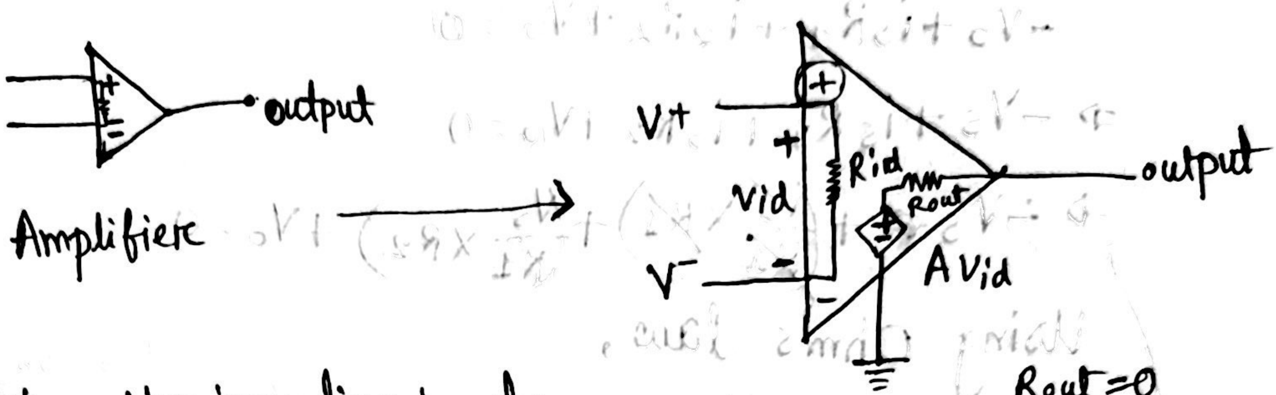
Operational Amplifiers & Application

অনেকগুলো Transistor এর cascade

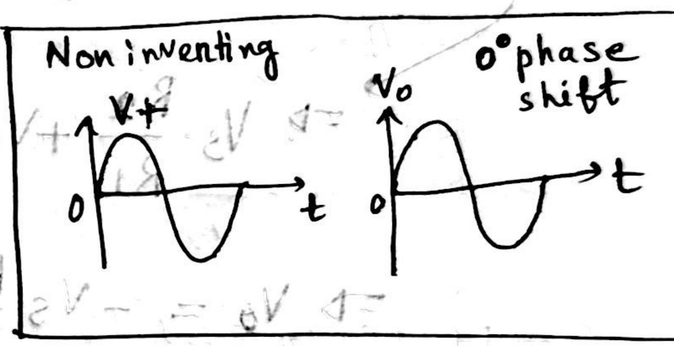


Rout = 0
Rid = high

$V^+ \rightarrow$ Non inverting input

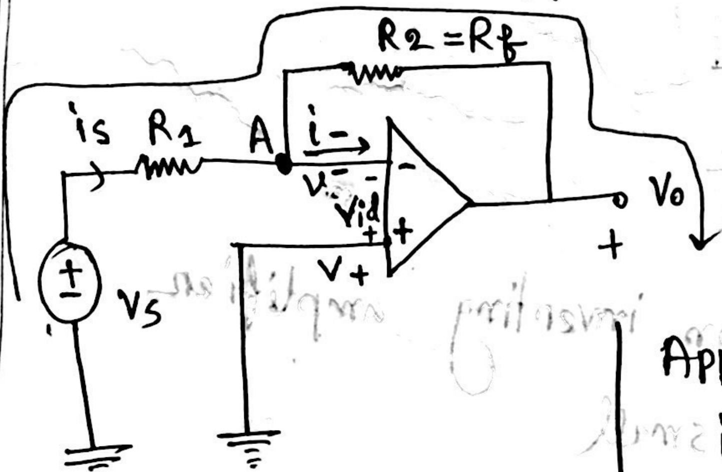
$V^- \rightarrow$ Inverting input

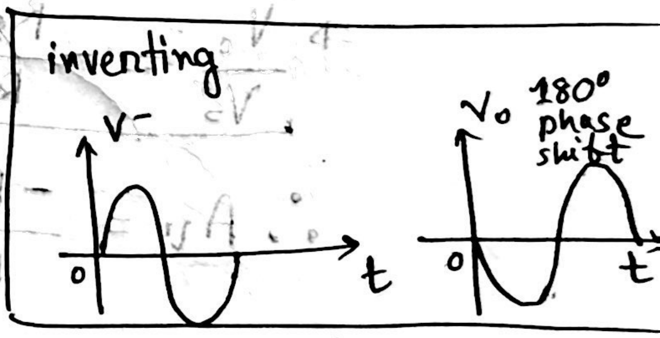
$A \rightarrow$ open circuit voltage gain



