Module- 3

Operational Amplifier & Applications.

Model Questions.

① Explain the following w.r.t. Opamp.
(i) I/P Impedance
(ii) O/P Impedance
(iii) Slew rate
(iv) CMRR
(v) Virtual ground.
(vi) Offset voltage & current
(vii) Input bias
(viii) Common mode gain A_c of Opamp

② List the characteristics of ideal & practical opamp

③ Explain the block diagram of Operational Amplifier

④ Explain the different i/p modes of an Opamp

⑤ Explain the operation of Opamp as non-inverting amplifier with neat diagram & waveforms. Hence derive the expression for gain.

⑥ Derive the expression for o/p voltage & gain of a inverting amplifier.

7. Derive the expression for o/p voltage of an opamp integrator.

8. Derive the expression for o/p vtg of Opamp differentiator.

9. Explain Opamp as subtractor with neat circuit diagram

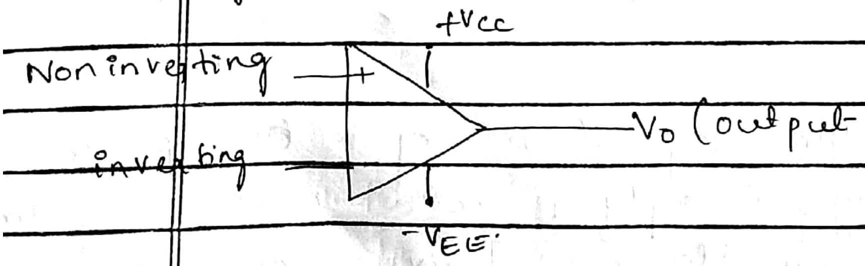
10. Explain Opamp as Voltage follower.

11. Draw 3 i/p inverting amplifier and derive an expression for o/p voltage.

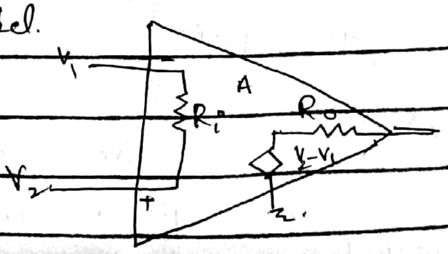
I Operational Amplifier.

- It is a high gain direct coupled differential amplifier which is used to amplify both ac and dc signals.
- It is used to perform mathematical functions such as addition, substraction, ~~Integration~~ Integration, differentiation etc. Hence the name.
- Most Commonly used Opamp is μA741

Symbol.



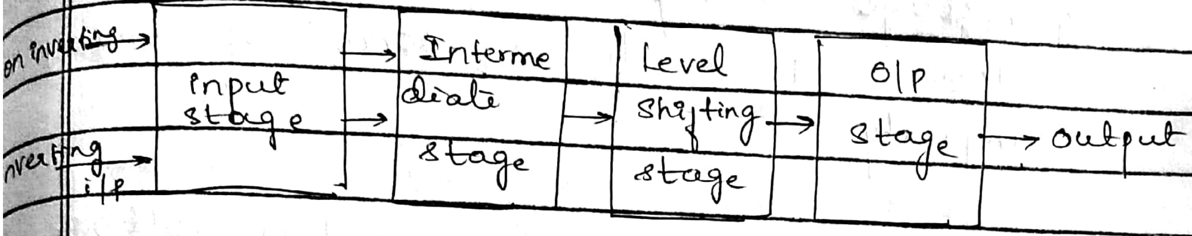
Equivalent circuit Model.



It has gain A, i/p resistance Ri, o/p resistance Ro,

An ideal ~~Op~~ Opamp has Rin = ∞, ~~Av~~ Ro = 0

Block diagram of Opamp



Input stage :- It is a dual i/p balanced o/p differential Amplifier. This stage provids most of the voltage gain & establishes i/p resistance of Opamp.

