SEMICONDUCTOR DIODE

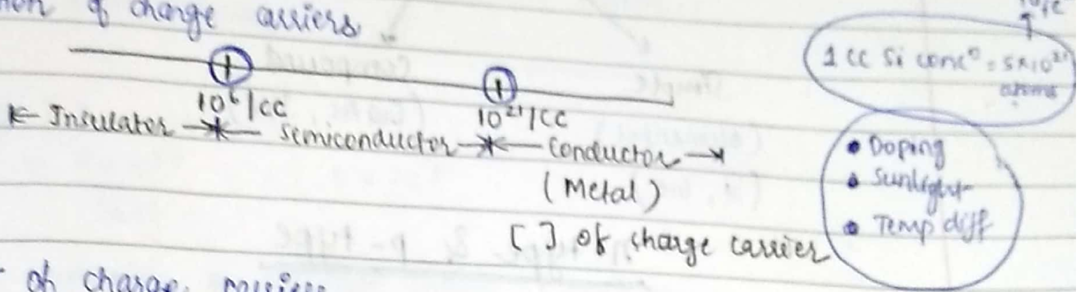
Q Why semiconductor?

It enhances the performance, reliability and cost effectiveness of electronic system (information & energy system)

Properties of Semiconductor –

① Polarity of charge carriers

② Concentration of charge carriers.



③ Transport of charge carriers.

▶ So, the conclusion is — In metal, current is only due to potential gradient, i.e. only drift current present.

▶ In semiconductor, all 3 types of current ① Drift ② diffusion & ③ Thermoelectric currents are present, so semiconductor can be used design different kinds of material.

④ Interaction with electromagnetic field.

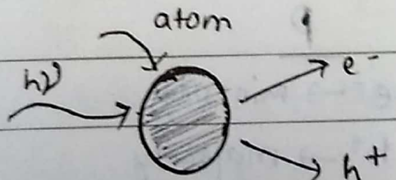
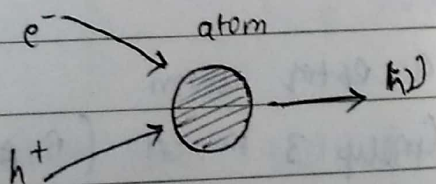
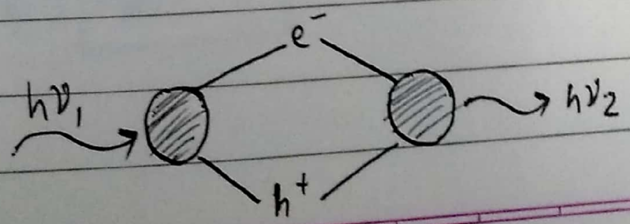


Photo conductivity | Photovoltaic



Electroluminiscence

Photoluminiscence



S/C

- **Intrinsic** — without any doping (approx. pure)
  - → may be 100% pure
  - → may be small impurity / defects but compensating each other [ ] of e^- & holes become constant
- **Extrinsic**
  - → which is not intrinsic
  - → At eq^b $n(e^-) \neq n(h^+)$
  - → subjected to doping process
  - →
- **Pure** (regular arrangement of e^- & atoms)
- **Simple** (elemental) (Si, Ge)
- **Compound** (GaAs, InP)

n-type & p-type

- n-type – (Donor) –

Any n-type can be created by introducing impurity element that has 5 valency e^- such as Sb, As, P.

p-type – (Acceptor) –

Any p-type is formed by doping a pure Ge / Si crystal with impurity atoms having 3 valence e^-(s). The elements most frequently used are ~~Be~~, Ga, Al, In.

n	p
$e^- \rightarrow$ majority $h^+ \rightarrow$ minority	$e^- \rightarrow$ minority $h^+ \rightarrow$ majority
donor atom	acceptor atom
Group 5 mixed (~~N~~, P, As, Sb)	Group 3 mixed (B, ~~Al~~, Ga, In)

$\rightarrow$ [eq^b conc]

Intrinsic [ ], n_i = 1.5×10^{10}/cc = X (e^-/h^+)

Atomic [ ] = 5×10^{22} / cc = Y.

Ratio of X & Y = 1 e^-/h^+
for every 5×10^{11} Si atom

This is very low conc^n as compared to metal.
So, 'Si' is semiconductor

Impurity [ ] = 10^{15}/cc

Ratio $= \dfrac{5 \times 10^{22}}{10^{15}} = 5 \times 10^{7}$

i.e 1 impurity is present inside 5×10^{7} atoms.

* Condition for impurity addition —
1. Structure shouldn't change
2. Impurity should be unaffected to each other (no force of interaction)

06/09/18.

The doping concentration ~~which~~ allow us to control the conc^n of free e^- & holes.

At thermal eq^n, $\boxed{n_0 p_0 = n_i^2}$ law of Mass Action.

where n_0 = thermal eq^b conc^n of free e^-(s)
p_0 = " " " " holes
n_i = intrinsic conc^n = fixed.

At room temp, each donor atom donate a free e^- to the semiconductor

if $\boxed{n_d \gg n_i}$

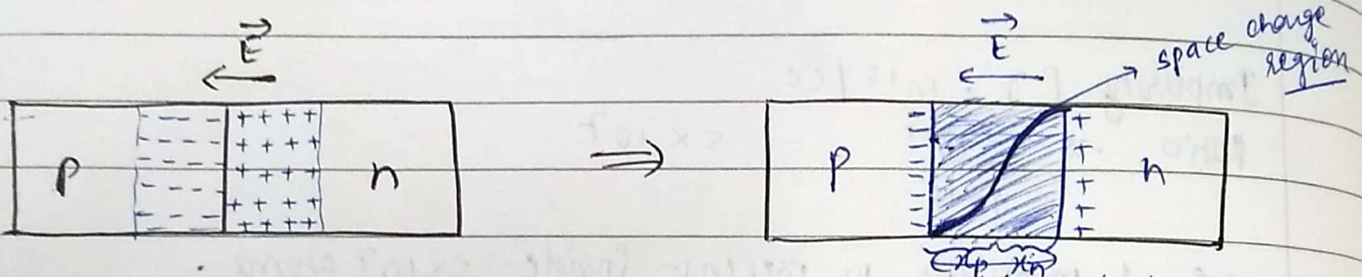
$n_0 \cong n_d$

$p_0 = \frac{n_i^2}{n_d}$

Similarly, $p_0 \cong n_a$

$\boxed{n_0 = \frac{n_i^2}{n_a}}$ Law of mass action.

