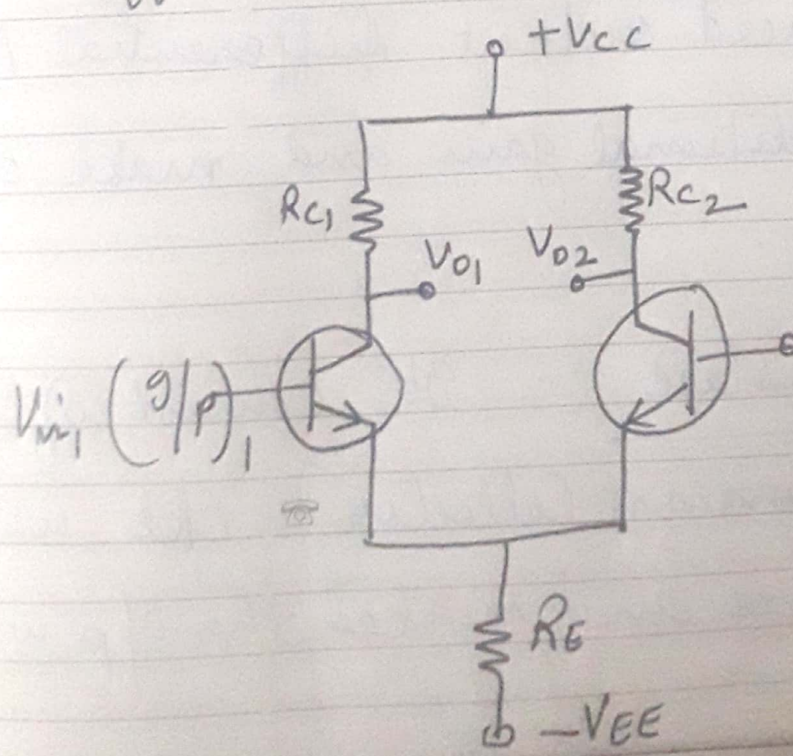
Operational Amplifiers (Op-Amp).

It is ~~an~~ an Integrated circuit which consist of a large no of Amplifiers connected to each other in addition to some passive elements. Op-Amp is the circuit which has a very high gain, high input resistance and low output resistance. In addition to amplification, the op-amp can do Mathematical operations also. like Addition, Subtraction, Integration, Differentiation etc.

~~Block Diagram:~~

Op-Amp is a high gain multistage amplifier. where the basic amplifier is the differential amp.

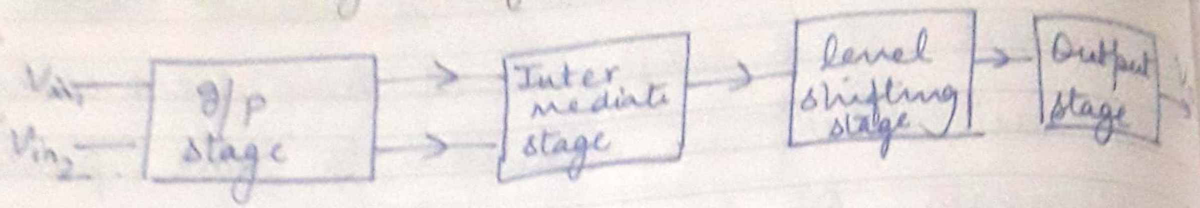
(Differential Amp).



$$V_o = V_{O_1} - V_{O_2}$$
$$= A[V_{in_1} - V_{in_2}]$$

where $A \to$ Gain

Block Diagram of Op-Amp



The whole ckt of Op-amp is divided into four stages :-

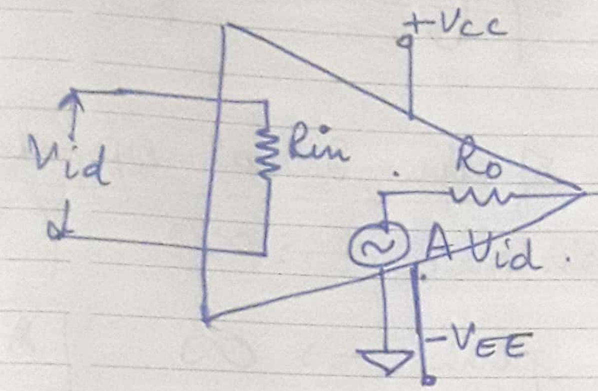
1) **Input stage** :- It consists of dual input balanced output differential Amplifier. It gives high gain as well as provide high input resistance.

2: **Intermediate Stage** :- It consists of dual input unbalanced output Differential Amplifier. It provides additional gain and make o/p as one terminal.

