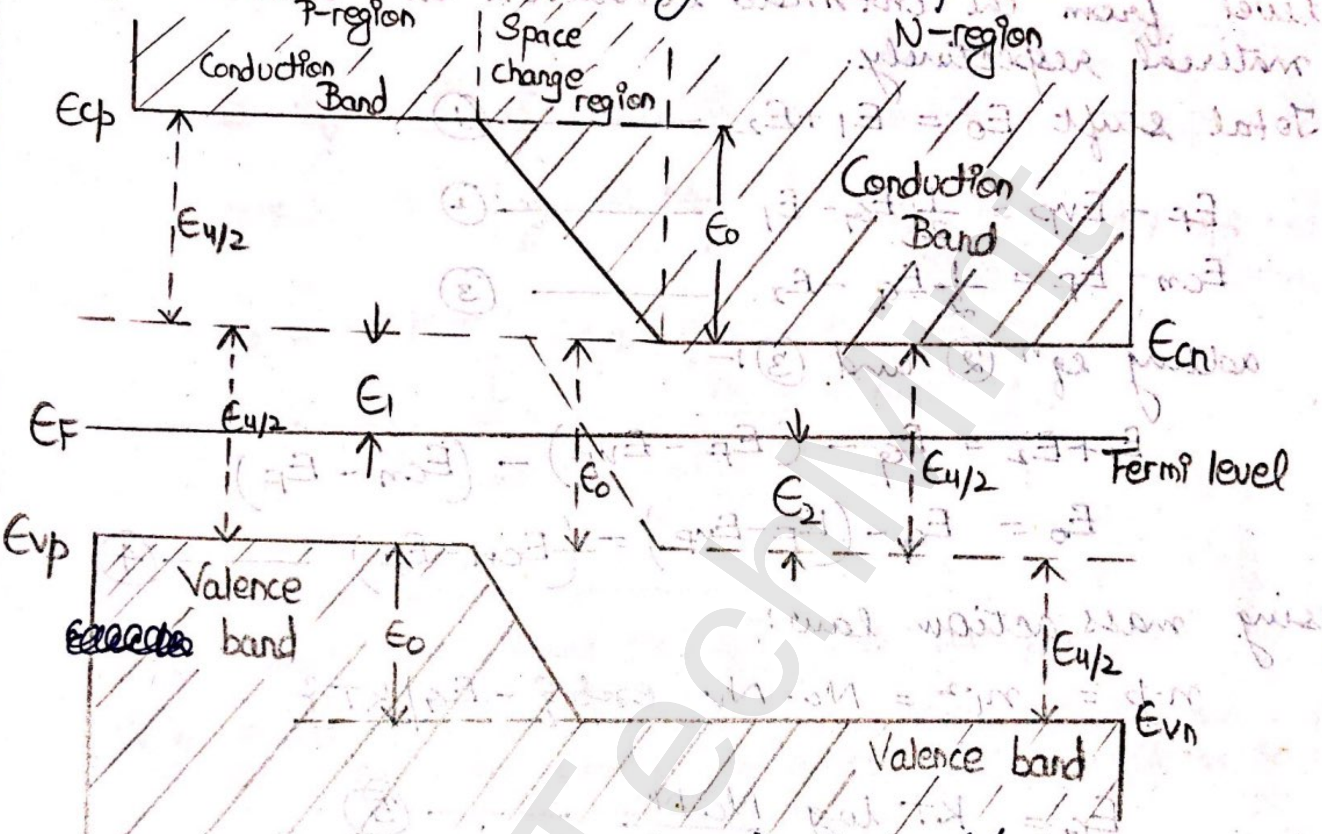
Band Structure of an Open-circuit P-N junction

consider that a p-n junc^n is formed by placing p and N-type materials on an atomic scale. The energy diagrams of both regions undergo relative shift to make the fermi level constant throughout the specimen.



Electrons on one side of the junc^n would have an avg. energy greater than those on the other side and this causes transfer of electron and energy until the fermi level on the two sides equalizes.

Fermi level E_F is closer to the conduction Band edge E_{cn} in N-type material and closer to the Valance band edge E_{vp} in p-type material. So, the conduction band edge ~~cannot be at same level as Ecn edge Similarly~~ ~~Evp~~ E_{cp} in p-material cannot be at same level as E_{cn} and similarly E_{vp} in p-material cannot be at same level as E_{vn} in n-material.

Hence conduction band edge E_{cp} in p-material is higher than E_{cn} in N-material and similarly Valance band edge E_{vp} in p-material is higher than in Valance band edge E_{vn} in N-material.

In fig. E_1 and E_2 represents the shifts the fermi-level from the intrinsic condition in P and N material respectively.

Total shift $E_0 = E_1 + E_2$ ——— ①

$$E_F - E_{vp} = \frac{1}{2} E_G - E_1 \quad \text{———} ②$$

$$E_{cn} - E_F = \frac{1}{2} E_G - E_2 \quad \text{———} ③$$

adding eq^n ② and ③:-

$$E_1 + E_2 = E_G - (E_F - E_{vp}) - (E_{cn} - E_F)$$

$$E_0 = E_G - (E_F - E_{vp}) - (E_{cn} - E_F) \quad \text{———} ④$$

using mass action law:-

$$n \cdot p = n_i^2 = N_c \cdot N_v \exp\{-E_G/KT\}$$

$$E_G = KT \log \frac{N_c N_c}{n_i^2} \quad \text{———} ⑤$$

conc. of electron in N-type

$$n_n = N_c\, e^{-(E_c - E_F)/KT}$$

is rewritten as

$$n_n = N_c\, e^{-(E_{cn} - E_F)/KT}$$

$$E_{cn} - E_F = KT \log \frac{N_c}{n_n}$$

$$= KT \log \frac{N_c}{N_D} \quad (n_n \approx N_D)$$

conc. of holes in p-type,

$$p_p = N_v e^{(E_v - E_F)|KT}$$

or $p_p = N_v e^{(E_{vn} - E_F)|KT}$

$$E_F - E_{vp} = KT \log \frac{N_v}{p_p} = KT \log \frac{N_v}{N_A}$$

——— ⑦ $(p_p \approx N_A)$

put eqⁿ ⑤, ⑥ and ⑦ in eqⁿ ④ :-

$$E_0 = KT \log \frac{N_c N_v}{n_i^2} - KT \log \frac{N_c}{N_D} - KT \log \frac{N_v}{N_A}$$

$$E_0 = KT \left[\log \frac{N_C N_D N_v N_A}{n_i^2 N_D N_A} \right]$$

$$\boxed{E_0 = KT \log \frac{N_D N_A}{n_i^2}}$$

E_0 = potential energy of e⁻ at juncⁿ.

E_0 depends upon equilibrium concentrations and not upon the charge density in transition region.

DIODE CURRENT EQUATION :

consider p-n $junc^n$ diode with switch S open. Let holes and electron densities in p-region are P_p and n_p respectively and in n-region are n_n and p_n respectively

Density of holes in p-region and density of holes in n-region are related by Boltzmann ~~constant~~ relation as:- $p_p = p_n e^{V_B/V_T}$

where V_B = Barrier potential
V_T = Volt equivalent of temp.

$$V_T = \frac{k'T}{e} = \frac{T}{11,600}$$

for open circuit p-n $junc^n$, $V_B = V_0$

$$p_p = p_n e^{V_0/V_T} \text{ ——— } (1)$$

consider that the $junc^n$ is biased in the forward direction by applying a voltage V i.e. by closing switch S. now, the barrier voltage V_B is decreased to V_0 by an amount $V_B = V_0 - V$ with F.B. hole density in p-region remains constant upto depletion region while in n-region just at $junc^n$, increase from p_n to $p_n + \Delta p_n$ due to diffusion of holes across $junc^n$. as the hole diffuse further in n-region they combine with electrons and their density decrease with increase of distance from the $junc^n$.

Hole density is :-

$$p_p = (p_n + \Delta p_n)\, e^{(V_0 - V)/V_T}$$

$$p_p = (p_n + \Delta p_n)\, e^{V_0/V_T} e^{-V/V_T} \text{ ——— } (2)$$

from eq^n ① and ② :-

$$p_n \, e^{V_0/V_T} = (p_n + \Delta p_n) \, e^{V_0/V_T} e^{-V/V_T}$$

$$p_n = (p_n + \Delta p_n) \, e^{-V/V_T}$$

$$p_n e^{V/V_T} = p_n + \Delta p_n$$

$$\Delta p_n = p_n (e^{V/V_T} - 1) \text{ ——— ③}$$

from eq^n ①

$$p_n = p_p e^{-V_0/V_T} \text{ ——— (4)}$$

putting eq^n ④ in eq^n ③ :-

$$\Delta p_n = p_p e^{-V_0/V_T} (e^{V/V_T} - 1) \text{ ——— (5)}$$

Diffusion of holes constitute the hole current

The hole current $I_p \propto \Delta p_n$

$$I_p \propto p_p e^{-V_0/V_T} (e^{V/V_T} - 1)$$

$$\text{or } I_p = I_{sp} (e^{V/V_T} - 1)$$

where I_{sp} = proportionality constant

similarly expression for electron current due to diffusion of electrons from N-region to p-region

$$I_n = I_{sn} (e^{V/V_T} - 1)$$

Total current $I = I_p + I_n$

$$I = I_{sp}(e^{V/V_T} - 1) + I_{sn}(e^{V/V_T} - 1)$$

$$\boxed{I = I_0 (e^{V/V_T} - 1)}$$ Diode current equation

I_0 = Saturation current

In general,

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

η = constant, depends upon the property of material

$\eta = 1$ (for Ge)

$\eta = 2$ (for Si)

for forward bias; $I_f = I_0 e^{V/\eta V_T}$

for reverse bias; $I_R = I_0 \left(e^{-V/\eta V_T} - 1\right)$

Reverse bias voltage is large as compared to V_T

$$e^{-V/\eta V_T} \longrightarrow 0$$

$$\boxed{\therefore\ I_R = -I_0}$$

REVERSE SATURATION CURRENT

Minority carriers consitute a small current called reverse current or reverse saturation current (I_S or I_0) which is extremely temp. dependent.

JUNCTION BREAKDOWN:

The breakdown voltage V_{BR} or junc^n breakdown is defined as the reverse voltage at which p-n junc^n breaks down with sudden rise in reverse current. It depends upon the width of depletion layer (i.e. doping level)

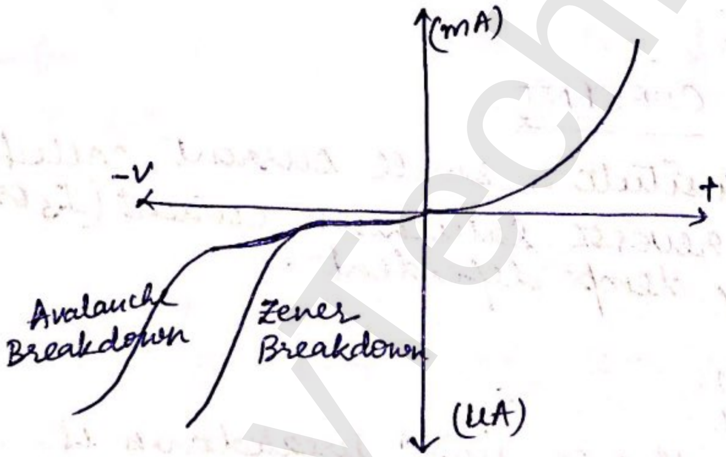
* Two types of junc^n breakdown are :-

1. Zener Breakdown:- It takes place in junc^n's which are heavily doped. When breakdown voltage is applied a very strong electric field appears across narrow depletion layer which breaks the bonds. Now electron-hole pairs are generated. A small further

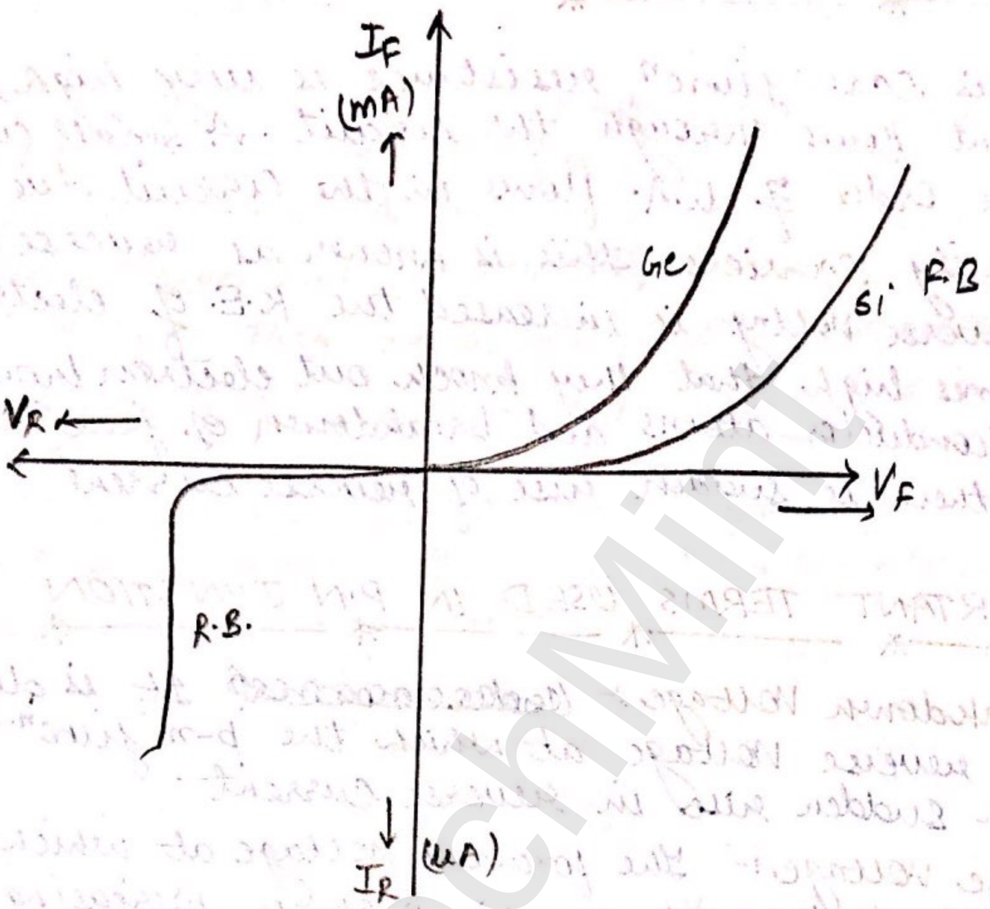
increase in reverse voltage produce large no. of current carriers which suddenly increases the reverse current

2. Avalanche Breakdown

Minority carriers under R.B. ~~gen~~ cond^{n}s flowing through the junc^n accquires the K.E. which increases with increase in Reverse Voltage. At a sufficiently high reverse voltage, K.E of minority carriers becomes so large that they knock out electrons from the covalent bonds of semiconductor material. As a result of collision the libereated electron inturn liberate more electrons and the current becomes very large leading to breakdown of the crystal structure itself This is called avalanche breakdown



V-I CHARACTERISTICS OF P-n jun^n



FORWARD CHARACTERISTICS

With the forward bias to the p-n junc^n very little current called the forward current, flows until the forward voltage exceeds the junction barrier potential (0.3V for Ge and 0.7v for Si). The characteristics follow an exponential law.

