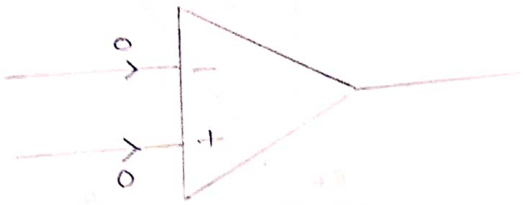
OPAMP



-ve → inverting terminal
+ve → non-inverting terminal

ideal properties of opamp :→

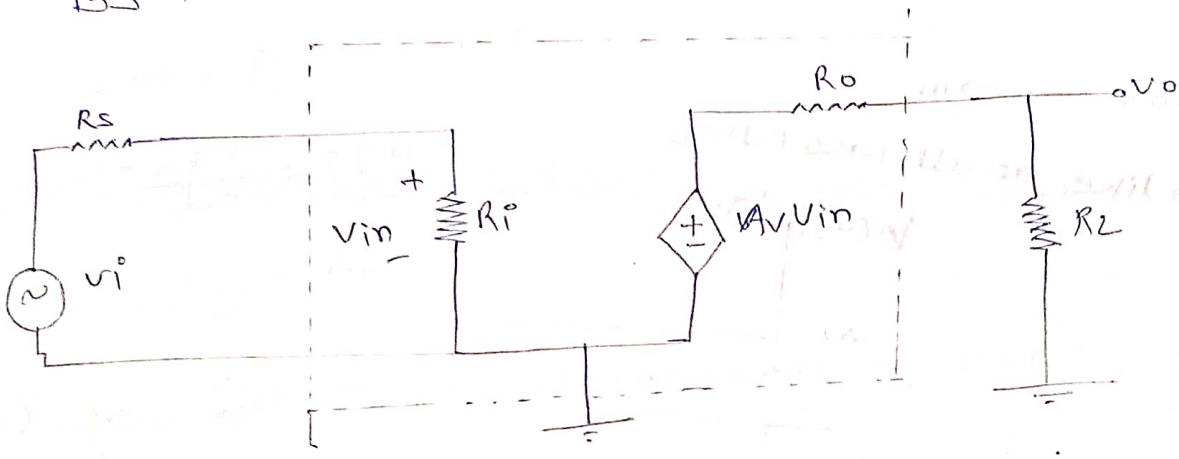
i) $R_i \longrightarrow \infty$

currents through (-ve) & (+ve) terminal of the OPAMP will be zero.

OPAMP is a VCVS

MOSFET is a VCCS

BJT is a CCCS



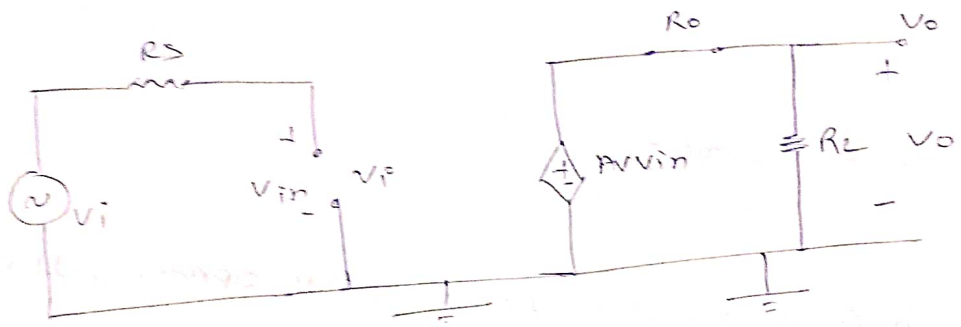
$$V_{in} = \frac{R_i}{R_s + R_i} v_i = v_i$$

$R_i \gg R_s$ $\quad R_i \longrightarrow \infty$

there is no loading effect at the i/p side and will get maximum o/p from the amplifier.

$R_i = 10^6 \Omega = 1 M\Omega = 1000 k\Omega$
(practical)

ii) $R_o \longrightarrow 0$



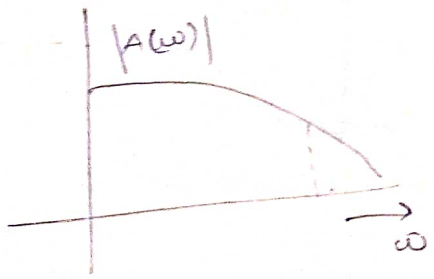
$$V_o = \frac{R_L}{(R_L + R_o)} (A_V V_{in})$$

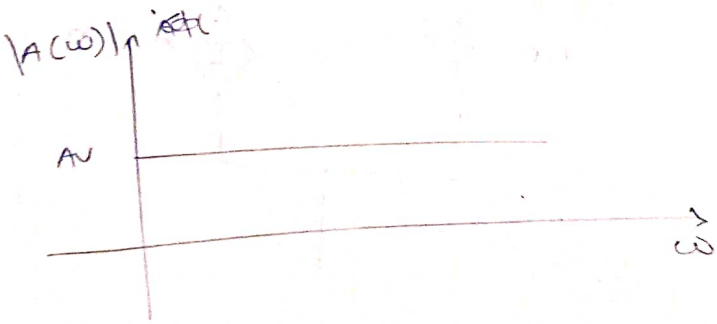
$R_o << R_L$

$R_o \longrightarrow 0$ there is no loading effect on the o/p side

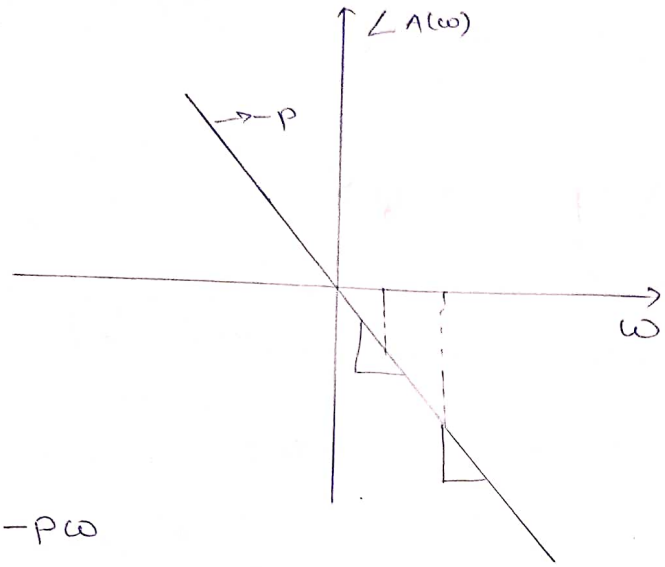
iii) Bandwidth $\longrightarrow \infty$

↳ like an all pass filters





iv) its phase response is linear



$\angle A(\omega) = -p\omega$

group delay $\quad \frac{-\phi(\omega)}{\omega} = \frac{-(p\omega)}{\omega} = p$

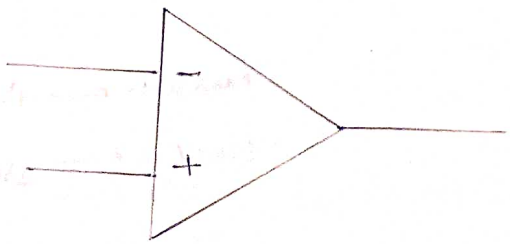
phase delay $\quad -\frac{d\phi\omega}{d\omega} = p$

$\angle A\omega = \phi(\omega) = -p\omega^2$

$-\frac{d\phi\omega}{d\omega} = 2p\omega$

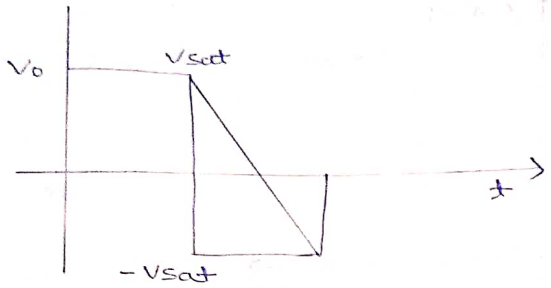
$-\frac{d(\omega)}{\omega} = p\omega$

v) slew rate is ∞, o/p can change any voltage in any time



$\frac{dv}{dt}$ (V/μsec)

100V/sec

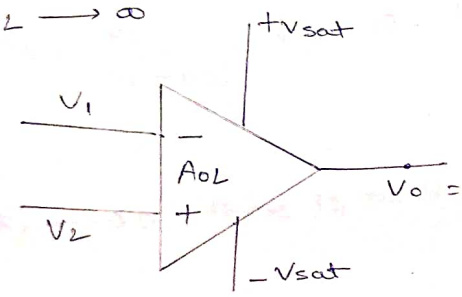


$$\frac{-2V_{sat}}{0} \rightarrow \infty$$

Important

vii)

$A_{OL} \longrightarrow \infty$



$V_o = A_{OL}[V_2 - V_1]$

case i) $V_1 = 0$, $V_2 = 0.1V$

(0.1 V)

$V_o = \infty = +V_{sat}$

$V_1 = 0$, $V_2 = 0.2V$

(0.2 V)

$V_o = \infty$ $\pm +V_{sat}$.

$V_1 = 0V$, $V_2 = 0.3V$
$(0.3V)$

$V_0 = \infty = +V_{sat}$

case ii) $V_1 = 0.1$, $V_2 = 0$
$(0.1V)$

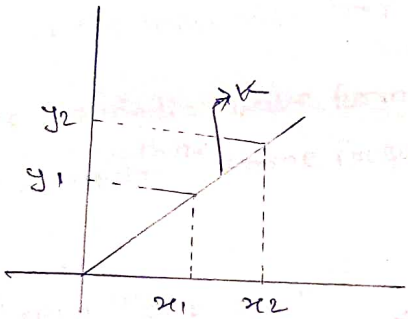
$V_0 = -\infty = -V_{sat}$

$V_1 = 0.2$, $V_2 = 0$
(-0.2)

$V_0 = -\infty = -V_{sat}$

$V = 0.3V$, $V_2 = 0$
$-0.3V$

$V_0 = -\infty = -V_{sat}$.



This circuit is a working as a comparator and o/p are this $+V_{sat}$, $-V_{sat}$

if
$V_2 > V_1 \longrightarrow +V_{sat}$

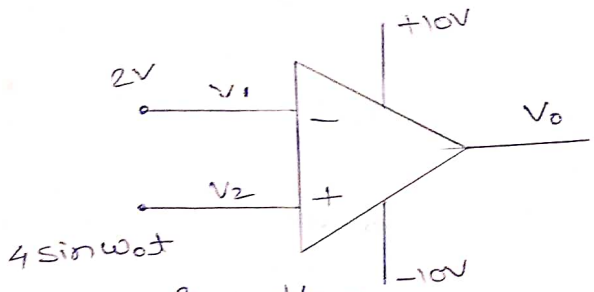
$V_1 > V_2 \longrightarrow -V_{sat}$

This ckt is ~~work~~ as a comparator because of the gain of ckt is ∞, if overall gain of system is ∞ then ~~OPAMP~~ opamp ckt will as a comparator and o/p of opamp only two o/p are possible +ve sat, -ve sat.

we can not equate ~~to~~ $V_+ = V_-$

Here we only varies independently V_+, V_-.

Q)



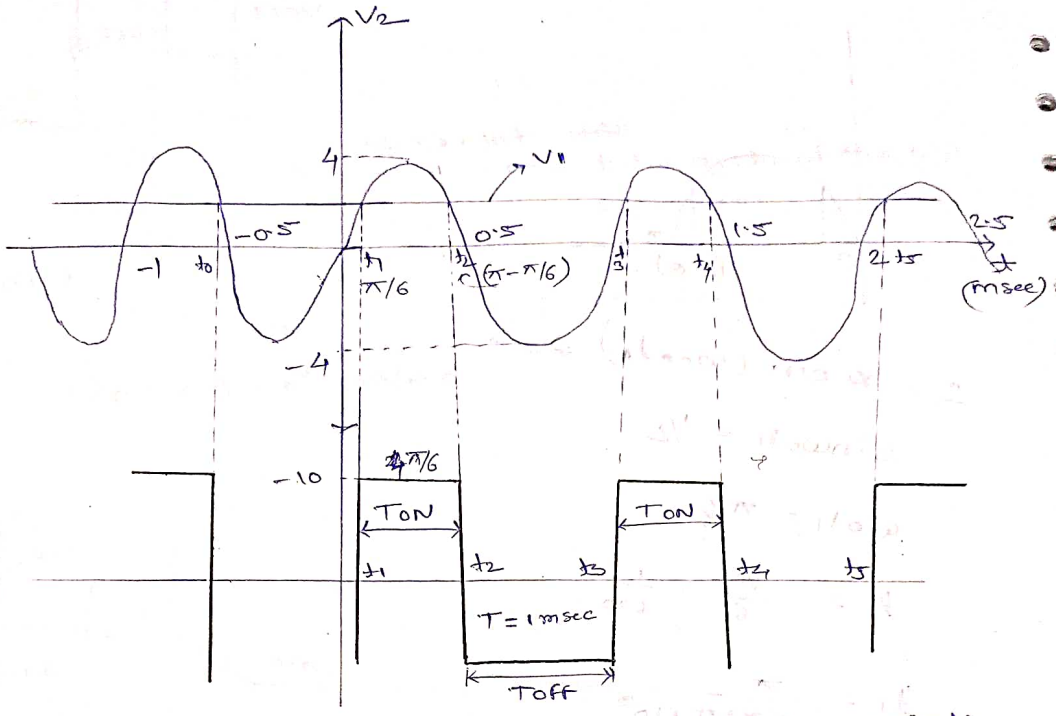
$\omega_0 = \pi \times 2 \times 10^3$ rad/sec.

duty cycle of the o/p waveform

$V_2 = 4 \sin \omega_0 t$, $V_1 = 2V$

$f_0 = \frac{\omega_0}{2\pi} = 10^3$ Hz

$T = \frac{1}{f} = \frac{1}{10^3}$ sec $= 10^{-3} = 1$ msec



- whenever OPAMP as a comparator if we applied the periodic wave on the input side then always we get a ~~periodic wave form~~ square periodic wave form in the o/p side of the same time period ~~of the~~ with the same frequency.

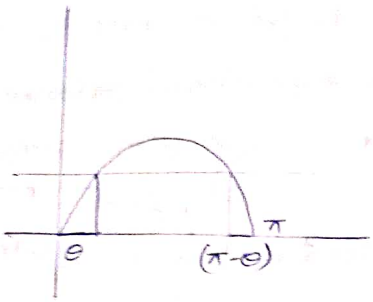
$$T_{ON} + T_{OFF} = T$$

$$\text{duty cycle} = \frac{T_{ON}}{T} \times 100\%$$

$T_{ON} = T_{OFF} \Rightarrow 50\%$ (duty cycle)

$T_{ON} < T_{OFF}$ $\times$ 50% $\quad \dfrac{1}{1 + \dfrac{T_{OFF}}{T_{ON}}} \times 100$

$T_{ON} > T_{OFF}$ $> 50\%$



$2 = 5 \sin(\omega_0 t_1) \Rightarrow$

$\sin \omega_0 t_1 = 1/2$

$\omega_0 t_1 = \pi/6$

$t_1 = \frac{\pi}{6} \times \frac{1}{\omega_0}$

$t_1 = \frac{\pi}{6 \times 2\pi \times 10^3}$

$t_1 = \frac{10^{-3}}{12} = \frac{1}{2}$ msec.

$t_2 = \frac{1}{2} - 1/12$

$= 5/12$ msec

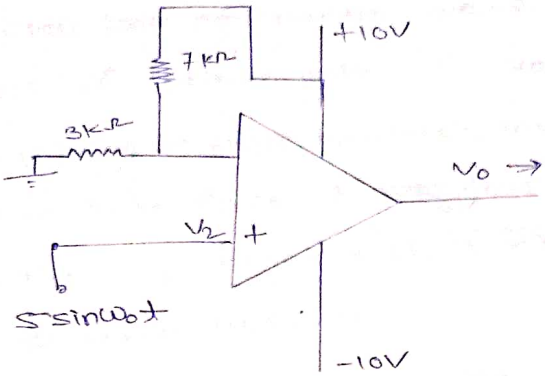
$T_{ON} = t_2 - t_1$

$= \frac{5}{12} - \frac{1}{12} = \frac{4}{12} = \frac{1}{3}$ msec.

duty cycle $= \frac{1/3}{1} \times 100 = 33.33\%$.

4.00

Q1)

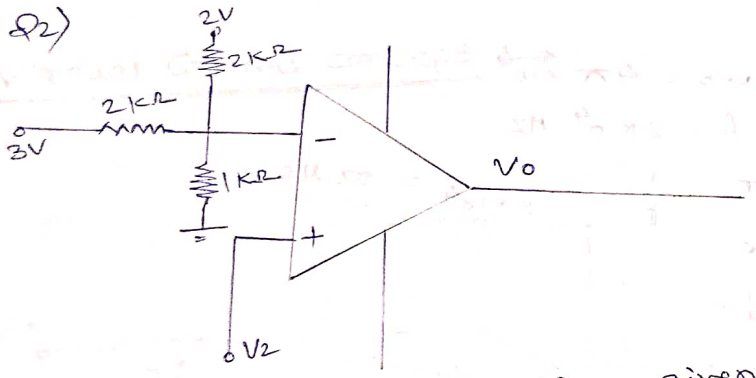


V_o ⇒ plot ~~and~~ and duty cycle of the o/p waveform

Ans 29.52%

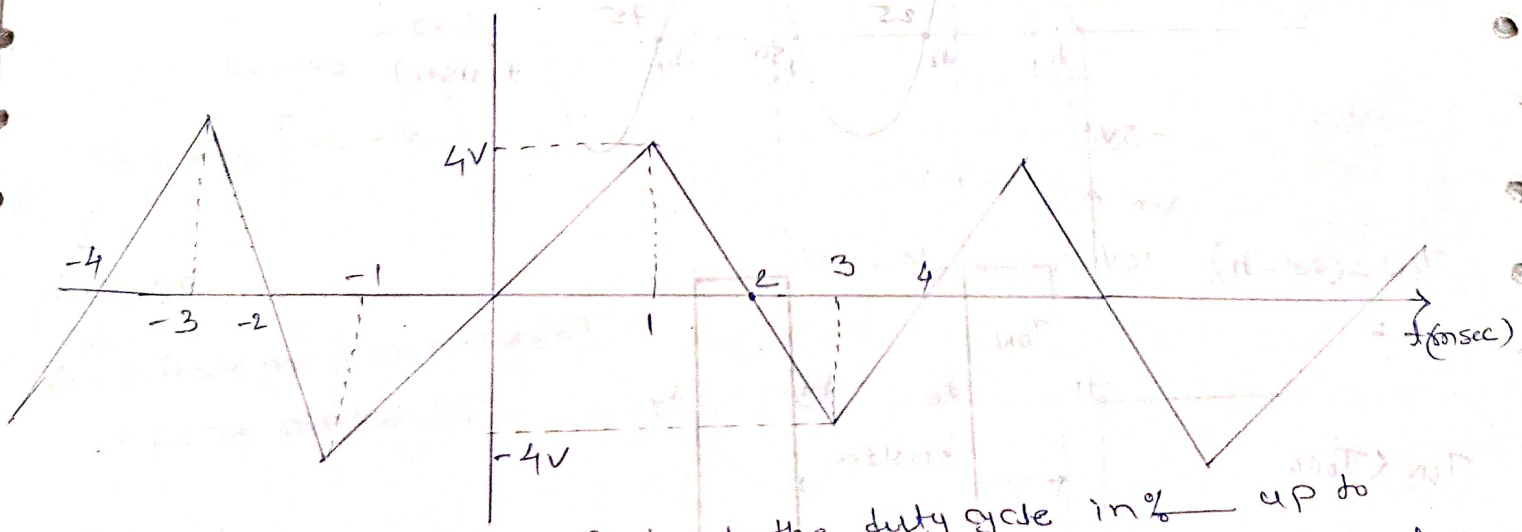
$\omega_0 = 4\pi \times 10^4$ rad/sec

Q2)



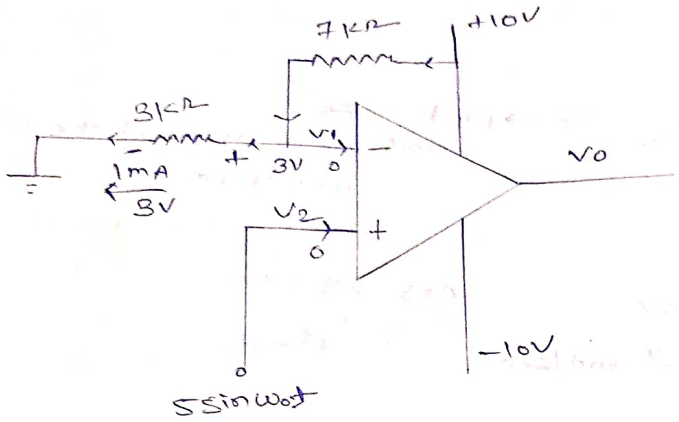
Ans:- 34.34 %

V_2 is an triangular waveform given as



Plot the o/p waveform & find out the duty cycle in% up to two decimal.

Q)



Soln:-

$V_- = 3V$

$V_+ = 5 \sin \omega_0 t$, $\omega_0 = 4\pi \times 10^4$

$f = 2 \times 10^4$ Hz

$3 = 5 \sin \omega_0 t_1$

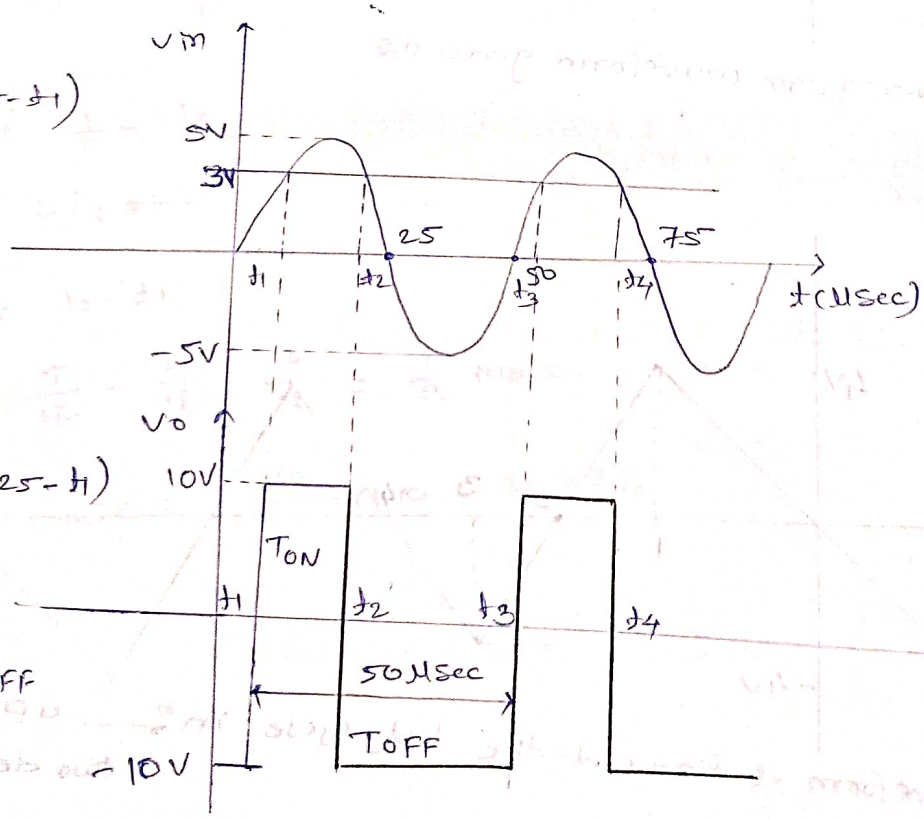
$\omega_0 t_1 = \sin^{-1} 3/5$

$t_1 = \frac{1}{\omega_0} \sin^{-1} 3/5 = 0.05\mu sec$

$T = \frac{1}{f} = \frac{1}{2 \times 10^4} = 50\mu sec$

$t_2 = (25 - t_1)$

=



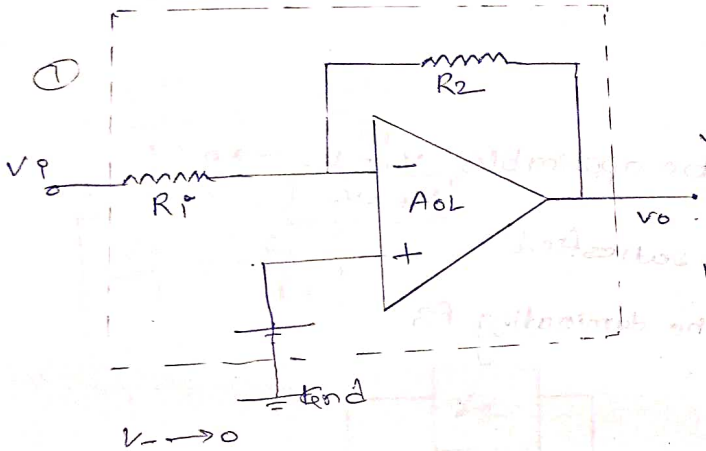
$T_{ON} = (25 - t_1)$

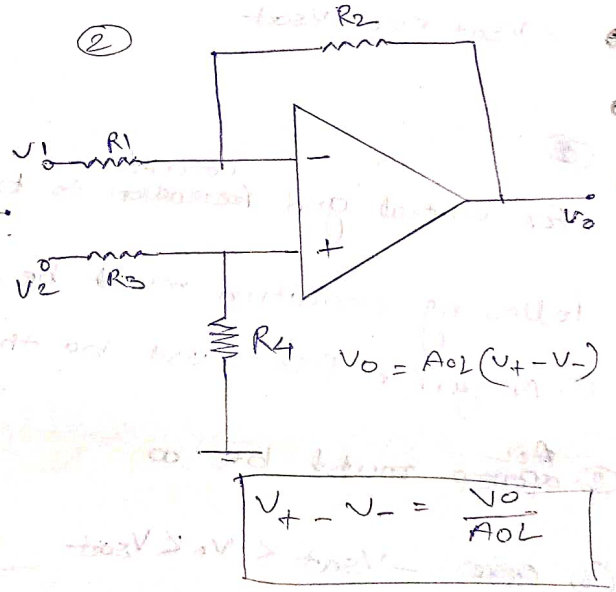
=

$T_{ON} < T_{OFF}$

- In open loop configuration opamp doesn't work as an amplifier because of infinite gain.
- by applying negative feedback we can make overall gain of the system to be finite & ~~does~~ thus can use the opamp as an Amplifier, so negative FB is very much nessecary for opamp to be use as an amplifier
- The Negative FB must be the dominating FB for opamp ckt to work as an amplifier.

Virtual Ground concept :→





$$V_o = A_{OL}\left[V_+ - V_-\right]$$

↓

finite O/P

↓

due to finite gain (overall gain) & finite applied I/P

$$\boxed{V_+ - V_- = \frac{V_o}{A_{OL}}}$$

$V_+ - V_- \rightarrow 0$

$$V_+ - V_- = \frac{V_o}{A_{OL}}$$

if $A_{OL} \rightarrow \infty$

$$\frac{V_o}{A_{OL}} \rightarrow 0$$

$V_+ \rightarrow V_-$

$V_+ \simeq V_-$

$$V_+ - V_- \rightarrow 0$$

$-\infty < V_o < \infty$

$-V_{sat} < V_o < V_{sat}$

For virtual gnd ~~formation~~ concept to be applicable $V_+ - V_- \rightarrow 0$ $\boxed{V_+ = V_-}$

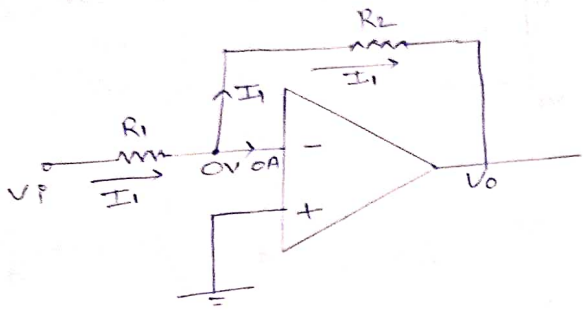
following condition must be satisfied

① Negative FB must be the dominating FB

② A_{OL} ~~opamp~~ must be ∞

③ $-V_{sat} < V_o < V_{sat}$

Inverting amplifier :→

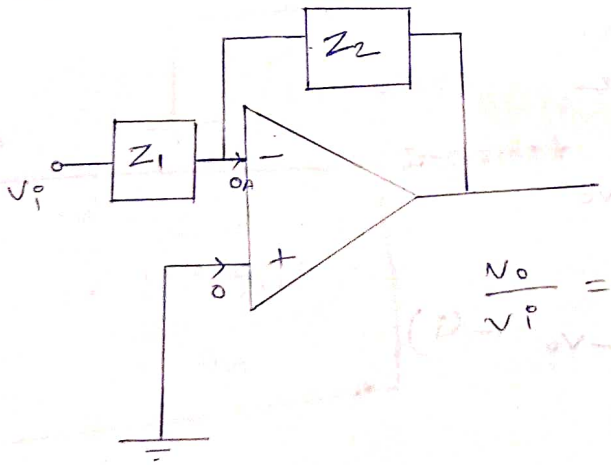


case i) ideal opAmp → $A_{OL} \to \infty$

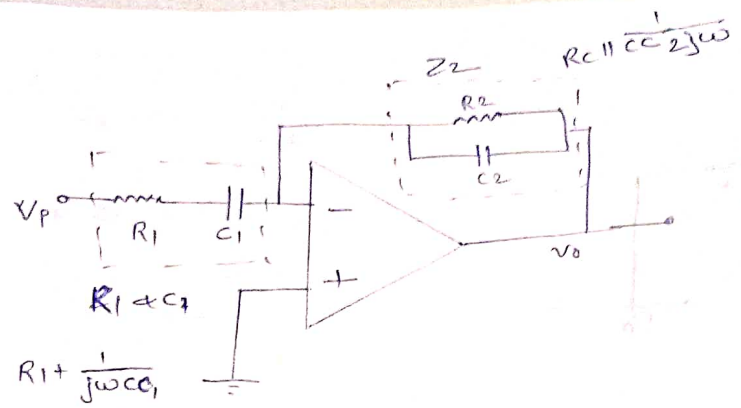
$$\frac{V_i - 0}{R_1} = 0 + \frac{0 - V_o}{R_2}$$

$$\frac{V_i}{R_1} = \frac{-V_o}{R_2}$$

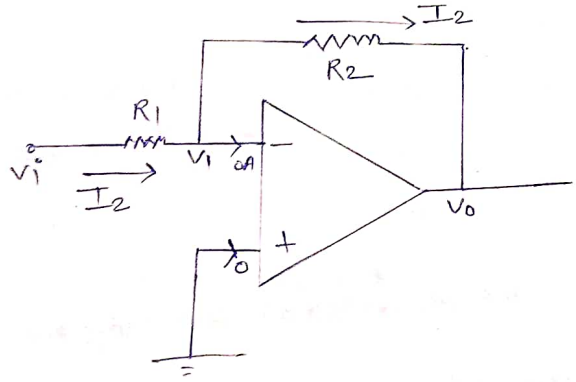
$$\boxed{\frac{V_o}{V_i} = -\frac{R_2}{R_1}}$$



$$\frac{V_o}{V_i} = -\left[\frac{Z_2}{Z_1}\right]$$



Case ii) $A_{OL} \longrightarrow$ finite, rest opamp is ideal



$V_+ \neq V_-$

$$\frac{V_i - V_1}{R_1} = 0 + \frac{V_1 - V_o}{R_2}$$

$$\frac{R_2}{R_1}\left[V_i - V_1\right] = V_1 - V_o$$

$$\frac{R_2}{R_1} V_i = \left(1 + \frac{R_2}{R_1}\right) V_1 - V_o \quad -(i)$$

$$V_o = A_{OL}[V_+ - V_-]$$

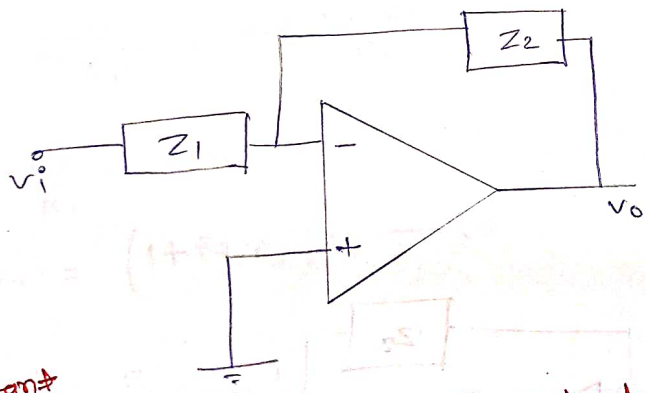
$$V_o = A_{OL}[0 - V_1]$$

$$V_1 = \frac{-V_o}{A_{OL}} \quad \text{— (11)}$$

$$\frac{R_2}{R_1} V_i = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{-V_o}{A_{OL}}\right) - V_o$$

$$\frac{R_2}{R_1} V_i = -V_o\left[1 + \frac{(1 + R_2/R_1)}{A_{OL}}\right]$$

$$\frac{V_o}{V_i} = \frac{-R_2/R_1}{1 + \frac{(1 + R_2/R_1)}{A_{OL}}}$$

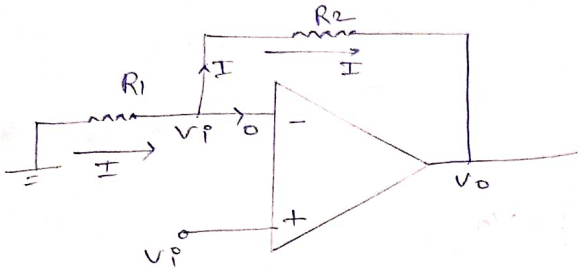


Important

Important

$$\boxed{\frac{V_o}{V_i} = \frac{-Z_2/Z_1}{1 + \frac{(1 + Z_2/Z_1)}{A_{OL}}}}$$

Non-inverting Amplifier :-



case i) ideal opamp

$V_+ = V_-$

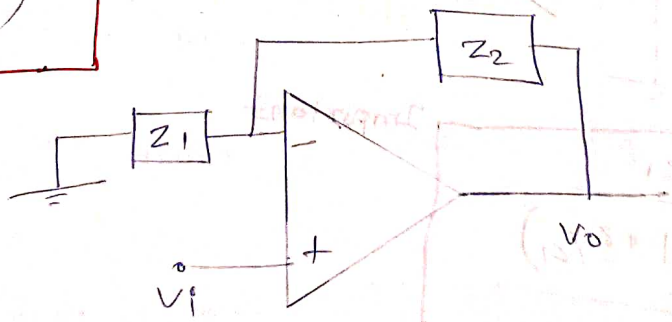
$V_i = V_-$

$$\frac{0 - V_i}{R_1} = 0 + \frac{V_i - V_o}{R_2}$$

$$\frac{R_2}{R_1} V_i = V_i - V_o$$

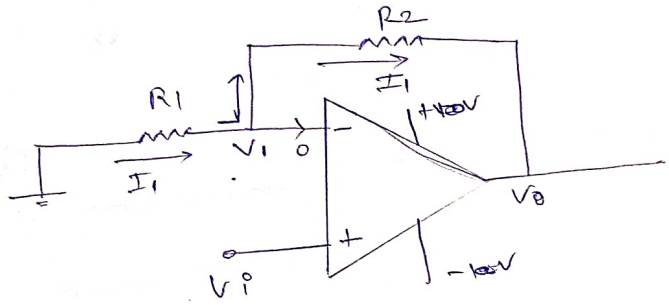
$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_i$$

$$\boxed{\frac{V_o}{V_i} = \left(1 + \frac{R_2}{R_1}\right)}$$



$$\boxed{\frac{V_o}{V_i} = 1 + \frac{Z_2}{Z_1}}$$

Case ii) $A_{OL} \longrightarrow$ finite, rest opamp is ideal



$V_+ \neq V_-$

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

$$-\frac{R_2}{R_1} V_1 = V_1 - V_o$$

$$V_o = \left(1 + R_2/R_1\right) V_1 \quad \text{—(i)}$$

$$V_o = A_{OL}\left[V_+ - V_-\right]$$

$$V_o = A_{OL}\left[V_i - V_1\right]$$

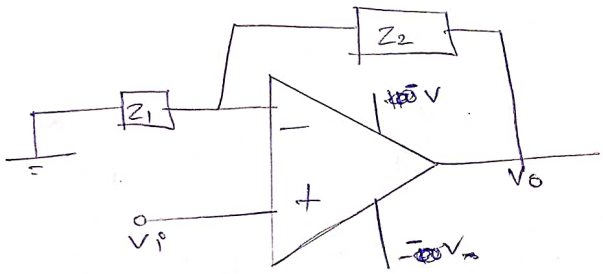
$$\frac{V_o}{A_{OL}} = V_i - V_1$$

$$\boxed{V_1 = V_i - \frac{V_o}{A_{OL}}} \quad \text{— (ii)}$$

$$V_o = \left[\frac{1+\frac{R_2}{R_1}}{A_{OL}}\right] = (1+R_2/R_1)\, V_i$$

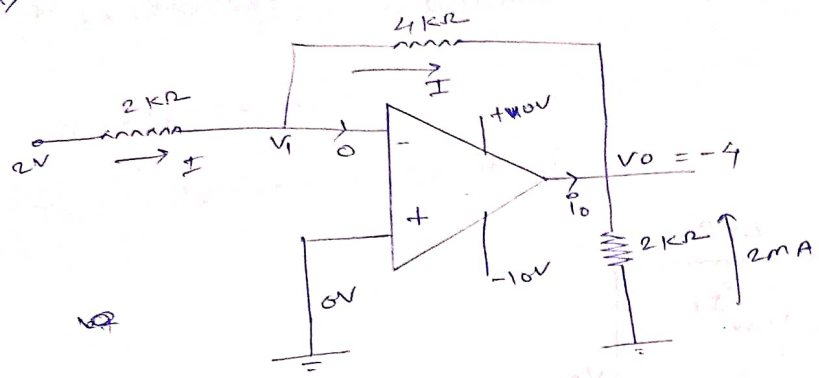
$$\frac{V_o}{V_i} = \frac{1+R_2/R_1}{1+\frac{(1+R_2/R_1)}{A_{OL}}}$$

$$\frac{V_o}{V_i} = \frac{(1+R_2/R_1)}{1+\frac{(1+R_2/R_1)}{A_{OL}}}$$



$$\frac{V_o}{V_i} = \frac{(1+Z_2/Z_1)}{1+\frac{(1+Z_2/Z_1)}{A_{OL}}}$$

Q)



Soln:-

i) ideal opamp

V_o ____ V

i_o ____ mA

$A_{OL} \longrightarrow \infty$ $\qquad V_+ = V_- =$

$$\frac{2 - V_1}{2} = \frac{V_1 - V_o}{4K\Omega}$$

$$\boxed{V_1 = 0V}$$

$$\frac{2}{2} = \frac{0 - V_o}{4K\Omega}$$

$$\boxed{V_o = -4V}$$

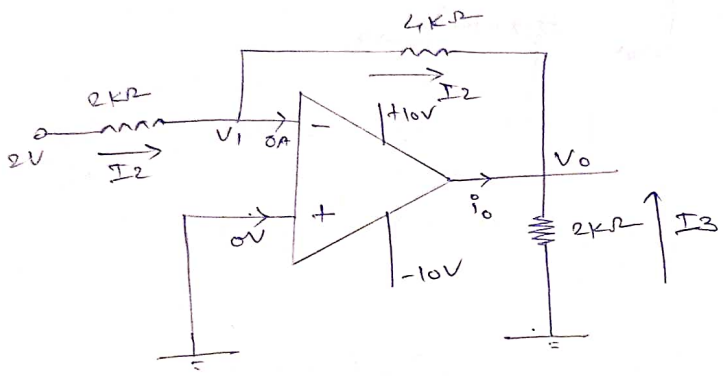
$$I = \frac{-4}{4} = 1mA$$

$$\frac{0+4}{2} = 2mA$$

$i_o + 2 + 1 = 0$

$\boxed{i_o = -3mA}$

ii) $A_{OL} = 100$



$V_+ \neq V_-$

$$\frac{2 - V_1}{2} = 0 + \frac{V_1 - V_o}{4}$$

$4 - 2V_1 = V_1 - V_o$

$V_o = 3V_1 - 4$ —(i)

$V_o = A_{OL}[V_+ - V_-]$

$V_o = 100[0 - V_1]$

$$V_1 = -\frac{V_o}{100} = -0.01 V_o$$

$V_o = -0.03V_o - 4$

$1.03V_o = -4$

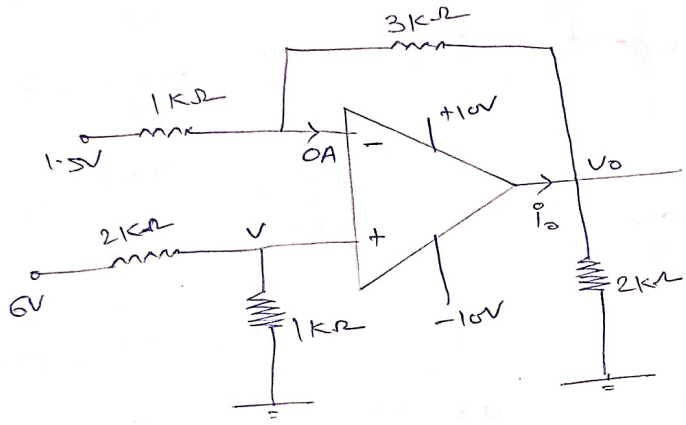
$\boxed{V_o = \frac{-4}{1.03} = -3.88 \text{ Volt}}$ $\boxed{V_1 = +0.388V}$

$I_3 = \frac{0-(0.388)}{2} = 1.94\,mA$

$I_0 + I_2 + I_3 = 0$

$\boxed{I_0 = -I_2 - I_3 = -2.92\,mA}$

Q)

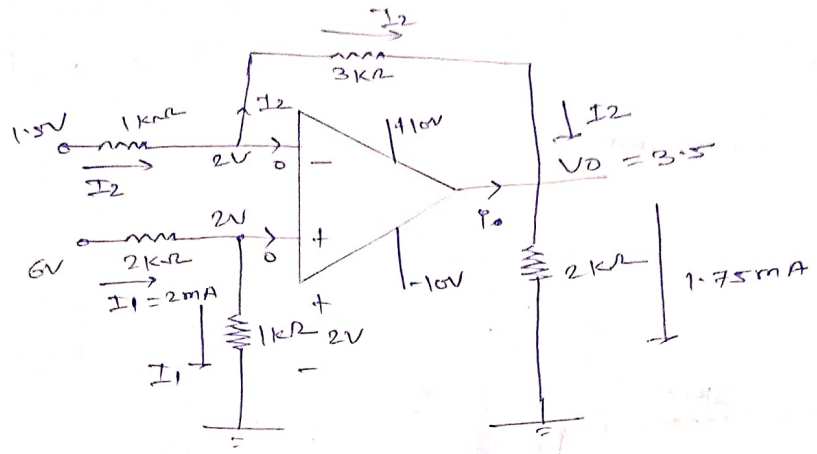


i) ideal V_o —
i_o —

ii) $A_{OL} = 100$ V_o —
i_o —

Sol^n ① $A_{OL} \longrightarrow \infty$

$V_+ = V_-$



$$I_1 = \frac{6}{3} = 2mA$$

$$\frac{1.5-2}{1} = 0 + \frac{2-V_o}{3}$$

$$-1.5 = 2 - V_o$$

$$\boxed{V_o = 3.5V}$$

$$I_2 = \frac{2-3.5}{3} = \frac{-1.5}{3}$$

$$= -0.5mA$$

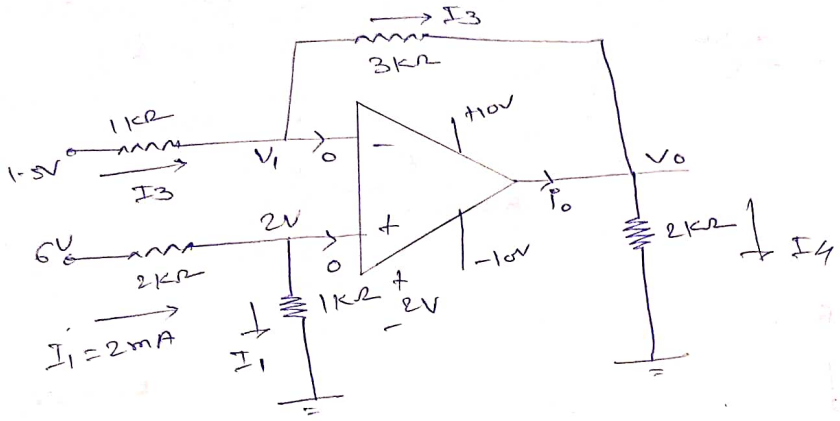
$$i_o + I_2 = 1.75$$

$$i_o = 1.75 + 0.5$$

$$\boxed{i_o = 2.25mA}$$

ii) $A_{OL} = 100$ $\quad V_o$ ____
i_o ____

$V_+ \neq V_-$



$\boxed{V_+ = 2V}$

$$\frac{1.5 - V_1}{1} = \frac{V_1 - V_o}{3} + 0$$

$$4.5 - 3V = V_1 - V_o$$

$$V_o = 4V_1 - 4.5 \quad \text{—— (i)}$$

$$V_o = A_{OL}(V_+ - V_-)$$

$$V_o = 100(2 - V_1)$$

$$V_1 = 0.01 V_o + 2 \quad \text{— (ii)}$$

$$V_o = 4(0.01 V_o + 2) - 4.5$$

$$1.04 V_o = 3.5$$

$$V_o = 3.5/1.04 = 3.36V$$

$V_1 = -0.01(3.36) + 2$

$\boxed{V_1 = 1.96}$

$I_3 = -0.46$

$I_4 = \frac{V_o - 0}{2} = \frac{3.36}{2}$

$= 1.68$

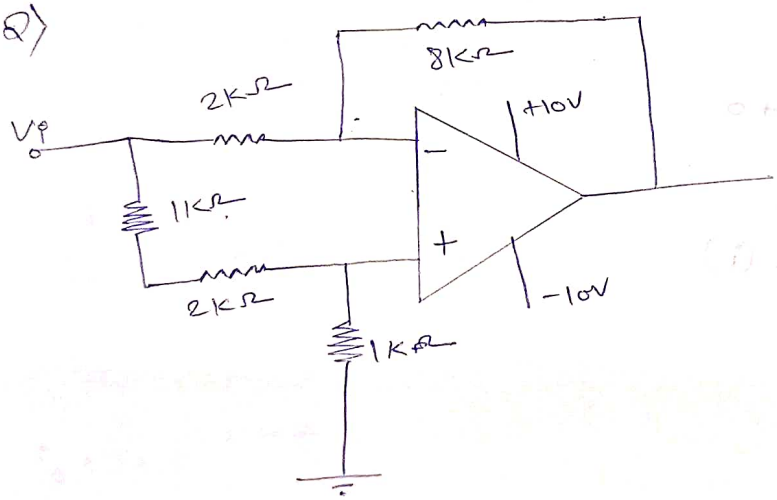
$i_o + I_3 = I_4$

$i_o = I_4 - I_3$

$= 1.68 + 0.46$

$\boxed{i_o = 2.14\,mA}$

Q)



i) ideal OPAMP

$\frac{V_o}{V_i}$ ——

ii) $A_{OL} = 50, \frac{V_o}{V_i}$ ——

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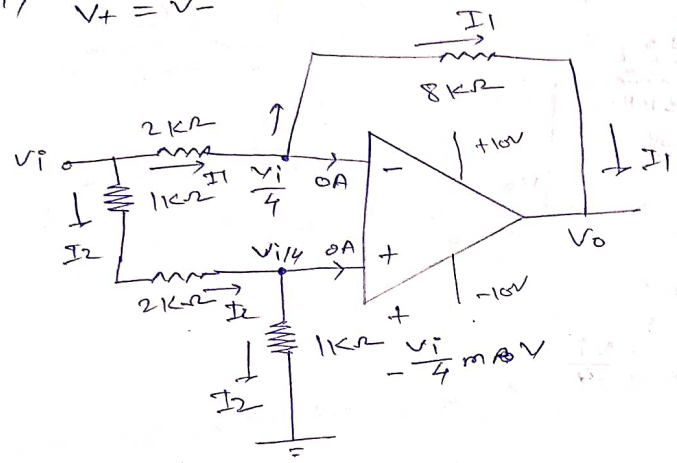
Soln:-

i) $V_+ = V_-$



$$I_2 = \frac{V_i}{4} = V_-$$

$$\frac{V_i}{4} = V_- = V_+$$

$$\frac{V_i - V_i/4}{2} = 0 + \frac{V_i/4 - V_o}{8}$$

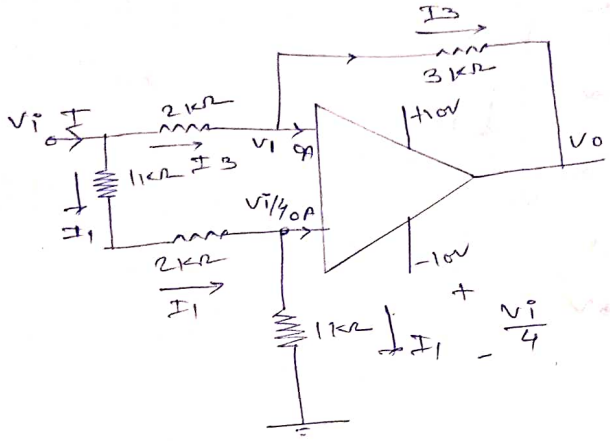
$$4V_i - V_i = V_i/4 - V_o$$

$$-V_o = 3V_i - \frac{V_i}{4}$$

$$= 11V_i/4$$

$$\boxed{\frac{V_o}{V_i} = -11/4 = -2.75}$$

ii) $A_{OL} = 50$, $\frac{V_o}{V_i}$ —



$V_+ \neq V_-$

$\frac{V_i}{4} = V_+$

$\frac{V_i - V_1}{2} = 0 + V_1 - V_o$

$4V_i - 4V_1 = V_1 - V_o$

$V_o = -4V_i + 5V_1$ — (I)

$V_o = A_{OL}(V_+ - V_-)$

$V_o = 50(V_i/4 - V_i)$

$0.02V_o = \frac{V_i}{4} - V_1$

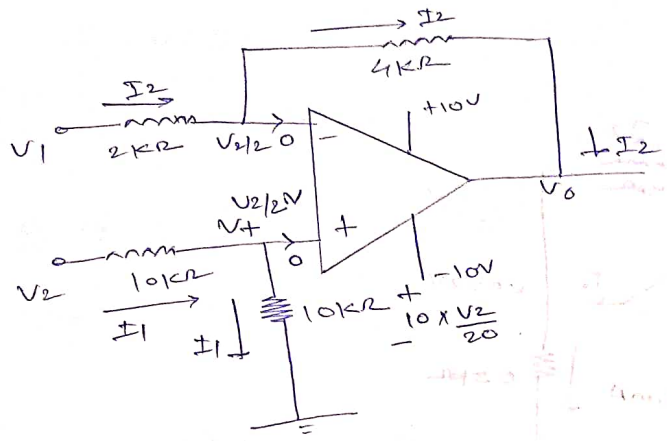
$V_1 = V_i/4 - 0.02V_o$ — (II)

$V_o = -4V_i + \frac{5V_i}{4} - 0.1V_o$

$1.1V_o = -\frac{11}{4}V_i$

$$\boxed{\frac{V_o}{V_i} = \frac{-2.75}{1.1} = -2.50}$$

Q)



for o/p Vo to be zero Vi is KV2, then the value of K ____ upto two decimal.

Soln:- $V_+ = V_-$

$$\frac{V_2 - 0}{20} = \frac{V_2}{20} = I_1$$

$$\frac{V_1 - \frac{V_2}{2}}{2} = \frac{\frac{V_2}{2} - V_o}{4}$$

$$2V_1 - V_2 = \frac{V_2}{2} - V_o$$

$$V_o = \frac{3}{2}V_2 - 2V_1$$

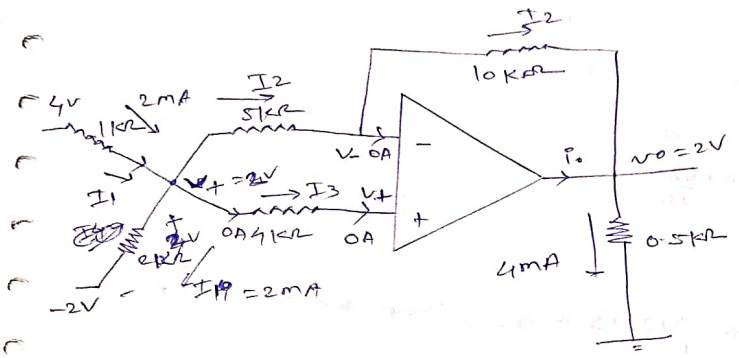
$$0 = \frac{3}{2}V_2 - 2V_1$$

$$V_1 = \frac{3}{4}V_2$$

$$\boxed{V_1 = KV_2}$$

$$\boxed{K = 0.75}$$

Q)



value of i_o ____ mA

upto two decimal

ideal $V_{OL} \longrightarrow \infty$

$V_+ = V_-$

$\frac{V_+ - V_-}{5} = \frac{0-0}{5} = 0 = I_2$

$\frac{4 + 2}{2} = 2mA$

$V_+ = 4V$

$V_- = 4V$

$V_+ - 4 + 2 = 0$

$\boxed{V_+ = 2V}$

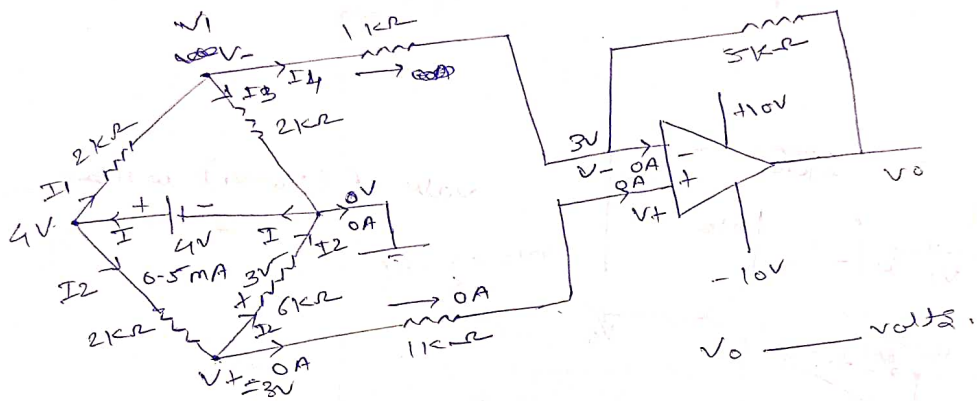
$i_o + 0 = 4$

$\boxed{i_o = 4mA}$

$$\frac{4 - V_+}{1} = \frac{V_+ + 2}{2} + \frac{V_+ - V_-}{5}$$

$\boxed{V_+ = 2V}$

Q)



V_o _____ volts.

