Electronics Unit - 1

Charge densities in a semiconductor

Electrical neutrality :

total +ve charge = total ⊖ve charge.

$$N_D + p = N_A + n \quad \text{—(1)}$$

$N_D \rightarrow$ conc. of donor atoms

$N_A \rightarrow$ conc. of acceptor atoms.

$p \rightarrow$ hole conc.

$n_i \rightarrow$ intrinsic carrier density

$n \rightarrow e^-$ conc.

Case(I): Consider n-type material.

$$N_A = 0$$

$$N_D = n - p. \qquad n >> p$$

$$\boxed{N_D \simeq n} \qquad \boxed{n_n \simeq N_D}$$

↳ e^- conc in n-type material.

$\because \quad np = n_i^2$

$$n_n p_n = n_i^2 \Rightarrow \frac{N_D p_n}{N_D} = \frac{n_i^2}{N_D}.$$

$$** \quad \boxed{p_n = \frac{n_i^2}{N_D}}$$

Case (II): Consider p-type material.

$$N_D = 0$$

$$N_A = p - n \qquad p >> n$$

$$\boxed{p_p \simeq N_A} \qquad n_p p_p = n_i^2$$

$$** \quad \boxed{n_p = \frac{n_i^2}{N_A}}$$

Conductivity of Semiconductors

* v_d is drift velocity of e^-

$$V_d \propto E$$

$$\boxed{V_d = \underbrace{\mu}_{\text{mobility}} E}$$

unit : $\mu = \frac{V_d}{E} = \frac{m/s}{V/m}$

$m^2/V\text{-}s$

* $i = neA\,V_d$ $\qquad J = \frac{i}{A} = ne V_d.$

$$J = ne\mu E$$

$$\boxed{J = \sigma E} \text{ ohm's law}$$

$\sigma \rightarrow$ conductivity.

$\mu \propto \frac{1}{m_{eff}}$ $\qquad (m_{eff})_h >> (m_{eff})_e.$

$$\mu_p << \mu_e.$$

$$J = (n\mu_n + p\mu_p)eE$$

$$\boxed{\sigma = (n\mu_n + p\mu_p)e}$$

Q→ The mobilities of free e^- and holes in a pure germanium are 0.38 and 0.18 $m^2/V\text{-}s$. Find value of intrinsic conductivity. Assume $n_i = 2.5 \times 10^{14}/m^3$ at room temp^r.

In case of intrinsic semiconductor

$$n = p = n_i$$

$$\sigma = (n\mu_n + p\mu_p)e$$

$\sigma = (0.38 + 0.18)\, 2.5 \times 10^{19} \times 1.6 \times 10^{-19}\ (\Omega\text{-m})^{-1}$

$\sigma = 2.24\ (\Omega\text{-m})^{-1}$

Q ⇒ In germanium sample, a donor type impurity is added to the extent of 1 atom per 10^8 germanium atoms. Show that resistivity of the germanium sample drops to 3.7 ohm-cm.

$\mu_n = 3800\ cm^2/V\text{-}sec$ $\quad n_i = 2.5 \times 10^{13}/cm^3$.

$\mu_p = 1800\ cm^2/V\text{-}sec$ $\quad N_{ge} = 4.41 \times 10^{22}/cm^3$.

Sol: resistivity $= \frac{1}{\sigma}$

$\sigma = (n\mu_n + p\mu_p)\, q$.

Donor type impurity ∴ n-type

$N_D = \frac{N_{ge}}{10^8}$

$N_D = 4.41 \times 10^{14}/cm^3$. $\quad n \simeq N_D$.

$n \simeq 4.41 \times 10^{14}/cm^3$

$np = n_i^2 \qquad N_D p = n_i^2$

$p = \frac{n_i^2}{N_D} = 1.4172 \times 10^{12}/cm^3$.

$\sigma = (n\mu_n + p\mu_p)\, q$

$= (4.41 \times 10^{14} \times 3800 + 1.4172 \times 10^{12} \times 1800) \times 1.6 \times 10^{-19}\ \Omega\text{-cm}$

$\sigma = (0.26884)\ (\Omega\text{-cm})^{-1}$

$\rho = \frac{1}{\sigma} = 3.719\ \Omega\text{-cm}$

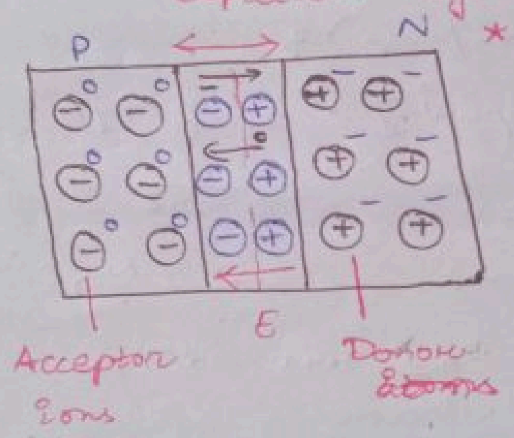
$$J = \underbrace{n\mu_n qE}_{\text{Electron component}} + \underbrace{p\mu_p qE}_{\text{hole component}}$$

of C.D.

PN Junction Diode (No applied bias)

* Minority charge carriers depends on temp^r and does not depend upon external voltage we are applying.

* Diffusion current : Majority charge carriers.
* Immobile ions will surface out because of diffusion
* Depletion region: no mobile charges but only uncovered immobile ions are there.



* Drift current : minority charge carries.
* Under steady state

$$\boxed{\text{Diffusion current} = \text{Drift current}}$$

net current = 0 open ckt PN Junction

Barrier Potential

$$\boxed{V_b = \left(\frac{kT}{e}\right) \ln\left(\frac{N_A N_D}{N_i^2}\right)}$$

V_T = thermal voltage.

k = Boltzmann constant = 1.38066×10^{-23} J/K.

T = absolute temp (K) $\boxed{T = 273 + T'(°C)}$

e = charge of e^- = 1.6×10^{-19} C

* Room temp^n

$T' = 27°C$ $\quad\quad$ $T = 300K$

$V_T = \frac{KT}{e}$ $\quad\quad$ $\boxed{V_T = 0.026 \text{ Volts}}$

* For any temp^n.

$$\boxed{V_T = \frac{KT}{e} = \frac{273+T'}{11600}}$$

Width of depletion

$$\boxed{W_d = \sqrt{\frac{2\varepsilon}{q}\left[\frac{1}{N_A}+\frac{1}{N_D}\right]V_b}}$$

$\varepsilon = \varepsilon_r\varepsilon_0$ = Electrical Permitivity.

For Si $\Rightarrow$ $\varepsilon = 1.04\times10^{-12}$ F/cm

For Ge $\Rightarrow$ $\varepsilon = 1.2448\times10^{-12}$ F/cm.

$q = 1.6\times10^{-19}$C.

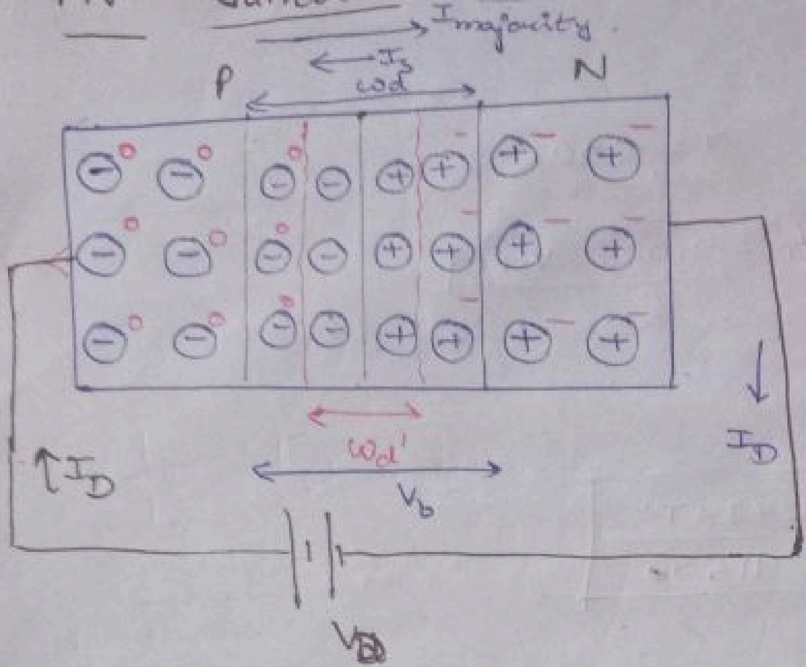
Q $\Rightarrow$ Consider a silicon pn junction at room temperature, doped at $N_A = 10^{16}/cm^3$ in the p-region and $N_D = 10^{17}/cm^3$ in n-region. Intrinsic carrier density is $1.5\times10^{10}/cm^3$ at room temperature. Calculate the width of depletion region.

Sol: $V_b = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.757V$

$V_T \to 0.026$

$W_d = \sqrt{\frac{2\varepsilon}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V_b} = 0.3290\ \mu m$

PN Junction Diode (Forward - bias condition)



$V_D = 0 \quad w_d$

$V_D > 0 \quad w_d'$

$\boxed{V_D \uparrow \quad w_d \downarrow}$

$\boxed{I_D = I_{maj} - I_S}$

I_S → remains same

* Barrier potential $= V_b - V_D$
* $Si \Rightarrow V_b = 0.7V$

  $V_D = 0.7V$

  B.P. $= 0.7 - 0.7 = 0$ → Current rises exponentially.

PN Junction Diode (Reverse - bias condition)

* Because of attraction b/w holes and -ve terminal and e^- and +ve terminal of battery, lead to increase in depletion region.

$$\boxed{(V_b)_{RB} = V_b + V_D}$$

Reverse Bias.

$V_D : \uparrow$	$(V_b)_{RB} \uparrow$
$w_d : \uparrow$	

* $(w_d)_{rb} > (w_d)_{no\ bias} > (w_d)_{Fb}$

* $(V_b)_{rb} > (V_b)_{nob.} > (V_b)_{Fb}$

* $I_{majority} \simeq 0$ $\longrightarrow I_{majority} = 0$ $\longleftarrow I_S$

* $I_D \simeq I_S$.
  ↳ remains same

Semiconductor Diode

* Processes like alloying, diffusion and ion implantation are used to make semiconductor diode.

* Diode current - voltage relation.

$$\left[I_D = I_S \left(e^{\frac{k V_D}{T_K}} - 1 \right) \right]$$

$I_D \rightarrow$ diode current

$I_S \rightarrow$ reverse saturation current.

$V_D \rightarrow$ Voltage across diode.

$T_K \rightarrow$ Temp^r (in K)

$k = \frac{11600}{\eta}$ $\quad$ $\eta \rightarrow$ Ideality factor range b/w 1 & 2.

* $\eta = 1$ For Ge
  $\eta = 2$ For Si] $I_D \rightarrow$ low

* $\eta = 1$] → For both Ge & Si $\Rightarrow I_D \rightarrow$ high

$$V_T = \frac{T_K}{11600} = \frac{T_K}{k\eta} \qquad \frac{k}{T_K} = \frac{1}{V_T \eta}$$

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

Q ⇒ A germanium diode displays a forward voltage of 0.25 V at 10 mA current at room temp^r. Find reverse saturation current.

$I_D = 10\,mA \qquad V_T = 0.026\,V \qquad \eta = 1$

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

$$10 = I_S \left(e^{\frac{0.35}{1 \times 0.026}} - 1\right)$$

$$I_S = 0.667 \times 10^{-6}\,A$$

V - I characteristics of PN Junction Diode

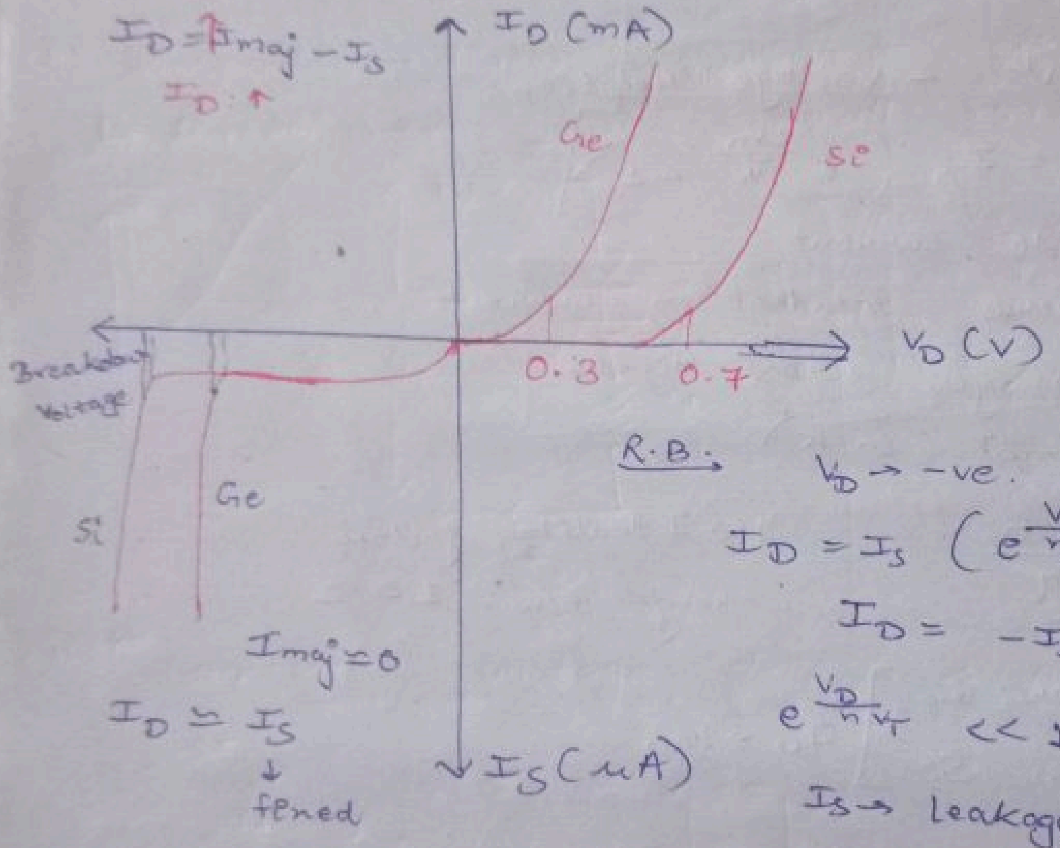
$I_D = I_{maj} - I_S$

$I_D \uparrow$

F.B. = 0

$\boxed{V_D = V_b}$

Current will increase exponentially



R.B. $V_D \to -ve$.