Intermediate stage :- It is one more differential amplifier which is driven by o/p of first stage. It is usually dual i/p and unbalanced o/p amplifier.

Level Shifting stage :- Because of direct Coupling, dc voltage level at o/p of intermediate stage is well above ground potential. ∴ Level shifter is used to shoft dc level at o/p to zero w.r.t. ground.

O/p stage :- It has push pull Amplifier. The o/p stage increases o/p voltage swing & raise current supplying capability of opamp. It also provides low o/p resistance

Op amp parameters.

⊛ Characteristics of ideal Opamp.

1. Infinite Input Impedance :- The ideal Opamp does not draw any current from voltage source connected to i/p terminals. This implies i/p impedance of Opamp is infinity.

2. Zero Output Impedance :- The voltage at o/p terminal is independant of current drawn from it. In other words o/p impedance is zero

3. Infinite Bandwidth :- This implies that amplifier can amplify any frequency from zero to infinity without attenuation. In other words, ideal Opamp will amplify signals of any frequency with equal gain

4. Infinite Voltage gain :- Open loop voltage gain of ideal Opamp is infinite.

5. Zero offset Voltage :- The o/p voltage is zero when equal voltages are present at two i/p terminals.

6. Infinite Common Mode Rejection Ratio :- The measure of an amplifier's ability to reject common mode signals

is called CMRR.

CMRR = ∞ for ideal Opamp

7. Infinite Slew rate:-

$$CMRR = \frac{A_{OL}}{A_{CM}}$$

In decibles,

$$CMRR = 20 \log\left(\frac{A_{OL}}{A_{CM}}\right)$$

8) Infinite Slew Rate: The maximum rate of change of o/p voltage in response to a step i/p is the slew rate of Opamp.

SR = ∞

9) Characteristics of opamp does not drift with temprature.

10. Zero noise contribution

Characteristics of Practical Opamp.

μA 741 is normally used as practical Opamp.

1. Finite input impedance (500kΩ - 2MΩ)
2. O/p impedance is very low (20-100Ω)
3. Finite Voltage gain (20 - 200)
4. Non zero offset Voltage

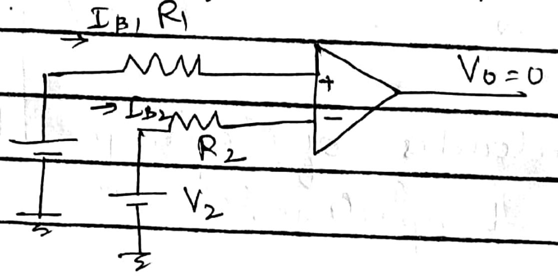
(*) Has Noise Contribution

(v) Limited Bandwidth

(*) Finite CMRR & Slew rate.

Definitions

1. **Input Offset Voltage**:- It is the voltag that must be applied b/w two i/p terminals of an opamp to null the o/p.



2 **Input Offset current** :- It is the differen b/w currents in to the input terminals of balance amplifier

$$I_{io} = |I_{B1} - I_{B2}|$$

3. **Input Bias Current**: It is the average of current entering the input terminal of Balanced amplifier $I_B = \left|\frac{I_{B1} + I_{B2}}{2}\right|$

4 Common mode rejection Ratio (CMRR)

It is defined as the ratio of Common Mode gain ~~to the~~ differential gain to Common mode gain

$$CMRR = \left|\frac{A_d}{A_c}\right|$$

In decibels $CMRR = 20 \log \left|\frac{A_d}{A_c}\right|$

5. PSRR (Power Supply rejection Ratio).
It is the ratio of change in i/p offset vtg to change in supply vtg producing it, keeping other power supply const.

