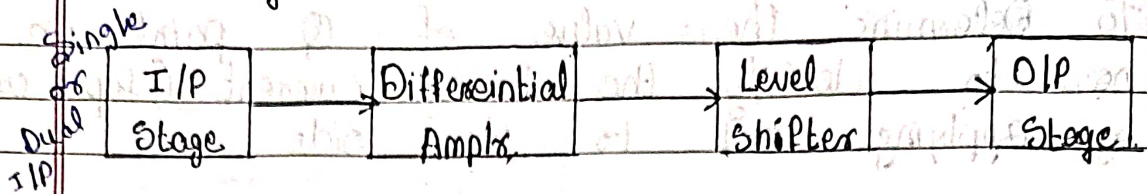
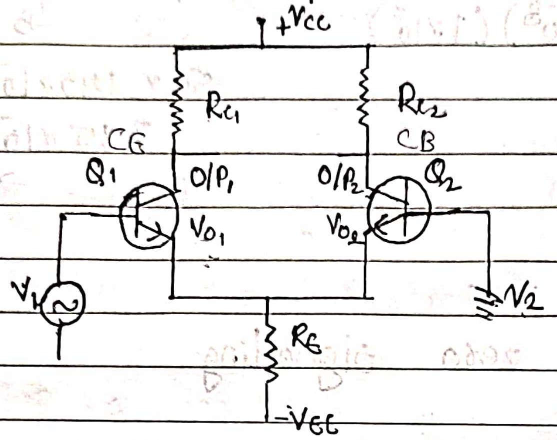
21/5/24 Operational Amplifier

* Block diagram



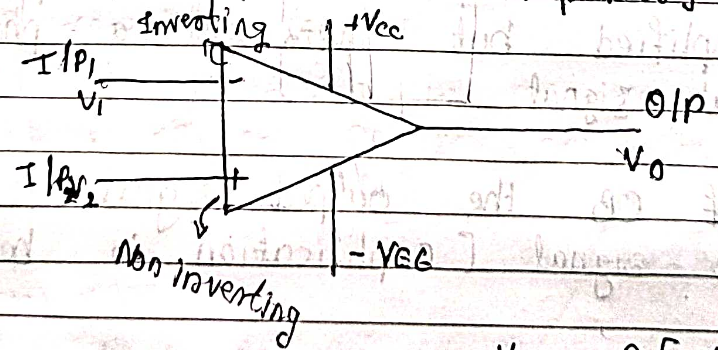
* Differential Amplifier [DA]

741 Operational Amplifier



- Contains two transistor which alternately acts as CB and CE the I/P signal goes to CE and become out of phase that out of phase signal goes to CB and the final output is in phase with the Input signal.

* Op Amp [Operational Amplifier] symbol.



$$V_0 = A[V_2 - V_1]$$

where A is the gain [voltage gain]

* Differential mode and common mode signals

- Differential Amplifier :- It is taking two different signals and the difference of those two signals are amplified is called differential amplified.

$V_{o/p} = A_V V_{in}$

$V_{in} = V_{in1} - V_{in2}$

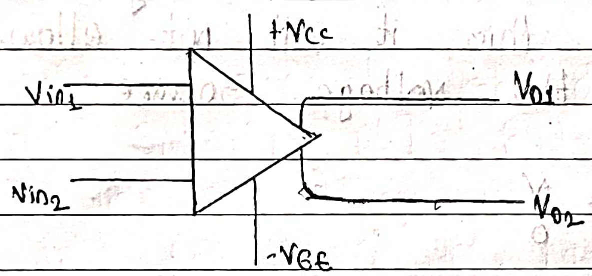
$$\boxed{V_{o/p} = A_V [V_{in1} - V_{in2}]}$$

In common mode the differential amplifier will take two input signal and those two input signals are in phase.

