24/6/16 Venkat sir

* **Electronics:** Electronics is a field of science and Engineering which deals with the Electronics devices and their utilisation.

(OR)

Electronics deals with the study of the movement of electrons under the influence of externally applied Electric field & magnetic field.

* **Electronic devices:** A device in which conduction takes place by movement of electrons through vaccum, gas & semi conductor

* **Circuit:** A set of components arranged in a systematic order is called "Circuit".

* **Applications of Electronics:**

1. In communication field

   Wired. Wireless

2. In defence

   Radar Guided missiles.

3. In medical

   → X-rays, ECG, SCAN, EG

4. In Instrumentation

(i) CRO → cathode ray oscilloscope.

(ii) DMM → Digital Multimeter.

(iii) Voltmeter

(iv) Powermeter.

5. For Industry

→ Robotics.

6. For Entertainment

→ Radio, TV.

Metric - prefix

10^{3} - Kilo - K

10^{6} - Mega - M

10^{9} - Giga - G

10^{12} - Tera - T

10^{15} - peta - P

10^{18} - Exa - E

10^{-3} - milli - m

10^{-6} - micro - μ

10^{-9} - Nano - n

10^{-12} - pica - p

10^{-15} - Femto - f

10^{-18} - atto - a

* Basic components

Electronic components

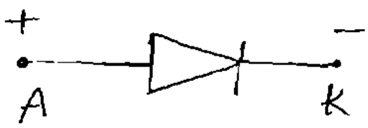
- Passive component (Static).
  - resistor
  - capacitor
  - Inductor
- Active component (Dynamic)
  - Semiconductor
  - Tube device
    - Vaccum Diode
    - Vaccum Triode
      - amplifier oscillator
    - Vaccum pentode (oscillator)

15/6/18

Semiconductor Devices

1. Junction Diode

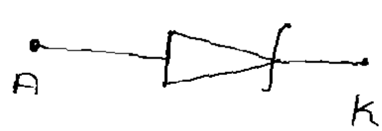
* Symbol :



* Applications: 1. Rectifier
2. Switching circuits.

2. Zerner Diode

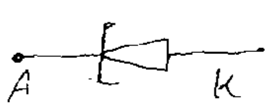
* Symbol:



* Applications: Voltage regulator (which maintain constant DC voltage).

3. Tunnel Diode

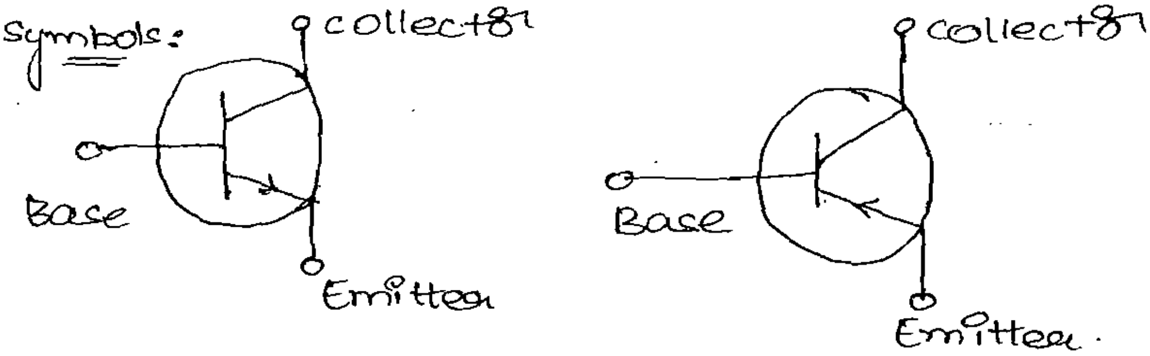
* Symbol :



* Applications : Oscillator (without any input it gives output)