$V_+ = V_-$

$A_{OL} \longrightarrow \infty$

$$I_2 = \frac{4}{8} = \frac{1}{2} mA$$
$$= 0.5 mA$$

$V_+ = 3V$

$V_- = 3V$

$$\frac{V_1 - 3}{1} = 0 + \frac{3 - V_o}{5}$$

$5V_1 - 15 = 3 - V_o$

$V_o = 5V_1 + 16$ — (1)

$$\frac{4-V_1}{2} = \frac{V_1-3}{1} + \frac{V_1-0}{2}$$

$$4-V_1 = 2V_1-6+V_1$$

$$4V_1 = 10$$

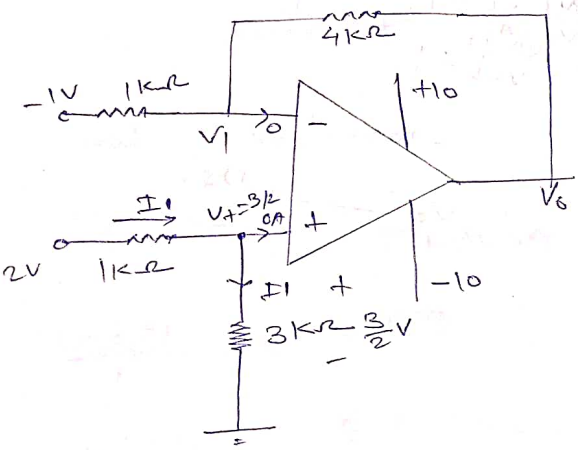
$$\boxed{V_1 = 2.5V}$$

$$V_o = -5\times 2.5+18$$

$$= -12.5+16$$

$$\boxed{V_o = 5.5V}$$

Q)



value of $(V_o - V_1)$ will be

Soln:-

$$V_+ = V_-$$

$$\frac{2-0}{4} = \frac{1}{2}\,mA = I_1$$

$$\boxed{0.5mA = I_1}$$

$$\boxed{V_+ = 3/2\,V = 1.5V} = V_-$$

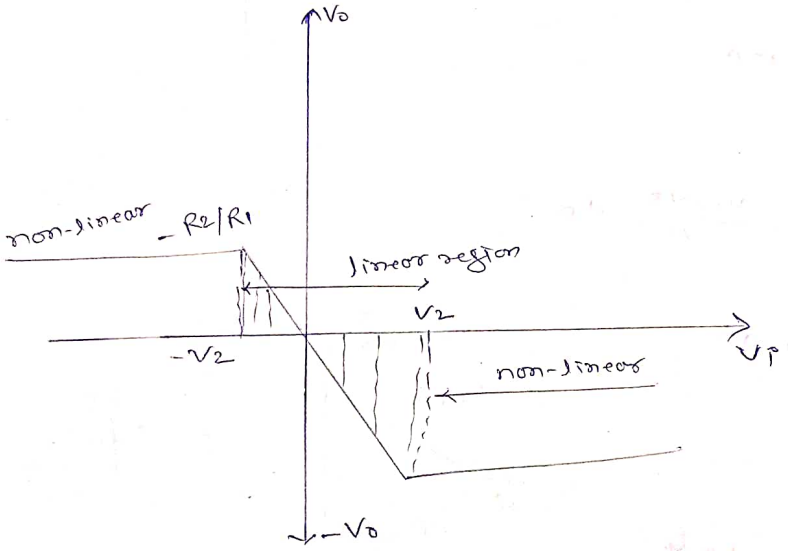
$$\frac{-1-3/2}{1} = 0 + \frac{3/2 - V_o}{4}$$

$$-10 = \frac{3}{2} - V_o$$

$\boxed{V_o = 11.5 \text{ volt}}$ ×

$\boxed{V_o = 10V}$ → saturation

$$V_o = \frac{-R_2}{R_1} V_i$$



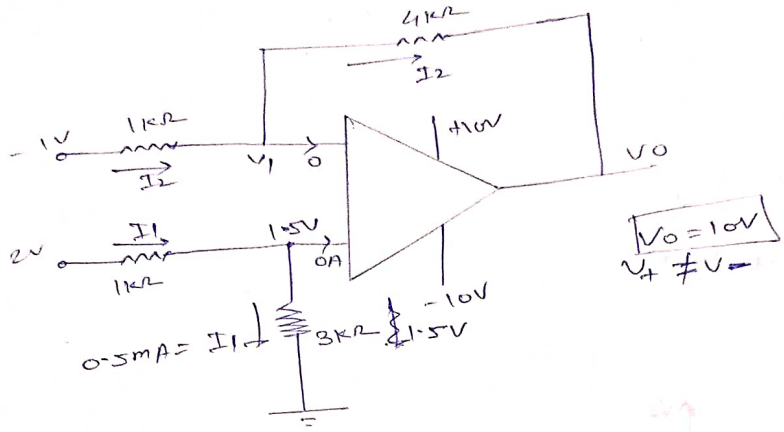
$V_o = -5V_i$

$V_i = 1$	$V_i = 2$
$V_o = -5V$	$V_o = -10V$
$V_i = 1.5V$	$V_i = 2.1$
$V_o = -7.5$	$V_o = -10.2$

$$V_+ - V_- = \frac{V_o}{A_{OL}}$$

$V_+ \neq V_-$

Q)



$V_o = 10V$

$V_+ \neq V_-$

$$\frac{2-0}{4} = \frac{1}{2}\ mA$$

$$\frac{-1-V_1}{1} = \frac{V_1 - V_o}{4} + 0$$

$$-4 - 4V_1 = V_1 - 10$$

$$5V_1 = 6$$

$$V_1 = 1.2V$$

$$V_o - V_1 = 10 - 1.2$$

$$V_o - V_1 = 8.8\ Volt$$

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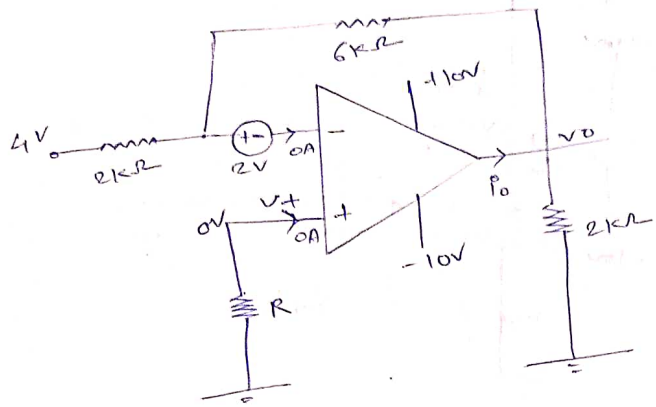
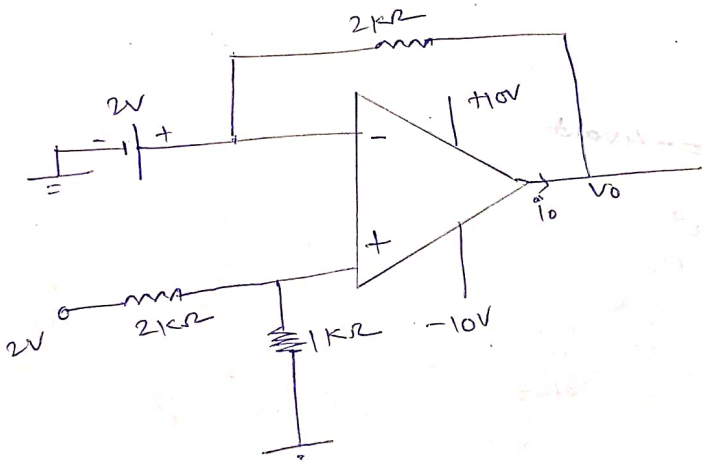
Q1)



I_o -3.0 mA.

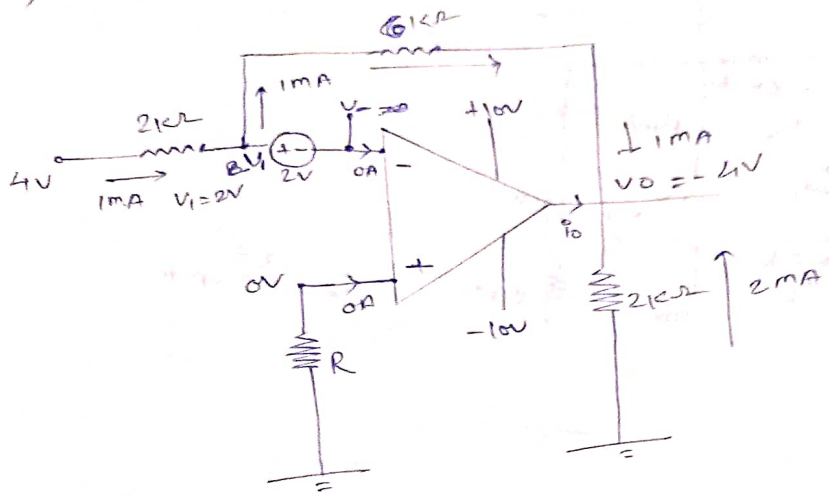
Q2)



I_o -6.0mA

V_o -10V

Q1)



$V_+ = V_-$

$V_- = (V_1 - 2)$

$V_- = 0V$

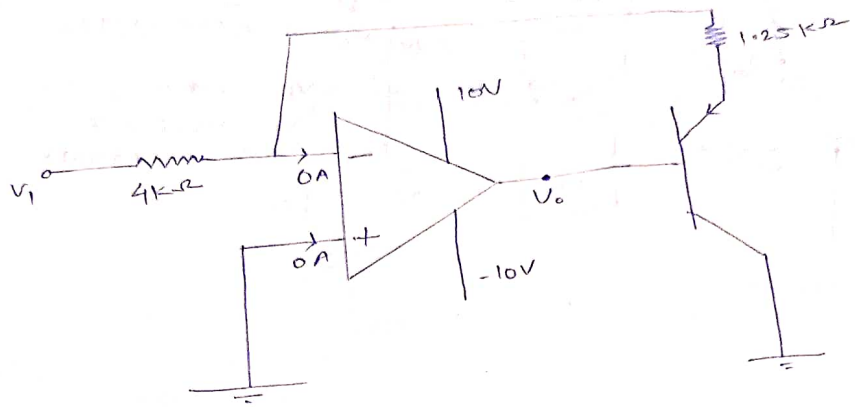
$V_1 - V_0 = 6$

$V_0 = V_1 - 6 = 2 - 6 = -4$ volt

$\boxed{i_0 = -3mA}$

Q)

$V_{EB} = 0.7V$
$V_{BE} = -0.7V$

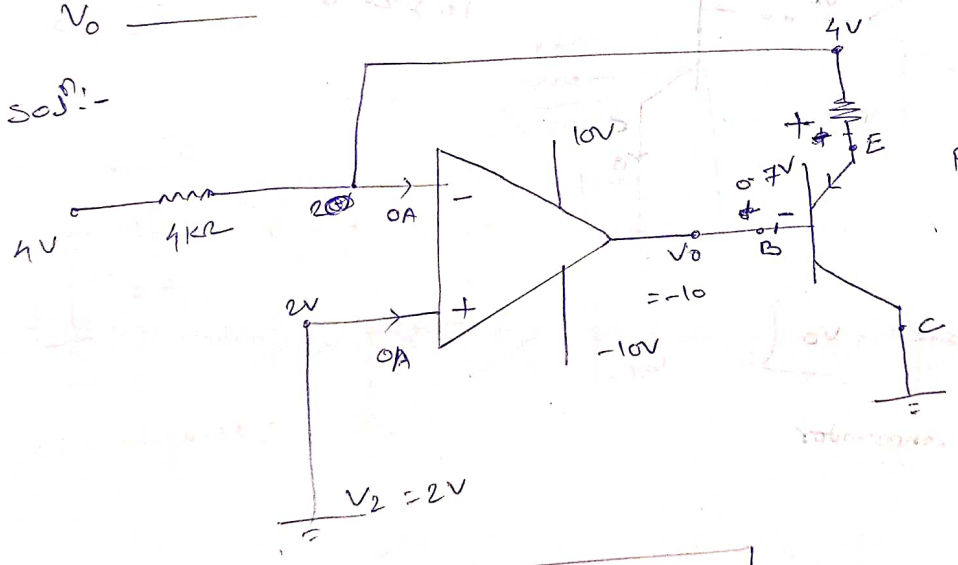


(i) $V_1 = 4V$, $V_2 = 2V$

(ii) $V_1 = 2V$, $V_2 = 4V$

V_o _____

Sol^n:-



PNP

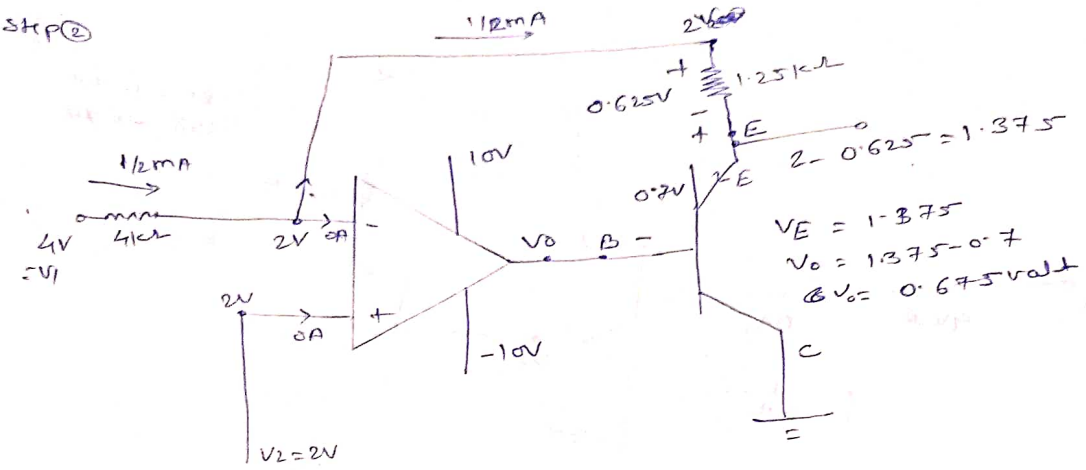
$p > n \rightarrow ON$

$4 > -10 \rightarrow ON$

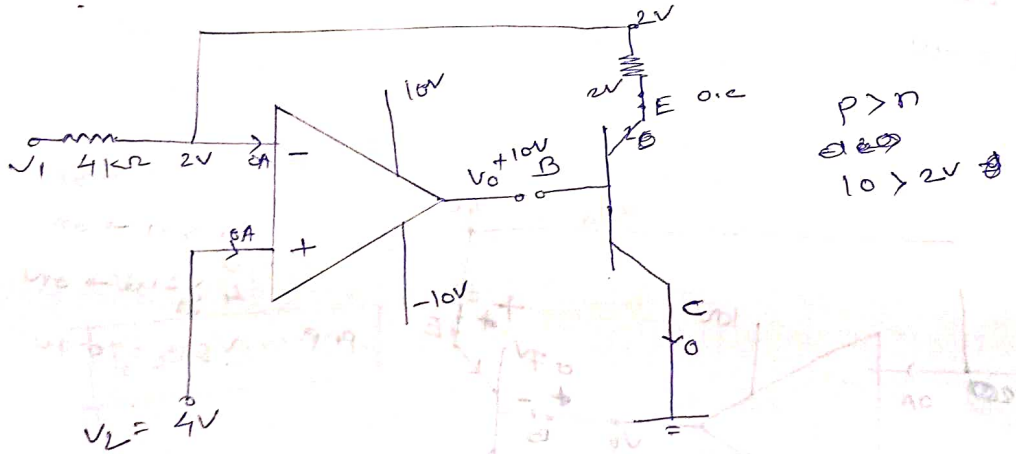
$V_{EB} = 0.7V$

$V_+ = V_- \rightarrow \boxed{-V_{sat} = 10V}$

Step ②



② $V_1 = 2V$, $V_2 = 4V$



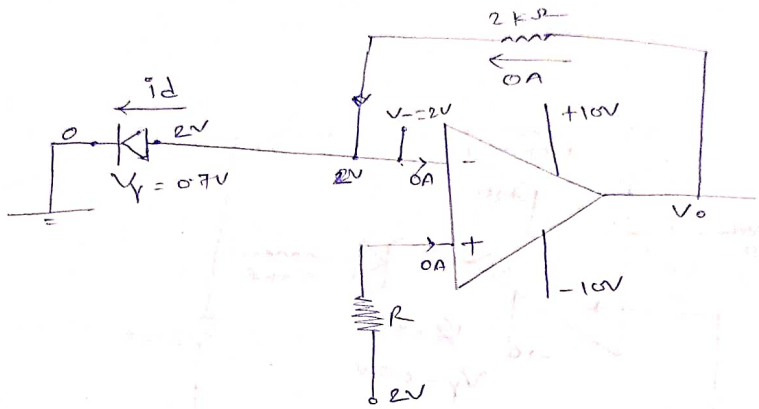
p > n

10 > 2V

$V_+ > V_- = \boxed{+10V \text{ sat} = V_o}$

its work as a comparator

Q)



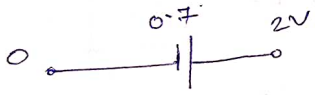
⇒ id ____ mA

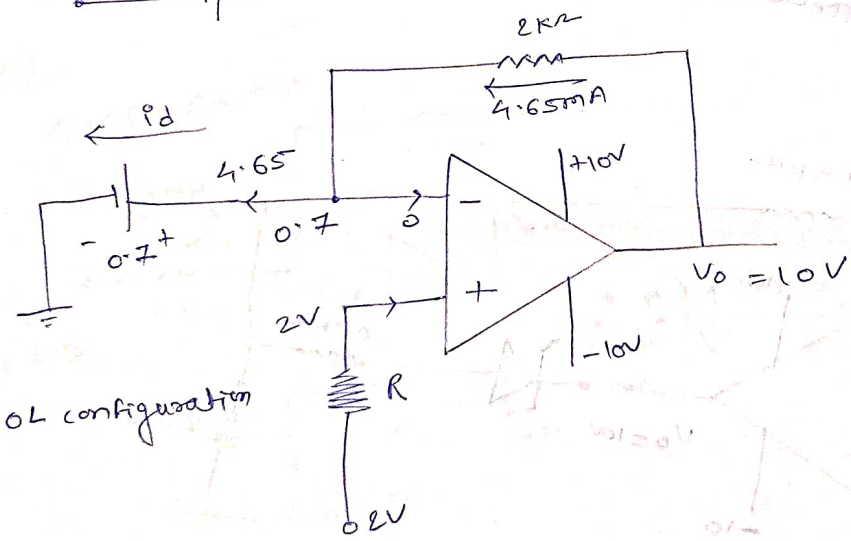
Soln:-

$V+ = V-$

$V_p - V_n > V_\gamma$

$2 > 0.7V$

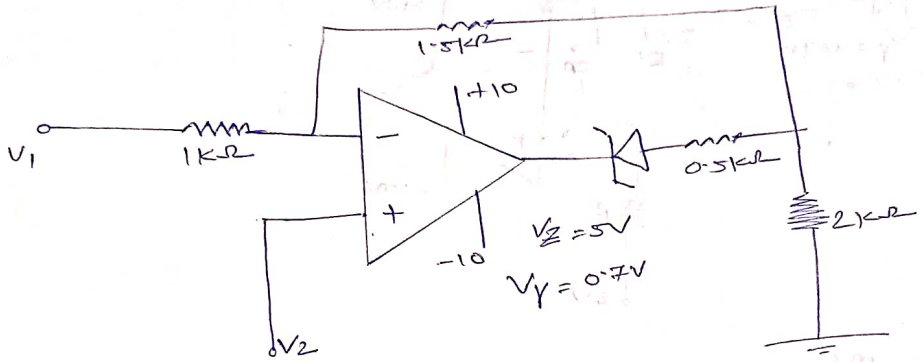




id = 4.65mA.

OL configuration

Q)



i) $V_1 = 0.5V$, $V_2 = 1V$

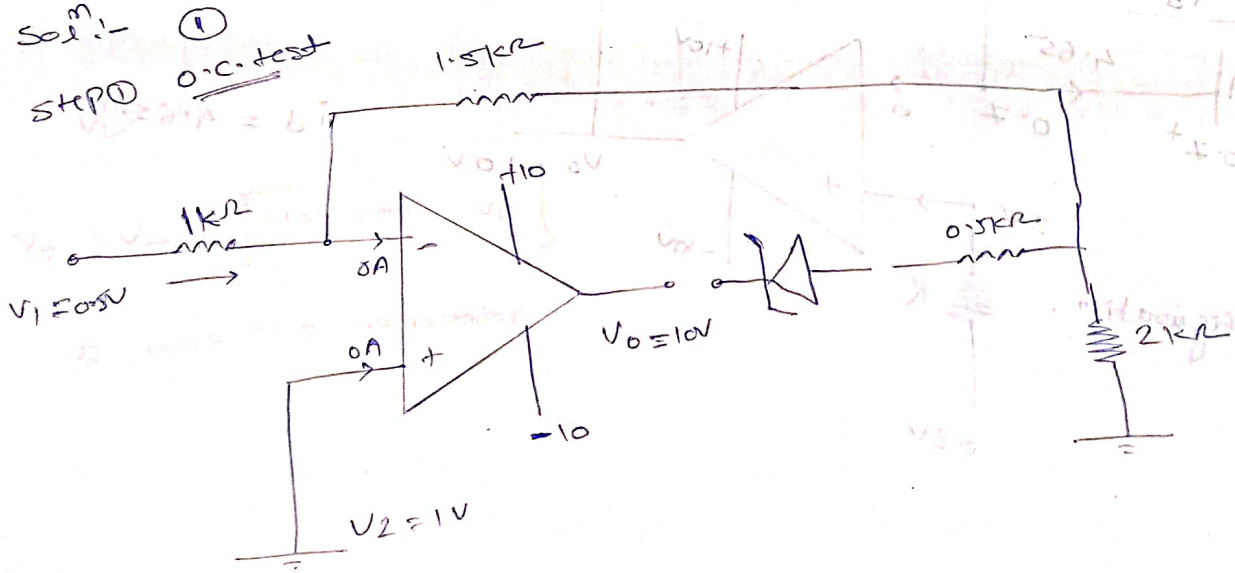
V_o _____ upto threedecimal

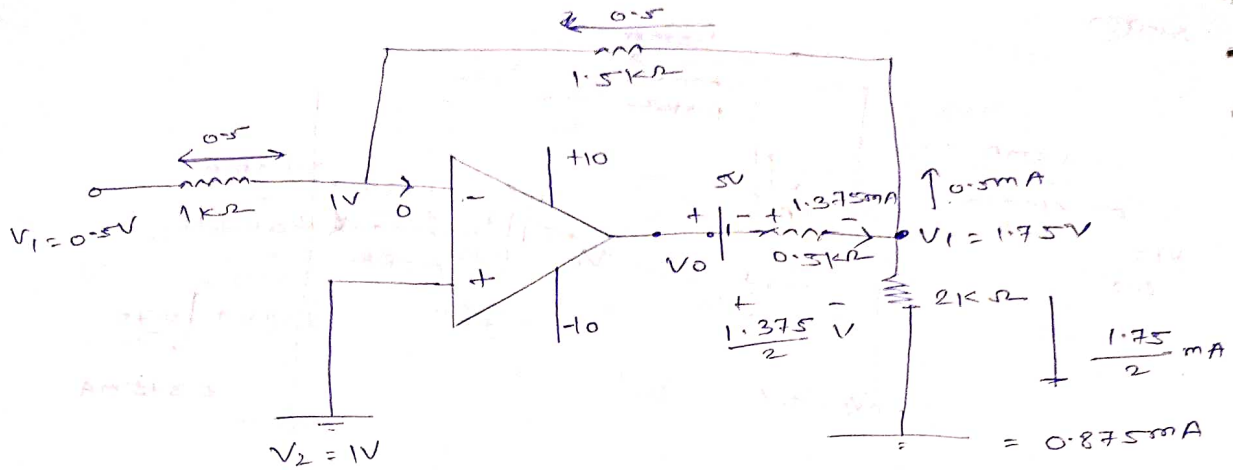
ii) $V_1 = 0.5V$, $V_2 = 3V$

V_o _____ upto threedecimal

Sol^n:- ①

step① O.C. test





$$\frac{0.5-1}{1} = \frac{1-V}{1.5}$$

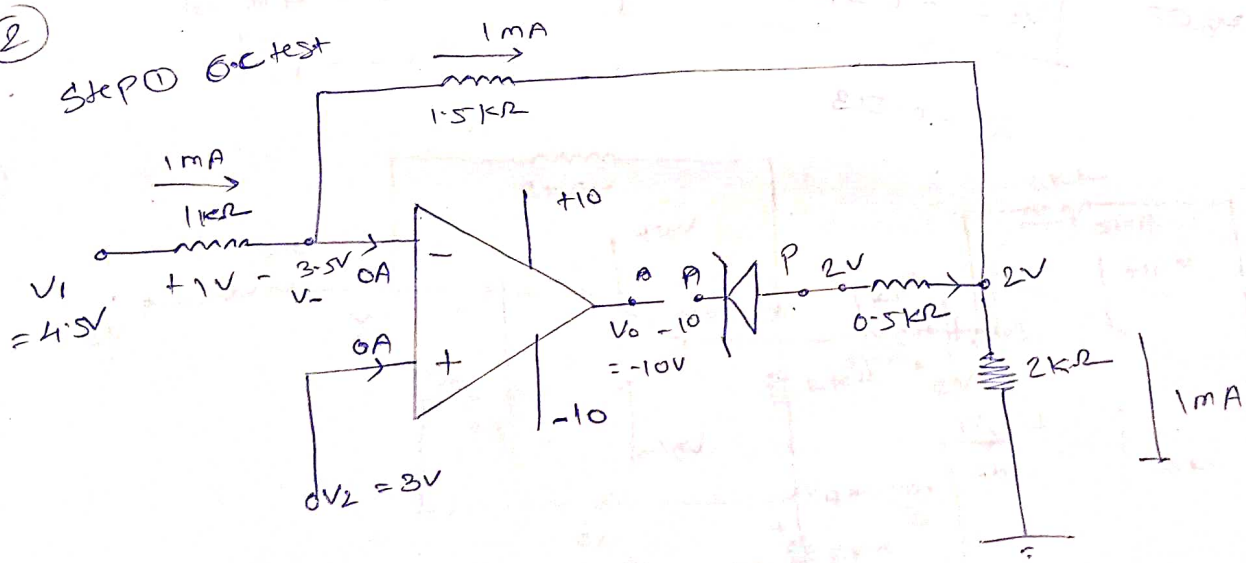
$1-V_1 = -0.75$

$\boxed{V_1 = 1.75\,V}$

$\boxed{V_0 = 7.4375\,V}$

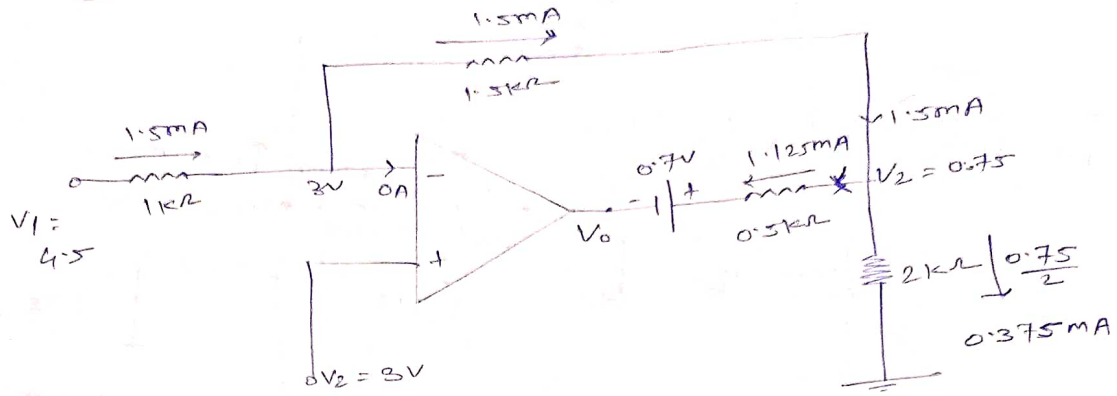
(2)

Step (1) O.C test



$V_p - V_n > V_\gamma$ (ON)

Step (2)



$$1.5 = \frac{3 - V_2}{1.5}$$

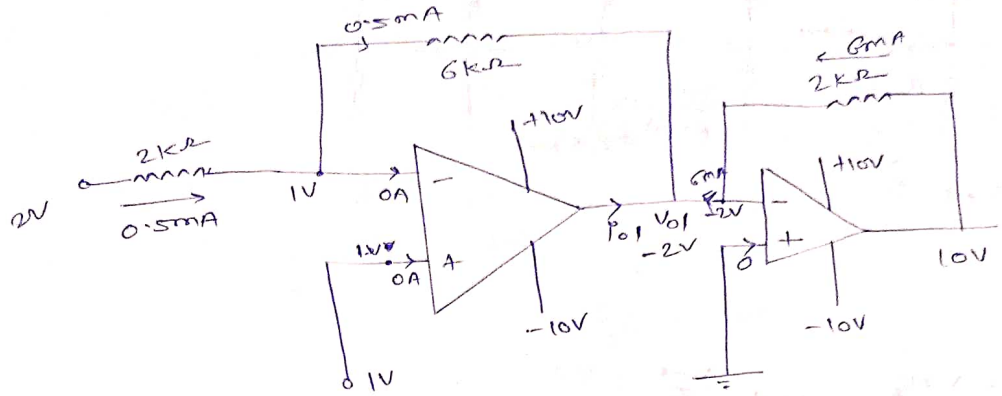
$$V_2 = 3 - 2.25 = 0.75V$$

$$\left(0.75 - \frac{1.125}{2} - 0.7\right) = V_o$$

$$\boxed{V_o = -0.5125 \text{ Volt}}$$

$$\approx -0.513$$

Q)



value of current i_{o1} ____ mA is upto two decimal.

Soln:-

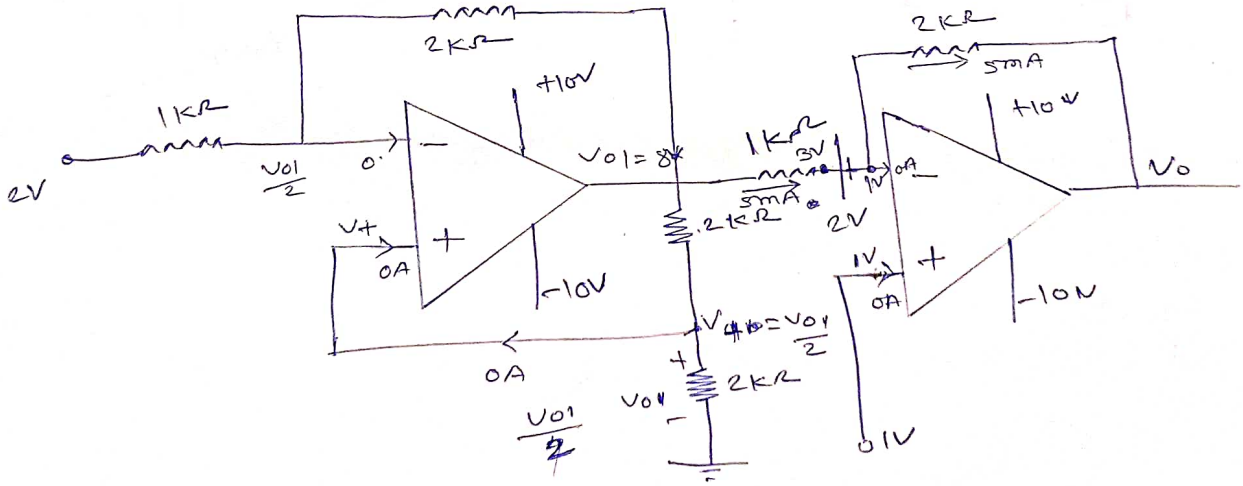
$$0.5 = \frac{1 - V_{o1}}{6}$$

$$V_{o1} = 1 - 3 = -2V$$

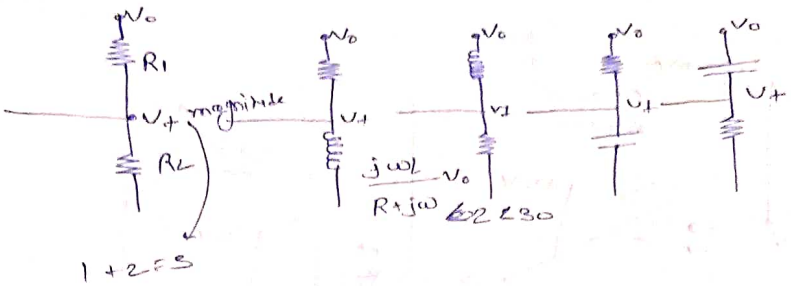
$$i_{o1} + 6 + 0.5 = 0$$

$$\boxed{i_{o1} = -6.50\ mA}$$

Q)



Q)



①

$$\frac{2 - V_{o1}/2}{1} = 0 + \frac{\frac{V_{o1}}{2} - V_{o1}}{2}$$

$$2 - V_{o1}/2 = \frac{-V_{o1}}{4}$$

$$2 = V_{o1}/4$$

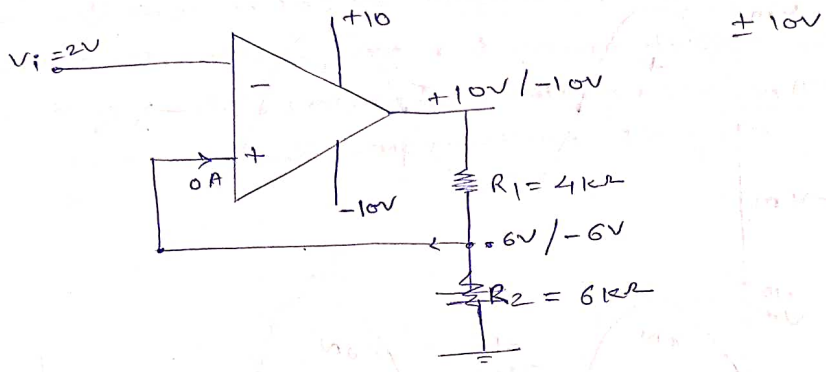
$$\boxed{V_{o1} = 8 \text{ volt}}$$

②

$$\frac{1 - V_o}{2} = 5$$

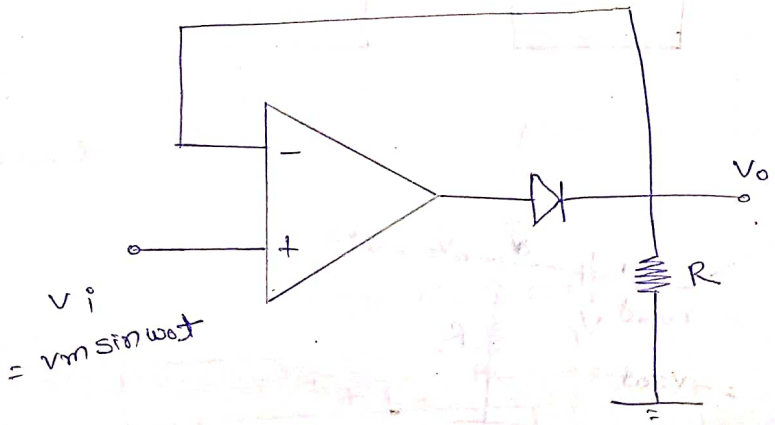
$$\boxed{V_o = -9V}$$

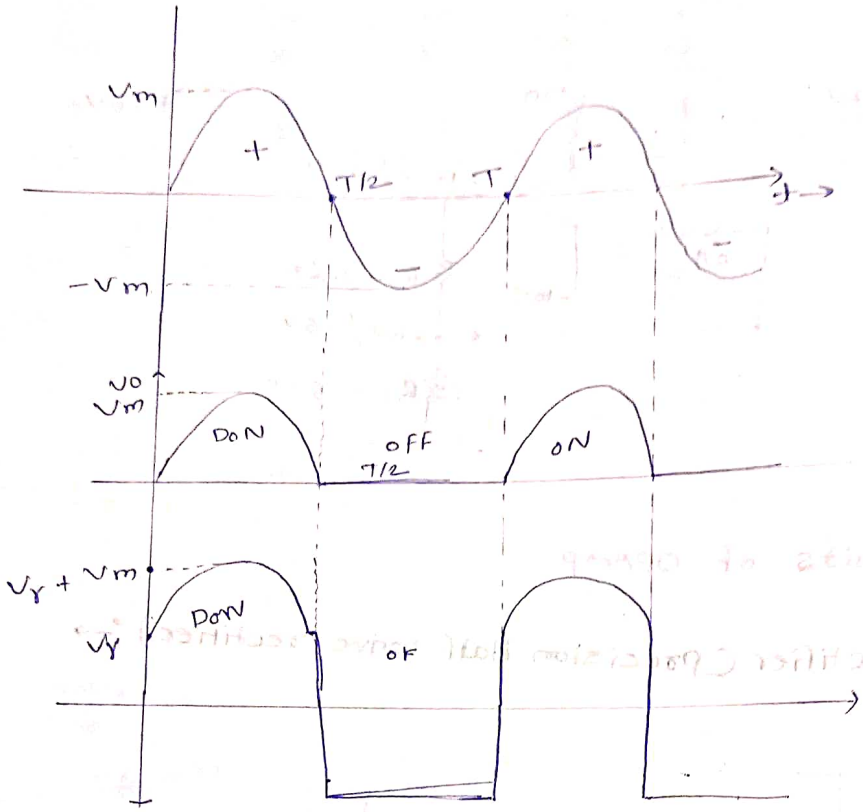
Q)

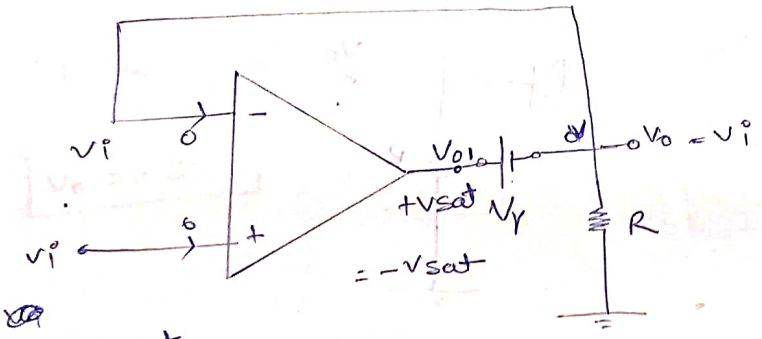


Standard circuits of OPAMP

Half wave rectifier (precision Half wave rectifier) :→







$= V_m \sin\omega t$

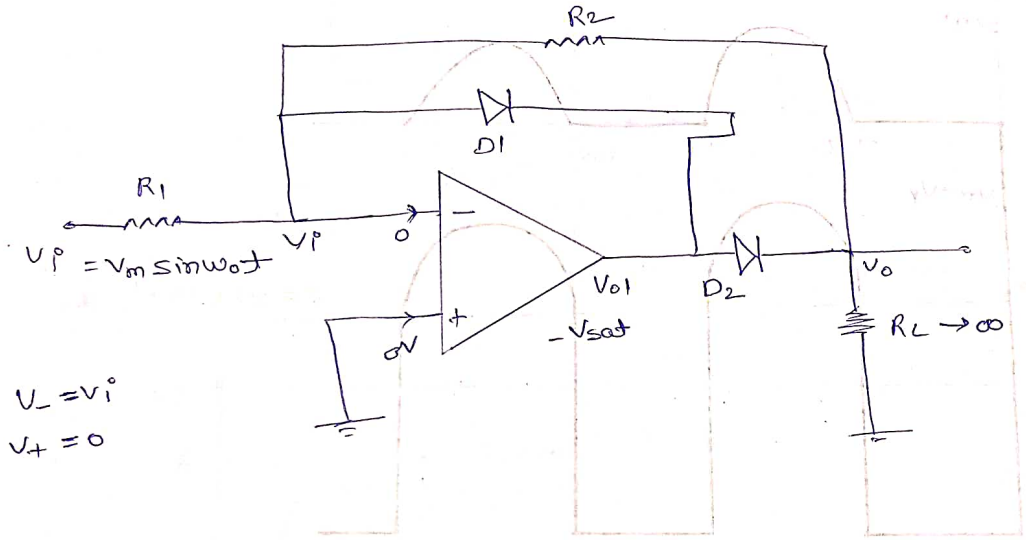
$0 < t < T/2 \rightarrow$ DON

$V_o = V_i$

$V_o = 0$

$T/2 < t < T$ – D – OFF

- In negative half cycle of the input waveform the output of opAmp V_{o1} goes into negative saturation value $-V_{sat}$. and its +ve half cycle it has to come out of saturation which takes time (practically) and we are not getting desired waveform. So we will try to avoid this negative saturation of the opAmp & try to design another half wave rectifier as given.



$V_- = V_i$

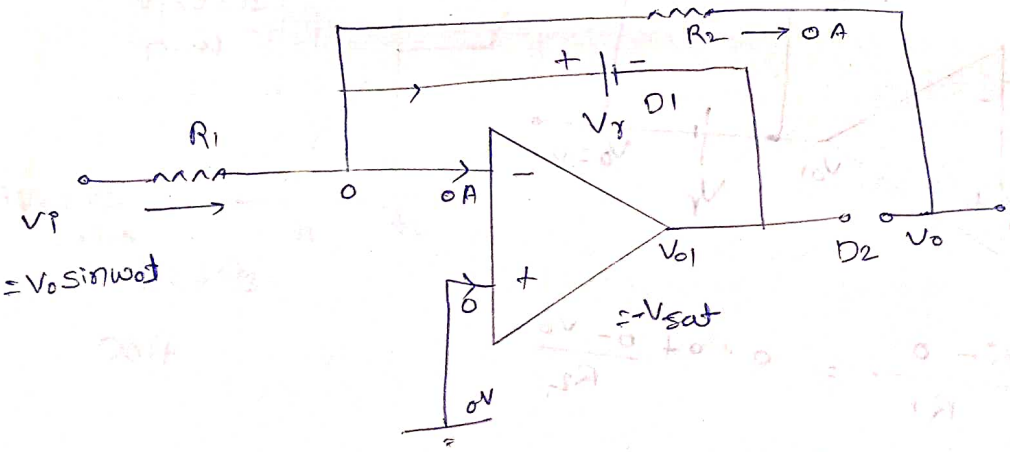
$V_+ = 0$

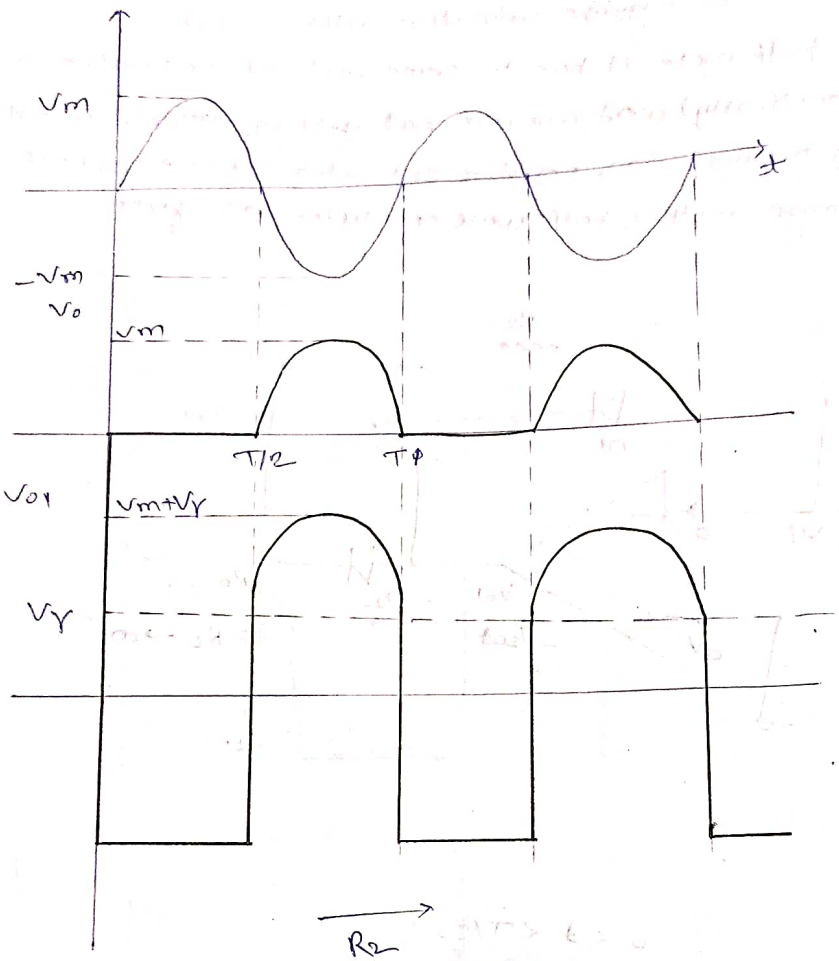
$V_i = V_m \sin w_o t$

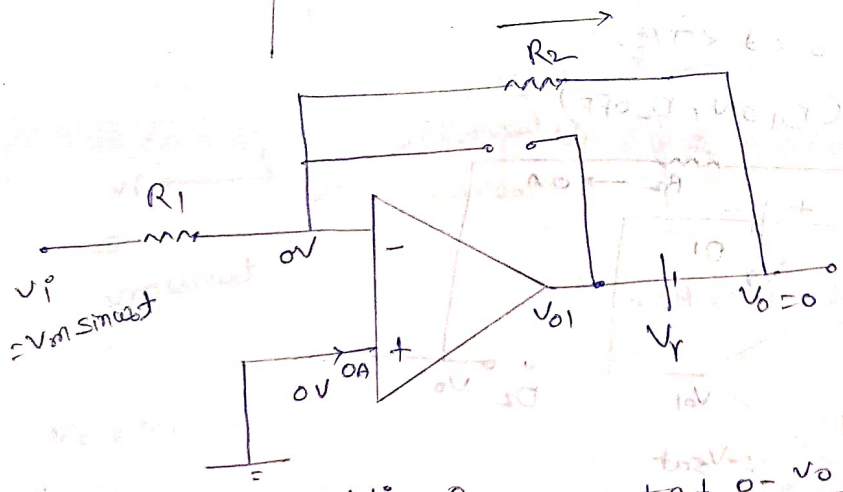
$V_o = 0$

$0 < t < T/2$

(D_1 ON, D_2 OFF)







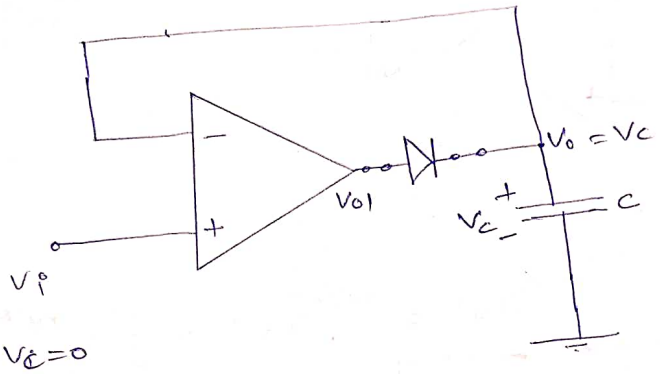
$$\frac{V_i - 0}{R_1} = 0 + 0 + \frac{0 - V_o}{R_2}$$

$$V_o = \frac{-R_2}{R_1} V_i$$

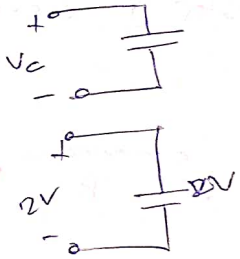
$T/2 < t < T$ (D_2 ON, D_1 OFF) :

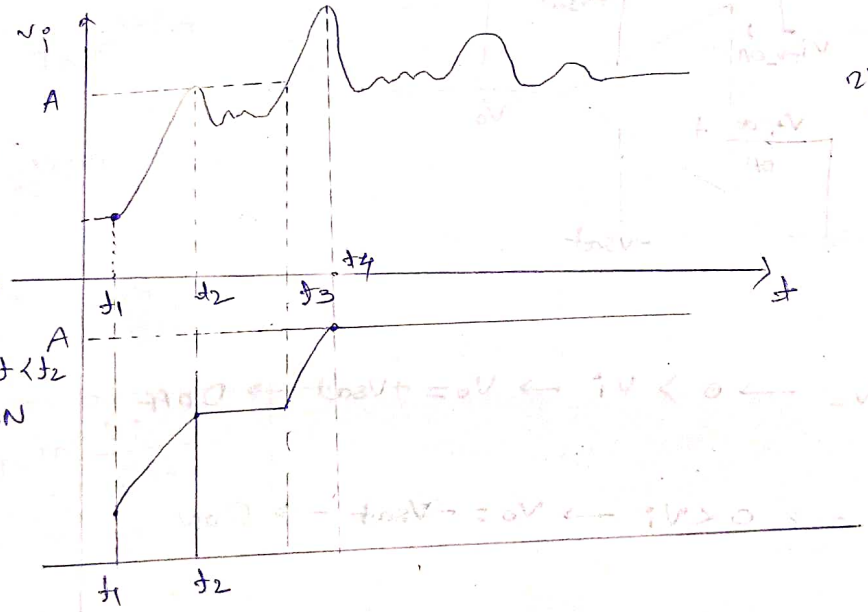
$-\frac{R_2}{R_1} v_1$

Active peak detector :→



at $t = t_1$, $V_c = 0$





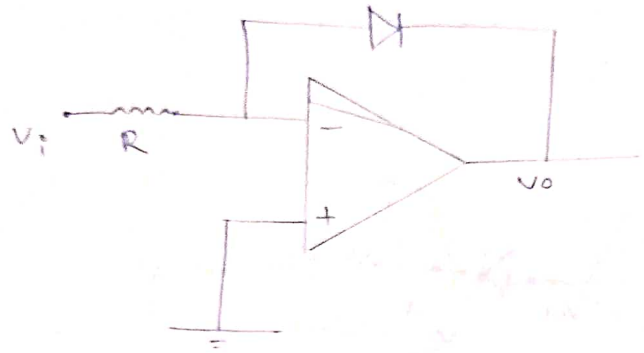
i) V_c follows V_i
$t_1 < t < t_2$
D-ON

ii) $V_o = V_c$
→ fix
$t_2 < t < t_3$
D OFF

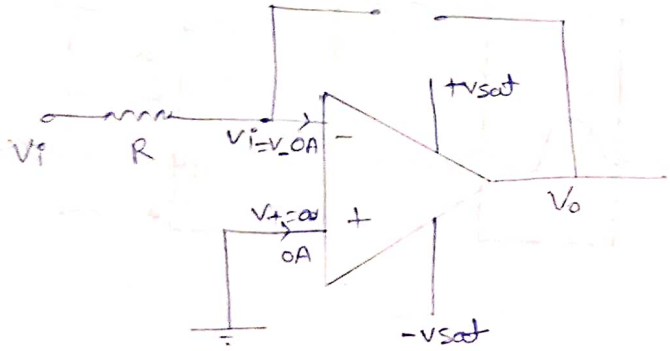
iii) V_c follows V_i
$t_3 < t < t_4$
D-ON

iv) $V_{o1} = -V_{sat}$
$t_4 < t$
D-OFF

Log Amplifier :-



Step ① O.C. test



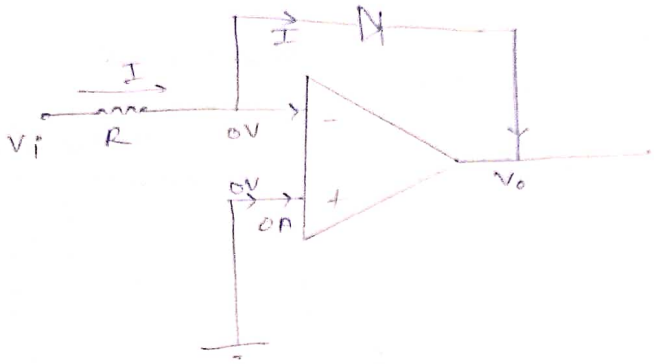
If $V_+ > V_- \rightarrow 0 > V_i \rightarrow V_o = +V_{sat} \rightarrow$ D off

if $V_+ < V_- \rightarrow 0 < V_i \rightarrow V_o = -V_{sat} \rightarrow$ D on.

if ① $V_i < 0 \rightarrow$ D off OPAMP $\rightarrow$ comparator

$V_o = V_{sat}$

(ii) if $V_i > 0 \longrightarrow$ DON $\rightarrow$ opamp works like amplifier and $V_+ = V_-$



$$I = \frac{V_i}{R}$$

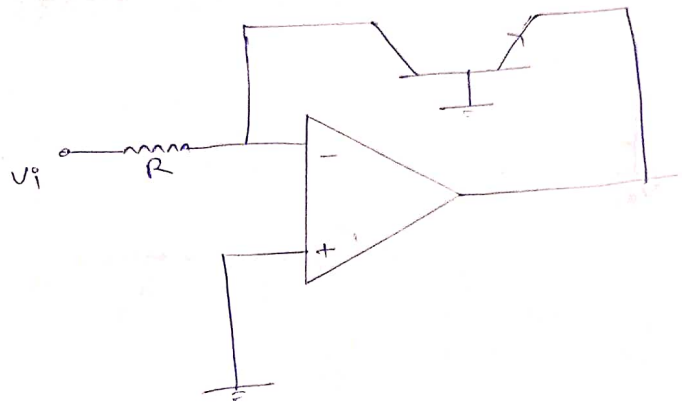
$$I = I_0\left[e^{V_d/V_T} - 1\right] \simeq I_0 e^{V_d/V_T} = I_0 e^{-V_o/V_T}$$

$$\frac{V_i}{R} = I_0 e^{-V_o/V_T}$$

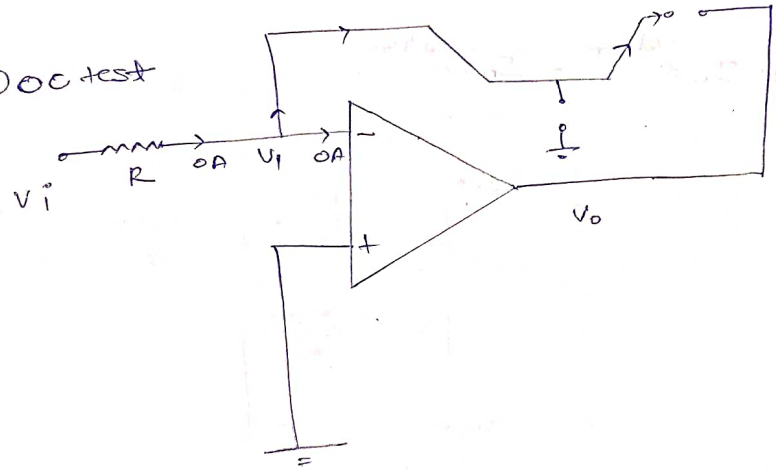
$$\frac{V_i}{I_0 R} = e^{-V_o/V_T}$$

$$\ln\left(\frac{V_i}{I_0 R}\right) = -\frac{V_o}{V_T}$$

$$\boxed{V_o = -V_T \ln \frac{V_i}{I_0 R}}$$



① OC test



$0 > V_i \longrightarrow +V_{sat} \longrightarrow$ BJT - OFF

$0 < V_i \longrightarrow -V_{sat} \longrightarrow$ BJT - ON

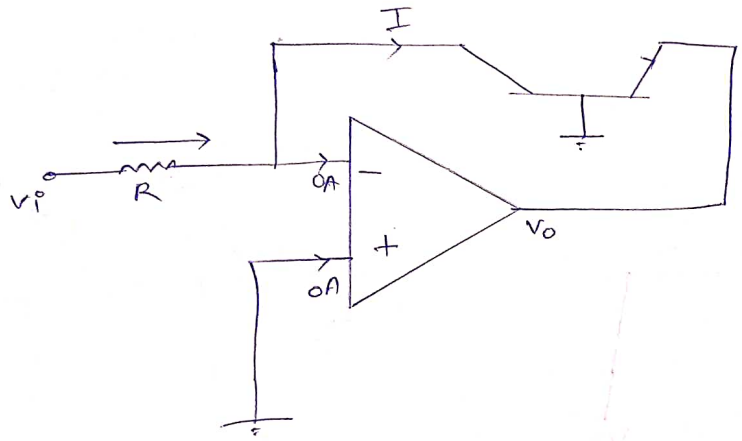
(II) (i) when

$V_i < 0 \longrightarrow$ BJT - OFF $\longrightarrow$ (OPAMP) comparator

$V_o = +V_{sat}$

(II) when

$V_i > 0 \longrightarrow$ BJT - ON $\longrightarrow$

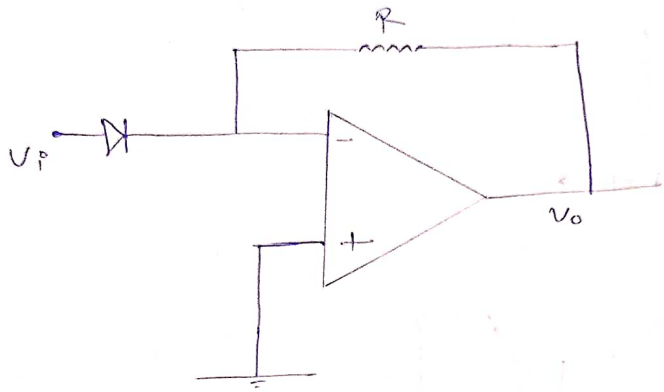


$$I = \frac{V_i - 0}{R} = \frac{V_i}{R}$$

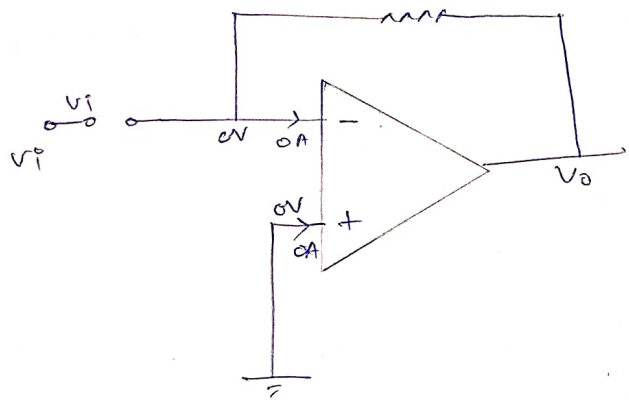
$$I_C = I = I_0 e^{V_{BE}/V_T}$$

$$\boxed{V_o = -V_T \ln \frac{V_i}{I_0 R}}$$

Antilog Amplifier



① o.c test



$$(V_p - V_n)_{o.c} = (V_i - 0) = V_i$$

if $V_i > 0 \longrightarrow$ D-ON

if $V_i < 0 \longrightarrow$ D-OFF

GARIMA NAGPUR

i) $V_i < 0 \longrightarrow$ D-off $\longrightarrow$ Amplifier

$\boxed{V = 0}$

ii) $V_i > 0 \longrightarrow$ Don $\longrightarrow$

$$I = I_0 \left(e^{V_d/V_T} - 1 \right) \cong I_0 e^{V_d/V_T}$$

$$I = I_0 e^{V_i/V_T}$$

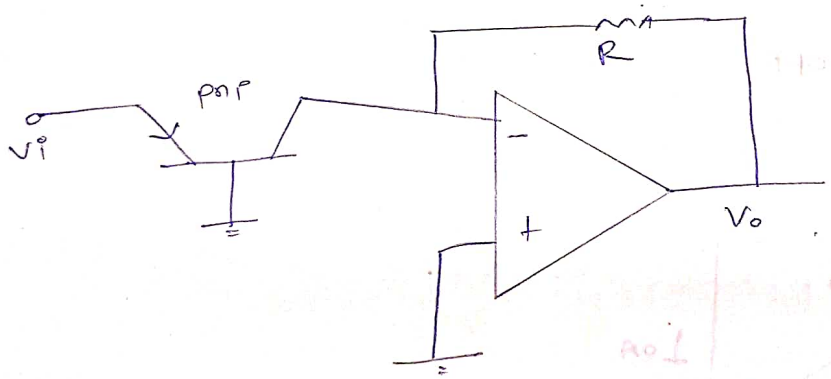
$$\frac{0 - V_o}{R} = I_0 e^{V_i/V_T}$$

$$\boxed{V_o = -I_0 R e^{V_i/V_T}}$$

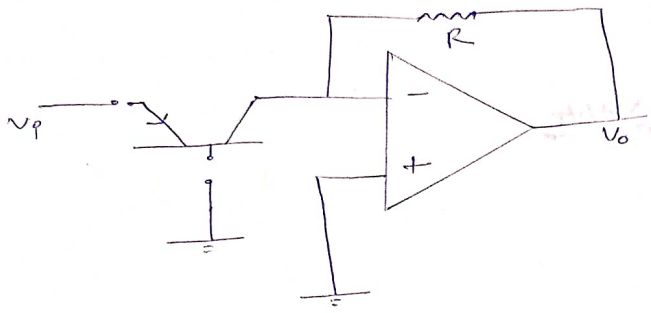
$B = \log_e A$

$\boxed{A = e^B}$

Eg:②



① O.C test



O.C.

