

MODULE-1

SEMICONDUCTOR DIODES AND APPLICATIONS

①

Syllabus: P-n junction diode, characteristics and Parameters, Diode approximations, Dc load line analysis, Half wave rectifier, Two-diode Full-Wave rectifier, Bridge rectifier, capacitor filter circuit (only qualitative approach), Zener diode voltage regulator: Regulator circuit with no load, loaded regulator. Numerical examples as applicable.

* Introduction:

Extrinsic Semiconductors are classified into

- ① n-type ② p-type

① n-type:

→ When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as n-type semiconductor.

→ Typical examples of pentavalent impurities are arsenic (As), antimony (Sb), phosphorus (P), bismuth (Bi) etc.

→ Electrons are majority carriers & holes are minority carriers.

② p-type:

→ When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor.

→ Typical examples of trivalent impurities are gallium (Ga), indium (In), aluminium (Al), Boron (B) etc.

→ Holes are majority carriers & electrons are minority carriers.

* P-n junction: (1) Semiconductor diode:

→ When a P-type Semiconductor is suitably joined to n-type semiconductor by special fabrication technique, a P-n junction is formed. (Fig 1)

→ P-n junction is called a Semiconductor diode or P-n junction diode or simply a Crystal diode.

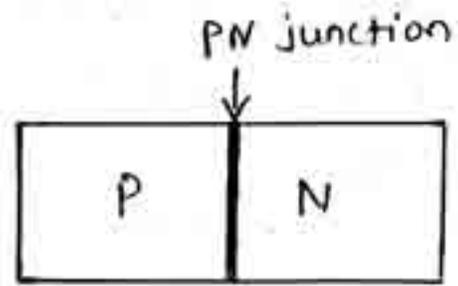
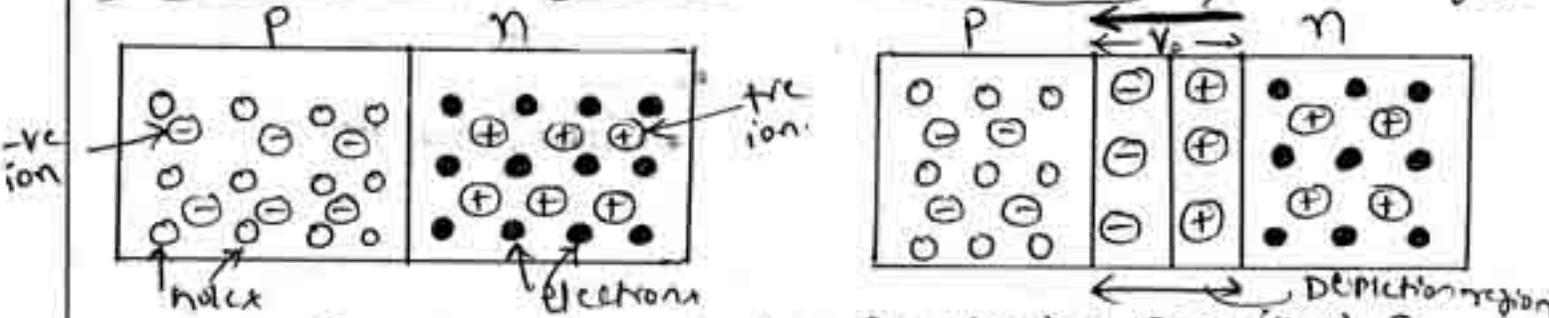


Fig 1: P-n junction

* Explanation: (Properties of Pn junction) (Formation of depletion layer): (Unbiased Pn junction):



→ The P-region has holes (majority carriers) & negatively charged impurity atoms, called negative ions (or acceptor ions).

→ The N-region has free electrons (majority carriers) & positively charged impurity atoms, called positive ions (or donor ions).

→ The holes, from the P-region diffuse to the N-region where they combine with the electrons. This creates a layer of negative charges (trivalent ions) near the junction.

→ The free electrons, from the N-region diffuse to the P-region, where they combine with holes. This creates a layer of positive charges (pentavalent ions) near the junction.

→ The region (layer) containing the positive & negative charges in the vicinity of the junction is called

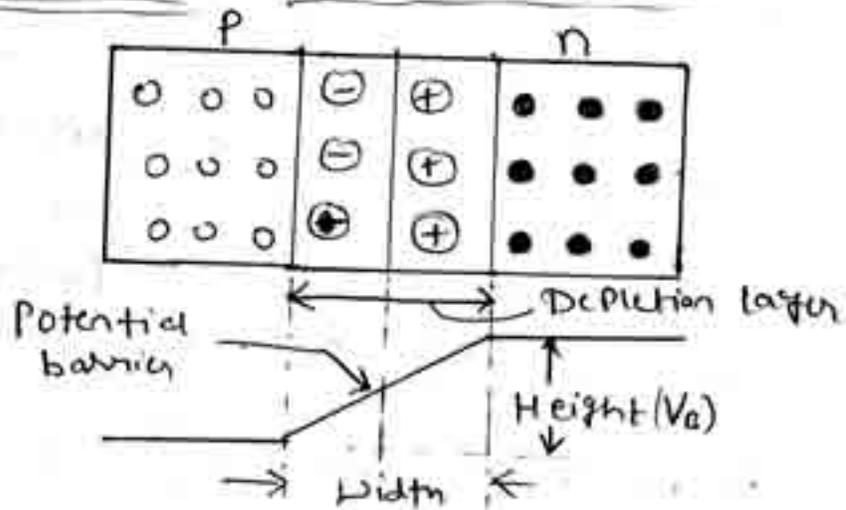
depletion region (depletion layer) (space charge region)
 (transition region)

→ The electrons, trying to diffuse into the p-region, are repelled by the negative charge of the acceptor ions. Similarly, the holes, trying to diffuse into n-region are repelled by the positive charge of the donor ions.

Note:

- ① Barrier Voltage ② Barrier Potential ③ Junction Potential ④ Built-in Potential ⑤ Cut-in Potential

→ Once pn junction is formed and depletion layer created, the diffusion of charge carriers stops.



→ The depletion region acts as a barrier to the further movement of charge carriers.

→ The depletion layer behaves like an insulator.

→ The positive & negative charges setup an electric field.

→ The potential difference across the depletion layer is called barrier potential (V_B).

→ $V_B = 0.6V$ for Si, $V_B = 0.2V$ for Ge.
 to $0.7V$ to $0.3V$

② Effect of temperature on Barrier Voltage

→ The barrier voltage depends upon ① Density
② Electronic charge & ③ Temperature.

→ For a given PN junction, the first two factors are constant.

→ For both Ge & Si, the value of V_B decreases by $2\text{mV}/^\circ\text{C}$

$$i.e. \Delta V_B = -0.002 \times \Delta t$$

where, $\Delta t \rightarrow$ Increase in temperature in $^\circ\text{C}$.

→ A PN junction, across which no external voltage source is connected, is known as unbiased PN junction.

③ In an unbiased PN junction, the majority carrier current & minority carrier current are equal in magnitude & flow in opposite directions. Thus there is no net flow of current across the junction.

④ The higher the doping level, the thinner will be the depletion layer and vice versa.

⑤ In 1919, William Henry Eccles coined the term 'diode' from the Greek roots dia means "through" & ode means "path".

* ⑥ Biassing the PN junction: (Applying DC Voltage across PN junction):

→ Connecting a PN junction to an external DC voltage is called biassing.

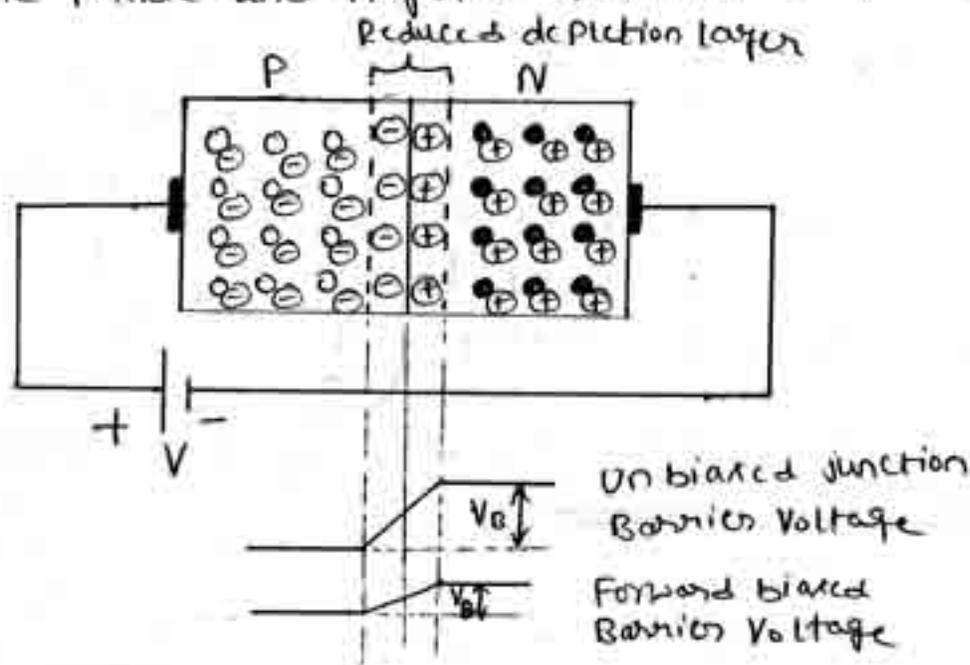
→ The biassing is classified into two types namely,

① Forward biassing ② Reverse biassing.

① Forward biasing:

When external dc voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing. ⓐ

A semiconductor diode is said to be forward biased, when the positive terminal of the voltage source is connected to the P-side and negative terminal to the N-side.



Explanation:

- The holes are repelled by the positive terminal of the voltage source and are forced to move towards the junction.
- The electrons are repelled by the negative terminal of the voltage source and move towards the junction.
- Some of the holes and electrons enter the depletion layer and recombine themselves, thus the width of the depletion layer ~~is~~ and the barrier potential (barrier voltage) reduces.
- The junction forward resistance reduces and a large current (forward current) flows through the PN junction. (of the order of mA)

Note: * Diffusion ⓑ Storage Capacitance :

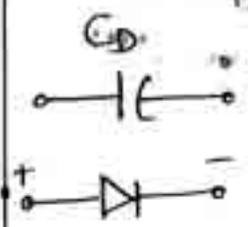
→ The capacitance which exists in a forward-biased junction, is called a diffusion capacitance.

→ ~~But~~ Diffusion capacitance is much larger than the transition capacitance. (∵ Width of the depletion layer is very less). Typical value of C_D is 0.02 MF

→ Diffusion capacitance C_D is given by,

$$C_D = \frac{dQ}{dV} = \frac{\tau I_F}{\eta V_T} = \frac{\tau I_F}{V_F}$$

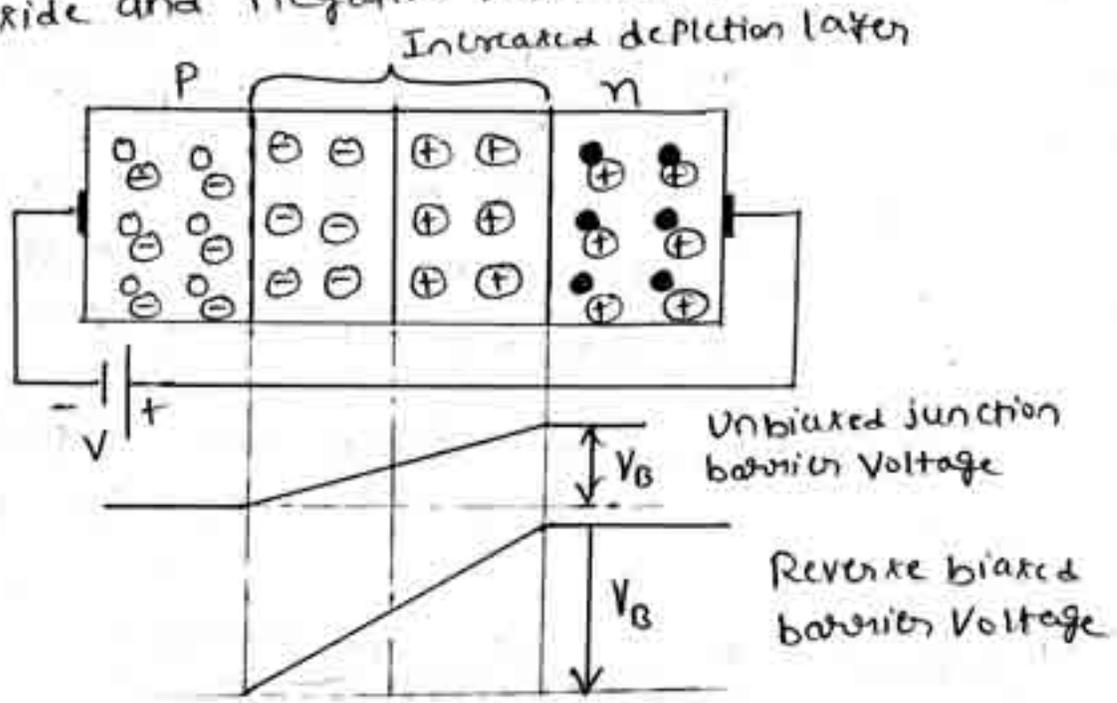
Where τ → Mean life time of the carriers,
 I_F → Value of forward current.
 η → A constant ($\eta = 1$ for Ge, $\eta = 2$ for Si)
 V_F → Forward voltage
 V_T → Volt equivalent of temperature.



② Reverse biasing:

When the external dc voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing. Ⓜ

A PN junction is said to be reverse biased, when the positive terminal of the voltage source is connected to the n-side and negative terminal to the p-side.



Explanation:

- The holes in the p-region are attracted towards the negative terminal of the voltage source.
- The electrons in the n-region are attracted towards the positive terminal of the voltage source.
- Thus the majority carriers are drawn away from the junction. This widens the depletion layer and increases the barrier potential.
- The junction reverse resistance becomes very high, and hence no current flows.
- However, a very small current flows due to minority carriers (of the order of μA to nA). This is called reverse saturation current (I_0).
- If reverse voltage is increased continuously, the kinetic energy of minority carriers increases & a large reverse current flows. This damages (destroys) the junction (diode) permanently. This is called the reverse breakdown of a diode.

→ The reverse breakdown (junction breakdown) causes due to two processes.

1. Zener breakdown:

- When the pn-junction is heavily doped, the depletion layer is narrow.
- When the reverse voltage is increased, the electric field at the junction also increases.
- This strong electric field breaks the covalent bond. As a result, a large number of minority carriers are generated and a large current flows through the

Junction. Such a phenomenon is called Zener effect

2. Avalanche effect: (Avalanche breakdown):

→ If the reverse voltage is increased, the minority carriers acquire a large amount of energy (or momentum).

→ These carriers collide with the atoms and break the covalent bonds and generate additional carriers (electron-hole pairs).

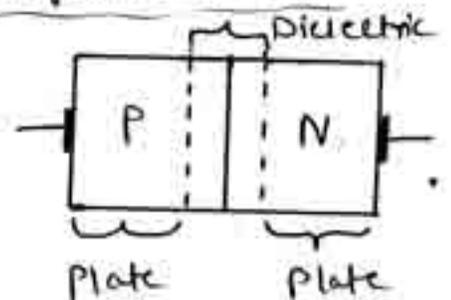
→ These additional carriers pickup energy from the applied voltage and generate still more carriers (carrier generation @ carrier multiplication).

→ As a result, the reverse current increases rapidly. This process is called Avalanche multiplication @ Avalanche effect @ Avalanche breakdown.

Note:

- ① Depletion layer capacitance ② Space-charge capacitance
- ③ Transition capacitance ④ depletion region capacitance

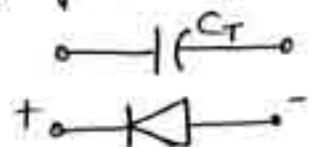
→ P region & N-region act as two plates of a capacitor, separated by a dielectric (i.e. depletion layer)



→ The capacitance which exists in a reverse-biased junction is called depletion layer capacitance.

→ The depletion layer capacitance C_T is given by,

$$C_T = \frac{K}{(V_B - V)^n}$$



Where $K \rightarrow$ A constant, depending upon the semiconductor
 $n \rightarrow$ emission voltage

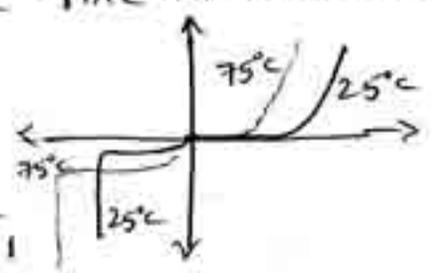
$V \rightarrow$ Applied reverse voltage

$n \rightarrow$ A constant depending upon the nature of the junction.

② Junction temperature effects (Effect of temperature on diode characteristics)

\rightarrow The reverse saturation current (leakage current) approximately doubles for each 10°C rise in temperature
 \rightarrow current at T_2 is,

$$I_0(T_2) = I_0(T_1) \left[2^{(T_2 - T_1)/10} \right]$$



Where, $I_0(T_1) \rightarrow$ reverse current at T_1

③ Diode equation @ diode current equation @ Shockley equation:

The equation relating Pn-junction current & voltage level is called the Shockley equation.

Shockley equation is,

$$I_D = I_0 \left[e^{V_D/nV_T} - 1 \right] \quad \text{--- ①}$$

- Where.
- $I_D \rightarrow$ Junction current.
 - $I_0 \rightarrow$ Reverse saturation current.
 - $V_D \rightarrow$ Junction Voltage
 - $n \rightarrow$ constant (1 for Ge, & 2 for Si)
 - $V_T \rightarrow$ Volt equivalent of temperature = $\frac{kT}{q}$
(Thermal Voltage)

- Where
- $k \rightarrow$ Boltzmann's const ($1.38 \times 10^{-23} \text{ J/K}$)
 - $T \rightarrow$ Temperature (in Kelvin)
 - $q \rightarrow$ Electronic charge ($1.6 \times 10^{-19} \text{ C}$)

$$T(\text{Kelvin}) = 273 + \text{temp } ^\circ\text{C}$$

① For an unbiased Pn junction: $V_D = 0 \therefore I_D = 0$

② For Forward biased $I_D = I_0 e^{V_D/nV_T}$

③ For Reverse biased $I_D = -I_0$

④ PN junction diode:

A PN junction diode is a two terminal unidirectional device, offering a low resistance when forward-biased, and behaving almost as an open switch when reverse biased.

The circuit symbol (or graphic symbol) is shown in fig ②

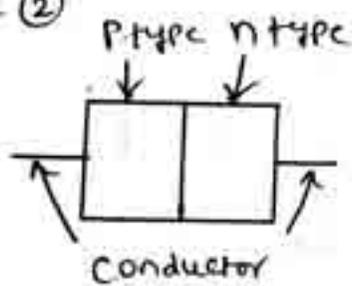


Fig ①: A semiconductor diode

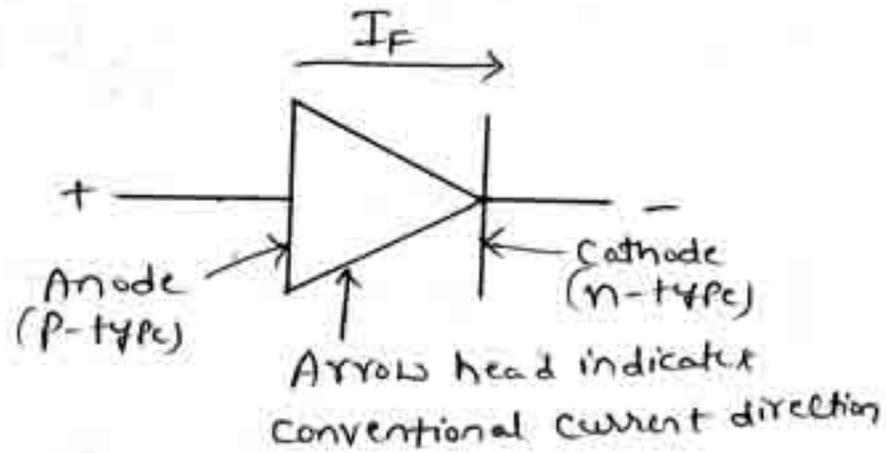


Fig ②: Diode circuit symbol

⑤ Types of diodes (Classification of diodes):

Depending upon physical size, diodes are classified into,

- ① Low current diodes
- ② Medium current diodes
- ③ High current diodes (Power diodes)

① Low current diodes:

- Low current diodes are 0.3cm long.
- Colour band is near the cathode (K).
- Capable of passing a maximum forward current of 100mA.
- Capable of withstanding 75V reverse voltage (without breaking down)
- Reverse current is usually less than 1μA (at 25°C)

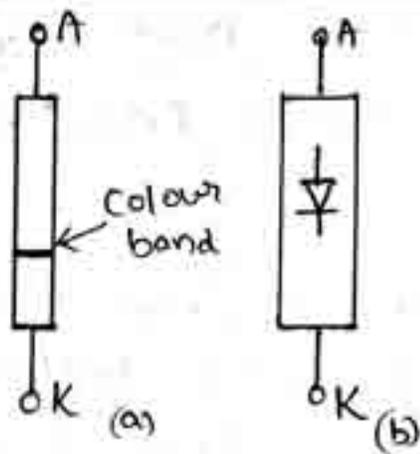


Fig ①: Low current diodes

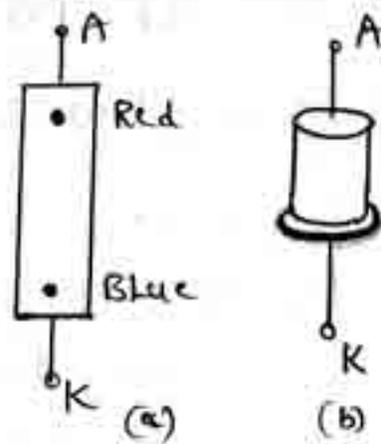


Fig ②: Medium current diode



Fig ③: High current diode

② Medium-current diodes:

- The end lying near the blue dot is a Cathode, while the other end is anode (fig 2 a)
- The diode is packaged in a metal can-like casing.
- The typical diameter is 8.9mm and length is 7.6mm.
- These diodes are bigger in size compared to low current diodes.
- The diodes can pass a forward current of about 400mA and withstand (Survive) reverse voltage of about 200V.

③ High-current diodes: (Power diodes)

- These diodes are mechanically connected to a metal heat sink (for the heat dissipation)
- The typical diameter is 7.8mm and the length is 31.2mm
- These diodes can pass a forward current of many amperes and can withstand reverse voltage of several hundred volts.
- These diodes are bigger in size compared to low current & medium current diodes.

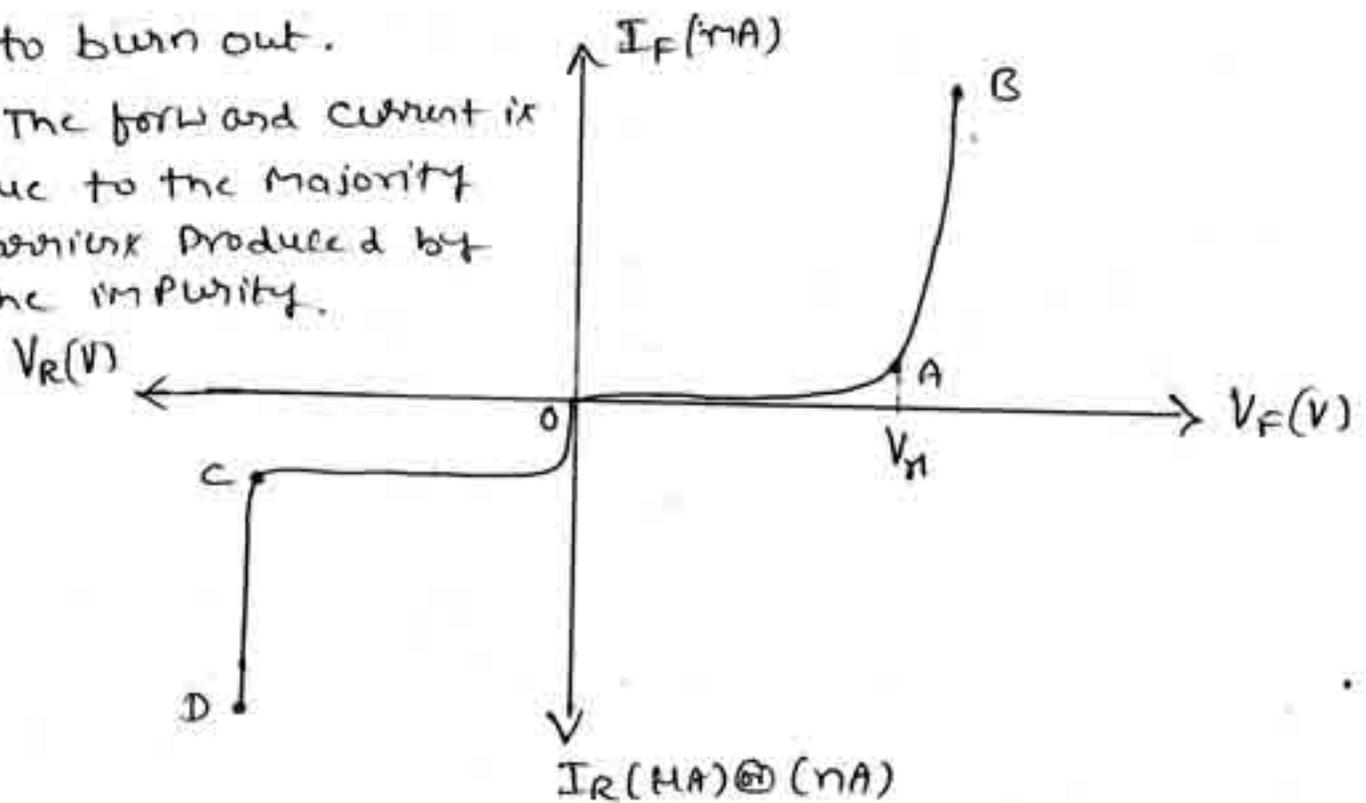
* V-I Characteristics of PN Junction (Diode) (07)

Forward & Reverse Characteristics of PN Junction

① Forward Characteristics:

- P-type is connected to positive terminal & n-type is connected to negative terminal of the battery.
- A very small forward current (I_F) flows until the forward voltage (V_F) exceeds the cut-in voltage (V_{in}) (Portion OA)
- when the forward voltage exceeds the cut-in voltage the current increases rapidly. (Portion AB)
- The applied voltage should not be increased beyond a certain safe limit, otherwise the diode is likely to burn out.

→ The forward current is due to the majority carriers produced by the impurity.



② Reverse Characteristics:

- P-type is connected to negative terminal & n-type is connected to positive terminal of the battery.
- When the applied reverse voltage (V_R) is below the break-down voltage (V_{bo}), the diode current is very

- Small and constant. This value of current is called reverse saturation current (I_0). (Region OC)
- When the reverse voltage exceeds breakdown voltage, the current increases very rapidly. (Region CD)
 - The applied voltage should not be increased beyond the breakdown voltage, otherwise the diode is destroyed permanently.
 - The reverse current is due to the minority carriers produced due to breaking of some covalent bonds.

Note: V-I characteristics of Ge & Si

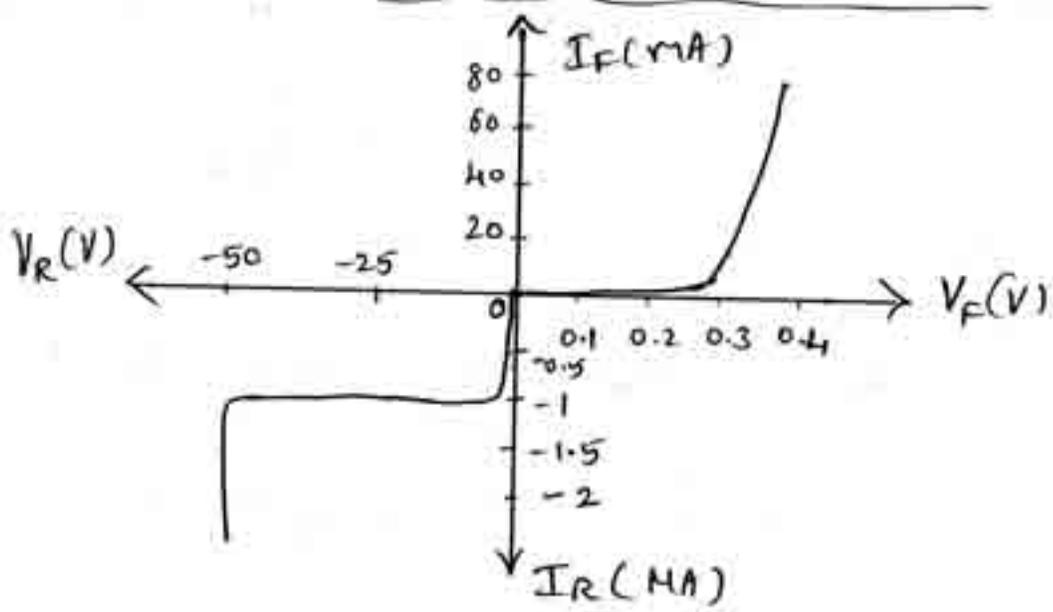


Fig ①: V-I characteristic of Ge

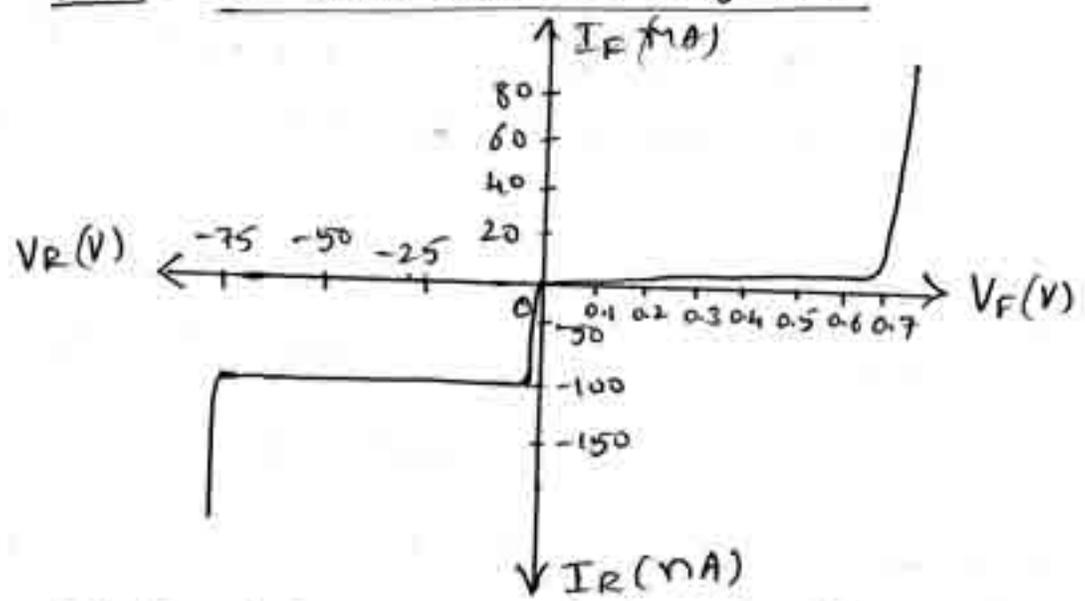


Fig ②: V-I characteristic of Si

Ge (Fig 1)

Forward characteristics:

(14)

- A very small forward current flows until the forward voltage exceeds 0.3V.
- When the forward voltage exceeds 0.3V, the current increases rapidly.

Reverse characteristics:

- When the applied reverse voltage is below the breakdown voltage, the diode current is very small, typically around 1 μ A. (which is larger than the reverse current for a silicon diode)
- When the reverse voltage exceeds breakdown voltage, (around 50V), the current increases very rapidly.
- Reverse breakdown voltage for Ge is less than that of Si
- From the characteristics, $|I_F| \gg |I_R|$

Si (Fig 2)

Forward characteristics:

- A very small forward current flows until the forward voltage exceeds 0.7V.
- When the forward voltage exceeds 0.7V, the current increases rapidly.

Reverse characteristics:

- When the applied reverse voltage is below the breakdown voltage, the diode current is very small, typically around (100 nA).
- When the reverse voltage exceeds breakdown voltage (around 75V), the current increases very rapidly.
- From the characteristics, $|I_F| \gg |I_R|$.