Semiconductor Diode



V_{bi} = built in potential

$\boxed{V_{bi} = \frac{KT}{q} \exp\left(\frac{N_a N_d}{N_i^2}\right) \approx 0.1\text{ V}}$

q → electronic charge

→ ideal condition (or 0.2 V)

N_a = acceptor conc^n = p_0

N_d = donor conc^n = n_0

N_i = intrinsic conc^n

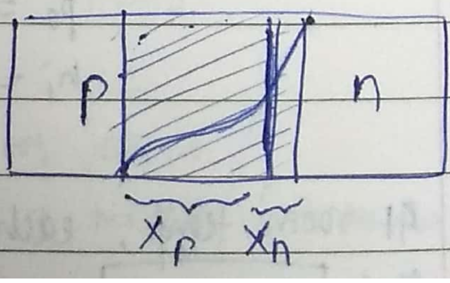
V_{bi} can't be measured by voltmeter (small V_{bi})

▶ Charge neutrality – $A\, q\, N_a X_p = q\, N_d X_n A$

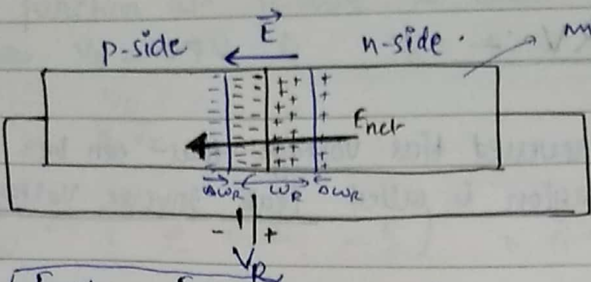
→ not symmetric

$\boxed{\frac{X_p}{X_n} = \frac{N_d}{N_a}}$ $= \frac{10^{16}}{10^{15}}$ [depends on donor conc^n].

$= 10$



Reverse Bias



→ minority holes will be repelled by V_R.

→ Recombination also takes place.

$C_j = \frac{q}{V}$ → Junction capacitance.

$\boxed{E_{net} = E + E_R}$ → Depletion width also increases.

$$\boxed{C_j = C_{j0}\left(1 + \frac{V_R}{V_{bi}}\right)^{-1/2}}$$

C_{j0} → Junction capacitance when $V_R = 0$

C_j → very small (pF) → Junction capacitance

\# When a reverse biased voltage is applied to a p-n junction the $\vec{E}$ in the space charge region increases. Due to this, very large $\vec{E}$, minority carriers get kinetic energy and thus, it collides with the covalent bond or crystal, it breaks the bond and e⁻-hole pair is generated

\# e⁻ are sweeped into the n-region & holes are swept into p-region by the high electric field, generating a large reverse saturation current (I_S). This phenomenon is called **Breakdown**.

① Avalanche Breakdown

- S/C is moderately (less) doped.
- Depletion layer is thick
- $\vec{E}$ is large, so e⁻ & holes will get K.E / acc^n $a = \frac{eE}{m}$
- Applied V_Z is around 12–14V. which is large as compared to zener.

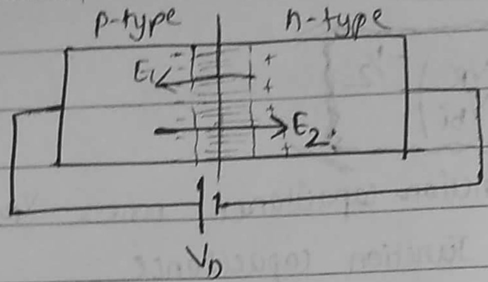
② Zener Breakdown

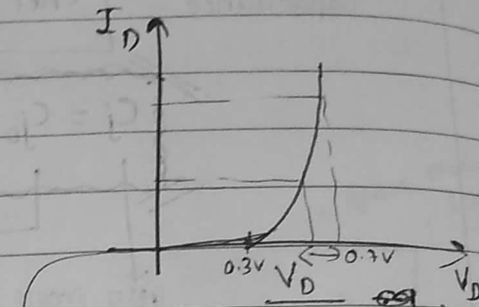
- S/C is heavily doped
- Depletion layer is very thin
- $\vec{E}$ is very large.
- Applied V_Z is around 6 V which is less as compared to avalanche

PIV - PRV :-

The max^m reversed bias voltage that can be applied before entering the zener region is called Peak Inverse Voltage (PIV)

Forward Bias :-





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

The formula is valid only if $E_{net} = E_1 - E_2 \geq 0$

I_D = diode current

I_S = saturation current

V_D = diode voltage

$V_T = \frac{KT}{q} = 0.026$ volt

η = ideality factor, for Si = 1, Ge = 2

Q Calculate the junction capacitance of p-n junction. Consider a Si p-n junction at T = 300k, with doping conc^n $N_a = 10^{16}/cc$ & $N_d = 10^{15}/cc$. Assume that $n_i = 1.5\times10^{10}/cc$ & $C_{j0} = 0.5\ pF$. Calculate C_j at $V_R = 1V$ & $V_R = 5V$.

Sol^n - $V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.637$ $\quad V_T = \frac{KT}{q}$

(1) $C_j = C_{j0}\left(1 + \frac{V_R}{V_{bi}}\right)^{-1/2}$ $\quad [V_R = 1]$

$= 0.312\ pF$ $\quad C_j \downarrow\ V_R \uparrow$

(2) $C_j = 0.168\ pF$ $\quad [V_R = 5]$

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$\boxed{V_D = 0.7V}$

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Q Consider a p-n junction at $T = 300K$ in which $I_s = 10^{-14}$. Find the diode current for $V_D = 0.7V$ & $V_D = -0.7V$ [$\eta = 1$ for Si]

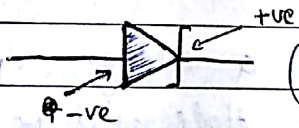
① $I_D = I_s\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$

$= 10^{-14}\left(e^{\frac{0.7}{0.026}} - 1\right) = 4.93A$

② $I_D = 10^{-14}\left(e^{-0.7/0.026} - 1\right) = 10^{-14} A$

Zener Diode

The diode breakdown voltage is constant over a wide range of current.



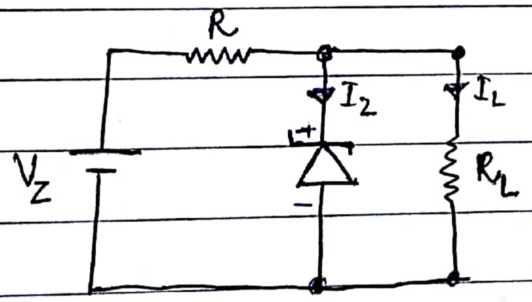
(Zener Diode)

V_Z = Zener breakdown voltage

I_Z = Reversed biase current when diode is in breakdown region.

