UNIT-IV

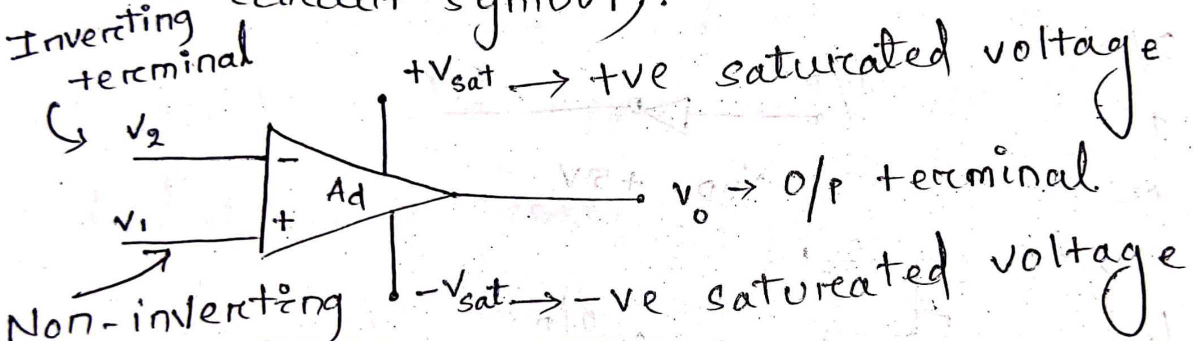
Op-Amp - Operational Amplifier :-

→ Op-Amp is a high gain differential amplifier with very high i/p impedance & very low o/p impedance and used for mathematical operations like addition, substraction, multiplication, differentiation, integration, exponential oper^n, log oper^n etc.

