UNIT - I
Semiconductor Devices

Valance and Conduction Band:-

* The Outermost electrons of an atom ie) those in the shell futhermost from the nucleus are called Valance electrons and have the highest energy (or) least binding energy.

* The band of energy Occupied by the Valance electrons is called Valance band (or) obviously highest Occupied band.

* The next higher Permitted energy band is called the conduction band may either be empty (or) Partially filled by electrons.

* The gap between these two bands is known as forbidden energy gap.

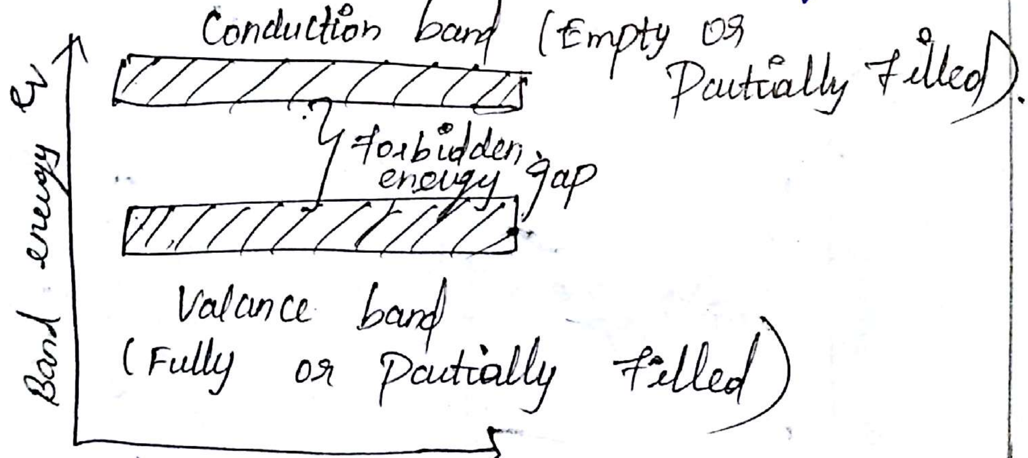


Fig:- Energy Band diagram with Valance and conduction Band

* In Valance band, If the valance electrons absorbs some energy, it jump across the forbidden energy ~~band~~. gap and enters the conduction band.

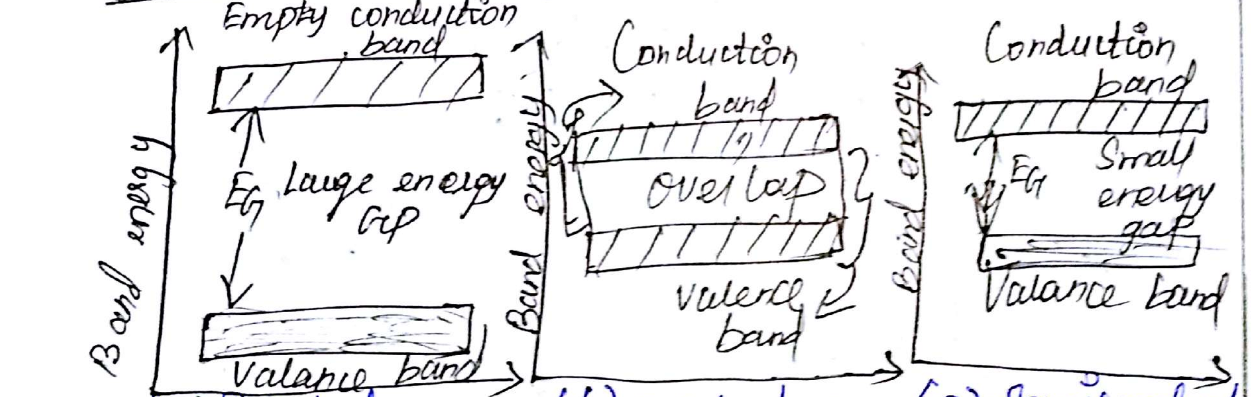
* Then in Valance band there is positively charged hole is created.

* Conduction electrons are freely flow in conduction band, and holes exist in and flow in valance band.

* Conduction electrons move almost twice as Valance band holes.

* For every electron which jumps to conduction band, a hole is created in Valance band. In this way electron-hole pair is created.

Insulators, Conductors and Semiconductors:-



(a) Insulator (b) conductor (c) Semiconductor

Insulators:-

It have a full valance band, and an empty conduction band and have a large energy gap between them.

Conductors:-

* In electrical conductors which have overlapping valance and conduction band. there is no physical distinction between the two bands.

* In the absence of forbidden energy gap in good conductors there no structure to establish holes. The total current in conductors is simply a flow of electrons.

Semiconductors:-

* A semiconductor is a one whose electrical properties are between those of insulators and conductors.

* In semiconductors, it have almost an empty conduction band and almost filled valance band with a very narrow energy gap separating the two.

Types of Semiconductors :-

There are two types,

* Intrinsic Semiconductor (or) Pure Semiconductor.
* Extrinsic (or) Impure Semiconductors
  - N-type
  - P-type.

Intrinsic Semiconductor :-

An Intrinsic Semiconductor is one which is made of the semiconductor material in its extremely pure form.

Examples: Pure germanium and Silicon.

* Forbidden energy gap for

  Ge ⇒ 0.72eV

  Si ⇒ 1.1 eV.

* Intrinsic carrier density (or) carrier concentration is,

$$n_i = N \exp(-E_g/2KT)$$

* where N is constant, E_g - Band gap energy

  K - Boltzmann's Constant

  $K = 1.38 \times 10^{-23}$ J/K

  T - Temperature in °K.

* In Intrinsic Semiconductor, the number of conduction electrons is equal to the number of holes.

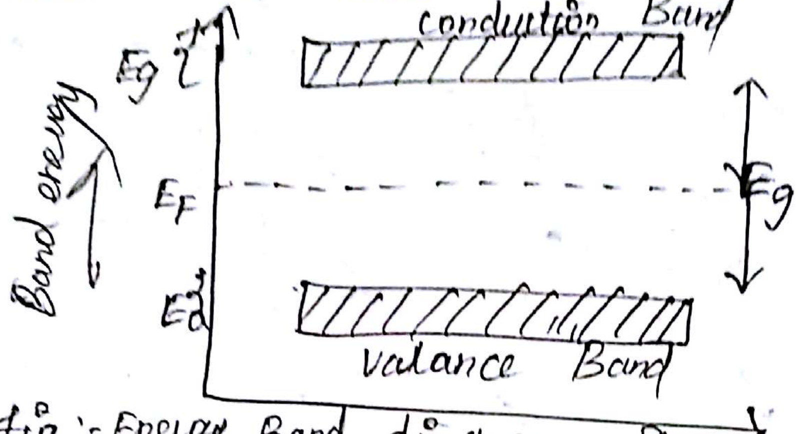


Fig :- Energy Band diagram with Fermi level

* E_F is the Fermi energy level, which is exactly lies between (or) in the middle of the energy gap.

Extrinsic Semiconductors :-

* Some Suitable impurity (or) doping agent (or) dopant has been added in extremly with intrinsic Semiconductor is called extrinsic (or) impure semiconductor.

* usual doping agents ⇒ { Pentavalent atoms, Trivalent atoms }

* Depending on the type of doping material used, it is classified into

⟹ N-type Semiconductor.

⟹ P-type Semiconductor.

N-type extrinsic Semiconductor:-

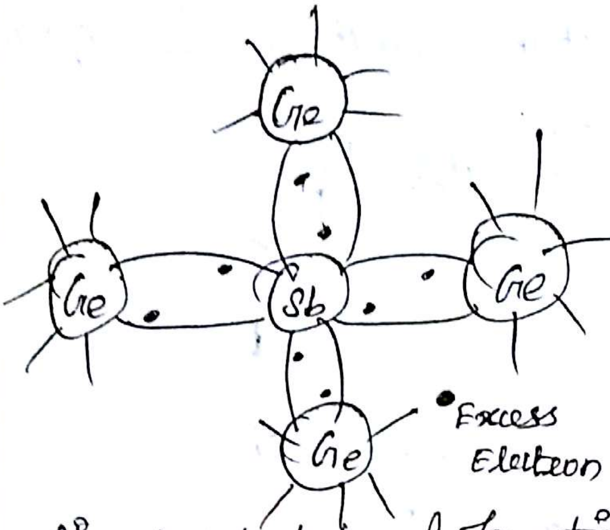


Fig:- covalent band formation.

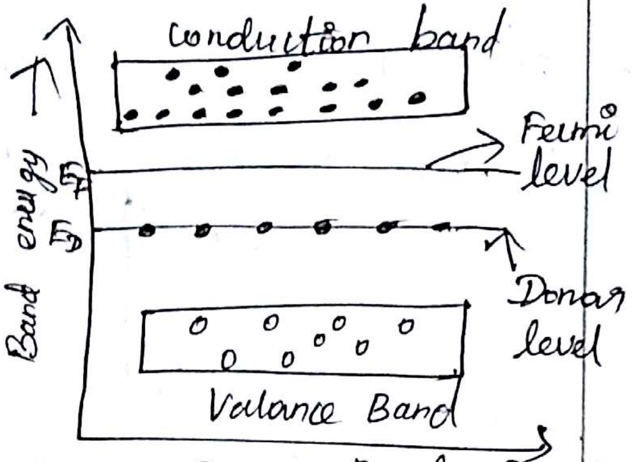


Fig:- Energy Band ~~with~~ for N-type extrinsic Semiconductor

* A Pentavalent material like antimony (Sb) is added to pure germanium crystal. Four antimony atoms forms covalent band with four germanium atoms.

* The fifth electron is superfluous and is loosely bound to the antimony atom.

* Now antimony is called "donar" impurity and makes the pure germanium as N-type extrinsic semiconductor.

* N-type means doNar and Negative charge carriers.

* Concentration of electrons increased in conduction band and exceeds the concentration of holes in valance band, Because of this, the Fermi level shifted to upward towards the bottom of conduction band.

* Electrons forms majority carrier
holes " minority carrier

P-type Extrinsic Semiconductor:-

* This type of semiconductor is obtained when traces of a trivalent like boron (B) are added to a pure germanium crystal

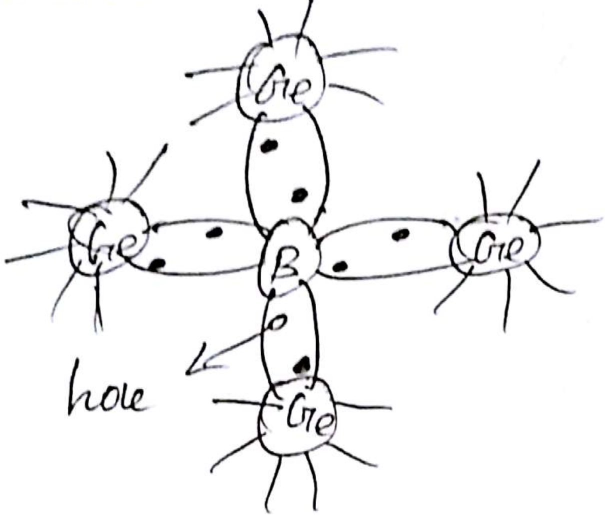


Fig:- Covalent Band with Boron atom

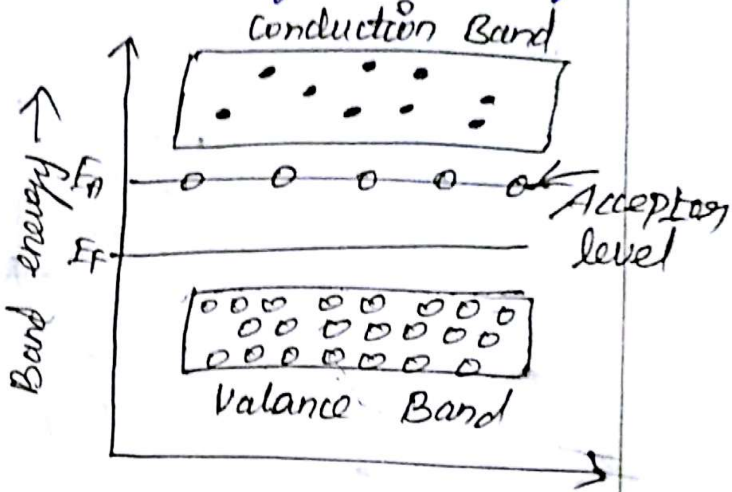


fig:- Energy Band diagram for P-type Extrinsic Semiconductor.

* The three valance electrons of boron atom form covalent bonds with four surrounding germanium atom, but one bond is left incomplete and gives rise to a hole

* Now Boron is called as "acceptor" impurity causes as many positive holes in a germanium, that makes P-type extrinsic semiconductor.

* P-type means acceptor with P is positive charge carriers.

* concentration of holes increased in valance band, concentration of electrons exceeds in conduction band: So the acceptor Fermi

level shifts nearer to Valance band.

* In this type holes form the majority carriers, whereas electrons constitute minority carriers.

P-N Junction:-

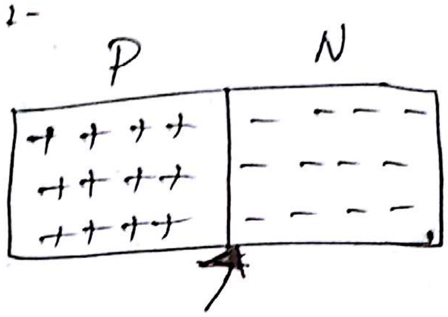


Fig:- P-N Junction Formation

* A single piece of a semiconductor material, half of which is doped by P-type ~~material~~ impurity and other half by N-type impurity.

* The Plane dividing the two zones is called Junction. The Junction plane is assumed to lie where the density of donors and acceptors are equal.

* The P-N Junction is fundamental to the operation of diodes, transistors and other solid state devices.

Let us, If anythink unusual happens at the Junction, It has following three Phenomenons

* A thin "depletion layer or region" is established on both sides of the Junction

* A "Barrier potential (or) Junction Potential" is developed across the Junction.

* The Presence of depletion layer gives rise to "Junction and diffusion capacitance"

Formation of depletion region:-

* The greater concentration in P region than N-region. (or) concentration of electrons is greater in N region than in P-region.

* Due to this concentration difference, holes diffuse from P-type to N-type and electrons from N to P-region there existence by recombination.

* This recombination of free and mobile electrons and holes Produces the narrow region at the Junction called "depletion layer."

