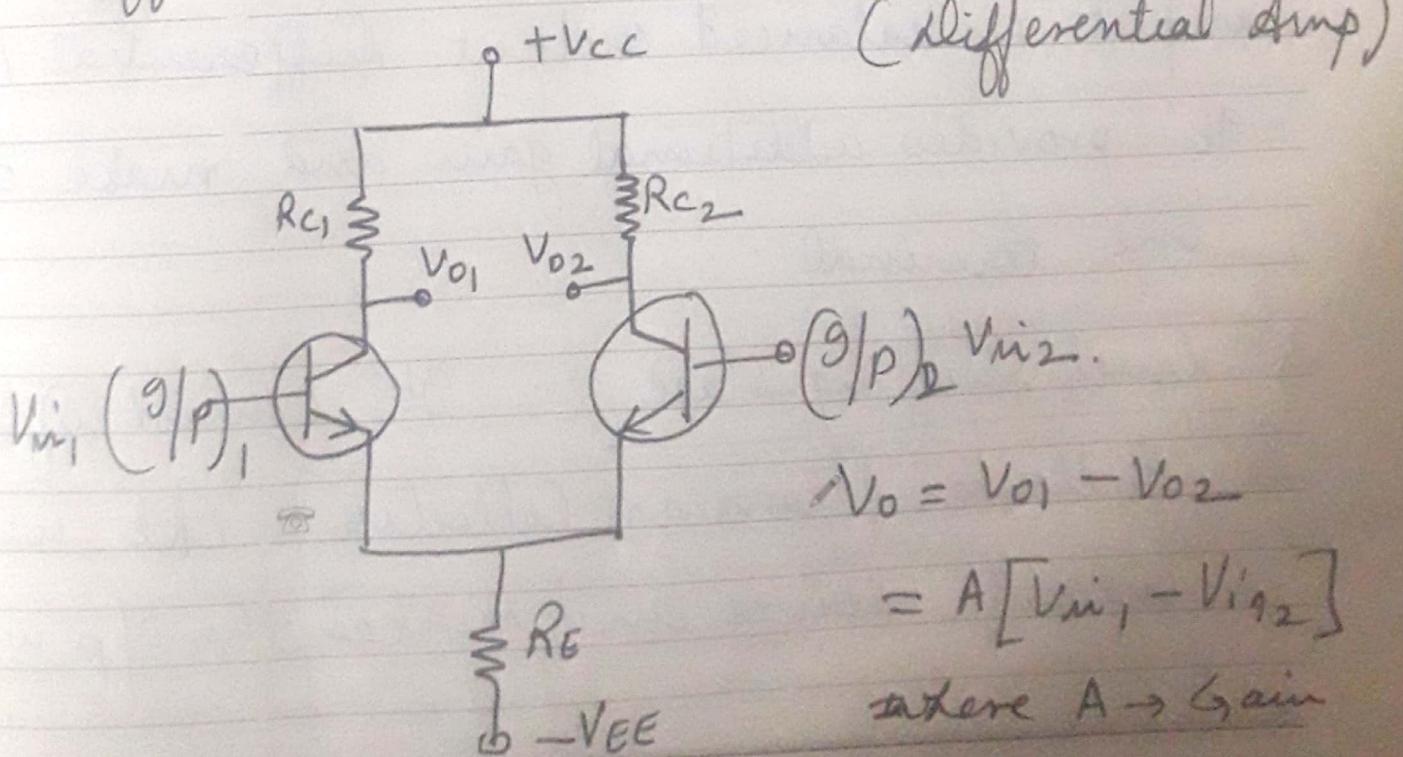
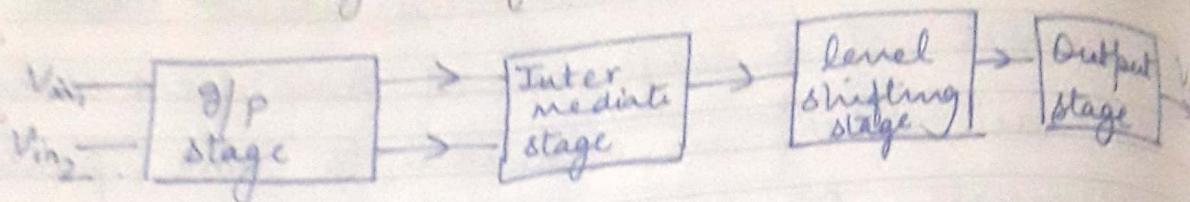


Operational Amplifiers (Op-Amp)

It is an integrated circuit which consists 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.