Inverting Amplifier:

Voltage gain: $A_v = \frac{v_o}{v_i}$





$\therefore V_{id} = V^+ - V^-$

$\therefore R_{id} =$ infinity, $i_- = 0$

Apply KCL at node A,

$i_s = i_2 + i_-$

$\therefore i_s = i_2 + 0$

$\therefore i_s = i_2$

$$A_v = \frac{\text{output}}{\text{Input}}$$

Applying KVL,

$$-V_S + i_S R_1 + i_2 R_2 + V_o = 0$$

$$\Rightarrow -V_S + i_S R_1 + i_S R_2 + V_o = 0$$

$$\Rightarrow \cancel{-V_S} + \left(\frac{\cancel{V_S}}{\cancel{R_1}} \times \cancel{R_1}\right) + \left(\frac{V_S}{R_1} \times R_2\right) + V_o = 0$$

Using Ohm's law,

$$i_S = \frac{V_S}{R_1}$$

$$\Rightarrow V_S \frac{R_2}{R_1} + V_o = 0$$

$$A_v = \frac{V_o}{V_S}$$

$$\Rightarrow V_o = A_v V_S$$

$$\Rightarrow V_o = -V_S \frac{R_2}{R_1}$$

$$\Rightarrow \boxed{\frac{V_o}{V_S} = -\frac{R_2}{R_1}}$$

$$\therefore A_v = \frac{-R_2}{R_1}$$

Voltage gain for inventing amplifier

$R_1 > R_2$ = gain small

$R_2 > R_1$ = gain বড় হবে

output resistance বের করতে Voltage add করে, Thevenin.

20 dB

$\Rightarrow 10 \times 2$

$\Rightarrow 10\log(100)$

∞ = open circuit

~~To find output resistance, Thevenin's Theor~~

$A_V = 20\,dB = (-10^{\frac{20}{10}}) = -100$ [Inverting amplifier]

$R_1 = 20\,k\Omega$

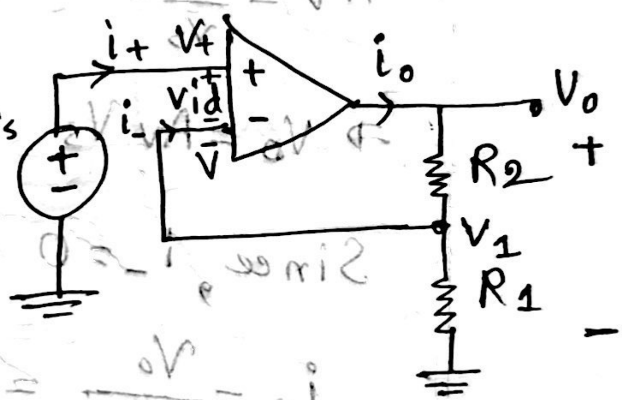
Determine R_2 for an inverting amplifier circuit, where $A_V = 20\,dB$ and $R_1 = 20\,k\Omega$.

$\therefore A_V = -\frac{R_2}{R_1}$

$\Rightarrow -100 = -\frac{R_2}{20k}$

$\Rightarrow R_2 = 2\,M\Omega$ (Ans)

Non-Inverting :-



Using VDR,

$$V_1 = \frac{V_o R_1}{R_1+R_2}$$

$$V_s = \frac{V_o R_1}{R_1+R_2}$$

$V_{id} = V_+ - V_- = V_s - V_1$

As $i_- = 0$, $V_{id} = 0$

$\therefore V_{id} = V_s - V_1$

$\Rightarrow 0 = V_s - V_1$

$\Rightarrow V_s = V_1$

$$\Rightarrow \frac{V_s}{V_o} = \frac{R_1}{R_1+R_2}$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{R_1+R_2}{R_1}$$

