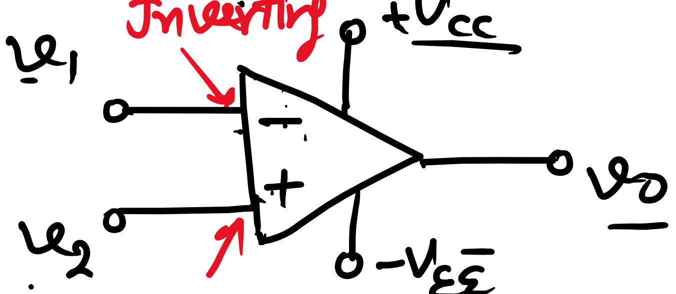
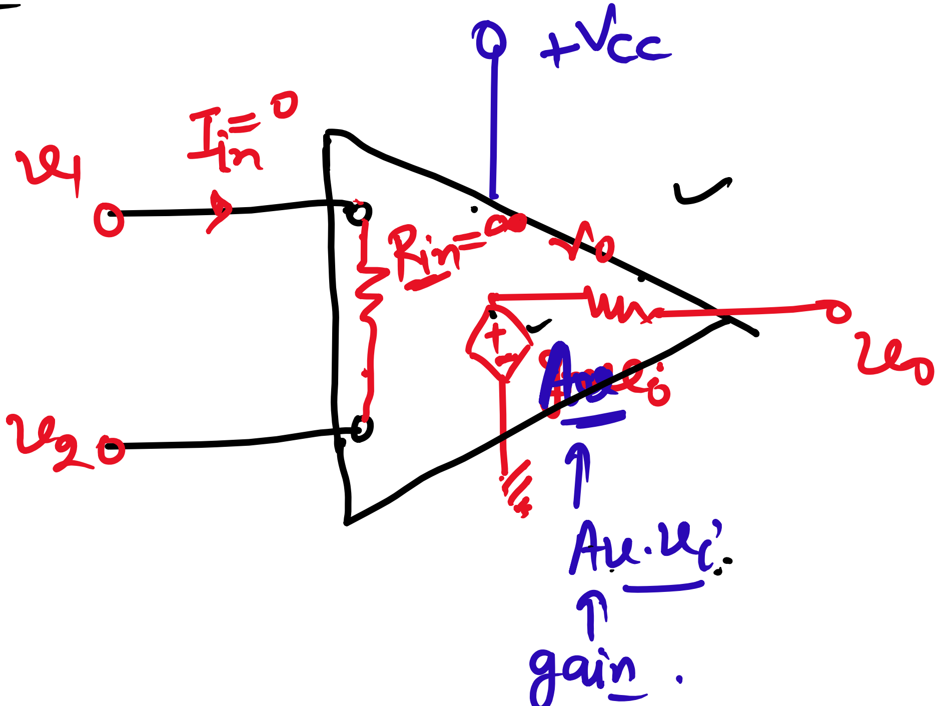
Unit-iv OP-Amp-

1. Active device
2. made up of combinations of BJT or FET
3. Can operate with DC & AC.
4. Can be used in Open loop & Closed loop Configurations.



Ideal OP-Amp-



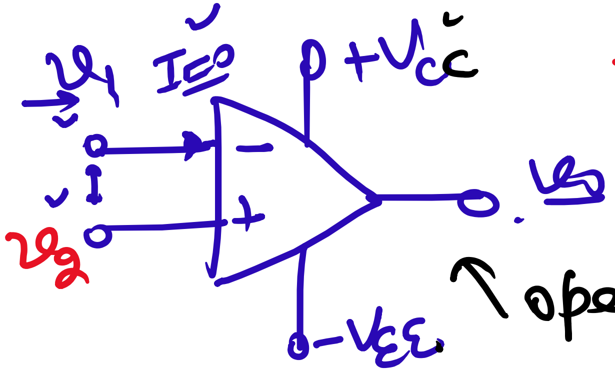
1. $R_{in} = \infty \Rightarrow I_{in} = 0$
2. Virtual short / Virtual ground.

The characteristics of Ideal op-Amp-

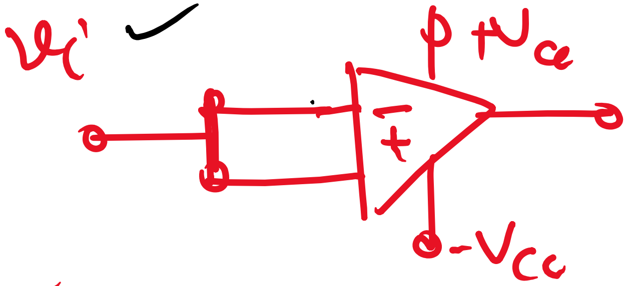
1. $R_{in} = \infty \Rightarrow$ I/P resistance.
2. $R_o = 0 \Rightarrow$ O/P resistance
3. $A_v = \infty \Rightarrow$ Voltage Gain. $= \frac{v_o}{v_i}$

(4) CMRR (common mode rejection ratio) -

$$CMRR = \frac{A_d}{A_c} \rightarrow \frac{\text{differential mode gain } (A_d)}{\text{Common mode gain } (A_c)} \Rightarrow \infty \text{ (Ideally)}$$



$$\Rightarrow A_v = \frac{v_o}{v_1 - v_2} = A_d$$



$$\Rightarrow A_c = \frac{v_o}{v_i} \Rightarrow A_c$$

Offset

$v_i = 0 \Rightarrow v_o \neq 0$.

We have to apply opposite voltage or current so o/p become zero.