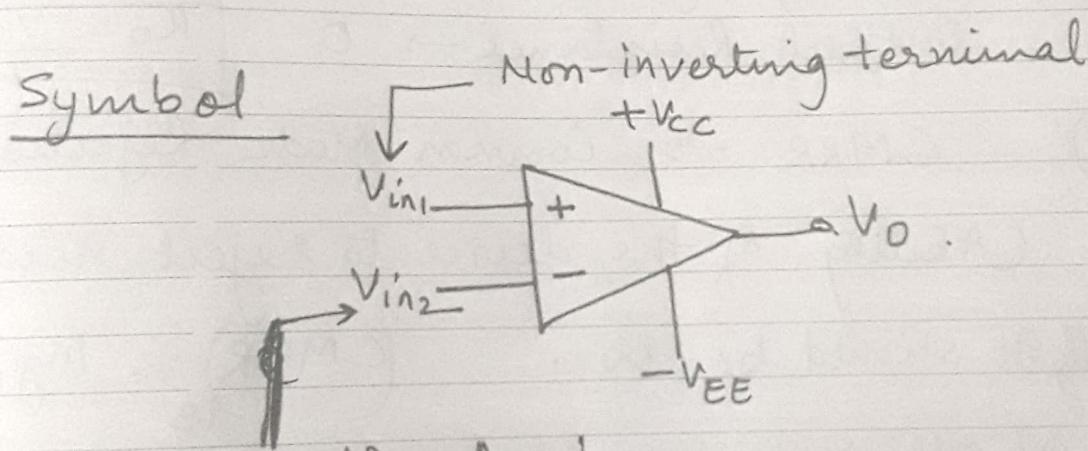
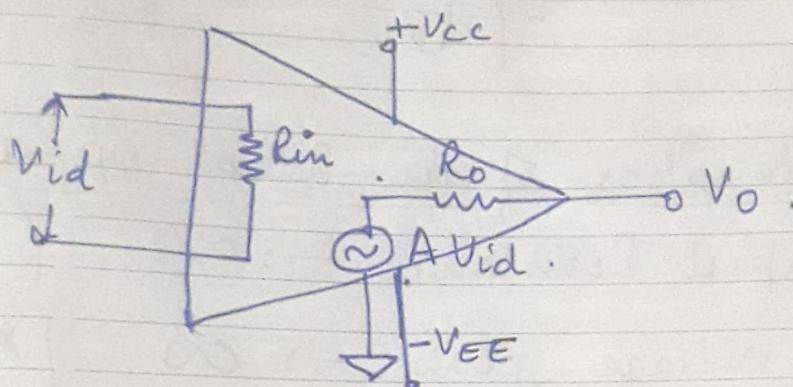
Block Diagram of Op-Amp.

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 ground.

4. Output stage :- It consists of complementary push pull amplifier which makes the output resistance very low.

Equivalent circuit of Op-Amp



Inverting Amp terminal

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

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.

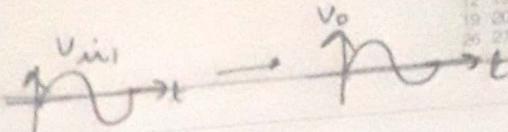
27

27-03-2018

Tuesday

MARCH

Day 086-279 • Week-13

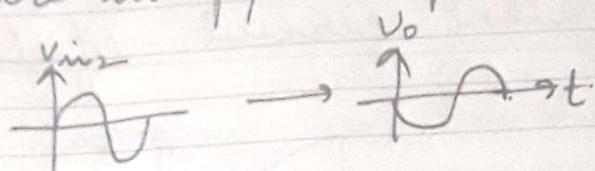


Appointments / Meetings

$$\text{if } V_{in1} = 0$$

$$\Rightarrow V_o = -A V_{in2}$$

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



Characteristics of an Ideal op-amp

- 1) Input Resistance $\rightarrow \infty$ $(R_i = \frac{V_{id}}{I_{b_1} + I_{b_2}})$
- 2) Voltage gain $\rightarrow \infty$ $(A = \frac{V_o}{V_{id}})$
- 3) Output Resistance $\rightarrow 0$. $(R_o = \frac{V_o}{I_o})$
- 5) CMRR \rightarrow Common Mode Rejection ratio

(Ability of the device to reject noise).

Ideally it should be ∞ .

$$(\text{CMRR}) = \log_{10} \left(\frac{A_d}{A_{cm}} \right)$$

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

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

$$V_{id} = [V_{+} - V_{-}] \quad \text{ideally} = 0$$

Great organizations demand a high level of commitment

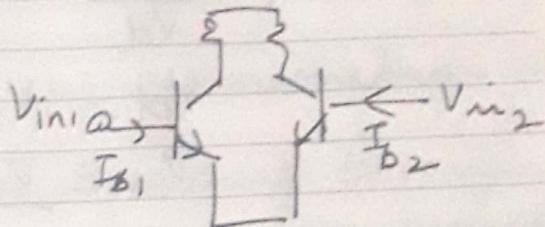
28

7) Input offset current :

$$I_{IO} = |I_{B1} - I_{B2}|$$

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

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



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

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

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

It gives the response of an op-amp.