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{cc}} \Bigg|_{V_{ee}\ \text{const.}}$$

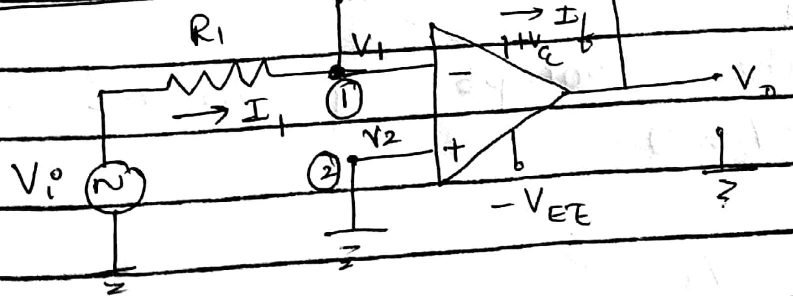
6. **Slew rate :-** It is defined as the maximum rate of change of o/p voltage per unit time

$$S.R = \frac{\Delta V_o}{\Delta t} \Big|\ V/\mu s$$

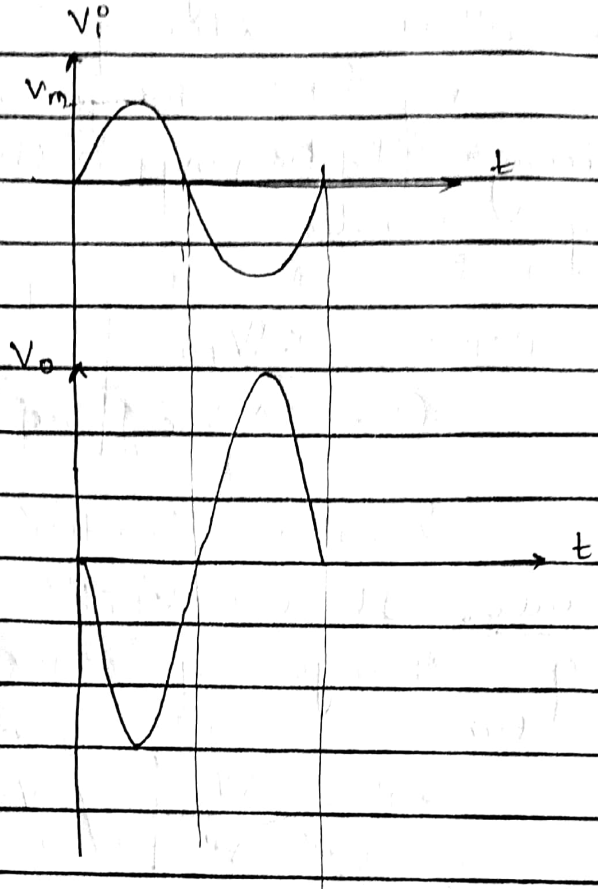
Applications

1. **Inverting Amplifier :-** An opamp circuit whose o/p voltage is out of phase (180°) w.r.t i/p voltage is called inverting Amplifier.

Circuit



Waveforms



Applying KCL at node 1

$$I_1 = I_f \quad \text{—} ①$$

Since i/p impedance of o/p is very high, no current enters the opamp

$$I_1 = \frac{V_i - V_1}{R_1} \text{—}②, \quad I_f = \frac{V_1 - V_o}{R_f} \text{—}③ \text{ (from ohm's law)}$$