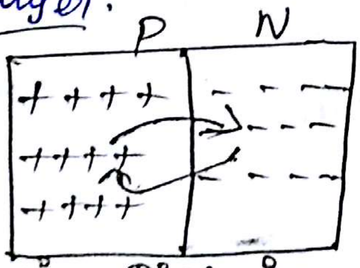


fig:- Diffusion

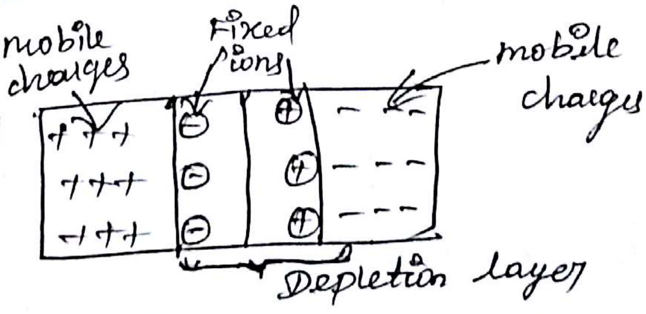


fig:- Formation of depletion layer

P-N Junction Diode:-

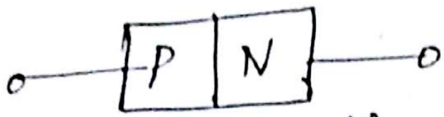


Fig :- P-N Junction Diode

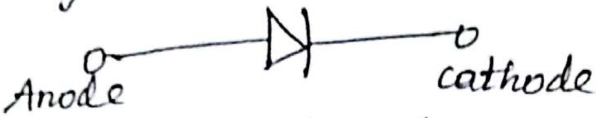
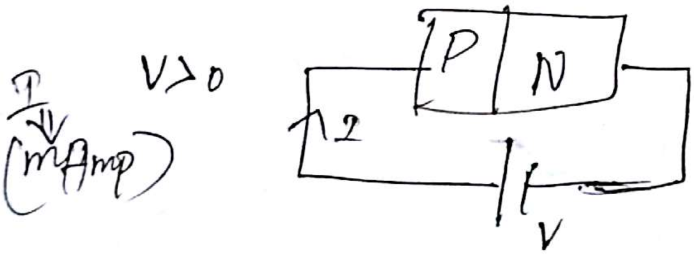


Fig :- Symbol of PN Junction Diode

* A P-N Junction diode is one-way device offering low resistance when forward-biased, and behaving almost as an insulator when reverse biased.

* Such diodes are mostly used as rectifiers ie) for converting alternating current into direct current.

Forward Bias:-



⇒ depletion region decreases

* When the diode is forward biased and the applied voltage increases from zero, then current flows through the device is in beginning.

* If the applied voltage is higher than the barrier voltage V_B, then current flows through the device starts.

* By Increasing applied voltage beyond cut in voltage, then current increases rapidly. upto cut in voltage current becomes constant.

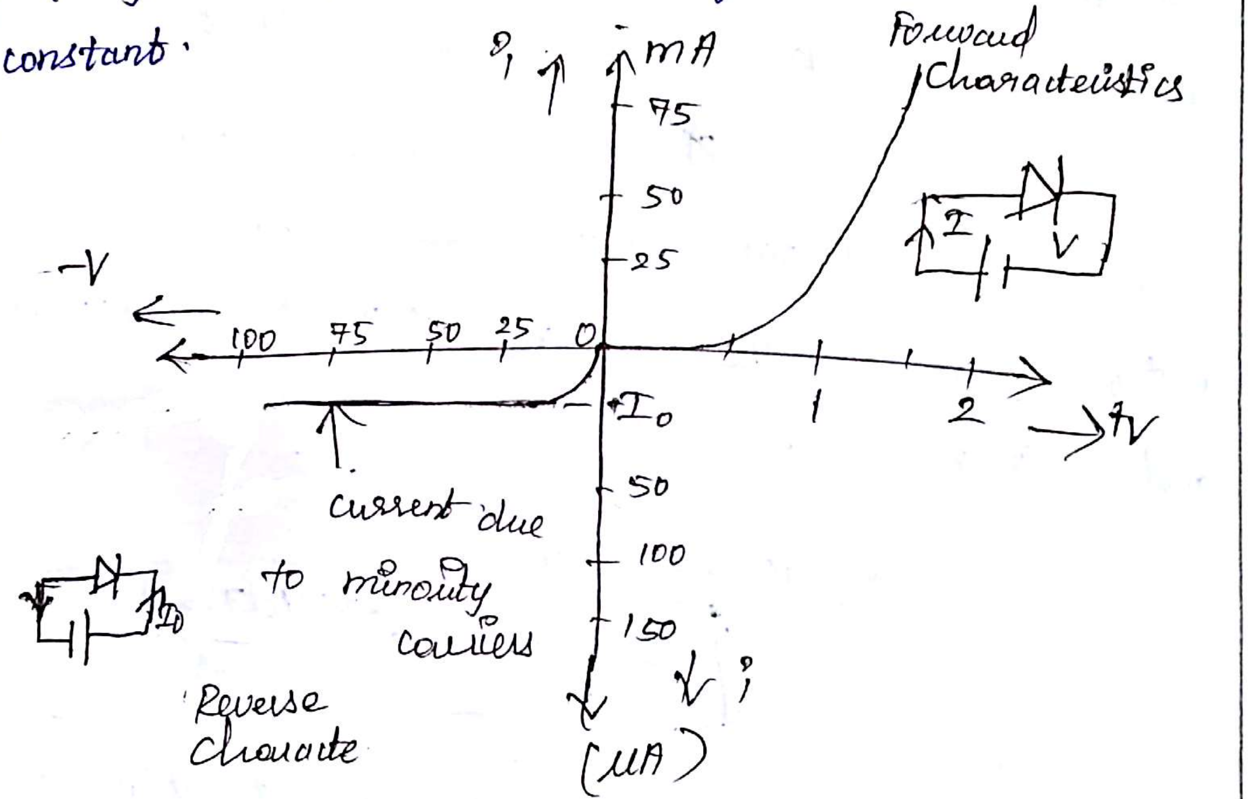
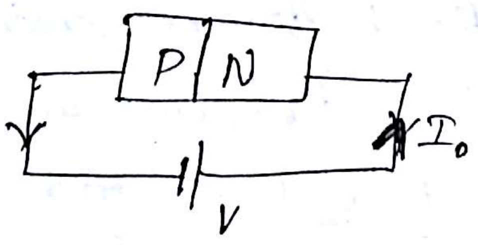


fig :- V-I characteristics of P-N Junction diode.

* In forward bias current produced due to majority carriers.

Reverse Bias:-



$V < 0$

$I \Rightarrow \mu A$

* When the diode is reverse biased due to the minority carriers, the current flows through the circuit.

* As the reverse voltage increased from zero, then the reverse current very quickly reaches its maximum (or) Saturation value I_0, which is also known as leakage current.

* When reverse voltage exceeds a certain value called breakdown voltage V_{BR}, the leakage current suddenly and sharply increases.

<u>Diode equation</u>:-

$$I = I_0 \left(e^{eV/\eta KT} - 1 \right) \text{ amp}$$

where, I_0 - diode reverse saturation current.

V - Voltage across Junction

⇒ +ve for forward bias

⇒ -ve for reverse bias

V_T = thermal voltage

$= 26\,mV$

$= \frac{KT}{q}$

K - Boltzmann constant $= 1.38 \times 10^{-23}\ J/°K$

T - Temperature in °K

$\eta = 1$ for germanium

$= 2$ for silicon.

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Applications of Semiconductor diodes:-

* As Power (or) rectifier diodes.

They convert ac current into dc current for dc power supplies.

* As signal diodes in communication circuits for modulation and demodulation.

* As zener diode in voltage stabilizing circuits.

* As Varactor diodes for voltage controlled tuning circuits.

* In logic circuits used in computers.

Zener diode:-

* It is a reverse biased heavily doped P-N Juntion diode which is operated in the breakdown region where current is limited in both external resistance and Power dissipation of the diode. * when a diode breaks down, both zener and avalanche effects are present. Based on reverse voltage one (or) other predominates

* If reverse voltage < 6V, then

zener effect Predominates, If above 6V avalanche effect is Predominant. First one is called as zener diode, second one as avalanche diode, but generally both are called as zener diodes.

* Zener breakdowns Occurs due to breaking of covalent bonds by the strong electric field set up in the depletion region by the reverse voltage.

* Ib Produces an extremely large number of electrons and holes which constitute the reverse saturation current called as zener current (I_Z).

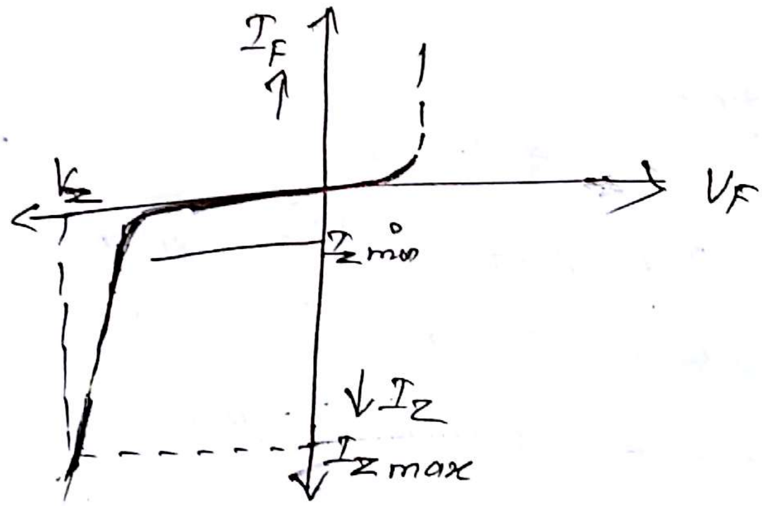


Fig :- V-I characteristics of Zener diode

* Voltage does not change once it goes into breakdown, Ib means V_Z remains constant even when I_Z Increases

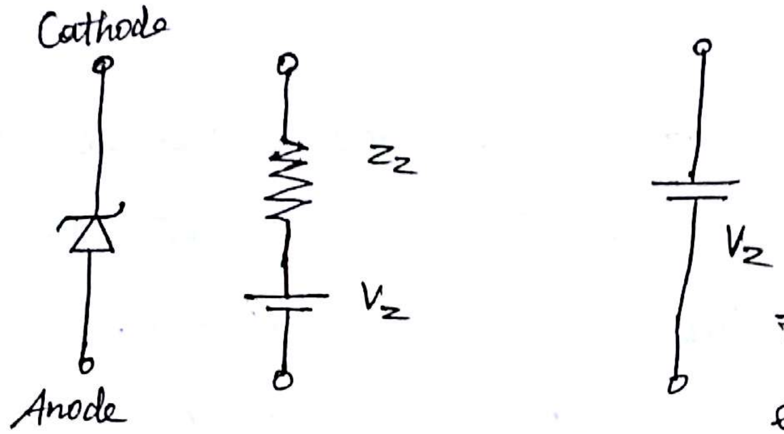


Fig:- Symbol of zener diode

Fig:- Complete Equivalent circuit of zener diode

Fig:- Approximate equivalent circuit of zener diode

* Zener voltages are 2.4V to 200V and their power dissipation is $V_Z I_Z$, rate varing from 150mW to 50W.

* For proper working it must
  1) be reverse biased.
  2) have voltage across it greater than V_Z.
  3) be in a circuit where current is less than I_{Z-max}.

Applications :-

* zener diodes are used
  1) as voltage regulator.
  2) as peak clipper (or) voltage limiters.
  3) for reshaping a waveform
  4) for meter protection against damage from biasing and comparision purposes.

Varactor diode :-

* It is also a reverse biased Junction diode whose mode of operation depends on its transition capacitance (C_T).

* It is a voltage dependent variable capacitor alternatively known as Varicap (or) voltacap (or) voltage variable capacitor (VVC) diode.

$$\text{Capacitance} \propto \frac{1}{V_R^{\,n}}$$

* where 'n' varies from $1/3$ to $1/2$

* As reverse voltage V_R is increased, depletion layer widens thereby decreasing the Junction capacitance. By we can change function ~~capacitance~~

* By changing V_R, change the diode capacitance, so silicon diodes which are optimised for this variable capacitance effect are called "Varactors".

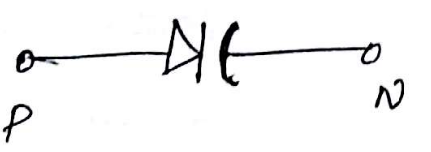


Fig :- Symbol of Varactor diode

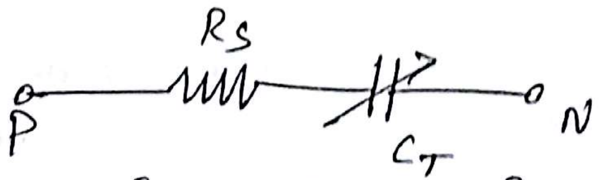


Fig :- Equivalent circuit of varactor diode.

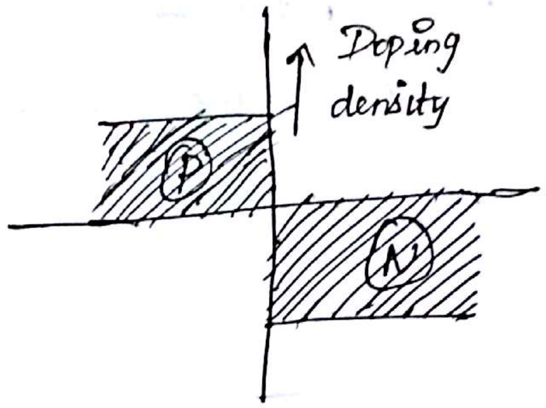


Fig:- doping Profile of abrupt - Junction diode

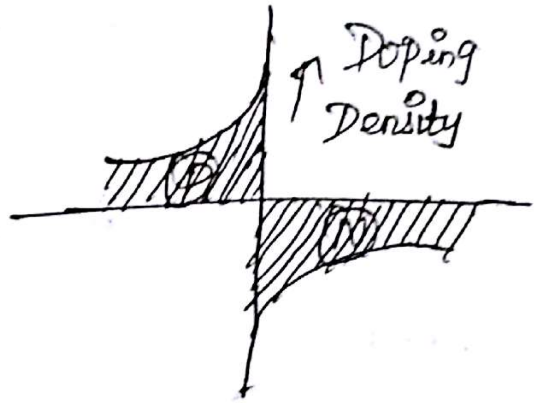


Fig:- doping Profile of hyperabrupt - Junction diode.

Abrupt Junction diode:-

* It has uniform doping and capacitive tuning ratio is (TR) 4:1.
(ie) its maximum transition capacitance is 100PF and minimum is 25 PF then its TR is 4:1
* It is not enough to tune a broadcast receiver over the entire frequency range of 550 to 1050 KHz.