② Conditions under which a p-n junction can be destroyed

- (i) Pn junction diode is overheated by a high forward current. $[I_{F(max)}]$
- (ii) A large reverse voltage causes the Pn junction to break down. $[V_{R(max)}]$

Diode Parameters (Important terms):

- (i) Forward Voltage ⁽ⁱⁱ⁾ (Knee Voltage) ⁽ⁱⁱⁱ⁾ (Forward Voltage drop) ^(iv) turn-on Voltage ^(v) Potential barrier Voltage : (V_n) :

→ It is the voltage applied across a forward biased device. ^(vi)

The forward voltage is the voltage at which the current through the junction starts to increase rapidly.

→ The knee voltage for Si diode is 0.7V and 0.3V for Ge diode

- (ii) Maximum forward current : $(I_{F(max)})$:

→ It is the maximum current that a diode can withstand under forward bias condition, without permanent damage to the Pn junction due to overheating.

- (iii) Forward Current : (I_F) :

→ It is the current flowing through a forward biased diode.

- (iv) Reverse breakdown Voltage ^(v) Breakdown Voltage : (V_{BR}) :

It is the reverse voltage at which the Pn junction diode breaks down and reverse current increases rapidly (permanently damages the diode) ^(vi)

It is the minimum reverse voltage at which Pn junction breaks down with sudden rise in reverse current.

→ The reverse breakdown voltage is around 50V for Ge diodes and 75V for Si diodes.

(vi) Reverse Voltage : (V_R)

→ It is the voltage across a reverse biased diode.

(vii) Reverse Current : (Reverse bias current) : (I_R) (Leakage current)

→ It is the direct current flowing through a reverse-biased diode. This current is due to the minority carriers.

(viii) Reverse Saturation Current : (I_0)

→ It is the nominal current, which flows through the diode when it is reverse biased. (i)

It is the constant reverse current flowing through the reverse biased diode.

→ It is in the order of μA for Ge diodes and nA for Si diodes.

(ix) Peak Inverse Voltage : (PIV)

→ It is the maximum reverse voltage that a diode can withstand without destroying the junction.

→ There are two types of PIV

(i) Repetitive PIV (ii) Non-repetitive PIV

→ PIV may be between 10V and 10kV depending upon the type of diode.

(x) Power Dissipation (P_D):

The power dissipated in a diode for a given value of diode voltage (V_D) and current (I_D)

$$\text{i.e. } P_D = V_D \times I_D$$

(X) Maximum Power Rating @ Maximum Power Dissipation Rating ($P_{D(max)}$):

It is the maximum power that can be dissipated at the junction without damaging it.

Maximum Power Rating is given by,

$$P_{D(max)} = V_D(max) \times I_D(max)$$

(Xi) Maximum Junction Temperature (T_J):

It is the maximum allowable junction temperature of the diode.

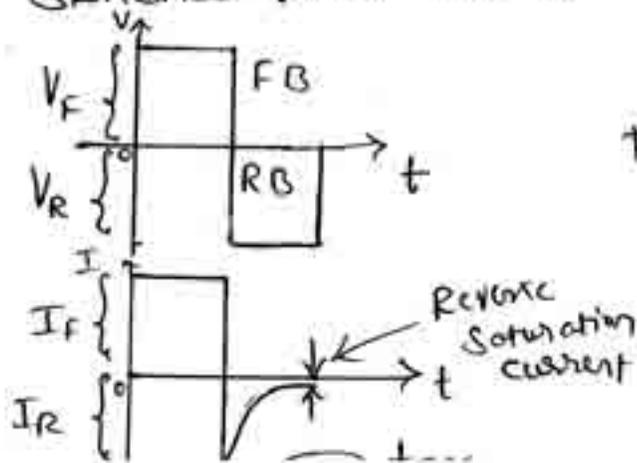
(Xii) Forward Recovery Time (t_{ff}):

It is the time required for the forward current @ voltage to reach a specified value after the diode has been abruptly switched from the reverse-biased state to the forward-biased state.

(Xiii) Reverse Recovery Time (t_{rr}):

It is the time required by the reverse current @ voltage to reach a specified value, when the diode is switched from the forward-biased condition to the reverse-biased condition abruptly.

① It is the time required for the current to decrease to the reverse saturation current level, when the diode is switched from the forward-bias to reverse bias.



The minimum fall time of the applied voltage pulse is,

$$t_{f(min)} = 10 t_{rr}$$

Note:

① The maximum power dissipation (W)

$$P_2 = (P_1 \text{ at } T_1) - (D \times \Delta T)$$

Where P_1 (W) → Power at temp T_1 (W)

D → Derating factor ($W/^\circ C$)

ΔT → Temperature change ($^\circ C$) ($T_2 - T_1$)

T_1 → Temperature ($^\circ C$)

② The diode forward voltage drop is, (at any temperature)

$$V_{F2} = (V_{F1} \text{ at } T_1) + [\Delta T (\Delta V_F / ^\circ C)]$$

Where, V_{F1} → Forward V_F drop at T_1 (V)

ΔT → ($T_2 - T_1$) → Temperature change ($^\circ C$)

$\Delta V_F / ^\circ C$ → Voltage / Temperature coefficient ($V/^\circ C$)
 $= -1.8 \text{ mV}/^\circ C$ for Si, $-2.02 \text{ mV}/^\circ C$ for Ge

③ Dynamic resistance of a forward-biased diode at any temperature is,

$$r_d' = \frac{26 \text{ mV}}{I_F} \left(\frac{T + 273^\circ C}{298^\circ C} \right)$$

Where, I_F → Forward current (A)

T → Junction temperature ($^\circ C$)

* Equivalent Circuits: (Model) : (Diode Model)

An equivalent circuit for a device is a circuit that represents the device behavior under forward and reverse bias conditions.

① AC equivalent circuits:

A Forward-biased diode can be represented by the dynamic resistance r_d in parallel with the diffusion capacitance $C_d(C_0)$ [Fig(1)]

A reverse-biased diode can be represented by the high reverse resistance R_r in parallel with the depletion layer capacitance $C_{pd}(C_T)$ [Fig(2)]

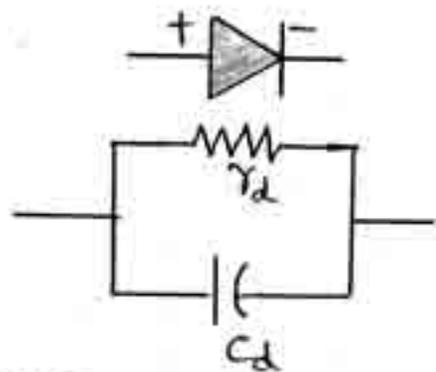


Fig ①: AC equivalent ckt for a forward-biased diode

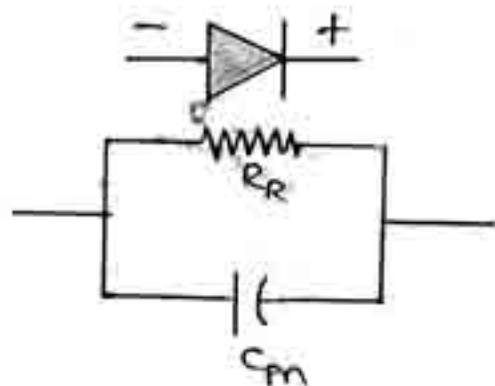


Fig ②: AC equivalent ckt for a reverse-biased diode

② DC equivalent circuits:

(i) Ideal diode equivalent ckt: [Fig(3)]

- The diode conducts when it is forward biased & has zero resistance (acts as closed switch)
- The diode blocks the conduction when it is reverse biased and has infinite resistance (acts as open switch)
- This equivalent ckt has ideal characteristics (Fig*)

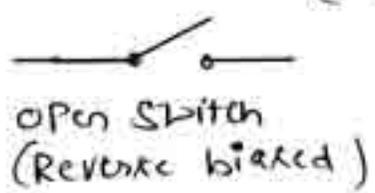
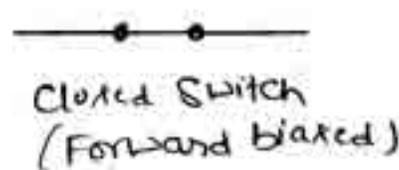
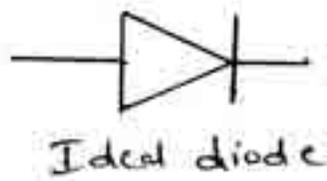
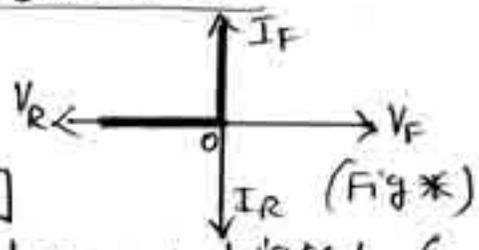
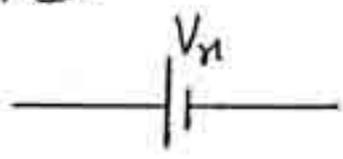


Fig ③: Ideal diode equivalent circuit

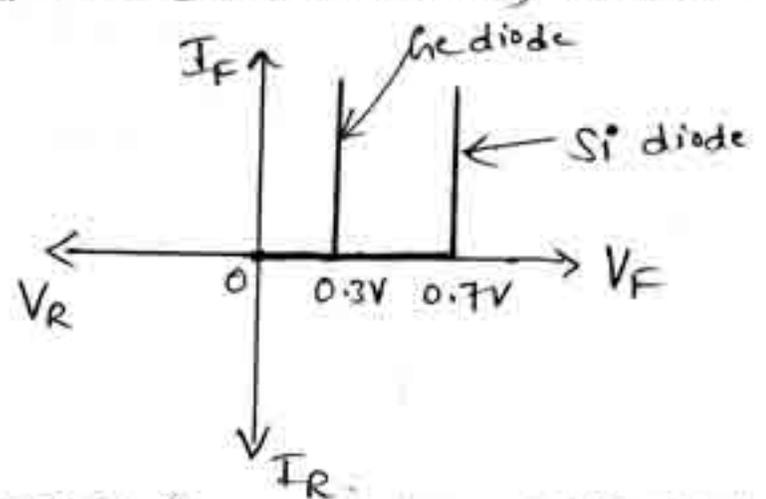
(ii) Near ideal diode equivalent circuit (Practical diode (Fig 4))

Approximate equivalent circuit @ Basic dc equivalent circuit

The diode equivalent circuit consists of a voltage source with a voltage V_{γ} and negligible forward resistance. This equivalent circuit has the second approximation characteristics (or approximate characteristics) shown in fig 5.



Fig(4): Basic dc equivalent circuit



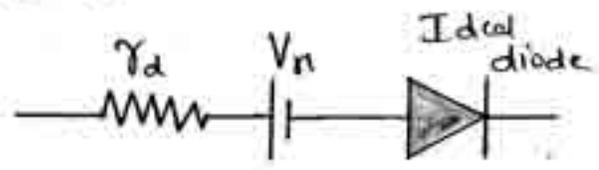
Fig(5): Ge & Si diode approximate characteristics

(iii) Piecewise linear equivalent circuit: (Complete DC equivalent circuit) (Third approximation equivalent circuit) (Fig 6)

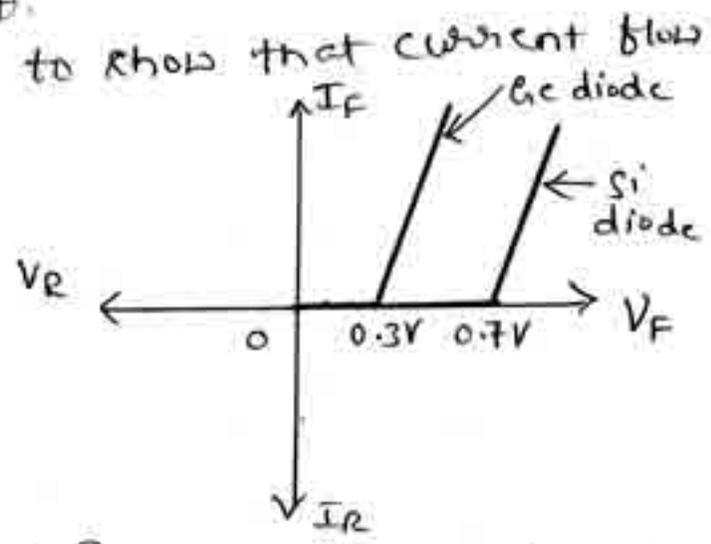
The equivalent circuit consists of diode dynamic resistance r_d in series with the voltage source V_{γ} .

This equivalent circuit has the piecewise linear characteristics shown in fig 7.

An ideal diode is included to show that current flows only in one direction.



Fig(6): Complete dc equivalent circuit



Fig(7): Ge & Si diode piecewise linear characteristics

* Diode approximations:

There are three diode approximations, namely

① Ideal diode approximations:

→ An ideal diode (Perfect diode) have forward resistance and infinite reverse resistance (Zero forward voltage drop @ cut-in voltage)

→ A forward biased diode can be replaced by a short circuit (SC) and reverse biased diode can be replaced by a open circuit (OC)

→ Fig ① shows the ideal diode characteristics.

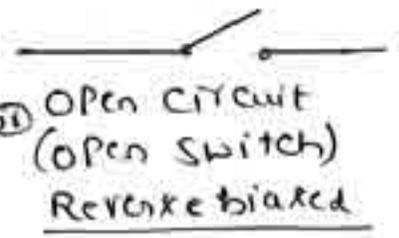
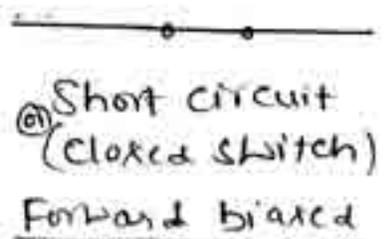
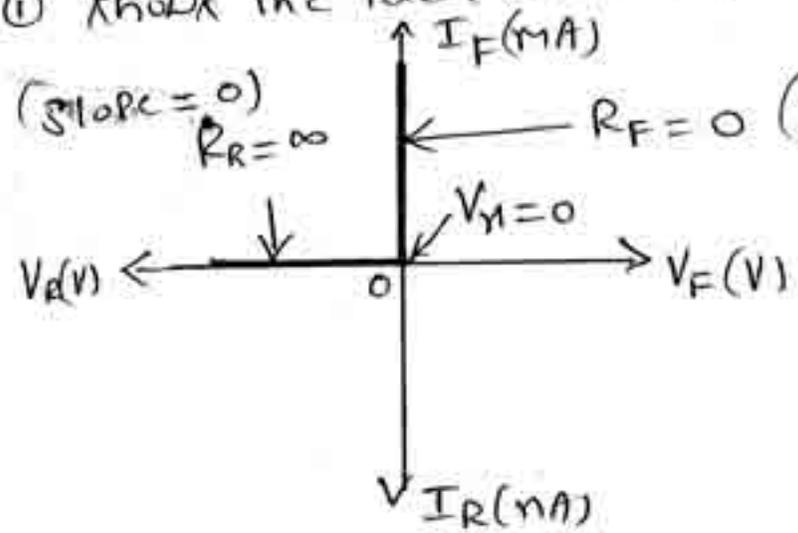


Fig ①: Ideal diode characteristics

② Near-ideal diode approximation ①

(Second ~~diode~~ approximation) ②

③ (Practical approximation) ④ (Approximate Simplified equivalent approximation) characteristic

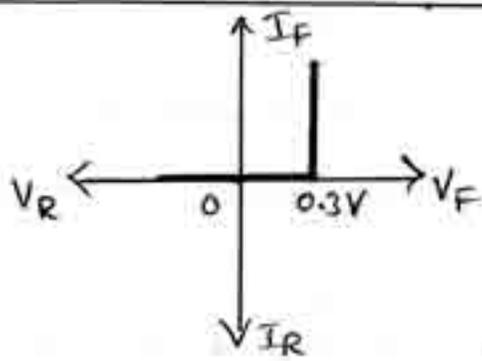
→ An ideal diode doesn't exist practically, there are many applications where diodes can be assumed to be near-ideal diodes.

→ The cut-in voltage is 0.3V for Ge & 0.7V for Si

→ The reverse current is very small so it can be ignored

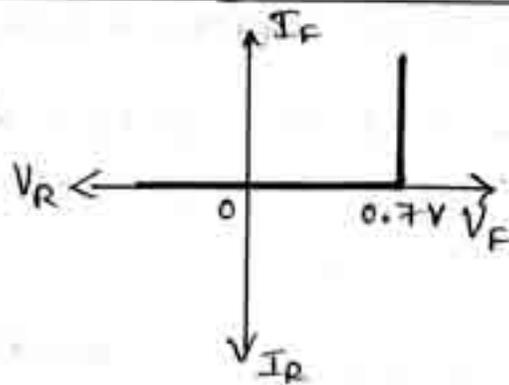
→ Fig ② shows the approximate diode characteristics





$V_M = 0.3V, R_F = 0, R_R = \infty, I_R = 0$

Fig: Approximate characteristics of Ge diode



$V_M = 0.7V, R_F = 0, R_R = \infty, I_R = 0$

Fig: Approximate characteristics of Si diode

Fig(2): Approximate characteristics

③ Piecewise linear approximations:

→ When the forward characteristic of a diode is not available, a straight line approximation called the piecewise linear approximation is used.

→ construction of piecewise linear characteristic

Step 1: Mark $V_F (V_M)$ on x-axis. [Point A ($V_F, 0$)]

Step 2: Draw a straight line (let AB) with a slope equal to the reciprocal of the dynamic resistance of the diode.

→ It consists of two straight line pieces, one horizontal and other with slope $1/r_d$

→ Fig ③ shows the piecewise linear characteristics

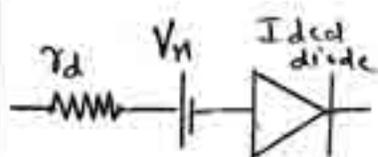


Fig: Simplified Equivalent circuit

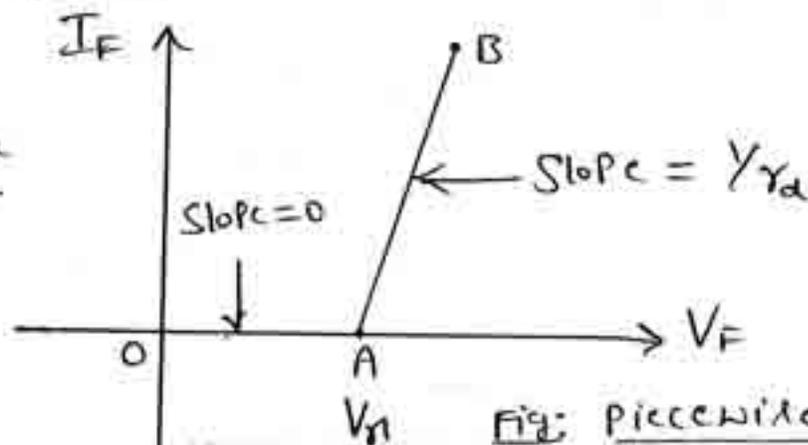


Fig: Piecewise Linear

* Resistance of diode:

① DC Static Resistance:

It is the opposition offered by the diode to the direct current.

② Static forward resistance @ DC forward resistance:

→ It is the opposition offered by the forward biased diode to the direct current, denoted by R_F @ R_f .

→ It is measured by the ratio of d.c. voltage across the diode to the resulting d.c. current through it.

→ From the forward characteristic of fig ①, the dc forward resistance at P is,

$$R_F = \frac{\text{Forward d.c. Voltage}}{\text{Forward d.c. current}} = \frac{OA}{OB}$$

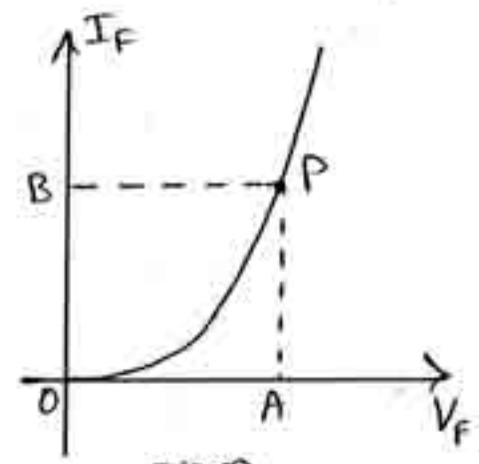


Fig ①

③ Static reverse resistance @ DC reverse resistance:

→ It is the opposition offered by the reverse biased diode to the direct current, denoted by R_R @ R_r .

→ It is measured by the ratio of reverse d.c. voltage across the diode to the reverse saturation current.

→ From the reverse characteristic of fig ②, the dc reverse resistance at C is,

$$R_R = \frac{\text{Reverse d.c. Voltage}}{\text{Reverse Saturation current}} = \frac{OP}{OQ}$$

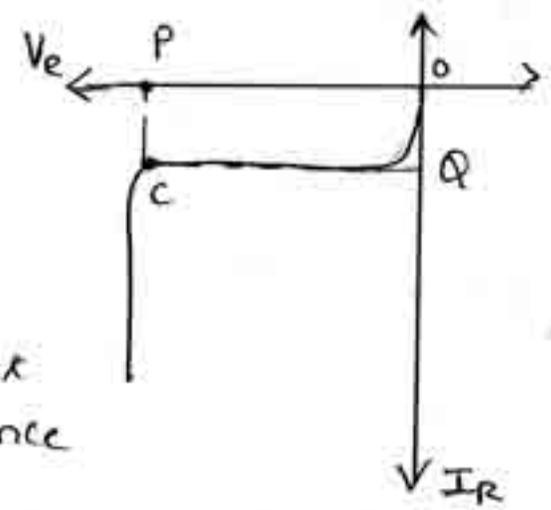


Fig ②

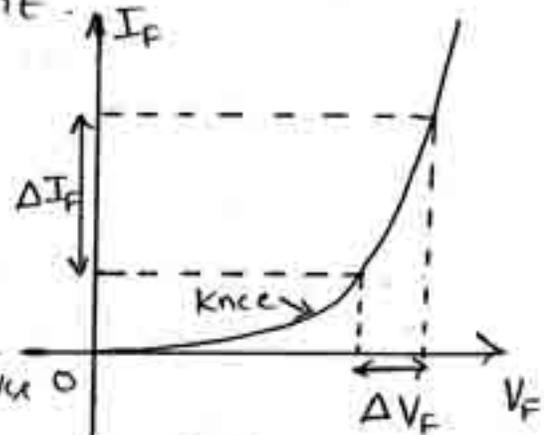
② AC ① Dynamic ② Incremental resistance :

→ It is the opposition offered by the forward biased diode under a.c conditions (When the applied voltage is a.c) ①

It is the reciprocal of the slope of the forward characteristic beyond its knee, denoted by r_d ① r_F ② r_F

→ It is measured by the ratio of change in applied voltage to the change in the current.

→ From the forward characteristic of fig ③, the dynamic forward resistance is:



$$r_d = \frac{\Delta V_F}{\Delta I_F} = \frac{1}{\text{slope of forward characteristic}}$$

→ r_d includes dc resistance of the semiconductor material. The pure ac resistance is given by,

$$r_d' = \frac{0.026}{I_F} \quad \text{Where } I_F \rightarrow \text{DC forward current}$$

Eqn ① is valid at 25°C only.

→ Semiconductor substrate resistance is,

$$r_{\text{substrate}} = r_d - r_d'$$

* DC load line :

A DC load line is a straight line on the diode characteristic which describes all the dc conditions that exist within the circuit.

Explanation:

The graphical analysis used to calculate the precise current and voltage is called dc load

Line analysis.

Consider a simple diode circuit as shown in fig ①.

→ The diode is forward biased,
So the diode forward current I_F
flows through resistor R .

→ Applying KVL to the circuit, we get

$$V - I_F R - V_F = 0$$

$$\Rightarrow V = I_F R + V_F \quad \text{--- (*)}$$

Put $I_F = 0$ in eqn (*)

$$V = V_F$$

$$\textcircled{a) \quad V_F = V$$

Now Mark Point ~~A(0,0)~~ A(V, 0)

Put $V_F = 0$ in eqn (*)

$$V = I_F R$$

$$\Rightarrow \boxed{I_F = \frac{V}{R}}$$

Now Mark Point B(0, $\frac{V}{R}$)

Join AB to get the dc load line

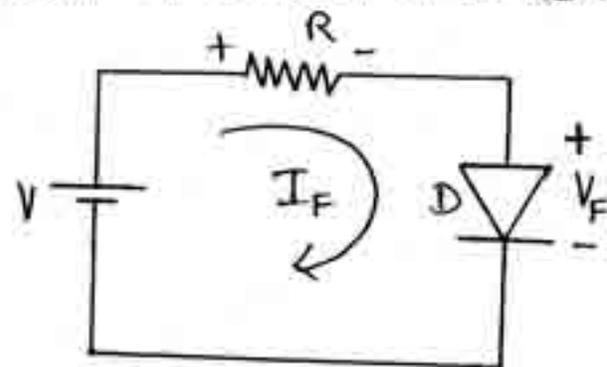
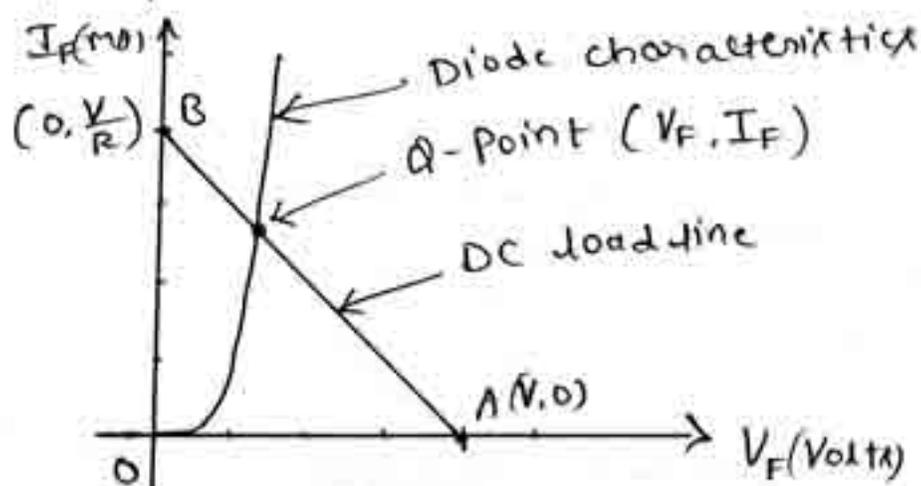


Fig ①: Simple diode circuit

From eqn (*), we can write

$$V - V_F = I_F R$$

$$\Rightarrow I_F = \left(-\frac{1}{R}\right) V_F + \frac{V}{R}$$

--- (**)

Q-Point (or) Quiescent Point (or) dc bias Point (or) operating Point (or) Working bias Point:

- The intersection of the diode forward characteristic and the dc load line is called the Q-Point.
- The values of forward current through the diode (I_F) and the voltage drop across the diode (V_F) can be found at Q-Point.

Note:

① To calculate the load resistance (R) and supply voltage (V)

consider eqn (**).

$$I_F = \left(-\frac{1}{R}\right)V_F + \frac{V}{R}$$

This equation is of the form $y = mx + c$

Where, $y = I_F$, $m = -\frac{1}{R}$, $x = V_F$, $c = \frac{V}{R}$

① Given Q-Point and Supply Voltage (V):

- Load line is drawn from Point A (V, 0) through Q-Point.
- Load resistance R is calculated from the slope of the load line.

② Given Q-Point and load resistance (R):

- Load line is drawn through Q-Point and having slope $1/R$.
- The intersection of the load line with x-axis gives the value of supply voltage (V).

② Transformer utilization factor (T.U.F) For HWR, T.U.F = 0.287
 For Full CR, T.U.F = 0.693
 For Full BR, T.U.F = 0.812

T.U.F = $\frac{\text{D.C Power delivered to the load}}{\text{A.C rating of the transformer}}$

* Rectifier:

A circuit (device) which converts a.c. Voltage into Pulsating d.c. Voltage is called rectifier.

The different types of rectifier circuits are

- (i) Half-Wave Rectifier
- (ii) Full-Wave Rectifier
 - (a) Centre tapped full Wave Rectifier
 - (b) Bridge full Wave Rectifier

① Half-Wave Rectifier: (HWR):

Definition: The rectifier which conducts current (Voltage) only during one half-cycle of the ac input is called Half-Wave Rectifier.

Circuit diagram and input & output wave forms:

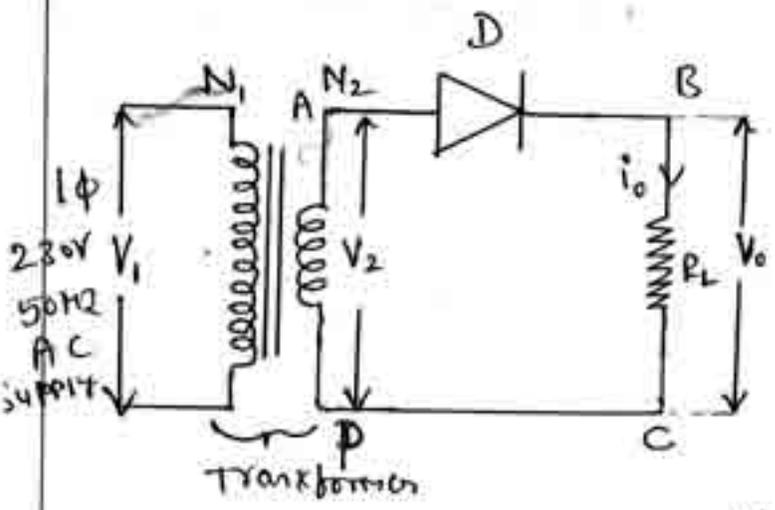
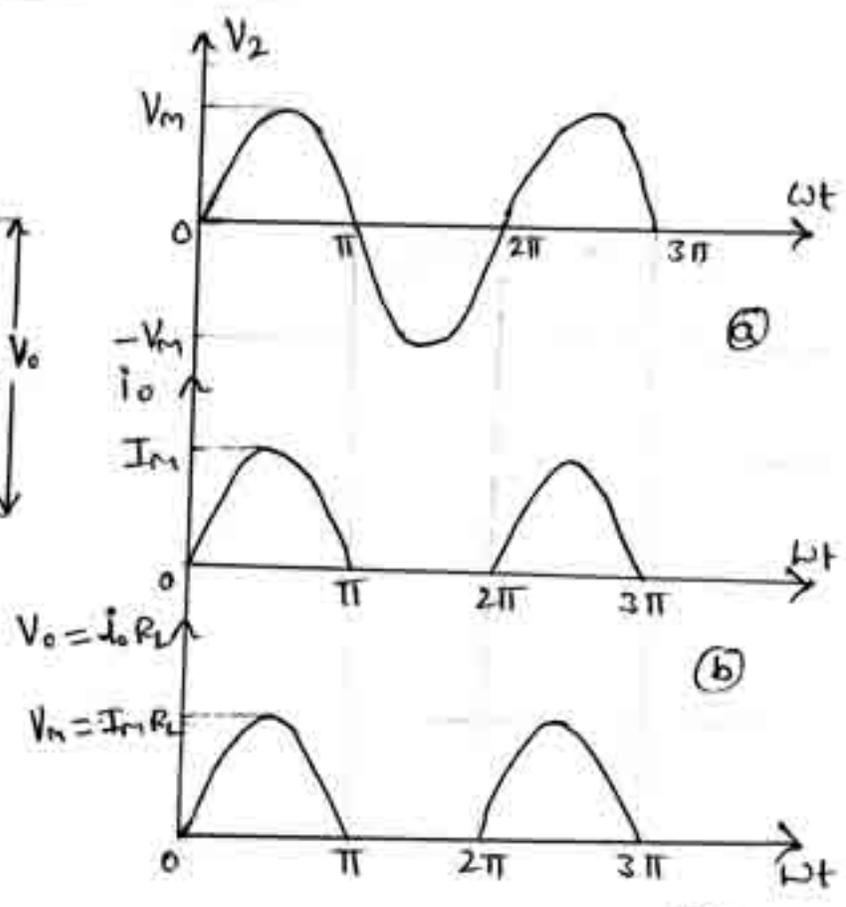


Fig: Half Wave Rectifier



- ① Waveform of Secondary transformer Voltage
- ② Load current wave form
- ③ Load Voltage wave form

Construction: It consists of a Step down transformer, a diode and a load resistor. The Primary coil of a transformer is connected to ac input and Secondary coil to a load resistor (R_L) through the diode (D).