From the concept of Virtual ground
$V_1 = V_2 = 0$

$$\therefore I_1 = \frac{V_i}{R_1}, \quad I_f = \frac{-V_o}{R_f}$$

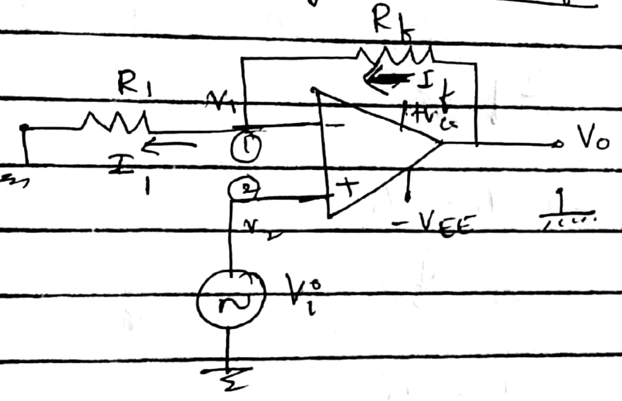
Substituting I_1 & I_f in ①

$$\frac{V_i}{R_1} = -\frac{V_o}{R_f}$$

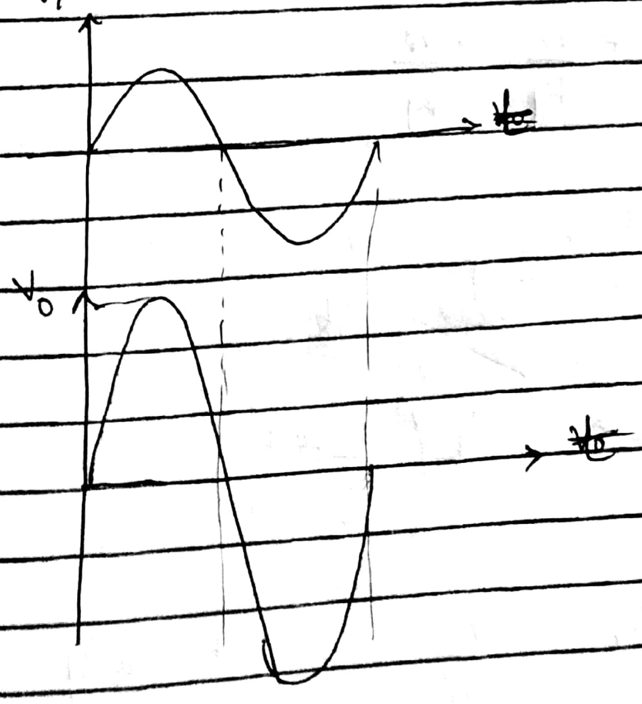
ltage
ain $\boxed{A_v = \left(\frac{V_o}{V_1}\right) = -\frac{R_f}{R_1}}$

/p voltage, $\boxed{V_o = -V_1\left(\frac{R_f}{R_1}\right)}$

II Non-inverting Amplifier.



Waveforms



The Opamp circuit in which o/p Voltage is inphase with the i/p voltage and is amplified is called Non-inverting amplifier.

Applying KCL at node 1

$$I_1 = I_f \quad \text{——} \quad ①$$

From Virtual ground

$$V_1 = V_2 = V_i$$

$$I_1 = I_f$$

$$= \frac{V_i}{R_1} = \frac{V_o - V_1}{R_f}$$

$$\Rightarrow \frac{V_i}{R_1} = \frac{V_o - V_i}{R_f}$$

$$\frac{V_i}{R_1} = \frac{V_o}{R_f} - \frac{V_i}{R_f}$$

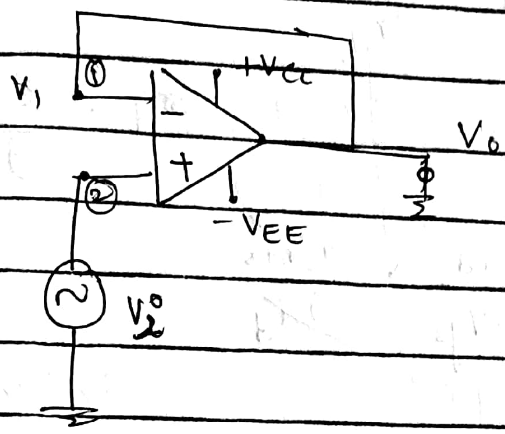
$$V_i\left(\frac{1}{R_1} + \frac{1}{R_f}\right) = \frac{V_o}{R_f}$$

