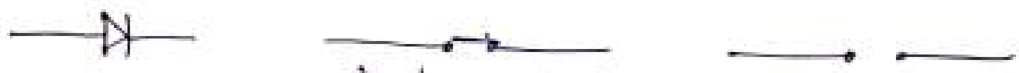
⇒ Diode Resistance

⇒ Ideal & Practical Resistance:

In an ideal diode resistance is zero in forward bias and infinite in reverse bias.



PN diode — Short circuited F.B, $R = 0\Omega$ — open circuited R.B $R = \infty$

Practical diode Resistance are

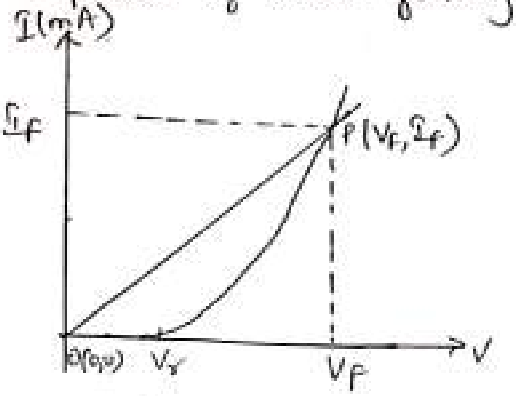
(i) DC (or) static resistance (iii) Average AC Resistance
(ii) AC (or) dynamic resistance (iv) Reverse Resistance
(iii) Average AC resistance
(iv) Reverse Resistance.

1.) DC (or) Static Resistance:

The resistance offered by the diode to the DC signal is called DC Resistance. (OR)

At any point the ratio of V/I is called DC resistance.

(OR) At any point on V-I characteristics, DC resistance is reciprocal of line joining origin to operating point (p)



$$\boxed{R = \frac{V_F}{I_F}}$$

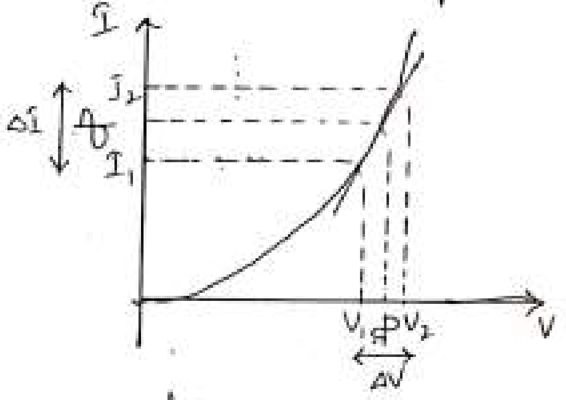
$$R = \frac{1}{\text{slope of line joining OP}}$$

$$R = \frac{1}{\frac{I_F}{V_F}} = \frac{V_F}{I_F}$$

2.) AC (or) Dynamic Resistance:

The resistance offered by the diode when the input is AC signal.

It is the reciprocal of slope of volt-ampere characteristics



$$r_d = \frac{1}{\text{Slope of V-I characteristics}}$$

$$\text{Slope} = \frac{\Delta I}{\Delta V}$$

$$\boxed{r_d = \frac{\Delta V}{\Delta I}}$$

$$r_d = \frac{dV}{dI} \quad \text{—— (1)}$$

$$I = I_0 (e^{V/nV_T} - 1) \quad \text{—— (2)}$$

$$I + I_0 = I_0 \cdot e^{V/nV_T} \quad \text{—— (3)}$$

diff (2) w.r.to V

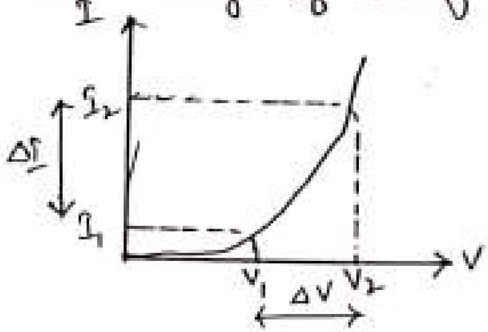
$$\frac{dI}{dV} = I_0 \cdot e^{V/nV_T} \times \frac{1}{nV_T}$$

$$r_d = \frac{dV}{dI} = \frac{nV_T}{I_0 \cdot e^{V/nV_T}} \quad \text{—— (4)}$$

$$r_d = \frac{nV_T}{I + I_0} \quad \text{as } I_0 \ll I \quad \boxed{r_d \approx \frac{nV_T}{I}}$$

3.) <u>Average AC Resistance:</u>

It is the resistance associated by the diode when the input signal is sufficiently large to produce a wide range of swing in current.



$$\text{Average AC Resistance} = \left.\frac{\Delta V}{\Delta I}\right|_{\text{point to point}}$$

4.) <u>Reverse Resistance</u>

Resistance offered by the diode in reverse biased.

Resistance is very high in reverse bias

$$\text{Reverse DC resistance} = \frac{V}{I_0}$$

$$\text{Reverse Dynamic resistance} = \frac{\eta V_T}{I_0 \, e^{V/\eta V_T}}$$

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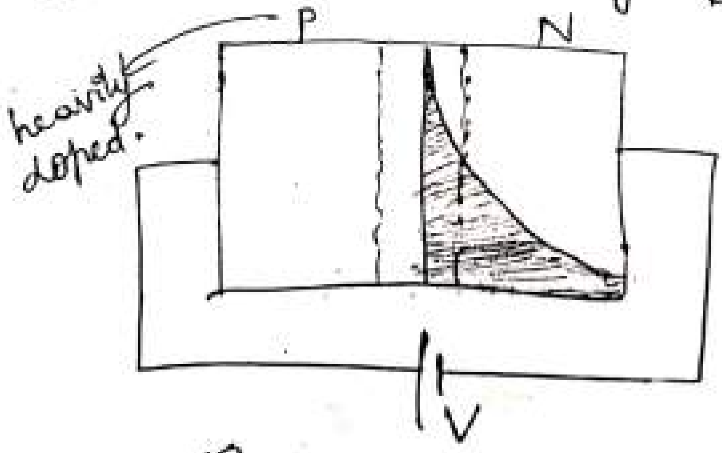
Capacitance:-

Diffusion capacitance:- In forward bias, the potential barrier at the junction is lowered and holes from p-side enter n-side and vice versa.

This process of minority carrier injection where the excess hole density falls off exponentially with distance is called <u>diffusion capacitance</u> 'C_D'

It is defined as rate of change of injected charge with applied voltage. This capacitance is also called '<u>storage capacitance</u>'.

<u>Derivation</u>:- For simplicity, we assume that one side say <u>p-material</u> is <u>heavily doped</u> in comparison with '<u>n-side</u>', that the current 'I' is carried across the function entirely by holes moving from p-side to n-side. (or) '<u>$I = I_{pn}(0)$</u>'. The excess minority charges 'Q' will then exist only on n-side and is given by the shaded area in the figure multiplied by the diode cross section 'A' and electronic charge 'e'.



$$Q = \int_0^\infty A e P_n(0) e^{-x/L_p} dx.$$

$$= A e P_n(0) \left[\frac{e^{-x/L_p}}{\left(\frac{-1}{L_p}\right)}\right]_0^\infty.$$

$$Q = AeL_p P_n(0) \longrightarrow ①$$

$$C_D = \frac{dQ}{dV} = AeL_p \frac{d(P_n(0))}{dV} \longrightarrow ②$$

The hole current 'I' is given by $I_{pn}(x)$ with $x=0$ (or) $I_{pn}(x) = \frac{AeD_p P_n(0)}{L_p} e^{-x/L_p}$.

at $x=0$; $I = \frac{AeD_p P_n(0)}{L_p} \longrightarrow ③$

$$P_n(0) = \frac{IL_p}{AeD_p} \longrightarrow ④$$

$$\frac{dP_n(0)}{dV} = \frac{L_p}{AeD_p}\left(\frac{dI}{dV}\right) \longrightarrow ④$$

Substitute ④ in ②

$\therefore C_D = AeL_p \cdot \frac{L_p g}{AeD_p}$

$g = \frac{dI}{dV}$ = diode conductance.

$$\boxed{C_D = \frac{L_p^2 g}{D_p}}$$

$$\boxed{\frac{dP_n(0)}{dV} = \frac{L_p g}{AeD_p}} \longrightarrow ④$$

Since, ~~from~~ eq ② the mean life time for holes,

$\tau_p = \tau$ is given by

$$\tau = \frac{L_p^2}{D_p}$$

$$\therefore \boxed{C_D = \tau g}$$

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From diode resistance, $r = \frac{\eta V_T}{I}$.

$$\Rightarrow g = \frac{I}{\eta V_T}.$$

$$\therefore \boxed{C_D = \frac{\tau I}{\eta V_T}}$$

$\therefore C_D \propto I$.

- diode current I is due to holes only.

$\therefore C_D$ is also due to holes.

Similarly C_D for $e^{\ominus}$'s is obtained.

Total C_D = C_D for holes + C_D for $e^{\ominus}$'s.

⇒ Effect of temperature on PN Junction diode :-

→ The rise in temperature increases the generation of $\bar{e}$-hole pairs in semiconductors, & increases their conductivity. As a result, the current through the PN diode increases with temperature as given by the diode-current equation

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

The reverse saturation current 'I_0' of a diode increases approximately "7% per degree centigrade for both Silicon & germanium or I_0 doubles for every 10° rise in temperature".

→ Hence, if the temperature is increased at fixed voltage, the current increases. To bring the current to its original value, the voltage has to be reduced. It is found that at room temperature for either germanium or silicon,

$$\frac{dV}{dT} = -2.5 mV/°C$$ in order to maintain the current 'I' at a constant value.

⟹ Diode Switching times:-

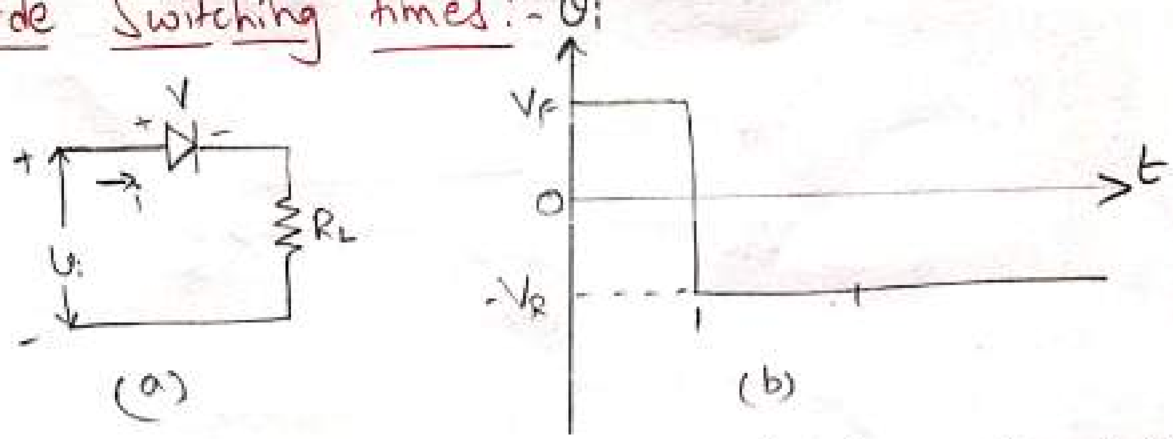


Fig1: Forward biased diode (a) circuit (b) input Voltage characteristics.

→ Diodes are often used in switching mode as shown in ~~above~~ Fig 1. When a forward Voltage is applied to the diode, the diode is in ON state. When the applied bias voltage to the PN diode is suddenly reversed in the opposite direction, the minority charge carriers in the P & N sides of the diode are not instantaneously removed & hence the diode is not switched to OFF-state immediately.

→ The diode response reaches a steady state only after an interval of time, called the recovery time.

→ The forward recovery time t_{fr}, is defined as the time required for forward Voltage or current to reach a specified value after switching the diode from its reverse - to forward - biased state.

→ The reverse recovery time, t_{rr}, has to be considered in practical applications.