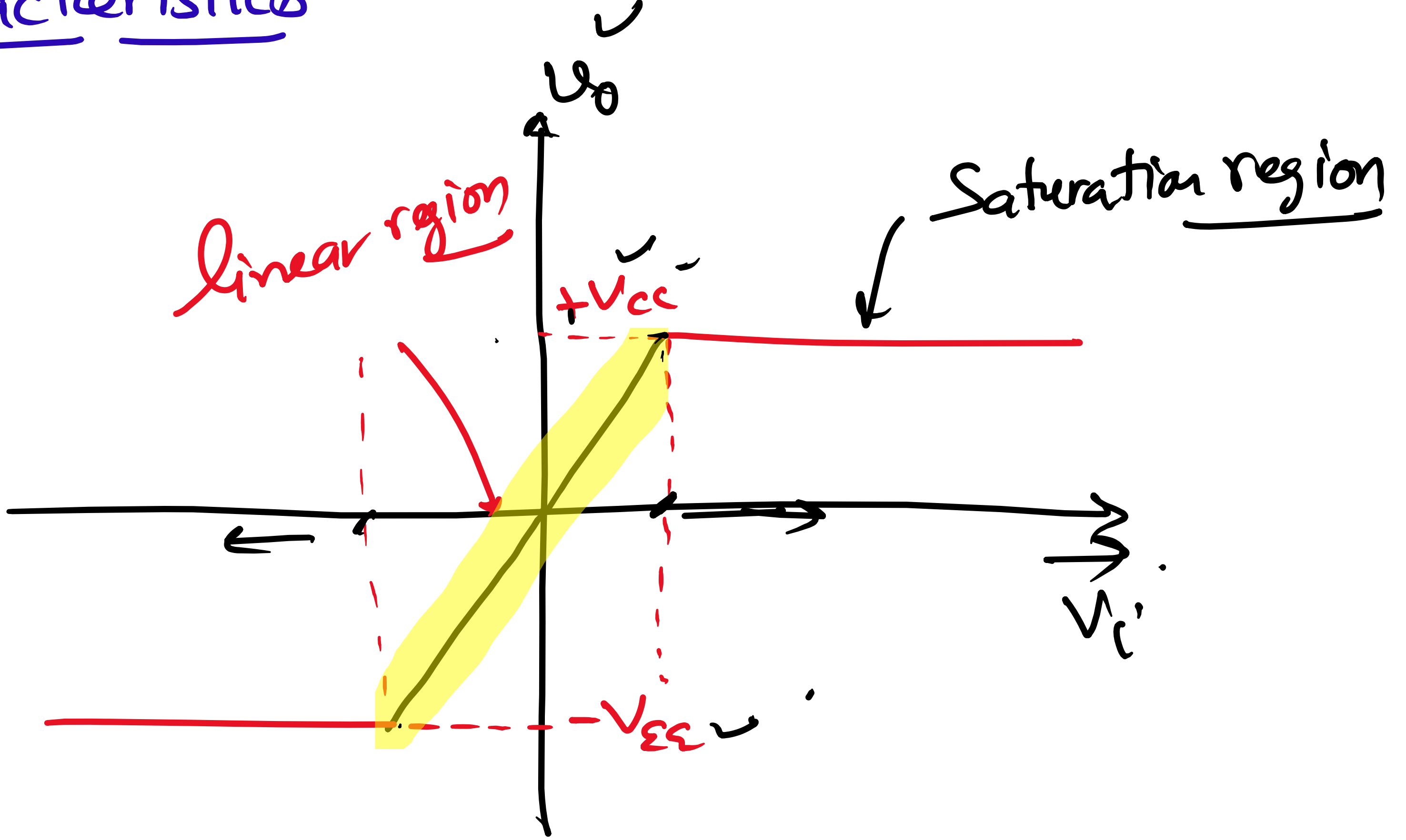
(5) Slew rate =

$$S = \text{maximum of } \frac{dV_o}{dt} \Rightarrow \text{maximum rate of change of voltage with time}$$

$S \simeq \infty$ for Ideal op-Amp.

Parameter	Ideal op-Amp.	Practical op-Amp.
(1) R_i	∞	very high.
(2) R_o	0	very low
(3) A_v	∞	very high
(4) CMRR	∞	very high
(5) SR	∞	very high.
(6) Input offset	0	very smal

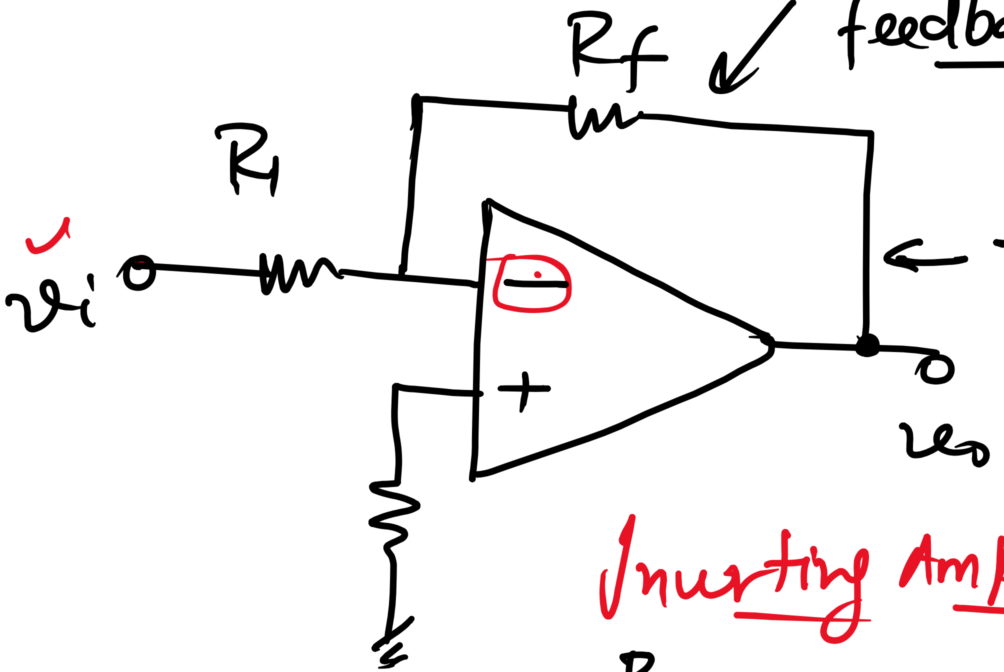
Characteristics -



⇒ Closed Loop Configuration -

feedback ← Closed Loop

feedback → +ve
           → -ve

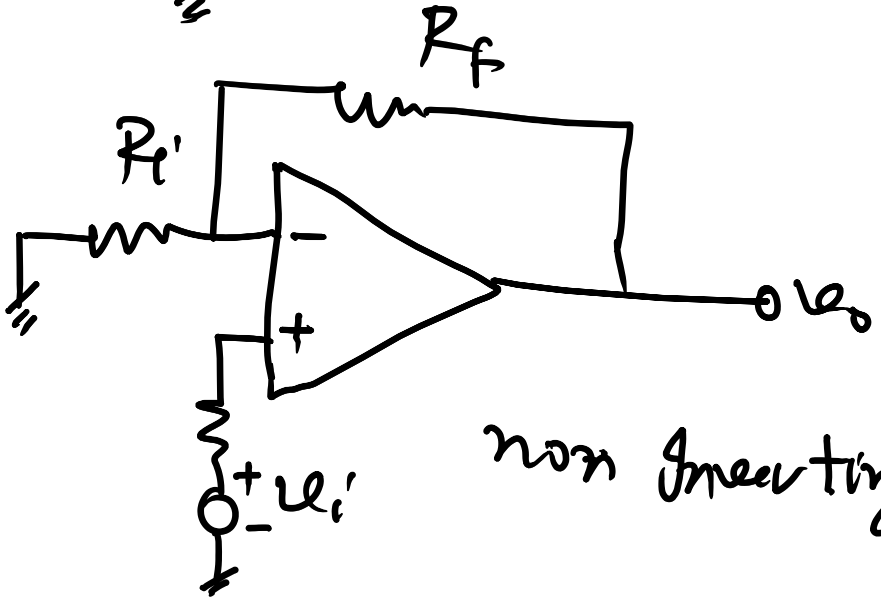


← -ve feedback

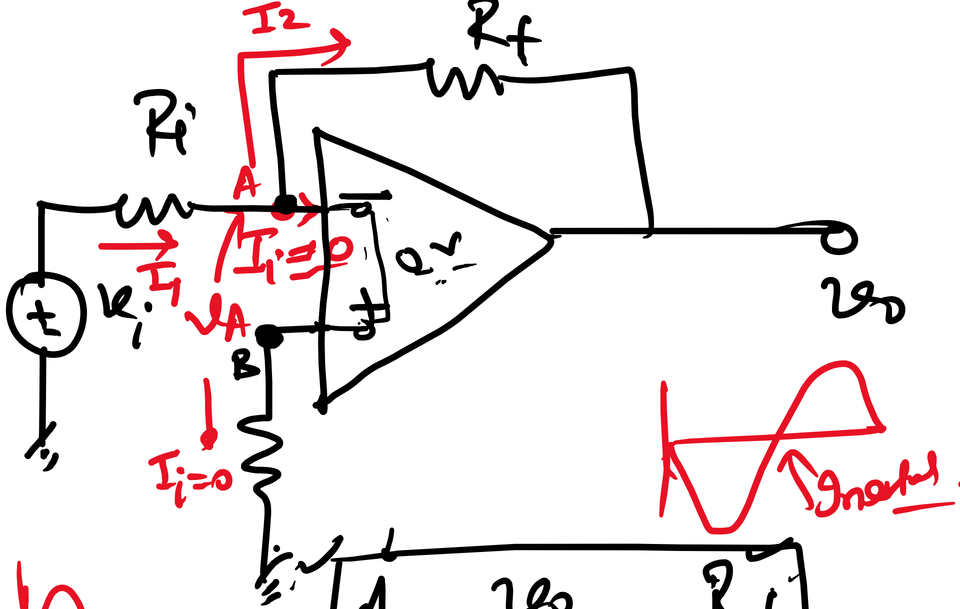
-negative feedback → Amplifier

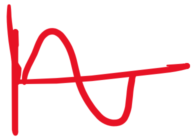
+ve feedback → Oscillator

Inverting Ampr.