Hyperabrupt Junction diode:-

* It has highest impurity concentration near the junction. It results in narrower depletion layer and larger capacitance.
* changes in V_R produces larger capacitance changes.

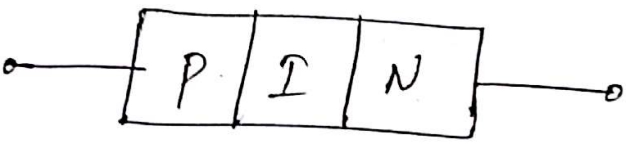
* Tuning ratio is 10:1 enough to tune a broadcast receiver through frequency range of nearly 3:1.

Applications:-

* Db is used as,

1) Automatic frequency control device.
2) FM modulator.
3) Adjustable band-pass filter
4) Parametric applications.

PIN Diode:-



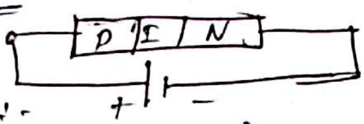
* The PIN diode is formed by an intrinsic layer (or) I-layer of Pure Silicon is Sandwiched between P and N-regions.

* Being intrinsic offers relatively high resistance. This high resistance region gives two advantages, as compared to P-N diode.

$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$ 1) Decreases in Capacitance Cpn because capacitance is inversely Proportional to the seperation of P and N-regions (d), Db allows the diode a faster response time. hence PIN diodes are used at high frequencies (more than 300 MHz)

2) Possibility of greater electric field between the P and N-Junction. It enhances the electron-hole pair generation thereby enabling PIN diode to Process even very week input signals.

FW Bias :- → current



* ↑ as Forward bias voltage ↓ing FB resistance

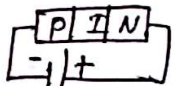
* So it works as Variable resistance

Diode resistance :-

1) when forward biased, its resistance $r_{ac} \cong \frac{50}{I}$, where I is dc current in mA

For large current, it would look like a short

2) when reverse biased, it looks like an open ie) infinite resistance.



* ↑ing Rev Bias voltage ↑ing depletion region, so the capacitance ↓es

* So it works as variable capacitor

Applications :- ⇒ * Variable Attenuator.

* Used as a Switching diode for signal frequencies upto GHz ranges.

* Used as a AM modulator of very high frequency signals.

Light Emitting Diode (LED) :- (Converts Electrical energy to light energy)

A forward biased P-N Junction which emits visible light when energized.

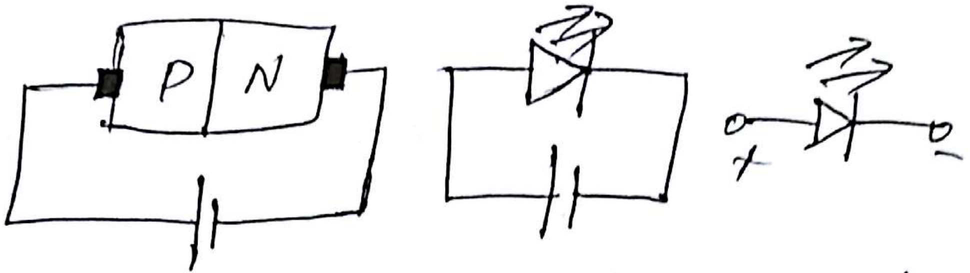


Fig :- Schematic diagrams for LED

* Charge carrier recombination takes place when electrons from the N-side cross the Junction and recombine with the holes on the P-side.

* Now, electrons are in the higher conduction band on the N-side whereas holes are in the lower valance band on the P-side.

* During this recombination. Some of the energy difference is given in the form of heat and light. [Energy release from band gap is like a infrared wave visible light]

* Si and Ge provides more heat energy so there is insufficient light energy But in other Semiconductor materials like galium arsenide (GaAs), GaP, GaAsP, a energy is in the form of light.

* If the Semiconductor material is transulent, light is emitted and the Junction becomes a light source called as Light emitting diode (LED)

* Colour of the emitted light depends on the type of material used as,

Gallium arsenide ⇒ GaAs — Infrared radiation (invisible). Ex :- Remote

Gallium phosphide ⇒ GaP — red or green light.

⇒ GaAsP — red or yellow light.

* LEDs that emit blue light are also available but red is the most common.

* LEDs emits no lights when reverse biased. In fact, operating LEDs in reverse direction will quickly destroy them.

Types of LED Based on Structure:-

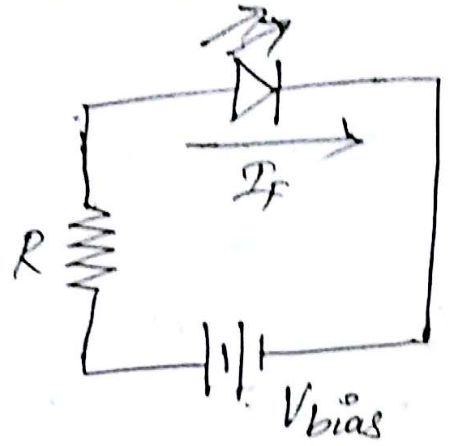
The LED Structures can be divided into two categories.

i) Surface emitting LEDS:-

These LEDS emits light in a direction Perpendicular to the PN Junction Plane.

ii) Edge emitting LEDs:-

These LEDs emits light in a direction Parallel to the PN Junction Plane.



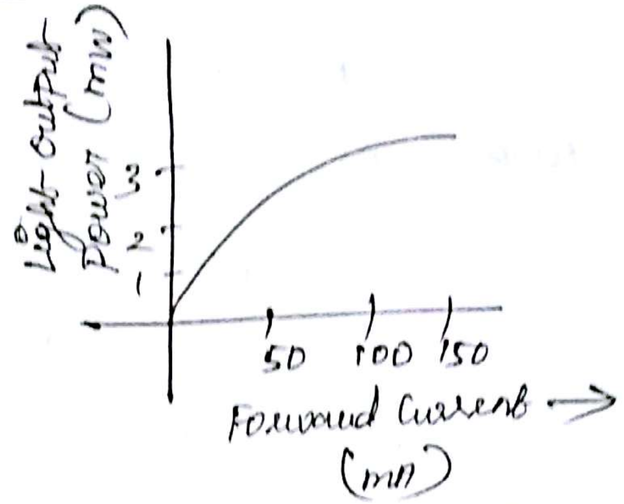


fig :- working of LED fig :- Current to Power relationship.

* The forward voltage across an LED is considerably greater than for a Silicon PN Junction diode.

* The maximum forward voltage for LED is between 1.2V and 3.2V. and revese breakdown voltage for an LED is 3V to 10V.

* The LED emits light in response to a Sufficient forward current.

* The amount of Power Output translated into light is directly Proportional to the forward current. ie) higher forward Current, higher the light Output

Applications:-

1) LEDs are used in burglar-alarm System
2) In data links and remote controls

3) In image sensing circuits used for "picturephone".

4) For numeric displays in hand-held (or) Pocket calculators.

5) For Solid State Video displays which are rapidly replacing cathode-ray tubes (CRT).

6) In arrays of different types for displaying alphanumeric (or) supplying input power to lasers.

<u>LASER</u> <u>Diodes</u>:-

LASER - Light amplification by stimulated emission of radiation

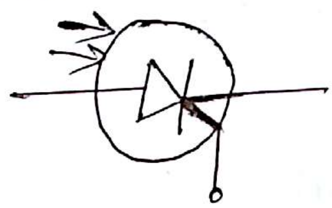


Fig :- Symbol of Laser diode.

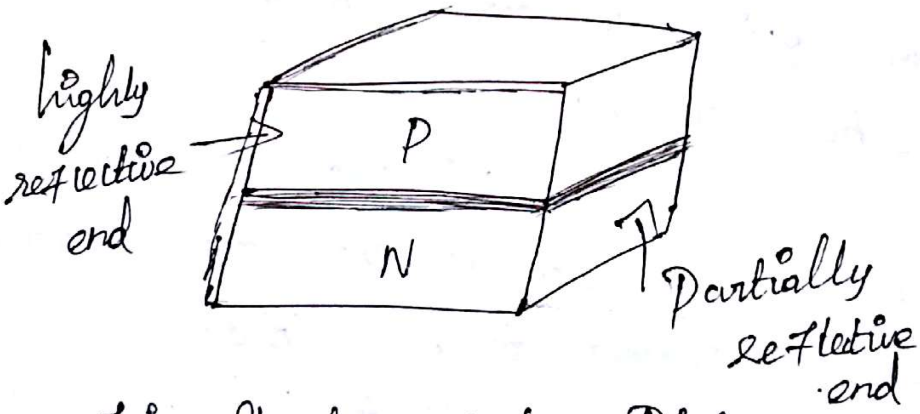


Fig :- Structure of Laser Diode.

Construction:

* A P-n Junction is formed by 2 layers of doped GaAs. The length of Pn Jn bears a Precise relationship with the wavelength of the light to be emitted.

* There is a highly reflective Surface at one end of the P-N Junction & a Partially reflective Surface as the end Produced by polishing the ends.

Operation:-

* Laser diode is forward biased. as electrons move through the Junction, recombination occurs Just as in case of a Ordinary diode.

* As electrons fall into holes to recombine, Photons are released. a released photon Strike an atom, causing another photon to be released.

* As the forward current is increased more electrons enter the depletion region & cause more photons to be emitted.

* Eventually some of photons that are randomly shifting within the depletion

region strike the reflected surfaces perpendicularly.

* This back & forth movement of photons increases as the generation of photons until a very intense beam of laser light is form by the photons, that pass through the partially reflected end of the P-N Junction.

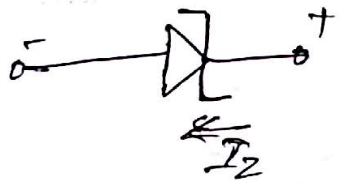
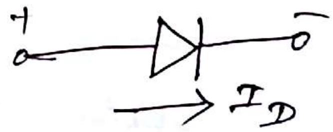
Applications:-
* Used for s/l transmission in Fiber optics
* Medical Equipments.
* Laser Printers.

Comparision Between Zener & Avalanche Breakdown.:-

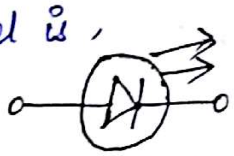
Zener Breakdown	Avalanche Breakdown.
1) Breaking of covalent Bonds is due to intense electric field across the narrow depletion region. This generates large number of free electrons to cause breakdown.	Breaking of covalent Bonds is due to collision of accelerated charge carriers having larger velocities and kinetic energy with adjacent atoms. This Process is called carrier multiplication
2) This occurs for zener diodes with V_Z less than 6V.	This occurs for zener diode with V_Z greater than 6V.
3) The breakdown Voltage decreases as junction temp Increases.	The Breakdown voltage Increases as junction temp Increases.

4) The temp coefficient is negative	The temp coefficient is positive.
5) The V-I characteristics is very sharp in breakdown region.	The V-I characteristics is not sharp

Comparison Between zener diode and P-N Junction Diode:-

zener diode	P-N Junction Diode
1) Operate in reverse breakdown region also.	Operate in only forward biased condition.
2) Dynamic zener resistance is very small in reverse breakdown condition.	The diode resistance in reverse biased condition is very high
3) zener diode Symbol 	P-N Junction diode Symbol 
4) Power dissipation capability is very high.	It is very low.
5) Applications :- * Voltage regulator. * Protection circuits. * Voltage limiters etc.	Applications :- * Rectifiers * voltage multipliers * clippers & clampers etc..

Comparision between LED & P-N Junction diode:-

LED	P-N Junction diode
1) It Emits light, when forward biased.	It does not emit light.
2) It made by materials like GaAs, GaAsp, Gap	It made up by materials like Silicon & germanium.
3) The voltage drop across forward biased LED is 2V.	The voltage drop across forward biased diode is 0.7V.
4) Reverse biased Voltage is about 3V to 10V	Reverse biased Voltage is about 50V.
5) Needs large power,	less power is enough.
6) Symbol is, 	Symbol, 
7) Applications:- * Seven segment Displays * alpha numeric Displays * ON-OFF Indicator.	Applications:- * Rectifiers. * clippers, clampers. * Voltage multipliers.

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Seven Segment Display:-

* A display consisting of seven LED's arranged in series segments called seven segment display. The seven LED's are arranged in a rectangular fashion and are labled A through G.

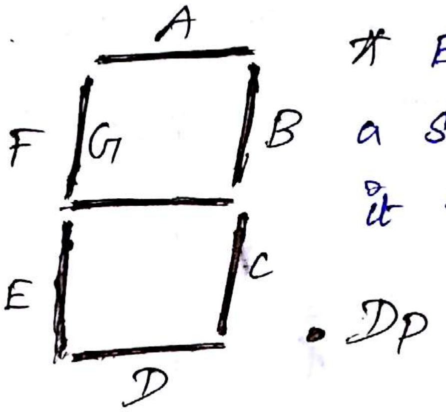


Fig :- Seven Segment display with LED's A through G.

* Each LED is called a segment because it forms a part of the digital being displayed.

* An additional LED is used for indication of a decimal point. (DP)

⟹ By forward biasing different LED's are displayed, the digits from 0 to 9.

Ex: To display a zero, the LED's A, B, C, D, E, F are forward biased. It can also display the capital letters A, C, E & F & small letters b and d.

Types of Seven Segment Display:-

* Common anode type.
* common cathode type.

Common Anode Type :-

* All anodes of LED's are connected together and common point is connected to +Vcc which is positive supply voltage.

* A current limiting resistor is required to be connected between each LED and ground.

* By applying ground to a particular segment that LED segment will light up

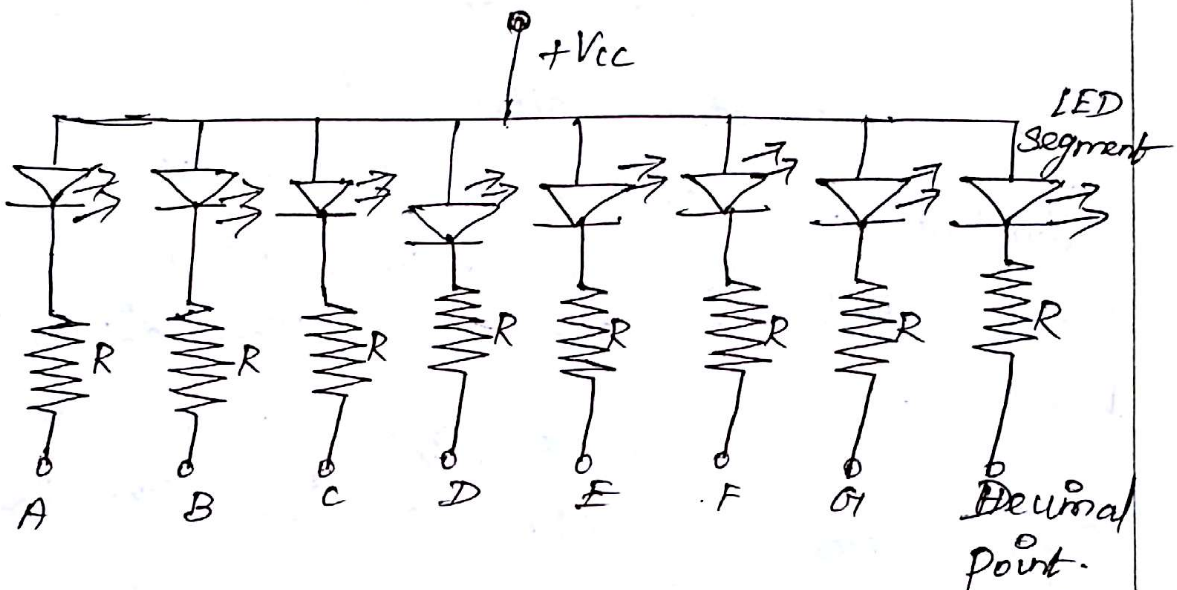


Fig :- Arrangement for common ~~cathode~~ anode type Display.