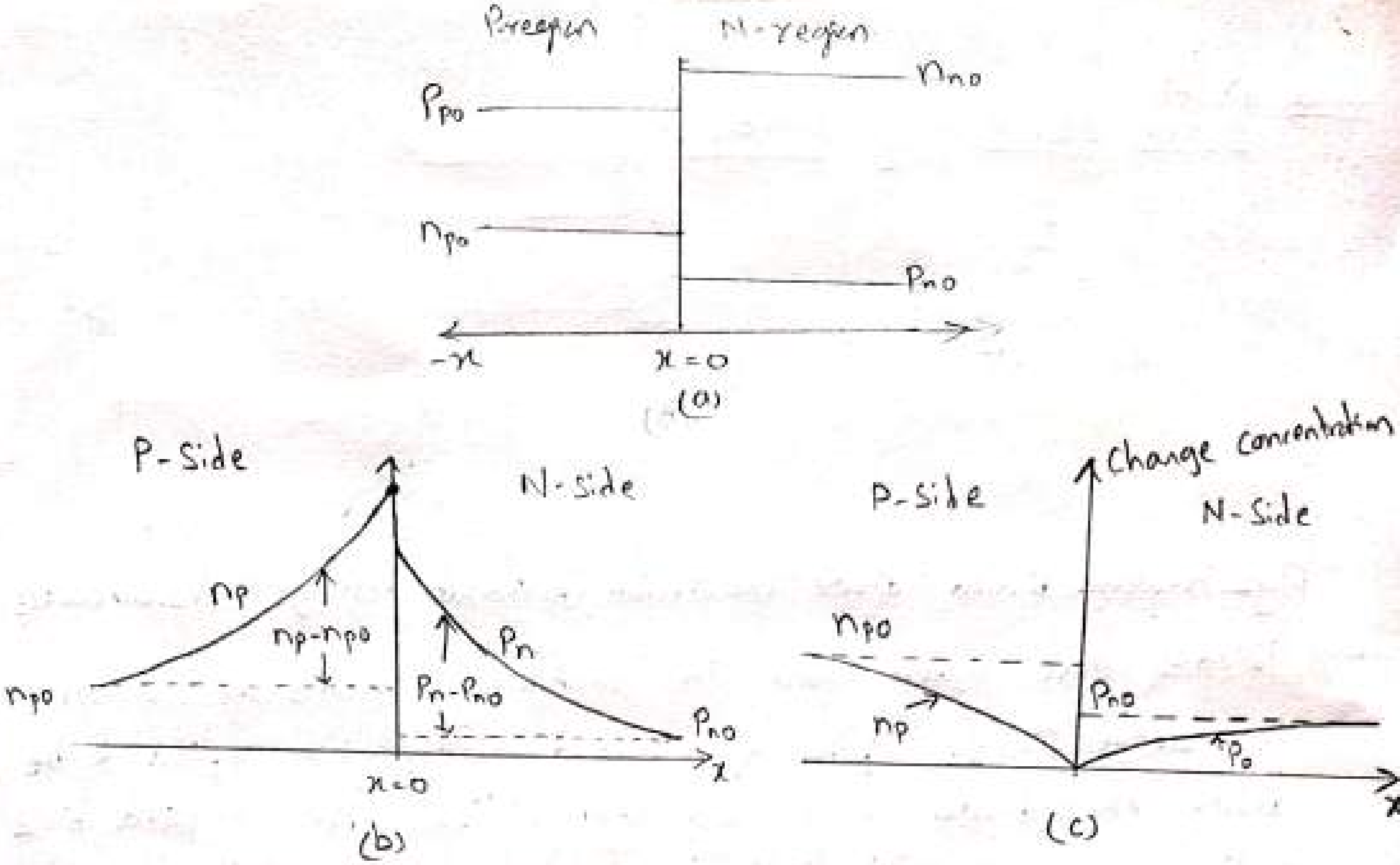


Fig 2: change carrier concentration with respect to distance x.

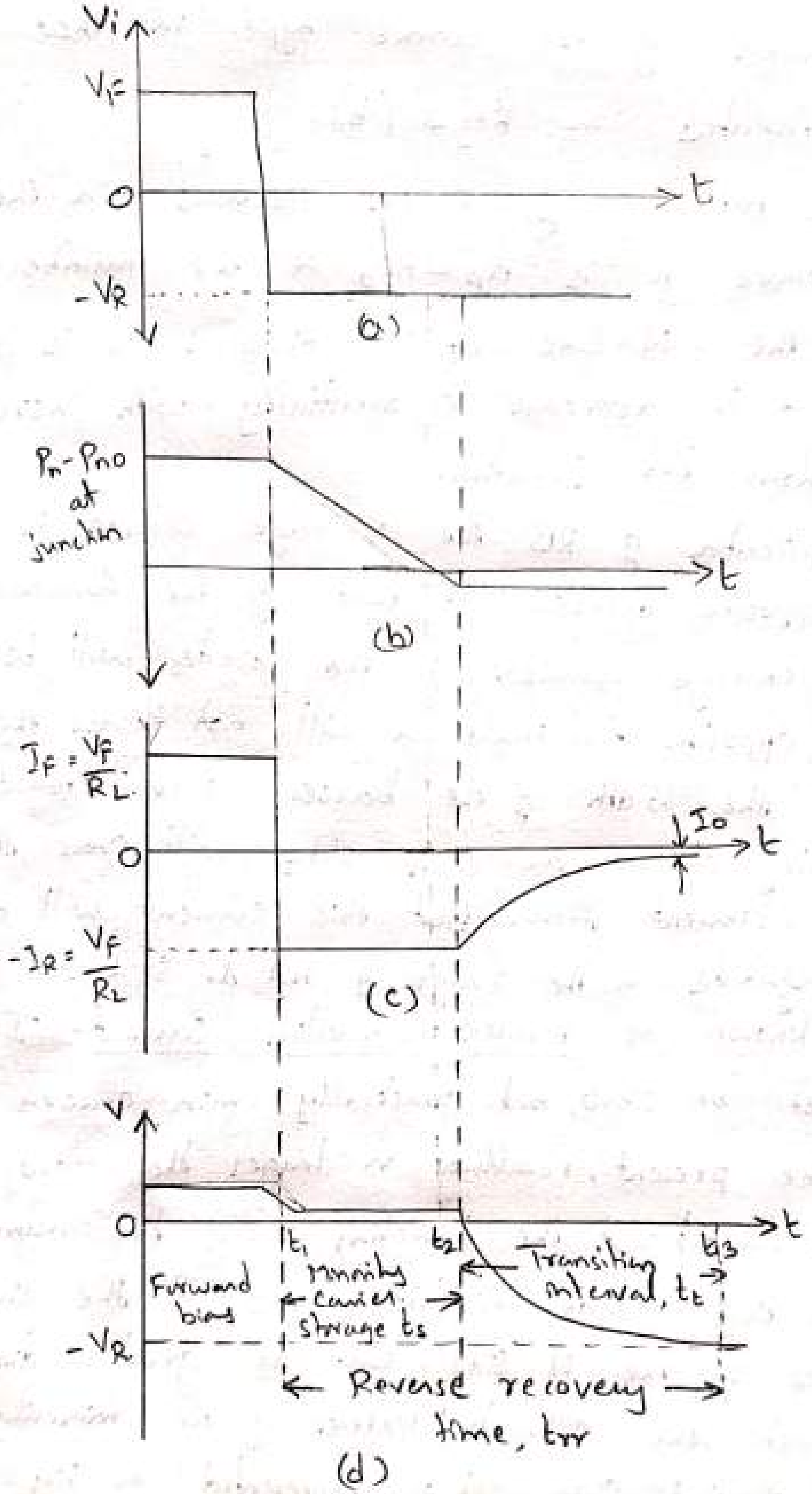
→ It is assumed that the N-side of the diode is heavily doped than the p-side. The distribution of Carrier Concentration over a distance x from the junction by neglecting the space change region is drawn as shown in Fig 2(a). Here n_{po}, p_{no} are minority change carriers & n_{no}, p_{po} are majority change carriers.

→ When the diode is FBed, the +ve terminal is connected to the p-side & the negative terminal is connected to the N-side. The holes in the p-side are repelled & they recombine with electrons in the N-side & vice versa for the electrons in the N side.

→ Therefore, at the junction x=0, the concentration of Specific change carriers will be maximum but decreases exponentially on entering the oppositely changed region until it reaches the concentration of the minority change carriers of the same type in that region. It is represented in fig 2 (b).

→ Now, the number of excess electrons in the p-side at a distance x is $n_p - n_{po}$ & the number of excess holes in the N-side at a distance x is $P_n - P_{no}$. Both n_p & P_n decrease exponentially with increase in distance from the junction.

→ On application of RB, the voltage source is connected in the opposite direction to that of the forward bias. Majority charge carriers in the diode will be attracted by its opposite terminals & will not cross the junction, & hence the width of the barrier will increase. However, the minority carriers on each side will cross the junction & hence current flows. But this current will be very less in magnitude in the range of nA for Si & μA for Ge. This is known as reverse saturation current. Ideally, this must be zero, but practically, min carriers will always be present, resulting in larger than zero reverse saturation current. At the junction x = 0, the number of e⁻'s in the p-side becomes zero & the same for the holes in the N-side. But at greater distances, it will reach the saturation values of the minority charge carriers of that side. It is represented in Fig 2(c).



Fig(3): switching characteristics of a PN Junction diode.

→ When the PN Jn diode is FB, the minority $\bar{e}$ concentration in the P-region is approx. linear. If the j'n is suddenly RB^sed, at t_1, then because of this stored electronic charge, the reverse current (I_R) is initially of the same magnitude as the forward current (I_F). The diode will continue to conduct until the injected or excess minority carrier density $(P-P_0)$ or $(n-n_0)$ has dropped to zero. However, as the stored electrons are removed into the N-region & the contact, the available charge quickly drops to an equilibrium level & a steady current eventually flows corresponding to the reverse bias voltage as shown in figure 3(b).

→ A shown in fig 3(a), the applied voltage $V_i = V_F$ for the time upto t_1 is in the direction to FB the diode. The resistance R_L is large so that the drop across R_L is large when compared to the drop across the diode. Then the current is $I \approx \frac{V_F}{R_L} = I_F$. Then, at the time $t = t_1$, the input voltage is suddenly reversed to the value of $-V_R$. Due to the reasons explained above, the current does not become zero & has the value $I = \frac{V_R}{R_L} = -I_R$ until the time $t = t_2$. At $t = t_2$, when the excess minority carries have reached the equilibrium stage, the magnitude of the diode current starts to decrease as shown in fig 3(c).

→ During the time interval from t_1 to t_2, the injected minority carriers have remained stored & hence, this time interval is called the storage time (t_s)

→ After the instant $t = t_2$, the diode gradually recovers & ultimately reaches the steady state.

The time interval between t_2 & the instant t_3 when the diode has recovered nominally, is called the transition time, t_t. The recovery is said to have completed

(i) When even the minority carriers remote from the junction have diffused to the junction & crossed it, &

(ii) When the junction transition capacitance C_T, across the reverse-biased junction has got charged through the external resistor R_L to the voltage $-V_R$.

→ As shown in fig 3(d), reverse recovery time of a diode, t_{rr}, is the interval from the current reversal at $t = t_1$ until the diode has recovered to a specified extent in terms either of the diode current or of the diode resistance, i.e, $t_{rr} = t_s + t_t$.

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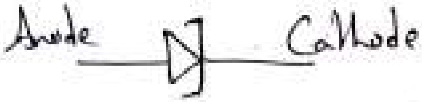
TUNNEL DIODE (ESAKI DIODE)

- It was introduced by Leo Esaki in 1958.
- Heavily doped PN junction - Impurity concentration is 1 part in 10^3 as compared to 1 part in 10^8 in PN Junction diode.
- Width of the depletion layer is very small (about 100A)
- It is generally made up of Ge & GaAs
- It shows tunneling phenomenon.
- Circuit Symbol of tunnel diode is



⟹ Electric Current in tunnel diode

- In tunnel diode, the valence band & Conduction band energy levels in the n-type semiconductor are lower than the valence band & Conduction band energy levels in the p-type semiconductor
- Quantum mechanics says that electrons will directly penetrate through the depletion layer or barrier if the depletion width is very small.
- The depletion layer of tunnel diode is very small. It is in nanometers. So the e⁻s can directly tunnel across the small depletion region from n-side CB to into the p-side VB.

- In TDs, the electrons need not overcome the opposing force from the depletion layer to produce electric current. The electrons can directly tunnel from the conduction band of n-region into the valence band of p-region. Thus, electric current is produced in tunnel diode.

