spikes and the time interval b/w the pulse spikes of one i/p. The time interval is proportional to phase difference.

## Schmitt trigger:-

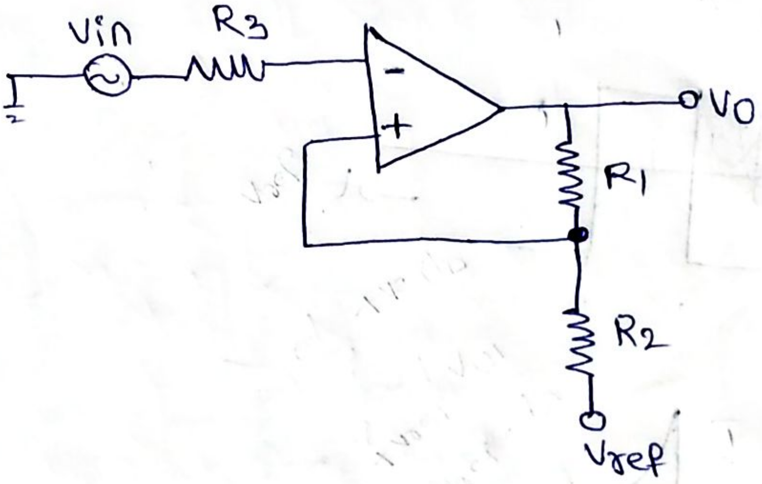
→ A Comparator with positive feedback is called Schmitt trigger.

→ It is also called Regenerative comparator.

There are basically two types of Schmitt triggers.

1. Inverting Schmitt trigger.
2. non-Inverting Schmitt trigger.

## Inverting Schmitt trigger:-




if $V_{in} > V_{ref} \Rightarrow V_0 = -V_{sat}$

$V_{in} < V_{ref} \Rightarrow V_0 = +V_{sat}$

Reference voltage is controlled by $R_1$ & $R_2$

$$+V_{ref} = \frac{V_0}{R_1+R_2} \times R_2 = \frac{+V_{sat} \times R_2}{R_1+R_2} = +\beta V_{sat}$$

$$-V_{ref} = \frac{V_0}{R_1+R_2} \times R_2 = -V_{sat} \times \frac{R_2}{R_1+R_2} = -\beta \cdot V_{sat}$$

→ At $+V_{ref}$, $V_O = +V_{sat}$. This is called upper threshold voltage $(+V_{ref} = V_{UT})$.

→ At $-V_{ref}$, $V_O = -V_{sat}$. This is called Lower threshold voltage $(-V_{ref} = V_{LT})$

$V_{in} > V_{UT} \Rightarrow V_O = -V_{sat}$

$V_{in} < V_{LT} \Rightarrow V_O = +V_{sat}$

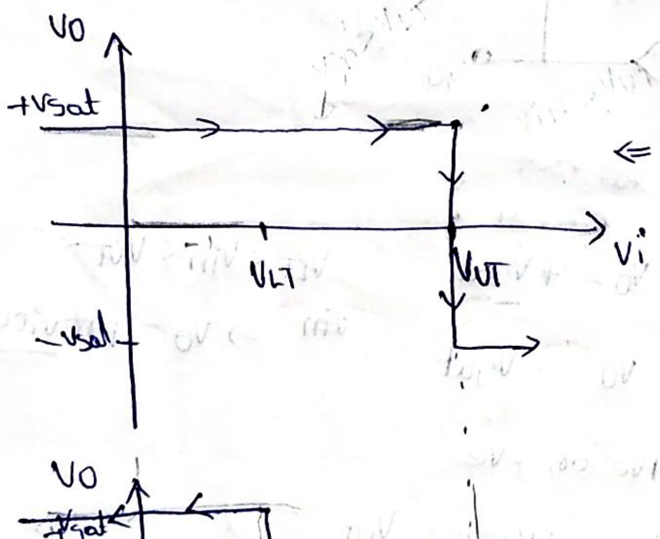
$V_{LT} < V_{in} < V_{UT} \Rightarrow$ $V_O$ = previous state

→ The difference b/w $V_{UT}$ & $V_{LT}$ is called as width of hysterisis. Denoted by H.

