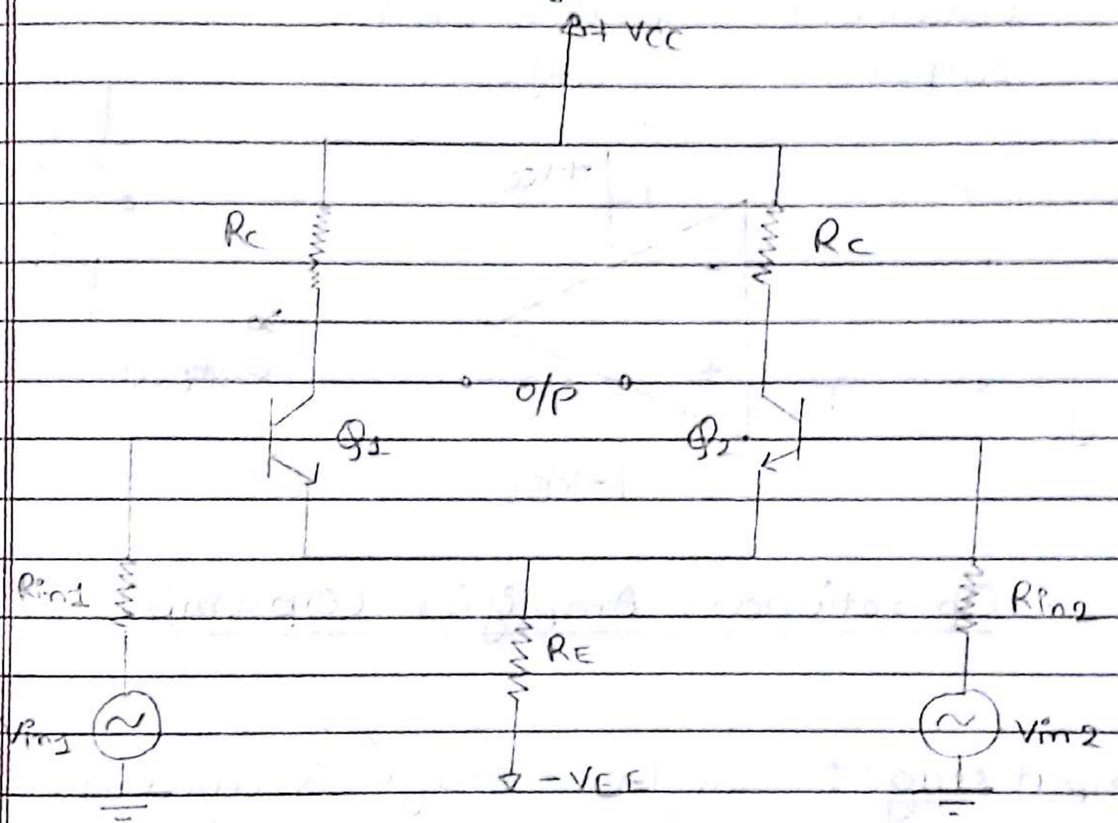
UNIT-I- Introduction to Op-Amp

Operational Amplifier

Operational Amplifier is a direct coupled high gain amplifier that consists of one or more differential amplifier.

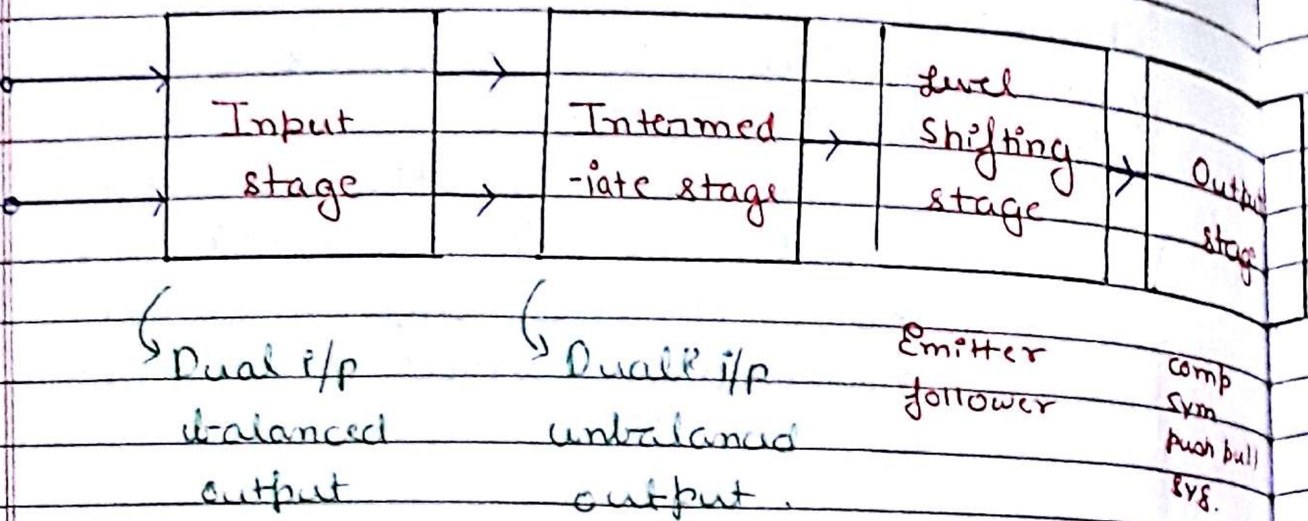
↳ it will amplify the diff of in i/p signal (b/w inverting & noninverting and hence the name differential amplifier.

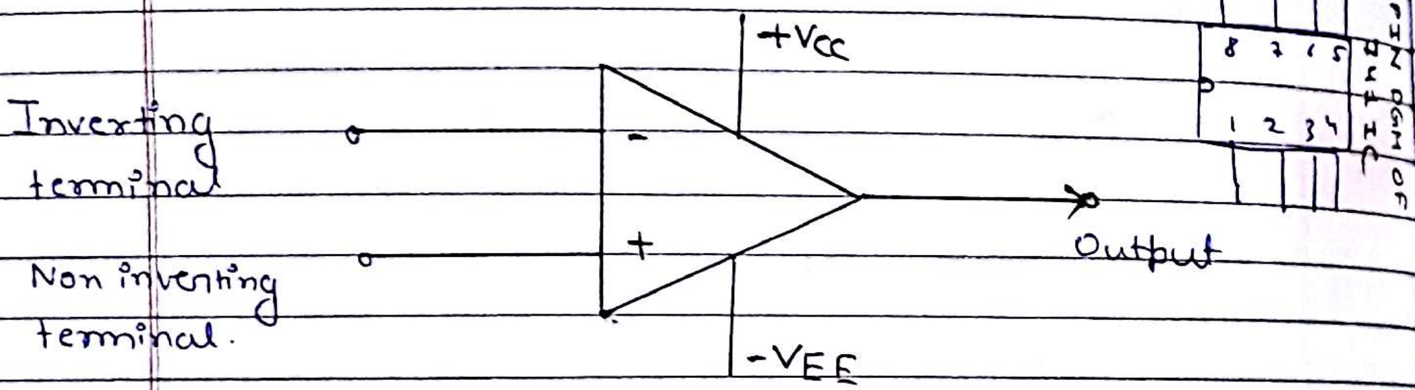


Differential amplifier

Op amp can be used to amplify DC as well as AC input signal and was designed for performing mathematical operation such as addition, subtraction, multiplication, integration, differentiation with addition of external feedback component.

BLOCK DIAGRAM OF OP-AMP





Operational Amplifier (Opamp)

1. **Input stage:** The input stage is dual input balanced output differential amplifier.

   This stage provides most of the voltage gain of the amplifier.

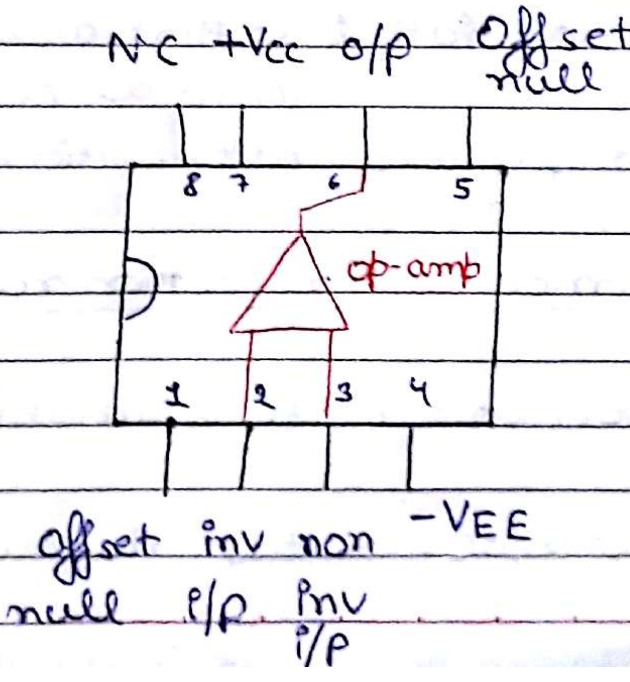
2. <u>Intermediate stage</u>: The intermediate stage is another differential amp. which is driven by output of first stage.

The intermediate is dual input unbalanced output because direct coupling is used, the DC voltage at the output of the intermediate stage is above the ground potential.

Therefore, in level translator circuit is used after the intermediate stage to shift the DC level to 0V wrt ground.

3. <u>Output stage</u>: The final stage is push-pull complementary amplifier, it increases the output voltage swing and raises the current supplying capacity of op-amp.

PIN DIAGRAM OF 741 IC



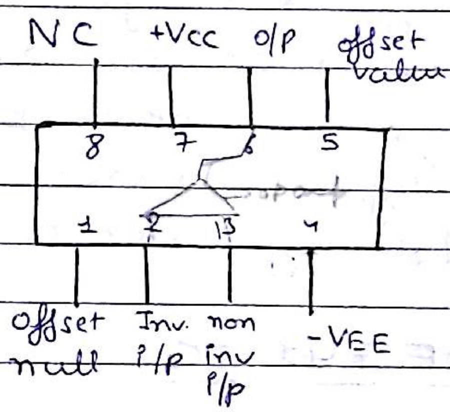
Characteristics of Ideal Op-Amp

1. Infinite voltage gain:

2. Infinite input resistance (Ri): so that any signal source cand drive it and there is no loading of the preeceeding stage.

3. Zero output resistance (Ro): so that output can drive an infinite number of other devices.

4. Zero output voltage: when input resistance is zero (offset value)

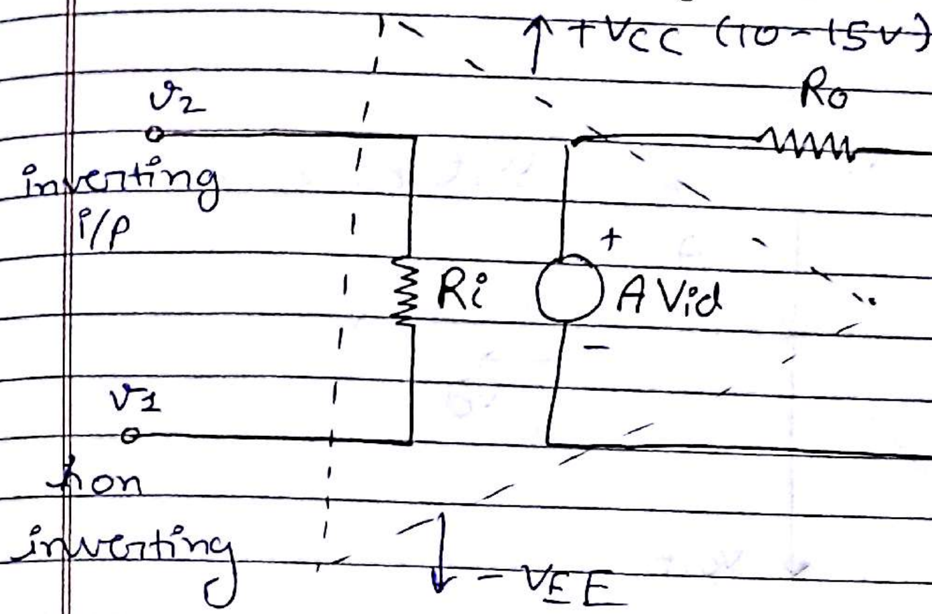


5. Infinite bandwidth: so that any signal from 0 to ∞ hertz can be amplified without any attenuation.

6. Infinite common volt rejection ratio: so that output common volt noise is small.

7. Infinite slew rate: so that the output voltage changes occur with the change in input voltage.

Equivalent circuit of op-Amp



$V_o = AVid$.

$A = \frac{V_{out}}{V_{in}}$.

$v_o = A(v_1 - v_2)$.

Equivalent circuit of an op-amp

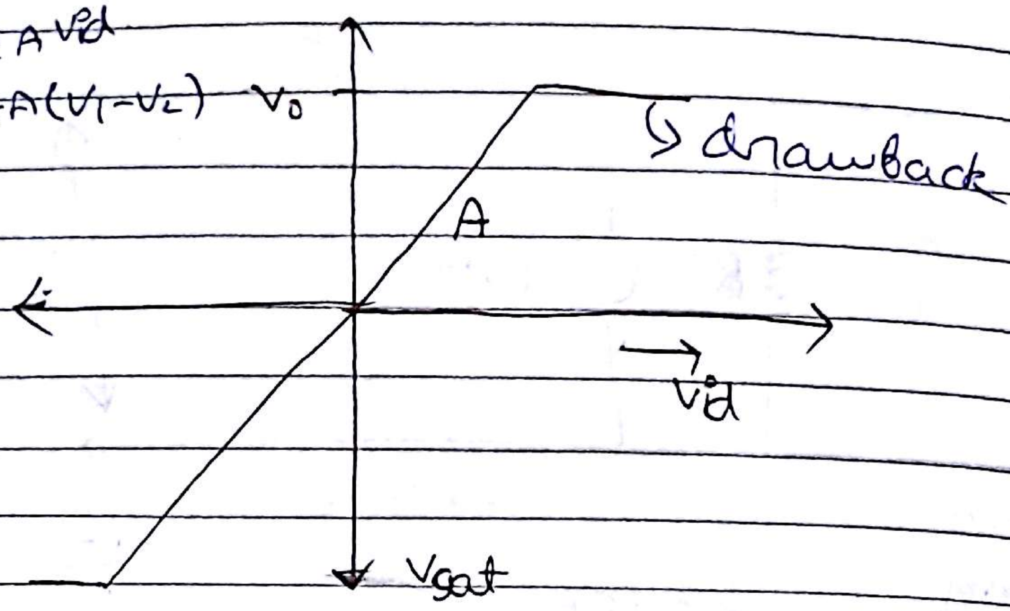
AVid is your equivalent thevenin voltage source and Ro is the thevenin equivalent resistance looking back through the op-amp o/p terminal circuit.

The equivalent circuit is useful in analyzing the basic principle of op-amp. (180° out of phase / in phase)

$$\boxed{V_o = A(V_1 - V_2) = AVid}$$

Ideal Voltage Transfer curve

$V_0 = A V_d$
$= A(V_1 - V_2)$

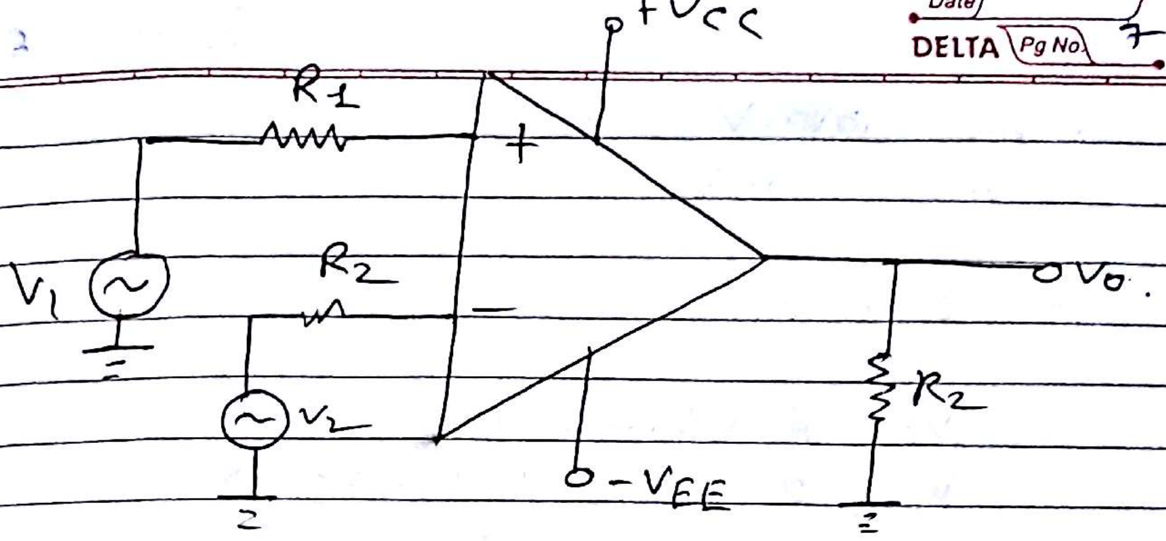


& The o/p voltage cannot exceed the +ve & -ve sat. voltage. These sat. voltage are specified by an o/p voltage swing rating of an op-amp for the given value of supply voltage.

This means that o/p voltage directly prop. to the i/p diff voltage until it reaches the sat. voltage thereafter o/p voltage remains const.

Open loop conf:-

1) Differential amplifier.
2) Inverting amplifier.
3) Non inverting amplifier.



Q1 Determine the o/p voltage for open loop diff. amplifier when $V_{in1} = 5mV$, $V_{in2} = 0.7mV$, opamp 741 w/ foll. specification:

$A = 200 \times 10^{3}$
$R_i = 2M\Omega$
$R_o = 75\Omega$
$V_{cc} = +15V$
$-V_{EE} = -15V$
$V_{o_{sat}} = \cancel{\pm 13V}\ \pm 14V$

$V_o = A(V_1 - V_2)$

$V_o = 200 \times 10^{3} \times (5 - 0.7) \times 10^{-3}$
$V_o = 200 \times 10^{3} \times (4.3)$
$V_o = 2400 mV$

Q2) $V_{1\,rms} = 10\,mV$

$V_{2\,rms} = 20\,mV$

$A = 200 \times 10^3$

$V_0 = A(V_1 - V_2)$

$V_0 = 200 \times 10^3 (10 - (20)) \times 10^{-3}$

$V_0 = 6000 \times 10^3 \times 10^{-3}$

$V_p = 6000 \times 10^3 \sqrt{2} \times 10^{-3}$

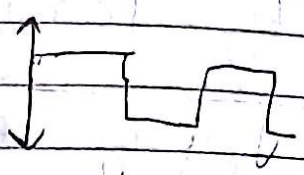
$V_p = 6\sqrt{2} \times 10^6\ V \times 10^{-3}$

$V_p = 6\sqrt{2} \times 10^3\ V$

$V_0 = 200 \times (-10)$

$V_0 = -2000$

$V_p = -2000\sqrt{2}\ V$



Op amp w/ -ve feedback

One of the problem that occur in open loop config when o/p attempts to exceed the sat. level of op-amp

* Drawbacks

1) In the case of open loop config, the OL gain is very ↑, only the smaller signal with v ↓ freq will be amplified w/o any distortion.

However these small signal are very susceptible to noise & are impossible to obtain in lab.

2) Open loop voltage gain of op-amp is not constant voltage gain, but varies with change in temperature and power supply.

3) Bandwidth of open loop op-amp is negligibly small. For this reason, the open loop op-amp is practically impossible.

dc ✓
ac ✗

4) Open loop op-amp is used as an non linear device because the gain of open loop op-amp is large which makes the op-amp unstable for linear application.

Therefore, we use closed loop op-amp in which feedback is introduced in the circuit so that gain of op-amp can be controlled.

The negative feedback in op-amp:

- stabilizes the gain
- increases the bandwidth
- Changes the i/p and o/p resistances

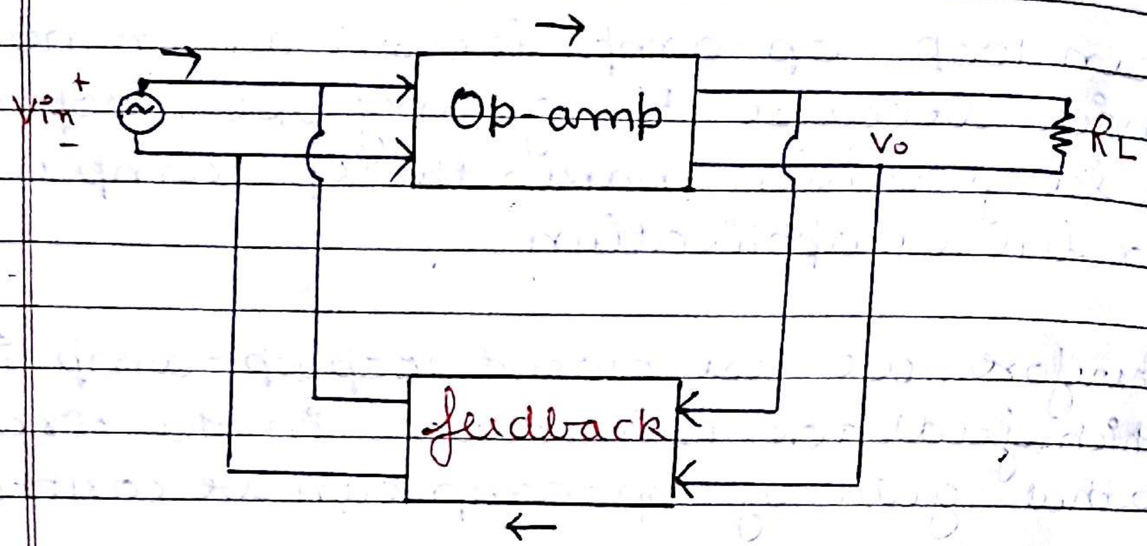
Other benefits are :-

- reduced distortion.
- reduced offset output ~~fo~~ voltage
- reduces the effect of temperature
- reduces the effect of supply voltage variation on the output of an op-amp.