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

$$I_D = -I_S$$

$$e^{\frac{V_D}{\eta V_T}} \ll 1$$

$I_S \to$ Leakage current.

$I_{maj} = 0$

$I_D \simeq I_S$
↓
fixed

* **Peak Inverse Voltage (PIV)**

Max^m R.B. voltage that can be applied across the diode before entering to zener or breakdown region.

Effect of Temp^r on VI characteristics

* In case of forward bias region, the characteristic of Si diode shift to left at a rate of 2.5 mV per °C rise in temp^r.

* For Reverse Bias cond^n, I_S doubles for 10° C rise in temp^r.

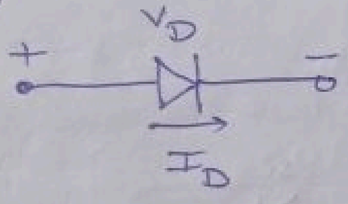
* I_S closer to 10 μA
  For ↑ temp^r application

	Ge	Si	GaAs
I_S	↑	↓	

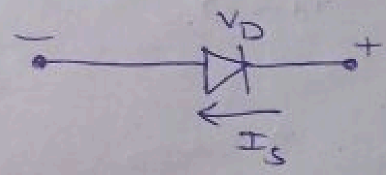
* Breakdown voltage may ↑ or ↓ depending on zener potential.

Ideal Vs Practical diode

Forward bias



Reverse bias

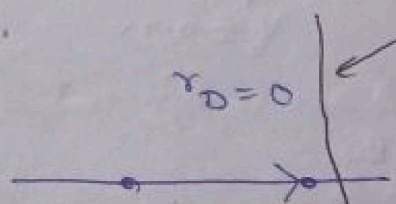


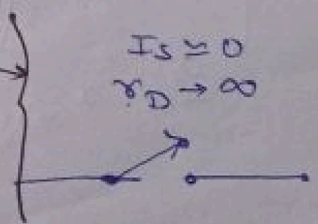
$I_D = I_{maj} - I_S$
$r_D \rightarrow$ very small

Practical diode

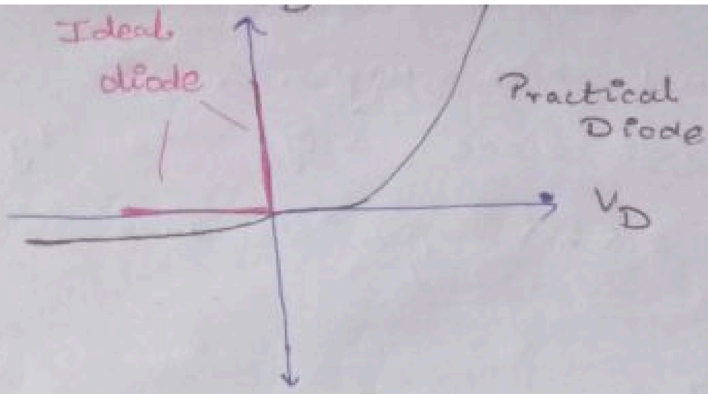
$r_D \rightarrow$ very large

Ideal





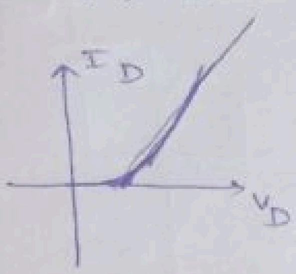
Diode only permits current I to flow in one direction

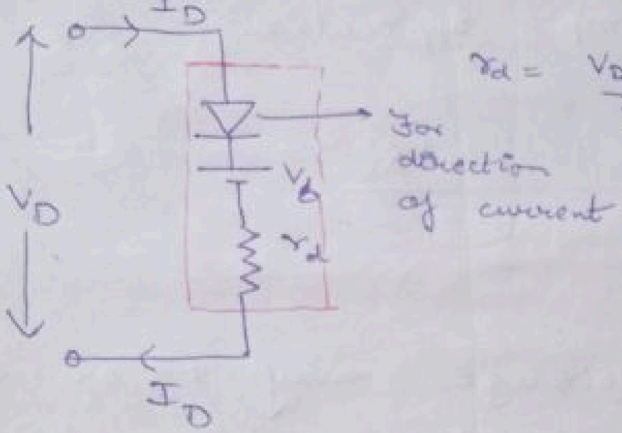


Diode Equivalent Circuit

(i) Piecewise – linear equivalent circuit

↳ linear even with small non-linearity.

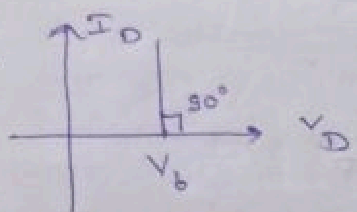


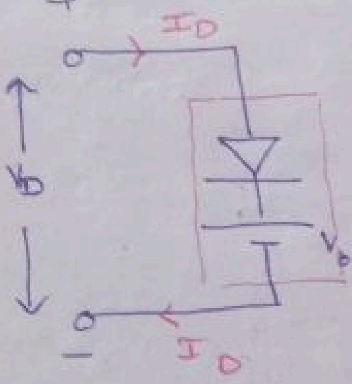


$$r_d = \frac{V_{D_2} - V_{D_1}}{I_{D_2} - I_{D_1}}$$

(ii) ** Constant voltage drop / simplified equivalent ckt.

$r_d = 0$.





F.B.

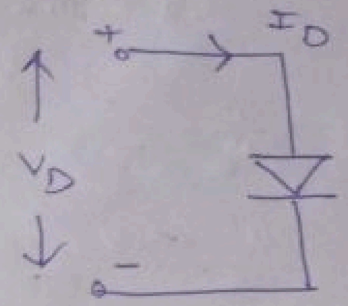
$V_b = 0.7V$

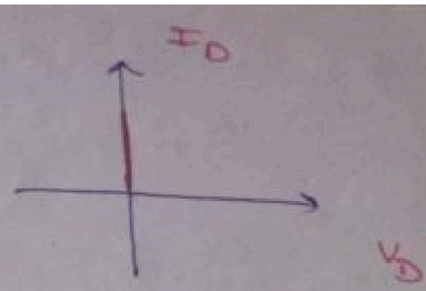
Si

R.B.

(iii) Ideal Eq. ckt.

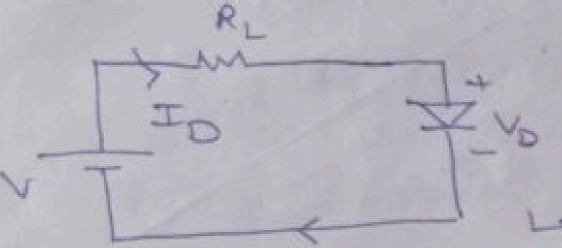
$r_D = 0 \quad V_b = 0$





Load Line Analysis

Non-linear Electronic ckt



Applying KVL:

$V - I_D R_L - V_D = 0.$

$V = I_D R_L + V_D$ — (1)

↳ when $V_D = 0$

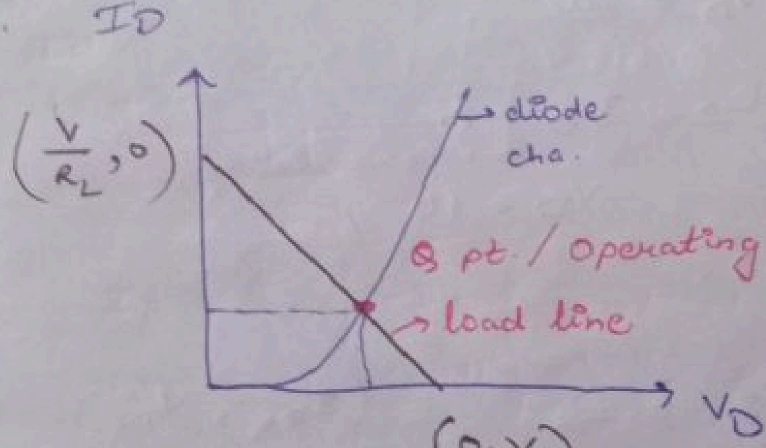
$V = I_D R_L + 0$

$$\left[I_D = \frac{V}{R_L}\right]$$

↳ when $I_D = 0$.

$V = 0 \times R_L + V_D$

$\boxed{V_D = V}$



Q pt ⇒ (I_{DQ}, V_{DQ})

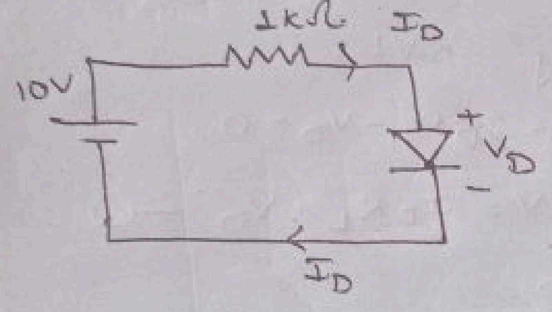
$$V = I_D R_L + V_D$$

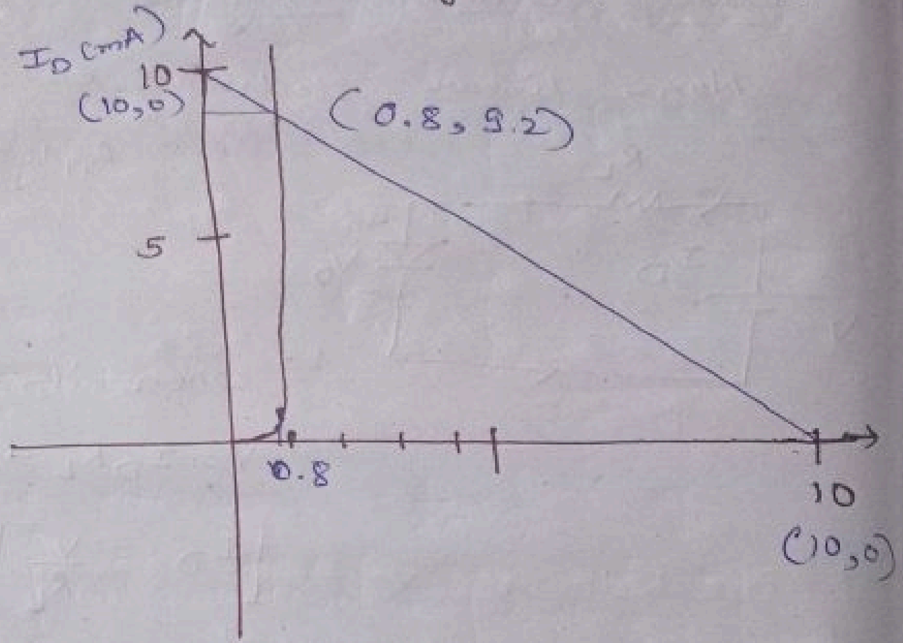
$$I_D = -\frac{V_D}{R_L} + \frac{V}{R_L} \qquad y = mx + c$$

$$c = \frac{V}{R_L} \qquad slope = -\frac{1}{R_L}.$$

* By varying R_L, slope will also vary (Q vary)

Q ⇒ Determine Q - pt and V_R (voltage drop across resistor).





$$-10 + I_D \times 1 \times 10^3 + V_D = 0$$

$$10^3 I_D + V_D = 10$$

↳ $V_D = 0$

$I_D = 0.01$

$= 10\ mA$

↳ $I_D = 0$

$V_D = 10$

$$Q\ pt \equiv (0.8, 9.2) \equiv (I_{DQ}, V_{DQ})$$

$$V_R = I_D R_L = 9.2 \times 10^{-3} \times 10^3$$

$$V_R = 9.2$$

① DC or static Resistance of diode

* Operating pt. remains same (I_{DQ}, V_{DQ}).