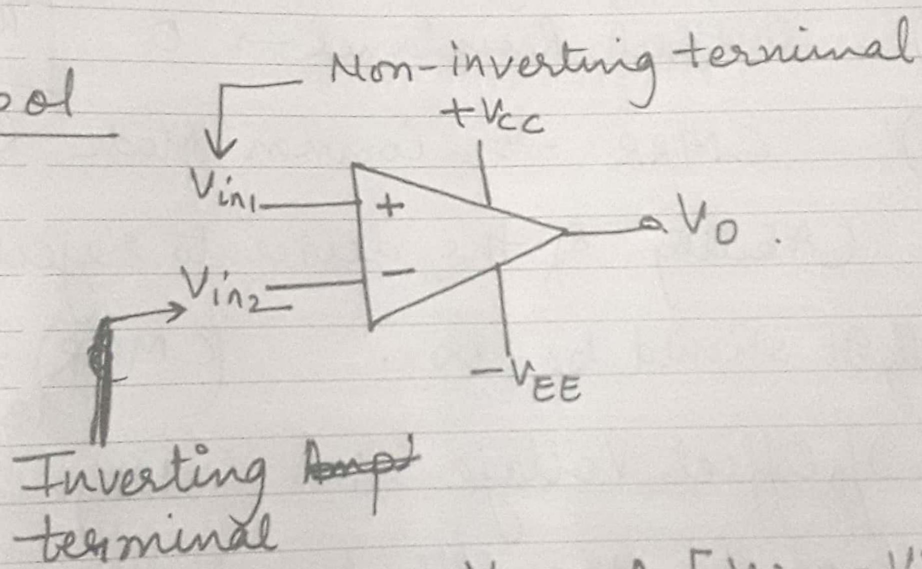
3. **Level Shifting Stage** :- It consist of emitter follower [Common Collector] ckt with constant current source and makes the o/p w.r.t gnd

4. <u>Output stage</u> :- It consist of complementary push pull Amplifier. which makes the output Resistance very low.

<u>Equivalent circuit of Op-Amp</u>



<u>Symbol</u>

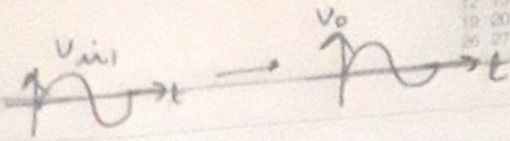


$$V_o = A\left[V_{in_1} - V_{in_2}\right]$$

if $V_{in_2} = 0$

$$\Rightarrow V_o = A V_{in_1}$$

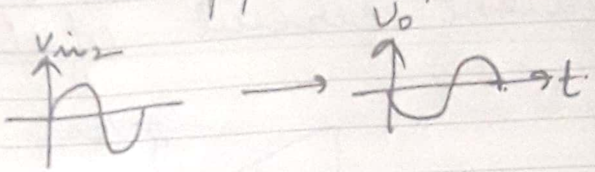
Thus this point is known as Non-inverting terminal as input and o/p are in same phase.



if $V_{in1} = 0$

$\Rightarrow V_o = -AV_{in2}$

This is known as inverting terminal as inp and output are in opposite phase.



<u>Characteristics of an Ideal op-amp</u>

1) Input Resistance $\rightarrow \infty$ $\left(R_i = \frac{V_{id}}{I_{b_1} - I_{b_2}} \right)$

2) voltage gain $\rightarrow \infty$ $\boxed{A = \frac{V_o}{V_{id}}}$

3) Output Resistance $\rightarrow 0$. $\boxed{R_o = \frac{V_o}{I_o}}$

5) CMRR $\rightarrow$ Common Mode Rejection ratio

(Ability of the device to reject noise).

Ideally It should be ∞. $(CMRR)_{dB} = \log_{10}\left(\frac{A_d}{A_{CM}}\right)$

6) <u>I/p Offset Voltage</u> :- Voltage required to nullify the offset voltage at the o/p.

(Offset voltage $\rightarrow$ the voltage at the o/p without input).

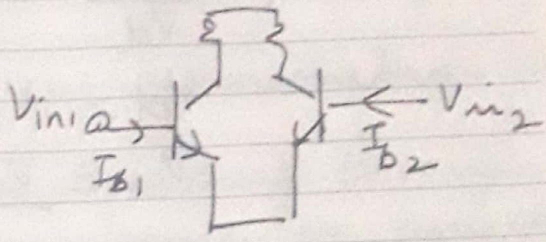
$V_{io} = \left[|V_1 - V_2| \right]$ ideally = 0

7) <u>Input offset current</u> :

$$I_{io} = |I_{b_1} - I_{b_2}|$$

difference of the current flowing at the base terminals of the transistors in a differential amplifier

$\boxed{\text{ideally} = 0}$



Note :- The input offset current value gives the mismatching of the transistors.