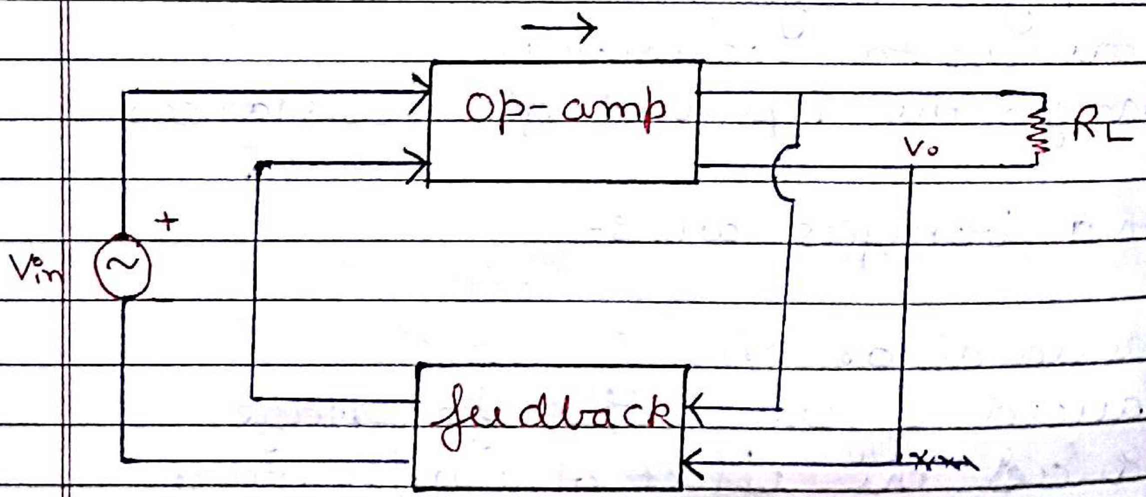
A closed loop amplifier can be represented by two blocks on for an op-amp and the other for a feedback circuits.

There are four following ways to connect these blocks:

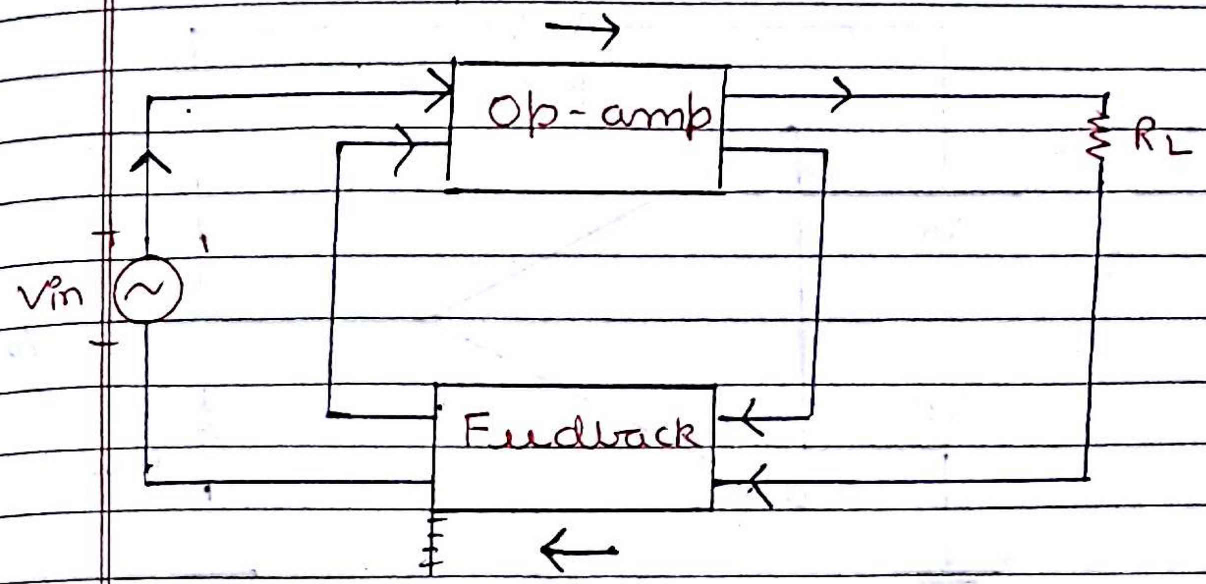
1) Voltage shunt feedback



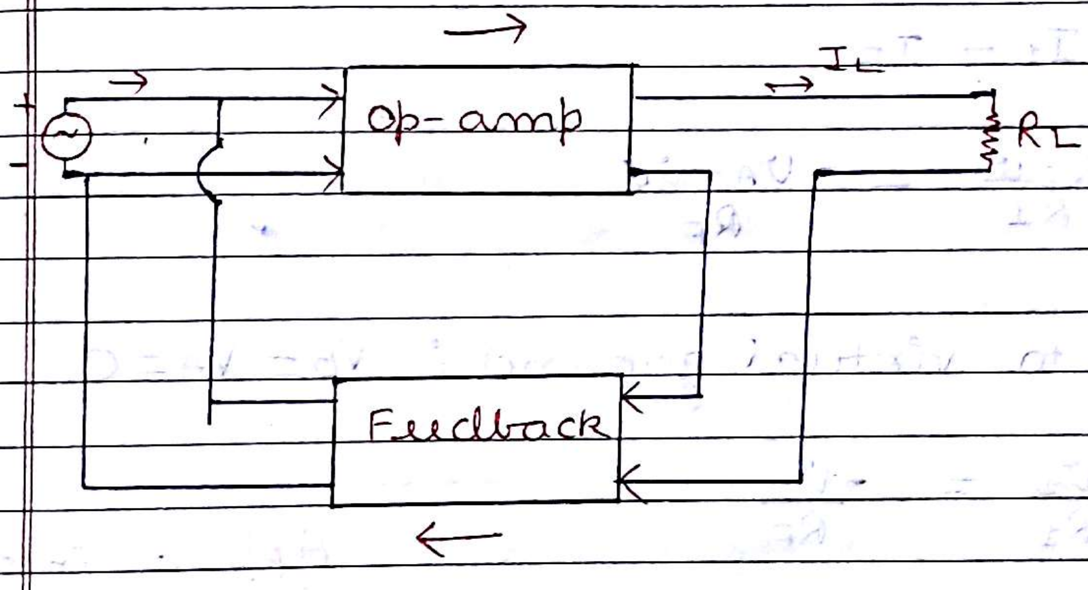
2) Voltage series feedback



3) Current series feedback



4) Current shunt feedback

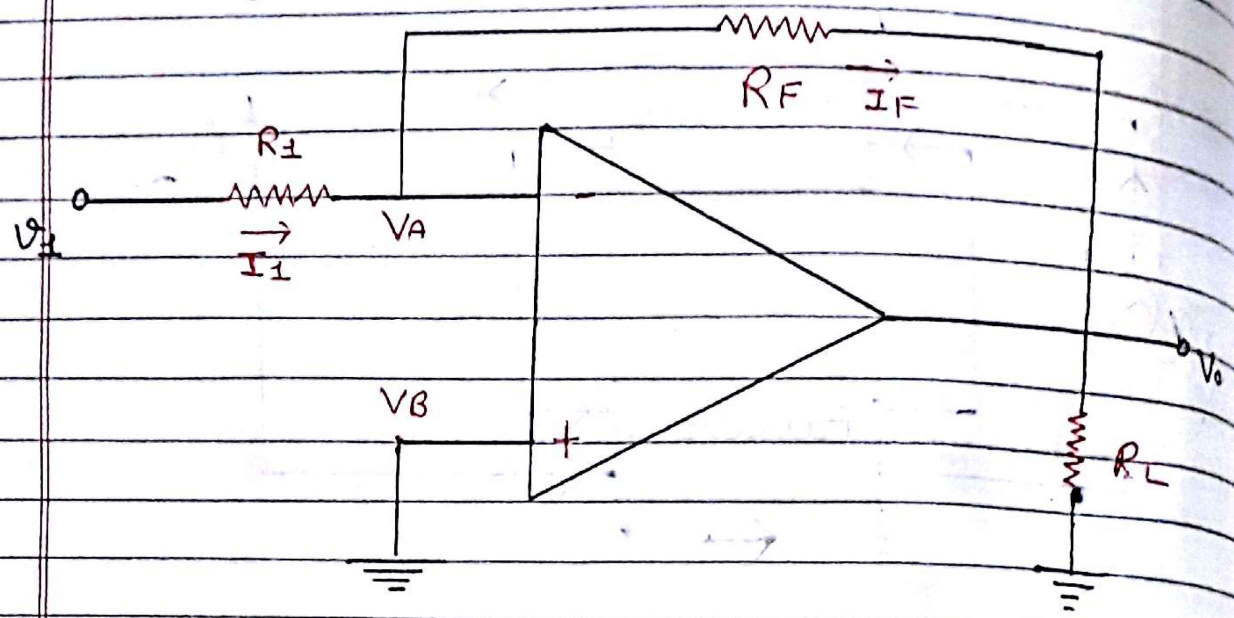


DATE

UNIT-2

22/01/19

- Gain for inverting amplifier



Derivation:

$\because \quad I_1 = I_F$

$$\frac{V_1 - V_A}{R_1} = \frac{V_A - V_0}{R_F}$$

Due to virtual ground : $V_B = V_A = 0$

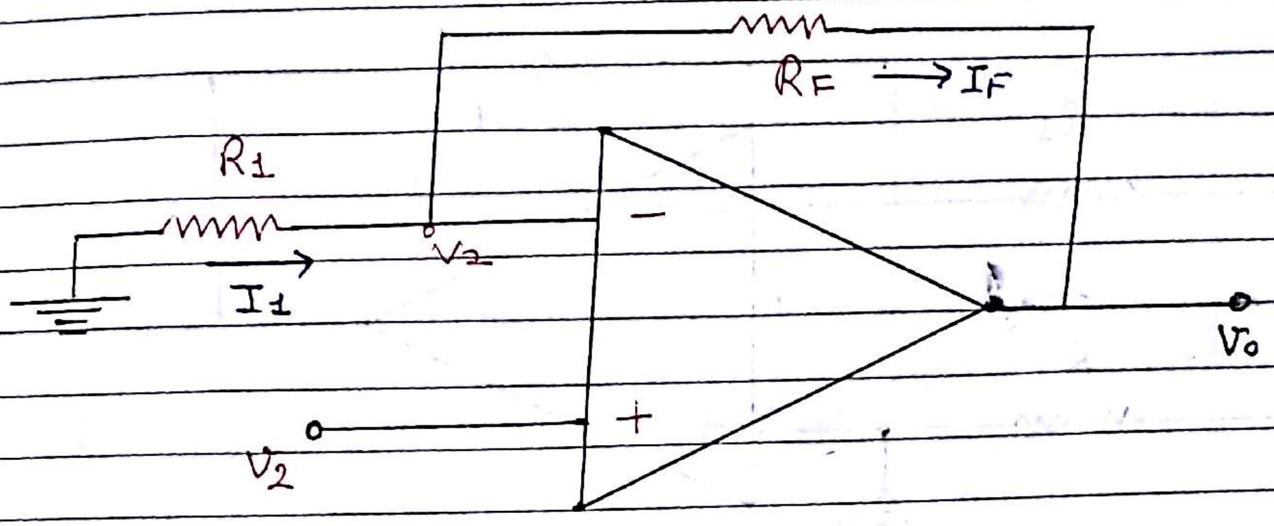
$$\frac{V_1}{R_1} = \frac{-V_0}{R_F}$$

$$\frac{V_0}{V_1} = -\frac{R_F}{R_1}$$

App. of inv. amp
↳ inverter
↳ scale changer
$\because V_{out} = -V_{in}$

$$\boxed{A_V = \frac{V_0}{V_1} = -\frac{R_F}{R_1}}$$

- Gain for non inverting amplifier



$\therefore \quad I_1 = I_F$

$$\frac{-V_2}{R_1} = \frac{V_2 - V_0}{R_F}$$

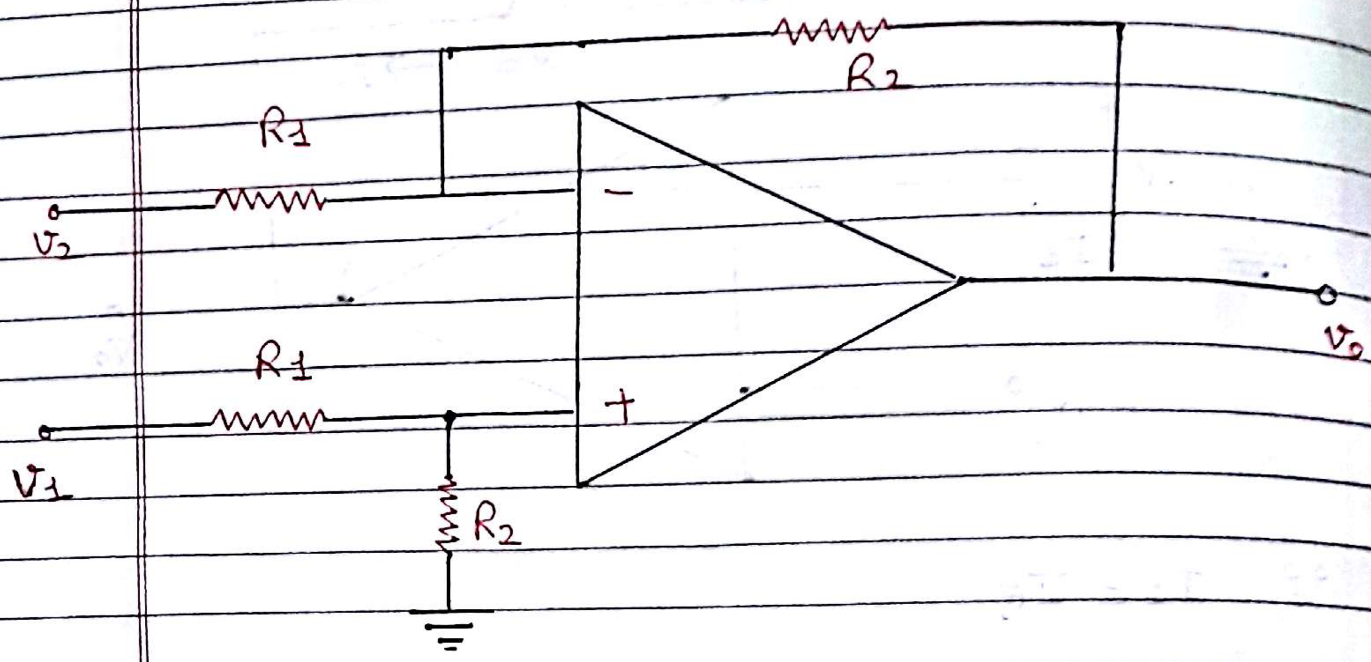
$$\frac{V_0}{R_F} = \frac{V_2}{R_F} + \frac{V_2}{R_1}$$

$$\frac{V_0}{V_2} = 1 + \frac{R_F}{R_1}$$

$$\boxed{A_V = \frac{V_0}{V_2} = 1 + \frac{R_F}{R_1}}$$

Note:-
Non inverting amplifier can be used as voltage follower (application for non inverting amplifier.

- **Gain for differential amplifier.**



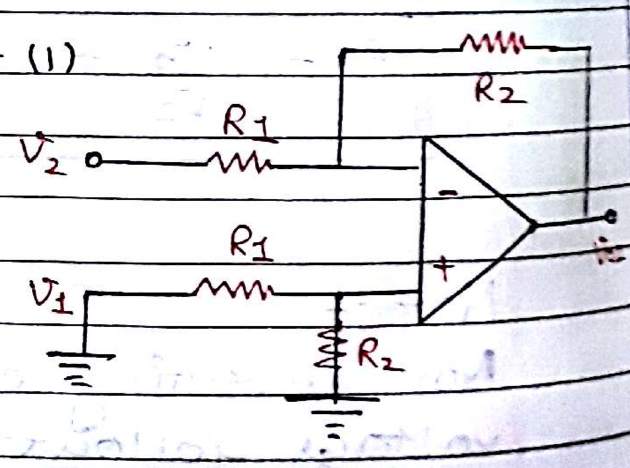
Using superposition theorem,

when input is from v_1 output is v_{o1}
when input is from v_2 output is v_{o2}.

$$v_o = v_{o1} + v_{o2}$$

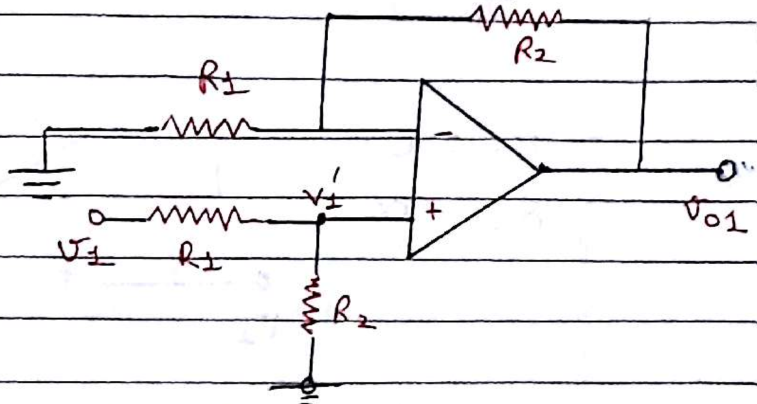
→ When input is given at inverting terminal :-

$$v_{o2} = \frac{-R_2}{R_1} \times v_2 \text{ ------ (1)}$$



→ When input is given at non inverting terminal:

$$v_{o1} = \left(1 + \frac{R_2}{R_1}\right) v_1'$$



$$v_1' = v_1 \times \frac{R_2}{R_1+R_2}$$

Substituting in above equation,

$$v_{o1} = \left(1 + \frac{R_2}{R_1}\right) v_1 \times \frac{R_2}{R_1+R_2}$$

$$v_{o1} = \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_2}{R_1+R_2}\right) \times v_1$$

$$v_{o1} = \frac{R_2}{R_1} \times v_1 \quad \text{------} \quad (2)$$

Adding (1) and (2), we get

$$v_o = v_{o1} + v_{o2}$$

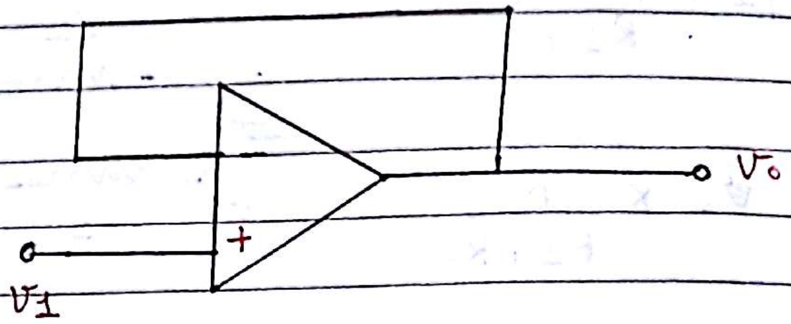
$$v_o = \frac{R_2}{R_1} \times v_1 - \frac{R_2}{R_1} \times v_2$$

$$v_o = \frac{R_2}{R_1}(v_1 - v_2)$$

$$\boxed{A = \frac{v_o}{v_1 - v_2} = \frac{R_2}{R_1}}$$

Voltage follower (app. of non-inv amp)

$R_F = 0$
$R_1 = \infty$



We know that,

$$v_o = \left(1 + \frac{R_F}{R_1}\right) \times v_1$$

$R_F = 0$
$R_1 = \infty$

$$\boxed{v_o = v_1}$$

Output voltage = Input voltage

Or output voltage follows the input voltage, hence the circuit is called a voltage follower.

The use of unity gain circuit (or voltage follower) lies in the fact that :-

- its input impedance is very high (i.e. MΩ)
- output impedance is zero.

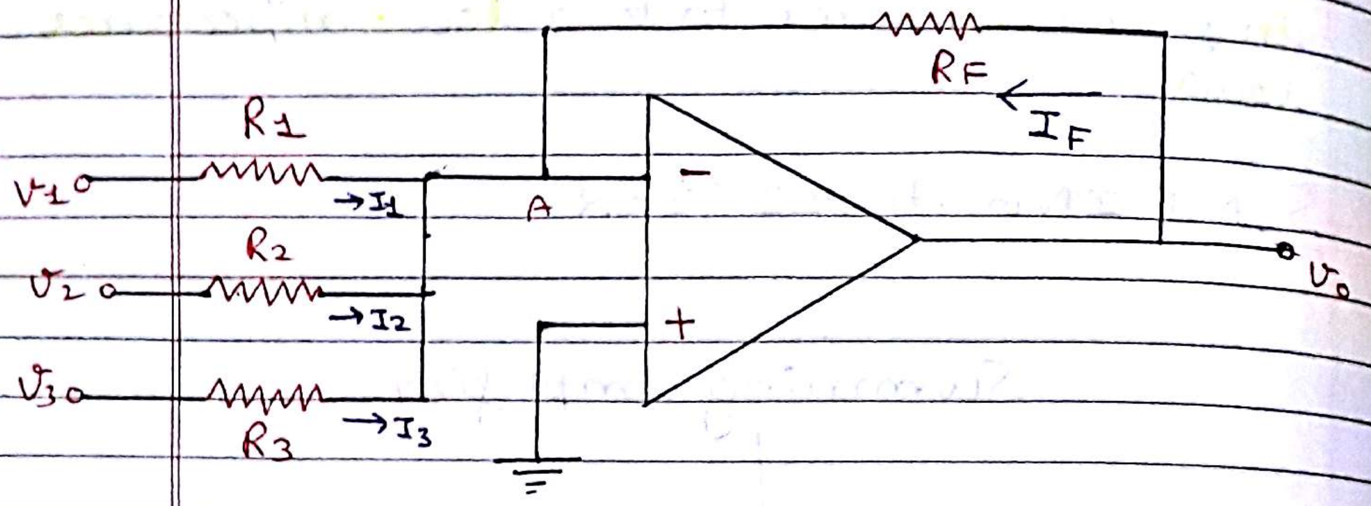
Thus a voltage follower ~~maye~~ may be used as buffer for impedance matching, that is, to connect a high impedance source to a low-impedance load.