As the forward Voltage is increased to the knee of char. barrier potential is reduced to zero, beyond the knee of the char. the potential barrier is completely eliminated forward current increases almost linearly with increase in forward voltage and p-n jun^n starts behaving as a resistor.

If forward Voltage is increased beyond certain values, extremely large current will flow and p-n junc^n may get destroyed ~~to~~ due to overheating

REVERSE CHARACTERISTIC

In this case junc^n resistance is very high, no current flows through the circuit. A small current of the order of μA flows in the circuit due to minority carriers. This is known as reverse current. If reverse voltage is increased the K.E. of electron becomes high that they knock out electron from the semiconductor atoms and breakdown of junc^n occurs and there is sudden rise of reverse current.

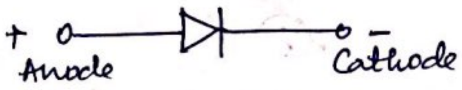
IMPORTANT TERMS USED IN P-N JUNCTION

1. Breakdown Voltage :- It is defined as the reverse voltage at which the p-n junc^n breakdown with sudden rise in reverse current.
2. Knee Voltage :- The forward voltage at which the current through the junc^n starts increasing rapidly is called the knee voltage or the cut in voltage.
3. Max. forward current :- It is the highest instantaneous forward current that a p-n junc^n can conduct without damage to the junc^n. In case the forward current exceeds this rating, the junc^n will get destroyed due to overheating.
4. Peak Inverse Voltage :- Max. reverse voltage that can be applied to the p-n junc^n without damage to the junc^n.

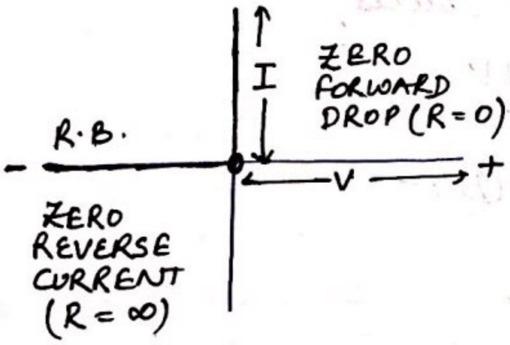
IDEAL DIODE

Ideal diode is a two terminal device that permits only unidirectional conduction. It conducts well in forward direction and poor in the reverse direction.

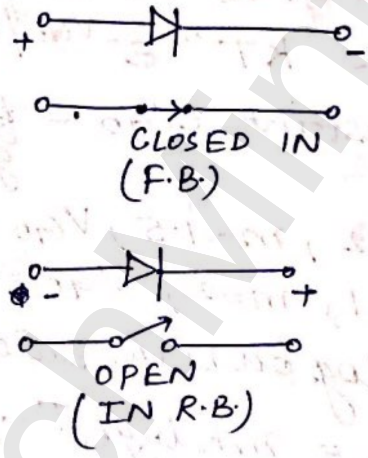
- * Ideal diode is acted as a perfect conductor (with zero resistance or zero voltage drop across it) when F.B.
- * and act as a perfect insulator (with an infinite resistance) or no current through it when R.B.



ⓐ Ideal Diode



(b) Ideal diode char.



(c.) Switching Analogy

EFFECT ON P-N JUNCTION DIODE DUE TO TEMP.

Diode current eqⁿ is

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

At room temp. about 22°C, T = 295°K

$$V_T = 0.025\,V$$

Thus,

$$I = I_0 \left(e^{40V} - 1\right) \text{ (for Ge)}$$

$$I = I_0 \left(e^{20V} - 1\right) \text{ (for Si)}$$

where I_0 is reverse saturation current at room temp. I_0 is temp. dependent. It increases 7% per °C for both Ge & Si.

Ge is more temp. dependent than silicon because its reverse Saturation current is approx 1000 times larger.

* The reverse saturation current I_0 will justabout double in magnitude for every 10°C increase in temp.

* For Ge or Si; $\frac{dV}{dT} = -2.5 mV/°C$

The dependence of I_0 on temp. T

$$I_0 = KT^m e^{-V_{G0}/\eta V_T} \text{ ——— } ①$$

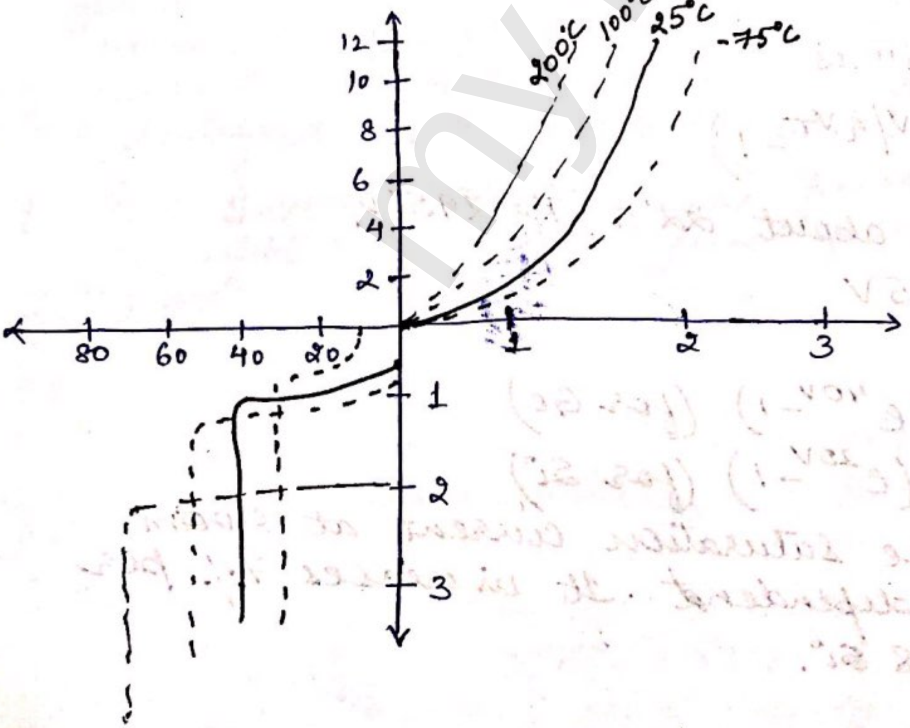
K = constant, eV_{G0} = forbidden energy band gap in Joules

for Si; $\eta = 2$, $m = 1.5$, $V_{G0} = 1.21V$
for Ge; $\eta = 1$, $m = 2$, $V_{G0} = 0.785V$

Taking log on both sides in ①:-

$$\log_e I_0 = mk \log_e T - \frac{V_{G0}}{\eta V_T}$$

$$\frac{d(\log_e I_0)}{dT} = \frac{1}{I_0}\frac{dI_0}{dT} = \frac{m}{T} + \frac{V_{G0}}{\eta T V_T}$$



* for a fixed level of forward voltage, forward current increases with the increase in temp.

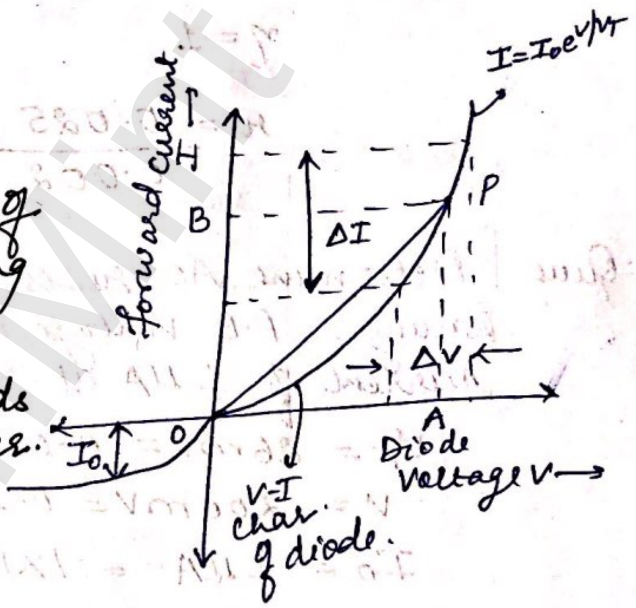
DIODE RESISTANCE

Forward Resistance :- The resistance offered by the diode in the circuit when F.B. is known as forward Resistance. Forward resistance is of two types :-

(i) DC or static Resistance :-

Resistance offered by a diode to direct current is DC resistance. It is ratio of dc voltage across the diode to the direct current flowing through it.

At point P, the static resistance is :- $R = \frac{OA}{OB} = \frac{V}{I}$



* It is simply the reciprocal of slope of line joining operating pt to origion.

* It is not constant but depends on the operating pt on V-I char. of the diode.

(ii) AC or Dynamic Resistance

It is resistance offered by diode to the changing forward current. It is also defined as reciprocal of slope of forward char. of diode.

$$r_{ac} = \frac{dV}{dt} = \frac{\eta V_T}{I_0 e^{V/\eta V_T}} \approx \frac{\eta V_T}{I}$$

from forward char. :-

$$\text{AC or dynamic resistance} = r = \frac{\text{Small change in forward voltage}}{\text{Small change in forward current.}}$$

Ques. Find the dynamic resistance of a p-n junc^n diode at a forward current of 2mA. Assume $\frac{K'T}{e} = 25mV$

Sol^n:- forward current $I = 2mA$
$= 0.002A$

Volt equivalent of temp. $V_T = \frac{K'T}{e} = 25mV = 0.025V$

dynamic resistance $= r = \frac{\eta V_T}{I}$

$\eta = 1$

$r = \frac{0.025}{0.002} = 12.5\Omega$

Ques. Determine AC resistance for a germanium diode having a F.B. voltage of 200mV and reverse saturation current of 1 μA at room temp.

$V_T = 26mV = 0.026V$
$V = 200mV = 0.2V$
$I_0 = 1\mu A = 1\times10^{-6}A$

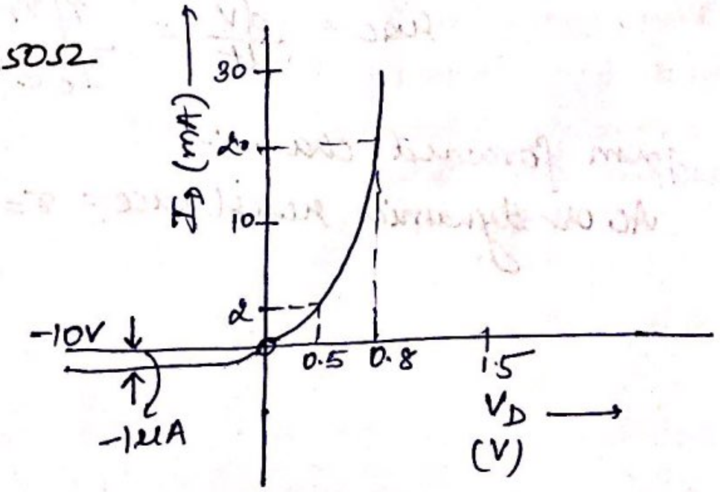
$$r = \frac{\eta V_T}{I_0 e^{V/\eta V_T}} = \frac{0.026}{1\times10^{-6}\times e^{0.2/0.026}} = 11.86\Omega.$$

Ques. Determine DC resistances level for the diode in following fig. at (i) $I_D = 2mA$ (ii) $I_D = 20mA$ (iii) $V_D = -10V$

(i) when $I_D = 2mA$, $V_D = 0.5$
$R_1 = \frac{V_D}{I_D} = \frac{0.5}{2\times10^{-3}} = 250\Omega$

(ii) $I_D = 20mA$, $V_D = 0.8V$
$R_2 = \frac{0.8}{0.02} = 40\Omega$

(iii) $V_D = -10V$
$I_D = -1\mu A$
$R_3 = \frac{-10}{-1\times10^{-6}} = 10M\Omega$



TRANSITION AND DIFFUSION CAPACITANCES

In a p-n semiconductor diode, there are two capacitive effects. Both types of capacitances are present in F.B. and R.B. regions, but one so outweighs the other in each region that we consider the effect of only one in each region. In R.B. region we have the transition or depletion region capacitance (C_T) while in F.B. region we have the diffusion or storage capacitance (C_D).

TRANSITION (OR-SPACE CHARGE) CAPACITANCE

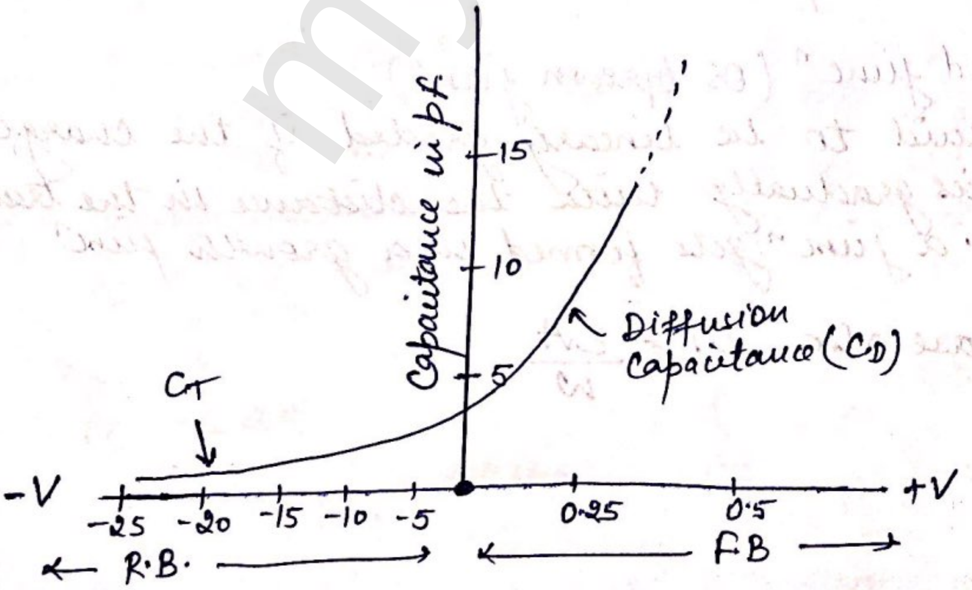
When a p-n junc^n is reverse biased, the depletion region acts like an insulator or dielectric material while the p- & n-type regions on either side have a low resistance and acts as the plates. Thus p-n junc^n may be considered as ||el plate capacitor. The jun^n capacitance is termed as transition or space charge capacitance.