Common Cathode type :-

* Power must be connected to which LED want to light up

* All cathods of LED's are connected together and common point is connected to ground.

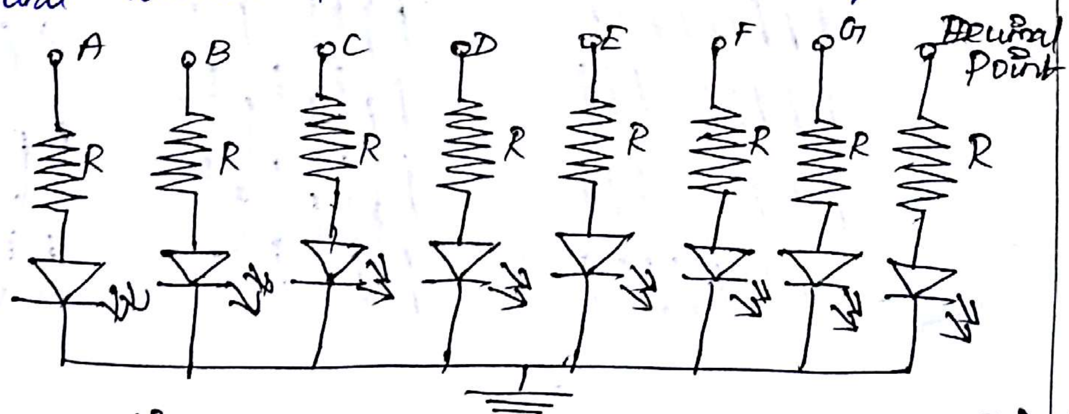


Fig :- Arrangement for common cathode type Display

Liquid Crystal Display (LCD):-

* The term liquid crystal refers to the fact that these components have a crystalline arrangement of molecules, yet the flow like a liquid. (It have both liquids as well as a Solid Crystal Properties).

* They do not emit or Generate light, but rather alter externally Generated illumination. Their ability to modulate light when electrical signal is applied, has made them Vary Very usefull in Flat Panel display technology.

* The crystal is made up of Organic molecules which are rod like in shape. The Orientation of rods like molecules defines the "director" of the liquid Crystal.

fig:- i) Smectic

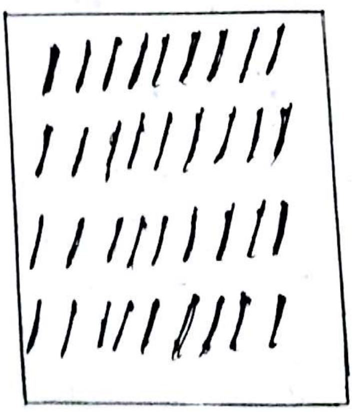


Fig: ii) Nematic

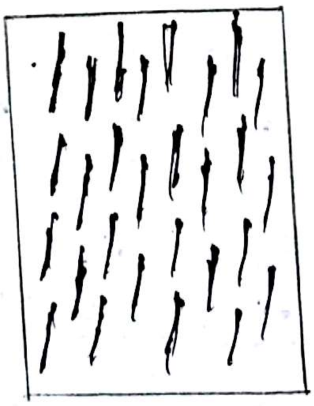
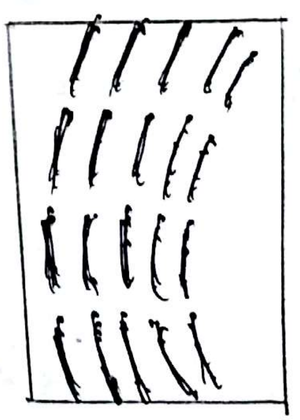


Fig: iii) Cholesteric



i) Smetic:-

* In this Structure molecules are arranged in layers. and within each layer there is Orientational Order over a long range in same direction.

* In this liquid Crystal both Orientation Order and Positional Order are Present.

ii) Nematic:-

* In this nematic Structure the positional Order between layer of molecules is lost, but Orientational Order is maintained

iii) Cholestic:-

* In this Cholestic Structure the rod like molecules are Oriented in different angles with in each layer.

Types of LCD:-

i) Dynamic Scattering LCD:-

* In this LCD, the liquid Crystal material is sandwitched between glass sheets with transparent metal film electrodes.

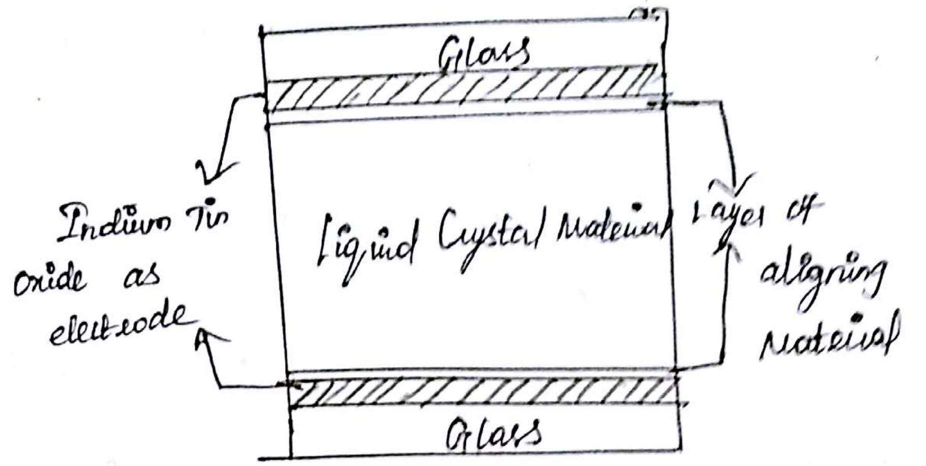


fig:- Structure of Dynamic Scattering LCD

* Thin Layer Indium Tin Oxide (ITO) on each surface acts as a electrode, then layer aligning is applied on the top of ITO. cell.

i) If cell is not activated ⇒ liquid crystal is transparent

ii) If cell is activated ⇒ the molecular turbulance causes the light

* This light to be scattered in all direction, so that the activated areas appear bright. This phenomenon is known as "dynamic scattering"

* Based on glass sheets the cell classified into two types.

i) Transmittive type cell.

ii) Reflective type cell.

Transmittive type cell:

If when both glass sheets are transparent, the cell is known as a transmittive type cell.

i) If cell is not activated ⇒ cell will transmit rear or edge lightening through the cell in straight lines

⇒ In this condition cell won't appear bright

ii) If cell activated ⇒ The incident light scatters

⇒ cell appears quite bright.

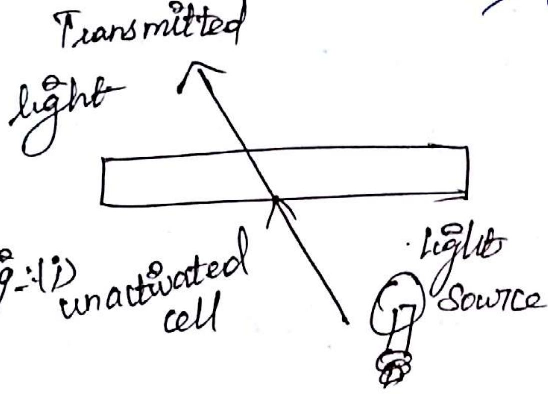


Fig:(i) unactivated cell

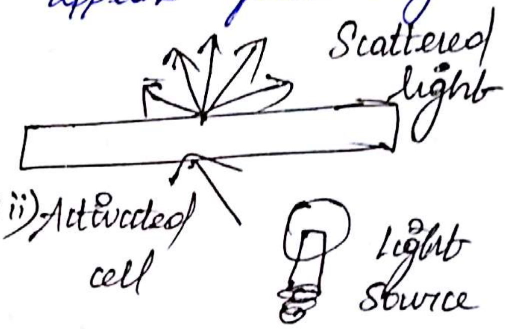


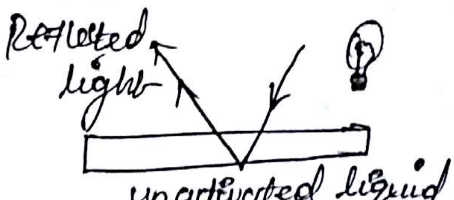
Fig: ii) Activated cell

Reflective type cell:-

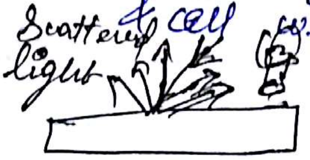
The reflective type cell operates from light incident on its front surface.

If cell is not activated ⇒ light is reflected in the usual way from mirror surface, & cell won't be bright.

If cell is activated ⇒ Dynamic scattering occurs & cell will be bright



unactivated liquid crystal cell



Activated cell

Field Effect LCD:-

* It consists of two glass Plates, a liquid crystal fluid, Polarizes and transparent conductors.

* The liquid crystal fluid is sandwiched between two glass plates. Each glass Plate is associated with light polarizes. The light polarizes are placed at right angle to each other.

* In the absence of electrical excitation, the light flow through front Polarizer is rotated to 90° in fluid and passed through rear polarizer. It is reflected back to the viewer by back mirror.

* On the application of electrostatic field, liquid crystal fluid molecules are alligned so light flow through the molecules are not rotated to 90° and also absorbed by rear polarizer so dark digit on a light background appeared.

Application:-

Computer monitors, Televisions, Instrumental Panel, digital cameras, watches, calculators, mobile telephones, and so on...

Diode Applications:-

- ⇒ Rectifiers.
- ⇒ Clipper, Clamper.
- ⇒ Voltage multiplier.
- ⇒ SMPS.

Before that some characteristics and applications are, load line analysis, Series diode configuration, Parallel series configuration, AND / OR Gates.

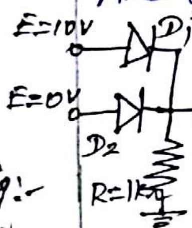
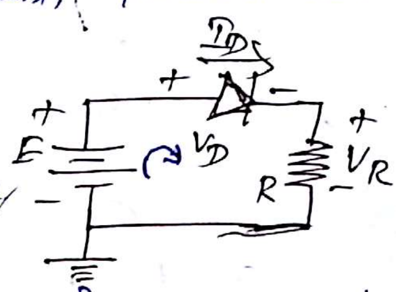
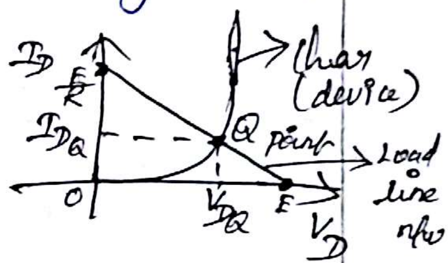


Fig:- Positive logic OR Gate

Load line analysis:-





consider a Load R, apply "KVL" in circuit.

$$E = V_D + I_D R$$

Intersection will occur when horizontal axis $I_D = 0A$ and vertical axis $V_D = 0V$.

i) $V_D = 0V$ $\quad E = 0 + I_D R = I_D R$

ii) $I_D = 0A$. $\quad E = V_D + 0 = V_D$.

The straight line drawn between these two points. it will cut the characteristics curve at one point that is called as "Quiescent point (Q Point)". From the Voltage is V_{DQ} & Current I_{DQ}

$$I_D = \frac{E}{R} - \frac{V_D}{R}$$

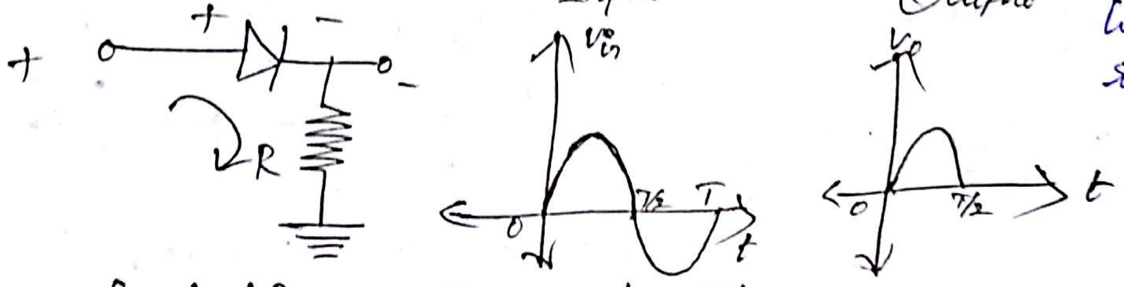
and. $$I_D = I_s\left(e^{V_D/nV_T} - 1\right). \quad \left(V_T = \frac{kT}{q}\right)$$

Rectifier:-

* Half-wave Rectifier.
* Fullwave Rectifier.

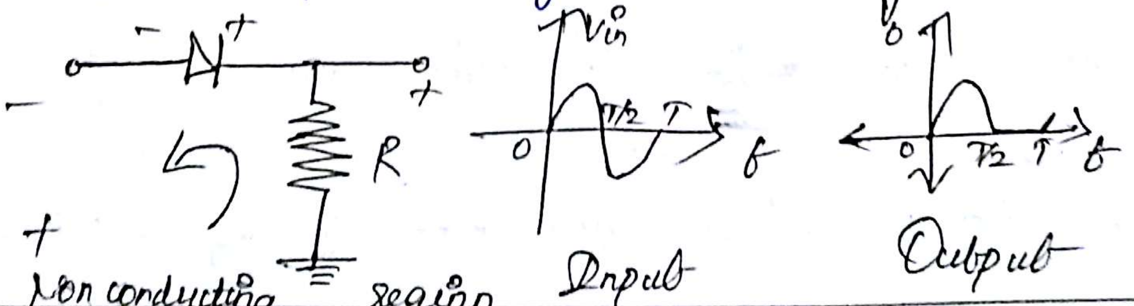
* Rectifier converts AC into pulsating DC.