SUMMING AMPLIFIER (application of op-amp).

Summing amplifier / Ideal circuit

- Inverting summer
- Non-inverting summer.

INVERTING SUMMER OR ADDER



KCL at node A,

$$I_1 + I_2 + I_3 + I_F = 0$$

$$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} + \frac{V_3 - V_A}{R_3} + \frac{V_o - V_A}{R_F} = 0$$

$\therefore V_A = 0$ (Virtual ground)

$$+\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_o}{R_F} = 0$$

o/p V for inv summer

$$\boxed{V_o = -\left(\frac{V_1}{R_1} \times R_F + \frac{V_2}{R_2} \times R_F + \frac{V_3}{R_3} \times R_F\right)}$$

−ve sign is there because we are applying input at inverting terminal.

→ If $R_1 = R_2 = R_3 = R_F$

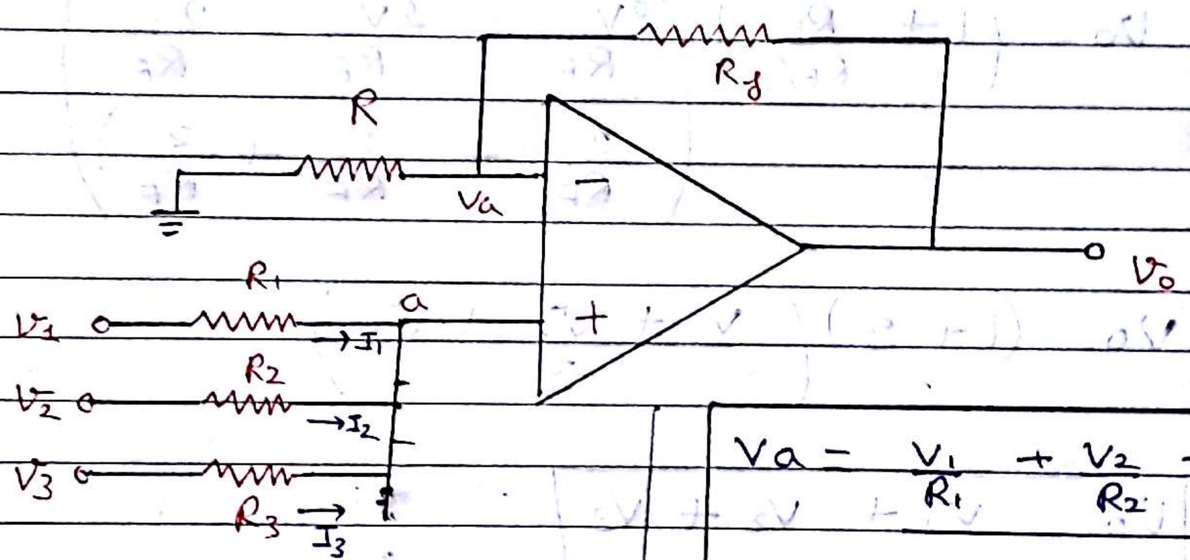
$$V_0 = -[V_1 + V_2 + V_3]$$ → works as adder

→ If $R_1 = R_2 = R_3 = 3R_F$

$$V_0 = -\left[\frac{V_1 + V_2 + V_3}{3}\right]$$

↳ The circuit will behave as average amplifier.

NON-INVERTING SUMMER AMPLIFIER



$$\boxed{V_a = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}}$$

KCL at node a,

$$I_1 + I_2 + I_3 = 0$$

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

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

We know that, for non inverting amplifier:

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

$$\boxed{V_0 = \left(1 + \frac{R_F}{R}\right)\left(\frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}\right)}$$

output voltage for non inv summer

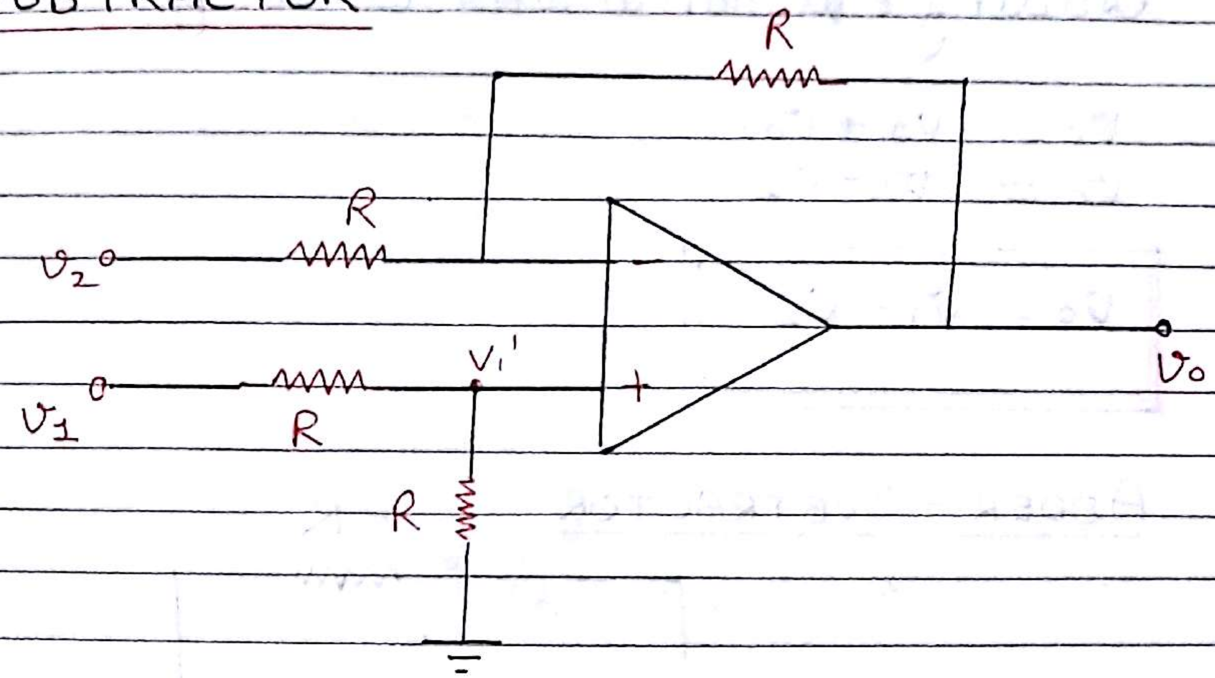
DATE 23/01/19 Substitute $R_1 = R_2 = R_3 = \frac{R_F}{2} = R$

$$V_0 = \left(1 + \frac{R_F}{R_F/2}\right)\left(\frac{\frac{2V_1}{R_F} + \frac{2V_2}{R_F} + \frac{2V_3}{R_F}}{\frac{2}{R_F} + \frac{2}{R_F} + \frac{2}{R_F}}\right)$$

$$V_0 = (1+2)\left(\frac{V_1 + V_2 + V_3}{3}\right)$$

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

SUBTRACTOR



We know that, for differential amplifier

$$A = \frac{v_0}{v_1 - v_2} = \frac{R}{R} = 1$$

$$v_0 = v_1 - v_2$$

- - - - - - - - - OR - - - - - - - - -

Apply superposition theorem,

→ When input is given at inverting terminal;

$$v_{02} = -\frac{R}{R} \times v_2 = -v_2$$

$$v_{02} = -v_2 \quad ---- (1)$$

→ When input is given at non inverting terminal

$$v_{01} = \left(1 + \frac{R}{R}\right) \times V_1' = 2 \times v_1 \times \frac{R}{R+R} = v_1$$

$$v_{01} = v_1 \quad ---- (2)$$

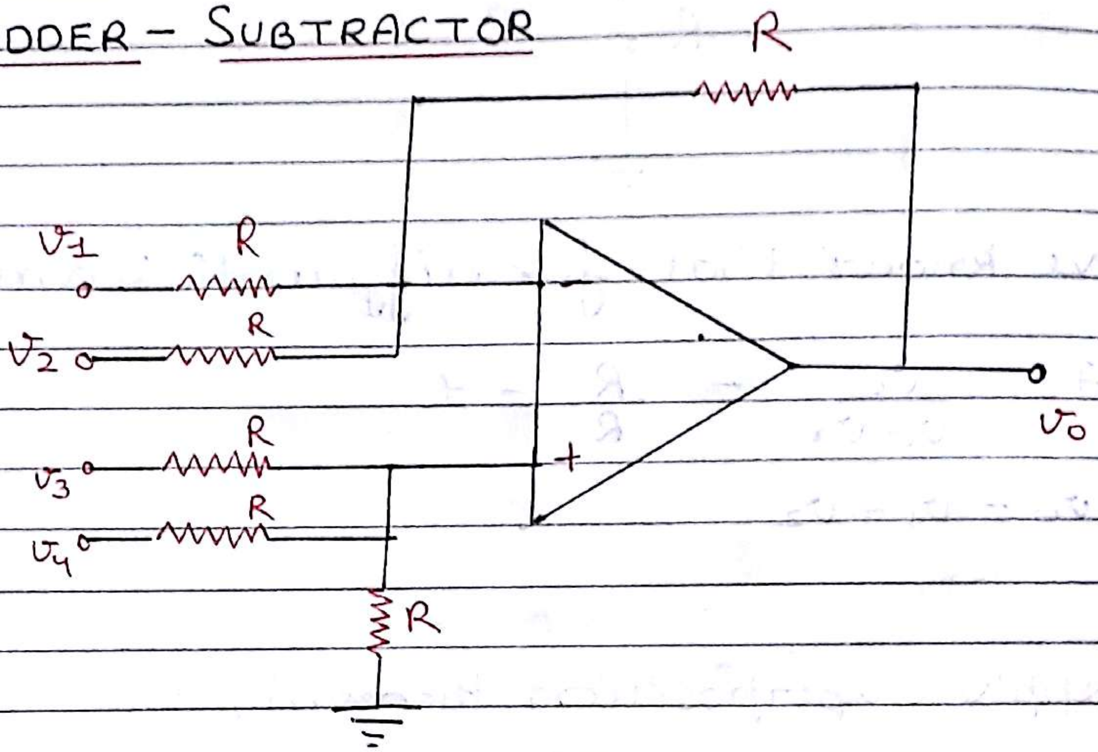
Adding equation (1) and (2) we get,

$v_0 = v_{01} + v_{02}$

$v_0 = v_1 - v_2$

$$\boxed{v_0 = v_1 - v_2}$$

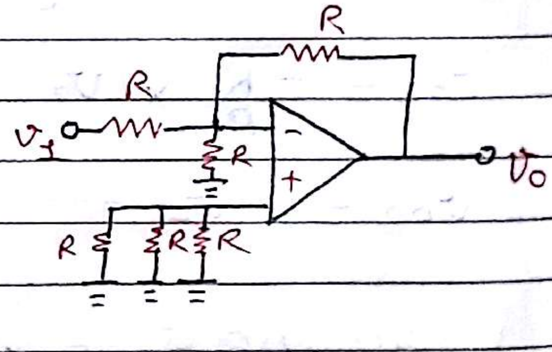
ADDER – SUBTRACTOR



→ When input is given at v_1 terminal.

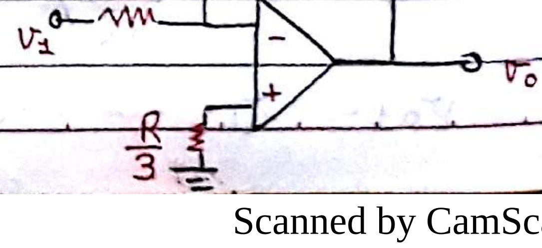
$$\cancel{v_{01} = -\frac{R}{R} \times v_1 \times \frac{R}{R+R}}$$

$$\cancel{v_{01} = -v_1 \times \frac{1}{2}}$$



⇓

$$v_{01} = -\frac{R}{R/2} \times \frac{v_1}{1} \times \frac{R}{R+R}$$

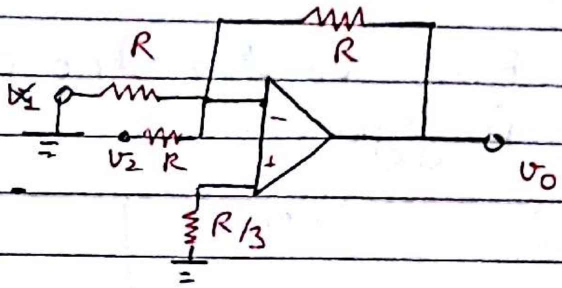


$$\boxed{v_{01} = -v_1} \quad \text{------ (1)}$$

→ When input is given at v_2 terminal

$$v_{o2} = \frac{-R}{R/2} \times v_2 \times \frac{R}{R+R}$$

$$v_{o2} = -v_2 \quad \text{---} (2)$$

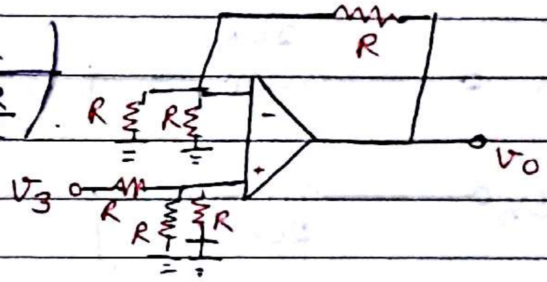


→ When input is given at v_3 terminal

$$v_{o3} = \left(1 + \frac{R \times 2}{R}\right) \times v_3 \times \left(\frac{R/2}{R+\frac{R}{2}}\right)$$

$$v_{o3} = 3 \times v_3 \times \frac{1}{3}$$

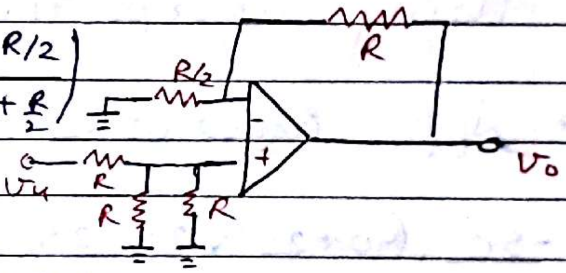
$$v_{o3} = v_3 \quad \text{----} (3)$$



→ When input is given at v_4 terminal

$$v_{o4} = \left(1 + \frac{R}{R/2}\right) \times v_4 \times \left(\frac{R/2}{R+\frac{R}{2}}\right)$$

$$v_{o4} = v_4 \quad \text{----} (4)$$



Adding eq (1), (2), (3) and (4)

$$\boxed{v_o = v_3 + v_4 - v_1 - v_2}$$

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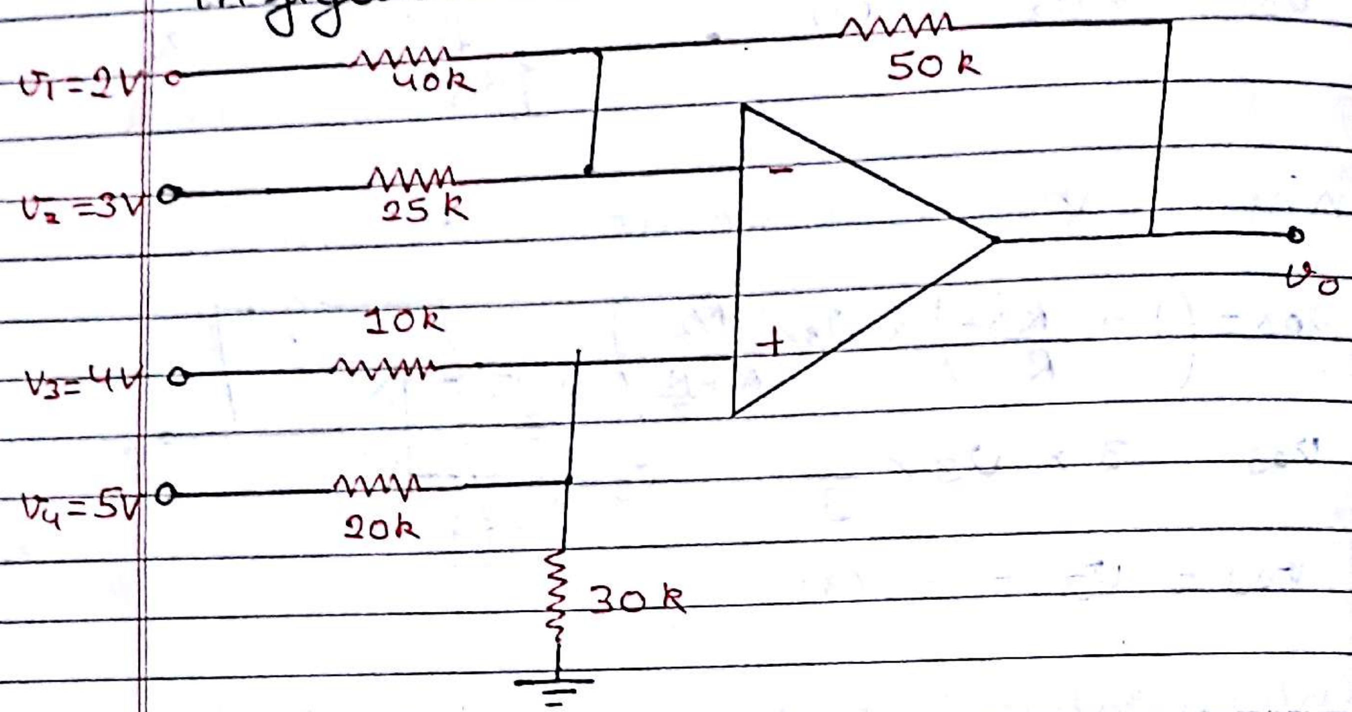
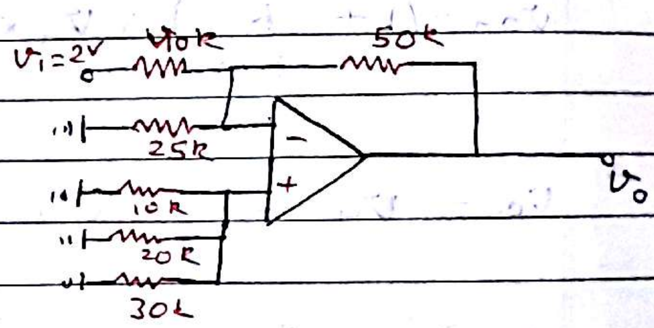
Numerical on Adder - Subtractor

Q1 Find v_o for the adder subtractor shown in figure.



Using superposition theorem,

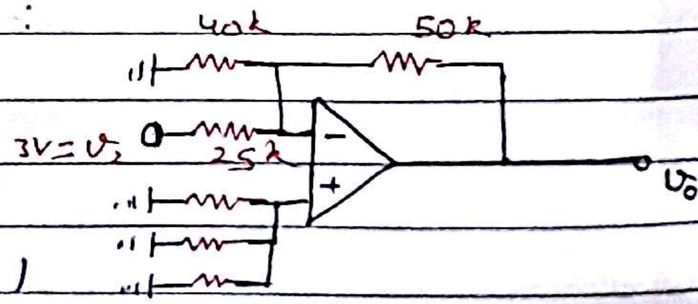
→ Apply input at V_1



$$v_{o1} = -\frac{50}{40\times25}\times(40+25)\times2\times\frac{25}{40+25}$$

$$v_{o1} = -\frac{100}{40} = -2.5V \quad ----(1)$$

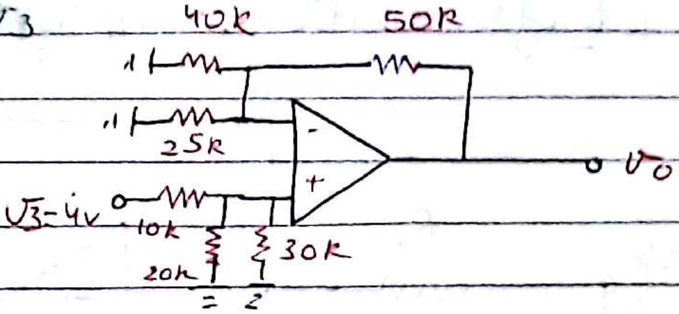
→ Apply input at V_2 :



$$v_{o2} = -\frac{50}{\cancel{40}\times25}\times\cancel{(40+25)}\times3\times\frac{\cancel{40}}{\cancel{40+25}}$$

$$v_{o2} = \frac{-150}{25} = -3V \quad --- (2)$$

→ Apply input at v_3

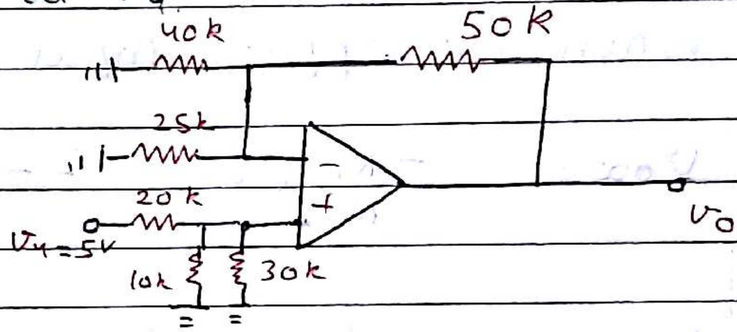


$$v_{o3} = \left(1 + \frac{50(40+25)}{(40\times25)}\right) \times 4 \times \frac{\frac{20\times30}{20+30}}{10 + \frac{20\times30}{20+30}}$$

$$v_{o3} = (1 + 3.25) \times 4 \times \frac{12}{10+12}$$

$$v_{o3} = 9.27V \quad ---(3)$$

→ Apply input at v_4



$$v_{o4} = \left(1 + \frac{50(40+25)}{40\times25}\right) \times 5 \times \frac{\frac{10\times30}{10+30}}{20 + \frac{10\times30}{10+30}}$$

$$v_{o4} = (1+3.25) \times 5 \times \frac{7.5}{27.5}$$

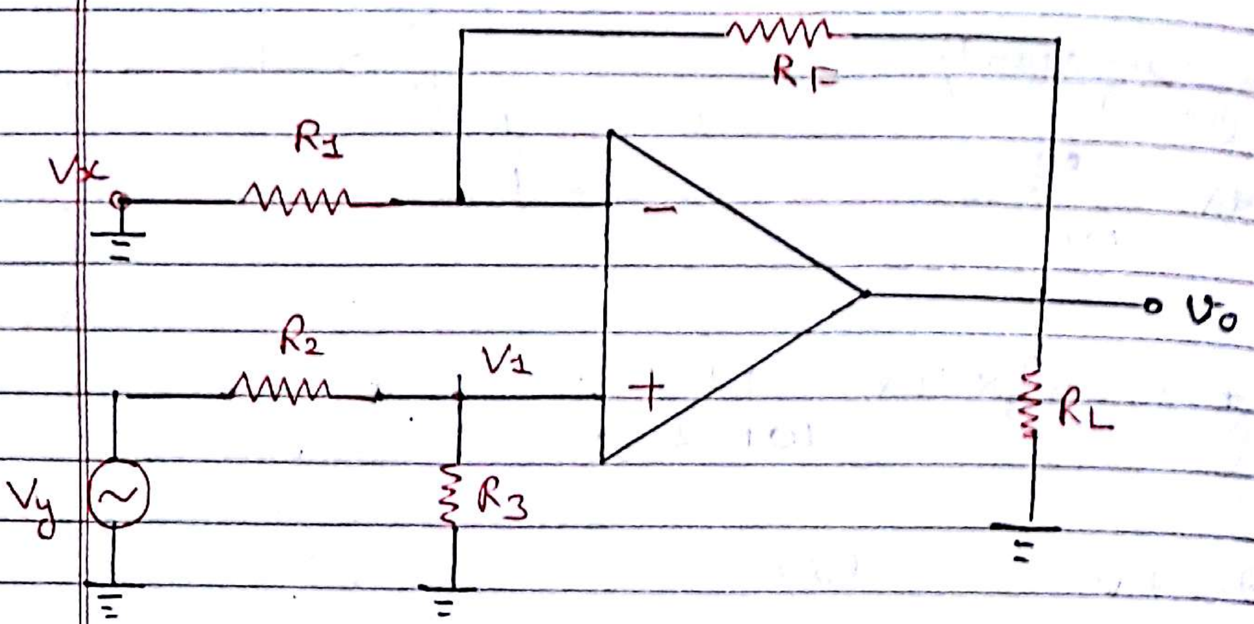
$$v_{o4} = 5.8V \quad ---(4)$$

$$v_o = v_{o1} + v_{o2} + v_{o3} + v_{o4}$$

$$v_o = -2.5 + (-6) + 9.27 + 5.8$$

$$\boxed{v_o = 6.57V}$$

Differential amplifier of one-amp



→ When we apply input at V_x

$$V_{ox} = -\frac{R_F}{R_1} \times V_x \quad \text{---} (1)$$

→ When we apply input at V_y

$$V_{oy} = \left(1 + \frac{R_F}{R_1}\right) \times V_y \times \frac{R_3}{R_2 + R_3} \quad \text{---} (2)$$