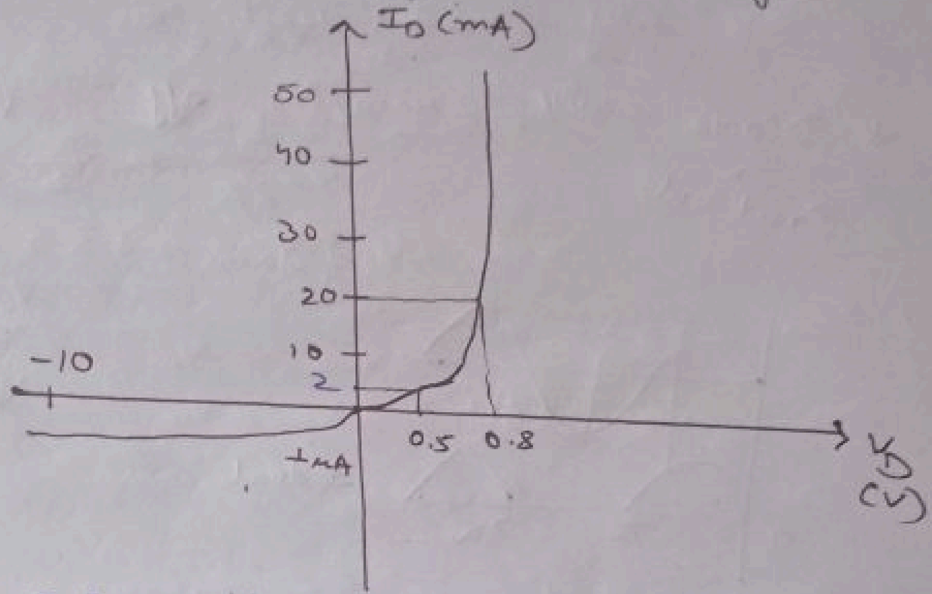
$$R_D = \frac{V_{DQ}}{I_{DQ}}$$

Q ⇒ Determine the dc resistance levels for the diode at

(a) $I_D = 2mA$

(b) $I_D = 20mA$

(c) $V_D = -10V$



(a) $R_D = \frac{V_D}{I_D} = \frac{0.8}{20 \times 10^{-3}} \frac{V}{A} = 40\,\Omega$.

same

② Diode Resistance Levels (AC Resistance)

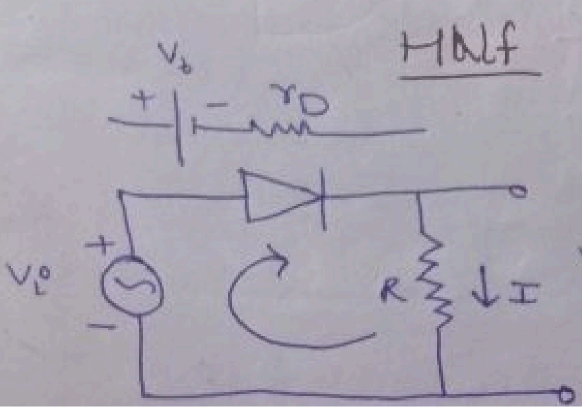
$\eta = 1 \quad V_T = 26mV$

$$\boxed{r_d = \frac{26mV}{I_D}}$$

Introduction to Diode Rectifier Circuit

Rectification → correction of errors / mixture.

Half Wave Rectifier



$$+V_i - V_b - Ir_D - IR = 0$$

$$I = \frac{V_i - V_b}{r_D + R}$$

$$V_o = IR = \left(\frac{V_i - V_b}{r_D + R}\right) \times R$$

$r_D << R$

$$\boxed{V_o = V_i - V_b}$$

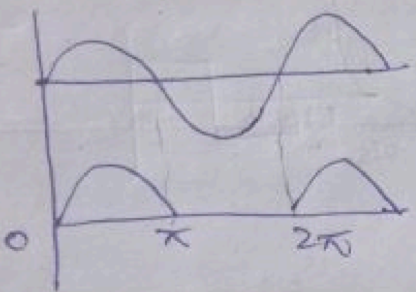
In reverse bias,

Diode → open ckt.

$$\boxed{V_o = 0}$$

* Diode will remain off for $V_b > V_i$.
Practical

V_b ↓ 0.7 for silicon



Ideal

$V_o = V_m \sin\omega t \quad 0 \le \omega t < \pi$

$V_o = 0 \quad \pi \le \omega t \le 2\pi$

$$V_{av} = \frac{\int_0^{2\pi} V_o \, d(\omega t)}{2\pi - 0}$$

$$V_{av} = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin\omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \, d(\omega t)\right]$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{V_m}{2\pi}\left[-\cos\pi - (-\cos 0)\right]$$

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

V_m → Peak voltage.

Average load current,

$$I_{av} = \frac{V_{av}}{R} = \frac{V_m/\pi}{R}$$

$$\boxed{I_{av} = \frac{I_m}{\pi}}$$

RMS load current,

$$\sqrt{\text{mean}(Sq(I))}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I^2 \, d(\omega t)}$$

$I = I_m \sin \omega t \qquad 0 \le \omega t \le \pi$

$I = 0 \qquad \pi \le \omega t \le 2\pi$

$$= \left[\frac{1}{2\pi}\left[\int_0^{\pi} I_m^2 \sin^2 \omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \, d(\omega t)\right]\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi \times 2}\int_0^{\pi} (1 - \cos 2\omega t) \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{4\pi} \times \pi\right]^{1/2}$$

$$\boxed{I_{rms} = I_m/2}$$

RMS load voltage

$$V_{rms} = I_{rms} R = \frac{I_m}{2} R.$$

$$= \frac{V_m}{2R} \times R$$

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

<u>Form Factor</u> : It is defined as the ratio of rms load voltage and average load voltage.

* rms value

5V rms ac = 5 V dc.

rms value < peak value

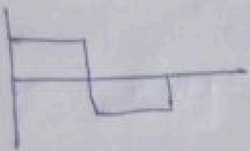
$$F.F = \frac{V_{rms}}{V_{avg}} \qquad F.F \geq 1 \quad rms \geq av$$

For half wave rectifier.

$$F.F = \frac{V_m/2}{V_m/\pi} = \frac{\pi}{2} = 1.57$$

$$\boxed{V_{rms} = 1.57 \times V_{av}}$$

Ex →



$V_{rms} = V_m$

$V_{av} = V_m$

$$F.F. = \frac{V_m}{V_m} = 1$$

<u>Ripple Factor</u> : It measures the % of ac component in the rectified output.

* Ideal value of ripple factor should be zero.

$\gamma = 0\%$

$$\gamma = \frac{\text{rms value of ac component of O/P}}{\text{av. value of O/P.}}$$

$$\gamma = \sqrt{(F.F)^2 - 1}$$

$$\gamma\% = \sqrt{(FF)^2 - 1} \times 100\%$$

Half wave, $FF = 1.57$

$$\gamma = \sqrt{(1.57)^2 - 1}$$

$$\boxed{\gamma = 1.21}$$

$$\boxed{\gamma\% = 121\%}$$

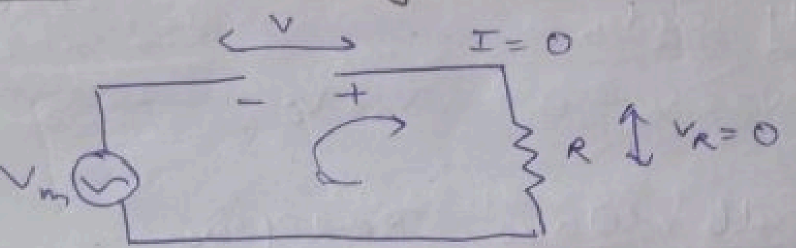
Efficiency : It is defined as ratio of dc power available to the load to input ac power.

$$\eta = \frac{P_{load}}{P_{in}} \times 100\% = \frac{I_{dc}^2 R}{I_{rms}^2 R} \times 100$$

$$= \frac{\left(I_m/\pi\right)^2}{\left(I_m/2\right)^2} \times 100\%$$

$$\eta = 40.56\%$$

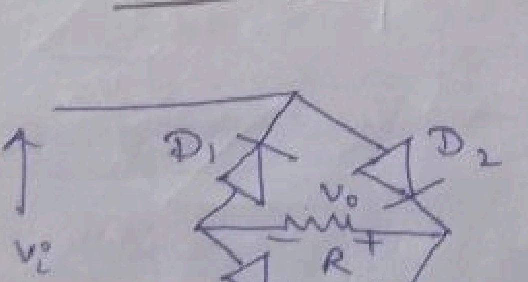
Peak Inverse Voltage

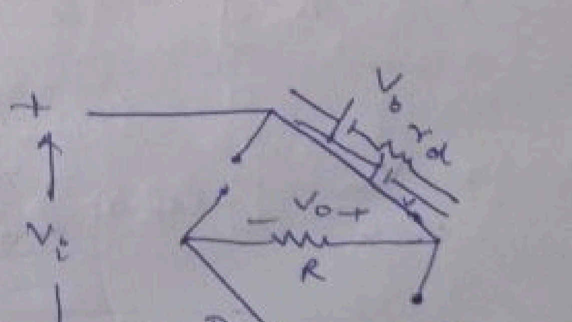


$-V_m + V = 0$ $\qquad$ $V = V_m$.

$\boxed{PIV = V = V_m}$ $\qquad$ $PIV \geq V_m$

Full Wave Bridge Rectifier



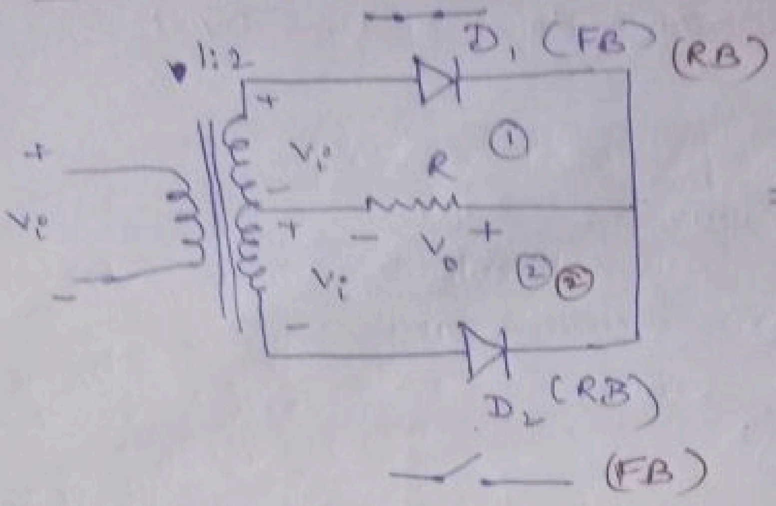


$\boxed{V_o = V_i - 2V_b}$ CVD model $\qquad$ $+V_i - V_o = 0$

$\boxed{V_o = V_i}$ ideal model

$V_o = V_i - 2V_D - 2I r_d$.

Full Wave Center Tapped Rectifier



$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

$$\Rightarrow \frac{1}{2} = \frac{V_P}{V_S}$$

$$V_S = 2V_i$$

1. $+V_i - V_o = 0 \qquad V_o = V_i$

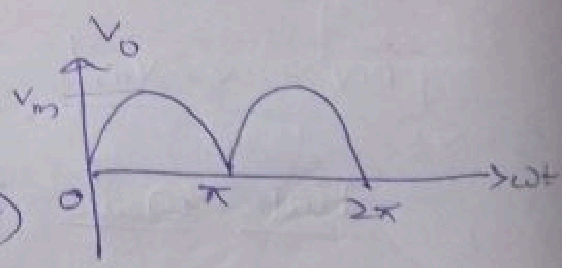
For −ve half cycle,

2. $+V_i - V_o = 0 \qquad V_o = V_i$

Full Wave Rectifier

Average load voltage :

$V_o = V_m \sin\omega t \qquad 0 \le \omega t < \pi$



$$V_{av} = V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \; d(\omega t)$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$\boxed{V_{av} = \frac{2V_m}{\pi}}$$

Average load current

$$I_{av} = \frac{V_{av}}{R} = \frac{2V_m}{\pi R}$$

$$\boxed{I_{av} = \frac{2I_m}{\pi}}$$

$$I_{av} = \frac{1}{\pi}\int_0 I_m \sin\omega t \; d(\omega t)$$

RMS load current

$$I_{rms} = \left[\frac{1}{\pi}\int_0^{\pi} I^2 \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{1}{\pi}\left[\int_0^{\pi} I_m^2 \sin^2\omega t \; d(\omega t)\right]\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi}(1-\cos 2\omega t)\; d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\left(\omega t - \frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]^{1/2}.$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

RMS load ~~on~~ voltage.

$$V_{rms} = I_{rms} \quad R$$

$$\left[V_{rms} = \frac{V_m}{\sqrt{2}}\right]$$

Form Factor

$$F.F. = \frac{V_{rms}}{V_{av}} \text{ or } \frac{I_{rms}}{I_{av}}$$

$$F.F. = \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{\pi}{2\sqrt{2}}$$

$$\boxed{F.F. = 1.11}$$

Ripple Factor :

$$\gamma = \sqrt{(F.F)^2 - 1} = \sqrt{(1.11)^2 - 1}$$

$$\boxed{\gamma\% = 48.1\%}$$ ac component

We have reduced ac component by 73% by using full wave rec. instead of half wave rec.