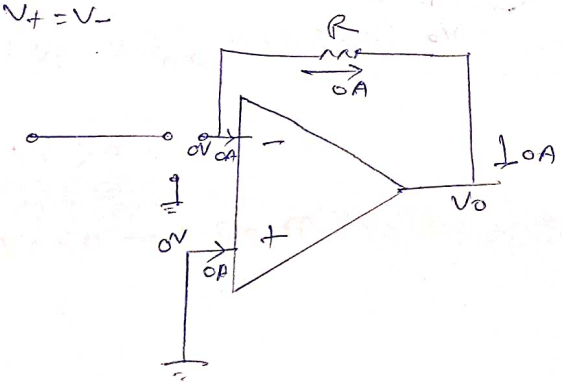
$V_E - V_B = (V_i - 0) = V_i$

if $V_i > (V_{EB})_{active} \longrightarrow V_i > 0 \longrightarrow ON$

$V_i < (V_{EB})_{active} \longrightarrow V_i < 0 \longrightarrow OFF$

i) $V_i < 0$ — BJT - OFF

$V_+ = V_-$

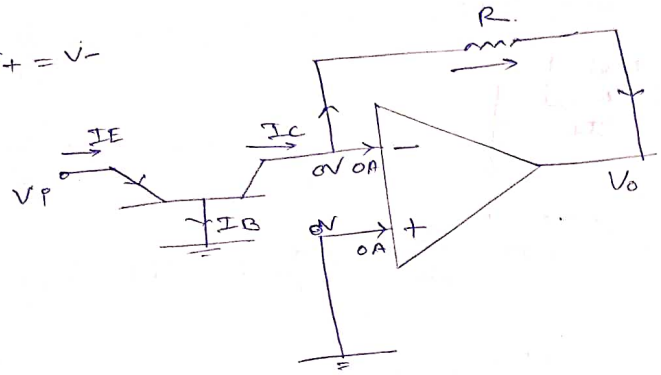


$V_o = 0$

ii)

ii) $V_i > 0 \longrightarrow$ BJT-ON

$V_+ = V_-$



$$I_C = \frac{0 - V_o}{R}$$

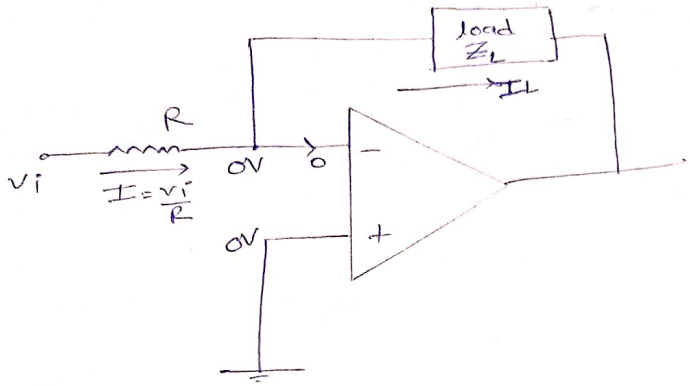
$$I_o e^{V_{EB}/V_T} = \frac{-V_o}{R}$$

$$I_o e^{V_i/V_T} = \frac{-V_o}{R}$$

$$\boxed{V_o = -I_o R e^{V_i/V_T}}$$

Imp

V-I converter :-

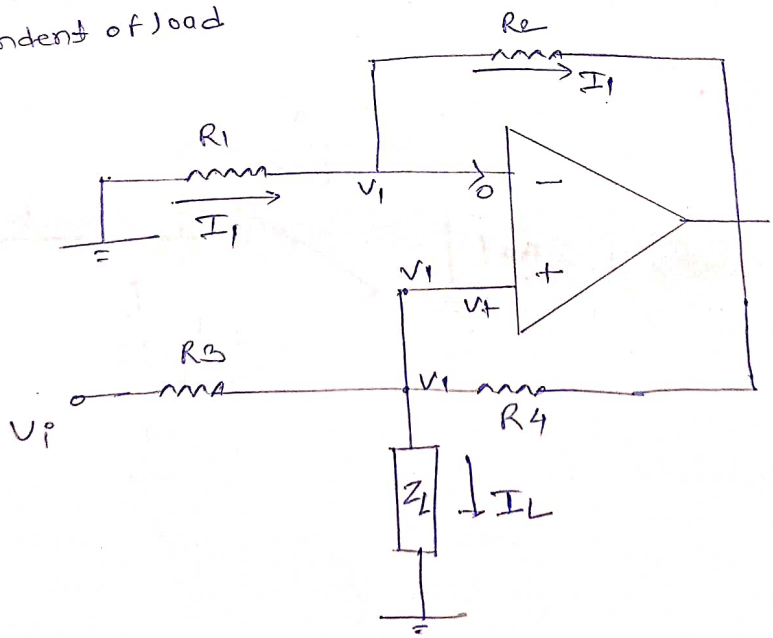


$V_+ = V_-$

$$\frac{V_i - 0}{R} = 0 + I_L$$

$$\boxed{I_L = \frac{V_i}{R}}$$ → V_i converted into current source

Independent of load



GARIMA NAGPUR

$$\frac{0-V_1}{R_1} = 0 + \frac{V_1 - V_0}{R_2}$$

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

$$\frac{V_i - V_1}{R_3} = 0 + \frac{V_1 - 0}{Z_L} + \frac{V_1 - V_0}{R_4}$$

$$V_i - V_1 = R_3 I_L + \frac{R_3}{R_4}\left[-\frac{R_2}{R_1} V_1\right]$$

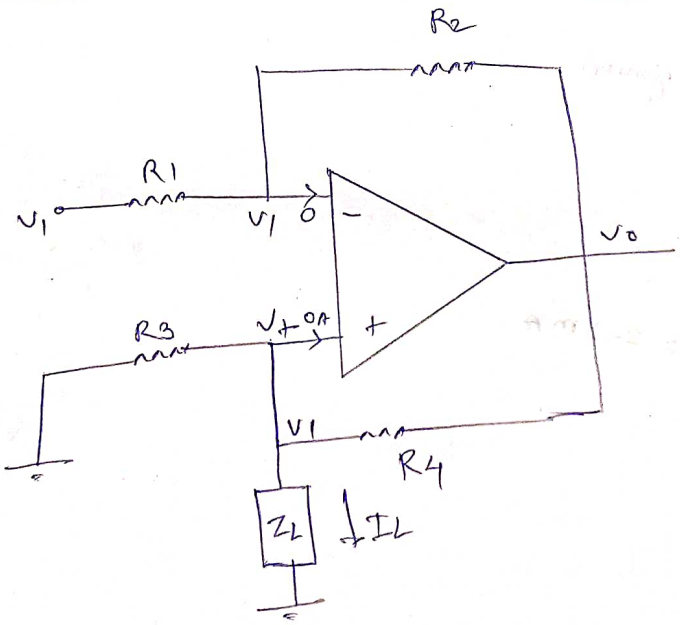
$$V_i = V_1\left[1 + \frac{R_3}{Z_L} - \frac{R_3 R_2}{R_4 R_1}\right] \quad \text{--- (1)}$$

if $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

from eqn (1) $V_i = V_1\left[\frac{R_3}{Z_L}\right] = I_L R_3$

$$\boxed{I_L = \frac{V_i}{3}}$$

if



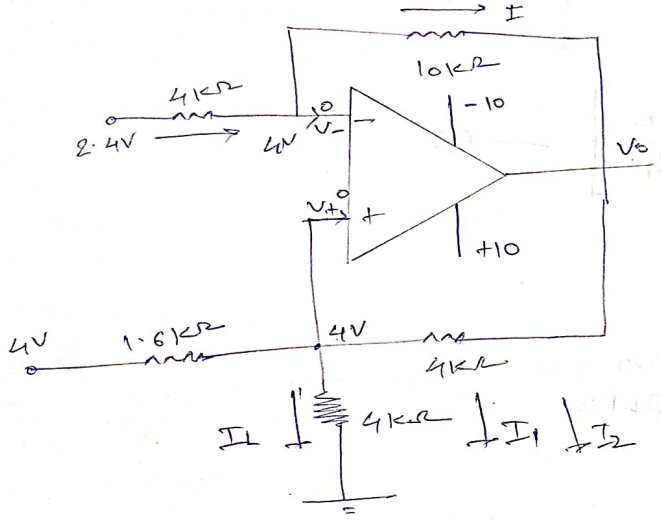
$$\frac{R_2}{R_1} = \frac{R_4}{R_3}$$

$$\boxed{I_L = \frac{-V_i}{R_3}}$$

Q)

$$\frac{2.4-4}{4} = 0.4 \quad \frac{4-V_o}{10}$$

$$\boxed{V_o = 8V}$$



V_o _____ volts

Super position theorm

2.4V → off → ground

4V → active

~~Vo = 4~~

$$I_1 = \frac{4}{1.6} = 2.5mA$$

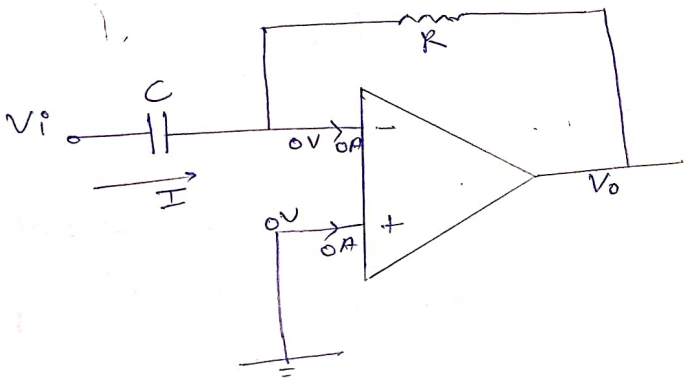
4V → off → current

2.4 V → ON

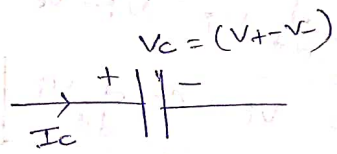
$$I_2 = \frac{-2.4}{1.6} = -1.5\,mA$$

$$I_L = I_1 + I_2 = 1\,mA.$$

Differentiator :→



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



$V_+ = V_-$

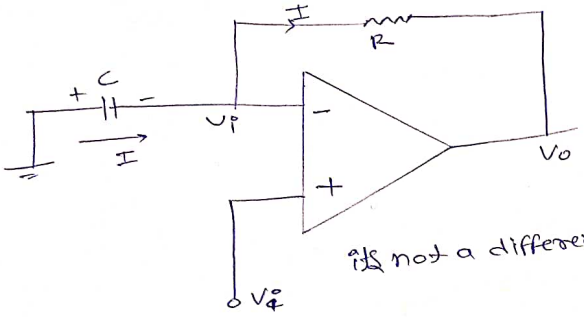
$$I = C\frac{d}{dt}\left[V_i - 0\right]$$

$$I = C\frac{dV_i}{dt} \quad -(i)$$

$$C\frac{dV_i}{dt} = 0 + \frac{0 - V_o}{R}$$

$$\boxed{V_o = -RC\frac{dV_i}{dt}}$$

e.g:-



it's not a differentiator

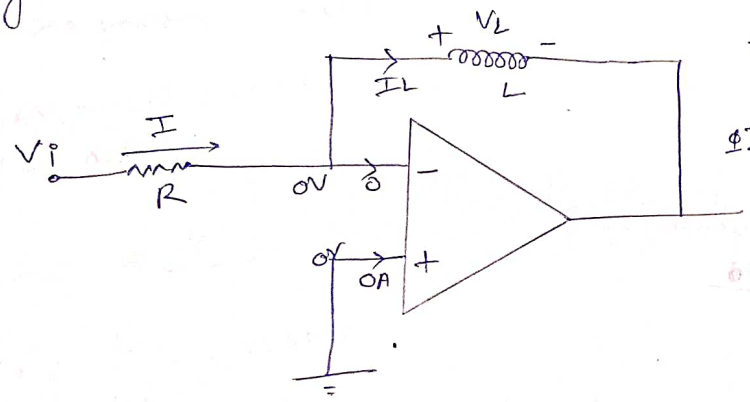
$$I = C\frac{dV_c}{dt} = C\frac{d}{dt}[0 - V_i] = -C\frac{d}{dt}V_i$$

$$-C\frac{d}{dt}V_i = 0 + \frac{V_i - V_o}{R}$$

$$-RC\frac{d}{dt}V_i = V_i - V_o$$

$$\boxed{V_o = V_i + RC\frac{d}{dt}V_i}$$

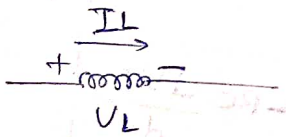
e.g:-



$$I = \frac{V_i - 0}{R} = 0 + I_L \quad \text{—(i)}$$

$$I = 0 + I_L \quad \text{—(i)}$$

$$I_L = \frac{V_i}{R} \quad \text{—(ii)}$$

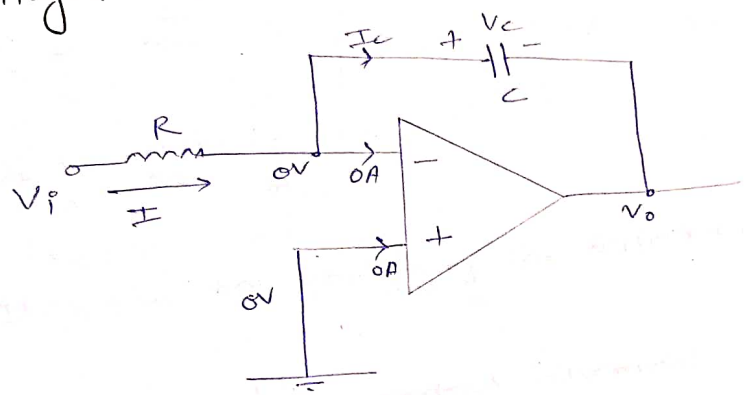


$$V_L = L\frac{dI_L}{dt}$$

$$0 - V_o = L\frac{d}{dt}(V_i/R)$$

$$\boxed{V_o = -\frac{L}{R}\frac{d}{dt}V_i}$$

Integrator :-



$V_+ = V_-$

$$I = \frac{V_i - 0}{R} = 0 + I_c$$

$$I_c = \frac{V_i}{R} \quad \text{—(i)}$$

$$C\frac{dV_c}{dt} = \frac{V_i}{R}$$

$$C\frac{d}{dt}[0 - V_o] = \frac{V_i}{R}$$

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

$$\frac{dV_o}{dt} = -\frac{1}{RC}V_i$$

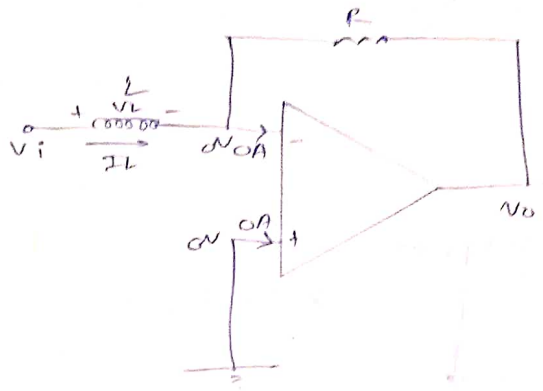
$$\int dV_o = -\frac{1}{RC}V_i\,dt$$

$$\int dV_o = -\int \frac{1}{RC}V_i\,dt + a$$

$\boxed{a = \text{const.}}$

$$\boxed{V_o = -\frac{1}{RC}\int V_i\,dt + a}$$

eg:-



$V_+ = V_-$

$$V_L = L\frac{dI_L}{dt}$$

$$(V_i - 0) = L\frac{dI_L}{dt} \quad -(1)$$

$$I_L = 0 + \left(\frac{0 - V_o}{R}\right) = \frac{-V_o}{R} \quad -(11)$$

$$V_i = L\frac{d}{dt}\left[\frac{-V_o}{R}\right] = \frac{-L}{R}\frac{d}{dt}V_o$$

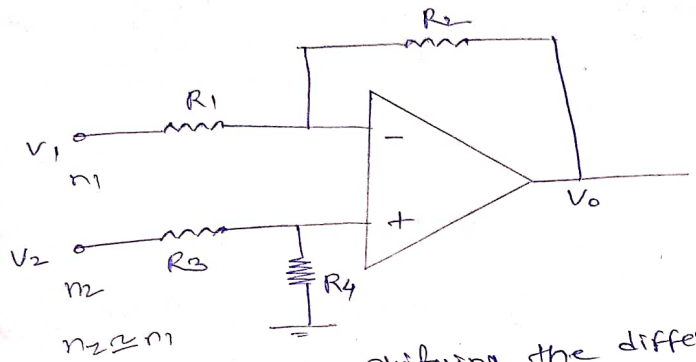
$$dV_o = \frac{-R}{L}\cdot V_i\,dt$$

$$\int dV_o = \frac{-1}{L/R}\int V_i\,dt$$

$$\boxed{V_o = \frac{-1}{L/R}\int V_i\,dt + a}$$

Important

Differential Amplifier :-



① It is used for amplifying the difference of i/p.

$V_o = A_d (V_2 - V_1)$ → perfect differential

$V_o = A_d (V_2 - V_1) + A_c \left(\frac{V_1 + V_2}{2}\right)$ → what we I do not desired

A_d ↓ differential gain

A_c ↓ common mode gain

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

for ideal differential amplifier, common mode gain $A_c = 0$.

$CMRR \longrightarrow \infty$

- for a good differential Amplifier A_c should be as small as possible so that the effect of common mode voltage is very less in the o/p

ie. Common mode is rejected at the output terminal.

→ and in ideal case this A_c should be zero.

for a differential Amplifier

CMRR should be as high as possible

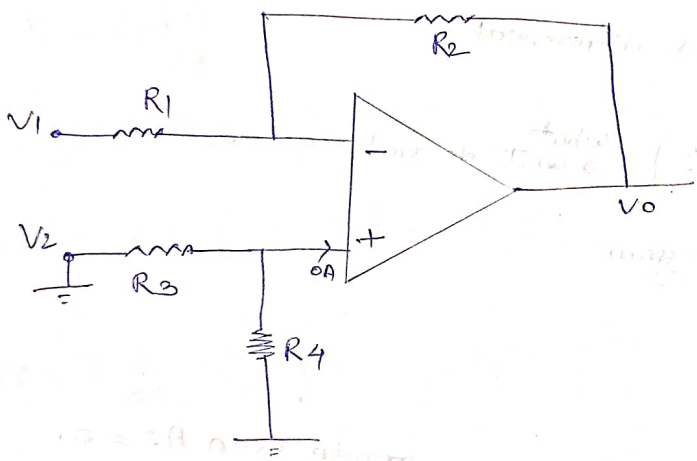
and ideal case

CMRR should be ∞

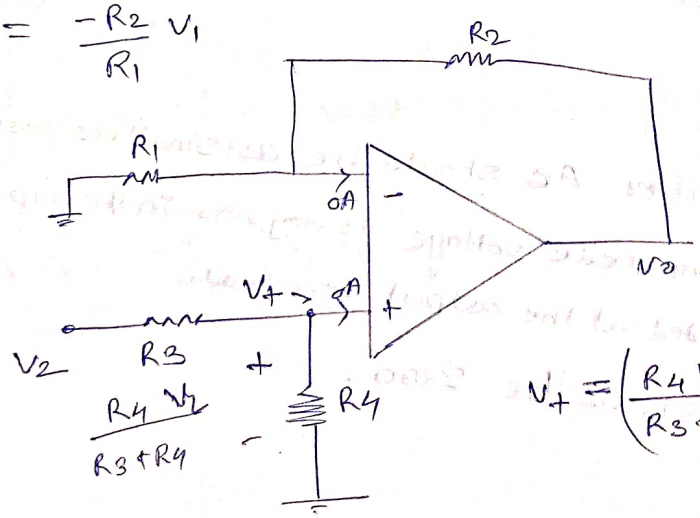
$$\boxed{V_o = A_d (V_d) + A_c V_c}$$

$V_d = V_2 - V_1$, $V_c = \frac{V_1 + V_2}{2}$

superposition



$$V_o = \frac{-R_2}{R_1} V_1$$



$$V_+ = \left(\frac{R_4 \cdot V_2}{R_3 + R_4}\right)$$

$$V_o = \left(\frac{+R_2}{R_1} V_1\right) + \left(\frac{R_4}{R_3+R_4}\right) V_2 \left(1+\frac{R_2}{R_1}\right)$$

$$\boxed{V_o = \frac{\left(\frac{R_4}{R_3}\right)}{1+R_4/R_3}\left(1+\frac{R_2}{R_1}\right) V_2 - \frac{R_2}{R_1} V_1}$$

$$V_d = V_2 - V_1 \longrightarrow V_2 = V_c + \frac{V_d}{2}$$

$$V_c = \frac{V_1+V_2}{2} \qquad V_1 = V_c - \frac{V_4}{2}$$

$$V_o = \frac{R_4/R_3}{(1+R_4/R_3)} (1+R_2/R_1)\left[V_c + V_d/2\right] - \frac{R_2}{R_1}(V_c - V_d/2)$$

$$V_o = \frac{V_d}{2}\left[\frac{R_4/R_3}{(1+R_4/R_3)}(1+R_2/R_1) + \frac{R_2}{R_1}\right] + V_c\left[\frac{R_4/R_3}{(1+R_4/R_3)}\left(1+\frac{R_2}{R_1}\right) - \frac{R_2}{R_1}\right]$$

$$A_d = \frac{1}{2}\left[\frac{R_4/R_3}{(1+R_4/R_3)}(1+R_2/R_1) + R_2/R_1\right] = \frac{a+b}{2}$$

$$\cancel{A_d} \; A_c = \left[\left(\frac{R_4/R_3}{1+R_4/R_3}\right)\left(1+\frac{R_2}{R_1}\right) - R_2/R_1\right] = (a-b)$$

$$CMRR = [A_d/A_c]$$

A_d & A_c are independent of V_1 & V_2

$\therefore$ CMRR is independent of V_1 & V_2

$$A_d = \left[\frac{R_4/R_3}{1+R_4/R_3} \left(1+R_2/R_1\right) + R_2/R_1 \right]$$

$$A_c = \left[\frac{R_4/R_3}{1+R_4/R_3} \left(1+R_2/R_1\right) - \frac{R_2}{R_1} \right]$$

if $\frac{R_4}{R_3} = \frac{R_2}{R_1} \longrightarrow A_d = \frac{1}{2}\left[\frac{R_2}{R_1} + \frac{R_2}{R_1}\right]$

$$= \frac{R_2}{R_1}$$

$$A_c = \left[\frac{R_2}{R_1} - \frac{R_2}{R_1}\right] = 0$$

CMRR $\longrightarrow \infty$

$V_o = A_d V_d + A_c V_c = \frac{R_2}{R_1}\left(V_2 - V_1\right) + 0$

(ideal case)

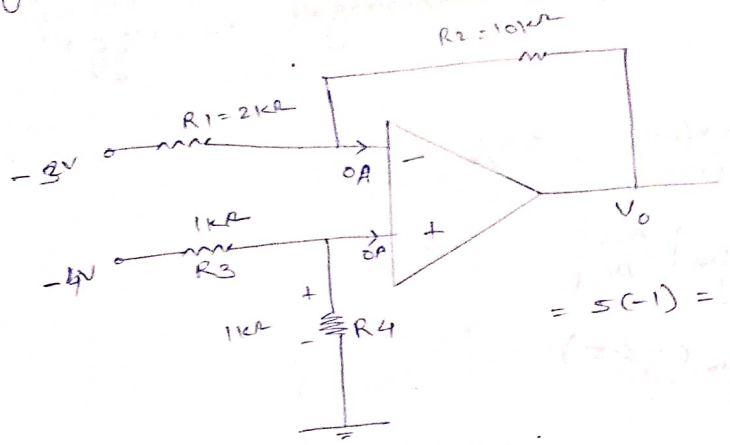
if

$\frac{R_2}{R_1} \neq \frac{R_4}{R_3}$ $\quad A_d \rightarrow$ non-zero

$A_c \rightarrow$ non-zero

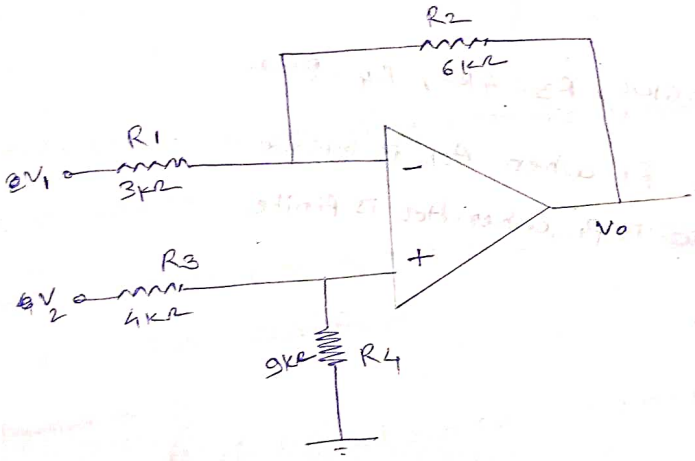
CMRR $\rightarrow$ finite

eg:-



$= 5(-1) = -5V$

Q)



i) $R_1 = 3k\Omega$, $R_2 = 6k\Omega$, $R_3 = 4k\Omega$, $R_4 = 9k\Omega$,

CMRR $\longrightarrow$ in dB

Soln:-

$$V_o = -2V_1 + \frac{9V_2}{13}(1+2) = -2V_1 + \frac{27}{13}V_2$$

$$V_o = -2\left(V_c + \frac{V_d}{2}\right) + \frac{27}{13}\left(V_c + \frac{V_d}{2}\right)$$

$V_d = V_2 - V_1$

$V_c = \frac{V_1 + V_2}{2}$

$$V_o = V_c\left[-2 + \frac{27}{13}\right] + \frac{V_d}{2}\left[2 + \frac{27}{13}\right]$$

$$A_c = \frac{1}{13}, \quad A_d = \frac{53}{26}$$

$$CMRR = \left|\frac{A_d}{A_c}\right| = \frac{53/26}{1/13} = 53/2 = 26.5$$

$$(CMRR)_{dB} = 20\log_{10}\left|\frac{A_d}{A_c}\right|$$

$$= 20\log_{10}(26.5)$$

ii) $R_1 = 3K\Omega$, $R_2 = 6K\Omega$, $R_3 = 4K\Omega$, $R_4 = 12K\Omega$

$V_o =$

iii) $R_1 = 3K\Omega$, $R_2 = 6K\Omega$, $R_3 = 4K\Omega$, $R_4 = 8K\Omega$

initially CMRR is P_1 when A_{OL} is infinite and finally CMRR is P_2 when A_{OL} is finite and equal to 100.

then

a) $P_1 = P_2$

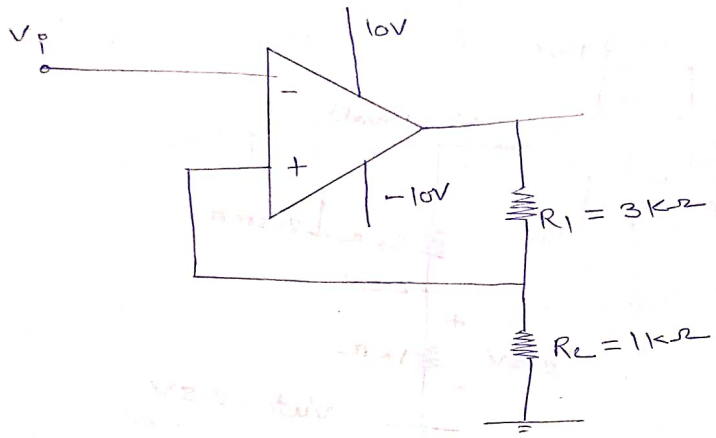
b) $P_1 > P_2$

c) $P_1 < P_2$

d) NOT.

Schimitt :→

Trigger or Regeneration comparator or square wave converter or Inverting schimit trigger



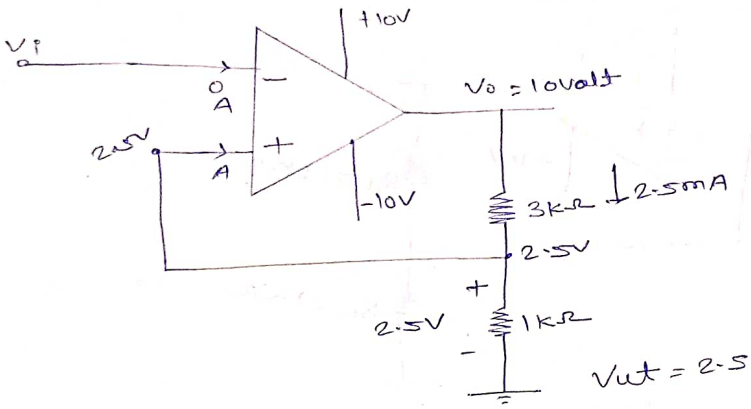
1) Schiitt trigger converts any periodic waveform into corresponding square waveform.

2) converted waveform will have same frequency and time period as of the input waveform.

3) Imp upper threshold voltage
V_{ut} :- value of i/p at which o/p takes transition from $+V_{sat}$ to $-V_{sat}$

4) Imp Lower threshold voltage
V_{Lt} :- value of i/p at which o/p take transition from $-V_{sat}$ to $+V_{sat}$

4) Hysterisis width = $|V_{ut} - V_{Lt}|$ volt

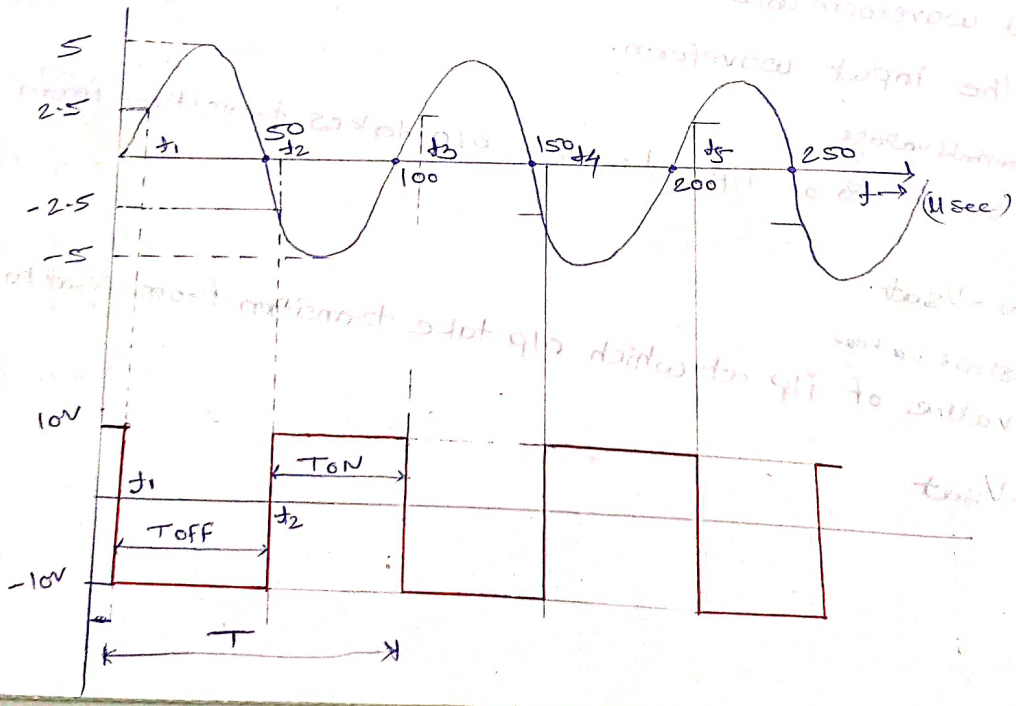


$V_{ut} = 2.5V$

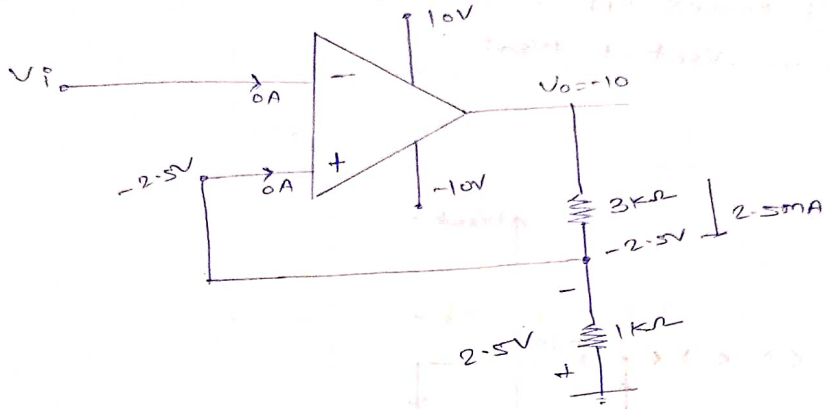
$V_{Lt} = -2.5V$

$V_i = 5 \sin \omega_0 t$

$\omega_0 = 2\pi \times 10^4$ rad/sec



$$\frac{2\pi}{\omega_0} = T = \frac{2\pi}{2\pi \times 10^4} = 100\mu sec$$



$V_+ = -2.5V$

$T = t_3 - t_1 = 100\mu sec \rightarrow$ same as i/p

How to calculate V_{ut}

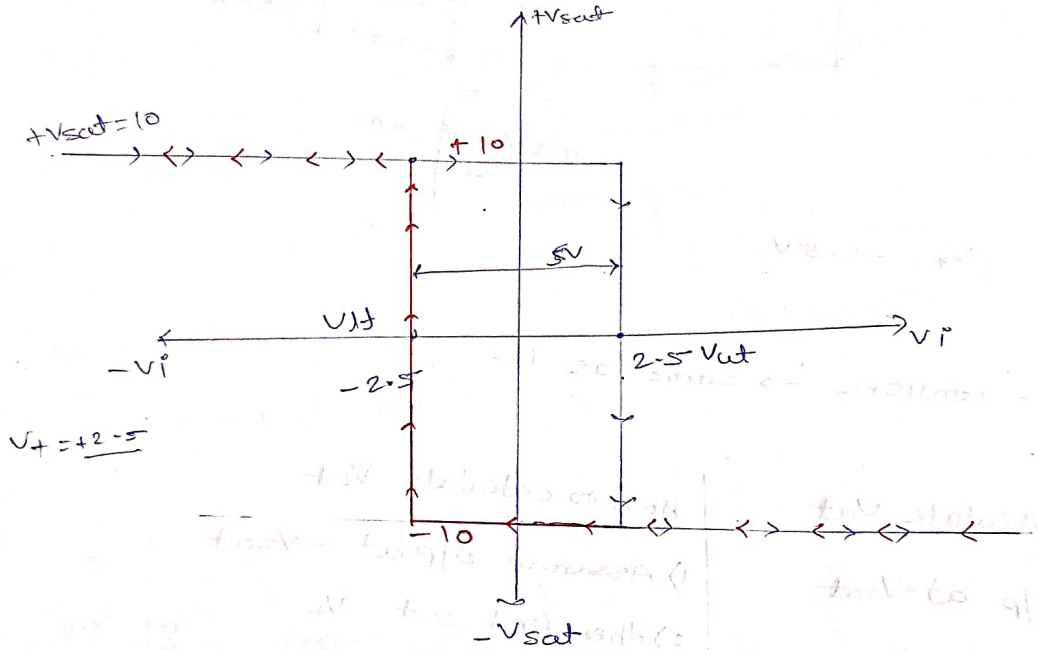
1) Assume o/p at $+V_{sat}$
2) then find out V_+
3) find out V_-
4) Equate $\boxed{V_+ = V_-}$
5) The value of vi from above eqn (4) will give you V_{ut} or V_{Lt}

How to calculate V_{Lt}

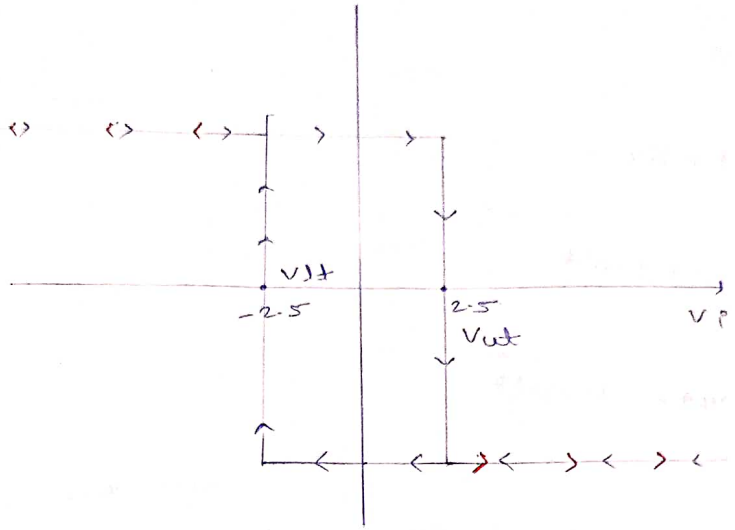
1) Assume o/p at $-V_{sat}$
2) then find out V_+
3) find out V_-
4) Equate $V_+ = V_-$

1) when V_i crosses V_{ut} in +ve slope then only o/p take transition from $+V_{sat}$ to $-V_{sat}$.

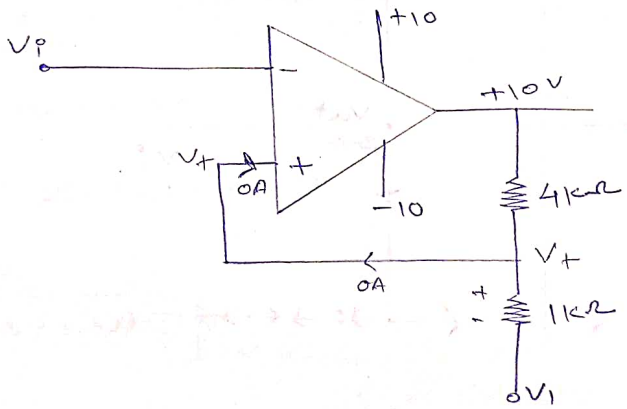
2) when V_i crosses V_{lt} in -ve slope then only o/p take transition $-V_{sat}$ to $+V_{sat}$



$V_t = \pm 2.5$



Q)



i) $V_1 = 1.5V$

V_{ut} = ___

V_{lt} ___

Hy ___

$$V_+ = \frac{V_o - V_1}{5} \times 1$$

$$V_+ = \frac{1}{5} V_o + \frac{4}{5} V_1$$

$V_{ut} \rightarrow V_o = +10$

$V_+ = 2 + 1.2 = 3.2$

$V_- = V_i$

$V_i = 3.2 \longrightarrow V_{ut} = 3.2$

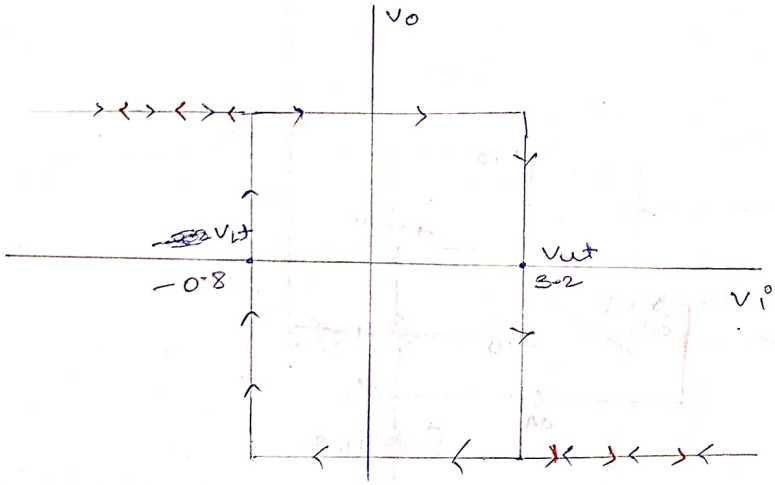
$V_{Lt} \rightarrow V_o = -10$

$V_+ = -2 + 1.2 = -0.8$ volt

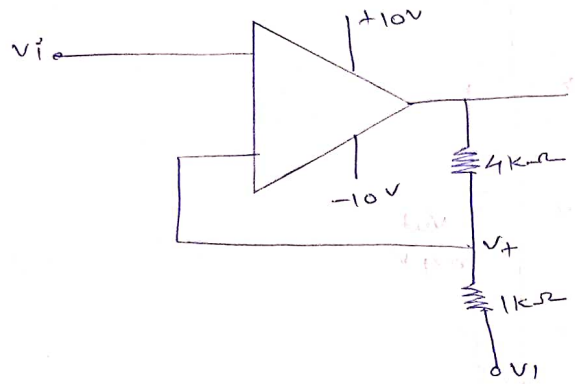
$V_- = V_i$

$V_i = -0.8\,V \longrightarrow V_{Lt} = -0.8$ volt

$V_{hy} = 4.0V$



ii) $V_1 = -2V$



$V_{ut} \Rightarrow V_o = +10$

$V_+ = 2 + (-1.6) = 0.4$ volt

$V_- = V_i$

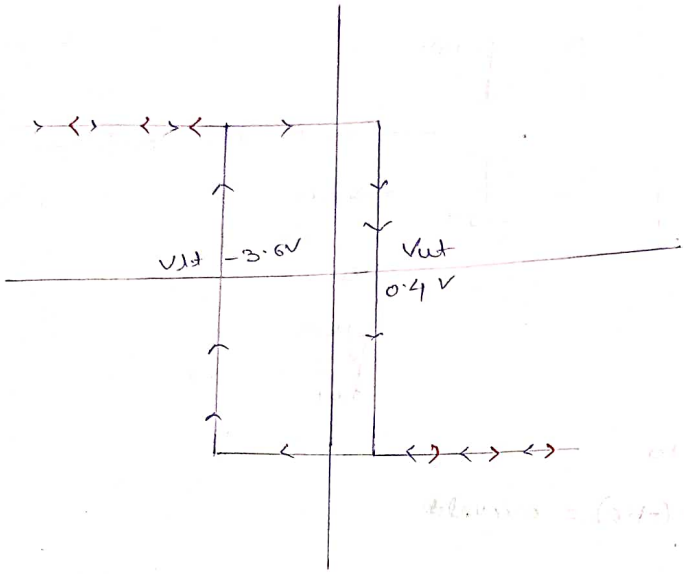
$\boxed{V_i = 0.4V = \cancel{\text{volt}}\ V_{ut}}$

$V_{lt} = V_o = -10V$

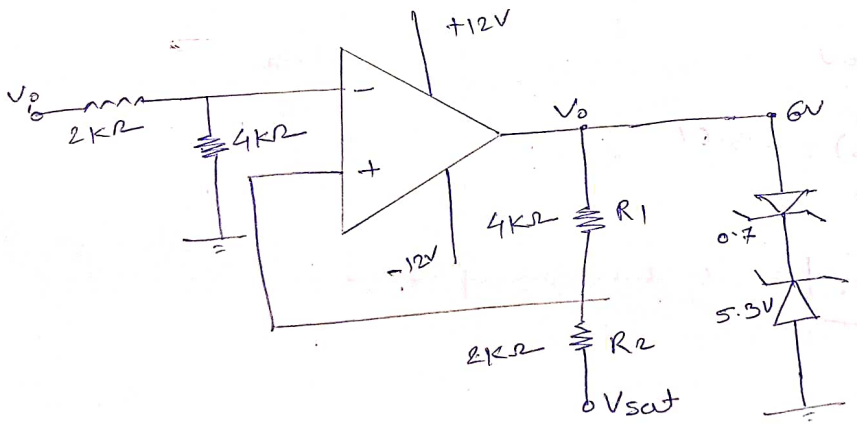
$V_+ = -2 + (-1.6) = -3.6V$

$V_1 = V_-$

$\boxed{-3.6 = V_i = V_{lt}.}$



Q)



i) $V_{sat} = 0$

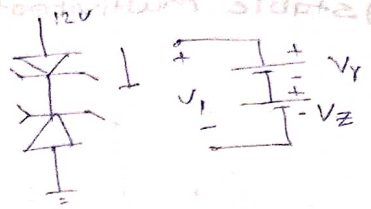
$V_{ut} =$

V_{Lt}

ii) $V_{sat} = 3V$

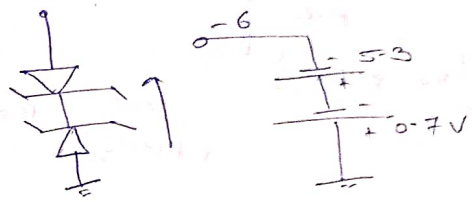
i) $V_o = +12$

$V_o = +6$

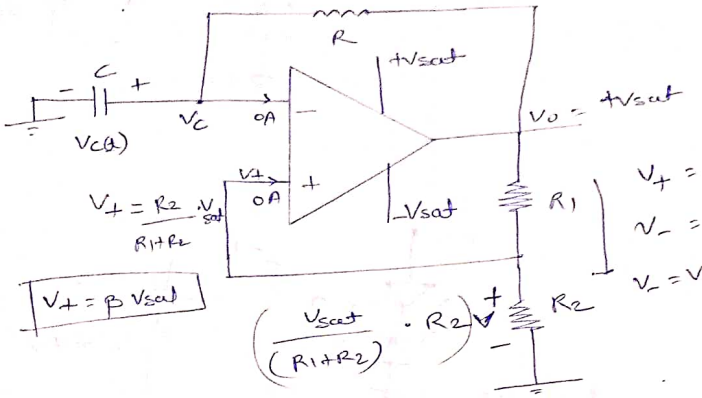


ii) $V_o = -12\,V$

$V_o = -6$



Astable multivibrator :→ square wave generator



$V_+ = \frac{R_2}{R_1+R_2} V_{sat}$

$\boxed{V_+ = \beta V_{sat}}$

$\left(\frac{V_{sat}}{(R_1+R_2)} \cdot R_2\right)$

$V_+ = -\beta V_{sat}$

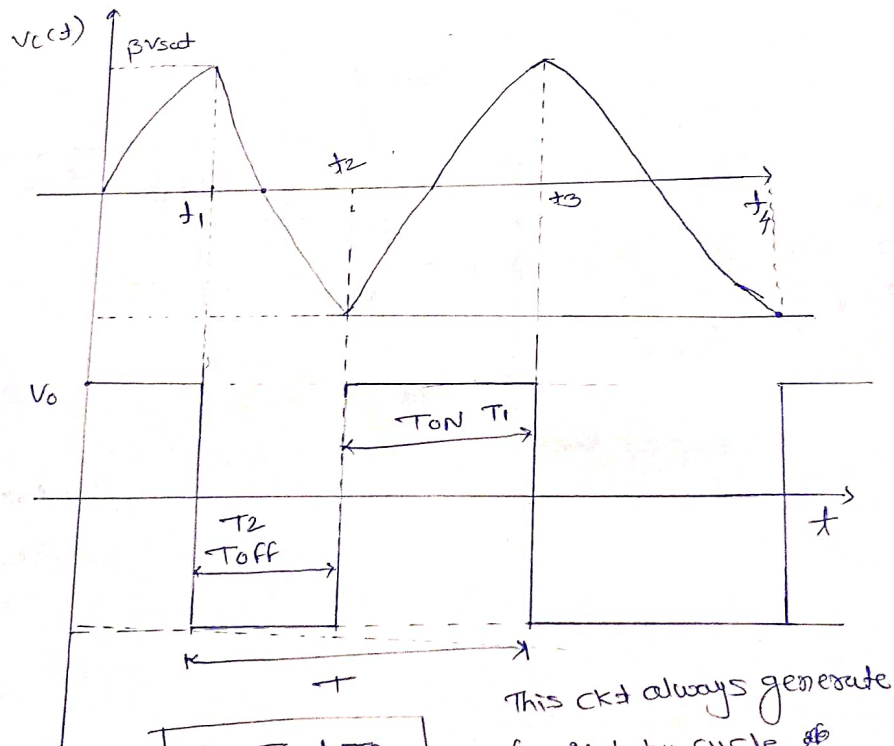
$V_- = +\beta V_{sat}$

$V_- = V_c = \pm \beta V_{sat}$

Comparator

$\boxed{V_- = V_c}$

$+V_{sat}$ or $-V_{sat}$



$\boxed{T = T_1 + T_2}$

This ckt always generate square waveform of 50% duty cycle

Imp o/p changes from $+V_{sat}$ to $-V_{sat}$ when V_- or V_c reaches to $+\beta V_{sat}$ value.