4. BJT (Bipolar Junction Transistor).

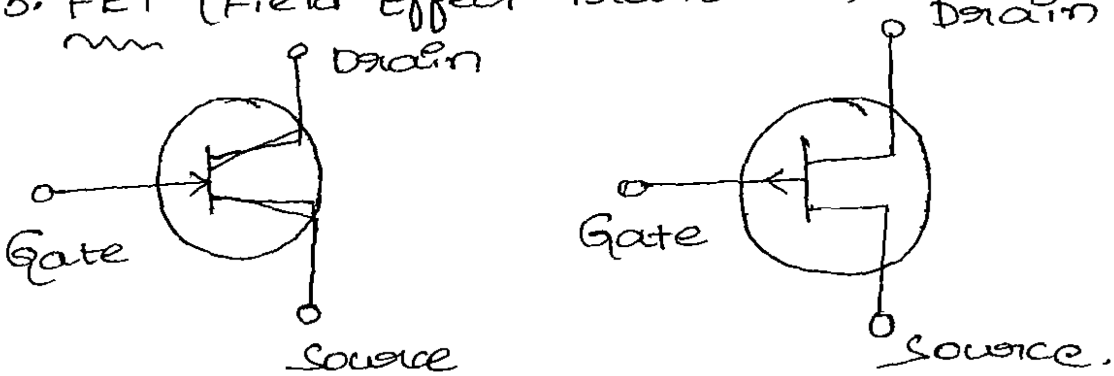
* Symbols:



NPN PNP

* Applications: Amplifier, oscillator.

5. FET (Field Effect Transistor).



* Applications: Amplifier, oscillator.

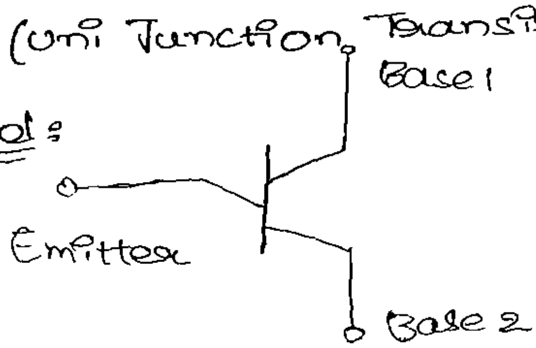
6. SCR (silicon controlled Rectifier).

* symbol:

* Applications: Speed control of motors.

7. UJT (Uni Junction Transistor).

* Symbol:



* Application: power control.

*Resistor

*Which resist the flow of Electrons.

(or)

*Flow of charge through any material Encounters an opposing force. This opposing force is called the resistance of the material.

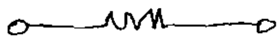
*the device of the component to do this is called resistor, It is measured in ohms(Ω).

Symbol: 
(R)

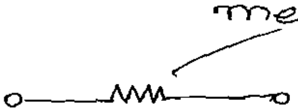
(i) Fixed resistor

(ii) Variable resistor

Fixed resistor: It has low voltage. It ranges from few ohms to 22mΩ.


R

Variable resistor: Variable resistor is also known as rheostart. In sometimes Electronic circuits is called potentiometer.

Symbol: 
R (or) 
(R)

*colour coading BB ROY GB VGW

Colour	Digit	Multiplier	Tolerance.
Black	0	10^0	–
Brown	1	10^1	–
Red	2	10^2	–
Orange	3	10^3	–

Yellow	4	10^4	-
Green	5	10^5	-
Blue	6	10^6	-
Violet	7	10^7	-
Gray	8	10^8	-
White	9	10^9	-
Gold	-	-	$\pm 5\%$
Silver	-	-	$\pm 10\%$
No colour	-	-	$\pm 20\%$

Eg 1: 1^{st} band - yellow

2^{nd} band - violet

3^{rd} band - orange - 47×10^3

$= 47$ kilo Ω

5% 47 kilo Ω

2) White, Black, Brown - $90 \times 10^1 = 900 \Omega$

3) Red

Orange

Orange $\rightarrow 23 \times 10^3 = 23$ kilo Ω

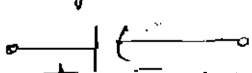
$= \pm 10\%$ 23 kilo Ω

$= 2300 \Omega$

Capacitor

It stores the Electrical Energy or Electrons. It is measured in faradays. It blocks the AC components.

DC $\rightarrow$ store



i) Fixed ii) capacitor

16/6/16 **Variable capacitor:** In some circuits such as tuning circuits it is desirable to able to change the value of capacitance. This is done by means of variable capacitor.

The most commonly used variable capacitor is Air-Gang capacitor.

capacitor consists of 2 parts seperated by a insulating material is known as di-Electric. According to the di-electric material the capacitor. They are.

1. Air capacitor
2. paper capacitor
3. mica capacitor.
4. seramic capacitor.
5. Electrolytic capacitor.
6. plastic film capacitor.

*Definition of capacitance: $C = \frac{Q}{V}$

Where Q = charge on the capacitor

V = applied voltage.