Operation: (Principle of operation):

→ During positive half cycle of the input voltage, end A becomes positive w.r.t end P. Hence the diode is forward biased and current flows through R_L (Path: ADBCPA). [$V_o = i_o R_L$]

→ During negative half cycle of the input voltage, end A becomes negative w.r.t end P. Hence the diode is reverse biased and no current flows in the circuit. [$V_o = 0$]

Therefore, current flows through the diode during positive half-cycles of input a.c. voltage only, it is blocked during the negative half-cycles.

Note:

① Uses of transformer:

- (i) It allows us to step up @ step down the a.c input voltage.
- (ii) It isolates the rectifier circuit from power line and thus reduces the risk of electric shock.

② Disadvantages @ Drawbacks of HWR: ① Demerits

- (i) The ripple factor is too high ($\gamma = 1.21$)
- (ii) Efficiency of rectification is low ($\eta = 0.406$)
- (iii) The T.U.F (Transformer utilization factor) is very low.
- (iv) D.C. Saturation of transformer secondary winding takes place.

③ Advantages @ Merits of HWR:

- (i) The a.c supply delivers power only half the time. Therefore, the output is low.

and a large filter capacitor is required to produce steady

direct current (pulsating current in the load contains alternating component whose basic frequency equal to the supply frequency).

Advantages & Merits of HWR:

- (i) only one diode is required
- (ii) No centre-tap on the transformer is required.

(iii) Current through diode $\approx I_o$ & Peak Load current \approx Peak diode current (I_m)

Instantaneous supply voltage is,

$V_m \gg I_m$

$V_1 = V_m \sin \omega t$ — ①

Instantaneous secondary voltage is,

$V_2 = \frac{N_2}{N_1} V_1$ — ②

Using ① in ②. We get

$V_2 = \frac{N_2}{N_1} V_m \sin \omega t$

Let $N_1 = N_2$, then

$V_2 = V_m \sin \omega t$ — ③

The equivalent circuit when the diode is conducting & not conducting is shown below.

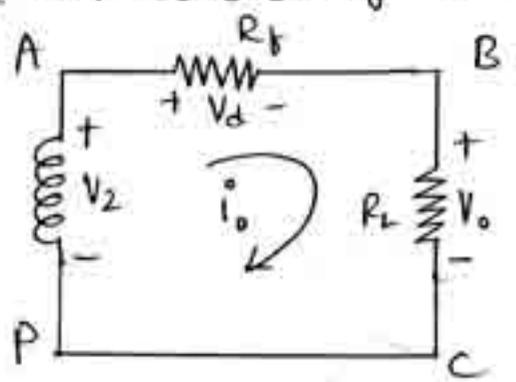


Fig 1 Equivalent circuit when diode is conducting

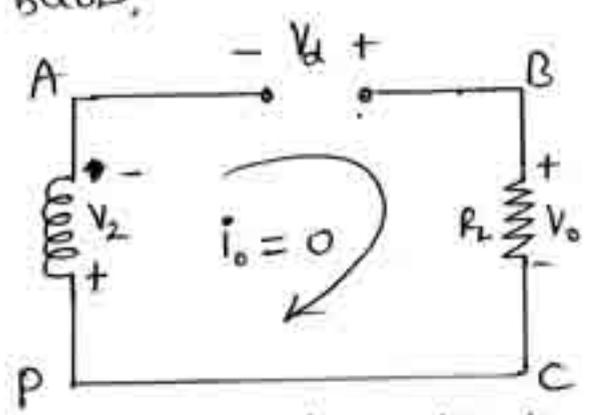


Fig 2 Equivalent circuit when diode is not conducting

Where

$R_f \rightarrow$ Forward resistance of the diode.

From eq ①

$$i_o = \frac{V_2}{R_f + R_L} ; 0 \leq \omega t \leq \pi \quad \text{--- ④}$$

Using ③ in ④, we get

$$i_o = \frac{V_m \sin \omega t}{R_f + R_L} ; 0 \leq \omega t \leq \pi$$

$$i_o = I_m \sin \omega t ; 0 \leq \omega t \leq \pi \quad \text{--- ⑥}$$

$$\text{Where } I_m = \frac{V_m}{R_f + R_L}$$

From eq ②

$$i_o = 0 ; \pi \leq \omega t \leq 2\pi \quad \text{--- ⑤}$$

From ⑤ & ⑥, we can write

$$i_o = \begin{cases} I_m \sin \omega t ; 0 \leq \omega t \leq \pi \\ 0 ; \pi \leq \omega t \leq 2\pi \end{cases}$$

current through diode

& R_L

⑦

$$\text{where, } I_m = \frac{V_m}{R_f + R_L}$$

Peak load current &

Peak diode current

⑧

Derivations:

① Average Load current @ DC load current @ DC output current @ Average output current (I_{dc}):

DC load current,

$$I_{dc} = \frac{\text{Area under one cycle of } i_o}{\text{Period of } i_o}$$

$$= \frac{\int_0^{2\pi} i_o d\omega t}{2\pi}$$

$$= \frac{1}{2\pi} \left[\int_0^{\pi} I_m \sin \omega t d\omega t + \int_{\pi}^{2\pi} 0 d\omega t \right] \quad (\text{Using ⑦})$$

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

$$= \frac{I_m}{2\pi} [-\cos\pi + \cos 0]$$

$$I_{dc} = \frac{I_m}{\pi} \text{ or } 0.3183 I_m \quad \text{--- (9)} \quad (\because \cos\pi = -1, \cos 0 = 1)$$

② Average Load Voltage or DC Load Voltage or DC Output Voltage or Average output Voltage (V_{dc}):

DC load voltage,

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

$$= \frac{I_m}{\pi} \cdot R_L \quad (\text{Using 9})$$

$$= \frac{1}{\pi} \left[\frac{V_m}{R_f + R_L} \right] R_L \quad (\text{Using 8})$$

$$V_{dc} = \frac{V_m/\pi}{1 + R_f/R_L} \quad \text{--- (10)}$$

If diode is ideal, $R_f = 0$

$$\therefore V_{dc} = \frac{V_m}{\pi} \quad \text{--- (11)}$$

③ RMS load current (I_{rms}):

RMS load current,

$$I_{rms} = \sqrt{\frac{\text{Area under one cycle of } i_o^2}{\text{Period of } i_o}}$$

$$= \sqrt{\frac{\int_0^{2\pi} i_o^2 d\omega t}{2\pi}}$$

$$= \sqrt{\frac{1}{2\pi} \left[\int_0^{\pi} I_m^2 \sin^2 \omega t d\omega t + \int_{\pi}^{2\pi} 0 d\omega t \right]} \quad (\text{Using 7})$$

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

$$= \frac{I_m}{2} \sqrt{\frac{1}{\pi} \left\{ (\omega t)^\pi - \left(\frac{\sin 2\omega t}{2} \right)^\pi \right\}} \quad [\because \sin n\pi = 0, n \in \mathbb{I}]$$

$$= \frac{I_m}{2} \sqrt{\frac{1}{\pi} (\pi - 0)}$$

$$\boxed{I_{rms} = \frac{I_m}{2}} \quad - (12)$$

4) RMS load voltage (V_{rms})

RMS load voltage.

$$V_{rms} = I_{rms} R_L$$

$$= \left(\frac{I_m}{2} \right) R_L$$

$$= \frac{1}{2} \left(\frac{V_m}{R_f + R_L} \right) R_L$$

$$\boxed{V_{rms} = \frac{V_m/2}{1 + R_f/R_L}} \quad - (13)$$

If diode is ideal, $R_f = 0$

$$\therefore \boxed{V_{rms} = \frac{V_m}{2}} \quad - (14)$$

5) RIPPLE factor (γ):

Ripple factor.

$$\gamma = \frac{V_{ac}}{V_{dc}} \quad - (5)$$

$$= \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} \quad [\because V_{rms}^2 = V_{ac}^2 + V_{dc}^2]$$

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

$$= \sqrt{\left(\frac{V_m/2}{1 + R_f/R_L} \right)^2 / \left(\frac{V_m/\pi}{1 + R_f/R_L} \right)^2 - 1} \quad (\text{using } (10) \& (13))$$

$$\gamma = \sqrt{\frac{\pi^2}{4} - 1}$$

$$\gamma = 1.21 \text{ (or) } 121\% \quad - (16)$$

Note:

① AC Components present in the dc output of a rectifier are called ripple.

② A measure of the smoothness of the dc output of a rectifier is called the ripple factor
(or)

The ratio of rms value of ac component present in the rectified output to the dc component in the rectified output is called ripple factor

$$\text{i.e. } \gamma = \frac{V_{ac}}{V_{dc}} \text{ (or) } \frac{I_{ac}}{I_{dc}}$$

③ We have

$$\left(\text{Total RMS Value of rectified output} \right)^2 = (\text{DC Value})^2 + \left(\text{RMS Value of ac component} \right)^2$$

$$\text{i.e. } I_{\text{RMS}}^2 = I_{\text{dc}}^2 + I_{\text{ac}}^2 \quad - (17)$$

$$\text{(or) } V_{\text{RMS}}^2 = V_{\text{dc}}^2 + V_{\text{ac}}^2 \quad - (18)$$

④ From (15) & (18), we can write

$$\gamma = \frac{V_{ac}}{V_{dc}} = 121\% \Rightarrow \boxed{V_{ac} = 121\% \cdot V_{dc}} \quad - (19)$$

\therefore AC or ripple component is 121% of the dc component.
Hence HWR is not recommended for practical application.

⑤ Efficiency or Rectification efficiency: (η) (Power Conversion Efficiency)

$$\text{Efficiency, } \eta = \frac{P_{dc}}{P_{in}} \quad - (20)$$

$$= \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_b + R_L)} \quad \left[\begin{array}{l} \therefore P_{dc} = I_{dc}^2 R_L \\ \& P_{ac} = I_{rms}^2 (R_b + R_L) \end{array} \right]$$

$$= \frac{(I_m/\pi)^2 R_L}{(I_m/2)^2 (R_b + R_L)} \quad [Using (9) \& (12)]$$

$$= \frac{4}{\pi^2} \frac{R_L}{R_b + R_L}$$

$$\eta = \frac{0.406}{1 + R_b/R_L} \approx \frac{40.6\%}{1 + R_b/R_L} \quad - (21)$$

If diode is ideal, $R_b = 0$

$$\therefore \eta = 0.406 \approx 40.6\% \quad - (22)$$

Note:

① The ratio of the dc output power to ac input power supplied to the rectifier is known as rectification efficiency.

② From (20) & (22), we can write

$$\eta = \frac{P_{dc}}{P_{ac}} = 40.6\% \Rightarrow P_{dc} = 40.6\% \text{ of } P_{ac} \quad - (23)$$

\therefore The dc output power is 40.6% of the ac input power (a maximum of 40.6% of a.c input power is converted into dc output power). Hence HWR has a very poor rectification efficiency.

③ The process of converting a.c voltage into pulsating d.c voltage is called rectification.

⑦ Percentage regulation ^(or) (Voltage regulation) (% Regulation)

$$\% \text{ Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 \quad - (24)$$

$$= \frac{V_m}{\pi} - \left(\frac{V_m}{\pi}\right) \frac{R_L}{R_f + R_L} \times 100$$

$$= \frac{\left(\frac{V_m}{\pi}\right) \frac{R_L}{R_f + R_L}}{\frac{R_L}{R_f + R_L}} \times 100$$

$$= \frac{1 - \frac{R_L}{R_f + R_L}}{\frac{R_L}{R_f + R_L}} \times 100$$

$$= \frac{R_f + R_L - R_L}{R_f + R_L} \times 100$$

$$= \frac{R_f}{R_f + R_L} \times 100$$

$$\left[\begin{aligned} \because V_{NL} &= \frac{V_m}{\pi} \\ V_{FL} &= \left(\frac{V_m}{\pi}\right) \frac{R_L}{R_f + R_L} \end{aligned} \right]$$

$\% \text{ Regulation} = \frac{R_f}{R_L} \times 100$

— (25)

If diode is ideal, $R_f = 0$

$\therefore \% \text{ Regulation} = 0$
— (26)

Note: ① From (26), For an ideal diode, a HWR behaves as an ideal dc Power Supply.

- ② $V_{NL} \rightarrow$ DC output voltage when load current is zero
 - ⓐ DC output voltage when no load
- $V_{FL} \rightarrow$ DC output voltage with load current
 - ⓑ DC output voltage with load

③ The variation of dc output voltage as a function of DC load current is called regulation

ⓐ The variation of dc output voltage as load changes from no load to full load is called regulation

④ Ideally, the dc voltage (O/P) is independent of load current.

$$\therefore V_{NL} = V_{FL}$$

Hence, % Regulation = 0

⑤ Lesser the value of the voltage regulation, better is the performance of the rectifier circuit.

$$⑥ V_{NL} = V_{dc} \Big|_{R_L = \infty} = \frac{V_m / \pi}{1 + R_f / \infty} = \frac{V_m}{\pi} \quad \left(\begin{array}{l} \text{From 10) } \\ \text{(Anything} / \infty = 0 \end{array} \right)$$

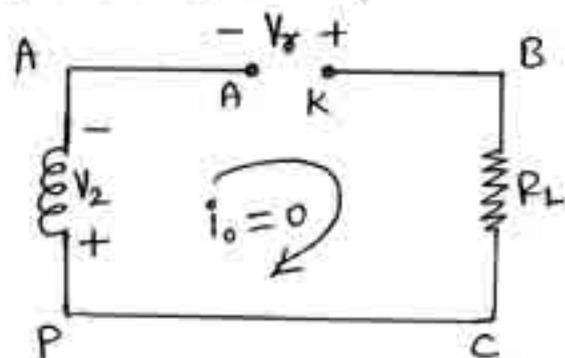
$$V_{FL} = V_{dc} = \frac{V_m / \pi}{1 + \frac{R_f}{R_L}} = \left(\frac{V_m}{\pi} \right) \frac{R_L}{R_f + R_L} \quad \left(\begin{array}{l} \text{⑦ } f_{out} = f_{in} \\ \text{(Freq of HWR}_{off}) = \text{(IF frequency)} \end{array} \right)$$

⑧ Peak inverse Voltage (or) Peak reverse Voltage (PIV)

The Peak inverse voltage is the maximum voltage across the reverse biased diode of a rectifier.

① The Peak inverse voltage is the maximum reverse voltage to which the diode can be subjected.

The equivalent circuit of a HWR when diode is reverse biased (not conducting) is shown below.



Applying KVL to the loop,

$$-V_2 + V_r - i_o R_L = 0$$

$$\Rightarrow V_r = V_2 \quad (\because i_o = 0)$$

$$\Rightarrow V_r = V_m \sin \omega t \quad (\because V_2 = V_m \sin \omega t)$$

$$\Rightarrow \boxed{V_{rmax} = V_m = PIV} \quad \text{--- (27)}$$

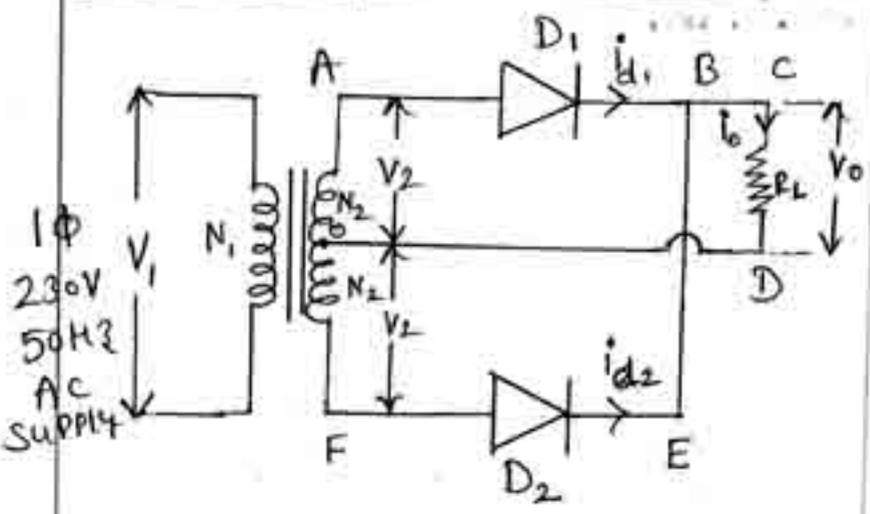
\therefore PIV for a HWR is equal to the Peak Secondary Voltage of the transformer.

(ii) Full-Wave Rectifier (FWR):

Definition: The rectifier which conducts current (voltage) during both positive and negative half-cycles of the ac input is called Full Wave Rectifier.

@ Centre tapped full wave rectifier:

Circuit diagram and input & output wave forms:



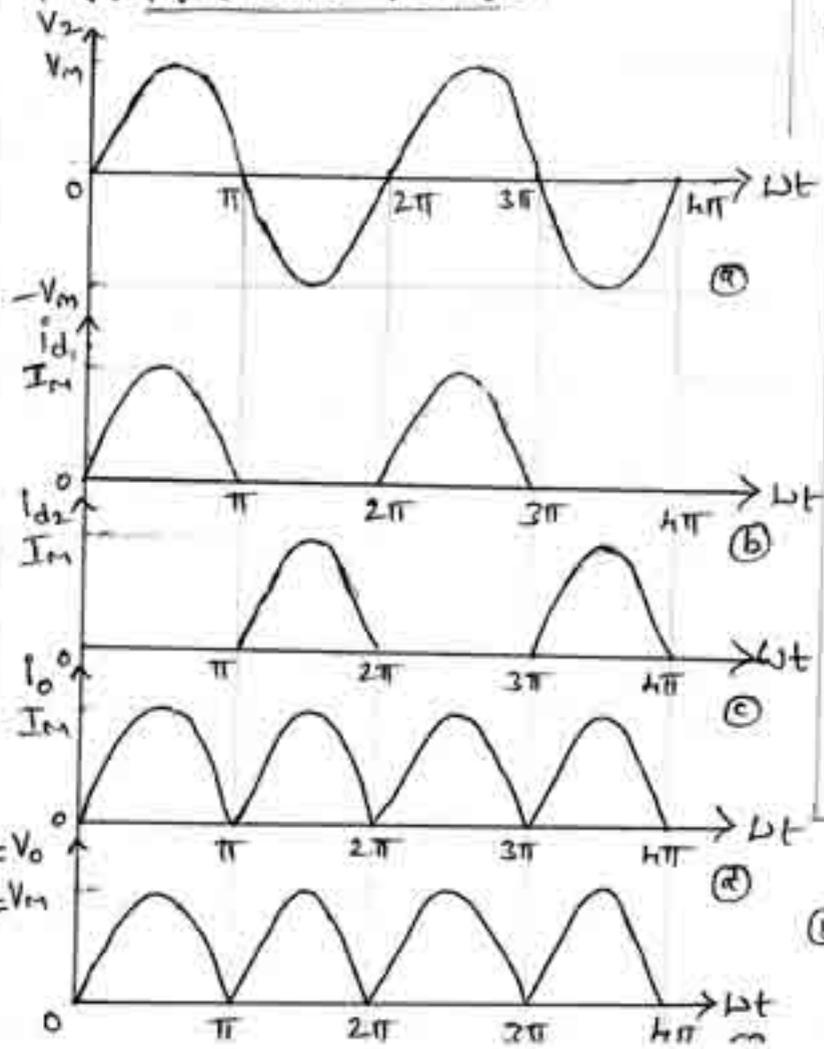
Construction:

It consists of step down transformer with a centre-tapped secondary winding, two diodes and a load resistor. The input signal is applied to the primary winding of the transformer. The centre-tapped secondary winding of the transformer is connected to two diodes.

Operation:

→ During positive half cycle of the input voltage, end A becomes positive w.r.t end F. Hence the diode D_1 conducts & D_2 is off & the current flows through R_L (Path: ABCDOA) (i_{d1})

Fig: Full wave rectifier



- (a) Secondary voltage wave form
- (b) & (c) Diode current wave form
- (d) Load current wave form
- (e) Load voltage wave form

→ During negative half cycle of the input voltage, end F becomes negative w.r.t end E. Hence the diode D_2 conducts & D_1 is off & the current flows through R_L (Path: FEBCDF) (i_{D_2})

Therefore, the current flows through R_L in the same direction (C to D) for both half-cycles of input ac voltage.

Note:

① Advantages @ Merits of Center-tapped FWR:

- (i) The dc output voltage and load current are twice than those of a HWR.
- (ii) The ripple factor is much less (0.482) than that of a HWR (1.21)
- (iii) The efficiency ^(81.2%) is twice that of HWR (40.6%)
- (iv) The T.U.F (Transformer utilization factor) is more
- (v) No D.C Saturation of transformer secondary winding takes place.

② Disadvantages @ Drawbacks @ Demerits of Center-tapped FWR:

- (i) The output voltage is half of the secondary voltage
- (ii) The Peak-inverse Voltage (PIV) of a diode is twice that of the diode used in the HWR.
- (iii) It is difficult to locate the centre tap on the secondary winding.
- (iv) Higher PIV diodes are larger in size & costlier.
- (v) It is expensive to manufacture a center-tapped transformer, which produces equal voltages on each half of the secondary winding.

③ current through diode or current through R_L (I_o)

↳ Peak load current (I_m):

Instantaneous supply voltage is,

$$V_1 = V_m \sin \omega t \quad \text{--- (28)}$$

Instantaneous secondary voltage is,

$$V_2 = \frac{N_2}{N_1} V_1 \quad \text{--- (29)}$$

Using (28) in (29), we get

$$V_2 = V_m \sin \omega t \quad \text{--- (30) (Let } N_1 = N_2)$$

The equivalent circuit when the diode D_1 is ON & D_2 is OFF is shown below,

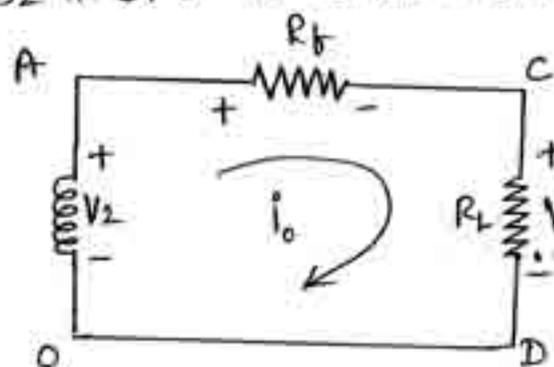


Fig: Equivalent circuit during positive half cycle of ac voltage

Applying KVL to the loop,

$$V_2 - i_o R_f - I_o R_L = 0$$

$$\Rightarrow i_o = \frac{V_2}{R_f + R_L}, \quad 0 \leq \omega t \leq \pi \quad \text{--- (31)}$$

Using (30) in (31), we get

$$i_o = \frac{V_m}{R_f + R_L} \sin \omega t, \quad 0 \leq \omega t \leq \pi$$

$$\Rightarrow i_o = I_m \sin \omega t; \quad 0 \leq \omega t \leq \pi$$

$$\text{Where, } I_m = \frac{V_m}{R_f + R_L} \quad \text{--- (32)}$$

R_f → Forward resistance of the diode.

Eqn (32) gives the current through R_L

Eqn (33) gives the peak load current.

Derivations:

① Average load current or DC load current or DC output current or Average output current (I_{dc}):

DC load current,

$$I_{dc} = \frac{\text{Area under one cycle of } i_o}{\text{Period of } i_o}$$

$$= \frac{\int_0^\pi i_o dt}{\pi}$$

$$= \frac{1}{\pi} \left[\int_0^\pi I_m \sin \omega t dt \right] \quad (\text{Using 32})$$

$$= \frac{I_m}{\pi} [-\cos \omega t]_0^\pi$$

$$\boxed{I_{dc} = \frac{2I_m}{\pi} \text{ (or) } 0.636 I_m} \quad - (34) \quad (\because \cos \pi = -1, \cos 0 = 1)$$

② Average load voltage or DC load voltage or DC output voltage or Average output voltage (V_{dc}):

DC load voltage,

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

$$= \frac{2I_m}{\pi} R_L \quad (\text{Using 34})$$

$$= \frac{2}{\pi} \left[\frac{V_m}{R_f + R_L} \right] R_L \quad (\text{Using 33})$$

$$\boxed{V_{dc} = \frac{2V_m/\pi}{1 + R_f/R_L}} \quad - (35)$$

If diode is ideal, $R_f = 0$

$$\therefore \boxed{V_{dc} = \frac{2V_m}{\pi} \text{ (or) } 0.636 V_m} \quad - (36)$$

Note: ① Comparing (9) & (34), we can write, $I_{dc} = 2 I_{dc} \text{ AVR}$

② Similarly from (10) & (11) & (35) & (36)

$$\textcircled{67} \quad V_{dc} = \frac{\text{Area under one cycle of } V_o}{\text{Period of } V_o}$$

$$= \frac{\int_0^\pi V_o dt}{\pi}$$

$$= \frac{\int_0^\pi i_o R_L dt}{\pi} \quad [\because V_o = i_o R_L]$$

$$= \frac{1}{\pi} \left(\int_0^\pi i_o dt \right) R_L$$

$$\Rightarrow = \frac{2V_m/\pi}{1 + R_f/R_L} \quad (\text{Same as } \textcircled{35})$$

③ RMS load current (I_{RMS}):

RMS load current.

$$I_{RMS} = \sqrt{\frac{\text{Area under one cycle of } i_o^2}{\text{Period of } i_o}}$$

$$= \sqrt{\frac{\int_0^\pi i_o^2 dt}{\pi}}$$

$$= \sqrt{\frac{1}{\pi} \left[\int_0^\pi I_m^2 \sin^2 \omega t dt \right]} \quad (\text{Using 32})$$

$$= \sqrt{\frac{I_m^2}{\pi} \int_0^\pi \left(\frac{1 - \cos 2\omega t}{2} \right) dt} \quad (\because \sin^2 \theta = \frac{1 - \cos 2\theta}{2})$$

$$= I_m \sqrt{\frac{1}{2\pi} \left\{ (\omega t) \Big|_0^\pi - \left(\frac{\sin 2\omega t}{2} \right) \Big|_0^\pi \right\}} \quad (\because \sin 2\pi = \sin 0 = 0)$$

$$= \frac{I_m}{\sqrt{2}}$$

$$\boxed{I_{RMS} = \frac{I_m}{\sqrt{2}}} \quad - (37)$$

Note: ① Comparing (12) & (37), we can write

$$I_{RMS}(FWR) = \sqrt{2} I_{RMS}(HWR) \text{ or } 1.414 I_{RMS}(HWR)$$

② Similarly from (13) & (14) & (35) & (39), we can write

$$V_{RMS}(FWR) = \sqrt{2} V_{RMS}(HWR) \text{ or } 1.414 V_{RMS}(HWR)$$

b) RMS load voltage (V_{RMS}):

RMS load voltage.

$$V_{RMS} = I_{RMS} R_L$$

$$= \frac{I_m}{\sqrt{2}} R_L \quad (\text{Using 37})$$

$$= \frac{1}{\sqrt{2}} \frac{V_m}{R_f + R_L} R_L \quad (\text{Using 33})$$

$$\boxed{V_{RMS} = \frac{V_m / \sqrt{2}}{1 + R_f / R_L}} \quad - (38)$$

If diode is ideal, $R_f = 0$

$$\therefore \boxed{V_{RMS} = \frac{V_m}{\sqrt{2}}} \quad - (39)$$

$$V_{RMS} = \sqrt{\frac{\text{Area under one cycle of } V_o^2}{\text{Period of } V_o}}$$

$$= \sqrt{\frac{\int_0^\pi V_o^2 dt}{\pi}}$$

$$= \sqrt{\frac{1}{\pi} \int_0^\pi i_o^2 R_L^2 dt} \quad (\because V_o = i_o R_L)$$

$$= \sqrt{\frac{1}{\pi} \int_0^\pi i_o^2 dt} \times R_L$$

$$= \frac{I_m}{\sqrt{2}} R_L$$

$$\Rightarrow = \frac{V_m / \sqrt{2}}{1 + R_f / R_L} \quad (\text{Same as (38)})$$

5) RIPPLE factor (γ):

RIPPLE factor,

$$\gamma = \frac{V_{ac}}{V_{dc}} \quad \text{--- (*)}$$

$$= \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} \quad \text{(Using 18)}$$

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

$$= \sqrt{\left(\frac{V_m/\sqrt{2}}{1 + R_f/R_L}\right)^2 / \left(\frac{2V_m/\pi}{1 + R_f/R_L}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} \quad \text{(Using 35 & 38)}$$

$\gamma = 0.483 \text{ @ } 48.3\% \quad \text{--- (40)}$

6) $\gamma = \frac{I_{ac}}{I_{dc}}$

$$= \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}} \quad \text{(Using 18)}$$

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

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

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

$= 0.483 \cdot \text{(Same as (40))}$

6) Efficiency @

- Rectification efficiency @
- Power conversion efficiency (η)

Efficiency,

$$\eta = \frac{P_{dc}}{P_{ac}} \quad \text{--- (**)}$$

$$= \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_L)}$$

$$= \frac{(2I_m/\pi)^2 R_L}{(I_m/\sqrt{2})^2 (R_f + R_L)}$$

$$= \frac{8}{\pi^2} \frac{R_L}{R_f + R_L}$$

$\eta = 81.2\% \text{ @ } 0.812 \quad \text{--- (41)}$

From (*) & (40), we can write

$$\gamma = \frac{V_{ac}}{V_{dc}} = 48.3\%$$

$$\Rightarrow V_{ac} = 48.3\% \text{ of } V_{dc}$$

If diode is ideal, $R_f = 0$

$\eta = 0.812 \text{ @ } 81.2\% \quad \text{--- (42)}$

Note: ① From (***) & (42), we can write

$$\eta = \frac{P_{dc}}{P_{ac}} = 81.2\% \Rightarrow \boxed{P_{dc} = 81.2\% \text{ of } P_{ac}} \quad \text{--- (43)}$$

② From (22) & (42), we can write

$$\eta_{(FWR)} = 2 \eta_{(HLR)}$$

⑦ Percentage regulation @ Voltage regulation (% Regulation)

$$\% \text{ Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 \quad \text{--- (44)}$$

$$= \frac{\frac{2V_m}{\pi} - \frac{(2V_m/\pi) R_L}{R_f + R_L}}{\frac{(2V_m/\pi) R_L}{R_f + R_L}} \times 100$$

$$= \frac{2V_m}{\pi} \left(1 - \frac{R_L}{R_f + R_L}\right) \times 100$$

$$= \frac{2V_m}{\pi} \left(\frac{R_f}{R_f + R_L}\right) \times 100$$

$$= \frac{R_f + R_L - R_L}{R_f + R_L} \times 100$$

$$= \frac{R_f}{R_f + R_L} \times 100$$

$$V_{FL} = V_{dc} = \frac{2V_m/\pi}{1 + R_f/R_L}$$

$$\Rightarrow V_{FL} = \frac{(2V_m/\pi) R_L}{R_f + R_L}$$

$$V_{NL} = V_{dc} |_{R_L = \infty}$$

$$= \frac{(2V_m/\pi)}{1 + R_f/\infty}$$

$$V_{NL} = \frac{2V_m}{\pi} \quad (\because \frac{R_f}{\infty} = 0)$$

$$\boxed{\% \text{ Regulation} = \frac{R_f}{R_L} \times 100} \quad \text{--- (45)}$$

If diode is ideal, $R_f = 0$

$$\therefore \boxed{\% \text{ Regulation} = 0} \quad \text{--- (46)}$$

From (25) & (45),
 $\% \text{ Regulation for HLR} =$
 $\% \text{ Regulation for FWR}$

⑧ Peak inverse Voltage @ Peak reverse Voltage (PIV)

The equivalent circuit of FWR when D_1 is ON & D_2 is OFF is shown in fig (**)

The equivalent circuit of FWR when D_1 is OFF & D_2 is ON is shown in fig (**)

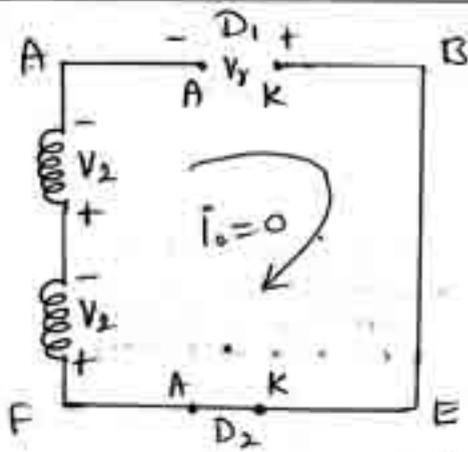


Fig (**): During negative half cycle of input

Applying KVL to the loop.

$$-V_2 - V_2 + V_r = 0$$

$$\Rightarrow V_r = 2V_2$$

$$\Rightarrow V_r = 2V_m \sin \omega t$$

$$\Rightarrow \boxed{PIV = V_{rmax} = 2V_m} \quad (\text{Using 30}) \quad (47)$$

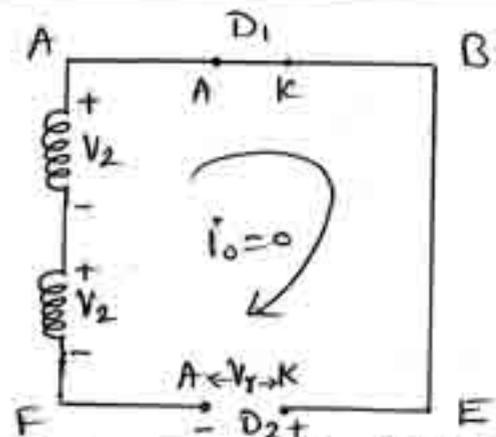


Fig (*): During Positive half cycle of input

Applying KVL to the loop.

$$+V_2 + V_2 - V_r = 0$$

$$\Rightarrow V_r = 2V_2$$

$$\Rightarrow V_r = 2V_m \sin \omega t$$

$$\Rightarrow \boxed{PIV = V_{rmax} = 2V_m} \quad (\text{Using 30}) \quad (47)$$

Note: From (27) & (47), we can write

$$(PIV)_{FLR} = 2(PIV)_{HLR}$$

(b) Full-Wave bridge rectifier:

Circuit diagram:

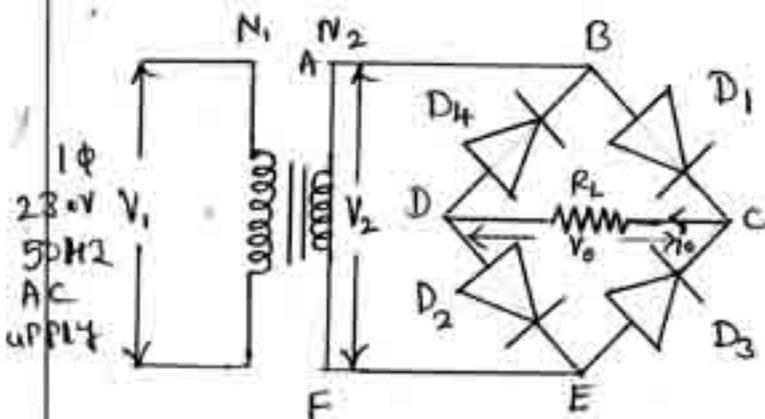


Fig: Full-Wave bridge rectifier

Operation:

→ During positive half cycle of the input voltage, end A becomes positive and end C becomes negative. Hence the diodes D1 & D3 are

Construction:

It consists of a Step down transformer, four diodes & a load resistor. The primary coil of a transformer is connected to ac input and secondary coil to a load resistor (RL) through diodes.