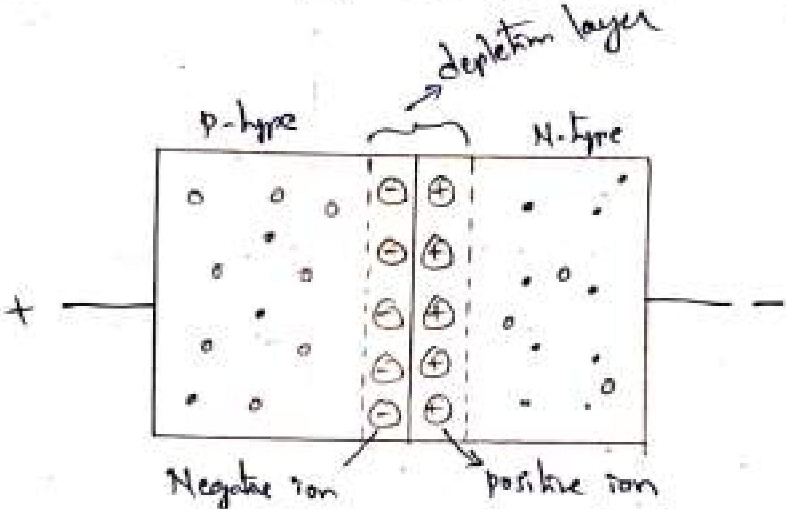
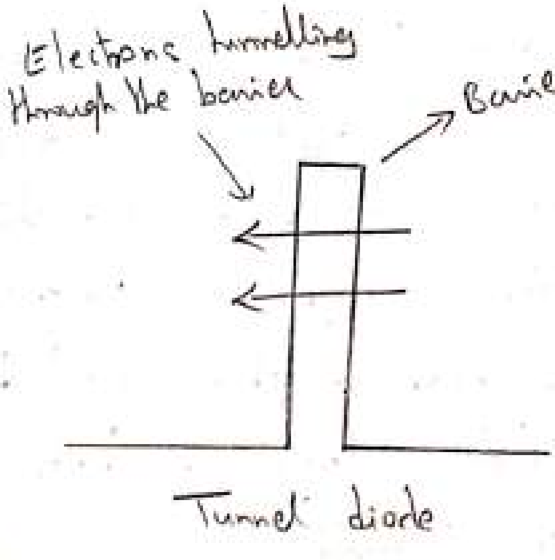
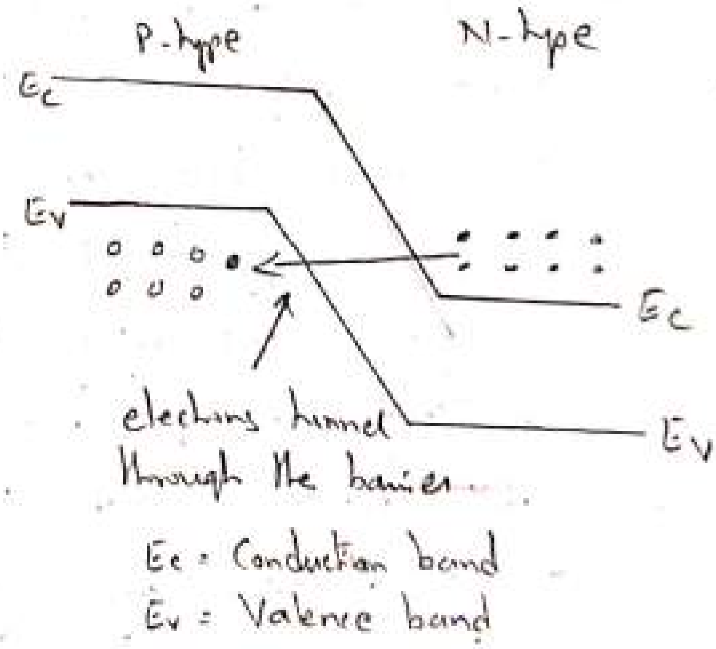


Fig: Forward bias tunnel diode

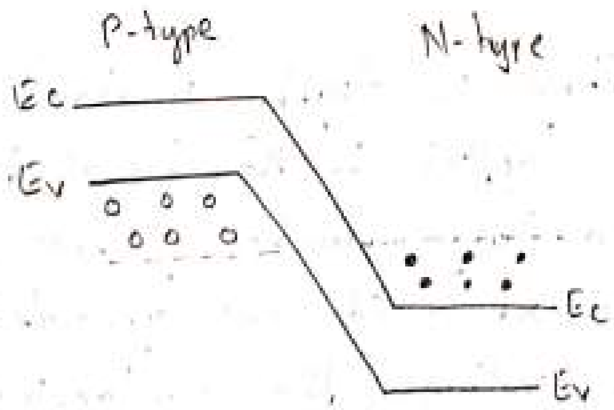


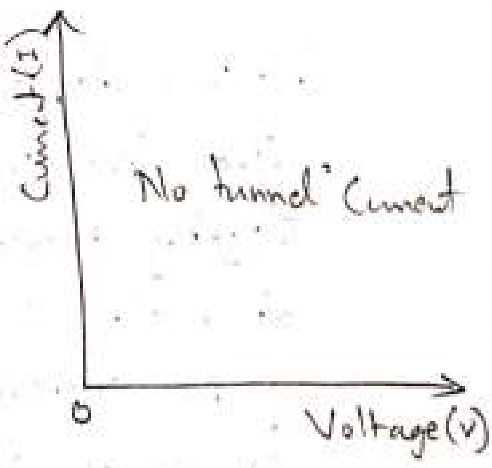


⟹ How tunnel diode works.

STEP 1: Unbiased tunnel diode.

- When no Voltage is applied to the tunnel diode, it's said to be an unbiased tunnel diode. In tunnel diode, the conduction band of the n-type material overlaps with the valence band of the p-type material because of the heavy doping.
- Because of this overlapping, the conduction band electrons at n-side and Valence band holes at p-side are nearly at the same energy level. So when the temperature increases, some electrons tunnel from CB of n-region to the VB of p-region. In a similar way, holes tunnel from the VB of p-region to the CB of n-region.
- However, the net Current flow will be zero because an equal number of charge carriers (Free electrons and holes) flow in opposite directions.

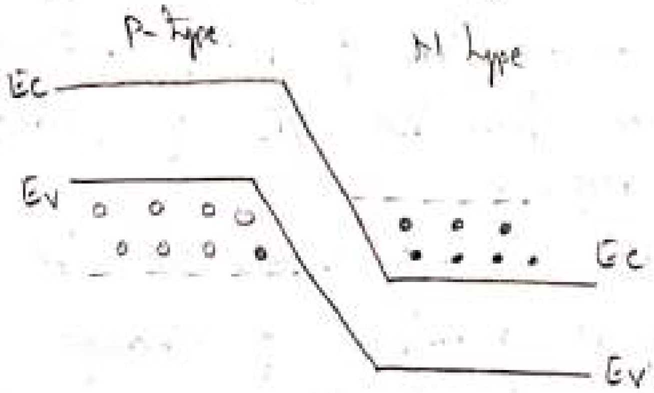


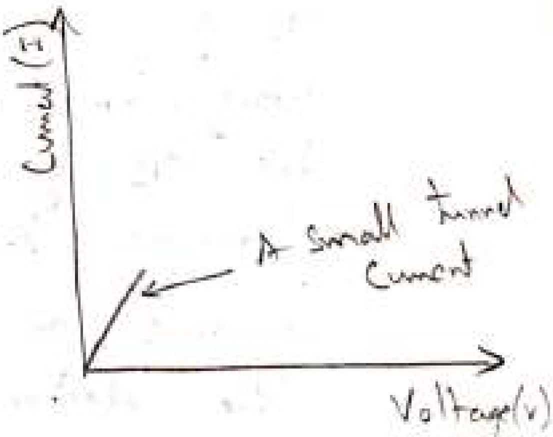


Unbiased tunnel diode

Step 2: Small Voltage applied to the tunnel diode

- When a small voltage is applied to the tunnel diode which is less than the built-in voltage of the depletion layer, no forward current flows through the junction.
- However, a small number of electrons in the conduction band of the n-region will tunnel to the empty states of the valence band in p-region. This will create a small forward bias tunnel current. Thus, tunnel current starts flowing with a small application of voltage.

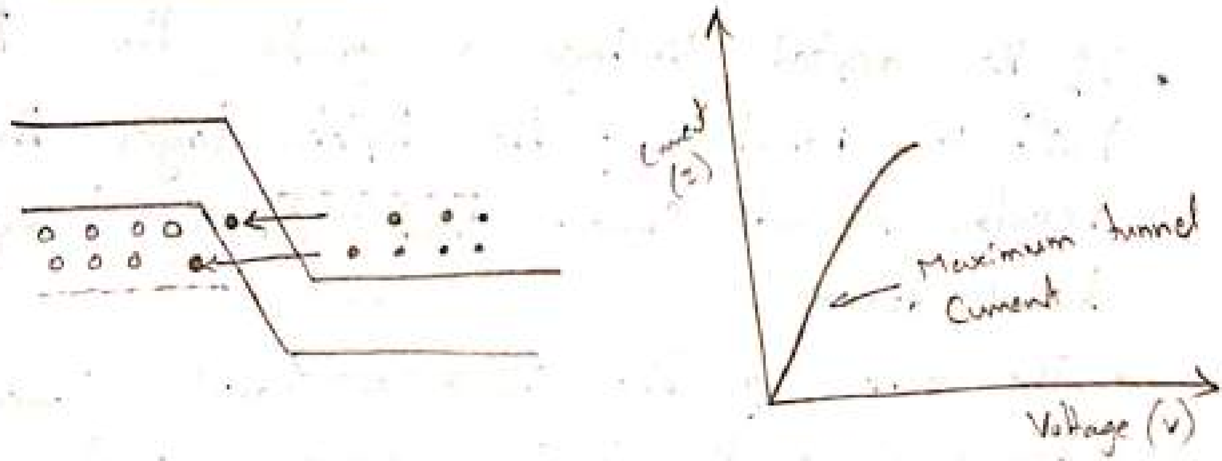




Small tunnel current

Step 3: Applied Voltage is slightly increased.

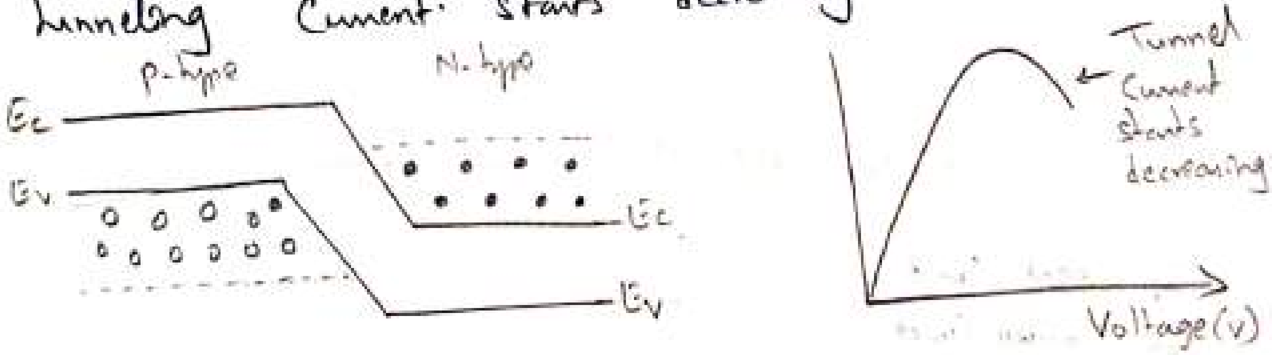
- When the voltage applied to the tunnel diode is slightly increased, a large number of free electrons at n-side & holes at p-side are generated. Because of the increase in voltage, the overlapping of the CB & VB is increased.
- In simple words, the energy level of an n-side CB becomes exactly equal to the energy level of a p-side VB. As a result, maximum tunnel current flows.



Maximum tunnel Current

Step 4 : Applied Voltage is further increased

- If the applied Voltage is further increased, a slight misalign of the CB & VB takes place.
- Since the CB of the n-type material & the VB of the p-type material still overlap. The electrons tunnel from the CB of n-region to the VB of p-region & cause a small current flow. Thus, the tunneling current starts decreasing.

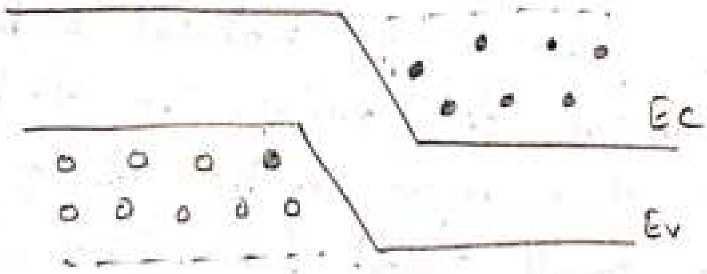


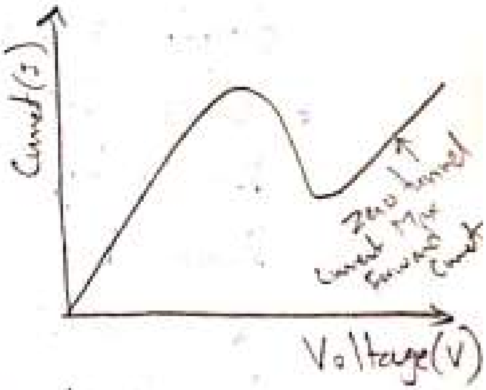
Tunnel Currents starts decreasing

Step 5 : Applied Voltage is largely increased

- If the applied Voltage is largely increased, the tunneling current drops to zero. At this point, the CB & VB no longer overlap & the tunnel diode operates in the same manner as a normal p-n junction diode.