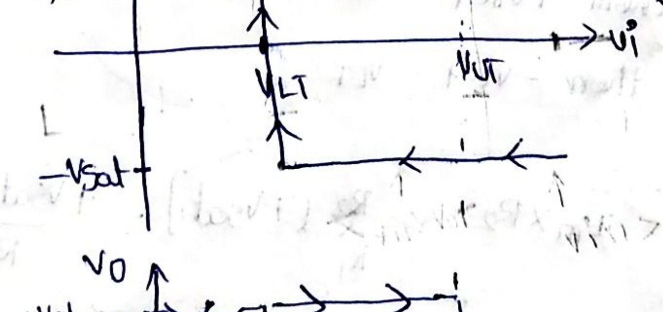
→ Hysterisis is also called as dead band or dead zone.

$H = V_{UT} - V_{LT} = +V_{sat}\frac{R_2}{R_1+R_2} + \left(+V_{sat}\frac{R_2}{R_1+R_2}\right)$

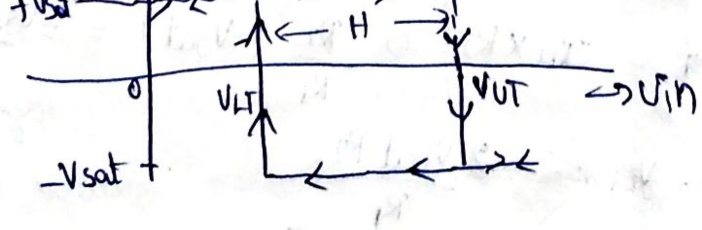
$$H = \frac{2V_{sat}R_2}{R_1+R_2} \qquad \left[\because H = V_{UT} - V_{LT}\right]$$