Efficiency

$$\eta\% = \frac{O/P \text{ dc power}}{i/p \text{ ac power}} \times 100\%$$

$$= \frac{I_{dc}^2 R}{I_{rms}^2 R} \times 100\% = \frac{4 I_m^2/\pi^2}{I_m^2/2} \times 100\%$$

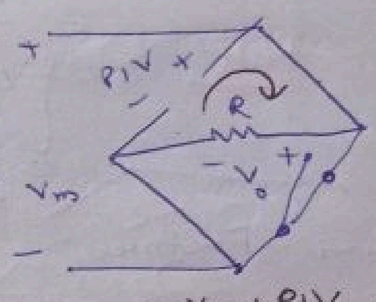
$$\boxed{\eta\% = 81.13\%}$$

Peak Inverse Voltage :

① Full wave bridge rectifier

when ideal diode

$$+V_m - V_o = 0$$



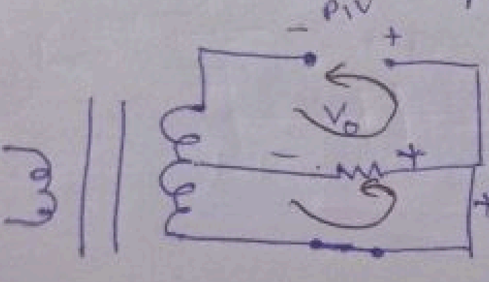
$$\boxed{V_o = V_m}$$

$$\boxed{PIV \geq V_m}$$

$$-V_o + PIV = 0$$

$$\boxed{PIV = V_m}$$

② Centre tapped rectifier



$$+V_m - V_o = 0$$

$$\boxed{V_o = V_m}$$

$$+V_o - PIV + V_m = 0$$

$$\boxed{PIV = 2V_m} \qquad PIV \geq 2V_m$$

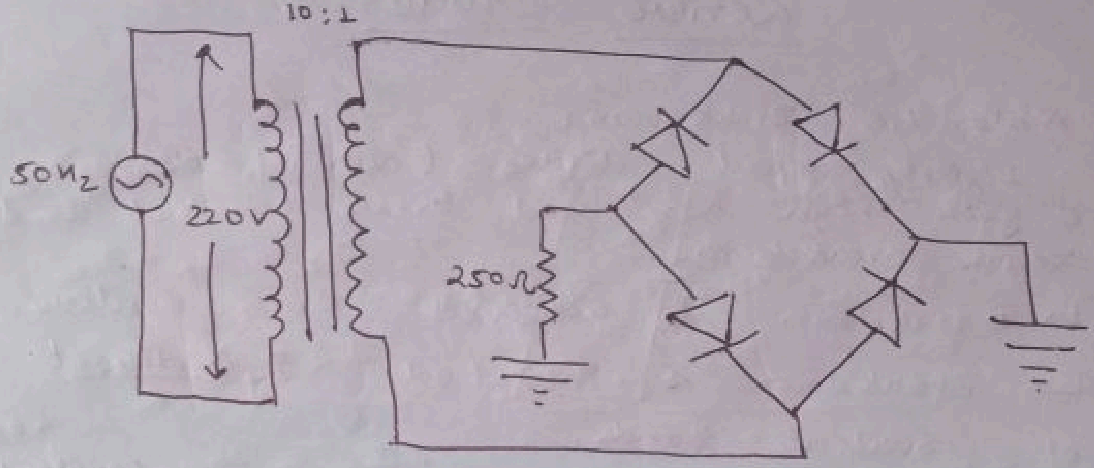
Q ⇒ Determine

(a) dc output voltage.

(b) Rectification efficiency

(c) Peak inverse voltage (PIV)

(d) output frequency.



$$\frac{N_p}{N_s} = \frac{10}{1} = \frac{V_p}{V_s} = \frac{220\,V}{V_s} \qquad V_s = V_i = 22 \text{ Volt}$$

(a) $V_{av} = \frac{2V_m}{\pi}$ $\qquad V_{rms} = \frac{V_m}{\sqrt{2}} = 22V$

$V_m = 22\sqrt{2}\ V = 31.11\ V$

$$V_{av} = \frac{2 \times 31.11}{\pi} = 19.81\ V = V_{dc}$$

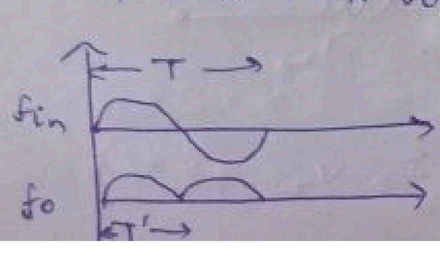
(b) $$\eta = \frac{P_{out}}{P_{in}} = \frac{I_{dc}^2 R}{I_{rms}^2 R} = \frac{V_{dc}^2}{V_{rms}^2} = \left(\frac{19.81}{22}\right)^2 \times 100\%$$

$\eta\% = 81.08\%$

(c) $PIV \geq V_m$

$PIV \geq 31.11$ volt

(d)



$f = \frac{1}{T}$ $\qquad T' = \frac{1}{2}T$

$T = 2T'$

$$f_0 = 2 f_{in} = 2 \times 50 = 100\,Hz$$

$\boxed{f_0 = 2 f_{in}}$ Full wave Rectifier

Zener Diode

* Avalanche Breakdown:
  Ligthly doped diodes (Normal diodes)
  e^- gain high K.E and break covalent bond
* Zener Breakdown:
  ↳ Breakdown is acheived much earlier.
  ↳ Breakdown is intiated by direct "rupture" (tearing of covalent bonds.) of covalent bonds.
  ↳ Happens ~~by~~ due to strong $\vec{E}$, developed by high reverse potential.

* Zener diodes have much more high power dissipation capability than any other normal diode.

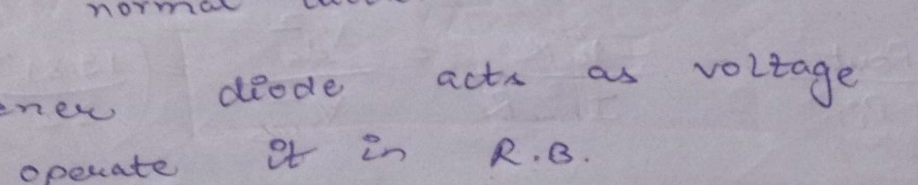
* Properties will not degrade in R.B.

* Zener diode in F.B. region is similar to normal diode.

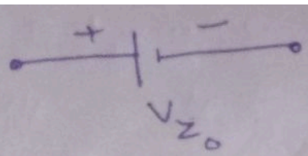
* Zener diode acts as voltage regular when we operate it in R.B.

* $(\text{Depletion layer})_{Zener} < (\text{Depletion layer})_{N.diode}$

↳

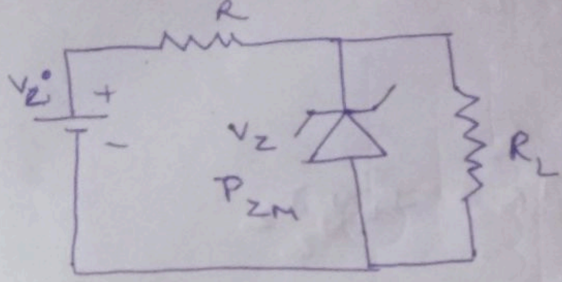


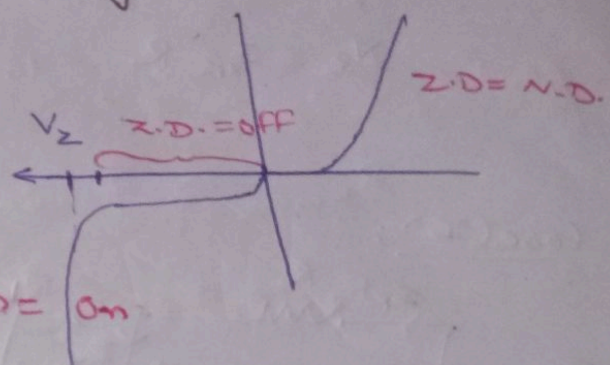
$$V_z = V_{z0} + I_z V_z$$

* $\Rightarrow$ 

$V_Z = V_{Z_0}$

Zener diode as voltage regulator

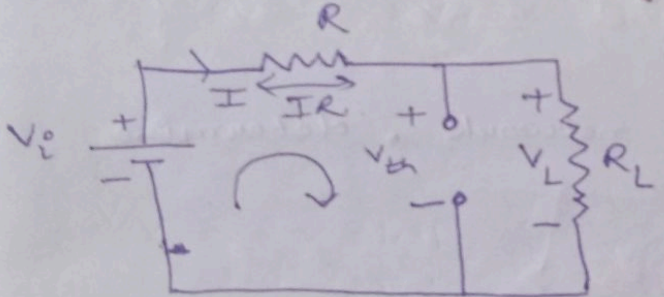




Voltage across the Z.D $\Rightarrow V_Z$

(i) V_i and R_L fixed.
(ii) V_i fixed R_L is variable.
(iii) V_i variable and R_L is fixed.
(iv) V_i and R_L var.

① V_i and R_L are fixed.



$V_i - IR - IR_L = 0.$

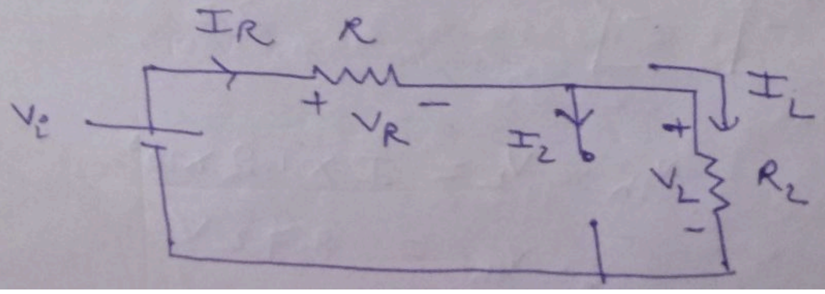
$$I = \frac{V_i}{R+R_L}$$

$$V_{th} = V_L = I R_L$$

$$V_{th} = \frac{V_i R_L}{R+R_L}$$

case (I): when $V_{th} \geq V_Z \rightarrow$ ON.
case (II): $V_{Th} < V_Z \rightarrow$ OFF

Case (II): $V_{th} < V_Z \rightarrow$ OFF



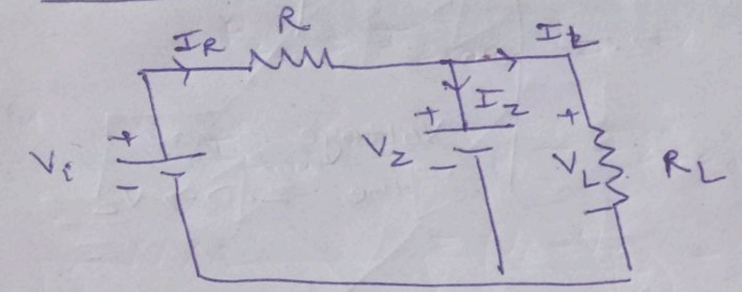
$I_Z = 0$
$P_Z = I_Z V_Z = 0$

$$I_R = I_L + I_Z$$

$$I_R = I_L = \frac{V_i}{R+R_L}$$

$$V_R = I_R R \qquad V_L = I_L R_L$$

Case(I):



$$I_R = I_L + I_Z$$

$$I_Z = I_R - I_L$$

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

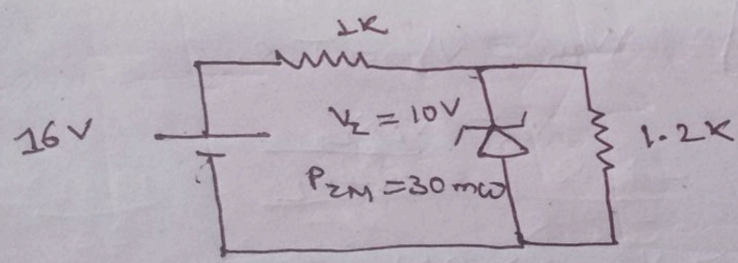
$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$$

* $\boxed{P_Z < P_{Zm}}$

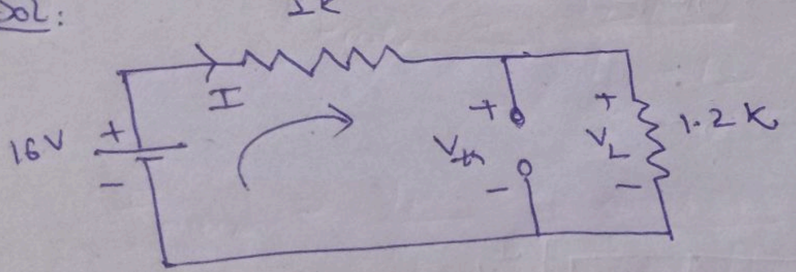
$$P_Z = I_Z V_Z$$

$$P_Z = \left(\frac{V_i - V_Z}{R} - \frac{V_Z}{R_L}\right) \times V_Z.$$

Q ⇒ For the zener diode network, determine V_L, V_R, I_Z and P_Z.