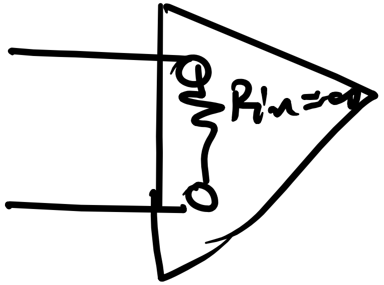


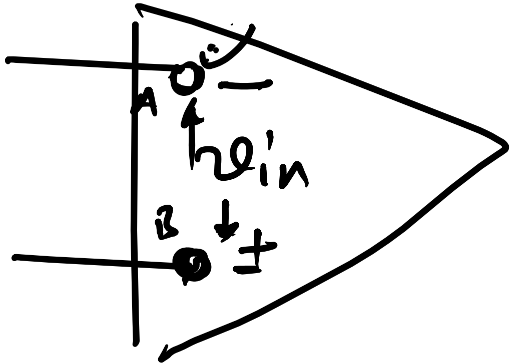
non Inverting Ampr





$$A_v = \frac{v_o}{v_i} = -\frac{R_f}{R_i}$$





Apply KCL at node-A.

$$I_1 = I_2 - I_i \Rightarrow \left[I_i = 0;\ R_{in} = \infty \right.$$

$$\Rightarrow I_1 = I_2$$

$$\frac{v_i - v_A}{R_i} = \frac{v_A - v_o}{R_f}$$

?

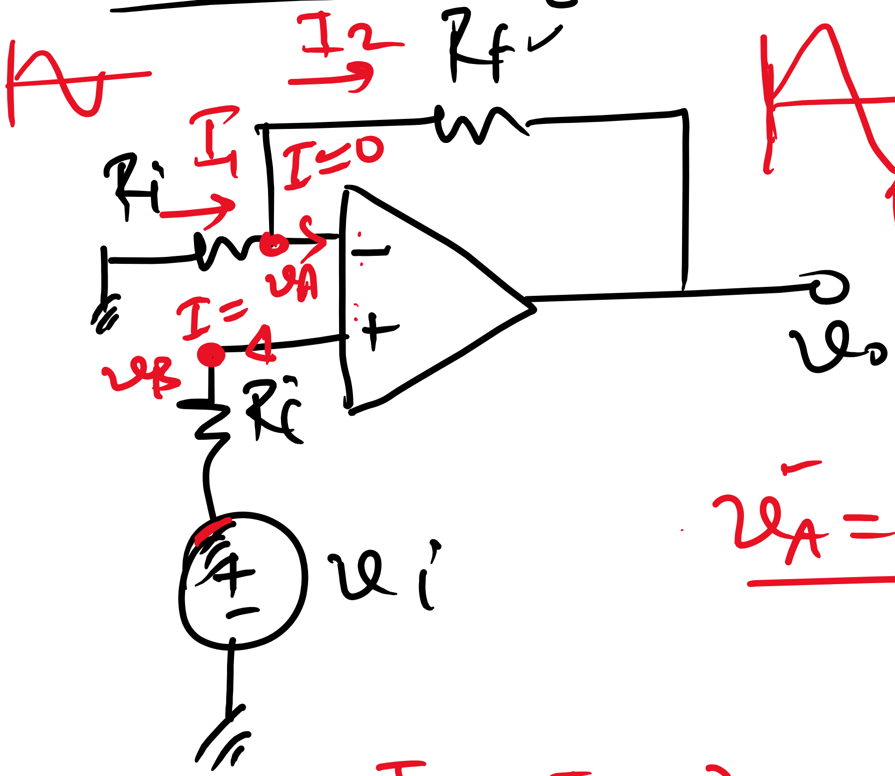
$$\Rightarrow \frac{v_i}{R_i} = v_A \left[\frac{1}{R_i} + \frac{1}{R_f} \right] - \frac{v_o}{R_f}$$

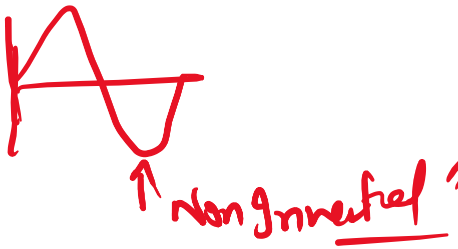
$$\Rightarrow v_A = v_B \Rightarrow \text{Virtual Short / virtual gnd.}$$

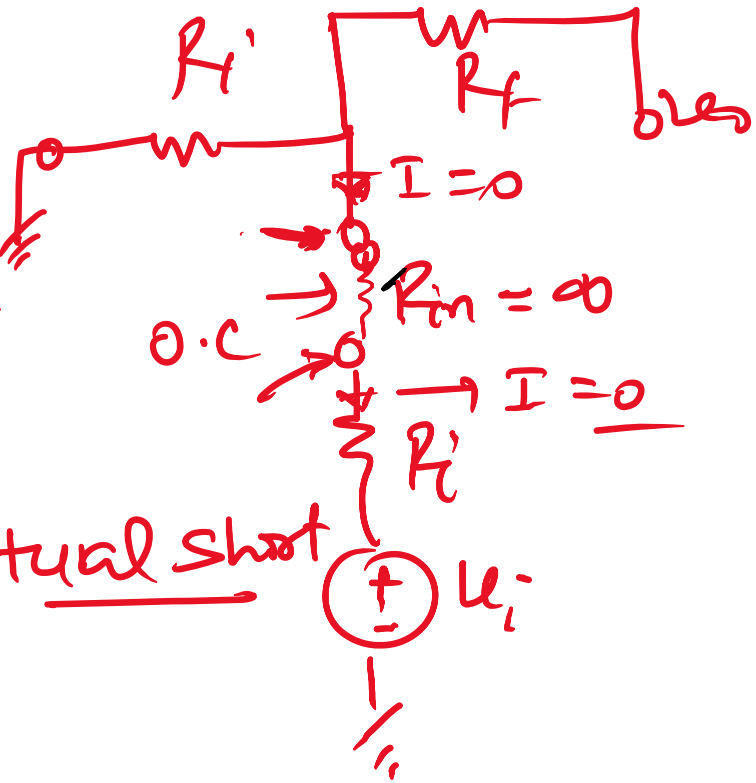
$$v_A = 0\,V$$

$$\frac{v_i}{R_i} = -\frac{v_o}{R_f} \Rightarrow \boxed{v_o = -\frac{R_f}{R_i} v_i}$$