Adding (1) and (2)

$$V_o = V_{ox} + V_{oy}$$

$$V_o = -\frac{R_F}{R_1} \times V_x + \left(1 + \frac{R_F}{R_1}\right) \times V_y \times \frac{R_3}{R_2 + R_3}$$

$$R_2 = R_1$$

$$R_3 = R_F$$

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$$V_o = -\frac{R_F}{R_1} \times V_x + \left(1 + \frac{R_F}{R_1}\right) \times V_y \times \frac{R_F}{R_1 + R_F}$$

$$V_o = -\frac{R_F}{R_1} \times V_x + V_y \times \frac{R_F}{R_1}$$

$$\frac{V_o}{V_y - V_x} = \boxed{A = +\frac{R_F}{R_1}}$$

$$\boxed{V_o = \frac{R_F}{R_1}(V_y - V_x)}$$

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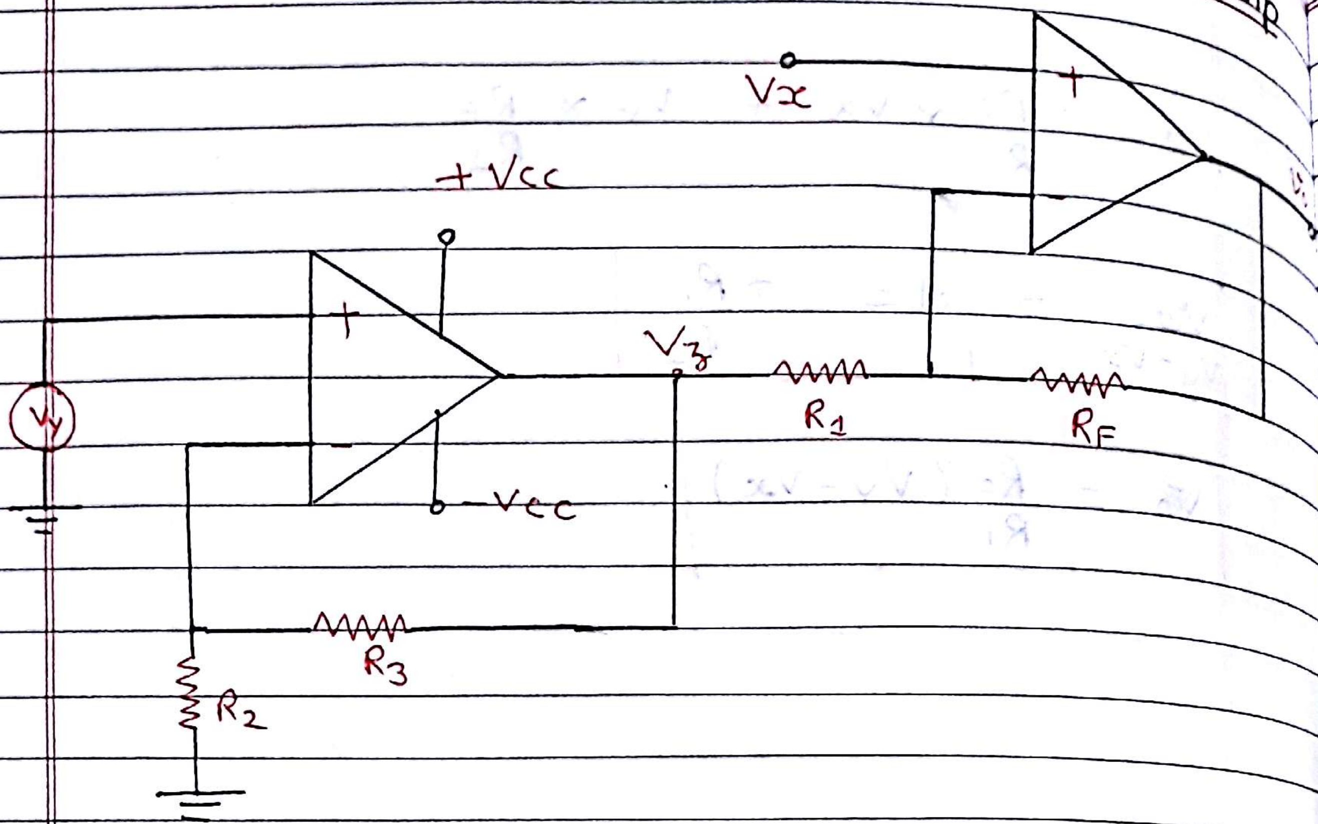
Differential amplifier with two op-amp



→ Output of first op-amp

$$V_z = \left(1 + \frac{R_3}{R_2}\right) \times V_y \quad \text{-----} (1)$$

→ Output of second op-amp

$$V_o = V_{ox} + V_{oz}$$

$$V_{ox} = \left(1 + \frac{R_F}{R_1}\right) \times V_x \quad \text{-----} (2)$$

$$V_{oz} = -\frac{R_F}{R_1} \times V_z$$

From (1)

$$V_{oz} = -\frac{R_F}{R_1} \times \left(1 + \frac{R_3}{R_2}\right) V_y$$

Substitute $R_3 = R_1$
$R_F = R_2$

$$V_{o2} = -\frac{R_F}{R_1} \times \left(1 + \frac{R_1}{R_F}\right) \times V_y$$

$$V_{o2} = -\left(1 + \frac{R_F}{R_1}\right) \times V_y \quad \text{--- (3)}$$

→ $V_o = V_{o1} + V_{o2}$ { Substituting eq(2) & (3) }

$$V_o = \left(1 + \frac{R_F}{R_1}\right) \times V_x - \left(1 + \frac{R_F}{R_1}\right) \times V_y$$

$$\boxed{V_o = \left(1 + \frac{R_F}{R_1}\right)(V_x - V_y)}$$

Input resistance for V_y

$$R_{iFy} = R_i(1 + A\beta)$$

$$\beta = \frac{R_2}{R_2 + R_3}$$

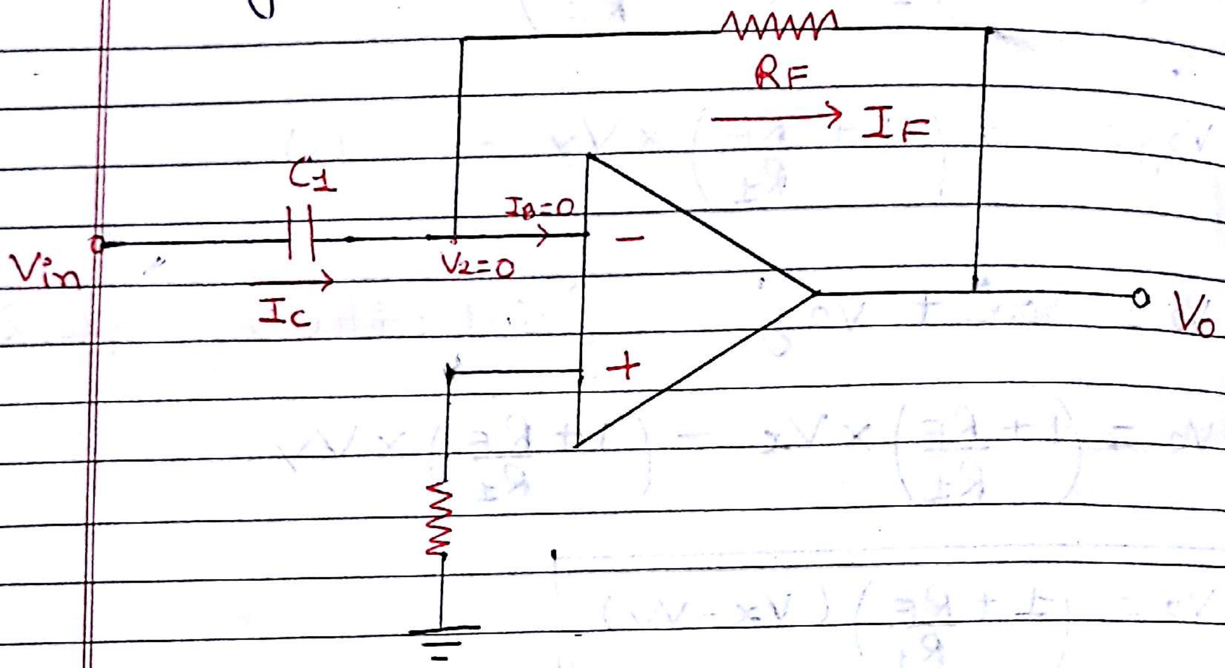
$$R_{iFx} = R_i(1 + A\beta)$$

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

Application of op amp - differentiator & integrator

DIFFERENTIATOR

The output waveform is the derivative of input waveform.



Apply KCL at V_2,

$$I_C = I_F$$

$$C_1 \frac{d(V_{in} - V_2)}{dt} = \frac{V_2 - V_o}{R_F}$$

$\because V_2 = 0$

$$C_1 \frac{dV_{in}}{dt} = \frac{-V_o}{R_F}$$

$$\boxed{V_o = -R_F C_1 \frac{dV_{in}}{dt}}$$

−ve sign indicate 180° phase shift.

→ Taking Laplace Transform on both sides of

$$V_o = -R_F C_1 \frac{dV_{in}}{dt}$$

$$V_o(s) = -R_F C_1 s \, V_{in}(s)$$

$$A = \frac{V_o(s)}{V_{in}(s)}$$

$$A = -R_F C_1 s$$

→ Substitute $s = \sigma + j\omega$

$\sigma = 0 \Rightarrow s = j\omega$

$$A = -R_F C_1 j\omega$$

$$|A| = R_F C_1 \omega$$

$$|A| = R_F C_1 (2\pi f)$$

Let $\boxed{f_a = \frac{1}{2\pi R_F C_1}}$

$$\boxed{|A| = \frac{f}{f_a}}$$

Drawback of Differentiator

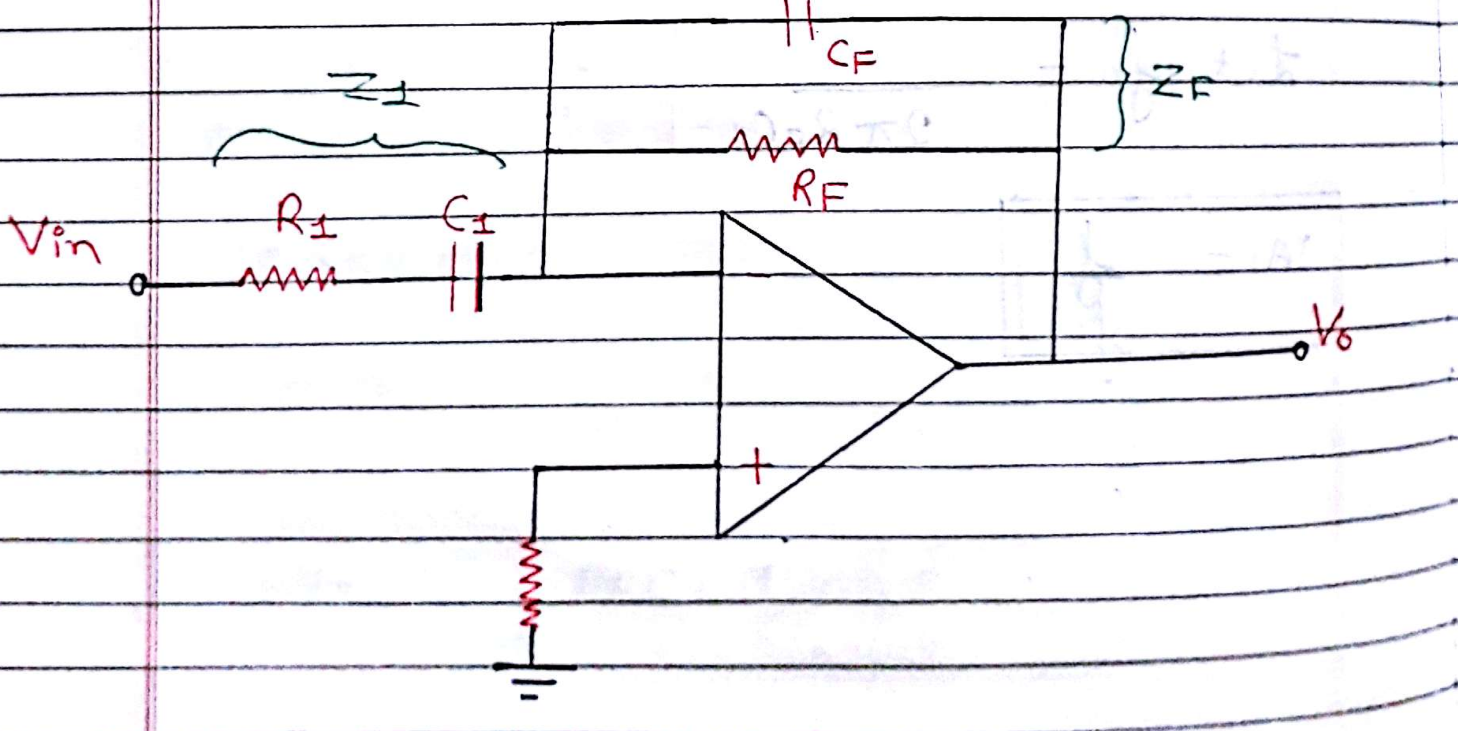
- At $f = f_a$

$$|A| = \frac{f}{f_a} = 1 \text{ i.e. } 0\,dB \left\{ \because 20\log 1 = 0 \right\}$$

- The gain increases at a rate of 20 dB/decade. Therefore at higher frequency differentiator becomes unstable and break into oscillation.

- There is one more problem in differentiator i.e. the input impedance $= \frac{1}{\omega C_1}$ ~~which~~ decreases with increase in frequency, hence the reactance decreases which makes the circuit very susceptible to high frequency noise.

Practical Differentiator



Practical differentiator has following advantages :-

1) Eliminates the problem of instability.

2) and high frequency noise.

The practical differentiator circuit increases the loading effect which makes the device less susceptible to noise and more devices can be connected over to this device.

The gain of the circuit is given by :-

$$A = \frac{V_o(s)}{V_i(s)} = -\frac{Z_F}{Z_1} = -\frac{\frac{1}{sC_F} \parallel R_F}{\frac{1}{sC_1} + R_1}$$

$$A = \frac{-\frac{\frac{R_F}{sC_F}}{R_F + \frac{1}{sC_F}}}{\frac{1 + sC_1R_1}{sC_1}} = -\frac{\frac{R_F}{(sR_FC_F + 1)}}{\frac{(1 + sC_1R_1)}{sC_1}}$$

$$\boxed{A = -\frac{sC_1R_F}{(1 + sC_1R_1)(1 + sC_FR_F)}} \quad \text{--- (1)}$$

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$$A = \frac{-sC_1R_F}{(1+sC_1R_1)(1+sC_FR_F)}$$

→ For $R_FC_F = R_1C_1$

$$A = \frac{-sC_1R_F}{(1+sR_1C_1)(1+sR_1C_1)}$$

$$A = \frac{-sR_FC_1}{(1+sR_1C_1)^2}$$

→ For $s = j\omega$

$$A = \frac{-sR_FC_1}{(1+j\omega R_1C_1)^2}$$

$$A = \frac{-sR_FC_1}{(1+j\times 2\pi f R_1C_1)^2}$$

$$\boxed{A = \frac{-sR_FC_1}{\left(1+j\frac{f}{f_b}\right)^2}}$$

where $f_b = \frac{1}{2\pi R_1C_1}$

Hence, as 'f' increases ⇒ gain decreases thereby reducing high frequency noise and stability problem

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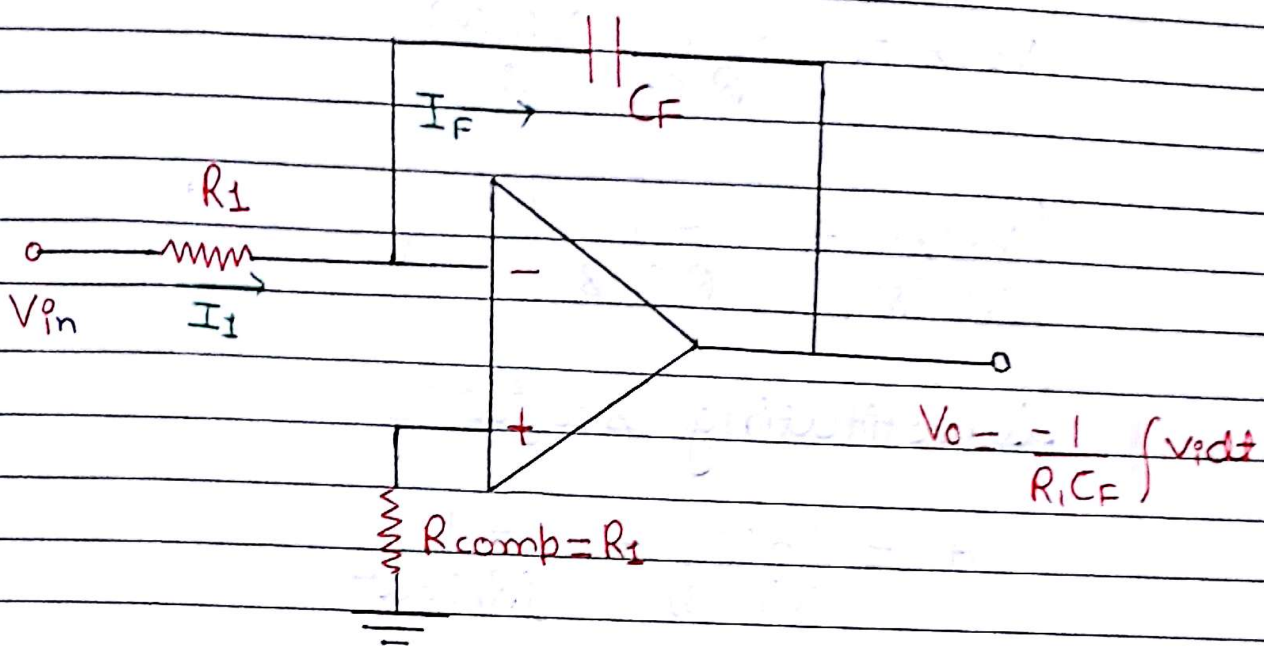
INTEGRATOR

If we interchange the resistor and capacitor of the differentiator, we get an integrator.



