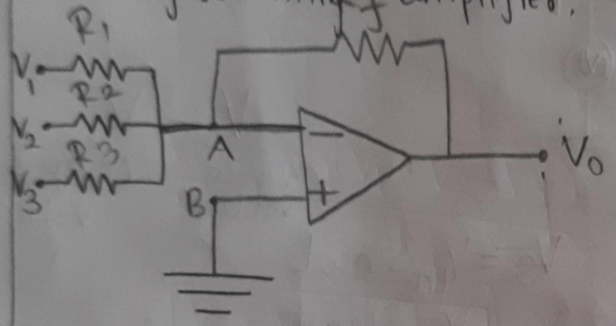
Applications of Operational Amplifier:

* Adder
* Subtractor
* I to V and V to I converter.
* Integrator
* Differentiator
* Instrumentation Amplifier.

(i) Adder | Summing amplifier:

The output voltage is the sum of all the input voltage.

Inverting summing amplifier:



* Two types:
  - (i) Inverting summing amplifier.
  - (ii) Non-inverting summing amplifier.

Apply KCL at node A,

$V_d = 0$

$V_A = V_B$

As $V_B = 0$ (grounded)

$V_A = 0$

$$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} + \frac{V_3 - V_A}{R_3} + \frac{V_0 - V_A}{R_f} = 0$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_0}{R_f} = 0$$

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

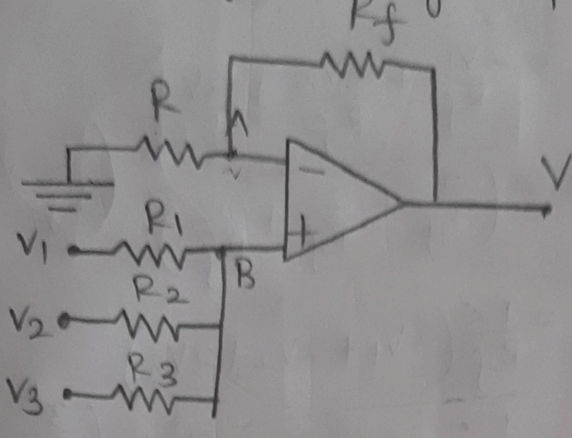
$$-R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right] = V_0$$

Consider $R_1 = R_2 = R_3 = R_f$

$$\boxed{V_0 = -(V_1 + V_2 + V_3)}$$

As it is connected to inverting terminal

Non-inverting summing amplifier:



At node a,

$$\frac{0 - V_A}{R} + \frac{V_0 - V_A}{R_f} = 0$$

$$\frac{V_0 - V_A}{R_f} = \frac{V_A}{R} \Rightarrow \frac{V_A}{R} + \frac{V_A}{R_f} = \frac{V_0}{R_f}$$

$$V_0 = R_f V_A \left(\frac{1}{R} + \frac{1}{R_f}\right) \rightarrow ①$$

At node b,

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

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = V_B\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = V_B\left(\frac{R_2R_3 + R_1R_3 + R_1R_2}{R_1R_2R_3}\right)$$

$$V_B = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\left(\frac{R_1R_2R_3}{R_2R_3 + R_1R_3 + R_1R_2}\right)$$

$$V_B = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)} \rightarrow ②$$

Sub ② in ①, $[V_A = V_B]$

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

Let $R_1 = R_2 = R_3 = R = \frac{R_f}{2}$

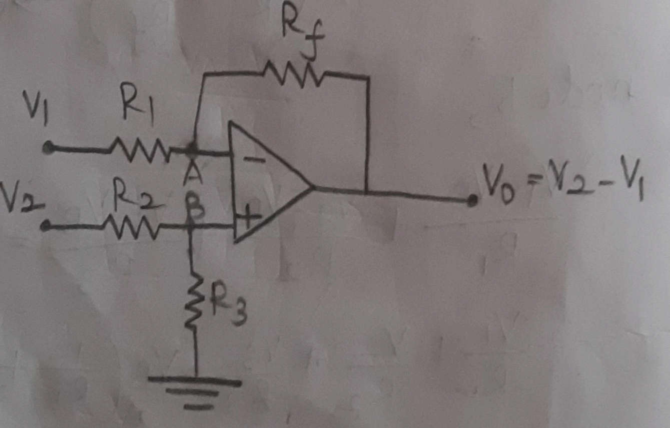
$$\frac{V_0}{R_f} = \frac{\frac{2V_1}{R_f} + \frac{2V_2}{R_f} + \frac{2V_3}{R_f}}{\left(\frac{2}{R_f} + \frac{2}{R_f} + \frac{2}{R_f}\right)} \left(\frac{2}{R_f} + \frac{1}{R_f}\right)$$

$$= \frac{\cancel{\frac{1}{R_f}}\left(2V_1 + 2V_2 + 2V_3\right)}{\cancel{\frac{1}{R_f}}\left(\cancel{6}_{2}\right)} \left(\frac{\cancel{3}^{1}}{R_f}\right)$$