C_T may be defined as:-

$$C_T = \left|\frac{dQ}{dV}\right|$$

where dQ is the increase in charge due to increase in voltage, dV

$$i = \frac{dQ}{dt} = C_T\frac{dV}{dt}.$$



1. Step graded junc^n

A junc^n is said to be step graded if there is an abrupt change from acceptor ion conc. on the p-side to donor ion conc. on the N-side.

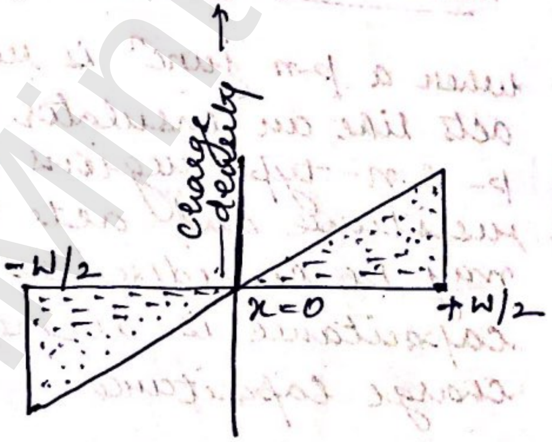
Such a junc^n is formed in alloyed junc^n or fused junc^n diode.

$$C_T = \frac{\varepsilon A}{W}$$

where ε = absolute permitivity of medium
W = width of depletion layer
A = area of cross-section of junc^n

$$W^2 = \left[\frac{2\varepsilon V_B}{e}\right]\left[\frac{1}{N_A}+\frac{1}{N_D}\right]$$

$$W = \sqrt{\frac{2\varepsilon V_B}{eN_D}} \quad \text{when } N_A >> N_D$$



$$\text{So, } C_T = \varepsilon A\sqrt{\frac{eN_D}{2\varepsilon V_B}}$$

$$= A\sqrt{\frac{N_D}{V_B}}\cdot\sqrt{\frac{\sigma\varepsilon}{2}}$$

C_T is inversely proportional to $\sqrt{V_B}$

$V_B = V_0 - V_R$
V_R = reverse bias voltage
V_0 = contact potential.

2. Linearly graded junc^n (or Grown junc^n)

A junc^n is said to be linearly graded if the charge densities varies gradually with the distance in the transition region. Such a junc^n gets formed in a growth junc^n diode.

In this case also, $C_T = \frac{\varepsilon A}{W}$

Diffusion (or Storage) Capacitance

When a p-n junc^n is F.B. holes from p-side enter into n-region and e⁻ from n-side enter into p-side. Carrier diffuse away from junc^n and progressively recombine. Density of carriers is high near the junc^n and decays exponentially with distance. Thus, a charge is stored on both side of the junc^n when F.B. voltage is applied. It is observed that amount of stored charge varies with the applied potential as for a true capacitor. Capacitance due to this change is called diffusion or storage capacitance

$$C_D = \frac{\text{Change in no. of minority carriers}}{\text{Change in voltage across } dV} = \frac{dq}{dV}$$

If τ is the mean lifetime

$$I = \frac{Q}{\tau} \quad \text{or} \quad Q = \tau I$$

$$I = I_0 (e^{V/\eta V_T} - 1)$$

$$Q = \tau I_0 (e^{V/\eta V_T} - 1) = \tau I_0 e^{V/\eta V_T} \quad (\because e^{V/\eta V_T} >> 1)$$

$$\text{So,} \quad C_D = \frac{dQ}{dV}$$

$$= \frac{d(\tau I_0 e^{V/\eta V_T})}{dV} = \frac{\tau I_0}{\eta V_T} e^{V/\eta V_T}$$

$$= \frac{\tau (I + I_0)}{\eta V_T}$$

So, for a F.B greater than few tenths of a volt,

$$\left[\frac{V}{\eta V_T}\right] >> 1; \quad (I >> I_0)$$

$$\text{So,} \quad C_D = \frac{\tau I}{\eta V_T} \qquad C_D \propto I \text{ (forward current)}$$

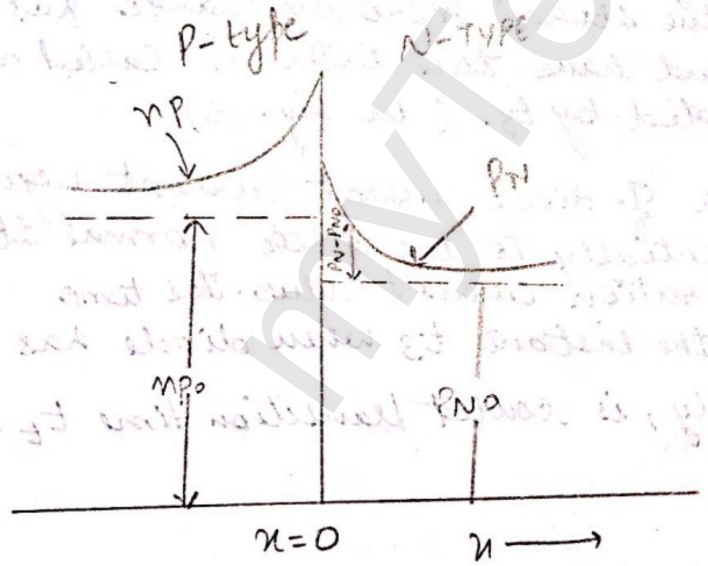
P-N junc^n diode Switching Characterstics

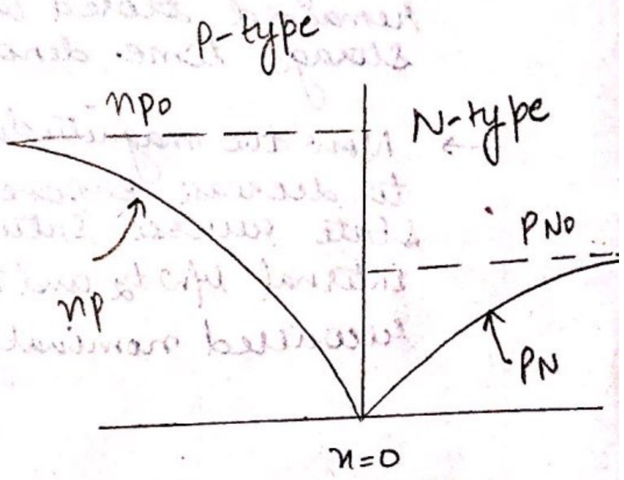
When the applied bias voltage is changed from forward to reverse or vice versa, the current takes definite time to reach a steady state value.

Recovery Time:- When the applied bias voltage to the P-n diode is suddenly reversed in the opp. direction the diode response reaches a steady states after an interval of time, called recovery time

Forward Recovery Time:- When a diode is switched from reverse bias cond^n to F.B. cond^n. It takes time t_{fr}, called forward recovery time

Diode Reverse Recovery Time:- When a diode carrying a current in forward direction is suddenly reversed biased, the diode current will not immediately fall to its steady state because the minority carrier distribution has to change to steady state situation (fig2.) from situation (fig.1). Diode will continue for a time called reverse recovery time (t_{rr}) until excess of minority carrier density ($P_n - P_{no}$) or ($n_p - n_{po}$) has dropped normally to zero.





Switching char:-

Fig. shows the various events occuring in sequence on reverse biasing a conducting diode.

→ Let us consider in time t_1 the i/p voltage v_i is applied to a diode resistance circuit of fig. ⓐ is reverse abruptly. Upto time t_1 the diode is conducting in the forward direction and voltage $v_i = V_F$

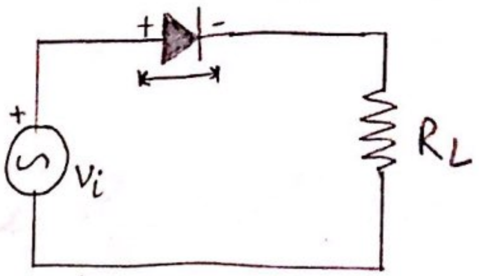
→ For large value of R_L, the voltage drop across R_L is large in comparision to voltage drop across diode and current flowing through R_L is $i \approx \frac{V_F}{R_L} = -I_R$ until $t = t_2$

→ At $t = t_2$, the injected minority carrier density at $x = 0$ has reached the equilibrium state as shown in fig. (c)

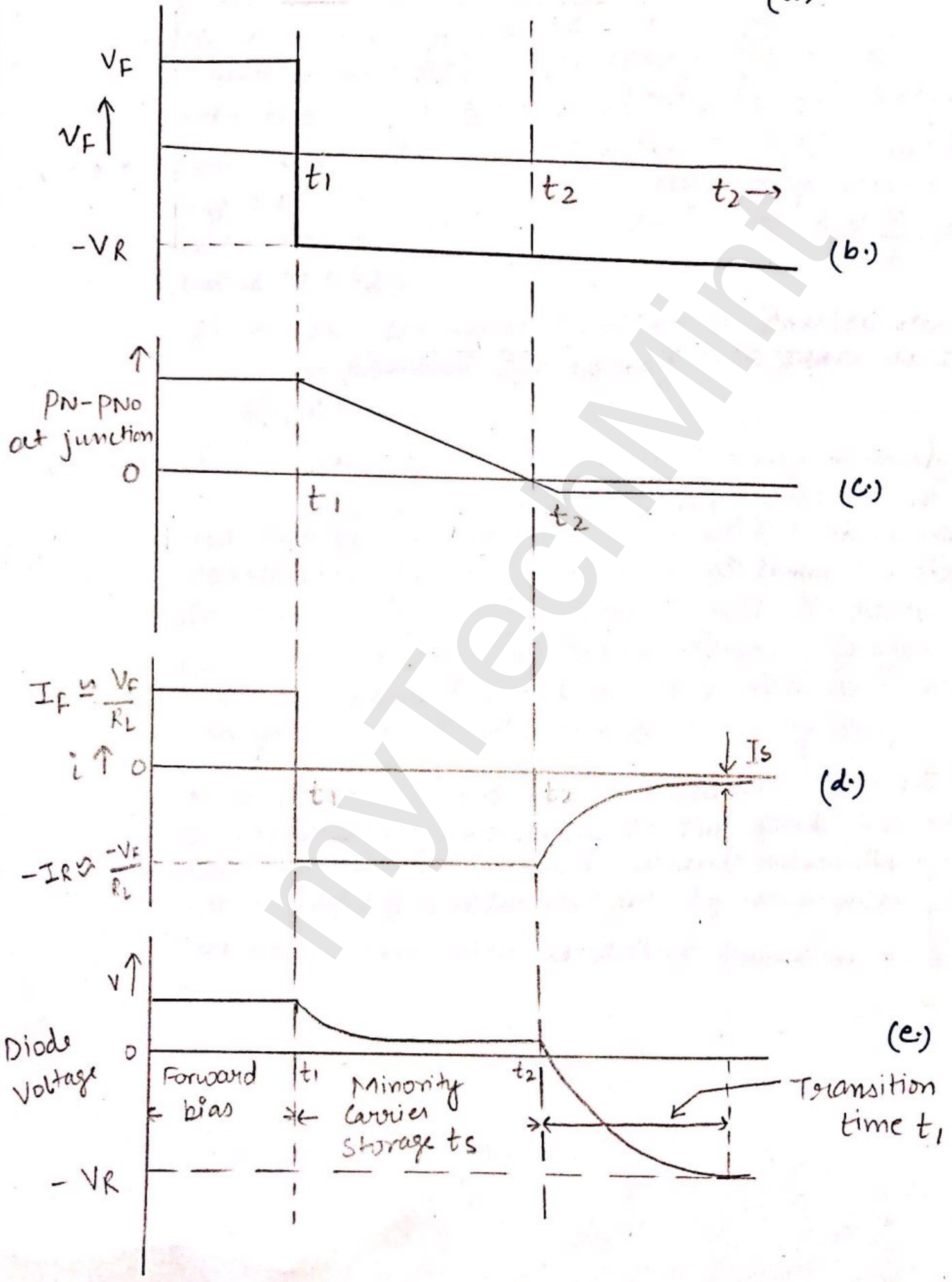
→ At t_1, the diode voltage falls slightly normally by $R_d(I_F + I_R)$ but doesnot reversed. At time $t = t_2$, the process of sweeping of the excess minority carriers in the vicinity of junc^n back has completed so, diode current magnitude begins to reduce.

→ During t_1 to t_2, the stored minority charge has remained stored and have this interval called as storage time denoted by t_s. (in fig. (e))

→ Now the magnitude of diode current current begins to decrease exponentially to the ~~diode~~ normal steady state reverse saturation current value. The time interval b/w t_2 and the instant t_3 when diode has recovered nominally, is called transition time t_t.


+
-
+
Vi
RL

(a.)