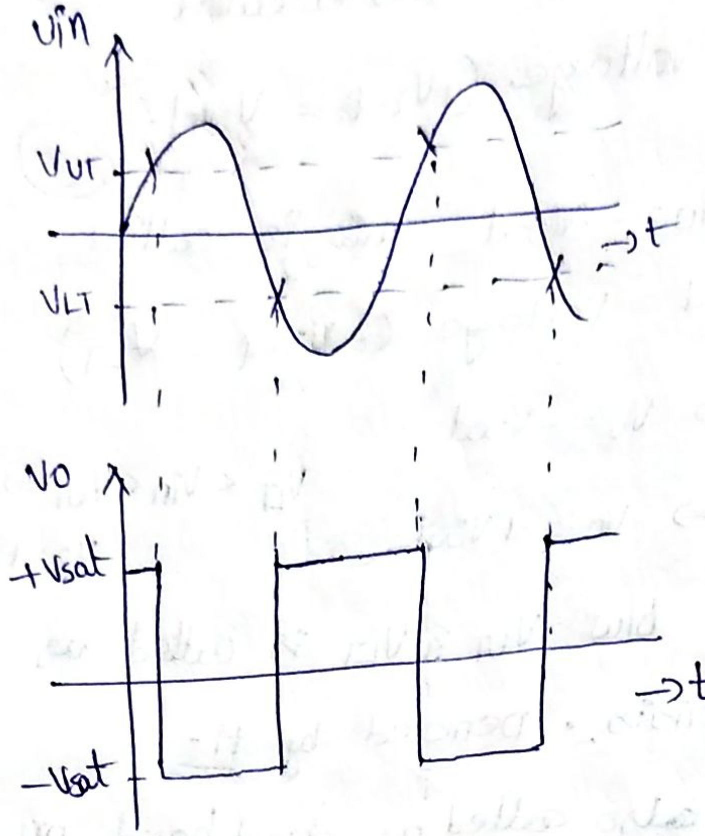



⇐ if i/p moves Low to high

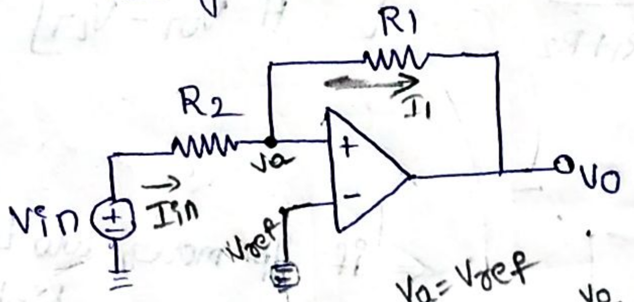



⇐ if i/p moves high to Low






## Non-Inverting schmitt trigger :-




$V_a = V_{ref}$

$I_{in} = I_1 = \frac{V_o}{R_1}$

if $V_{in} > V_{ref} \Rightarrow V_o = +V_{sat}$

$V_{in} < V_{ref} \Rightarrow V_o = -V_{sat}$

$V_{LT} < V_{in} < V_{UT}$

$\Rightarrow V_o =$ previous state

$V_{ref}$ is either +ve or, -ve

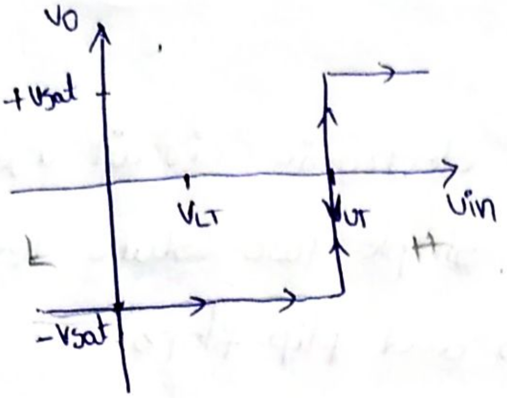
if it is +ve them $+V_{ref} = V_{UT}$

it is -ve then $-V_{ref} = V_{LT}$

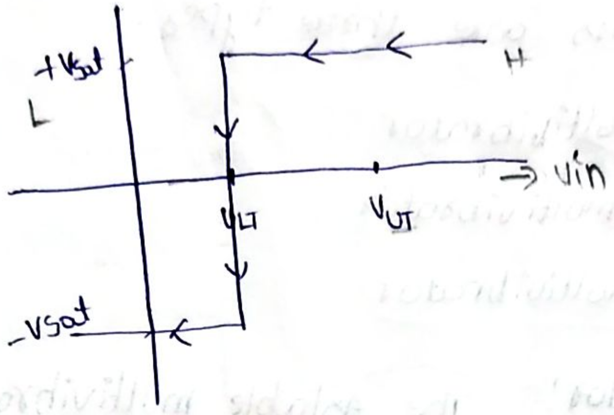
Here $V_{UT} = I_{in} \times R_2 \Rightarrow \frac{R_2}{R_1}(+V_{sat}) = \frac{+V_{sat} R_2}{R_1}$

$V_{LT} = I_{in} \times R_2 \Rightarrow \frac{R_2}{R_1}(-V_{sat}) = \frac{-V_{sat} R_2}{R_1}$

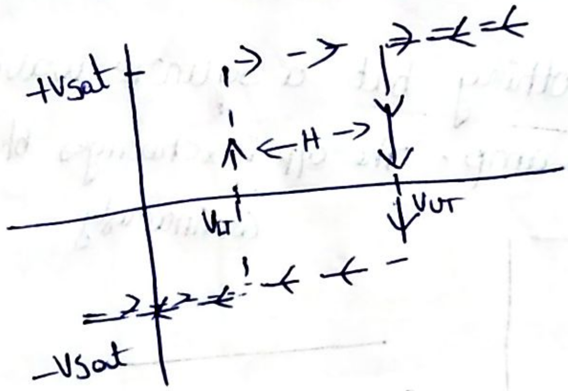
$H = V_{UT} - V_{LT} = \frac{2 V_{sat} R_2}{R_1}$



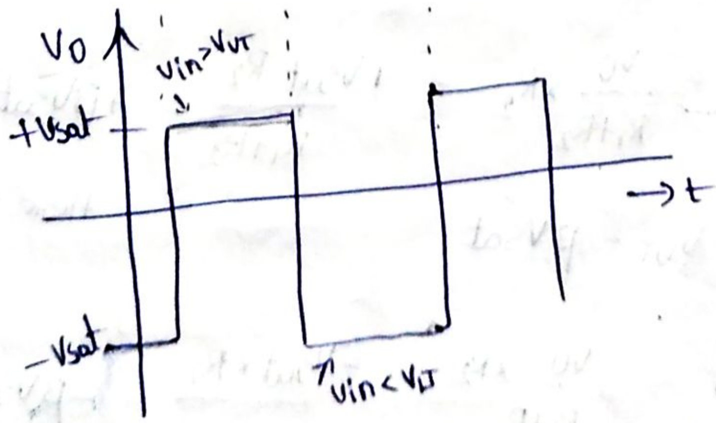

if i/p moves from Low to high




if i/p moves from high to Low.








Hysterisis:- The output changes its states whenever i/p voltage exceeds certain voltage levels. i.e $V_{UT}$ & $V_{LT}$.