$$\frac{V_o}{V_s} = 1 + \frac{R_2}{R_1}$$

$$\boxed{\therefore A_v = 1 + \frac{R_2}{R_1}}$$

Non inverting Example

$R_1 = 3k\Omega$

$R_2 = 43k\Omega$

$V_s = 0.1V$

$$A_v = 1 + \frac{R_2}{R_1}$$

$$= 1 + \frac{43k\Omega}{3k\Omega}$$

$$= 15.3$$

$$A_v = \frac{V_o}{V_s}$$

$$\Rightarrow V_o = A_v V_s = 15.3 \times 0.1 = 1.53V$$

Since, $i_- = 0$

$$i_o = \frac{V_o}{R_2 + R_1} = \frac{1.53}{43k\Omega + 3k\Omega} = 33.3\mu A$$

Final

β = feedback factor

$$V_o = AV_{id} = A(V_+ - V_-)$$
$$= A(V_S - V_1)$$
$$= A(V_S - \beta V_o)$$

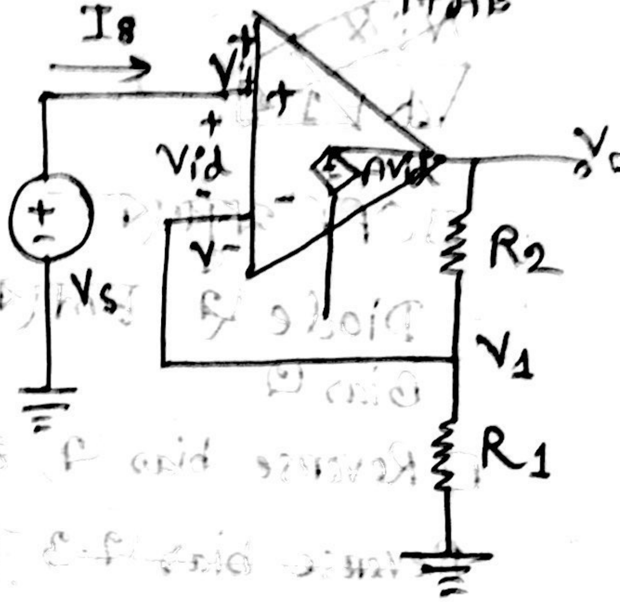
$\Rightarrow V_o + A\beta V_o = AV_S$

$\Rightarrow V_o(1 + A\beta) = AV_S$

$\Rightarrow \frac{V_o}{V_S} = \frac{A}{1+A\beta}$

$\Rightarrow A_v = \frac{A}{1+A\beta}$

Voltage gain, $A_v = \frac{V_o}{V_S}$



$$V_1 = \frac{R_1 V_o}{R_1 + R_2}$$

$$V_1 = \frac{R}{R_1 + R_2} \times V_o$$
$$= \beta V_o$$

$$\boxed{A_v = 1 + \frac{R_2}{R_1} = \frac{1}{\beta}}$$

Ideal gain

$$\boxed{A_v = \frac{A}{1+A\beta}}$$

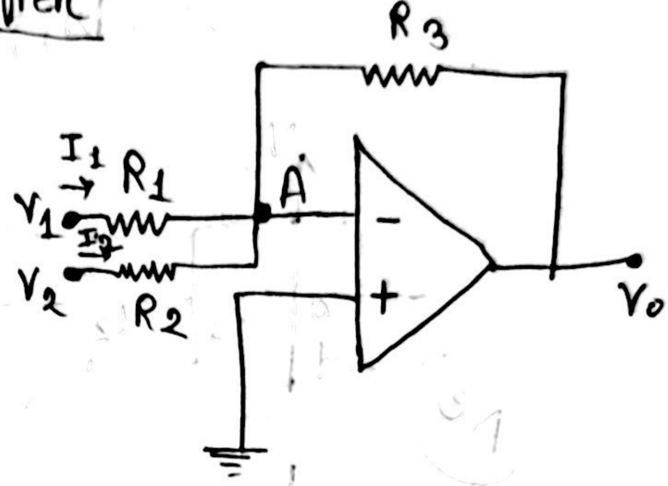
Actual gain

Gain error

Ideal gain − Actual gain = gain error.