ON & D₃ and D₄ are OFF. The current flows through R_L (Path: A B C D E F A)

→ During negative half cycle of the input voltage, end A becomes negative w.r.t end F. Hence the diodes D₃ & D₄ are ON & D₁ & D₂ are OFF. The current flows through R_L (Path: F E C D B A F)

Therefore, the current flows through R_L in the same direction (C to D) for both half-cycles of input ac voltage.

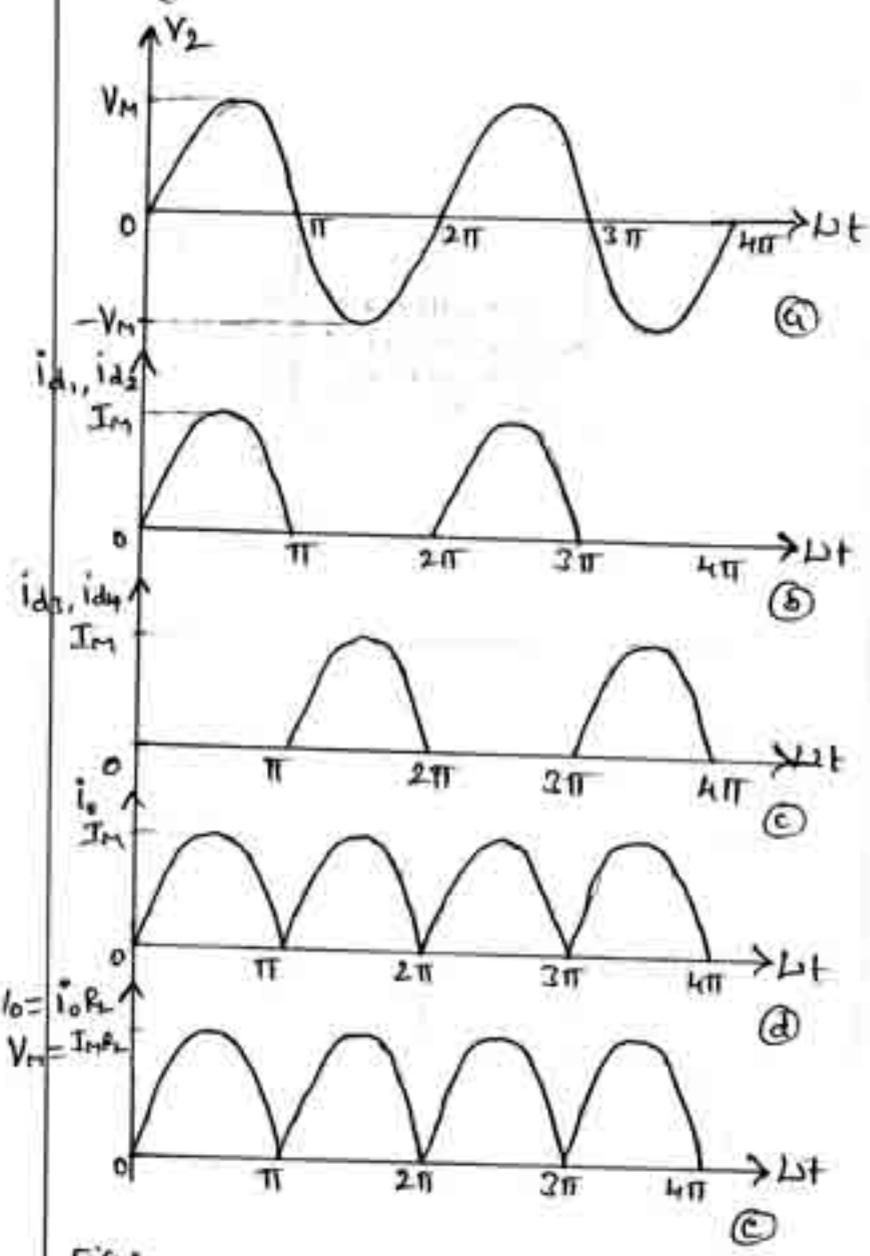


Fig:

- Ⓐ Secondary voltage Wave form
- Ⓑ & Ⓒ Diode current Waveforms
- Ⓓ Load current Wave form
- Ⓔ Load Voltage Wave form.

Note:

- Ⓐ Advantages
- Ⓑ Merits of Full-Wave bridge rectifier
 - (i) The center-tapped transformer is not required.
 - (ii) The transformer is less costly.
 - (iii) The PIV is one-half that of the Centre-tap circuit.
 - (iv) The output is twice that of the Centre-tap circuit for the same secondary voltage.

- (vi) The T.U.F (Transformer Utilization factor) is more.
- (vii) Less D.C Saturation of transformer Secondary Winding
- (viii) It can be used in applications where floating output terminals are allowed.

② Disadvantages @ Drawbacks @ Demerits of Full Wave bridge rectifier:

- (i) It requires four diodes
- (ii) As during each half-cycle of a.c input two diodes that conduct are in series, therefore, voltage drop in the internal resistance of the rectifying unit will be twice as compared to centre tap circuit.

③ Current through R_L (i_o) & Peak load current (I_m):

Instantaneous supply voltage is,

$$V_1 = V_m \sin \omega t \quad \text{--- (48)}$$

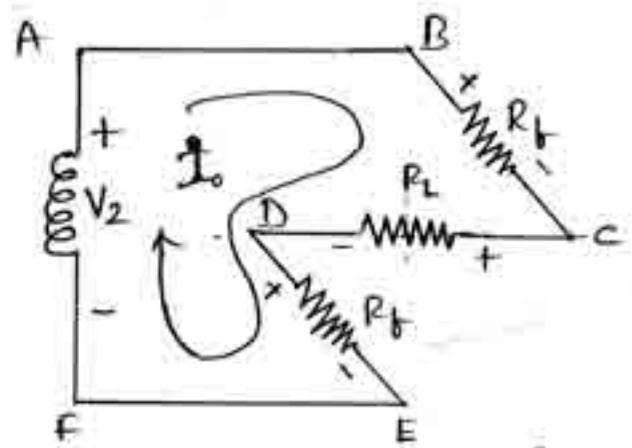
Instantaneous secondary voltage is,

$$V_2 = \frac{N_2}{N_1} V_1 \quad \text{--- (49)}$$

Using (48) in (49), & assuming $N_1 = N_2$, we can write,

$$V_2 = V_m \sin \omega t \quad \text{--- (50)}$$

The equivalent circuit when the diodes D_1 & D_2 are on & the diodes D_3 & D_4 are off is shown below,



Equivalent circuit during first cycle

Applying KVL to the loop

$$V_2 - i_o R_f - i_o R_L - i_o R_f = 0$$

$$\Rightarrow i_o = \frac{V_2}{2R_f + R_L}, \quad 0 \leq \omega t \leq \pi \quad \text{--- (51)}$$

Using (50) in (51), we get

$$i_o = \frac{V_m}{2R_f + R_L} \sin \omega t, \quad 0 \leq \omega t \leq \pi$$

$$\Rightarrow i_o = I_m \sin \omega t ; 0 \leq \omega t \leq \pi \quad \text{--- (52)}$$

Where, $I_m = \frac{V_m}{2R_f + R_L}$ --- (53)

Where, $R_f \rightarrow$ Forward resistance of the diode

Eqn (52) gives the current through R_L

Eqn (53) gives the peak load current @ maximum load current

Derivations

① Average load current @ DC load current @ DC output current @ Average output current (I_{dc}):

$$I_{dc} = \frac{\text{Area under one cycle of } i_o}{\text{Period of } i_o}$$

$$I_{dc} = \frac{2I_m}{\pi} \text{ @ } 0.636I_m \text{ @ } \frac{2V_m/\pi}{2R_f + R_L} \quad \text{--- (54) (Using 53)}$$

② Average load Voltage @ DC load Voltage @ DC output Voltage

@ Average output voltage (V_{dc}):

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

$$= \frac{2I_m}{\pi} R_L \quad \text{--- (Using 54)}$$

$$V_{dc} = \frac{2V_m/\pi}{1 + 2(R_f/R_L)} \quad \text{--- (55) (Using 53)}$$

If diode is ideal, $R_f = 0$

$$\therefore V_{dc} = \frac{2V_m}{\pi} \text{ @ } 0.636V_m \quad \text{--- (56)}$$

③ RMS load current (I_{rms}):

$$I_{rms} = \sqrt{\frac{\text{Area under one cycle of } i_o^2}{\text{Period of } i_o}}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} \text{ @ } \frac{V_m/\sqrt{2}}{2R_f + 0} \quad \text{--- (57) (Using 53)}$$

④ RMS Load Voltage (V_{rms}):

$$V_{rms} = I_{rms} R_L$$

$$V_{rms} = \frac{V_m / \sqrt{2}}{1 + 2(R_f / R_L)} \quad \text{--- (58)}$$

If diode is ideal, $R_f = 0$.

$$\therefore V_{rms} = \frac{V_m}{\sqrt{2}} \quad \text{--- (59)}$$

⑤ Ripple factor (γ):

$$\gamma = \frac{V_{ac}}{V_{dc}}$$

$$\gamma = 0.483 @ 48.3\% \quad \text{--- (60)}$$

⑥ Efficiency @ Rectification efficiency @ Power Conversion efficiency (η):

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

$$\eta = \frac{0.812}{1 + 2(R_f / R_L)} \quad \text{--- (61)}$$

If diode is ideal, $R_f = 0$

$$\therefore \eta = 0.812 @ 81.2\% \quad \text{--- (62)}$$

⑦ Percentage regulation @ Voltage regulation (% Regulation):

$$\begin{aligned} \% \text{ Regulation} &= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 \\ &= \frac{\frac{2V_m}{\pi} - \frac{(2V_m / \pi) R_L}{2R_f + R_L}}{\frac{(2V_m / \pi) R_L}{2R_f + R_L}} \times 100 \end{aligned}$$

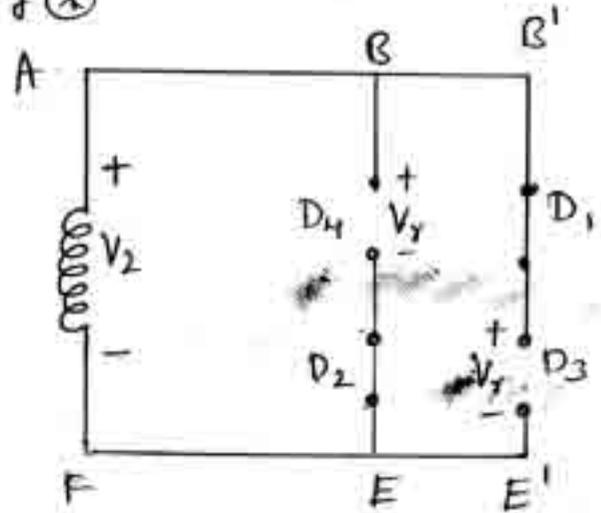
$$\% \text{ Regulation} = \frac{2R_f}{R_L} \times 100 \quad \text{--- (63)}$$

If diode is ideal, $R_f = 0$

$$\therefore \% \text{ Regulation} = 0 \quad \text{--- (64)}$$

⑧ Peak inverse Voltage @ Peak reverse Voltage (PIV) @ (PRV)

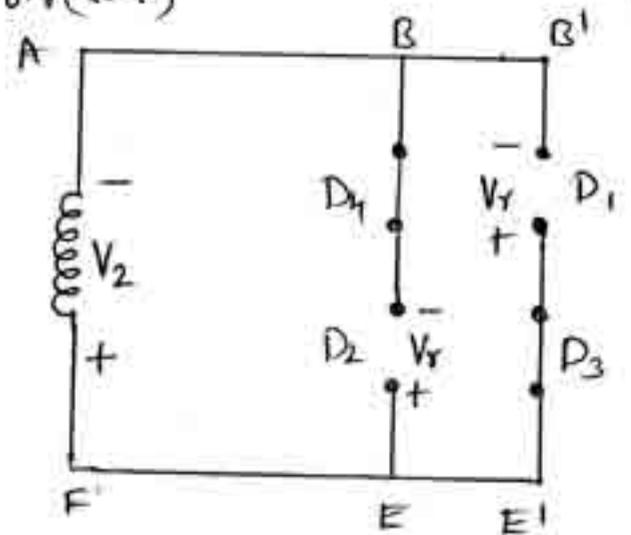
The equivalent circuit of full wave bridge rectifier when D_1 & D_2 are ON and D_3 & D_4 are OFF is shown in fig (*)



Applying KVL to ABFEFA @
 $V_2 - V_r = 0$ (A B B' E' E F A)
 $\Rightarrow V_r = V_2 = V_m \sin \omega t$ (Using 50)
 $\Rightarrow \text{PIV} = V_{r\max} = V_m$

Note: ① $f_{out} = 2 f_{in}$
 (FLR o/p freq) = (2 x i/p freq)

The equivalent circuit of full wave bridge rectifier when D_3 & D_4 are ON and D_1 & D_2 are OFF is shown in fig (**)

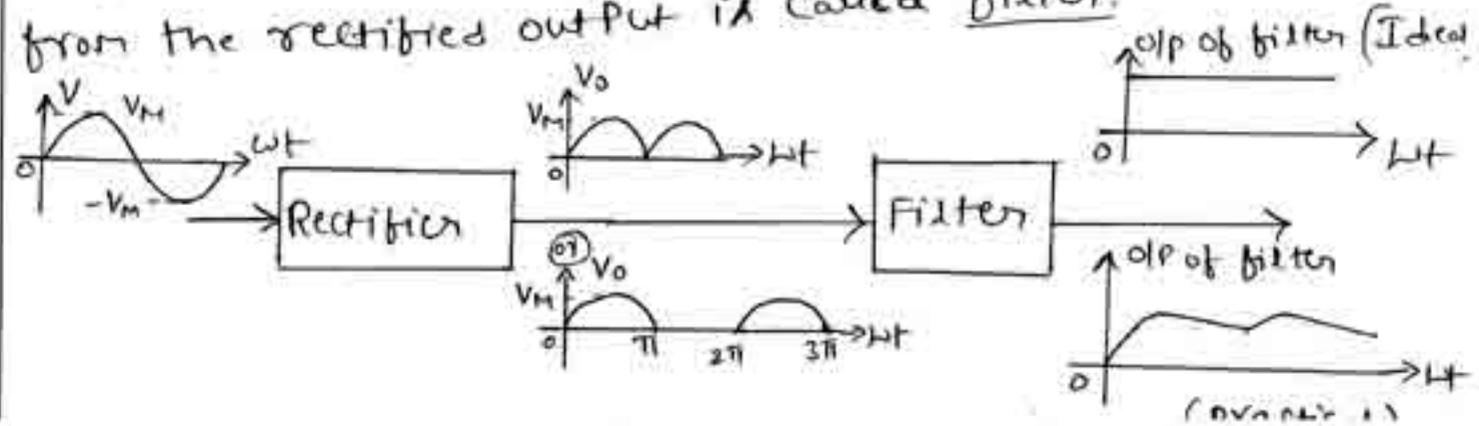


Applying KVL to ACEFA @
 @ A B B' E' E F A
 $-V_2 + V_r = 0$
 $\Rightarrow V_r = V_2 = V_m \sin \omega t$
 $\Rightarrow \text{PIV} = V_{r\max} = V_m$

* Filters @ Filter circuits:

The output of the rectifier is pulsating dc i.e. it contains ac and dc components.

A device which ^(filter out) removes the a.c component (ripple) from the rectified output is called filter.



The most commonly used filter circuits are
 ① Capacitor filter ② Inductor filter ③ Choke input (LC) filter ④ π -filter (Capacitor input)

① HWR With Capacitor filter:

Fig ① Shows a HWR with capacitor filter.

- The reactance of a capacitor is $X_c = \frac{1}{2\pi f c}$
- For d.c, $f=0$. $\therefore X_c = \infty$ i.e capacitor offers infinite reactance to d.c (capacitor passes a.c signal but blocks d.c)

Fig ② Shows different waveforms

→ During the positive half-cycle of the ac input voltage, the diode is forward biased (conducts) and it charges the capacitor to the peak value of secondary transformer voltage (V_m) (indicated by oa). The charging time is negligible.

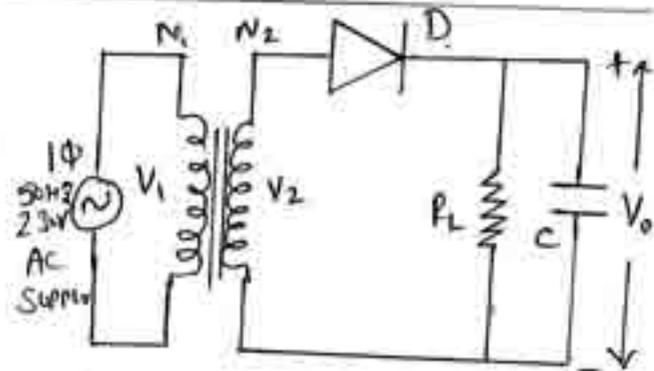
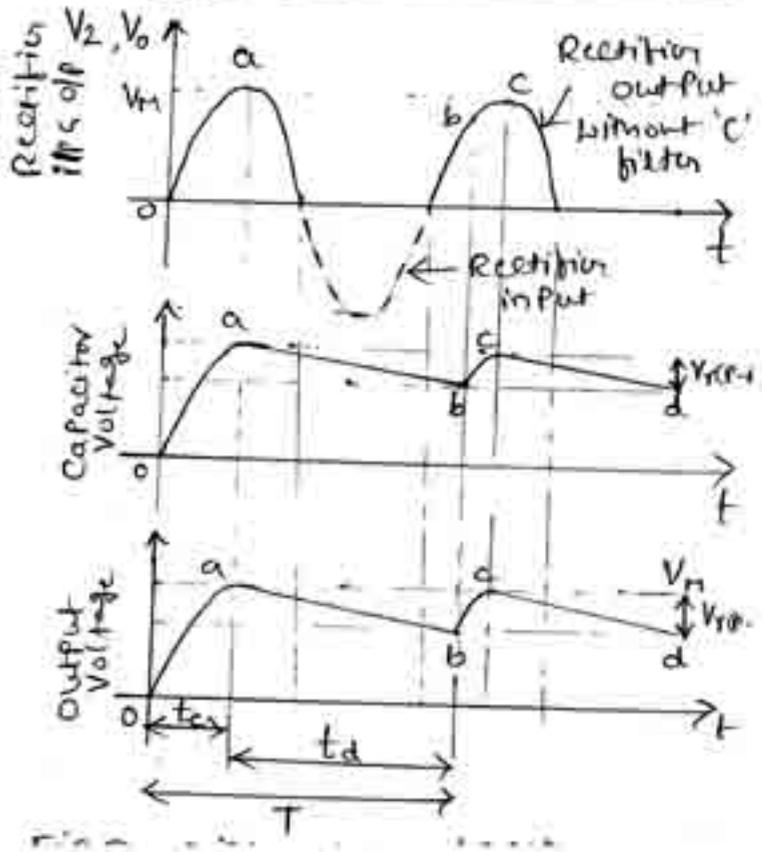


Fig ①: HWR With capacitor filter

When the ac input voltage falls below V_m , the capacitor discharges through the load resistance (indicated by ab). This discharging ~~is done~~ of the capacitor continues until the diode starts conducting again.

This process is repeated again and again, and the output voltage waveform becomes 'oabcd'.



The ripple factor with 'C' filter is,

$$\gamma = \frac{1}{2\sqrt{3} f R_L C}$$

$f \rightarrow$ Frequency of the supply $\frac{V}{Hz}$
 $R_L \rightarrow$ Load resistance
 $C \rightarrow$ Capacitance value of capacitor

Note: ① The process of removing ac components (ripples) from the rectified output is called filtering.

② The discharging time (t_d) is,

$$t_d = C \cdot R_L$$

where, $C \rightarrow$ capacitance value of the capacitor
 $R_L \rightarrow$ Load resistance.

③ Without capacitor filter, output varies between Zero & V_m
With capacitor filter, output varies between $[V_m - V_{r(p-p)}]$ & V_m

④ $V_{r(p-p)} = \frac{I_{dc}}{fC} = \frac{V_{dc}}{fC R_L}$ $V_{r(p-p)} \rightarrow$ Peak to Peak ripple voltage on capacitor.

$$V_{dc} = V_m - \frac{I_{dc}}{2fC} = V_m - \frac{V_{dc}}{2fC R_L}$$

$$V_{dc} = \frac{V_m}{\left(1 + \frac{1}{2fC R_L}\right)}$$

2) Full Wave Rectifier with Capacitor filter:

Fig ③ shows a FWR with capacitor filter.

Fig ④ shows different waveforms.

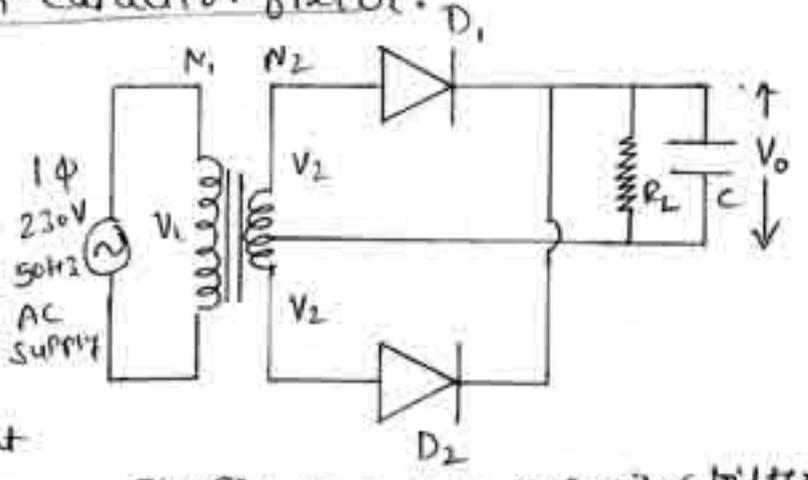


Fig ③: FWR with capacitor filter

\rightarrow During the positive half-cycle of the ac input voltage, the diode D_1 is forward biased and it

charges the capacitor to the peak value of secondary transform

Voltage (V_m) (indicated by oa).
 When the transformer Secondary Voltage falls below V_m , the capacitor discharges through the load resistance (D_1 stop conducting) and this continues until the diode D_2 start conducting again. This process is repeated again and again and the output waveform becomes 'o abcdefg'.

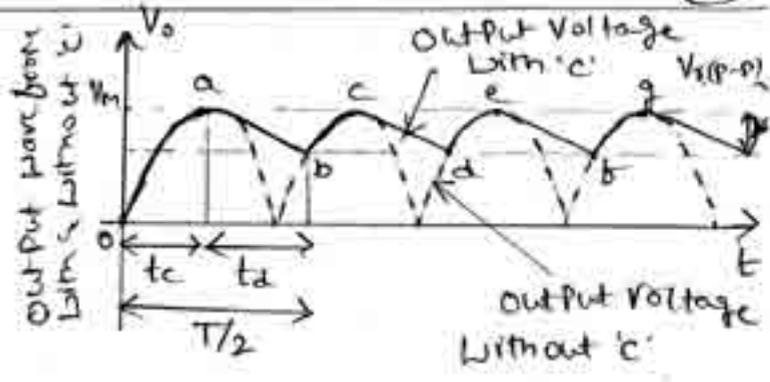


Fig 4: Different Waveform

The ripple factor with 'c' filter is,

$$\gamma = \frac{1}{4\sqrt{3} f R_L C}$$

③ Full Wave bridge rectifier with capacitor filter:

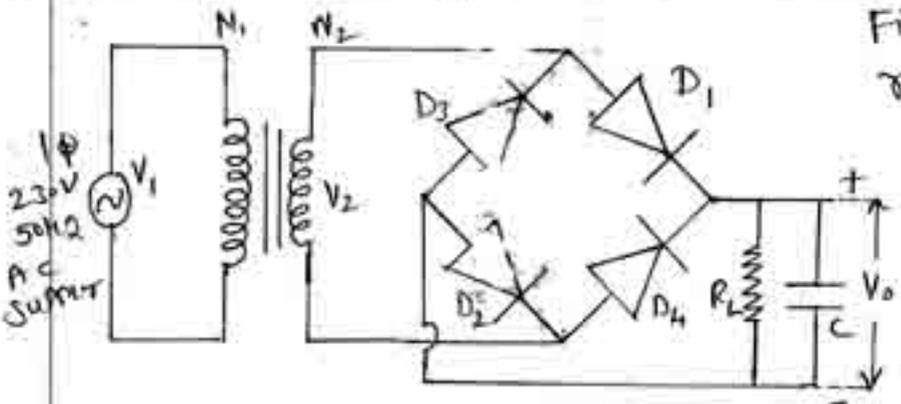


Fig 5 shows a Full bridge rectifier with capacitor filter.

Fig 5: Full Wave bridge rectifier with capacitor filter

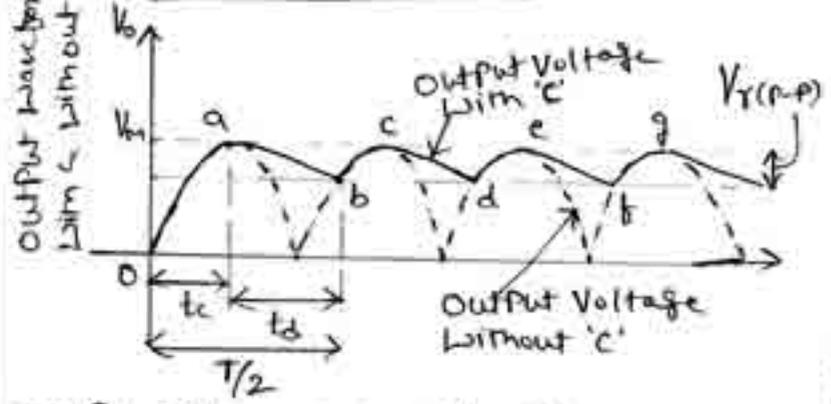


Fig 6: Different waveform

Fig 6 shows different waveform.

→ During the positive half-cycle of the ac input voltage, diodes D_1 and D_2 conduct & charge the capacitor to the peak value of the secondary transformer voltage (V_m) (indicated by oa).

When the transformer secondary voltage falls below V_m (D_1 & D_2 stop conducting), the capacitor discharges through the load resistance and this continues

discharges through the load resistance and this continues

until the diodes D3 & D4 start conducting (indicated by ab) again. This process is repeated again & again and output waveform becomes 'oabcdebf'.

The ripple factor with 'C' filter is,

$$\gamma = \frac{1}{4\sqrt{3}fRC}$$

Note:

① $V_{r(p-p)} = \frac{I_{dc}}{2fc} = \frac{V_{dc}}{2fcRL}$

② $V_{dc} = V_m - \frac{I_{dc}}{4fc} = V_m - \frac{V_{dc}}{4fcRL}$ ③

$V_{dc} = \frac{V_m}{1 + \frac{1}{4fcRL}}$

For FW center tap rectifier & FW bridge rectifier

③ Advantages of capacitor filter:

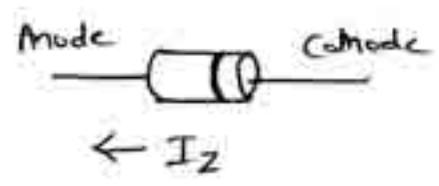
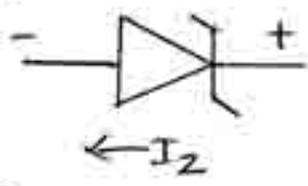
- (i) Low cost (ii) Small size (iii) Little weight
- (iv) Good characteristics (v) An inexpensive filter for light loads (ie load with larger value of resistance)
- (vi) Suitable for small load currents (say upto 50mA) [used in transistor radio battery eliminators]

④ Disadvantages of capacitor filter:

- (i) Not suitable for heavy loads (ie a load with smaller value of resistance)
- (ii) Ripple factor depends on load resistance

Note: ① Zener diode

(i) Circuit Symbol:



(ii) Junction breakdown:

When a junction diode is reverse biased, a very small

reverse saturation current flows through the diode. Zener diodes are the diodes which are designed to operate in the breakdown region. They are also called as breakdown

⊗ Avalanche diodes

When the reverse voltage is sufficiently increased, the junction breaks down and a large reverse current flows. If a resistor (R_1) is connected in series with the diode, the current is limited & will not destroy the device.