Reactance of the capacitor.

$$X_C = \frac{1}{\omega C} \Omega$$

Where $\omega = 2\pi f$

f = frequency.

Series capacitance

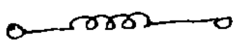
If two capacitors C_1 and C_2 are in series then the resultant capacitance is $\boxed{1/C = 1/C_1 + 1/C_2}$

parallel capacitance: $C = C_1 + C_2$

* **Current in a capacitor**

$$i_C = C \cdot \frac{dv}{dt}$$

Inductor: When a current flows through a wire that has been coiled it generates a magnetic field. This magnetic field react so as to oppose any change in the current. This reaction of magnetic field is known as Inductance. The Electronic component producing inductance is called "INDUCTOR".



Air core fixed.

Units are henry's

Inductor

- Fixed
- Variable.

* **Variable Inductor**

Air core variable.

Note: one of the most important property of inductor it opposes sudden changes in current.

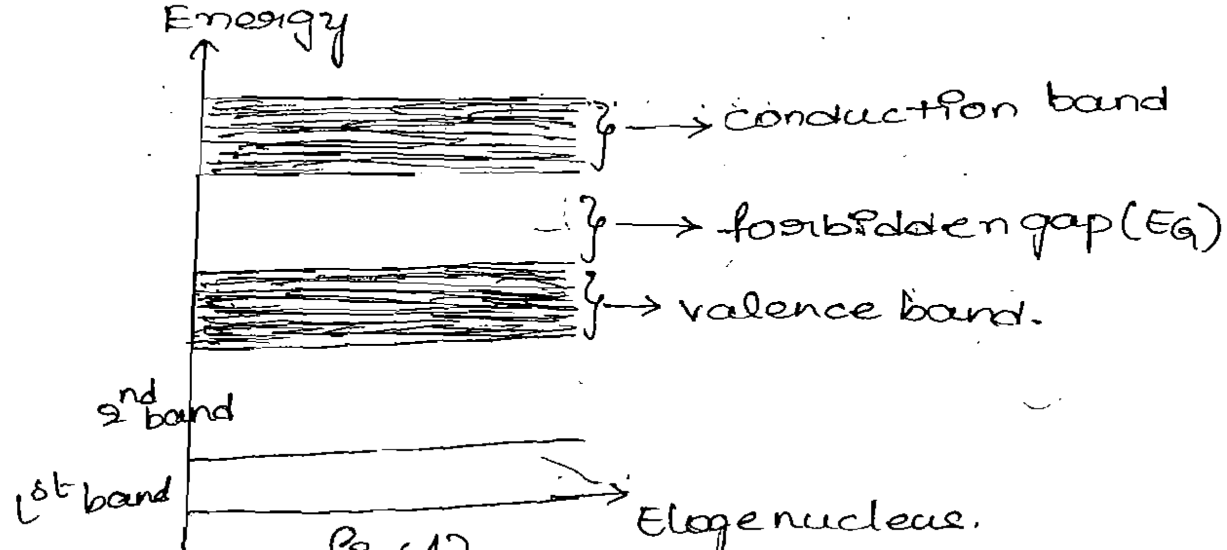
Inductive reactance: $X_L = \omega L \ \Omega$

$\omega = 2\pi f$

f = frequency.

$X_L = 2\pi f L \ \Omega$

17/6/2016 * Energy band diagram



fig(1)

The energy levels of electrons in each orbit merge into each other to form a energy band.

→ The energy levels of valency electrons merged to each other to form a valency band.

→ When a valency electrons absorbs energy it becomes free electron the energy levels of all the free electrons merg into each other to form a conduction band.

→ The energy difference b/w conduction band and VB is called forbidden gap energy denoted by EG.

→ The graphical representation of energy bands is called energy band diagram as shown in fig(a).

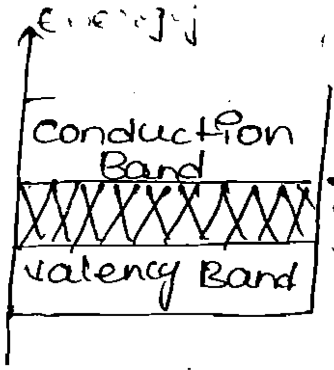
→ EG measured in the unit electron volt $\boxed{E_G \geq eV}$

Classification of material in the bases of electron conductivity

1. conductors.
2. Insulators
3. Semiconductor.