$|I_{\text{ideally}} = \infty|$

29

29-03-2018

Thursday

MARCH

Day 088 - 277 • Week 13

FEB							MAR				
M	T	W	T	F	S	S	M	T	W	TH	F
1	2	3	4	5	6	7	8	9	10	11	12
9	10	11	12	13	14	15	16	17	18	19	20
18	19	20	21	22	23	24	25	26	27	28	29
26	27	28	29	30	31	1	2	3	4	5	6

Appointments / Meetings

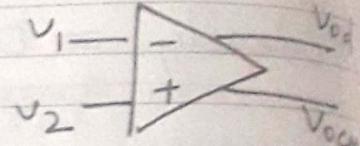
$$\underline{CMRR}_{dB} = \log_{10} \frac{A_d}{A_{cm}}$$

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

Common mode voltage is referred to as noise
 where $A_d = \frac{V_{od}}{V_d}$ or $A_{cm} = \frac{V_{ocm}}{V_{cm}}$.

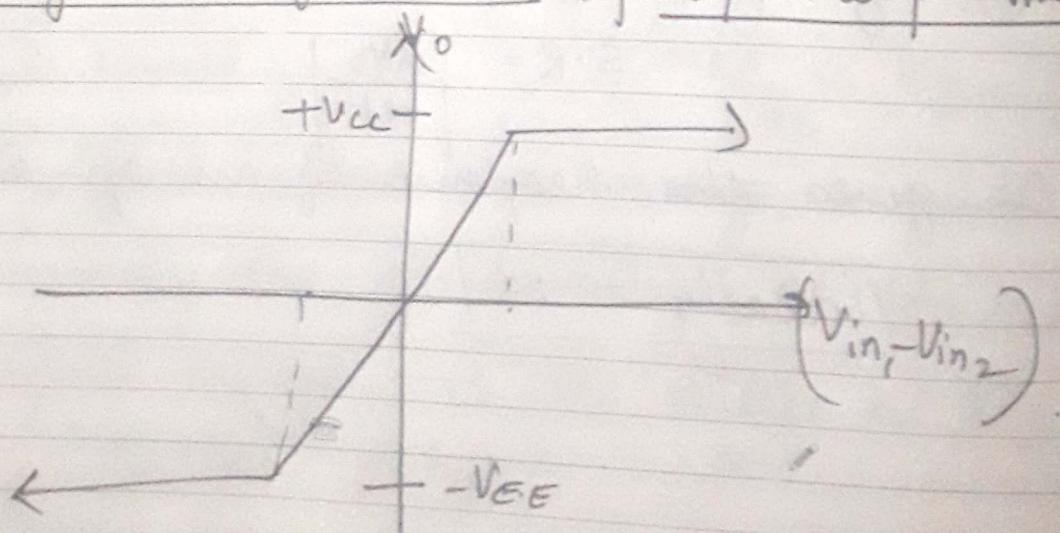
where $V_d = V_1 - V_2$

$$V_{cm} = \frac{V_1 + V_2}{2}$$



Total o/p voltage $|V_o = A_d V_d + A_{cm} V_{cm}|$

Voltage Transfer Curve of open loop Amp:



There are two things to Aim at to get what you want and one

APR					MAY				
M	T	W	T	F	S	S	M	T	W
1	2	3	4	5	6	7	8	9	10
8	9	10	11	12	13	14	15	16	17
15	16	17	18	19	20	21	22	23	24
22	23	24	25	26	27	28	29	30	31
29	30	31	1	2	3	4	5	6	7

30-03-2018

Friday

MARCH

30

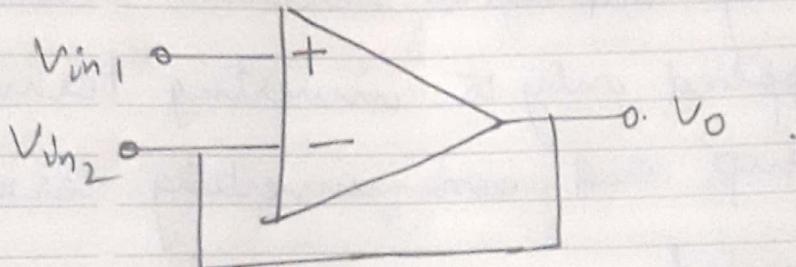
Day 689 / 276 • Week 13

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 materials.