VF
VF
t1
t2
t2→
-VR
(b.)
PN-PNO
at junction
0
t1
t2
(c.)
IF ≃ VF/RL
i
0
t1
t2
Is
(d.)
-IR ≃ -VF/RL
V
Diode
Voltage
0
(e.)
Forward
bias
t1
Minority
carrier
storage ts
t2
Transition
time t1
- VR

RECTIFIERS

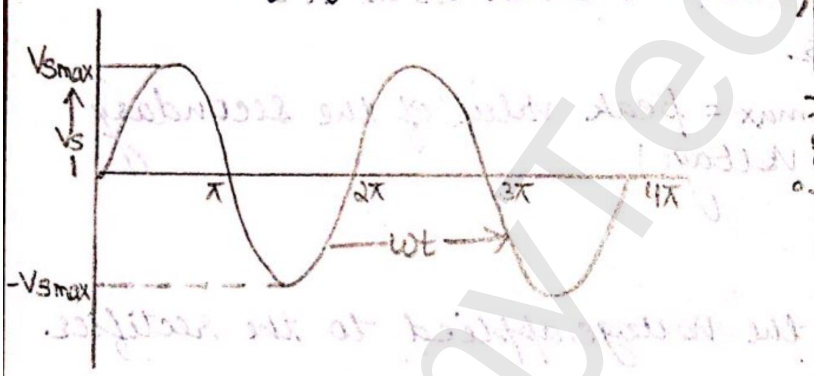
Rectifier is a device which converts the sinusoidal ac voltage into either +ve or -ve pulsating dc. p-n junc^{n} diode which conducts when F.B. and practically does not conduct when R.B., can be used for rectification i.e. for conversion of ac into dc.

Rectifiers may be either half wave or full wave (centre tap or bridge) type.

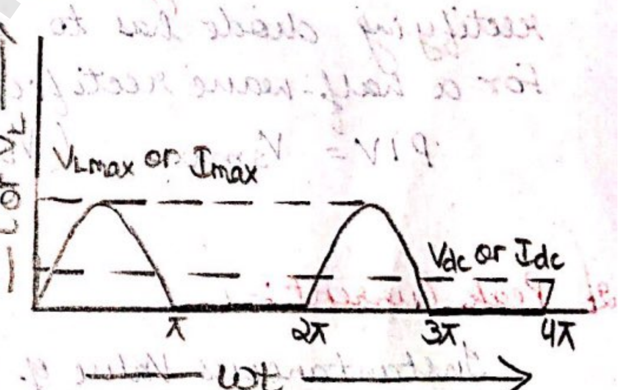
HALF-WAVE RECTIFIERS

In half-wave rectifier, the rectifier conducts current only during the +ve half cycle of input ac supply.

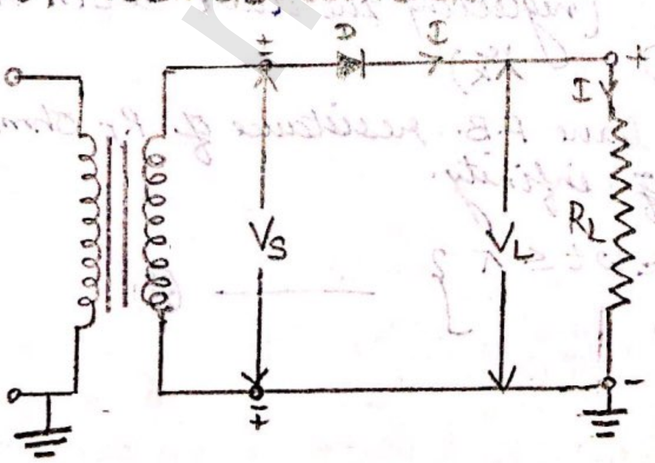
In half-wave rectification only one diode is used during half cycle of the input ac suppy the diode conducts and during -ve half of cycle of input ac, ~~the~~ diode is R.B and doesnot conducts. So, output is obtained only during +ve half cycle of the input.



INPUT VOLTAGE WAVEFORM



RECTIFIED OUTPUT VOLTAGE, CURRENT WAVEFORMS



Working :-

(i) AC Voltage to be rectified is applied to primary of a transformer

(ii) The AC stepped to a suitable low Value, so that the diode may not be spoiled

(iii) During +ve half cycle of input ac Voltage the diode gets F.B. and hence it conducts current & during the -ve half cycle of input ac voltage the diode gets R.B. and doesnot conduct any current

(iv) The current flows through the load resistance R_L only during the +ve half cycle so, current through R_L is obtained in one direction i.e. only half cycle of input ac are used.

Analysis of Half-Wave Rectifier

1. Peak Inverse Voltage :- It is the max. Voltage that the rectifying diode has to withstand when it is R.B.
For a half-wave rectifier

$$PIV = V_{s\,max} \quad (V_{s\,max} = \text{peak value of the secondary voltage})$$

2. Peak Current :-

Instantaneous Value of the voltage applied to the rectifier is given as :-

$$V_s = V_{s\,max} \sin\omega t \quad \text{——} ① \quad (\text{neglecting the diode cut in voltage } V_K)$$

If diode is assumed to have F.B. resistance of R_F ohms and reverse resistance of infinity.

$$\left.\begin{aligned} i &= I_{max} \sin\omega t \,, \quad 0 \le \omega t \le \pi \\ i &= 0 \,, \quad \pi \le \omega t \le 2\pi \end{aligned}\right\} \text{——} ②$$

where peak value of current flowing through the diode is $I_{max} = \frac{V_{smax}}{R_F + R_L}$ ——— ③

3. Dc output Current :

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i \, d(\omega t)$$

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

$$= \frac{1}{2\pi} I_{max} \left\{-\cos\omega t\right\}_0^{\pi}$$

$$= \frac{I_{max}}{\pi} = 0.318 I_{max} \text{ ——— ④}$$

using eqⁿ ③ and ④

$$I_{dc} = \frac{V_{smax}}{\pi(R_L + R_F)} = \frac{V_{smax}}{\pi R_L} \left(\text{if } R_L >> R_F\right) \text{ ——— ⑤}$$

4. DC output Voltage :-

$$V_{dc} = I_{dc} R_L$$

$$= \frac{V_{smax}}{\pi(R_L + R_F)} \cdot R_L = \frac{V_{smax}}{\pi\left(1 + \frac{R_F}{R_L}\right)} \text{ ——— ⑥}$$

if $R_L >> R_F$

$$V_{dc} \approx \frac{V_{smax}}{\pi} \text{ ——— ⑦}$$

5. RMS value of current :-

$$I^2_{rms} = \frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)$$

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

$$I^2_{rms} = \frac{I^2_{max}}{4}$$

$$I_{rms} = \frac{I_{max}}{2} \text{ ——— ⑧}$$

$$I_{rms} = \frac{V_{smax}}{2(R_F + R_F)} \text{ ——— ⑨. } \{\text{from ③}\}$$

6. RMS Value of Output Voltage:-

$$V_{L\,rms} = I_{rms} R_L$$

$$= \frac{V_{smax} \times R_L}{2(R_F + R_L)}$$

$$= \frac{V_{smax}}{2\left[1 + \frac{R_F}{R_L}\right]}$$

If $R_L >> R_F$,

$$V_{LRms} = \frac{V_{smax}}{2}$$

7. Form factor and peak factor:-

* Form factor is defined as the ratio of rms value to the avereage value

$$K_f = \frac{\text{RMS Value}}{\text{Avg. value}} = \frac{I_{rms}}{I_{dc}} = \frac{V_{smax}}{2(R_F + R_L)} \times \frac{\pi(R_L + R_f)}{V_{smax}}$$

$$K_f = \frac{\pi}{2} = 1.57$$

* Peak factor is defined as the ratio of peak value to the rms value

$$K_p = \frac{\text{Peak Value}}{\text{RMS Value}} = 2.$$

8. Output Frequency:- Output freq. is same as the input freq.

$$f_{out} = f_{in}.$$

9. **Rectification Efficiency :-** It is defined as the ratio of dc output power to the ac input power.

$$\eta = \frac{\text{DC power delivered to the load}}{\text{AC i/p power from the transformer}}$$

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L = \left(\frac{I_{max}}{\pi}\right)^2 R_L$$

P_{ac} = Power dissipated in diode junc^n + power dissipated in load resistance R_L

$$= I_{rms}^2 R_F + I_{rms}^2 R_L$$

$$= \left(\frac{I_{max}}{2}\right)^2 R_F + \left(\frac{I_{max}}{2}\right)^2 R_L = \frac{I_{max}^2}{4}(R_F + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{4}{\pi^2}\frac{R_L}{R_F+R_L} = \frac{0.406}{1+\frac{R_F}{R_L}}$$

If R_F is neglected

$\eta = 0.406$ or 40.6%. (max. possible η of a rectifier)

10. **Ripple factor :-** The pulsating output of a rectifier can be considered to contain a dc component and ac component called ripples.

Ripple factor is defined as the ratio of effective value of of the ac components of voltage (or current) present in the output from the rectifier to the direct or avg-value of the o/p voltage (or current)

$$\text{ripple factor} = \gamma = \frac{I_{ac}}{I_{dc}} = \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1}$$

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

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

$$\gamma = 1.21$$

11. **Transformer Utilization factor (TUF) :-**

It is defined as the ratio of power delivered to the load and ac rating of the transformer secondary,

$$TUF = \frac{P_{dc}}{P_{ac(rated)}} = \frac{I^2_{dc} R_L}{V_{s\,rms}\, I_{rms}}$$

$$= \frac{(I_{max}/\pi)^2 R_L}{\frac{V_{s\,max}}{\sqrt{2}} \cdot \frac{I_{max}}{2}}$$

$$= \frac{2\sqrt{2}}{\pi^2} \frac{I_{max} R_L}{V_{s\,max}}$$

$$V_{s\,max} = I_{max}(R_F + R_L)$$

$$\text{So, } TUF = \frac{2\sqrt{2}}{\pi^2} \cdot \frac{I_{max} R_L}{I_{max}(R_F + R_F)}$$

$$= \frac{0.286\, R_L}{R_L + R_F}$$

Neglecting R_L, $TUF = 0.286$

12. **Regulation :-** The variation of dc o/p voltage as a func^n^ of dc load current is called regulation.

% Regulation is given as :-

$$\%\ \text{Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{\frac{V_{max}}{\pi} - I_{dc} R_F}{I_{dc} R_F} \times 100$$

13. **Cond^n^ for Max. DC output power in a Half-Wave Rectifier :-**

$$P_{dc} = I^2_{dc} R_L = \left(\frac{I_{max}}{\pi}\right)^2 R_L = \frac{V_s{}^2_{max} R_L}{\pi^2 (R_L + R_F)^2}$$

diff. above eq^n^ w.r.t. R_L

$$\frac{dP_{dc}}{dR_L} = \frac{V^2_{s\,max}}{\pi^2}\left[\frac{(R_L^2 + R_F^2 + 2R_L R_F) - R_L(2R_L + R_F)}{(R_L^2 + R_F^2 + 2R_L R_F)}\right]$$

$$\frac{dP_{dc}}{dR_L} = \frac{V_{s\,max}^2 \, (R_F^2 - R_L^2)}{\pi^2 (R_L^2 + R_F^2 + 2R_F R_L)^2}$$

Output will be max. if, $\frac{dP_{dc}}{dR_L} = 0$

or $R_F^2 - R_L^2 = 0$

or $\boxed{R_L = R_F}$

→ **Advantages of Half-Wave Rectifier :-**

- * Simple circuit
- * Low cost

→ **Disadvantages of Half-Wave Rectifier :-**

- * TUF is low
- * power o/p and therefore rectification η is quite low. This is due to the fact that power is delivered only half the time.
- * Ripple factor is high.

Ques 1. A sinusoidal voltage of 40V and freq. 50 HZ is applied to a half-wave rectifier.

$R_L = 200\Omega$, $V_\gamma = 0$, $R_F = 20\Omega$, $R_R = \infty$

Find V_{dc}, I_{dc}, I_{max}, I_{rms}, P_{dc}, η, ripple factor, % regulation

Solution :-

$$I_{max} = \frac{V_{s\,max}}{R_L + R_F} = \frac{40\sqrt{2}}{200 + 20} = 0.257A \text{ or } 257mA$$

$$I_{rms} = \frac{I_{max}}{2} = 128.5mA$$

$$I_{dc} = \frac{I_{max}}{\pi} = \frac{257}{\pi} = 81.8mA$$

$$V_{dc} = I_{dc} R_L = 81.8 \times 10^{-3} \times 200 = 16.36V$$

$$P_{dc} = I^2_{dc} R_L = (81.8 \times 10^{-3})^2 \times 200$$
$$= 1.338 W$$

$$P_{ac} = \frac{I^2_{max}}{4}(R_F + R_L) = \frac{(257 \times 10^{-3})^2}{4} \times (20 + 200)$$
$$= 3.63 W$$

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{1.338}{3.63} \times 100 = 36.86\%$$

$$\text{Ripple factor}, \gamma = \left(\frac{I^2_{rms}}{I^2_{dc}} - 1\right)^{1/2}$$
$$= \left(\left(\frac{128.5}{81.8}\right)^2 - 1\right)^{1/2} = 1.21$$

$$V_{dc} = \frac{V_{max}}{\pi} - I_{dc} R_F = \frac{40\sqrt{2}}{\pi} - 81.8 \times 10^{-3} \times 20$$
$$= 16.364 V$$

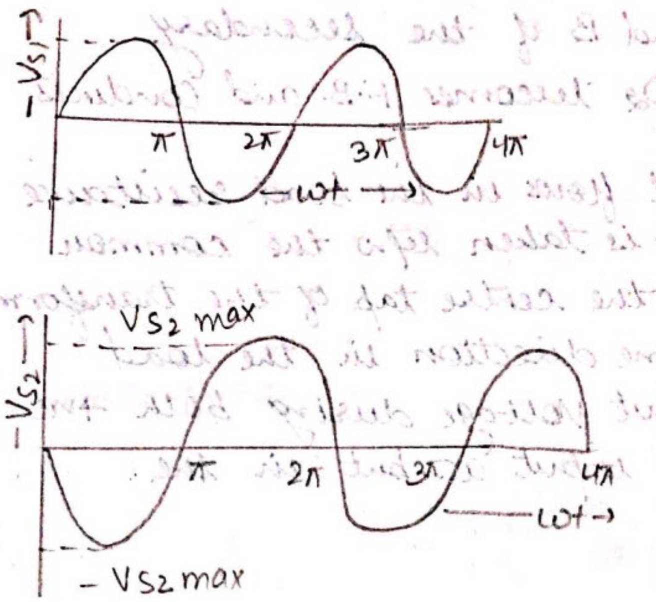
$$\text{Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{\frac{V_{max}}{\pi} - I_{dc}R_F}{I_{dc}R_F}$$
$$= \frac{18 - 1.636}{1.636} \times 100$$
$$= 9.998\%$$

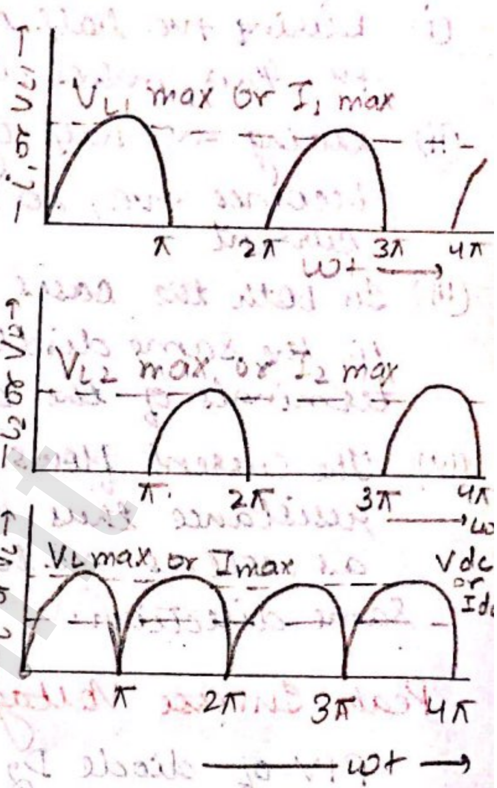
Ques 2. A half-wave Rectifier uses a diode with $R_F = 100\Omega$. If the input ac Voltage is 220V and load resistance is $2K\Omega$, determine the TUF.