Sol:



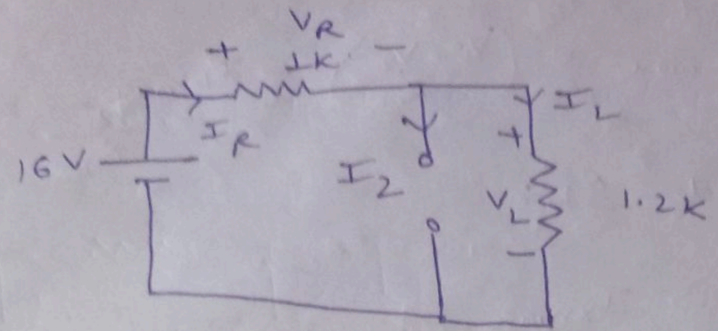
$$16 - I \times 1 - I \times 1.2 = 0$$

$$I = \frac{16}{2.2} = 7.27\,mA$$

$$V_{th} = V_L = I \times 1.2 \times 10^3$$

$$V_L = V_{th} = 8.72V$$

$V_{th} < V_Z$. $\longleftrightarrow$ Diode OFF



$I_Z = 0$. $P_Z = 0$.

$I_R = I_L$.

$V_R = I_R \times 1k$

$$I_R = \frac{16}{1+1.2} = 7.27 \text{ mA}$$

$V_R = 7.27 \text{ mA} \times 1k\Omega$

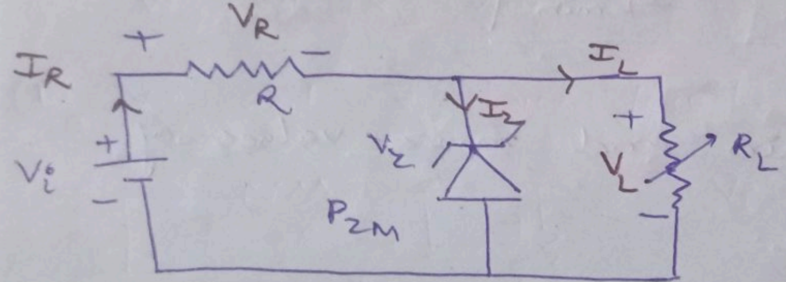
$V_R = 7.27 \text{ V}$

$$V_L = I_L \times 1.2 \text{ k}\Omega$$

$$= 7.27 \text{mA} \times 1.2 \text{k}\Omega$$

$$V_L = 8.64 \text{ V}$$

② V_i is fixed and R_L is variable.



<u>Cond^n</u> <u>for</u> <u>min^m</u> <u>load</u> <u>resistance</u> <u>(R_L)</u>:

Voltage across Z.D. = V_Z .

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

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

*

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

*

$$I_{L\,max} = \frac{V_L}{R_{L\,min}} = \frac{V_Z}{R_{L\,min}}$$

$$I_R = I_{Zmin} + I_{Lmax}$$

$$I_{Zmin} = I_R - I_{Lmax} = \left(\frac{V_i - V_Z}{R}\right) - I_{Lmax}$$

<u>Cond^n</u> <u>for</u> <u>max^m</u> <u>load</u> <u>R_L</u>:

$$R_{Lmax} \Rightarrow I_{Lmin} \Rightarrow I_{Zmax}$$

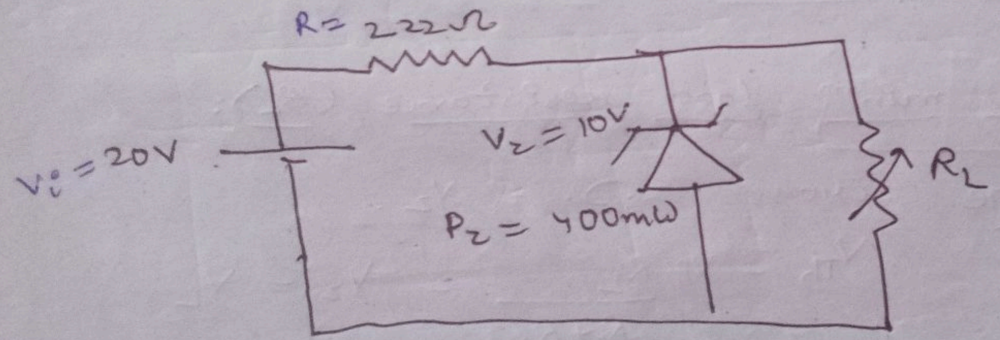
$$P_{Zm} = I_{Zmax} V_Z \Rightarrow I_{Zmax} = \frac{P_{Zm}}{V_Z}$$

$$I_{Lmin} = I_R - I_{Zmax}$$

$$= \left(\frac{V_i - V_Z}{R}\right) - \frac{P_{Zm}}{V_Z}$$

$$\boxed{R_{Lmax} = \frac{V_L}{I_{Lmin}} = \frac{V_Z}{I_{Lmin}}}$$

Q ⇒ Determine the min and max values of load resistance R_L.



<u>Sol</u>: $R_{Lmin} = \frac{V_Z R}{V_i - V_Z} = \frac{10 \times 222}{20 - 10} = 222\Omega$

$$I_{Lmax} = \frac{V_Z}{R_{Lmin}} = \frac{10V}{222\Omega} = 45mA$$

$P_{zm} = 400\,mW$.

$I_{zmax} V_z = 400\,mW$. $\qquad I_{zmax} = 40\,mA$.

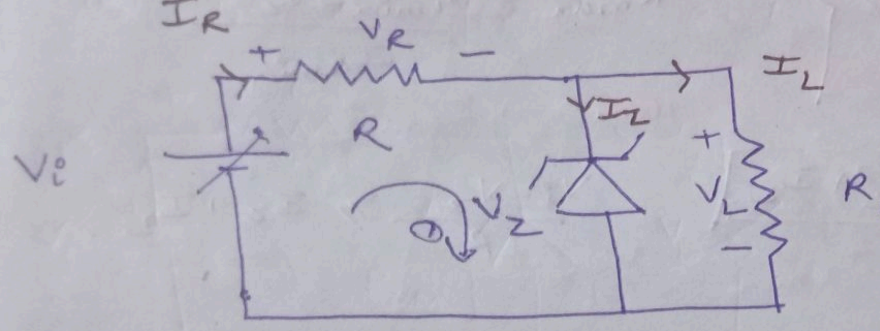
$I_{Lmin} = I_R - I_{zmax}$

$= \left(\frac{V_i - V_z}{R}\right) - 40\,mA \quad = 45\,mA - 40\,mA$

$= 5\,mA$

$R_{Lmax} = \frac{V_z}{5\,mA} = \frac{10}{5\,mA} = 2\,k\Omega$.

③ Variable V_i and fixed R_L.



<u>Condⁿ for min V_i</u>

$V_{Th} \geq V_z \rightarrow$ ON.

$V_{th} < V_z \rightarrow$ OFF

$V_{th} = V_z$

$\frac{V_i \times R_L}{R + R_L} = V_z$

$$\boxed{V_{i\,min} = \frac{V_z (R + R_L)}{R_L}}$$

Cond^n for max V_i →

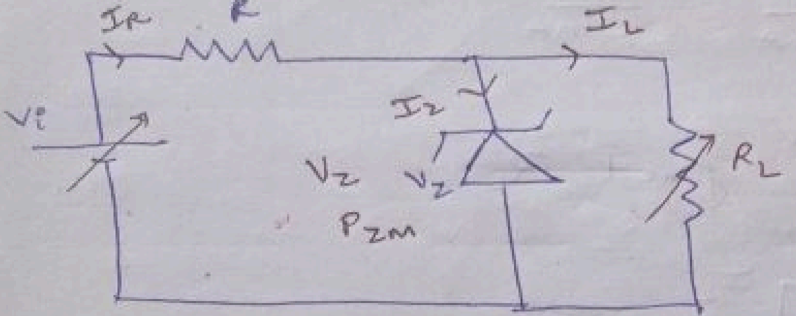
$V_{i\,max}$ is limited by $I_{Z\,max}$.

$I_{R\,max} = I_{Z\,max} + I_L$ $\qquad I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$

①, $V_i - V_{R\,max} - V_Z = 0 \Rightarrow V_{i\,max} = V_{R\,max} + V_Z$

$$\boxed{V_{i\,max} = I_{R\,max} R + V_Z}$$

④ V_i & R_L both are variable.



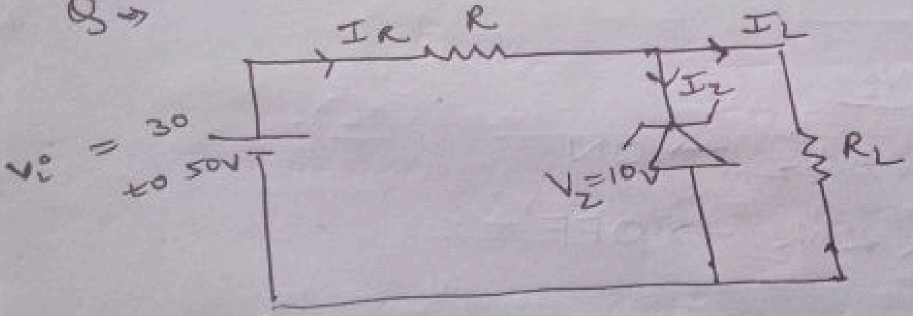
$R_{min} = \frac{V_{i\,max} - V_Z}{I_{R\,max}}$

$R_{max} = \frac{V_{i\,min} - V_Z}{I_{R\,min}}$

$$\boxed{I_R \geq I_Z + I_L}$$

$\frac{V_i - V_Z}{R} \geq I_Z + I_L$

Q →



$I_L = 10\,mA$
$I_Z = 1\,mA$

$V_i = 30$ V $\qquad V_Z = 10V$

$\frac{30-10}{R} \geq 1mA + 10\,mA$

$R \leq \frac{20}{11\,mA}$

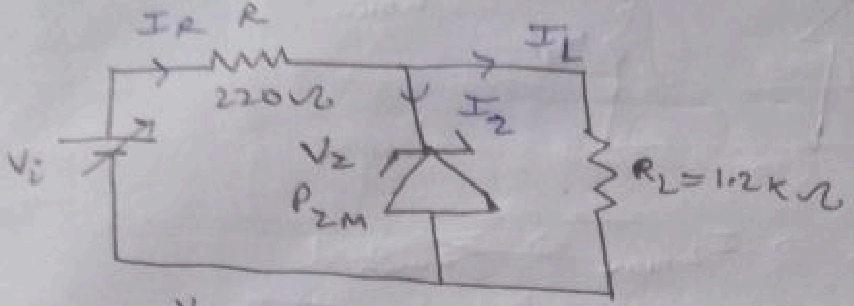
$\underline{R \leq 1.818\ K\Omega}$ Ans

$V_i = 50$ V

$\frac{50-10}{R} \geq 11\,mA$

$R \leq 3.636\ k\Omega$

Q ⇒ Determine the range of input voltage (V_i) that will maintain zener diode in ON state.



$V_Z = 20V$, $I_{Zmax} = 60mA$

$$V_{imin} = \frac{V_Z(R+R_L)}{R_L}$$

$$= \frac{20(220+1200)}{1200}$$

$$V_{imin} = 23.67\ V$$

$$V_{imax} = V_{Rmax} + V_Z$$

$$V_{imax} = I_{Rmax} \times R + V_Z \quad \text{— (1)}$$

$$I_R = I_Z + I_L$$

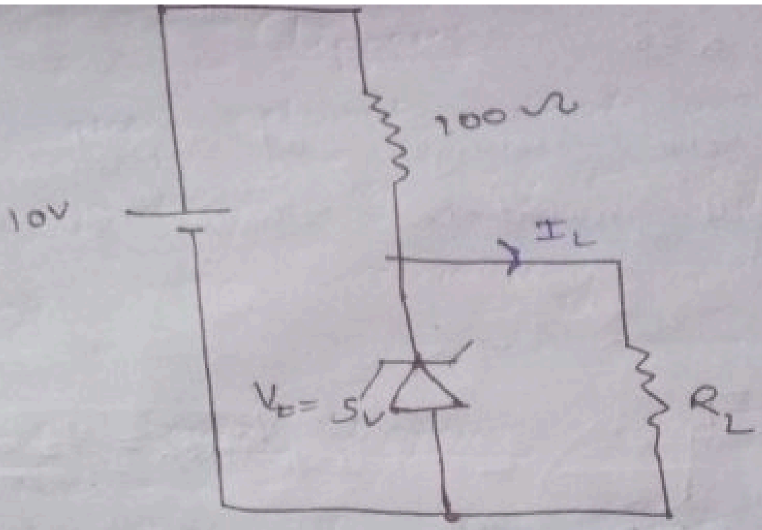
$$I_{Rmax} = I_{Zmax} + I_L = 60mA + \frac{20}{1.2}mA = 76.6mA$$

$$V_{imax} = 76.67\ mA \times 220\Omega + 20V$$

$$= 36.867\ V.$$

Range of V_i = 23.67 V – 36.867 V.