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

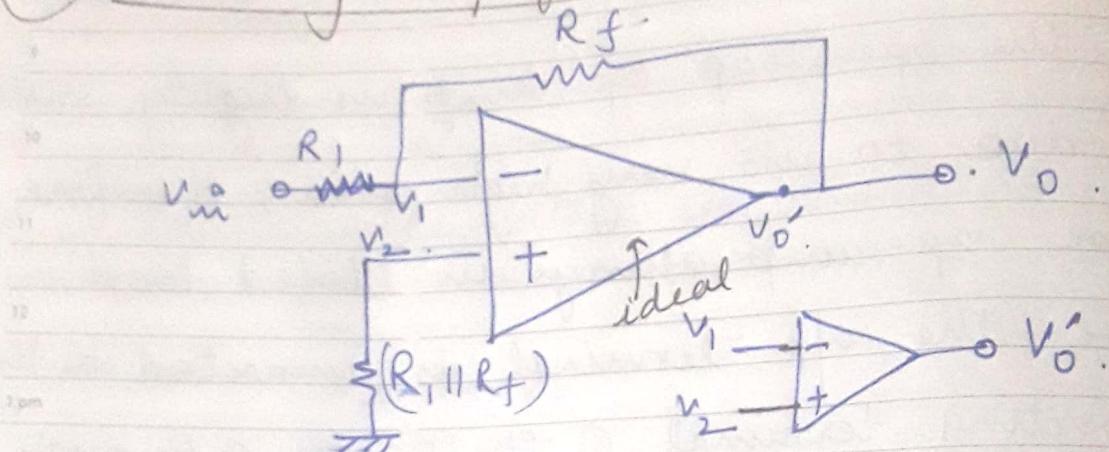
This is called Negative feedback. as it stabilizes the circuit.

31

31/03/2018
Saturday
MARCH

M	T	W	T	F	S	S
*	*	*	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	*	*	*	*

① Inverting Amplifier



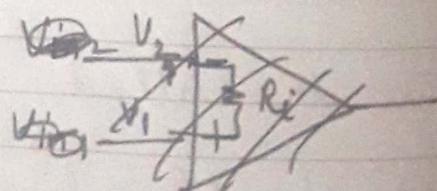
Inverting amplifier means when input is applied only to inverting terminal of op-amp and non-inverting terminal is grounded.

Virtual Ground Concept

If we see the open-loop op-amp,

we have ① $R_{in} = \infty$

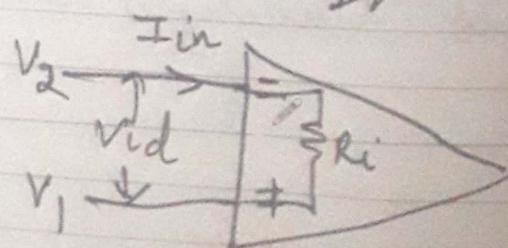
$$R_{in} = \frac{V_{id}}{I_{in}}$$



for $R_{in} = \infty$

$$I_{in} = 0$$

(No current flows through terminals of an op-amp)



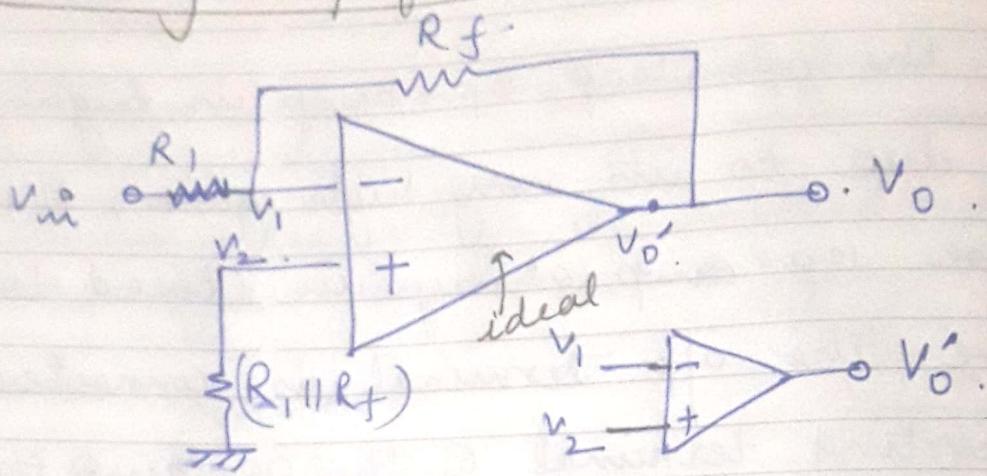
Individual commitment to a group effort is what makes a company work

31

31-03-2018
Saturday
MARCH

FEB							MAR						
M	T	W	T	F	S	S	M	T	W	T	F	S	S
1	2	3	4	5	6	7	8	9	10	11	12	13	14
9	10	11	12	13	14	15	16	17	18	19	20	21	22
17	18	19	20	21	22	23	24	25	26	27	28	29	30
24	25	26	27	28	29	30	31	1	2	3	4	5	6