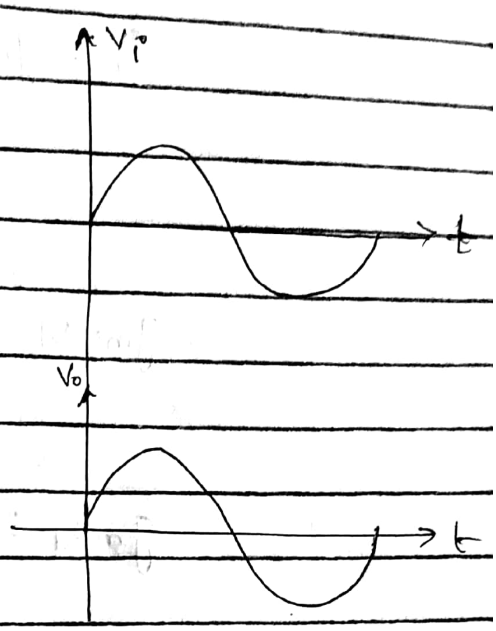
$$\Rightarrow \frac{V_o}{V_i} = R_f\left(\frac{1}{R_f} + \frac{1}{R_1}\right)$$

Gain $\boxed{A_v = \frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_1}\right)}$

$$\boxed{\text{O/P V/g} \quad V_o = V_i\left(1 + \frac{R_f}{R_1}\right)}$$

III Voltage follower





Opamp circuit in which o/p follows the input Voltage is called voltage follower.

$V_1 = V_2 = V_i$ (from virtual ground)

Applications

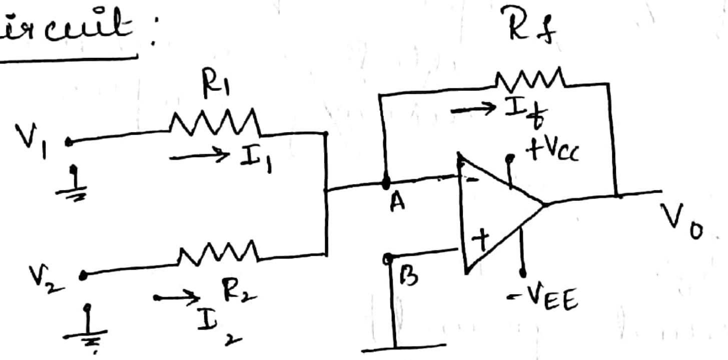
1- It is used as Isolator circuit for impedance Matching.

Opamp as Adder / summer.

i) Inverting Summer

In this circuit, all the i/p signals to be added are applied to inverting input terminal of opamp.

circuit:



As point B is ground potential, due to virtual ground concept at node A is also at virtual ground potential

i e $V_A = V_B = 0$

From i/p side,

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

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

Applying KCL at node A

$$I_1 + I_2 = I_f$$

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

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

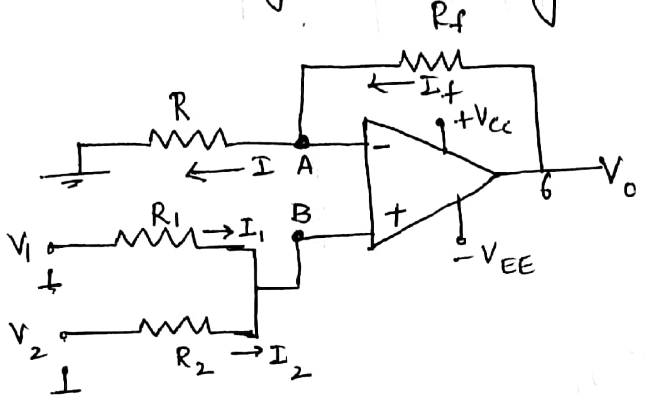
$$\boxed{V_0 = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)}$$

If $R_1 = R_2 = R_f$

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

Thus the magnitude of o/p vlg is sum of i/p vlg and hence circuit is called as summer.

ii) Non-inverting Summing Amplifier



→ summer that gives non inverted sum of input signals is called non-inverting summing amplifier.

Let vlg at node B is V_B.