11/11/19

Schematic diagram of op-amp :-

(Circuit symbol):-

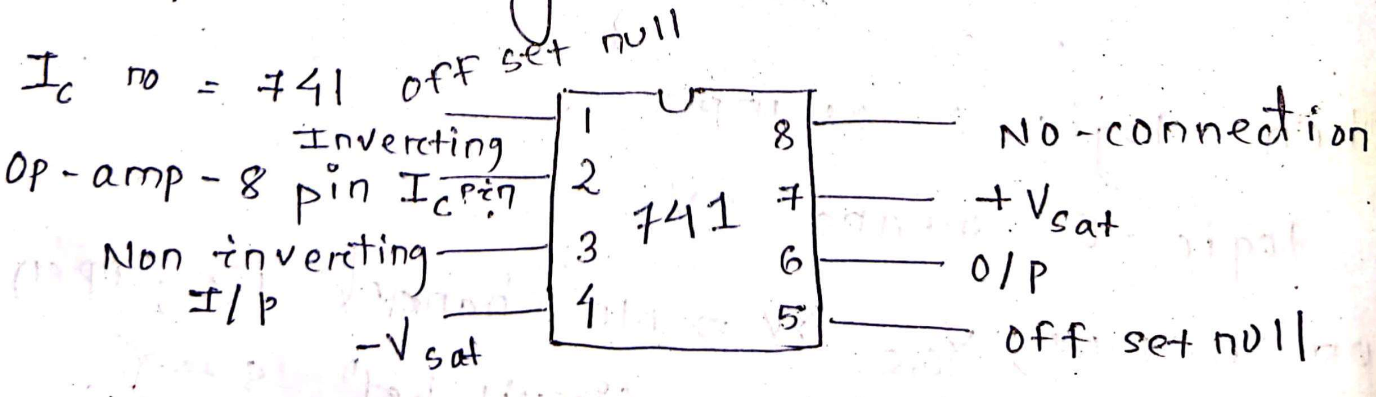


$$\boxed{V_D = A_d (V_1 - V_2)}$$

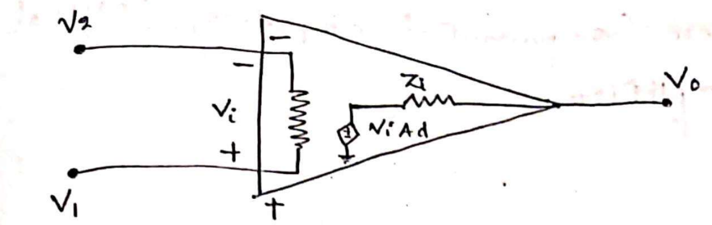
PIN / Ic configuration of OP-amp :-

Ic no = 741

Op-amp - 8 pin Ic pin



Internal st^re of op-Amp :-



Characteristics of ideal op-Amp :-

→ I/P impedance is very high ; $Z_i = \infty$

→ O/P impedance is very small , $Z_i = 0$.

→ voltage gain = very high ;

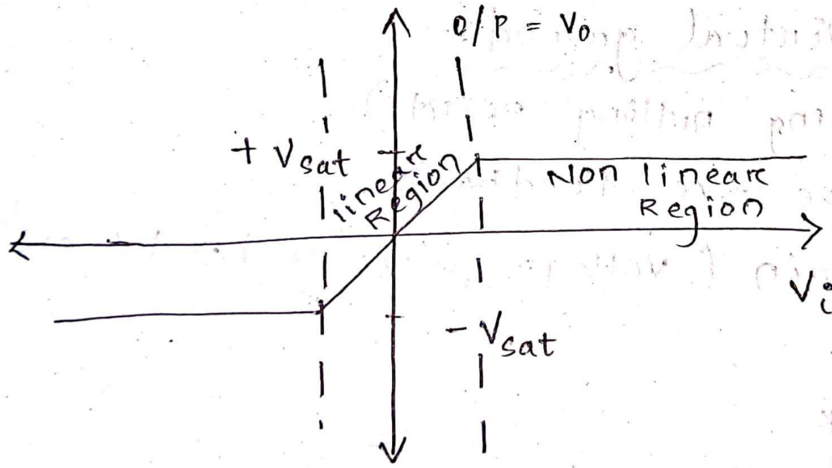
$$A_d = \infty$$

→ there is no offset voltage.

→ Very high CMRR ; CMRR $= \infty$
(common mode rejection ratio)

→ Very slow slew rate , slew rate = 0 .

Transfer characteristics :-



App. of op-Amp in linear region :-

→ Inverting amplifier

→ Non-inverting amplifier

→ Summing amplifier (Adder)

→ Subtracter

→ Buffer (voltage "follower")
→ Log amplifier
→ Antilog amplifier (exponential amplifier) } optional
→ Differential amplifier.
→ Differentiate
→ Integrator

Virtual Ground :-

13/11/2019

→ Earth surface is equipotential surface, so, the potential diff. betⁿ 2 points on the earth's surface is always 0.

→ Ground is also equipotential surface in which each point is having 0V potential.
So P.V betⁿ two points on ground is 0V.

→ Current into the ground is maxᵐ. (I_{max})

→ In case of virtual ground, P.V is 0 and current into the virtual ground is 0A.

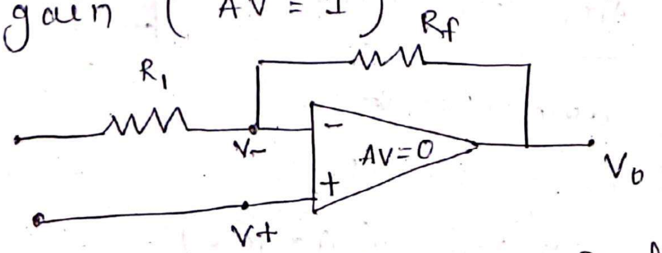
Condⁿ for virtual ground :-

(Establishing nulling point)

→ There must be -ve feedback.
→ Very high gain (voltage gain = ∞) ⇒ $AV = \infty$.

or

→ +ve feedback
→ Unit gain ($AV = 1$)