- If this applied Voltage is greater than the built in potential of the depletion layer, the regular forward Current starts flowing through the tunnel diode.
  - The portion of the Curve in which Current decreases as the Voltage increases is the negative resistance region of the tunnel diode. The negative resistance region is the most important & most widely used characteristic of the tunnel diode.

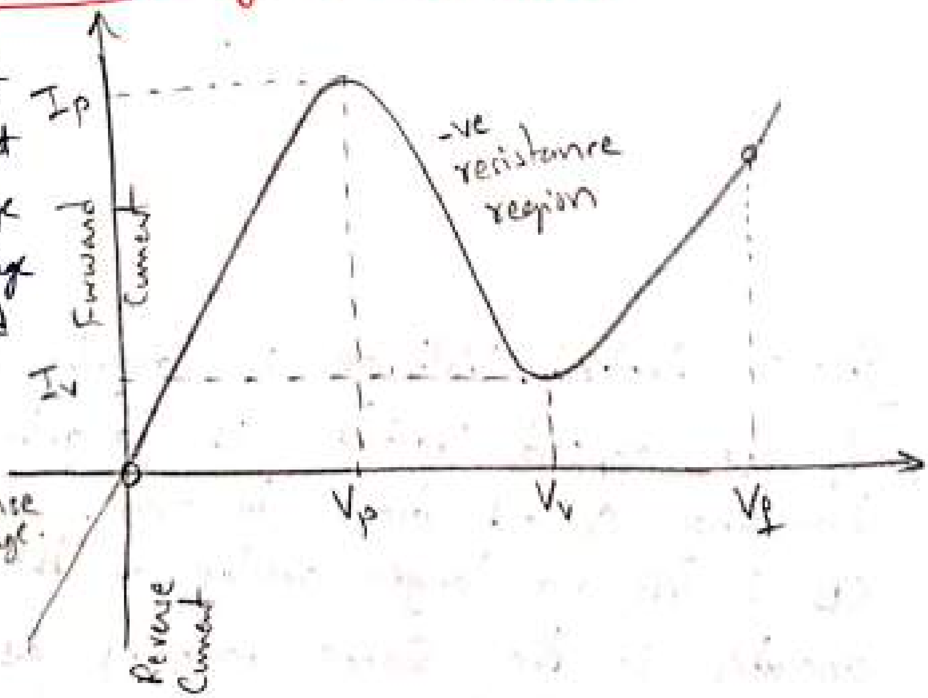




Zero tunnel Current
Maximum forward Current

Characteristics of Tunnel diode

Ip - peak Current
Iv - Valley Current
Vp - peak Voltage
Vv - Valley Voltage
Vf - peak forward Voltage.



Advantages of tunnel diode

- long life
- High speed operation
- low noise
- low power consumption

Disadvantages of tunnel diodes

- Tunnel diodes cannot be fabricated in large numbers
- Being a two terminal device, the input & output are not isolated from one another

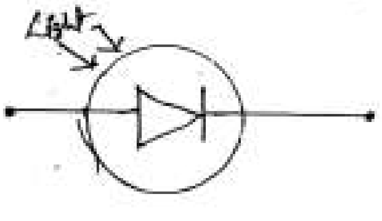
Applications of tunnel diode

- Tunnel diodes are used as logic memory storage devices.
- Tunnel diodes are used in relaxation oscillator circuits.
- Tunnel diode is used as an ultra high-speed switch.
- Tunnel diodes are used in FM receivers.

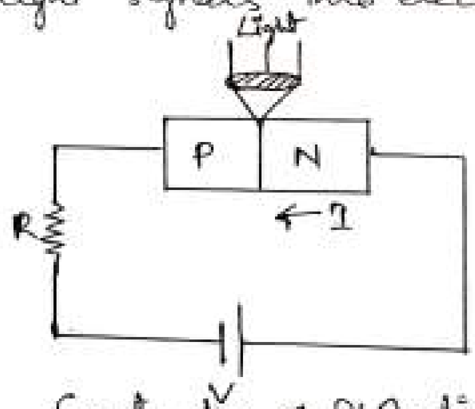
PHOTO DIODE

Silicon photodiode is a light sensitive device also called photo detectors, which converts light signals into electrical signals.

Construction & Symbol:



Symbol of Photodiode



Construction of Photodiode

The diode is made of semiconductor PN junction kept in a sealed plastic or glass casting The cover is so designed that the light rays are allowed to fall on one surface across the junction and remaining sides of plastic are either black (or) embedded in a metallic case.

<u>Principle of Operation</u>

A lens permitts light to fall on the junction. When light falls on reverse biased PN photo diode junction then the photons in the light collide with p-n junction & some energy is imparted to valence electrons of Si-atom hence ~~eb~~ hole-electron pairs are created. The movement of hole-electron pairs results in current flow. The magnitude of the photo current depends on number of charge carriers generated & hence on the illumination of diode element. This current also affected by the frequency of light falling on junction of photodiode. The magnitude of current under large reverse bias is given by

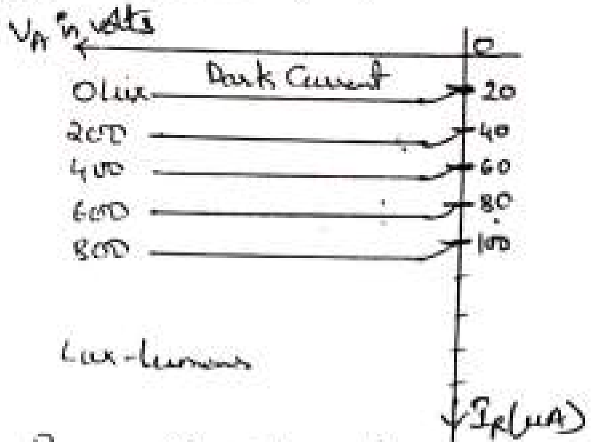
$$I = I_s + I_0 (1 - e^{V/\eta V_T})$$

where I_s - short circuit current which is proportional to light intensity

I_0 - reverse saturation current.

<u>Characteristics</u>

The reverse current increases in direct proportion to level of illumination. Even when no light is applied, there is a minimum reverse leakage current called dark current, flow through the device. Germanium has a higher dark current than Silicon. It also has a higher level of reverse current.



Reverse Bias Characteristics

<u>Applications:-</u>

They are used in computer card punching & tapes, light operated switches, sound track films & electronic control circuits

Diode Clipping Circuits:

Definition: Clipper Circuits are the Circuits that clip off or removes a portion of an input signal, without causing any distortion to the remaining part of the Waveform. These are also Known as Clippers, Clipping Circuits, limiters, slicers etc.

→ Clippers are basically wave shaping Circuits that Control the shape of an Output Waveform. It Consists of linear and non-linear elements but does not contain energy storing elements.

→ The Basic Operation of diode clipping Circuits is such that, in forward biased Condition, the diode allows current to pass through it, clamping the Voltage. But in reverse biased Condition no any Current flows through the diode, and thus Voltage remains unaffected across its terminals.

→ Clipper circuits are basically termed as Protection devices. As electronic devices are Voltage sensitive and Voltage of large amplitude can permanently destroy the device. So, in order to Protect the device clipper circuits are used.

→ Usually, Clippers employ resistor-diode Combination in its

Types of Clippers

Positive Series Clippers

Negative Series Clippers

Parallel Positive Clippers

Parallel Negative Clippers

Clipping of Both Half Cycles

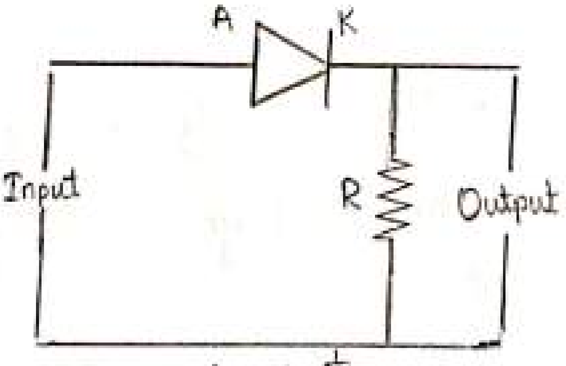
Positive Bias Diode Clipping

Negative Bias Diode Clipping

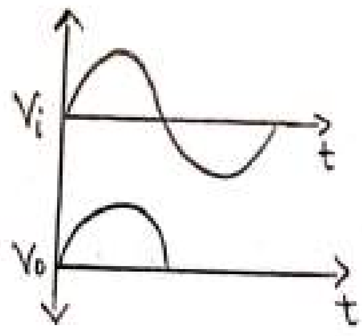
1.) Series Negative Clipper

During the Positive half Cycle the diode (considered as Ideal diode) appears in the forward biased and Conducts such that the entire positive half Cycle of input appears across the resistor Connected in parallel as Output Waveform.

→ During the negative half Cycle the diode is in negative biased. No Output appears across the resistor. Thus, it clips the negative half cycle of the input waveform, and therefore, it is called as a series negative clipper.

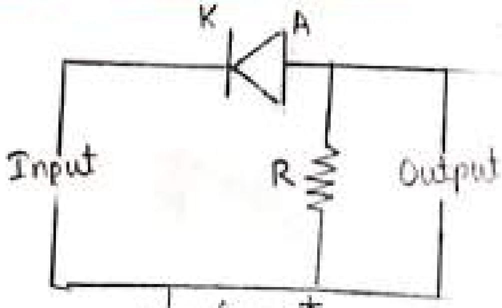


Circuit

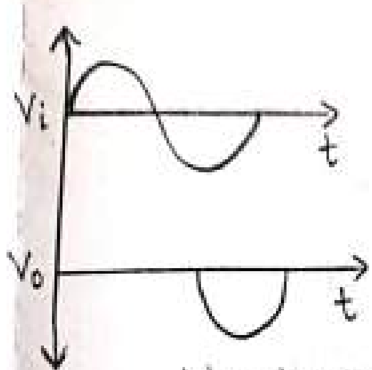


Waveforms

2) Series Positive Clipper



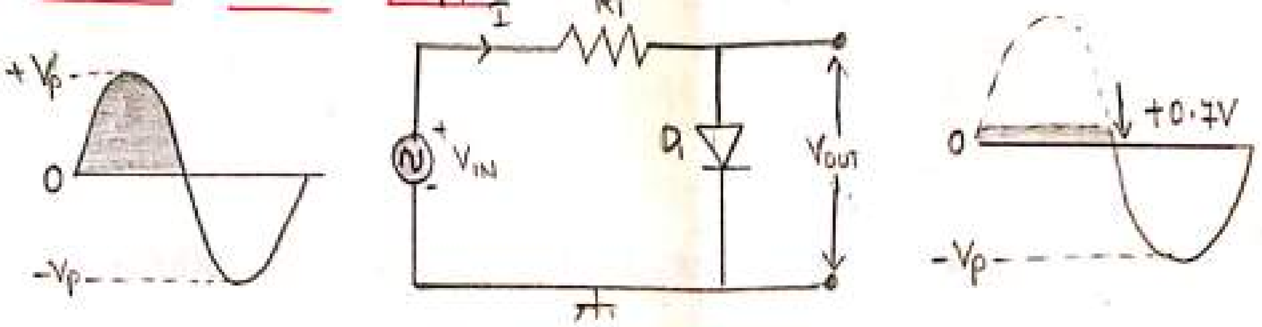
Circuit



Waveforms

The series Positive Clipper Circuit is Connected as shown in the figure. During the Positive half Cycle, diode becomes reverse biased, and no Output is generated across the resistor, and during the negative half cycle, the diode conducts and the entire input appears as Output across the resistor.