I_{ZM} = Max^m current that zener diode can sustain.

a) **V_i, R, & R_L all fixed** –



$V_L = \frac{R_L V_i}{R + R_L}$

$V_L \geq V_Z$

$V_L < V_Z$

$V_Z = V_L$

$I_Z = I_R - I_L$

$= \frac{V_i - V_Z}{R} - \frac{V_Z}{R_L}$

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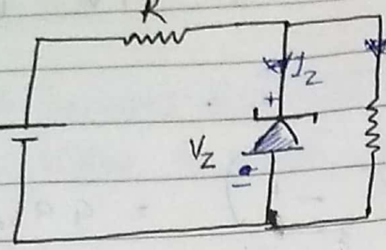
② V_i fixed & R_L is variable —

→ calculate Test in every case

$$V_Z = V_L = \frac{V_i R_L}{R+R_L}$$

$V_L < V_Z$ → off



$$\boxed{R_{L\,min} = \frac{R V_Z}{V_i - V_Z}}$$

→ for which zener diode is in active mode.

$$(I_L)_{max} = \frac{V_L}{(R_L)_{min}}$$

~~$(I_L)_{min} = I_R - I_{ZM}$~~

I_{ZM}
P_{ZM}
always remember in case of zener.

If $V_L \geq V_Z \longrightarrow$ ON
$V_L < V_Z \longrightarrow$ OFF

- Two small R_L will result in a voltage V_L across the load resistance $< V_Z$ and the zener diode will be in 'OFF' state
- Any load resistance $> R_L$ will ensure that zener diode is in 'ON' state and it can be replaced by V_Z.

$$(I_L)_{min} = I_R - I_{ZM}$$

$(I_L)_{min}$ → $(R_L)_{max} = \dfrac{V_Z}{(I_L)_{min}}$

I_R → fixed

③ 'R_L' is fixed and 'V_i' is variable —

✓ $V_L = V_Z = \dfrac{R_L V_i}{R+R_L}$

$$(V_i)_{min} = \frac{(R+R_L)\, V_Z}{R_L}$$

✓ $(V_i)_{max} = I_R R + V_Z = (I_{Zmax} + I_L) R + V_Z$

DC gives average nature of signal.

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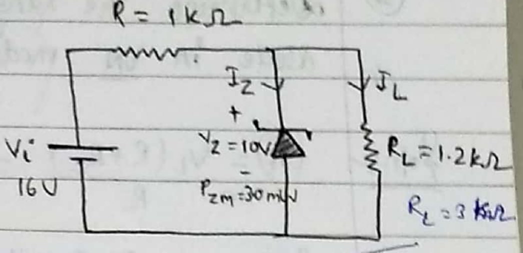
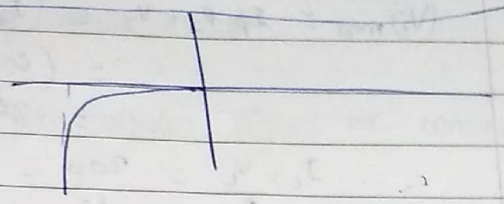
Ex① For given zener diode network, determine V_L, V_R, I_Z, P_Z.



Sol^n - $V_L = \frac{16 \times \cancel{1.2}^{6}}{\cancel{2.2}_{11}} = 8.72\ V$

$V_R = 1 \times I = 1 \times \frac{\cancel{160}^{80}}{\cancel{22}_{11}} = 7.27\ V$

~~$I_Z = P_{ZM}$~~



$V_L = 10V$

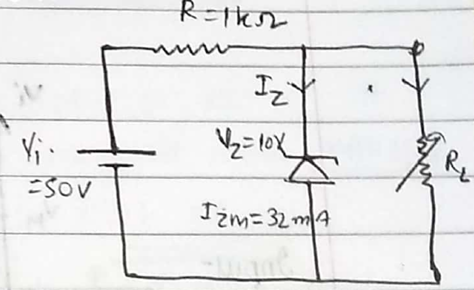
$V_R = 6V$

$I_Z = 1.67\ mA$

$P_Z = V_Z I_Z = 10 \times 1.67 = 26.7 < P_{ZM}$ — only to compare

Ex② For a given network, a) determine the range of R_L & I_L that will result in V_{RL} being maintained at 10V.

b) determine the max^m wattage rating of diode.



a) $V_L = \left(\frac{R_L}{R_L + R}\right) V_i = 10$

$R_L \times 50 = 10 R_L + 10 \times 1$

$\boxed{(R_L)_{min} = 0.25\ k\Omega}$

$(R_L)_{max} = \frac{V_Z}{I_{L min}}$

$= \frac{10}{8}$

$= 1.25\ k\Omega$

$(I_L)_{min} = I_R - I_{ZM}$

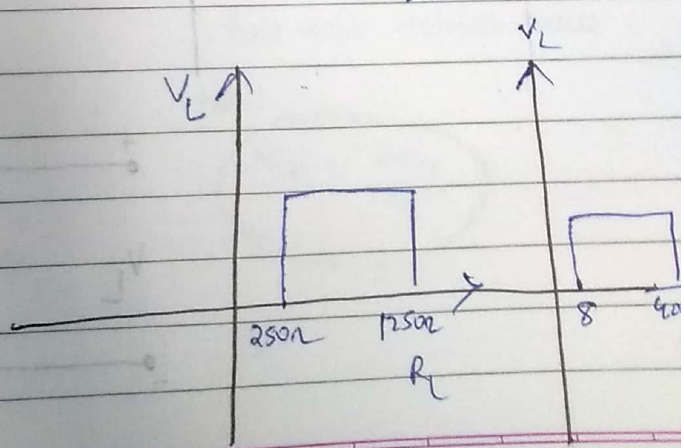
$I_R = \frac{V_R}{R} = 40mA$

$40 - 32 = 8\ mA$

b) $P_{max} = V_Z I_{ZM}$

$= 10 \times 32$

$= 320\ mW$



FT LT ZT WT DCT WT

Time & Spatial domain → $\omega = 0 \Rightarrow DC$

$X(\omega) = \int_{-\infty}^{\infty} x(t)\, e^{-j\omega t}\, dt$ → Fourier's transform

$X(0) = \sum_{n=0}^{N} x[n]$

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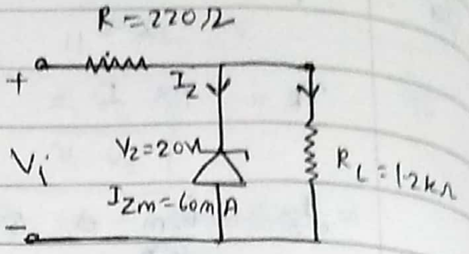
(8) Determine the range of value of V_i that will maintain zener diode in 'ON' mode.