Calculation of T_1

capacitor is charging through $+V_{sat}$

Time constant $= RC = \tau_1$

$$V_c(t) = \left[V(\infty) - [V(\infty) - V(0)]\, e^{-t/\tau_1}\right]$$

$V(\infty) = +V_{sat}$

$V(0) = -\beta_{sat}$

$$V_c(t) = V_{sat} - [1+\beta] V_{sat}\, e^{-t/\tau_1}$$

at $t = T_1$, $V_c(t) = \beta V_{sat}$

$$\beta V_{sat} = V_{sat} - (1+\beta) V_{sat}\, e^{-T_1/\tau_1}$$

$$(1+\beta)\cancel{V_{sat}}\, e^{-T_1/\tau_1} = (1-\beta)\cancel{V_{sat}}$$

$$e^{-T_1/\tau_1} = \frac{1+\beta}{(1+-\beta)}$$

$$\boxed{T_1 = \tau \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

Capacitor is charging through $-V_{sat}$

$V(\infty) = -V_{sat}$, $V_c(0) = \beta V_{sat}$

$\tau_2 = RC$

$V_c(t) = -V_{sat} - [-V_{sat} - \beta V_{sat}]$

$V_c(t) = -V_{sat} + [1+\beta] V_{sat} e^{-t/\tau_2}$

at $t = T_2$, $V_c(t) = -\beta V_{sat}$

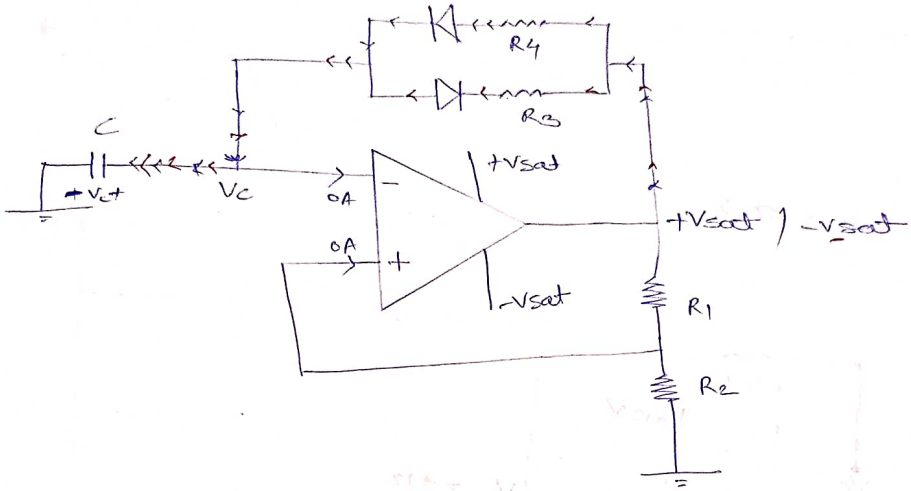
$-\beta V_{sat} = -V_{sat} + (1+\beta) V_{sat} e^{-T_2/\tau_2}$

$T_2 = \tau_2 \ln\left(\frac{1+\beta}{1-\beta}\right)$

$$\boxed{T = \ln\left(\frac{1+\beta}{1-\beta}\right)(\tau_1 + \tau_2) = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

$$\boxed{T_1 = T_2}$$

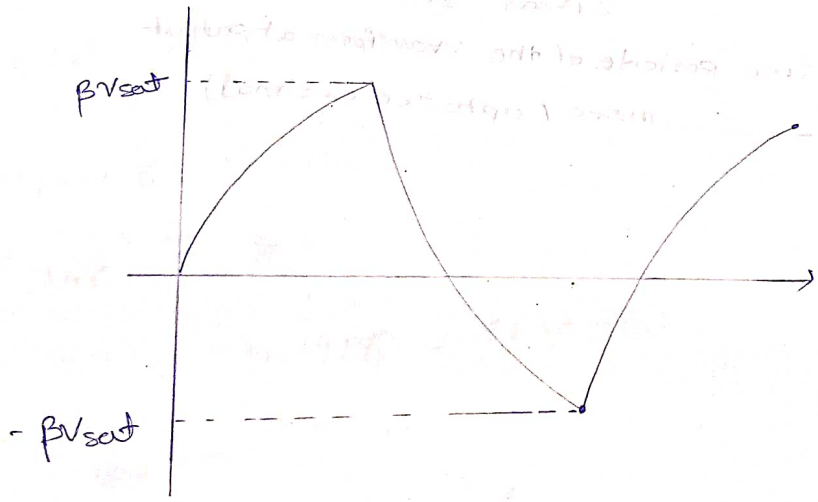
~~By~~ Duty cycle other than 50%



$\tau_1 = R_4 + C$

$T_1 = \tau_1 \ln\left(\frac{1+\beta}{1-\beta}\right) = R_4 + C \ln\left(\frac{1+\beta}{1-\beta}\right)$

$T_2 = \tau_2 \ln\left(\frac{1+\beta}{1-\beta}\right) = R_3 + C \ln\left(\frac{1+\beta}{1-\beta}\right)$



The capacitor voltage swings the value of V+ & V-
+Vsat & -Vsat

$R_4 \cdot C > R_3 \cdot C$

$\tau_1 > \tau_2$

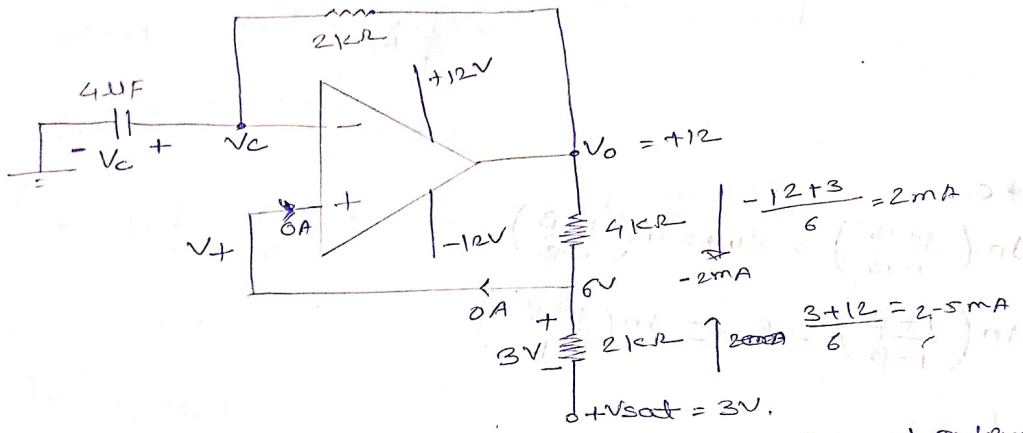
$T_1 > T_2 \rightarrow > 50\%$

$R_4 \cdot C < R_3 C$

$\tau_1 < \tau_2$

$T_1 < T_2 \rightarrow < 50\%$

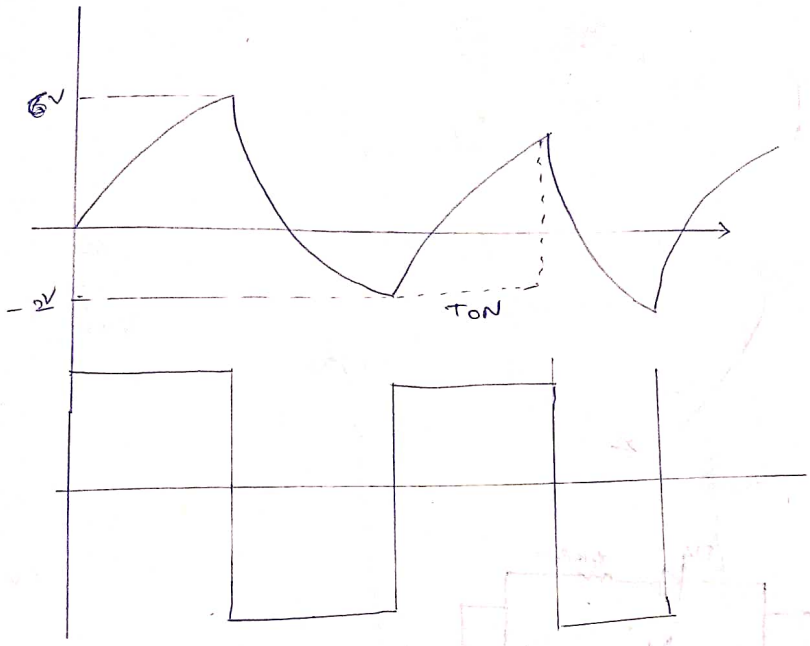
Q)



i) Vsat = 3Volt → Time periode of the waveform at output V_o _____ msec (upto two decimal)

$\xleftarrow{+Vsat} V_2 = V_+ = 6V$

$\xleftarrow{-Vsat} V_1 = V_+ = -2V$



$V_C(0) = -2, V(\infty) = 12,$

$V_C(t) = 12 - [12 + 2]\, e^{-t/\tau}$

$T_1 \rightarrow 6 = 12 - 14 e^{-T_1/\tau}$

$14 e^{-T_1/\tau} = 6$

$-T_1 = \tau \ln 14/6 = RC \ln(7/3)$

$T_2 \quad 18 e^{-T_2/\tau} = 10$

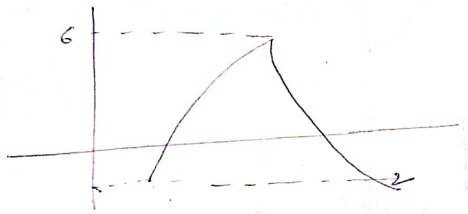
$T_2 = \tau \ln(9/5)$

$T = RC[\ln(7/3) + \ln(9/5)]$

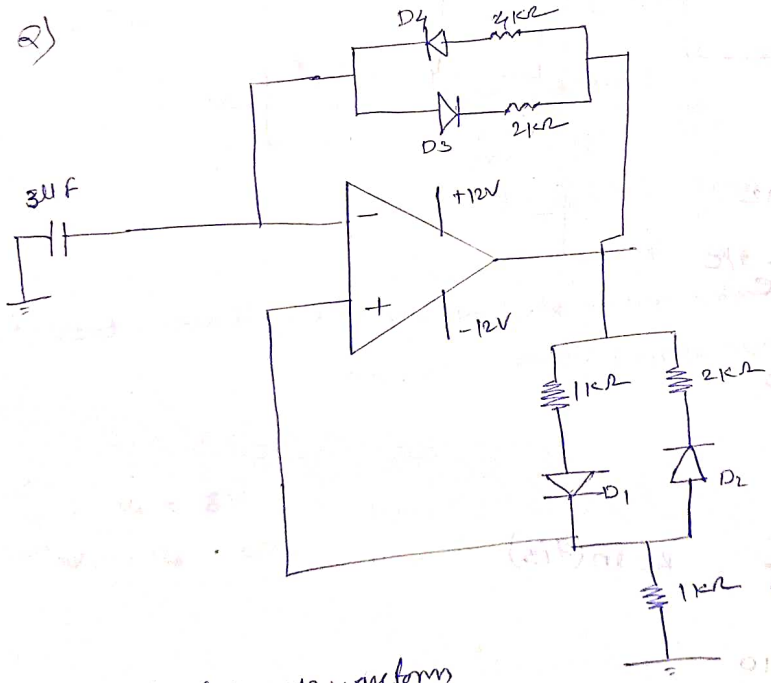
$= 2 \times 10^3 \times 4 \times 10^{-6}$ sec

$RC = 8$ msec

$V_o = 11.48$ msec



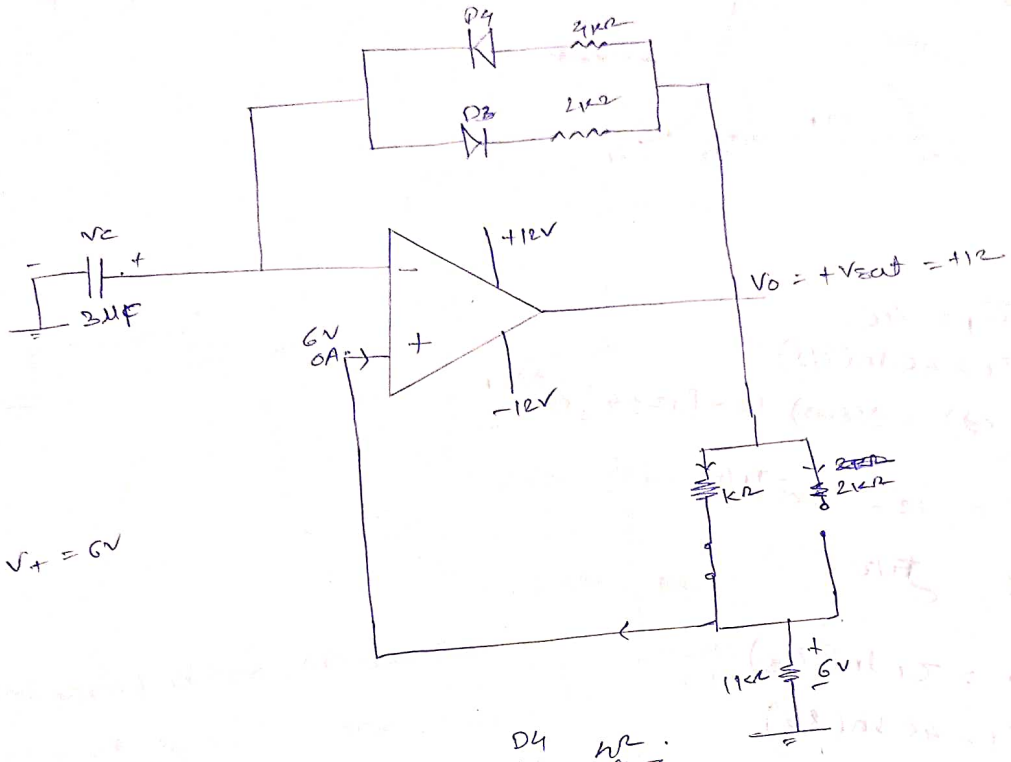
Q)



Time period of the o/p waveform

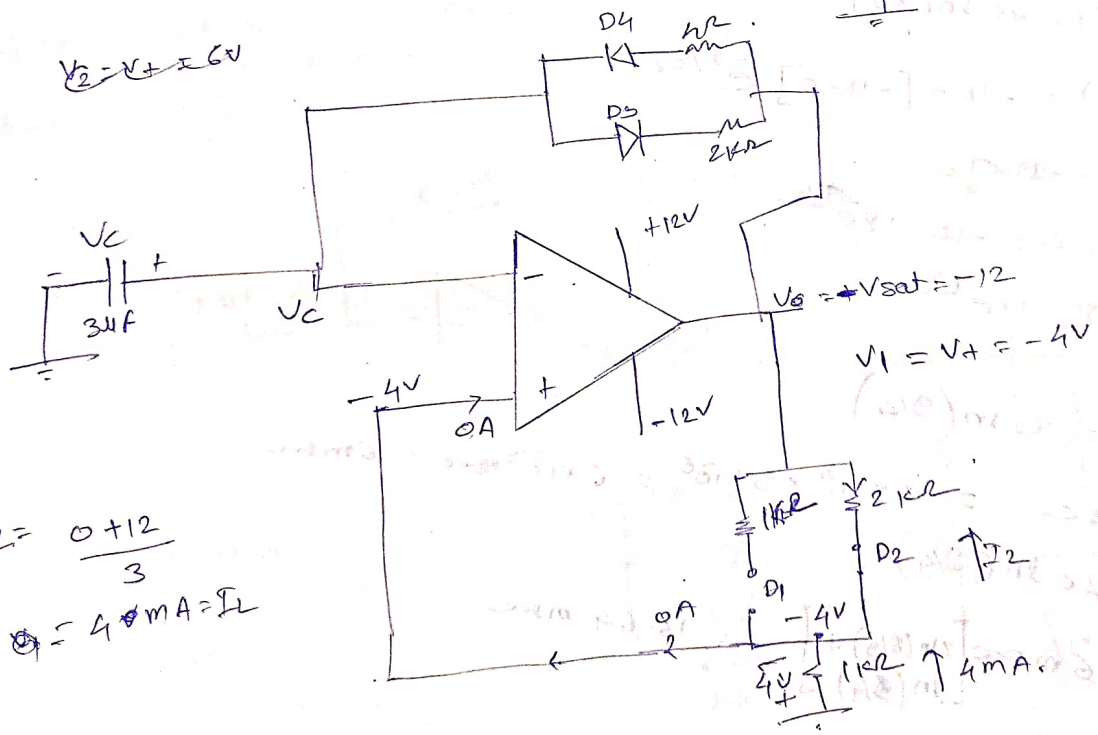
_____ msec upto two decimal.

Q Sol:-



$V_2 = V_+ = 6V$

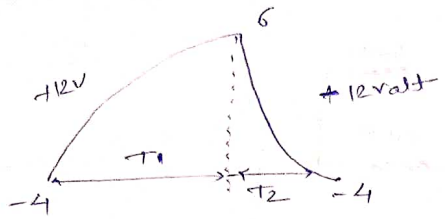
$V_2 = V_+ = 6V$



$V_1 = V_+ = -4V$

$I_2 = \frac{0+12}{3}$

$= 4mA = I_2$



$\tau_1 = 4C$

$T_1 = 4C \ln(8/3)$

① $V_c(t) = 12 - [12+4]\, e^{-t/\tau_1}$

$6 = 12 - 16\, e^{-T_1/\tau_1}$

$\frac{16}{6} = e^{T_1/\tau}$

$T_1 = \tau_1 \ln(8/3)$

$T_1 = 4C \ln(8/3)$

② $V_c(t) = -12 - [-12-6]\, e^{-t/\tau_2}$

at $t = T_2$

$-4 = -12 + 18\, e^{-T_2/\tau_2}$

$8 = 18\, e^{-T_2/\tau_2}$

$T_2 = \tau_2 \ln(9/4)$

$\tau_2 = 2C = 2\times10^{3} \times 3\times10^{-6} = 6\times10^{-3}\,\text{sec} = 6\,\text{msec}$

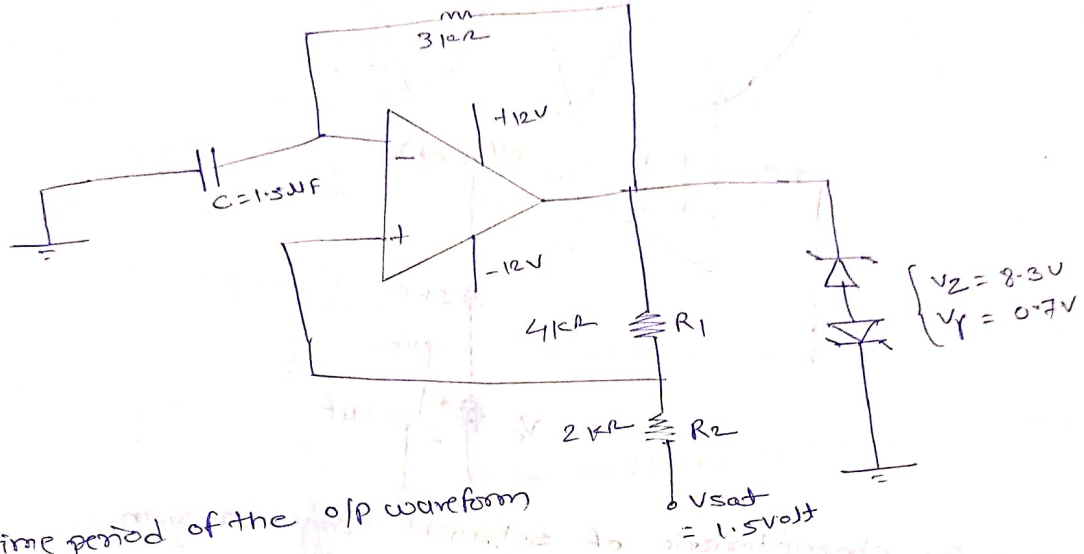
$T_2 = 2C \ln(9/4)$

$T = 6\,\text{msec}\left[2\ln(8/3) + \ln(9/4)\right] = 16.64\ \text{msec}$

$T_{1\,ON} > T_{2\,off}$ = 70.77% → duty cycle.

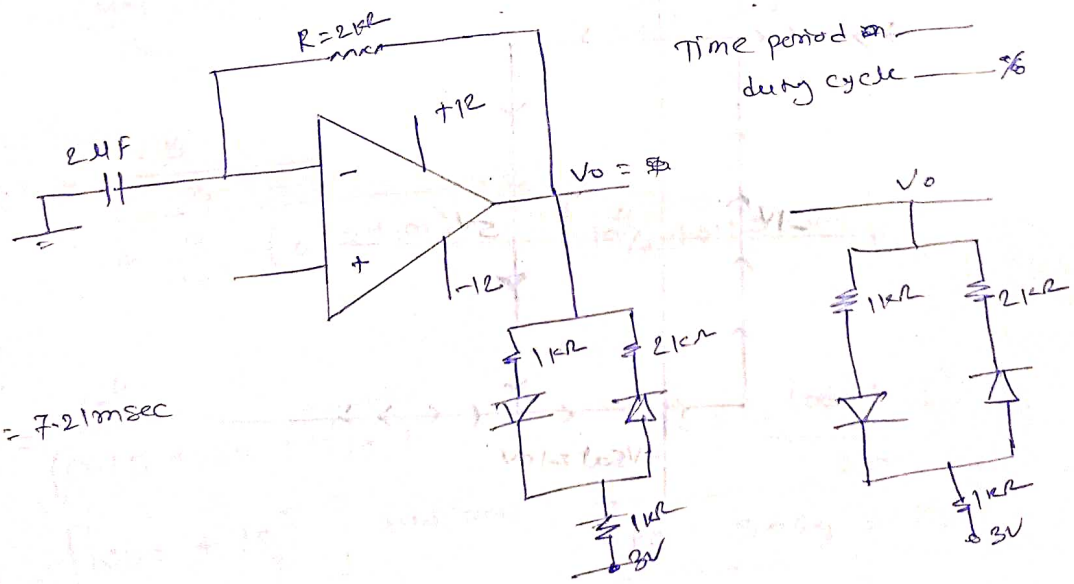
H.W

Q1)



The time period of the o/p waveform generated at V_o ____ in msec upto two decimal. ~~4.26msec~~ 6.33msec

Q2)

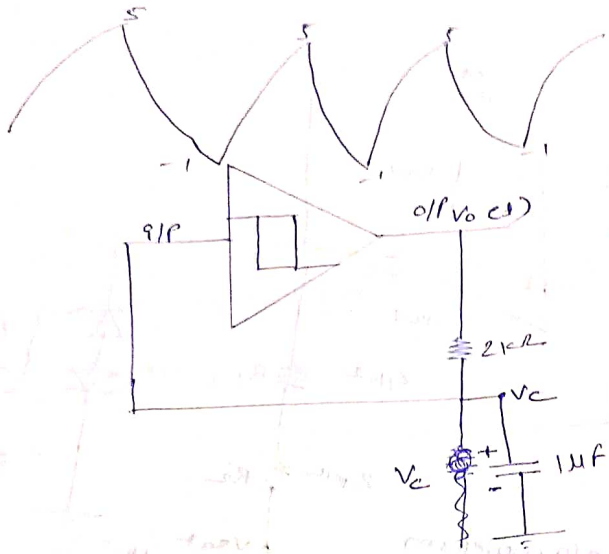


Time period ____

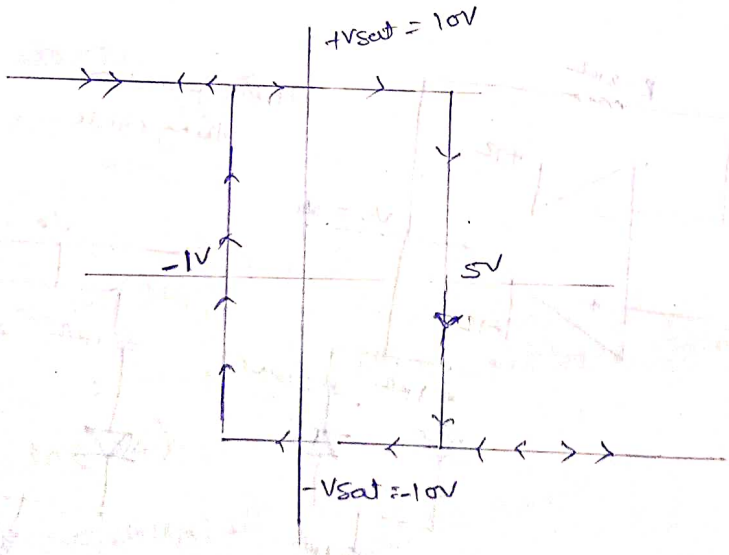
duty cycle ____ %

V_o = 7.21msec

Q) An oscilator circuit using schimit trigger is given below

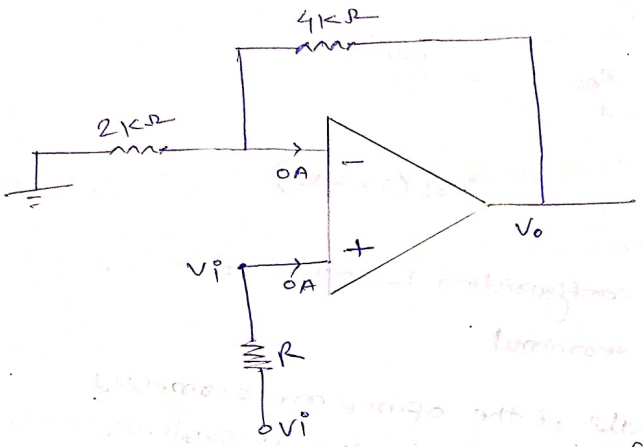


Transfer characteristic of schimitt trigger is given below



Q) open loop gain of OPAMP used in amplifier circuit given below is

$$A_{OL} = \frac{10^4}{0.1S + 100} \qquad \omega_{OL} = 1000$$



The 3dB cutoff frequency of the amplifier will be _____ kHz (upto two decimal).

$$\frac{V_o}{V_i} = \frac{1 + R_2/R_1}{1 + \frac{(1 + R_2/R_1)}{A_{OL}}} = H(S) = \frac{3}{1 + \frac{3}{\left(\frac{10^4}{0.1S + 100}\right)}}$$

$$H(S) = \frac{\frac{3}{3}}{1 + \frac{3}{10^4}(0.1S + 100)} = \frac{10^4}{\left[10^4/3 + 0.1S + 100\right]}$$

$$H(S) = \frac{10^4}{(0.1S + 100 + 10^4/3)}$$

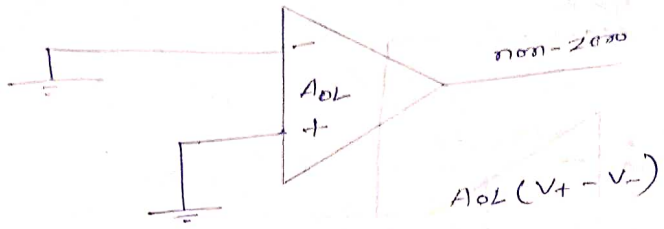
$$H(S) = \left[1000 + \frac{10^5}{3}\right] \text{ rad/sec}$$

$$f_c = \frac{1000 + \frac{10^5}{3}}{2\pi} \text{ Hz}$$

$$\boxed{f_c = 5464.31 \text{ Hz}}$$

Non-ideal effects :-

input offset voltage :- V_{IOS}

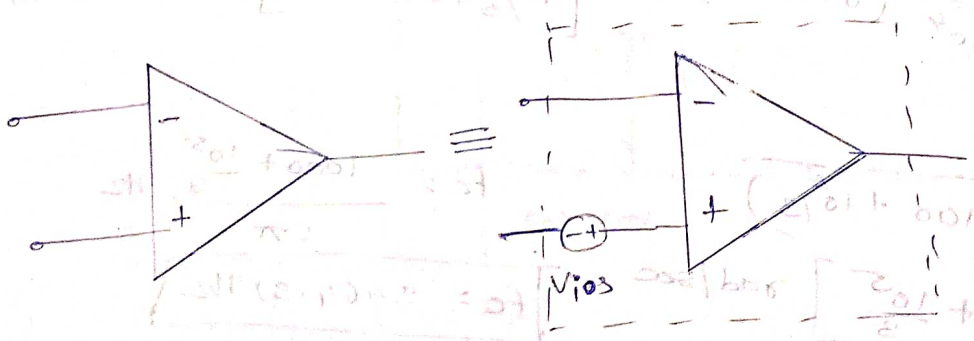


when opAmp in open loop configuration is connected at zero volt at both the terminal

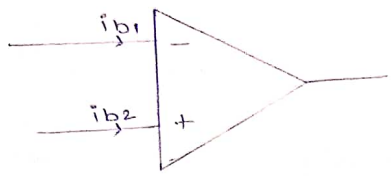
1) when +ve & -ve terminals of the opamp are connected at zero potential in open loop configuration it produces a non zero output instead of zero o/p due to non-ideal behaviour

2) This non zero o/p generated because of some i/p voltage difference present between the two terminals of the opAmp is called input offset voltage.

in ideal case offset voltage is zero



input bias current :-



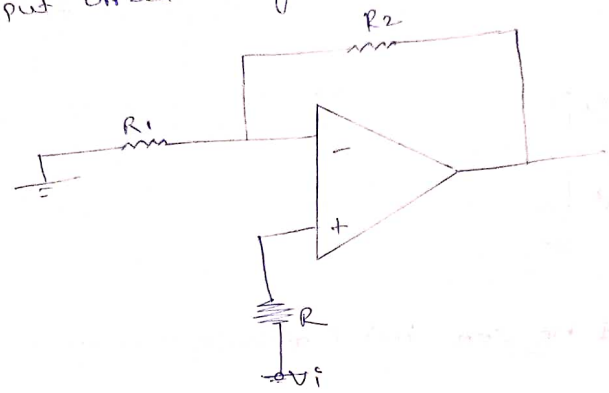
ideally i_{b1}, i_{b2} should be zero but practically they are non-zero and said to be bias current

$\{i_b = i_{b1} = i_{b2}\} \longrightarrow$ it is not always there

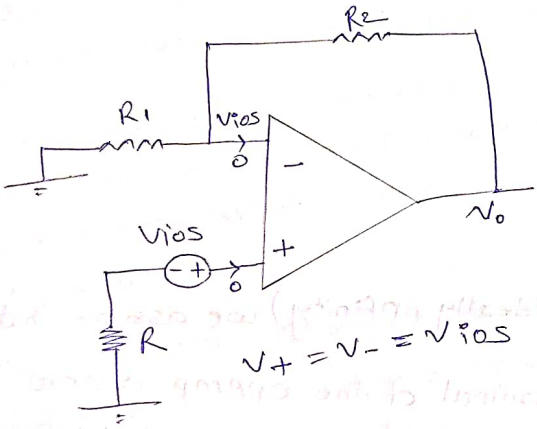
$i_{os} = (i_{b1} - i_{b2})$

- due to very high i/p resistance (ideally infinity) we assume that the current through -ve & +ve terminal of the OPAMP is zero but practically there is very small current flows through this two terminals and that current is called as bias current

input offset voltage :- Vios



|||

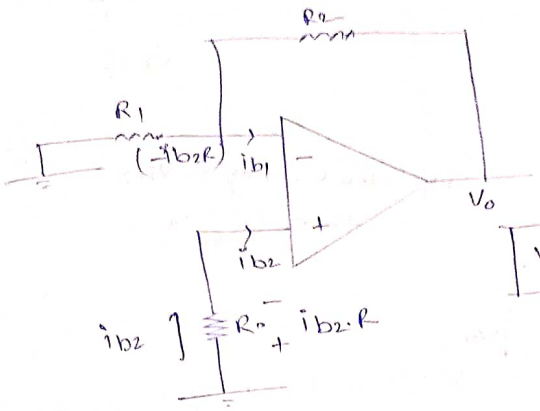


$$\frac{0 - V_{ios}}{R_1} = \frac{V_{ios} - V_o}{R_2}$$

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

$$V_+ = V_- = V_{ios}$$

Q)



$$\frac{0 + i_{b2}R}{R} = i_{b1} + \frac{-i_{b2} - V_o}{R_2}$$

$$\frac{R_2}{R_1} R\, i_{b2} = i_{b1} R_2 - i_{b2} R - V_o$$

$$\boxed{V_o = i_{b1} - R i_{b2} - [1 + R_2/R_1]}$$

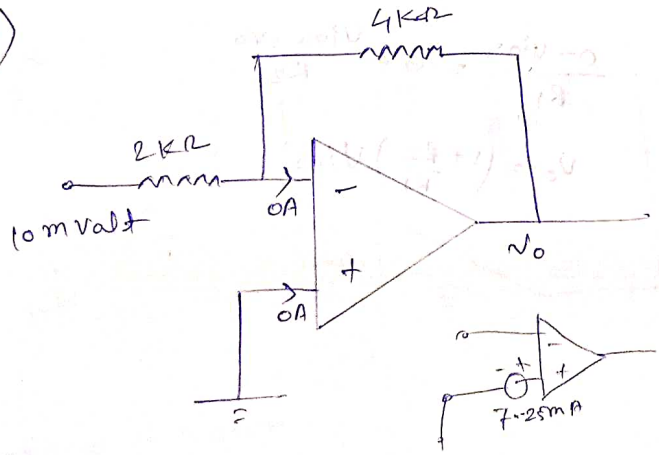
if $R = 0 \longrightarrow \boxed{V_o = i_b R_2}$

$R = R_1 \| R_2$

$$V_o = i_b \left[R_2 - \frac{R_1 R_2}{R_1 + R_2} \left(\frac{R + R_2}{R_1} \right) \right]$$

$V_o = 0$

Q)



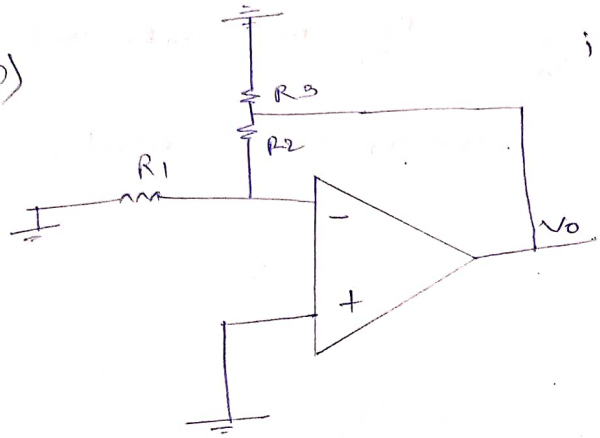
i/p offset voltage is 7.25 mVolt then o/p voltage Vo of the circuit given is _____ mV.

$= 7.25(3) + (-2)\times 10$

$= 21.75 + (-20)$

$= 1.75\,mV$

Q)

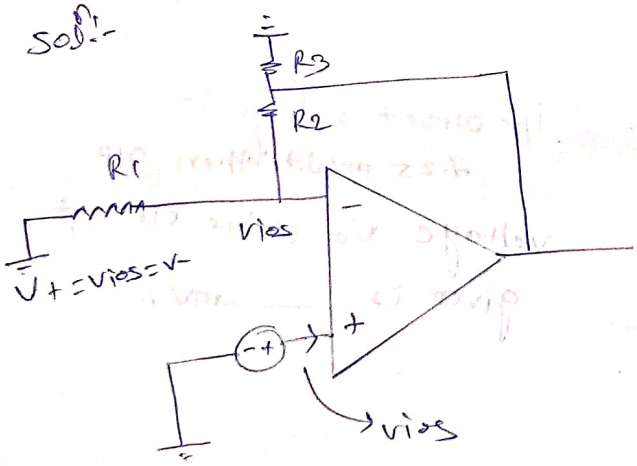


i/p offset voltage is Vios then o/p Vo is :-

a) $\left(1+\frac{R_2}{R_1}\right)V_{ios}$ b) $\left(\frac{-R_3}{R_2+R_1}\right)V_{ios}$

c) $\left(1+\frac{R_3}{R_1+R_2}\right)V_{ios}$ d) $\left(\frac{R_3}{R_1+R_2}\right)V_{ios}$

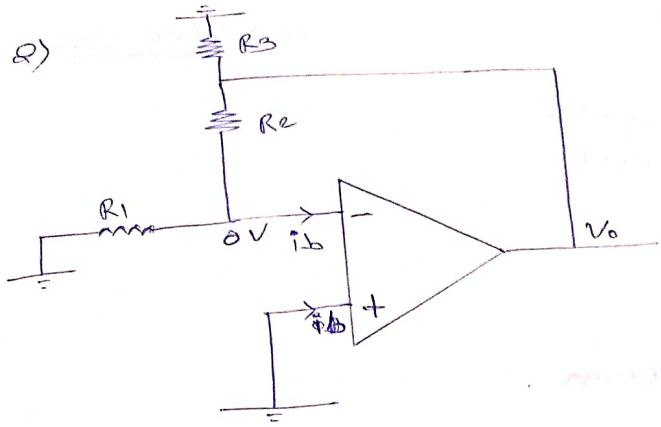
Sol:-



$$\frac{0-V_{ios}}{R_1} = 0 + \frac{V_{ios}-V_o}{R_2}$$

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

Q)



Q) bias current ib then o/p Vo

a) $-ib(R_1+R_2)$ b) $ib\,R_2$

c) $ib(R_2 \| R_3)$ d) $ib(R_2 \| R_3 + R_1)$

Solⁿ:-

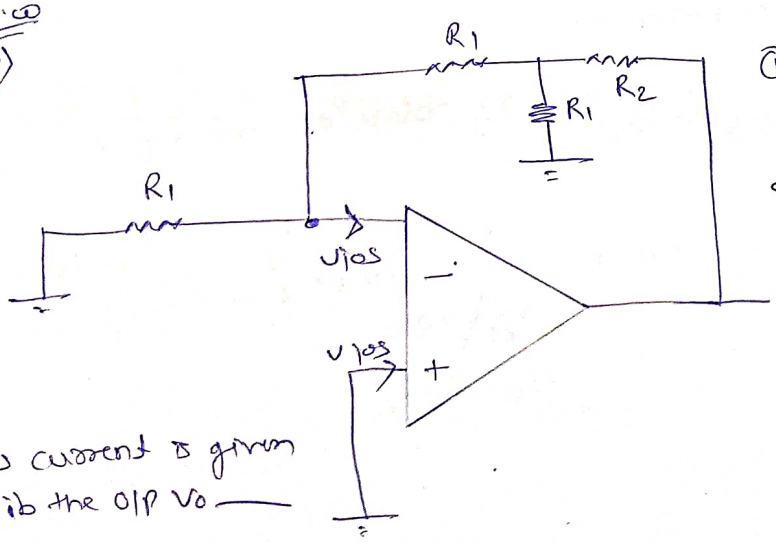
$$\frac{0-0}{R_1} = ib + \frac{0-V_o}{R_2}$$

$$0 = ib - \frac{V_o}{R_2}$$

$$\boxed{V_o = ib R_2}$$

N.Q

Q)



① i/p offset voltage is Vios, then o/p Vo will be

a) $V_{ios}\left(1+\frac{3R_2}{2R_1}\right)$

b) $2V_{ios}\left(1+\frac{3R_2}{2R_1}\right)$

c) $V_{ios}\left(1+\frac{R_2}{R_1}\right)$

d) $V_{ios}\left(1+\frac{2R_2}{3R_1}\right)$

② bias current is given as ib the o/p Vo ——

Sol ①

$$\frac{0 - V_{ios}}{R_1} = 0 + \frac{V_{ios} - V_o}{R_1 + R_2}$$

$$\frac{-V_{ios}}{R_1} = \frac{V_{ios} - V_o}{R_1 + R_2}$$

$$\frac{R_1 + R_2}{R_1} = \frac{V_{ios} - V_o}{-V_{ios}}$$

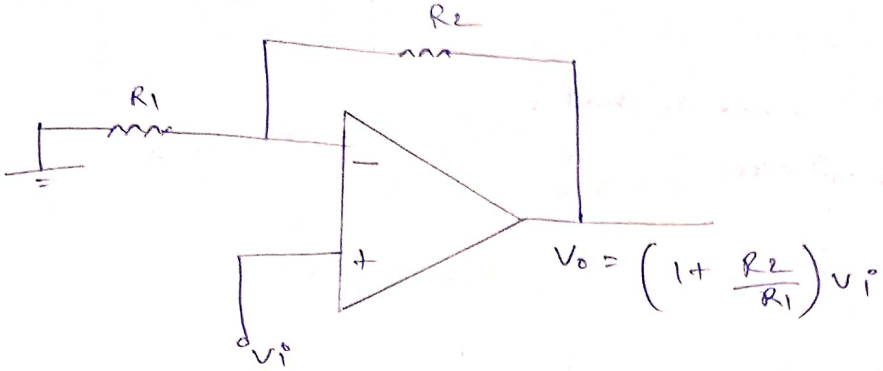
$$-\left(\frac{R_1 + R_2}{R_1}\right) V_{ios} - V_{ios} = -V_o$$

$$+\left(\frac{R_1 + R_2}{R_1} - 1\right) V_{ios} = +V_o$$

$$\frac{\cancel{R_1} + R_2 - \cancel{R_1}}{R_1} V_{ios} = V_o$$

$$\frac{R_2}{R_1}$$

Slew rate :→



i) It is specification of opAmp in close loop configuration

ii) and it is a constant fix value for a given opAmp.

~~10) eg.~~

Defination:- ~~It is the maximum rate of change of~~

It is defined as the maximum rate at which output of an opAmp can change its o/p voltage with respect to time in close loop configuration.

eg:- slewrate 10^4 V/sec meaning is that this opAmp can change maximum 10^4 volt in 1sec at its o/p.

can change ?

20V → 1 μsec → can not do that.

$20V / 10^{-6}$

2×10^7 volt/sec

e.g:- 1 volt in 0.1 msec

$1V/0.1\,ms \longrightarrow 10^4\ V/sec$

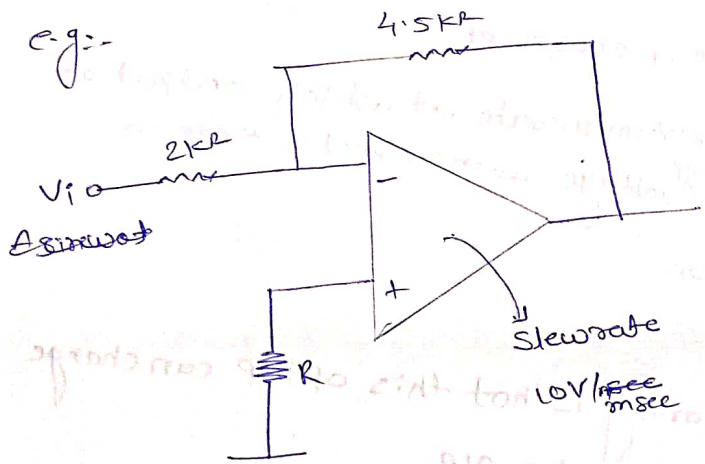
E.g:- $1V \longrightarrow 1\,msec$ → can do that.

$1V/1\,msec \rightarrow 10^3\ V/sec$

$$\left|\frac{dV_o}{dt}\right|_{max} \leq \text{slew rate}$$

for undistorted o/p

e.g:-

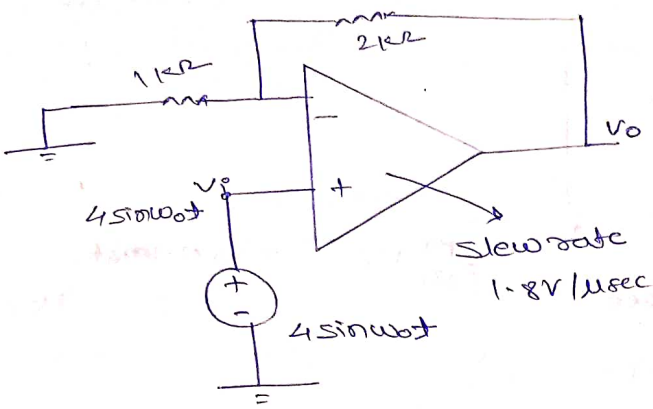


Q) which i/p Vi waveform will be amplified at the o/p undistorted

a) $4\sin 2\pi \times 10^3 t$ b) $2.25 \times 10 \sin 2000\pi t$ c) $\sin 500\pi t$

d) $2\sin 1500t$

Q2)



$\left(1+\frac{2}{1}\right) V_i = 3\times 4\sin\omega_0 t$

$3V_i = 12\sin\omega_0 t$

maximum value of ω_0 for which we get undistorted o/p V_o

_____ m rad/sec (upto two decimal)

Sol^n:→

$3V_i = 12\sin\omega_0 t$

$$\frac{dV_o}{dt} = \frac{d}{dt}\left(12\sin\omega_0 t\right) = 12\omega_0\cos\omega_0 t$$

$\omega_0 t = 0, \pi, 2\pi, 3\pi$ ---

$$\left|\frac{dV_o}{dt}\right|_{max} = 12\omega_0$$

$12\omega_0 \leq$ slew rate

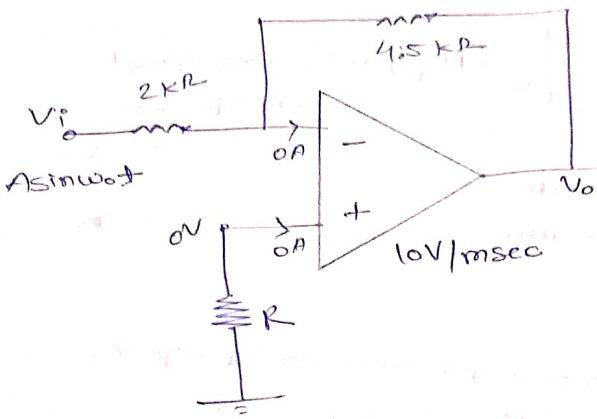
$12\omega_0 \leq 1.8\times10^6$ V/sec

$$\omega_0 \leq \frac{18\times10^5}{12}$$

$\omega_0 \leq 1.5\times10^5$ rad/sec

$\omega_0 \leq 0.15\times$ rad/sec

Q)



$$V_o = -\frac{R_2}{R_1} V_i = -2.25 A \sin\omega_0 t$$

$$\frac{dV_o}{dt} = -2.25 A\omega_0 \cos\omega_0 t$$

$$\left|\frac{dV_o}{dt}\right| = 2.25\, A\omega_0 \left|\cos\omega_0 t\right|$$

$$\left|\frac{dV_o}{dt}\right|_{max} = 2.25\, A\omega_0$$

$$\left|\frac{dV_o}{dt}\right|_{max} \leq 10\,V/10^{-3}\,sec$$

$$\left|\frac{dV_o}{dt}\right| \leq 10^4\,V/sec$$

$$\boxed{2.25 A\omega_0 \leq 10^4\,V/sec}$$

i) $2.25 \times 4 \times 2\pi \times 10^3 = 5.4 \times 0^4$ ✗

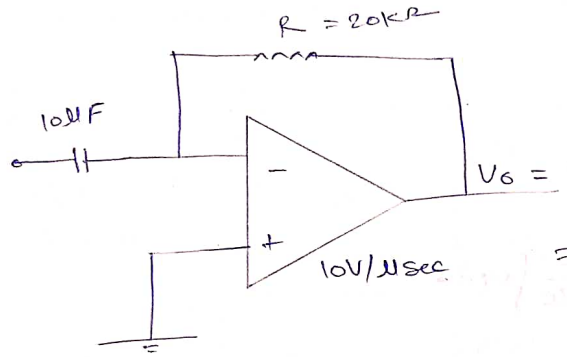
ii) $2.25 \times 10 \times 2000\pi$ ✗

iii) $2.25 \times 8 \times 500 \times \pi \neq \cancel{<} 10^4$ ✗

iv) $2.25 \times 2 \times 1500$

$= 4.5 \times 1.5 \times 10^3 < 10^4$ ✓

Q)



$V_o = -RC\frac{dv_i}{dt}$

$= -RC\,A(2\pi f)\cos 2\pi f t$

Vi is in form of $A \sin 2\pi f t$ when $A = 2$ Volt, then the maximum value of f (in Hz) for which o/p will be undistorted ____ Hz upto two decimal.

soln:-

$$\frac{dV_o}{dt} = +RCA(2\pi f)^2 \sin 2\pi f t$$

$$\left|\frac{dV_o}{dt}\right|_{max} = +RCA(2\pi f)^2 \left|\sin 2\pi f t\right|$$

$$\Rightarrow RCA\,4\pi^2 f^2 \leq 10$$

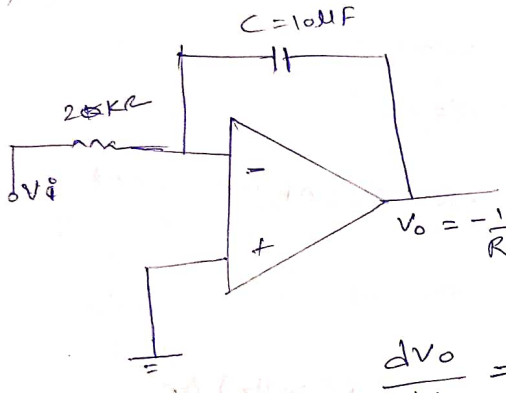
$$(4\pi^2 f^2) \leq \frac{10 \times 10^6 \text{ V/sec}}{20 \times 10^3 \times 10 \times 10^{-6} \times 2}$$

$$4\pi^2 f^2 \leq \frac{10^7}{4 \times 10^{-1}}$$

$2\pi f \leq \frac{10^4}{2}$

$$\boxed{f \leq \frac{5000}{25} \text{ Hz}}$$

Q)



$$V_o = -\frac{1}{RC}\int V_i\,dt + C$$

$$\frac{dV_o}{dt} = -\frac{1}{RC} V_i + 0$$

$$\left|\frac{dV_o}{dt}\right|_{max} = \frac{1}{RC} A\,|\sin 2\pi f t|_{max} = \frac{A}{RC}$$

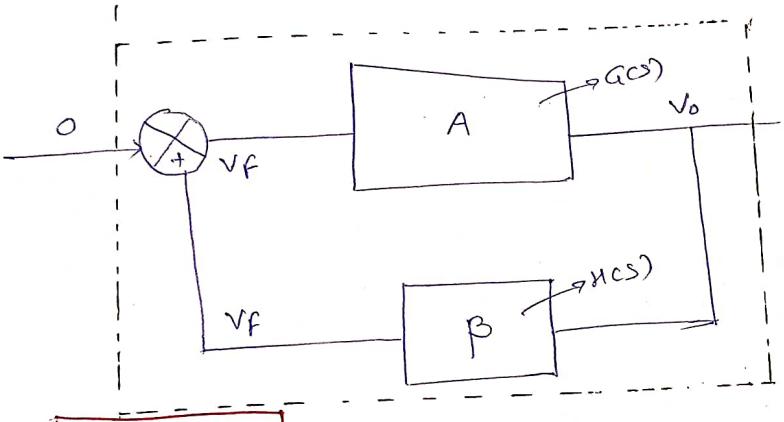
independent of frequency

$$\frac{A}{RC} < 10\,V/sec$$

Oscillator :→

Sinusoidal Waveform generator

An amplifier with positive feedback and without any input that generates sinusoidal waveform is called as oscillator.



$$\boxed{\beta = \frac{V_f}{V_o}}$$

1) oscillator can not be modeled by transfer function

$$\frac{V_o}{V_i} = \infty = \frac{A}{(1 - A\beta)} =$$

$$\boxed{1 - A\beta = 0} \longrightarrow \text{Barkhausen Criterion}$$

↓

condition for oscillation

$$\frac{V_o(s)}{V_i(s)} = \frac{G(s)}{1 - G(s)H(s)}$$

$$1 - G(s)H(s) = 0$$

② we can model oscillator in the form of characteristic eqn

Magnitude criteria :-

$$1 - A\beta = 0$$

$$A\beta = 1 = 1\angle 2\pi \text{ or } 0$$

Angle criteria :-

$$\angle(A\beta) = 2\pi \text{ or } 0$$

Note:-

1) Angle criteria always ~~gives~~ ~~gets~~ gives the value of frequency of oscillation at which oscillator can oscillate.

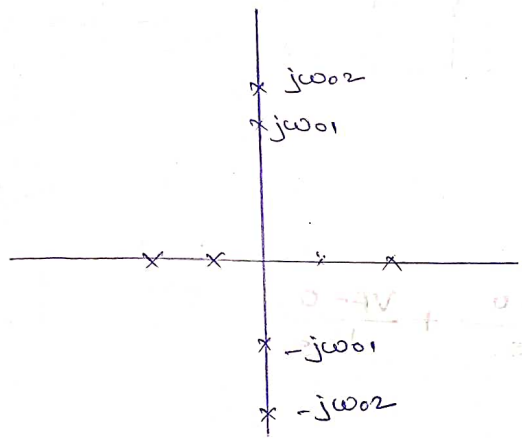
2) oscillator will oscillate at the frequency of oscillation given by Angle criteria if the magnitude criteria also satisfies at the frequency of oscillation.

$$\frac{1}{s+a} = e^{-at}u(t)$$

$$\frac{\omega_0}{s^2+\omega_0^2} \rightarrow \sin\omega_0 t$$

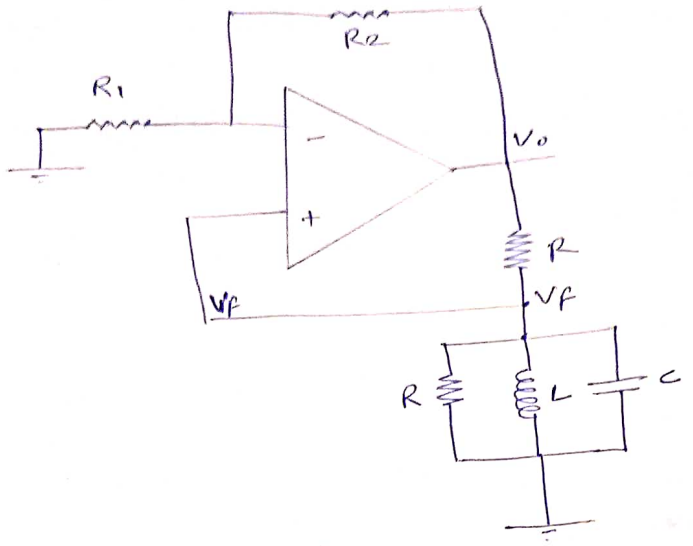
$L \rightarrow Ls$

$C \rightarrow \frac{1}{Cs}$



- for the designing of oscillator we need to have atleast two independent energy storage element.