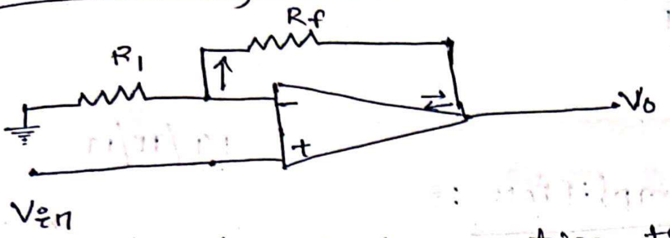
In case of OP-AMP, with -ve feedback and high gain, that exist virtual ground, betⁿ inverting & non-verting terminal.

→ In the above fig, $V_+ = V_-$ where,

$V_+ \rightarrow$ Potential at non-inverting terminal.

$V_- \rightarrow$ Potential at inverting terminal.

Non-inverting amplifier :-



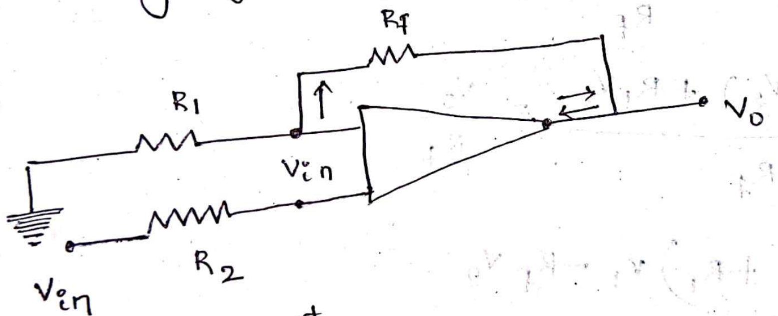
Applying nodal eqⁿ at Inverting terminal :-

$$\frac{V_{in} - 0}{R_1} + \frac{V_{in} - V_0}{R_f} + 0$$

$$\boxed{V_0 = \left(1 + \frac{R_f}{R_1}\right) V_{in}}$$

$$\frac{V_0}{V_{in}} = \text{Voltage gain} = \left(1 + \frac{R_f}{R_1}\right)$$

Q:-

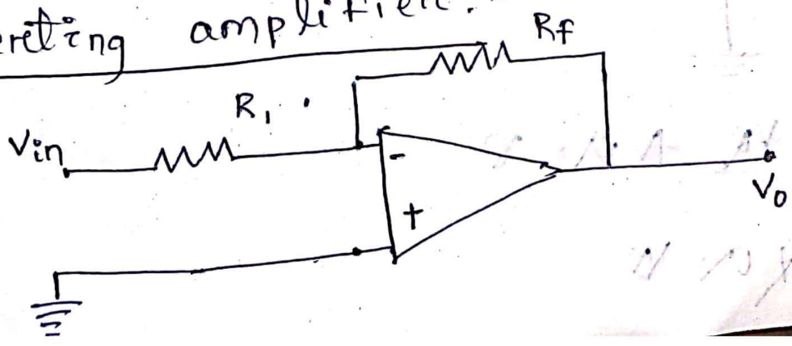


Calculate the output.

$$\frac{V_{in} - 0}{R_1} + \cancel{\frac{V_{in} - 0}{R_2}} + \frac{V_{in} - V_0}{R_f} + 0 = 0$$

$$V_0 = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

Inverting amplifier :-



$$\cancel{\frac{0-V_{in}}{R_1} + \frac{V_{in}-V_i}{R_f} + 0 = 0}$$

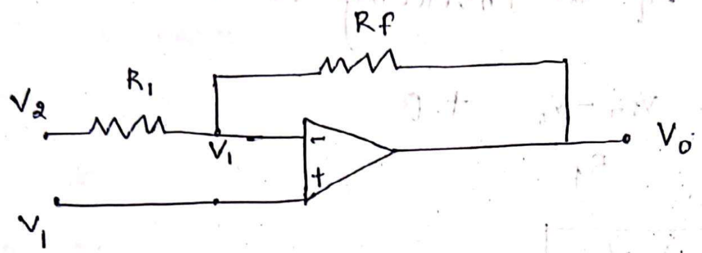
$$\cancel{V_o = \left(1 + \frac{R_1}{R_f}\right) V_{in}}$$