(iii) Voltage regulators:

A circuit which converts unregulated dc to regulated (constant) dc is called voltage regulator

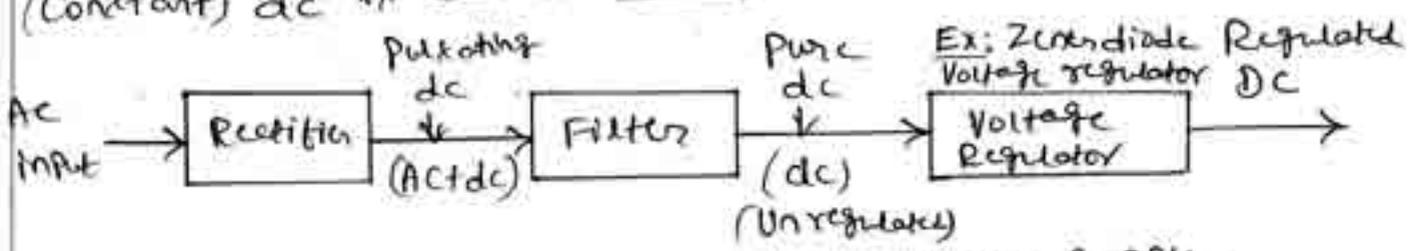


Fig: Block diagram of Regulated dc Power Supply

* Zener diode Voltage regulators:

Under reverse bias condition, the voltage across the zener diode remains constant (even input changes). Hence Zener diode is sometimes called as voltage regulator

The Zener current (I_Z) must satisfy the condition

$$I_{ZK} < I_Z < I_{ZM}$$

I_Z should be selected as I_{ZT} (Specified test current (usually 20mA))

Where I_{ZK} → Diode Knee Voltage @ minimum reverse current to sustain breakdown

I_{ZM} → maximum Zener current limited by the maximum power dissipation (P_D)

$$P_D = V_Z I_{ZM}$$

① Zener diode Voltage regulator Under no load (Regulator circuit with no load) Under no load

Fig shows the Zener voltage regulator with no load

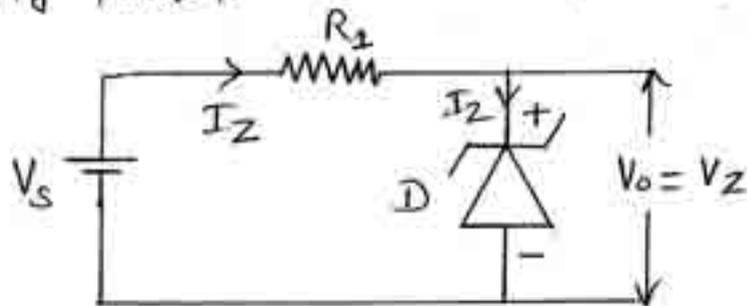


Fig: Zener voltage regulator with no load

→ V_s is the unregulated dc voltage (output from rectifier with filter) greater than the Zener breakdown voltage (V_Z).

→ Hence $V_o = V_Z \rightarrow$ constant

→ Current I_Z must satisfy the condition.

$$I_{ZK} < I_Z < I_{ZM}$$

Where

$I_{ZK} \rightarrow$ minimum Zener current to sustain breakdown

$I_{ZM} \rightarrow$ maximum Zener current (to have power dissipation less than the maximum permissible value (P_o))

→ Normally I_Z is selected as I_{ZT} (specified test current).

→ Applying KVL to the loop

$$V_s - I_Z R_1 - V_Z = 0$$

$$\Rightarrow I_Z = \frac{V_s - V_Z}{R_1} \quad \text{or} \quad R_1 = \frac{V_s - V_Z}{I_Z}$$

minimum Zener current,

$$I_{Zmin} = \frac{V_{smin} - V_Z}{R_1}$$

Maximum Zener current,

$$I_{Zmax} = \frac{V_{smax} - V_Z}{R_1}$$

→ Power dissipated in R_1 ,

$$P_{R_1} = I_Z^2 R_1$$

② Loaded regulator (Shunt regulator) Loaded Zener voltage regulator

Fig shows the Zener voltage regulator with load

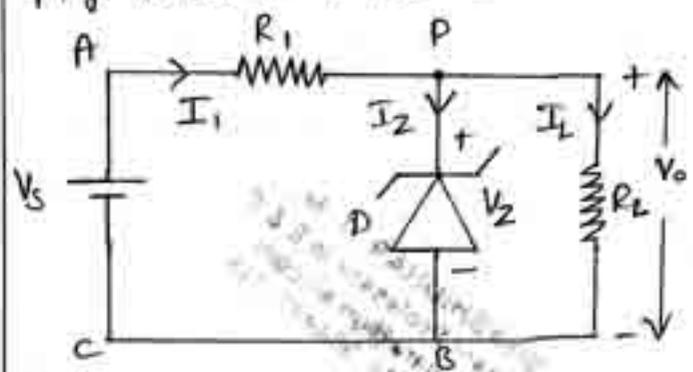


Fig: Zener Voltage regulator with load

→ V_s is the unregulated dc voltage (output from rectifier with filter)

→ Voltage across $R_L =$ voltage across Zener diode

$$i.e. V_o = V_z \quad \text{--- (1)}$$

→ We have from KCL at node P.

$$I_1 = I_2 + I_L \quad \text{--- (2)}$$

→ Applying KVL to loop APBC, we get.

$$V_s - I_1 R_1 - V_z = 0$$

$$\Rightarrow I_1 = \frac{V_s - V_z}{R_1} \quad \text{--- (3)}$$

→ When $I_L = I_{Lmax}$, $I_z = I_{zmin}$, we get (from con 2)

$$I_1 = I_{zmin} + I_{Lmax} \quad \text{--- (4)}$$

For a Zener diode with an $I_{zT} = 20mA$, $I_{zmin} = 5mA$

→ When $I_L = 0$, entire I_1 flows through the Zener diode.

We should ensure that the total current does not exceed the maximum Zener diode current (I_{zm}), Now con (2) becomes,

$$I_1 = I_{zm} \quad \text{--- (5)}$$

[∵ $I_z = I_{zm}$, $I_L = 0$ in con 2]

→ Equating (4) & (5), we get

$$I_{zm} = I_{zmin} + I_{Lmax} \quad \text{--- (6)}$$

→ Using (5) in (3), we get

$$I_{zm} = \frac{V_s - V_z}{R_1} \quad \text{--- (7)}$$

$$R_1 = \frac{V_s - V_z}{I_{zm}} \quad \text{--- (8)}$$

Note: ① I_b input voltage V_s varies

Using ② & ③, $I_z = \left(\frac{V_s - V_z}{R_1} \right) - I_L$

$\Rightarrow \frac{V_{smin} - V_z - I_{Lmax}}{R_1} > I_{zmin}$ ④ $R_{1(max)} = \frac{V_{smin} - V_z}{I_{zmin} + I_{Lmax}}$

⑤ $\frac{V_{smax} - V_z - I_{Lmin}}{R_1} < I_{zmax}$ ⑥ $R_{1(min)} = \frac{V_{smax} - V_z}{I_{zmax} + I_{Lmin}}$

② Power Supply Performance

The dc output voltage in a dc power supply varies due to

- ① source effect
- ② load effect

① Source effect

Without load

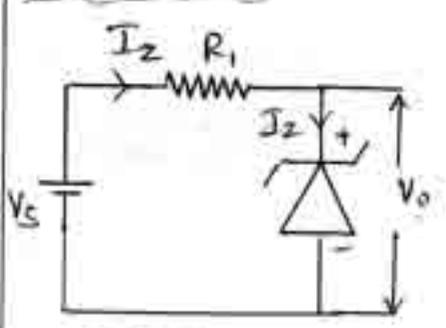


Fig 1

\Rightarrow

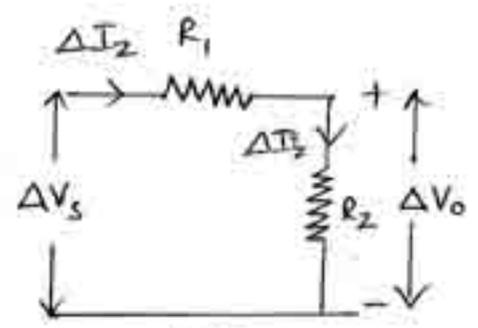


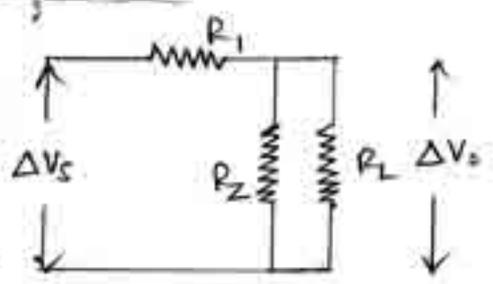
Fig 2

The Equivalent circuit of Zener voltage regulator under no load is shown in fig 2.

From voltage divider rule,

$$\Delta V_o = \frac{\Delta V_s R_z}{R_1 + R_z}$$

With load



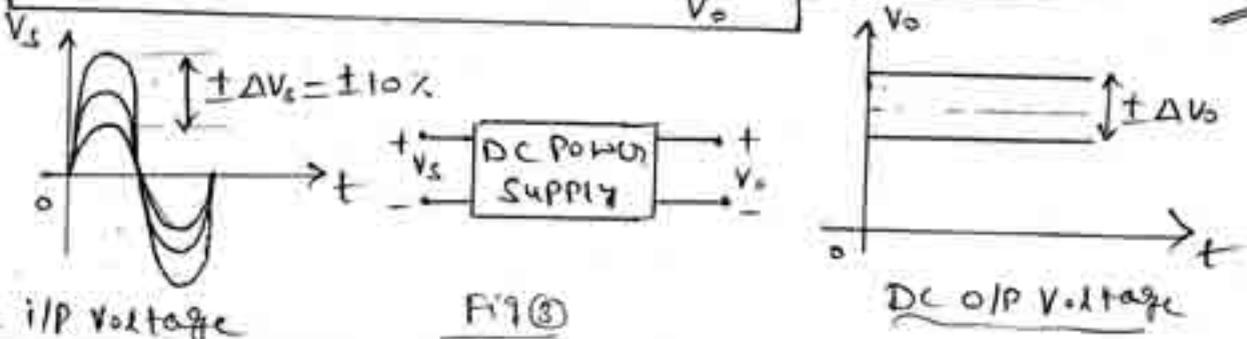
$$\Delta V_o = \frac{\Delta V_s (R_z || R_L)}{R_1 + (R_z || R_L)}$$

The change in the output voltage ΔV_o due to the change in the d.c. voltage (ac supply voltage) is called source effect

ie Source effect = ΔV_o for a 10% change in V_s

→ The source effect expressed as a percentage of the dc output voltage V_o is called the line regulation @
Source regulation

ie line regulation = $\frac{\Delta V_o \text{ for a 10\% change in } V_s \times 100\%}{V_o}$

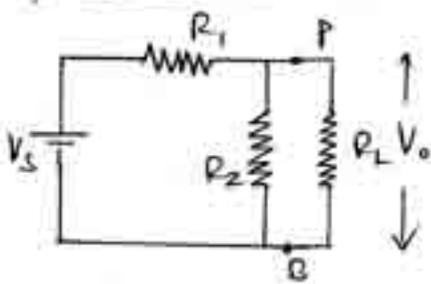


AC i/p voltage

Fig 3

DC o/p voltage

⑥ Load effect:



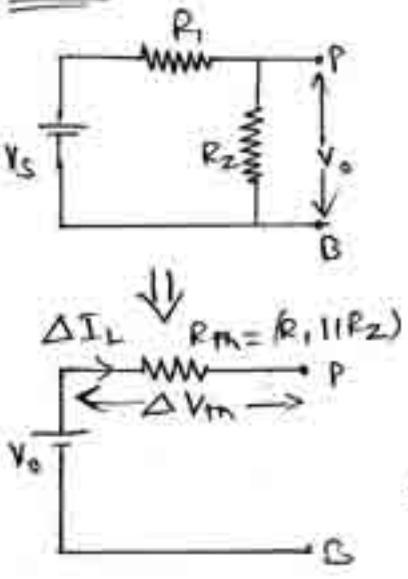
Thevenin's equivalent circuit of the Zener voltage regulator with load is shown in fig 5

$\Delta V_{th} = \Delta I_L (R_1 || R_2)$

→ The change in load voltage is due to the change in voltage ΔV_{th} , which is due to change in current.

→ The change in the output voltage (ΔV_o) due to the change in the load current (ΔI_L) is called load effect.

Fig 4



ie load effect = ΔV_o for ΔI_L

→ The load effect expressed as a percentage of the dc output voltage (V_o) is called the load regulation

Fig 5

ie load regulation = $\frac{\Delta V_o \text{ for } \Delta I_L \times 100\%}{V_o}$

Problem 1:

- ① Determine the level of reverse saturation current at temperature of 35°C and 45°C for a junction which has $I_0 = 30\text{nA}$ at 25°C .

Sol: Given $I_0(T_1) = 30 \times 10^{-9}\text{A}$ at $T_1 = 25^\circ\text{C}$

$$I_0(T_2) = ? \text{ at } T_2 = 35^\circ\text{C}$$

Likewise

$$I_0(T_2) = I_0(T_1) \left[2^{\frac{(T_2 - T_1)}{10}} \right]$$

$$I_0(T_2) = 30 \times 10^{-9} \left[2^{\frac{(35 - 25)}{10}} \right]$$

$$\boxed{I_0(T_2) = 60\text{nA}} \text{ at } T_2 = 35^\circ\text{C}$$

$$I_0(T_2) = ? \text{ at } T_2 = 45^\circ\text{C}$$

$$I_0(T_2) = 30 \times 10^{-9} \left[2^{\frac{(45 - 25)}{10}} \right]$$

$$\boxed{I_0(T_2) = 120\text{nA}} \text{ at } T_2 = 45^\circ\text{C}$$

- ② A Silicon pn-junction has a reverse saturation current of $I_0 = 30\text{nA}$ at a temperature of 300K . Calculate the junction current when the applied voltage is (a) 0.7V forward bias, (b) 10V reverse bias.

Sol:

(a) Given $I_0 = 30 \times 10^{-9}\text{A}$,

$$T = 300\text{K}$$

$$V_D = 0.7\text{V}$$

Likewise

$$I_D = I_0 \left(e^{\frac{V_D}{\eta V_T}} - 1 \right)$$

$$= 30 \times 10^{-9} \left(e^{13.46} - 1 \right)$$

$$\boxed{I_D = 21\text{mA}}$$

(b) Given $I_0 = 30 \times 10^{-9}\text{A}$

$$T = 300\text{K}$$

$$V_D = -10\text{V}$$

$$I_D = 30 \times 10^{-9} \left(e^{-19.2} - 1 \right)$$

$$\boxed{I_D = -30\text{nA}}$$

$$\left(\frac{V_D}{\eta V_T} = \frac{-10}{2 \times 1.38 \times 10^{-23} \times 300} = -19.2 \right)$$

$$\left(\therefore \frac{V_D}{\eta V_T} = \frac{V_D}{\eta \cdot kT/q} = \frac{0.7}{2 \times 1.38 \times 10^{-23} \times 300} = 13.46 \right)$$

③ A Silicon pn-junction has a reverse saturation current of 30nA at a temperature of 300k. Calculate the junction forward-bias voltage required to produce a current of (a) 0.1mA, (b) 10mA.

Sol: We have,

$$I_D = I_0 (e^{V_D / nV_T} - 1)$$

$$\Rightarrow V_D = nV_T \ln \left(\frac{I_D}{I_0} + 1 \right)$$

Given, $n = 2$ (Si)
 $I_0 = 30 \times 10^{-9} \text{ A}$
 $T = 300 \text{ K}$
 (a) $V_D = ?$ at $I_D = 0.1 \times 10^{-3} \text{ A}$
 (b) $V_D = ?$ at $I_D = 10 \times 10^{-3} \text{ A}$
 $V_T = 26 \times 10^{-3} \text{ V}$ at $T = 300 \text{ K}$

(a)

$$V_D = 2 \times 26 \times 10^{-3} \ln \left(\frac{0.1 \times 10^{-3}}{30 \times 10^{-9}} + 1 \right)$$

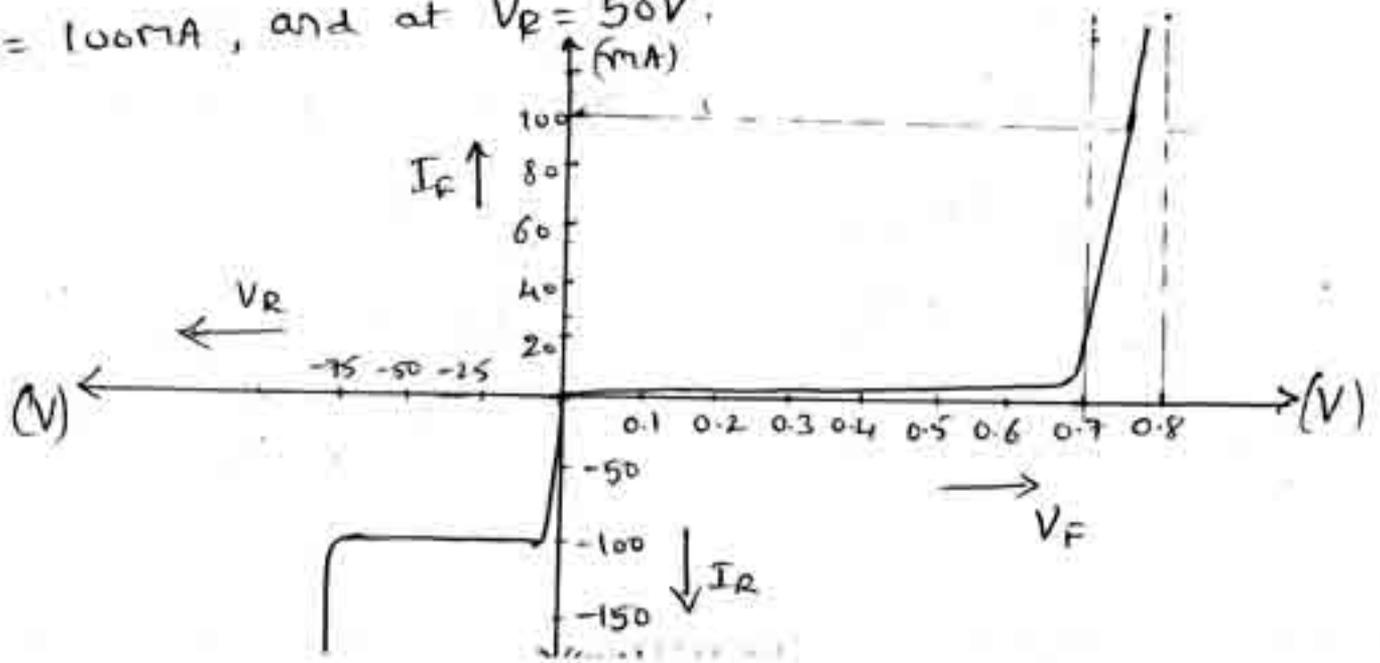
$V_D = 421.8 \text{ mV}$

(b)

$$V_D = 2 \times 26 \times 10^{-3} \ln \left(\frac{10 \times 10^{-3}}{30 \times 10^{-9}} + 1 \right)$$

$V_D = 661.27 \text{ mV}$

④ Calculate the forward and reverse resistances offered by a silicon diode with the characteristics in fig (a) at $I_F = 100 \text{ mA}$, and at $V_R = 50 \text{ V}$.



Sol: From the characteristics,

At $I_F = 100\text{mA}$, $V_F \approx 0.75\text{V}$

∴ Forward resistance,

$$R_F = \frac{V_F}{I_F}$$

$$= \frac{0.75}{100 \times 10^{-3}}$$

$$R_F = 7.5 \Omega$$

At $V_R = 50\text{V}$, $I_R \approx 100\mu\text{A}$

∴ Reverse resistance,

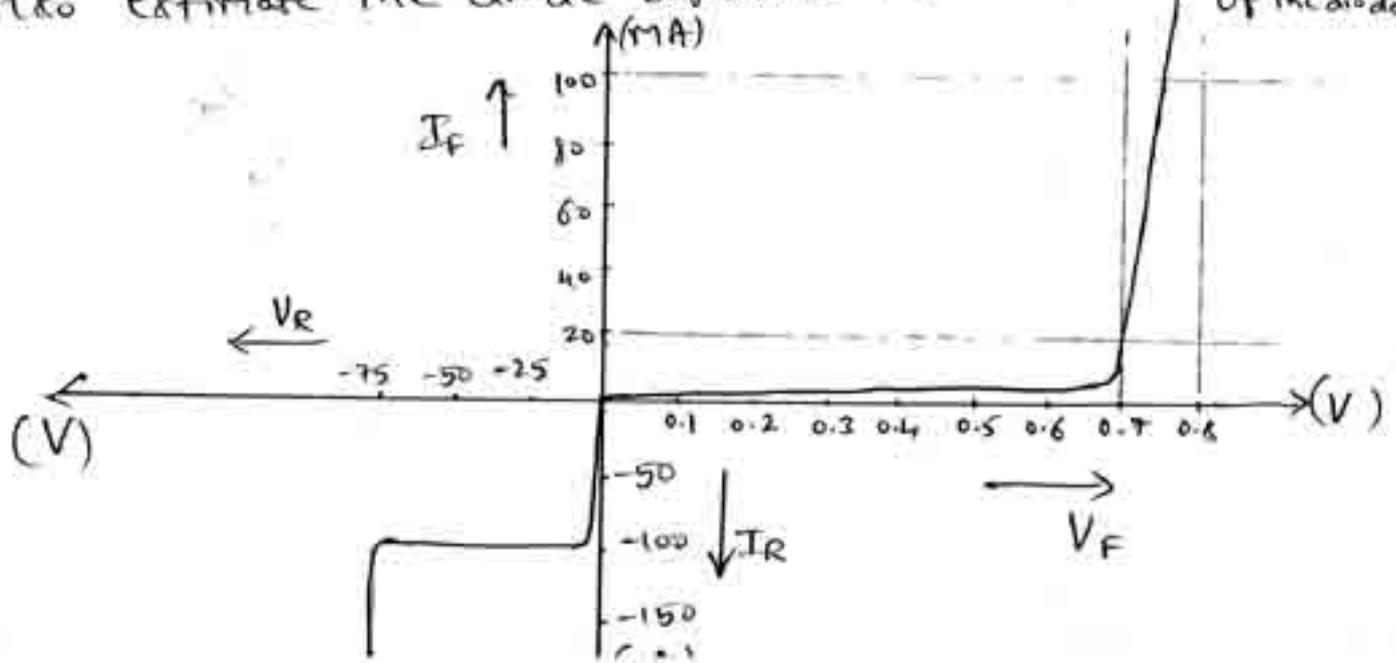
$$R_R = \frac{V_R}{I_R}$$

$$= \frac{50}{100 \times 10^{-9}}$$

$$R_R = 500\text{M}\Omega$$

∴ $I_R \ll I_F$
 $R_R \gg R_F$

⑤ Determine the dynamic resistance at a forward current of 70mA for the diode characteristics given in fig ⑤. Also estimate the diode dynamic resistance & cut-in voltage of the diode.



sol: Dynamic resistance, r_d

$$r_d = \frac{\Delta V_F}{\Delta I_F} = \frac{V_{F2} - V_{F1}}{I_{F2} - I_{F1}}$$

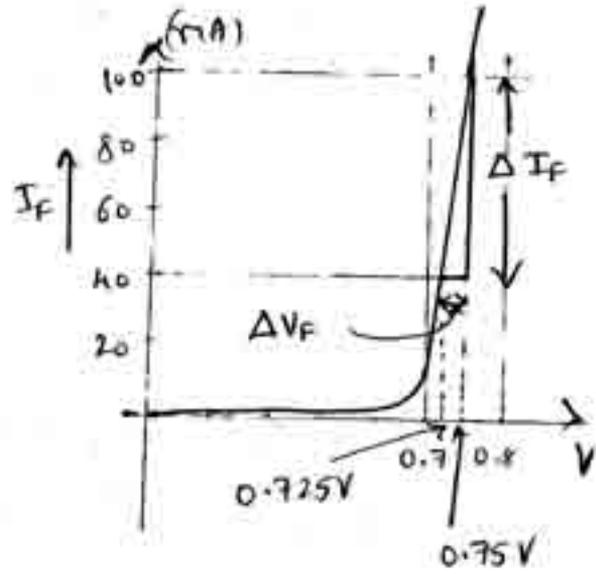
Let us take two points on the curve at $(70\text{mA} \pm 30\text{mA})$

At $I_{F2} = 100\text{mA}$, $V_{F2} =$

At $I_{F1} = 40\text{mA}$, $V_{F1} =$

$$\therefore r_d = \frac{0.75 - 0.725}{100 \times 10^{-3} - 40 \times 10^{-3}}$$

$$r_d = 0.4166 \Omega$$

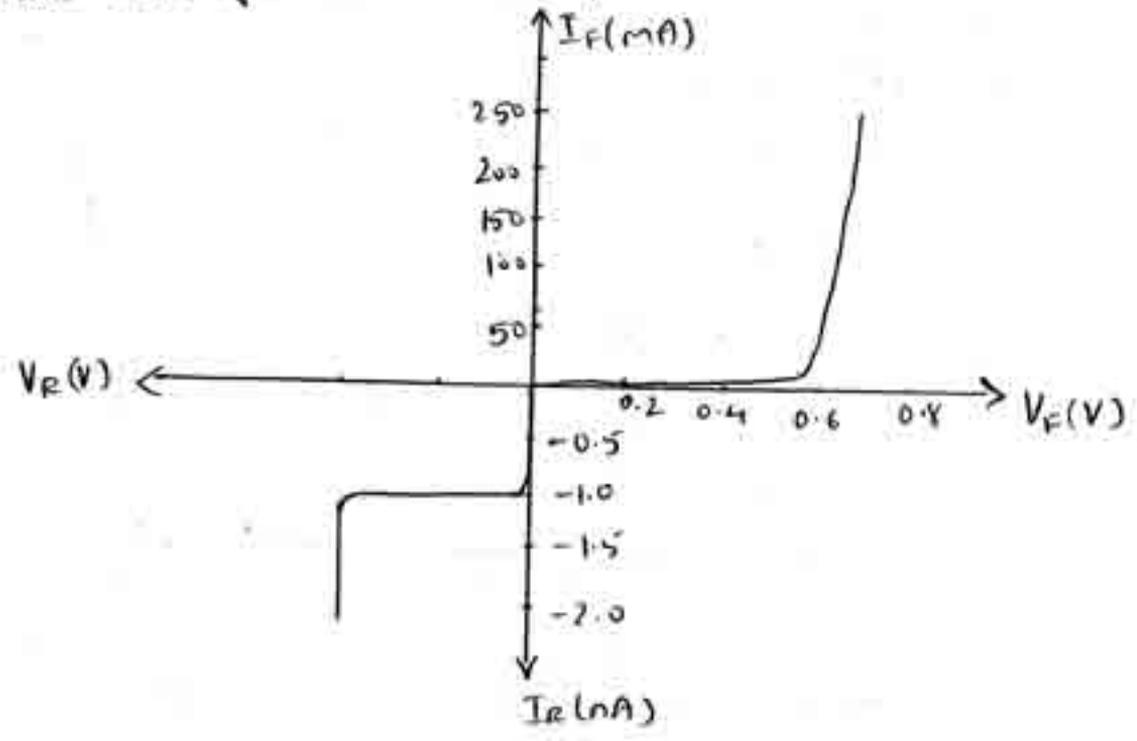


Diode dynamic resistance

$$r_d' = \frac{26 \times 10^{-3} \text{V}}{I_F} = \frac{26 \times 10^{-3}}{70 \times 10^{-3}} = 0.371 \Omega$$

From the knee of the characteristic, $V_{th} = 0.7 \text{V}$

6 From the characteristic shown below identify the diode and give its rating.



Sol: From the knee of the characteristic,

$$V_n \approx 0.6V$$

\therefore Diode used in the given characteristic is a Silicon diode

Rating:

Maximum forward current, $I_{F(\max)} = 250mA$

Cut-in voltage, $V_n = 0.6V$

Reverse saturation current, $I_o = 1mA$

Reverse breakdown voltage $V_{BR} = 100V$

Maximum reverse voltage, $V_{R(\max)} = 75V$ (75% of 100V)

Ⓣ Plot the forward & reverse characteristics of a diode, given the following data:

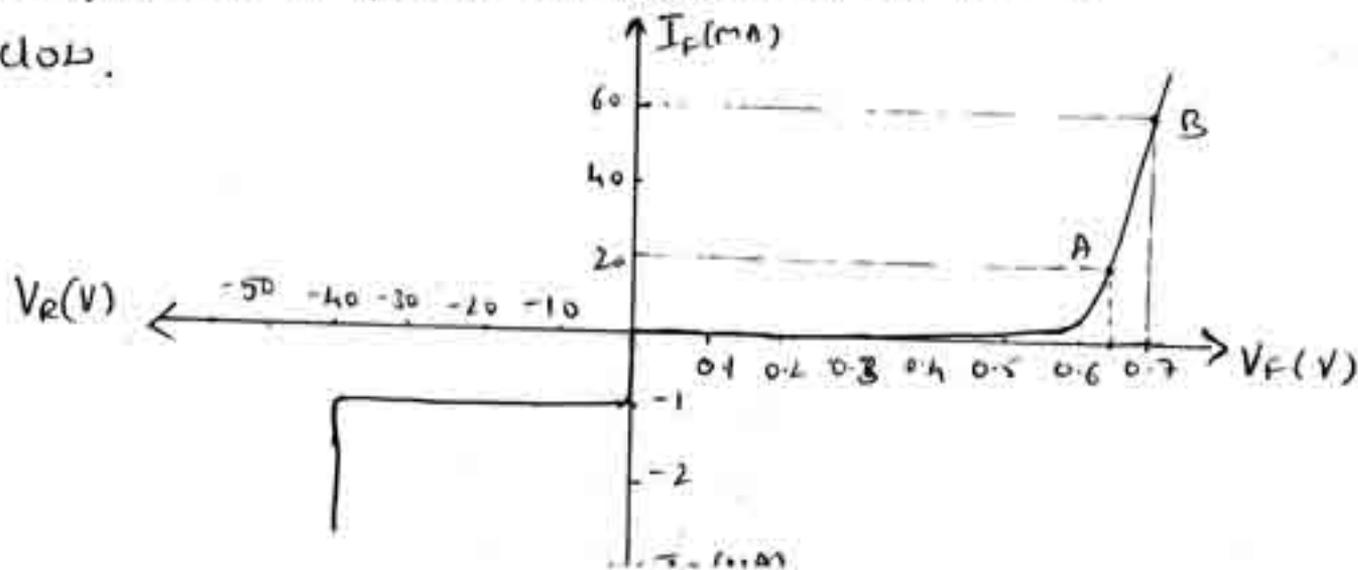
Cut-in voltage = 0.6V, Reverse breakdown voltage = 40V,

Nominal reverse current = 1mA, Forward current = 20mA at a forward voltage of 0.65V, Forward current = 60mA at a forward voltage of 0.7V.

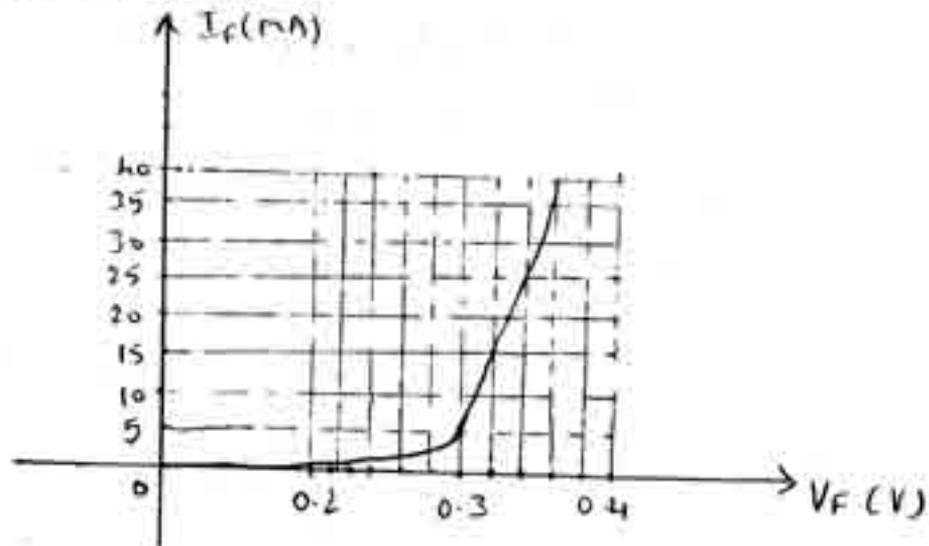
Sol: Given, $V_n = 0.6V$, $I_o = 1mA$, $V_{BR} = 40V$,

$I_F = 20mA$ at $V_F = 0.65V$ (Point A), $I_F = 60mA$ at $V_F = 0.7V$ (Point B)

The forward & reverse characteristics of the diode is shown below.



- ⑧ Find the static forward resistance at a forward current of 20mA for the diode whose characteristic is shown below. Further, find the dynamic resistance at 20mA using (i) the characteristic and (ii) the forward current. Estimate the value of the substrate resistance.