① 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

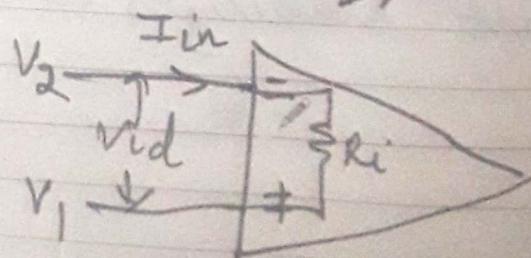
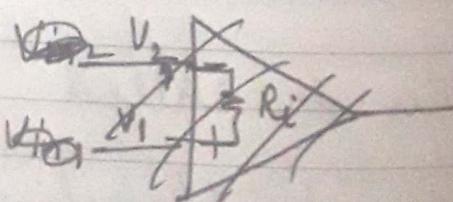
if we see the open-loop op-amp, then

we have ① $R_{in} = \infty$

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

for $R_{in} = \infty$ $\rightarrow I_{in} = 0$

(No current flows through terminals of an op-amp)



②

$$A = \infty$$

where $A = \frac{V_o}{V_{id}}$

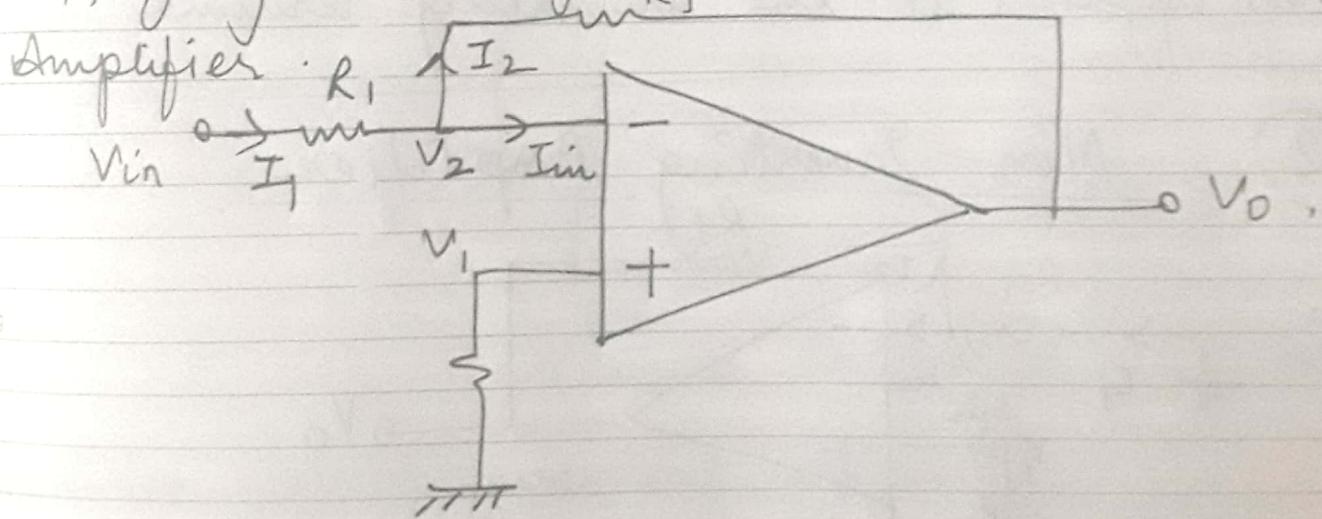
for $A = \infty$

$$V_{id} = 0 \Rightarrow V_1 - V_2 = 0$$

$$\text{or } \boxed{V_1 = V_2}$$

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

=) Applying virtual ground concept to Inverting Amplifier



①

$$I_{in} = 0$$

$$\Rightarrow \boxed{I_1 = I_2} \quad \text{--- } ①$$

$$\Rightarrow \frac{V_{in} - V_2}{R_1} = \frac{V_2 - V_o}{R_f} \quad \text{--- } ②$$

The nice thing about team work is that you always have others on your side

Assignments / Meetings

8 am

(2)

$$\boxed{V_1 = V_2 = 0.}$$

(∴ V_1 is grounded)

∴ V_2 is also virtually grounded

putting these values in eqn (2)

we have

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

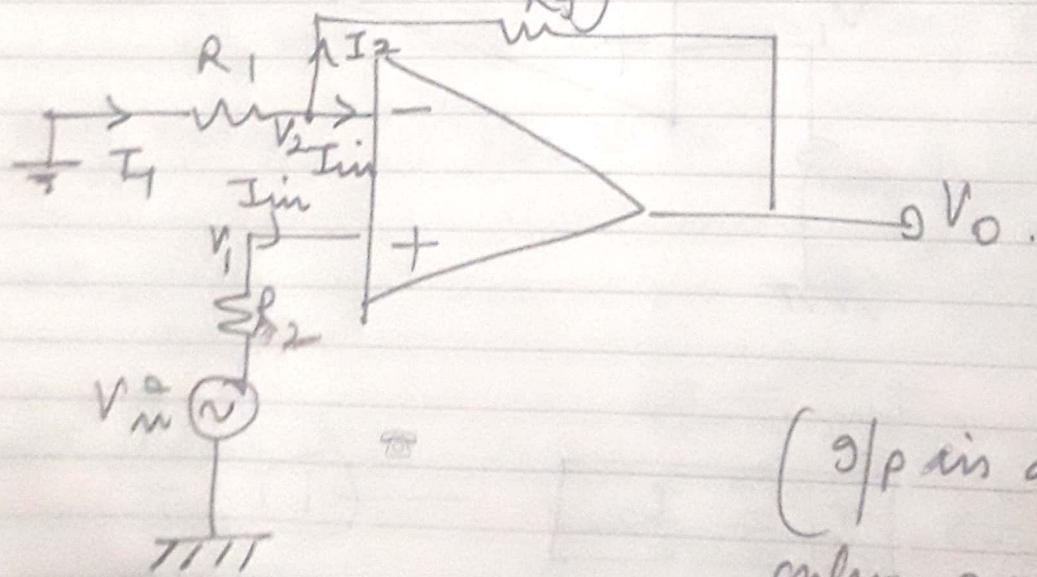
closed loop gain
of any inverting
amp.