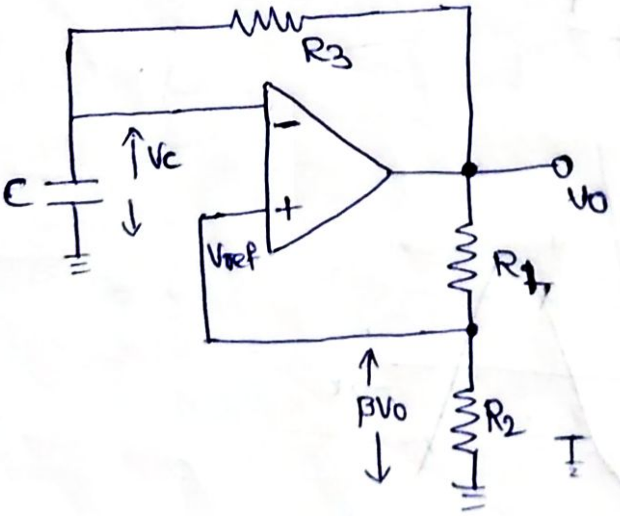
# Multivibrators:-

• Multivibrator is an electronic circuit used to implement a variety of simple two-state devices such as oscillators, timers and flip-flops.

• The multivibrators are three types.

1. Astable multivibrator
2. Monostable multivibrator
3. Bi-stable multivibrator.

1. **Astable multivibrator:-** The Astable multivibrator using op-amp is nothing but a square wave generator using op-amp. The o/p is changes b/w two states continuously




$$+V_{ref} = V_{UT} = \frac{V_o}{R_1+R_2} \times R_2 = \frac{+V_{sat} R_2}{R_1+R_2} = +\beta V_{sat}$$

Here $\beta = \frac{R_2}{R_1+R_2}$

$$\therefore V_{UT} = \beta V_{sat}$$

$$-V_{ref} = V_{LT} = \frac{V_o}{R_1+R_2} \times R_2 = \frac{-V_{sat} \times R_2}{R_1+R_2} = -\beta V_{sat}$$

$$V_{LT} = -\beta V_{sat}$$

→ if $V_C < V_{UT} \Rightarrow V_O = +V_{sat}$ then

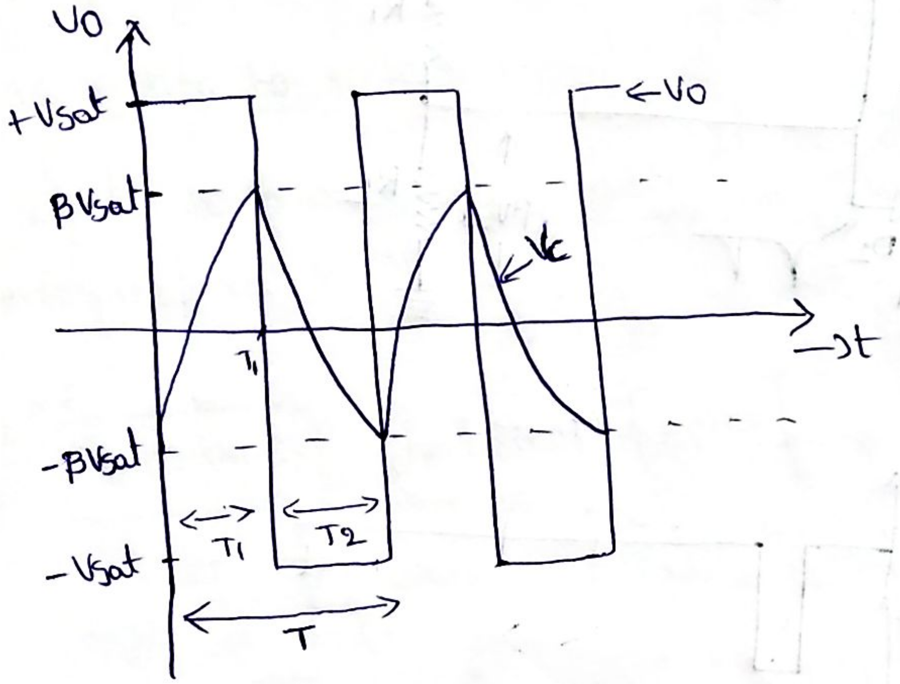
capacitor charges upto $\beta V_{sat}$ ($V_{UT}$).