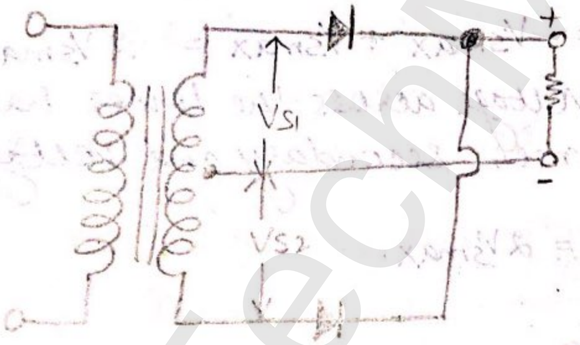
Solution :-
$$TUF = \frac{0.286}{1 + \frac{R_F}{R_L}} = \frac{0.286}{1 + \frac{0.1K\Omega}{2K\Omega}}$$
$$= 0.2724 \text{ Ans.}$$

FULL-WAVE RECTIFIERS

CENTRE-TAP FULL-WAVE RECTIFIER







In a full-wave rectifier two diodes are used. For +ve half cycle of input voltage one diode supplies current and for -ve half cycle another diode supplies current. In this p-side of the two diodes is connected to the two ends of the secondary of transformer and n-sides are connected together and output is taken from the common point of the diodes and the mid point of the secondary of the transformer. So, in a full wave rectifier the secondary of transformer is provided with centre tapping so, it is called centre tap transformer.

WORKING :-

(i) During +ve half cycle the end A of the secondary becomes +ve this makes diode D_1 F.B, So D_1 conducts.

(ii) During -ve half cycle the end B of the secondary becomes +ve, so the diode D_2 becomes F.B. and conducts current

(iii) In both the cases the current flows in the load resistance in the same direction. The o/p is taken b/w the common terminals of the diodes and the centre tap of the tranformer

(iv) The current flows in the same direction in the load resistance thus we get output voltage during both +ve as well as -ve half cycle of input ac but in the same direction.

Peak Inverse Voltage :-

PIV of diode $D_2 = V_{smax} + V_{smax} = 2V_{smax}$

(Sum of voltage across the lower half of transformer secondary and voltage across R_L)

also PIV of diode $D_1 = 2V_{smax}$.

BRIDGE RECTIFIER

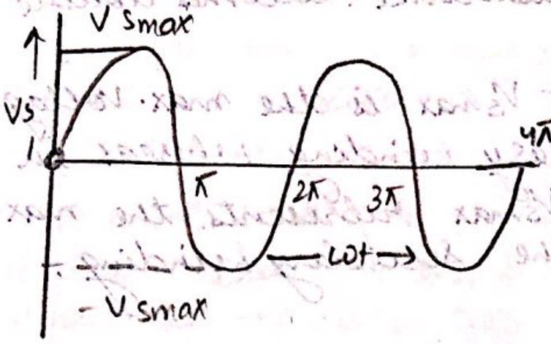
In bridge rectifier circuit four diodes are connected in the form of a wheatstone bridge, two diametrically opposite junc's of the bridge are connected to the secondary of a transformer and the other two are connected to the load.

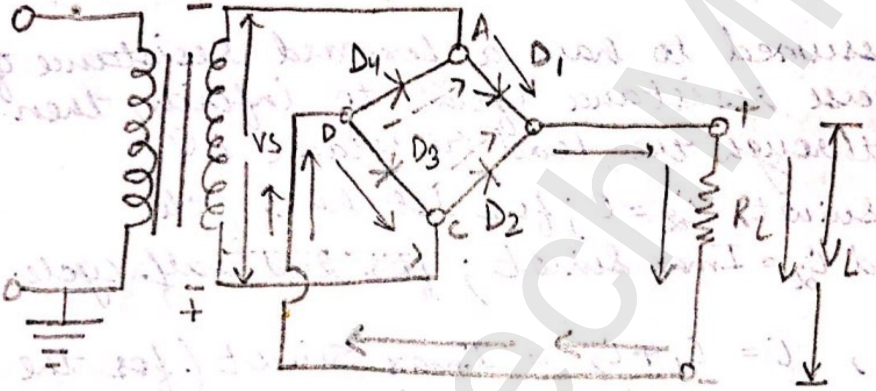
(i) During the +ve half cycle of input supply diode D_1 and D_3 are FB and current flows through the arm AB, enters the load at +ve terminal, leaves the load at -ve terminal and returns back flowing to arm DC. During this period D_2 and D_4 are R.B. and current don't flow in arm AD and BC.

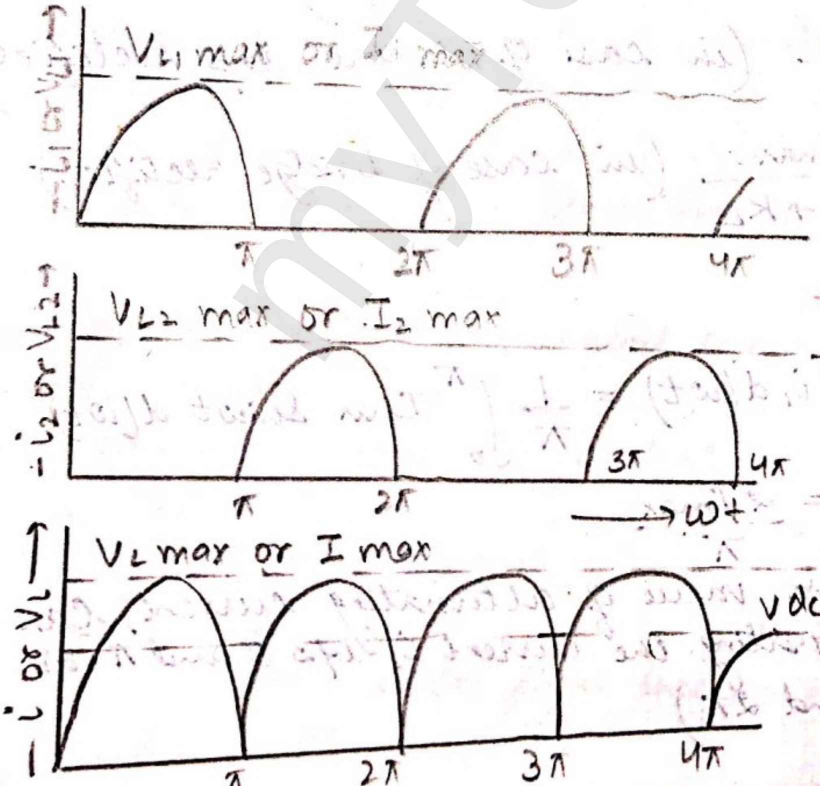
(ii) During the 2nd half of the input cycle, diodes D_2 and D_4 are F.B. and current flows through arm CB, enters the load at +ve terminal, leaves the load at ~~+~~ -ve terminal and returns back flowing through arm DA. (flow of current is shown by dotted lines)

→ Peak inverse Voltage (PIV)

$$PIV = V_{smax}.$$







Circuit Analysis :-

The analysis of both of the full-wave rectifier circuits (i.e. centre-tap and bridge type) is same except that :-

1.) In a bridge rectifier circuit two diodes conduct during each half cycle and forward resistance becomes double i.e. $2R_F$

2.) In a bridge rectifier circuit V_{smax} is the max. voltage across the transformer secondary winding whereas in centre tap recifier circuit V_{smax} represents the max. voltage across each half of the secondary winding.

(I) Peak Current :-

$$v_s = V_{smax} \sin \omega t$$

If the diode is assumed to have a forward resistance of R_F ohms and reverse resistance equal to infinity, then current flowing through the load resistance is

$$i_1 = I_{max} \sin \omega t \quad i_2 = 0 \text{; for 1st half cycle}$$

and $i_1 = 0$ and $i_2 = I_{max} \sin \omega t$; for 2nd half cycle.

Total current, $i = i_1 + i_2 = I_{max} \sin \omega t$ (for the whole cycle)

$$I_{max} = \frac{V_{smax}}{R_F + R_L} \quad \text{(in case of centre-tap rectifier)}$$

and $$I_{max} = \frac{V_{smax}}{2R_F + R_L} \quad \text{(in case of bridge rectifier)}$$

(II) Output Current :-

$$\text{So, } I_{dc} = \frac{1}{\pi}\int_0^{\pi} i_1 \, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I_{max} \sin \omega t \, d(\omega t)$$

$$= \frac{2I_{max}}{\pi}$$

(I_{dc} is equal to avg. value of alternating current, can be obtained by integrating the current i_1 b/w 0 and π or current i_2 b/w π and 2π)

(III) Dc Output Voltage:-

$$V_{dc} = I_{dc} R_L$$

$$= \frac{2}{\pi} I_{max} R_L$$

(IV) RMS value of current:-

$$I^2_{rms} = \frac{1}{\pi}\int_0^{\pi} i_1^2 \, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} I^2_{max} \sin^2 \omega t \, d(\omega t)$$

$$= \frac{I^2_{max}}{2}$$

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

(V) RMS value of output voltage:-

$$V_{L\,rms} = I_{rms} R_L = \frac{I_{max}}{\sqrt{2}} R_L$$

(VI) Form factor and Peak factor:-

$*$ form factor $= \frac{\text{RMS Value}}{\text{Avg. value}} = \frac{I_{rms}}{I_{dc}} = \frac{I_{max}/\sqrt{2}}{2I_{max}/\pi}$

$$= \frac{\pi}{2\sqrt{2}} = 1.11$$

$*$ Peak factor $K_p = \frac{\text{Peak Value}}{\text{RMS Value}} = \frac{I_{max}}{I_{max}/\sqrt{2}} = \sqrt{2}$

(VII) Output freq.:-

for full wave rectifier,

$$f_{out} = 2 f_{in}$$

(VIII) Rectification Efficiency:-

Power delivered to load,

$$P_{dc} = I^2_{dc} R_L = \left(\frac{2}{\pi} I_{max}\right)^2 R_L = \frac{4}{\pi^2} I^2_{max} R_L$$

Ac input power,

$$P_{ac} = I^2_{rms}(R_L + R_F) = \frac{I^2_{max}}{2}(R_L + R_F)$$

Rectification efficiency, $\eta = \frac{P_{dc}}{P_{ac}}$

$$\eta = \frac{\frac{4}{\pi^2} I^2_{max} R_L}{\frac{1}{2} I^2_{max}(R_L + R_F)} = \frac{8}{\pi^2} \frac{1}{\left(1 + \frac{R_F}{R_L}\right)}$$

$$= \frac{0.812}{1 + \frac{R_F}{R_L}}$$

In case of bridge rectifier, rectification η is

$$\eta = \frac{0.812}{1 + \frac{2R_F}{R_L}}$$

(IX) Ripple factor:

$K_f = 1.11$ for full wave rectifier

So, Ripple factor, $\gamma = \sqrt{K_f^2 - 1} = \sqrt{(1.11)^2 - 1} = 0.482$

(X) Regulation:-

$$V_{dc} = \frac{2}{\pi} I_{max} R_L = \frac{2 V_{s\,max} R_L}{\pi(R_F + R_L)}$$

$$= \frac{2 V_{s\,max}}{\pi}\left[1 - \frac{R_F}{R_F + R_L}\right]$$

$$= \frac{2 V_{s\,max}}{\pi} - I_{dc} R_F$$

In case of a bridge rectifier,

$$V_{dc} = \frac{2V_{s\,max}}{\pi} - 2I_{dc}R_F$$

(XI) Transformer Utilization Factor for Centre-tap Transformer :-

The avg. TUF is found by considering the primary and secondary windings.

$$\text{TUF of primary} = \frac{P_{dc}}{\text{VA rating of primary}}$$

$$= \frac{I^2_{dc}R_L}{V_{s\,rms}\,I_{rms}} = \frac{\left(\frac{2I_{max}}{\pi}\right)^2 R_L}{\frac{V_{s\,max}}{\sqrt{2}} \times \frac{I_{max}}{\sqrt{2}}}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{(R_F+R_L)} = \frac{8}{\pi^2} \times \frac{1}{\left(1+\frac{R_F}{R_L}\right)}$$

$$\simeq 0.812$$

Centre tap transformer can be thought of as equivalent to two half-wave rectifiers feeding to a common load. Hence TUF of two half secondaries can be written as

$$\text{TUF(full secondary)} = 2 \times \text{TUF (half-wave)}$$
$$= 2 \times 0.286 = 0.572$$

$$\text{The avg. TUF} = \frac{\text{TUF(primary)} + \text{TUF(secondary)}}{2}$$
$$= \frac{0.812 + 0.572}{2} = 0.692$$

(XII) TUF for Bridge Rectifier :-

The current flow through both primary & secondary windings are sinusoidal. ~~So~~ Due to this both the primary & ~~secondary~~ secondary are 0.812

$$\boxed{\therefore\ \text{TUF(avg)} = 0.812}$$

Merits & Demerits of Full-Wave Rectifiers Over Half-Wave Rectifiers

Merits :- 1. The rectification efficiency of full-wave rectifier is double of that of a half-wave rectifier.