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

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

(ii) Subtractor / Difference amplifier:



* A circuit that takes the difference b/w two signals is called subtractor.

Output = Difference of i/p.

Assume,

$$R = R_1 = R_2 = R_3 = R_f$$

At inverting terminal (or) A,

$V_2 = 0$, $V_1 = \text{applied}$

$$V_0 = -\left(\frac{R_f}{R_1}\right)V_1$$

$$\boxed{V_0 = -V_1}$$

At non-inverting terminal (or) at B,

$V_1 = 0$, $V_2 = \text{applied}$

$$V_0 = \left[1 + \frac{R_f}{R_1}\right]V_A \rightarrow ①$$

At node 'a',

$$V_A = V_2 \times \frac{R_3}{R_2 + R_3} \rightarrow ②$$

Sub ② in ①,

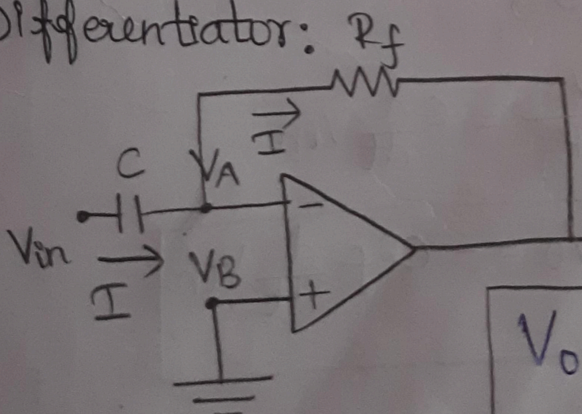
$$V_0 = \left[1 + \frac{R_f}{R_1}\right]\left[V_2 \times \frac{R_3}{R_2 + R_3}\right]$$

$$V_0 = 2\left(V_2 \times \frac{R_f}{2R_f}\right)$$

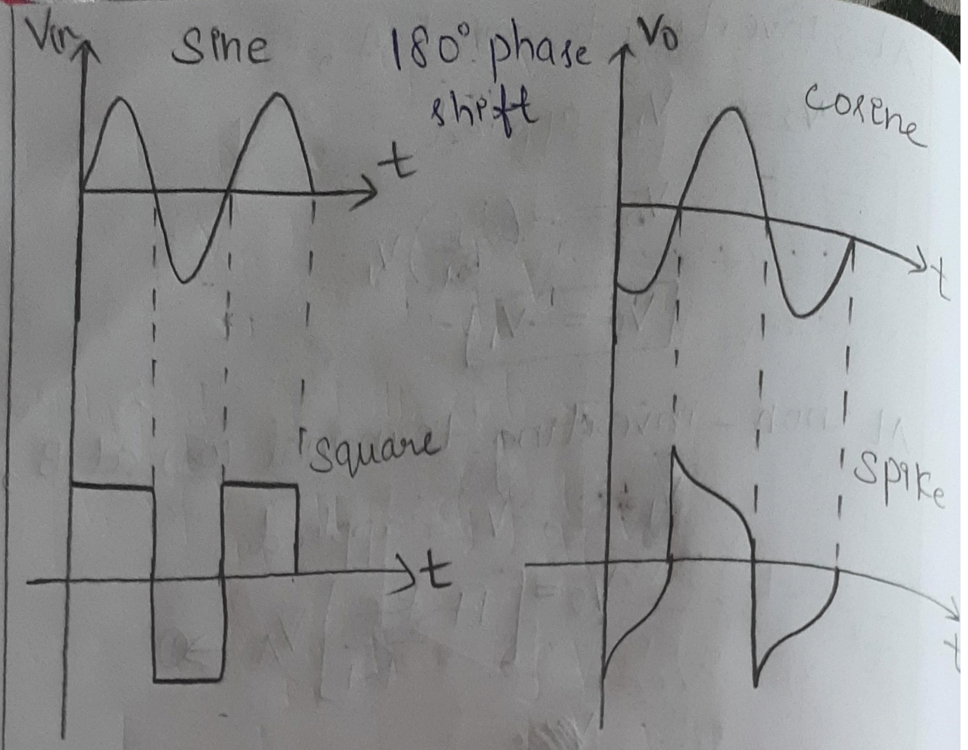
$$\boxed{V_0 = V_2}$$

Output voltage = Inverting amplifier + Non-inverting amplifier.