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

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

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

(2) Non-Inverting Amplifier.



(Op-amp is applied to only non-inverting terminal).

02

02-04-2018

Monday
APRIL

Day 092-273 • Week-14

Appointments / Meetings

②

$$V_1 = V_2 = 0.$$

putting these values in
eqn ②

we have

$$\frac{V_m}{R_i} = -\frac{V_o}{R_f}$$

($\because V_1$ is grounded)

$\therefore V_2$ is also
virtually grounded

Closed loop gain
of any inverting
amp.

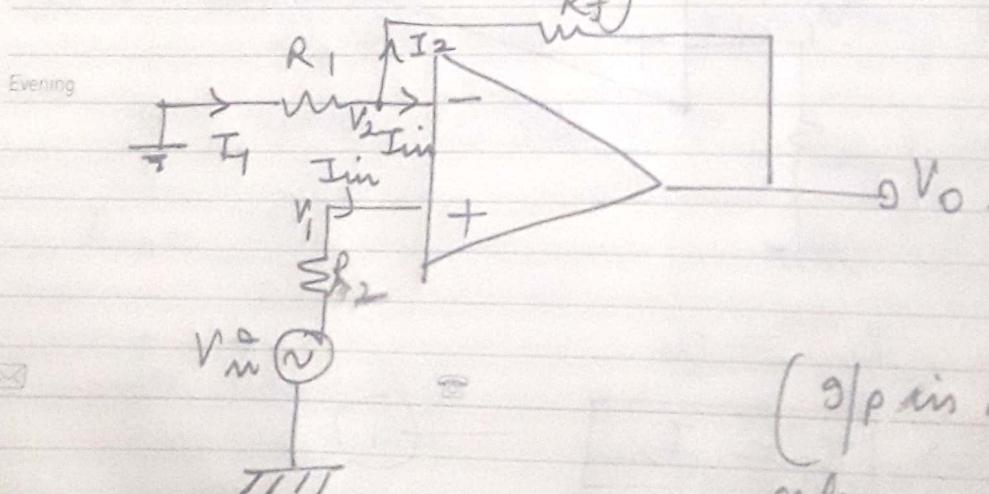
$$\text{or } V_o = -\frac{R_f + R_i}{R_i} V_m$$

$$\text{or } \frac{V_o}{V_m} = -\frac{R_f}{R_i}$$

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

②

Non-Inverting Amp.ifier



(β/ρ is applied to
only non-inverting
terminal)

Win together, lose together, play together, stay together

1	2	3	4	5	6	7	8	9	10
8	9	10	11	12	13	14	15	16	17
15	16	17	18	19	20	21	22	23	24
22	23	24	25	26	27	28	29	30	31
29	30	31							

Appointments / Meetings

8 am

$$\begin{array}{l} \textcircled{1} \quad \boxed{V_1 = V_2 = V_{in}} \\ \textcircled{2} \quad \boxed{I_1 = I_2} \end{array} \quad \left. \right\} \boxed{N.C.G.}$$

$$\Rightarrow \frac{0 - V_2}{R_1} = \frac{V_2 - V_0}{R_f}$$

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

$$\Rightarrow \frac{V_0}{R_f} = V_{in} \left[\frac{1}{R_f} + \frac{1}{R_1} \right]$$