→ $V_C > V_{UT} \Rightarrow V_O = -V_{sat}$ then, [& if $V_C < V_{LT} \Rightarrow V_O = -V_{sat}$]

capacitor discharges upto $-\beta V_{sat}$ ($V_{LT}$)

→ $V_C > V_{LT} \Rightarrow V_O = +V_{sat}$ then

capacitor charges upto $\beta V_{sat}$ ($V_{UT}$)




The time period of waveform is

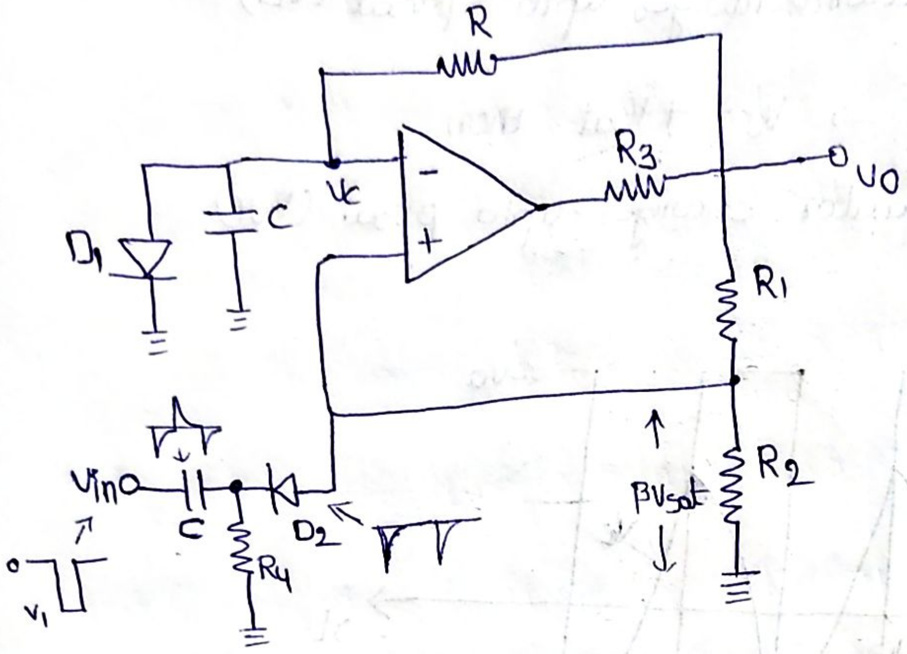
$$\therefore T = 2RC \ln\left[\frac{1+\beta}{1-\beta}\right] \qquad \left[\text{Here } \beta = \frac{R_2}{R_1+R_2}\right]$$

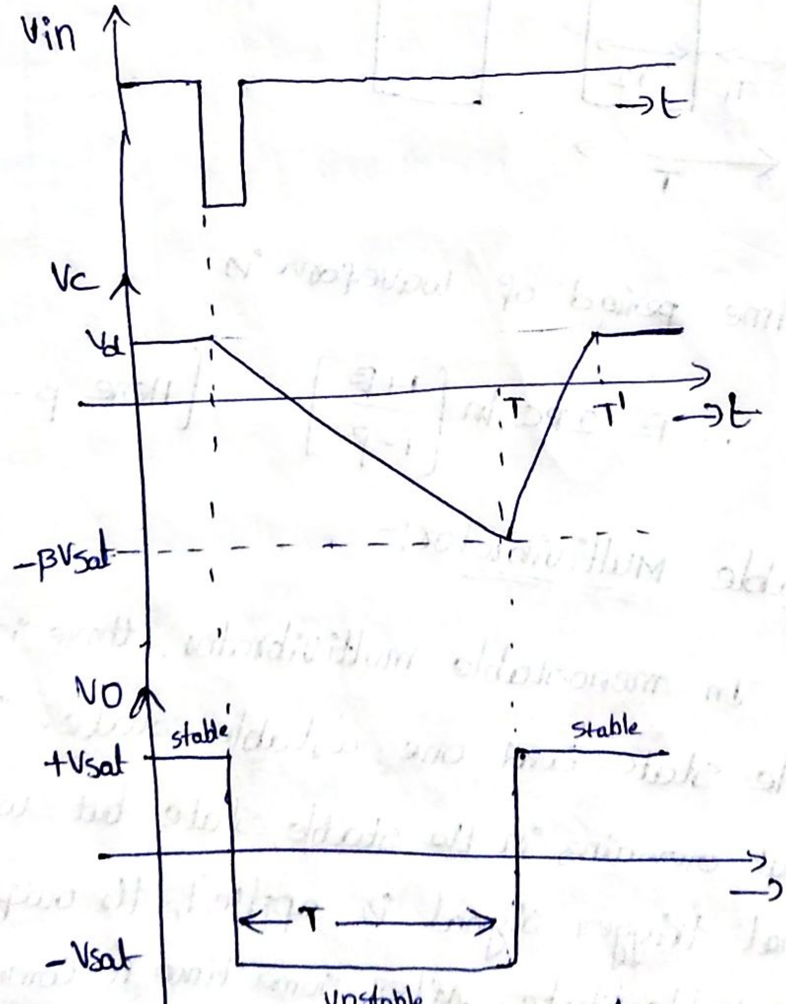
② <u>Monostable</u> <u>Multivibrator</u>:-