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

$$V_0 = -\frac{R_f}{R_1}$$

14/11/19

Differential Amplifier :-



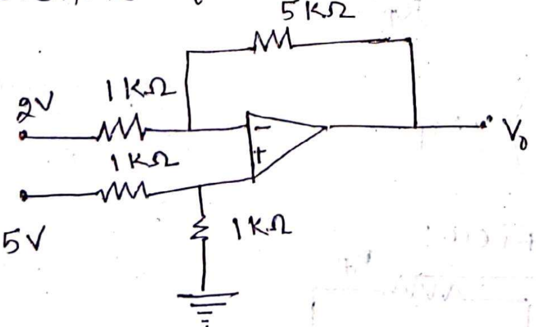
Applying nodal at inverting terminal

$$\frac{V_1-V_2}{R_1} + \frac{V_1-V_0}{R_f} + 0 = 0$$

$$\Rightarrow \frac{R_f(V_1-V_2) + R_1 V_1}{R_1 R_f} = \frac{V_0}{R_f}$$

$$\Rightarrow V_0 = \frac{(R_f+R_1)V_1 - R_f V_2}{R_1}$$

Q:- Determine V_0 for the following circuit.



$$\cancel{\frac{5-2}{1} + \frac{5-V_0}{5} + 0 = 0}$$

$$\cancel{\Rightarrow 3 + \left(1 - \frac{V_0}{5}\right) + 0 = 0}$$

$$V_+ = \frac{5 \times 1K\Omega}{1K + 1K\Omega} = \frac{5}{2} V = 2.5 V$$

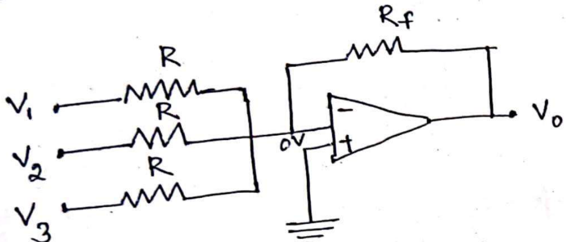
$$V_- = \frac{5}{2} V = 2.5 V$$

Applying nodal at inverting terminal,

$$\frac{2.5 - 2}{1K\Omega} + \frac{2.5 - V_0}{5K\Omega} + 0 = 0$$

$$\Rightarrow \boxed{V_0 = 5V}$$

Summing Amplifier :- (Adder)



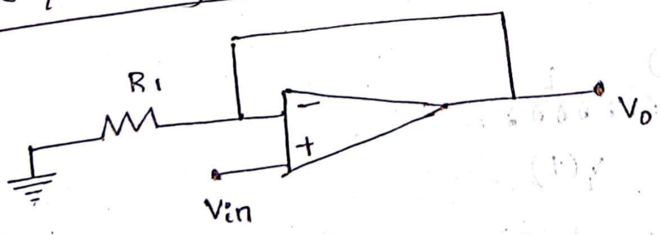
Apply nodal at inverting terminal,

$$\frac{0 - V_0}{R_f} + \frac{0 - V_1}{R} + \frac{0 - V_2}{R} + \frac{0 - V_3}{R} + 0 = 0$$

$$\Rightarrow \frac{0 - V_0}{R_f} + \left(\frac{-1}{R}\right)(V_1 + V_2 + V_3) = 0$$