Halfwave Rectifier ⇒ To Establish a dc level, the Process of removing one half of i/p s/l is called halfwave rectification



Conducting region 0 to $T/2$

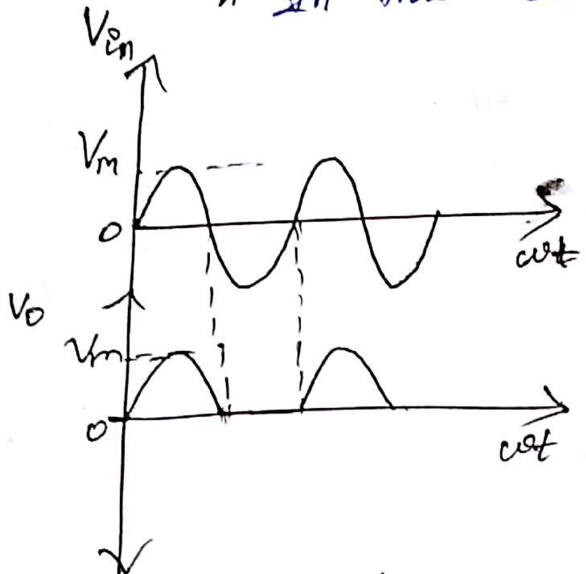
* During the positive half cycle (Interval from 0 to $T/2$), the diode is forward biased and conducts current through the resistor, the current produces output voltage across R_L which has the shape as the half cycle of the input voltage



Non conducting region ($T/2 \to T$)

* During the negative half cycle (Interval from T/2 to T) the diode is in reverse biased and no current through the resistor because it becomes open circuit, so the voltage across load resistor is "0V."

* In this diode is Ideal.



$V_{in} = V_m \sin \omega t$

$$V_o = \begin{cases} V_m \sin \omega t & 0 < \omega t < \pi \\ 0 & \pi < \omega t < 2\pi \end{cases}$$

Average value of half wave Output Voltage :-

$$V_{AVG} = V_{DC} = \frac{1}{2\pi} \int_0^{2\pi} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{1}{2\pi} \int_0^{\pi} V_m \sin \omega t \, d(\omega t) + \int_{\pi}^{2\pi} V_m \, 0 \, d(\omega t)$$

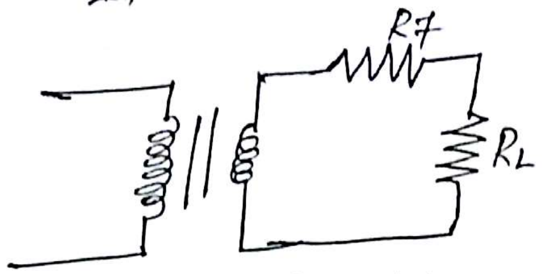
$$= \frac{1}{2\pi} \left[-V_m \cos \omega t \right]_0^{\pi}$$

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

$$= \frac{-V_m}{2\pi} \left[-1 - 1 \right] = \frac{\not{-}V_m(\not{-}\not{2})}{\not{2}\pi}$$

$$\boxed{V_{AVG} = V_{DC} = \frac{V_m}{\pi}} \qquad \boxed{I_{DC} = \frac{I_m}{\pi}}$$

If the diode is Practical,



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

RMS Value of Current :-

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

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

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

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

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

$$= \frac{V_m}{2}\left[\frac{1}{\pi}\left[\pi - 0 - 0 + 0\right]\right]^{1/2}$$

$$= \frac{V_m}{2}\left[\frac{1}{\pi} \times \pi\right]$$

$$\therefore \boxed{V_{rms} = \frac{V_m}{2}} \qquad \boxed{I_{rms} = \frac{I_m}{2}}$$

Rectifier Efficiency :-

$$\eta = \frac{\text{dc Power Supplied to load}}{\text{Total i/p ac Power}}$$

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

$$\eta = \frac{V_{dc} I_{dc}}{V_{ac} I_{ac}} \times 100 \qquad (\because P = VI)$$

$$= \frac{\frac{V_m}{\pi} \cdot \frac{I_m}{\pi}}{\frac{V_m}{2} \cdot \frac{I_m}{2}} \times 100$$

$$= \frac{1/\pi^2}{1/4} \times 100 = \frac{4}{\pi^2} \times 100$$

$$\boxed{\eta = 40.6\%}$$

Maximum of 40.6% of ac Power is converted to dc Power.

(or)

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100 \qquad (P = I^2 R)$$

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2}{\pi^2} R_L$$

$$P_{ac} = I_{ac}^2 R_L = \frac{I_m^2}{4} [R_f + R_L]$$

$$= \frac{I_m^2 R_L / \pi^2}{I_m^2 (R_f + R_L)/4} \times 100$$

$$= \frac{4}{\pi^2} \left[\frac{R_L}{R_f + R_L} \right] \times 100$$

$$= \frac{4}{\pi^2} \times 100$$

(R_f is negligible to R_L $\because R_f \ll R_L$)

$$\boxed{\eta = 40.6\%}$$

Maximum of 40.6% of ac Power is converted to dc Power.

Ripple Factor:-

The amount of ac component present in that dc Output.

$$\text{Ripple Factor} = \gamma = \frac{\text{RMS Value of Ac Component}}{\text{Average Value of Dc component}}$$

$$\gamma = \frac{I_{AC} \text{ of ripple}}{I_{DC}}$$

$$I_{rms}^2 = I_{dc}^2 + I_r^2 (ac)$$

$$I_r^2(ac) = I_{rms}^2 - I_{dc}^2$$

$$I_r(ac) = \sqrt{I_{rms}^2 - I_{dc}^2}$$

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

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

$$= \sqrt{\frac{\pi^2}{4} - 1} = 1.21$$

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

$$\text{Form Factor} = \frac{I_{rms}}{I_{DC}} = \pi/2 = 1.51$$

Transformer Utilization Factor:-

$$TUF = \frac{\text{DC Power delivered to load}}{\text{AC rating of Secondary transformer}}$$

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

$$= \frac{I_m^2}{\pi^2} \times \frac{R_L}{V_m \cdot I_m} 2\sqrt{2} = \frac{2\sqrt{2}}{\pi} \frac{I_m^2 R_L}{I_m^2 (R_L + R_F)}$$

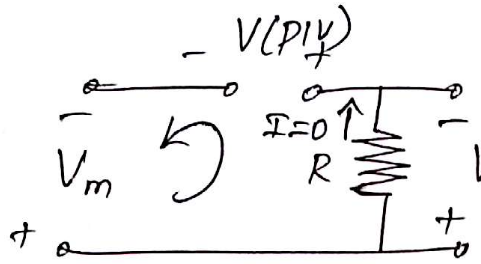
$$\boxed{TUF = 0.287} \quad (\because R_L >> R_F)$$

PIV [PRV] :-

* Peak Inverse Voltage (or) Peak reverse Voltage.

$$\boxed{PIV_{rating} \geq V_m}$$

* Voltage rating not must be exceeded in the reverse bias region.



$V_0 = IR = (0)R = 0V$

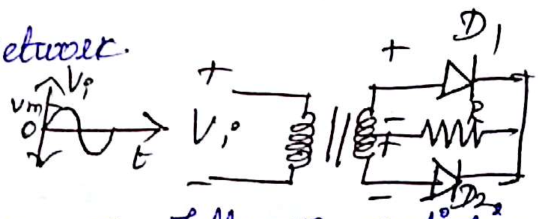
Full wave rectification :-

* The dc level obtained from a sinusoidal input can be improved 100% using a process called fullwave rectification.

⇒ Center Tapped Transformer

⇒ Bridge Network.

Center Tapped Transformer:-



* This type of fullwave rectifier appears with only two diodes but required center-tapped transformer to establish the input signal across each section of secondary of the transformer.

* During positive half cycle of the diode D_1 assumes short circuit & D_2 assumes open circuit equivalent

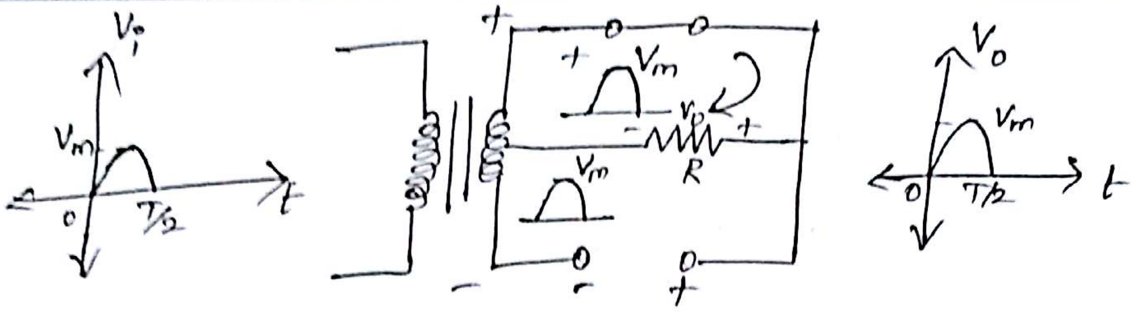


Fig:- During +ve half cycle of i/p.

⇒ D_1 is forward biased (conduct in half cycle of i/p)
⇒ D_2 is reverse biased

* During negative half cycle of diode reversing roles of the diodes but maintaining the same polarity for the voltage across the load resistor R.

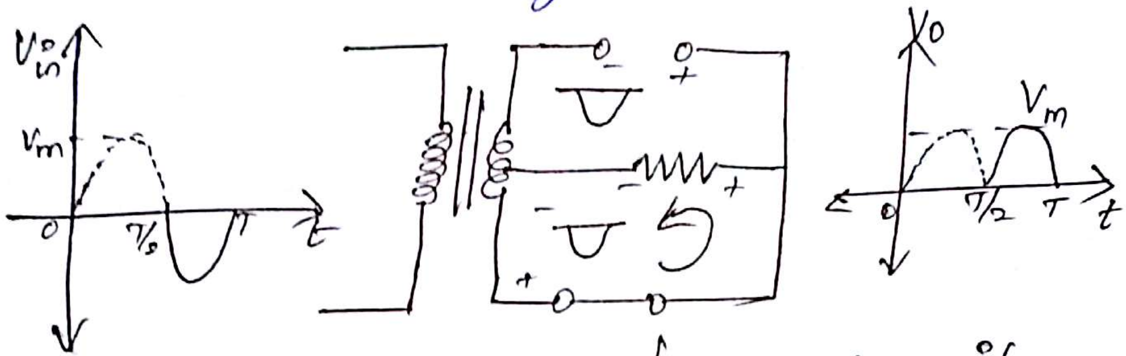


Fig:- During -ve half cycle of i/p

⇒ D_1 is reverse biased
⇒ D_2 is forward biased (conduct)

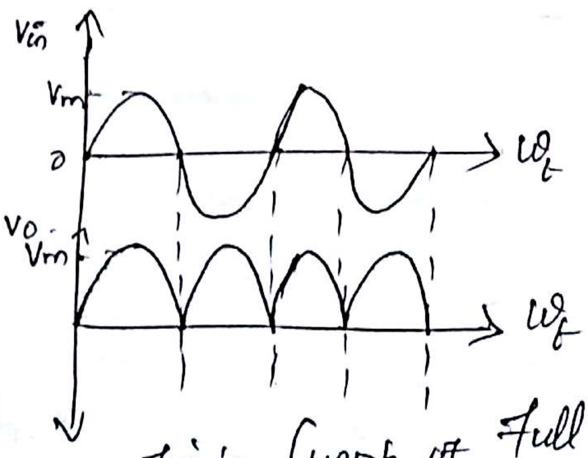


Fig:- Graph of full wave rectifier

Average Value:

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

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

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

RMS Current:-

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

$$V_{Rms} = \frac{V_m}{\sqrt{2}}$$

Efficiency:-

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{4}{\pi^2} \times 2 \times 100 = 81.2\%$$

Maximum of 81.2% of AC component converted to DC component.

Ripple Factor:-

$$\gamma = \frac{\text{Rms of AC}}{\text{Avg of DC}} = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1} = \sqrt{\frac{\left(\frac{I_m}{\sqrt{2}}\right)^2}{\left(\frac{2I_m}{\pi}\right)^2} - 1}$$

$$\gamma = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\gamma = 0.483$$

Form Factor = 1.11

TUF:-

$$TUF = \frac{(TUF)_s + (TUF)_p}{2}$$

$(TUF)_p$ = 2 × TUF of half wave

= 2 × 0.287

= 0.574

$$(TUF)_s = \frac{I_{dc}^2 R_L}{V_{rms} I_{rms}} = \left(\frac{2I_m}{\pi}\right)^2 R_L \Big/ \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}}$$

$$= \frac{2^2 I_m^2 R_L}{\pi^2} \times \frac{2}{I_m R_L I_m}$$

$$= \frac{4}{\pi^2} \times 2$$

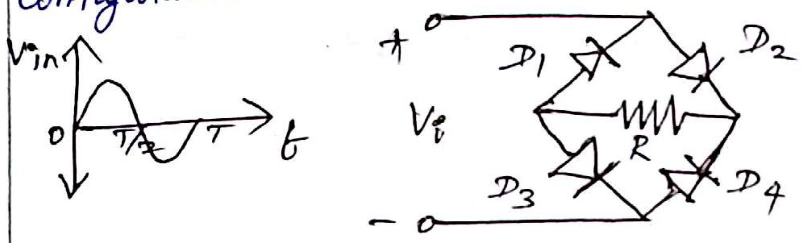
$$(TUF)_s = 0.812$$

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

$$TUF = \frac{0.574 + 0.812}{2} = 0.693$$

Bridge wave Rectifier:-

* This types of dc rectifiers appears with its four diodes in a bridge configuration.



* During Positive half cycle, D_2, D_3 are conducting whereas D_1 & D_4 are off state.

i.e) D_2 & D_3 are forward biased (conduct)

D_1 & D_4 are Reverse biased.