In monostable multivibrator, there is one stable state and one astable state. i.e., The output remains in the stable state but whenever an external trigger signal is applied, the output goes to astable state. After some time it comes back into stable state.

→ The time required to come back into the stable state depends on the passive components like R & C.

→ It is used in timer applications.

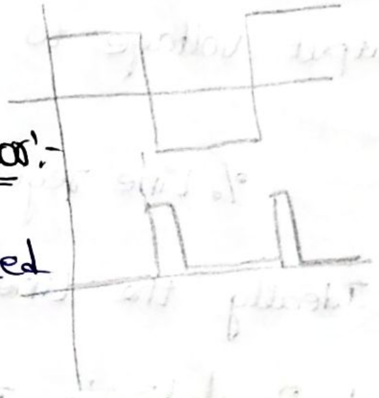



$$\beta = \frac{R_2}{R_1+R_2}$$

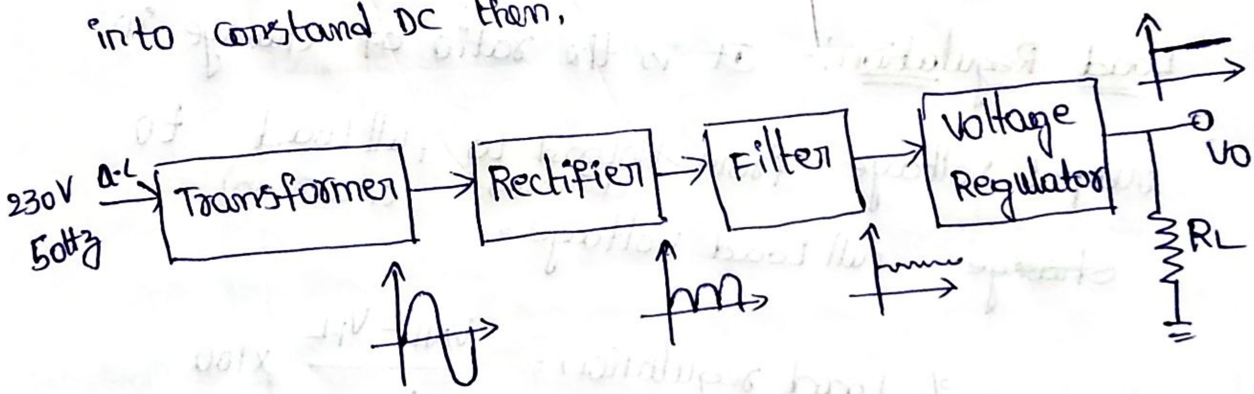
where $T = RC \ln\left[\frac{1+V_{D1}/V_{sat}}{1-\beta}\right]$

**Bistable multivibrator:-** It has two stable states. The output used to be in any one of the two stable states. whenever an external trigger signal is applied the output goes from one stable state to another stable state. If no triggering action is applied, then it remains in the new stable state. It is used in flip-flop circuits.



## * Introduction to voltage Regulator:-

If the AC powersupply converted into constand DC then,




- → if we are giving the AC powersupply to transformer, the o/p is AC signal.
- → The o/p of transformer a.c signal is i/p of Rectifier. It will convert AC into pulsating D.C or Ripples.
- → The o/p of Rectifier is i/p of filter. then it will convert pure D.C. but any changes in i/p or Load then o/p will changed [distorted]
- → To maintain constant o/p [DC], voltage regulator is used. It gives the o/p or constant DC.

Voltage Regulator:- The voltage Regulator is an electronic component of power supply, to make the output voltage constant irrespective of the changes in the Load or, line voltages [i/p voltages]

Line Regulation:- It is the ratio of change in output voltage to change in input voltage.

$$\% \text{ Line regulation} = \frac{\Delta V_O}{\Delta V_{in}} \times 100$$

Ideally the Line regulation is 0%.