$$\Rightarrow \boxed{V_0 = \frac{-R_f}{R}(V_1 + V_2 + V_3)}$$

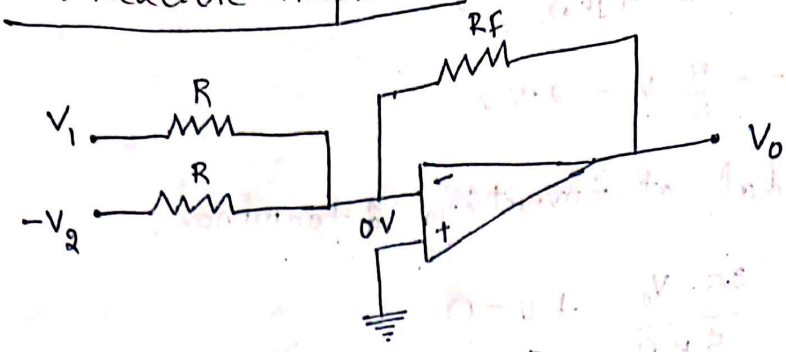
Buffer / voltage follower:-



$V_0 = V_{in}$

gain = AV = 1

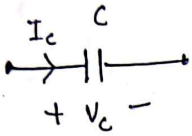
Subtractor Amplifier :-



$$\frac{0-V_0}{R_f} + \frac{0-V_1}{R} + \frac{0+V_2}{R} = 0$$

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

Note-1



$$\boxed{I_c = C\frac{dV}{dt}}$$

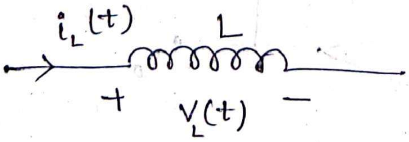
$$\Rightarrow C\frac{dV}{dt} = i_C$$

$$\Rightarrow \frac{dV_c}{dt} = \frac{1}{C} t_c$$

$$\Rightarrow \int dV_c = \frac{1}{C}\int i_c\,dt$$

$$\Rightarrow \boxed{V_c(t) = \frac{1}{C}\int_{-\infty}^{t} i_c(t)\,dt}$$

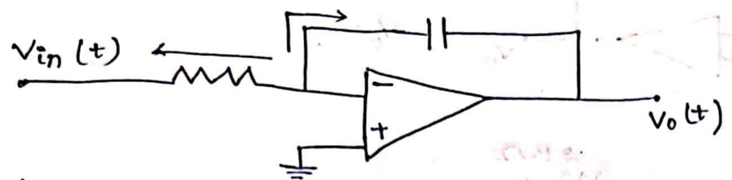
Note-2 Inductor (L)