8) <u>Slew rate</u> :- The rate of change of o/p voltage w.r.t time

$$S.R = \left|\frac{dV_0}{dt}\right|$$

It gives the response of an op-amp.

$\boxed{\text{ideally} = \infty}$

$$(\text{CMRR})_{dB} = \log_{10} \frac{A_d}{A_{cm}}.$$

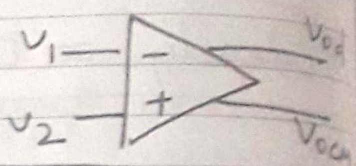
where $A_d \rightarrow$ Differential gain
$A_{cm} \rightarrow$ Common mode gain

[Common mode voltage is referred to as noise

where $A_d = \dfrac{V_{od}}{V_d}$. or $A_{CM} = \dfrac{V_{oCM}}{V_{CM}}$.

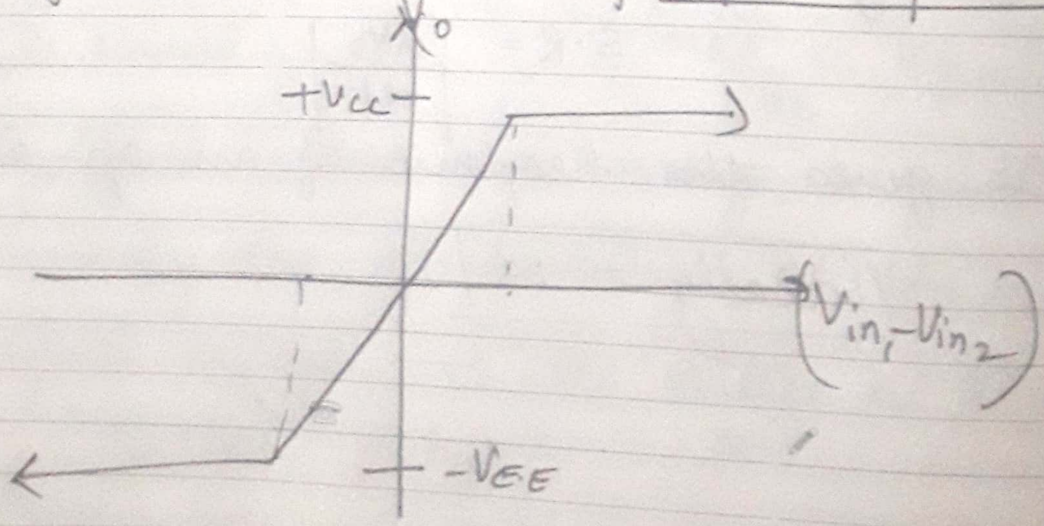
where $V_d = V_1 - V_2$

$V_{CM} = \dfrac{V_1 + V_2}{2}$.



Total o/p voltage $\boxed{V_0 = A_d V_d + A_{cm} V_{cm}}$

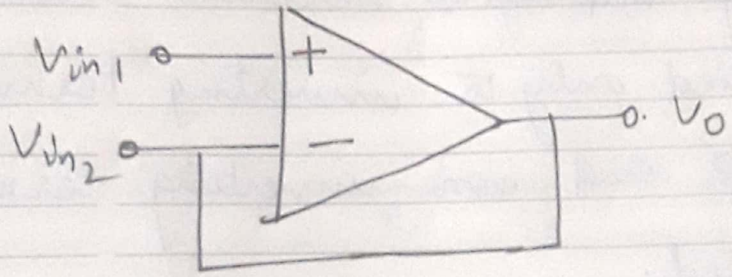
Voltage Transfer Curve of open loop Amp.



Appointments / Meetings

Need of feedback

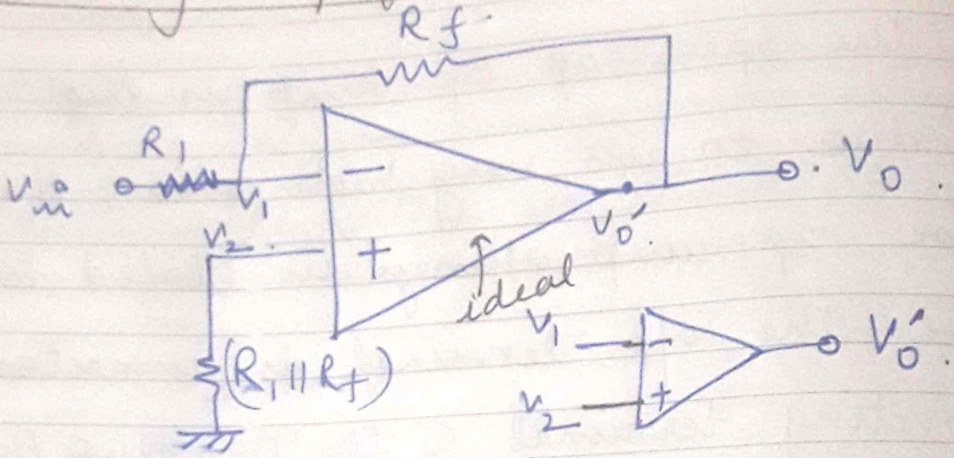
Since the open loop op-amp is highly unstable ckt due to its very high gain, therefore we use op-amp always in Closed loop. where the o/p terminal is connected to the inverting terminal of the op-amp through a wire, resistance, capacitance or any component ~~material~~.