2. The ripple voltage is low and of higher freq. in case of a full-wave rectifier, so simple filtering circuit is required

3. Higher o/p voltage, higher o/p power and higher TUF in case of a full-wave rectifier

Demerits :- Full wave rectifier circuit needs more circuit elements and is costlier.

DIODE CLIPPERS

A circuit with which the waveform is shaped by removing a portion of the applied wave to suit a particular device is called a clipping circuit or clipper. For a clipping circuit a diode and a resistor are required. Sometimes a dc battery is also used to fix the clipping level.

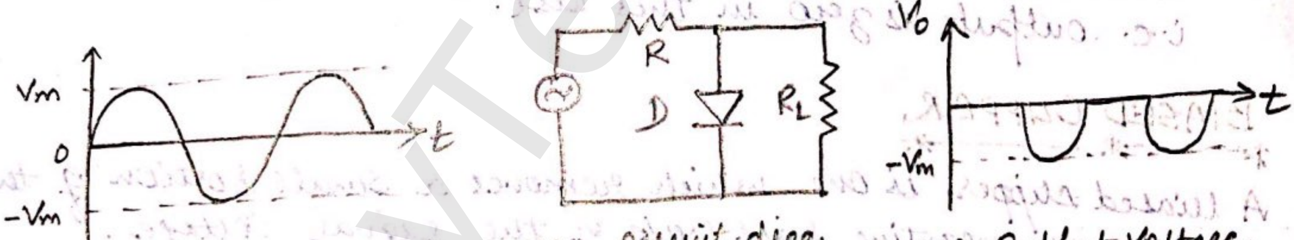
Clippers are used in digital devices, electronic devices, RADAR etc.

Important clipping circuits or clippers are :-

- * positive clipper
- * negative clipper
- * biased clipper
- * Combination clipper.

POSITIVE CLIPPER

A positive clipper is one which removes (or clipps off) the +ve half cycles of the input voltage.



(a) Input Voltage (b) circuit diag. (c) Output Voltage.

* During +ve half cycle of input ac signal, the diode is F.B. and conducts heavily. Therefore diode acts as short circuit and voltage across it is zero. Hence Voltage across RL is zero i.e. o/p voltage during +ve half cycle is zero.

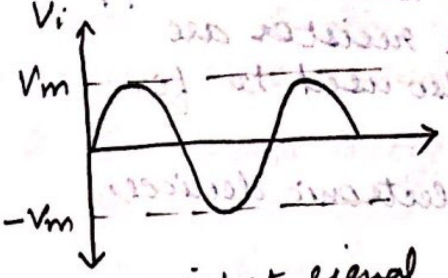
* During -ve half cycle the diode is R.B. and behaves as an open circuit. In this case the ckt. behaves as potential divider with o/p V_0 is

$$V_0 = \frac{R_L}{R+R_L} V_i$$

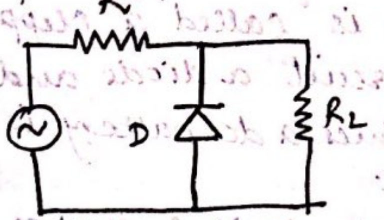
Generally $R_L >> R \Rightarrow V_0 = V_i$

NEGATIVE CLIPPER

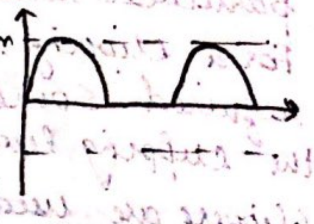
A -ve clipper is one which removes all the -ve cycle of the input voltage



(a) input signal



(b) circuit diag.



(c) output signal.

* During the +ve half cycle the diode is R.B. and acts as an open circuit. In this case circuit behaves as an potential divider with V_0 as

$$V_0 = \frac{R_L}{R+R_L} V_i$$

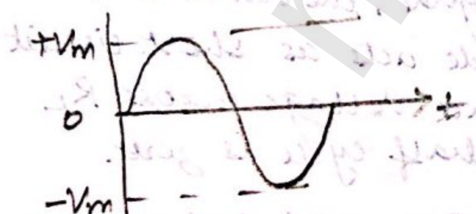
$$R_L >> R$$

$$\therefore V_0 = V_i$$

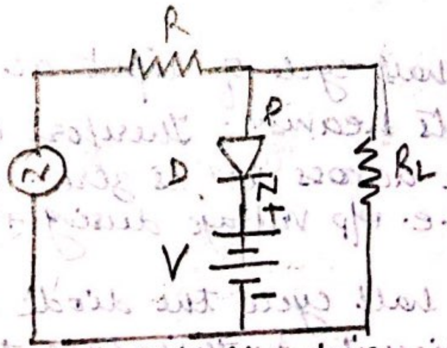
* During the -ve half cycle, the diode is F.B. and acts as a short circuit and hence voltage across R_L is zero i.e. output is zero in this case.

BIASED CLIPPER

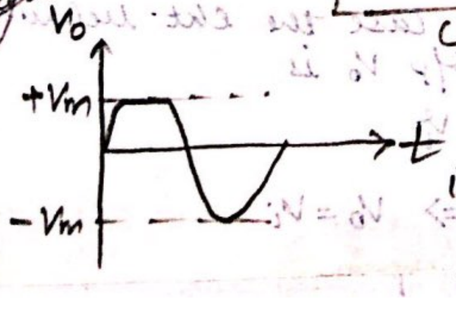
A biased clipper is one which removes a small portion of the positive or negative half cycle of the signal voltage.



ⓐ i/p signal



(b) Ckt diag.



(c) o/p signal.

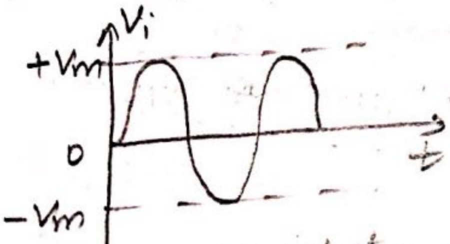
* During +ve half cycle the diode is F.B. if the voltage exceeds the battery voltage +V. Under this cond^n a diode acts as a short - circuit and o/p voltage remains equal to +V. But if the i/p voltage is less than +V, the diode is R.B. and acts as an open circuit. Therefore most of the input voltage appears across the output

* During -ve half cycle, the diode is R.B. Therefore almost entire -ve half cycle appears across the load.

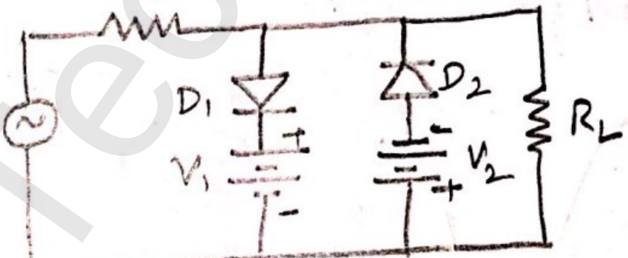
→ If it is desired to remove the portion of -ve half cycle, the polarities of diodes or batteries are reversed. such a ckt. is called biased -ve clipper.

COMBINATION CLIPPER

A combination clipper is a combination of biased +ve and -ve clippers and removes a portion of both +ve and -ve half cycle of input voltages.



(a) input signal



(b) circuit diag.

(c) o/p signal

* During +ve half cycle, when +ve input voltage is greater than $+V_1$, the diode D_1 is forward biased and acts as short ckt. and D_2 being R.B. acts as open circuit. Therefore a voltage V_1 appears across the load.

* During -ve half cycle, the i/p voltage is greater than $-V_2$, the diode D_2 is F.B. and acts as short ckt. while diode D_1 is R.B. and acts as open circuit. Therefore o/p voltage remains $-V_2$.

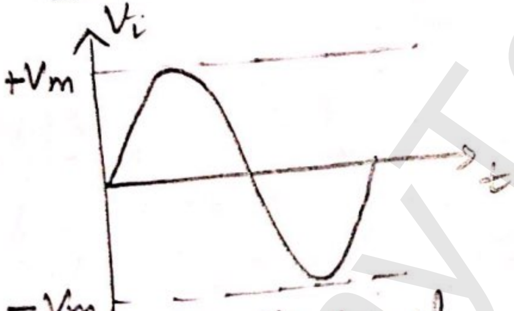
→ This clipping ckt. gives square wave output if max. value of clipping voltage is much greater than clipping levels.

DIODE CLAMPERS

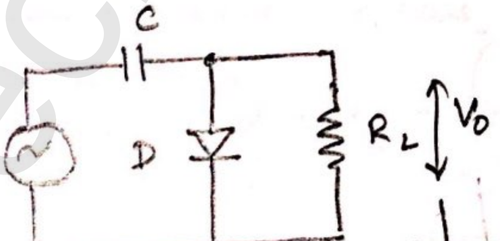
A circuit that introduces a dc level into an ac signal is called clamping circuit or a clamper.

Positive Peak Clamper or -ve DC Restoring circuit

The +ve peak clamper shifts the +ve peak to zero level.

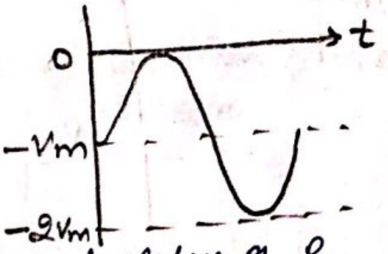


(a) i/p signal



(b) circuit diag

(c) o/p signal



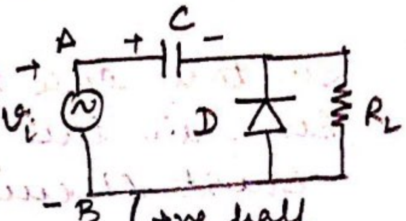
Let us assume that the diode is ideal and value of R_L and C are chosen such that R_LC has large value.

During +ve half cycle of input signal, diode is F.B. and acts as a short circuit.

Capacitor C charges through diode D and the i/p voltage source.

As diode is real, the potential drop across diode is zero and across capacitor $\cong V_m$

and in steady state o/p voltage $V_0 = V_i - V_m$



(+ve half cycle)

If $V_i = V_m \sin \omega t$

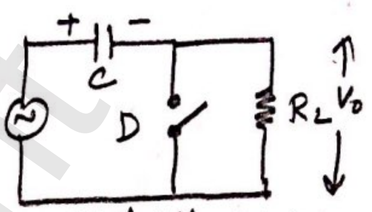
$V_o = V_m \sin \omega t - V_m$

and at $t = \frac{T}{4}, \frac{5T}{4} - - -$; $V_o = V_m - V_m$

$V_o = 0$

i.e. +ve peak is clamped to zero volt and +ve half cycle in o/p lies b/w $-V_m$ to 0V.

* During -ve half cycle, the diode is R·B and acts as open circuit



-ve half cycle

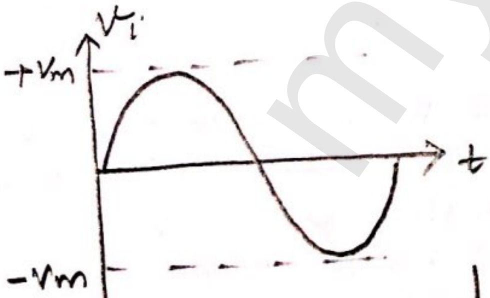
$V_o = V_i - V_m = -V_m \sin \omega t - V_m$

and at $t = \frac{3T}{4}, \frac{7T}{4}, - - -$

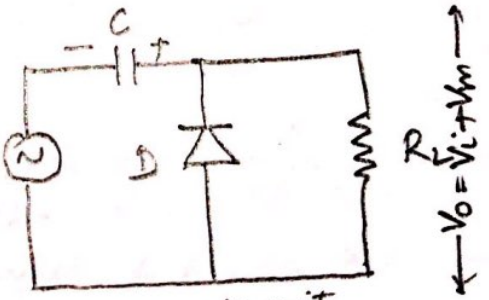
$V_o = -2V_m$

Clearly, this circuit introduces a dc level $-V_m$ to ac signal and +ve peak is clamped at 0V, due to which this circuit is called +ve peak clamping circuit.

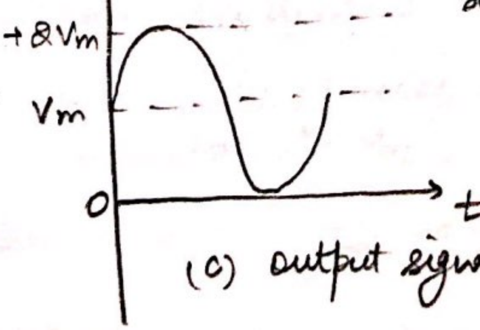
Negative Peak clamping circuit or +ve DC Restoring circuit



(a) Input signal



(b) circuit diag



(c) output signal.

In this case the polarities of capacitor are reversed since in this case the diode is F.B. and acts as a short circuit during -ve half cycle

The o/p Voltage, $V_0 = V_i + V_m$ i.e. dc level of $+V_m$ is introduced in ac level and -ve peak is shifted to zero volt.

Ques 1. A germanium diode carries a current of 1mA at room temp. when a F.B. of 0.15V is applied. Estimate the reverse saturation current at room temp.

Solution: Applied forward bias Voltage, $V = 0.15\ V$

Forward Current = 1mA

$V_T = 26mV = 0.026\ V$

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

$$I_0 = \frac{I}{\left(e^{V/\eta V_T} - 1\right)} = \frac{1 \times 10^{-3}}{\left(e^{0.15/0.026} - 1\right)}$$

$I_0 = 3.12 \times 10^{-6} A = 3.12 \mu A$

Ques 2. A silicon diode has reverse saturation current of 2.5μA at 300K. Find forward Voltage for a forward current of 10mA.

Solution:-

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

$$e^{V/\eta V_T} = \frac{0.01}{2.5 \times 10^{-6}} + 1$$

$= 4 \times 10^3 + 1 = 4001$

($\eta = 2$ for Si

V_T at 300K = 26mV)

$$\frac{V}{\eta V_T} = \log_e 4001$$

$V = \eta \times V_T \times \log_e 4001$

$= 2 \times 0.026 \times \log_e 4001$

$= 0.43V$

Ques 3. What is the ripple 2V on average of 50V.