3) Parallel Positive clipper

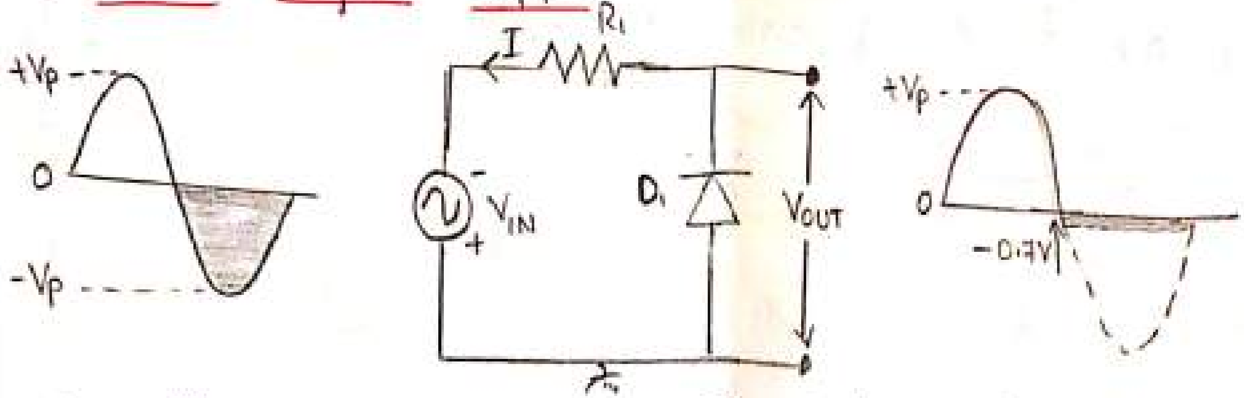


In this diode clipping circuit, the diode is forward biased (anode more positive than cathode) during the Positive half Cycle of the sinusoidal input waveform. For the diode to become forward biased, it must have the input Voltage magnitude greater than +0.7 Volts (0.3 Volts for a germanium diode).

→ When this happens the diodes begins to Conduct and holds the Voltage across itself Constant at 0.7V until the sinusoidal waveform falls below this Value. Thus the Output Voltage which is taken across the diode can never exceed 0.7 Volts during the positive half Cycle.

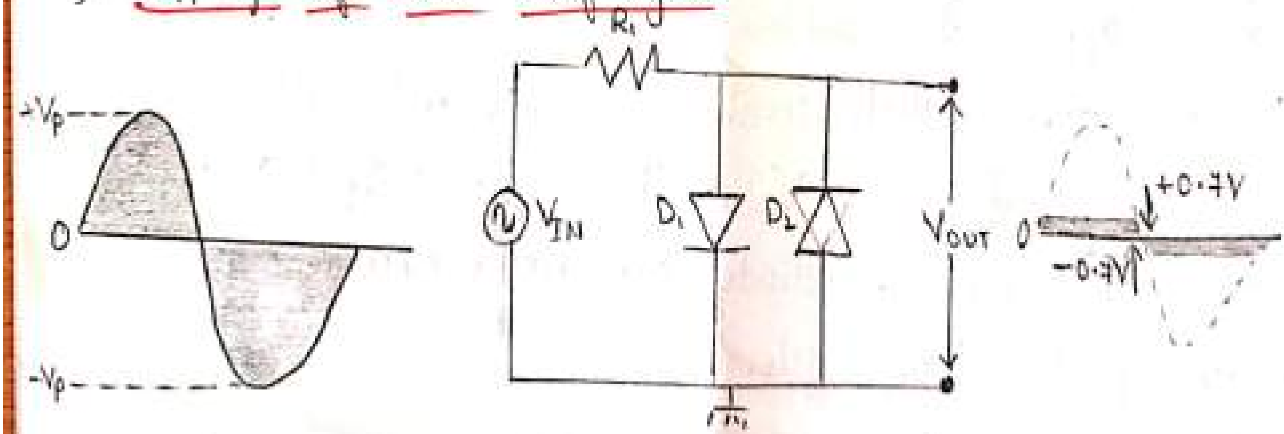
→ During the negative half cycle, the diode is reverse biased (cathode more positive than anode) blocking Current flow through itself and as a result has no effect on the negative half of the sinusoidal Voltage which passed to the load unaltered. Then the diode limits the Positive half of the input Waveform and is Known as a Positive clipper Circuit.

4) Parallel Negative Clipper:



Here the reverse is true. The diode is forward biased during the negative half Cycle of the sinusoidal waveform and limits or clips it to -0.7 volts while allowing the Positive half Cycle to pass unaltered when reverse biased. As the diode limits the negative half Cycle of the input voltage it is therefore called a negative clipper Circuit.

5) Clipping of Both Half Cycles



If we connected two diodes in inverse Parallel as shown, then both the Positive and negative half Cycles would be clipped as diode D_1 clips the Positive half cycle of the sinusoidal input waveform while diode D_2 clips the negative half cycle. Then diode clipping circuits can be used to clip the Positive half cycle, the negative half cycle or both.

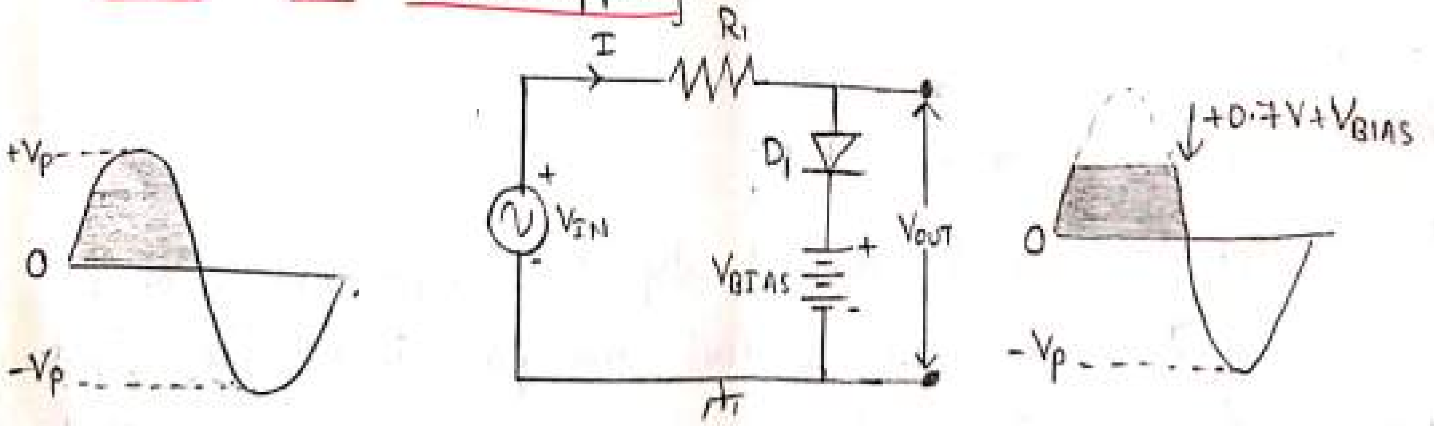
6) Biased Diode Clipping Circuit

To produce diode clipping circuits for voltage waveforms at different levels, a bias voltage, V_{Bias} is added in series with the diode as shown.

→ The voltage across the series combination must be greater than $V_{BIAS} + 0.7V$ before the diode becomes sufficiently forward biased to conduct.

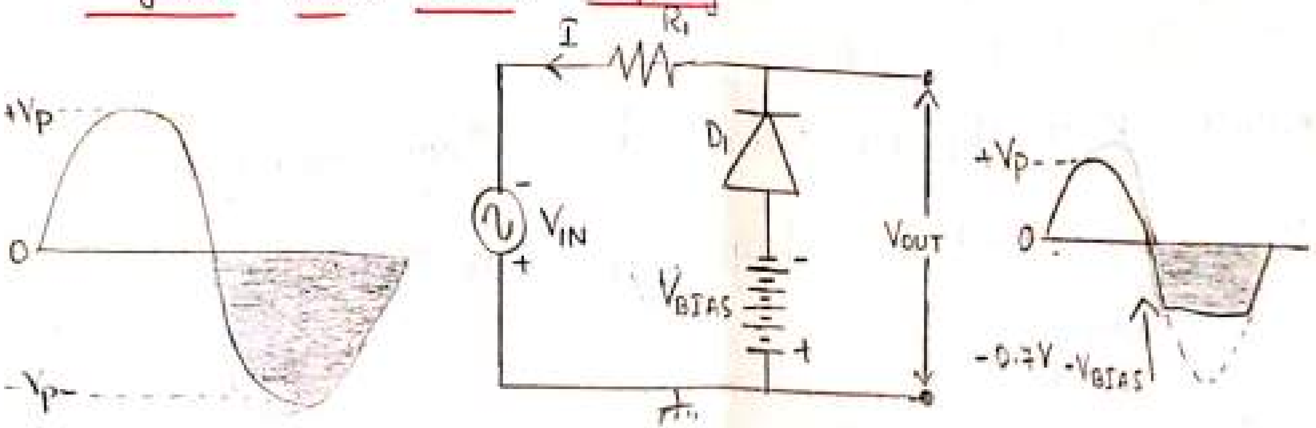
→ For example, if the V_{BIAS} level is set at 4.0 volts, then the sinusoidal voltage at the diode's anode terminal must be greater than $4.0 + 0.7 = 4.7$ Volts for it to become forward biased. Any anode voltage levels above this biased point are clipped off.

7) Positive Bias Diode Clipping



likewise, by reversing the diode and the battery bias Voltage, when a diode Conducts the negative half cycle of the Output waveform is held to a level $-V_{BIAS} - 0.7V$ as shown

2) Negative Bias Diode Clipping:



A Variable diode clipping or diode limiting level can be achieved by Varying the bias Voltage of the diodes. If both Positive and the negative diode clipping half cycles are to be clipped, then two biased clipping diodes are used. But for both Positive and negative diode clipping, the bias Voltage need not be the same. The Positive bias Voltage could be at one level, for example 4 Volts, and the negative bias Voltage at another, for example 6 Volts as shown.

Diode Clipping summary

Diodes can be used to clip the top, or bottom, or both of a Waveform at a Particular dc level and pass it to the Output without distortion. In or above examples we have assumed that the waveform is sinusoidal but in theory any shaped input waveform can be used.

→Diode Clipping Circuits are used to eliminate amplitude noise or Voltage spikes, Voltage regulation or to Produce new Waveforms from an existing signal such as squaring off the peaks of a sinusoidal Waveform to Obtain a rectangular Waveform as seen above.

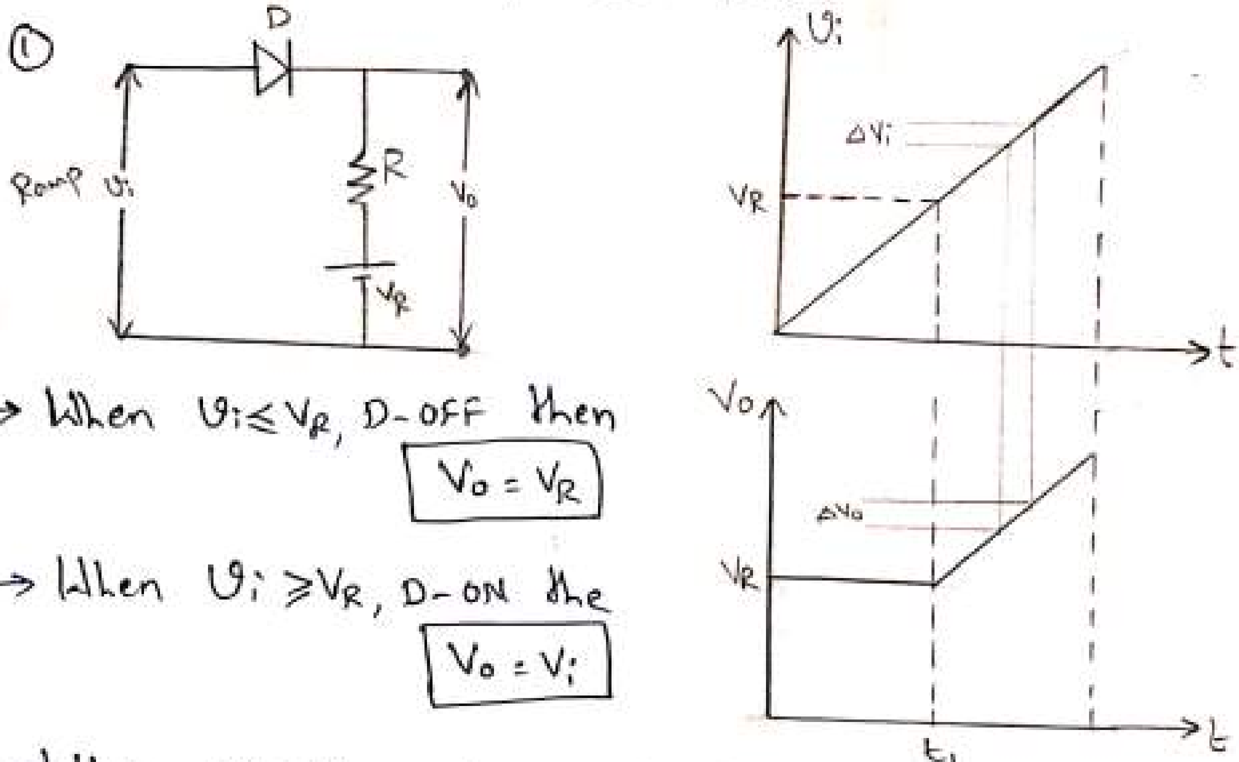
→The most Common application of a "diode clipping" is a flywheel or free-wheeling diode connected in Parallel across an inductive load to Protect the switching transistor from reverse Voltage transients.