$\therefore \quad I_1 = I_F$

$$\frac{V_{in}}{R_1} = -C_F \frac{dV_0}{dt}$$

$$dV_0 = \frac{-V_{in}}{R_1} \times \frac{1}{C_F} dt$$

Integrating both sides

$$\boxed{V_0 = \frac{-1}{R_1 C_F} \int_0^t V_{in}\, dt}$$

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$$V_o = \frac{-1}{R_1 C_F} \int_0^t V_{in}\, dt$$

Taking Laplace transform on both the sides

$$V_o(s) = \frac{-1}{R_1 C_F} \frac{V_{in}(s)}{s}$$

$$\boxed{\frac{V_o(s)}{V_{in}(s)} = \frac{-1}{R_1 C_F s}}$$

Substituting $s = j\omega$

$$A = \frac{V_o(s)}{V_{in}(s)} = \frac{-1}{j R_1 C_F \omega}$$

$$\boxed{|A| = \frac{+1}{R_1 C_F \omega}}$$

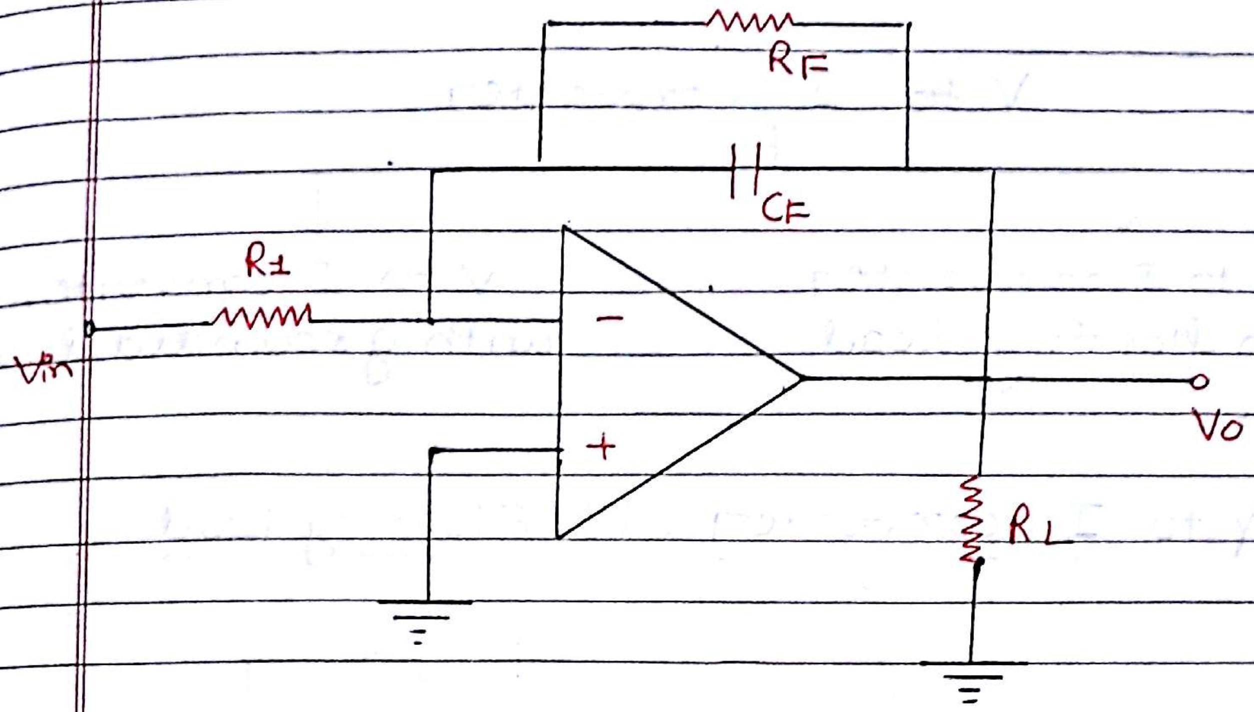
Drawback of differentiator

1) At low frequencies such as at dc ($\omega \simeq 0$), the op-amp thus operates in open loop, resulting in an infinite gain.

(or saturates at a voltage close to the op-amp positive or negative power supply depending on the polarity of the input dc signal.

2) Clipping of signal takes place (as in open loop

PRACTICAL INTEGRATOR



$$\frac{V_{in}(s)}{R_1} = \frac{-V_o(s)}{1/sC_F} - \frac{V_o(s)}{R_F}$$

$$V_o(s) = \frac{\frac{V_{in}(s)}{R_1}}{\left(\frac{-1}{1/sC_F} - \frac{1}{R_F}\right)} = \frac{-V_{in}(s)\,R_F}{R_1(sC_FR_F + 1)}$$

$$\frac{V_o(s)}{V_{in}(s)} = -\frac{1}{sR_1C_F + R_1/R_F} = \frac{-1}{j\omega R_1C_F + R_1/R_F}$$

$$|A| = \left|\frac{V_o}{V_{in}}\right| = \frac{1}{\sqrt{\omega^2R_1^2C_F^2 + R_1^2/R_F^2}} = \frac{R_F/R_1}{\sqrt{1+(\omega R_F C_F)^2}}$$

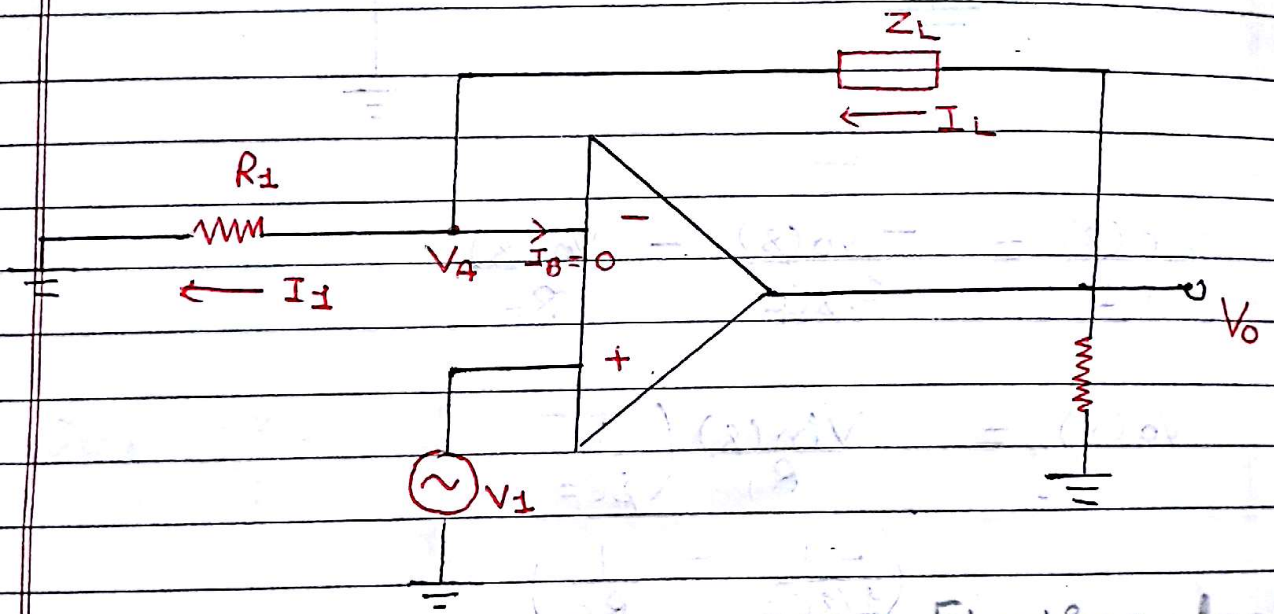
Hence, at low frequency the gain is not infinite rather it reaches a constant value i.e. $\frac{R_F}{R_1}$

VOLTAGE TO CURRENT CONVERTER

V to I converter

- V to I converter with floating load
- V to I converter with grounded load

1) V to I converter with Floating load



Floating load means the load is not grounded, ie load is floating.

Applying KCL at V_A,

$I_1 = I_1$

~~Vxxx~~ $I_L = \frac{V_A - 0}{R_1}$

Due to virtual ground; $V_A = V_1$

$$\boxed{I_L = \frac{V_1}{R_1}}$$

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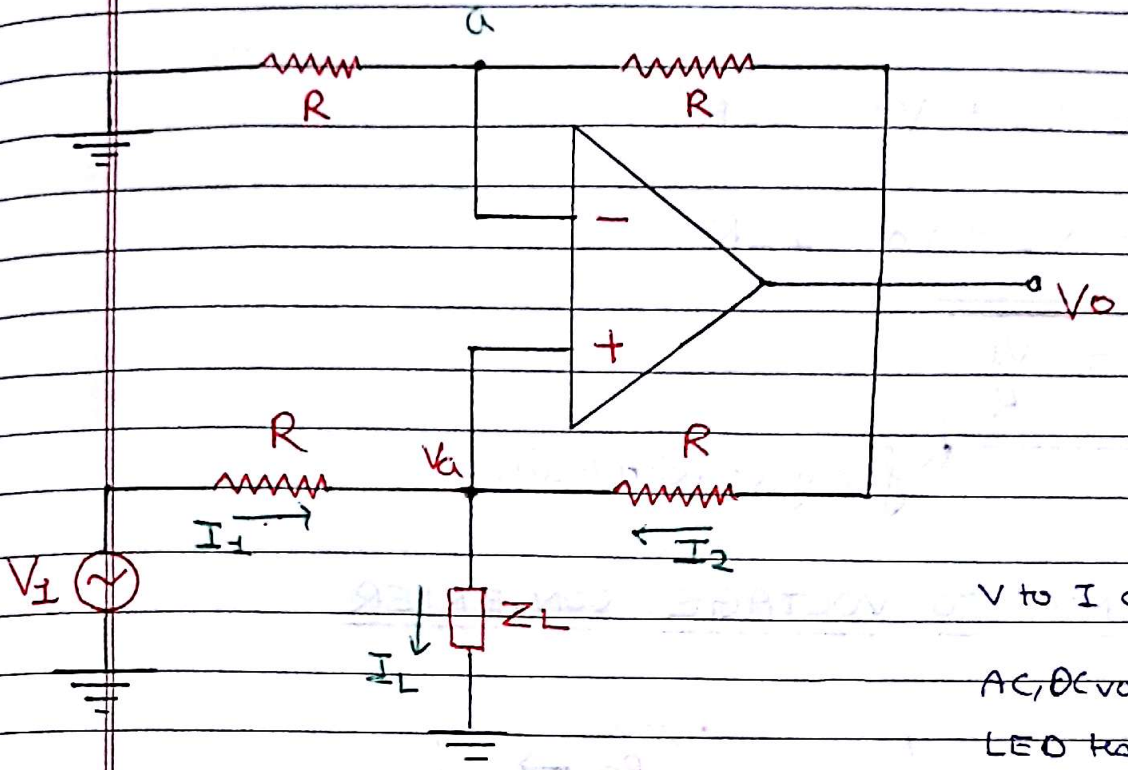
2) V to I converter with grounded load.



V to I converter app:

~~AC, DC voltmeter tester~~
~~LED tester~~
~~Zener diode tester~~.

Applying KCL at Va,

$$I_L = I_1 + I_2$$

$$I_L = \frac{V_1 - V_a}{R} + \frac{V_o - V_a}{R}$$

$$I_L = \frac{V_1 + V_o - 2V_a}{R}$$

$$I_L R = V_1 + V_o - 2V_a$$

$$2V_A = V_1 + V_o - I_L R \quad \text{-----} (1)$$

Since we are applying i/p at non inverting terminal

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

$$V_o = 2V_a \quad \text{-----} (2)$$

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Substituting (2) $V_0 = 2V_A$

in (1) $2V_A = V_1 + V_0 - I_L R$

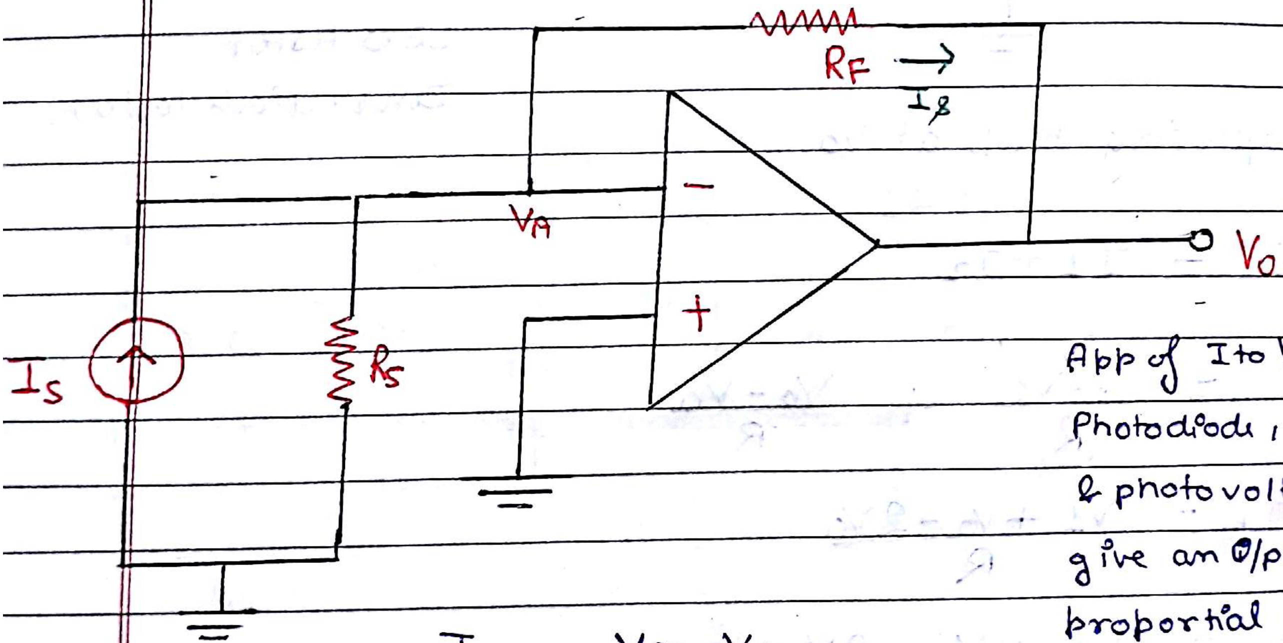
$$2 \times \frac{V_0}{2} = V_1 + V_0 - I_L R$$

$$\cancel{V_0} = V_1 + \cancel{V_0} - I_L R$$

$$\boxed{I_L = \frac{V_1}{R}}$$

for grounded load.

CURRENT TO VOLTAGE CONVERTER



App of I to V conv: Photodiode, Photocell & photovoltaic cell give an O/p current proportional to an incident radiant energy or light.

$$I_s = \frac{V_A - V_o}{R_F}$$

Due to virtual ground $V_A = 0$

$$\boxed{V_o = -I_s R_F}$$

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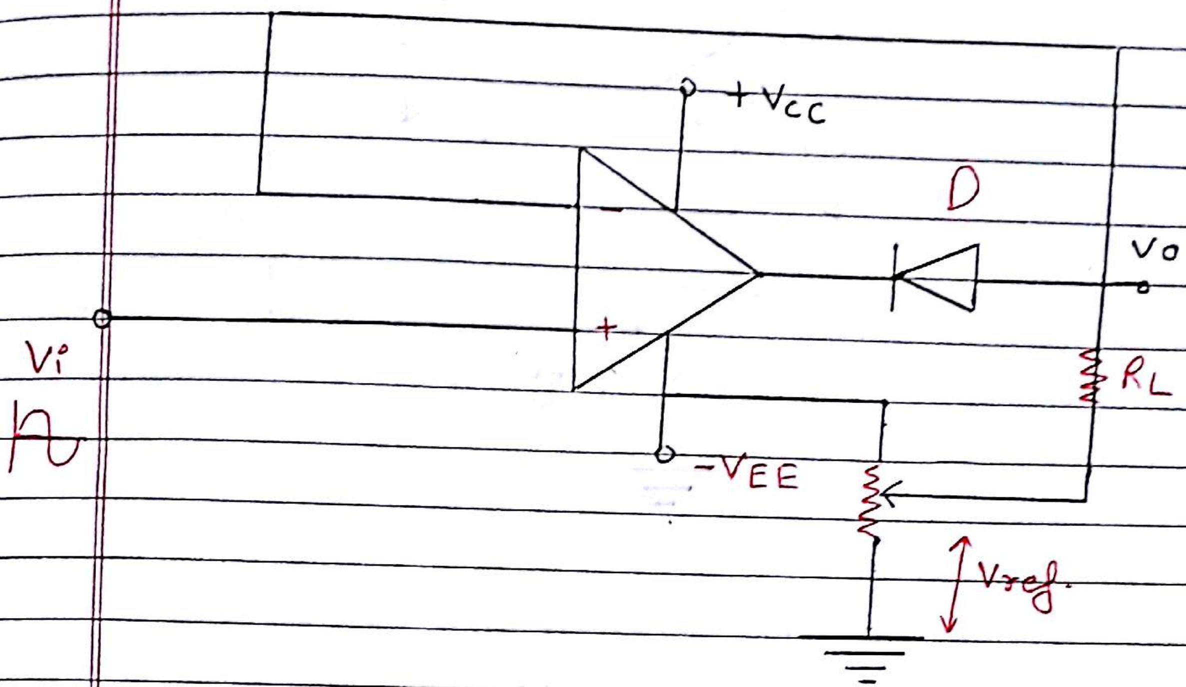
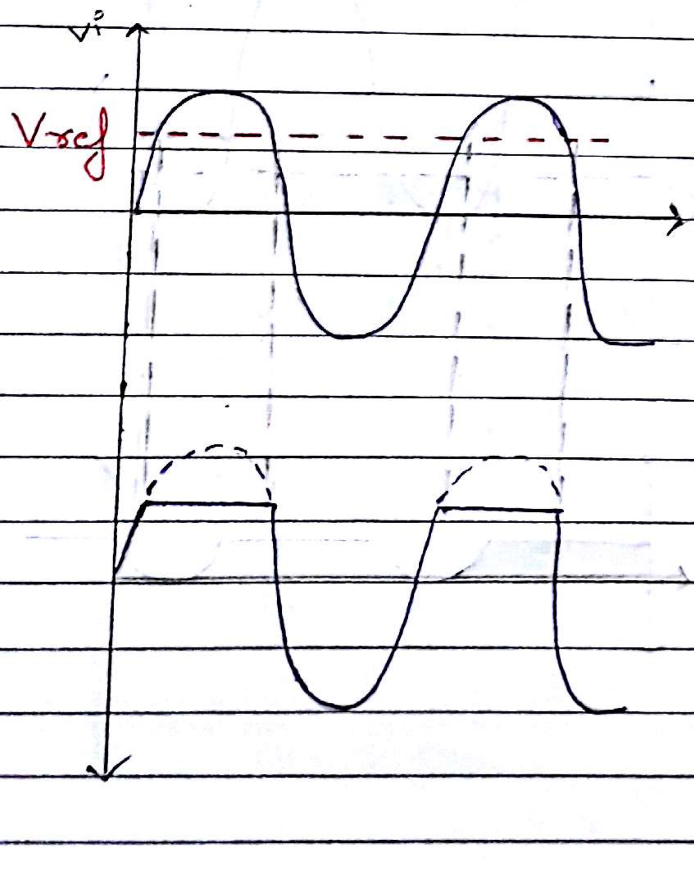
CLIPPER AND CLAMPER

CLIPPER (POSITIVE)

1) Vref is positive



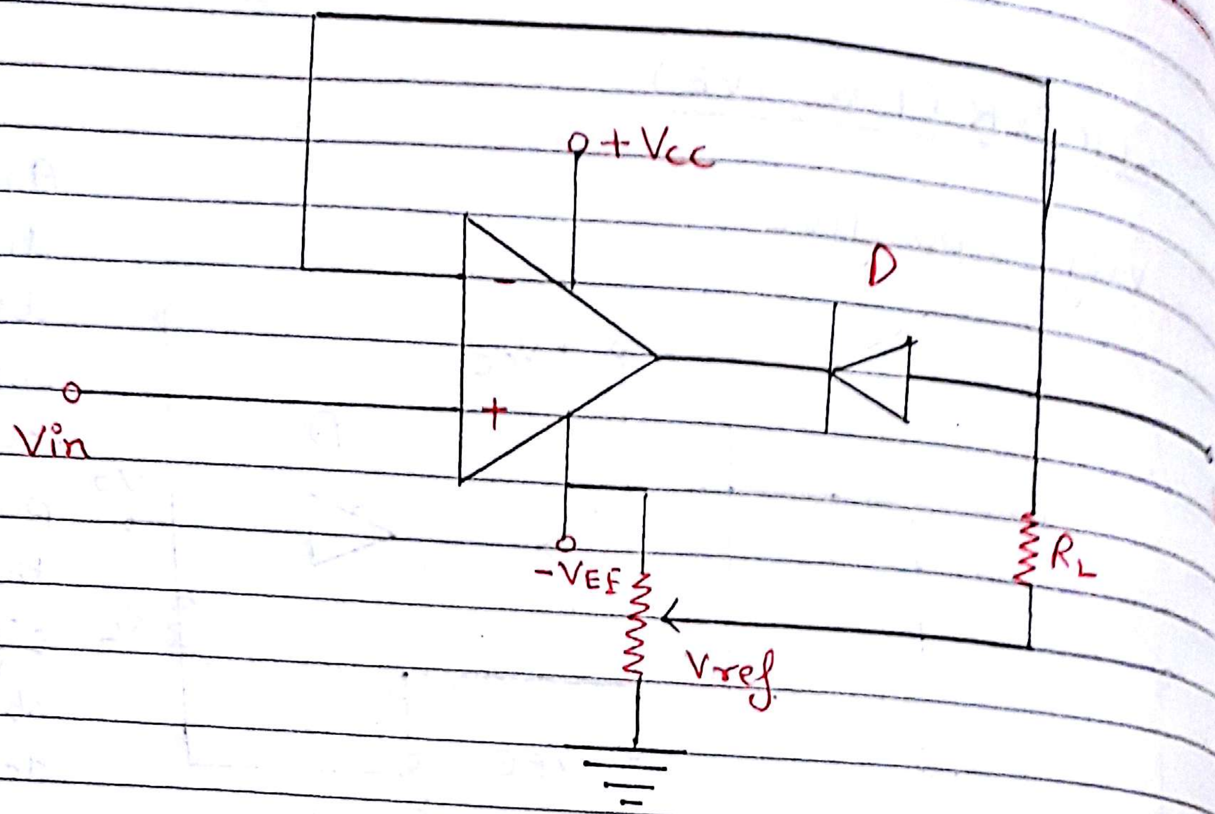
A precision diode may be used to clip-off a certain portion of the i/p signal to obtain a desired o/p waveform.



