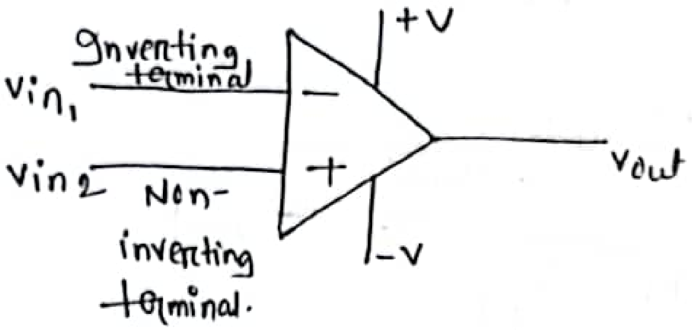
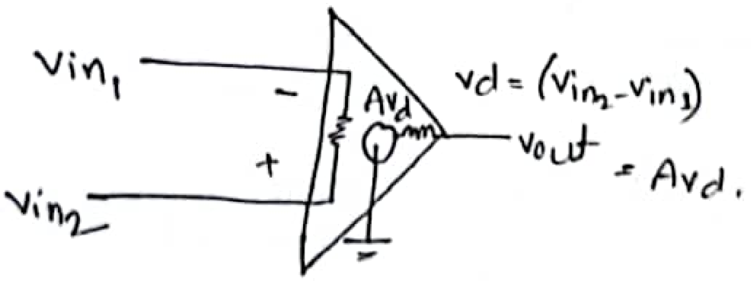
Operational - Amplifier

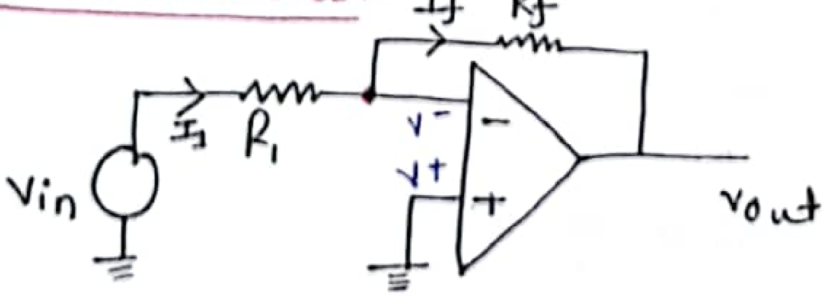
OP-Amp:- An operational Amplifier is an integrated circuit that can amplify weak electric signals it can perform some mathematical function like addition, subtraction, Differentiation, Integration etc.

An OP-amp has high input impedance (∞) and low output impedance (0).





Inverting Amplifier:-



Apply KCl

$I_1 - I_f = 0$

$I_1 = I_f$

$V^- = V^+ = 0$

$V^- = V^+$

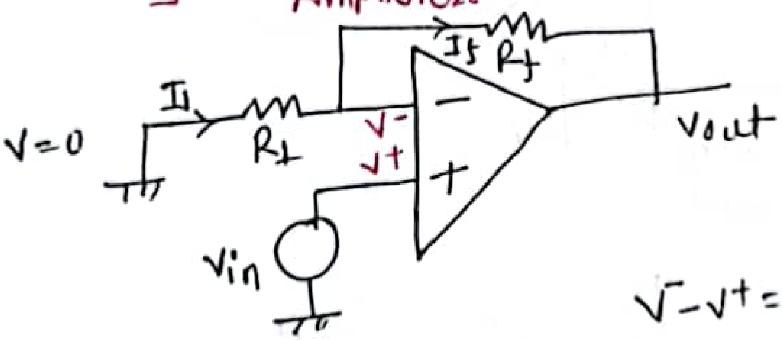
$$\therefore \frac{V_{in} - V^-}{R_1} = \frac{V^- - V_{out}}{R_f}$$