Sol:
Static forward resistance.

$$R_F = \frac{V_F}{I_F} = \frac{0.33V}{20 \times 10^{-3}A} = \underline{\underline{16.5 \Omega}} \quad \left(\text{At } I_F = 20\text{mA}, V_F = 0.33V \right)$$

(i) Dynamic resistance from the characteristic.

$$r_d = \frac{\Delta V_F}{\Delta I_F} = \frac{V_{F2} - V_{F1}}{I_{F2} - I_{F1}} = \frac{0.35 - 0.31}{(30 - 10) \times 10^{-3}} = \underline{\underline{2 \Omega}}$$

(ii) Dynamic resistance using forward current (Pure ac resistance)

$$r_d' = \frac{0.026}{I_F} = \frac{0.026}{20 \times 10^{-3}} = \underline{\underline{1.3 \Omega}}$$

Substrate resistance.

$$r_{\text{Substrate}} = r_d - r_d' = 2 - 1.3 = \underline{\underline{0.7 \Omega}}$$

$$\text{At } I_{F1} = 20\text{mA} - 10\text{mA} = 10\text{mA} \quad V_{F1} = 0.31V$$

$$\text{At } I_{F2} = 20\text{mA} + 10\text{mA} = 30\text{mA} \quad V_{F2} = 0.35V$$

- 9) Construct the piecewise linear characteristic for a Si diode that has a 0.25Ω dynamic resistance and a 200 mA maximum forward current.

Sol:
Cut-in voltage of Si diode, $V_H = 0.7 \text{ V}$

STEP 1: Draw the voltage and current axis.

STEP 2: Mark Point A at $V_F = 0.7 \text{ V}$ on the V_F axis i.e. $A(0.7, 0)$

STEP 3: By definition,

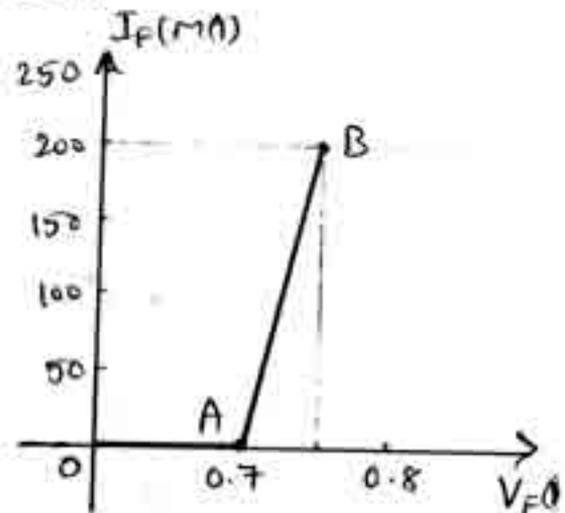
$$r_d = \frac{\Delta V_F}{\Delta I_F}$$

$$\Rightarrow \Delta V_F = r_d \times \Delta I_F = 0.25 \times 200 \times 10^{-3} = 0.05 \text{ V}$$

$$\therefore V_F = 0.7 + 0.05 = 0.75 \text{ V}$$

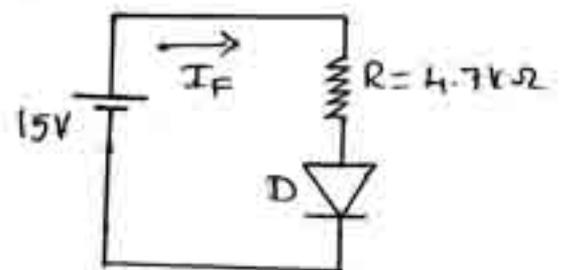
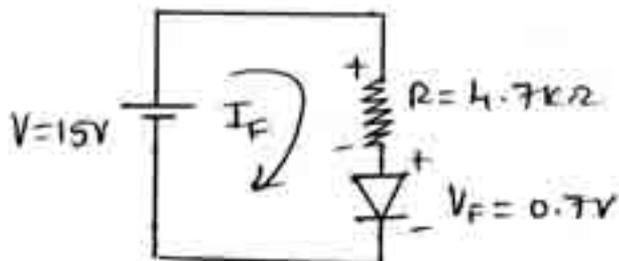
Now mark Point B at $V_F = 0.75 \text{ V}$ & $I_F = 200 \text{ mA}$ i.e. $B(0.75, 200 \times 10^{-3})$

STEP 4: Join AB to get the piecewise linear characteristic of Si diode



- 10) A Silicon diode is used in the circuit shown in fig 10. Calculate the diode current.

Sol:

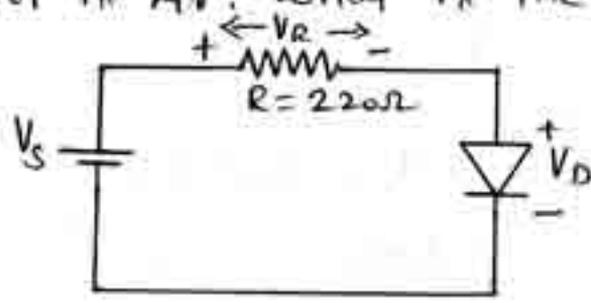


Applying KVL to the loop,

$$V - I_F R - V_F = 0$$

$$\Rightarrow I_F = \frac{V - V_F}{R} = \frac{15 - 0.7}{4.7 \times 10^3} = \underline{\underline{3.042 \text{ mA}}}$$

11) A diode is in series with 220Ω and the voltage across the resistor is $4V$. What is the current through the diode?



Sol: Current through the diode is,

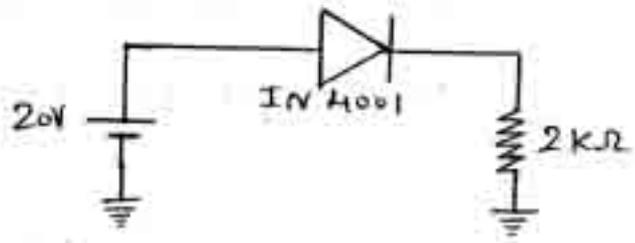
$$I_D = \text{Current through resistor}$$

$$= \frac{\text{Voltage across the resistor}}{\text{Resistance}}$$

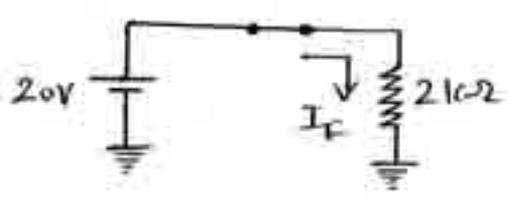
$$= \frac{4}{220}$$

$$I_D = 18.18 \text{ mA}$$

12) Calculate the load current for the circuit shown in fig (2). (Ideal diode)



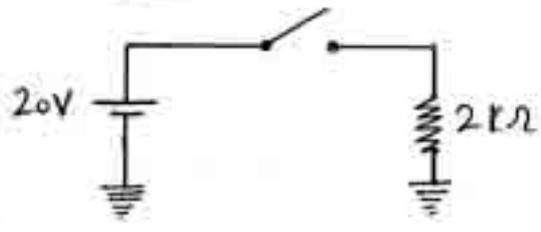
Sol: During Forward bias



$$I_F = \frac{20V}{2 \times 10^3 \Omega}$$

$$I_F = 10 \text{ mA}$$

During Reverse bias



$$I_F = 0$$

13) In fig (3), calculate the load current, load voltage, load power, diode power and total power.

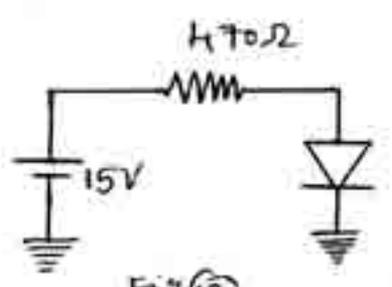


Fig (3)

Sol: Given $V = 15V$, $R = 470\Omega$

Load Current $I_R = \frac{15}{470} = 3.2 \times 10^{-2} A //$

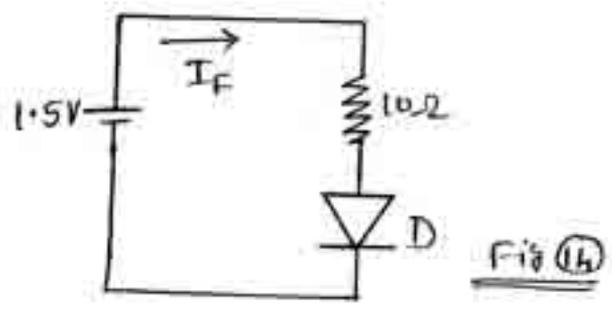
Load Voltage $V_R = I_R \times R = 3.2 \times 10^{-2} \times 470 = \underline{\underline{15V}}$
(\because Diode is ideal)

Load Power $P_D = I_R \times V_R = 3.2 \times 10^{-2} \times 15 = 0.48W //$

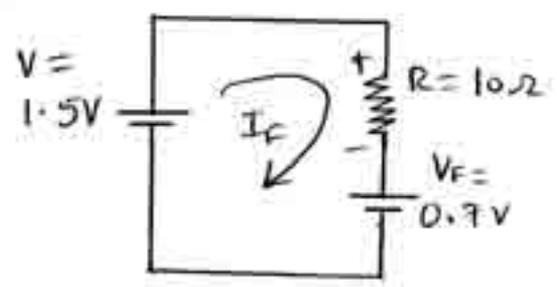
Diode Power $P_{diode} = \text{Diode } V_{td} \times \text{Diode Current}$
 $= 0 // (\because \text{Diode Voltage} = 0)$

Total Power $P_t = V \times I = 15 \times 3.2 \times 10^{-2} = \underline{\underline{0.48W}}$

14) Calculate I_F for the diode circuit in fig (14) assuming that the diode has $V_F = 0.7V$ and $r_d = 0$. Then recalculate the current taking $r_d = 0.25\Omega$.



Sol: With $r_d = 0$

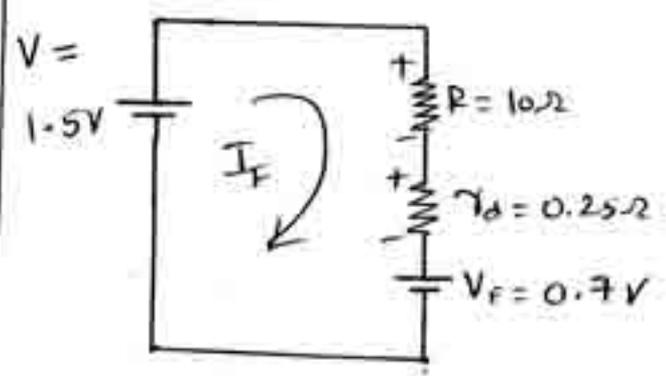


Applying KVL

$$+1.5 - I_F R - 0.7 = 0$$
$$\Rightarrow I_F R = 1.5 - 0.7$$
$$I_F = \frac{1.5 - 0.7}{10}$$

$I_F = 80mA //$

With $r_d = 0.25\Omega$



Applying KVL

$$1.5 - I_F R - I_F r_d - V_F = 0$$
$$\Rightarrow I_F = \frac{1.5 - 0.7}{10 + 0.25}$$

$I_F = 78mA //$

- 15) Find the value of resistor R in the circuit shown in fig (15).
 Given, dynamic resistance of the diode is 0.4Ω & the circuit current is 100 mA .

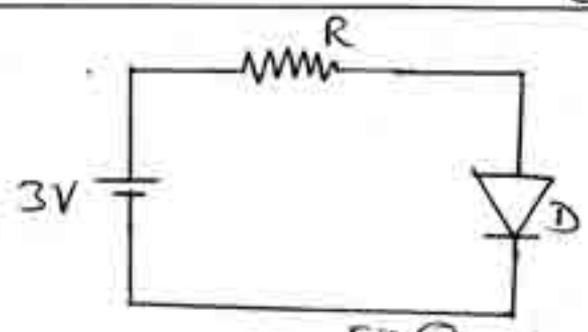
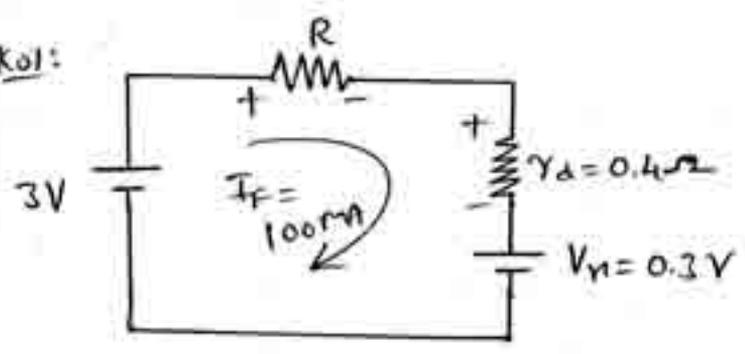


Fig (15)

Sol:



Applying KVL to loop

$$3 - RI_F - r_d I_F - V_D = 0$$

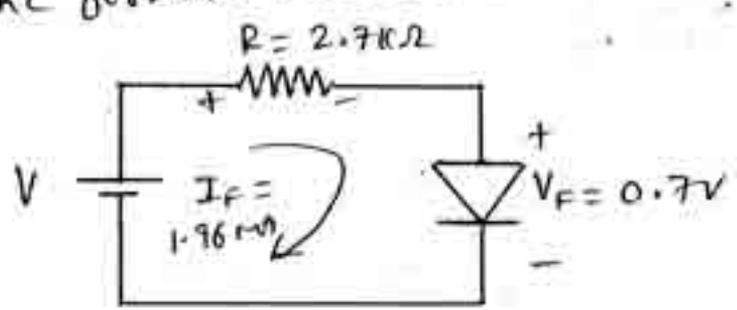
$$\Rightarrow R = \frac{3 - 0.4 \times 100 \times 10^{-3} - 0.3}{100 \times 10^{-3}}$$

$$= \frac{2.66}{100 \times 10^{-3}}$$

$$R = 26.6 \Omega$$

- 16) A circuit consists of a silicon diode in series with a $2.7 \text{ k}\Omega$ resistor and a battery. Find the supply voltage if the forward current is 1.96 mA .

Sol:



Applying KVL

$$V - I_F R - V_F = 0$$

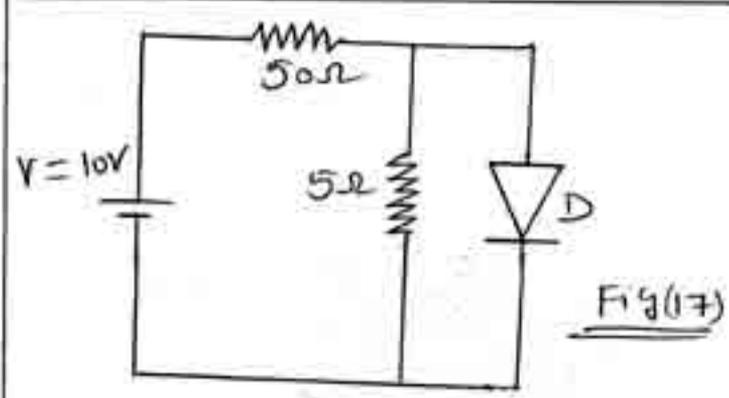
 \Rightarrow

$$V = I_F R + V_F$$

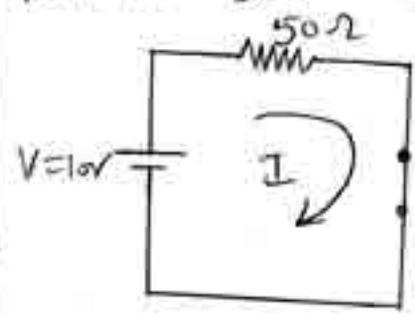
$$= 1.96 \times 10^{-3} \times 2.7 \times 10^3 + 0.7$$

$$V = 5.992 \text{ V}$$

- 17) Find the current through the diode in the circuit shown in fig (17). Assume diode to be ideal.



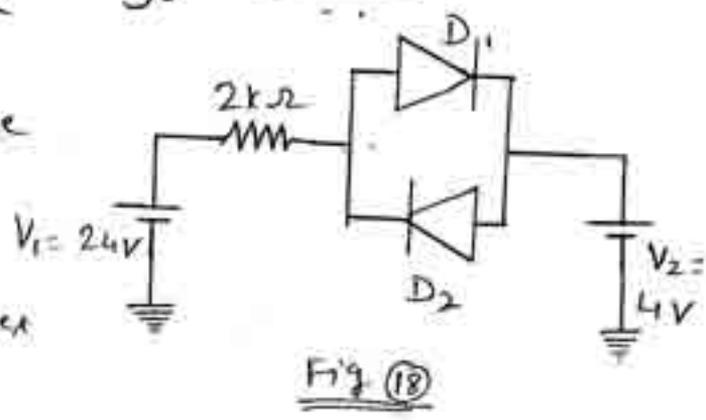
Sol: Since diode D is ideal, it acts as a Short circuit. Resistor 5Ω can be neglected since it is in parallel with SC.



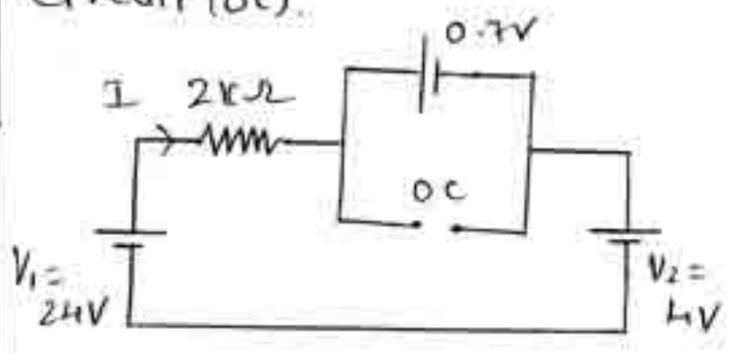
∴ Current through the diode is,

$$I = \frac{V}{R} = \frac{10}{50} = \underline{\underline{0.2A}}$$

18) Determine the current I in the circuit shown in fig 18. Assume the diodes to be of Silicon and forward resistance of diodes to be zero.



Sol: Here diode D₁ is forward biased and diode D₂ is reverse biased. ∴ D₁ acts as ^{V_f across of 0.7V} short circuit and D₂ acts as open circuit (OC).



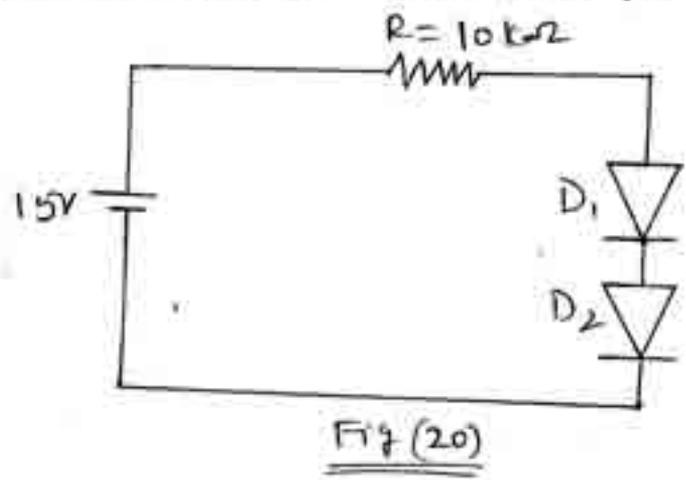
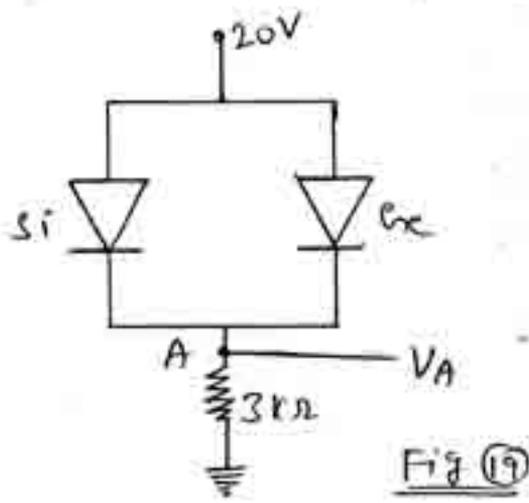
Applying KVL,
 $V_1 - 2kI - 0.7 - V_2 = 0$

$$\Rightarrow I = \frac{V_1 - V_2 - 0.7}{2 \times 10^3}$$

$$= \frac{24 - 0.7 - 4}{2 \times 10^3}$$

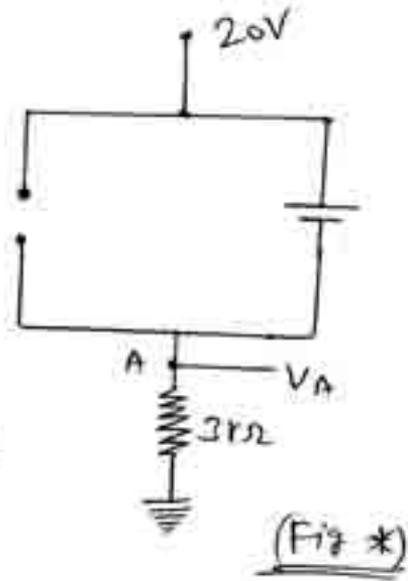
$$\boxed{I = 9.65mA}$$

19) Find the voltage V_A in the circuit shown in fig 19.



Sol:

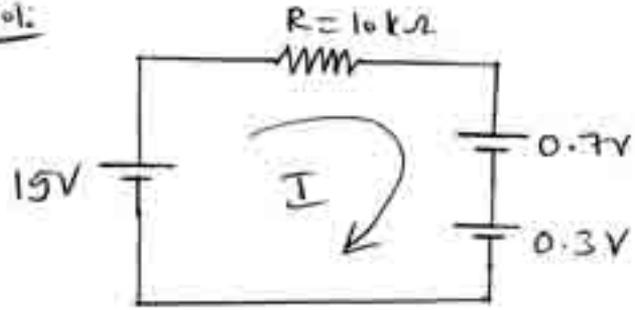
When voltage is applied, Ge diode ($V_{th} = 0.3V$) will turn on first and a drop of 0.3V is maintained across the parallel circuit. The Silicon diode never gets the opportunity to have 0.7V across it and therefore, remains in open-circuit state as shown in fig (*).



$$\therefore V_A = 20 - 0.3 = \underline{19.7V}$$

20) Calculate the diode current in the circuit shown in fig 20. Assume D_1 as Si diode and D_2 as Ge diode.

Sol:



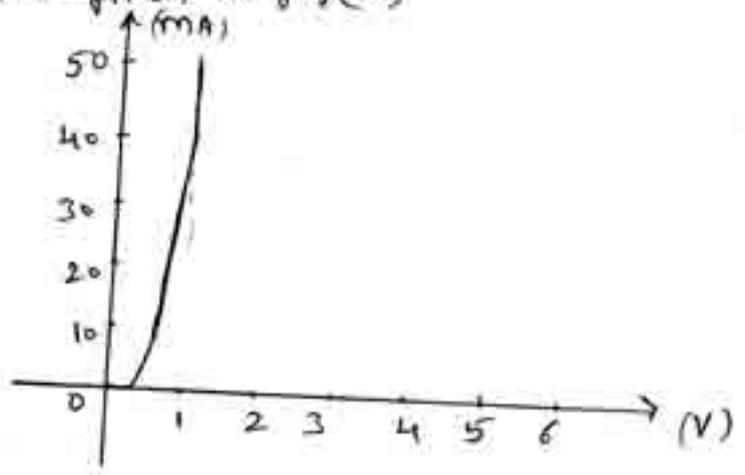
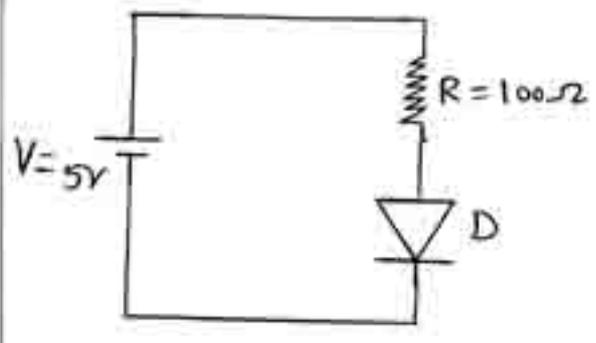
Applying KVL to the loop,

$$15 - IR - 0.7 - 0.3 = 0$$

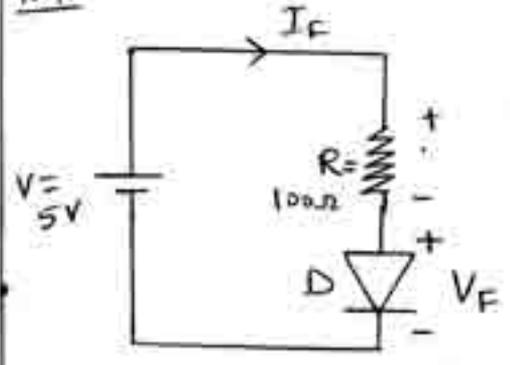
$$\Rightarrow I = \frac{15 - 1}{R} = \frac{14}{10 \times 10^3}$$

$$I = 1.4 \text{ mA}$$

21) Draw the dc load line for the circuit in fig (21) on the diode forward characteristic given in fig(*)



Sol:



Applying KVL to the loop,

$$V - I_F R - V_F = 0$$

$$\Rightarrow V = I_F R + V_F \quad (*)$$

Put $I_F = 0$ in eqn(*)

$$V = V_F$$

$$\Rightarrow V_F = V = 5V$$

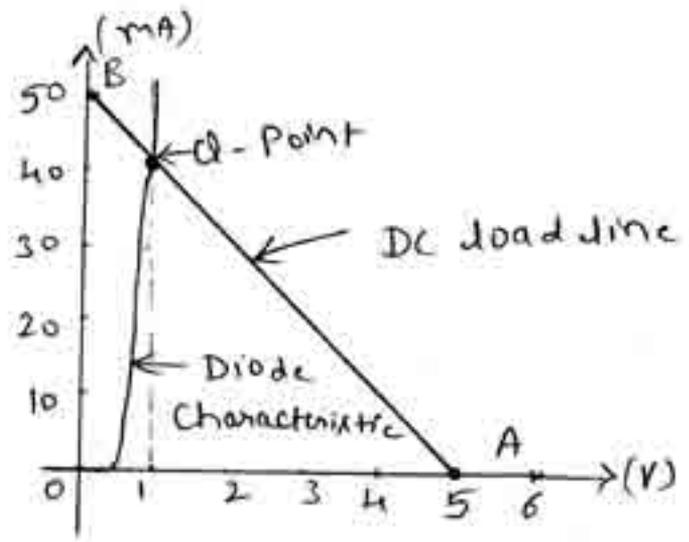
Put $V_F = 0$ in eqn(*)

$$V = I_F R$$

$$\Rightarrow I_F = \frac{V}{R} = \frac{5}{100} = 50mA$$

Mark Point A at $V_F = 5V$ & $I_F = 0$ & Mark Point B at $V_F = 0$ & $I_F = 50mA$.

Join AB to get the dc load line [fig(**)]



Fig(**)

22) Using the device characteristics in fig (22), determine the required load resistance for the circuit in fig(***)

to give $I_F = 30\text{mA}$.

~~Req~~

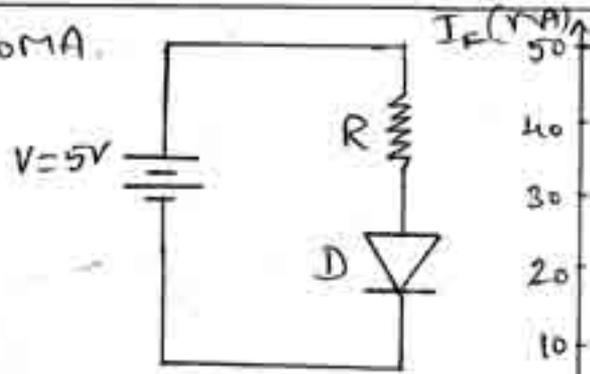


Fig (***)

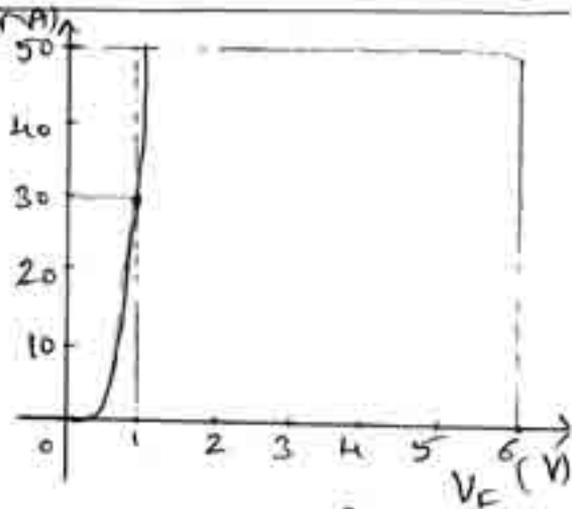
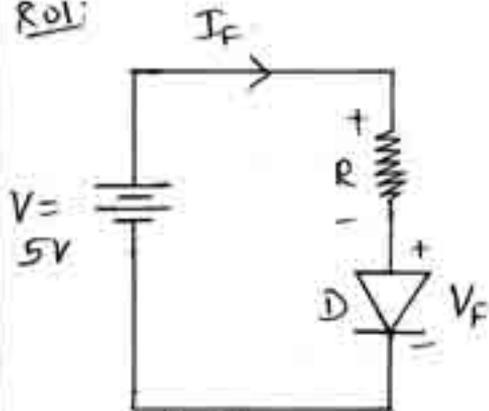


Fig (22)

sol:



Applying KVL to the loop,

$$V - I_F R - V_F = 0$$

$$\Rightarrow V = I_F R + V_F$$

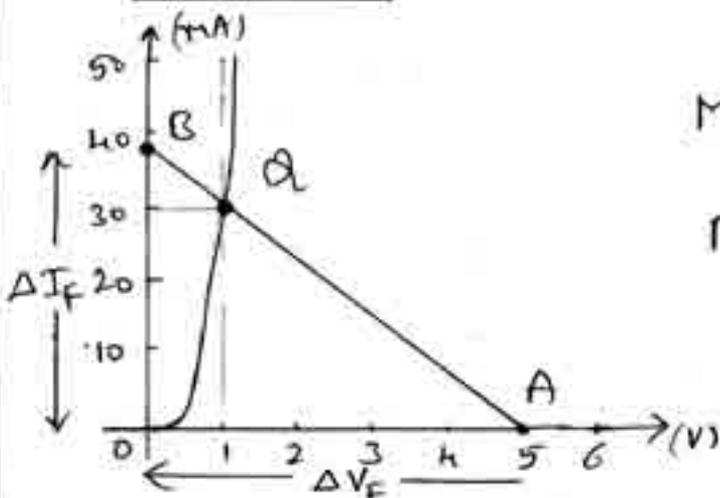
Put $I_F = 0$

$$V_F = V = 5\text{V}$$

Mark Point A at $V_F = 5\text{V}$ & $I_F = 0$

Now Plot Point Q at $I_F = 30\text{mA}$

Draw the dc load line from Point A through Q.



From the load line

$$R = \frac{\Delta V_F}{\Delta I_F} = \frac{5}{37.5 \times 10^{-3}} = 13 \Omega$$

23) Determine a new supply voltage for the circuit in fig (1) to give a 50mA diode forward current when $R = 100\Omega$. Also draw the dc load line on the characteristic graph in fig (2)

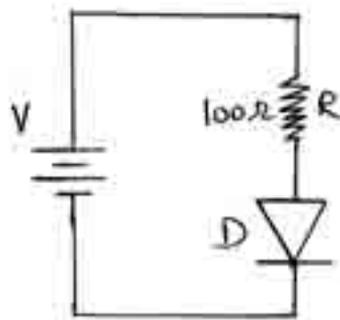


fig (1)

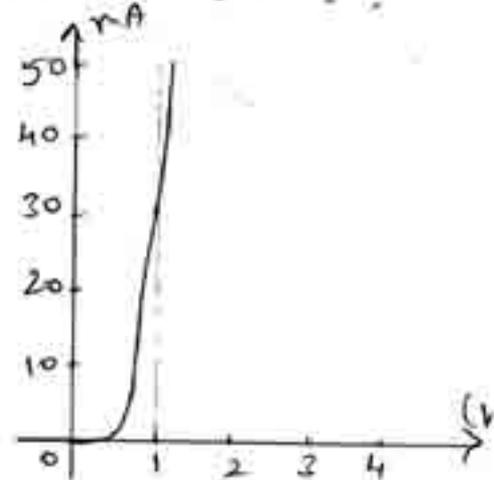
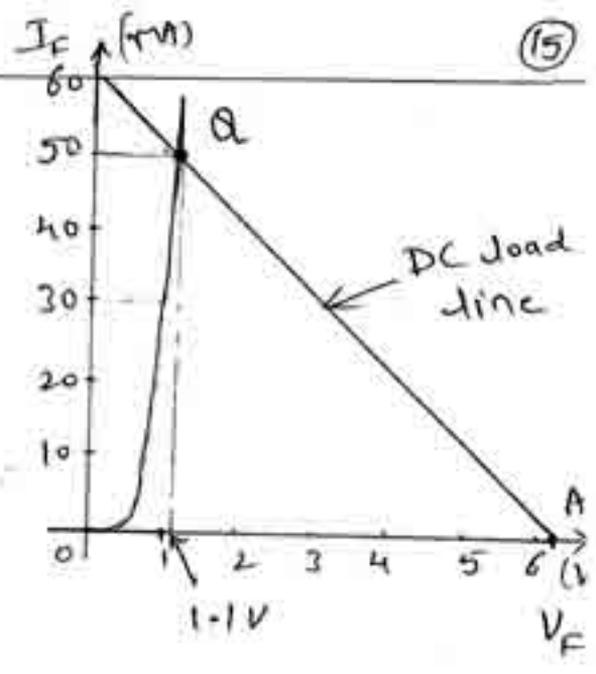


Fig (2)

Sol:

Plot Point Q on the diode characteristic at $I_F = 50\text{mA}$



Project Point Q on V_F axis,

$\therefore V_F = 1.1\text{V}$

We know that

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

$$\Rightarrow \Delta V_F = \Delta I_F \times R = 50 \times 10^{-3} \times 100 = \underline{5\text{V}}$$

Now supply voltage.

$$V = V_F + \Delta V_F = 1.1 + 5 = \underline{6.1\text{V}}$$

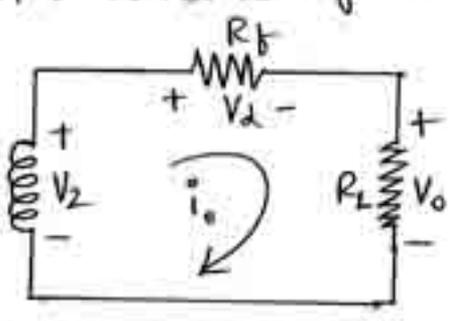
Mark Point A at $I_F = 0$ & $V_F = 6.1\text{V}$

Draw dc load line through A & Q.