Q)



$$\beta = \frac{V_f}{V_o}$$

$$\frac{V_o - V_f}{R} = 0 + \frac{V_f - 0}{R} + \frac{V_f - 0}{Ls} + \frac{V_f - 0}{1/Cs}$$

$$V_o - V_f = V_f + \frac{V_f \cdot R}{Ls} + RCs\,V_f$$

$$V_o = \left[2 + \frac{R}{Ls} + RCs\right] V_f$$

$$\boxed{\beta(s) = \frac{V_f}{V_o}} = \frac{1}{2 + \frac{R}{Ls} + RCs}$$

$$\beta(j\omega) = \frac{1}{2 + \frac{R}{j\omega L} + RCj\omega}$$

$$\beta(j\omega) = \frac{j\omega L}{R + 2j\omega L - RLC\omega^2}, \quad \beta(j\omega) = \frac{1}{2}$$

$A = (1 + R_2/R_1)$ real & +ve

$\angle A\beta = \angle A + \angle \beta$

$\angle A = 0$ or 2π

$\beta(j\omega) = 2\pi$ or 0

$R - RLC\omega^2 = 0$

$\omega^2 = \frac{R}{RLC} = \frac{1}{LC}$

$$\boxed{\omega = \frac{1}{\sqrt{LC}}}$$

$|A\beta| = 1$

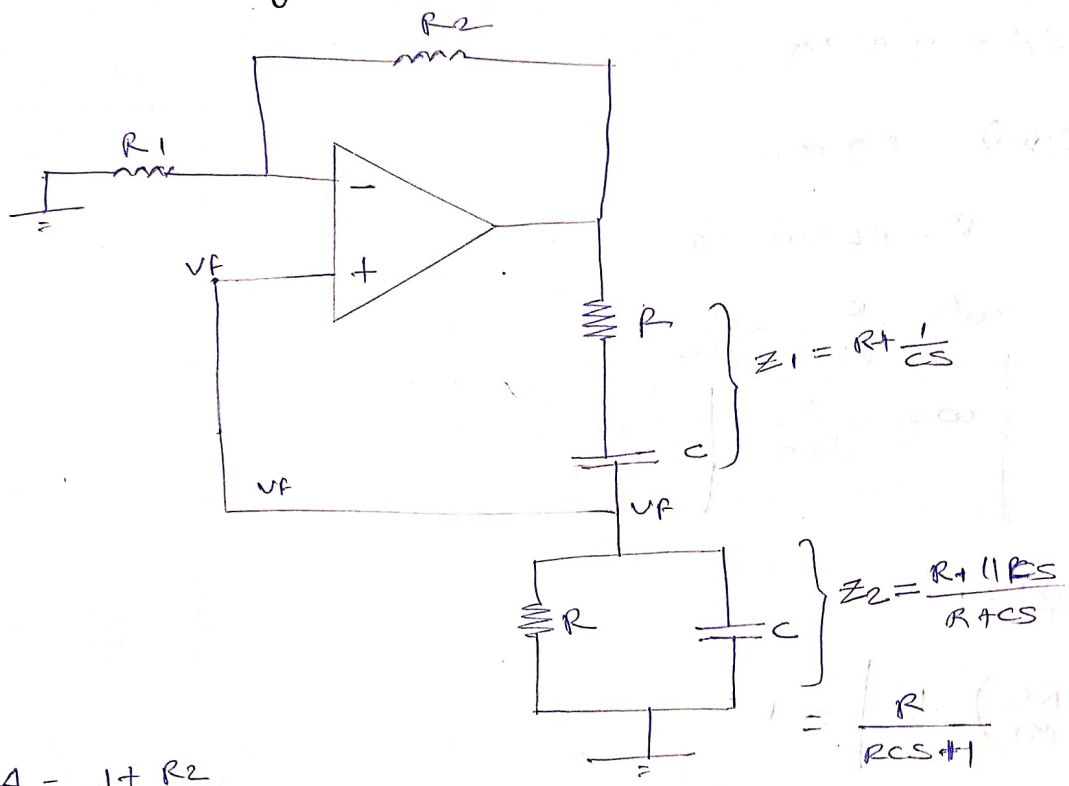
$$\left| \left(1 + \frac{R_2}{R_1}\right) \frac{1}{2} \right| = 1$$

$R_2 = R_1$

$1 + \frac{R_2}{R_1} = 2$

$$\boxed{\frac{R_2}{R_1} = 1}$$

Wein bridge oscillator :→



$$A = 1 + \frac{R_2}{R_1}$$

$$\beta = \frac{V_f}{V_o}$$

$$\frac{V_o - V_f}{\left(R + \frac{1}{CS}\right)} = 0 + \frac{V_f - 0}{(RCS+1)}$$

$$(V_o - V_f) = \left(R + \frac{1}{CS}\right) V_f \left(\frac{1 + RCS}{R}\right)$$

$$(V_o \cancel{\ldots}) = \frac{(1+RCS)^2}{RCS} V_f$$

$$V_o = V_f\left[1+\frac{(1+RCs)^2}{RCs}\right] = \frac{1+3RCs+R^2C^2s^2}{RCs}$$

$$\beta(s) = \frac{V_f}{V_o} = \frac{RCs}{1+3RCs+R^2C^2s^2}$$

$$\beta(j\omega) = \frac{RCj\omega}{1+3RCj\omega-\omega^2R^2C^2}$$

$$\omega = \frac{1}{RC}$$

$$\left(1+\frac{R_2}{R_1}\right)\frac{1}{3}$$

$$\angle A\beta = \angle A + \angle\beta$$
$$= 2\pi \text{ or } 0$$

$$\angle A = 0$$

$$|A\beta| = 1 = \left|\left(1+\frac{R_2}{R}\right)\frac{1}{3}\right| = 1$$

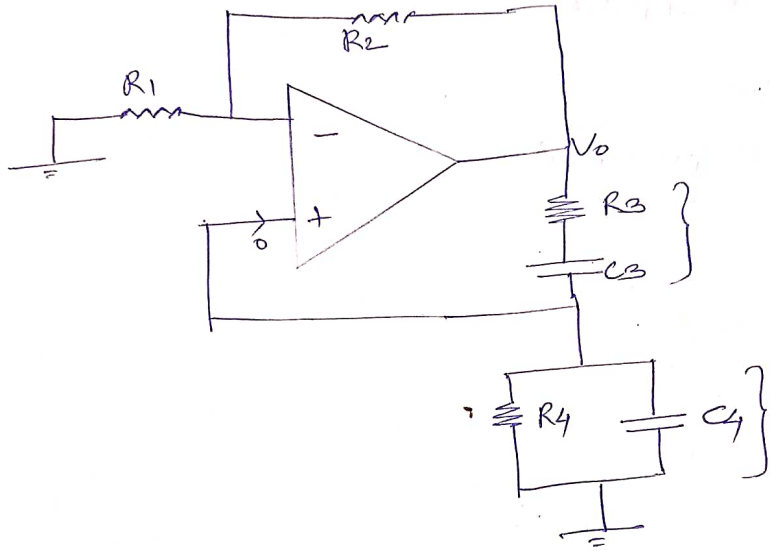
$$\left(1+\frac{R_2}{R_1}\right)\frac{1}{3} = 1$$

$$1+\frac{R_2}{R_1} = 3$$

$$\frac{R_2}{R_1} = 2$$

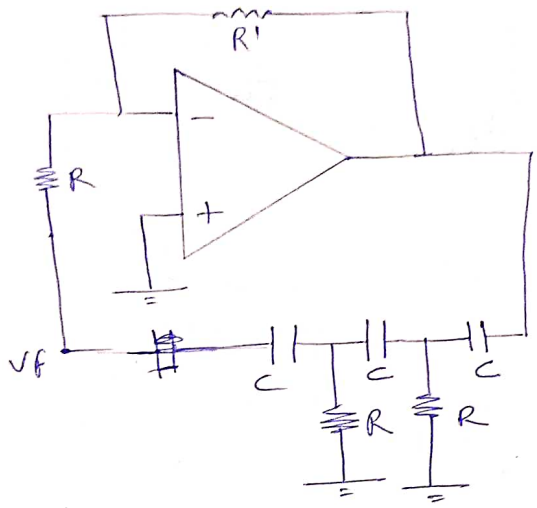
$$\boxed{R_2 = 2R_1} \rightarrow \text{condition.}$$

e.g:-

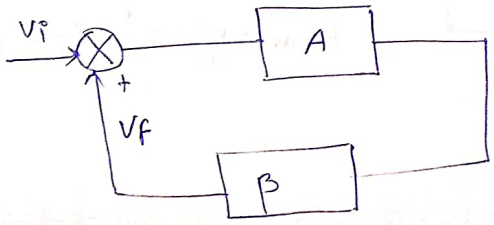


$$\omega_0 = \frac{1}{\sqrt{R_3 R_4 C_3 C_4}}$$

RC phase shift oscillator :→



$$A = \frac{R'}{R}$$



$$\beta = \frac{V_f}{V_o} = \frac{-j\omega^3 C^2 R^3}{1 - 6\omega^2 C^2 R^2 + j(5\omega CR - \omega^3 C^3 R^3)}$$

$\angle A\beta = 0$ or 2π

$\angle A + \angle \beta = 0$ or 2π

$\angle \beta = \pi$

$$1 - 6\omega^2 C^2 R^2 = 0$$

$$\boxed{\omega = \frac{1}{\sqrt{6}RC}}$$

$$|A\beta| = 1 - \frac{\frac{1}{6\sqrt{6}}}{\frac{5}{\sqrt{6}} - \frac{1}{6\sqrt{6}}} = \frac{-1}{29}$$

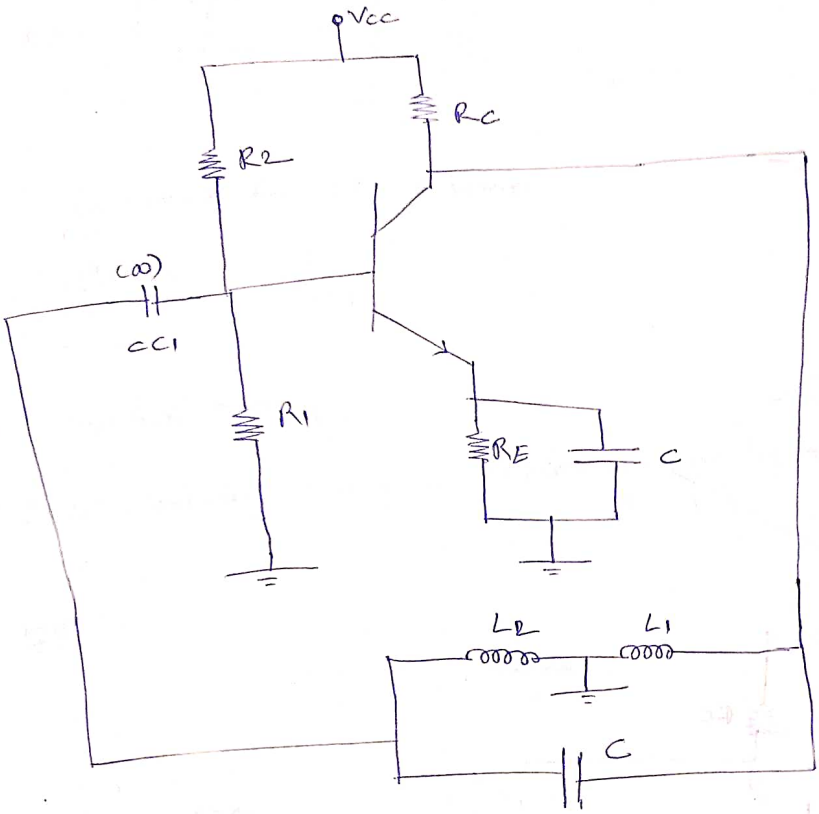
$$\cancel{\left|\frac{-R'}{R}\right|}$$

$$\left|-\frac{R'}{R} \cdot -\frac{1}{29}\right| = 1$$

$$\frac{R'}{R} \cdot \frac{1}{29} = 1$$

$$\boxed{R' = 29R}$$ → condition for oscillation at frequency $\frac{1}{2\pi \cdot \sqrt{6} \cdot RC}$

Hartelay oscillator:→



$$A = -g_m R_C$$

$$\omega = \frac{1}{\sqrt{L_{eq} \cdot C}} = \frac{1}{\sqrt{(L_1 + L_2) C}}$$

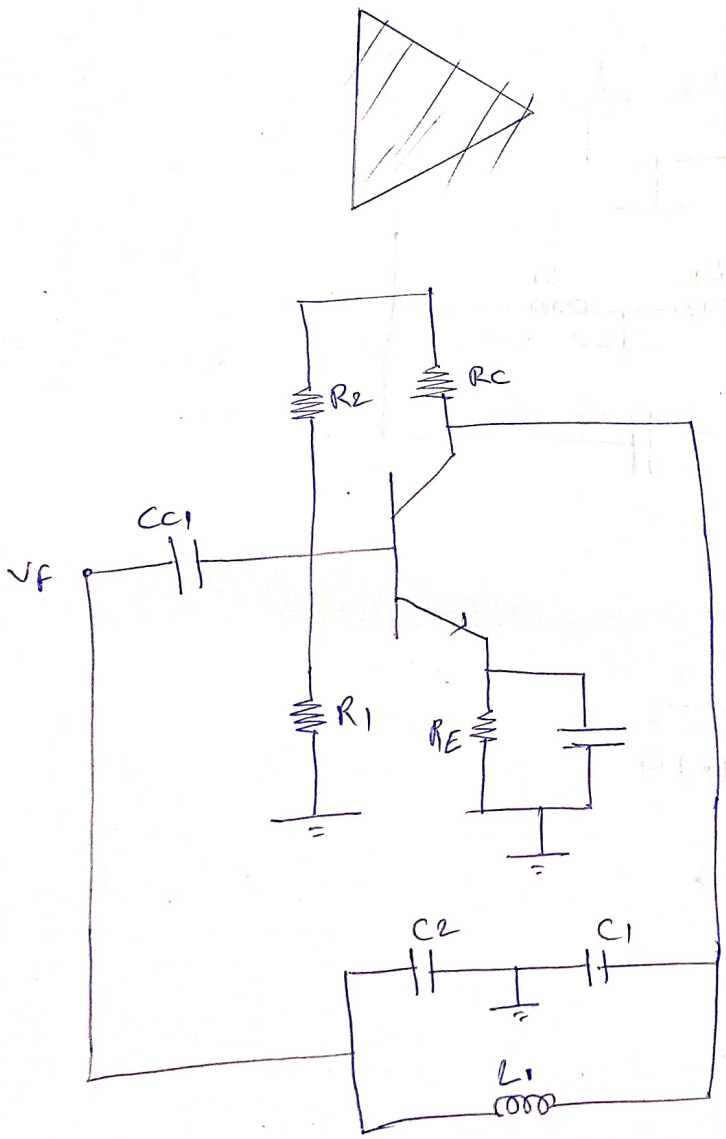
condition for oscillation →

$$\boxed{g_m R_C = \frac{L_1}{L_2}}$$

i) capacitive tuning is used

ii) bulkier due to use of two inductors.

Calpitt oscillator :-



$A = -g_m R_C$

$$\omega = \sqrt{\frac{1}{LC_{eq}}} = \sqrt{\frac{1}{L\left(\frac{C_1 C_2}{C_1 + C_2}\right)}}$$

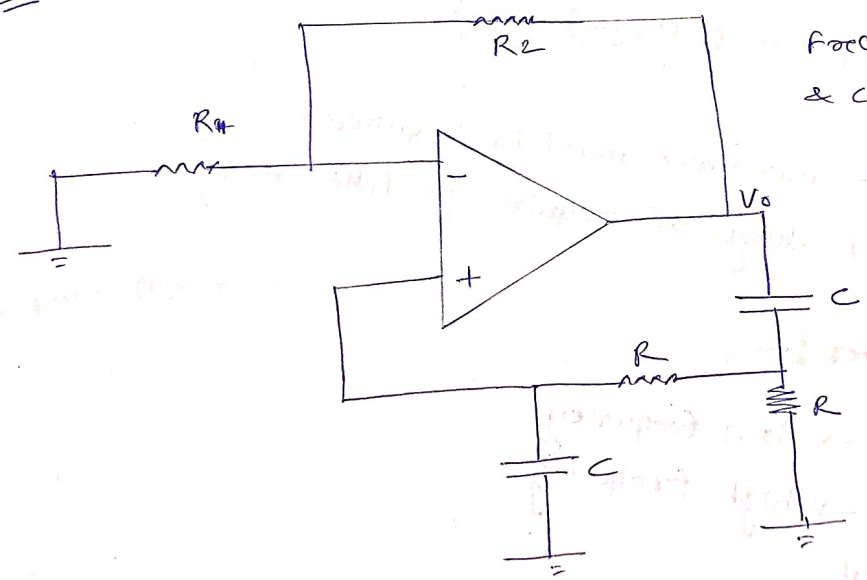
condition for oscillation

$$\boxed{g_m R_C = \frac{C_2}{C_1}}$$

i) Inductive tuning

ii) Less bulking compare to hartelay oscillator

Q) H.W



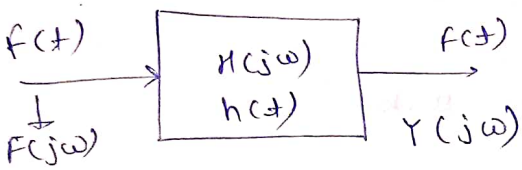
Frequency of oscillation & condition for oscillation.

Filter :→

Unwanted frequency → to block

wanted frequency → to pass

↳ gain of the filter is good for wanted frequency and bad (very low) for unwanted frequency.

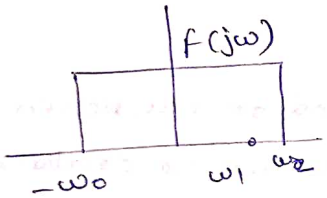


$Y(j\omega)$

$= F(j\omega)\, H(j\omega)$

$= H(j\omega)\, F(j\omega)$

$Y(j\omega) = H(j\omega)\, F(j\omega)$



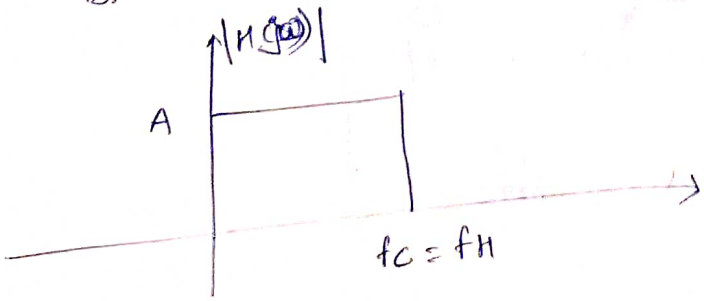
frequency dependent impedance must be required,

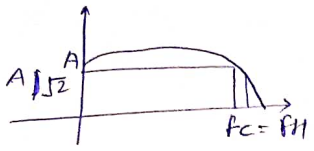
so L or C must always be required for filter design.

1) Low pass filter :-

pass band → low frequency

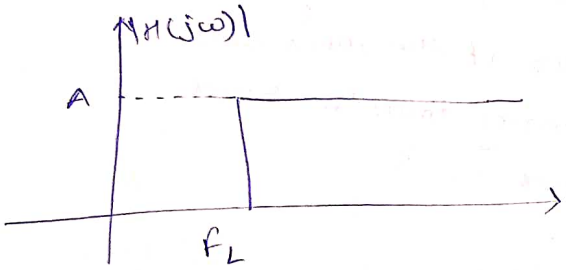
Block → high frequency.

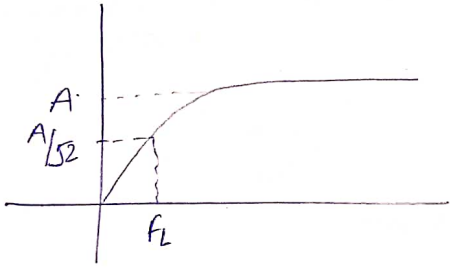




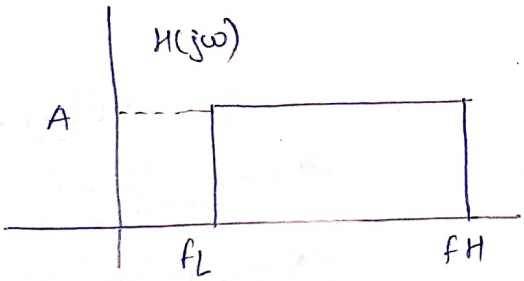
2) High pass filter :-

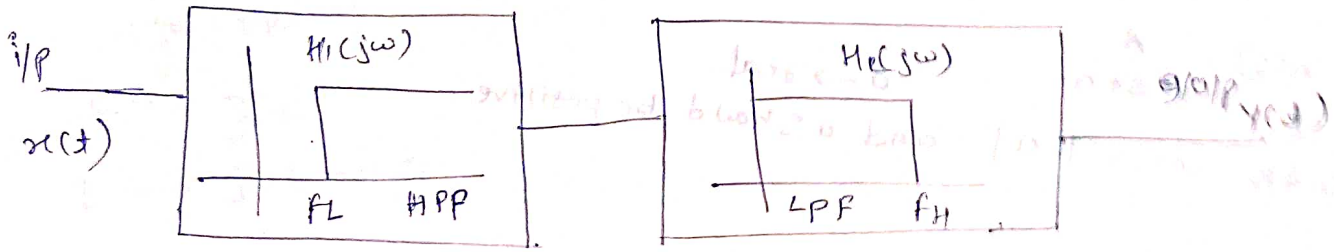
Pass → High frequency , Block → low frequency





3) Band pass filter





$y(t) = [x(t) \cdot h_1(t)] \, [h_2(t)]$

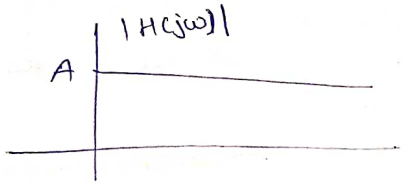
$Y(j\omega) = X(j\omega) \, \underline{H_1(j\omega) H_2(j\omega)}$

$\cancel{H(j\omega)}$

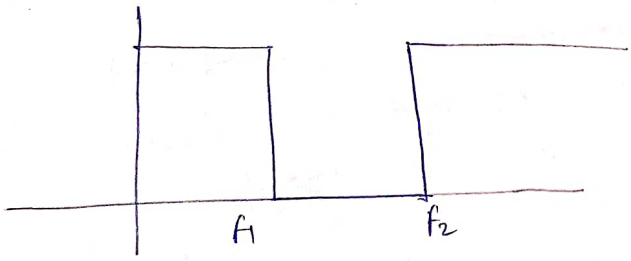
$f_L > f_H \rightarrow H(j\omega) = 0$

- we can design a ~~high~~ band pass filter by cascading a low pass filter & high pass filter if the upper cutoff frequency of low pass filter is greater than the lower cutoff frequency of high pass filter.

All pass filter:-



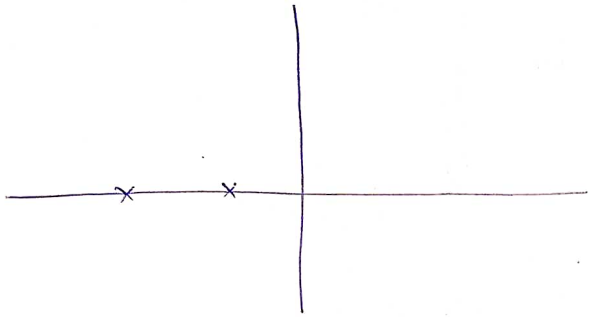
Band reject filter:-



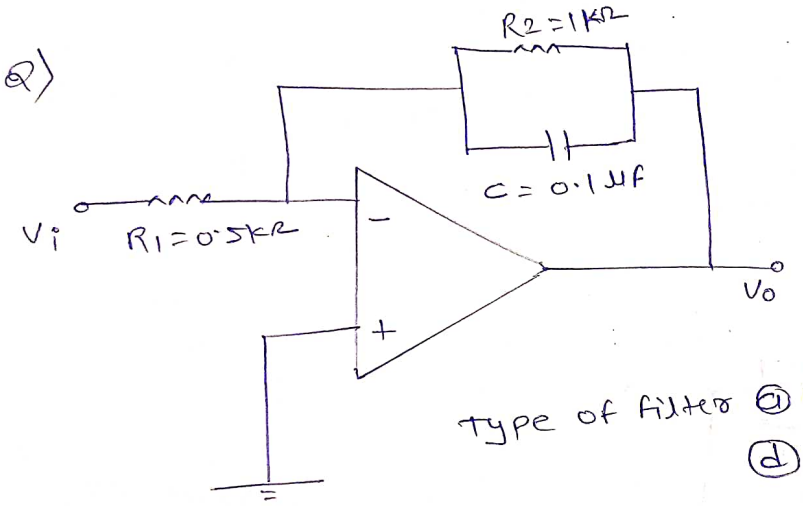
$H(s) = \dfrac{A}{s+a}$ $\quad a \rightarrow$ real

3-dB $\omega_c = |-a|$ and a should be positive.

$$H(j\omega) = \frac{A}{1 + \frac{j\omega}{\omega_c}} = \frac{A}{(1 + jf/f_c)}$$



Q)



Type of filter (a) HPF (b) LPF (c) BPF (d) BRF

Cutoff frequency ___ KHz (upto two decimal)

Sol:-

low frequency

$C \longrightarrow \frac{1}{j\omega C} \longrightarrow \infty$

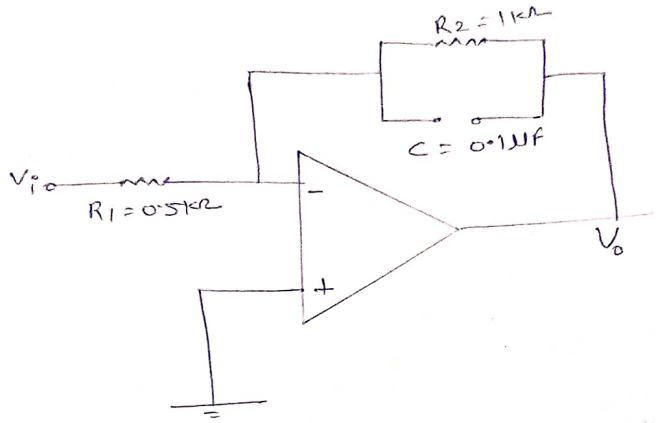
$L \longrightarrow j\omega L \longrightarrow 0$

High frequency

$C \longrightarrow \frac{1}{j\omega C} \longrightarrow 0$

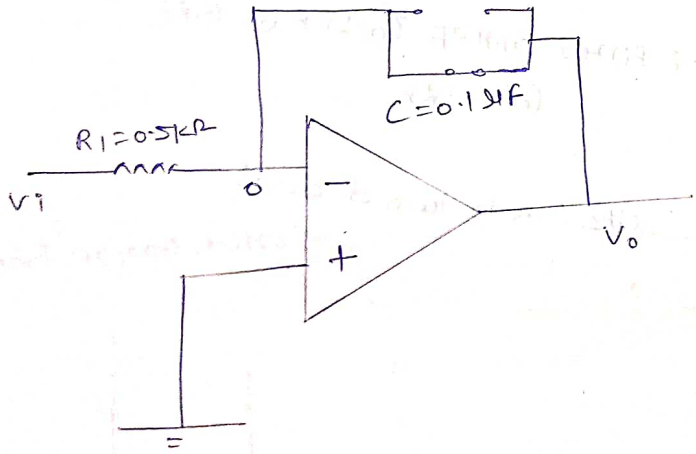
$L \longrightarrow j\omega L \longrightarrow \infty$

Low frequency.



$$\frac{V_o}{V_i} = \frac{-R_2}{R_1} = -2$$

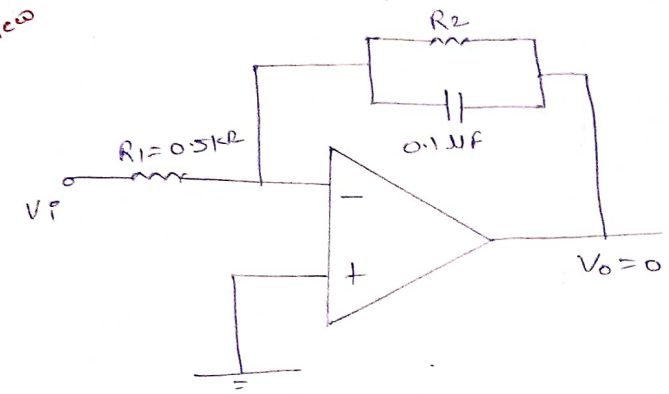
High frequency



$$\frac{V_o}{V_i} =$$

ask in interview

cutoff frequency.



$$H(S) = \frac{-Z_2}{Z_1} = \frac{\left(\frac{R_2 \cdot 1/CS}{R_2 + 1/CS}\right)}{R_1} = \frac{R_2}{R_1(R_1(S+1))}$$

$$= \frac{(-R_2/R_1)}{(R_2(S+1))}$$

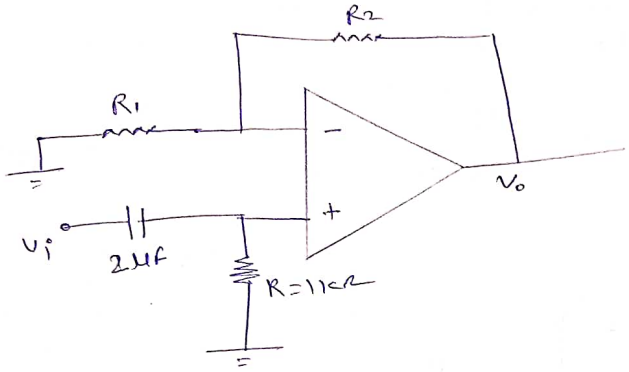
$$S = -\frac{1}{R_2 C}$$

$$\omega_c = \frac{1}{R_2 C}$$

$$f_c = \frac{1}{2\pi R_2 C}$$

If R_2 is not present then the system is marginally stable or unstable and it offers a very very high gain in at low frequency signal and due to this that low frequency signal are not properly passed at the output. (because opamp behaving like a comparator)

Q)



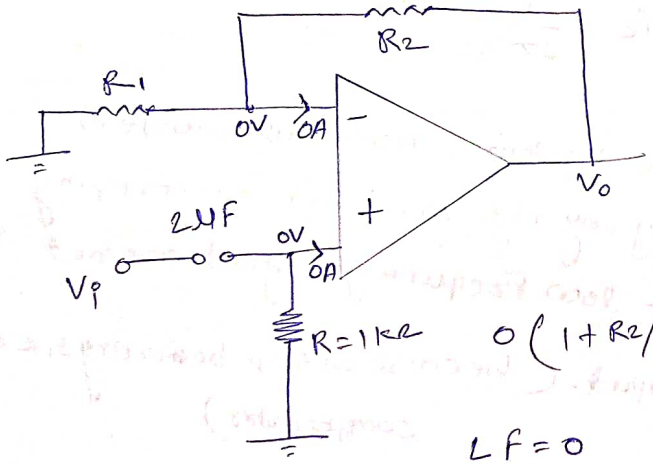
type of filter

a) LPF b) HPF c) BPF d) BRF

& cutoff frequency —— upto two decimal in Hz.

Sol:-

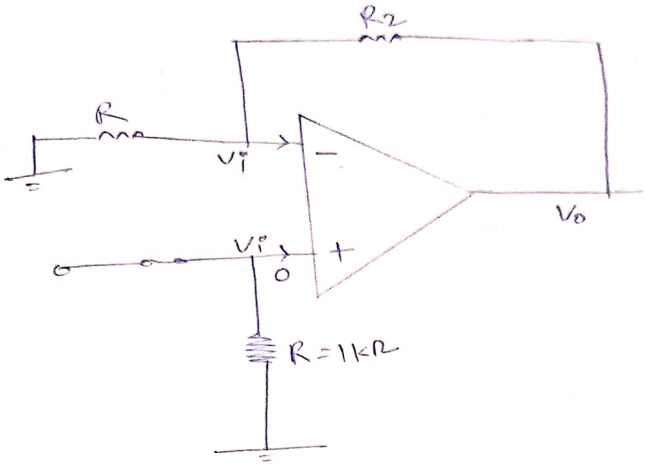
Step① Low frequency.



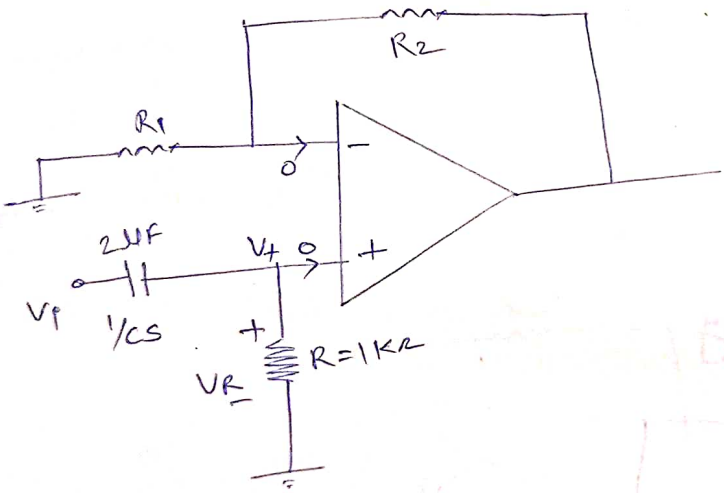
$0\left(1+R_2/R_1\right)=0$

$Lf=0$

step ②



$$V_i\left(1+\frac{R_2}{R_1}\right) \Rightarrow \underline{\underline{HPF}}$$



$$V_o = \left(1+\frac{R_2}{R_1}\right) \frac{RCS}{RCS+1} V_i$$

$$H(S) = \left(1+\frac{R_2}{R_1}\right)\left(\frac{RCS}{RCS+1}\right)$$

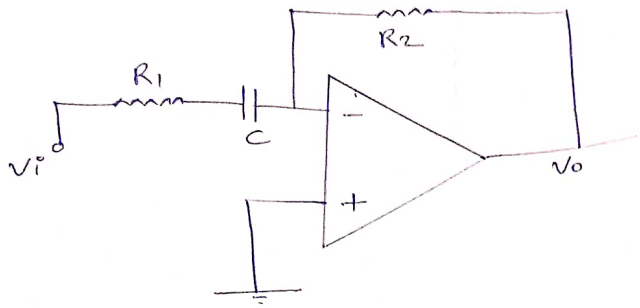
$S = -1/RC$

$\omega_c = 1/RC$

$f_c = \frac{1}{2\pi RC}$

$$\boxed{f_c = 79.57\ Hz}$$

Q)



above circuit is

a) HPF with $f_c = \frac{1}{2\pi R_2 C}$

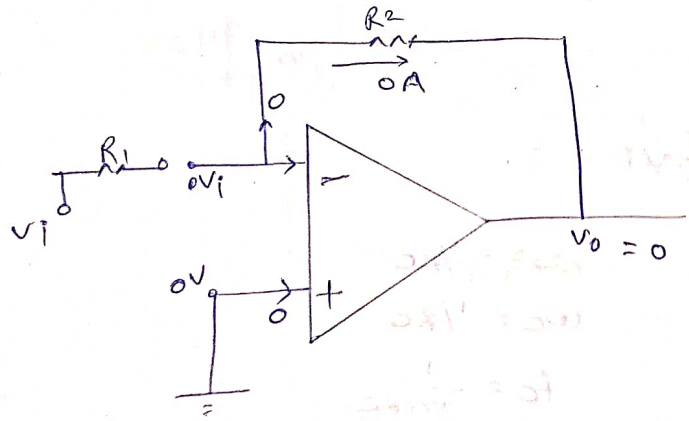
b) HPF with $f_c = \frac{1}{2\pi (R_1 + R_2) C}$

c) LPF with $f_c = \frac{1}{2\pi R_1 C}$

d) HPF with $f_c = \frac{1}{2\pi R_1 C}$

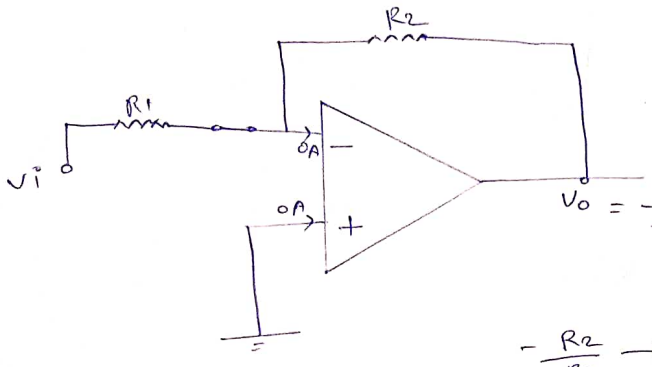
Sol:-

Step ① Low frequency



$$\frac{V_i - V_o}{R_2} = 0$$

Step② High frequency.



$V_o = -\frac{R_2}{R_1} V_i$

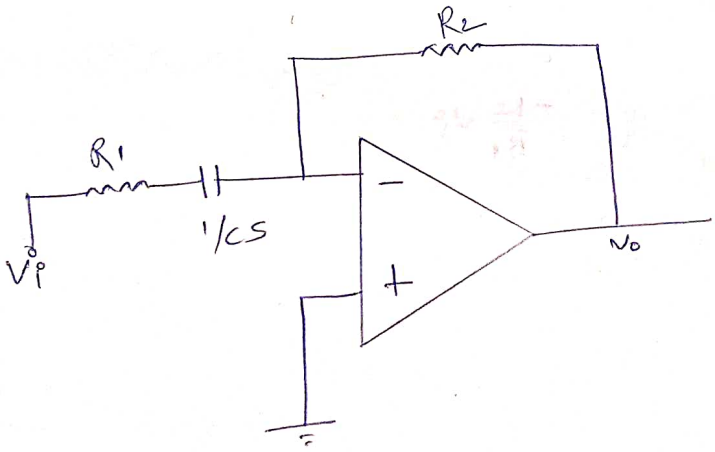
$-\frac{R_2}{R_1} \rightarrow$

High → ✓

low → ✗

High pass filter with $f_c = \frac{1}{2\pi R_1 C}$

cutoff frequency.



$$\frac{V_o}{V_i} = \frac{-Z_2}{Z_1} = \frac{-R_2}{(R_1 + 1/cs)}$$

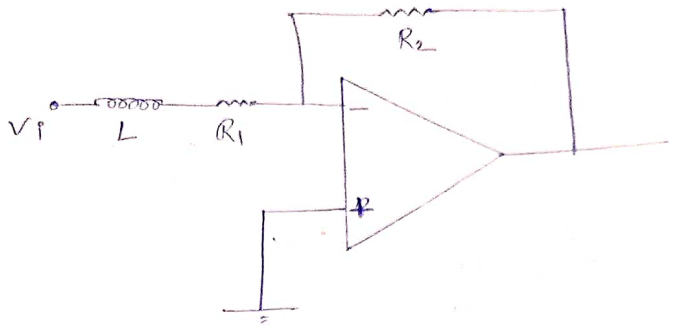
$$= \frac{-R_2 cs}{(R_1 cs + 1)}$$

$$s = \frac{-1}{R_1 C}$$

$$\omega_c = \frac{1}{R_1 C}$$

$$f_c = \frac{1}{2\pi R_1 C}$$

Q)



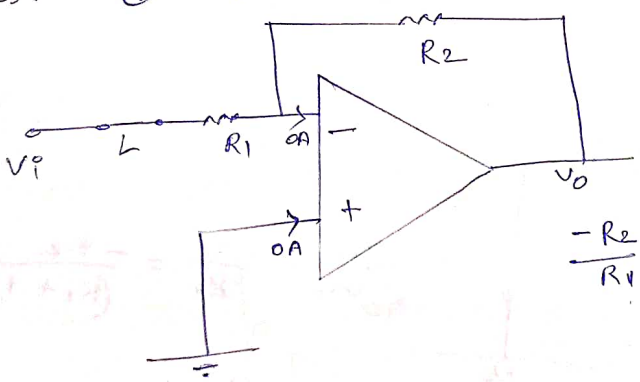
a) LPF with $f_c = \frac{L}{R_1}$ ✗

b) HPF with $f_c = \frac{L}{2\pi R_1}$ ✗

✓ c) ~~HPF~~ LPF with $f_c = \frac{R_1}{2\pi L}$

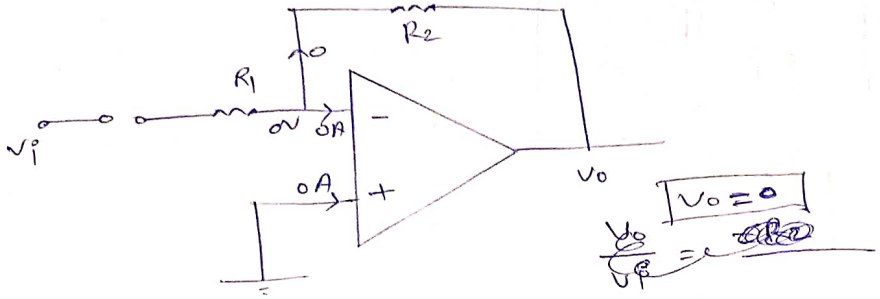
d) LPF with $f_c = \frac{R_2}{2\pi L}$ ✗

Sol:- ① Low frequency

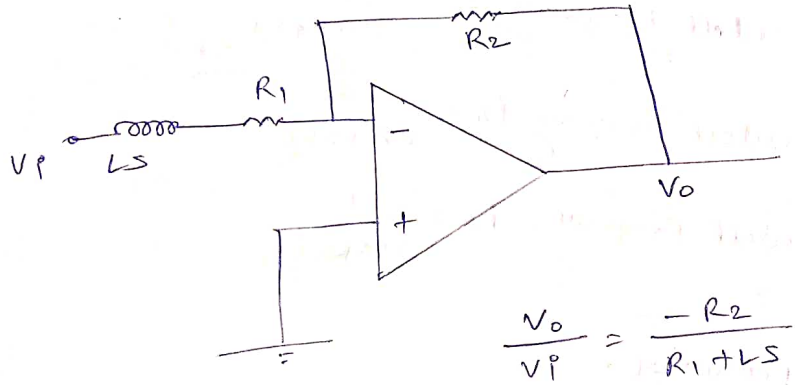


$\frac{-R_2}{R_1} V_i$

High frequency.



Cutoff frequency.



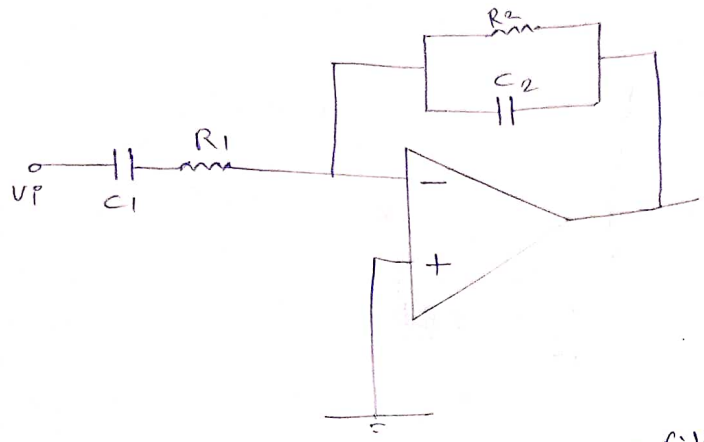
$$\frac{V_o}{V_i} = \frac{-R_2}{R_1 + LS}$$

$$S = \frac{-R_1}{L}$$

$$\omega_c = \frac{R_1}{L}$$

$$f_c = \frac{R_1}{2\pi L}$$

Q)



This ckt works as a band pass filter with

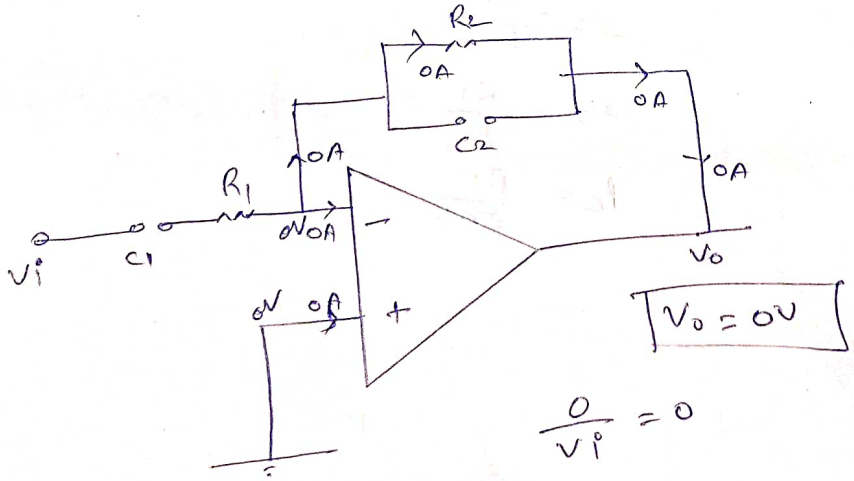
a) upper cutoff frequency $f_H = \frac{1}{2\pi R_1 C_1}$

b) BPF with lower cutoff frequency $f_L = \frac{1}{2\pi R_2 C_1}$

c) BPF with upper cutoff frequency $f_H = \frac{1}{2\pi R_2 C_2}$

d) BPF with lower cutoff frequency $f_L = \frac{1}{2\pi R_2 C_2}$

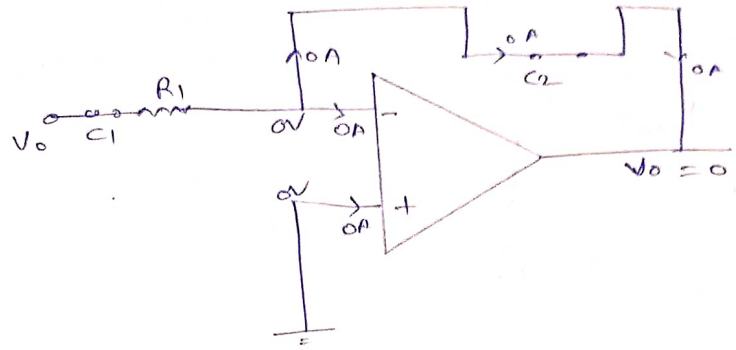
Sol:- low frequency.



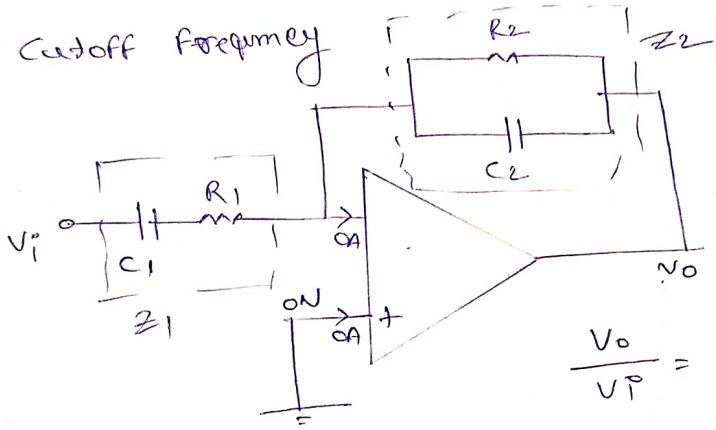
$\boxed{V_o = 0V}$

$\frac{0}{V_i} = 0$

high frequency



Cutoff frequency



$$\frac{V_o}{V_i} = \frac{-Z_2}{Z_1}$$

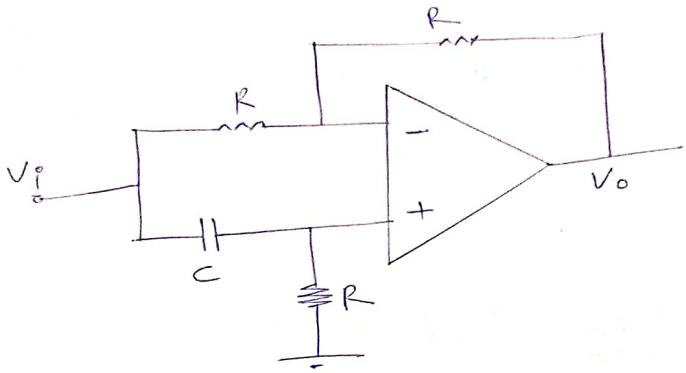
$$= \frac{-R_2/R_2C_2S+1}{\frac{R_1C_1S+1}{C_1S}}$$

$$= \frac{-R_2(C_1S)}{R_2(C_2S+1)(R_1C_1S+1)}$$

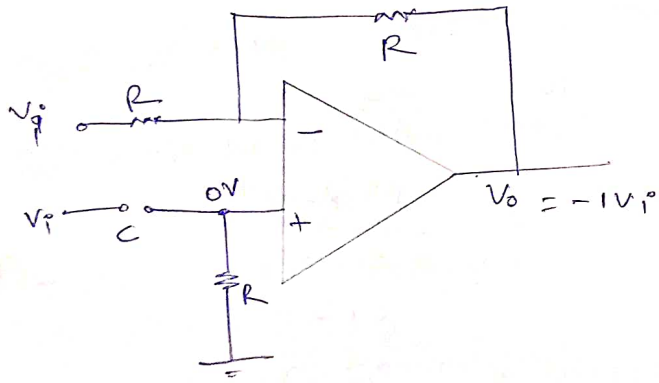
$$\omega_1 = \frac{1}{R_2C_2} \rightarrow f_H$$

$$\omega_2 = \frac{1}{R_1C_1} = f_L$$

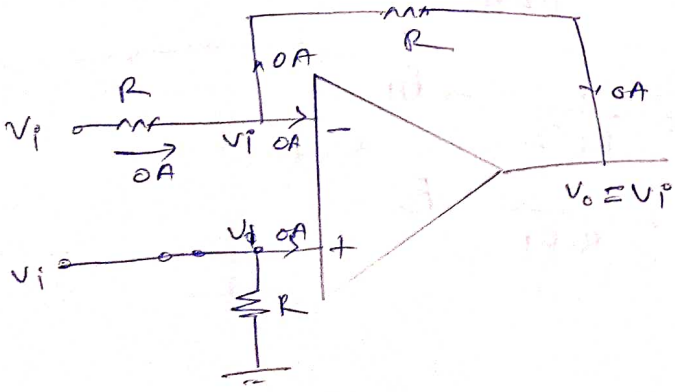
ALL pass filter

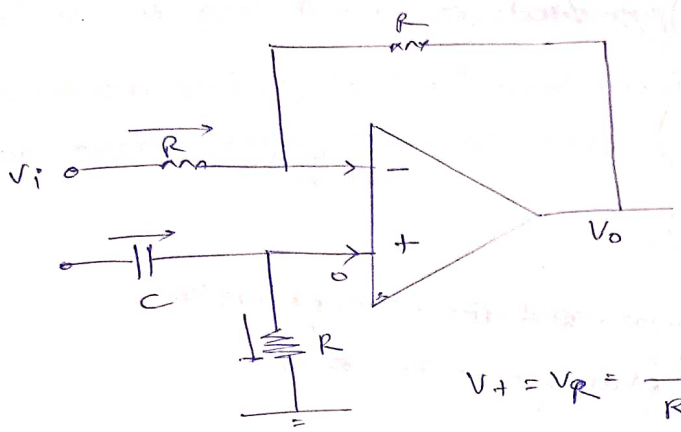


Step ① L f test



Step ② H f test.





$$V_+ = V_R = \frac{R}{R + \frac{1}{CS}} V_i$$

$$= \frac{RCS}{RCS+1} V_i$$

$$\frac{V_i - V_R}{R} = 0 + \frac{V_R - V_o}{R}$$

$$V_o = 2V_R - V_i$$

$$= \left[\frac{2RCS}{2CS+1} - 1\right] V_i$$

$$= \left(\frac{RCS-1}{RCS+1}\right) V_i$$

$$H(S) = \frac{(RCS-1)}{(RCS+1)}$$

$$H(j\omega) = \left(\frac{RCj\omega - 1}{RCj\omega + 1}\right)$$

$$\left|H(j\omega)\right| = \frac{\sqrt{(-1)^2 + R^2C^2\omega^2}}{\sqrt{1^2 + R^2C^2\omega^2}} = 1$$

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

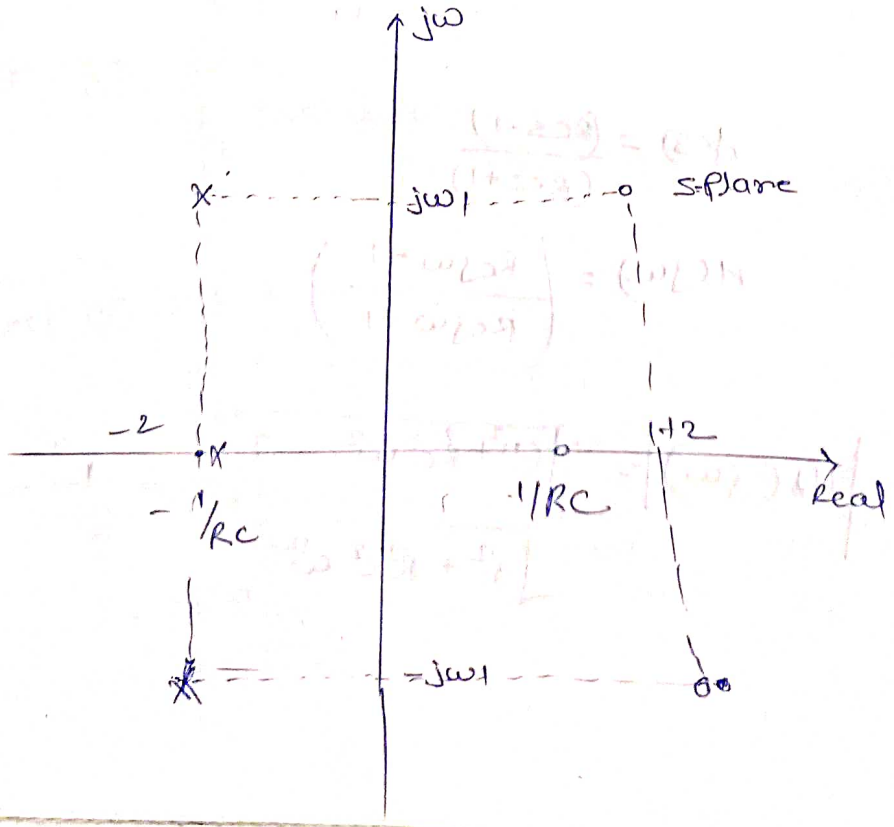
$$= -\tan^{-1}\left(\frac{RC\omega}{1}\right)$$

$$= -2\tan^{-1}(RC\omega)$$

- All pass filter is never used for filtering action rather it is use for phase correction to of two group of frequencies.

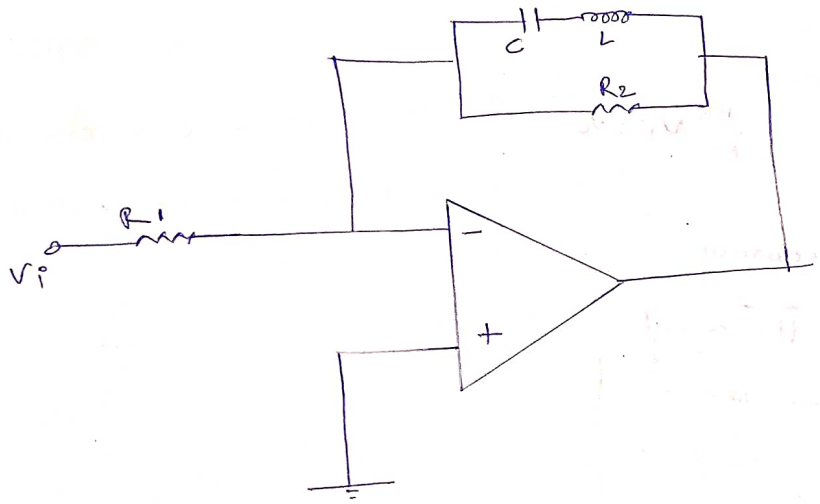
- It is basically used to taylor the group delay is specification / group delay requirement.

- It offers different phase shift for different i/p frequency but offers no gain one all frequencies



- for an all pass filter corresponding to every pole (whether real or complex) there must be a zero which should be mirror image of pole about jω axis.

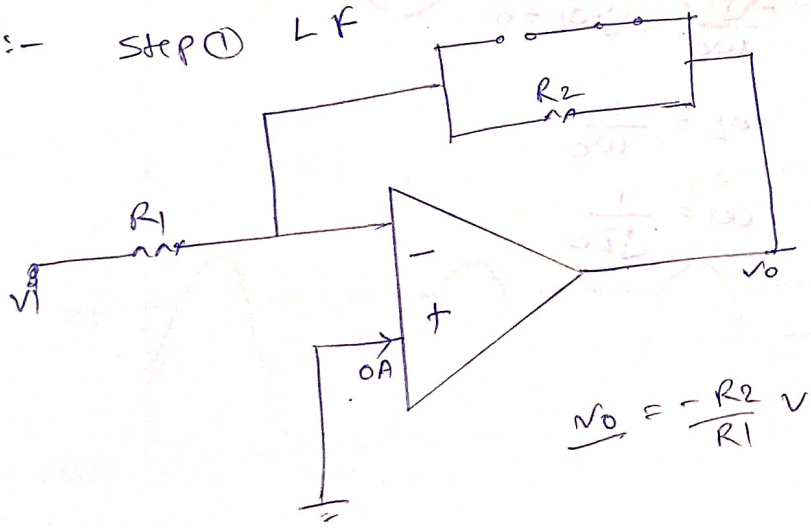
Q)



The circuit is

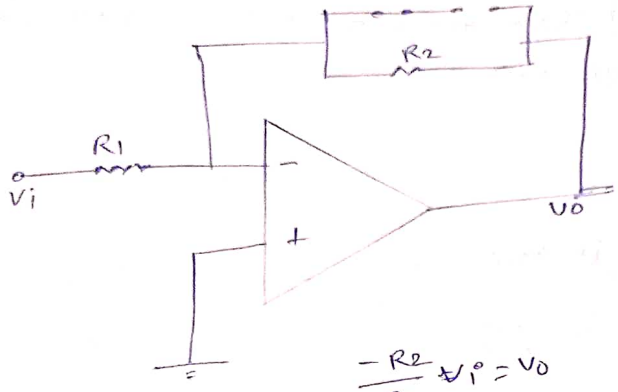
a) BRF b) APF c) HPF d) LPF

Soln:- Step ① LF



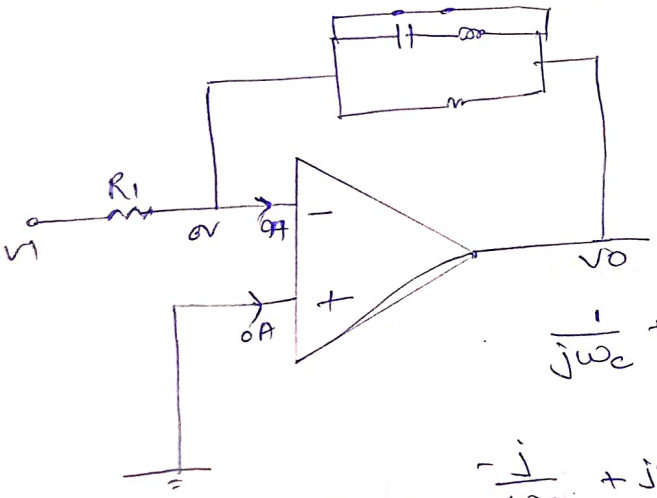
$$V_o = -\frac{R_2}{R_1} V_i$$

Step ② HF



$$\frac{-R_2}{R_1} V_i = V_o$$

Cutoff frequency



$$\frac{1}{j\omega_c} + j\omega L = 0$$

$$-\frac{j}{\omega c} + j\omega L = 0$$

$$\omega L = \frac{1}{\omega c}$$

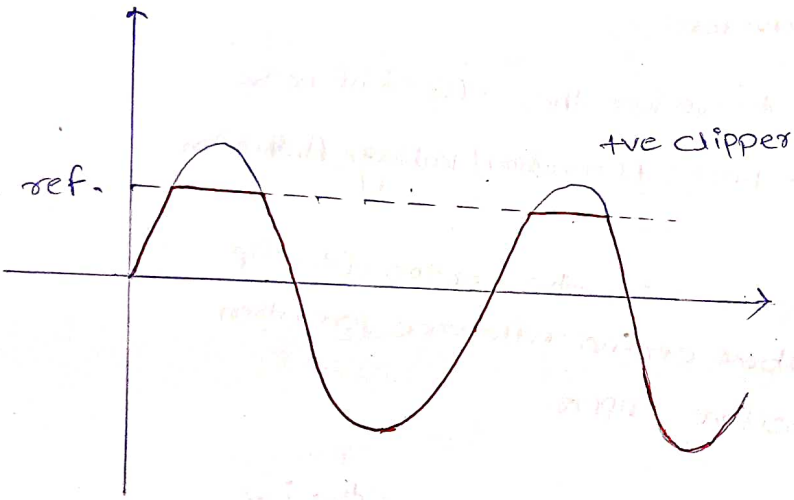
$$\omega = \frac{1}{\sqrt{Lc}}$$

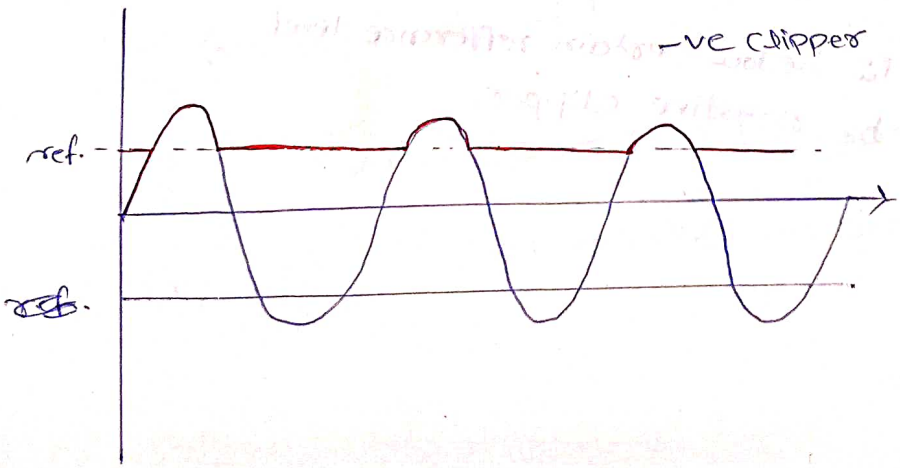
Clippers

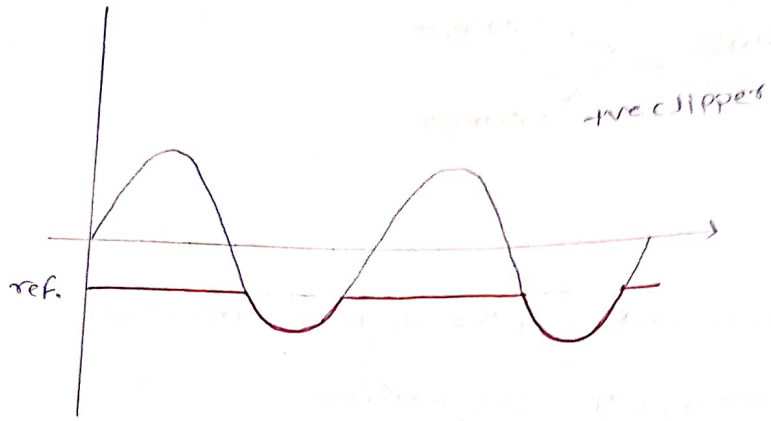
wave shaping circuits :- clipper, clamper

Clipper :-

1) It removes certain portion of the i/p waveform and retains other portion of the i/p waveform.