2023
(iii) Differentiator:



$$\boxed{V_0 = \frac{dV_{in}}{dt}}$$



(i) $V_A = V_B$ $\quad$ V_B = grounded

$\boxed{V_A = 0}$

Current at i/p side,

current passes through capacitor

$$I = C\frac{d}{dt}(V_{in} - V_A)$$

$$\boxed{I = C\frac{dV_{in}}{dt}} \rightarrow ①$$

Current at o/p side,

$$I = \frac{V_A - V_0}{R_f}$$

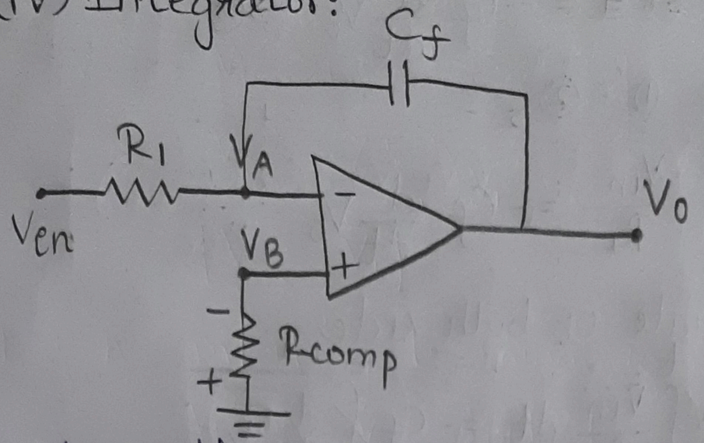
$$\boxed{I = \frac{-V_0}{R_f}} \rightarrow ②$$

Equate ① & ②,

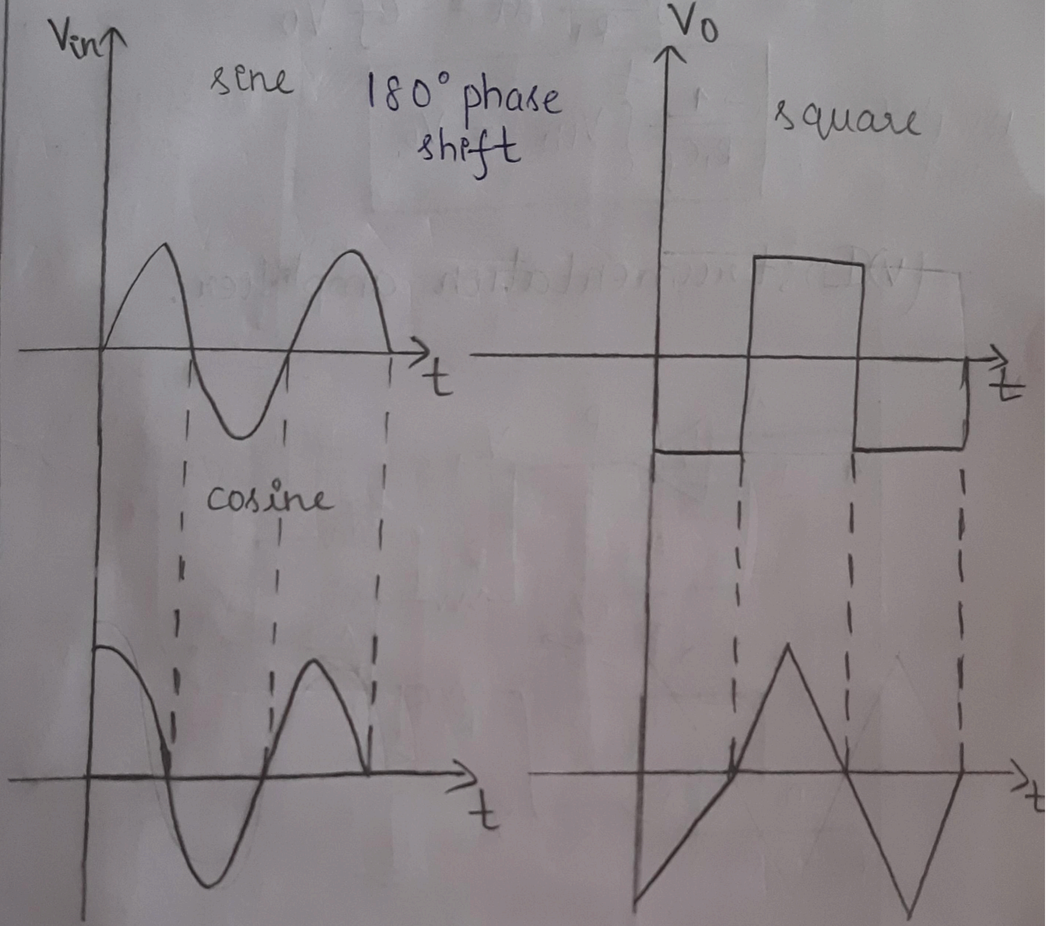
$$\frac{-V_0}{R_f} = C\frac{d}{dt}V_{in}$$