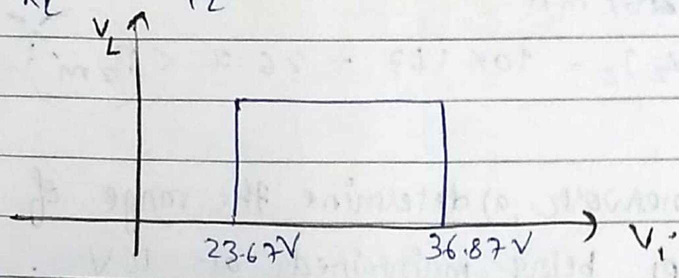
Soln:- $(V_i)_{min} = \dfrac{V_L(R+R_L)}{R} = 23.67\,V$

$(V_i)_{max} = I_R R + V_Z = (I_{ZM} + I_L)R + V_Z$

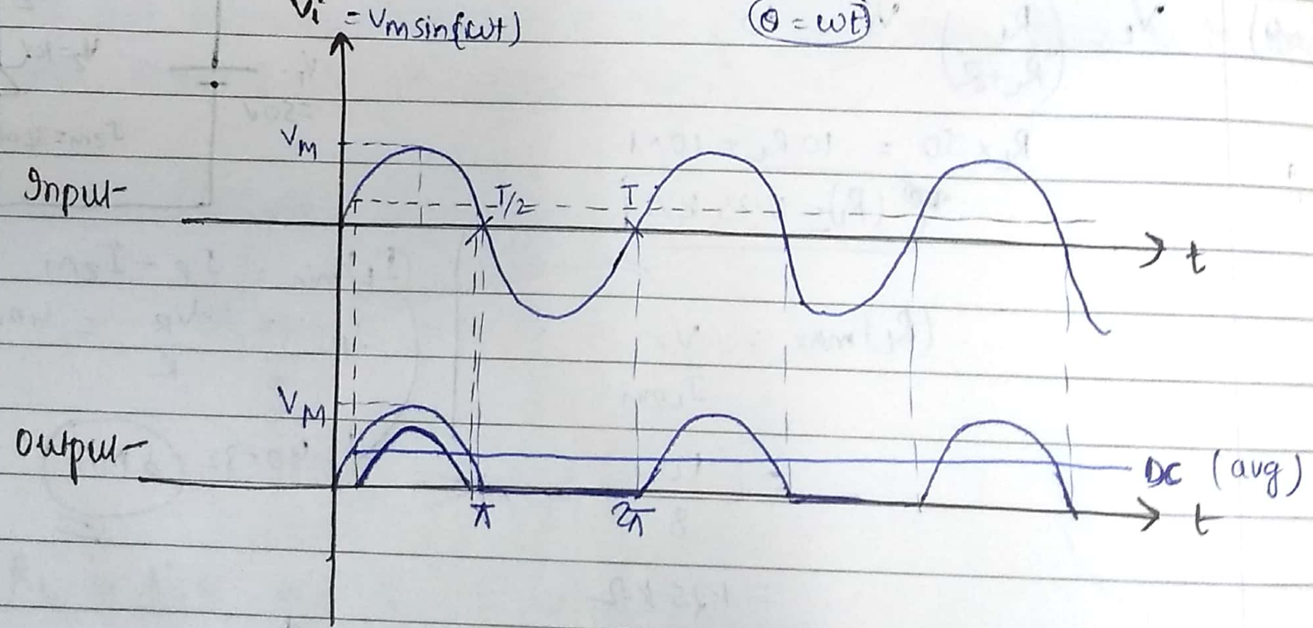
$= (60 + 16.67) \times 220 + 20$

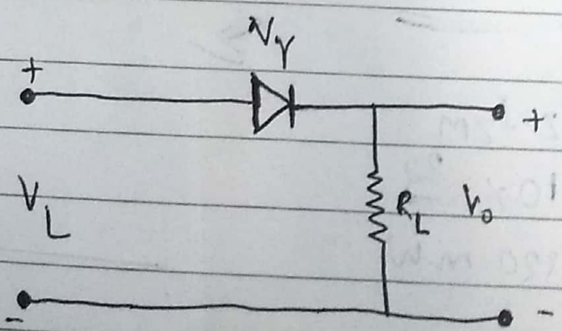
$= 36.87V$

$I_L = \dfrac{V_L}{R_L} = \dfrac{200}{12} = 16.67mA$



RECTIFIER





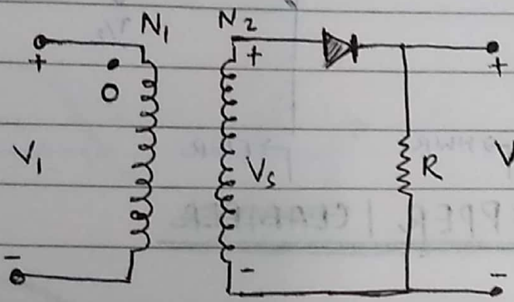
$$V_{avg} = V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\theta \, d\theta$$

$$= \frac{V_m}{2\pi}\left(\int_0^{\pi} \sin\theta \, d\theta + \int_{\pi}^{2\pi} 0 \, d\theta\right)$$

$$\boxed{V_{avg} = V_{dc} = \frac{V_m}{\pi}} = 0.318\, V_m$$

↳ pulsating dc का avg value = const.

(Def) # **Rectifier** converts bipolar signal into unipolar signal or converts Ac into pulsating dc.