(As o/p voltage V_o increases, it tries to decrease the input voltage and hence decreases the o/p voltage)

This is called ~~Needback~~ Negative feedback as it stabilizes the circuit.

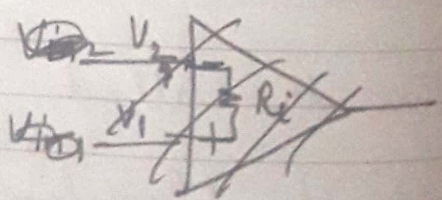
(f) Inverting Amplifier.



Inverting amplifier means when input is applied only to inverting terminal of an op-amp and non-inverting terminal is grounded.

Virtual Ground Concept

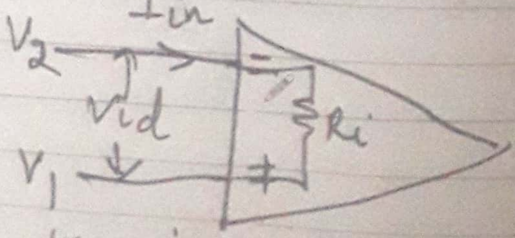
if we see the open-loop op-amp, then we have (1) $R_{in} = \infty$



$$R_{in} = \frac{V_{id}}{I_{in}}$$

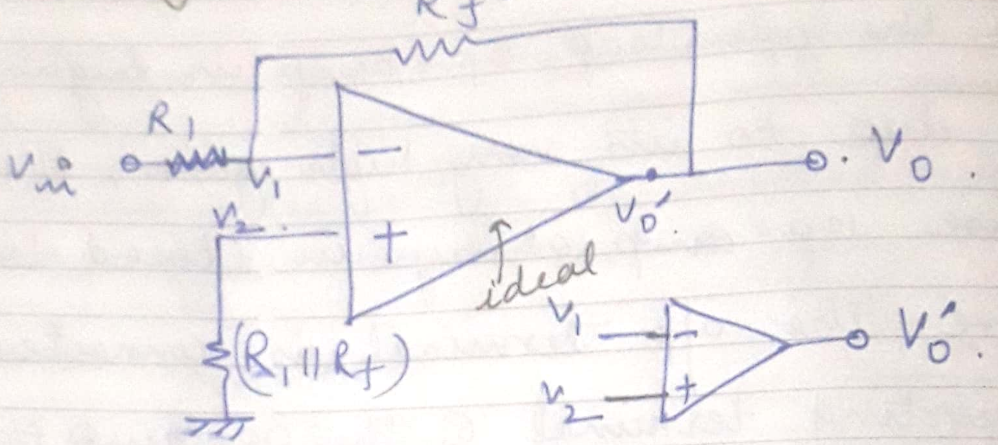
for $R_{in} = \infty$

$\boxed{I_{in} = 0.}$



(No current flows through terminals of an op-amp

(1) Inverting Amplifier.



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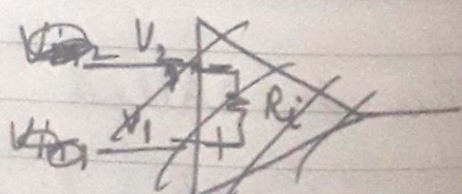

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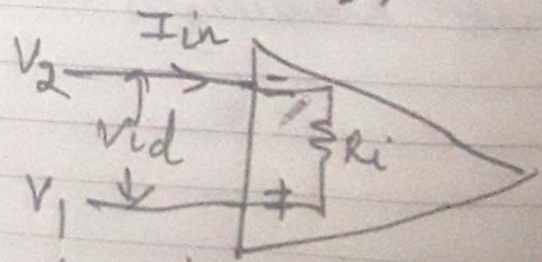