RMS value of AC component, $V_{rms} = 2V$

Avg. value of o/p voltage, $V_{dc} = 50V$

$$\text{Ripple factor } \gamma = \frac{V_{rms}}{V_{dc}}$$

$$\gamma = \frac{2}{50} = 0.04 \text{ Ans.}$$

Ques4. A half wave rectifier is used to supply 10V dc to a resistive load of 400Ω. If the crystal diode has a forward resistance of 20Ω, determine the value of ac voltage supplied to the circuit.

Sol^n $$V_{smax} = V_{dc} \times \pi \left\{ 1 + \frac{R_F}{R_L} \right\}$$

$$= 10 \times \pi \left\{ 1 + \frac{20}{400} \right\}$$

$$\approx 33V.$$

RMS value of ac voltage applied to the circuit

$$V_s = \frac{V_{smax}}{\sqrt{2}} = \frac{33}{\sqrt{2}} = 23.3V \text{ Ans}$$

Ques5. The load resistance of a centre tapped full wave rectifier is 500Ω and the necessary voltage is 60 sin(100πt). Calculate

(i) peak, avg. and rms value of current

(ii) ripple factor (iii) η of the rectifier.

Each diode has an idealised I-V char. having slope corresponding to a resistance of 50Ω.

Sol^n $V_{smax} = 60V$

$R_F = 50Ω$

$R_L = 500Ω$

(i) Peak current, $I_{max} = \frac{V_{smax}}{R_L + R_F}$

$$= \frac{60}{500+50} = 0.109A$$

Avereage current, $I_{dc} = \frac{2I_{max}}{\pi} = \frac{2 \times 0.109}{\pi}$

$$= 0.0695A.$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{0.109}{\sqrt{2}} = 0.077A$$

(ii) $$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{0.077}{0.0695}\right)^2 - 1}$$

$$= 0.482 \text{ Ans}$$

(iii) $\eta = \frac{0.812}{1+\frac{R_f}{R_L}} \times 100 = \frac{0.812 \times 100}{1+\frac{50}{500}}$

$\eta = 73.82\%$.

Ques 5. In a bridge rectifier circuit the peak value of secondary voltage is $240\sqrt{2}$ V and freq. is 50 Hz. Determine no load dc voltage, PIV and o/p freq.

Solution $V_{s\,max} = 240\sqrt{2}$ V

no-load dc voltage $= \frac{2V_{s\,max}}{\pi}$

$= \frac{2 \times 240\sqrt{2}}{\pi}$

$= 216$ V

PIV rating of diodes, PIV $= V_{s\,max} = 240\sqrt{2}$

$= 339.4$ V.

output freq., $f_{out} = 2 f_{in}$

$= 2 \times 50$

$= 100$ Hz.

Ques 6. Determine the rating of a transformer to deliver a 100W of dc power to a full load under full wave rectifier

Solution: Transformer rating $= \frac{P_{dc}}{TUF}$

$= \frac{100}{0.692} = 144.5$ VA (in case of centre-tap transformer)

Transformer rating $= \frac{100}{0.812} = 123$ VA (in case of bridge rectifier)

Ques 7. A full wave bridge rectifier use $R_L = 2K\Omega$, each diode is to have forward resistance $R_F = 2\Omega$ and $R_R = \infty$. A Sinusoidal Voltage having peak amplitude of 20V is applied. Find

(i) Peak, dc and rms Value of load Current
(ii) dc and rms output Voltages
(iii) dc o/p power
(iv) ac i/p power
(v) efficiency.

Solution:- $V_{Smax} = 20V$
$R_F = 2\Omega$
$R_R = \infty$
$R_L = 2k\Omega = 2000\Omega$

(i) $$I_{max} = \frac{V_{Smax}}{2R_F + R_F} = \frac{20}{2\times2+2000} = 9.98mA$$

$$I_{dc} = \frac{2I_{max}}{\pi} = \frac{2\times9.98}{\pi} = 6.35mA$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{9.98}{\sqrt{2}} = 7.06mA$$

(ii) $$V_{dc} = \frac{2}{\pi} I_{max} R_L$$
$$= \frac{2}{\pi} \times 0.00998 \times 2000$$
$$= 12.7V$$

$$V_{rms} = \frac{I_{max}}{\sqrt{2}} \times R_L$$
$$= \frac{0.00998 \times 2000}{\sqrt{2}}$$
$$= 14.1V$$

(iii) $P_{dc} = I^2_{dc} R_L$

$$= \left(\frac{6.35}{1000}\right)^2 \times 2000$$

$$= 80.65 mW$$

(iv) $P_{ac} = I^2_{rms}(R_L + 2R_F)$

$$= \left(\frac{7.06}{1,000}\right)^2 \times (2000 + 4)$$

$$= 99.89 mW$$

(v) $\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{80.65}{99.89} \times 100 = 80.74\%.$

Ques A zener diode has specifications $V_Z = 5.2V$ and $(P_Z)_m = 260mW$ Assume $R_Z = 0$. Find the max. allowed current when zener diode acts as a Regulator.

$P_{ZM} = 260mW$

$V_Z = 5.2V$

$R_Z = 0$

$I_{ZM} = \frac{P_{ZM}}{V_Z} = \frac{260 \times 10^{-3}}{5.2}$

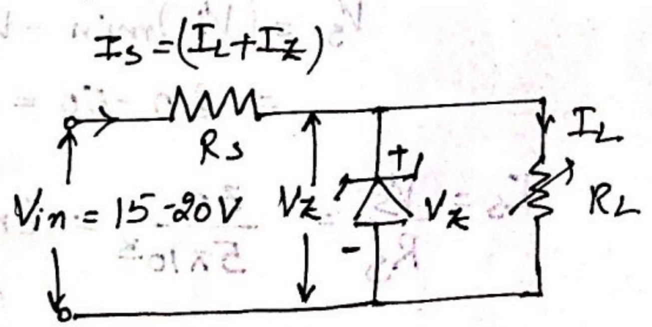
$I_{ZM} = 50mA$ Ans.

Ques. A zener diode regulator has to suppy a load current that changes from 0-200mA at 10V. Input voltage ranges from 15-20V. Zener diodo stabilizes at a min. current of 10mA. Find the series resistance.

$I_L = 0-200mA$

$V_Z = 10V$

$(I_Z)_{min} = 10mA$



If I_Z is min. $(I_Z)_{min}$, then load current will be max $(I_L)_{max}$ and i/p voltage will be $(V_{in})_{min}$.

∴ Total current through R_S

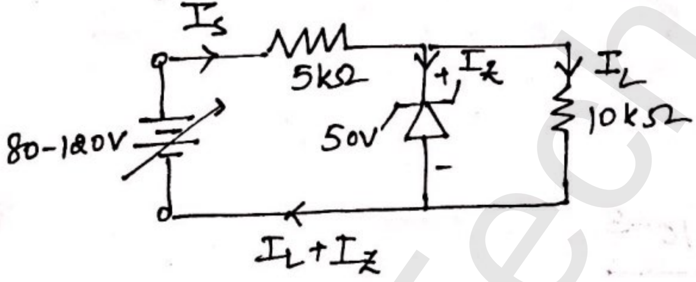
$$I_S = (I_Z)_{min.} + (I_L)_{max}$$
$$= (10 + 200)mA$$
$$= 210 mA$$

voltage across R_S, $V_S = (V_{in})_{min} - V_Z$

$$= (15-10)V = 5V$$

$$R_S = \frac{V_S}{I_S} = \frac{5}{210} = 23.8\Omega$$

Ques. For the circuit shown in fig., find the max. and min. values of Zener current.



solution:-

(i) For min. current, input voltage should be min.

$V_{in} = 80V$

$V_Z = 50V$

from KVL, $(V_{in})_{min} = V_S + V_Z$

$$V_S = (V_{in})_{min} - V_Z$$
$$= 80 - 50 = 30V$$

$$I_S = \frac{V_S}{R_S} = \frac{30}{5\times10^3} = 6mA$$

$$\therefore I_L = \frac{V_L \text{ or } V_Z}{R_L} = \frac{50}{10} = 5mA$$

$$I_S = I_Z + I_L$$

Min. value of $I_Z = I_S - I_L$

$= 6 - 5 = 1\,mA$

(ii) for max. value of Zener current

$V_{in} = 120V$

$V_Z = 50V$

$(V_{in})_{max} = V_S + V_Z$

$V_S = 120 - 50$

$V_S = 70V$

$I_S = \dfrac{V_S}{R_S}$

$I_S = \dfrac{70}{5\times10^3} = 14\,mA$

Since $I_L = 5\,mA$

$(I)_{Z\,max} = I_S - I_L$

$= 14 - 5 = 9\,mA.$

Ques. A varactor diode with a linearly graded junc^n^ has a capacitance of 100 μF when no bias is applied to the diode. Determine the junc^n^ capacitance for the Si diode when reverse bias of 8 V is applied to the diode

Sol^n^ :-

$C_T(0) = 100\,pF$

$V_K = 0.7V$

$V_R = 8V$

$n = 1/3$

$$C_T(V) = \frac{C_T(0)}{\left(1+\frac{V_R}{V_K}\right)^n} = \frac{100}{\left(1+\frac{8}{0.7}\right)^{1/3}} = 43.18\,PF$$

Ques. A Varactor diode has a capacitance of 15 pF at 5V reverse bias voltage. Determine the capacitance if the diode bias voltage is increased to 20V

Solⁿ: Given, $C_1 = 15\,\mu F$
$V_1 = 5V$
$V_2 = 20V$

$$C \propto \frac{1}{V^{1/2}}$$

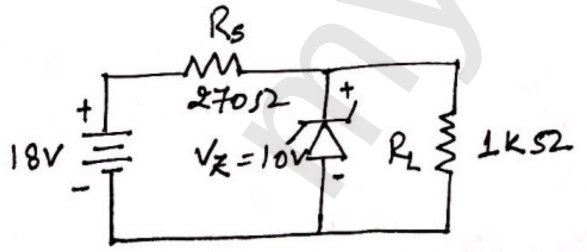
$$\therefore \frac{C_1}{C_2} = \sqrt{\frac{V_2}{V_1}}$$

$$\Rightarrow C_2 = \sqrt{\frac{V_1}{V_2}} \cdot C_1$$

$$= \sqrt{\frac{5}{20}} \times 15$$

$$\boxed{C_2 = 7.5\,pF}$$ Ans.

Ques. If the zener diode of the fig. is operating in the breakdown region? If yes, calculate
(i) I_S (ii) I_L and (iii) I_Z



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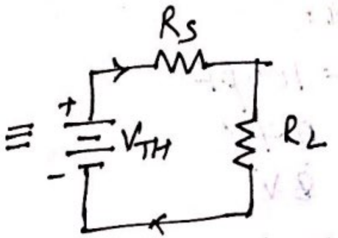


Thevenin Equivalent Circuit.

Yes, the zener diode of above fig. is operated in breakdown region.

(i) Condⁿ for breakdown operation $V_{TH} > V_L$

$$V_{TH} = \left(\frac{R_L}{R_L + R_S}\right) \cdot V_{in} = 14.2V$$

Since Thevenin Voltage is greater than Zener Voltage, The Zener diode is opereating in breakdown region

$$I_S = \frac{V_{in} - V_Z}{R_S}$$

$$= \frac{18-10}{270} = 29.6mA$$

(ii) Load current $I_L = \frac{(V_L = V_Z)}{R_L}$

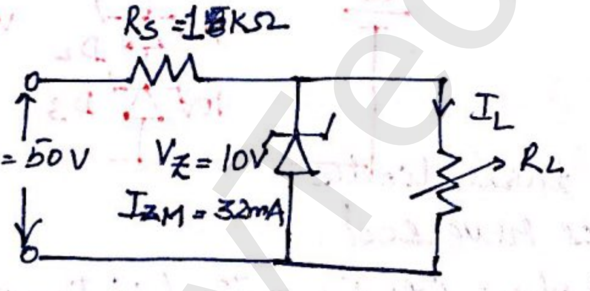
$$= \frac{10}{10^3} = 10mA$$

(iii) Zener current $I_Z = I_S - I_L$

$$= (29.6 - 10)mA$$

$$= 19.6mA.$$

Ques. A Zener diode rated 10V, 32mA can be considered ideal. Calculate the range of R_L (load) and I_L for V_L to maintained constant. What is max. wattage consumed by diode.



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

$$= \frac{1\times10^3 \times 10}{50-10} = \frac{10K\Omega}{40} = 250\Omega$$

The Voltage across the resistor R

$$V_R = V_i - V_Z$$

$$= (50-10)V = 40V$$

Thus $I_R = \frac{V_R}{R_S} = \frac{40}{1\times10^3} = 40mA.$

The min. level of I_L

$$I_{L\,min.} = I_R - I_{Zm}$$
$$= 40mA - 32mA$$
$$= 8mA.$$

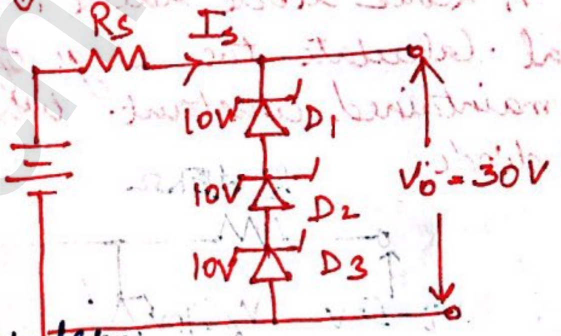
Now, determining the max. value of R_L

$$R_{L\,max} = \frac{V_Z}{I_{L\,min.}} = \frac{10V}{8mA} = 1.25\,K\Omega$$

The max. wattage rating of the diode

$$P_{Z\,max} = V_Z I_{Zm} = 10\times 32\times 10^{-3}$$
$$= 320mW$$

Ques. What value of series resistance is required when three 10W, 10V, 1000mA zener diodes are connected in series to obtain a 30V regulated output from a 45V input supply.