Load Regulation:- It is the ratio of change in output voltage from NoLoad (minimum) to Full Load (maximum) to ~~change~~ Full Load voltage.

$$\% \text{ Load regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

Ideally the Load regulation is 0%.

Voltage Regulator has four components.

1. Reference voltage circuit
2. Error amplifier
3. pass transistor
4. Feed back network.

Depending on the connection of components the voltage regulators are classified as 2 types.

1. series voltage Regulator [ Tr & Load Connected in series]
2. shunt voltage Regulator [Tr & Load Connected in parallel].

Depending on the operation, It is classified as:

1. Series or Linear Regulator
2. Switching Regulator.

1. Series or Linear Regulator:-

→ In this regulators, the transistor connected in series b/w the unregulated dc i/p and the Load.

→ Linear regulators may have fixed output voltage [i.e +ve or -ve].

→ IC 723 is a Linear voltage regulator

2. Switching Regulator:-

→ In switching Regulators, the transistor as a high frequency on/off switch.

→ The transistor does not conduct current continuously.

→ This gives improved efficiency over series regulator.

IC 723 [General purpose Regulator]

Features:

→ Series voltage Regulator provides +ve & -ve voltage.

→ provides current upto 150 mA

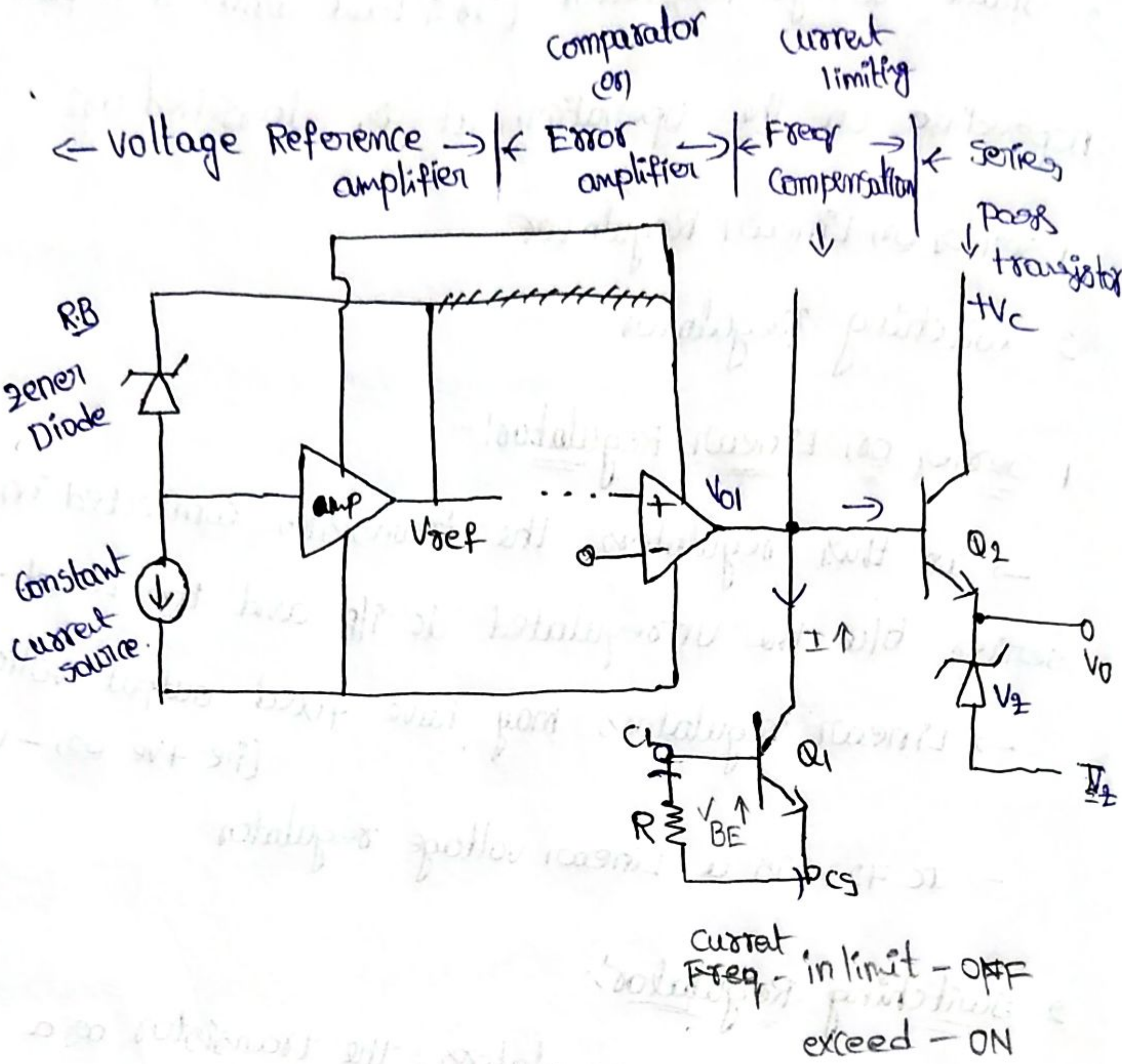
• with external resistor current upto 10 A