⟹ COMPARATORS:

The non linear circuits which are used to perform the operation of clipping may also used to perform the operation of comparision. So that they are called as "comparators"

"A comparator is one which may be used to mark the instant when an arbitrary waveform attains some reference level".

①



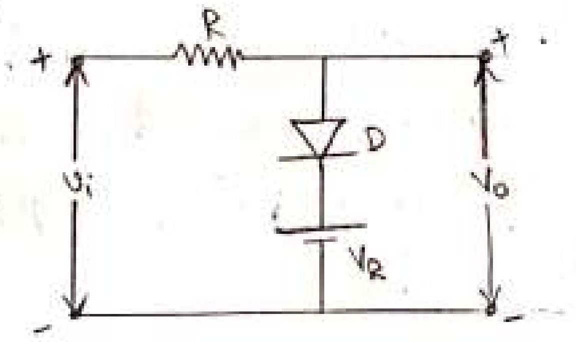
→ When $V_i \leq V_R$, D-OFF then
$\boxed{V_o = V_R}$

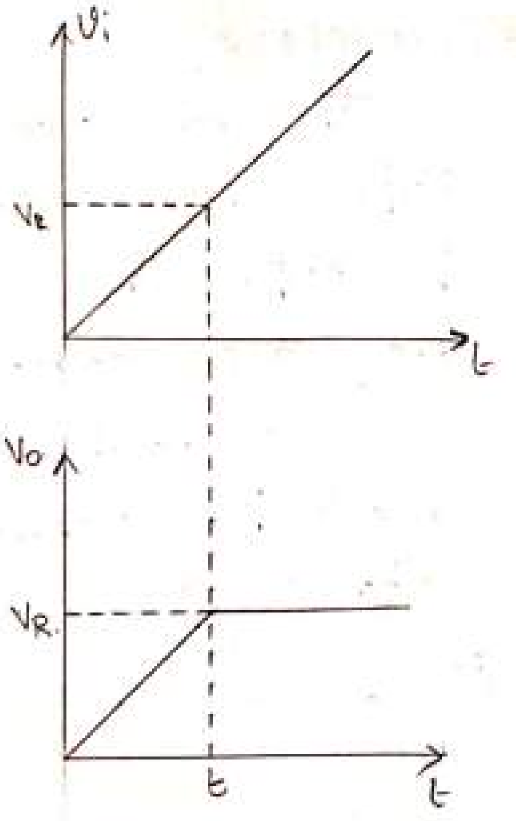
→ When $V_i \geq V_R$, D-ON the
$\boxed{V_o = V_i}$

→ When $V_i > V_R$, D-ON. As V_i increasing, current passing through the diode increases and when an excess current passes, D-breakdown occurs, So that D is called "PICK-OFF DIODE"

Scanned by CamScanner

②





When $v_i \leq V_R$, $V_o = V_i$

When $v_i > V_R$, $V_o = V_R$

Introduction: HALF WAVE AND FULL WAVE RECTIFIERS

All electronic circuits need DC power supply either from battery or power pack units. Hence many electronic equipment contain circuits which convert the ac supply voltage into DC voltage at the required level.

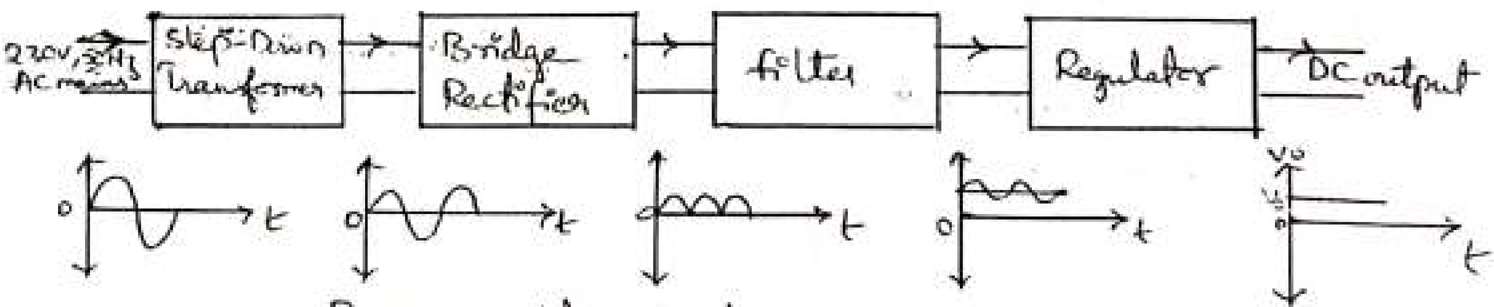
(i) Linear Mode Power Supply (LMPS): AC/DC power supply - Converter

(ii) Switched Mode Power Supply (SMPS):

a.) DC/DC Power Supply - Converter   b.) DC/AC power supply - Inverter

Linear Mode Power Supply:

The basic building blocks of the linear power supply units are step-down transformer, Bridge Rectifier, filter-Regulator with inputs as AC mains & output as DC.



Basic Building Blocks of Linear Mode Power Supply

Step-Down Transformer:

This will step down the AC voltage level to a level required for desired DC level (output). for example to get a 30V DC, a 230V AC is converted to 30VDC by this step down transformer.

Rectifier:

It converts AC into pulsating unidirectional DC. for better performance we use bridge rectifier.

Filter:

It removes unwanted AC components (ripples).

Regulator:

Here we use a Voltage Regulator which is used to keep DC output voltage constant inspite of variations in input voltage & load. It also removes the ripples.

PN Junction Diode as a Rectifier

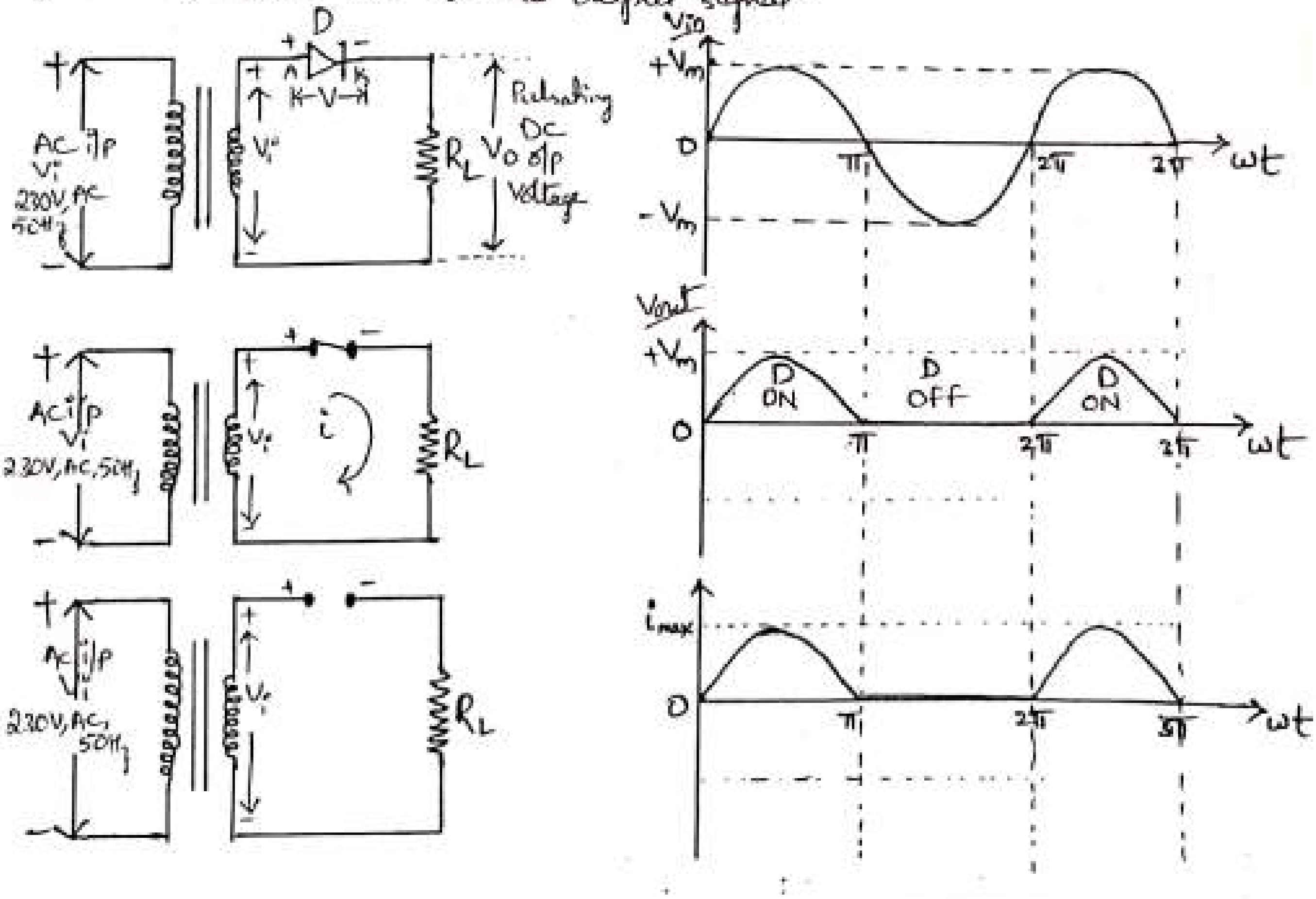
The PN Junction Diode is a two terminal device which is polarity sensitive. When a Diode is forward bias, the diode conducts & allows current to flow through it with zero resistance i.e., the diode is ON. When the diode is Reverse Bias, the diode does not conduct & no current flows through it with infinite Resistance i.e., the diode is OFF. Thus an ideal diode acts as a switch, either open (OFF) or closed (ON), depending upon the polarity of the voltage placed across it.

Rectifiers

It is defined as an electronic device used for converting ac voltage into unidirectional voltage. It uses vaccum diode or PN Junction diode. These are classified as Half Wave & full Wave Rectifier. The full wave is further classified as centre-tap & Bridge rectifier.

Half Wave Rectifier

It converts an ac voltage into a pulsating dc voltage using only one half of the applied ac voltage. The rectifying diode conducts during one half of the ac cycle only. During positive half cycle of input, diode gets forward bias and acts as short circuited. Hence the output is equal to input ie, same input signal follows output. During negative half cycle of input, diode gets reverse bias and acts as open circuited. Hence the output is equal to zero. ie, there will be no output signal.



Let V_i be the primary voltage of the transformer which is given by

$$V_i = V_m \sin \omega t \qquad 0 \le \omega t \le \pi$$
$$= 0 \qquad \pi \le \omega t \le 2\pi$$
$$i = i_m \sin \omega t$$

where V_m - peak amplitude & ω - angular frequency.

$$\boxed{i_m = \frac{V_m}{R_f + R_s + R_L} \approx \frac{V_m}{R_L}} \quad \text{--- (1)}$$

$R_s \rightarrow$ Resistance of secondary transformers
$R_f \rightarrow$ forward Resistance of diode
$R_L \rightarrow$ Load Resistance of circuit

Since $R_L >> R_s$, $R_L >> R_f$, so $i_m = \frac{V_m}{R_L}$

<u>DC o/p</u> <u>or</u> <u>Load Current</u> <u>or</u> <u>Average Current</u> (I_{DC}):

By definition average of a periodic function is given by the area of one cycle divided by the base (period). By keeping an DC ammeter across the output we get I_{DC} practically.

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i \, d\omega t = \frac{1}{2\pi}\int_0^{2\pi} i_m \sin \omega t \, d\omega t = \frac{i_m}{2\pi}\Big[-\cos \omega t\Big]_0^{2\pi}$$

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

$$= \frac{-i_m}{2\pi}\left[\cos \pi - \cos 0\right] = \frac{-i_m}{2\pi}\left[-1-1\right] = \frac{-i_m}{2\pi}\left[-2\right]$$

$$\boxed{I_{DC} = \frac{i_m}{\pi}} \quad \text{--- (2)}$$

<u>DC o/p</u> <u>or</u> <u>Load Voltage</u> <u>or</u> <u>Average Voltage</u> (V_{DC}):

$$V_{DC} = I_{DC} \cdot R_L$$

$$V_{DC} = \frac{i_m}{\pi} \cdot R_L \qquad \because I_{DC} = \frac{i_m}{\pi}\ ; \ i_m = \frac{V_m}{R_L}$$

$$V_{DC} = \frac{V_m}{R_L \cdot \pi} \cdot R_L = \frac{V_m}{\pi}$$

$$\boxed{V_{DC} = \frac{V_m}{\pi}} \quad \text{--- (3)}$$

RMS value of Load Current or AC o/p current (I_{rms}):

By definition it is defined as the square root of area of one cycle of the curve which represents the square of the function divided by the base (period).