Q ⇒ The knee current of ideal zener diode is 10 mA. To maintain 5V across the load R_L, the minimum value of R_L in Ohm's and the minimum power rating of the zener diode in mW respectively are



$I_{z\,min} = 10\,mA$

$V_z = 5V$.

$V_i = 10V$

$R_{L\,min} = ?$

$R_{L\,min} \Rightarrow I_{L\,max} \Rightarrow I_{z\,min}$

$I_R = I_{z\,min} + I_{L\,max}$

$\frac{V_i - V_z}{R} = 10\,mA + I_{L\,max}$

$\frac{10-5}{100} = 10mA + I_{L\,max}$

$50mA = I_{z\,max} + \cancel{I_L}^{0}$

$I_{L\,max} = 40\,mA$

$R_{L\,min} = \frac{V_L}{I_{L\,max}} = \frac{V_z}{40\,mA} = \frac{5}{40\,mA}$

$R_{L\,min} = 125\,\Omega$

min Power Rating Z.D $= I_{z\,max} \times V_z$

$= 50mA \times 5V$

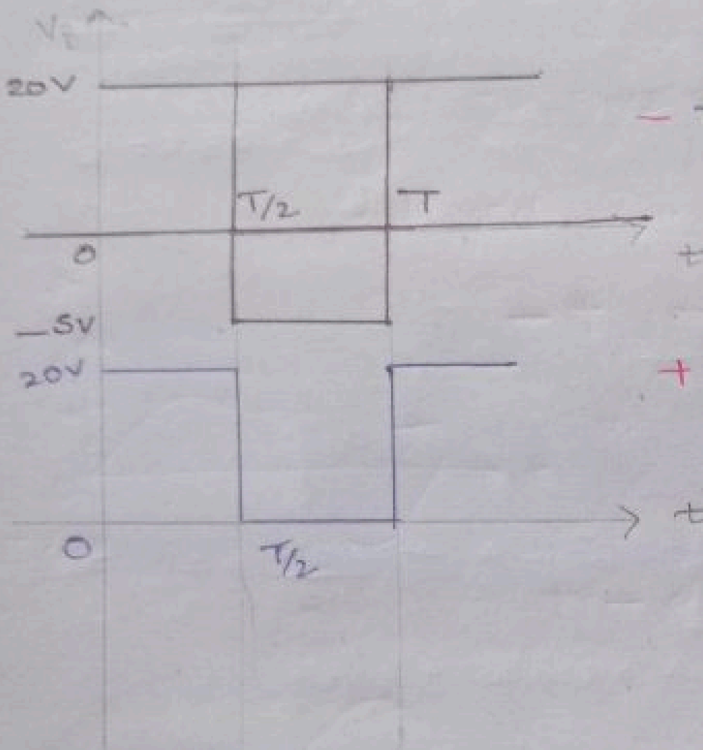
$= 250\,mW$

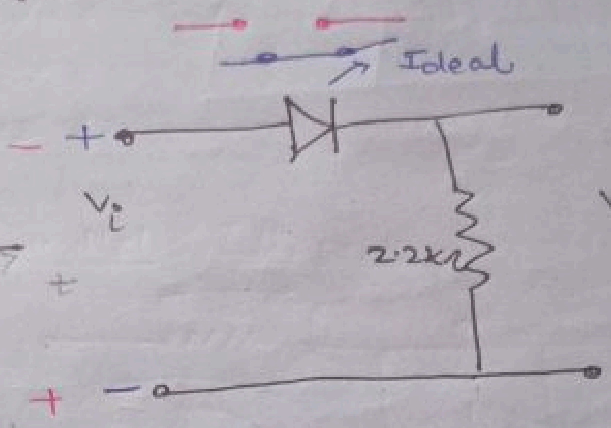
Clippers

Clippers are networks that use diodes to clip a portion of input signal without distorting the remaining part of waveform.

Unbiased Series Clippers

Q → Determine V_o for input shown.

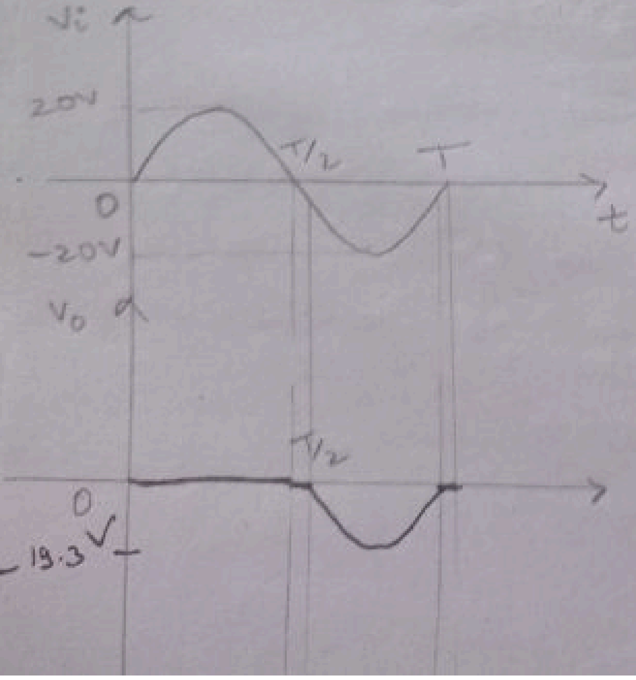


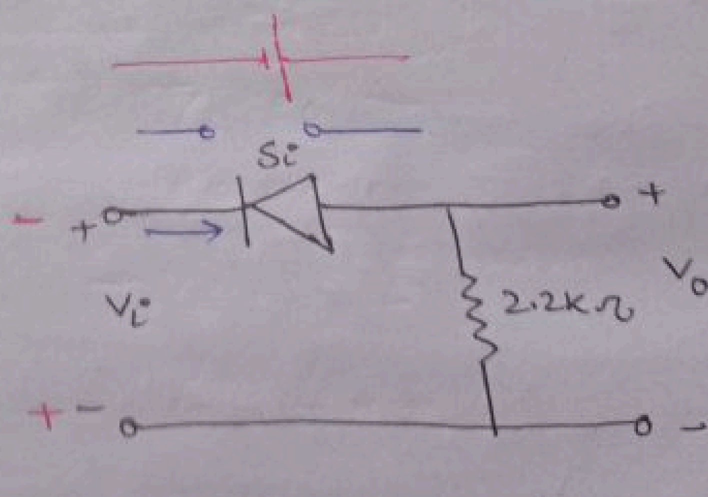


$\boxed{V_o = V_i} = 20V \quad 0 \le t < T/2$

$\boxed{V_o = 0} \quad T/2 \le t \le T$

Q → Determine V_o for input shown





$V_o = 0V$ $+ve$

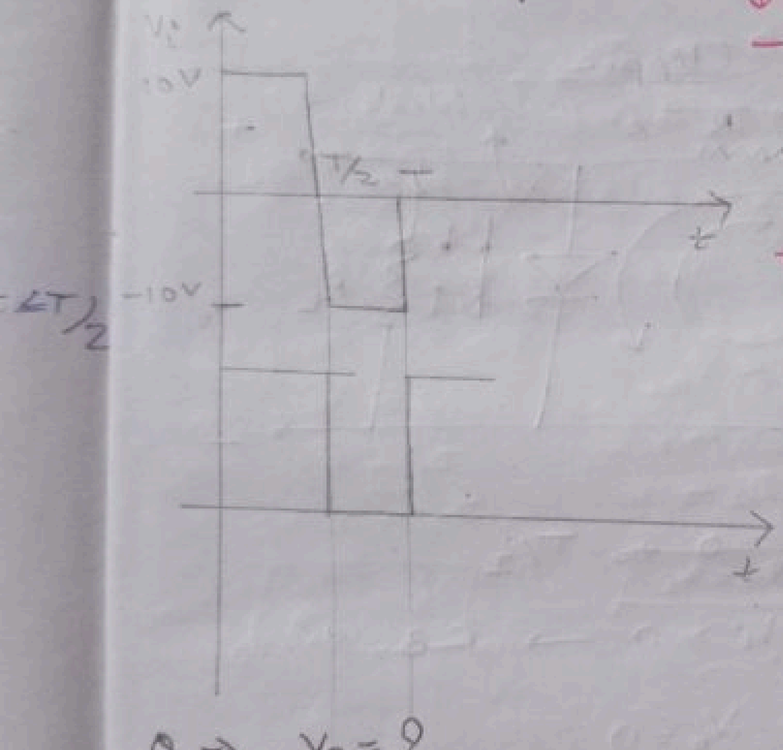
$V_o = 0$ $V_i < V_b$

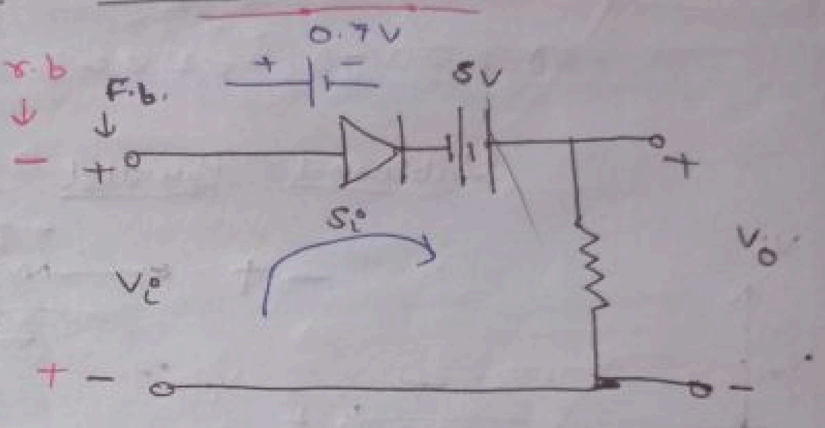
$+V_i + 0.7V - V_o = 0.$

$$\left.\begin{aligned} V_o &= V_i + 0.7V \\ &= -20V + 0.7 = -19.3V \end{aligned}\right\} V_i > V_b.$$

Biased Series Clipper

Q ⇒ $V_o = ?$





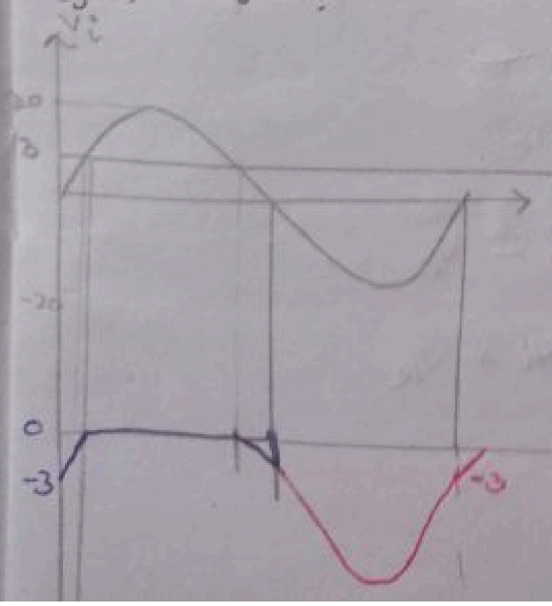
$V_o = V_i - 0.7V + 5V$

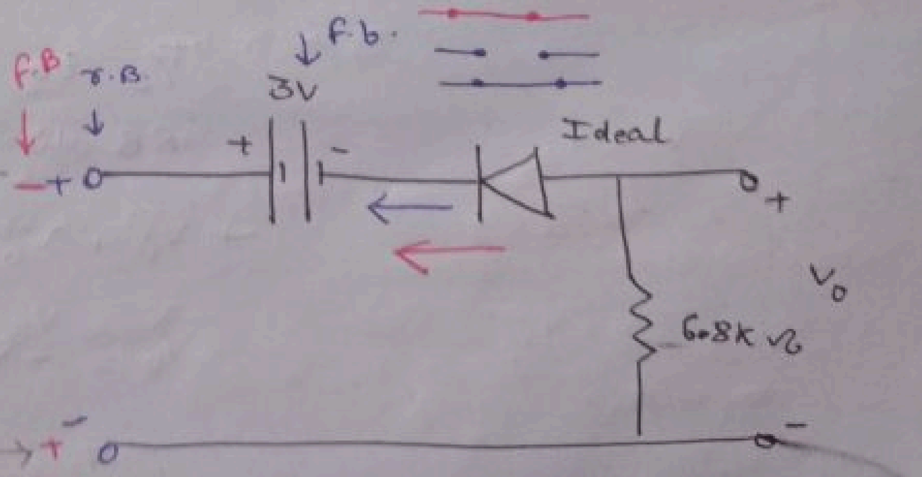
$= 10 - 0.7 + 5$

$V_o = 14.3V$

$V_o = 0$

Q ⇒ $V_o = ?$





① F.B → $V_i < 3V$ $V_o = V_i - 3V$

R.B. → $V_i > 3V$ $V_o = 0V$.