$V_{in} = 45V$

$V_o = 30V$

$I_Z = 1000mA$

To obtain 30V O/P, all three diodes are connected in series reversed biased. Let output is open i.e. $I_Z = I_S$ $(\because I_L = 0)$

∴ From Kirchoff's Voltage law,

$$V_{in} = I_S R_S + V_{D1} + V_{D2} + V_{D3}$$

$$R_S = \frac{V_{in} - (V_{D1} + V_{D2} + V_{D3})}{I_Z\,(= I_S)}$$

$$= \frac{45 - 30}{1000\times 10^{-3}}$$

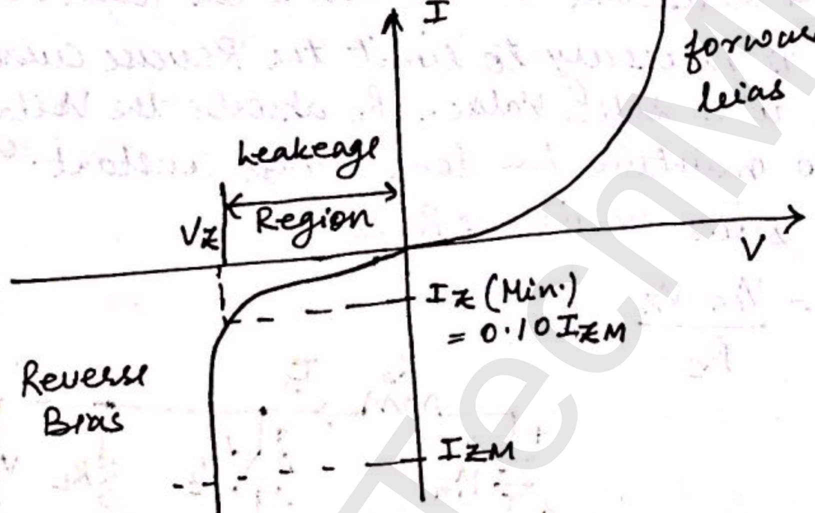
$$= 15\Omega$$

SPECIAL DIODES

ZENER DIODE

Normal p-n junc^n diode Can easily opereate in F.B. and also in R.B. If the reverse voltage exceeds the breakdown voltage, large current flows through the junc^n, which may destroy the diode. The Zener diode may be designed to opereate in breakdown region. The Voltage across Zener diode is almost constant over most of the breakdown region.

* Zener diode normally remains safe as long as current doesnot exceeds the max. permissible value I_{ZM}. If current is greater than I_{ZM}, the diode may be destroyed



V-I char of Zener diode

circuit symbol.

* It is found that V-I curve is similar to that of a normal diode in the forward region. A very small current flows in the leakeage region. As reverse voltage reaches the breakdown voltage V_Z, breakdown occurs.

Power dissipation through Zener diode

$$P_Z = V_Z I_Z$$

and $$I_{ZM} = \frac{P_{ZM}}{V_Z}$$

where I_{ZM} = max. rated Zener current

P_{ZM} = Power rating and V_Z = Zener Voltage.

There are two mechanisms for large reverse current in breakdown region :- (i) Avalanche Breakdown
(ii) Zener Breakdown.

Zener diode as Voltage Regulator

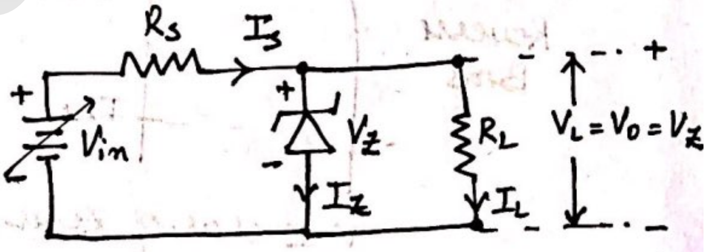
Zener diode under R.B. maintains a constant voltage across itself even if current through it changes. This property of Zener diode is exploited to design a voltage regulator circuit for maintaining the output voltage of power supply constant.

- Fig. shows the circuit of voltage regulator. The Zener diode is R.B. so that it can operate in breakdown region and maintain the load voltage constant (equal to Zener Voltage). Any variation of input voltage or load resistance cannot disturb the load voltage.

A series resistor R_S is necessary to limit the Reverse current through Zener diode to a safer value. R_S absorbs the voltage fluctuations so as to maintain the load voltage constant.

The current through series resistance R_S is

$$I_S = \frac{V_{in} - V_Z}{R_S}$$



Zener Voltage Regulator circuit.

applying KCL,

$$I_S = I_Z + I_L$$

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

$(V_L = V_Z)$

→ When Vin increases, I_S increases and at the same time I_Z also increases without much change in Zener voltage. Hence load voltage $(V_L = V_Z)$ remains constant.

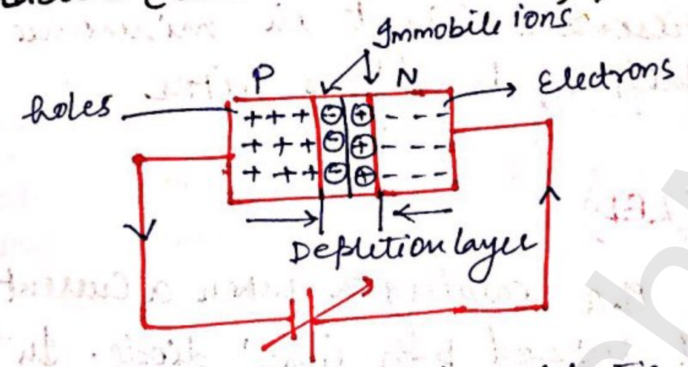
→ On the other hand, R_L decreases by keeping input voltage V_{in} constant and load current I_L increases.

→ Since I_S remains constant, I_Z will be decreased. Any small change in I_Z will not affect Zener voltage so, o/p voltage V_L remains constant.

VARACTOR DIODE

It is a two terminal p-n junc^n diode with small doping. At the p-n junc^n depletion layer is formed which acts like a dielectric in a capacitor having a capacitance of the order of some pico-Farad (pF) known as junc^n barrier or transition capacitance (P and N regions of the diode behaving like plates of capacitor)

When diode is R.B., depletion width increases with the reverse voltage and its capacitance becomes smaller. Since thickness of depletion region varies with applied-bias voltage, capacitance of the diode can be made to vary. It is known as Varactor (Variable + reactor), Varicap etc.



(a) R.B. p-n junc^n with depletion layer

(b) circuit symbol.

"capacitance is inversely proportional to the square root of external applied voltage"

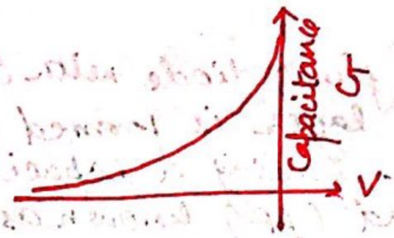
$$C_T(V) = \frac{K}{(V_T + V_R)^n} = \frac{C_T(0)}{\left(1 + \frac{V_R}{V_K}\right)^n}$$

where K is constant depends upon semiconductor material V_T is volt equivalent of temp. and V_R is reverse applied voltage

$n = \frac{1}{2}$ for alloyed junc^n and $n = 1/3$ for diffused junc^n

$C_T(0)$ is capacitance at zero voltage

V_K is potential barrier.



The above fig shows the Variation of capacitance with reverse Voltage. At 0V, depletion region is small and hence capacitance is large ($\approx 600pF$). Capacitance decreases with increase in reverse Voltage and it becomes approx. 30pF at reverse Voltage of 15V.

* Varactor diodes are used in FM reciever, TV recieves and in tuning of LC parallel resonant circuit in microwave freq. multiplier, parametric amplifier, band pass filter.

LIGHT EMITTING DIODE (LED)

The LED emits visible light of a wavelength when a current is passed through the forward biased p-n junc^n diode. In this electric current (electrons) are converted into light (Visible or invisible)

.LED and its circuit symbol.

A free electron in the conduction band recombines with a free hole in the valance band by crossing the barrier at the P-N junc^n. In the process of recombination, electromagnetic radiation of energy equals to the band gap of the semiconducting material, is released

Some semiconducting materials like GaAs, GaP, GaAsP etc. have Band gap energy in the range of about 1.5–3.0eV which provides radiations in the visible | infrared region. Freq. of emitted radiation is :-

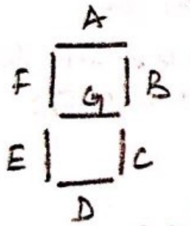
$$\nu = \frac{\Delta E_g}{h}$$

where h = planck's constant = 6.63×10^{-34} Js

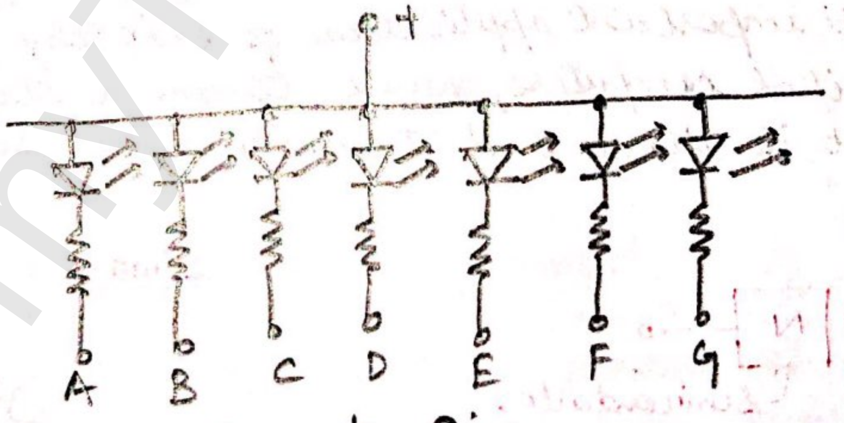
- LED's are widely used in small indicator, warning lights and in alphanumeric display devices (like Calculators etc.)
- LED's with invisible radiation may find application in remote control devices, burglar alarm system etc.
- Operation of LED ceases, if it is R.B. and eventually LED may get destroyed.

Seven-segment Display

It has seven LED's (A to G). Each LED is called a segment. Here external resistors are used to control the current to safe levels.



(a) Seven segment display



(b) Schematic Diag.

Typical value of forward voltage for a TTL 222 (green) varies from 1.8 V to 3V for a current of 25mA.

SCHOTTKY BARRIER DIODE

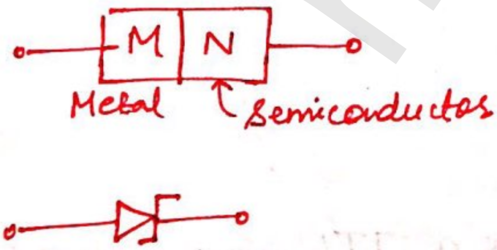
A diode consisting of a metal semiconductor (Schottky barrier) is shown in fig. which has V-I char. curve similar to ordinary PN-diode. It is unipolar device ~~because~~ because it has only electrons as majority carriers on both sides of the junc^n.

* A schottky diode differs from the P-N junc^n diode in that the diode forward voltage is lower for a commonly used material. (0.20V – 0.25V)

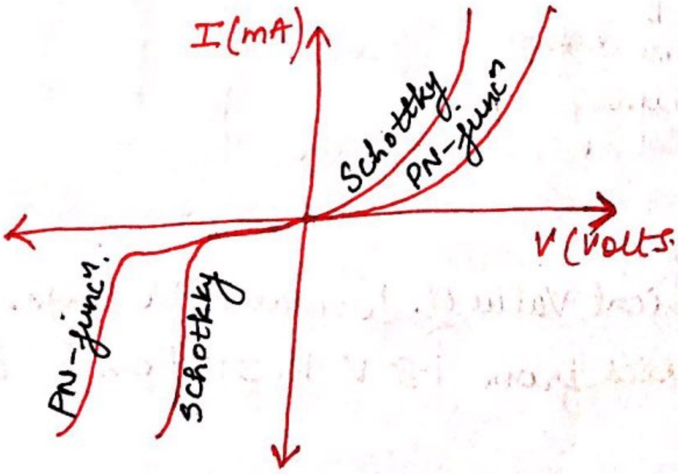
* In this diode no depletion layer is formed near the junc^n because of unipolar carriers (electrons). As a result no charge stored when it is opereated in forward bias.

* Schottky diode offers a lower resistance in F.B. due to large contact area b/w the metal and semiconductor when F.B. is applied electrons on the N- side gain sufficient energy so that it crosses the barrier and enters into the metal region. These high energy electron are known as hot carriers and diode is called as hot carrier diode.

* These diodes can rectify the signals of freq. upto 300MHz. Most important application of schottky diodes is in digital computers, where computer speed depends on how fast its diodes and transistors can switch ON & OFF



* Schottky diode and its circuit symbol



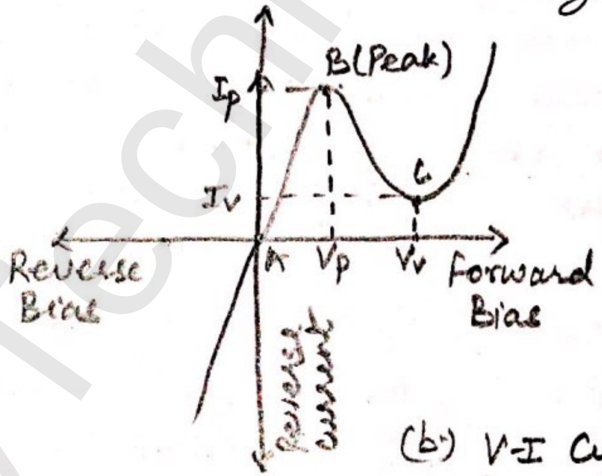
TUNNEL DIODE

It is also known as Esaki diode. It is a P-N junc^n diode with extremely high doping (1 part in 10^3) on each side of the junc^n. The P-N junc^n diode with nearly zero breakdown voltage is known as tunnel diode because of very thin depletion layer, electrons can tunnel across the junc^n in the F.B. voltage.

* With increasing forward bias, the tunnel effect contribution becomes small, as a result -ve resistance region is produced on the diode characteristics. Further increase in the bias voltage, producing V-I curve like that of an ordinary P-N junc^n. Tunneling occurs in both forward and reverse directions near to zero voltage ($V \neq 0$)

circuit symbol

(a.) circuit symbol



(b) V-I Curve of a tunnel diode.

* 'Do tunnel diode and ~~photodiode~~ photodiode from book'

= 'Do Piecewise linear model from Book'