$$GE = \frac{1}{\beta(1 + A\beta)}$$

Summing Amplifier



$$I_1 = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2}{R_2}$$

Applying KCL at node A,

$$I_1 + I_2 = I_3$$

$$\Rightarrow \frac{V_1}{R_1} + \frac{V_2}{R_2} = -\frac{V_0}{R_3} \quad \text{output to input.} \quad \text{——— (1)}$$

if, $V_1 = V_2 = V_3$

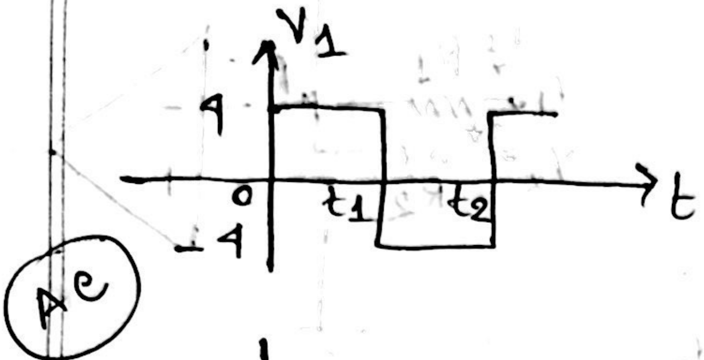
From eqn(1), $\frac{V_1}{R_1} + \frac{V_2}{R_2} = -\frac{V_0}{R_3}$

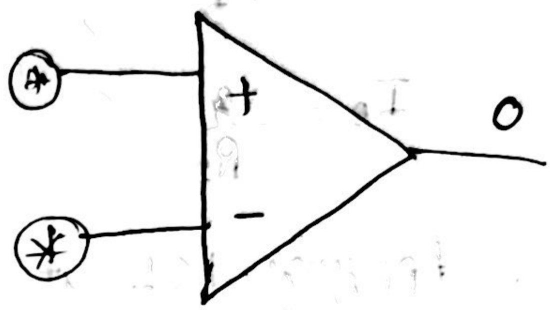
$$\Rightarrow V_s\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = -\frac{V_0}{R_3}$$

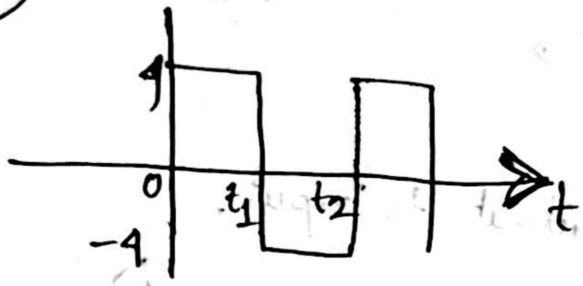
$$\Rightarrow R_3\left(\frac{1}{R_1} + \frac{1}{R_3}\right) = -\frac{V_0}{V_S}$$