$\therefore V_1 = V_2$

In case of differential mode the two input signals to the differential amplifier are out of phase (180)

$\boxed{V_1 = -V_2}$



V_{in1} (sine wave), V_{in2} = Grounded V_{o1} = (inverted sine wave), V_{o2} = (sine wave)

- In case of common mode the chance of getting O/P is zero volt.
- In case of differential mode the output is two times of i/p I/P

* Parameters of OP. AMP

- Common mode rejection ratio :-
  It is the ratio of differential mode gain to the common mode gain i.e $CMRR = \frac{A_{DM}}{A_{CM}}$

A = gain, DM = Diff mode, CM = common mode

- It will be better when CMRR should be infinite
∴ ($A_{CM} = 0$)

- O/P offset voltage :-
The actual O/P voltage when the input of OP.AMP is zero is called O/P offset voltage.

- I/P offset voltage :-
Because of the unavoidable imbalance inside the OP. AMP a small voltage is being applied b/w the two input terminals that makes output zero.

- I/P resistance :-
It is measured b/w inverting and non inverting terminal. due to this it will not allow the current to draw from the voltage source.

∴ $I = 0$

$$R = \frac{V}{0}$$

$R = \infty$ → ideally.

- O/P resistance :-
This resistance is measured b/w the output terminal of an OP. AMP and the ground.

∴ $R_{O/P} = 0$ [ideally]

- Slew rate :-
It is defined as how fast the output of an OP-APM can change to the change in input i.e the maximum rate at which the output can change.

- Op.

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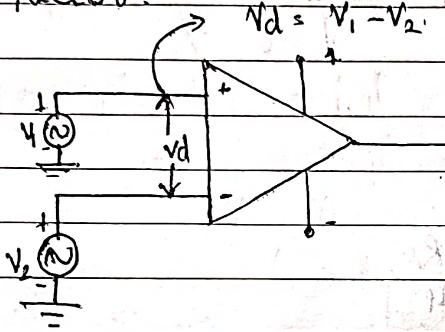
* Open loop and closed loop configuration :

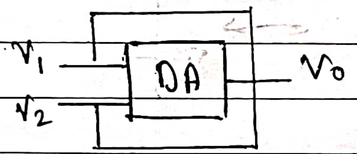
In case of open loop system the output is directly proportional to input with some proportionality const [Open loop gain]. In this case the system is unstable and gain is very high.

In case of closed loop system the feedback structure is existing and this will control the system it provides stabled system with less gain factor.



$V_0 = A[V_1 - V_2]$

$V_1 - V_2 = 2V$



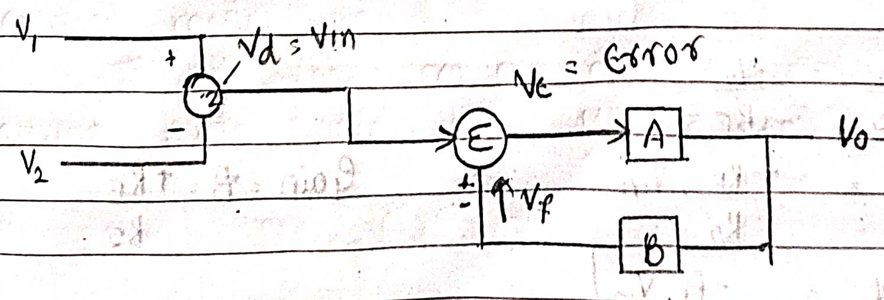
Open loop

Gain = A = 10, B = 0.1

Positive Gain = $\frac{A}{1 \mp AB}$ $\frac{A}{1 + AB}$

closed Gain +ve = ∞ (with +ve feedback)   closed Gain -ve = 5 (with -ve feedback)

* +ve feedback system is uncontrollable / unstable
* -ve " " " controlled / stable