$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_f}$$

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

$$\therefore \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$$

Non-inverting Amplifier:-



$$V^- - V^+ = 0$$

$$V^- = V^+$$

Here

$$\boxed{\begin{array}{l} V_{in} = V^+ \\ \therefore V^- = V_{in} \end{array}}$$

$$I_1 = I_f$$

$$\frac{V - V_{in}}{R_1} = \frac{V_{in} - V_{out}}{R_f}$$

$$\frac{0 - V_{in}}{R_1} = \frac{V_{in} - V_{out}}{R_f}$$

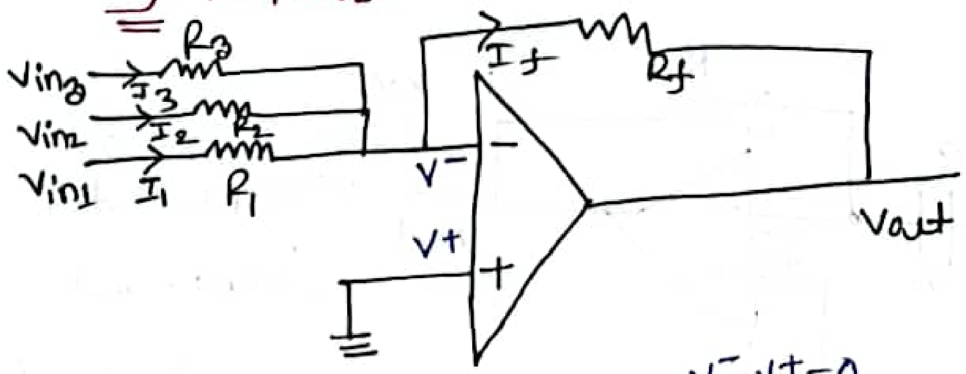
$$-V_{in} R_f = V_{in} R_1 - R_1 V_{out}$$

$$-V_{in} R_f - V_{in} R_1 = -R_1 V_{out}$$

$$V_{in}(R_1 + R_f) = R_1 V_{out}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_1 + R_f}{R_1} = \left(1 + \frac{R_f}{R_1}\right)$$

Summing Amplifier:-



$V^- = V^+ = 0$

$V^- = V^+$

$$I_1 + I_2 + I_3 = I_f$$

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

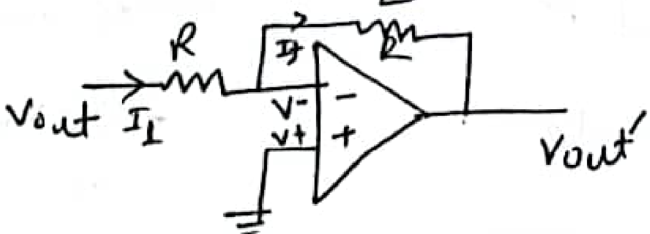
$$\frac{V_{in1}}{R_1} + \frac{V_{in2}}{R_2} + \frac{V_{in3}}{R_3} = \frac{-V_{out}}{R_f}$$

$$\therefore V_{out} = -R_f \left[\frac{V_{in1}}{R_1} + \frac{V_{in2}}{R_2} + \frac{V_{in3}}{R_3}\right]$$

if, $R_f = R_1 = R_2 = R_3 = R$

$$\therefore V_{out} = -R\left[\frac{V_{in1}}{R} + \frac{V_{in2}}{R} + \frac{V_{in3}}{R}\right]$$

$$V_{out} = -\left[V_{in1} + V_{in2} + V_{in3}\right]$$



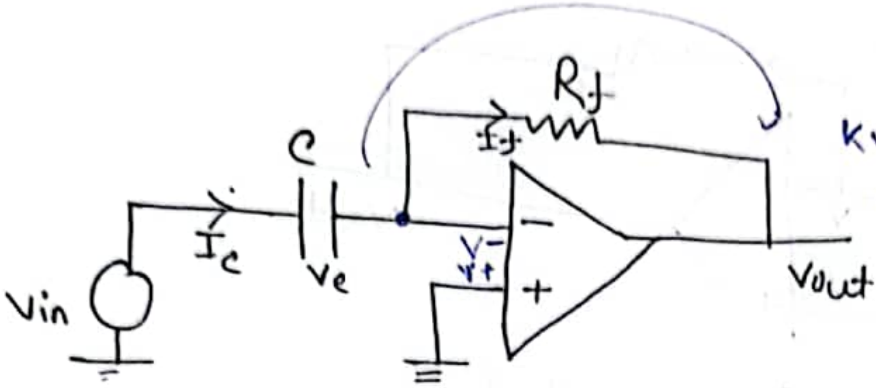
$$\frac{V_{out} - V}{R} = \frac{V - V_{out}'}{R}$$

$$V_{out} = -V_{out}'$$

$$\therefore V_{out}' = -V_{out}$$

$$= -\left[-(V_{in1} + V_{in2} + V_{in3})\right] = V_{in1} + V_{in2} + V_{in3}.$$

Differentiator:



KVL

$\Rightarrow$

$V^- - I_f R_f - V_{out} = 0$

$-I_f R_f = V_{out}$

$\therefore V_{out} = -I_f R_f$

$$I_c = I_f$$

the current eq^n for Capacitor is

$$I_c = C\frac{dV_c}{dt}$$

$$C\frac{dV_{in}}{dt} = \frac{V^- - V_{out}}{R_f}$$

Here,

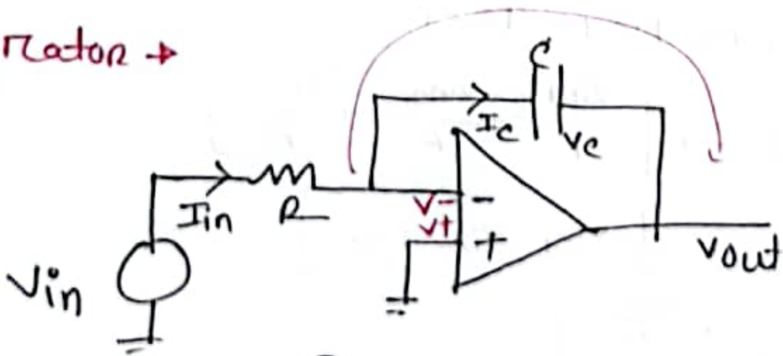
$V_{in} = V_c$

$\therefore I_c = C\frac{dV_{in}}{dt}$

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

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

Integrator:



KVL $\Rightarrow$

$V^- - V_c - V_{out} = 0$

$-V_c = V_{out}$

$\therefore V_c = -V_{out}$

$$I_{in} = I_c$$

$$\frac{V_{in} - V^-}{R} = C\frac{dV_c}{dt}$$

$$\frac{V_{in}}{R} = C\frac{d}{dt}(-V_{out})$$

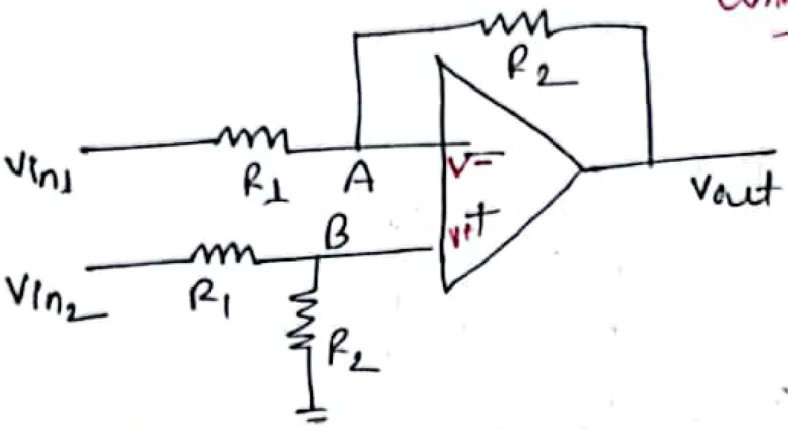
$$\frac{V_{in}}{R} = -C\frac{d}{dt}V_{out}$$

$$\frac{d V_{out}}{dt} = -\frac{V_{in}}{RC}$$

Now, integrate on both side,

$$V_{out}(t) = -\frac{1}{RC}\int V_{in}(t)$$

Subtractor Amplifier → (Differential Amplifier using OP-Amp)



Step-1: Select Inverting terminal

$$\frac{V_{in_1} - V_A}{R_1} = \frac{V_A - V_{out}}{R_2}$$

$V^- - V^+ = 0$

$V^- = V^+$

Also,

$V^- = V_A$

$$\therefore \frac{V_{in_1} - 0}{R_1} = \frac{0 - V_{out}}{R_2}$$

$$V_{out_1} = -\left(\frac{R_2}{R_1}\right) V_{in_1} \quad \text{—(1)}$$

Step-2: Select Non-Inverting terminal →

Apply Voltage Divider Rule in Point B

$$V_B = \frac{R_2 V_{in_2}}{R_1 + R_2}$$

$$V.D.R \Rightarrow V_x = \frac{R_x E}{R_T}$$

Now, By using Non-inverting output eqn →

$$V_{out2} = \left(1 + \frac{R_2}{R_1}\right) V_B$$

$$= \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_2 V_{in2}}{R_1 + R_2}\right)$$

$$= \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_2 V_{in2}}{R_1 + R_2}\right)$$

$$V_{out2} = \frac{R_2}{R_1} V_{in2} \quad \text{—} \; (ii)$$

(ii) — (i) OR (i) — (ii)

$$V_{out1} - V_{out2} = \frac{R_2}{R_1} V_{in1} - \frac{R_2}{R_1} V_{in2}$$

$$V_{out} = \frac{R_2}{R_1}\left(V_{in1} - V_{in2}\right)$$

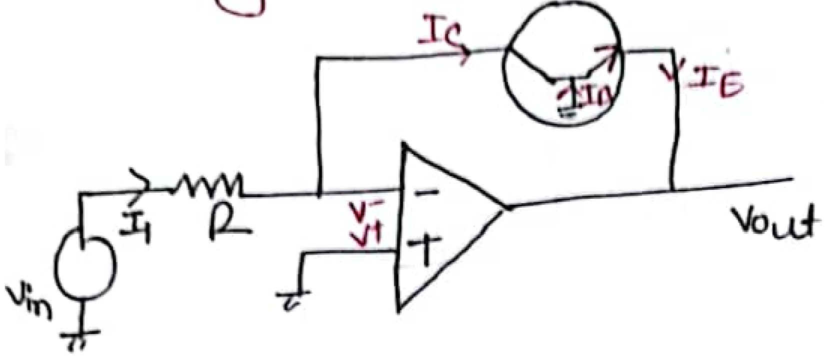
if $\Rightarrow R_2 = R_1 = R$

$$\therefore V_{out} = \frac{R}{R}\left(V_{in1} - V_{in2}\right)$$

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

Differential Amplifier/OP-Amp behave as a Subtractor Circuit.