$$\Rightarrow A_v = -R_3\left(\frac{R_1 R_2}{R_1 + R_2}\right)$$

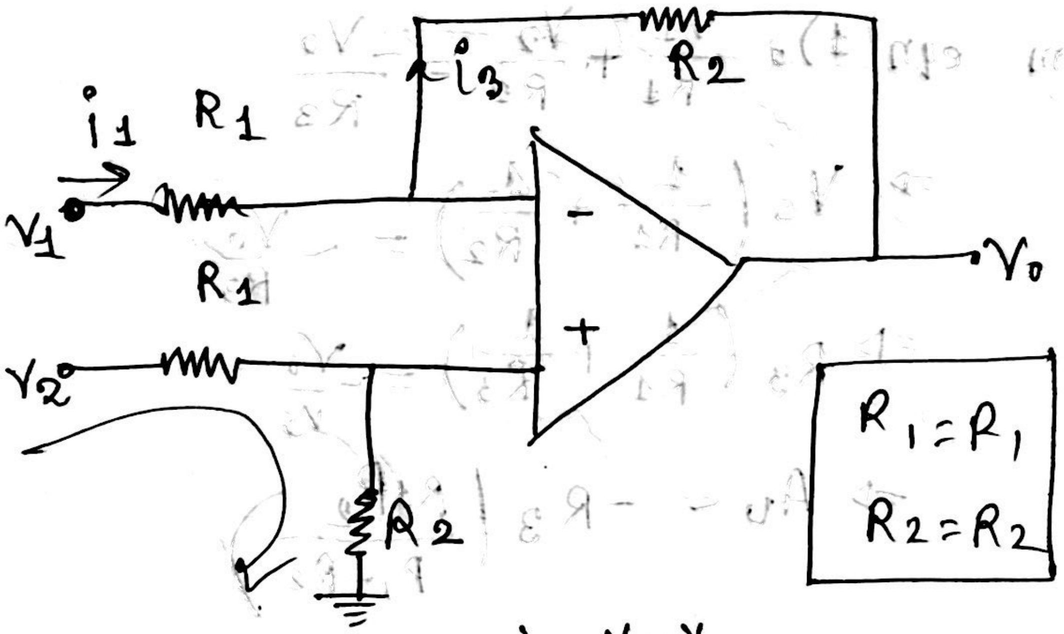
Difference Amplifier







এরকম হলে output 0 হবে।



$$V_o = V_- - i_2 R_2$$
$$= V_- - i_1 R_2 \rightarrow = V_- - \frac{V_1 - V_-}{R_1} R_1 = V_- - \frac{R_2}{R_1}(V_1 - V_-)$$

$$i_1 = \frac{V_1 - V_-}{R_1}$$

$$= V_- - \frac{R_2}{R_1} V_1 + \frac{R_2}{R_1} V_-$$

$$= \left(1 + \frac{R_2}{R_1}\right) V_- - \frac{R_2}{R_1} V_1$$

Applying VDR,

$$V_+ = \frac{V_2 R_2}{R_1 + R_2}$$

$$V_- = V_+ = \frac{V_2 R_2}{R_1 + R_2}$$

$$\Rightarrow \left(1 + \frac{R_2}{R_1}\right) V_- - \frac{R_2}{R_1} V_1 = \frac{V_2 R_2}{R_1 + R_2}$$

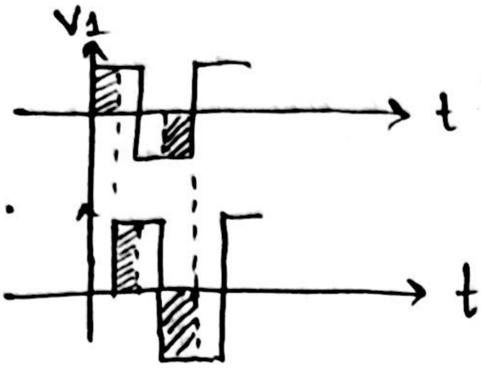
$$\therefore V_0 = \frac{-R_2}{R_1} (V_1 - V_2)$$

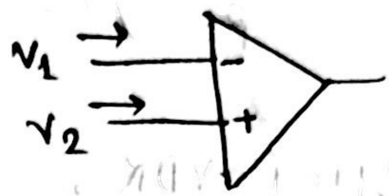
if $R_1 = R_2$

$$\therefore V_0 = -(V_1 - V_2) \rightarrow \text{unit gain amplifier}$$

C-W
22/02/28

CMRR → Common Mode Rejection Ratio





A_{dm} → Differential Mode Voltage gain

For difference Amplifier,

$$A_{dm} = -\frac{R_2}{R_1}$$

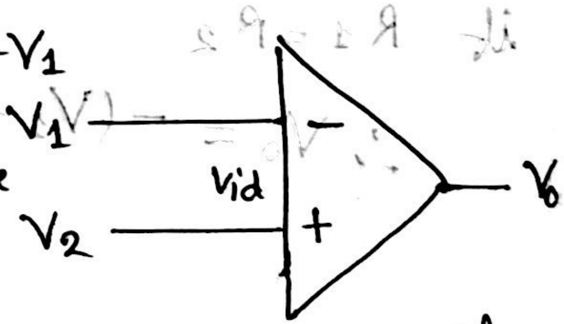
$$\therefore V_0 = -\frac{R_2}{R_1}(V_1 - V_2)$$

$$= A_{dm}(V_1 - V_2)$$

$V_{id} = V^+ - V^- \approx V_1 - V_2 \approx V_2 - V_1$

V_{ic} = Common mode Voltage

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



Output Voltage :-

$$V_0 = A_{dm}(V_1 - V_2) + A_{cm}\frac{V_1+V_2}{2}$$

A ⇒ open circuit Voltage gain

A_{cm} ⇒ Common mode Voltage gain.