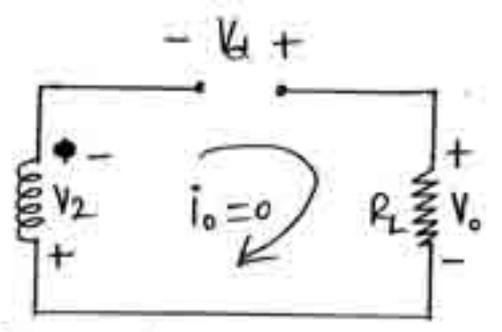
Q4

S.T in a HWR, the dc voltage across the diode is equal but opposite in polarity of the dc voltage across R_L .

Sol: The equivalent circuit when the diode is conducting & not conducting is shown below,



① Equivalent circuit when diode is conducting



② Equivalent circuit when diode is not conducting

Instantaneous diode voltage (fig 1),

$$V_d = i_o R_f$$

$$\Rightarrow V_d = I_m R_f \sin \omega t, \quad 0 \leq \omega t \leq \pi \quad (\because i_o = I_m \sin \omega t)$$

Applying KVL to the loop of fig 2.

$$-V_2 + V_d - i_o R_L = 0, \quad \pi \leq \omega t \leq 2\pi$$

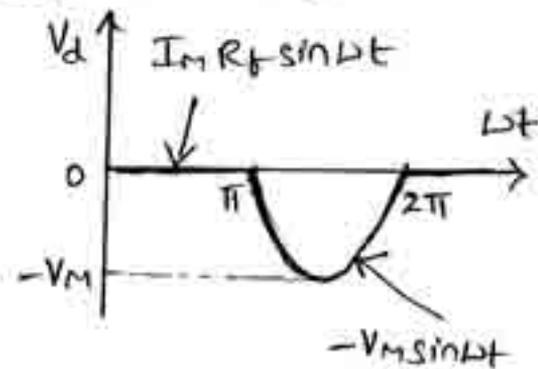
$$\Rightarrow V_d = V_2 = V_m \sin \omega t, \quad \pi \leq \omega t \leq 2\pi \quad \text{--- (2)}$$

$$\left(\begin{array}{l} \because i_o = 0 \text{ sec} \\ V_2 = V_m \sin \omega t \end{array} \right)$$

From ① & ②, we can write

$$V_d = \begin{cases} I_m R_f \sin \omega t & ; 0 \leq \omega t \leq \pi \\ V_m \sin \omega t & ; \pi \leq \omega t \leq 2\pi \end{cases}$$

The voltage across diode ' V_d ' is shown below (Assuming $R_f = 0$).



Average @ dc voltage across diode,

$$V_{dc}' = \frac{\text{Area under one cycle of } V_d}{\text{Period of } V_d}$$

$$= \frac{\int_0^{2\pi} V_d d\omega t}{2\pi}$$

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

$$= \frac{1}{2\pi} \left[V_m (-\cos \omega t) \Big|_{\pi}^{2\pi} \right]$$

$$= \frac{V_m}{2\pi} (-\cos 2\pi + \cos \pi)$$

$$V_{dc}' = -\frac{V_m}{\pi} \quad (\because \cos \pi = -1, \cos 2\pi = 1)$$

$$\boxed{V_{dc}' = -V_{dc}} \quad \text{--- (3)} \quad \left(\because V_{dc} = \frac{V_m}{\pi} \right) \text{ (from ①, Page 31)}$$

Eqn ③, shows that the dc voltage across the diode is equal but opposite in polarity of the dc voltage across R_L .

25) Show that the power delivered to the load is maximum in a half-wave rectifier when the load resistance is equal to the forward resistance of the diode. Also find the maximum dc output power.

Sol: W.K.T $P_{dc} = \frac{V_{dc}^2}{R_L}$

$$\Rightarrow P_{dc} = \frac{1}{R_L} \left[\frac{(V_m/\pi) R_L}{R_f + R_L} \right]^2 \quad \left(\because V_{dc} = \frac{V_m/\pi}{1 + R_f/R_L} \right)$$

$$P_{dc} = \left(\frac{V_m}{\pi} \right)^2 \frac{R_L}{(R_f + R_L)^2} \quad \text{--- (*)}$$

DC output power is maximum, when $\frac{dP_{dc}}{dR_L} = 0$

$$\Rightarrow \left(\frac{V_m}{\pi} \right)^2 \left\{ \frac{(R_f + R_L)^2 \cdot 1 - R_L \cdot 2(R_f + R_L)}{(R_f + R_L)^4} \right\} = 0$$

$$\Rightarrow (R_f + R_L)^2 - 2R_L(R_f + R_L) = 0$$

$$\Rightarrow (R_f + R_L)(R_f + R_L - 2R_L) = 0$$

$$\Rightarrow (R_f + R_L)(R_f - R_L) = 0$$

$$\Rightarrow R_f - R_L = 0 \quad \left(\because R_f + R_L \neq 0 \text{ @ } R_f \neq -R_L \right)$$

$$\boxed{R_L = R_f} \quad \text{// Here proof}$$

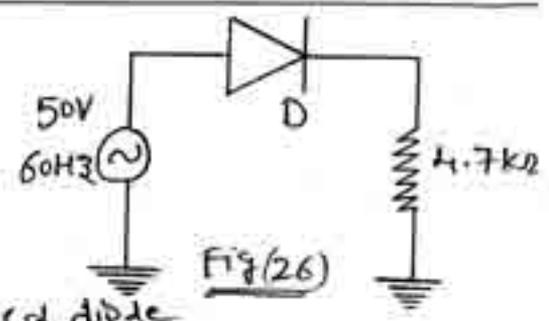
Now maximum output dc power is,

$$P_{d(max)} = \left(\frac{V_m}{\pi} \right)^2 \frac{R_L}{(R_f + R_L)^2} \Big|_{R_L = R_f}$$

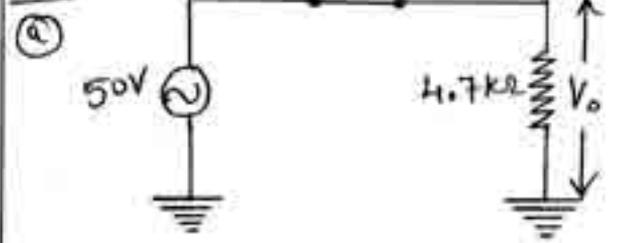
$$= \left(\frac{V_m}{\pi} \right)^2 \frac{R_L}{(R_L + R_L)^2}$$

$$\boxed{P_{d(max)} = \left(\frac{V_m}{\pi} \right)^2 \frac{1}{4R_L} \text{ @ } \left(\frac{V_m}{\pi} \right)^2 \frac{1}{4R_f}}$$

26) What is the peak output voltage in the fig (26) if the diode is ideal? What is the average value? What is the dc value? Sketch the output waveform.

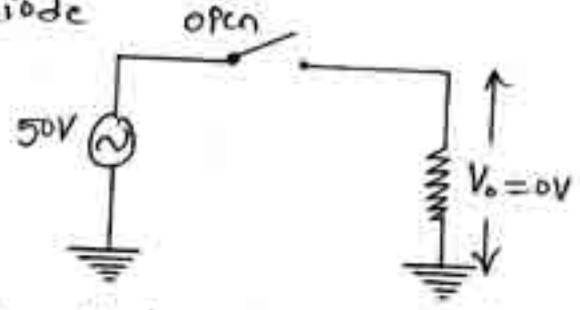


Sol:



Circuit in Positive half cycle

Repeat part (a) if the ideal diode is replaced by a Si diode



Circuit in negative half cycle

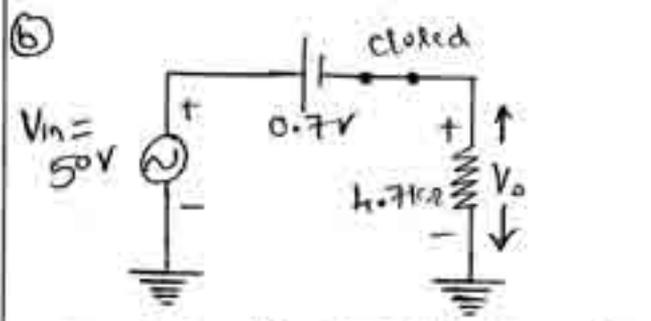
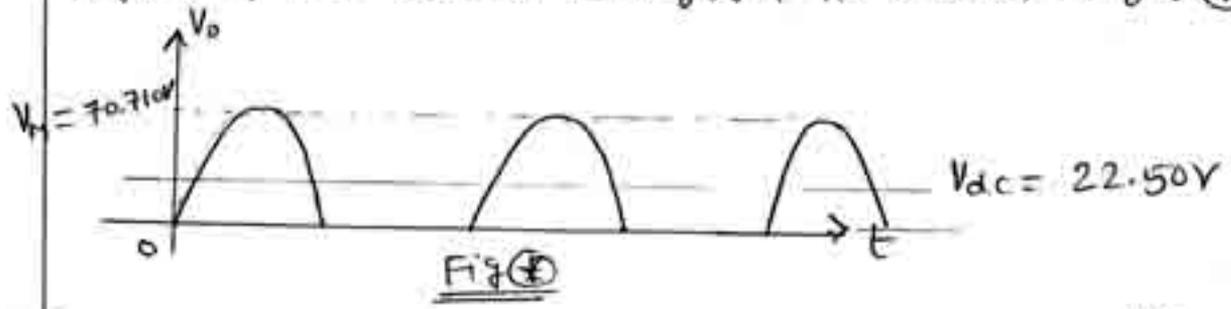
Given $V_{in} = 50V$ (rms)

$\therefore V_m = \sqrt{2} V_{in} = \sqrt{2} \times 50 = 70.710V \rightarrow$ Peak output voltage
(Peak input voltage)

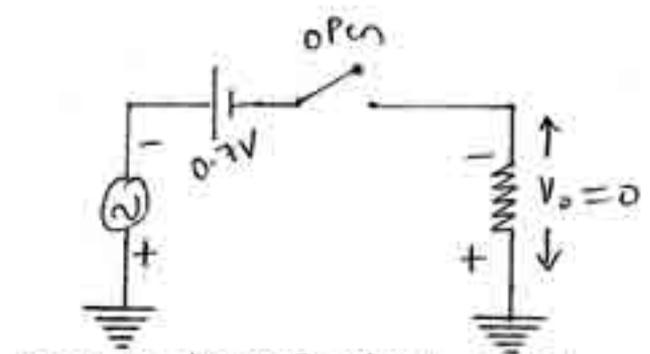
W.K.T Average value @ DC Value

$V_{dc} = \frac{V_m}{\pi} = \frac{70.710}{\pi} = 22.50V \rightarrow$ Average Value @ DC Value

The diode conducts only for positive half cycle of input signal & the output waveform is shown in fig (*)



Circuit in Positive half cycle



Circuit in negative half cycle

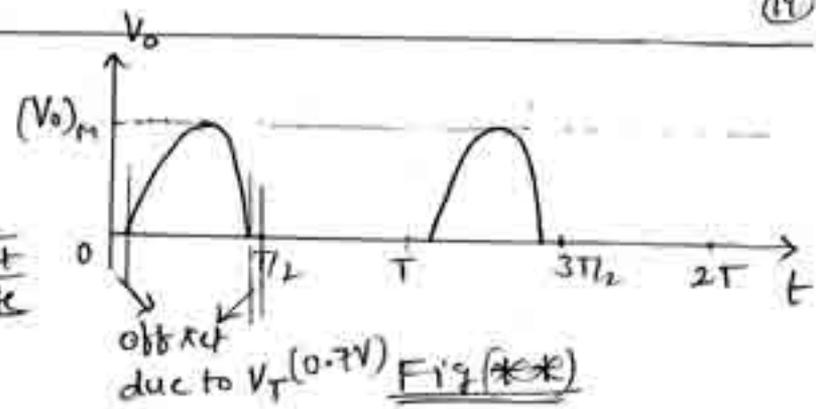
Applying KVL to the loop

$V_{in} - 0.7 - V_o = 0$
 $\Rightarrow V_o = V_m - 0.7$

$$\Rightarrow (V_o)_m = (V_{in})_m - 0.7$$

$$= \sqrt{2} \times 50 - 0.7$$

$$= \underline{\underline{70.010V}} \rightarrow \text{Peak Output Voltage}$$

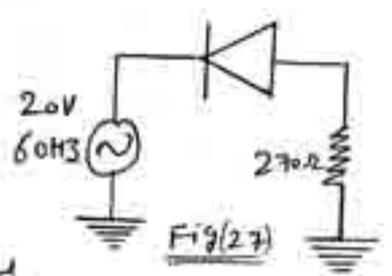


Let Average @ DC Value is,

$$V_{dc} = \frac{(V_o)_m}{\pi} = \frac{70.010}{\pi} = \underline{\underline{22.28V}} \rightarrow \text{Average Value @ DC Value}$$

The diode conducts only when the input voltage is atleast 0.7V. For levels of V_{in} less than 0.7V, the diode is still in an open-circuit state. The output waveform is shown in fig (**)

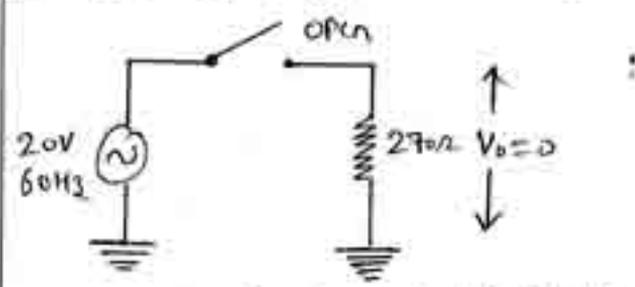
- 27) (a) What is the peak output voltage in fig (27) if the diode is ideal?
 What is the average @ dc value?
 Sketch the output waveform



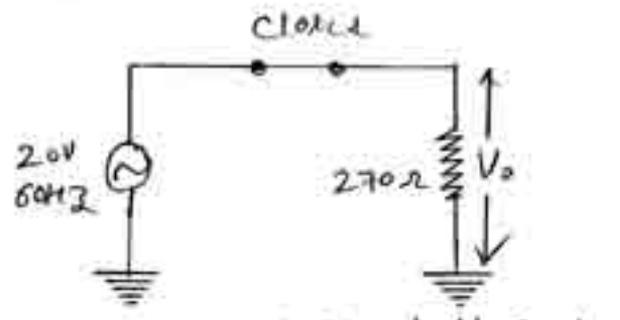
- (b) Repeat part (a) if the ideal diode is replaced by second approximation of the diode.

Sol:

(a) Let us assume the given diode as Si diode (Cut-in voltage = 0.7V)



Circuit in positive half cycle



Circuit in negative half cycle

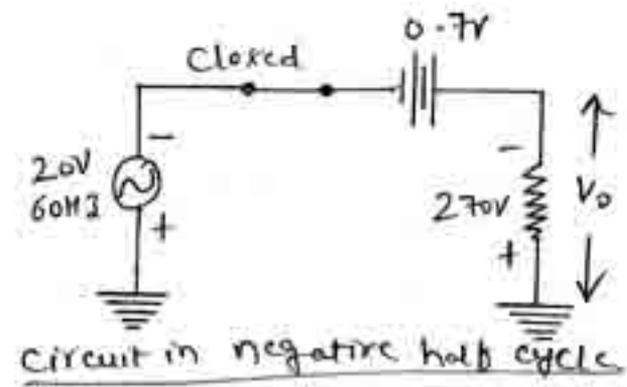
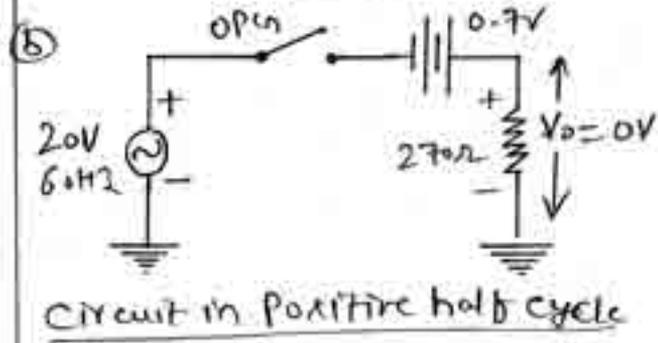
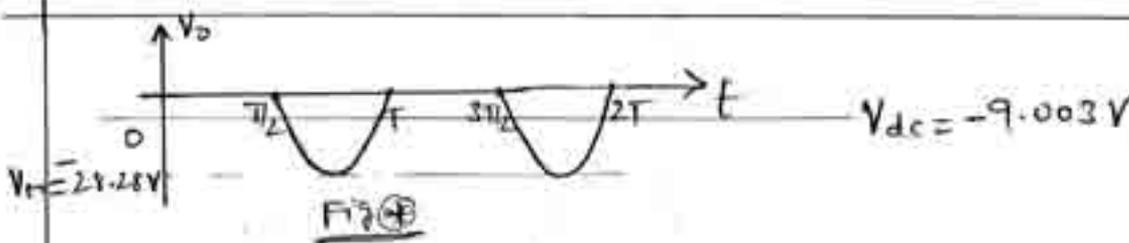
Given $V_{in} = 20V$ (RMS)

$$\therefore V_m = \sqrt{2} V_{in} = \sqrt{2} \times 20 = \underline{\underline{28.28V}} \rightarrow \text{Peak Output Voltage (Peak Input Voltage)}$$

Let Average Value @ DC Value,

$$V_{dc} = \frac{V_m}{\pi} = \frac{28.28}{\pi} = \underline{\underline{9.003V}} \rightarrow \text{Average Value @ DC Value}$$

The diode conducts only for negative half cycle of input signal & the output waveform is shown in fig (*)



Applying KVL to the loop,

$$-V_m + 0.7 + V_o = 0$$

$$\Rightarrow V_o = V_m - 0.7$$

$$\Rightarrow (V_o)_m = (V_m)_m - 0.7$$

$$= \sqrt{2} \times 20 - 0.7$$

$$(V_o)_m = 27.58V$$

Peak Output Voltage

Average Value @ DC Value

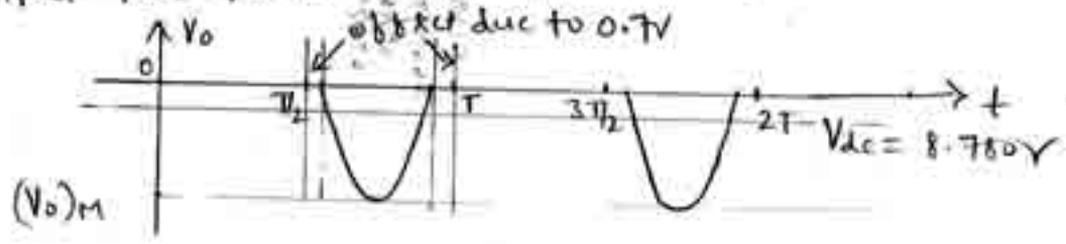
$$V_{dc} = \frac{(V_o)_m}{\pi} = \frac{27.58}{\pi} = 8.780V$$

Average Value @ DC Value

Peak load current (maximum)

$$I_o = \frac{V_m - 0.7}{R_L} \Rightarrow I_m = \frac{(V_m)_m}{R_L}$$

Diode doesnot conduct during positive half cycle of input signal & during negative half cycle, the diode conducts only when the input voltage is $> 0.7V$. The wave form is shown in fig (**)



A diode whose internal resistance is 20Ω , is used to supply power to a $1k\Omega$ load from a $110V$ (rms) source of supply. Calculate (a) Peak load Voltage (b) Peak load current (c) DC load Voltage (d) DC load current (e) Peak load current (f) DC diode V_{avg}

- (h) Total input power to the circuit (i) Power delivered to the load (j) PIV (k) % Regulation

Sol: Given $R_f = 20\Omega$, $R_L = 1000\Omega$, $V_i = 110V$ (rms)

(a) Peak load voltage (V_M)

Sol: $V_2 = \frac{N_2}{N_1} V_1 = V_1 = 110V$ (Assume $N_1 = N_2$)

$V_M = \sqrt{2} V_2 = \sqrt{2} \times 110 = 155.56V$

(b) Peak load current (I_M)

Sol: $I_M = \frac{V_M}{R_f + R_L}$
 $= \frac{155.56}{20 + 1000}$

$I_M = 152.5mA$

(c) DC load voltage (V_{dc})

$V_{dc} = \frac{V_M/\pi}{1 + R_f/R_L}$
 $= \frac{155.56/\pi}{1 + 20/1000}$

$V_{dc} = 48.54V$

(d) DC load current (I_{dc})

$I_{dc} = \frac{I_M}{\pi}$
 $= \frac{152.5 \times 10^{-3}}{\pi}$

$I_{dc} = 48.54mA$

(e) AC load voltage

(RMS load voltage) (V_{rms})

$V_{rms} = \frac{V_M/2}{1 + R_f/R_L}$
 $= \frac{155.56/2}{1 + 20/1000}$
 $= 76.25V$

(f) RMS load current

(AC load current) (I_{rms})

$I_{rms} = I_M/\sqrt{2}$
 $= 76.25mA$

(g) DC diode voltage

(V_{dc}')

$V_{dc}' = -V_{dc}$
 $V_{dc}' = -48.54V$

(h) Total input power to the circuit (P_{in})

$P_{in} = I_{rms}^2 (R_f + R_L)$
 $P_{in} = 5.93W$

(i) Power delivered to load (P_{dc})

$P_{dc} = \frac{V_{dc}^2}{R_L} @ I_{dc}^2 R_L$
 $= \frac{(48.54)^2}{1000}$
 $P_{dc} = 2.356W$

(j) PIV (PIV)

$PIV = V_M$
 $PIV = 155.56V$

① % Regulation

% Regulation = (Vt / RL) x 100 = (20 / 1000) x 100 = 2

29

The input to a half-wave rectifier is given through a 10:1 transformer from a supply given by 230 sin 314 t V. If Rf = 50Ω & RL = 500Ω, determine

- ① DC load voltage ② maximum load voltage ③ Peak load current ④ RMS load voltage ⑤ PIV across the diode ⑥ Rectification efficiency ⑦ DC power delivered to the load ⑧ Frequency of the input & output voltage.

Sol: Given, N1 : N2 = 10 : 1, V1 = 230 sin 314 t V,

Rf = 50Ω, RL = 500Ω, V2 = (N2 / N1) V1 = (1 / 10) 230 sin 314 t V

V2 = 23 sin 314 t V

Comparing with V2 = Vm sin ωt V

∴ Vm = 23V, ω = 314

2πf = 314

f = (314 / 2π) = 50Hz

① Vdc

Vdc = (Vm / π) / (1 + Rf / RL) = (23 / π) / (1 + 50 / 500)

Vdc = 6.66V

② Vm

Vm = 23V

③ Im

Im = Vm / (Rf + RL) = 23 / (50 + 500)

Im = 0.0418 A

④ Vmrf

Vmrf = (Vm / 2) / (1 + Rf / RL) = (23 / 2) / (1 + 50 / 500)

Vmrf = 10.45V

⑤ PIV

PIV = Vm = 23V

⑥ η%

η% = (40.6 / (1 + Rf / RL)) = (40.6 / (1 + 50 / 500))

η = 36.91%

⑦ Pdc

Pdc = Idc^2 RL @ Vdc^2 / RL = 6.66^2 / 500 = 88.7 mW

⑧ fm & fout

ωR + fout = fm = f = 50Hz

30) A half wave rectifier is used to supply 50V d.c to a resistive load of 800Ω. The diode has a resistance of 25Ω calculate a.c voltage required.

sol: Given: $V_{dc} = 50V$, $R_L = 800\Omega$, $R_f = 25\Omega$

W.K.T $V_{dc} = \frac{V_m/\pi}{1 + R_f/R_L}$

$\Rightarrow V_m = V_{dc} \times \pi \times (1 + R_f/R_L) = 161.988V$

A.C Voltage of maximum value 161.988V is required

31) A half wave rectifier circuit is supplied from a 230V, 50Hz supply with a 3:1 transformer. The diode forward resistance is 50Ω, load resistance is 1kΩ & transformer secondary ~~load~~ resistance is 10Ω. Calculate peak load current & AC power to the circuit.

sol: Given, $V_1 = 230V$, $N_1 : N_2 = 3 : 1$, $R_f = 50\Omega$, $R_L = 1000\Omega$, $R_s = 10\Omega$, $I_m = ?$, $P_{in} = ?$

I_m
 $I_m = \frac{V_m}{R_s + R_f + R_L}$
 $= \frac{108.42}{10 + 50 + 1000}$
 $= \underline{\underline{102.28\text{ mA}}}$

$V_2 = \frac{N_2}{N_1} V_1$
 $= \frac{1}{3} 230$
 $V_2 = 76.66V$

$\therefore V_m = \sqrt{2} \times V_2 = \sqrt{2} \times 76.66$
 $V_m = \underline{\underline{108.42V}}$

P_{in}
 $P_{in} = I_{rms}^2 (R_s + R_f + R_L)$
 $= (51.14 \times 10^{-3})^2 [10 + 50 + 1000]$

$I_{rms} = \frac{I_m}{2}$
 $= \frac{102.28 \times 10^{-3}}{2}$
 $= 51.14\text{ mA}$

$P_{in} = \underline{\underline{2.772W}}$

- 32) The applied input a.c. Power to a half-wave rectifier is 100 Watts. The d.c. output Power obtained is 40 Watts.
- What is the rectification efficiency?
 - What happens to remaining 60 Watts?

Sol:

$$(i) \eta = \frac{\text{DC output Power}}{\text{AC input Power}} = \frac{40}{100} = 40\%$$

- (ii) 40% Efficiency of rectification does not mean that 60% of Power is lost in the rectifier circuit. In fact, a crystal diode consumes little Power due to its small internal resistance. The 100W a.c. Power is contained as 50Watts in positive half cycle and 50Watts in negative half cycle. The 50W in the negative half-cycle are not supplied at all. Only 50Watts in the positive half-cycle are converted into 40Watts.

$$\therefore \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

- \(\therefore\) Efficiency of rectification is 40% & not 80% (which is Power efficiency)

- 33) In a FWR, the forward resistance of the diode is 10Ω , the load resistance is $2k\Omega$. The secondary voltage w.r.m reference to center tap is 220V. Calculate
- Peak load Voltage
 - Peak load Voltage
 - RMS load voltage
 - RMS load current
 - DC load Voltage
 - DC load current
 - DC current in each diode
 - DC output Power
 - Percentage regulation
 - PIV across each diode
 - RMS current through each diode

Sol: Given $R_f = 10\Omega$, $R_L = 2k\Omega$, $V_2 = 220V$ (r.m.s)

(a) Peak load Voltage (V_M) \Rightarrow

$$V_M = \sqrt{2} V_2 = \sqrt{2} \times 220 = 311.12V$$

b) $I_m = \frac{V_m}{R_f + R_L}$
 $I_m = \frac{311.12}{10 + 2000}$
 $I_m = 0.154A$
 @
154.78 mA

d) V_{rms}
 $V_{rms} = \frac{I_m}{\sqrt{2}}$
 $= \frac{154.78 \times 10^{-3}}{\sqrt{2}}$
 $= \underline{\underline{109.45 mA}}$

e) V_{rms}
 $V_{rms} = \frac{V_m}{\sqrt{2}}$
 $= \frac{311.12}{\sqrt{2}}$
 $V_{rms} = \underline{\underline{219.99 V}}$

c) $V_{dc} = \frac{2V_m/\pi}{1 + R_f/R_L}$
 $= \frac{2 \times 311.12/\pi}{1 + 10/2000}$
 $= \underline{\underline{197.07 V}}$

f) $I_{dc} = \frac{2I_m}{\pi}$
 $= \frac{2 \times 154.78 \times 10^{-3}}{\pi}$
 $= \underline{\underline{98.53 mA}}$

g) Since each diode acts as HWR, the dc current through each diode is,
 $I_{dc}(\text{diode}) = \frac{I_m}{\pi}$
 $= \frac{154.78 \times 10^{-3}}{\pi}$
 $= \underline{\underline{49.26 mA}}$

h) $P_{dc} = I_{dc}^2 R_L$
 @ V_{dc}^2
 $= \frac{V_{dc}^2}{R_L}$
 $= \frac{(197.07)^2}{2000}$
 $= \underline{\underline{19.41 W}}$

i) % Regulation = $\frac{R_f}{R_L} \times 100$
 $= \frac{10}{2000} \times 100$
 $= \underline{\underline{0.5\%}}$

j) $PIV = 2V_m$
 $= 2 \times 311.12$
 $= \underline{\underline{622.24 V}}$

k) Since each diode acts as HWR, the rms current through each diode is,
 $I_{rms}(\text{diode}) = \frac{I_m}{2} = \frac{154.78 \times 10^{-3}}{2} = \underline{\underline{77.39 mA}}$

39) The center-tap FWR has a load of $2k\Omega$, the forward resistance of the diode is 10Ω , The ac voltage applied to the diodes is $200V-0-200V$. Calculate
 a) Average load current b) Average load voltage

① Voltage ~~factor~~ ② Efficiency ③ Ripple Voltage

④ if a capacitor of 25μF is connected across the load

sol: Given, $R_L = 2k\Omega$, $R_f = 10\Omega$, $V_2 = 200V$
 $C = 25\mu F$
 $\Rightarrow V_m = \sqrt{2} V_2 = \sqrt{2} \times 200$
 $V_m = 282.84V$

① $I_{dc} = \frac{2 I_m}{\pi}$
 $= \frac{2 \times 140.71 \times 10^{-3}}{\pi}$
 $= 89.57mA$

② $V_{dc} = I_{dc} R_L$
 $= 89.57 \times 10^{-3} \times 2000$
 $= 179.15V$

$$I_m = \frac{V_m}{R_f + R_L}$$

$$= \frac{282.84}{10 + 2000}$$

$$= 140.71mA$$

③ W.Let

$$\gamma = \frac{V_{ac}}{V_{dc}}$$

$\Rightarrow V_{ac} = \gamma V_{dc}$
 $= 0.483 \times 179.15$ ($\because \gamma = 0.483$ for FLR)
 $V_{ac} = 86.53V$

④ $\eta = \frac{81.2\%}{1 + R_f/R_L}$
 $= \frac{81.2\%}{1 + 10/2000}$
 $= 80.79\%$

⑤ If capacitor is connected across the load, then

Ripple factor $\gamma = \frac{1}{4\sqrt{3} f R_L C} = \frac{1}{4\sqrt{3} \times 50 \times 2000 \times 25 \times 10^{-6}} = 0.0577$

Let $f = 50Hz$

New ripple Voltage,

$V_{ac} = \gamma V_{dc}$ [W.Let FLR,
 $V_m = V_m - \frac{I_{dc}}{4fc}$ @ $\frac{V_m}{1 + \frac{1}{4fcR_L}}$]
 $= \gamma (V_m - \frac{I_{dc}}{4fc})$
 $= 0.0577 \left(282.84 - \frac{89.57 \times 10^{-3}}{4 \times 50 \times 25 \times 10^{-6}} \right)$
 $= 15.28V$

35) What is AC input power from the transformer secondary used in FWR to deliver 100W of DC power to the load?