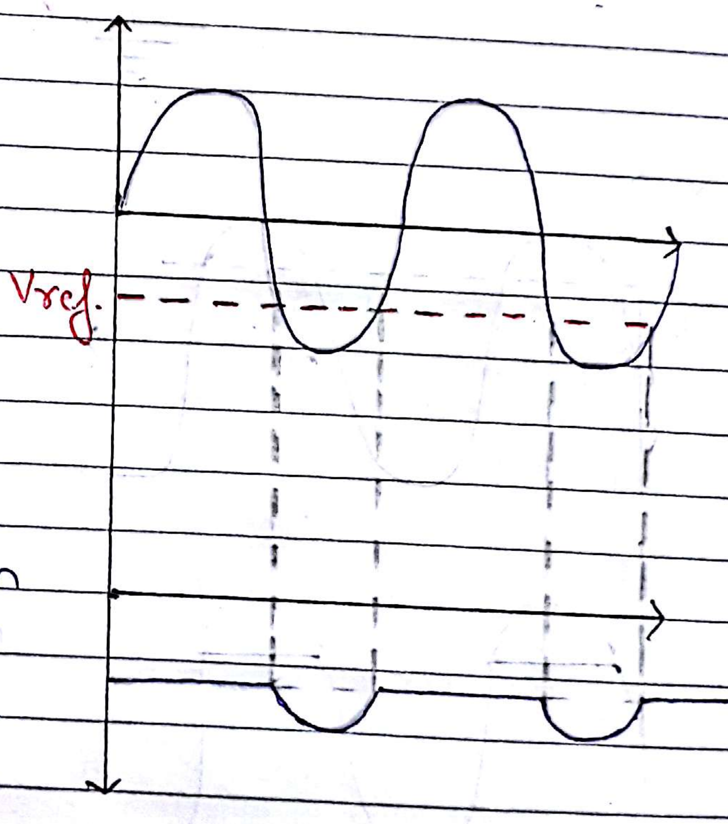
Input waveform of clipper ~~(+ve)~~

Output waveform of clipper ~~(+ve)~~

2) When Vref is negative

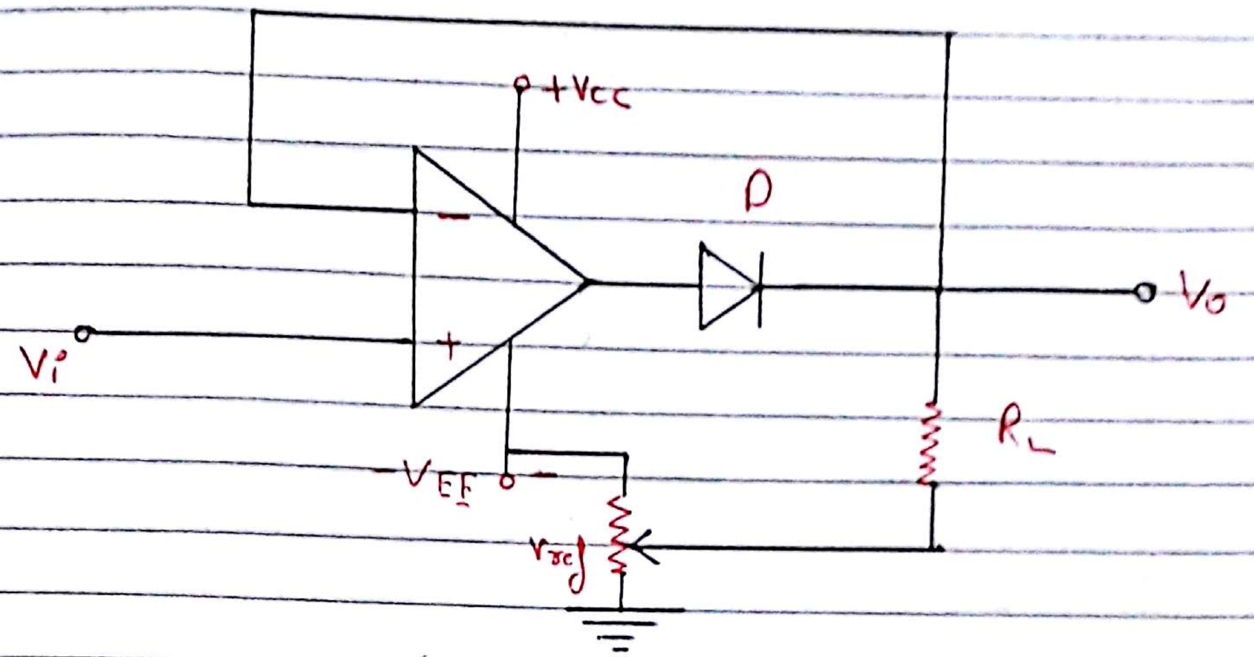


Input waveform of -ve clipper



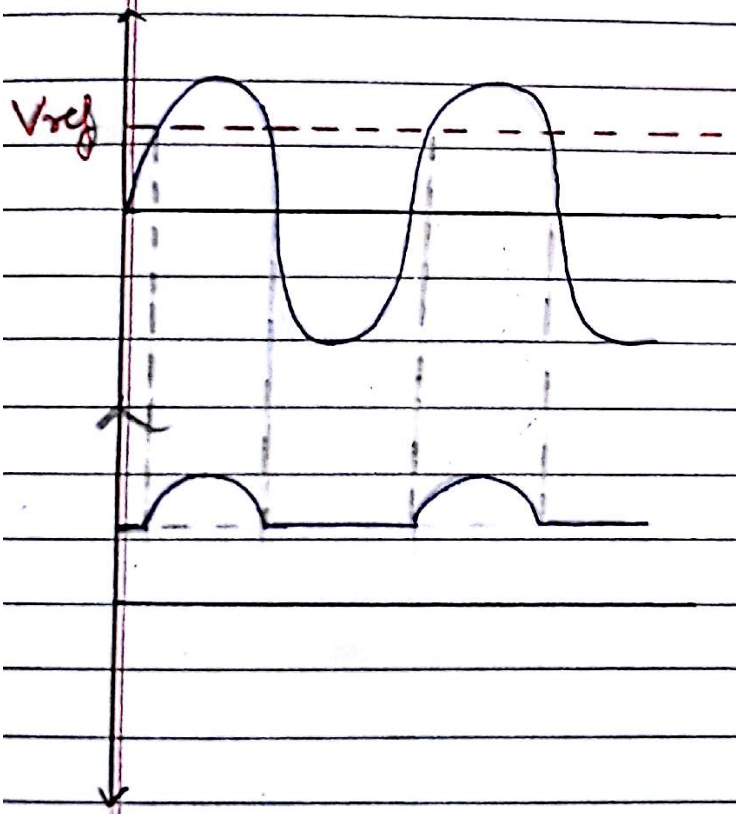
Output waveform of -ve clipper.

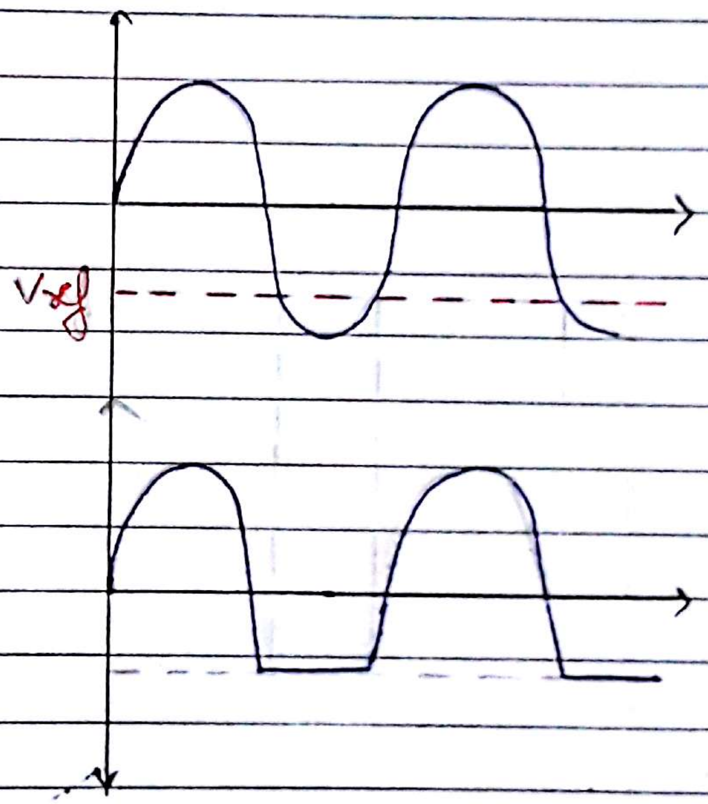
CLIPPER (NEGATIVE).



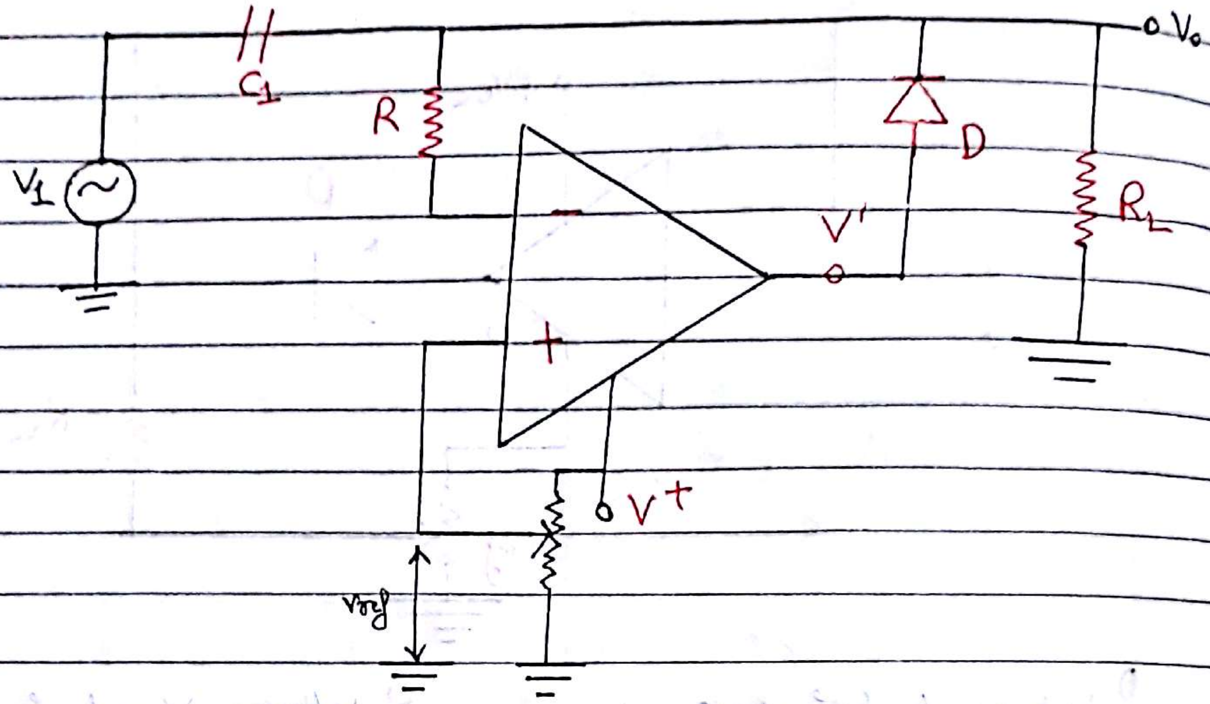
1) When Vref is +ve

2) When Vref is -ve.





CLAMPER (POSITIVE)



Applying superposition to the above circuit,

→ When V_1 is applied and V_{ref} is grounded.

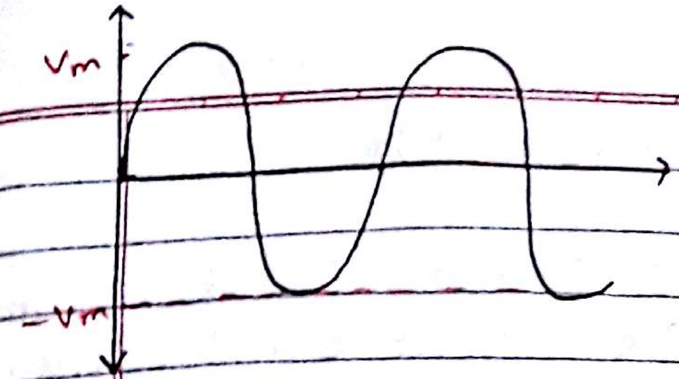
input = $V_m + V_m$ (Due to capacitor)

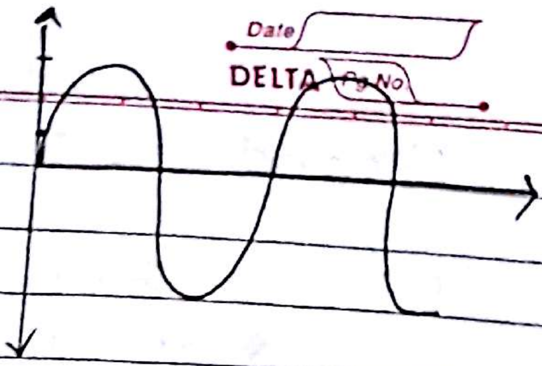
= $2V_m$.

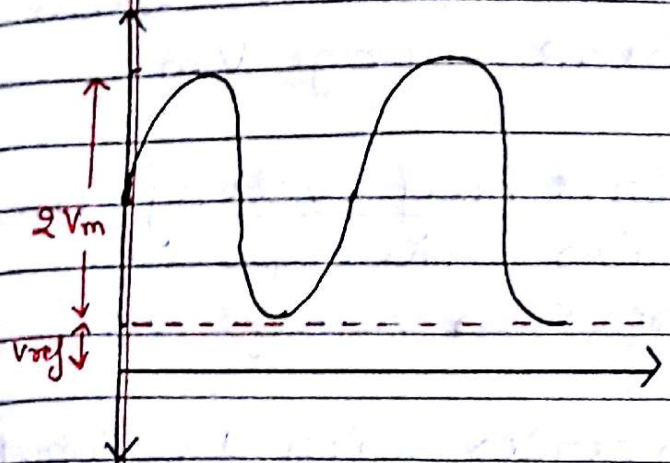
→ When V_{ref} is applied.

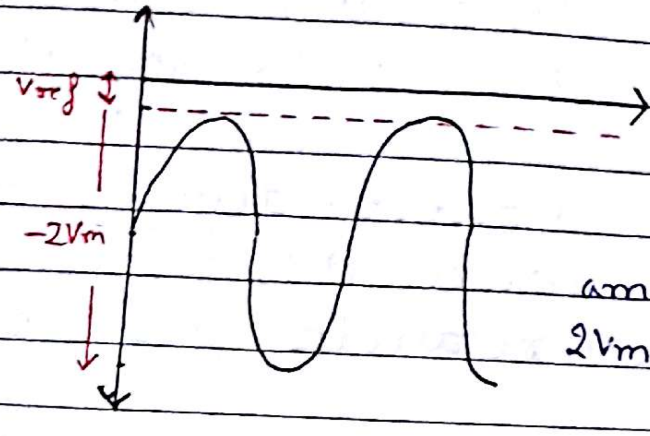
input = V_{ref}

Total output = $2V_m + V_{ref}$.









amp = 2Vm + Vref

WAVEFORM FOR +Vref

WAVEFORM FOR -Vref

1) First case: (Vref)

For +Vref the voltage V' is also positive, so diode is forward bias, the circuit operates as voltage follower.

∴ output voltage = Vref.

2) Second case:- ($V_{in} = V_m \sin\omega t$)

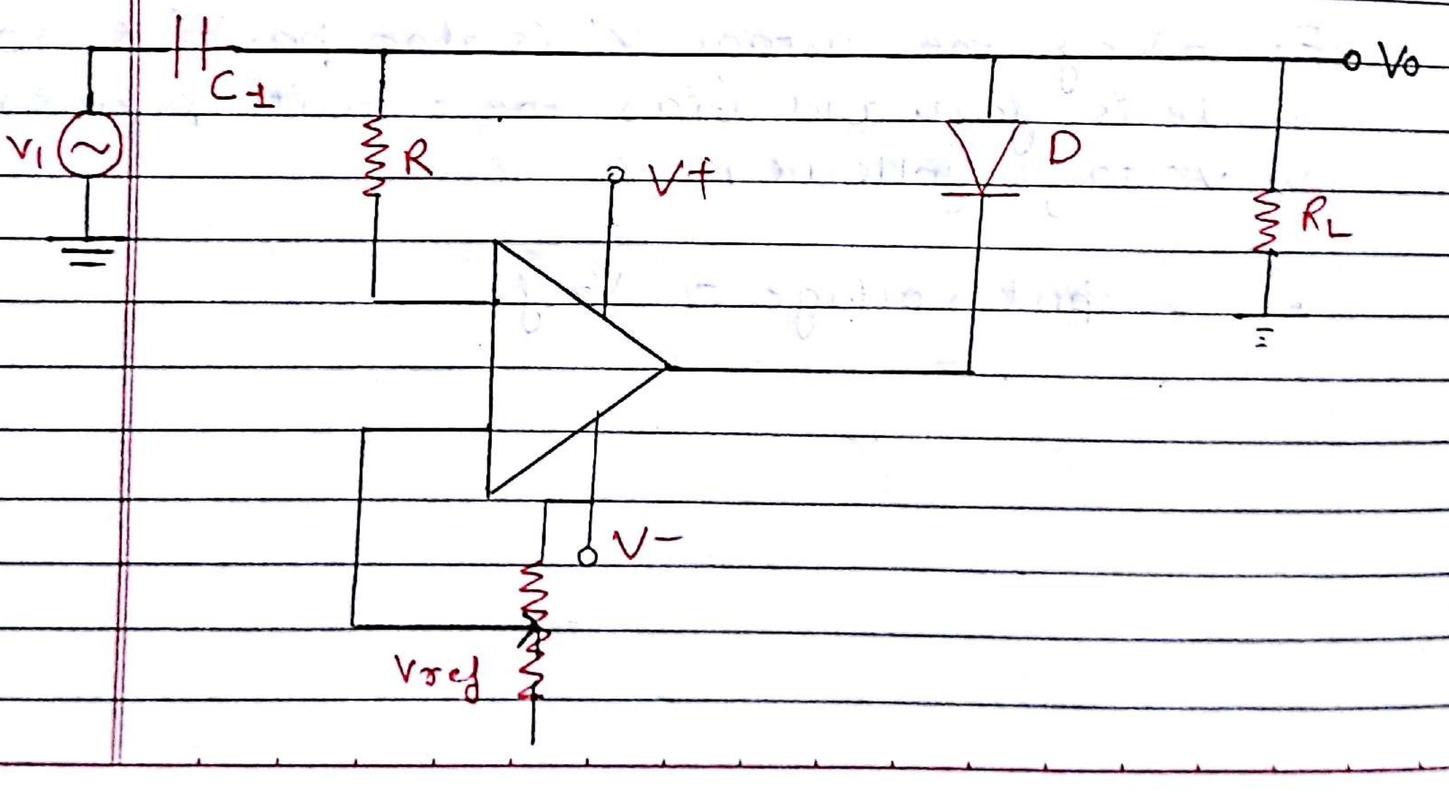
Now consider the A.C input signal $V_{in} = V_m \sin$ applied at the negative input terminal. During negative half cycle of V_{in} (to make D fwd bias), the diode D conducts, the capacitor C_1 charges D diode to negative peak voltage V_m.

However during positive half cycle of V_{in}, diode D is reversed bias, the capacitor retain its positive previous voltage V_m

∴ the voltage V_m is in series with A.C. input signal, the output voltage = $V_i + V_m$

Total output voltage: $V_{ref} + V_i + V_m$
$\Rightarrow V_{ref} + 2V_m$

CIRCUIT DIAGRAM OF NEGATIVE CLAMPER



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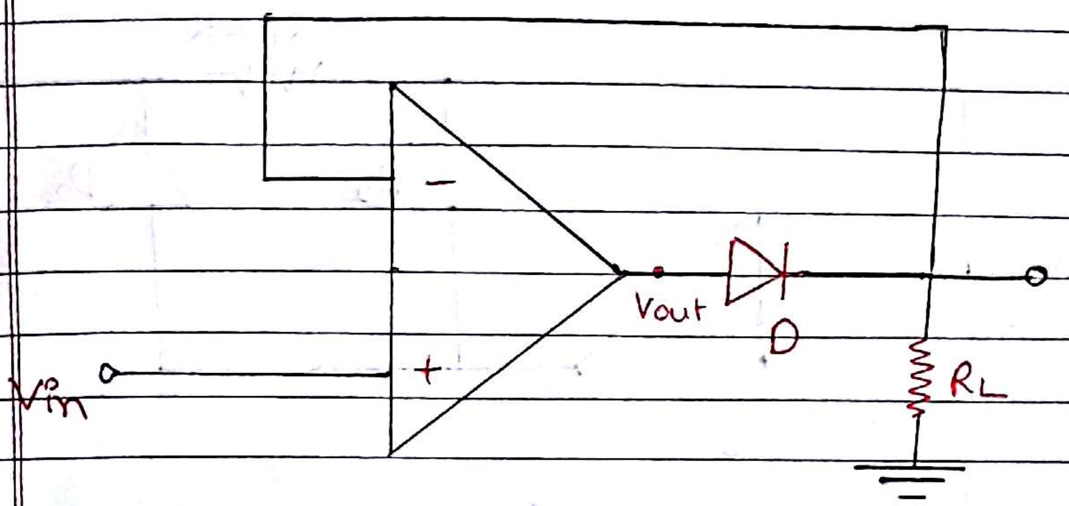
PRECISION RECTIFIERS (using op-amp)

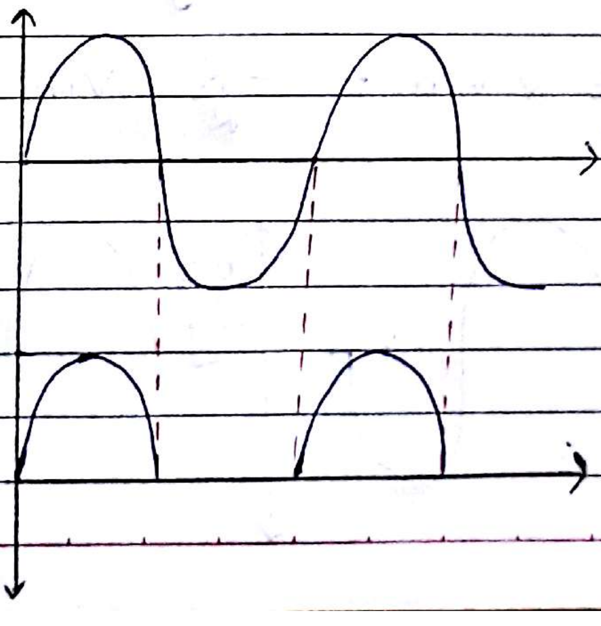
It is a small signal rectifier which is capable of rectifying signals of very small piece of the order of few milivolts.