$V_i = 0$ $V_o = -3V$.

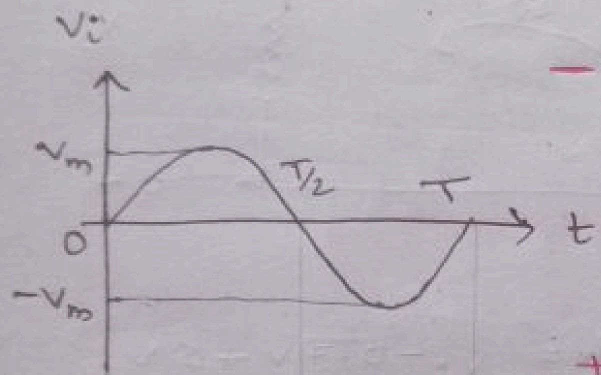
$V_i = 3V$ $V_o = 0V$

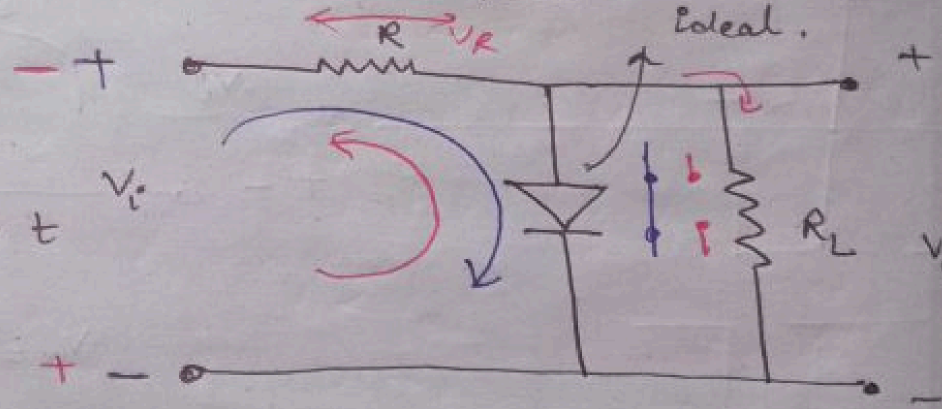
② $V_o = -V_i - 3V$

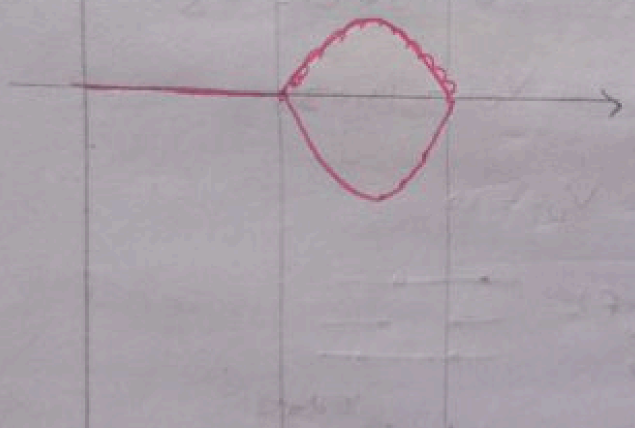
$V_i = 0 \Rightarrow V_o = -3V$

$V_o = -20 - 3 = -23V$.

Unbiased Parallel Clippers







0 to $T/2$.

$V_i \geq 0$. ⟶ F.B. diode.

$V_o = 0$

$T/2$ to T

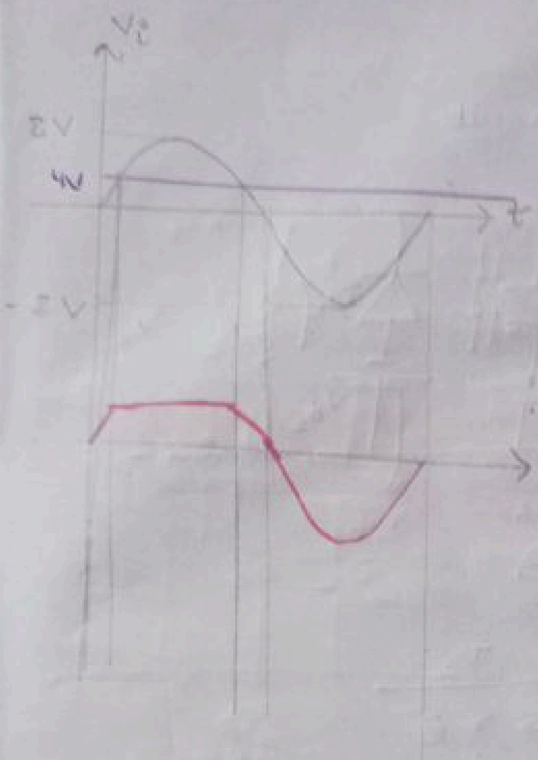
RB diode

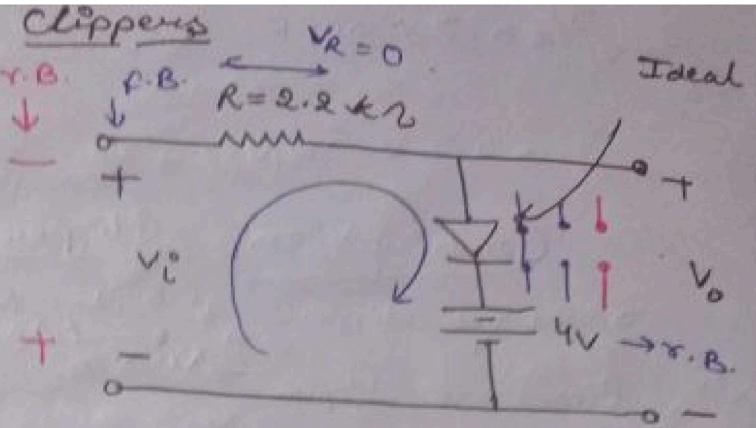
$+V_i + V_o - V_R > 0$

$V_o = -V_i + V_R$

$V_o = -V_i$

Biased Parallel Clippers





0 to T/2.

F.B. → $V_i > 4V$ $\quad V_o = 4V$.

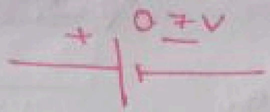
R.B. → $V_i < 4V$ $\quad V_o = V_i$

T/2 to T.

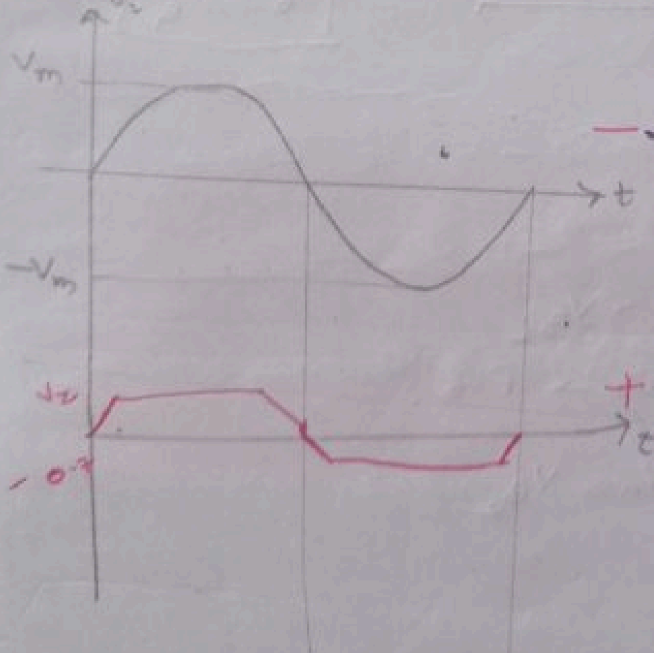
$V_o = V_i$.

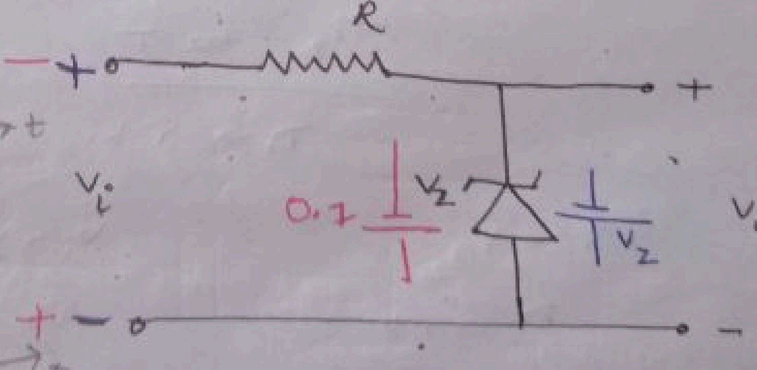
Zener Diode Clipping Circuits

F.B.



R.B. $\quad V_{rb} < V_z$ $\qquad\qquad V_{rb} > V_z$

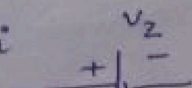




R.B. $V_i < V_z$

①

$V_o = V_i$



② $V_i > V_z$

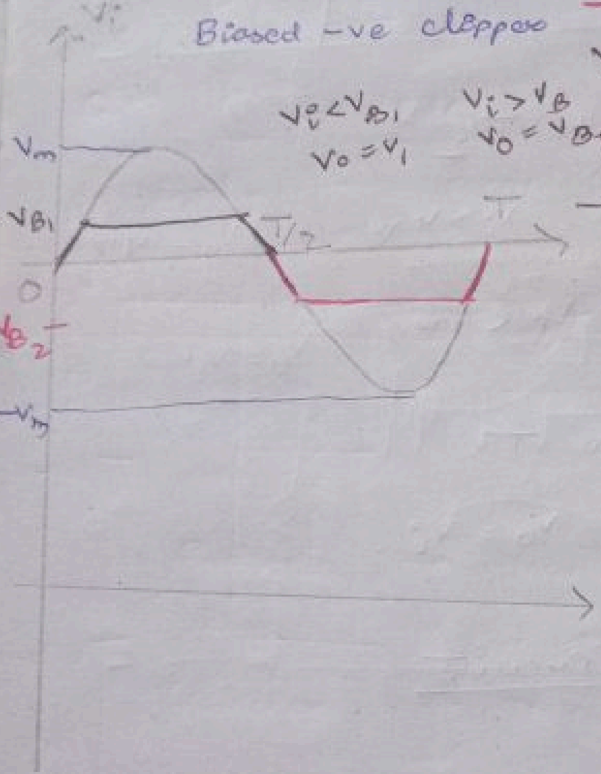
$V_o = V_z$

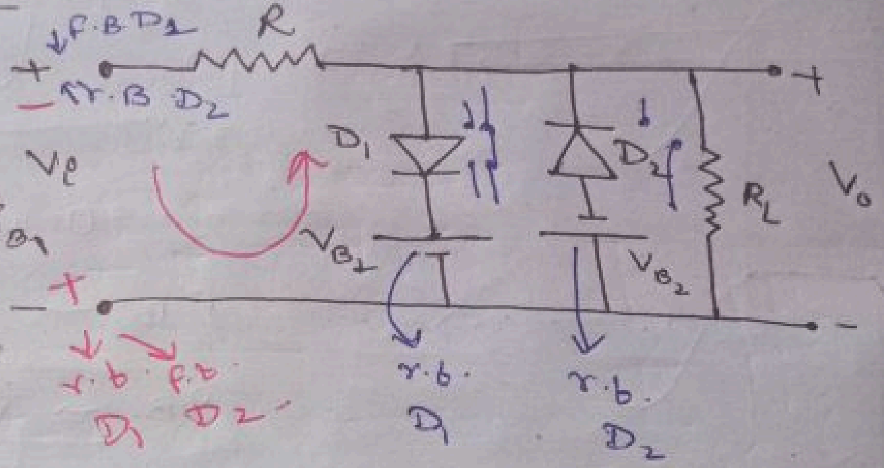
$V_i < 0.7V \rightarrow$ off $\quad V_o = V_i$

$V_i > 0.7V \rightarrow$ ON $\quad V_o = 0.7V$.

Combination Clipper Circuit

Biased +ve clipper
+
Biased -ve clipper





0 to T/2

$D_2 \rightarrow$ r.B. $\quad V_R \simeq 0$.

$R << R_L$

$D_1 \rightarrow$ r.b. by V_{B1}

F.b. by V_i

$V_i < V_{B1}$

$D_1 \rightarrow$ r.b.