$$\boxed{V_0 = -CR_f\frac{d}{dt}V_{in}}$$

(iv) Integrator:



* O/p is the integral of input.



6/09/23 ~~Instrumentation amplifier.~~

Find i at i/p side,

$$I = \frac{V_{in} - V_A}{R_1}$$

$$I = \frac{V_{in}}{R_1}$$

'I' at o/p side,

$$I = C_f \frac{d}{dt}(V_A - V_o)$$

$$I = -C_f \frac{d}{dt} V_o \rightarrow (2)$$

Equate (1) & (2),

$$\frac{V_{in}}{R_1} = -C_f \frac{d}{dt} V_o$$

Integrate on both sides,

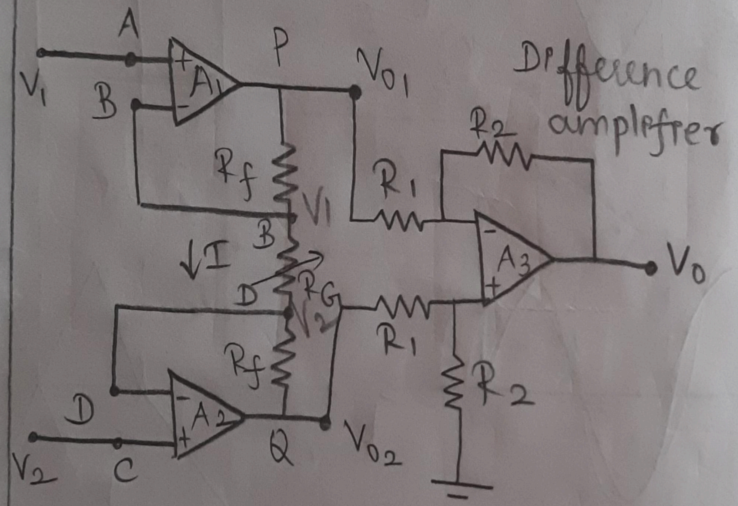
$$\int_0^t \frac{V_{in}}{R_1} dt = -C_f \int_0^t \frac{d}{dt} V_o$$

$$\int_0^t \frac{V_{in}}{R_1} dt = -C_f V_o$$

$$\boxed{\ominus \frac{1}{R_1 C_f} \int_0^t V_{in} = V_o}$$

180° phase shift

(V) Instrumentation amplifier:



* Also known as data amplifier.
* Mainly used in industries.
* It is used to measure and control physical quantities.
(Temp, Pressure, Humidity, intensity, light)
* Transducers convert physical quantities to electrical quantities. Here the o/p is weak so for amplifying instrumentation amplifier is used.

Features:

(i) High gain accuracy.

(ii) High CMRR.

* A_1, A_2 = Voltage follower & act as a buffer stage.

* Gain can be varied by varying R_G.