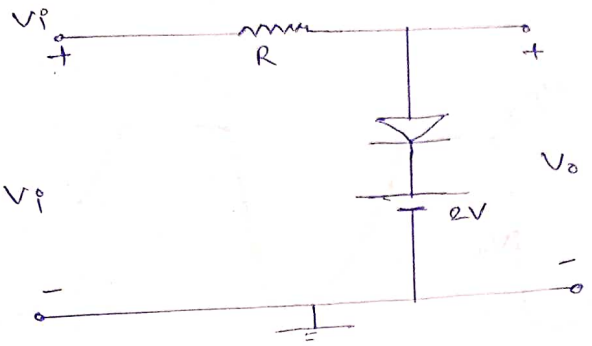


- Clipper is basically used to ~~cut~~ clip unwanted portion of the i/p waveform.
- Clipper is also used to reduce the effect of noise on the o/p side, e.g:- Power fluctuation / voltage fluctuation

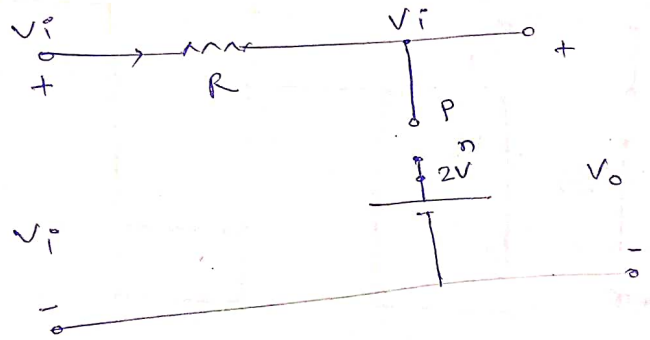
Positive clipper:- if clipper clips the portion of the i/p waveform which is above certain refference level then it is said to be positive clipper.

Negative clipper:- if clipper clips the portion of the i/p waveform which is below certain refference level then it is said to be negative clipper.

ask every alternate year



Soln:-
O.C. test
step ①



$V_p = V_i$

$V_n = 2V$

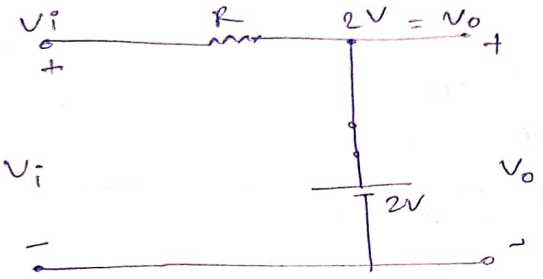
$(V_p - V_n)_{o.c} = (V_i - 2)$

$(V_i - 2) > 0 \rightarrow ON \rightarrow V_i > 2$ – D-ON

$(V_i - 2) < 0 \rightarrow OFF \rightarrow V_i < 2 \rightarrow$ D-off

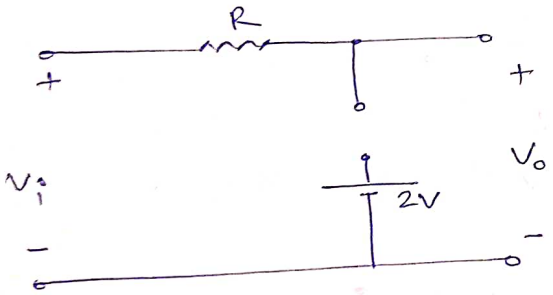
i) $V_i > 2$ - D-ON $\rightarrow V_o = 2V$

$V_o = 2V$

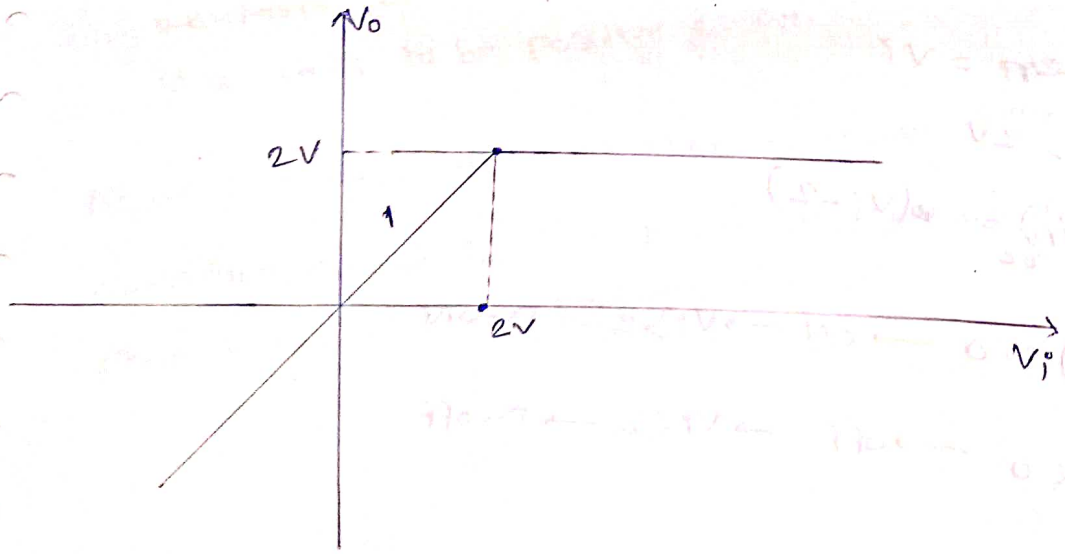


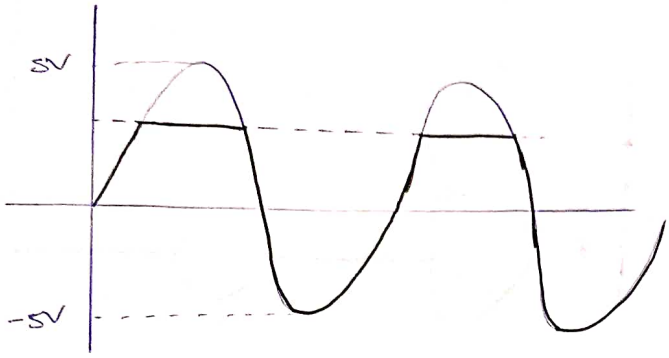
ii) $V_i < 2$ - D-off $\rightarrow V_o = V_i$

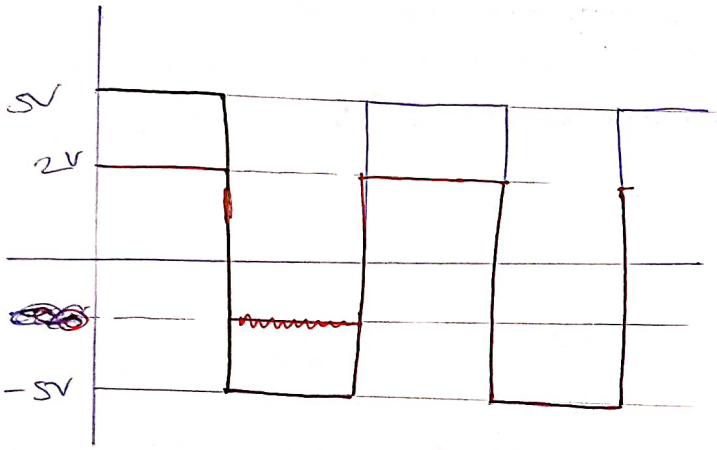
$y = mx + c = 0$



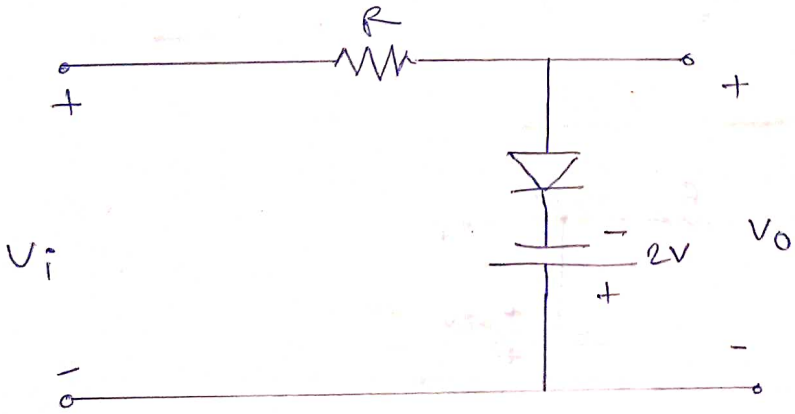
+ve clipper





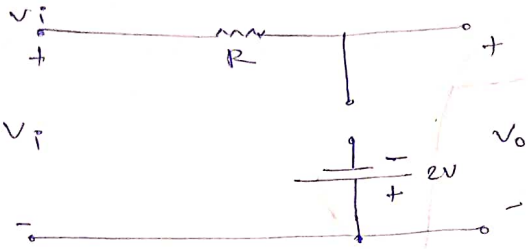


Q)



Sol:-

Step ① o.c. test

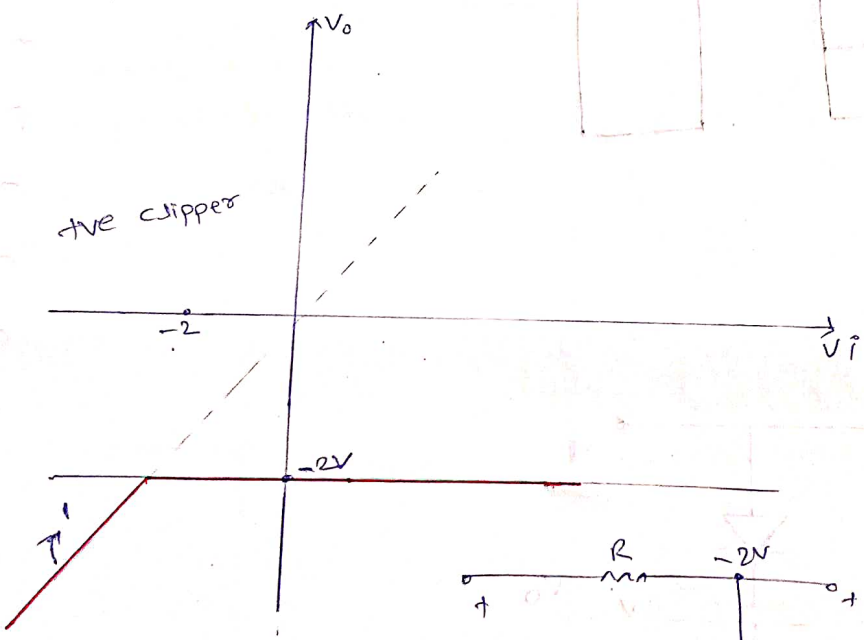


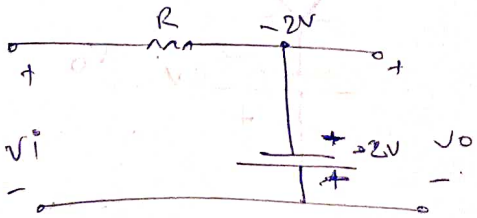
$(V_p - V_n)_{oc} = (V_i + 2)$

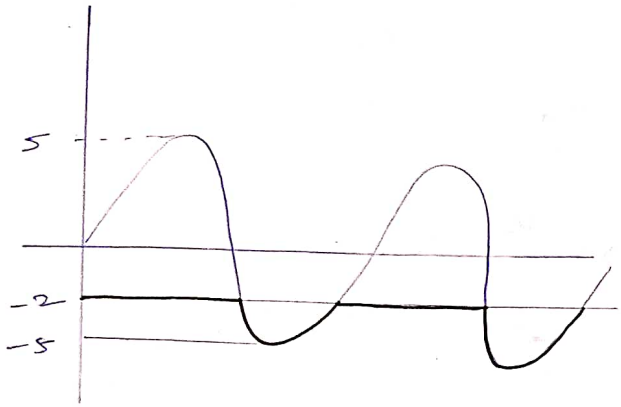
① $(V_i+2) > 0 \longrightarrow ON \longrightarrow V_i > -2V \rightarrow V_o = -2V$

$(V_i+2) < 0 \longrightarrow OFF \rightarrow V_i < -2 \rightarrow V_o = V_i$

①

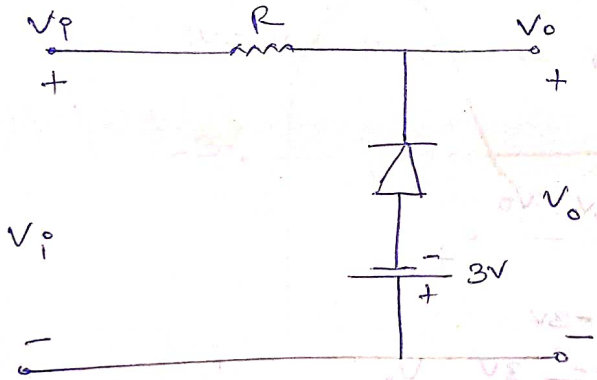






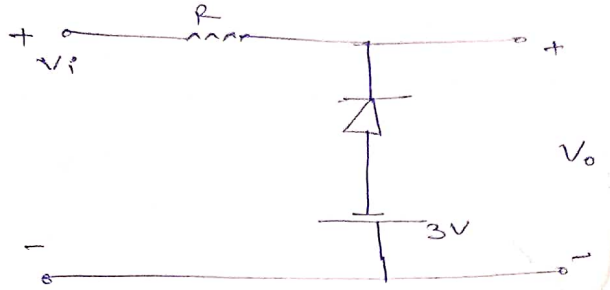
Note:- In periodic waveform (i/p of clipper) they generate clipped wave form on o/p side that wave is also a periodic waveform of the same time period & frequency.

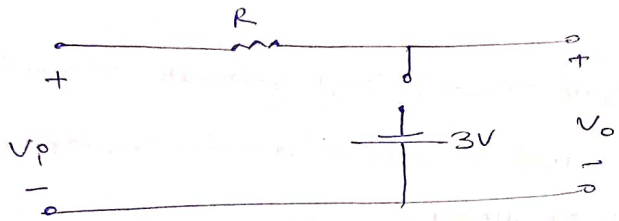
Q)



Sol^n:-

Step ① o.c. test



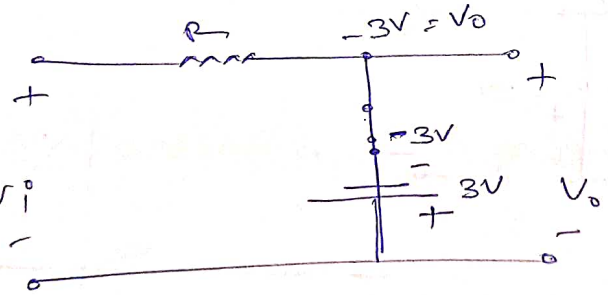


$$(V_p - V_n)_{oc} = (-3 - V_i)$$

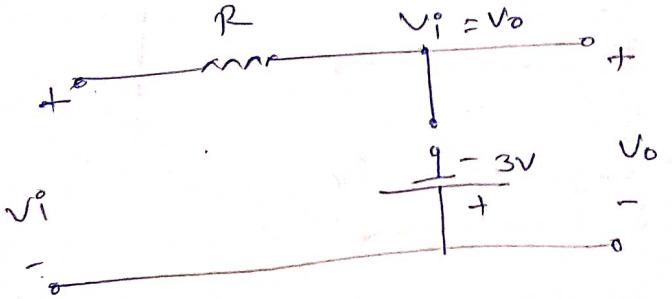
① $-3 - V_i \geq 0 \longrightarrow$ D-ON $\rightarrow V_i < -3 \rightarrow V_o = -3V$

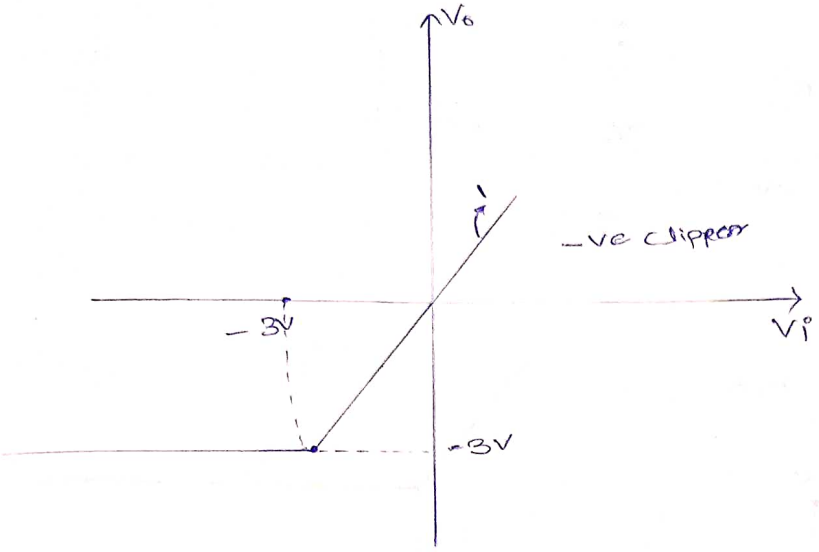
② $-3 - V_i < 0 \longrightarrow$ D-off $\rightarrow V_i > -3 \rightarrow V_o = V_i$

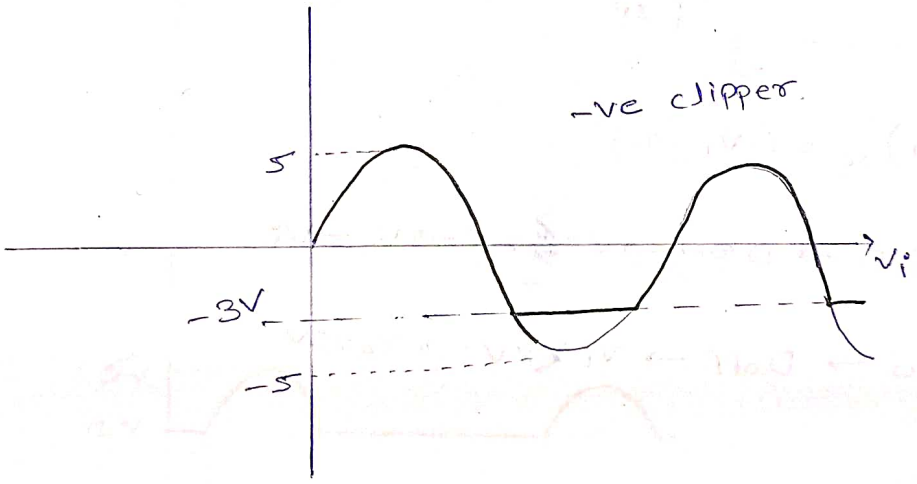
①



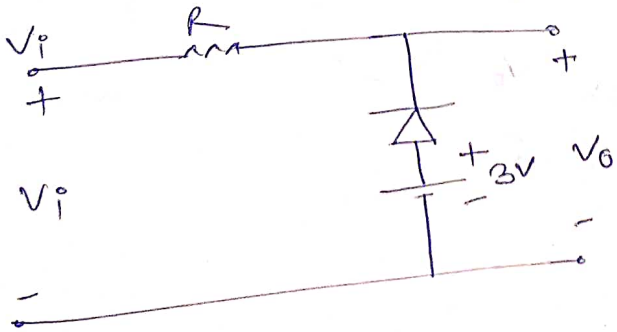
②



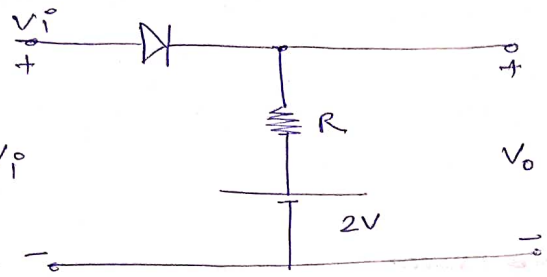




4.10

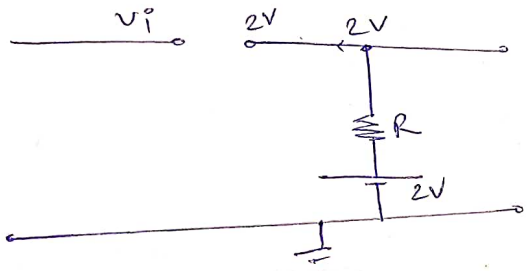


Q)



Sol:-

Step ① o.c test

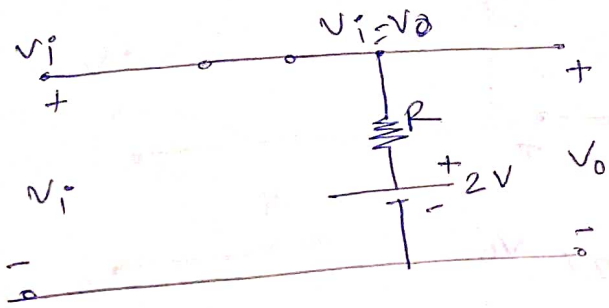


$(V_p - V_n)_{oc} = (V_i - 2)$

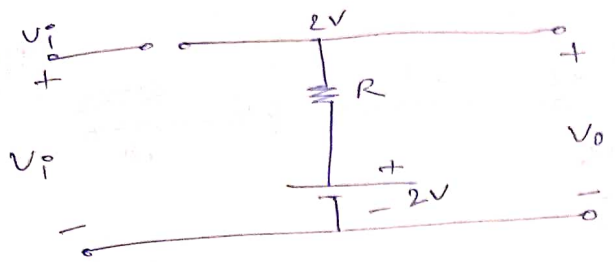
① $V_i - 2 > 0 \rightarrow$ D ON $\rightarrow V_i \geq 2V \rightarrow V_o = V_i$

② $V_i - 2 < 0 \rightarrow$ D.off $\rightarrow V_i < 2V \rightarrow V_o = 2V$

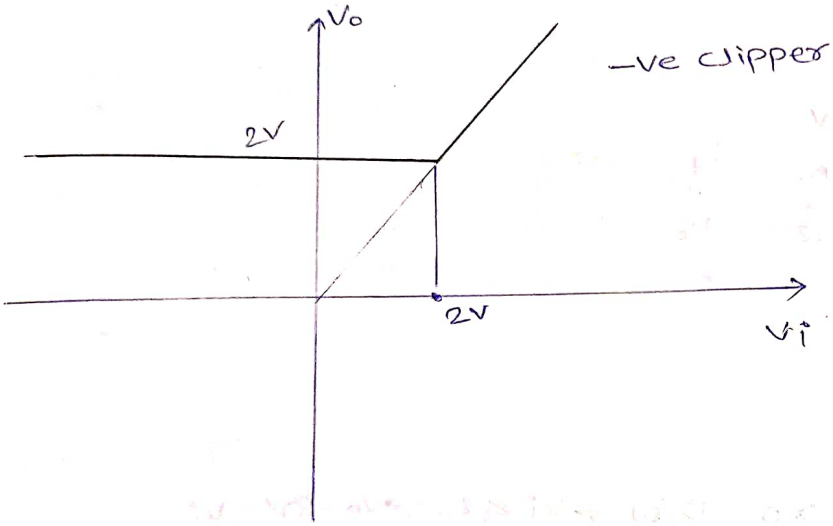
④

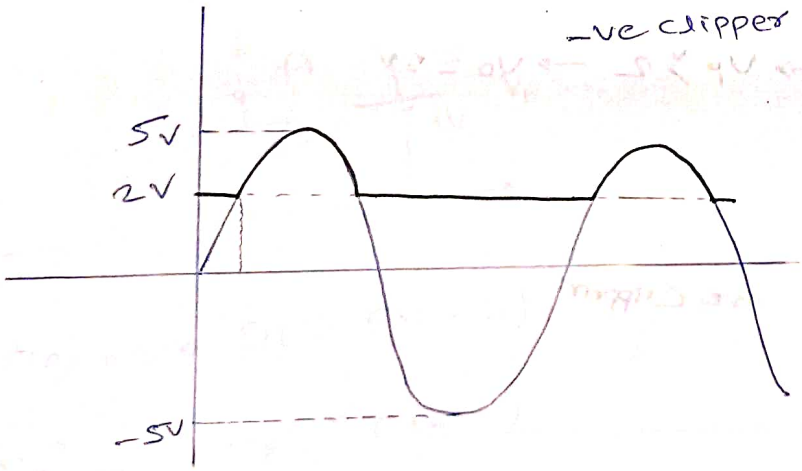


(2)

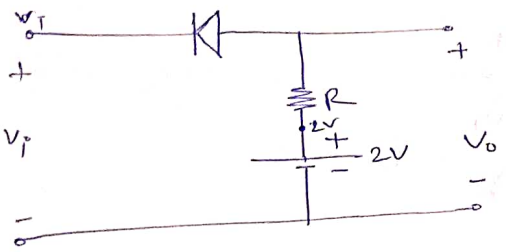


$V_o = 2V$



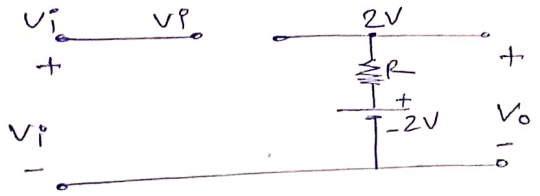


Q)



Soln:-

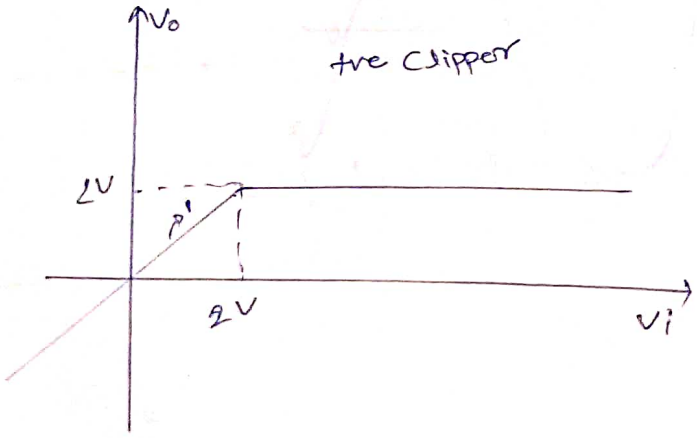
Step ① o.c. test



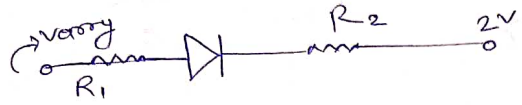
$(V_p - V_n)_{o.c} = (2 - V_i)$

① $2 - V_i > 0$ D on → $V_i < 2$ → $V_o = 2V = V_i$

② $2 - V_i < 0$ D off → $V_i > 2$ → $V_o = 2V$



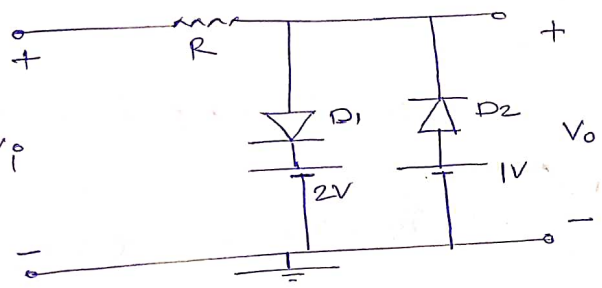
e.g.:-



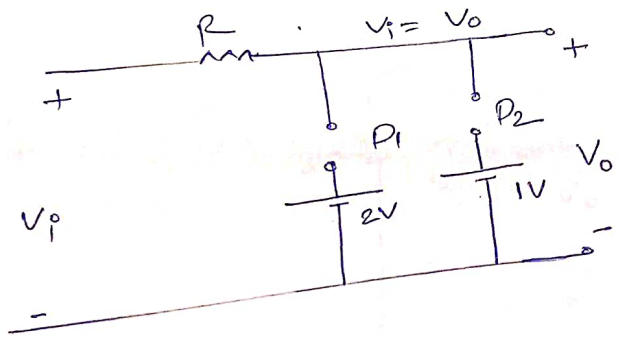
$V_p - V_n > 0$

$V_p > V_n$

Q)



sol^n:- step ① O.C. test



$(V_p - V_n)_{oc} = D_1 = (V_i - 2)$

$(V_p - V_n)_{oc} = D_2 = (1 - V_i)$

D_1 - ON $\longrightarrow (V_i - 2) > 0 \longrightarrow V_i > 2$

OFF $\longrightarrow (V_i - 2) < 0 \longrightarrow V_i < 2$

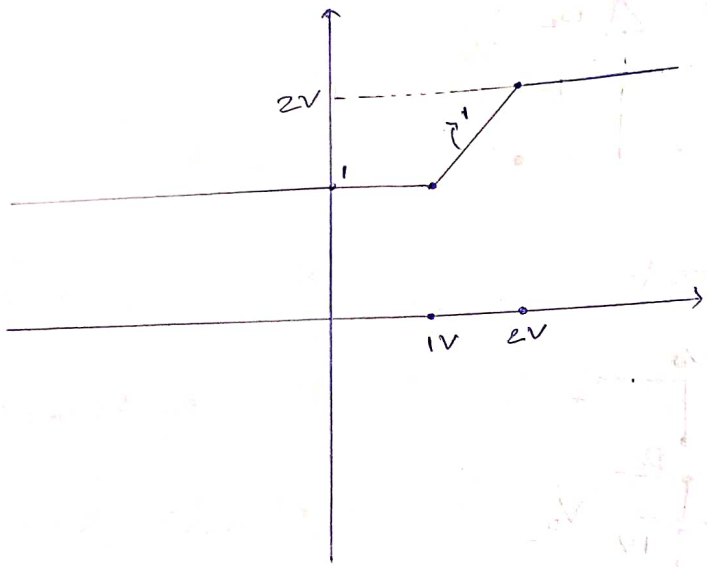
D_2 - ON $\rightarrow 1 - V_i > 0 \longrightarrow V_i < 1$

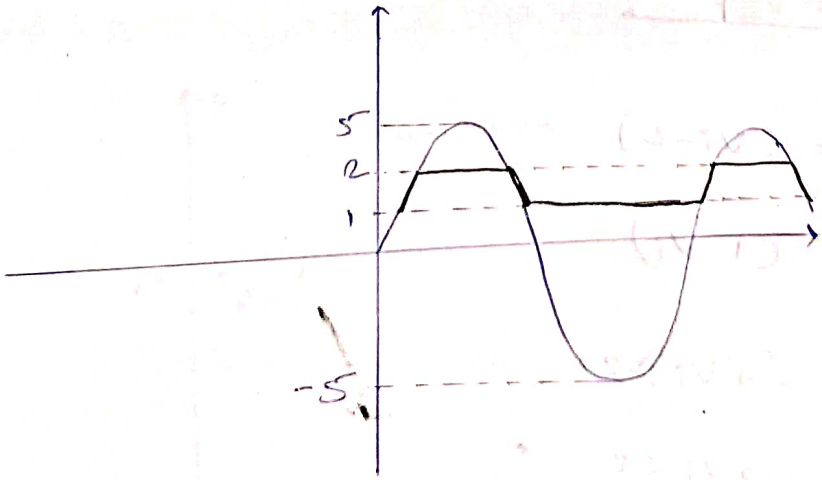
Off $\rightarrow 1 - V_i < 0 \longrightarrow V_i > 1$

i) $1 < V_i < 2 \longrightarrow D_1, D_2 \rightarrow$ off $\quad V_o = V_i$

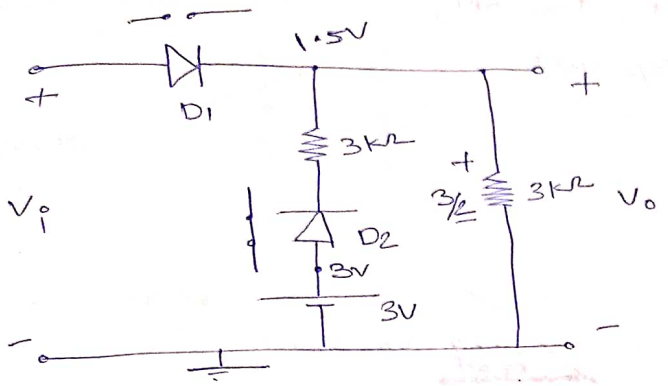
ii) $V_i < 1 \longrightarrow D_1$ off, D_2 - ON $\quad V_o = 1V$

iii) $V_i > 2 \longrightarrow D_1$ ON, D_2 off $\quad V_o = 2V$





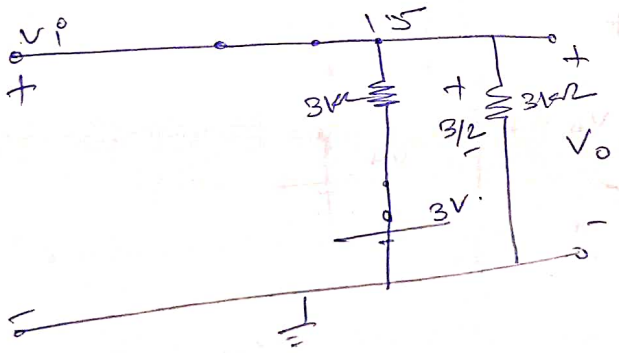
Q)



$V_i > 0 \longrightarrow D_1$ off, D_2 - ON

$1.5 > V_i > 0 \longrightarrow D_1$ off, D_2 ON.

$V_i > 1.5 \longrightarrow D_1$ ON, D_2 ON.



$3 > V_i > 1.5$ D_1 ON, D_2 ON

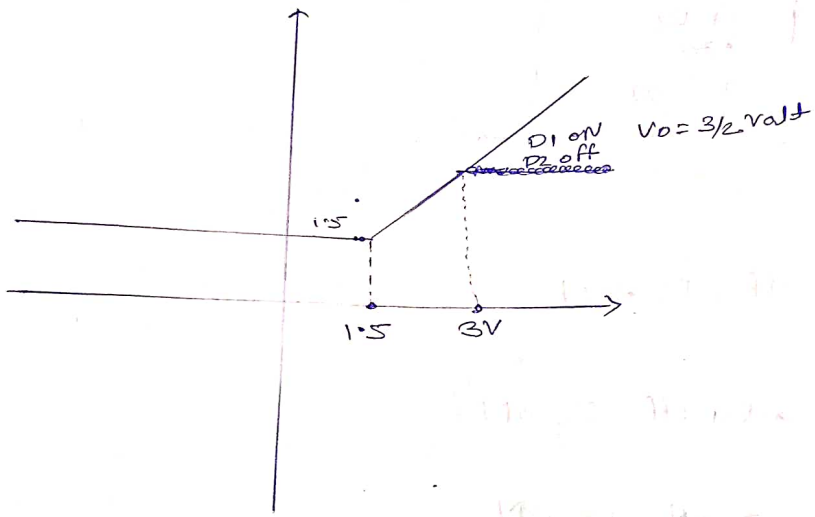
$V_o = V_i$

$V_i > 3$ D_2 off, D_1 ON

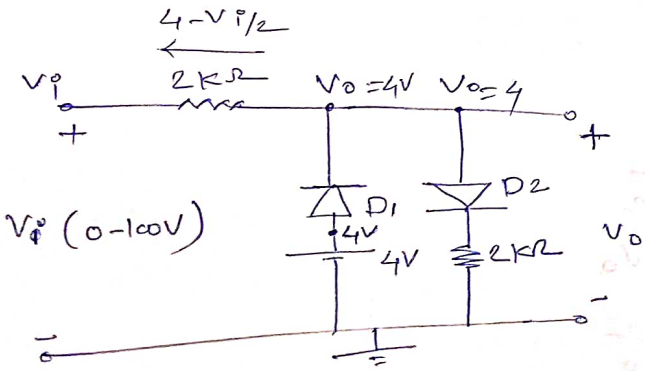
$\boxed{V_o = V_i}$

$V_i < 0 \longrightarrow D_1$ off, D_2 - ON

$V_o = 3/2$ Volt



Q)

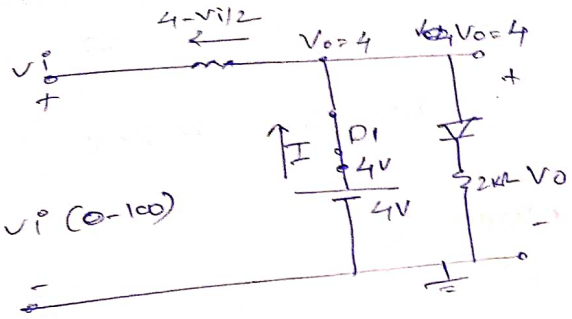


Sol:-

$V_i > 0$ D1 ON, D2 ON

~~KCL at Vo~~

~~$V_i = V_o$~~



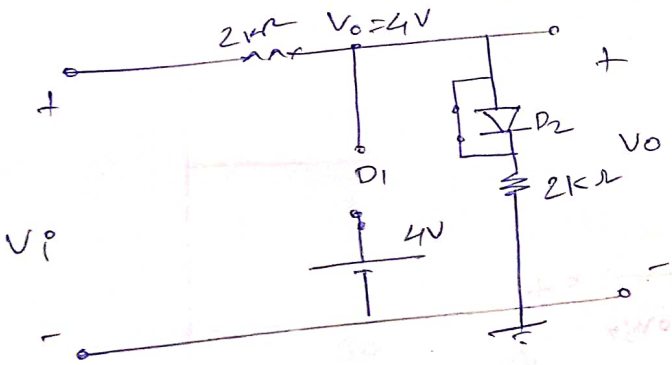
$$I = \frac{4-V_i}{2} + 2$$

$$\frac{4-V_i}{2} + 2 > 0$$

$$2 - \frac{V_i}{2} + 2 > 0$$

$$\boxed{V_i < 8V}$$

$V_i > 8V \longrightarrow$ D1 off , D2 - ON

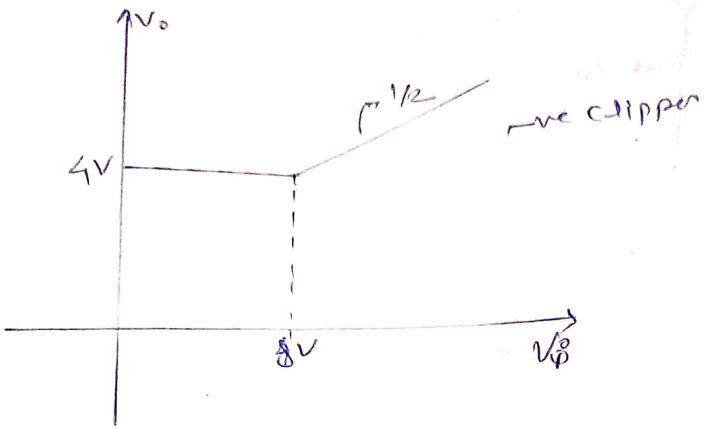


$$I = \frac{4-V_i}{2} + 2$$

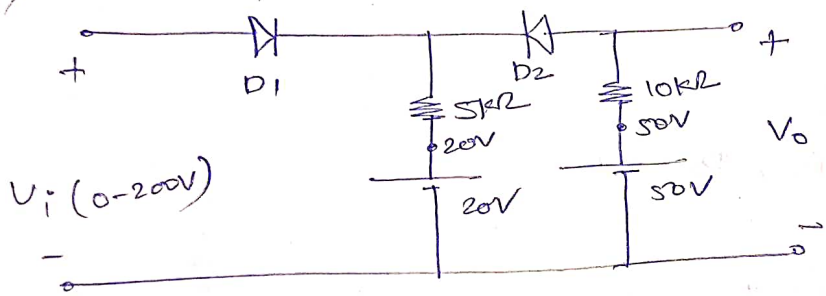
$$\frac{4-V_i}{2} + 2 > 0$$

$$2 - \frac{V_i}{2} + 2 > 0$$

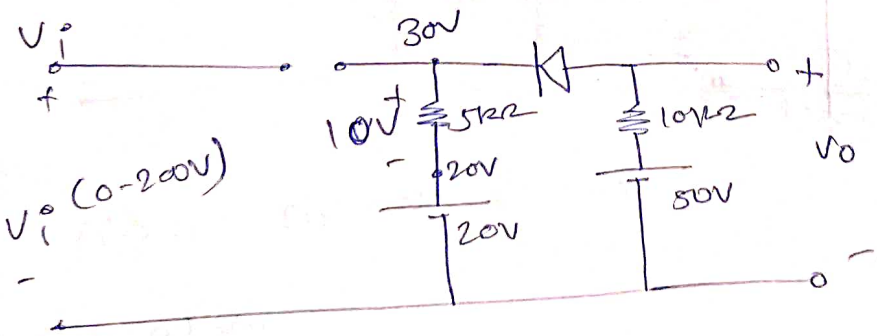
$$\boxed{V_i < 8V}$$



Q)

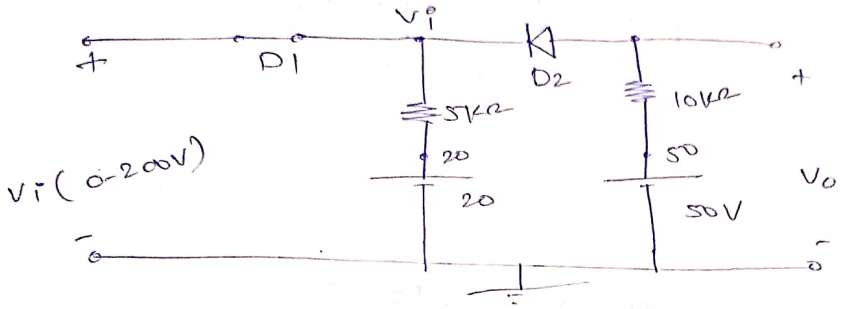


Vi > 0 , D1 off, D2 ON



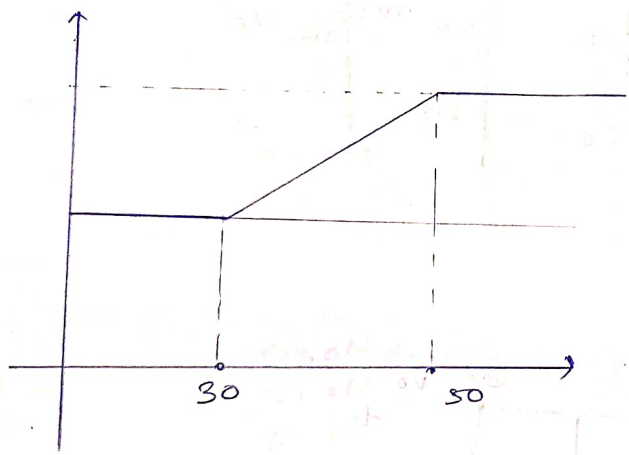
$V_o = 30$, $30 > V_i > 0$ D_1 off , D_2 ON

$V_i > 30$, D_1 ON

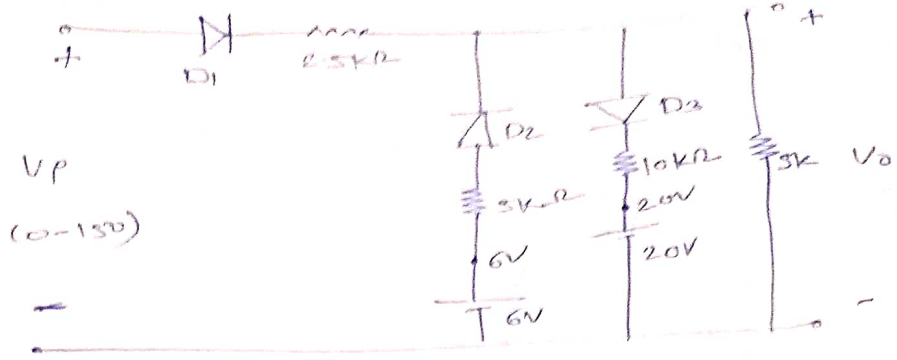


$V_o = V_i$ $50 > V_i > 30$ D_1 ON , D_2 ON

$V_o = 50V$, $V_i > 50$, D_1 ON , D_2 off



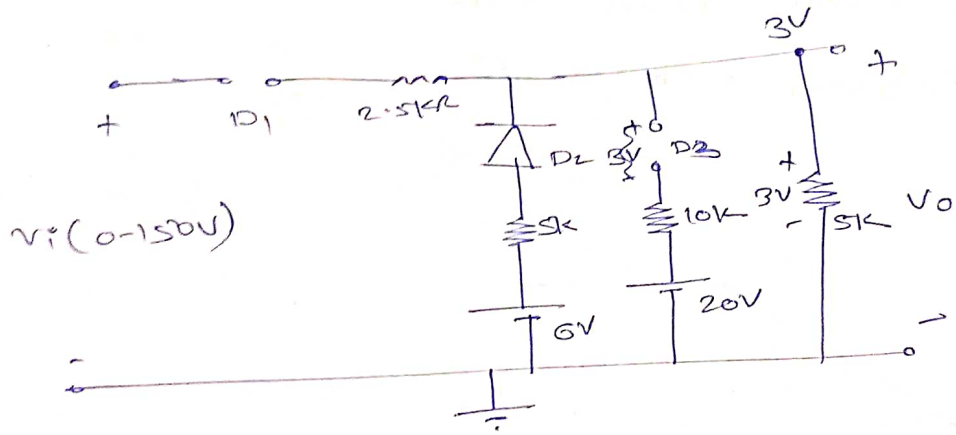
Q)



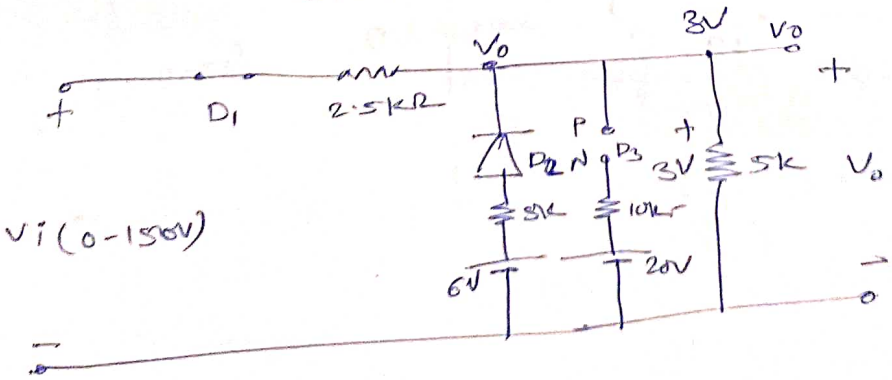
Sol^n

assumption

$0 < V_i$. D1 off, D3 off, D2 ON



$V_o = 3$ D1 ON,
D3, off



$$\frac{V_i - V_o}{2} + \frac{6 - V_o}{5} = \frac{V_o - 0}{5}$$

$2V_i - 2V_o + 6 - V_o = V_o$

$4V_o = 2V_i + 6$

$V_o = \left(\frac{1}{2}V_i + 1.5\right)$

$\frac{1}{2}V_i + \frac{3}{2} = 6$

$\boxed{V_i = 9V}$

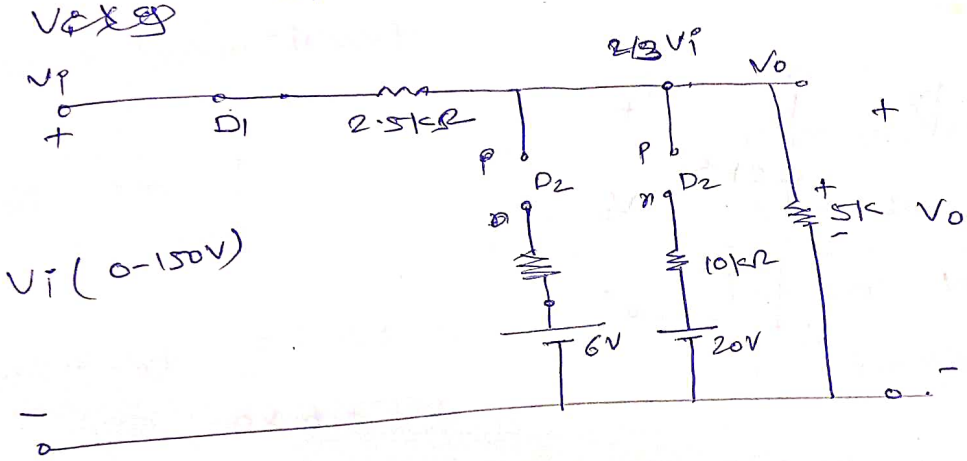
$9 > V_i > 3$ - D1 ON

$\frac{1}{2}V_i + \frac{3}{2}$ D3 off
D2 ON

$V_i > 9 \rightarrow$ D1 ON, D2 off, D3 off

$V_o = 2/3 V_i$ D3 off.

$V_i > 9$



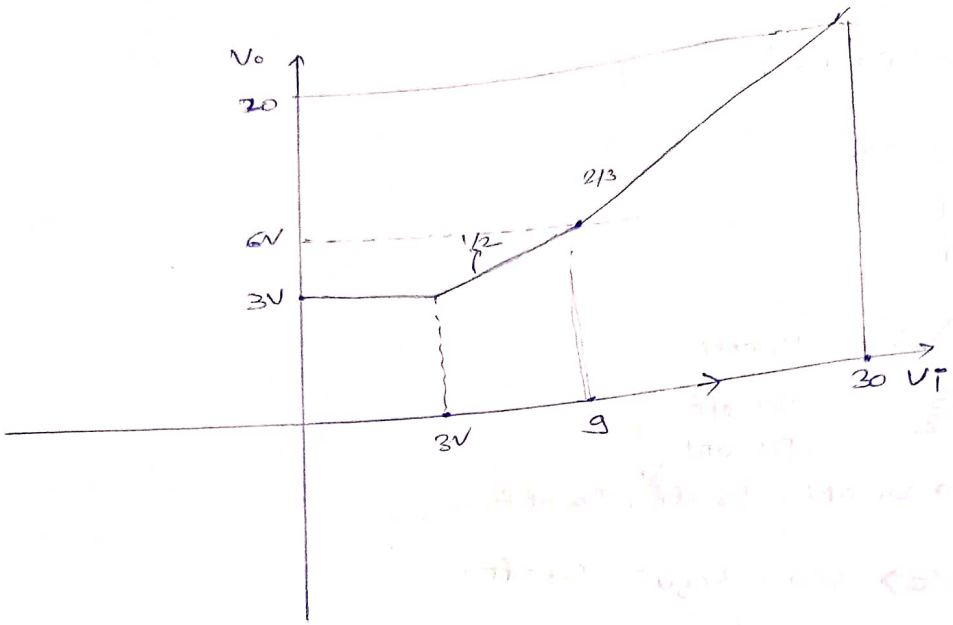
$V > 30$ D3 ON
D1 ON
D2 off

$$\frac{V_i - V_o}{2.5} = \frac{V_o - 20}{10} + \frac{V_o}{5}$$

$4V_i - 4V_o = V_o - 20 + 2V_o$

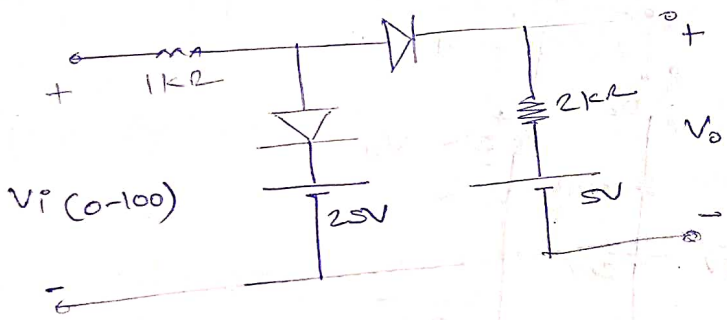
$7V_o = 4V_i + 20$

$V_o = \frac{4}{7}V_i + 20/7$

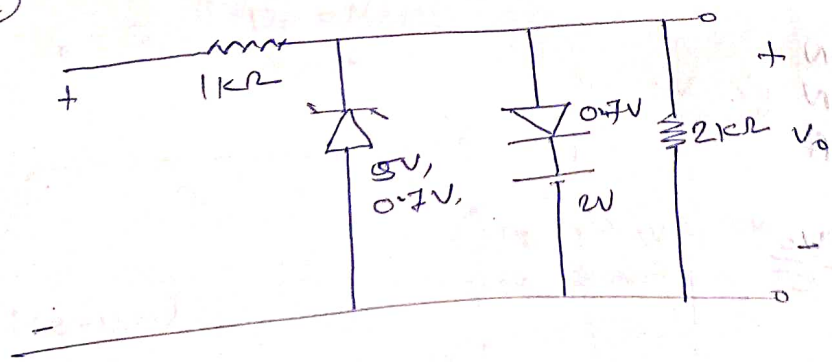

Vo
20
6V
3V
1/2
2/3
3V
9
30
Vi

H.W

①

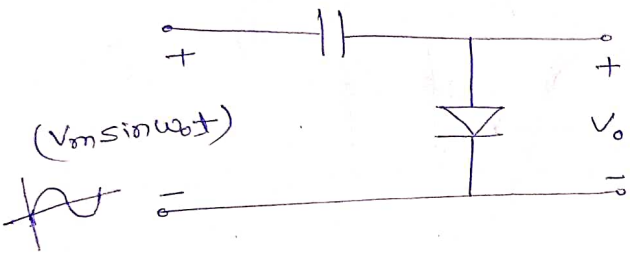

+
1KΩ
2KΩ
Vo
Vi (0-100)
25V
5V
-

②


+
1KΩ
0.7V
2KΩ
Vo
5V,
0.7V,
2V
-

Clamper :→
(DC inserter)

- No change in the shape of i/p waveform
- To meet our requirement



$(V_+ - V_-) = V_m \sin\omega_0 t$

$\boxed{\omega_0 T = 2\pi}$

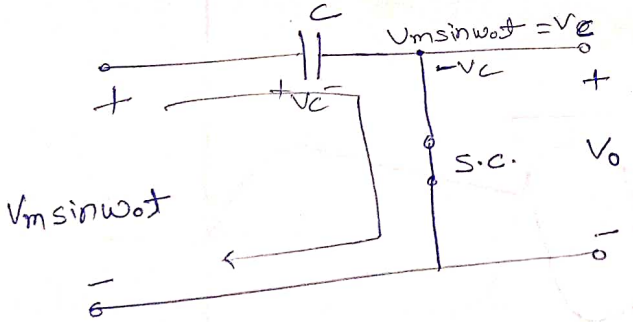
$V_m \sin\omega_0 t = \dfrac{0 < \omega_0 t < t}{0 < t < T/2}$

RC → small
↓
charging fast

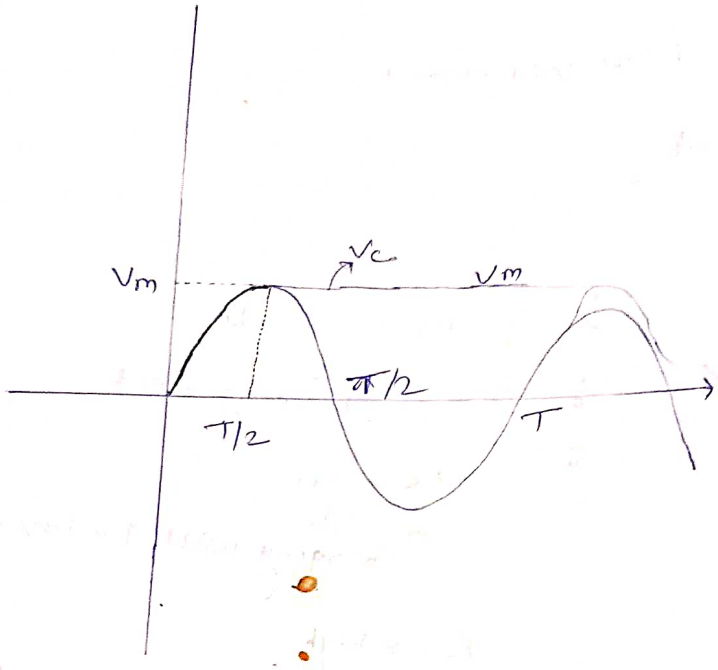
RC → 0
↓
charging will be instantaneous

RC → high
charging or discharging will be very slow

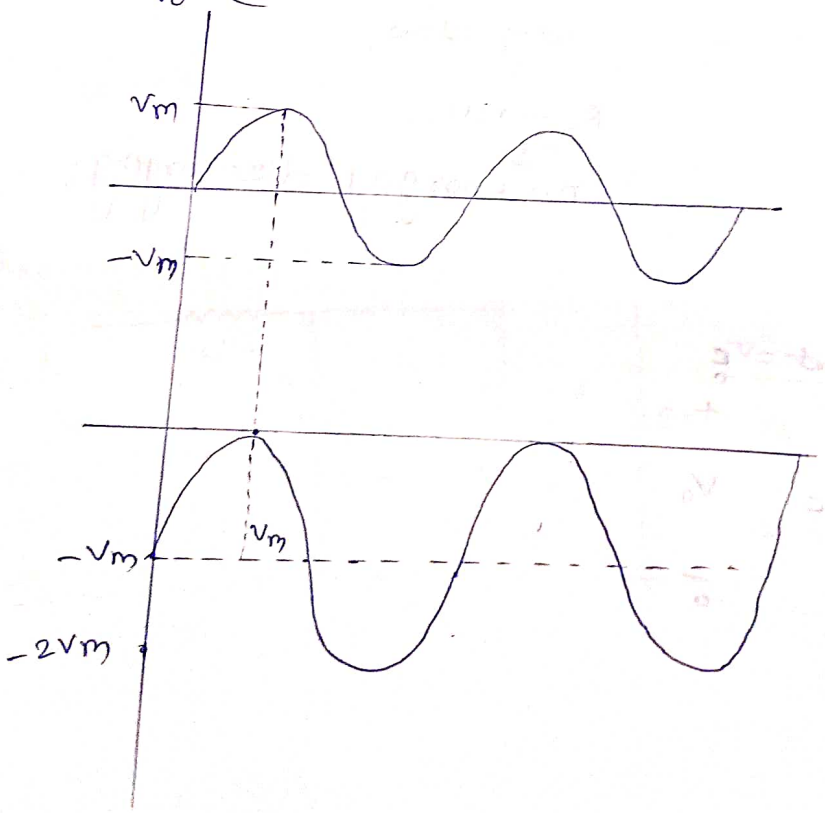
RC → ∞
↓
no charging / discharging.