→ I/p voltage between 9 to 40V.

→ O/p voltage between 2 to 37V

→ Load and Line regulation is 0.01%

## Block diagram of IC 723:




→ In IC 723, It has 4 blocks.

→ In voltage Reference amplifier, zener Diode is connected with constant current source. It operates Reverse Bias.

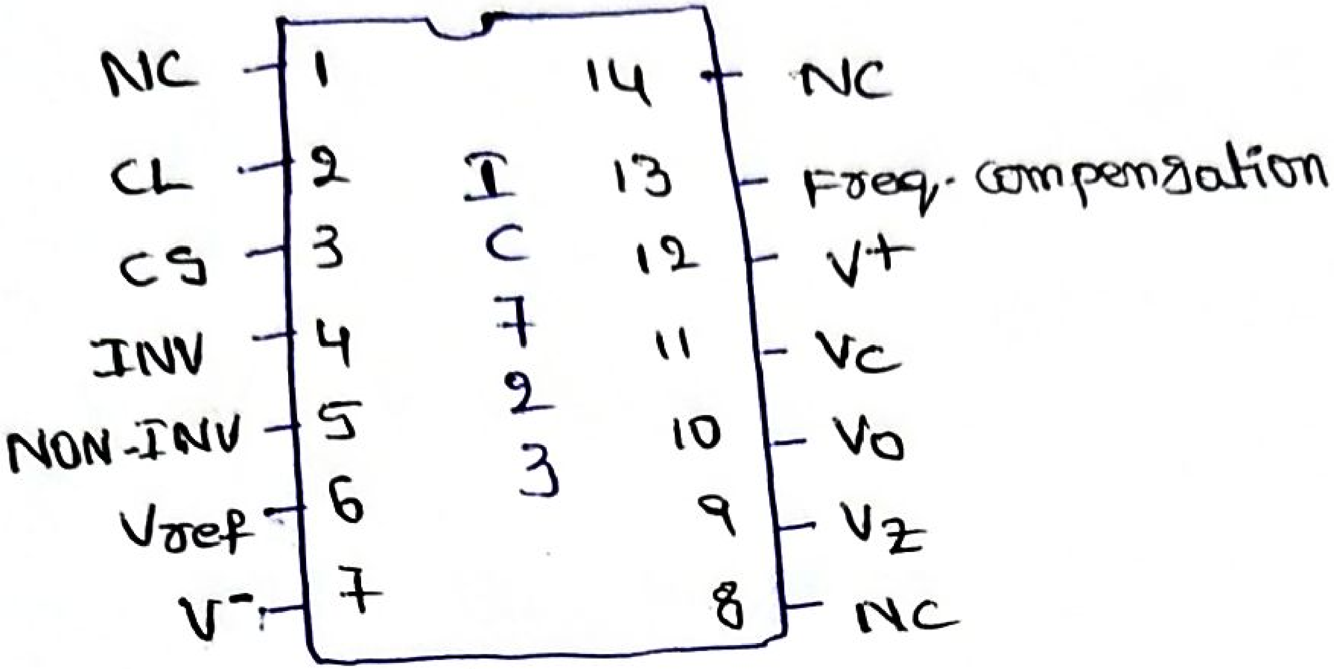
→ The output of voltage ref. amp gives to non-inverting input of the error amplifier.

→ The Inverting input is connected to total o/p voltage.

→ The output of error amplifier is connected to series pass transistor $Q_2$.

→ Transistor $Q_1$ acts as current limitter. It acts as ON / OFF switch.

PIN Diagram of IC 723 :-




Dual - in - line package