18/6/16 CONDUCTORS

Def: A metal which is very good carrier of electricity is called conductor



There is no Energy gap.

No forbidden gap overlapping of valence band & conduction band.

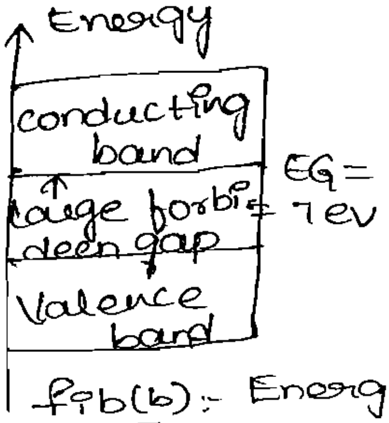
fig(a):- Energy band diagram of conductor.

→ In conductor large no. of free Electrons exists at normal room temparature so Energy gap E_G does not Exist. The valency band conduction band are overlapped. This is shown in fig(a).

Ex:- copper, Al, silica etc.

*INSULATOR

Def:- A very poor conductor of Electricity is called "Insulator".



fib(b):- Energy Band diagram of Insulator.

→ In Insulator the Energy gap E_G is very high about seven Electron volt ie $\boxed{E_G \simeq 7ev}$ at very high voltage or temparature also the Electrons cannot move from valency band to conduction band. This is shown in fig (b).

Ex:- Wood, Mica, paper etc.

* Semiconductors

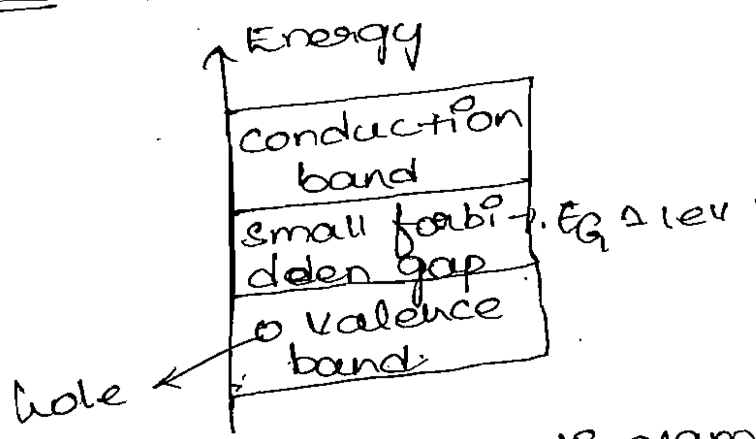


fig (c):- Energy band diagram of semiconductor

→ A metal having conductivity level some where b/w the extremes of an Insulator and conductor ie is semiconductors.

→ At 0°K the semiconductor materials behaves like perfect Insulator. At room temparature they acts as Insulator.

→ As the temparature increases it acts as a good conductor.

→ In case of semiconductors Energy band gap depends on the temparature

→ For Germanium (Ge) Energy gap (E_G)

$E_G \simeq 0.78ev$

For silicon $E_G \simeq 1.21ev$

For Galium Asimate (GaAs) $E_G = 1.41ev$

These are at 0°K.

* Classification of semiconductor

1. Intrinsic semiconductor.
2. Extrinsic semiconductor.

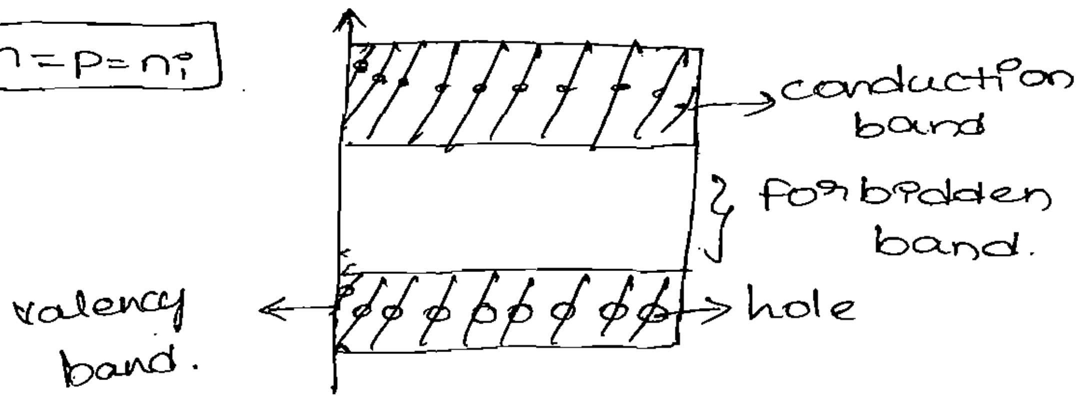
* Intrinsic Semiconductor

→ Pure semiconductors are called Intrinsic semi-conductors.