(No current flows through terminals of an op-amp

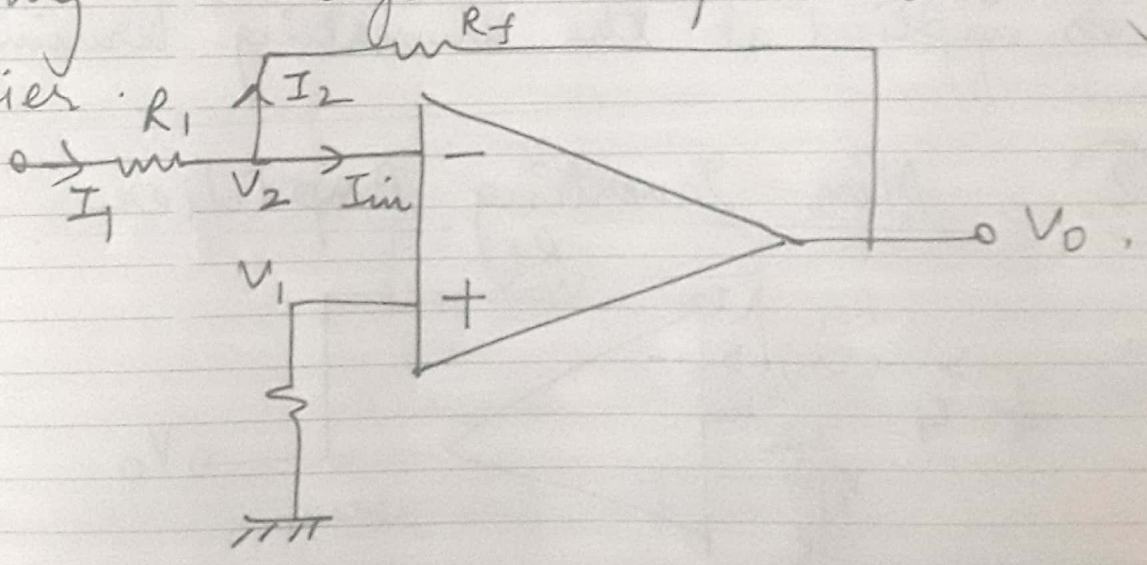
(2) $A = \infty$.

where $A = \dfrac{V_o}{V_{id}}$.

for $A = \infty$
$V_{id} = 0 \Rightarrow V_1 - V_2 = 0$
or $\boxed{V_1 = V_2}$

* To solve any closed loop ckt of an op-amp, we always apply virtual ground concept.

$\Rightarrow$ Applying virtual ground concept to Inverting Amplifier.



(1) $I_{in} = 0$

$\Rightarrow \boxed{I_1 = I_2}$ —— (1).

$\Rightarrow \dfrac{V_{in} - V_2}{R_1} = \dfrac{V_2 - V_o}{R_f}$ —— (2)

(2) $\boxed{V_1 = V_2 = 0.}$ ($\because$ V_1 is grounded $\therefore$ V_2 is also virtually grounded)

putting these values in eqn (2)

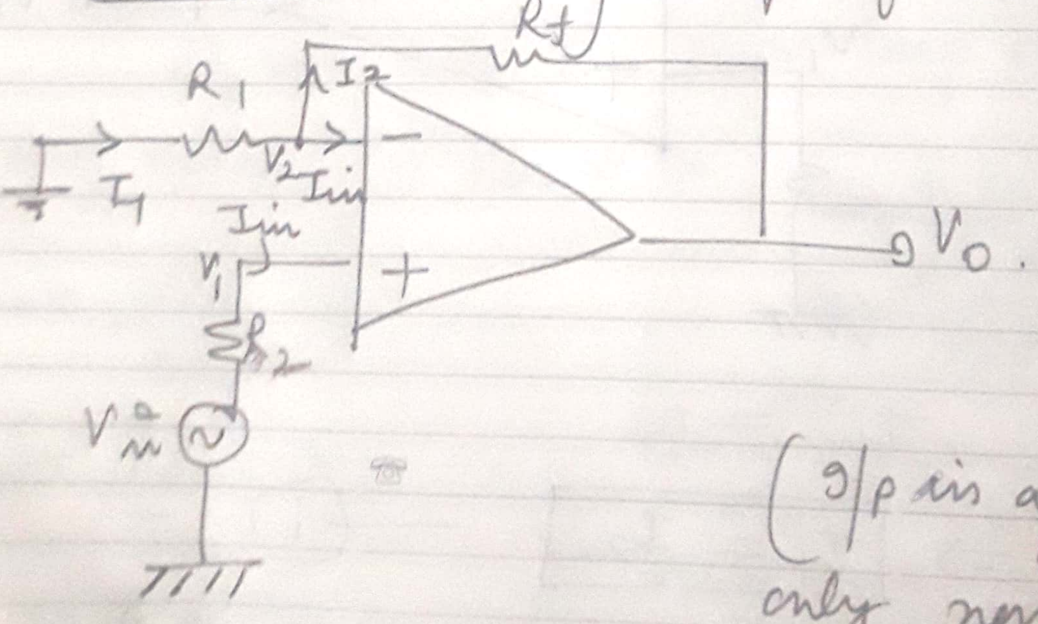
we have

$$\frac{V_{in}}{R_1} = \frac{-V_0}{R_f}$$

or $\boxed{V_0 = \frac{-R_f V_{in}}{R_1}}$ or $\boxed{\frac{V_0}{V_{in}} = \frac{-R_f}{R_1}}$ closed loop gain of an inverting amp.

negative sign indicates that input is applied at the inverting terminal.