$V_0 = V_G A$ — ①

$V_f = V_0 B$ — ②

$V_G = V_{in} \pm V_f$

$V_0 = V_G A$

$= (V_{in} \pm V_f) A$

$= V_{in}A \pm V_0 AB$

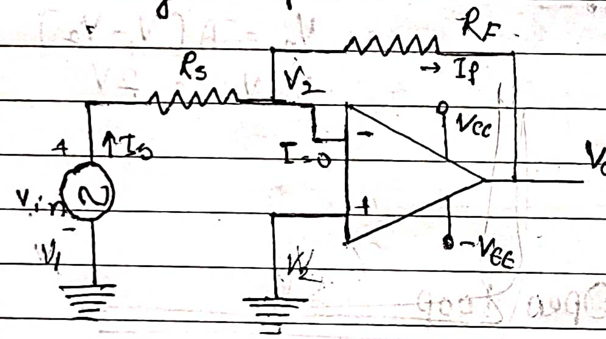
$V_0 \mp V_0 AB = V_{in} A$

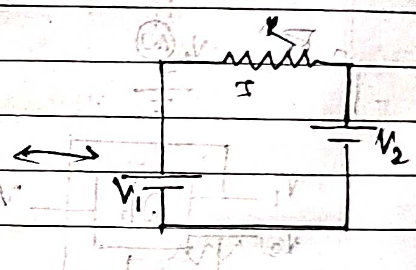
$V_0 [1 \mp AB] = V_{in} A$

$$V_0 = V_{in}\left[\frac{A}{1 \mp AB}\right]$$

$$\text{Gain} = \frac{A}{1 \mp AB}$$

* Inverting amplifier.





$I_S = I + I_f$ $\qquad V_1 = \text{Ground} = V_2$

$I_S = I_f$ $\qquad V_1 = V_2 = 0$

$V_{in} - I_S R_S - V_B$

$I_S = \frac{V_{in} - V_B}{R_S}$

$V_2 - R_f - V_0 = 0$

$V_B - I_F R_F - V_0 = 0$

$V_B - V_0 = I_F R_F$

$I_F = \frac{V_B - V_0}{R_F}$

$I_S = \frac{V_{in} - V_2}{R_S}$ $\qquad I_F = \frac{V_2 - V_0}{R_F}$

$I_S = \frac{+V_{in}}{R_S}$, $I_F = \frac{-V_0}{R_F}$

$$\frac{V_{in}}{R_S} = \frac{-V_0}{R_F}$$

$$V_0 = \frac{-R_F}{R_S} \cdot V_{in}$$

$$\text{Gain} = A = +\frac{R_F}{R_S}$$

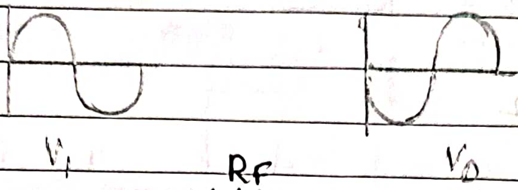
$$\boxed{V_0 = -A \cdot V_{in}}$$

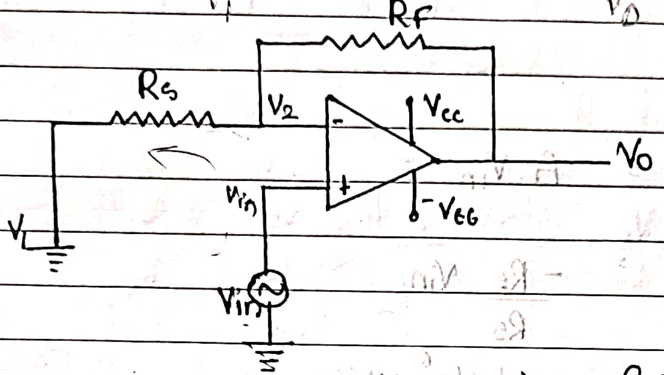
i) $R_F > R_S$ — $A\uparrow$, $V_o \downarrow$ → Amplified but out of phase.