Non-Inverting Amplifier-







$v_A = v_B \Rightarrow$ Virtual short

(A) $\rightarrow$ $I_1 = I_2 \Rightarrow$

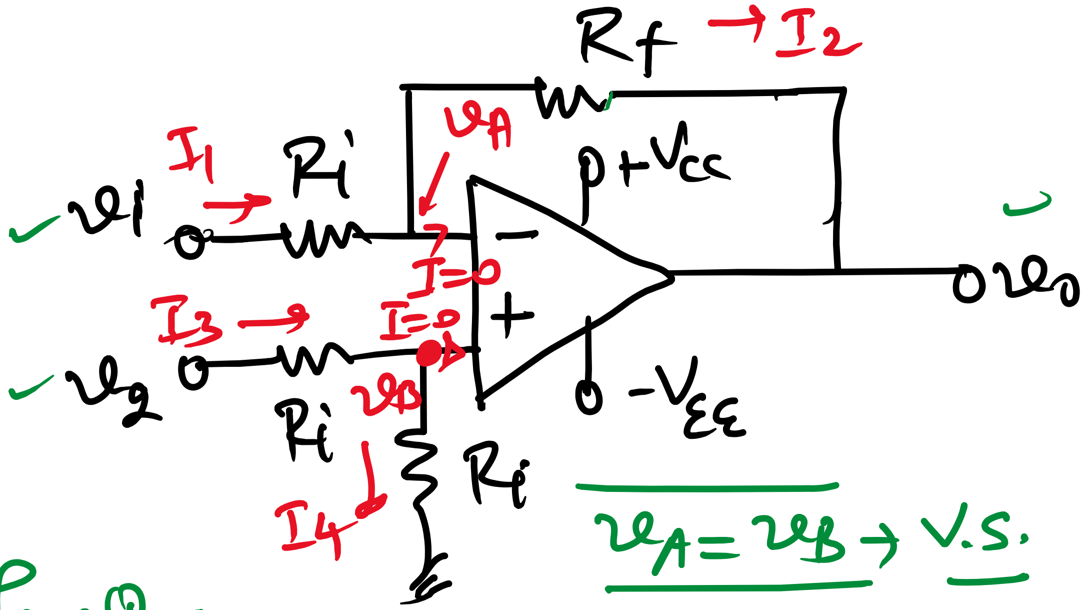
$$\frac{0 - v_A}{R_i} = \frac{v_A - v_o}{R_f} \Rightarrow \frac{0 - v_i}{R_i} = \frac{v_i - v_o}{R_f}$$

$$\Rightarrow \boxed{+v_o = +v_i\left(1 + \frac{R_f}{R_i}\right)} \Rightarrow \boxed{A_v = \left[1 + \frac{R_f}{R_i}\right]}$$

Non-Inverting

① $R_i = \infty$
② Virtual Short } → Operation of OP-Amp. is Based on these Two chs.

① Difference Amplifier – (Subtractor)



$v_A = v_B$ → V.S.

At node (A) –

$I_1 = I_2 \Rightarrow \frac{v_i - v_A}{R_i} = \frac{v_A - v_o}{R_f}$ —— ①

At node-(B) –

$I_3 = I_4$

$\Rightarrow \frac{v_2 - v_B}{R_i} = \frac{v_B - 0}{R_i}$ —— ②

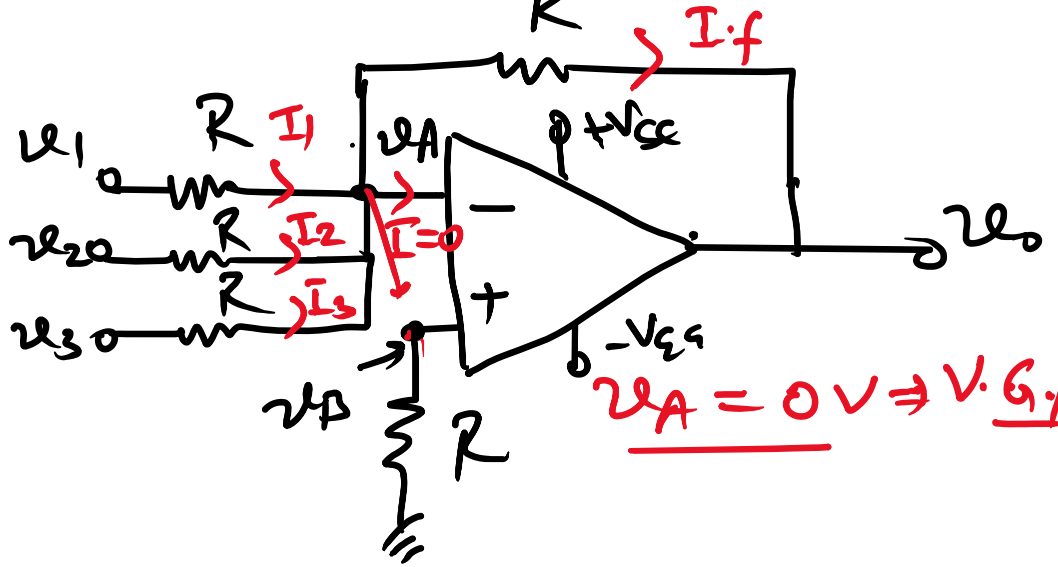
$$\boxed{v_B = \frac{v_2}{2}}$$ —— ③

from ① –

$\frac{v_1 - v_2/2}{R_i} = \frac{v_2/2 - v_o}{R_f}$ → If $\boxed{R_i = R_f}$ $\Rightarrow$ $\boxed{v_1 - v_2 = -v_o}$ $\Rightarrow$ $\boxed{v_o = v_2 - v_1}$

Inverting adder -

Adder → Summer



$v_A = 0V \Rightarrow$ V.G./V.S.

At node-(A) →

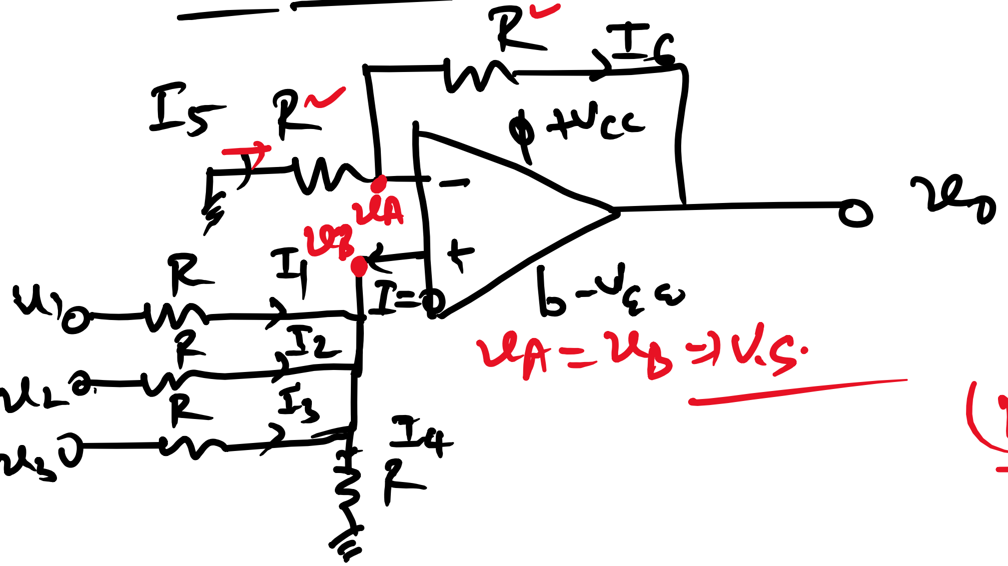
$$I_1 + I_2 + I_3 = I_f$$

$$\frac{v_1 - v_A}{R} + \frac{v_2 - v_A}{R} + \frac{v_3 - v_A}{R} = \frac{v_A - v_o}{R}$$