Since such small AC signals are not able to drive a diode directly due to cutting voltage of the diode.

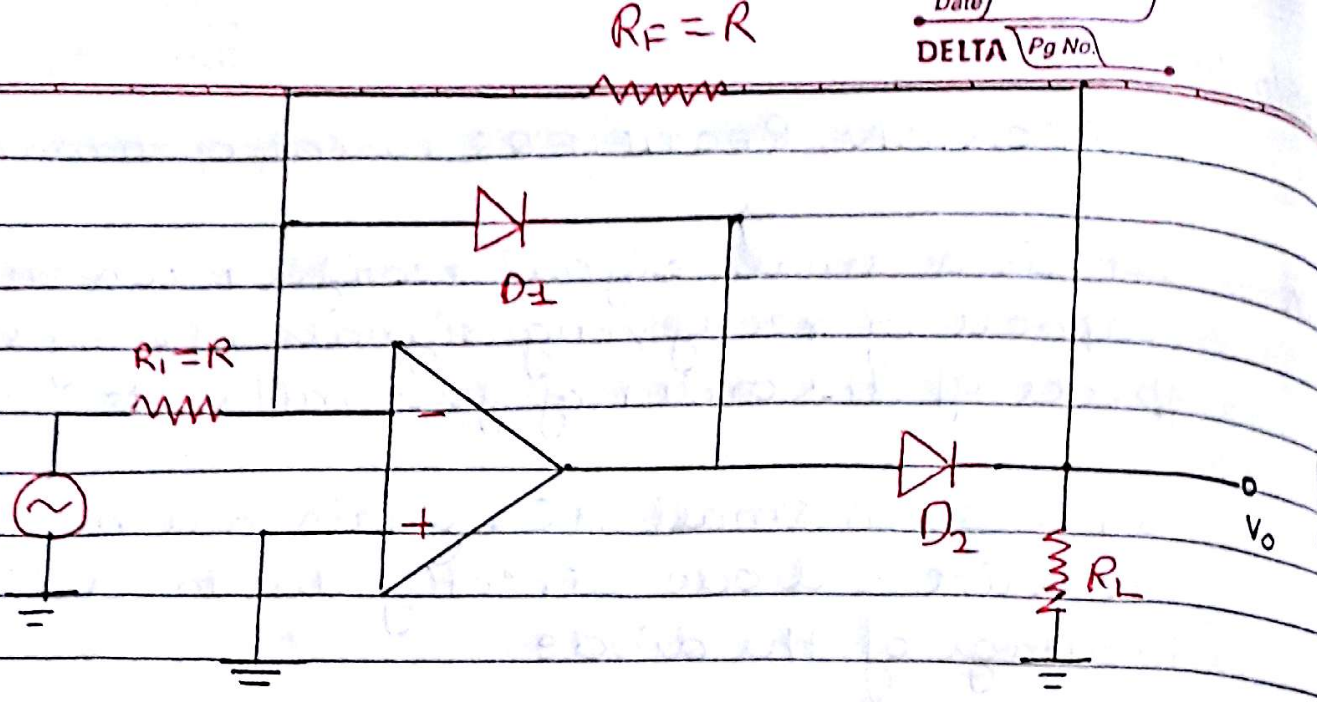
∴ op-amp is introduced in the circuit.



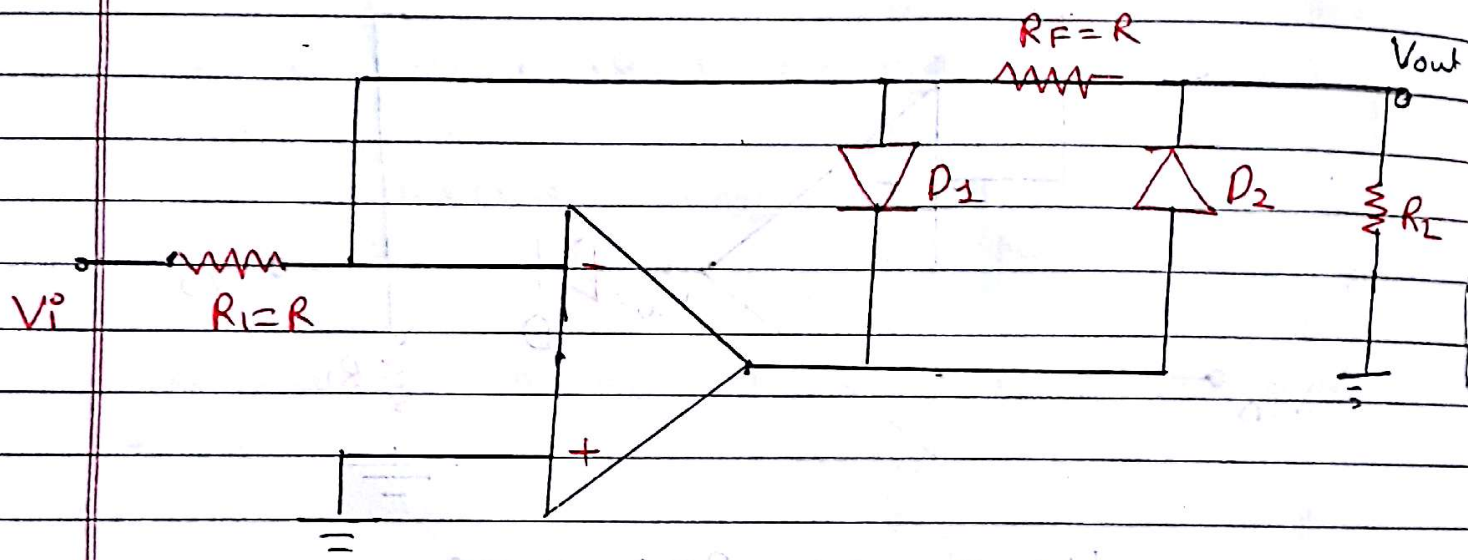
HALF WAVE RECTIFIER



Hence the circuit behaves as half wave rectifier.

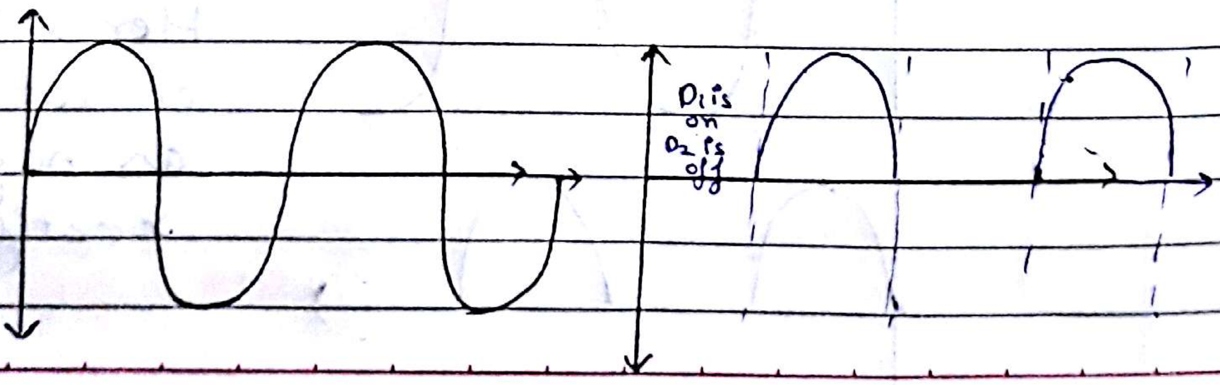


OR

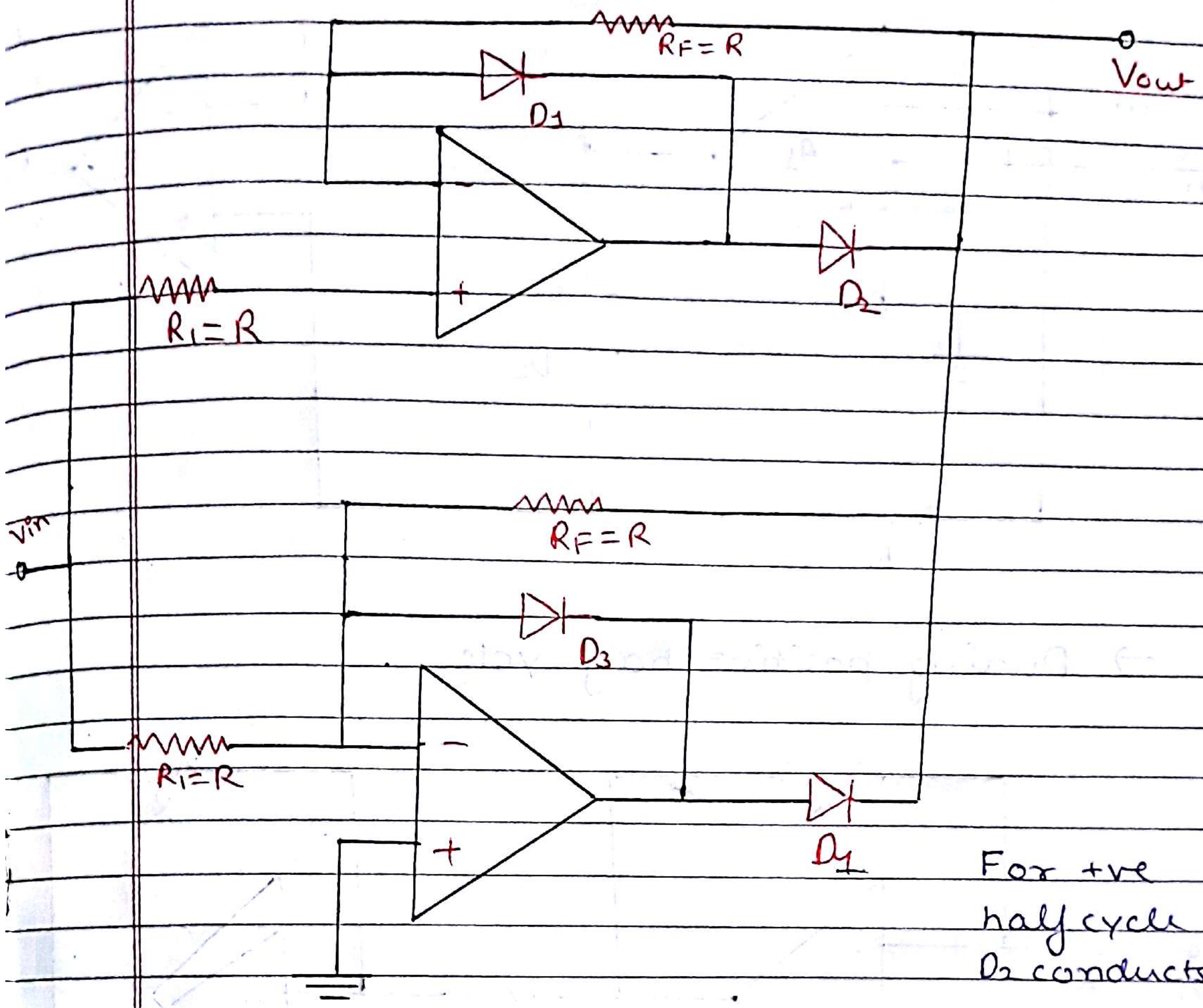


Since it is an inverting amplifier.

$$V_{out} = -\frac{R_F}{R_1} \times V_{in} = -\frac{R}{R} \times V_{in} \Rightarrow \boxed{V_o = -V_{in}}$$

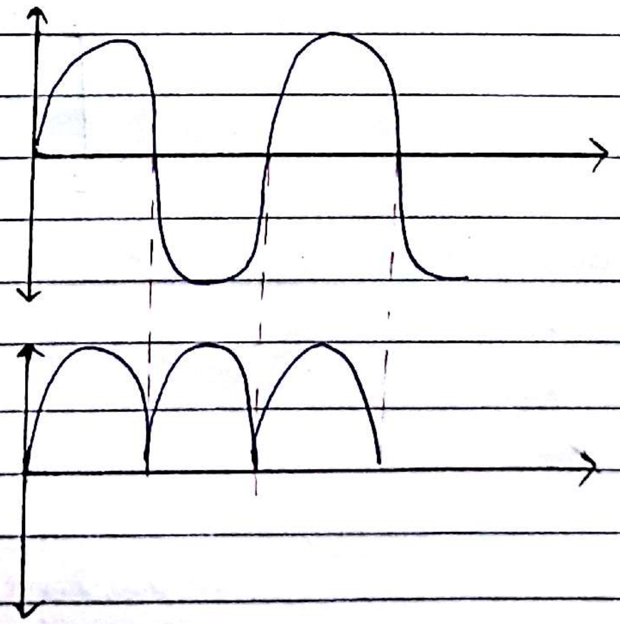


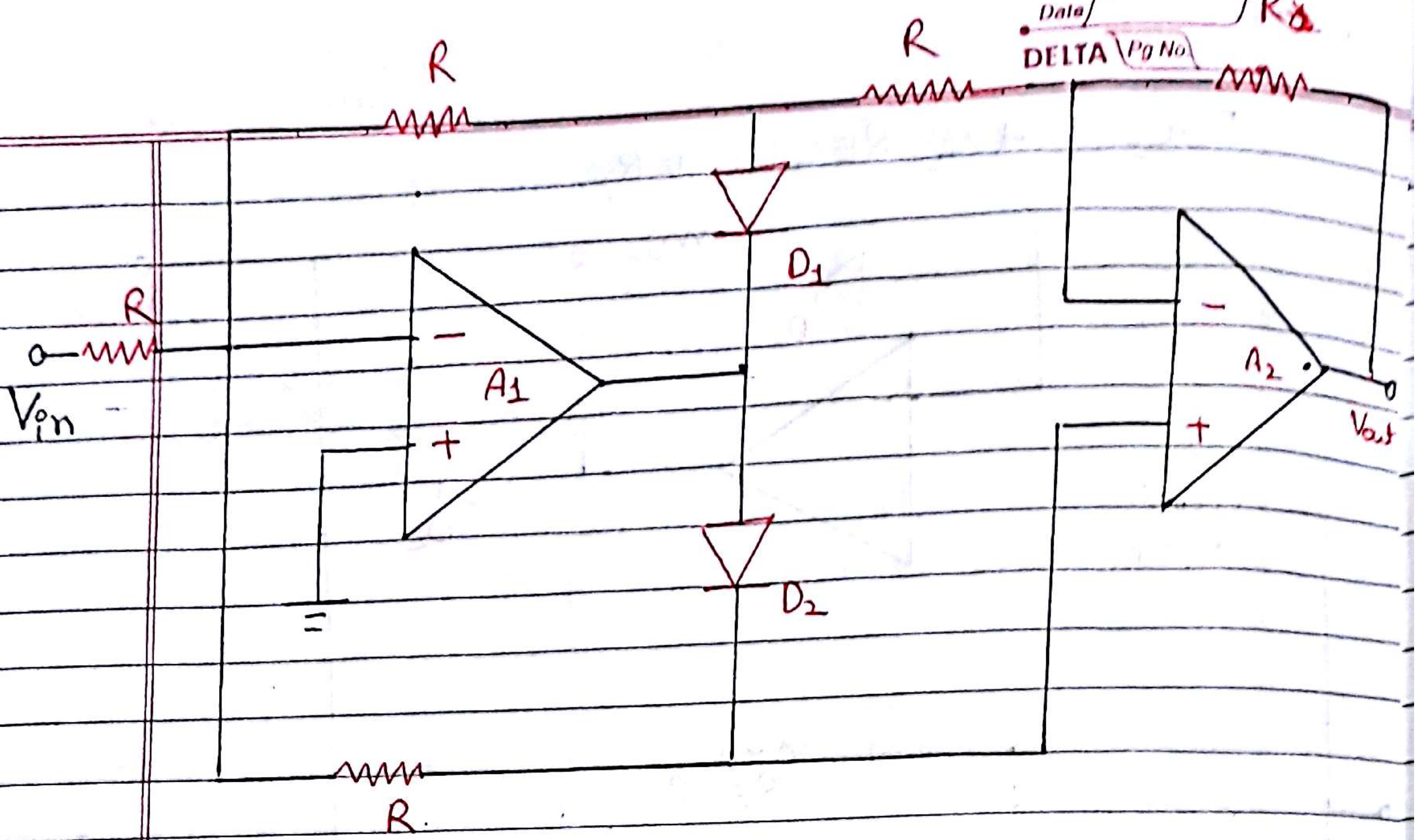
FULL WAVE RECTIFIER :



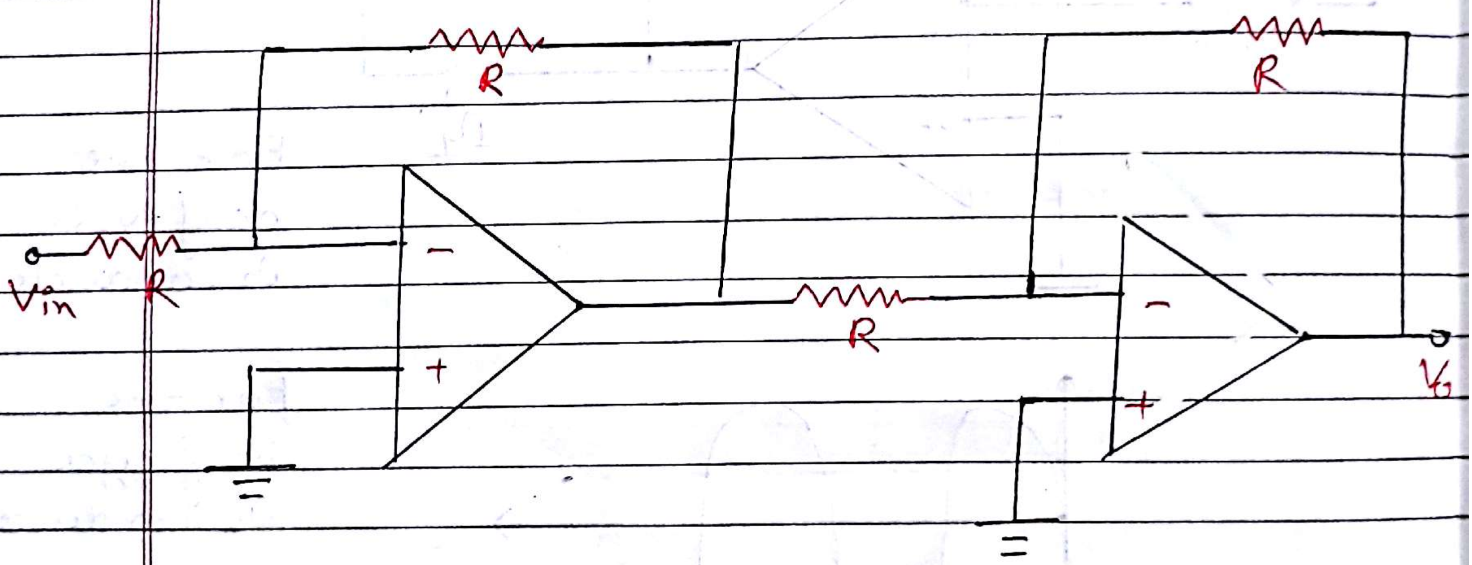
For +ve half cycle D_2 conducts,

For -ve half cycle D_4 conducts

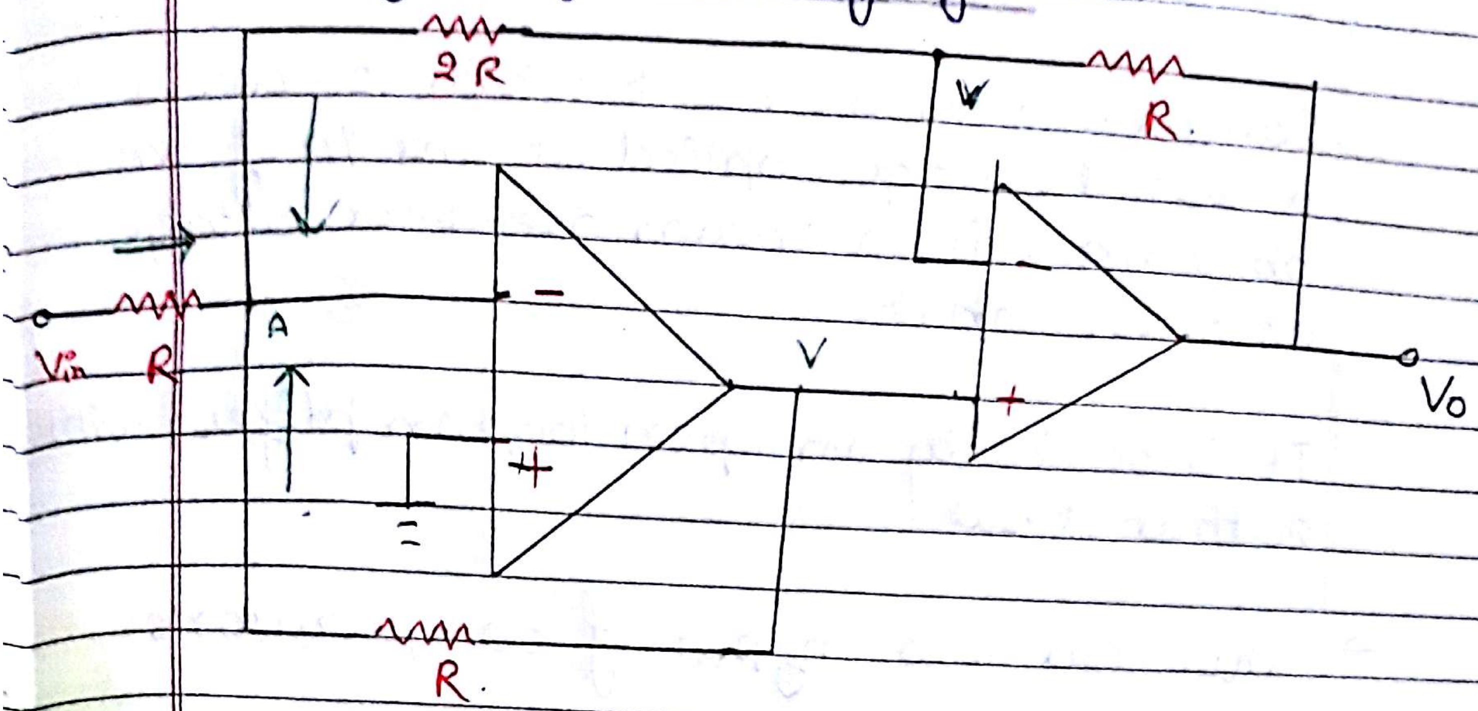




→ During positive half cycle.