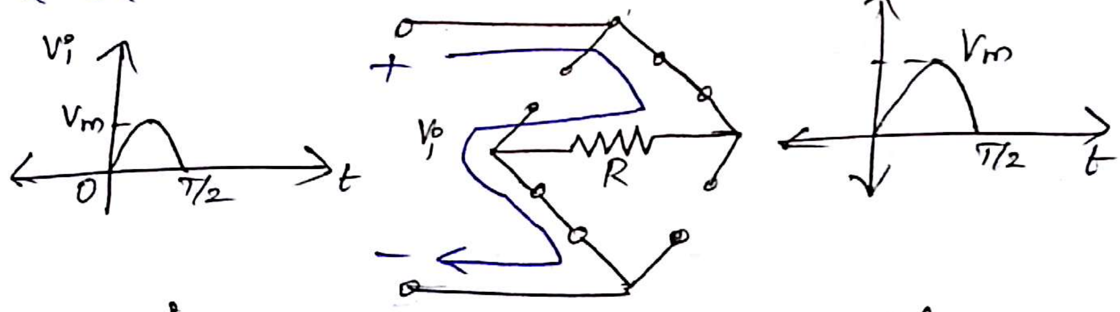


Fig:- During +ve half cycle of i/p

* During the negative half cycle the diode D_1 & D_4 are conducting where as D_2 & D_3 are off i.e) D_1 & D_4 is Forward biased D_2 & D_3 is reverse biased.

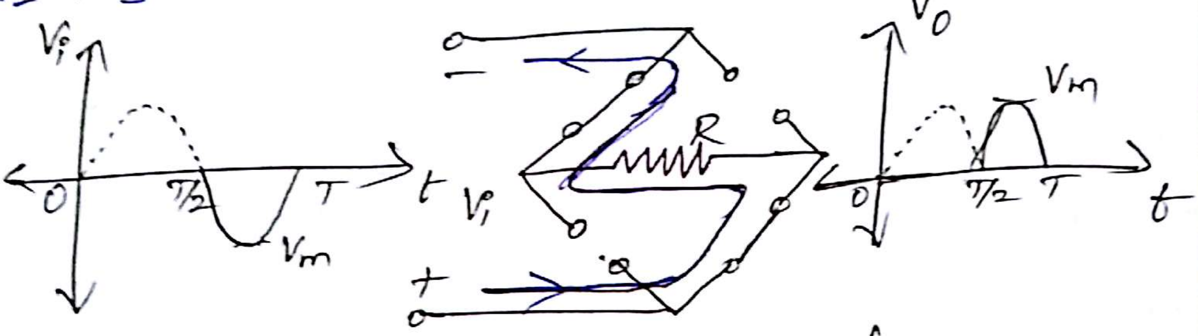


Fig:- During the -Ve half cycle of i/p

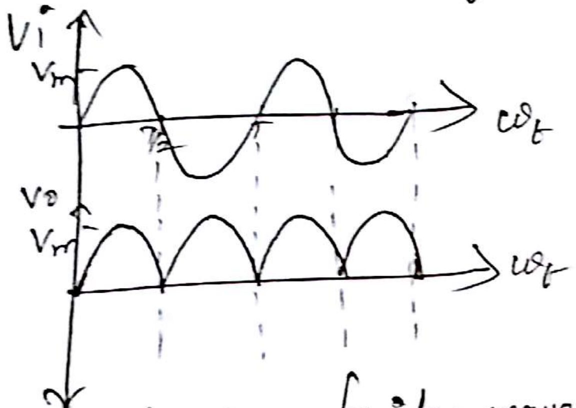


Fig:- Graph of bridge wave rectifier.

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

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

$$PIV = V_m$$

$$\eta = 81.2\%$$

$$r = 0.483$$

$$TUF = 0.812$$

Filters:-

* It is used to minimize the ripple content in the o/p of the rectifier.

Capacitor filter:-

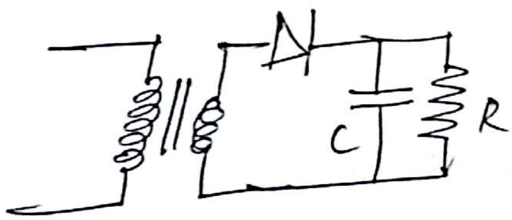


Fig:- RC Filter

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$f = \infty \quad X_C = 0$

$f = 0 \quad X_C = \infty$

* During Positive half cycle of ac i/p diode is forward biased, so the current passes through the diode.

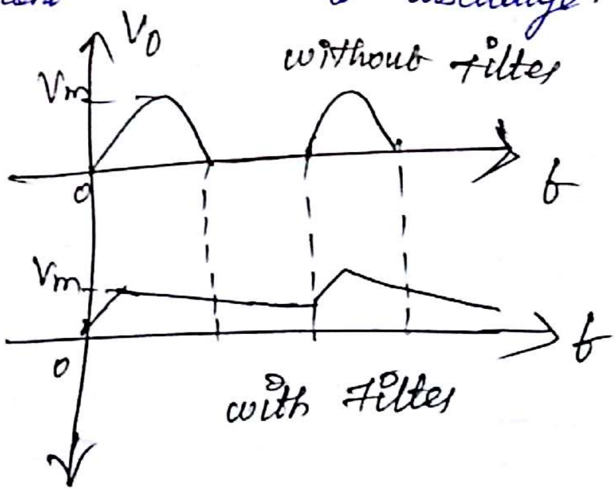
* It allows the capacitor to quickly charge up to the peak i/p voltage V_m because charging time constant is almost zero since there is no resistance in charging path except the diode forward resistance which is negligible.

* After fully charged. capacitor holds the charge till i/p ac supply to rectifier goes negative.

* During negative half cycle of Ac i/p diode is reverse biased, so the capacitor discharges through R_L.

* The discharging time constant $R_L C$ is very large, so the capacitor does not have sufficient time to discharge.

Fig:- Output waveforms of halfwave rectifier



Analysis:-

$$\text{Ripple Factor} = \frac{V_{r(rms)}}{V_{dc}}$$

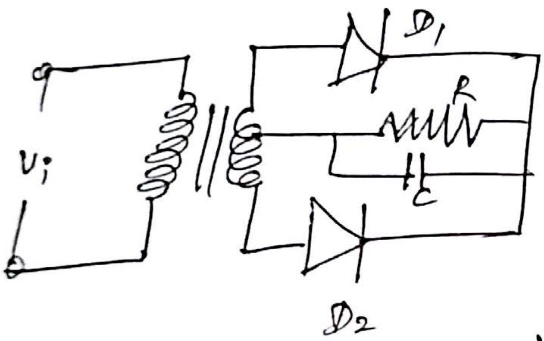
$$V_{r(P-P)} = \frac{Q}{C} = \frac{I_{dc} T_r}{C} = \frac{V_{dc}}{f_r C R_L}$$

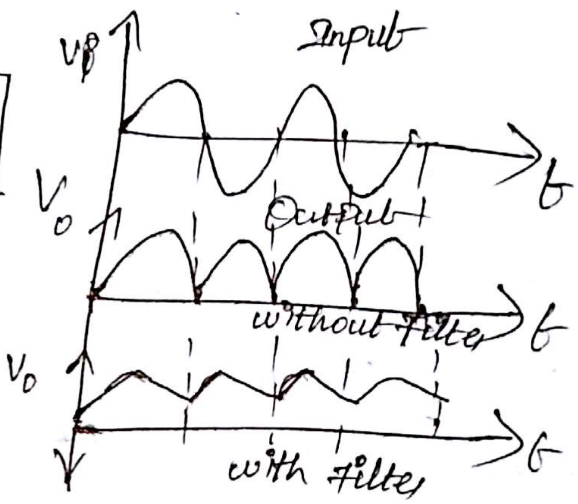
$$V_r(rms) = \frac{V_r(P-P)}{2\sqrt{3}} = \frac{V_{dc}}{2\sqrt{3} f_r C R_L}$$

$$\gamma = \frac{V_r(rms)}{V_{dc}} = \frac{V_{dc}}{2\sqrt{3} f_r C R_L} \propto \frac{1}{V_{dc}}$$

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

Full wave rectifier with capacitor filter:-





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

Comparison of rectifiers:-

	Halfwave	Full wave center-tapped	Full wave Bridge
no of diodes	1	2	4
PIV of diode	V_m	$2V_m$	V_m
D.C Output Voltage	$0.318V_m$	$0.636V_m$	$0.636V_m$
Ripple Factor	1.21	0.482	0.482
Ripple Frequency	$2f_{in}$	$2f_{in}$	$2f_{in}$
TUF	0.287	0.693	0.812

Clipper and clamper:-

* It is widely used in analog television receivers and FM transmitters.

* The variable frequency interference can be removed by using the clamping method in television receivers and FM transmitters.

* In FM transmitters, the noise peaks are limited to a specific value, above which the excessive peaks can be removed by using the clipping method.

Clipper circuit:-

An electronic circuit that used to avoid the output of circuit to go beyond the preset value without varying the remaining part of the input waveform.

Clamper circuit:-

An electronic circuit that is used to alter the positive peak (or) negative peak of the input signal to a definite value by shifting the entire signal up (or) down to obtain the output signal peaks at desired level.

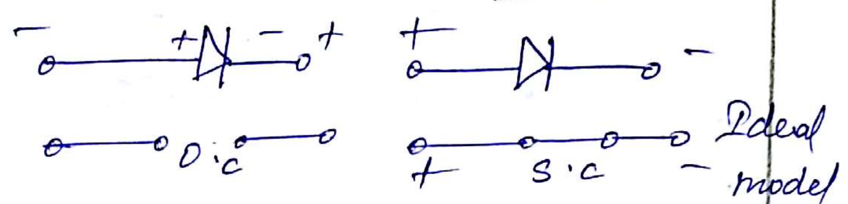
(*) Clipper circuit is designed by resistors, diodes (or) transistors (it don't have any energy storage element like capacitors)

Different types of clippers:-

1) Positive clipper
2) Negative clipper
3) Biased clipper
4) Combination clipper.

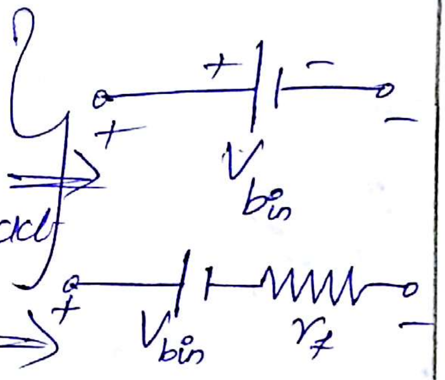
Positive clipper:-

Diode R.B   Diode F.B



V_{bin} ⇒ built in potential (or) voltage source

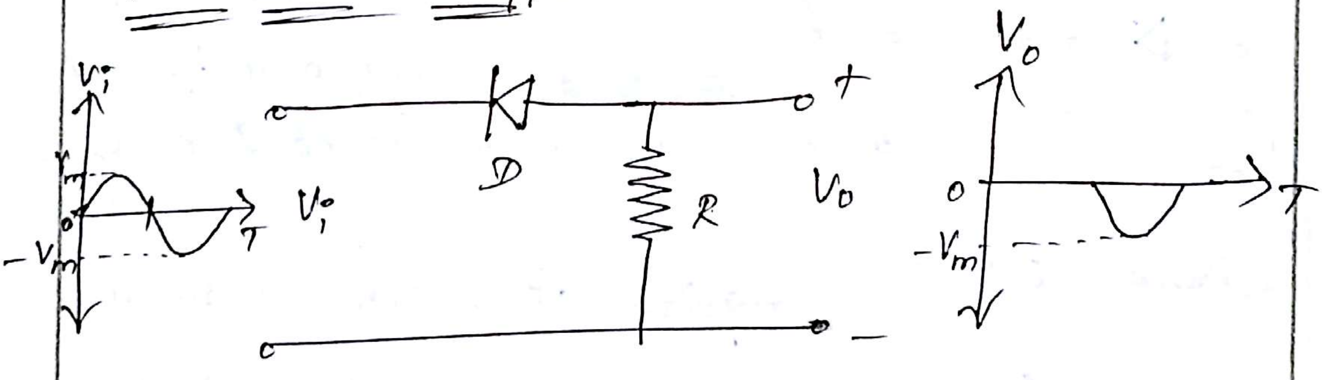
* In F.B, If diode replaced by built in potential that circuit is simplified equivalent ckt



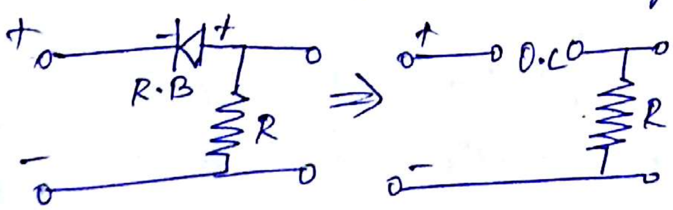
* Approximate equivalent ckt

* for Si $V_{bin} = 0.7V$

Positive Series clipper:-



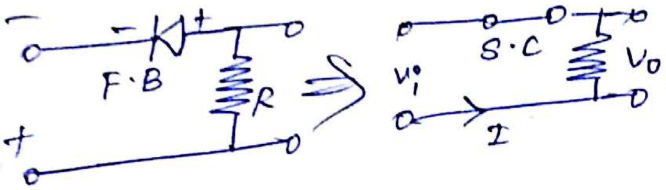
+ve half cycle of i/p Voltage ⇒ Diode Reverse Bias



⇒ replaced with open ckt
⇒ no current flow I = 0
⇒ o/p V = IR = 0

−ve half cycle ⇒ Diode Forward Bias

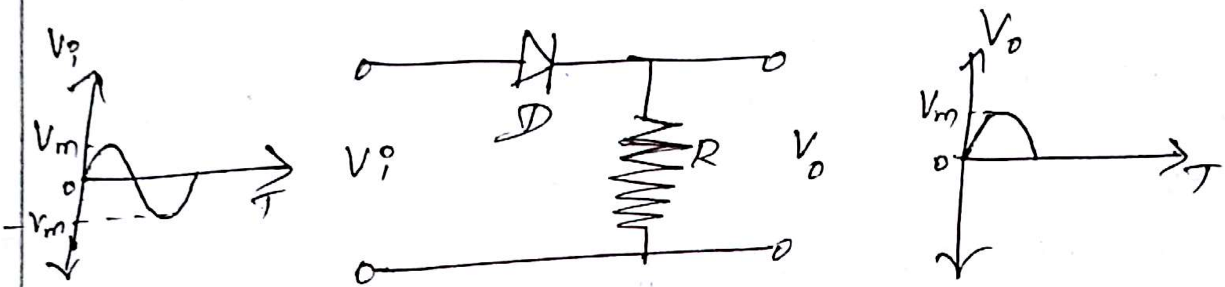
⇒ replaced by Short ckt



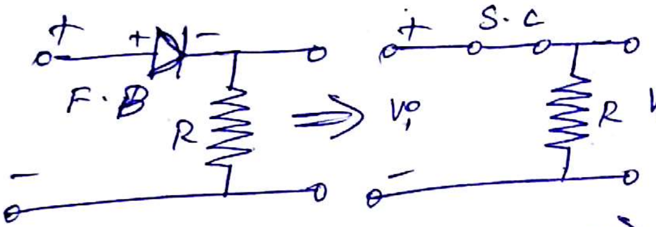
⇒ Current flow from +ve terminal to −ve terminal through R