ii) $R_F < R_S$ — $A\downarrow$, $V_o \downarrow$ -

iii) $R_F = R_S$ — $A = \text{const}$ — $V_o \neq V_1$ but inverted

$R_F = R_S$





V_{1A} = Grounded

$V_1 = V_2$

$\cdot V_{1A} - R_S - V_{in}$

$V_1 - V_{in} = R_S I_S$

$I_S = \frac{V_1 - V_{in}}{R_S} = \frac{-V_{in}}{R_S}$

$V_2 - V_F - V_o$

$V_o = V_2 - V_F$

$I_F = \frac{-V_{in} + V_o}{R_F}$

$I_S = I_F$

$\frac{-V_{in}}{R_S} = \frac{-V_o + V_{in}}{R_F}$

~~$-V_o = -\frac{R_F}{R_S} V_{in}$~~

~~$V_o = \frac{R_F}{R_S} V_{in}$~~

$\frac{-V_{in} R_F}{R_S} = -V_o + V_{in}$

$\frac{V_{in}}{R_S} + \frac{V_{in}}{R_F} = \frac{V_o}{R_F}$

$V_o = R_F V_{in} \left[\frac{1}{R_S} + \frac{1}{R_F}\right]$

$V_o = V_{in} \left[\frac{R_F}{R_F} + \frac{R_F}{R_S}\right]$

$V_o = V_{in} \left[1 + \frac{R_F}{R_S}\right]$

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① For Inverting Amplifier Determine closed loop gain if $R_f = 1 M\Omega$ & $R_s = 20 k\Omega$ Also find V_{in} & $V_o = 2V$

② For non Inverting Amplifier find V_o if $V_{in} = 3V$ & $V_{in} = 0.2V$ $R_f = 360 k\Omega$ & $R_s = 120 k\Omega$

① $R_f = 1 \times 10^6 \Omega$

$R_s = 20 \times 10^3 \Omega$

$V_o = 2V$

$V_{in} = ?$

$$V_o = -A \cdot V_{in}$$

$$2 = -\frac{R_f}{R_s} V_{in}$$

$$2 = -\frac{1 \times 10^6}{2 \times 10^4} \cdot V_{in}$$

$$-\frac{2 \times 10^4}{1 \times 10^6} = V_{in}$$

$$-2 \times 10^{-2} V = V_{in}$$

②(i) $V_{in} = 3V$

$R_f = 360 \times 10^3$

$R_s = 120 \times 10^3$

$V_o = ?$

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

$$= 3\left[1 + \frac{360 \times 10^3}{120 \times 10^3}\right]$$

$$V_o = 12V$$

when $V_{in} = -0.2V$

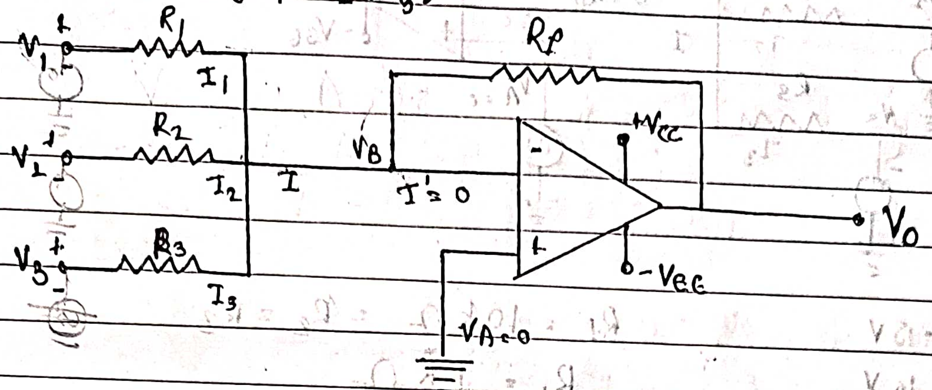
$$V_o = -0.2\left[1 + \frac{360 \times 10^3}{120 \times 10^3}\right]$$