(2) Non-Inverting Amplifier.



(I/p is applied to only non-inverting terminal).

② $\boxed{V_1 = V_2 = 0.}$ ($\because$ V_1 is grounded $\therefore$ V_2 is also virtually grounded)

putting these values in eqⁿ ②

we have

$$\frac{V_{in}}{R_1} = \frac{-V_0}{R_f}$$

or $\boxed{V_0 = \frac{-R_f V_{in}}{R_1}}$ or $\boxed{\frac{V_0}{V_{in}} = -\frac{R_f}{R_1}}$ closed loop gain of an inverting amp.

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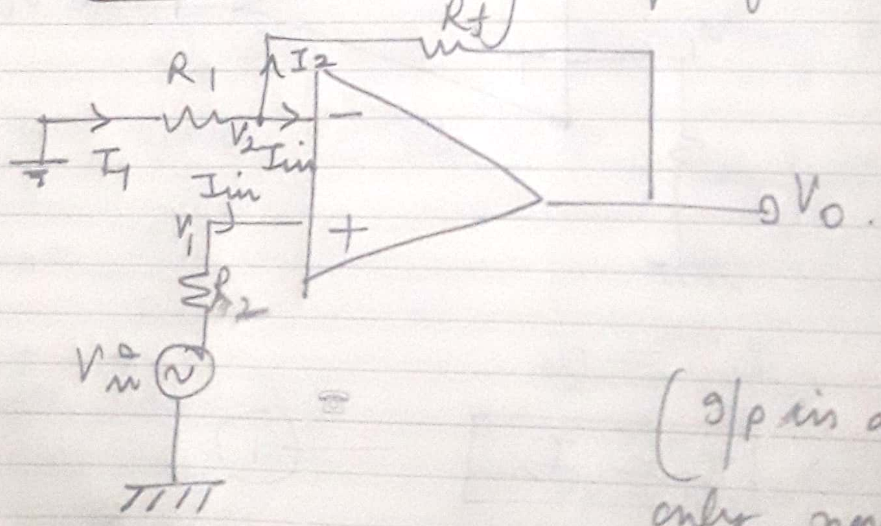
② Non-Inverting Amplifier



(I/p is applied to only non-inverting terminal)

Appointments / Meetings

8am

① $\boxed{V_1 = V_2 = V_{in}}$

② $\boxed{I_1 = I_2}$ $\Big\}$ $\boxed{V.C.G.}$

$$\Rightarrow \frac{0 - V_2}{R_1} = \frac{V_2 - V_o}{R_f}$$

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

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

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

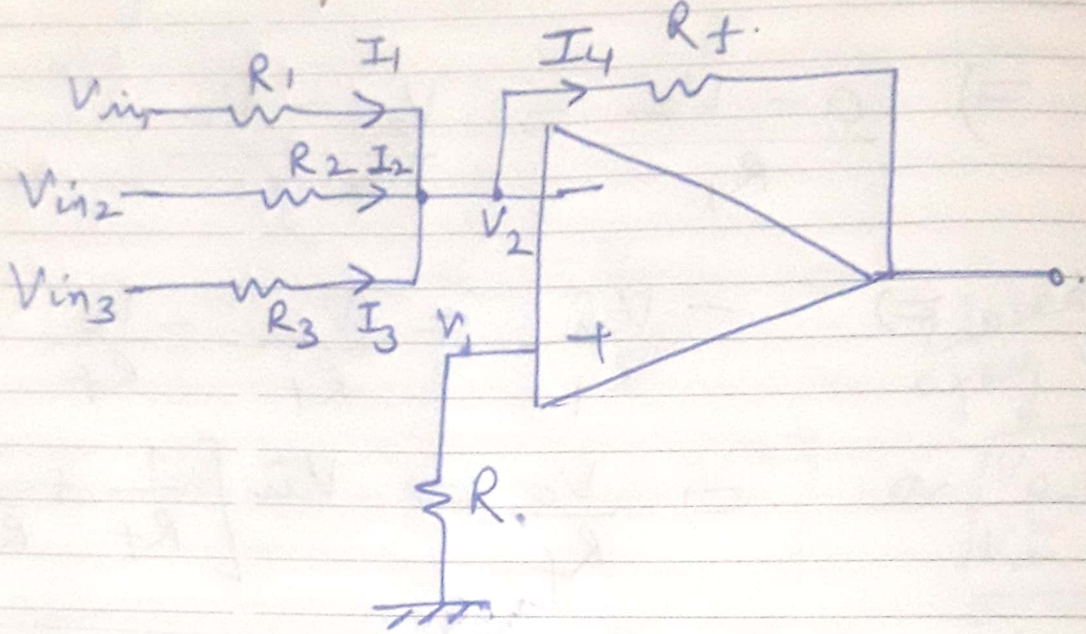
or $$\boxed{\frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}}$$

↓

closed loop gain of ~~a~~ a ~~closed loo~~ non-inverting op-amp.