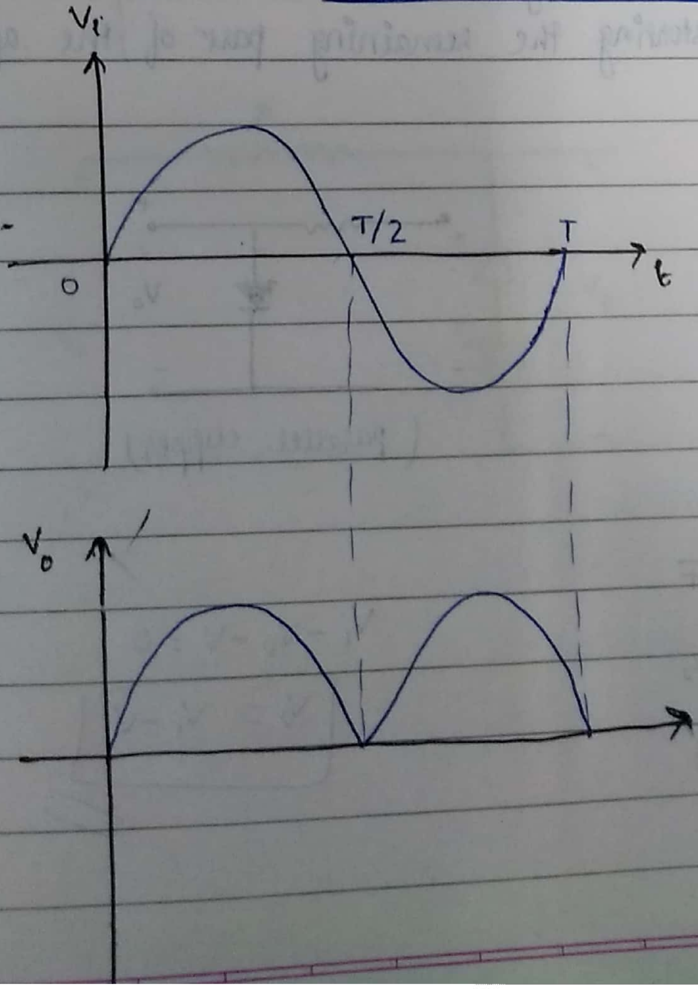


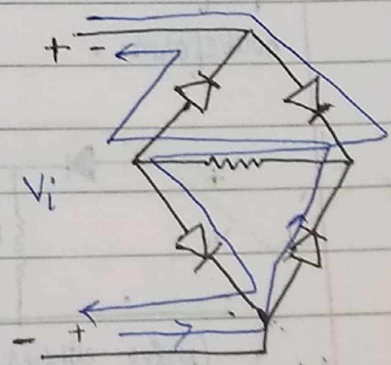
• → incurrent
o → outcurrent

$$\boxed{\frac{V_1}{V_s} = \frac{N_1}{N_2}}$$

FULL WAVE RECTIFIER

14/09/18



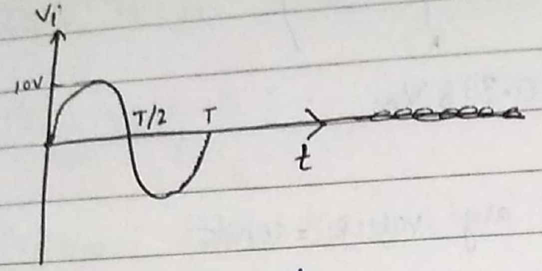


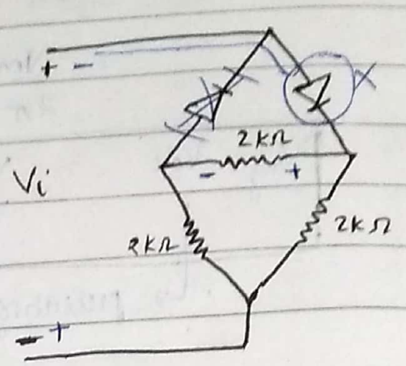
Full wave rectifier circuit

#

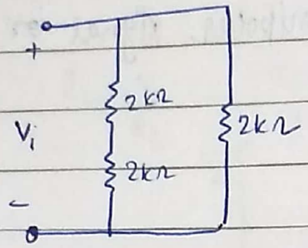
$$V_{dc} = \frac{2V_m}{\pi}$$

Q. Determine the output waveform for the given network, calculate the output dc level

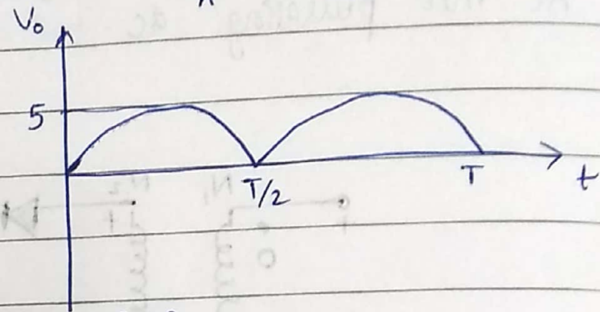




For (+ve) half cycle -



$V_{dc} = \frac{2 \times 5}{\pi} = \frac{10}{\pi} = 3.18V$

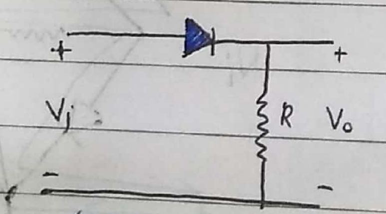


→ HWR

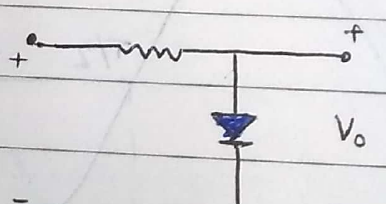
→ FWR

CLIPPER | ~~CLAMPER~~

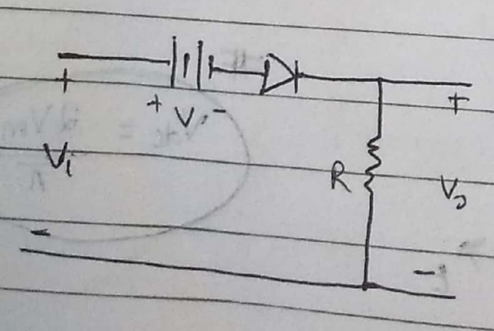
\# In case of clipper circuit, half wave rectifier is a clipper circuit which eleminate portions of a signal that are above or below a specified level without distorting the remaining part of the applied waveform.



(series clipper)



(parallel clipper)



$V_i - V_0 - V = 0$

$\boxed{V_0 = V_i - V}$

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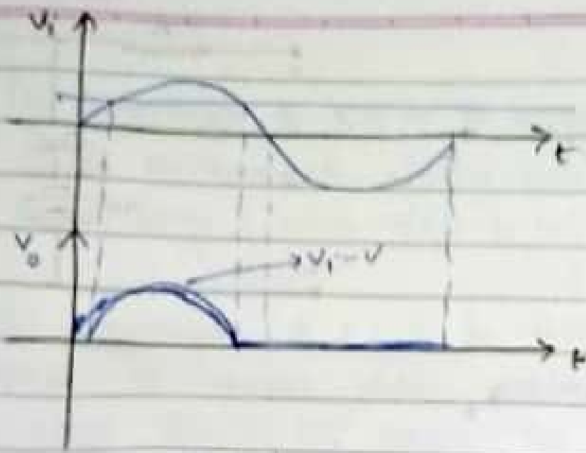
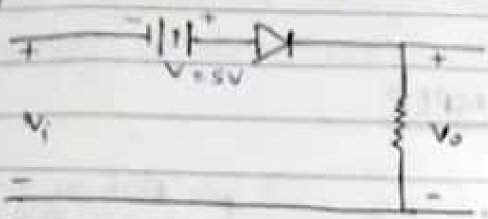
Sol^n



Q2.