$$V_L(t) = L\frac{di(t)}{dt}$$

$$\boxed{i_L(t) = \frac{1}{L}\int_{-\infty}^{t} V_L(t)\,dt}$$

Integrator :-



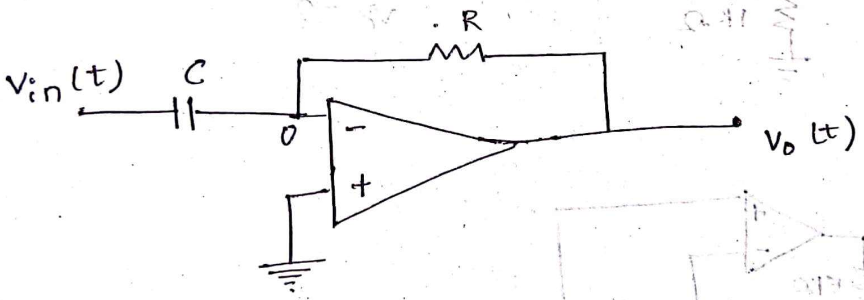
Applying nodal at inverting terminal,

$$\frac{0 - V_{in}(t)}{R} + C\frac{d}{dt}(0 - V_o(t)) + 0 = 0$$

$$\Rightarrow -C\frac{dV_o(t)}{dt} = \frac{V_{in}(t)}{R}$$

$$\Rightarrow \frac{dV_o(t)}{dt} = \frac{-1}{RC}V_{in}(t)$$

$$\Rightarrow \boxed{V_o(t) = -\frac{1}{RC}\int_{-\infty}^{t} V_{in}(t)\,dt}$$

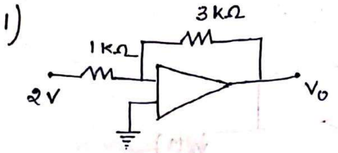


$$C\frac{d}{dt}(0 - V_{in}(t)) + \frac{0 - V_o(t)}{R} + 0 = 0.$$

$$\Rightarrow \boxed{V_o(t) = -RC\frac{d}{dt}V_{in}(t)}$$

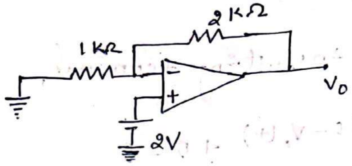
18/11/19

Q:- 1)



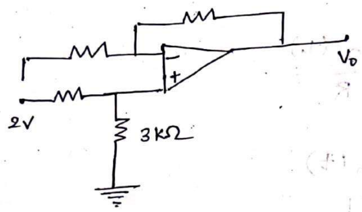
$V_o = ?$

Q:- 2)

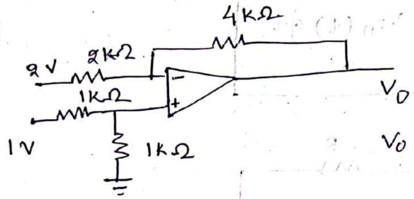


$V_o = ?$

Q:- 3)

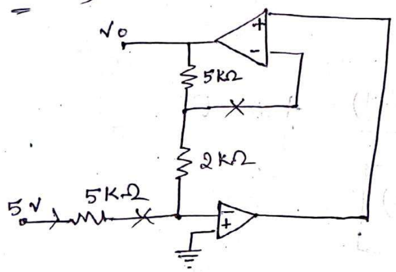


Q:- 4)

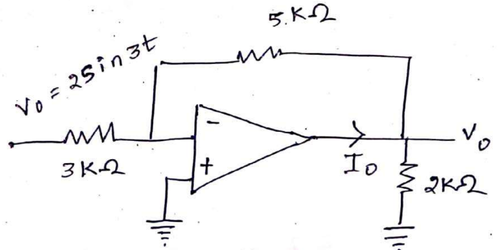


$V_o = ?$

Q:- 5)



Q:- 6)



$V_o = ?$ $I_o = ?$

1) Applying nodal at inverting terminal,

$$\frac{0-V_0}{R_f} + \frac{0-V_1}{R} + 0 = 0$$

$$\Rightarrow V_0 = \frac{-R_f}{R_1}(V_1 - V_2)$$

$$\Rightarrow V_0 = \frac{-3}{1}(2-0)$$

$$\Rightarrow \boxed{V_0 = -6\ V}$$

4) Applying nodal at inverting terminal,

$$\cancel{V_+ = \frac{1\times 2}{2+1} = \frac{8}{3} = 2.6}$$

$$V_- = \frac{1}{2}V = 0.5\ V$$

$$\frac{0.5-2}{2} + \frac{0.5-V_0}{4} = 0 \Rightarrow \frac{-3+0.5-V_0}{4} = 0$$

$$\Rightarrow -2.5 - V_0 = 0 \Rightarrow \boxed{V_0 = -2.5\ V}$$

2) $$\frac{2-0}{1K} + \frac{2-V_0}{2K} + 0 = 0$$

$$\Rightarrow V_0 = \left(1+\frac{2}{1}\right)\times 2 = 3\times 2 = 6\ V$$

$$\Rightarrow \boxed{V_0 = 6\ V}$$

3) $$V_+ = \frac{2\times 3K}{3K+3K} = 1\ V$$

$$\frac{1-0}{6K} + \frac{1-V_0}{6K} + 0 = 0$$

$$\Rightarrow \boxed{V_0 = 2V}$$

5) Here ; $$\frac{0-5}{5K} + \frac{0-V_0}{7K} + 0 = 0$$

$$\Rightarrow \frac{-35-5V_0}{35} = 0 \Rightarrow -35-5V_0 = 0 \Rightarrow 5V_0 = -35$$