Applications of an Op-Amp.

(1) Op-Amp as an adder.



Applying V.C.G we have,

(1) $\boxed{V_1 = V_2 = 0}$

(2) $\boxed{I_1 + I_2 + I_3 = I_4}$

$$\Rightarrow \frac{V_{in} - 0}{R_1} + \frac{V_{in_2} - 0}{R_2} + \frac{V_{in_3} - 0}{R_3}$$

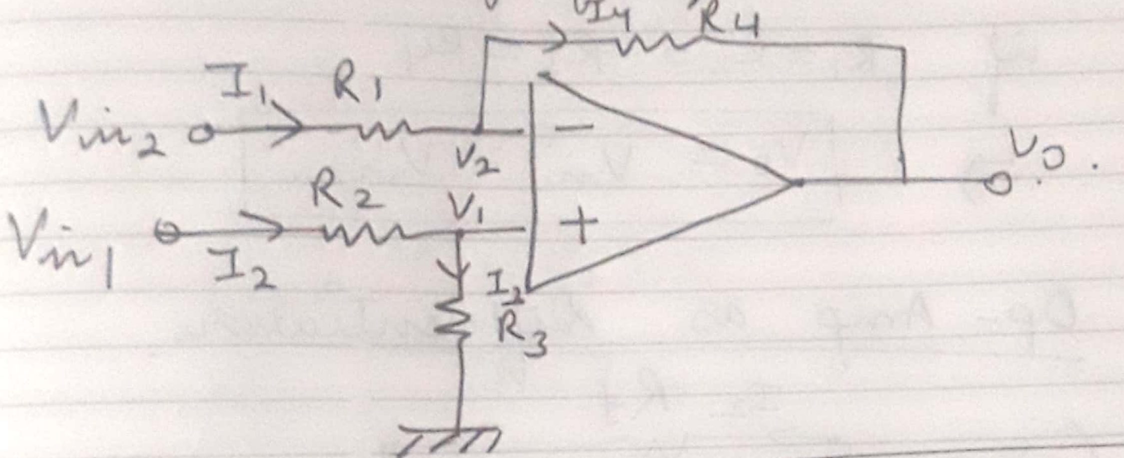
$$= \frac{0 - V_o}{R_f}.$$

or $V_o = -\frac{R_f}{R_1} V_{in_1} - \frac{R_f}{R_2} V_{in_2} - \frac{R_f}{R_3} V_{in_3}$

if $R_f = R_1 = R_2 = R_3$.

$\Rightarrow \boxed{V_o = -(V_1 + V_2 + V_3)}$

(2) Op-amp as a subtractor (Differential Amplifier).



we have (1) $\boxed{V_1 = \dfrac{V_{in_1} \times R_3}{R_2 + R_3} = V_2}$ (V.C.G)

$(\because I_2 = I_3)$

(2). $\boxed{I_1 = I_4}$

$$\frac{V_{in_2} - V_2}{R_1} = \frac{V_2 - V_o}{R_4}$$

$$\frac{V_{in_2} - \dfrac{V_{in_1} \times R_3}{R_2 + R_3}}{R_1} = \frac{\dfrac{V_{in_1} \times R_3}{R_2 + R_3} - V_o}{R_4}$$

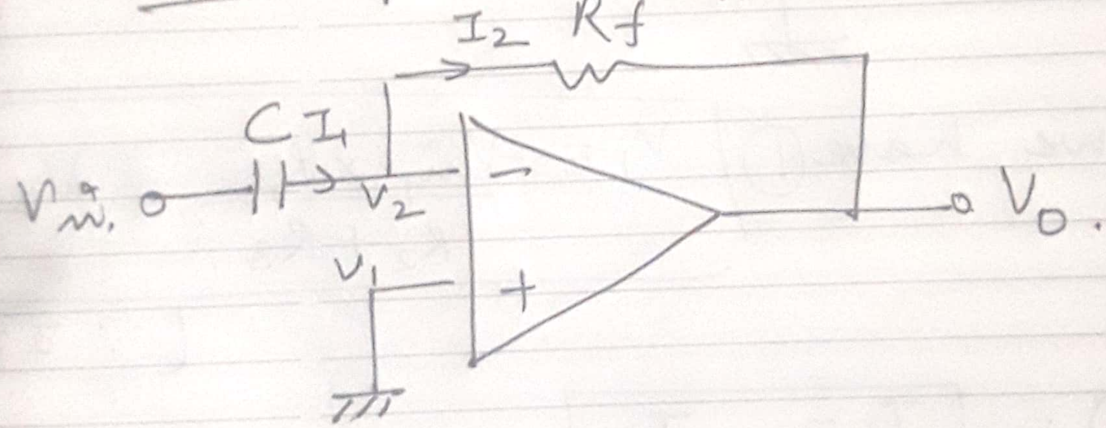
$$\Rightarrow V_o = \frac{V_{in_1} \times R_3}{R_2 + R_3} + \frac{V_{in_1} \times R_3}{R_2 + R_3}\left(\frac{R_4}{R_1}\right) - V_{in_2}\left(\frac{R_4}{R_1}\right)$$