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} i^2 d\omega t + \int_{\pi}^{2\pi} i^2 d\omega t} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i^2 d\omega t + 0}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} (i_m \sin\omega t)^2 d\omega t}$$

$$= \sqrt{\frac{i_m^2}{2\pi}\int_0^{\pi} \sin^2\omega t \, d\omega t} = \sqrt{\frac{i_m^2}{2\pi}\int_0^{\pi} \left(\frac{1-\cos 2\omega t}{2}\right) d\omega t}$$

$$= \sqrt{\frac{i_m^2}{2\pi}\left(\frac{\pi}{2} - \frac{\sin 2\pi}{4}\right)} = \sqrt{\frac{i_m^2}{2\cancel{\pi}} \times \frac{\cancel{\pi}}{2}}$$

$$I_{rms} = \sqrt{\frac{i_m^2}{4}}$$

$$\boxed{I_{rms} = \frac{i_m}{2}} \quad \text{(4)}$$

RMS value of Load voltage or AC o/p voltage (V_{rms}):

$$V_{rms} = I_{rms} \cdot R_L = \frac{i_m R_L}{2} = \frac{V_m}{2}$$

$$\boxed{V_{rms} = \frac{V_m}{2}} \quad \text{(5)}$$

DC output Power (P_{DC}):

$$P_{DC} = I_{DC}^2 \cdot R_L$$

$$\boxed{P_{DC} = \frac{i_m^2}{\pi^2} \cdot R_L} \quad \text{(6)}$$

AC Input Power (P_{AC}):

$$P_{AC} = I_{rms}^2 (R_f + R_L + R_s)$$

$$\boxed{P_{AC} = \frac{i_m^2}{4}(R_f + R_L + R_s)} \quad \text{(7)}$$

Input power is dissipated across three resistance.

Efficiency or Ratio of Rectification (η)

It is the ratio of dc power delivered to load or output dc power to the ac input power.

$$\boxed{\eta = \frac{\text{DC output power}}{\text{AC input power}} = \frac{P_{DC}}{P_{AC}}}$$

$$\eta = \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{I_m^2 (R_f + R_L + R_s)} = \frac{4R_L}{\pi^2} \times \frac{1}{R_L\left(1 + \frac{R_s + R_f}{R_L}\right)}$$

$$\eta = \frac{4}{\pi^2}\left[\frac{1}{1 + \left(\frac{R_f + R_s}{R_L}\right)}\right] \qquad \because R_L > R_f$$

$$\boxed{\eta = \frac{4}{\pi^2} = 0.406 = 40.6\%} \qquad (8)$$

Ripple factor (γ):

A measure of the fluctuating components is given by ripple factor (γ). It is the ratio of RMS value of AC component of output to the average or dc component of output.

$$\boxed{\gamma = \frac{\text{RMS value of AC component of output } (I'_{rms})}{\text{dc component of output } \quad I_{DC}}} \qquad (9)$$

$$\gamma = \frac{I'_{rms}}{I_{DC}} = \frac{V'_{rms}}{V_{DC}} = \frac{(V_\gamma)_{rms}}{V_{DC}} = \frac{(I_\gamma)_{rms}}{V_{DC}}$$

$$(V_\gamma)_{rms} = \sqrt{V_{rms}^2 - V_{DC}^2}$$

$$\gamma = \frac{\sqrt{V_{rms}^2 - V_{DC}^2}}{V_{DC}} = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

The instantaneous ac component of current is given by

$$i' = i - I_{DC} \text{ then}$$

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i')^2 d\omega t} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i - I_{DC})^2 d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i^2 + I_{DC}^2 - 2iI_{DC})\, d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\omega t + \frac{1}{2\pi}\int_0^{2\pi} I_{DC}^2 d\omega t - \frac{2}{2\pi}\int_0^{2\pi} i I_{DC}\, d\omega t}$$

$$I'_{rms} = \sqrt{I_{rms}^2 + I_{DC}^2\left[\frac{1}{2\pi}\int_0^{2\pi} d\omega t\right] - 2I_{DC}\left[\frac{1}{2\pi}\int_0^{2\pi} i\, d\omega t\right]}$$

$$I'_{rms} = \sqrt{I_{rms}^2 + I_{DC}^2 - 2I_{DC}[I_{DC}]} = \sqrt{I_{rms}^2 + I_{DC}^2 - 2I_{DC}^2}$$

$$\boxed{I'_{rms} = \sqrt{I_{rms}^2 - I_{DC}^2}} \quad \text{—— (10)}$$

then substitute eq (10) in eq (9) we get

$$\gamma = \frac{\sqrt{I_{rms}^2 - I_{DC}^2}}{I_{DC}} = \frac{\sqrt{I_{rms}^2 - I_{DC}^2}}{\sqrt{I_{DC}^2}} = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}$$

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}$$

$$\gamma = \sqrt{\left(\frac{i_m/2}{i_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = \sqrt{(1.57)^2 - 1} = 1.21$$

$$\boxed{\gamma = 1.211 = 121\ \%}$$

This shows that amount of ac present in the output is 121% of dc voltage. Half Wave Rectifier is a relatively poor circuit for converting ac into dc.

<u>Form factor (F)</u>

$$\boxed{F = \frac{\text{rms value}}{\text{dc value}}} = \frac{I_{rms}}{I_{DC}} = \frac{i_m/2}{i_m/\pi} = \frac{\pi}{2} = \underline{1.57}$$

<u>Peak factor</u>

$$\boxed{= \frac{\text{Peak value}}{\text{rms value}}} = \frac{I_m}{I_{rms}} = \frac{i_m}{i_m/2} = \underline{2} \text{ or } \frac{V_m}{V_{rms}} = \frac{V_m}{V_m/2} = \underline{2}$$

<u>Peak Inverse Voltage (PIV):</u>

It is the maximum reverse voltage that a diode can withstand in reverse bias without destroying the junction. The peak Inverse voltage across a diode is peak of negative (-ve) half cycle ($-V_m$). for Half wave rectifier PIV is V_m

$$\boxed{PIV = V_m}$$

Transformer Utilization factor (TUF):

It is the ratio of DC power delivered to the load to the ac rating of the transformer secondary

$$\boxed{TUF = \frac{\text{DC power delivered to the load}}{\text{AC power rating of transformer secondary}}}$$

$$\boxed{TUF = \frac{P_{DC}}{P_{AC\,rated}}}$$

$P_{DC} = \frac{i_m^2 R_L}{\pi^2}$; $P_{AC\,rated} = V_{rms} \cdot I_{rms}$

V_{rms} rated of transformer secondary is $\frac{V_m}{\sqrt{2}}$ & $I_{rms} = \frac{i_m}{2}$

$$P_{AC\,rated} = \frac{V_m}{\sqrt{2}} \times \frac{i_m}{2} = \frac{V_m}{\sqrt{2}} \times \frac{V_m}{2R_L} = \frac{V_m^2}{2\sqrt{2}R_L}$$

$$TUF = \frac{i_m^2 R_L}{\pi^2} \times \frac{2\sqrt{2}R_L}{V_m^2} = \frac{\frac{V_m^2}{R_L^2} \times R_L}{\pi^2} \times \frac{2\sqrt{2}R_L}{V_m^2} = \frac{V_m^2}{R_L \pi^2} \times \frac{2\sqrt{2}R_L}{V_m^2}$$

$$TUF = \frac{2\sqrt{2}}{\pi^2} = 0.287$$

$$\boxed{\% \, TUF = 28.7\%}$$

Voltage Regulation

The degree to which the power supply varies in output voltage under condition of load variations is measured by voltage regulation. The variation of dc output voltage as a function of dc load current is called Regulation.

$$\boxed{\% \text{ Voltage Regulation} = \frac{(V_{DC})_{\text{no load}} - (V_{DC})_{\text{full load}}}{(V_{DC})_{\text{full load}}} \times 100}$$

For Ideal power supply, the output voltage is independent of load & percentage of regulation is zero.

In general $V_{DC} = I_{DC} \cdot R_L$

$$V_{DC} = \frac{I_m}{\pi} \cdot R_L$$

$$V_{DC} = \frac{V_m}{(R_s + R_f + R_L)} \times \frac{R_L}{\pi} = \frac{V_m}{\left(\frac{R_L + R_s + R_f}{R_L}\right)} \times \frac{1}{\pi}$$

$$V_{DC} = \frac{V_m}{\pi}\left[\frac{1}{1+\frac{R_s+R_f}{R_L}}\right]$$

Under No load condition take R_L as ∞ (load resistance to be infinity) then

$$(V_{DC})_{NL} = \frac{V_m}{\pi}\left[\frac{1}{1+\frac{R_s+R_f}{\infty}}\right] = \frac{V_m}{\pi}\left[\frac{1}{1+0}\right]$$

$$\boxed{(V_{DC})_{NL} = \frac{V_m}{\pi}}$$

for full load condition the V_{DC} is taken consider as same

$$\boxed{(V_{DC})_{FL} = \frac{V_m}{\pi}\left[\frac{1}{1+\frac{R_s+R_f}{R_L}}\right]}$$

$$\% \text{ Reg} = \frac{(V_{DC})_{NL}-(V_{DC})_{FL}}{(V_{DC})_{FL}} \times 100$$

$$= \frac{\frac{V_m}{\pi} - \frac{V_m}{\pi}\left[\frac{1}{1+\frac{R_s+R_f}{R_L}}\right]}{\frac{V_m}{\pi}\left[\frac{1}{1+\frac{R_s+R_f}{R_L}}\right]} \times 100$$

$$= \frac{\cancel{\frac{V_m}{\pi}}\left[1 - \frac{R_L}{R_L+R_s+R_f}\right]}{\cancel{\frac{V_m}{\pi}}\left[\frac{R_L}{R_L+R_s+R_f}\right]} \times 100 = \frac{\left[\frac{\cancel{R_L}+R_s+R_f-\cancel{R_L}}{\cancel{R_L+R_s+R_f}}\right]}{\left[\frac{R_L}{\cancel{R_s+R_L+R_f}}\right]} \times 100$$

$$\boxed{\% \text{ Reg} = \frac{R_s+R_f}{R_L} \times 100}$$

<u>Advantages</u>

(i) Only one diode is sufficient and circuit is easy to design

(ii) No centre tap is required for Half wave rectifier at transformer.

<u>Disadvantages</u>

(i) Efficiency (η) is less 40%

(ii) Ripple factor (γ) is 1.21 which is quite high value

(iii) T.U.F is very low showing transformer is not fully utilized.

Summarise Half Wave Rectifier

a) $I_m = \frac{V_m}{R_L + R_S + R_f}$

b) $I_{DC} = \frac{I_m}{\pi}$, $I_{rms} = \frac{I_m}{2}$

c) $V_{DC} = I_{DC} \cdot R_L = \frac{i_m}{R_L + R_S + R_f} \times R_L$

d) $\eta = \frac{P_{DC}}{P_{AC}} = \frac{I^2_{DC} \cdot R_L}{I^2_{rms}(R_S + R_L + R_f)}$