⇒ o/p voltage $V_o = V_i$

Negative Series clipper:-

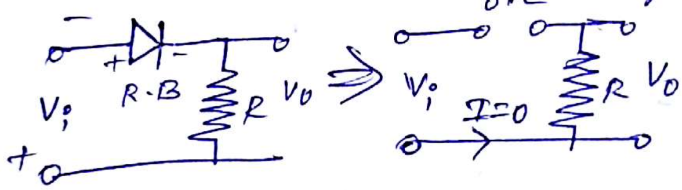


+ve half cycle ⇒ Diode Forward Bias, replaced by Short ckt, so current flow from +ve terminal to −ve terminal through RL



⇒ o/p voltage $V_o = V_i$

−ve half cycle of i/p voltage ⇒ Diode reverse bias



$V_o = IR = 0$ ⇒ replaced by open ckt ⇒ Current $I = 0$, $V_o = 0$

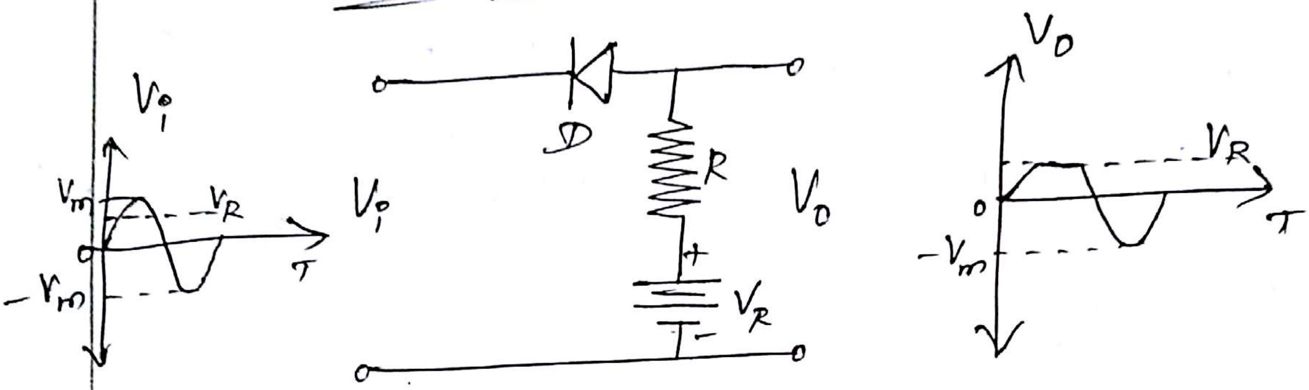
Biased clipper:- ⇒ required to remove a small portion from positive (or) negative half cycle of input voltage.

⇒ Biased Positive series clipper.

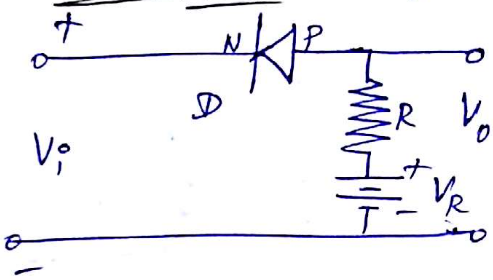
⇒ Biased Negative Series clipper.

Biased Positive Series clipper:-

+ve Series clipper with +ve Bias :-



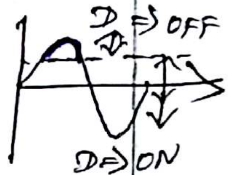
+ve half cycle :- ⇒ I/p voltage V_i try to keep the diode in R·B



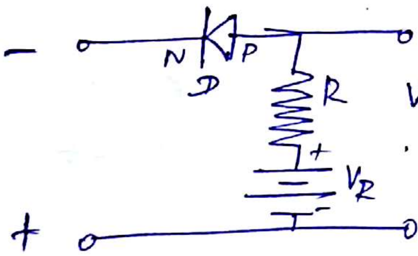
⇒ Ref voltage V_R try to diode in F·B

i) $V_i > V_R$ $V_o = 0 + V_R$

ii) $V_i < V_R$ $V_o = V_i$



-ve half cycle :-

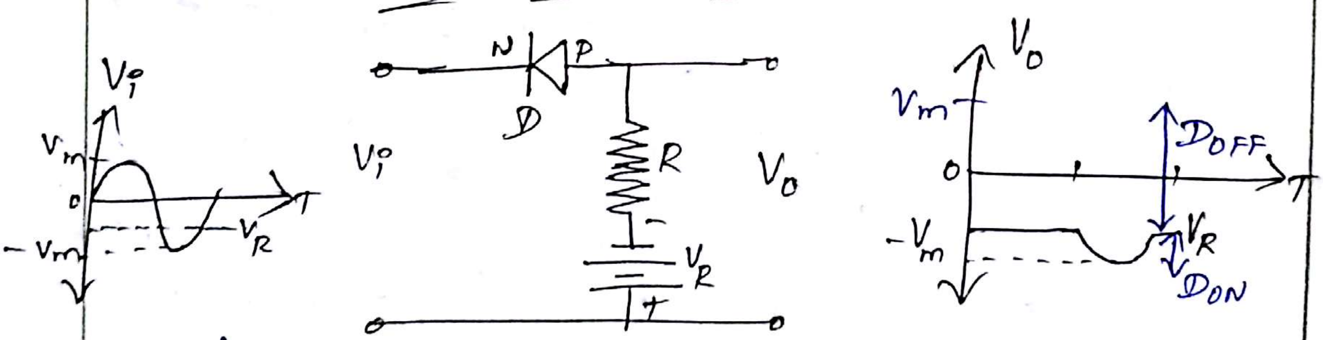


⇒ I/p V_i ⇒ Diode F·B

⇒ when V_R ⇒ Diode F·B.

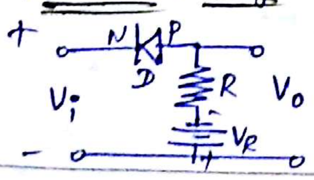
F·B· ⇒ $V_i < V_R$ ⇒ $V_o = V_i$

+ve Series clipper with -ve Bias :-



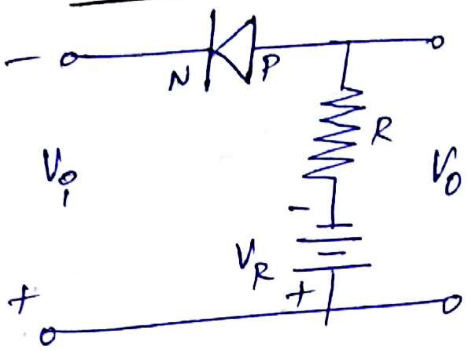
+ve half cycle ⇒ I/p V_i try to diode in R·B

When V_R " " " R·B



R·B ⇒ ckt will o·c· $V_o = -V_R$, Diode is off

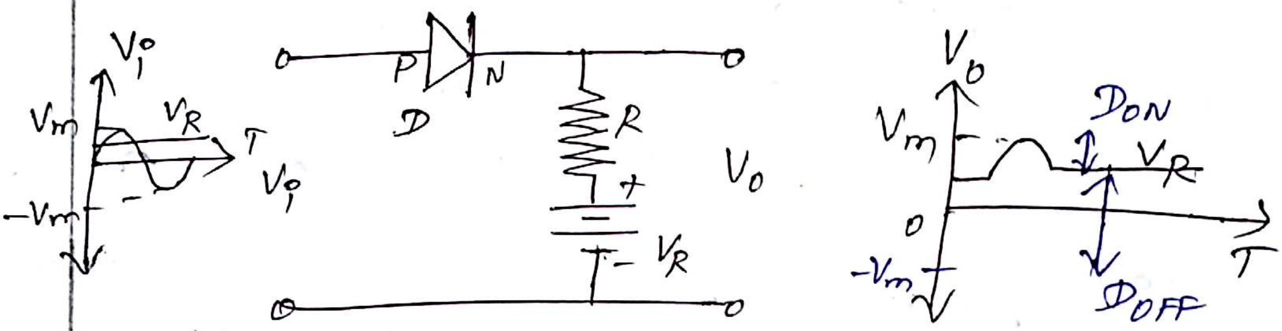
-ve half cycle ⇒ I/p V_i try to diode in F.B
⇒ Ref Volt V_R try to " " R.B



$V_i > V_R$ ∴ Diode ON,
$V_0 = V_i$
$V_i < V_R$ Diode OFF $V_0 = -V_R$

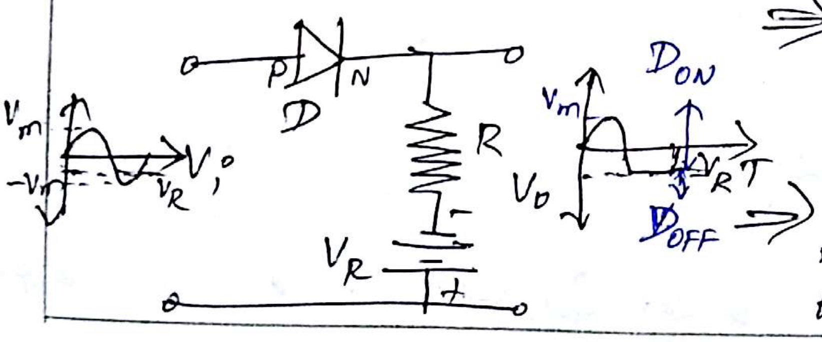
Biased Negative Series clipper:-

-ve Series clipper with +ve Bias :-



+ve half cycle
V_i ⇒ Diode in F.B ⇒ $V_i > V_R$ Diode ON $V_0 = V_i$
V_R ⇒ Diode in R.B ⇒ $V_i < V_R$ Diode OFF $V_0 = +V_R$
-ve half cycle
V_i ⇒ Diode in R.B }
V_R ⇒ Diode in R.B } $V_i < V_R$ Diode OFF $V_0 = +V_R$

-ve Series clipper with -ve Bias :-



⇒ +ve half cycle both
V_i & V_R try to keep
Diode in F.B $V_0 = V_i$
-ve half cycle.
V_i ⇒ Diode in R.B $V_i < V_R$
V_R ⇒ Diode in F.B $V_0 = +V_R$
$V_i > V_R$ ⇒ $V_0 = V_i$

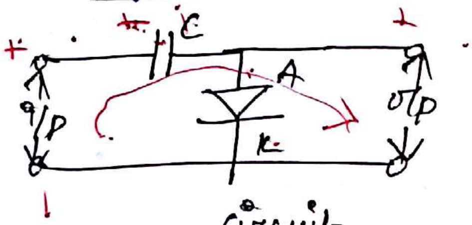
Different types of clamper circuit:-

* Shift the levels of Peaks of Signal by using a clamper, hence called as level shifter.

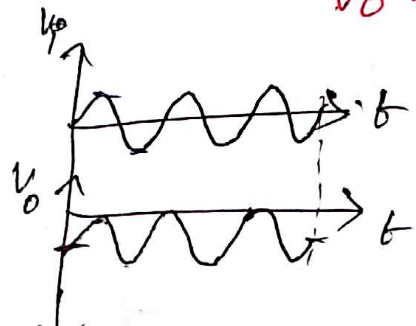
* clamper circuit consists of a capacitor and diode connected in Parallel across the load. So it depends on change in the time constant of the capacitor. $V_i - V_C - V_0 = 0$

$V_0 = V_i - V_C$

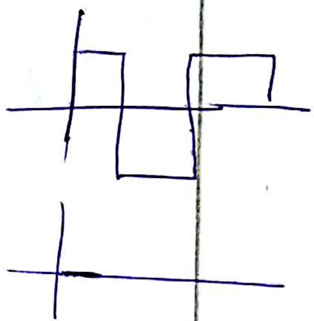
a) Negative Clamper:-



circuit



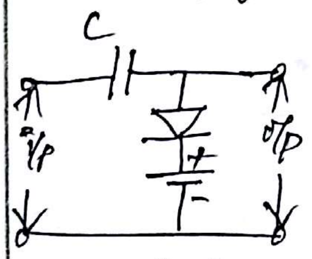
waveform



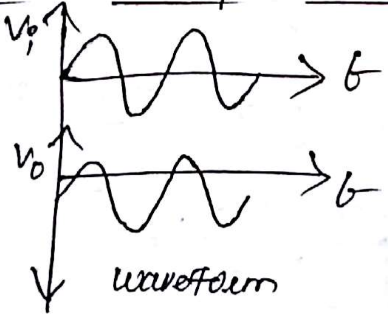
* During +ve half cycle, the i/p diode is in forward bias, and conducts – capacitors gets charged (upto Peak Value of i/p Supply).

* During –ve half cycle. Reverse – does not conduct and o/p Voltage becomes equal to Sum of i/p Voltage and Voltage stored across the capacitors.

Negative clamper with +ve Vr:-



Circuit

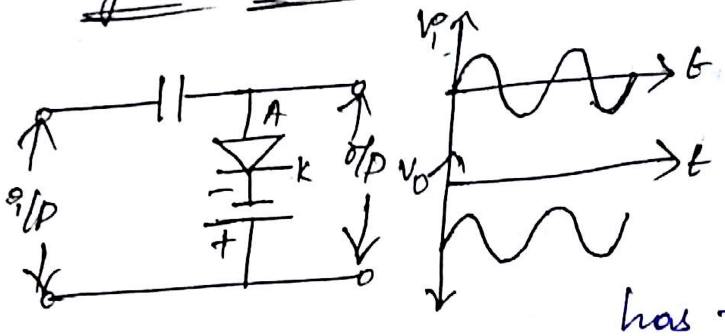


waveform

* Similar to negative clamper, but the o/p waveform is Shifted towards the +ve direction by a positive reference voltage.

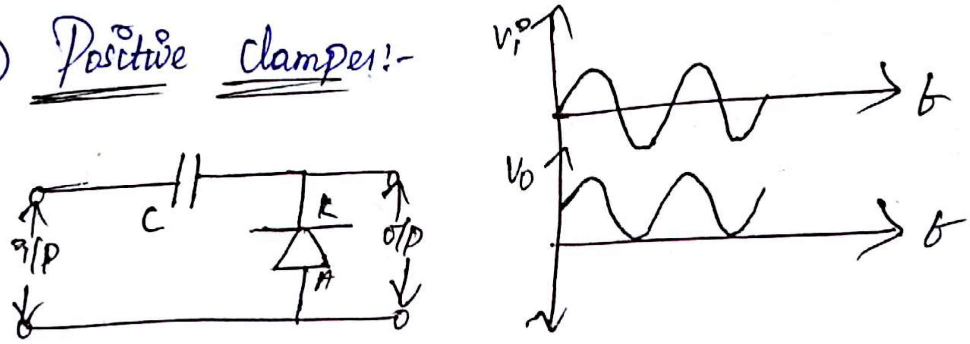
* During +ve half cycle, the diode conducts, o/p voltage becomes equal to reference voltage

Negative clamper with -ve V_r:-



* During the +ve half cycle, the diode conducts starts before zero, as the cathode has the -ve reference voltage which is less than that of zero and anode voltage.