$$v_1 + v_2 + v_3 = -v_o$$

$$\boxed{v_o = -(v_1 + v_2 + v_3)}$$

Non-Inverting adder -



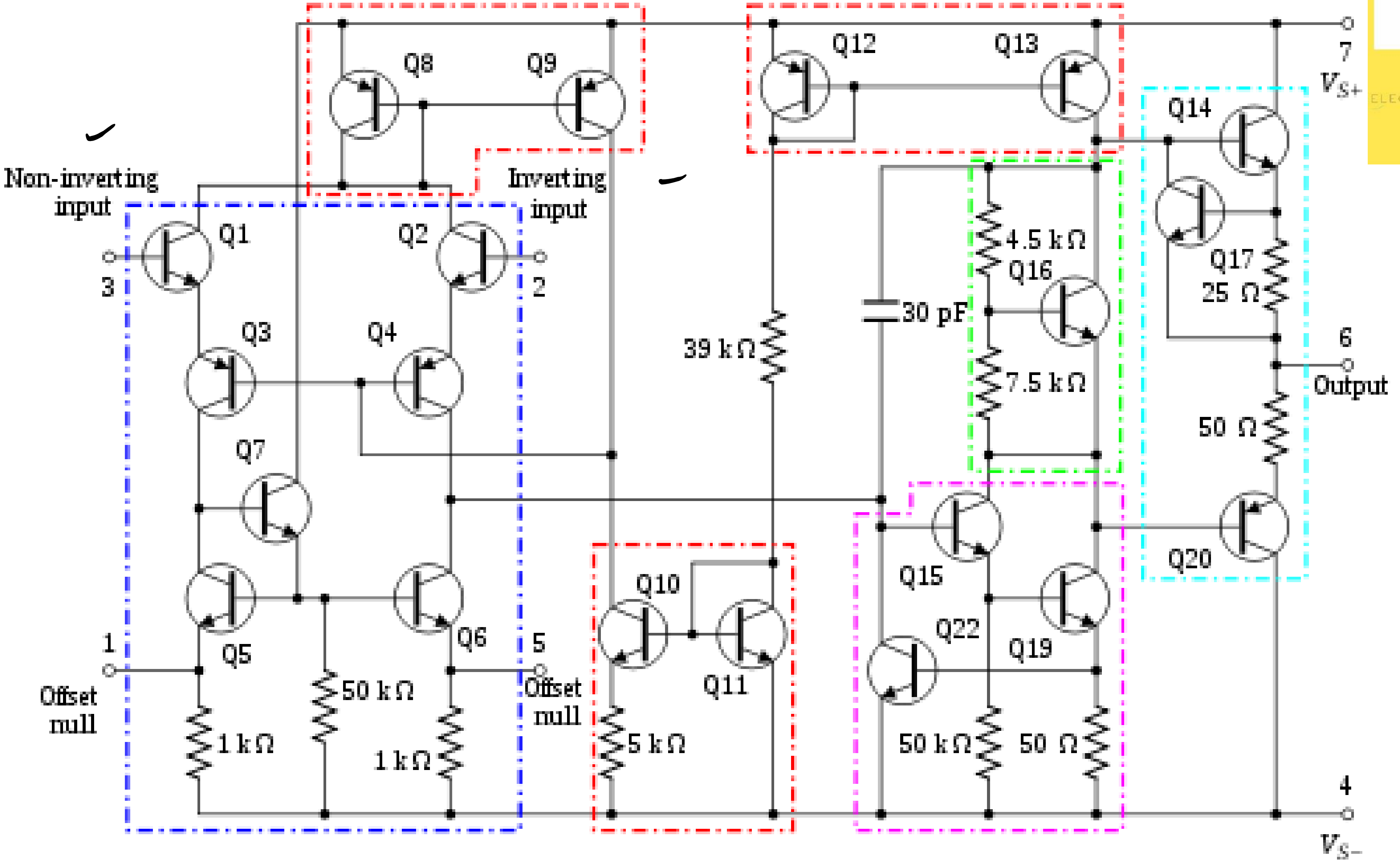
$v_A = v_B \Rightarrow$ V.S.

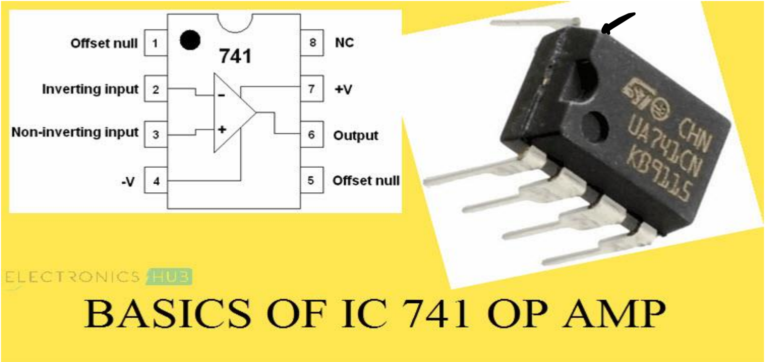
(A) → $$\frac{0 - v_A}{R} = \frac{v_A - v_o}{R} \Rightarrow \frac{v_o}{2} = v_A \quad \text{—(1)}$$

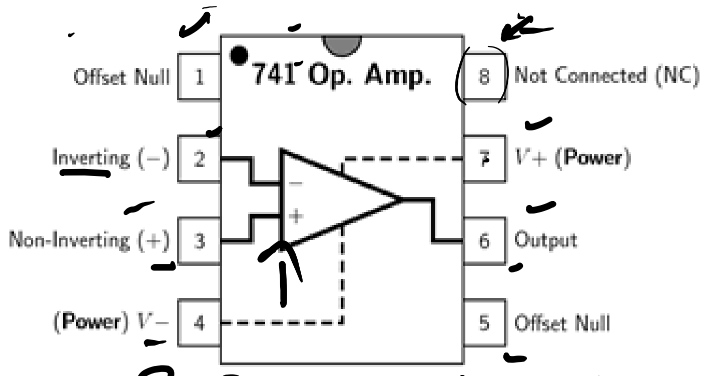
(B) → $$I_1 + I_2 + I_3 = I_4 \Rightarrow \frac{v_1 - v_A}{R} + \frac{v_2 - v_A}{R} + \frac{v_3 - v_A}{R} = \frac{v_A - 0}{R} \quad \text{—(2)}$$

$$(v_1 + v_2 + v_3) - \frac{3v_o}{2} = \frac{v_o}{2} \Rightarrow \boxed{v_o = \frac{1}{2}(v_1 + v_2 + v_3)}$$

Internal ckt diagram of OP-Amp (IC-741)