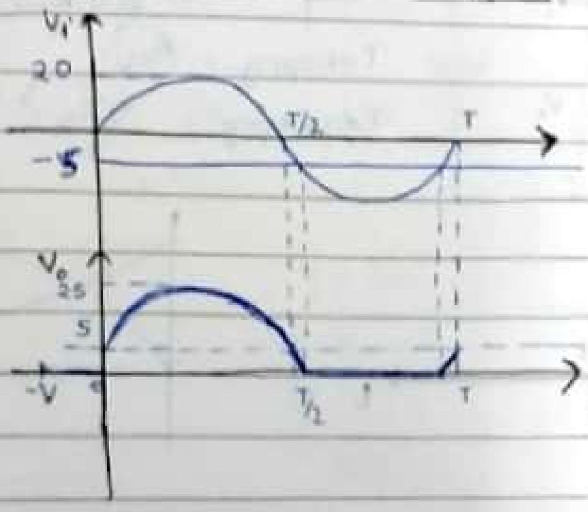


$$\boxed{V_i + V = V_o}$$

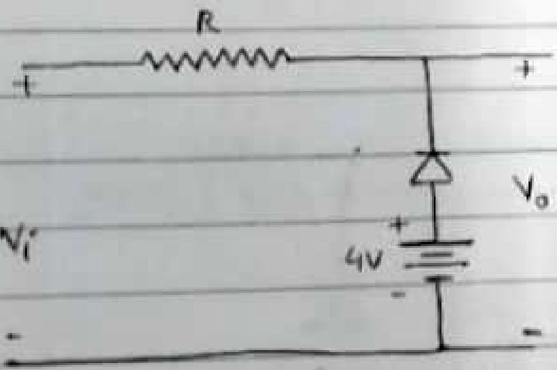
$V_o = 20 + 5 = 25$ V

$V_o = 0 + 5 = 5$ V

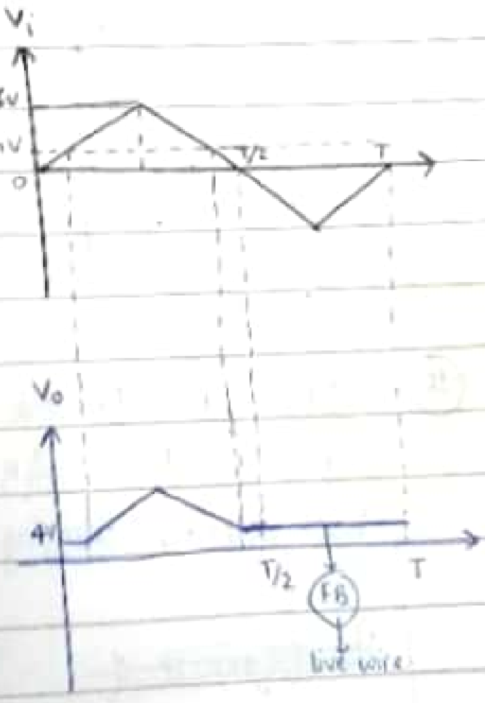
Sol^n -



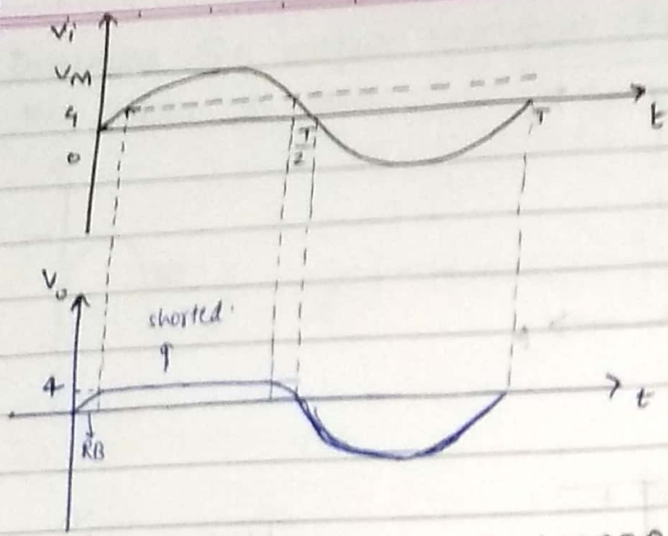
Q3.

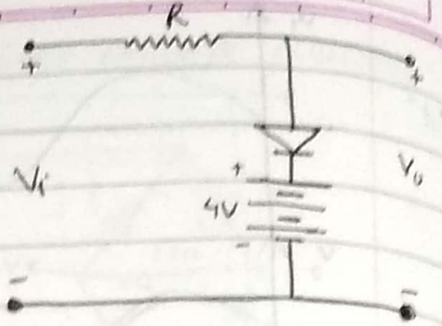


Sol^n:

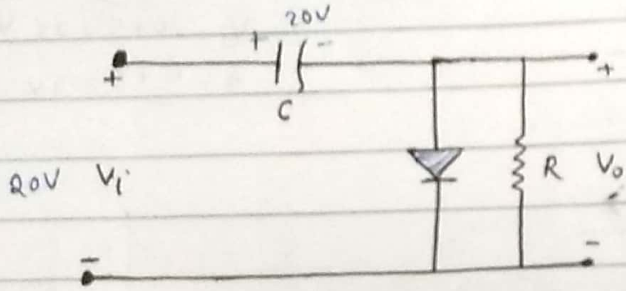


Q4





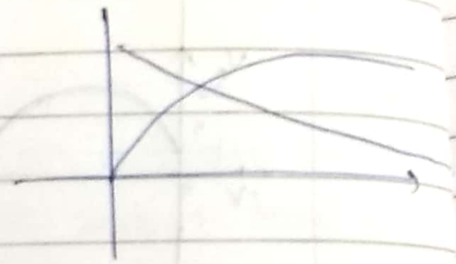
CLAMPER

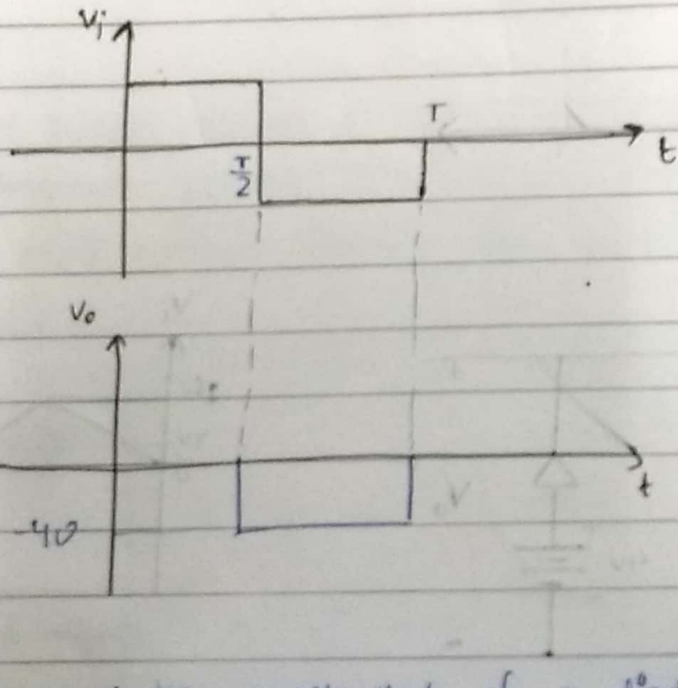


fast charging, very small

$\tau_{charging} = (R_{eq}) C$

$\tau_{discharging} = 5 (R_{eq} C)$ very long as compared to T/2 to T



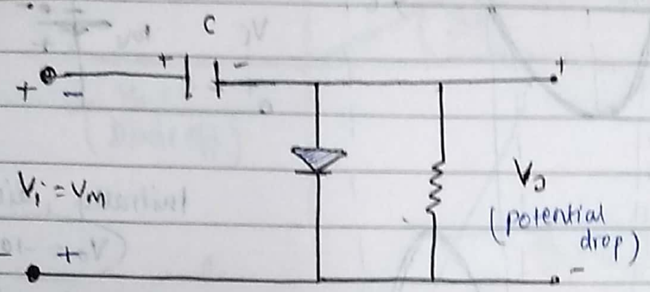


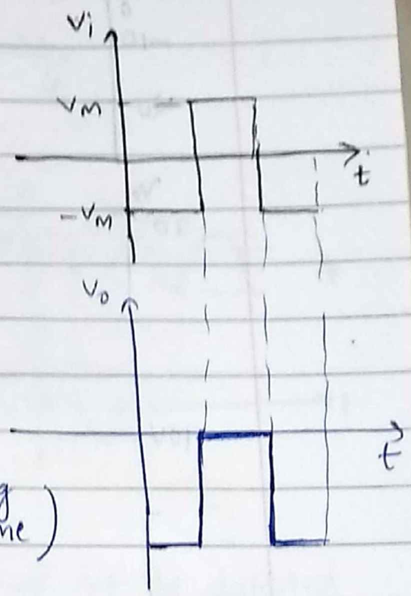
(#) Clamper is a network constructed of a diode, a resistor and a capacitor that shifts / clamp a waveform to a different DC/AC level without changing the appearance of the applied signal.

our aim is to gain max^{m} output

The magnitude of R & C is chosen such that $\tau = RC$ is sufficiently small ~~so that~~ to ensure that capacitor become charged immediately. (when diode is in forward biased)

The magnitude of R & C is chosen such that $\tau = RC$ is sufficiently large to ensure that voltage across capacitor doesnot discharge significantly during the interval, the diode is not conducting. (when diode is in reverse biased)





$\tau = RC$

$V_i - V_c = 0$

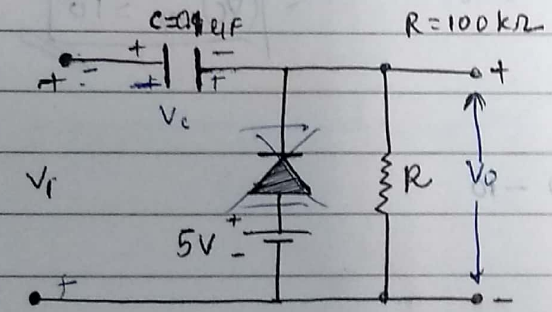
$V_i = V_c$

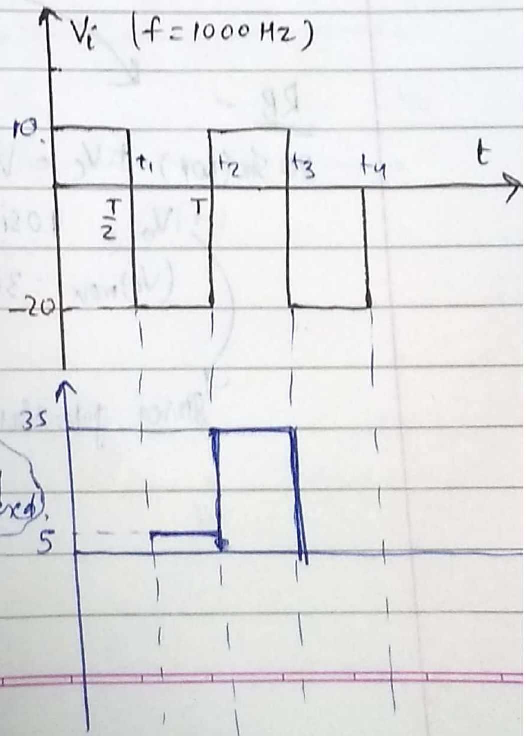
(net swing is same)

$-V_M - V_c - V_o = 0$

$\boxed{V_o = -2V_M}$

Q.





diode → forward: $-20V$ cycle ($t_1 \to t_2$)

$-V_i + V_c - 5 = 0$

$\boxed{V_c = V_i + 5} = 25$

signs is already considered.

diode → reverse: $+10V$ cycle ($t_2 \to t_3$)

$\boxed{V_i + V_c = V_o}$

$10 + 25 = 35 = V_o$

Short circuit ⇒ 0.7 V (of diode) लेना है उधार

Page No.:

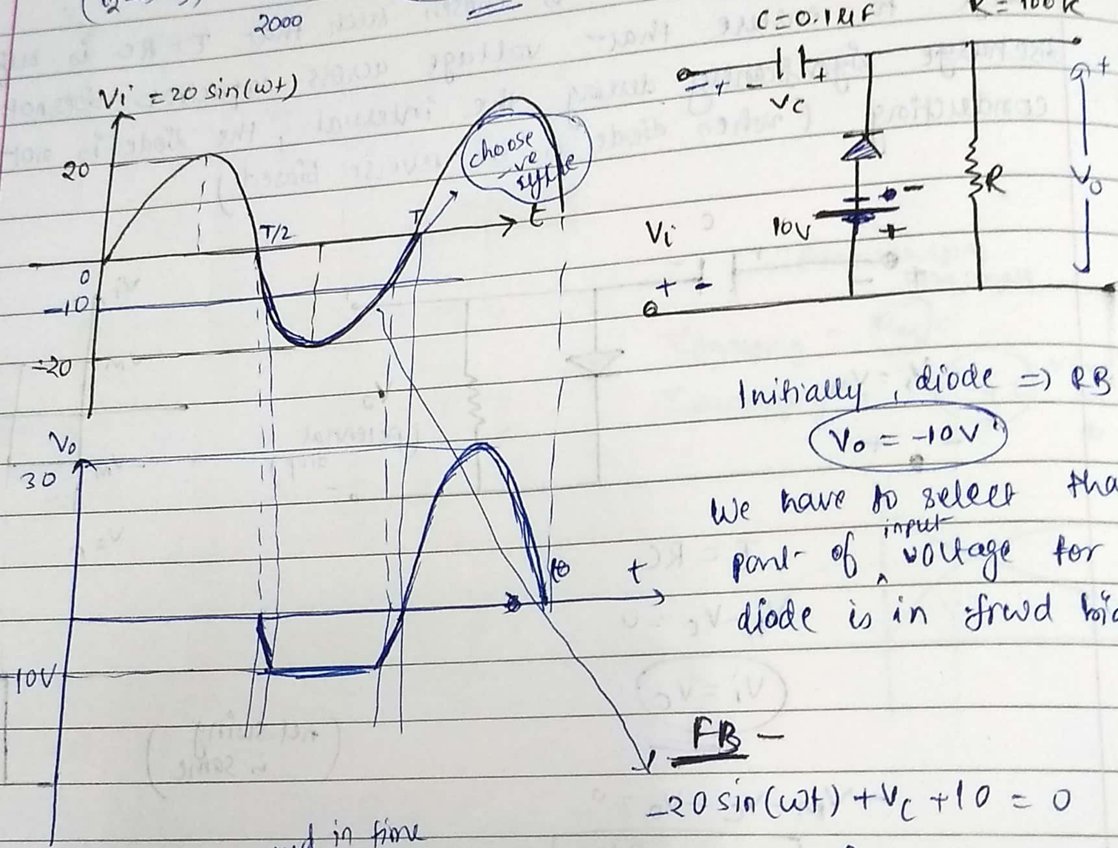
(1)

$T_{charging} = RC = 100\,K \times 1\,\mu F = 10\,ms$.

Q. $T_{discharging} = 5T_{charging} = 50\,ms$.

$(t_2 \to t_3) = \frac{1}{2000} = 0.5\,ms$

Q2



Initially, diode ⇒ RB

$V_o = -10V$

We have to select that part of input voltage for which diode is in frwd biased

FB –

$-20\sin(\omega t) + V_C + 10 = 0$

$V_C = 20\sin(\omega t) - 10$

$\boxed{(V_C)_{max} = 10}$

used in time of discharging

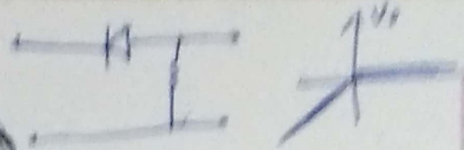
RB –

$20\sin(\omega t) + V_C = V_o$

$V_o = 40\sin(\omega t) - 10$

$(V_o)_{max} = 30$

Stored potential difference of capacitor is used (while discharging)



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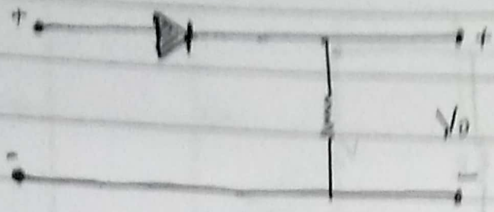
Put

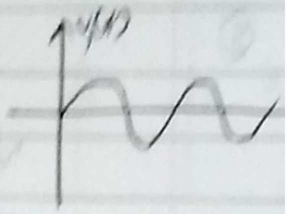
clipper

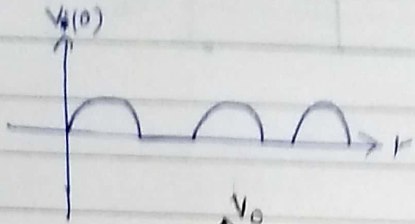
①



Find o/p V_0

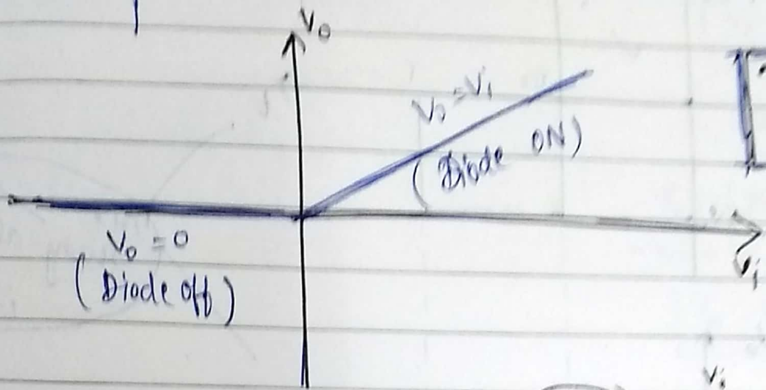
(series clipper)





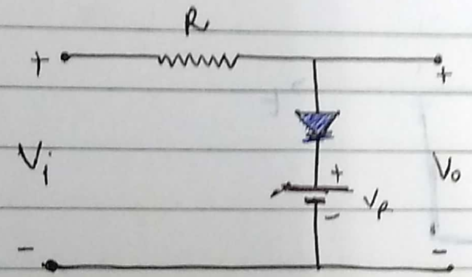
$V_0 = V_i$ (diode on) FB

$V_0 = 0$ RB



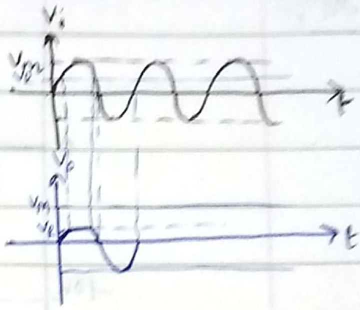
Transfer Characteristics

②

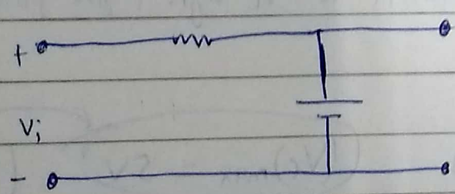


($V_m > V_R$)

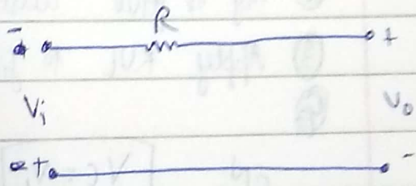
(|| clipper)



In case of clipper problems, input signals should not be distorted.



(ON)



(OFF)