$$V_o = -0.8V$$

* OP AMP as a SUMMER

Three input signals to inverting

$V_0 = -(V_1 + V_2 + V_3)$



$I = I_1 + I_2 + I_3$ $\qquad R_1 = R_2 = R_3 = R_f$

$I = I' + I_f$

$I = I_f$

$I_f = (I_1 + I_2 + I_3)$

$V_B - V_f - V_0 = 0$

$V_B - V_0 = I_f R_f$

$$\frac{-V_0}{R_f} = I_f$$

$$I_1 = \frac{V_1 - V_B}{R_1} \qquad I_2 = \frac{V_2 - V_B}{R_2}$$

$$\frac{-V_0}{R_f} = I_1 + I_2 + I_3$$

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

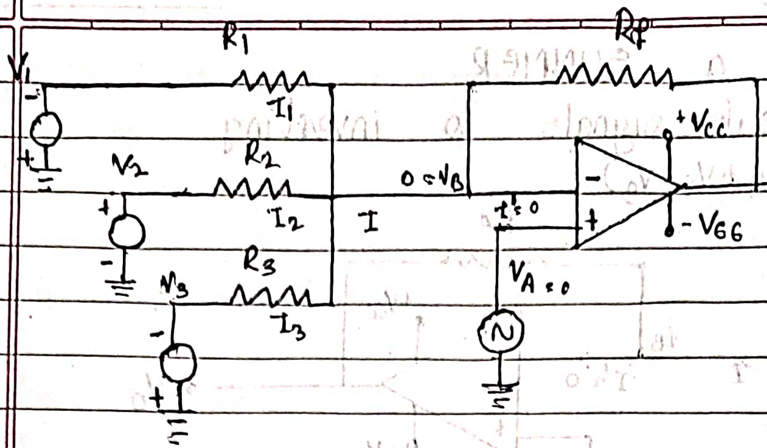
$(R_1 = R_2 = R_3 = R_f)$

$-V_0 = V_1 + V_2 + V_3$

$V_0 = -(V_1 + V_2 + V_3)$

Q Let $V_1 = -5V$, $V_2 = 10V$, $V_3 = -12V$. Draw the summer circuit with inverting configuration and determine V_0. If $R_f = 10\,k\Omega$, R_2 & $R_3 = 10\,k\Omega$, $R_1 = 1\,k\Omega$

→



$V_1 = -5V$

$V_2 = 10V$

$V_3 = -12V$

$V_o = ?$

$R_f = 10k\Omega = R_2 = R_3$

$R_1 = 1k\Omega$

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

$$\frac{-V_o}{1\times10^4} = \frac{-5}{1\times10^3} + \frac{10}{1\times10^4} - \frac{12}{1\times10^4}$$

$$\frac{-V_o}{1\times10^4} = \frac{-5}{1\times10^3} - \frac{2}{1\times10^4}$$

$$= -5\times10^{-3} - 2\times10^{-4}$$

$$\frac{-V_o}{1\times10^4} = -5.2\times10^{-3}$$

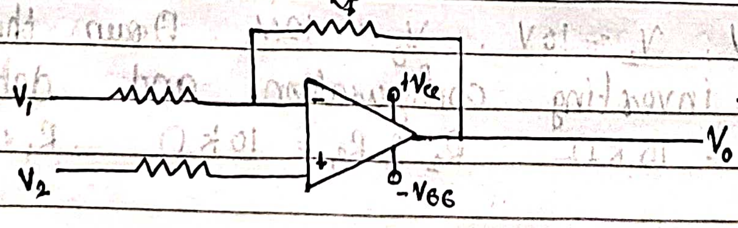
$$+V_o = +5.2\times10^{-3}\times1\times10^4$$

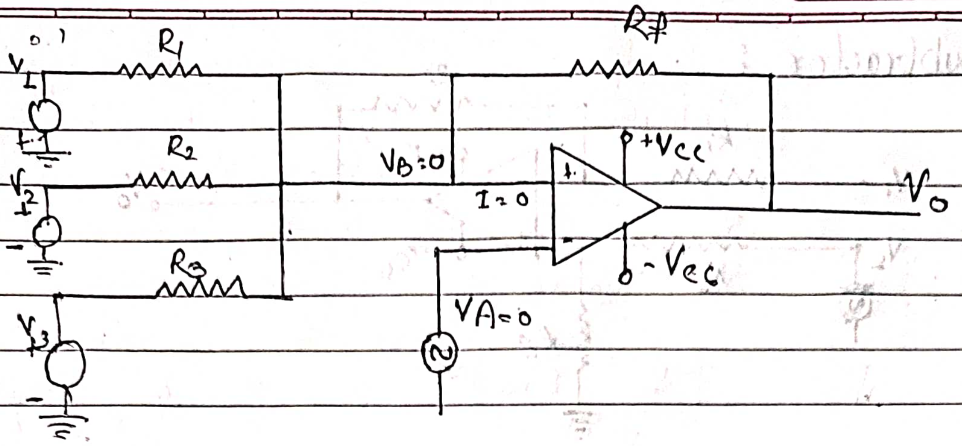
$$V_o = 52V$$

Q Design the summer circuit with $R_f = 10k\Omega$ to obtain the O/P $V_o = -(0.1V_1 + V_2 + 10V_3)$