Consider PQ,

Node $A = V_1$ so $V_B = V_1$

Node $C = V_2$ so $V_D = V_2$

$$I = \frac{V_{01} - V_{02}}{R_f + R_f + R_G}$$

$$I = \frac{V_{01} - V_{02}}{2R_f + R_G} \rightarrow ①$$

since o/p stage is difference amplifier.

so $V_0 = V_{01} - V_{02}$

Apply ohm's law at BD,

$$I = \frac{V_1 - V_2}{R_G} \rightarrow ②$$

Equate ① & ②,

$$\frac{V_{01} - V_{02}}{2R_f + R_G} = \frac{V_1 - V_2}{R_G}$$

$$V_{01} - V_{02} = \frac{V_1 - V_2}{R_G}(2R_f + R_G)$$

Output voltage, (V_0)

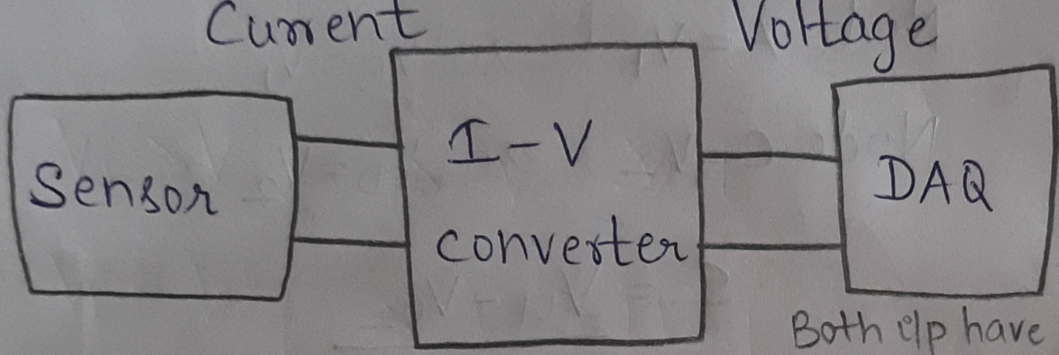
$$V_0 = \frac{R_2}{R_1}(V_{01} - V_{02})$$

$$V_0 = \frac{R_2}{R_1}\left(\frac{V_1 - V_2}{R_G}(2R_f + R_G)\right)$$

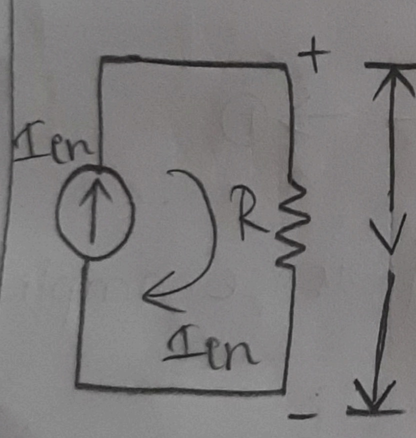
$$\boxed{V_o = \frac{R_2}{R_1}(V_1 - V_2)\left(\frac{2R_f}{R_G} + 1\right)}$$

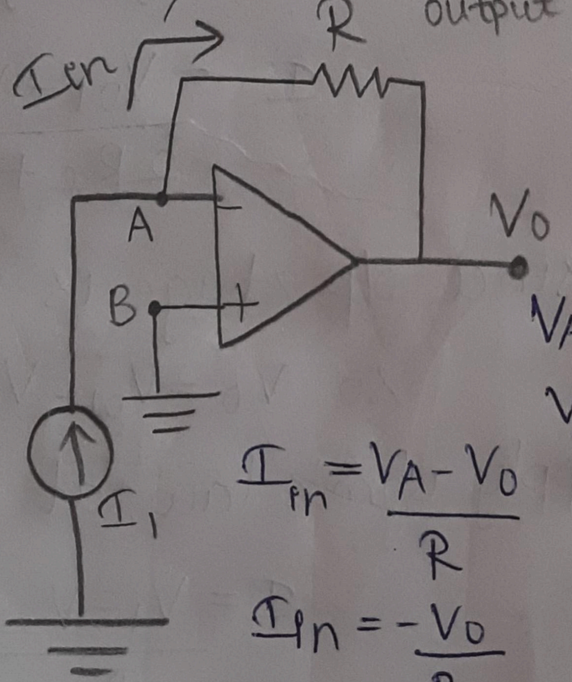
$$\boxed{\frac{V_o}{V_1 - V_2} = A = \frac{R_2}{R_1}\left(\frac{2R_f}{R_G} + 1\right)}$$

(vi) I to V amplifier:



Both i/p have resistance so it flows through output resistance





$V_A = V_B$

$V_A = 0$

$$I_{in} = \frac{V_A - V_0}{R}$$

$$I_{in} = -\frac{V_0}{R}$$

$$\boxed{V_0 = -I_{in}R}$$