$D_2 \rightarrow$ r.b.

$\boxed{V_o = V_i}$

$V_i > V_{B1}$

$D_1 \rightarrow$ F.b.

$D_2 \rightarrow$ r.b.

$\boxed{V_o = V_{B1}}$

T/2 to T

$D_1 \rightarrow$ r.b.

$V_i < V_{B2}$

$D_2 \rightarrow$ r.b.

$V_o = V_i$

$V_i > V_{B2}$

$D_2 \rightarrow$ F.b.

$V_o = V_{B2}$.

Clampers

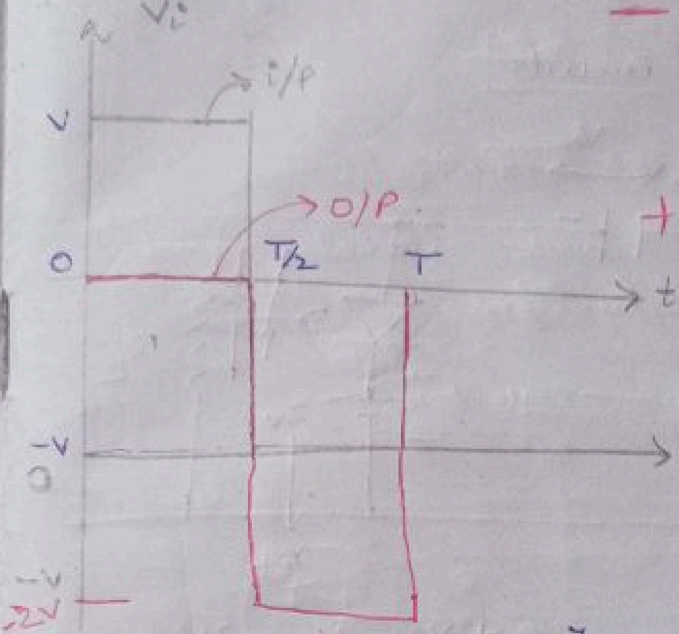
τ (Time constt) = RC.

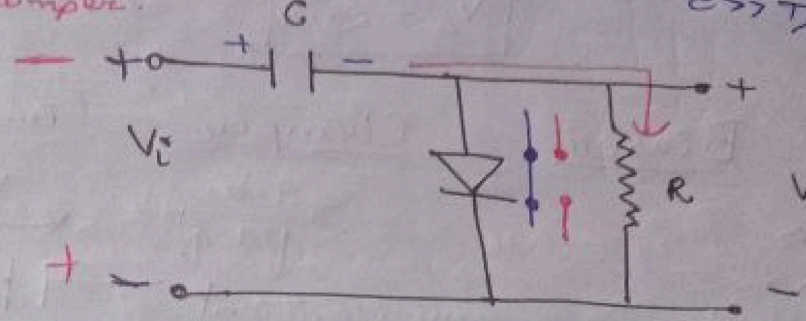
T/2 → T

T/2 → OFF

$\tau >> T/2$

Negative clamper.





0 to T/2 $\quad V_i = +V$.

Forward B. $V_o = 0$

Resistance = 0

$\tau = 0$ $\quad \tau = RC$.

$+V_i - V_c = 0 \Rightarrow V_c = V_i = +V$

From T/2 to T,

$+V_i + V_o + V = 0$.

$V_o = -V_i - V$.

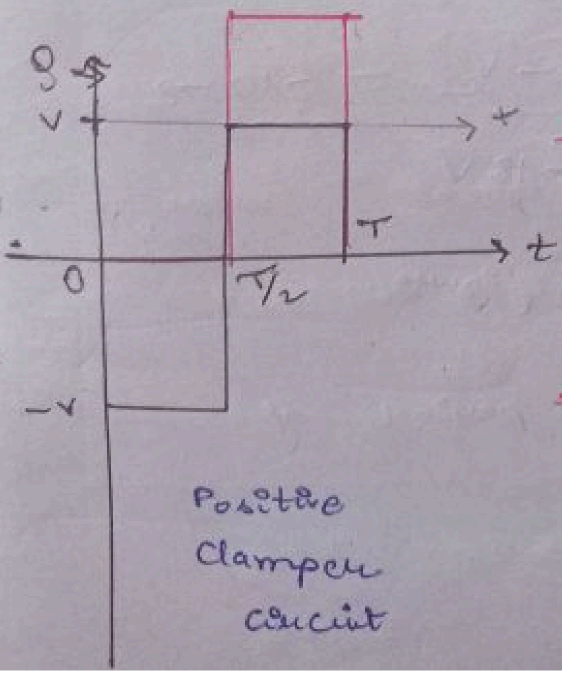
$V_o = -2V$

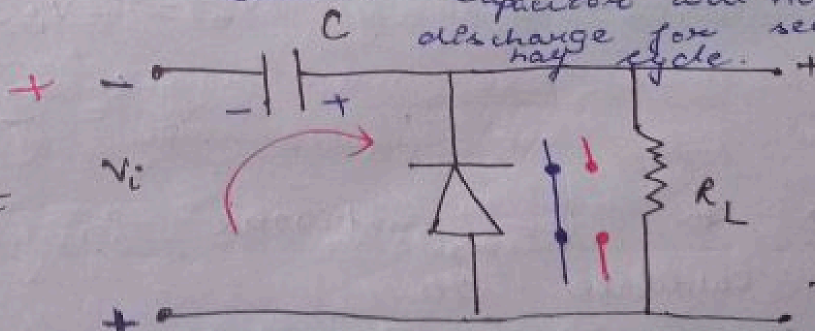
(i) RMS value will remains same.

(ii) peak value changes.

d.t. = 5τ

capacitor will not discharge for second half cycle.





Positive Clamper circuit

0 to T/2

$V_i = -V$ ← V_i (+ve) $\quad V_i$ (-ve) ↓

$V_o = 0$ $\quad V_c = V_i = -(-V)$

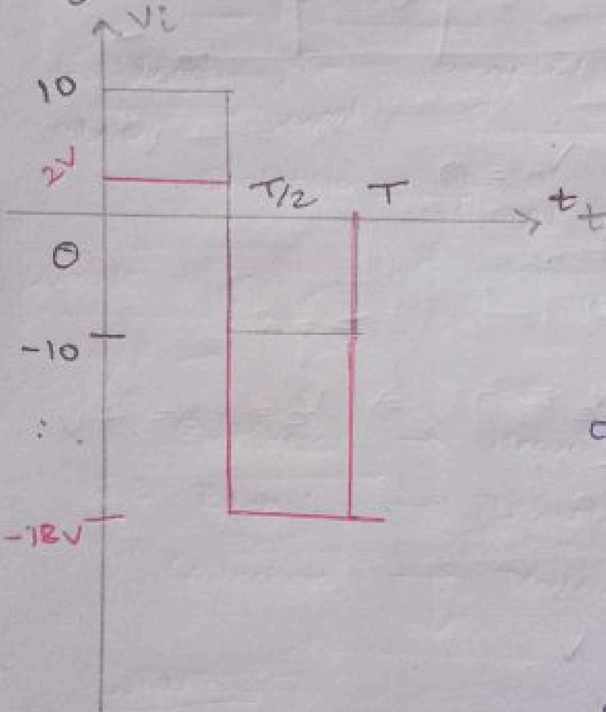
$+V_i - V_o = 0$ $\quad V_c = V$

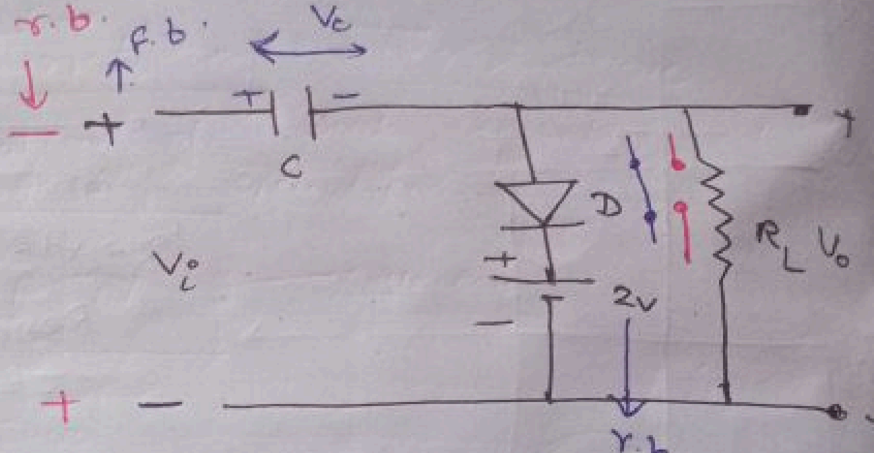
T/2 to T

$$V_o = V_i + V_c$$
$$= V + V$$
$$\boxed{V_o = 2V}$$

Biased Clamper Circuit

Q ⇒





0 to T/2

$V_i = 10V$

$V_o = 2V$

$+V_i - V_c - 2V = 0$

$V_c = V_i - 2V$

$\boxed{V_c = 8V}$

T/2 to T

$V_i = -10V$

$+V_i + V_o + V_c = 0$

$V_o = -V_i - V_c = -10 - 8$

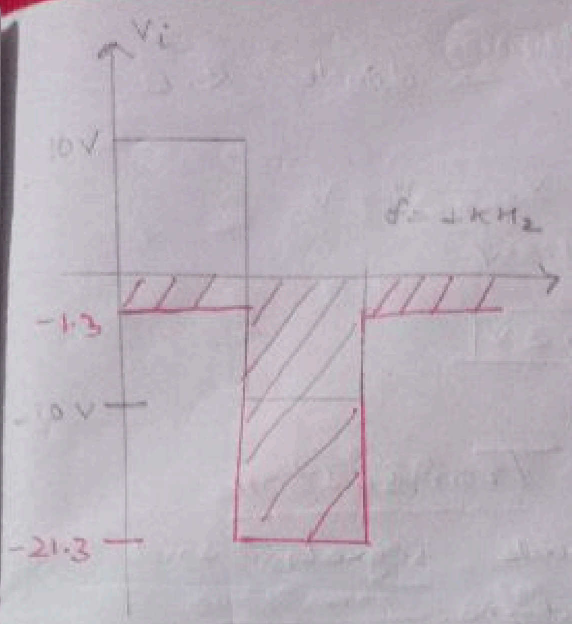
$V_o = -18V$

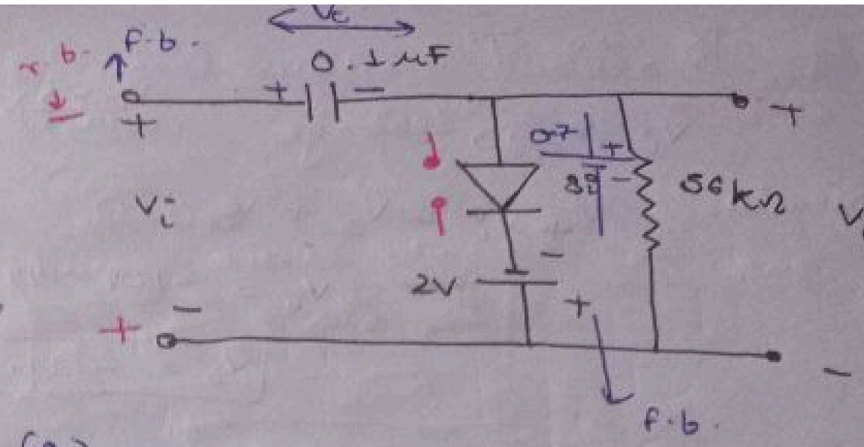
Q ⇒ For the network in figure.

(a) Calculate 5τ.

(b) Compare 5τ to half the period of applied signal.

(c) Sketch V_o.





(a) $\tau = RC$

$= 56 \times 10^{3} \times 0.1 \times 10^{-6}$

$= 5.6 \times 10^{-3}$

$\tau = 5.6 \text{ m sec}$

$5\tau = 28 \text{ m sec}$

(b) $T = \frac{1}{f} = 10^{-3} \text{ s} = 1 \text{ m sec}$

$\frac{T}{2} = 0.5 \text{ m sec}$

$5\tau >> T/2$

$28 \text{ msec} >> 0.5 \text{ m sec}$

$\frac{5\tau}{T/2} = \frac{28}{0.5} = \frac{56}{1}$

$5\tau = 56(T/2)$

(c) $\underline{0 \text{ to } T/2}$

$V_i = 10 \text{ V}$

$-0.7 \text{ V} + 2 \text{ V} + V_o = 0$

$V_o = -1.3 \text{ V}$

$+V_i - V_c - 0.7 \text{ V} + 2 \text{ V} = 0$

$V_c = 10 - 0.7 + 2$

$V_c = 11.3 \text{ V}$

$T/2$ to T

$V_i > 2V \rightarrow$ diode R.B

$V_i = -10$

$+V_i + V_o + V_c = 0 . \quad V_o = -V_i - V_c$

$V_o = -10V - 11.3V$

$$\boxed{V_o = -21.3V}$$