$$\Rightarrow \boxed{V_0 = -7V}$$

6) $\dfrac{0 - V_{in}}{3K} + \dfrac{0 - V_0}{5K} + 0 = 0$

$\Rightarrow V_0 = \dfrac{-5}{3} V_{in}$

$= \dfrac{-10}{3} \sin 3t \ V$

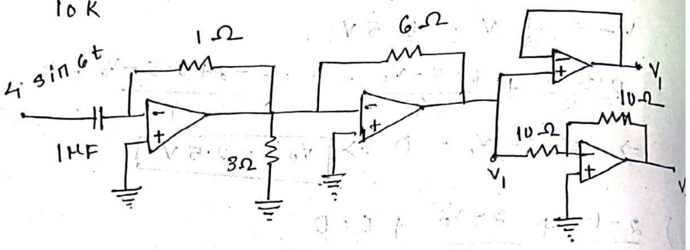
Applying KVL ;

$-I_0 + \dfrac{V_0 - 0}{5K} + \dfrac{V_0 - 0}{2K} = 0$

$\Rightarrow \dfrac{V_0}{5K} + \dfrac{V_0}{2K} = I_0$

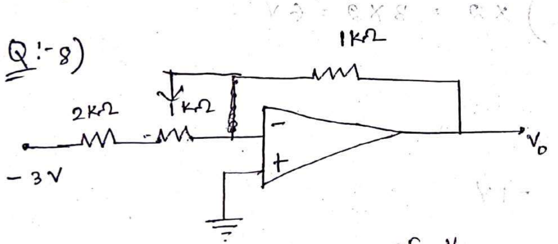
$\Rightarrow I_0 = \dfrac{7V_0}{10K} = \dfrac{-7}{3} \sin 3t \ mA.$

Q:- 7)



Find relationship betn V_1 & V_2.

Q:- 8)



Find the range of V_0.

Ans:-

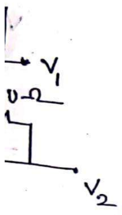
7) $\dfrac{0 - V_2}{10} + \dfrac{0 - V_1}{10} = 0$

$\Rightarrow \dfrac{-V_2}{10} = \dfrac{V_1}{10}$

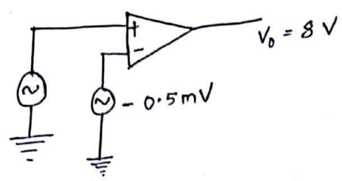
$\Rightarrow \boxed{V_1 = -V_2}$ or $\boxed{V_2 = -V_1}$

8) $V_0 = \frac{-1}{\cancel{3}} \times \cancel{-3} = 1V$

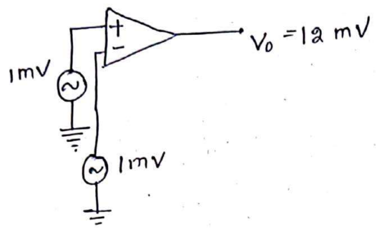
$V_0 = \frac{-1}{2} \times -3 = \frac{3}{2} = 1.5\,V$



Q:- For an experimental set up, which op-Amp as shown below:-



CMRR = ?



$$CMRR = \frac{A_d}{A_c}$$

$$A_d = \frac{V_{id}}{V_{id}} = \frac{8V}{V_1 - V_2} = \frac{8V}{0.5 + 0.5mV} = 8000 .$$

$$A_c = \frac{V_{oc}}{\left(\frac{V_1 + V_2}{2}\right)} = \frac{12\ mV}{1\ mV} = 12$$

$$CMRR = \frac{8000}{12} \rightarrow \text{Absolute state}$$

$$CMRR|_{dB} = 20\log_{10}\left(\frac{8000}{12}\right) dB .$$

Q:- Determine the o/p voltage of Op-Amp for the i/p voltage $V_{i1} = 200\mu V$, $V_{i2} = 140\mu V$. The amplifier has the differential gain $A_d = 6000$ and CMRR is 200,