→ During negative half cycle



Apply KCL at node A,

$$\frac{V_{in}}{R} + \frac{V}{2R} + \frac{V}{R} = 0$$

$$V\left(\frac{1}{2R} + \frac{1}{R}\right) = \frac{-V_{in}}{R}$$

$$V\left(\frac{3}{2R}\right) = -\frac{V_{in}}{R}$$

$$\boxed{V = \frac{-2}{3} V_{in}}$$

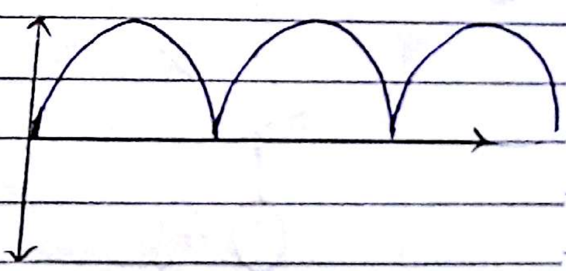
→ For 2^{nd} op-amp.

$$V_o = \left(1 + \frac{R}{2R}\right) \times V$$

$$V_o = \frac{3}{2} \times \frac{-2}{3} V_{in}$$

$$\boxed{V_o = -V_{in}}$$

Hence,



FULL WAVE RECTIFIER

DATE 06/02/19

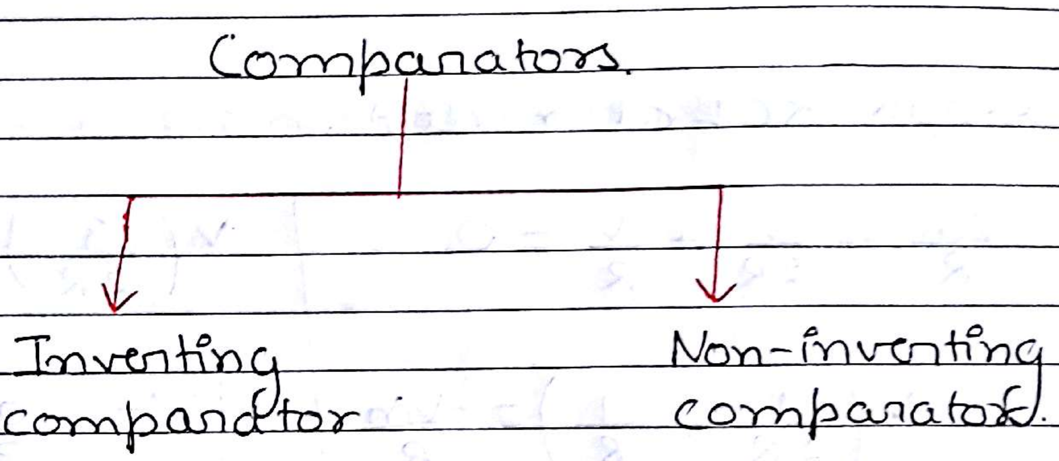
An op-amp in the open loop configuration operates in non-linear manner. There are no. of app in this mode, such as, comparators,

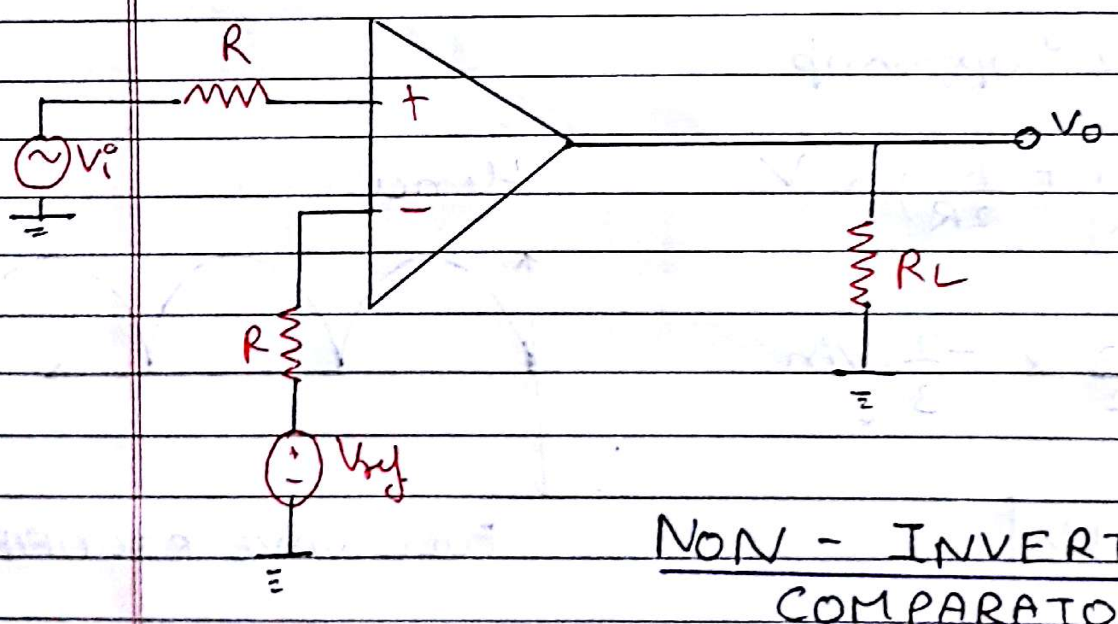
COMPARATORS

Comparator is a circuit which compares a signal voltage applied at one i/p of an op-amp with a known reference voltage at other input.

It is basically an open loop amplifier with output $\pm V_{sat}$.

→ There are two types of comparators.





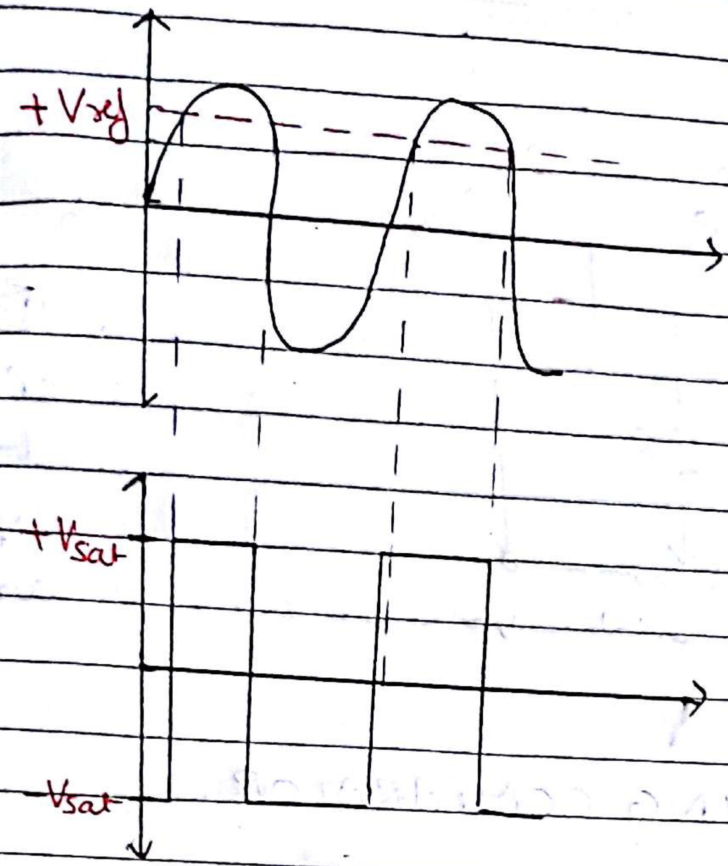
NON - INVERTING COMPARATORS

tors! ... converters.

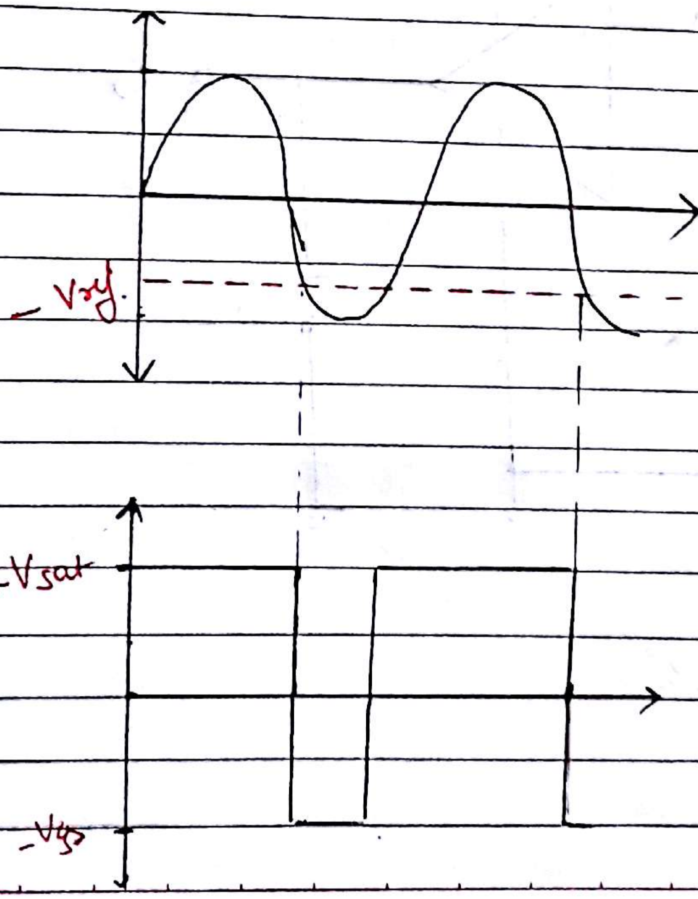
Date

DELTA Pg No

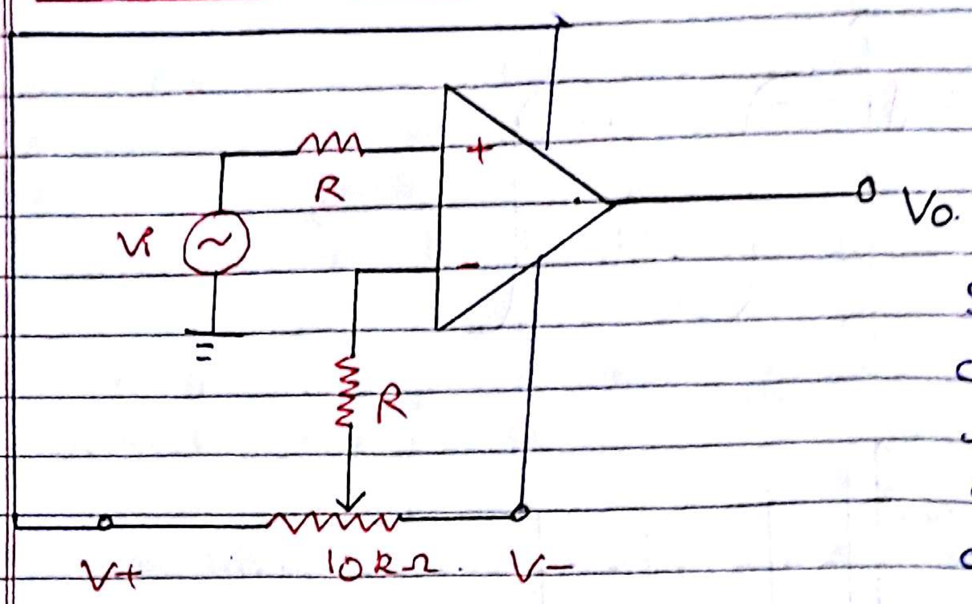
→ When Vref > 0



→ When Vref < 0

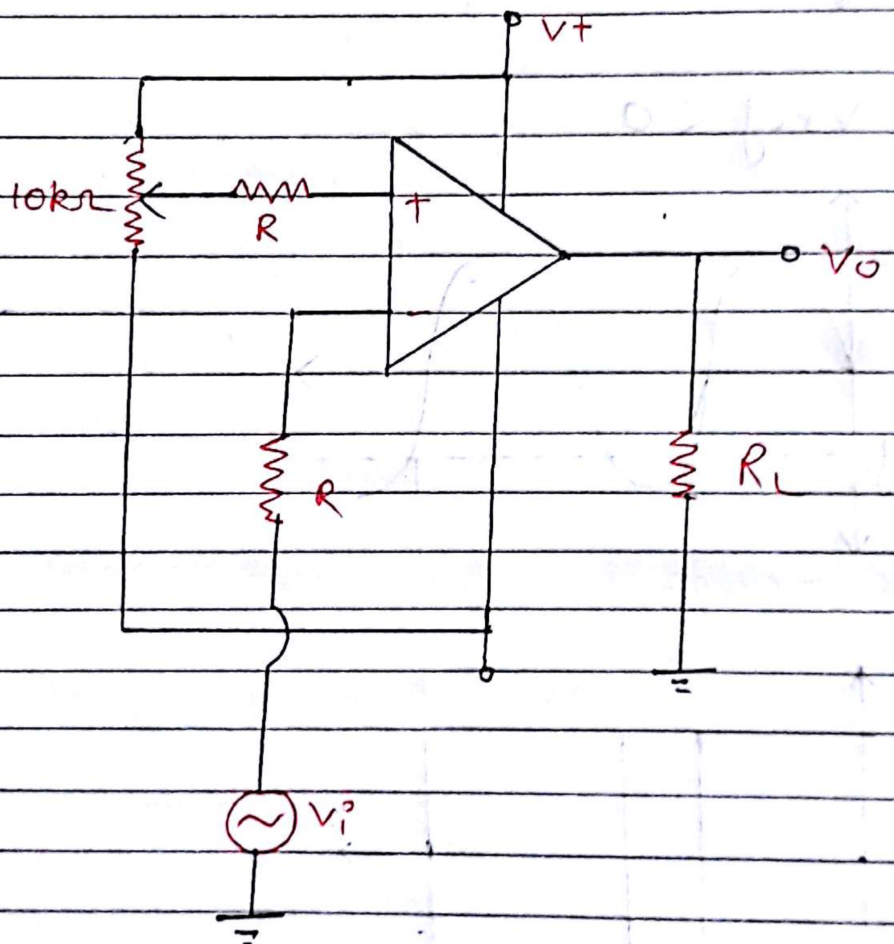


PRACTICAL NON-INVERTING COMPARATOR.

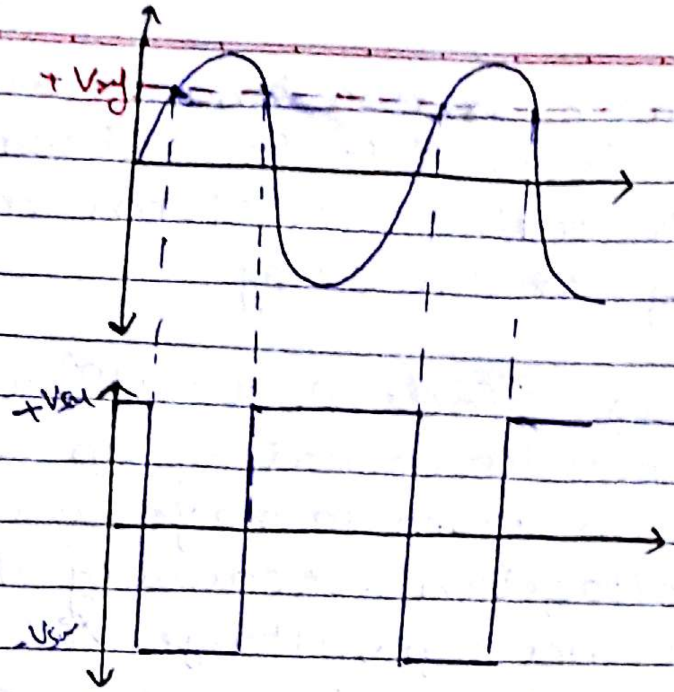


Same circuit can be used to apply +Vref and -Vref.

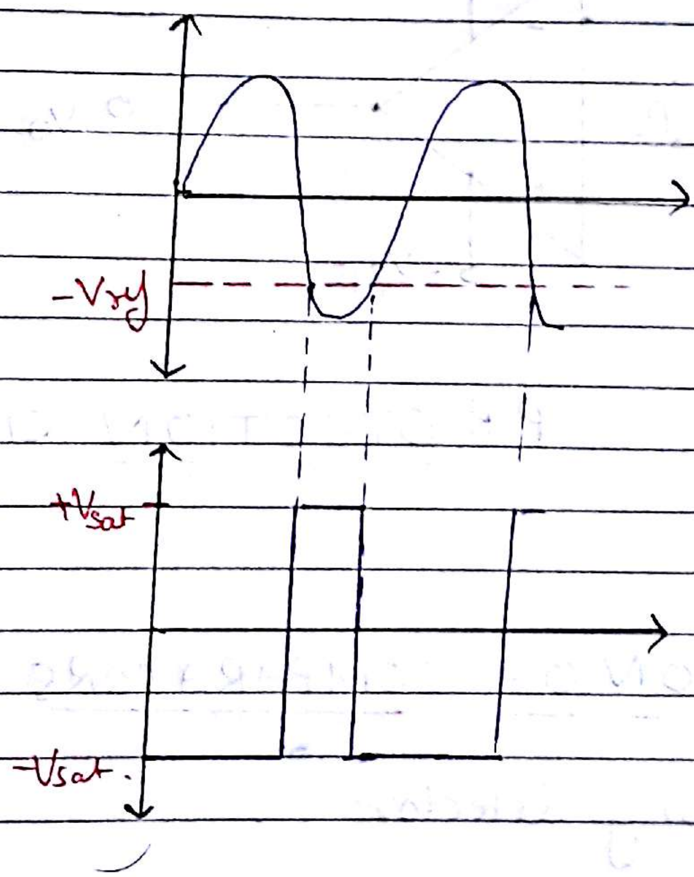
INVERTING COMPARATOR.



→ $V_{ref} > 0$. When V_{ref} is positive.

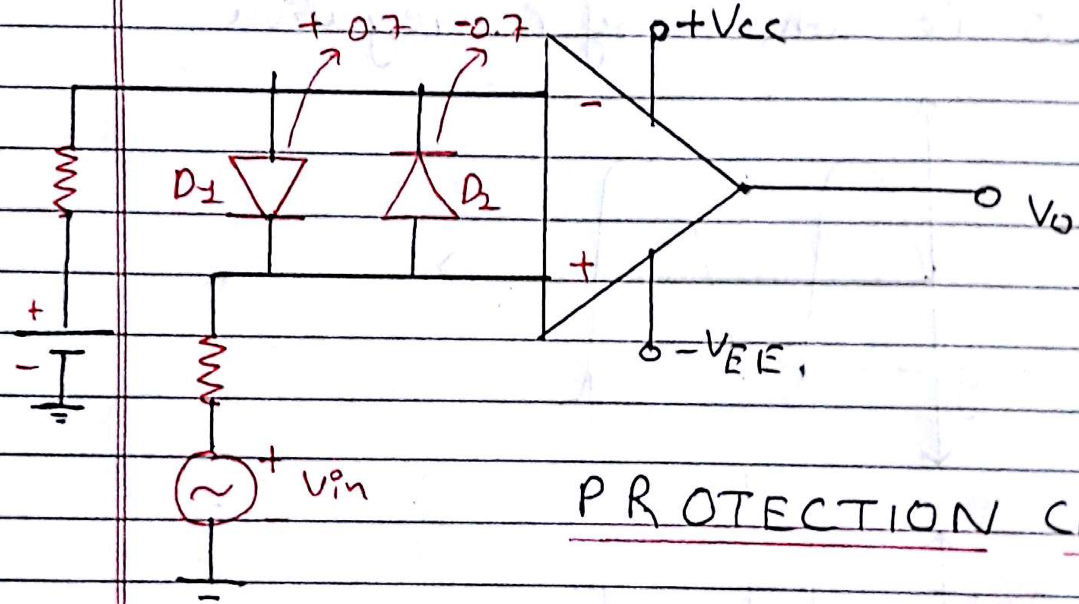


→ $V_{ref} < 0$ ie when V_{ref} is negative.



Comparator is also known as voltage level detector because at any time the output waveform shows rather $V_{in} > V_{ref}$ or $V_{in} < V_{ref}$.

Sometimes diode D_1 and D_2 are connected at the input terminal of op-amp to protect the op-amp from damage due to excessive input voltage V_{in} because of these diodes the difference i/p voltage V_{id} of op-amp is clampped to either $-0.7V$ or $+0.7V$.



PROTECTION CIRCUIT

APPLICATION OF COMPARATORS

1) Zero crossing detector
2) Window detector
3) Time marker generator
4) Phase meter.