$V_A = V_B = 0$ (Virtual ground]

$I_1 = \frac{V_1 - V_B}{R_1}$, $I_2 = \frac{V_2 - V_B}{R_2}$, $I_f = \frac{V_0 - V_A}{R_f}$.

At node B,

~~$V_1 + V_2$~~ $I_1 + I_2 = 0$ ——— ①

$$\Rightarrow \cancel{\frac{V_1 - \cancel{V_B}}{R_1}} + \frac{V_2 - \cancel{V_B}}{R_2} = 0$$

$$\frac{V_1}{R_1} + \cancel{\frac{V_2}{R_2}} = 0$$

$$\frac{V_1 - V_B}{R_1} + \frac{V_2 - V_B}{R_2} = 0 \text{ ——— ②}$$

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

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = V_B\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \text{ ——— ③}$$

At node A,

$$I = I_f$$

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

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

$$V_A = V_B$$

$$\Rightarrow \frac{V_B}{R} = \frac{V_0}{R_f} - \frac{V_B}{R_f} \quad \text{———} \quad ④$$

From eqⁿ ③

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

④ becomes

$$\frac{\frac{V_1 R_2 + V_2 R_1}{R_2 + R_1}}{R} = \frac{V_0}{R_f} - \frac{1}{R_f}\left(\frac{V_1 R_2 + V_2 R_1}{R_2 + R_1}\right)$$

$$= \frac{1}{\cancel{}}$$

$$V_0 = R_f\left(\frac{\frac{V_1 R_2 + V_2 R_1}{R(R_2 + R_1)}}{\cancel{R}}\right) + \frac{1}{R_f}\left(\frac{V_1 R_2 + V_2 R_1}{R_2 + R_1}\right)$$

If $R_1 = R_2 = R_f = R$

$$\Rightarrow V_0 = \cancel{R_f}\left(\frac{V_1 R + V_2 R}{\cancel{R}(R_2 + R_1)}\right) + \frac{1}{R}\left(\frac{V_1 R + V_2 R}{R + R}\right)$$

$$V_0 = \frac{\cancel{R}}{2\cancel{R}}(V_1 + V_2) + \frac{\cancel{R}}{2\cancel{R}}(V_1 + V_2)$$

$$V_0 = \frac{1}{2}(V_1 + V_2) + \frac{1}{2}(V_1 + V_2)$$

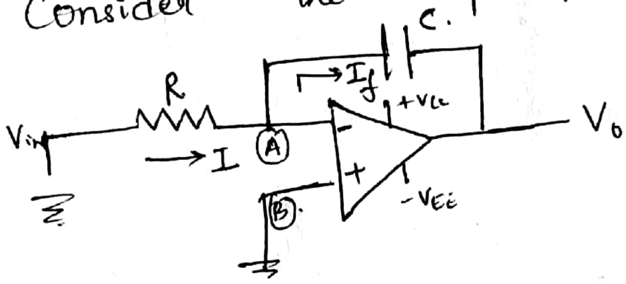
$$\boxed{V_0 = V_1 + V_2}$$

As there is no phase difference b/w i/p & o/p. It is called non-inverting summer.

Integrator using Opamp

In an integrator circuit, o/p voltage is the integration of i/p voltage.

Consider the opamp integrator ckt as shown.



From fig,

node B is grounded. ∴ Node A is also at ground from the concept of virtual ground.

∴ $V_A = V_B = 0$.

As i/p current is zero, entire current flowing through R flows through capacitor C.