e) γ (ripplefactor) $= \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}$

$\gamma = 1.21$

f) $TUF = \frac{P_{DC}}{P_{AC\ rated}} = 28.7\%$

g) $\%\eta = 40.6\%$

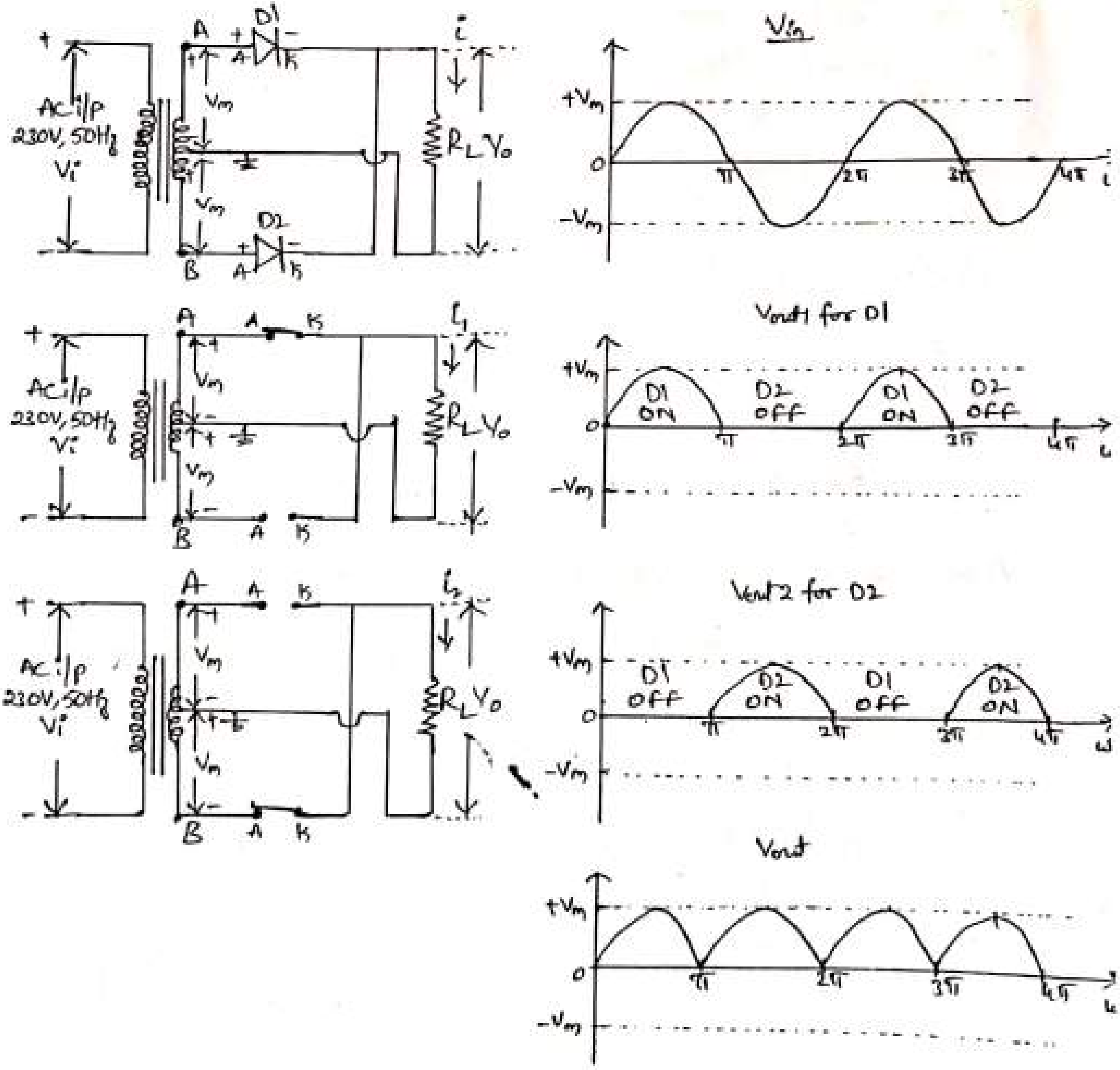
Full Wave Rectifier

This converts ac to pulsating dc voltage using both half cycles of applied ac voltage. There are two types of full wave Rectifier

(i) Center tapped transformer full wave Rectifier

(ii) Bridge Rectifier

It uses two diodes of which D1 conducts during one half cycle while D2 conducts during other half cycle of applied ac voltage.



During positive (+ve) half cycle of AC input signal, where terminal A is positive & B is negative due to center tapped transformer. Hence Diode D1 will be forward biased & conducts where Diode D2 will be reverse biased & D2 does not conducts. then current flows in circuit will be i_1.

During negative (−ve) half cycle of AC input signal, where terminal A will be negative & B becomes positive due to center tapped transformer. Hence Diode D1 will be reverse biased (open ckt) does ~~not~~ conducts where Diode D2 which is in forward biased (short ckt) conducts then the current flowing in the circuit will be i_2.

Load current flows in both half cycles of AC input signal in same direction through load resistance (R_L). then total current $i = i_1 + i_2$

<u>Maximum Current</u> $I_m = \dfrac{V_m}{R_s + R_f + R_L}$

$$i = I_m \sin \omega t$$

$$i_1 = I_m \sin \omega t \qquad 0 < \omega t < \pi$$
$$= 0 \qquad \pi < \omega t < 2\pi$$

$$i_2 = 0 \qquad 0 < \omega t < \pi$$
$$= -I_m \sin \omega t \qquad \pi < \omega t < 2\pi$$

<u>Average or DC Load Current (I_{DC})</u>:

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i\, d\omega t = \frac{2}{2\pi}\int_0^{\pi} i\, d\omega t = \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t\, d\omega t$$

$$I_{DC} = \frac{I_m}{\pi}\left[-\cos \omega t\right]_0^{\pi} = \frac{I_m}{\pi}\left[-(-1) - (-1)\right]$$

$$I_{DC} = \frac{I_m}{\pi}[1+1] = \frac{2I_m}{\pi}$$

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

Average (or) DC Load Voltage (V_{DC}):

$$V_{DC} = I_{DC} \cdot R_L$$

$$= \frac{2I_m}{\pi} \cdot R_L$$

$$= \frac{2V_m}{(R_f+R_s+R_L)} \cdot \frac{R_L}{\pi} \quad \because \text{ if } R_f+R_s << R_L$$

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

RMS Value of Load Current (I_{rms}):

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

$$= \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi}(\sin\omega t)^2\,d\omega t} = \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right)d\omega t}$$

$$= \sqrt{\frac{I_m^2}{\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^{\pi}}$$

$$= \frac{I_m}{\sqrt{\pi}} \cdot \sqrt{\left[\frac{\pi}{2}\right]} = \frac{I_m}{\cancel{\sqrt{\pi}}} \times \frac{\cancel{\sqrt{\pi}}}{\sqrt{2}} = \frac{I_m}{\sqrt{2}}$$

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

RMS Value of Load Voltage (V_{rms}) or AC o/p voltage:

$$V_{rms} = I_{rms} \cdot R_L = \frac{I_m}{\sqrt{2}} \times R_L = \frac{V_m}{\sqrt{2}}$$

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

DC output Power (P_{DC}):

$$P_{DC} = I_{DC}^2 \cdot R_L$$

$$P_{DC} = \left(\frac{2I_m}{\pi}\right)^2 \times R_L$$

$$\boxed{P_{DC} = \frac{4I_m^2 R_L}{\pi^2}}$$

AC Input Power (P_{AC}):

Input AC power is dissipated across three resistors.

$$P_{AC} = I_{rms}^2 (R_f + R_s + R_L)$$

$$\boxed{P_{AC} = \frac{I_m^2}{2} (R_f + R_s + R_L)}$$

where $R_s \rightarrow$ resistance of secondary winding of transformer

$R_f \rightarrow$ forward resistance of Diodes

$R_L \rightarrow$ load resistance of circuit.

Efficiency or Ratio of Rectification (η):

$$\boxed{\eta = \frac{\text{DC output Power}}{\text{AC input Power}} = \frac{P_{DC}}{P_{AC}}}$$

$$= \frac{4 \cancel{I_m^2} \times R_L}{\pi^2} \times \frac{2}{\cancel{I_m^2} (R_f + R_s + R_L)} \qquad \because R_f + R_s << R_L$$

$$\eta = \frac{4 \cancel{R_L}}{\pi^2} \times \frac{2}{\cancel{R_L}} = \frac{8}{\pi^2} = 0.812$$

$$\boxed{\% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = 0.812 \times 100 = 81.2\%}$$

Ripple factor (γ):

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1} = \sqrt{\left(\frac{\cancel{I_m}}{\sqrt{2}} \times \frac{\pi}{2 \cancel{I_m}}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = \sqrt{\frac{\pi^2}{4 \times 2} - 1}$$

$$\gamma = \sqrt{0.2337} = 0.4834$$

$$\boxed{\% \gamma = 0.4834 \times 100 = 48.34\%}$$

This shows that amount of ac present in the output is 48.34% of dc voltage.

Form factor (F):

$$F = \frac{\text{rms value}}{\text{dc value}} = \frac{I_{rms}}{I_{DC}} = \frac{I_m}{\sqrt{2}} \times \frac{\pi}{2I_m} = \frac{\pi}{2\sqrt{2}}$$

$$\boxed{F = 1.11}$$

Peak factor

$$\boxed{\frac{\text{Peak Value}}{\text{rms value}}} = \frac{I_m}{I_{rms}} = \frac{I_m}{I_m/\sqrt{2}} = \frac{\cancel{I_m} \times \sqrt{2}}{\cancel{I_m}} = \sqrt{2}$$

Peak Inverse Voltage (PIV):-

The voltage across center tap to each end is V_m & the voltage across R_L is V_m. So the total voltage across the diode D2 is $2V_m$.

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

Transformer Utilization factor (TUF):

In full wave rectifier the secondary current flows through each half separately in every cycle. While the primary of the transformer carries current continuously. Hence TUF is calculated for both primary & secondary windings separately & then average TUF is determined.

$$\boxed{TUF = \frac{\text{DC Power delivered}}{\text{AC power rating of Transformer secondary}}}$$

$$\text{Secondary T.U.F} = \frac{\text{DC Power delivered by load}}{\text{AC power rating of transformer secondary}}$$

$$= \frac{I_{DC}^2 \cdot R_L}{V_{rms_{sec}} \cdot I_{rms_{sec}}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}} \qquad \because V_m = I_m \cdot R_L$$

$$= \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\frac{I_m \cdot R_L}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}} = \frac{\frac{4 I_m^{\cancel{2}}}{\pi^2} \cdot \cancel{R_L}}{\frac{\cancel{I_m} \cdot \cancel{R_L}}{\sqrt{2}} \cdot \frac{\cancel{I_m}}{\sqrt{2}}} = \frac{8}{\pi^2} = \underline{0.81}$$

$S.TUF = 0.81$

$P.TUF = 2 \times TUF = 2 \times 0.287 = \underline{0.574}$

$$\text{Average} = \frac{0.81 + 0.574}{2} = \underline{0.692}$$

$$\boxed{\% TUF = 0.692 \times 100 = 69.2\% .}$$

<u>Voltage Regulation</u>

$$\boxed{\% \text{ Voltage Regulation} = \frac{(V_{DC})_{NL} - (V_{DC})_{FL}}{(V_{DC})_{FL}} \times 100 .}$$

$$(V_{DC})_{NL} = \frac{2V_m}{\pi}$$

$$(V_{DC})_{FL} = I_{DC} \cdot R_L = \frac{2I_m}{\pi} \cdot R_L = \frac{2V_m}{\pi(R_F + R_S + R_L)} \cdot R_L$$

$$V.R = \frac{\frac{2V_m}{\pi} - \frac{2V_m}{\pi} \frac{R_L}{R_F + R_S + R_L}}{\frac{2V_m}{\pi} \frac{R_L}{R_F + R_S + R_L}} = \frac{\frac{2V_m}{\pi}\left(1 - \frac{R_L}{R_F + R_S + R_L}\right)}{\frac{2V_m}{\pi} \cdot \frac{R_L}{R_F + R_S + R_L}}$$

$$= \frac{R_F + R_S + \cancel{R_L} - \cancel{R_L}}{\cancel{R_F + R_S + R_L}} \times \frac{\cancel{R_F + R_S + R_L}}{R_L} = \frac{R_F + R_S}{R_L}$$

$$= \frac{R_F}{R_L} \quad \because R_F > R_S$$

$$\boxed{\% V.R = \frac{R_F}{R_L} \times 100 .}$$

<u>Output frequency:</u> Output time period = Input time period divide by two.

$$t_o = \frac{t_i}{2} \Rightarrow \frac{1}{f_o} = \frac{1/f_i}{2}$$

$$\frac{2}{f_o} = \frac{1}{f_i} \Rightarrow f_o = 2f_i$$

Advantages of FWR

(i) Efficiency is High (81%)

(ii) Ripple factor is less (48%)

(iii) T.U.F of FWR (69.2%) is better than HWR (28.7%).

Disadvantages of FWR

(i) Peak Inverse Voltage (PIV) of diode is high.

(ii) Higher PIV diodes are larger in size & costlier.

(iii) cost of Center tapped transformer is high.

Summarise of FWR

a.) $I_m = \frac{V_m}{R_L + R_S + R_F}$ b.) $I_{DC} = \frac{2I_m}{\pi}$, $I_{rms} = \frac{I_m}{\sqrt{2}}$

c.) $V_{DC} = \frac{2V_m}{\pi} = 2I_{DC} \cdot R_L = \frac{2I_m}{\pi} \cdot R_L = \frac{2V_m \cdot R_L}{\pi(R_L + R_S + R_F)}$

d.) $\eta = \frac{P_{DC}}{P_{AC}} = \frac{I^2_{DC} \cdot R_L}{I^2_{rms}(R_S + R_L + R_F)} = \frac{\frac{4I_m^2}{\pi^2} \cdot R_L}{\frac{I_m^2}{2} \cdot (R_S + R_L + R_F)}$

e.) γ (ripple factor) $= \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1} = 0.483$

f.) $TUF = \frac{P_{DC}}{P_{AC} \text{ rated of secondary}} = 0.692$ g.) $\% \eta = 81.0\%$.