Using op Amp and transistor :



Here,

$V_{BE} = V_B - V_E$

$I_E = I_B + I_C$

$I_B \cong 0$

$\therefore I_E = I_C$.

$I_1 = I_C$

$$\frac{V_{in} - V^-}{R} = I_C$$

The collector current eqn

$$I_C = I_S\left(e^{\frac{V_{BE}}{\eta V_T}} - 1\right)$$

$$= I_S e^{\frac{V_{BE}}{\eta V_T}}$$

η = ideality factor

I_S = Saturation current

V_T = threshold voltage

V_{BE} = Base-emitter voltage.

I_C = Collector current.

$$\therefore \frac{V_{in}}{R} = I_S e^{\frac{V_{BE}}{\eta V_T}}$$

Now,

$V_{BE} = V_B - V_E$

$V_{BE} = 0 - V_E$

$V_E = -V_{BE}$

$\downarrow$

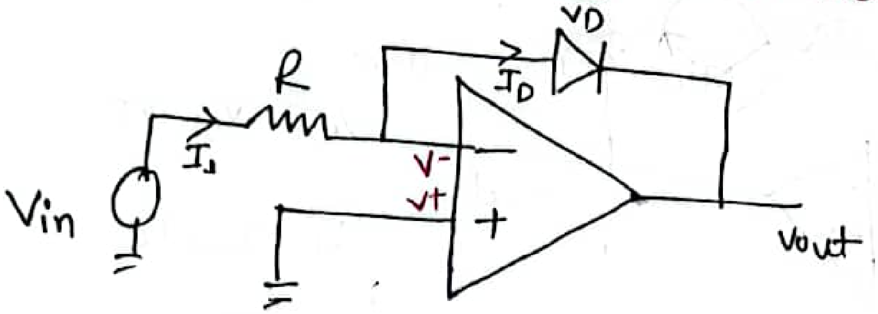
$V_{out} = -V_{BE}$

$\therefore V_{BE} = -V_{out}$

Now, we can write,

$$\frac{V_{in}}{R} = I_S e^{\frac{-V_{out}}{\eta V_T}} \quad [\text{Put}, V_{BE} = -V_{out}]$$

logarithmic Amplifier: using Diode and OP-Amp.



$$I_1 = I_D$$

$$\frac{V_{in} - V^-}{R} = I_0 e^{\frac{V_D}{\eta V_T}}$$

$$\frac{V_{in} - 0}{R} = I_0 e^{\frac{-V_{out}}{\eta V_T}}$$

$$\frac{V_{in}}{R} = I_0 e^{\frac{-V_{out}}{\eta V_T}}$$

$$e^{\frac{-V_{out}}{\eta V_T}} = \frac{V_{in}}{R I_0}$$

$$\ln e^{\frac{-V_{out}}{\eta V_T}} = \ln \frac{V_{in}}{R I_0}$$

$$\frac{-V_{out}}{\eta V_T} = \ln \frac{V_{in}}{R I_0}$$

$$\boxed{V_{out} = -\eta V_T \ln \frac{V_{in}}{R I_0}}$$

from diode current eqn →

$$I_d = I_0 \left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

$$= I_0 e^{\frac{V_D}{\eta V_T}}$$

Here,

η = ideality factor

V_T = thresold voltage

V_D = Diode voltage

I_0 or I_s = Saturation current

I_d = diode current

$$V^- = V_D - V_{out} = 0$$

$$V_D = -V_{out}$$

* Derive output voltage eqn for log Amplifier Using Diode and OP-Amp.

$$e^{-\frac{V_{out}}{\eta V_T}} = \frac{V_{in}}{R I_s}$$

$$\ln e^{-\frac{V_{out}}{\eta V_T}} = \ln \frac{V_{in}}{R I_s}$$

$$\frac{-V_{out}}{\eta V_T} = \ln \frac{V_{in}}{R I_s}$$

$$-V_{out} = \eta V_T \ln \frac{V_{in}}{R I_s}$$

$$\boxed{\therefore V_{out} = -\eta V_T \ln \frac{V_{in}}{R I_s}}$$

* Derive o/p voltage eqn for op-Amp using transistor ... and op-Amp.

OR op-Amp can be used as a log Amplifier → Prove.