Sol: W.k.t $\eta = \frac{P_{dc}}{P_{ac}} \times 100$

$\Rightarrow P_{ac} = \frac{P_{dc} \times 100}{\eta}$

$= \frac{100 \times 100}{81.2} \quad (\because \eta = 81.2\% \text{ for FWR})$

$P_{ac} = 123.15W$

36) In the Centre-tap circuit shown in fig (36), Find

- (i) DC output voltage
- (ii) PIV
- (iii) Rectification efficiency
- (iv) Frequency of output waveform

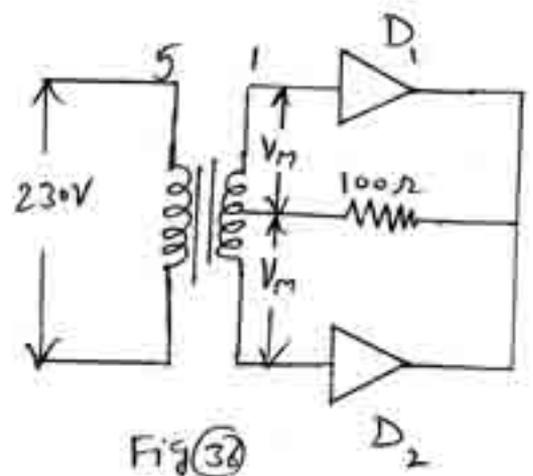


Fig (36)

Sol: Given $N_1 : N_2 = 5 : 1$, $V_1 = 230V$, $R_L = 100\Omega$

W.k.t $V_2 = \frac{N_2}{N_1} V_1 = \frac{1}{5} 230 = 46V$

Maximum voltage across secondary = $\sqrt{2} V_2 = \sqrt{2} 46 = 65.05V$

\therefore Maximum voltage across half secondary winding is,

$V_m = \frac{65.05}{2} = 32.52V$

(i) $V_{dc} = \frac{2V_m}{\pi} \times \frac{R_L}{1 + R_f/R_L} = 20.70V \quad (\because R_f = 0)$

(ii) $PIV = 2V_m = 2 \times 32.52 = 65.05V$

(iii) $\eta = \frac{81.2\%}{1 + R_f/R_L} = 81.2\% \quad (\because R_f = 0)$

(iv) $f_{out} = 2f_m = 2 \times 50 = 100Hz \quad (L_f f_m = 50Hz)$

37) If ac supply voltage is $220 \sin 314t$ V (for FLR) find maximum voltage across secondary winding, for 10:1 turns ratio

Sol Given

$N_1 : N_2 = 10 : 1$ $V_1 = 220 \sin 314t$ V

$V_2 = \frac{N_2}{N_1} V_1 = \frac{1}{10} 220 \sin 314t$

$V_2 = 22 \sin 314t$ ($V_2 = V_m \sin \omega t$)

\Rightarrow Maximum voltage across secondary = 22V

\therefore Maximum voltage across secondary winding = $\frac{22}{2} = \underline{\underline{11V}}$

38) A full wave bridge rectifier uses transformer secondary voltage of $100 \sin \omega t$ V. The forward resistance of each diode is 25Ω & load resistance is 950Ω . Calculate

- (i) DC output voltage (ii) DC value of current through R_L
- (iii) PIV across non-conducting diode. (iv) Percentage regulation (v) Peak diode current (Peak load current)
- (vi) DC current through each diode (vii) RMS current through each diode

Sol Given, $V_2 = 100 \sin \omega t$ V, $R_f = 25 \Omega$, $R_L = 950 \Omega$
 $\Rightarrow V_m = 100$

(i) $V_{dc} = \frac{2V_m/\pi}{1 + 2R_f/R_L}$
 $= \frac{2 \times 100/\pi}{1 + 2 \times 25/950}$
 $= \underline{\underline{60.48V}}$

(ii) $I_{dc} = \frac{2I_m}{\pi}$
 $= \frac{2 \times 100 \times 10^{-3}}{\pi}$
 $= \underline{\underline{63.66mA}}$

(v) $I_m = \frac{V_m}{2R_f + R_L}$
 $= \frac{100}{2 \times 25 + 950}$
 $= \underline{\underline{100mA}}$

(iii) $PIV = V_m$
 $= \underline{\underline{100V}}$

(iv) % Regulation = $\frac{2R_f}{R_L} \times 100$
 $= \underline{\underline{5.26\%}}$

(vii) $I_{dc}(\text{diode}) = \frac{I_m/\pi}{2}$
 $= \underline{\underline{31.83mA}}$

$$(viii) I_{max}(diode) = \frac{I_m}{2} = \frac{100mA}{2} = \underline{\underline{50mA}}$$

(Each diode acts as HWR)

- 39) A FW bridge rectifier uses four diodes & a transformer of ratio of 230V:110V. The forward resistance of each diode is 25Ω & load resistance is 500Ω . Find Maximum value of current in the circuit

Sol: Peak value of Secondary V_2 ,

$$V_m = \sqrt{2} \times 110 = \underline{\underline{155.57V}}$$

Maximum value of current in the circuit,

$$I_m = \frac{V_m}{2R_f + R_L} = \frac{155.56}{2 \times 25 + 500} = \underline{\underline{282.8mA}}$$

- 40) A bridge rectifier consisting of 4 identical diodes produces a direct current of $124.49mA$ across a $2k\Omega$ resistive load. If the rms value of primary input supply is $220V$, calculate the primary to secondary ratio of the transformer if each diode has a forward resistance of 10Ω .

Sol: Given $I_{dc} = 124.49mA$, $R_L = 2k\Omega$, $V_1 = 220V$, $R_f = 10\Omega$

$$\text{We have, } I_{dc} = \frac{2I_m}{\pi}$$

$$\Rightarrow I_m = \frac{\pi I_{dc}}{2} = \frac{\pi \times 124.49 \times 10^{-3}}{2} = \underline{\underline{0.195A}}$$

$$\text{G. Let } V_m = I_m (2R_f + R_L) = 0.195 (2 \times 10 + 2000) = \underline{\underline{393.9V}}$$

Also we have, $V_m = \sqrt{2} V_2$

$$\Rightarrow V_2 = \frac{V_m}{\sqrt{2}} = \frac{393.9}{\sqrt{2}} = \underline{\underline{278.5V}}$$

$$\text{Now, } V_2/V_1 = N_2/N_1$$

$$\Rightarrow \frac{N_2}{N_1} = \frac{278.5}{220} = 1.26$$

$$\Rightarrow \underline{N_1:N_2 = 1:1.26}$$

- (41) A bridge rectifier is driving a load resistance of 100Ω . It is driven by a source voltage of $230V, 50Hz$. Neglecting diode resistances, Calculate
 (a) frequency of output waveform. (b) Average output V_{dc}

Sol: Given $V_2 = 230V, f = 50Hz, R_L = 100\Omega$.

$$V_M = \sqrt{2} V_2 = 141.42V$$

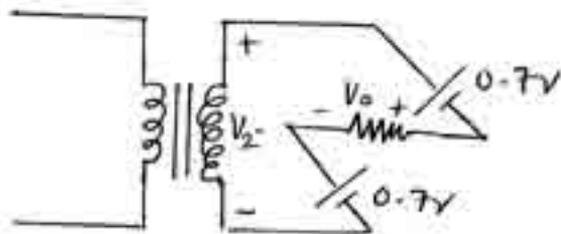
$$(a) f_{out} = 2f = 100Hz$$

$$(b) V_{dc} = \frac{2V_M/\pi}{1 + 2R_D/R_L} = \frac{2 \times 141.42/\pi}{1 + 2(0)/100} = \underline{\underline{90.03V}}$$

- (42) The bridge rectifier is shown in fig(42) (Use Si diodes). Find

- (i) DC output V_{dc} (ii) DC output current
 (iii) Sketch the output V_{dc}

Sol:



KVL

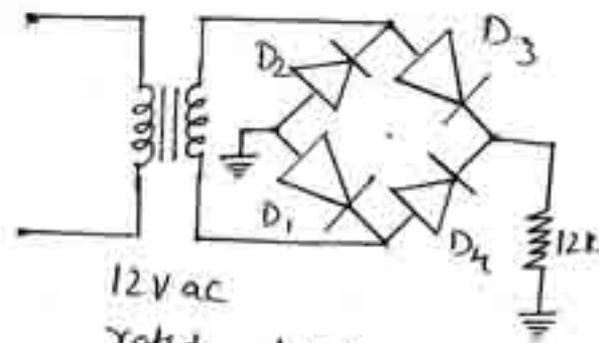
$$V_2 - 0.7 - V_0 - 0.7 = 0$$

$$\Rightarrow V_0 = V_2 - 1.4$$

$$\Rightarrow (V_0)_m = (V_2)_m - 1.4$$

$$= 16.97 - 1.4$$

$$(V_0)_m = \underline{\underline{15.57V}} \rightarrow \text{Peak output voltage}$$



Given $R_L = 12k\Omega$
 $V_2 = 12V$

$$V_M = \sqrt{2} V_2 = \underline{\underline{16.97V}}$$

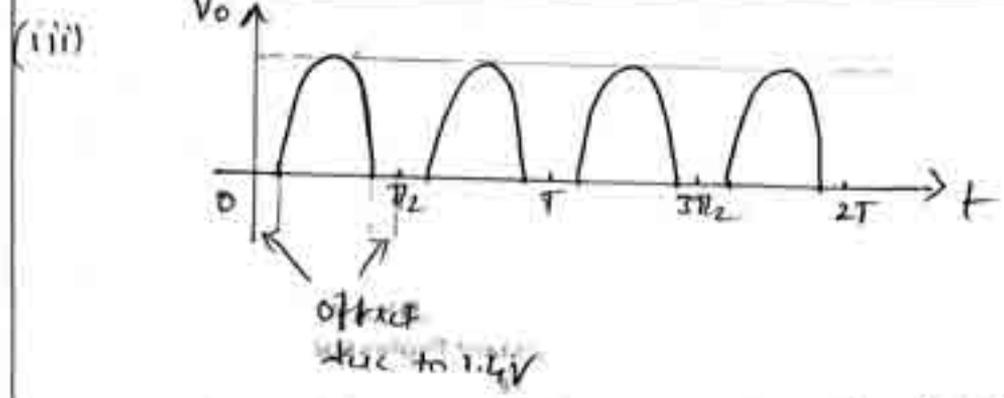
- (i) DC @ Average output V_{dc}

$$V_{dc} = \frac{2(V_0)_m}{\pi} = \frac{2 \times 15.57}{\pi}$$

$$V_{dc} = \underline{\underline{9.91V}}$$

- (ii) Average @ DC output current

$$I_{dc} = \frac{V_{dc}}{R_L} = \underline{\underline{825.8 \mu A}}$$



Q3) A HWR with capacitor filter is supplying a resistive load of $1000\ \Omega$. The value of filter capacitor is $200\ \mu\text{F}$. If the supply voltage to the rectifier is $220\ \text{V}$ at $50\ \text{Hz}$. Calculate
 (a) Ripple factor
 (b) DC output voltage
 (c) DC load current
 (d) PIV across the diode
 (e) RMS ripple output voltage

Given: $R_L = 1000\ \Omega$, $C = 200\ \mu\text{F}$, $V_2 = 220\ \text{V}$
 $f = 50\ \text{Hz}$ $V_m = 220\sqrt{2} = 311.13\ \text{V}$

(a)
$$r = \frac{1}{2\sqrt{3}fR_L C}$$

$$= \frac{1}{2\sqrt{3} \times 50 \times 1000 \times 200 \times 10^{-6}}$$

$$= 0.0288 \text{ @ } \underline{\underline{2.88\%}}$$

(b)
$$V_{dc} = V_m - \frac{I_{dc}}{2fC}$$

(c)
$$V_{dc} = \frac{V_m}{1 + \frac{1}{2fCR_L}}$$

$$= \frac{311.13}{1 + \frac{1}{2 \times 50 \times 200 \times 10^{-6} \times 1000}}$$

$$= \underline{\underline{296.31\ \text{V}}}$$

(c)
$$I_{dc} = \frac{V_{dc}}{R_L}$$

$$= \frac{296.31}{1000}$$

$$= \underline{\underline{0.296\ \text{A}}}$$

(d)
$$\text{PIV} = V_m$$

$$= \underline{\underline{311.13\ \text{V}}}$$

(e)
$$V_{ac} = r V_{dc} \left(\because r = \frac{V_{ac}}{V_{dc}} \right)$$

$$\Rightarrow V_{ac} = 0.0288 \times 296.31$$

$$V_{ac} = \underline{\underline{8.533\ \text{V}}}$$

44) In a FWR with a capacitor filter, the load current from the circuit operating from 230V, 50Hz supply is 10mA. Estimate the value of capacitor required to keep the ripple factor less than 1%. Also find minimum value of capacitance

Sol: Given, $V_2 = 230V$, $f = 50Hz$, $I_{dc} = 10mA$, $C = ?$
 $V_m = \sqrt{2} V_2 = \sqrt{2} \times 230 = 325.269V$
 $\gamma < 0.01 @ 1\%$

Let $\gamma = \frac{1}{4\sqrt{3} f R_L C} < 0.01$ Let $R_L = \frac{V_{dc}}{I_{dc}}$
 $\Rightarrow \frac{1}{C} < 0.01 \times 4\sqrt{3} \times 50 \times 32.52 \times 10^3$ $R_L = \frac{V_m}{I_{dc}} (\because V_{dc} \approx V_m)$
 $\Rightarrow C > \frac{1}{0.01 \times 4\sqrt{3} \times 50 \times 32.52 \times 10^3}$ $= \frac{325.269}{10 \times 10^{-3}}$
 $C > \underline{\underline{8.87\mu F}}$ $= 32.5269k\Omega$

$C_{min} = 8.87\mu F$ → Minimum Value

45) A FW bridge rectifier supplies a load of 400Ω in parallel with a capacitor of 500μF. If the ac supply voltage is 230 sin 314t (V), find @ Ripple factor.

ⓐ DC load current.

Sol: Given $R_L = 400\Omega$, $C = 500\mu F$, $V_2 = V_1 = 230 \sin 314t$
 $\Rightarrow V_m = \underline{\underline{230V}}$

ⓑ $\gamma = \frac{1}{4\sqrt{3} f R_L C} = \frac{1}{4\sqrt{3} \times 50 \times 400 \times 500 \times 10^{-6}}$ $\omega = 314$
 $\gamma = 0.0144 @ 1.44\%$ $f = \frac{314}{2\pi} = \underline{\underline{50Hz}}$

Ⓒ $V_{dc} = \frac{V_m}{1 + \frac{1}{1.0 - \gamma}} = \frac{230}{1 + \frac{1}{1.0 - 0.0144}} = 224.39V$ $\therefore I_{dc} = \frac{V_{dc}}{R_L}$

$$I_{dc} = \frac{224.39}{400} = \underline{\underline{0.56A}}$$

46) A HWR dc power supply has to supply 20V to a 500Ω load. The peak-peak voltage should not exceed 10% of the average output voltage and the ac input frequency is 60Hz. Calculate the required capacitor value.

Sol: Given $V_2 = 20V$, $R_L = 500\Omega$,
 $V_m = \sqrt{2} \times 20 = 28.28V$, $f = 60Hz$, $V_{r(p-p)} = 10\%$ of V_{dc}
 $C = ?$

Consider, $V_{r(p-p)} = 10\%$ of V_{dc}

$$\Rightarrow V_{r(p-p)} = 0.1 V_{dc}$$

$$\Rightarrow 2\sqrt{3} V_{ac} = 0.1 V_{dc} \quad (\because V_{r(p-p)} = 2\sqrt{3} V_{ac})$$

$$\Rightarrow \frac{V_{ac}}{V_{dc}} = \frac{0.1}{2\sqrt{3}} = 0.02886$$

$$\Rightarrow \gamma = 0.02886$$

Let $\gamma = \frac{1}{2\sqrt{3} f R_L C}$

$$\textcircled{a} C = \frac{1}{2\sqrt{3} \gamma f R_L} = \frac{1}{2\sqrt{3} \times 0.02886 \times 60 \times 500} = \underline{\underline{343.66\mu F}}$$

47) A 12V reference source is to use a series-connected Zener diode & resistor connected to a 30V supply. Select suitable components & calculate the circuit current when the supply voltage drops to 25V.

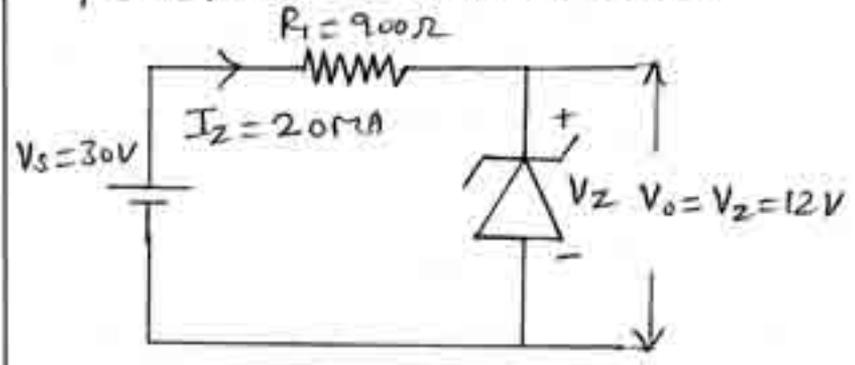
Sol: \textcircled{a} Given $V_s = 30V$, $V_o = V_z = 12V$, \textcircled{b} $V_s = 25V$, $I_z = ?$

\textcircled{c} Let $I_z = I_{zT} = 20mA$

We have,

$$R_1 = \frac{V_s - V_z}{I_z} = \frac{30 - 12}{20 \times 10^{-3}} = 900 \Omega$$

The circuit is shown below

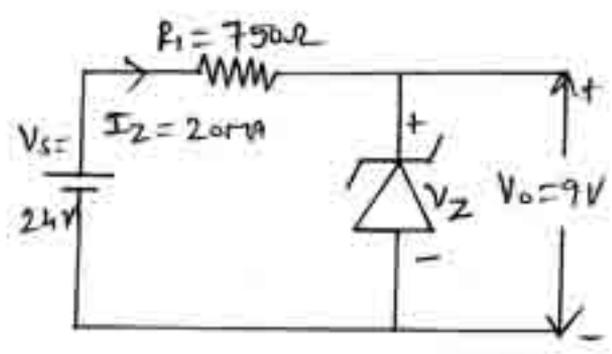


⑥ We have
$$I_z = \frac{V_s - V_z}{R_1} = \frac{25 - 12}{900} = \underline{14.44 \text{ mA}}$$

⑦ Design a 9V dc reference source consisting of a Zener diode & series connected resistor to operate from a 24V supply. Determine the effect on the diode current when the supply voltage drops to 20V & power dissipation in resistor.

Sol: ① Given, $V_s = 24V, V_o = V_z = 9V,$ ② $I_z = ?, V_s = 20V,$
 $P_{R_1} = ?$
 let $I_z = I_{ZT} = 20 \text{ mA}$.

① We have
$$R_1 = \frac{V_s - V_z}{I_z} = \frac{24 - 9}{20 \times 10^{-3}} = \underline{750 \Omega}$$



② Let
$$I_z = \frac{V_s - V_z}{R_1} = \frac{20 - 9}{750} = 14.66 \text{ mA}$$

$$P_{R_1} = (I_z)^2 R_1 = (20 \times 10^{-3})^2 (750) = \underline{0.3 \text{ W}}$$

⑧ A Zener diode has a breakdown voltage of 10V. It is supplied from a voltage source varying between 20 & 40V

in series with a resistance of 820Ω . Using an ideal Zener diode model obtain minimum & maximum Zener current.

Sol: Given. $V_z = 10V$, $R_1 = 820\Omega$, $V_s = 20V - 40V$

$V_{smin} = 20V$, $V_{smax} = 40V$

We have,

$$I_z = \frac{V_s - V_z}{R_1}$$

When $V_s = V_{smin}$, $I_z = I_{zmin}$

$$I_{zmin} = \frac{V_{smin} - V_z}{R_1}$$

$$= \frac{20 - 10}{820}$$

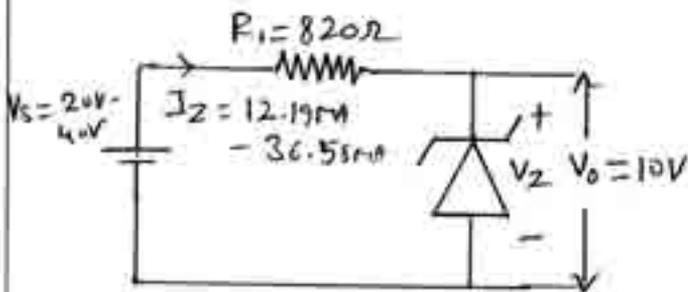
$$= 12.19mA$$

When $V_s = V_{smax}$, $I_z = I_{zmax}$

$$I_{zmax} = \frac{V_{smax} - V_z}{R_1}$$

$$= \frac{40 - 10}{820}$$

$$= 36.58mA$$



Determine the minimum & maximum value of load current for which the Zener diode shunt regulator shown in fig (50) will maintain regulation

What is the minimum R_L

Given $V_z = 12V$, $I_{zmin} = 3mA$, $I_{zmax} = 90mA$, $r_z = 0$ Fig (50)

Sol: Minimum load current

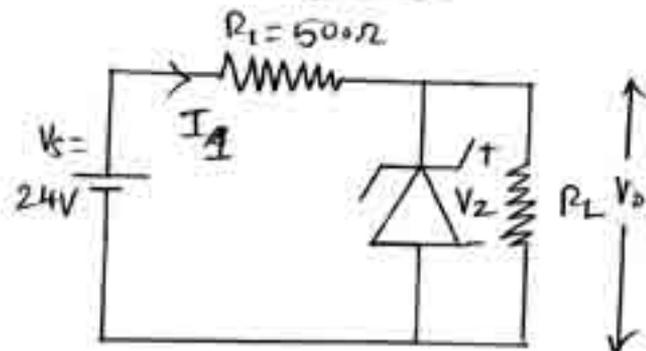
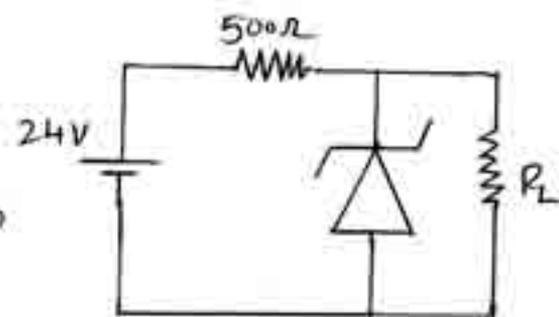
We have

$$I_1 = \frac{V_s - V_z}{R_1} = \frac{24 - 12}{500}$$

$$I_1 = 24mA$$

Since $I_1 \ll I_{zmax}$

$$I_{Lmin} = 0$$



Maximum load current

$$I_{L(max)} = I_1 - I_{Zmin} = 24 - 3 = \underline{\underline{21mA}}$$

Minimum load resistance

$$R_{Lmin} = \frac{V_Z}{I_{Lmax}} = \frac{12}{21 \times 10^{-3}} = \underline{\underline{571\Omega}}$$

51

For a Zener shunt regulator if $V_Z = 10V$, $R_S = 1k\Omega$, $R_L = 2k\Omega$, & the input varies from 22 to 40V, find the maximum & minimum values of Zener current.

Sol. Given. $V_Z = 10V$, $R_S = 1k\Omega$, $R_L = 2k\Omega$, $V_{smin} = 22V$, $V_{smax} = 40V$.

W.k.t $I_L = \frac{V_Z}{R_L} = \frac{10}{2 \times 10^3} = 5mA$ (Assume $I_L = I_{Lmin}$ & $I_{Lmin} = 0$)

Maximum Zener current

$$I_Z(max) = \frac{V_{smax} - V_Z}{R_S} - I_{Lmin} = \frac{40 - 10}{1 \times 10^3} - 0 = \underline{\underline{30mA}}$$

Minimum Zener current

$$I_Z(min) = \frac{V_{smin} - V_Z}{R_S} - I_{Lmax} = \frac{22 - 10}{1 \times 10^3} - 5 \times 10^{-3} = \underline{\underline{7mA}}$$

52

Design a Zener voltage regulator for $V_o = 5V$, $V_{in} = 12 \pm 3V$, $I_L = 20mA$, $P_Z = 500mW$ (Zener Voltage), $I_{Zmin} = 5 \times 10^{-3}$

Sol. Given $V_o = V_Z = 5V$, $V_{inmin} = 12 - 3 = 9V$, $V_{inmax} = 12 + 3 = 15V$.

$P_Z = 500mW$. Assume $I_{Lmin} = 0$, $I_{Lmax} = 20mA$

Max $I_{Zmax} = \frac{P_{Zmax}}{V_Z} = \frac{500 \times 10^{-3}}{5} = \underline{\underline{100mA}}$ ($P_{Zmax} = P_Z$)

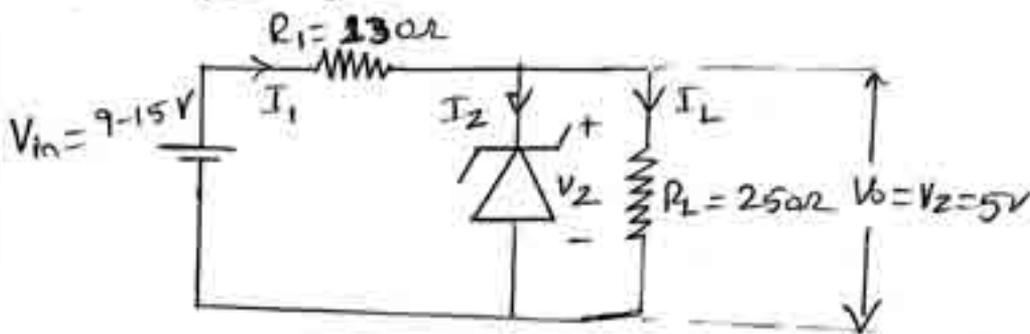
R_{min} $R_{min} = \frac{V_{inmax} - V_Z}{I_{Zmax} + I_{Lmin}} = \frac{15 - 5}{100 \times 10^{-3} + 0} = 100\Omega$

R_{1min} $R_{1max} = \frac{V_{in\ min} - V_Z}{I_{Zmin} + I_{Lmax}} = \frac{9-5}{5 \times 10^{-3} + 20 \times 10^{-3}} = 160 \Omega$

Let $R_1 = \frac{R_{1min} + R_{1max}}{2} = \frac{100 + 160}{2} = \underline{130 \Omega}$

R_L
NoL $R_L = \frac{V_o}{I_L} = \frac{5}{20 \times 10^{-3}} = 250 \Omega$

Voltage Regulator is shown below



33

Design a 6V dc reference source to operate from a 15V supply. The circuit has to provide a maximum possible load current. Calculate the maximum load current that can be drawn from the circuit. Also find Power dissipation in series resistor.

Sol: Given $V_o = V_Z = 6V$, $V_s = 15V$.

Assume $I_{ZT} = 20mA$, $P_D = 400mW$ & $I_{Zmin} = 5mA$

We have, $I_{ZT} = \frac{P_D}{V_Z} = \frac{400 \times 10^{-3}}{6} = \underline{66.67mA}$

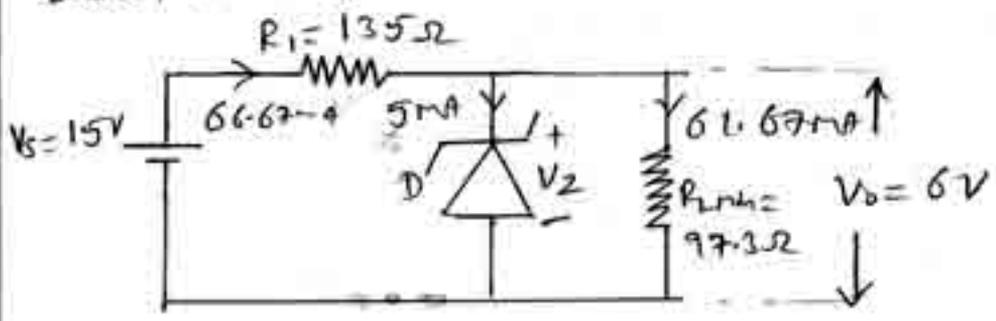
Also we have, $R_1 = \frac{V_s - V_Z}{I_{ZT}} = \frac{15 - 6}{66.67 \times 10^{-3}} = \underline{135 \Omega}$

Power dissipation in R_1 , $P_{R1} = (I_{ZT})^2 R_1 = (66.67 \times 10^{-3})^2 \times 135$
 $P_{R1} = \underline{0.6W}$

We have, $I_{ZT} = I_{Lmax} + I_{Zmin}$
 $\Rightarrow I_{Lmax} = I_{ZT} - I_{Zmin} = 66.67mA - 5mA$
 $I_{Lmax} = \underline{61.67mA}$

$$R_{Lmin} = \frac{V_o}{I_{Lmax}} = \frac{6}{61.67 \times 10^{-3}} = \underline{\underline{97.3 \Omega}}$$

Zener voltage regulator is shown below



- 54) A 24V, 600mW Zener diode is used for providing a 24V stabilized supply to a variable load. If the input voltage is 32V, calculate the following
- (i) value of series resistance (ii) Diode current when $R_L = 2.4k\Omega$
 - (iii) minimum R_L (iv) power dissipated in resistor (series)

Sol Given $V_s = 32V$, $V_o = V_z = 24V$, $P_D = 600mW$

Ans: Assume $I_{zm} = 5mA$

(i) $R_1 = \frac{V_s - V_z}{I_{zm}} = \frac{32 - 24}{25 \times 10^{-3}} = \underline{\underline{320 \Omega}}$

$$\left[\begin{aligned} I_{zm} &= \frac{P_D}{V_z} = \frac{600 \times 10^{-3}}{24} \\ \Rightarrow I_{zm} &= 25mA \end{aligned} \right]$$

(ii) $I_z = I_{zm} - I_L$ ($\because I_{zm} = I_z + I_L$)
 $= 25 \times 10^{-3} - 10 \times 10^{-3}$ ($I_L = \frac{V_o}{R_L} = \frac{24}{2.4 \times 10^3} = 10mA$)
 $= \underline{\underline{15mA}}$

(iii) $R_{Lmin} = \frac{V_o}{I_{Lmax}} = \frac{24}{20 \times 10^{-3}} = \underline{\underline{1200 \Omega}}$

$$\left[\begin{aligned} \because I_{zm} &= I_{Lmax} + I_{zm} \\ \textcircled{ii} I_{Lmax} &= I_{zm} - I_{zm} \\ &= 25 \times 10^{-3} - 10 \times 10^{-3} \\ &= 15mA \end{aligned} \right]$$

(iv) $P_{R1} = (I_{zm})^2 R_1$
 $= (25 \times 10^{-3})^2 \times 320$
 $= \underline{\underline{0.2W}}$

Q5) The output voltage of a dc power supply varies from 30V to 29.6V when the load current is increased from 360 to maximum. The voltage also increases to 30.7V when the ac supply increases by 10%. Calculate the load & source effect & the load & line regulation.

Sol. Given

$$\Delta V_o = 30 - 29.6 \text{ (for } \Delta I_{L(\max)}) , V_o = 30V$$

$$= 0.4V \text{ (for } \Delta I_{L(\max)})$$

$$\Delta V_o = 30.7 - 30 \text{ (for 10% change in } V_s)$$

$$= 0.7V \text{ (for 10% change in } V_s)$$

Load effect = ΔV_o for $\Delta I_{L(\max)} = \underline{0.4V}$

Source effect = ΔV_o for 10% change in $V_s = \underline{0.7V}$

Load regulation = $\frac{\Delta V_o \text{ for } \Delta I_{L(\max)}}{V_o} \times 100 = \frac{0.4}{30} \times 100 = \underline{1.33\%}$

Line regulation = $\frac{\Delta V_o \text{ for 10% change in } V_s}{V_o} \times 100 = \frac{0.7}{30} \times 100 = \underline{2.33\%}$