$$\boxed{V_o = \frac{V_{in_1} \times R_3}{R_2 + R_3}\left(1 + \frac{R_4}{R_1}\right) - V_{in_2}\frac{R_4}{R_1}}$$

if $R_1 = R_2 = R_3 = R_4$

$$\Rightarrow \boxed{V_o = V_{in_1} - V_{in_2}}$$

3) Op-Amp as Differentiator.



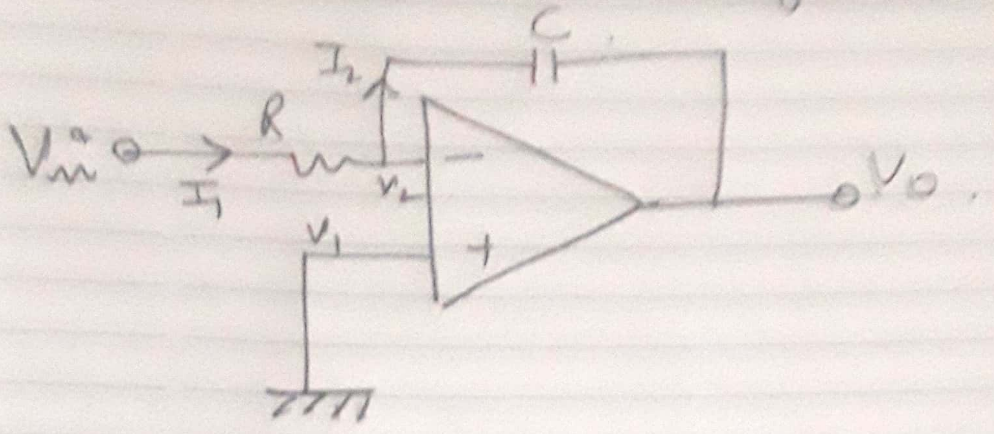
1) $V_1 = V_2 = 0$.

2) $I_1 = I_2$.

$$C\,\frac{d(V_{in} - 0)}{dt} = \frac{0 - V_o}{R_f}$$

$$\Rightarrow \boxed{V_o = -R_f C\,\frac{dV_{in}}{dt}}$$

(4) Op-Amp as Integrator



(1) $V_1 = V_2 = 0$.

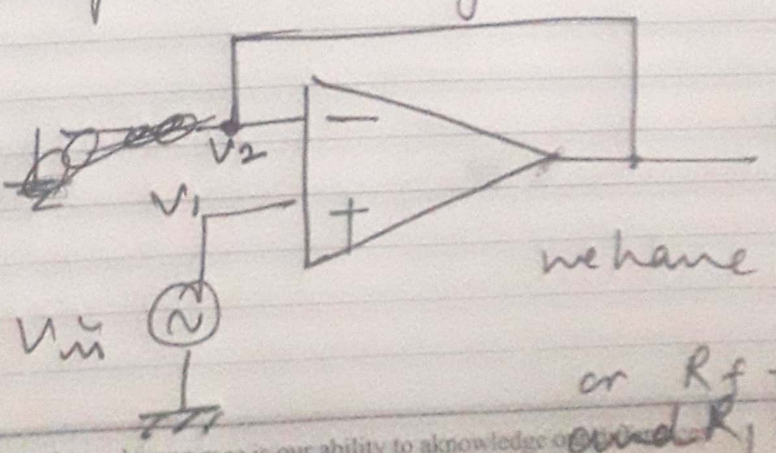
(2) $I_1 = I_2$.

$$\Rightarrow \frac{V_{in} - 0}{R} = C\frac{d(0 - V_o)}{dt}.$$

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

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

(5) Op-Amp as Voltage follower (Buffer).



we have $V_o = V_2 = V_1 = V_{in}$.

or $R_f = 0$.

~~and~~ $R_1 = \infty$.