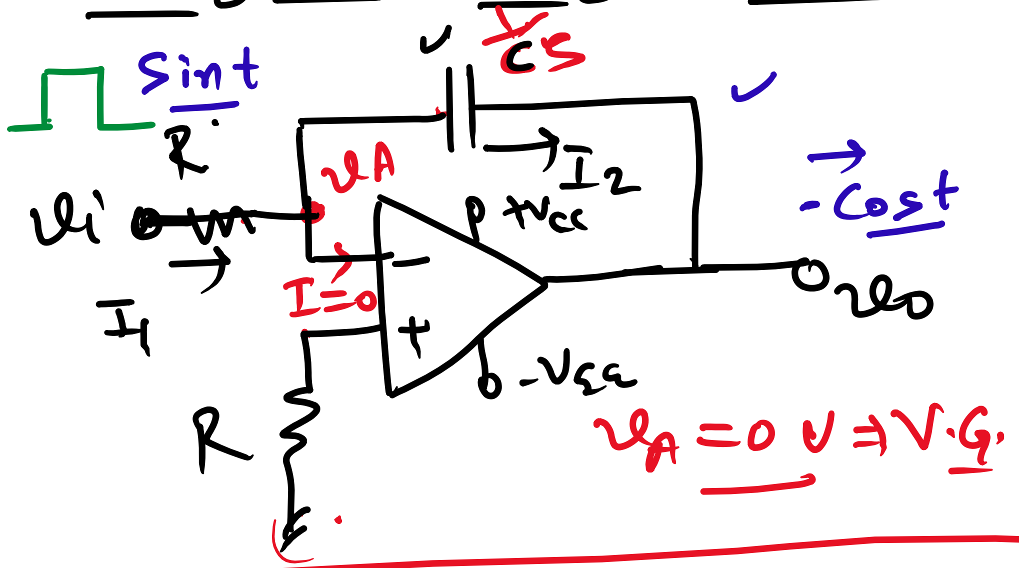






8-Pin Configuration

Integrator using OP-Amp



$v_A = 0\ V \Rightarrow$ V.G.

② $\frac{v_i - 0}{R} = C\frac{d(0 - v_o)}{dt}$

$\frac{v_i}{R} = -C\frac{dv_o}{dt}$

$$\Rightarrow \boxed{v_o = \frac{-1}{RC}\int v_i\, dt}$$

At node-(A) - ①

$I_1 = I_2$

$\frac{v_i - 0}{R_1} = \frac{0 - v_o}{(1/CS)}$

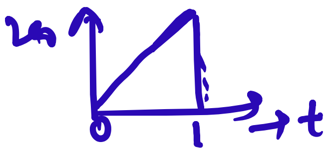
$v_o CS = -\frac{v_i}{R_1}$

$v_o = -\frac{1}{RC(S)} v_i$

$$\boxed{v_o = -\frac{1}{RC}\int v_i\, dt}$$

$v_o = \frac{-1}{RC}\int_0^1 1 \cdot dt$

$v_o = -\frac{1}{RC}(t)$



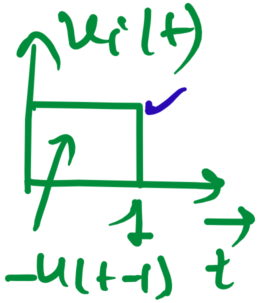
$\rightarrow \frac{1}{s} \rightarrow \int dt$

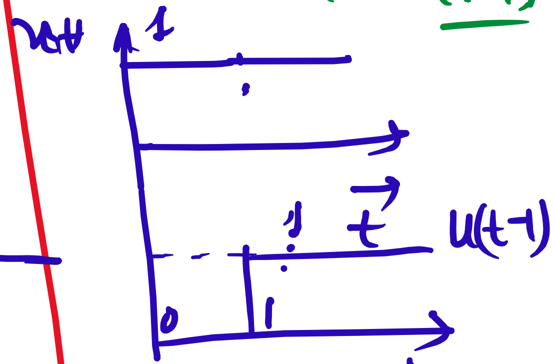
$\rightarrow s \rightarrow \frac{d}{dt}$

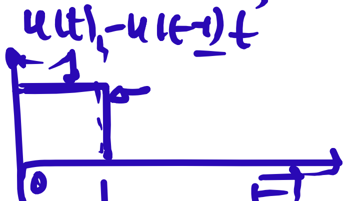
Q

$v_i = u(t) - u(t-1)$

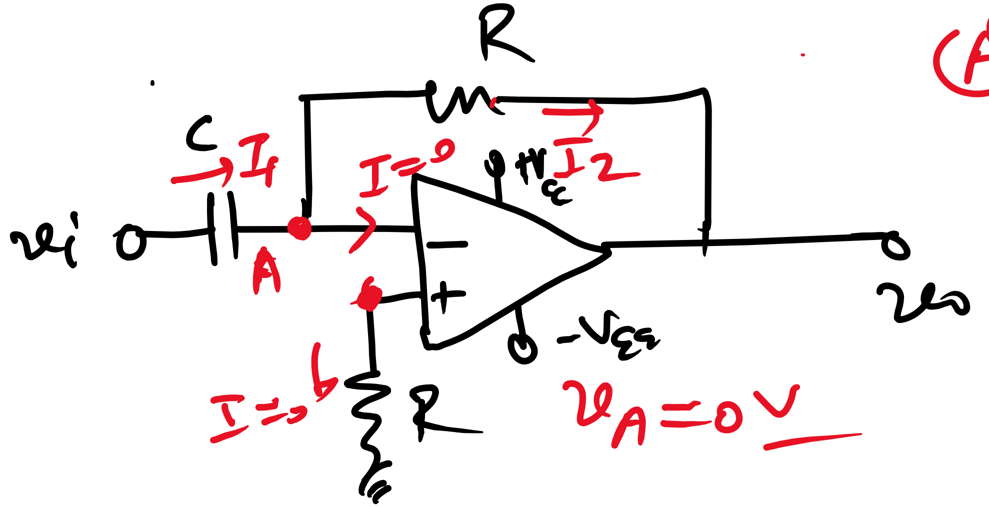
$v_o = ?$







Differentiator – (capacitor at down position)



(A) → $I_1 = I_2 \Rightarrow C\dfrac{d(v_i - 0)}{dt} = \dfrac{0 - v_o}{R}$

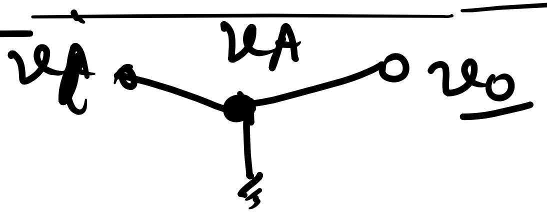
$$\Rightarrow \boxed{v_o = -RC\frac{dv_i}{dt}}$$