→

Subtractor :





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

$$\frac{-V_0}{10\times10^3} =$$

$$\frac{-(0.1V_1 + V_2 + 10V_3)}{10\times10^3} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$-0.1V_1 - V_2 - 10V_3 = 10\times10^3\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

$$-0.1V_1 - V_2 - 10V_3 = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3$$

$$\frac{R_f}{R_1} = 0.1 \qquad \frac{R_f}{R_2} = 1 \qquad \frac{R_f}{R_3} = 10$$

$$\frac{10\times10^3}{R_1} = 0.1 \qquad \frac{10\times10^3}{R_2} = 1 \qquad \frac{10\times10^3}{R_3} = 10$$

$$R_1 = 100\,k\Omega \qquad R_2 = 10\,k\Omega \qquad R_3 = 1\,k\Omega$$

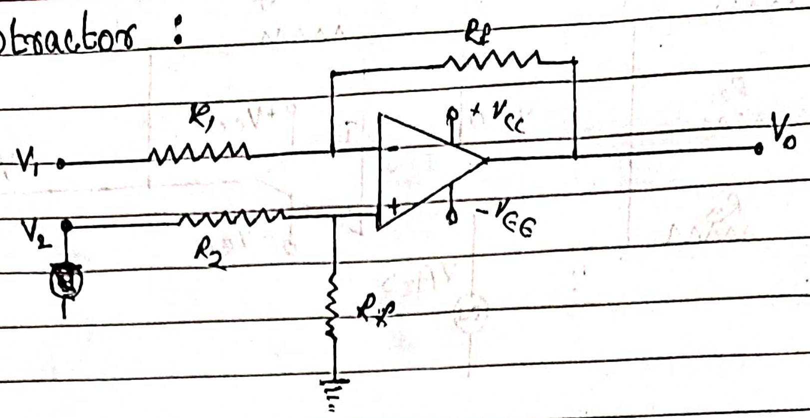
$$-V_0 = R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

$$= 10\times10^3\left(\frac{10}{100\times10^3}V_1 + \frac{10}{10\times10^3}V_2 + \frac{10}{1\times10^3}V_3\right)$$

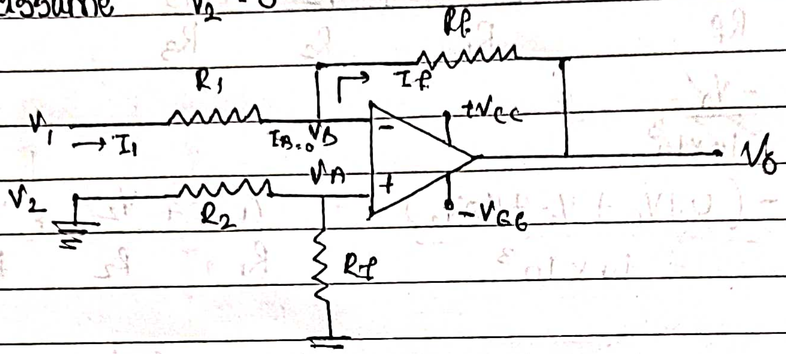
$$= \left(\frac{10}{100}V_1 + \frac{10}{10}V_2 + \frac{10}{1}V_3\right)$$

$$V_0 = -(0.1V_1 + V_2 + 10V_3)$$

* Subtractor :