From i/p side

$\Rightarrow I = I_f$

$$\Rightarrow \frac{V_i - V_A}{R} = C\frac{d}{dt}(V_A - V_o)$$

$$= \frac{V_i}{R} = C\frac{d}{dt}(-V_o)$$

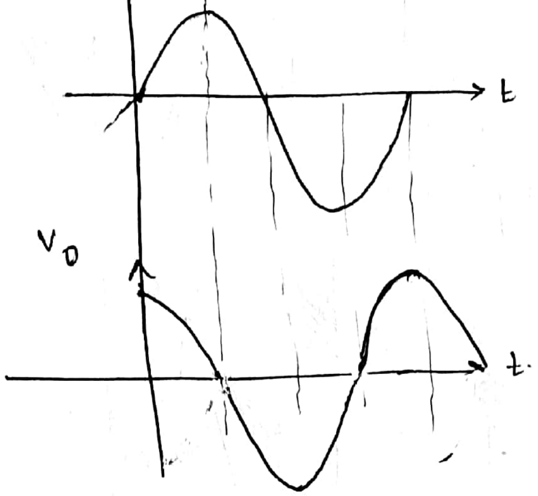
$$= \frac{V_i}{R} = -C\frac{dV_o}{dt}$$

$$= \frac{-V_i}{RC} = \frac{dV_o}{dt}$$

$$\boxed{V_o = \frac{-1}{RC}\int V_i \cdot dt.} \quad \text{—} ④$$

Above equation shows o/p is $\frac{-1}{RC}$ times of i/p V_i.

& RC is called time constant of integrator.



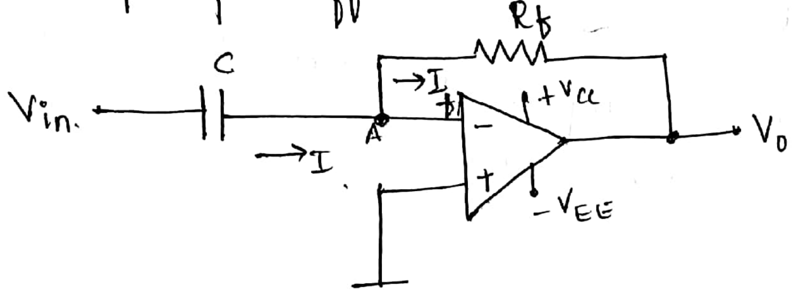
i/p → Sine wave

o/p → coswave.

Differentiator using Opamp.

The circuit which produces differentiation of i/p voltage at its o/p is called differentiator.

Opamp differentiator circuit is as shown.



The node B is grounded ∴ Node A is also at the ground potential. ∴ $V_A = 0$.

KCL at A, $I = I_f$

$$\downarrow$$

$$C\frac{d}{dt}(V_{in}-\cancel{V_A}) = \frac{\cancel{V_A}-V_0}{R_f}.$$

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

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

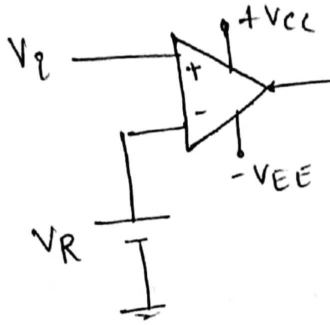
The eq^n shows o/p is CR_f times differentiation of i/p

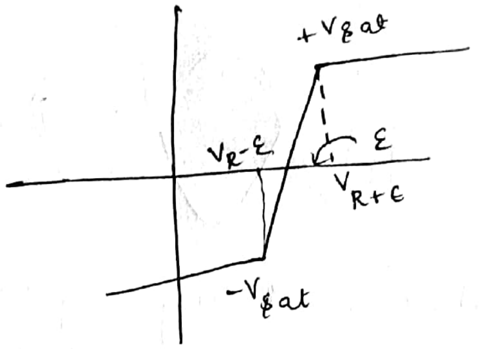
CR_f is called time constant of differentiator.

'−ve' sign indicates that there is a phase shift of 180° b/w i/p & o/p.

Operational Amplifier as Comparator

The saturation characteristics of an opamp in an openloop is made use of determining if a signal is more or less than certain reference (V_R)





I/o characteristics

If $V_i > V_R$, $V_o = +V_{sat}$

$V_i < V_R$, $V_o = -V_{sat}$.

→ When V_i is sine wave, comparator can be used for sine to square wave conversion or sine to rectangular conversion.