Q. $v_i = \sin t$, calculate v_o for a differentiator ckt.

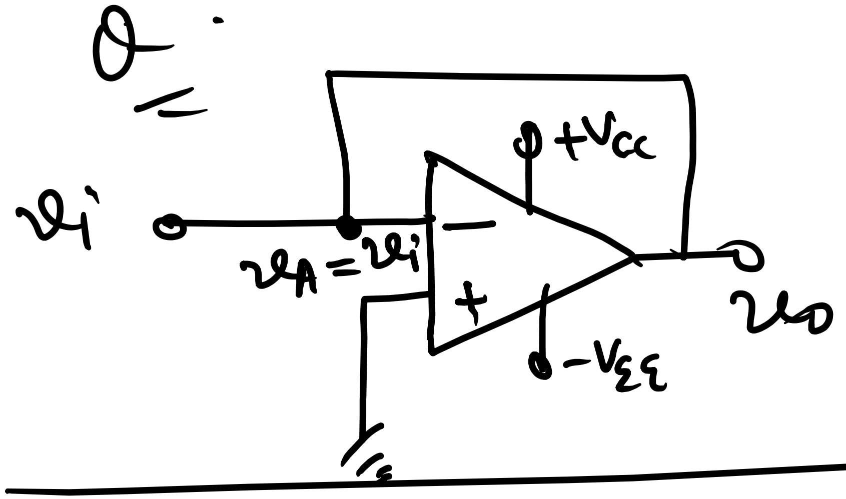
$$\boxed{v_o = -RC\cos t}$$

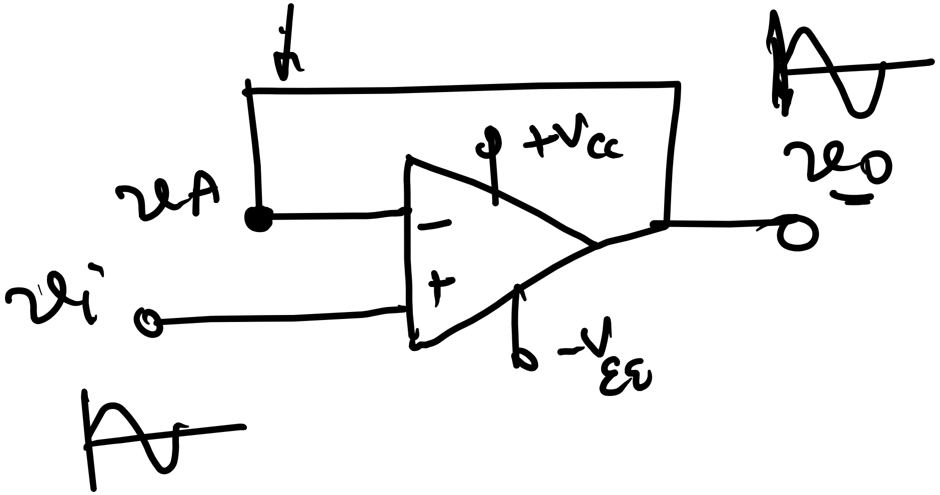
Q $v_i = u(t) - u(t-1) \Rightarrow v_o = ?$

Voltage follower -



$v_A = ?$





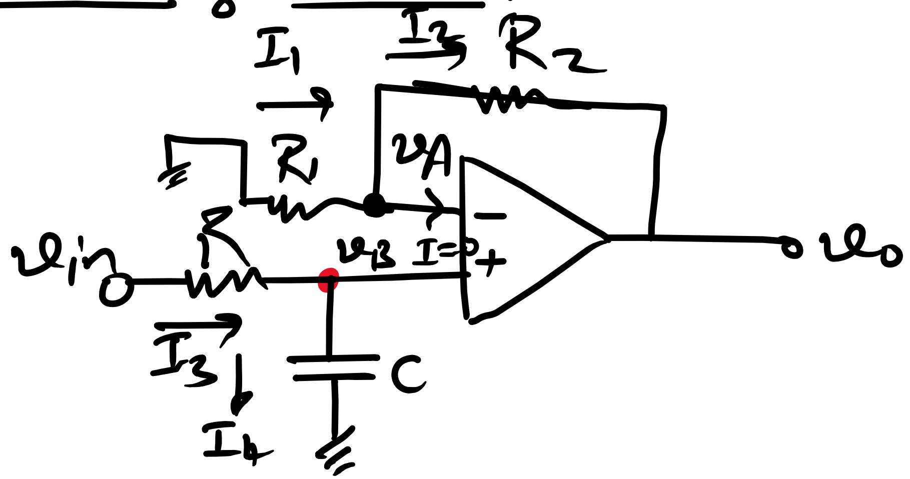
$v_A = v_i$

$\boxed{v_o = v_i}$ ← O/P voltage = I/P voltage

Voltage follower ckt

Active filters using OP-Amp -

1. LPF
2. HPF
3. BPF
4. BSF



At node (A) -

$$I_1 = I_2$$

$$\frac{0 - v_A}{R_1} = \frac{v_A - v_o}{R_2}$$

$$v_A = \frac{v_o}{R_2}\left(\frac{R_1 R_2}{R_1+R_2}\right) \quad -(1)$$

At node (B) -

$$I_3 = I_4$$

$$\frac{v_{in} - v_B}{(R)} = C\frac{d(v_B - 0)}{dt}$$

from - Virtual Short - $v_A = v_B$

$$\frac{v_{in}}{R} - \frac{v_o R_1}{R_1+R_2} = \frac{Cd}{dt}\left(\frac{v_o R_1}{R_1+R_2}\right)$$

take Laplace transform -

$$\frac{v_{in}}{R} - \frac{v_o R_1}{R(R_1+R_2)} = (s)C\,\frac{v_o R_1}{R_1+R_2}$$

$$\frac{v_{in}}{R} = \frac{v_o R_1}{R_1+R_2}\left(\frac{1}{R} + sC\right)$$

$$= \frac{v_o (R_1)}{(R_1+R_2)}\left(\frac{1+sRC}{R}\right)$$

If $R_1 \gg R_2 \Rightarrow$

$$\frac{v_{in}}{R} = v_o\left(\frac{1+sRC}{R}\right)$$

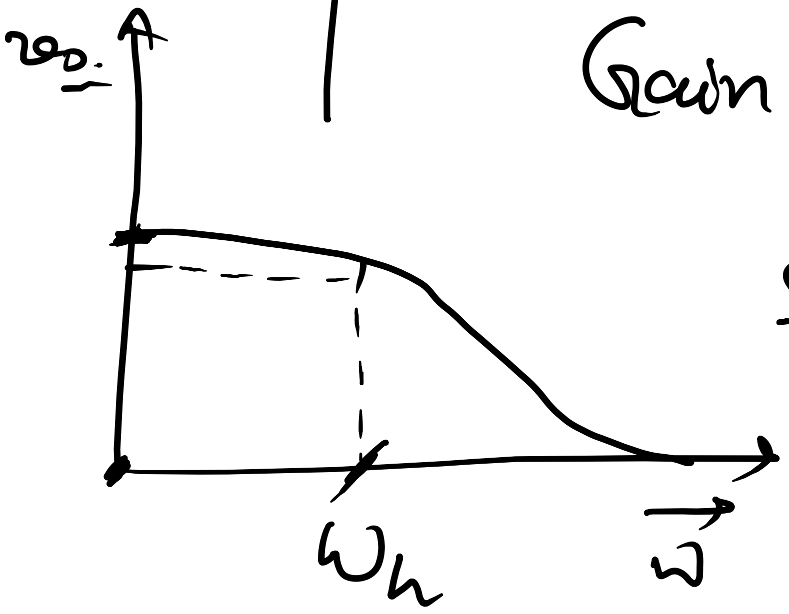
$$v_o = \frac{v_{in}}{1+sRC}$$

① for $s = j\omega = 0$

$v_o = v_{in}$

② for $s = j\omega = \infty$

$v_o = 0$



→ Transfer function -

$$\frac{v_o(s)}{v_{in}(s)} = \frac{1}{1+sRC}$$

$$\text{Gain} \Rightarrow \left|\frac{v_o(s)}{v_{in}(s)}\right| = \left|\frac{1}{1+sRC}\right|$$