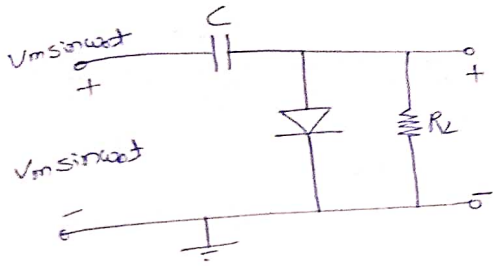


$R_f \cdot C \simeq 0$

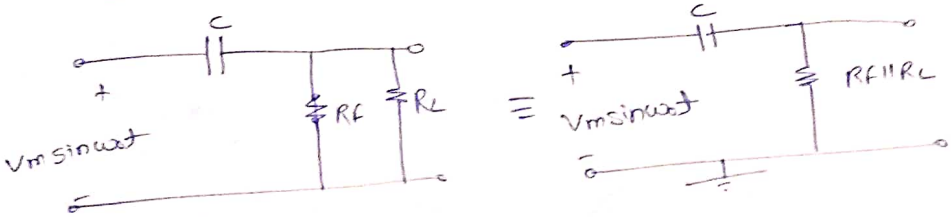


$V_o = (V_m \sin w_o t - V_m)$

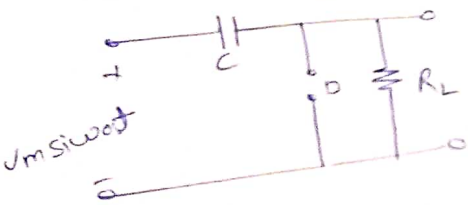




D-ON

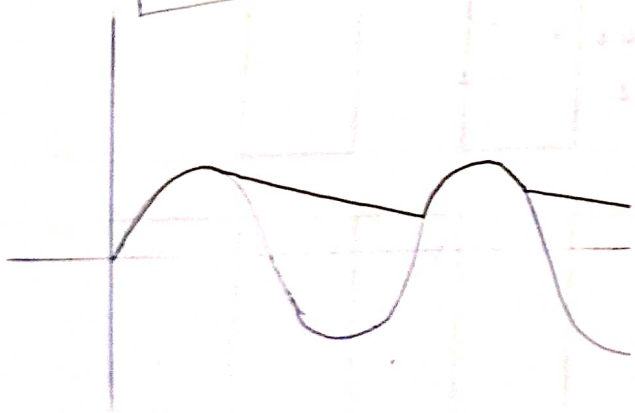


D-OFF

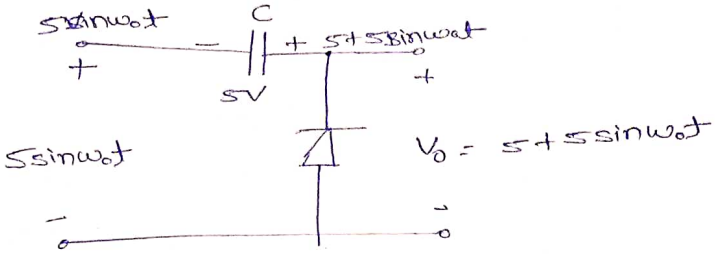


$R_L C \gg T$

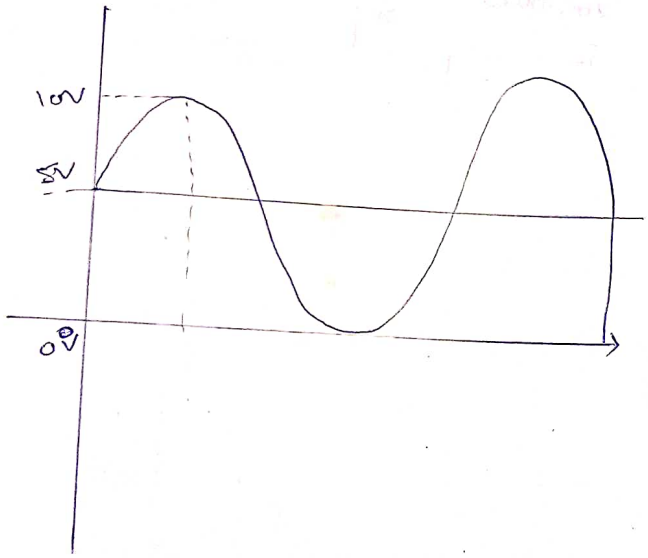
$$\boxed{R_L \cdot C \gg T}$$



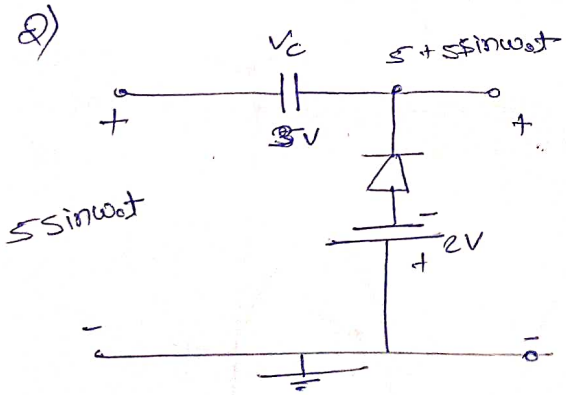
Q)



$V_0 = 5 + 5\sin\omega_0 t$

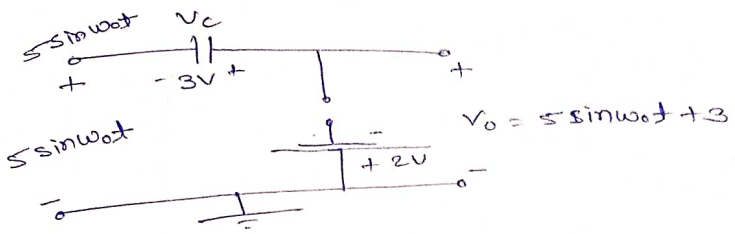


Q)

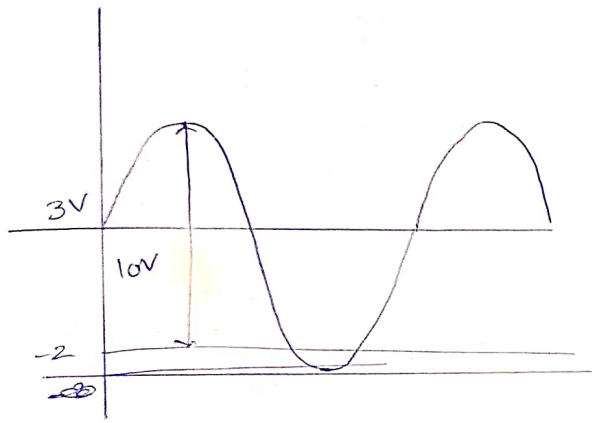


$V_+ > V_-$

$-2 \quad -5$



$V_o = 5\sin w_o t + 3$



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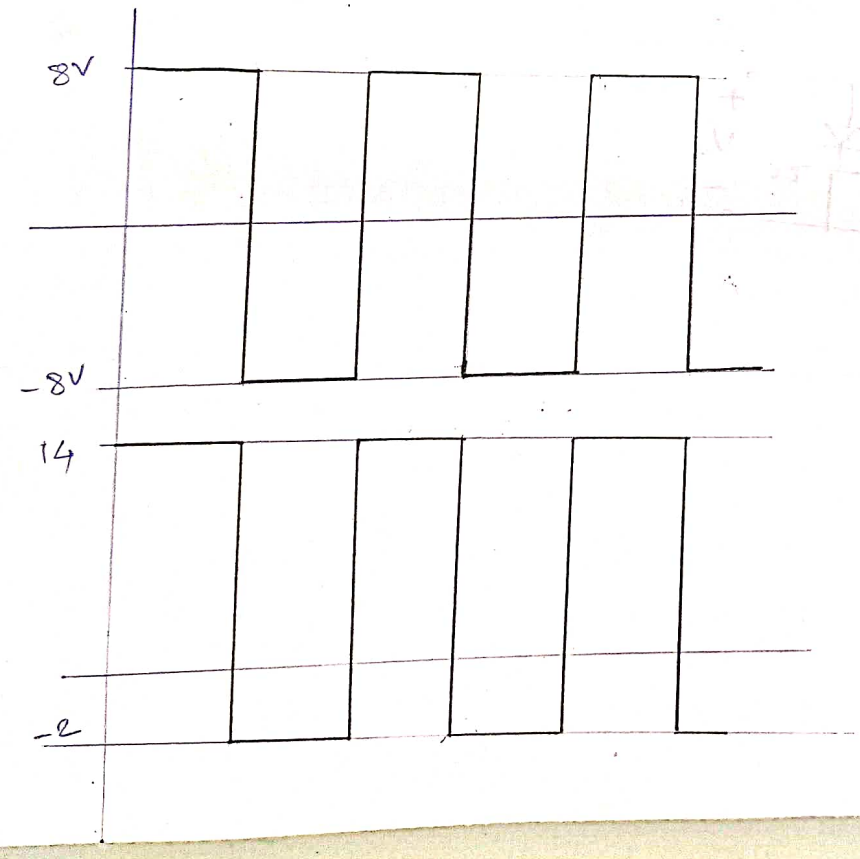
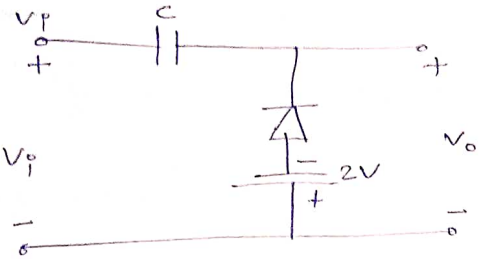
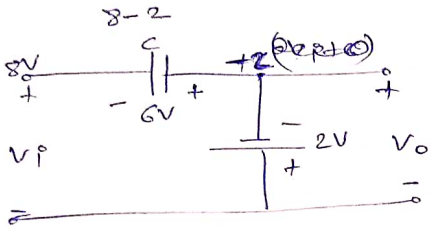
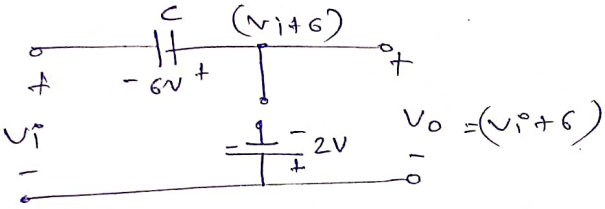
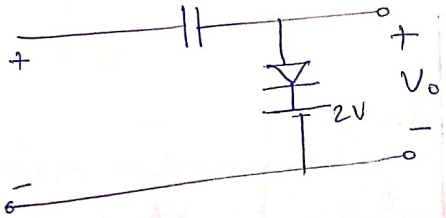


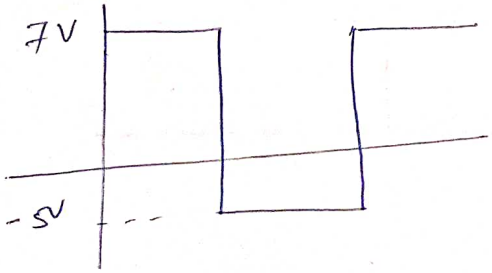


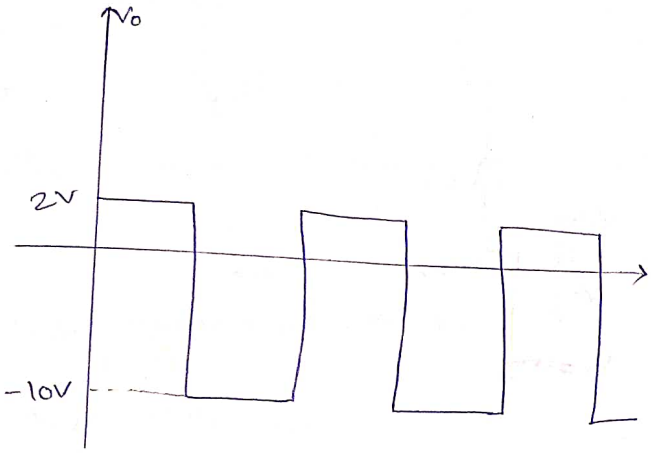


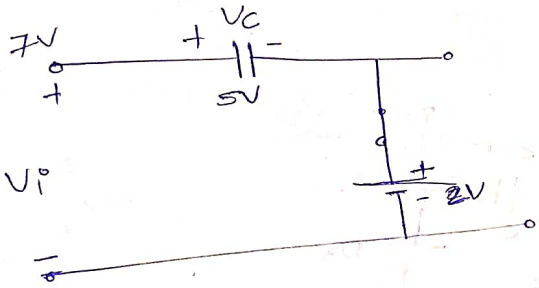


Q)



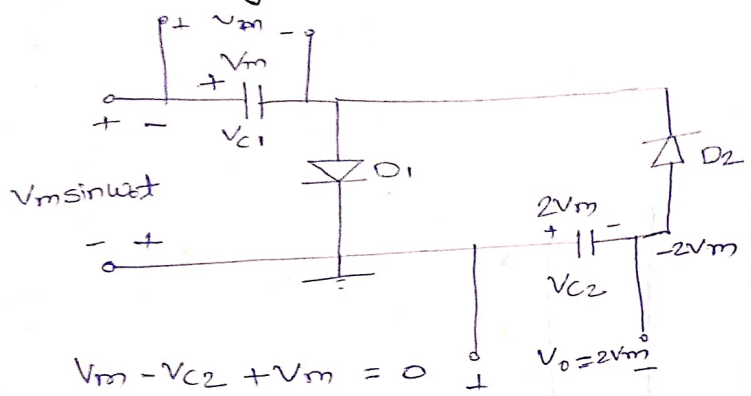



Vo
2V
-10V


7V
+
Vc
-
+
5V
Vi
+
2V
-

Imp

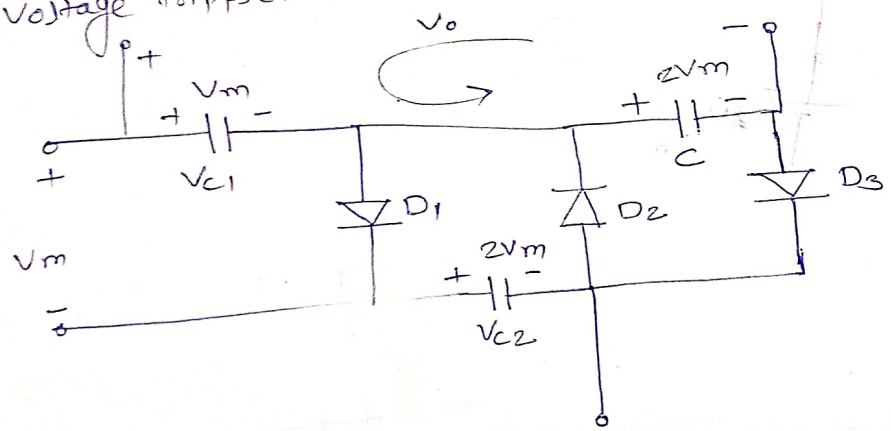
Voltage doubler circuit



$V_m - V_{C2} + V_m = 0$

$V_{C2} = 2V_m$

Voltage tripler circuit

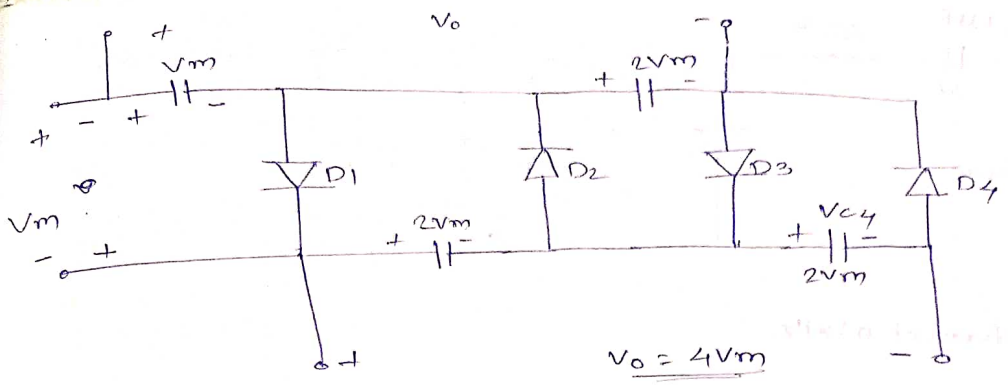


$V_m - V_m - V_{C3} + 2V_m = 0$

$\boxed{V_{C3} = 2V_m}$

$V_o - V_m - 2V_m = 0$

$\boxed{V_o = 3V_m}$

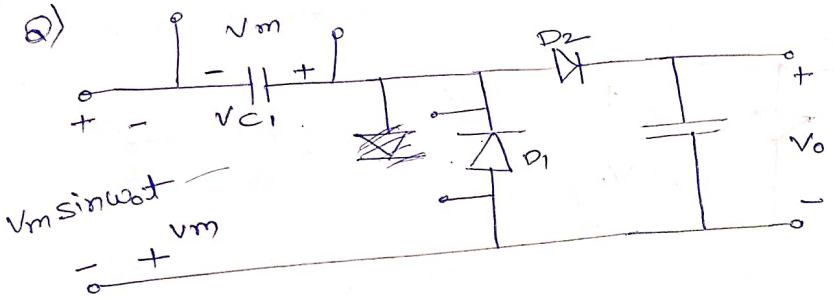


$V_o = 4V_m$

$V_m - 2V_m - V_{C4} + 2V_m + V_m = 0$

$V_{C4} = 2V_m$

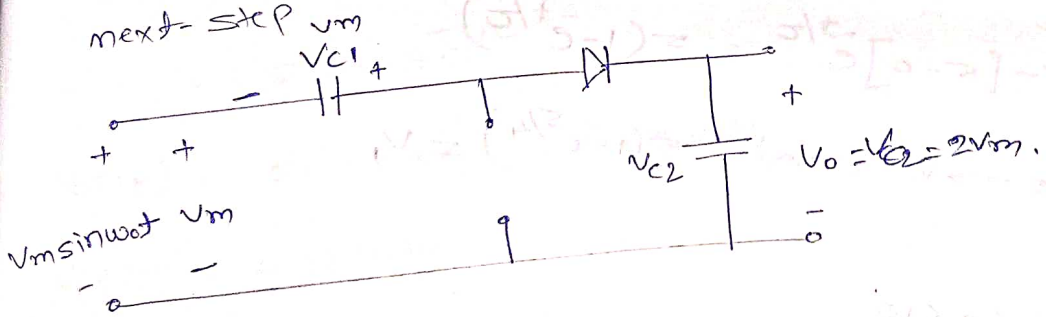
Q)



$V_m - V_{C1} = 0$

$\boxed{V_{C1} = V_m}$

next step

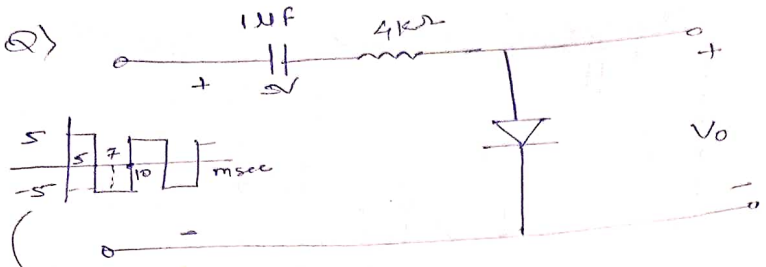


$V_o = V_{C2} = 2V_m$.

$V_m + V_m - V_{C2} = 0$

$\boxed{V_{C2} = 2V_m}$

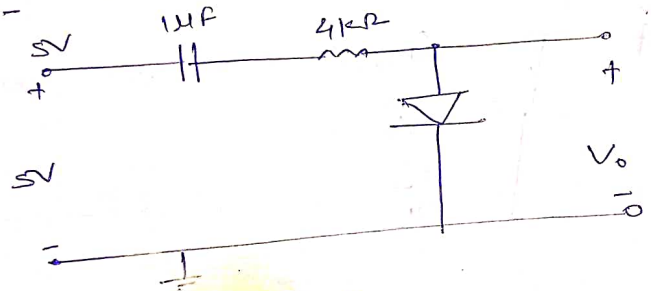
Q)

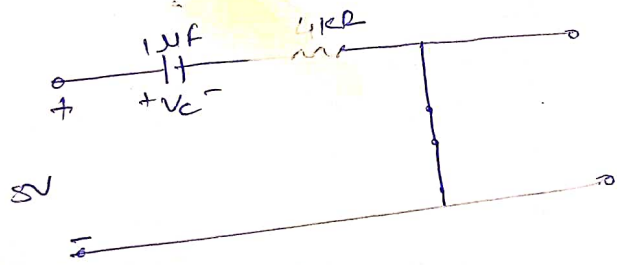


Square waveform of 0.1kHz.

$V_o \longrightarrow$ at $t = 7$ msec
V_o — at $t = 13$ msec } upto two decimal place.

Sol^n:-



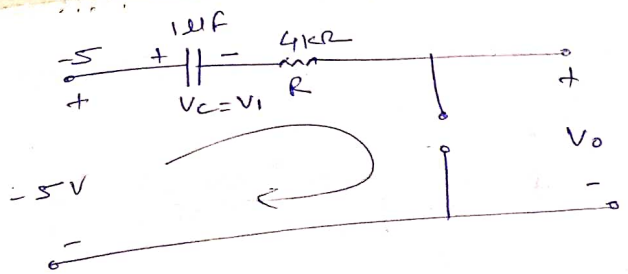


5 to 10 msec

$$V_c(t) = 5 - [5 - 0]e^{-t/\tau} = 5(1 - e^{-t/\tau})$$

at $t = 5$ msec $\longrightarrow V_c(5\text{msec}) = 5(1 - e^{-5/4}) = V_1$

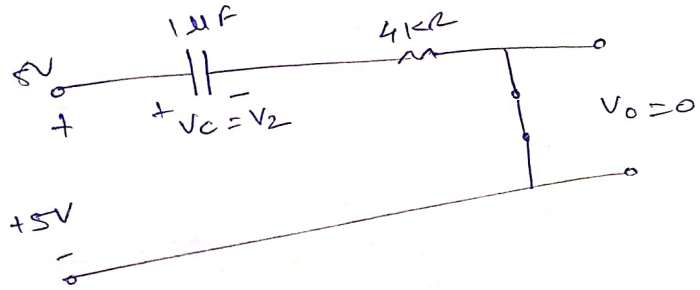
$V_1 = V_c = 5 \leq t \leq 10$



$-5 - V_1 - V_o = 0$

$V_o = -5 - V_1 = -5 - 3.57$
$= -8.57$ volt

10 to 15 msec



$V_c(t) =$

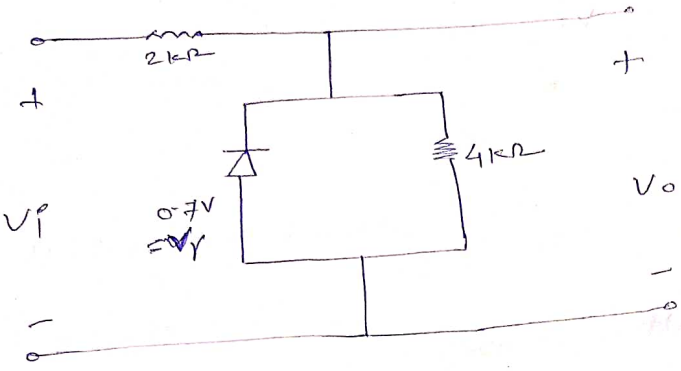
$V_c(t) = 5 - (5 - 3.57)\, e^{-t/\tau}$

$= 5 - 1.43\, e^{-t/\tau}$

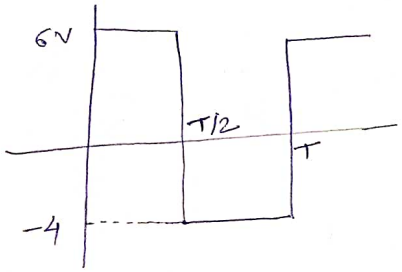
$V_c(15) = 5 - 1.43\, e^{-5/4} = 4.59$ volt

$V_c(13) = 4.32$ volt

Q)

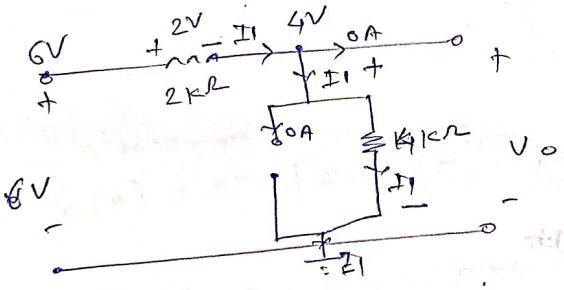


V_o → avg value of the o/p voltage upto two decimal



Soln:-

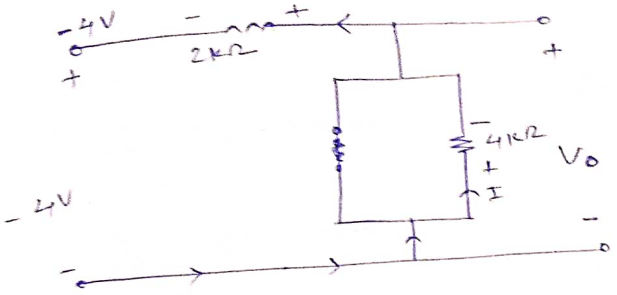
0 → T/2 → 6V



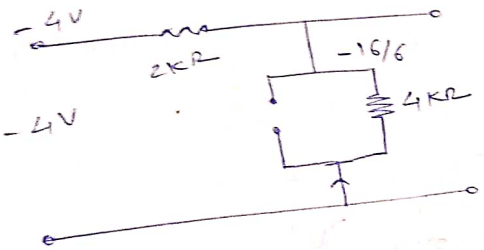
$$\boxed{\frac{6}{6} = 1mA = I_1}$$

$V_o = 4V$

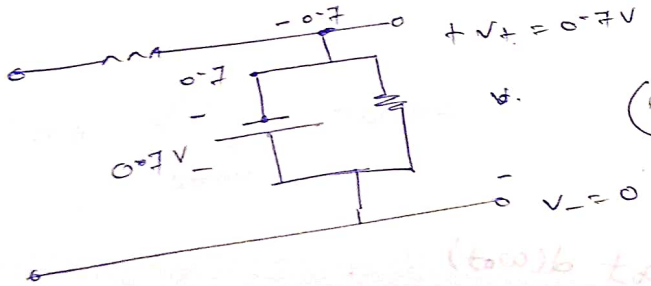
T/2 to T



$V_p - V_n > 0.7$



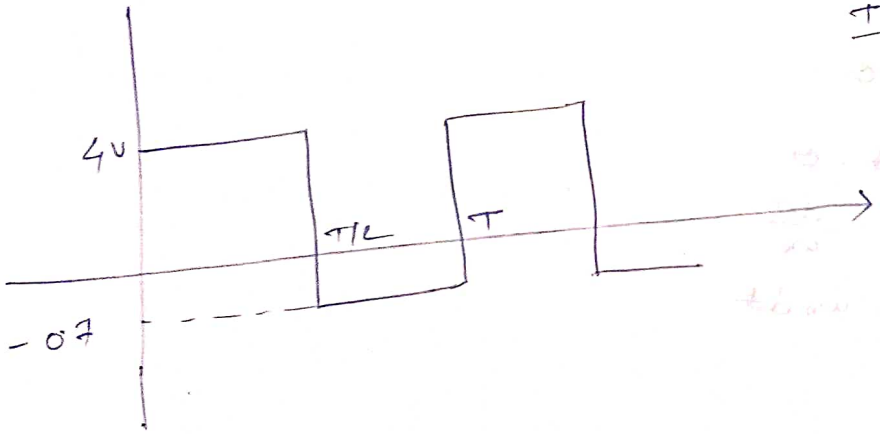
$-\frac{16}{6}$ $+$ $-$ $= -\frac{4\times4}{6} = \frac{-16}{6}$



$+V_+ = 0.7V$

$(V_o = -0.7V \quad T/2 \text{ to } T)$

$$\frac{\int_T f(t)\,dt}{T}$$

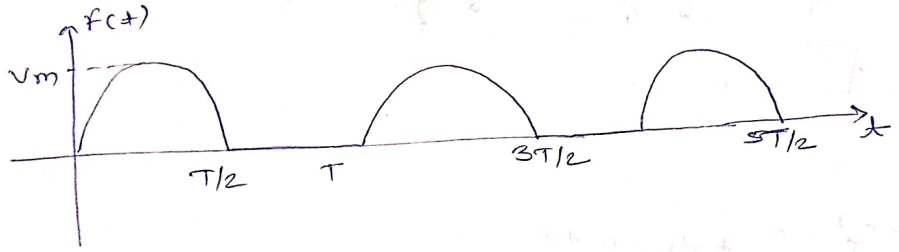


$$\frac{\int_T f(t)\,dt}{T} = \int_0^{T/2} 4\,dt + \int_{T/2}^{T} -0.7\,dt$$

$$= \frac{4\,T/2 + (-0.7)\,T/2}{T}$$

$$= \frac{3.3}{T}$$

Power supply



$$\frac{1}{T}\int_T f(t)\,dt = V_{avg} = \frac{V_m}{\pi}$$

$$\frac{1}{T}\int_T f(t)\,dt = \frac{1}{T}\int_0^{T/2} \underline{V_m \sin\omega_0 t}\; d(\omega_0 t)$$

$V_m \sin\theta$

$$\omega_0 t = \theta$$

$$dt = \frac{d\theta}{\omega_0}$$

$$d\theta = \omega_0\, dt$$

$$= \frac{1}{2\pi}\int_{0}^{\pi} V_m \sin \omega_0 t$$

$$= \frac{1}{2\pi}\int V_m \sin\theta \, d\theta$$

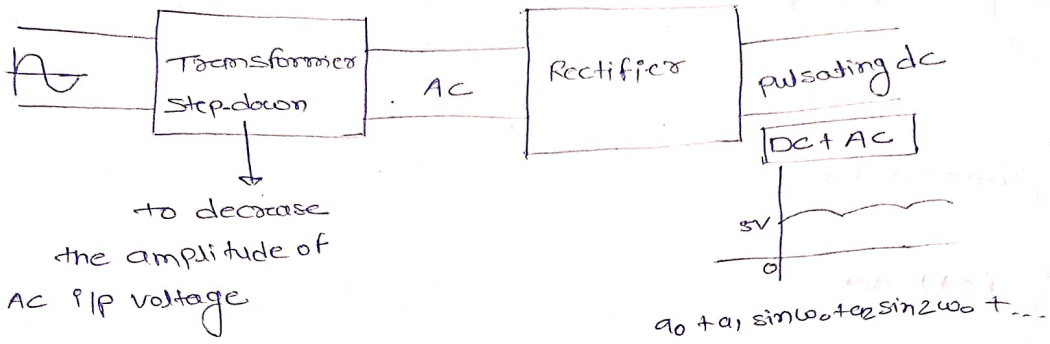
$$= \frac{1}{2\pi}\int_{2\pi} f(t)\, d\theta$$

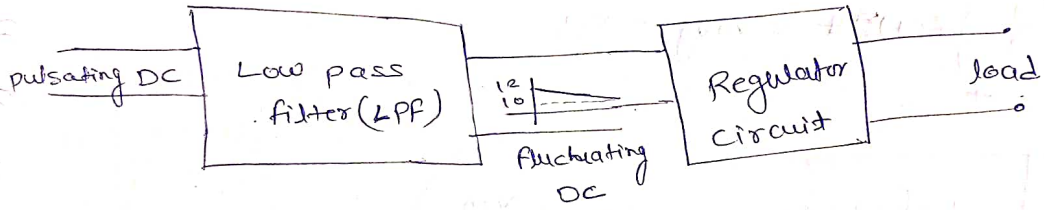
$$\cancel{f(t)} = V_{avg} = \frac{1}{T}\int_{T} f(t)\, dt = V_{avg} = \frac{V_m}{\pi}$$

$$\sqrt{\frac{1}{T}\int_{T} f^2(t)\, dt} = V_{rms} = \frac{V_m}{2}$$

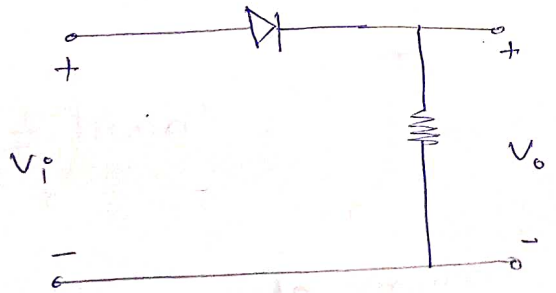
root avg mean square

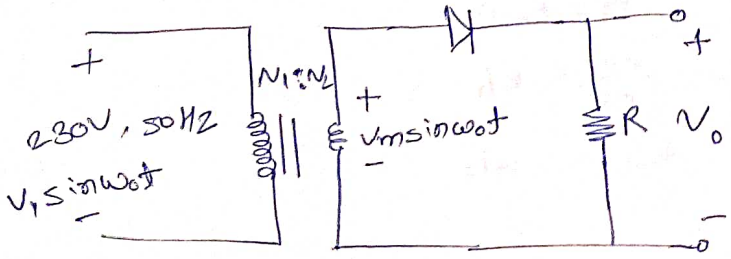
~~average~~





Half wave Rectifier :→



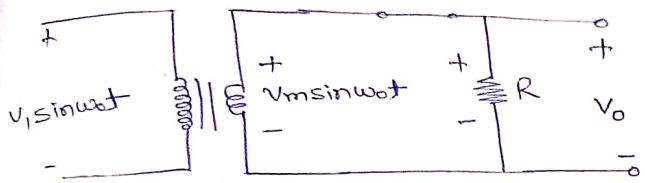


$$\frac{V_m}{V_1} = \frac{N_2}{N_1} \longrightarrow \frac{V_1}{V_m} = \frac{N_1}{N_2}$$

if

case ①

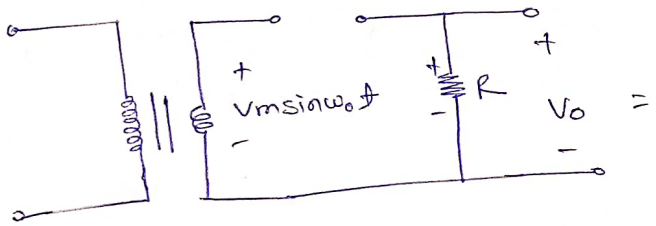
$0 < t < T/2$ - ON



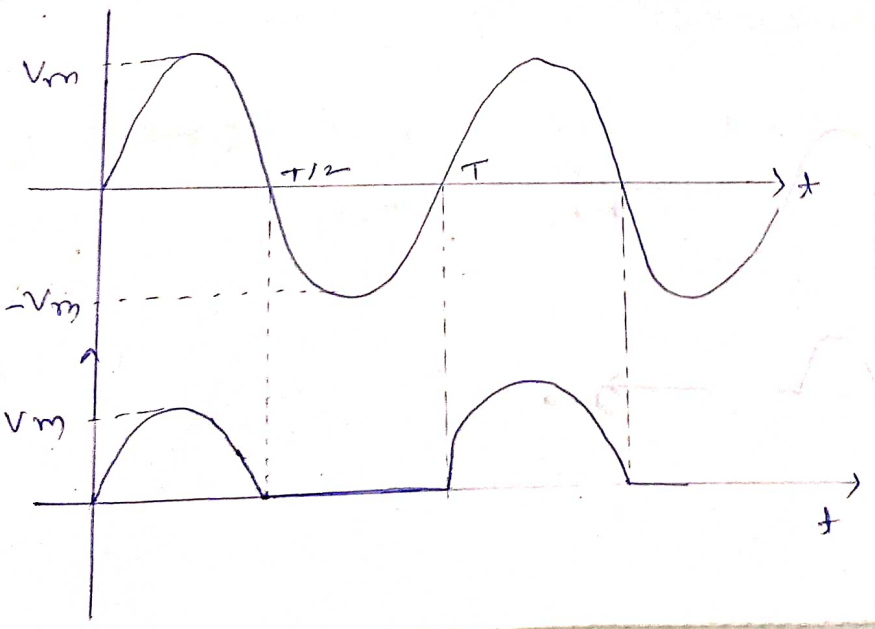
①

$V_o = V_m \sin\omega_0 t$

case ② $T/2 < t < T \longrightarrow$ off

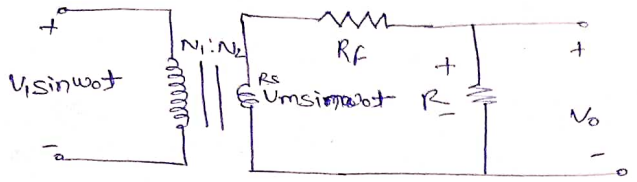


$V_o = 0$



(ii) F.B resistance diode is R_f, ideal

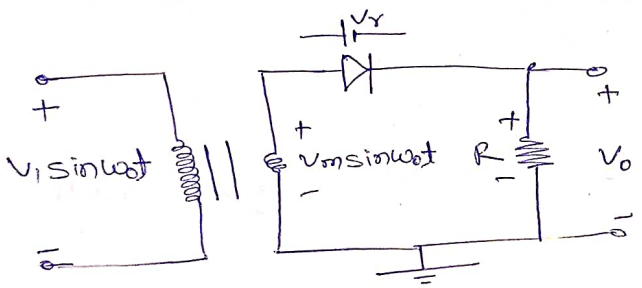
Secondary winding → R_s



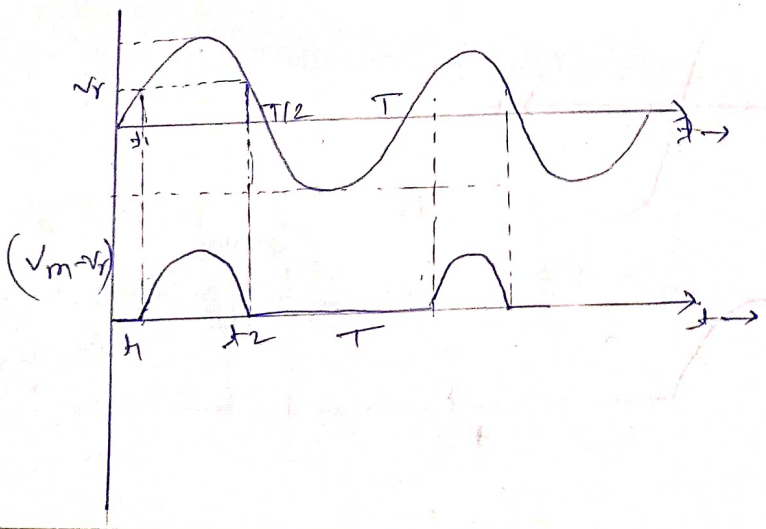
$$V_o = \frac{R \quad V_m \sin\omega_0 t}{R + R_f + R_s}$$

$$\boxed{V_o = 0}$$

iii) diode − V_γ → ideal



$$V_o = (V_m \sin\omega_0 t - V_\gamma)$$



Half wave Rectifier :→

i) $V_{avg} = \frac{V_m}{\pi}$

$V_{rms} = V_m/2$

ii) $V_{avg} = \frac{V_m'}{\pi}$

$V_{rms} = \frac{V_m'}{2}$

$V_m' = \frac{R}{R+R_f+R_s} V_m$

form factor :→

$F = \frac{V_{rms}}{V_{avg}}$, $\boxed{F_{ideal} = 1}$

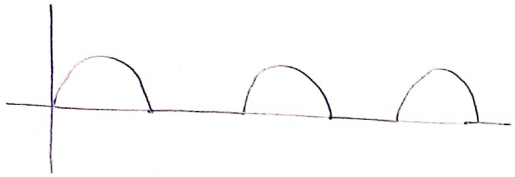
$= \frac{V_m/2}{V_m/\pi}$

$\boxed{F = \pi/2 = 1.57}$

Crest factor :- $\frac{V_{max}}{V_{rms}} = \frac{V_m}{V_m/2} = 2 = C$

$C_{ideal} = 1$

Ripple factor (γ) =

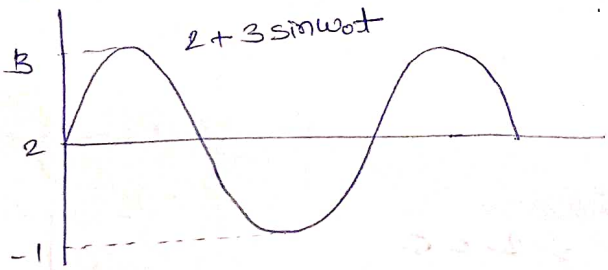


$= a_0 + a_1 \sin\omega_0 t + a_2 \cos 2\omega_0 t + \dots + b_1 \sin\omega_0 t + b_2 \sin 2\omega_0 t$

$$V_{rms} = \sqrt{a_0^2 + \frac{a_1^2}{2} + \frac{a_2^2}{2} + \frac{a_3^2}{2} + \dots \quad \frac{b_1^2}{2} + \frac{b_2^2}{2} + \frac{b_3^2}{2} + \dots}$$

$$V_{rms} = \sqrt{V_{dc}^2 + (V_{ac}^2)_{max}}$$

e.g.:-



$$\gamma = \left(\frac{(V_{ac})_{rms}}{V_{ac}}\right)$$

$$\gamma = \sqrt{F^2 - 1} = 1.21$$

efficiency $\eta = \dfrac{\text{dc o/p power}}{\text{Total power}} \times 100$

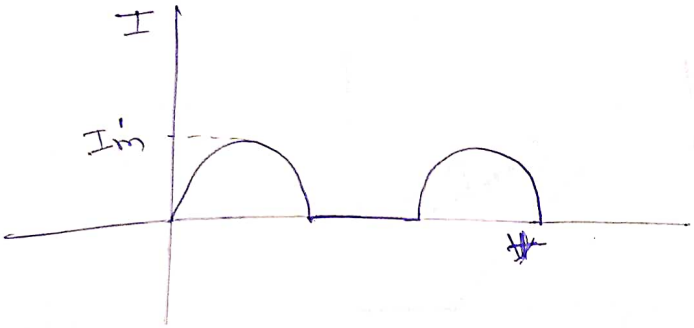
i) $V_o = \dfrac{R}{R+R_f+R_s} V_m \sin\omega_o t$

$0 < t < T/2$

$I = \dfrac{V_m \sin\omega_o t}{(R+R_f+R_s)}$

$= 0$

$T/2 < t < T$



$I_{dc} = \dfrac{I_m'}{\pi}$

$I_{rms} = \dfrac{I_m'}{2}$

$\therefore \eta = \dfrac{I_{dc}^2 \cdot R}{I_{rms}[R+R_f+R_s]}$

$= \dfrac{\left(\dfrac{I_m'}{\pi}\right)^2 R}{\left(\dfrac{I_m'}{2}\right)^2 [R+R_f+R_s]} \times 100$

$$\eta = \frac{4}{\pi^2}\left(\frac{R}{R+R_f+R_s}\right)\times 100$$

$$\eta = \frac{4}{\pi^2}\left[\frac{1}{1+\left(\frac{R_f+R_s}{R}\right)}\right]\times 100$$

$$\frac{R_f+R_s}{R} << 1$$

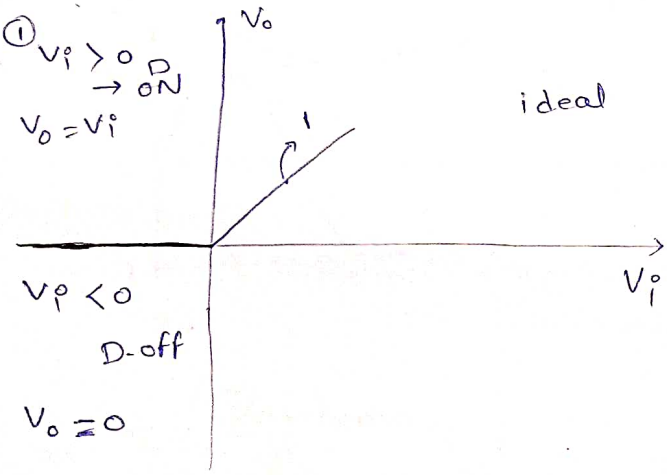
$$R_f+R_s << R$$

$$\boxed{\eta_{max} = \frac{4}{\pi^2}\times 100 = 40.8\%}$$

~~PIV rating of the diode~~

① $V_i > 0$ → D ON

$V_o = V_i$



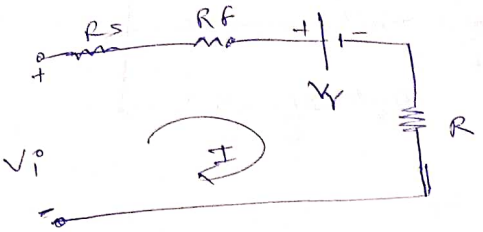
ideal

$V_i < 0$

D-off

$V_o = 0$

ii) V_γ, R_f



$V_i < V_\gamma \rightarrow$ D-off

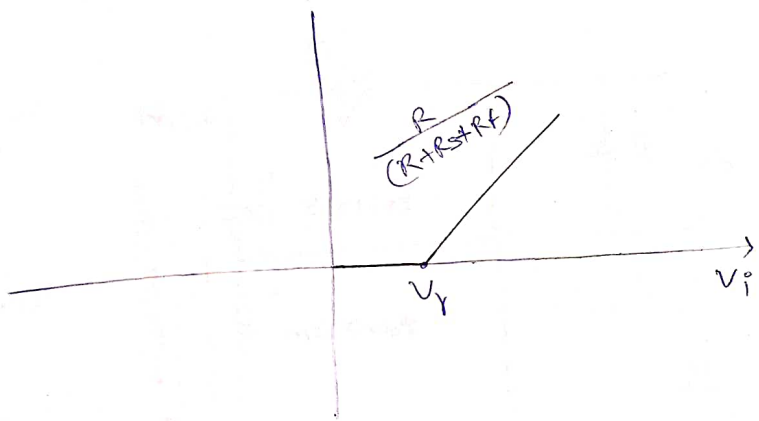
$V_o = 0$

$V_i > V_\gamma \longrightarrow V_o = \left(\frac{V_i - V_\gamma}{R + R_s + R_f}\right) R$

$I = \frac{V_i - V_\gamma}{(R + R_s + R_f)}$

$V_o = \left(\frac{R}{R + R_s + R_f}\right) V_i$

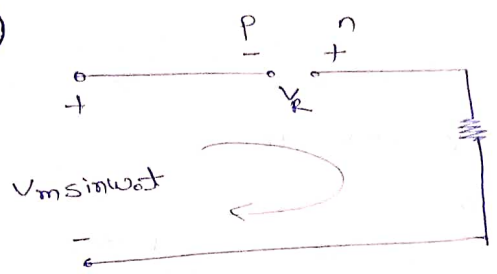
$- \frac{V_\gamma R}{R + R_s + R_f}$



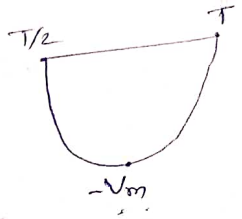
PIV :- peak inverse voltage

The max. voltage that can appear across the diode in R.B condition in Rectifier ckt is called as peak inverse voltage.

A-



$\frac{T}{2} < t < T$



$V_m \sin\omega_0 t + V_R = 0$

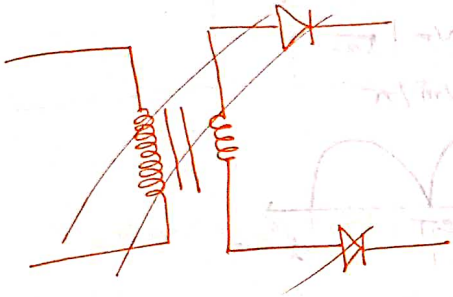
$V_R = -V_m \sin\omega_0 t$

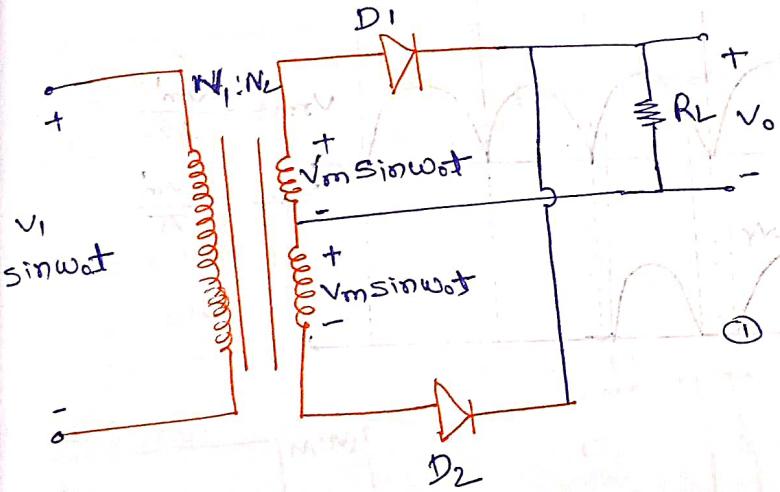
$\boxed{V_{R\,max} = V_m}$ ← PIV

diode rating ⩾ PIV.

Full wave Rectifier

- → centre tape type
- → Bridge type





$$\left\{ \frac{V_1}{V_m} = \frac{N_1}{N_2} \right\}$$

① $0 < t < T/2$

D_1 ON,

$V_o = V_m \sin w_o t$

D_2, off

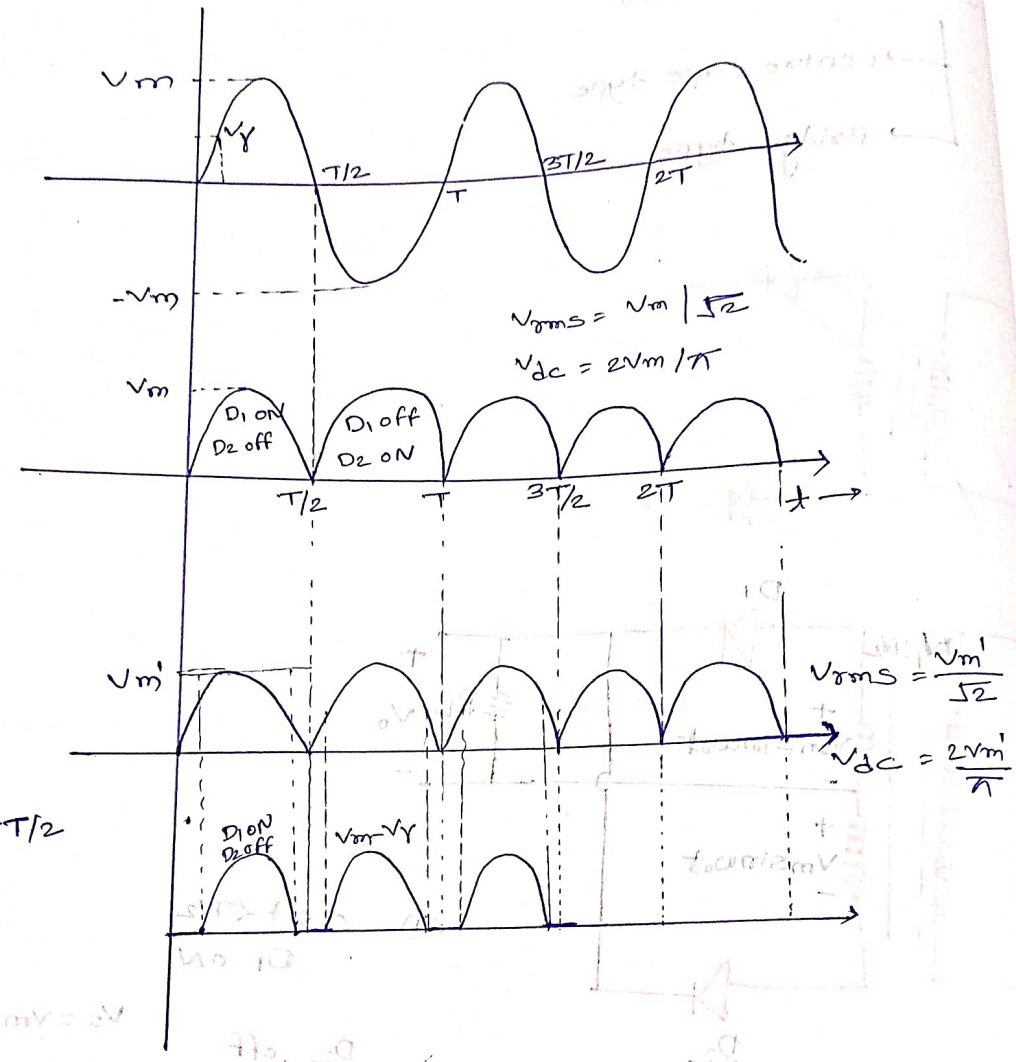
② $T/2 < t < T$

$V_o = -V_m \sin w_o t$

$V_m \sin w_o t + V_o = 0$

D_1 off

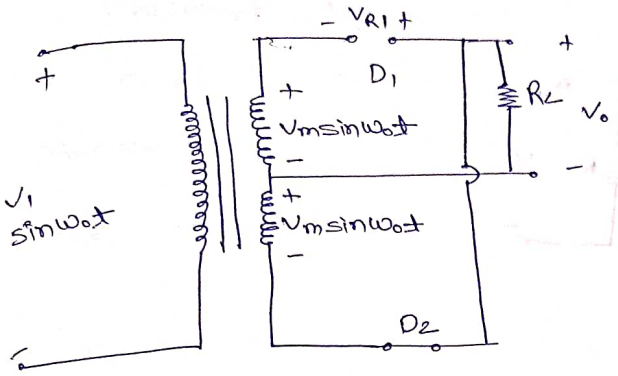
D_2 ON.