$$\therefore V_o = A_{dm}(V_{id}) + A_{cm}(V_{ic})$$

$$V_1 = V_{ic} + \frac{V_{id}}{2}$$

$$V_2 = V_{ic} - \frac{V_{id}}{2}$$

$$\therefore V_o = A_{dm}(V_{id}) + A_{cm}(V_{ic})$$

$$\Rightarrow V_o = A_{dm}\left(V_{id} + \frac{A_{cm}}{A_{dm}}(V_{ic})\right)$$

$$\therefore V_o = A_{dm}\left(V_{id} + \frac{V_{ic}}{\cancel{eN}\frac{A_{dm}}{A_{cm}}}\right)$$

$$\therefore V_o = A_{dm}\left(V_{id} + \frac{V_{ic}}{CRMM}\right) \quad = 20\log_{10}(CMRR)$$

Finite CRMM example

$$= 2500\left((5.001 - 4.999) + \left(\frac{\frac{5.001+4.999}{2}}{10^4}\right)\right)$$

80dB

$$V_o = 6.25V$$

$$\text{Gain error} = \frac{6.25-5}{5} \times 100\%$$

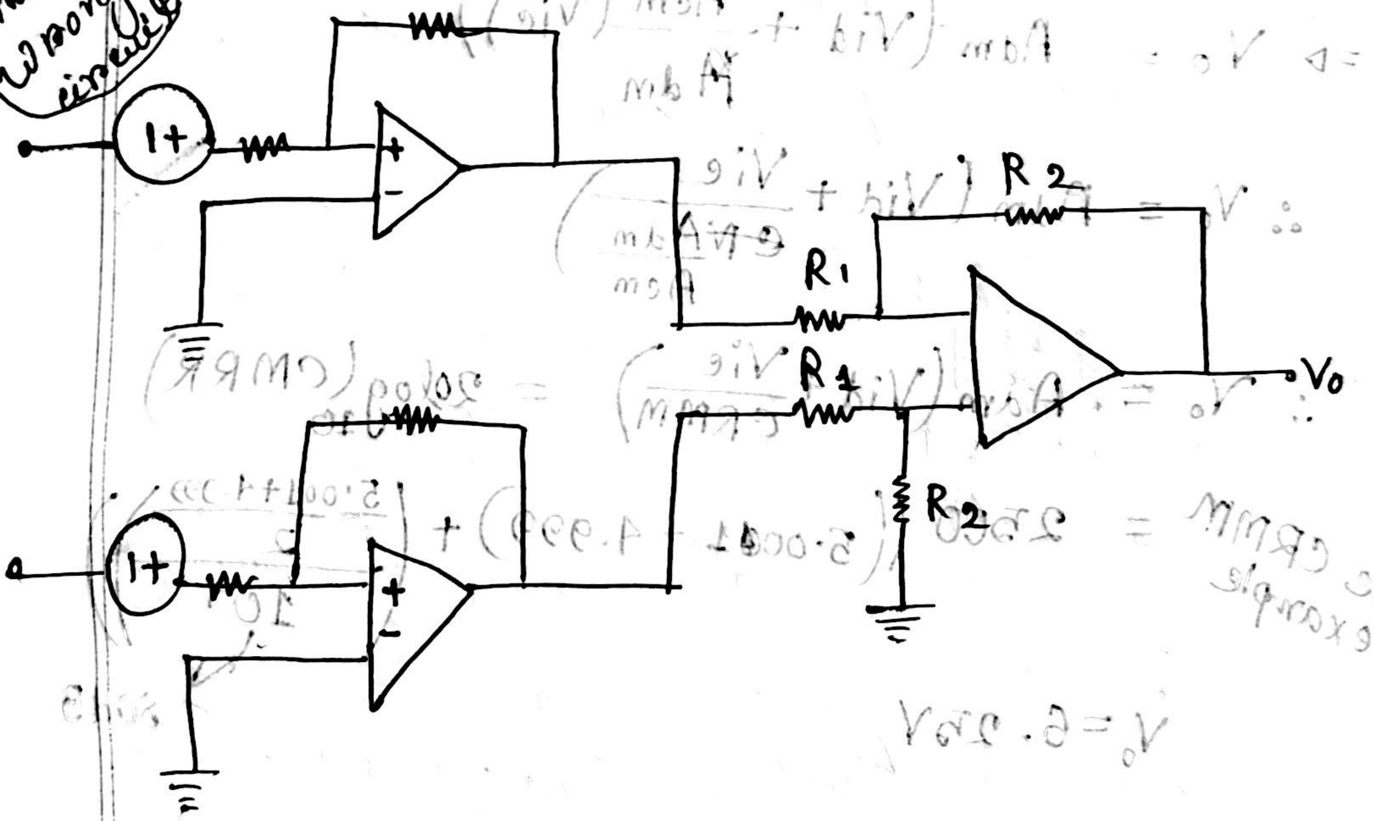
$$= 25\%$$

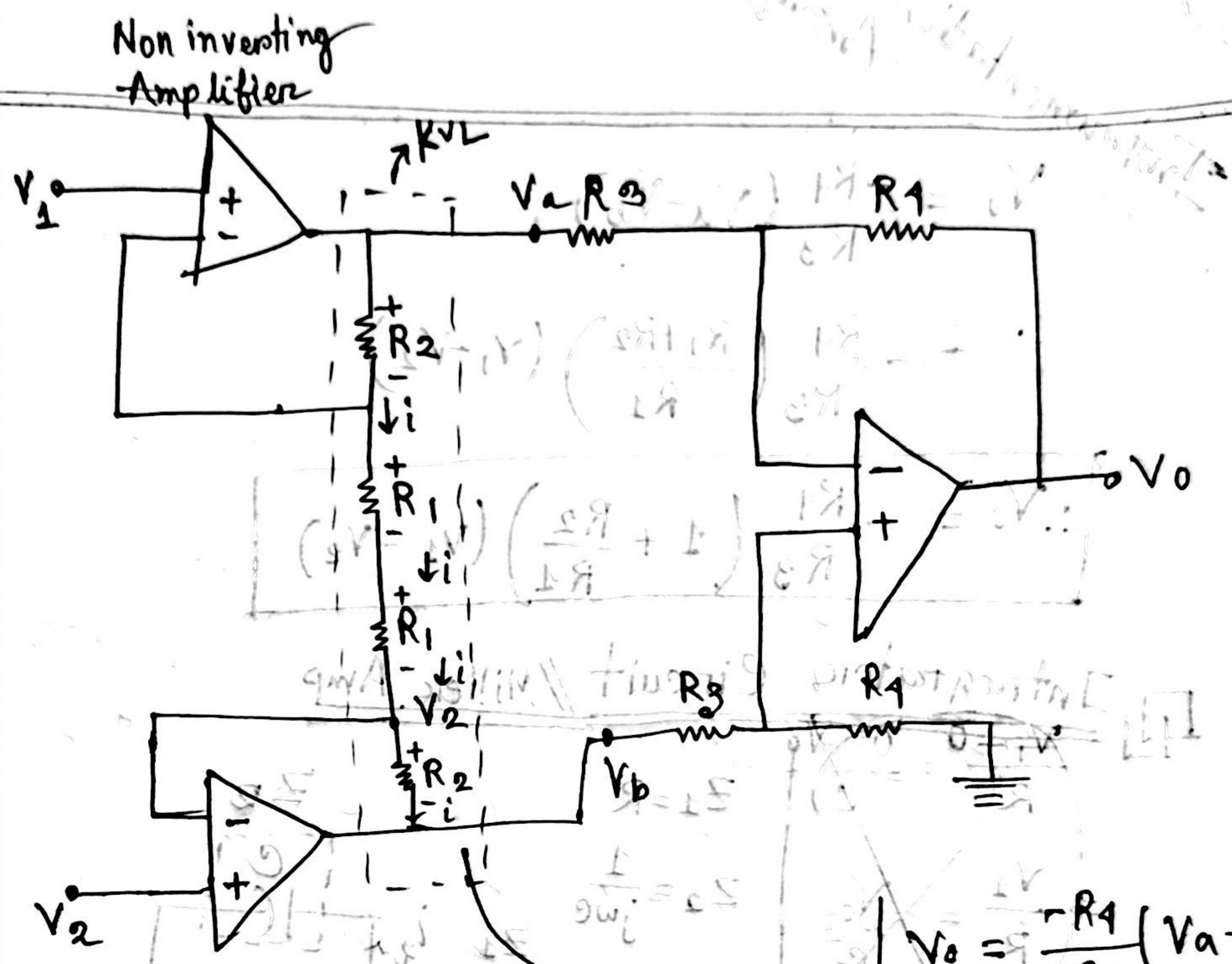
Instrumentation amplifier

2 non inverting amplifier + difference amplifier এর cascade.