$$\text{or } \boxed{V_0 = \left[1 + \frac{R_f}{R_1} \right] V_{in}}$$

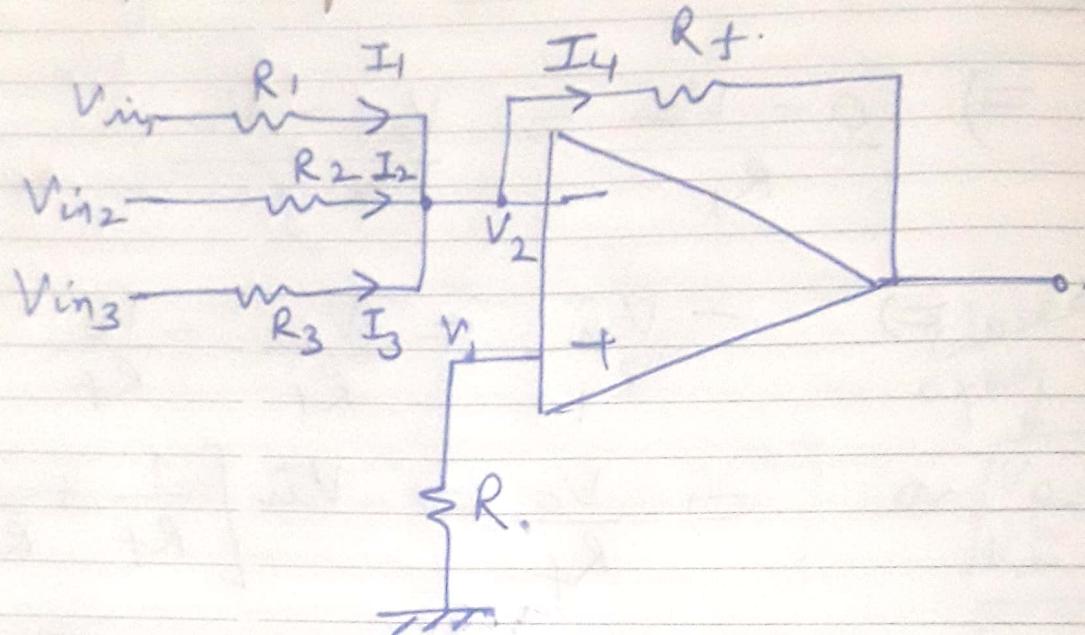
$$\text{or } \boxed{\frac{V_0}{V_{in}} = 1 + \frac{R_f}{R_1}}$$

↓
closed loop gain $\frac{V_0}{V_{in}}$

~~closed loop~~ non-inverting op-amp

Applications of an Op-Amp.

① Op-Amp as an adder.



Applying V.C.L we have,

$$\textcircled{1} \quad V_1 = V_2 = 0$$

$$\textcircled{2} \quad I_1 + I_2 + I_3 = I_4$$

$$\Rightarrow \frac{V_{in1} - 0}{R_1} + \frac{V_{in2} - 0}{R_2} + \frac{V_{in3} - 0}{R_3} = \frac{0 - V_o}{R_f}$$

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

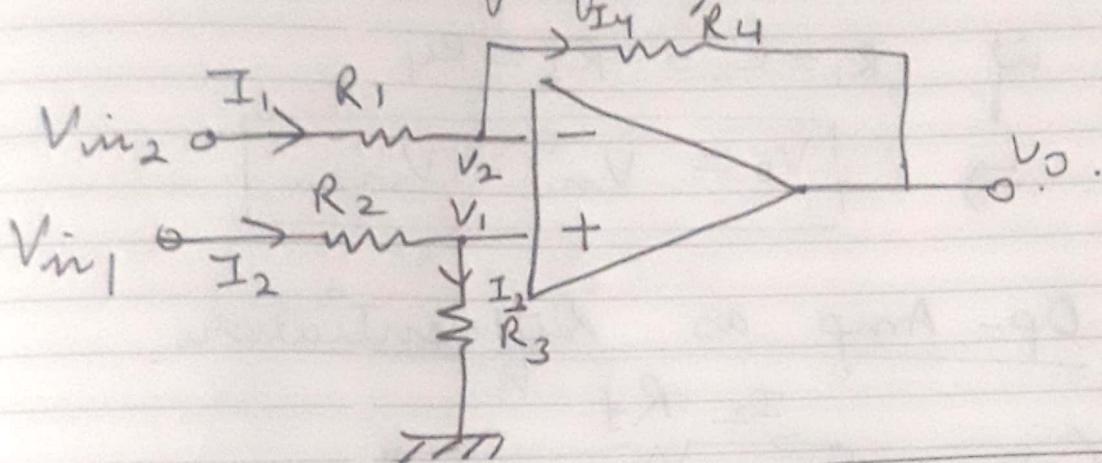
$$\text{or } V_o = -\frac{R_f}{R_1} V_{in1} - \frac{R_f}{R_2} V_{in2} - \frac{R_f}{R_3} V_{in3}$$

$$\text{if } R_f = R_1 = R_2 = R_3$$

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

②

Op-amp as a subtractor (Differential Amplifier)



$$\text{we have } ① \left| \begin{array}{l} V_1 = \frac{V_{in_1} \times R_3}{R_2 + R_3} = V_2 \\ (\because I_2 = I_3) \end{array} \right. \quad (V.C.C)$$