$0 < t < T/2$

D_1 on

D_2 off



$+V_m \sin\omega_0 t + V_{R1} - V_0 = 0$

$V_{R1} = V_0 - V_m \sin\omega_0 t = -2V_m \sin\omega_0 t$

$\boxed{(V_{R1})_{max} = 2V_m}$ peak inverse voltage

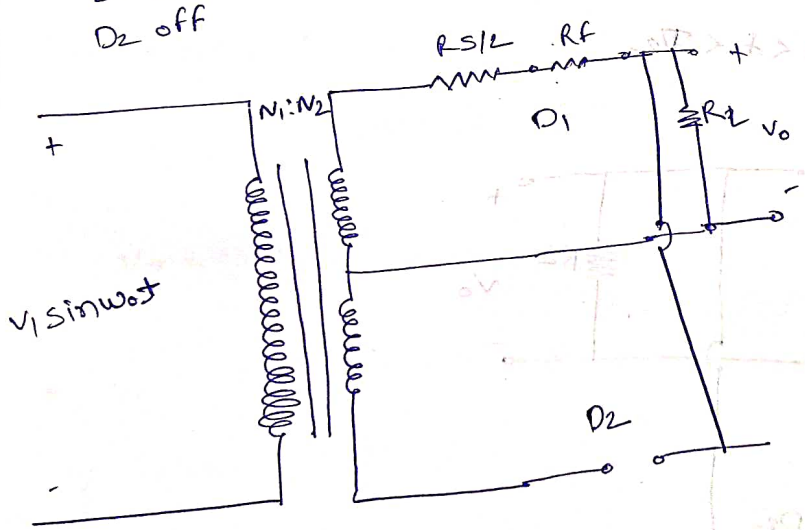
$= \frac{V_m'}{\sqrt{2}}$

$= \frac{2V_m'}{\pi}$

$0 < t < T/2$

D_1 ON

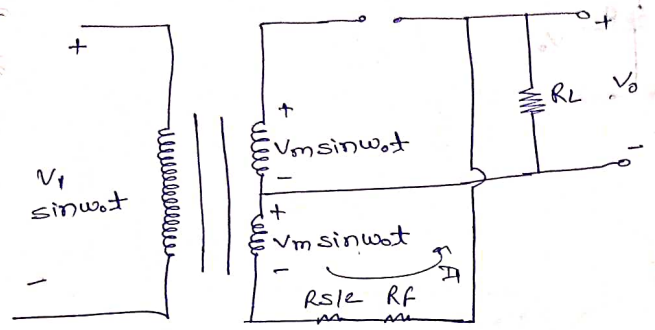
D_2 off



$\left\{ \frac{N_1}{V_m} = \frac{N_1}{N_2} \right\}$

$V_0 = \frac{R_L}{R_L + \frac{R_S}{2} + R_f}$

$T/2 < t < T$

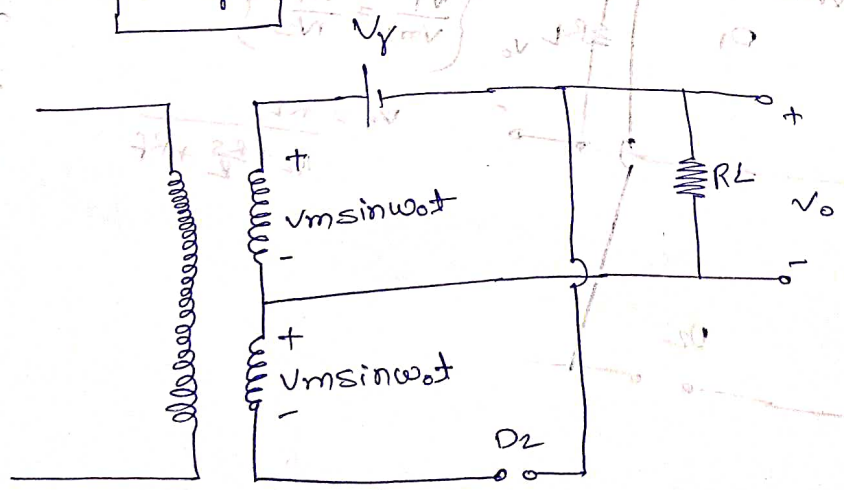


$$-V_m \sin\omega_0 t - I_1 R_S/2 - I_1 R_f - I_1 R_L = 0$$

$$I_1 = \frac{-V_m \sin\omega_0 t}{R_L + \frac{R_S}{2} + R_f}$$

$$V_o = I_1 \cdot R_L = \frac{-R_L}{R_L + \frac{R_S}{2} + R_f} V_m \sin\omega_0 t$$

* $\boxed{D - V_\gamma}$ $\quad 0 < t < T/2$



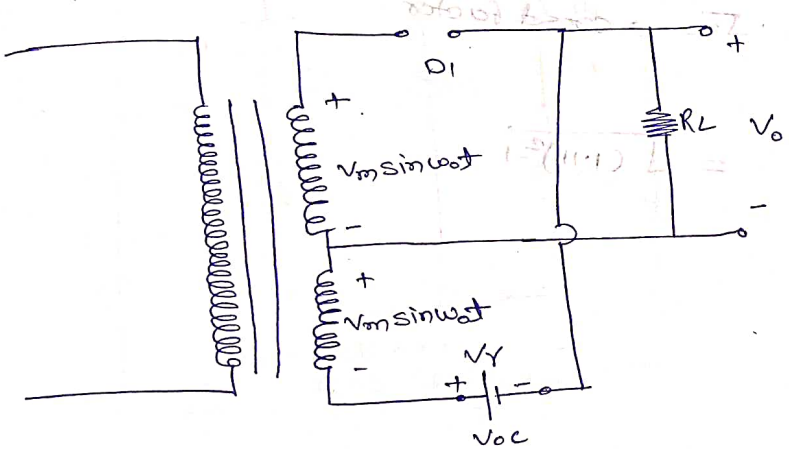
$V_m \sin\omega_o t > V_\gamma$

D_1 off D_2 off

$V_m \sin\omega_o t - V_\gamma - V_o = 0$

$V_o = V_m \sin\omega_o t - V_\gamma$

* $T/2 < t < T$



$V_m \sin\omega_o t + V_o + V_{oc} = 0$

$V_{oc} = -V_m \sin\omega_o t > V_\gamma$

$V_m \sin\omega_o t < -V_\gamma \rightarrow$ D_2 ON, D_1 off

* $V_m \sin\omega_o t + V_o + V_\gamma = 0$

$V_o = -V_m \sin\omega_o t - V_\gamma$

form factor F :-

$$\frac{V_{rms}}{V_{dc}} = \frac{V_m/\sqrt{2}}{2V_m/\pi}$$

$$\boxed{F = \frac{\pi}{2\sqrt{2}}}$$

Ripple factor :- (γ)

$$C = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2} \rightarrow \text{crest factor}$$

$$\gamma = \sqrt{F^2 - 1} = \sqrt{(1.11)^2 - 1}$$

$$\boxed{** \ \gamma = 0.48}$$

efficiency η :-

$$\eta = \frac{\text{dc o/p power}}{\text{Total power}} \times 100$$

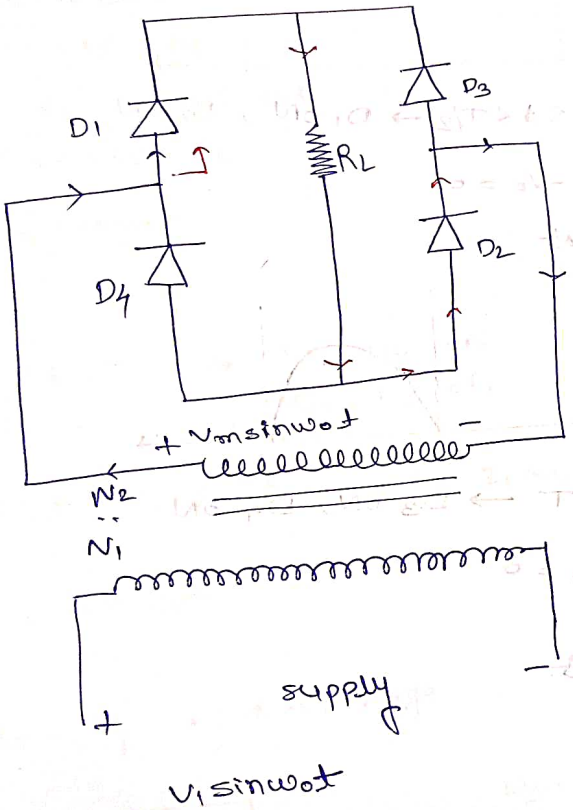
$$I_{dc} = \frac{V_{dc}}{R_L}, \quad I_{rms} = \frac{V_{rms}}{R_L}, \quad \frac{I_{dc}}{I_{rms}} = \frac{2\sqrt{2}}{\pi}$$

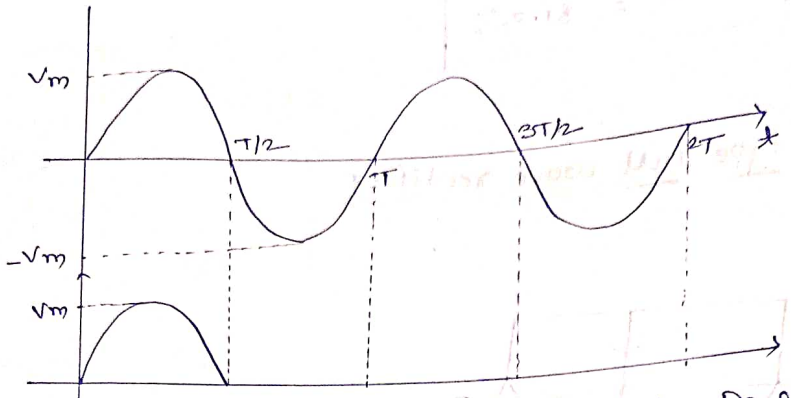
$$\eta = \frac{I_{dc}^2 \cdot R_L}{I_{rms}^2\left[\frac{R_S}{2} + R_f + R_L\right]} \times 100$$

$$= \frac{8}{\pi^2}\left[\frac{R_L}{\frac{R_S}{2} + R_f + R_L}\right] \times 100$$

$$\eta_{max} = \frac{8}{\pi} \times 100 = 81.2\%$$

Bridge type full wave rectifier

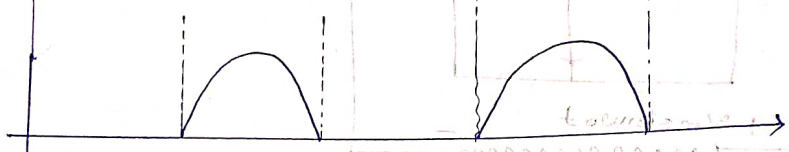




ideal $\quad 0 < t < T/2 \rightarrow D_1$ ON, D_2 ON

$V_m \sin\omega_0 t - V_0 = 0$

$V_0 = V_m \sin\omega_0 t$



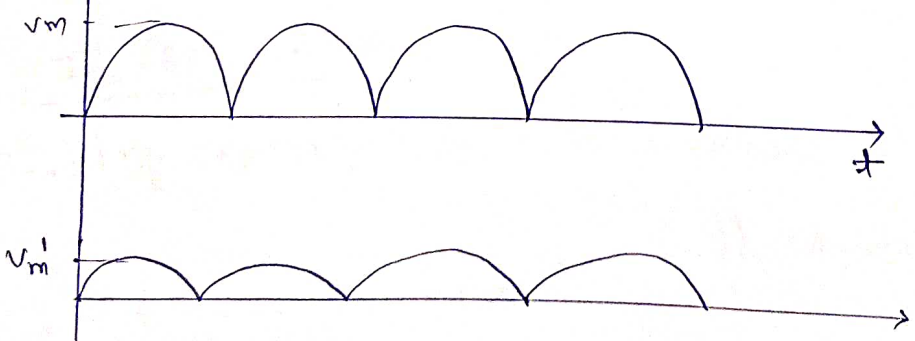
P ideal

$T/2 < t < T \rightarrow D_3$ ON, D_4 ON

$V_m \sin\omega_0 t + V_0 = 0$

$-V_0 = V_m \sin\omega_0 t$

$V_0 = -V_m \sin\omega_0 t$



practical Bridge Rectifier

R_s, R_f.

① $0 < t < T/2$, D_1 ON , D_2 ON
D_3 off , D_4 off

$$I = \frac{V_m \sin\omega_0 t}{R_s + 2R_f + R_L}$$

$$V_o = \frac{R_L \quad V_m \sin\omega_0 t}{R_s + 2R_f + R_L}$$

$$= V_m' \sin\omega_0 t$$

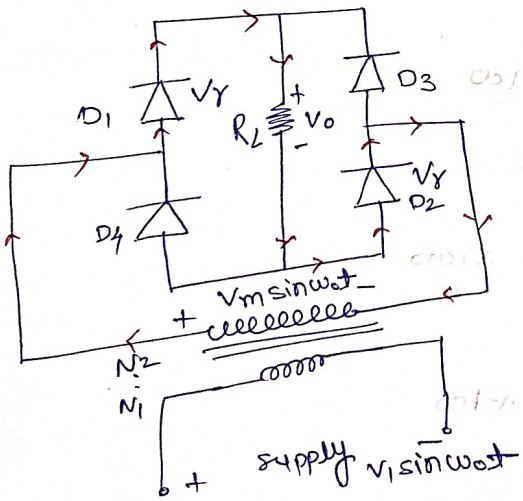
② $\frac{T}{2} < t < T \longrightarrow$ D_3, D_4 ON
D_1, D_2 off

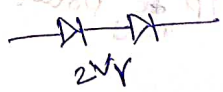
$$-V_m \sin\omega_0 t - I_1 R_f - I_1 R_L - I_1 R_s - I_1 R_s = 0$$

$$V_o = -V_m' \sin\omega_0 t$$

③ Diode – V_γ → cutin voltage

D_3 off , D_4 off



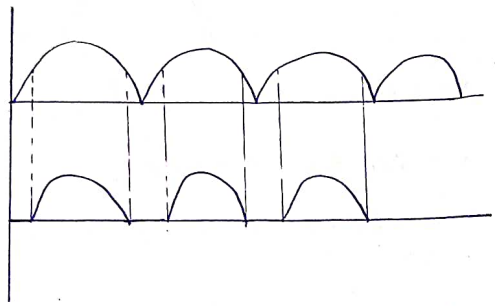
⇒ 

$V_m \sin\omega_0 t < 2V_\gamma$ $\quad V_0 = 0$ $\quad 0 < t < T/2$ $\quad D_1\ D_2\ D_3\ D_4$ off

$V_m \sin\omega_0 t > 2V_\gamma$ $\quad V_0 = (V_m \sin\omega_0 t - 2V_\gamma)$

D_1 & D_2 ON

D_3 & D_4 off



$V_{rms} = V_m/\sqrt{2}$

$V_{dc} = 2V_m/\pi$

$V_{rms} = V_m'/\sqrt{2}$

$V_{dc} = 2V_m'/\pi$

$F = \frac{\pi}{2\sqrt{2}} = 1.11$

$C = \sqrt{2}$

$\gamma = \sqrt{F^2 - 1} = 0.48$

$I_{dc} = \frac{V_{dc}}{R_L}$

$I_{rms} = \frac{V_{rms}}{R_L}$

efficiency η :- $\frac{\text{o/p dc power}}{\text{i/p total power}} \times 100$

$= \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_s + R_f + R_s)} \times 100$

$= \frac{8}{\pi^2} \left(\frac{R_L}{R_s + R_f 2 + R_s} \right) \times 100$

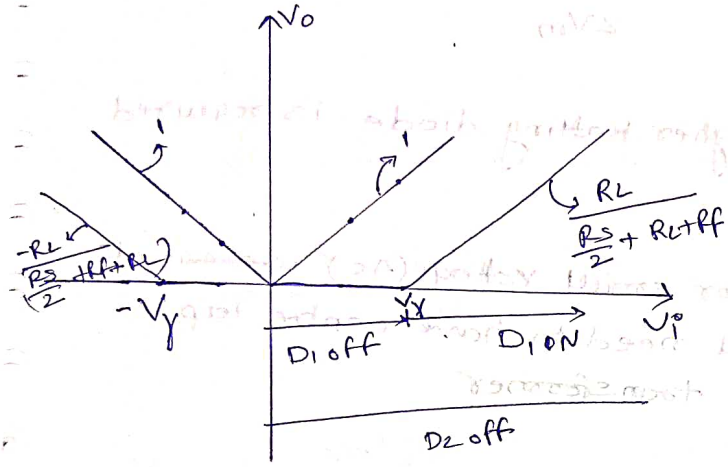
$\eta_{max} = \frac{8}{\pi^2} \times 100 = 81.2\%$

Bridge type	centre tap
V_m	$2V_m$
lower ratting of diode can do the work	higher Ratting diode is required
- for small voltage (AC) we can directly apply it to rectifier circuit (need not to step down)	- for small voltage(AC) ~~we can~~ also you need to have centre tap transformer

Centre tap

$V_o = V_i$ $\quad V_i > 0$

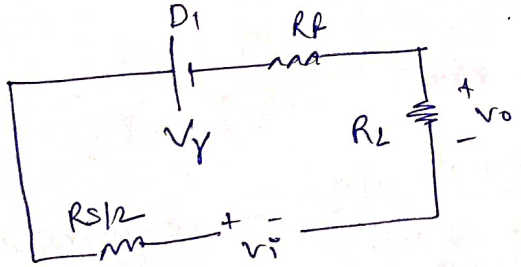
$V_o = -V_i$ $\quad V_i < 0$



$V_i > V_\gamma$ $\quad D_1$ ON, D_2 off

$V_o = 0$ $\quad 0 < V_i < V_\gamma$

D_1 off, D_2 off

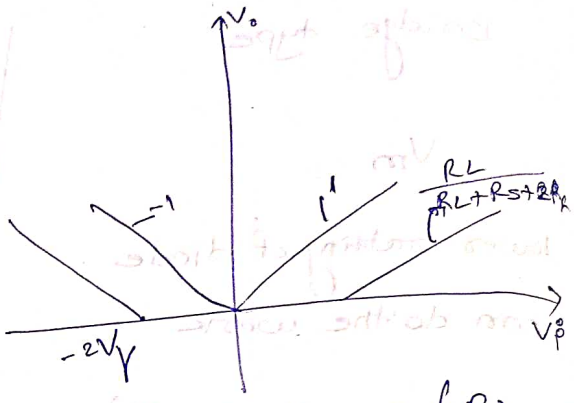


$$V_i - IR_s/2 - V_\gamma - IR_f - IR_1 = 0$$

$$V_o = R_L I = \frac{(V_i - V_\gamma) R_L}{\left(\frac{R_s}{2} + R_f + R_L\right)}$$

$$V_o = \frac{R_L V_L}{(R_s/2 + R_f + R_L)} - \frac{V_\gamma R_L}{R_s/2 + R_f + R_L}$$

Bridge type



$$V_o = \frac{R_L V_i}{R_L + R_s + 2R_f} - \left(\frac{R_L}{R_L + R_s + 2R_f}\right) \times 2V_\gamma$$

$V_i > V_\gamma$

$v_i < 0$

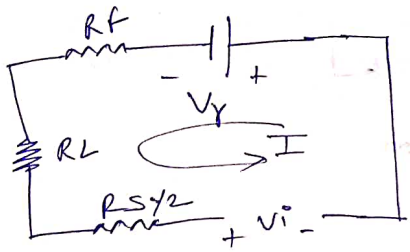
$v_o = 0 \qquad -v_i < V_\gamma$

D_1 off , D_2 off

$v_o = 0 \qquad v_i > -V_\gamma$

$-v_i > V_\gamma$

$v_i < -V_\gamma$



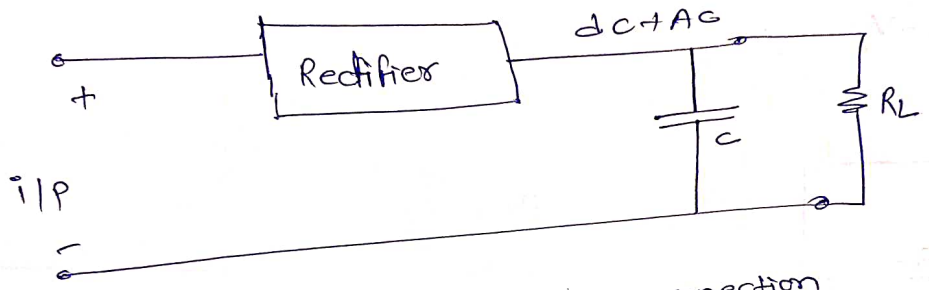
$$v_i + I R_s/2 + I R_L + I R_f + V_\gamma = 0$$

$$R_L I = \frac{-(v_i + V_\gamma) R_L}{(R_s/2 + R_L + R_f)}$$

$$= \frac{-R_L v_i}{\left(\frac{R_s}{2} + R_f + R_L\right)} - \frac{R_L V_\gamma}{\frac{R_s}{2} + R_f + R_L}$$

filter :→

we want to have dc o/p voltage, so we need to filter out the AC and retain dc and filter that pass dc or low frequency and block AC a high frequency is a LPF



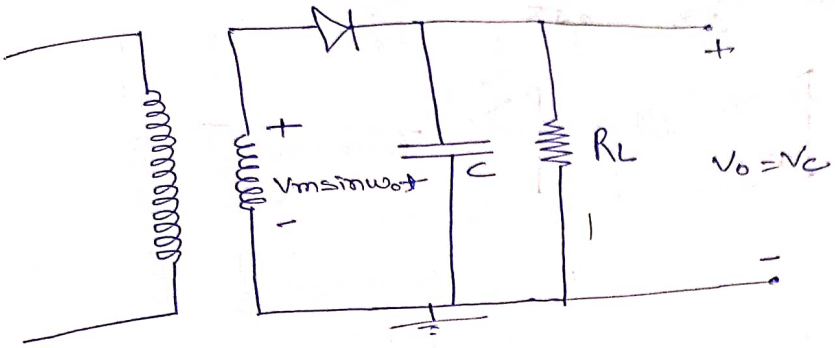
capacitor is not use in series connection

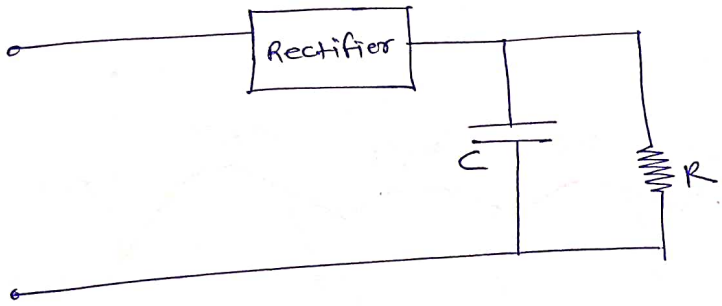
its use in parallel connection

L Inductor → series → ✓

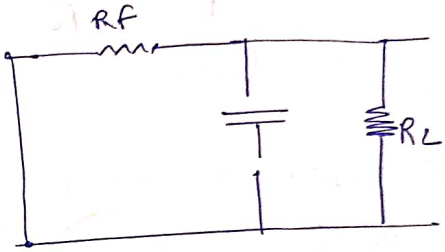
parallel → ✗

Half wave Rectifier using capacitive filter





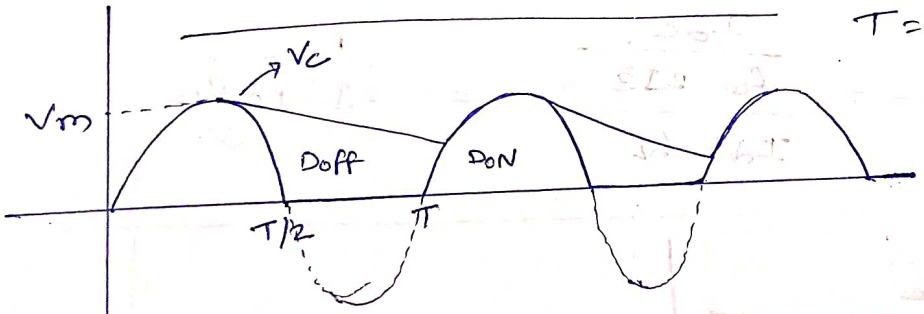
$(R_f \| R_L) \cdot C$

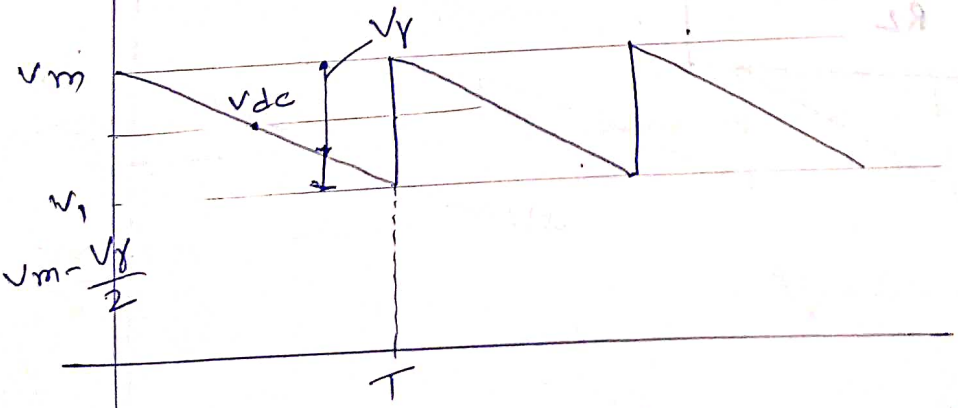


discharging time constant $= R_L \cdot C$

$T = T_d + T_c$

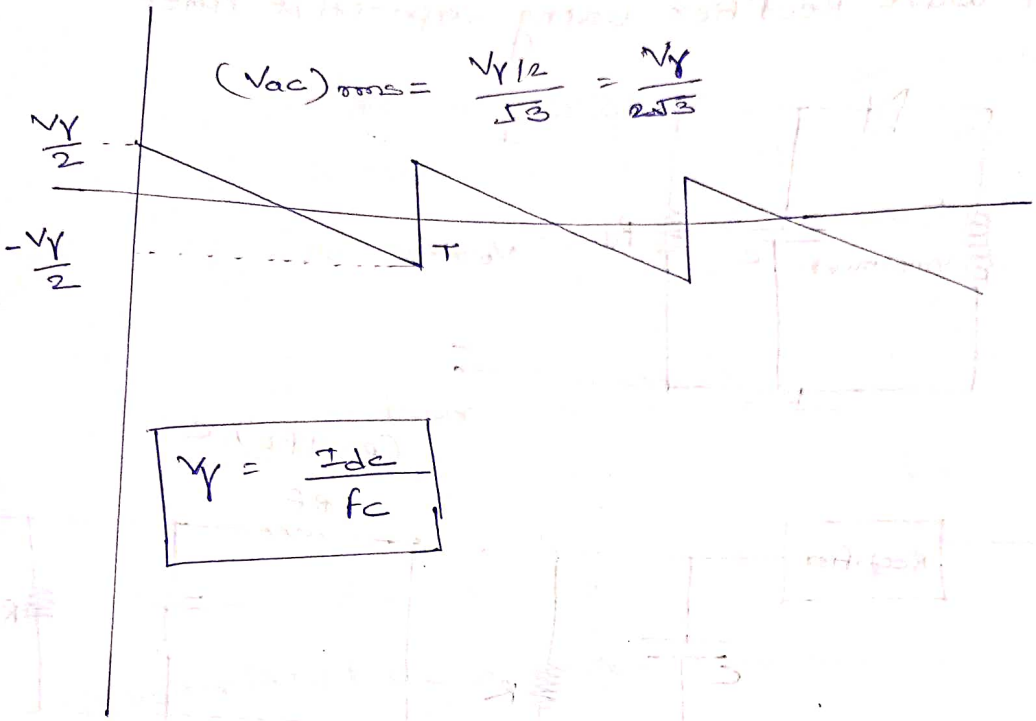
$T_d \gg T_c$





$V_{dc} = V_m - \frac{V_\gamma}{2}$

$$(V_{ac})_{rms} = \frac{V_r/2}{\sqrt{3}} = \frac{V_r}{2\sqrt{3}}$$



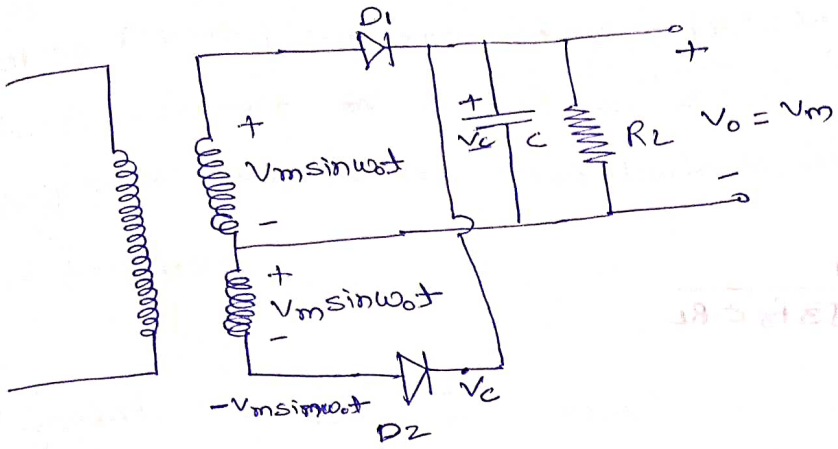
$$\boxed{V_r = \frac{I_{dc}}{f_c}}$$

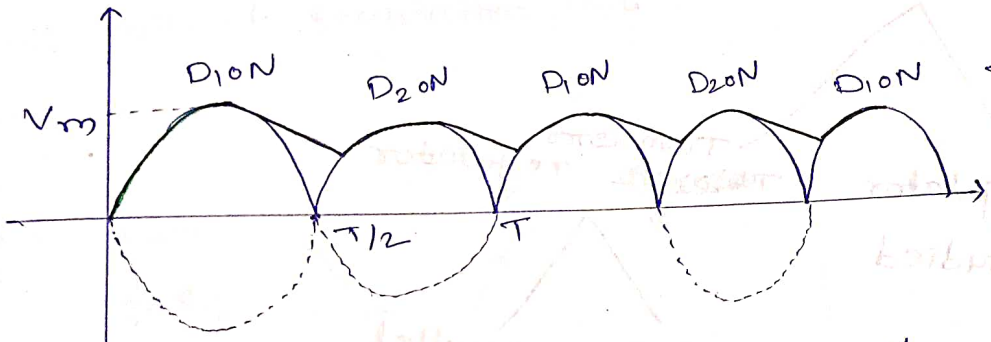
$$\gamma = \frac{(V_{ac})_{rms}}{V_{dc}}$$

$$\gamma = \frac{V_r/2\sqrt{3}}{V_{dc}} = \frac{\frac{I_{dc}}{f_c \cdot 2\sqrt{3}}}{I_{dc} \cdot R_L} = \frac{1}{2\sqrt{3} \cdot f_c R_L}$$

$$\boxed{V_{dc} = V_m - \frac{V_{dc}}{2 f_c R_L}}$$

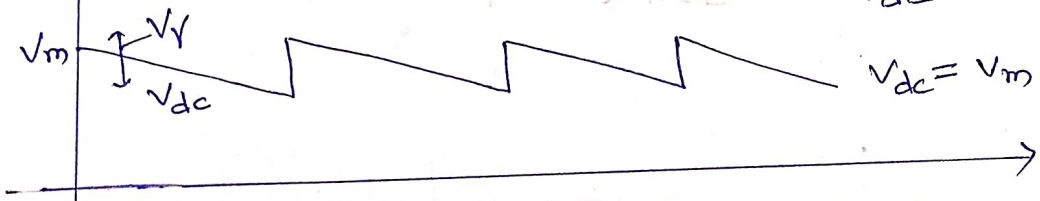
Centre tap Rectifier with filter





$T_d + T_c = T/2$

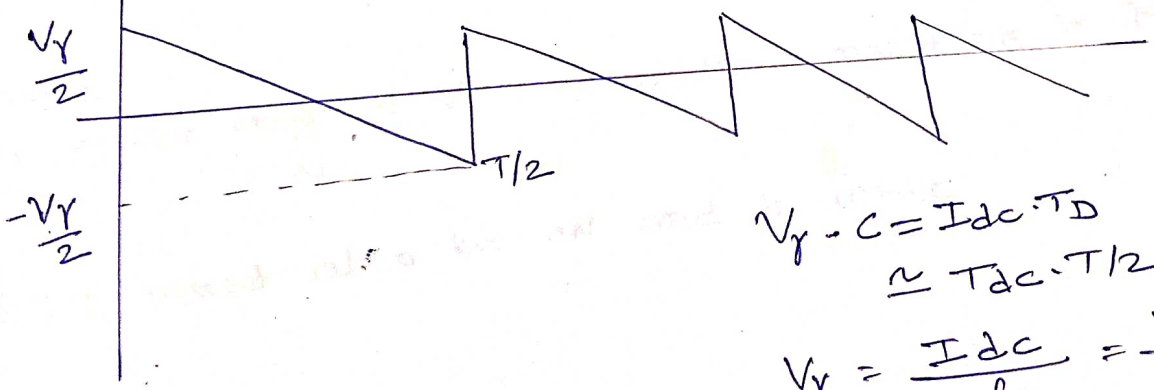
$T_d \gg T_c$



$$V_{dc} = V_m - \frac{V_r}{2}$$

$$V_{dc} = V_m - \frac{V_{dc}}{4R_L \cdot f \cdot C}$$

$$(V_{ac})_{rms} = \frac{V_r/2}{\sqrt{3}}$$



$$V_r \cdot C = I_{dc} \cdot T_D$$

$$\simeq I_{dc} \cdot T/2$$

$$V_r = \frac{I_{dc}}{2Cf} = \frac{I_{dc}}{f_r \cdot C}$$

$$\gamma = \frac{V_r / 2\sqrt{3}}{V_{dc}}$$

$$= \frac{\frac{I_{dc}}{4\sqrt{3} f C}}{I_{dc} \cdot R_L}$$

$$= \frac{1}{4\sqrt{3} f C R_L} = \frac{1}{2\sqrt{3} f_r C \cdot R_L}$$

Regulator ckt

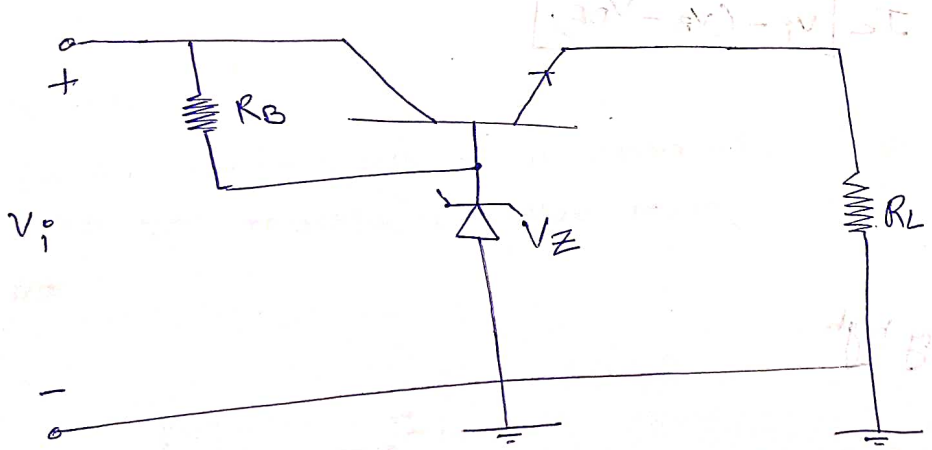
- Normal Regulator
  - Imp already studied
- Transistor regulator
  - Series
  - parallel

Series Transistor Regulator ckt

- after filtering we are getting a fluctuating dc. so in order to have constant or perfect dc across the load terminal we use Regulator ckt. where zener diode is use for the purpose of Regulation.

$$\% \text{ regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

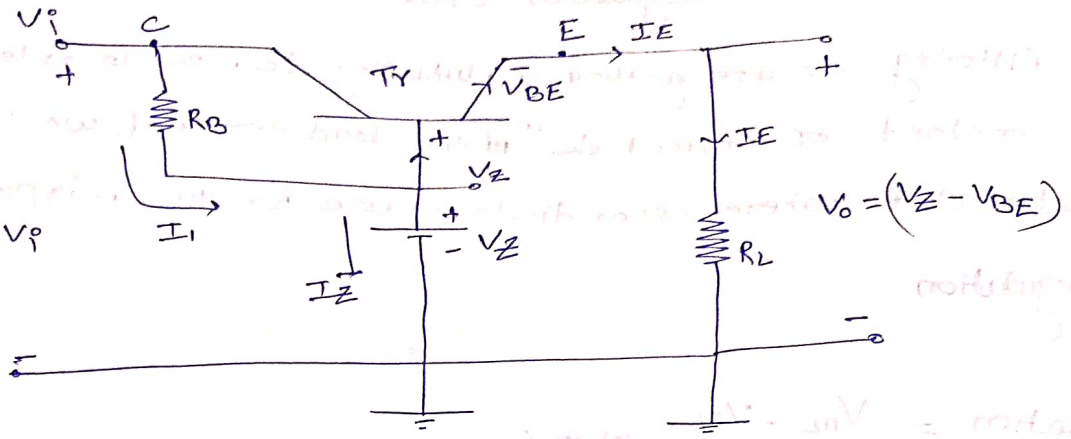
ideal value of Regulation should be zero %



Assume

i) for entier range of V_i, zener diode must be in breakdown.

ii) BJT must also be ON and in active



$$I_1 = \frac{V_i - V_Z}{R_B}$$

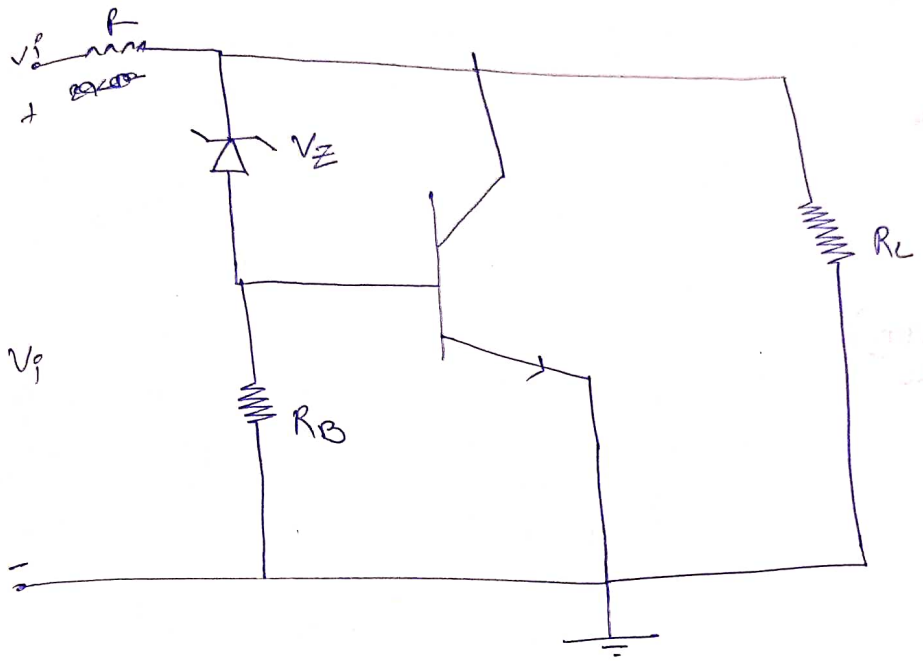
$$V_{CE} = V_i - (V_Z - V_{BE})$$

$$P_{Tr} = I_C \cdot V_{CE} = I_C\left[V_i - (V_Z - V_{BE})\right]$$

$$I_E = \frac{V_Z - V_{BE}}{R_L}$$

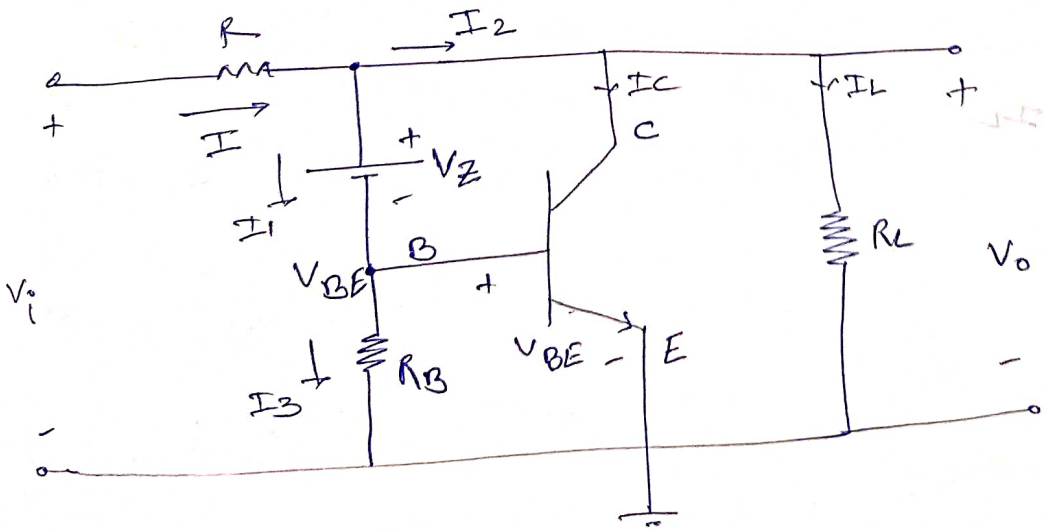
$I_1 = I_Z$ if β is very high

Parallel Transistor Regulator circuit



Assume

i) for the entire range of i/p zener diode must be in breakdown and BJT must be in active region.



$$I_L = \frac{V_Z + V_{BE}}{R_L}$$

$$V_{CE} = V_Z + V_{BE}$$

$$V_o = V_Z + V_{BE}$$

$$I = V_i - \frac{(V_Z + V_{BE})}{R}$$

$$I = I_1 + I_2$$

$$I_2 = I_c + I_L$$

$$I_3 = \frac{V_{BE} - 0}{R_B}$$

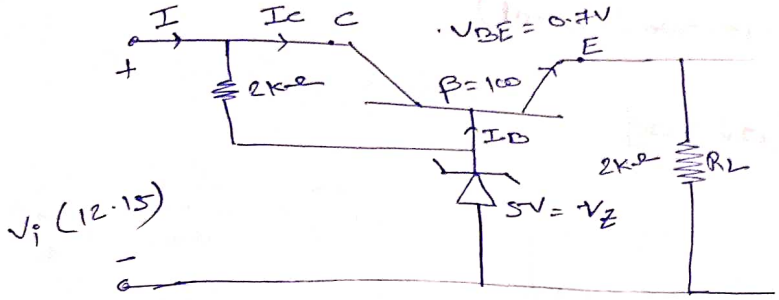
if β is very high

$$\boxed{I_3 = I_1}$$

$$\therefore I_2 = I - I_1$$

$$I_c = I - \underset{\substack{\downarrow \\ I_3}}{I_1} - I_L$$

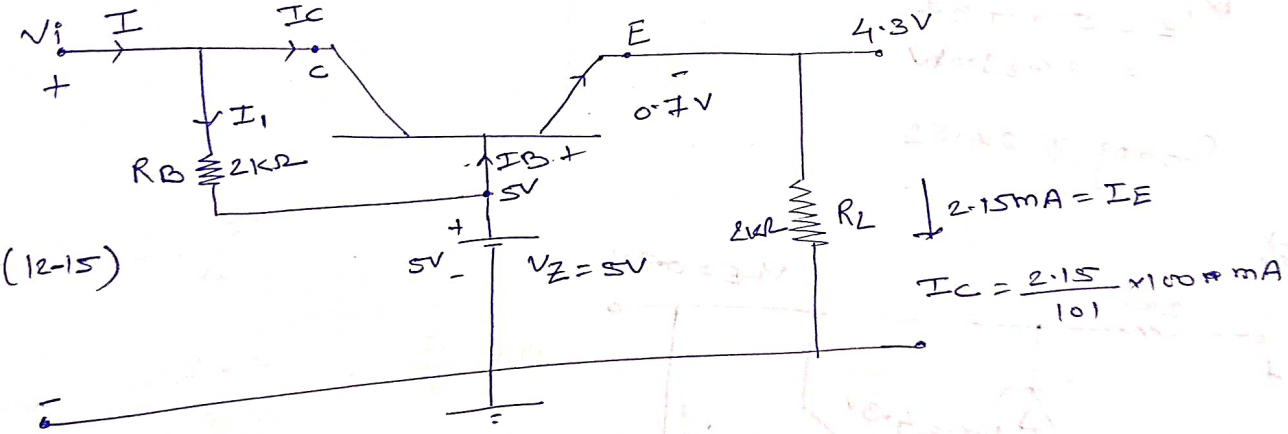
2)



a) maximum power desipation across BJT in mW ——— upto two decimal.

sol:-

$$(P_c)_T = I_c V_{CE} = (I_c)_{fixed}\left[V_i - 4.3\right]$$



$$I = I_1 + I_c$$

$$V_{CE} = (V_i - 4.3)$$

$$(P_c)_{max} = \frac{2.15}{101} \times 100\left[15 - 4.3\right]$$

$$= 22.76 \text{ mW}$$

b) minimum power rating of the zener diode that is required _____ mW (upto two decimal)

$(P_{ed})_{min} = \cancel{\frac{2.15}{101} \times 100 [\approx 49.89]}$

$P_Z = V_Z I_Z$

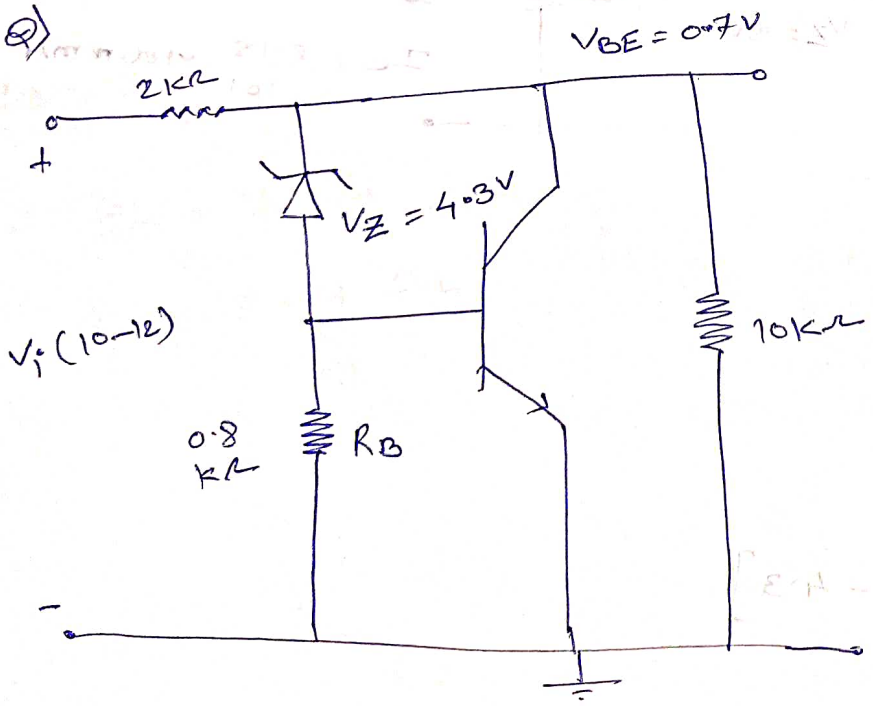
$I_1 = I_Z + I_B \Rightarrow I_Z = \frac{V_i - 5}{2} = \frac{2.15}{101}$

$(I_Z)_{max} = 5 - \frac{2.15}{101} \simeq 4.97\,mA$

$P_Z = 5 \times 4.97$
$= 24.89\,mW$

$P_{rating} \geq 24.89$

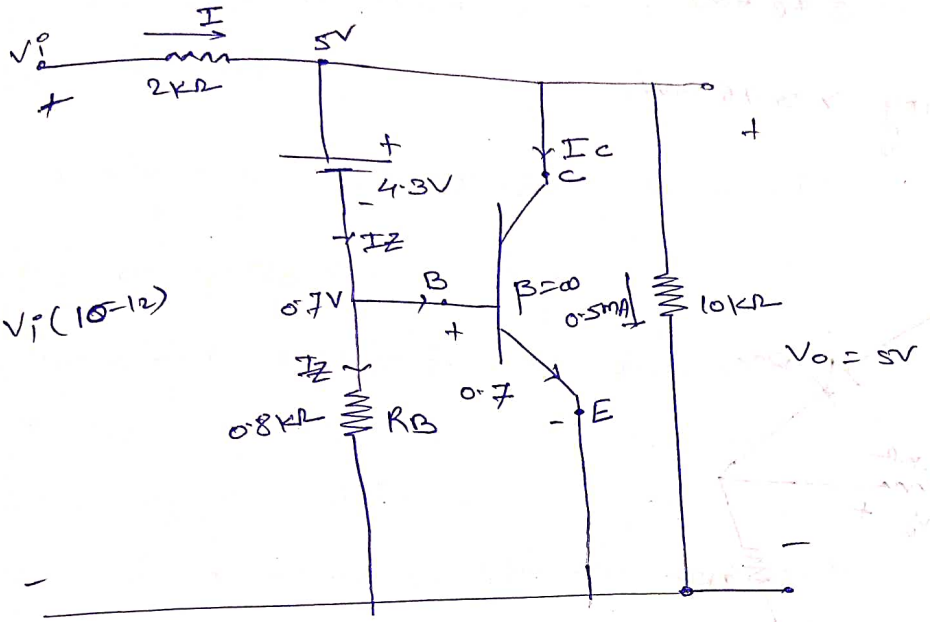
Q)



i) max^m Power dissipation across BJT ——— mW upto two decimal

Soln:-

$P_C = I_C \cdot V_{CE} = 5 \times I_C$



$$I = \frac{V_i - 5}{2}$$

$$I_Z = \frac{0.7 - 0}{0.8} = \frac{7}{8} \text{ mA}$$

$$I - I_Z = I_C + I_L$$

$$\frac{V_i - 5}{2} - \frac{7}{8} = I_C + 0.5$$

$$I_C = \frac{V_i - 5}{2} - \frac{7}{8} - 0.5$$

$$I_{C\,max} = \left(\frac{12 - 5}{2} - \frac{7}{8} - 0.5\right)$$

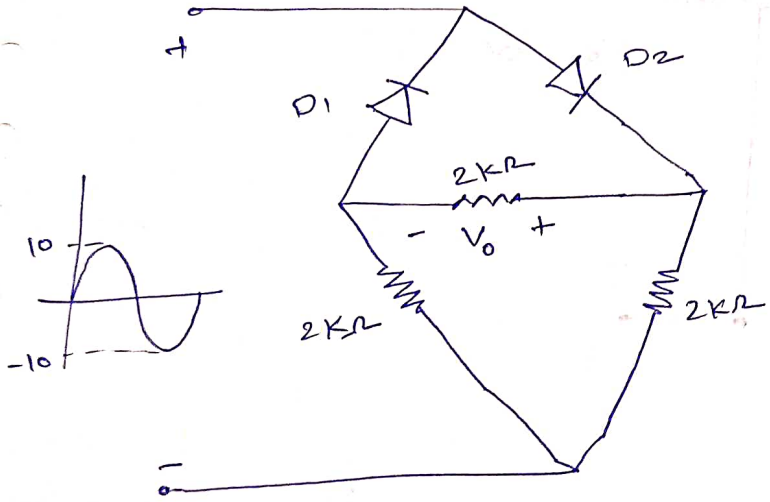
$P_C = 10.63$ mW

ii) minimum power rating of the zener diode

$$P_Z = V_Z I_Z$$
$$= 4.3 I_Z$$
$$= 4.3 \times \frac{7}{8} = 3.76 \text{ mW}$$

$P_{rating} \geq 3.76$ mW.

Q)



$V_o \longrightarrow$

V_{avg} _____

V_{rms} _____

PIV of diode D_1 & D_2

Current mirror :-

1) A circuit in which output current is forced to equal to input current. basically in current mirror ckt output current is mirror image of input current i.e the name is current ckt.

2) It is widely use in designing of differential Amplifier and I'c or VLSI ~~Degi~~ Design.

3) ~~Th~~ and the reason for its wide use
   i) low cost
   ii) easy to fabricate
   iii) Low number of Elements required.

- widlar
- wilson

for designing current mirror ckt required

a) Transistor must be identical

→ Q_1 & Q_2 identical

BE

$$I_S = qA \frac{D_n}{W} n_p \rightarrow npn$$

$$I_S = qA \frac{D_p}{W} p_n \rightarrow pnp$$

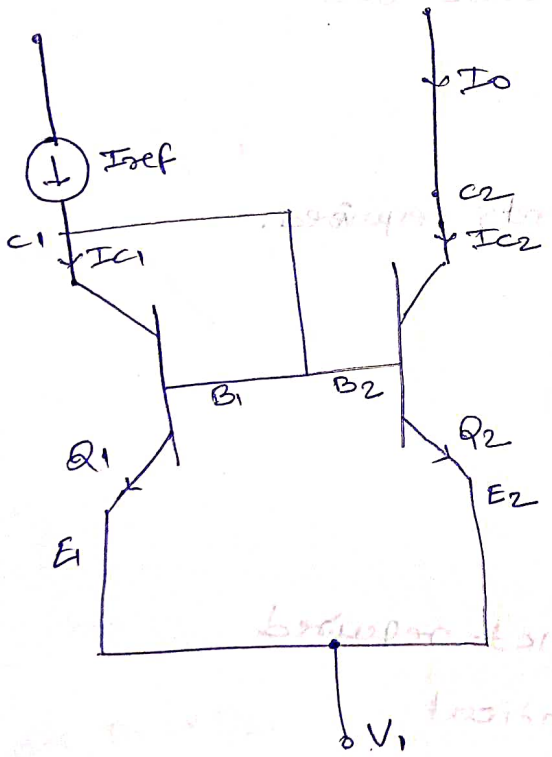
1) Reverse saturation I_s of B-E will be for both

2) current gain α, β, γ will be same

$$\boxed{I_c = I_s e^{V_{BE}/V_T} \longrightarrow npn}$$

3) Identical transistor will have same current if the base & Emmiter terminal of transistor of at same potential.

widlar :→



Q_1 and Q_2 are identical transistors

$I_{S1} = I_{S2} = I_S$

$\beta_1 = \beta_2 = \beta$

$I_{C1} = I_{C2}$ $\quad I_{C1} = I_S e^{(V_{BE})_1/V_T}$, $I_{C2} = I_S e^{(V_{BE})_2/V_T}$

$I_o = I_{C2}$

$I_{ref} = I_{C1} + I_{B1} + I_{B2} = I_{C2} + I_{B2} + I_{B2}$

$\beta I_{B2} + 2 I_{B2} = I_{ref}$

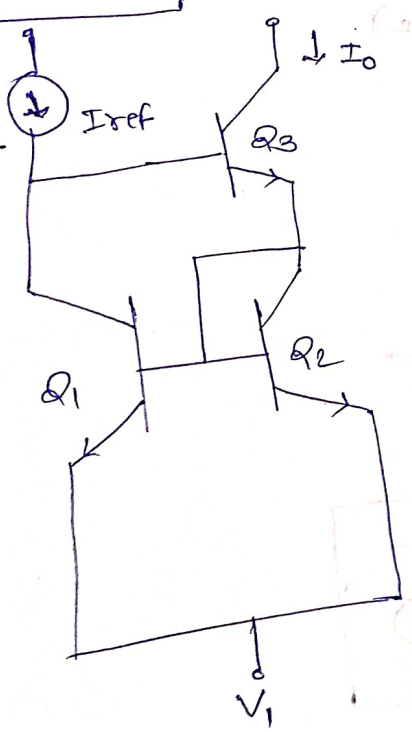
$$I_{B2} = \frac{I_{ref}}{(\beta+2)}$$

$$I_{C2} = I_o = \beta \frac{I_{ref}}{(\beta+2)} = \frac{I_{ref}}{(1+2/\beta)}$$

β = very high

$$\boxed{I_o \simeq I_{ref}}$$

Wilson :-



Q_1, Q_2, Q_3 are identical

$I_{S1} = I_{S2} = I_{S3} = I_S$

$\beta_1 = \beta_2 = \beta_3 = \beta$

$I_{C1} = I_{C2}$

$I_{ref} = I_{B3} + I_{C1}$ — ①

$I_{E3} = I_{C2} + I_{B1} + I_{B2}$

$= I_{C1} + 2 I_{B1} = (1 + 2/\beta) I_{C1}$

$$I_{C1} = \frac{\beta+1}{(1+2/\beta)} I_{B3}$$

$$I_{ref} = I_{B3} + \frac{(\beta+1)}{(1+2/\beta)} I_{B3}$$

$$= I_{B3}\left[1 + \frac{\beta(\beta+1)}{\beta+2}\right]$$

$$I_{B3} = \frac{(\beta+2)\, I_{ref}}{(\beta+2) + \beta(\beta+1)}$$

$$I_o = I_{C3} = \frac{\beta(\beta+2)\, I_{ref}}{(\beta+2) + \beta(\beta+1)}$$

$$I_o = \frac{I_{ref}}{\frac{1}{\beta} + \left(\frac{\beta+1}{\beta+2}\right)} = \frac{I_{ref}}{\frac{(\beta+2) + \beta(\beta+1)}{\beta(\beta+2)}}$$

$$= \frac{I_{ref}}{\frac{\beta^2 + 2\beta + 2}{\beta(\beta+2)}}$$

$$= \frac{I_{ref}}{\frac{(\beta+2)+2}{\beta(\beta+2)}}$$

$$\boxed{I_o = \frac{I_{ref}}{1 + \frac{2}{\beta(\beta+2)}}}$$