non inverting er output = difference Amplifier এর input

Drawn wrong circuit





$$V_o = \frac{-R_4}{R_3}(V_a - V_b)$$

KVL;

$$i = \frac{V_1 - V_2}{2R_1}$$

Applying KVL,

$$V_a - iR_2 - i2R_1 - iR_2 = V_b$$

$$\Rightarrow V_a - i2R_2 - i2R_1 = V_b$$

$$\Rightarrow V_a - V_b = i2(R_1 + R_2)$$

$$= \frac{V_1 - V_2}{2R_1} \times 2 \times (R_1 + R_2)$$

$$\therefore V_a - V_b = \frac{R_1 + R_2}{R_1}(V_1 - V_2)$$

Instrumentation Amplifier

$$V_o = -\frac{R_4}{R_3}(V_a - V_b)$$

$$= -\frac{R_4}{R_3}\left(\frac{R_1+R_2}{R_1}\right)(V_1 - V_2)$$

$$\boxed{\therefore V_o = -\frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right)(V_1 - V_2)}$$

Intregrator Circuit // Miller Amp

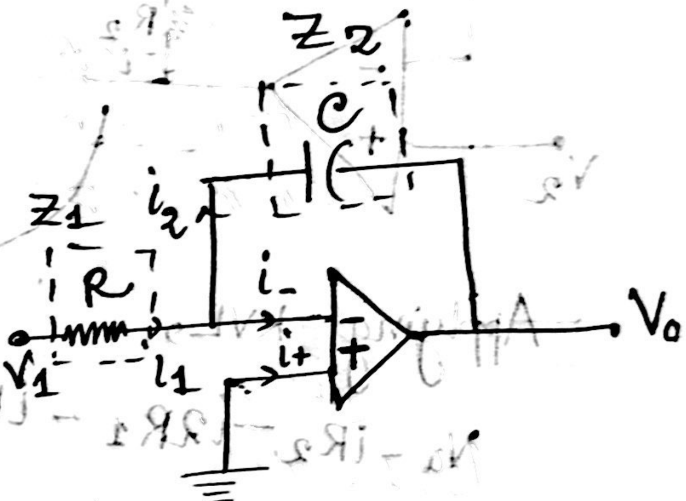
$$\frac{i}{R} = \frac{0 - V_0}{C}$$

$$\frac{V_1}{R} = -\frac{V_0}{C}$$

$$\therefore V_0 = -\frac{V_1 C}{R}$$

$Z_1 = R$

$Z_2 = \frac{1}{j\omega C}$



$$A_v = -\frac{Z_2}{Z_1} = -\frac{\frac{1}{j\omega C}}{R}$$

$$\therefore A_v = \frac{-1}{j\omega RC} = -\frac{1}{SRC} \quad [S = j\omega]$$

$$V_0 = V_C - \frac{1}{C}\int_0^t i_2(t)\,dt$$

Let, $V_C = 0V$

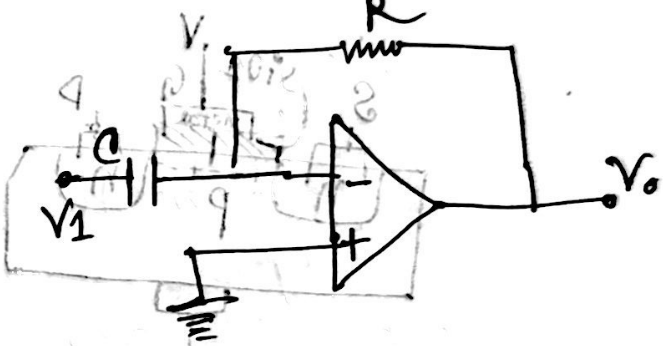
$$V_0(t) = -\frac{1}{C}\int_0^t i_2(t)\,dt$$

$$= -\frac{1}{C}\int_0^t i_1(t)\,dt$$

$$= -\frac{1}{RC}\int_0^t V_1(t)\,dt \qquad \left[i = \frac{V_1}{R}\right]$$

With V_c,

$$V_o(t) = -\frac{1}{RC}\int_0^t V_1(t)\,dt - V_c$$



~~Differenciate Amp~~

$$A_v = -\frac{R}{\frac{1}{j\omega C}}$$

$$A_v = -SRC = -j\omega RC$$

$$V_o(t) = -CR\frac{dV_1(t)}{dt}$$

Quiz 2 → 29/12/2024
Sunday

- Non-inverting
  - gain error
  - Ideal gain / Actual gain
- Summing
- Buffer
- difference
- Instrumentation

Integrator	figure
Differencial	gain