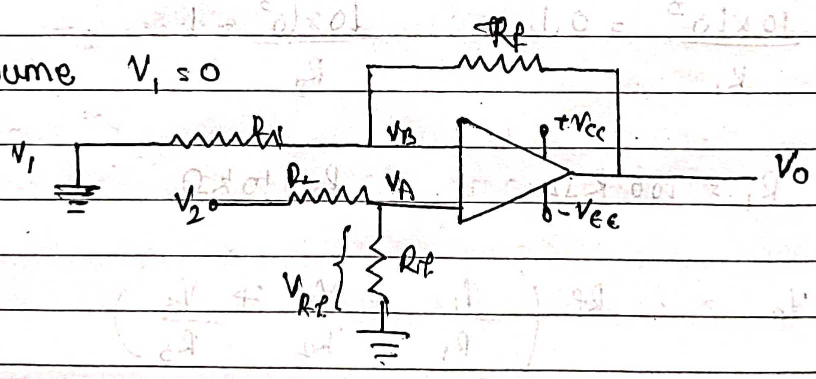
Let assume $V_2 = 0$



Since the Voltage $V_A = 0$ due to $V_2 = 0$ the circuit look like inverting amplifier hence the relation between V_o w.r.to V_1 is

$$V_0 = -\frac{R_f}{R_1} V_1 \quad — (1)$$

Let assume $V_1 = 0$



Since R_2 and R_f are connected in series the current through R_2 is same as current through R_f hence

$$V_{Rf} = I \cdot R_f$$

$$I = \frac{V_2}{R_2 + R_f} = \frac{V_2 R_f}{R_2 + R_f}$$

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

$$V_0 = V_{Rf}\left[1 + \frac{V_2 R_f}{R_1 (R_2+R_f)}\right]$$

$$V_0 = \frac{V_2 R_f}{R_2+R_f}\left[1 + \frac{R_f}{R_1}\right]$$

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

Assume $R_1 = R_2 = R$

$$= \frac{V_2 R_f}{R+R_f}\left[\frac{R+R_f}{R}\right]$$

$$V_0 = \frac{V_2 R_f}{R} \quad — (2)$$

$$V_{02} = \frac{V_2 R_f}{R} \quad — (2)$$

$$V_{01} = -\frac{R_f V_1}{R} \quad — (1)$$

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

$$\frac{V_2 R_f}{R} - \frac{R_f V_1}{R}$$

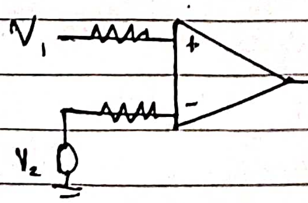
$$V_0 = -\frac{R_f}{R}\left[V_2 - V_1\right]$$

If $A = 1$

$$V_0 = V_2 - V_1$$

* Open loop and Closed loop

- Both loops [Open & Closed] are considering 3 configuration namely inverting, noninverting and differential



V_0 - Inverting

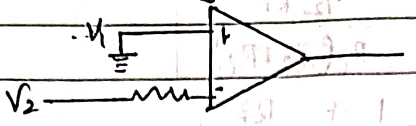
$V_0 = V_d . A$

$$A = \frac{V_0}{V_d} = \frac{V_0}{V_2 - V_1} = -\frac{V_0}{V_1} \quad [V_2 = 0]$$

$$V_0 = -A . V_1$$

Non - inverting

(2)

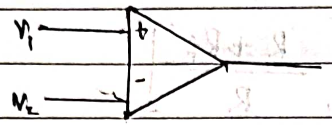


$V_o = A . V_d$

$A = \frac{V_o}{V_d} = \frac{V_o}{V_2}$ $(V_1 = 0)$

$\boxed{V_o = AV_2}$

(3)



V_o = Differential

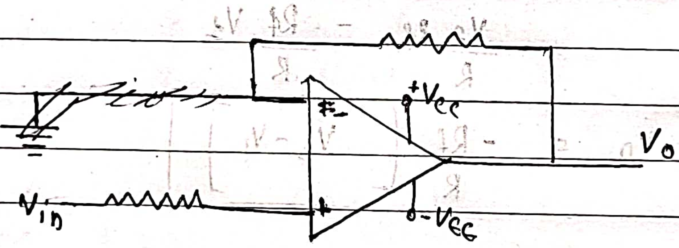
$V_d = V_2 - V_1$

$A = \frac{V_o}{V_d}$

$V_o = A . V_d$

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

* Voltage follower :



$V_{in} = V_o$

No phase difference , no amplification.