②

$$\boxed{I_1 = I_4}$$

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

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

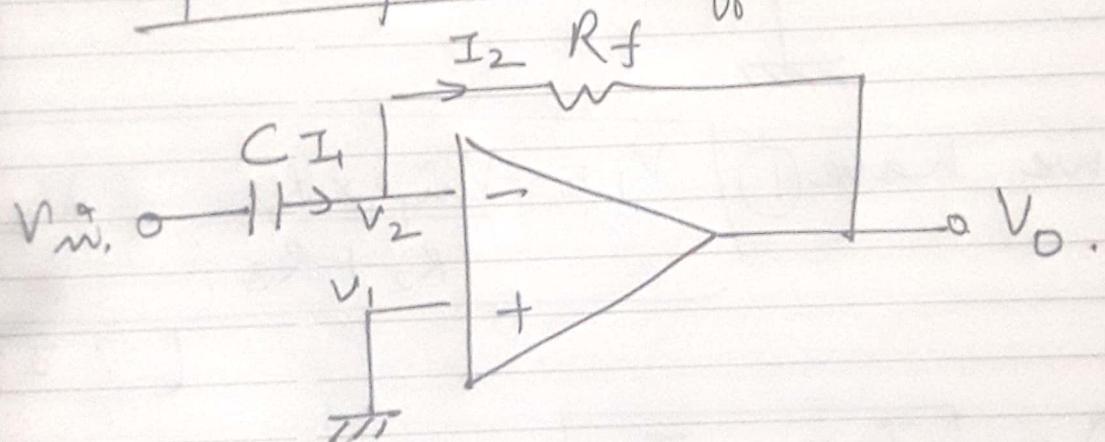
$$\Rightarrow V_o = \frac{V_{in_1} \times R_2}{R_2 + R_3} + \frac{V_{in_1} \times R_3}{R_2 + R_3} \left(\frac{R_4}{R_1} \right) - V_{in_2} \left| \frac{R_4}{R_1} \right|$$

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

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 $V_1 = V_2 = 0$.

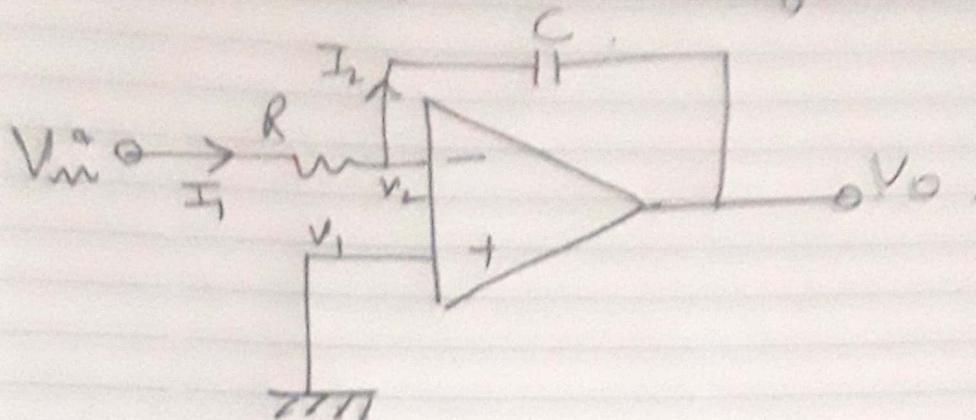
② $I_1 = I_2$.

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

$$\frac{dV_o}{dt} = -\frac{V_o}{R_f C}$$

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

(4)

Op-Amp as Integrator

$$\textcircled{1} \quad v_1 = v_2 = 0$$

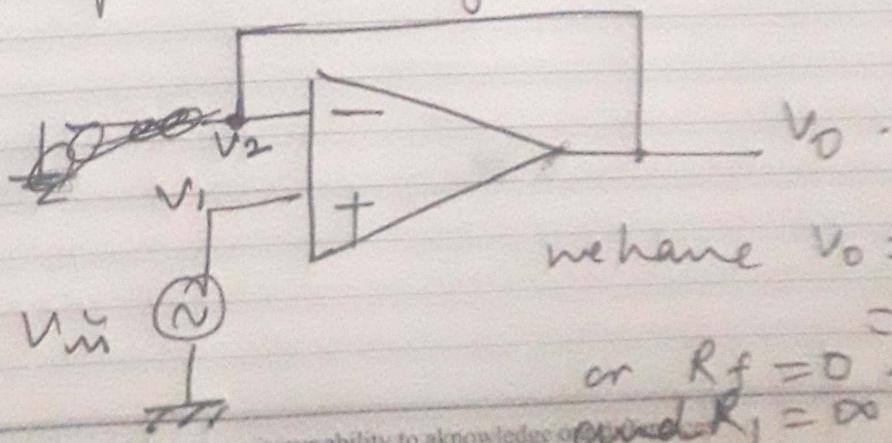
$$\textcircled{2} \quad I_1 = I_2$$

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

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

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

(5)

Op-Amp as Voltage follower (Buffer).

$$\text{we have } V_o = V_2 = V_1$$

$$\text{or } R_f = 0 \quad \text{and } R_1 = \infty$$

Our greatest Strength as a human race is our ability to acknowledge our own limitations.