$V_{i1} = 200\ \mu V$

$V_{i2} = 140 \mu V$

$CMRR = 200$

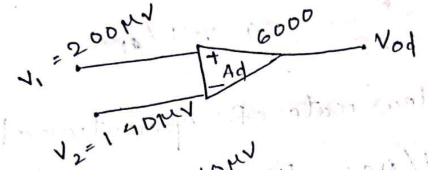
$A_d = 6000$

$V_{id} = V_{11} - V_{12} = 200 - 140 = 60 \mu A$

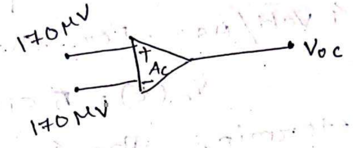
$V_{ic} = \frac{V_{11} + V_{12}}{2} = 170 \mu V.$

$CMRR = \frac{A_d}{A_c}$

$\Rightarrow \cancel{200} = \frac{\overset{30}{\cancel{6000}}}{A_c}$



$\Rightarrow \boxed{A_c = 30}$



$A_d = \frac{V_{od}}{V_{id}} = \frac{V_{od}}{60\mu V}$

$\Rightarrow V_{od} = 6000 \times 60 \mu V$

$= 360 mV.$

$A_c = \frac{V_{oc}}{V_{ic}} = \frac{V_{oc}}{170 \mu V}$

$\Rightarrow V_{oc} = 30 \times 170 \mu V = 5100 = 5.1 mV$

$V_D = V_{od} + V_{oc}$

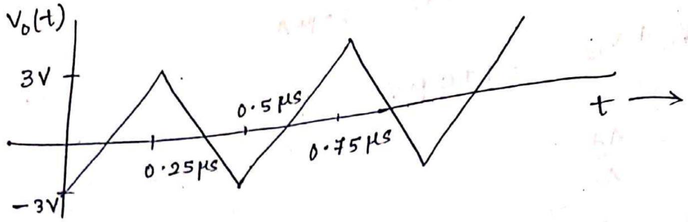
$= 360 + 5.1 = 365.1 mV.$

Slew Rate:-

This is the characteristics of Op-Amp and defined as max^m rate of change of o/p for any applied input.

Mathematically, $SR \triangleq \left. \frac{dV_B}{dt} \right|_{max}$. $\left(\text{Volt}/\mu s \right)$

Q:- Determine the slew rate ;



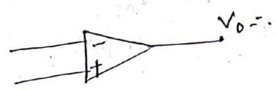
$$SR \triangleq \frac{6}{0.25} = 24 \text{ Volt}/\mu s.$$

Q:- The slew rate of operational amplifier is 24 Volt/μs . For the output ~~$v_o = A_M \sin 2\pi F_m t$~~

$$V_o(t) = 5 \sin 2\pi f_o t \ V.$$

Determine the frequency of O/P signal of Op-Amp.

$SR \triangleq = 24$ Volt/μs .



$$Sl = \frac{dV_B}{dt}\bigg|_{max}$$

$$= 10\pi f_o \cos 2\pi f_o t \bigg|_{max}$$

$$24 \, V/\mu s = 10\pi f_o$$

$$f_o = \frac{24}{10\pi} \times 10^6 \text{ Hz} = \frac{24}{\pi} \text{ MHz}$$

Significance of slew rate:-

→ It is used to calculate the frequency of O/P signal and also used to calculate the max^m swing in O/P signal.

Write the block diagram of Op-Amp :-

I/P → Differential amplifier stage → gain stage → level shifter → Matching stage → o/p stage → Load

Differential amplifier stage: $V_o = A_d(V_1 - V_2)$

gain stage: gain

level shifter: Used to remove the dc part at the o/p of gain stage.

Matching stage: Used to transfer the max^m power of level shifter to the o/p stage