$s = j\omega \rightarrow$

$$\text{Gain} = \left|\frac{1}{1+j\omega RC}\right|$$

$$\text{Gain} = \frac{1}{\sqrt{1+(\omega RC)^2}}$$

Phase -

$$Tf = \frac{1}{(1 + j\omega RC)}$$

$$\phi = \tan^{-1}(1) - \tan^{-1}\left(\frac{\omega RC}{1}\right)$$

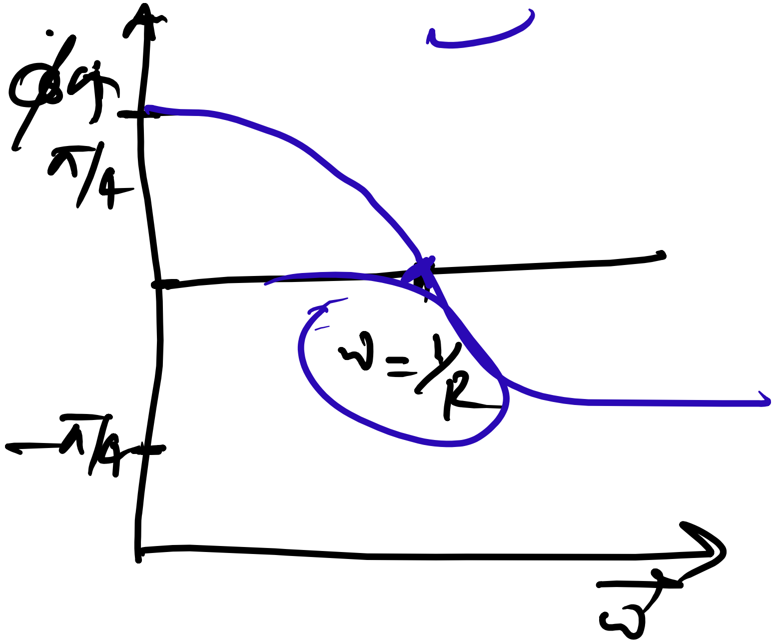
$$\phi = \frac{\pi}{4} - \tan^{-1}(\omega RC)$$

$$\phi = \frac{\pi}{4} - \tan^{-1}(\omega RC)$$

① $\omega = 0 \Rightarrow \phi = \pi/4$

② $\omega = 1/RC \Rightarrow \phi = \frac{\pi}{4} - \frac{\pi}{4} = 0$

③ $\omega = \infty \Rightarrow \phi = \frac{\pi}{4} - \pi/2 = -\frac{\pi}{4}$



magnitude - Gain = $\frac{1}{\sqrt{1+(\omega RC)^2}}$ —① 3dB (L)

Phase - $\phi = \frac{\pi}{4} - \tan^{-1}(\omega RC)$ —②

Gain -

① $\omega = 0 \Rightarrow$ Gain $= 1$

② $\omega = 1/RC \Rightarrow$ Gain $= 1/\sqrt{2}$

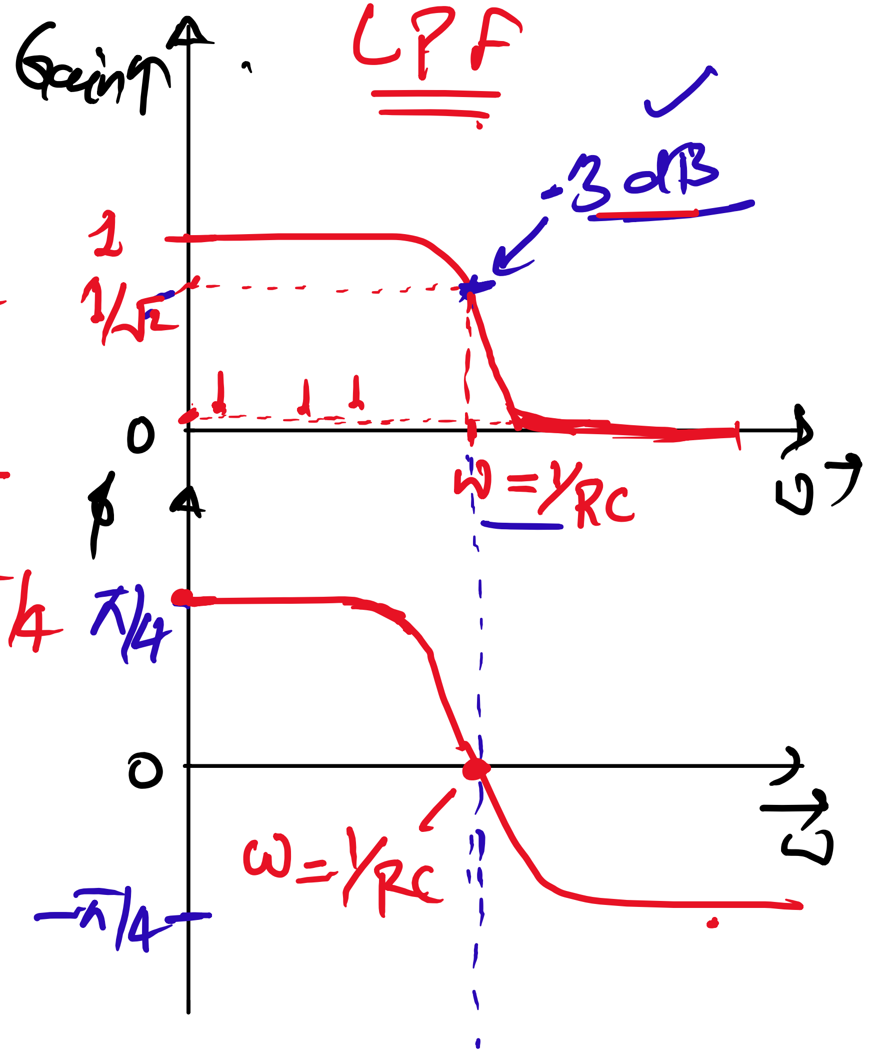
③ $\omega = \infty \Rightarrow$ Gain $= 0$

Phase -

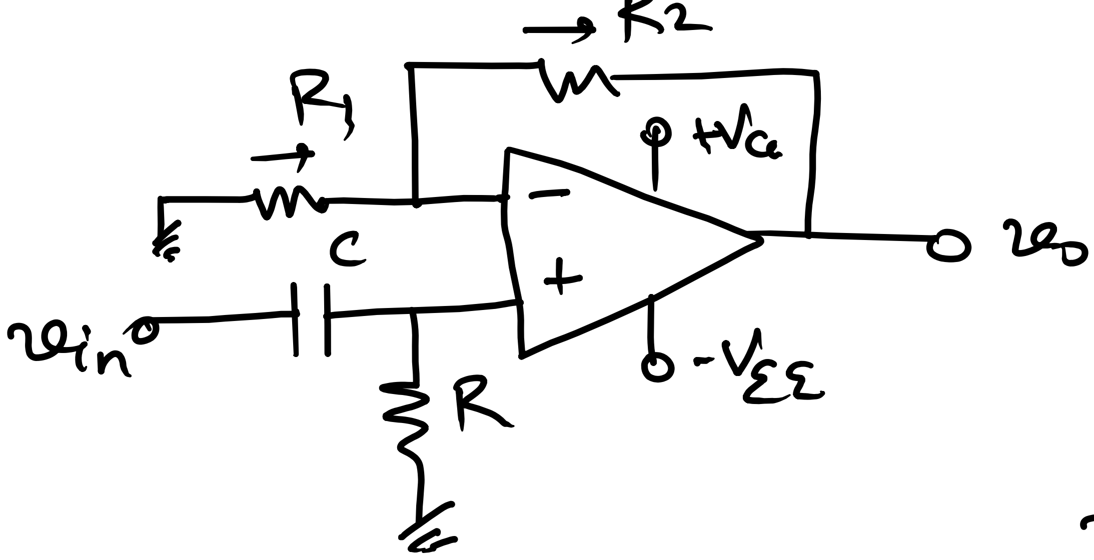
① $\omega = 0 \Rightarrow \phi = \pi/4$

② $\omega = \frac{1}{RC} \Rightarrow \phi = 0$

③ $\omega = \infty \Rightarrow \phi = -\pi/4$



High Pass Filter



Find ① Transfer function

$$TF = \frac{v_o(s)}{v_i(s)}$$

② Gain = |TF| = mag|TF|

③ Phase → ϕ ⇒

Draw the plot for Gain & Phase.