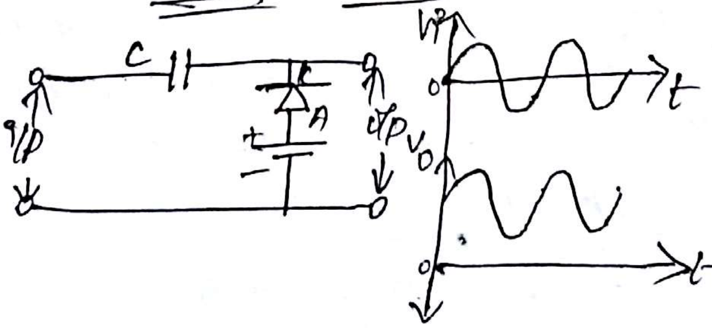
b) Positive clamper:-



* During +ve half cycle, the voltage across the output terminals becomes equal to sum of i/p voltage and capacitor voltage. (consider the capacitor as fully charged)

* During -ve half cycle of the i/p, the diode conducts and charges the capacitor rapidly to its peak value. Thus waveforms are clamped towards the +ve direction.

Positive clamper with +ve ety V_r:-

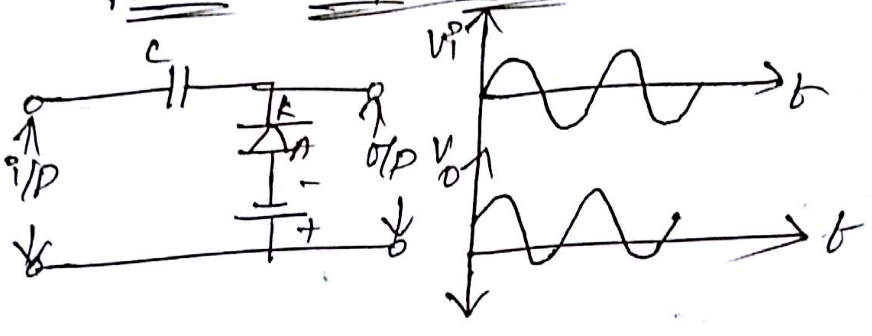


* During +ve half cycle the diode conducts, the supply voltage is less than anode +ve ref voltage.

* Once the cathode voltage is greater than anode voltage then the diode stops conduction.

* During negative half cycle, the diode conducts and charges the capacitor.

Positive clamper with -ve V_r :-



* During +ve half cycle the diode will be non conducting, the o/p is equal to capacitor voltage and i/p voltage.

* During -ve half cycle the diode starts conducting only after the cathode voltage becomes less than anode voltage.

Applications :-

⇒ clippers normally used in,

* Generation of new waveforms or shaping the existing waveform,

* Half wave rectifier in Power Supply kit is a typical example of a clipper.

* Excessive noise spikes above a certain level can be limited (or) clipped in FM transmitters by using the series clippers.

⇒ clampers normally used for. For,

* Removing the distortions.
* Improving the overdrive recovery time.
* Used as voltage doublers (or) Voltage multipliers.
* Used in test equipments, Sonar and radar etc.

Voltage multiplier:

* In Voltage multiplier circuit two (or) more peak rectifiers are cascaded to produce a d.c. voltage equal to multiplier of the peak input voltages V_p. ie) $2V_p$, $3V_p$, $4V_p$

* Voltage multiplier is a modified capacitor filter circuit that delivers a dc voltage twice (or) more times of the peak value of the input ac voltage. Such power supplies are used for high-voltage and low current devices such as cathode ray-tubes (Picture tubes in TV receivers, Osilloscopes and computer display)

* Voltage Doubler → Halfwave Voltage Doubler, Fullwave Voltage Doubler.
* Voltage Tripler & Quadrupler

Voltage Doubler:

Halfwave Voltage Doubler:

* During +ve half cycle, D_1 forward biased and conducts and then capacitor charges (C_1

upto peak values of secondary voltage $V_{S\,max}$ with the the polarity.

* During -ve half cycle, diode D_2 gets forward biased and conducts charging capacitor C_2

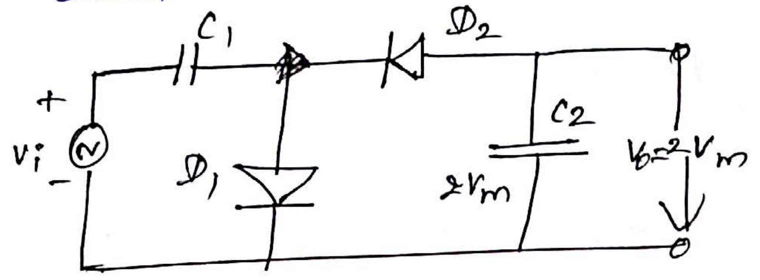


Fig:- Halfwave Voltage Doubler

* Voltage across the capacitor C_1 is in series with the input voltage ie) V_m, the total voltage presented to capacitor C_2 is equal to $2V_m$ during the negative half cycle.

* On the next +ve half cycle, the diode D_2 is non-conducting and capacitor will discharge through the load. If no load is connected across capacitor C_2 both capacitors stay charged at their full values.

Fullwave Doubler:-

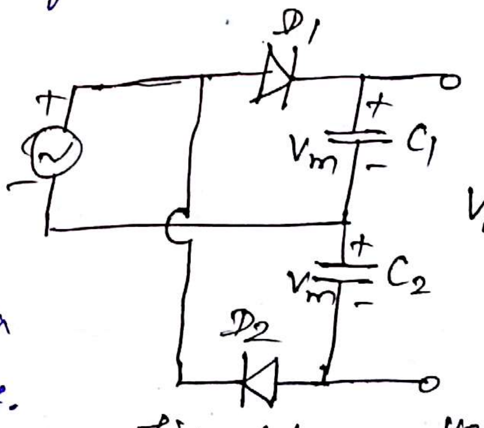


Fig:- Fullwave Voltage Doubler

* During +ve half cycle of a.c i/p voltage, the diode D_1 conducts charging capacitor C_1 to a peak voltage V_m & D_2 cut off.

* During -ve half cycle, Diode D_2 conducts charging the capacitor C_2 to V_m. If load is connected across the output then output voltage $= 2V_m$.

Voltage Tripler:-

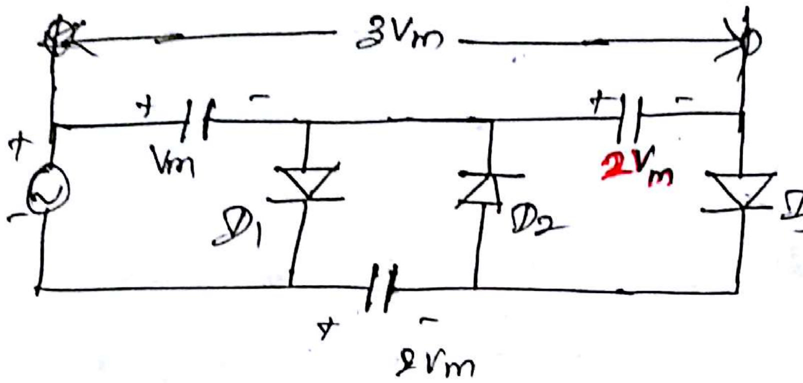


Fig:- Voltage Tripler circuit.

* During first +ve half cycle, the capacitor C_1 charges through Diode D_1 to Peak Voltage V_m.

* During -ve half cycle, capacitor C_2 charges through Diode D_2 to twice the Peak voltage $2V_m$. (ie) Sum of voltage across capacitor C_1 and i/p signal)

* During Second +ve half cycle, the diode D_3 conducts, voltage across C_2 Charges the capacitor C_3 to the Same $2V_m$ Peak Voltage.

* The triple Output taken across C_1 and C_3 connected in Series, the O/p voltage is 3 times the I/p Voltage.

Voltage Quadrupler:-

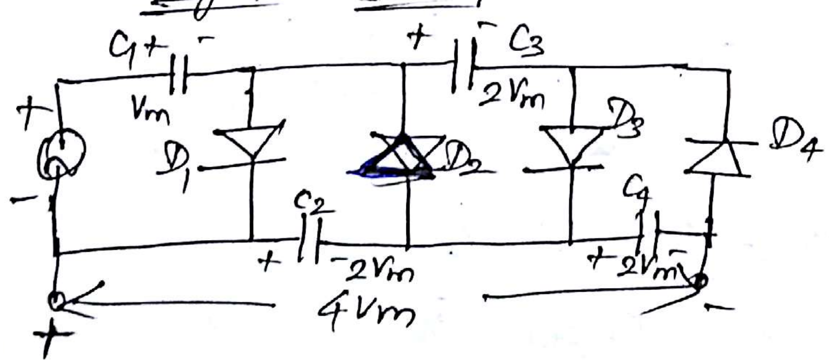


Fig:- Voltage Quadrupler Circuit

* C_1 charges to V_m through D_1, and C_2 charges through D_2, C_3 and C_4 charges through D_4,

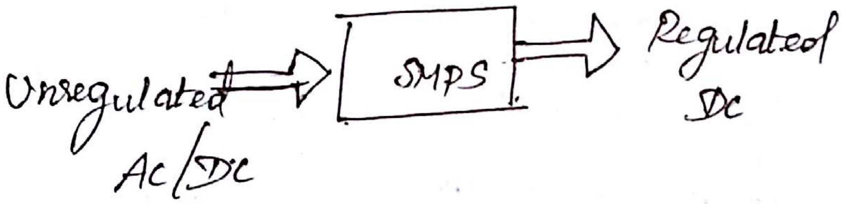
* C_2, C_3, C_4 charges upto $2V_m$.

The Output $4V_m$ is taken across C_2 & C_4

SMPS: (Switched mode Power Supply):-

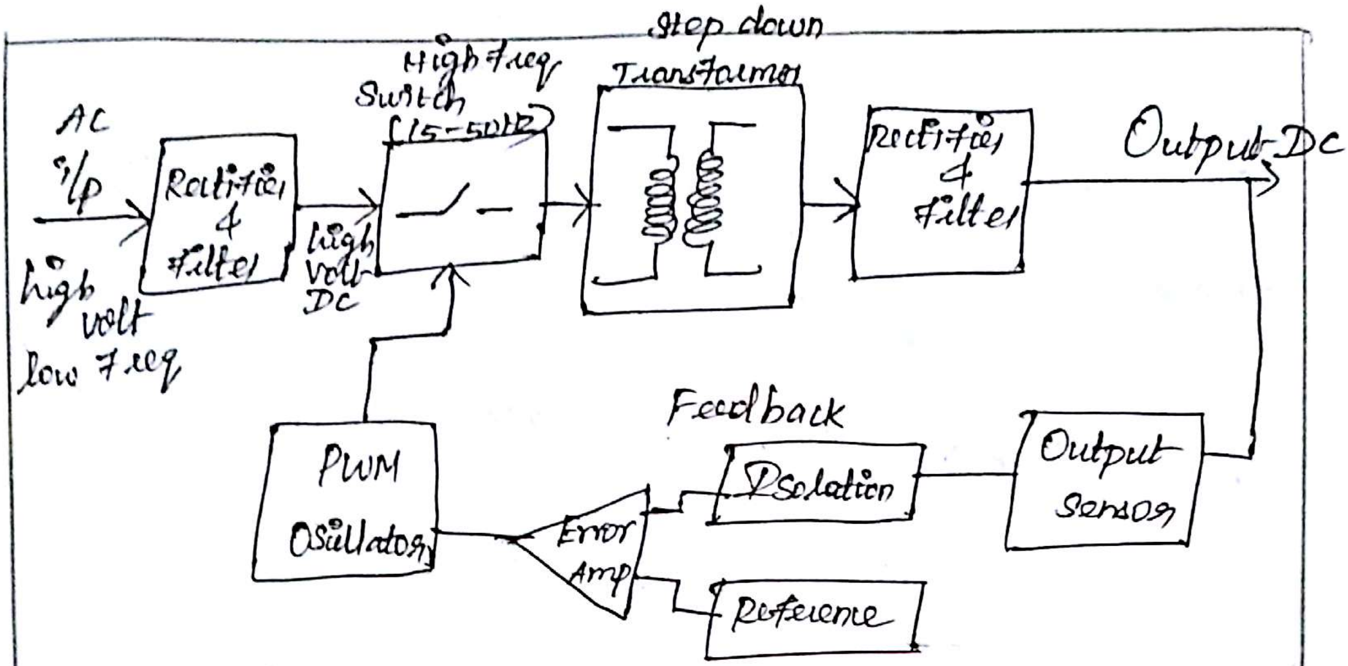
* Power Supply is integrated with the switching regulator for converting the electrical power efficiently from one form to another form with desired characteristics is called Switch-mode Power Supply.

* It is used to Obtain regulated DC Output voltage from unregulated AC or DC i/p voltage



* Linear Power supplies becomes Very bulky with increases in its current ratings. So we needed Something which will allow to handle large amount of currents without taking a lot of space

* SMPS is the best solution for this Problem, It works on very high frequency compared to that Linear PS, as size of transformer reduces with increase in frequency. [overall size of SMPS is small compared to LPS]



* SMPS has an AC input, It is converted into DC by rectification Process using a rectifier and filter.

* This unregulated DC voltage is fed into large filter capacitor for correction of Power Factor as it is affected

* High voltage DC Power is Switched at a Very high switching speed usually in the range of 15KHz to 50KHz. Switching action is controlled by feedback. circuit.

* It is fed into Step down transformer which have the characteristics of a transformer unit of 50 Hz.

* O/P of transformer is further fed into rectifier. This filtered and ratified Output DC power is used as a source for loads. and Sample of this Output power is used as a feedback

for controlling the Output voltage

* with this feedback the ON time of the Oscillator is controlled and closed loop regulator is formed.

* The Output of SMPS is regulated by using PWM (Pulse width modulation). The switch is driven by PWM osillator, such that the Power fed to the transformer is controlled indirectly

* This PW signal and Output Voltage are inversely Proportional to each other.

* If the duty cycle is 50% , then the maximum amount of Power is transferred through the step down transformer.

* Amount Power transferred will decreases by decreasing the Power dissipation.

* A Feedback circuit is used to control o/p voltage by comparing it with the reference Voltage.