→ The absence of an Electron in valency band is represented by a small circle called "hole".

→ Intrinsic Semiconductors have equal concentration of Electrons and holes under the conditions of thermal equilibrium.

$\boxed{n = p = n_i}$



Extrinsic Semiconductor

In order to change the properties of intrinsic semiconductor a small amount of some other material is added to it. This process of adding other material to the crystal of intrinsic material to improve its conductivity is called doping. Doped semiconductor material is called Extrinsic Semiconductor

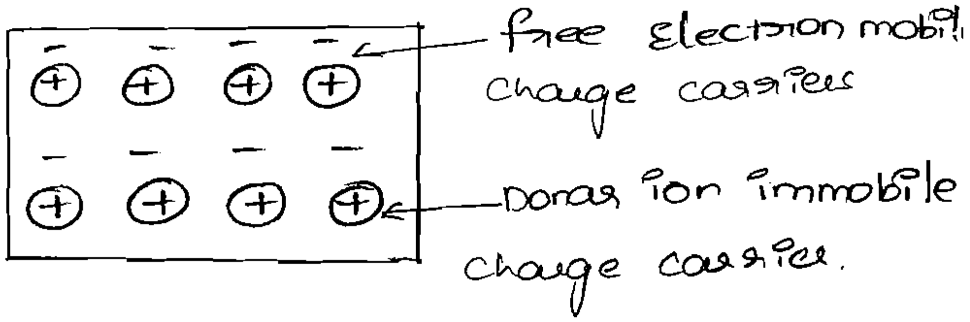
→ There are basically 2 types of impurities.

1. Pentavalent impurity./D/n-type imp
2. Trivalent impurity./A/P.

N-type

When small amount of pentavalent impurity is added to the pure semiconductor is called N-type semiconductor.

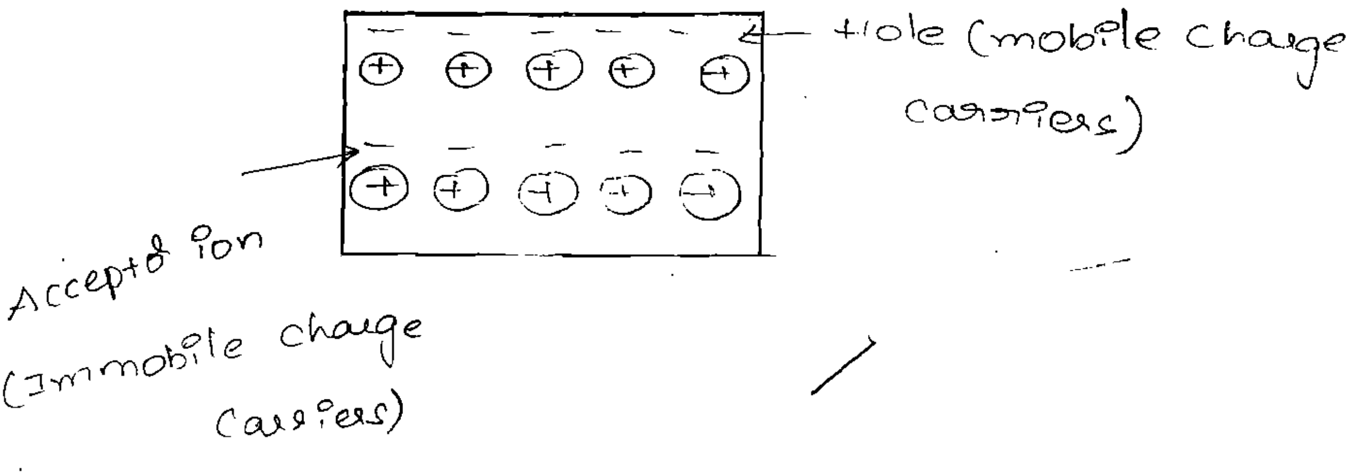
In N-type semiconductor majority charge carriers are electrons minority charge carriers are hole



P-type Semiconductor

When small amount of trivalent impurity is added to pure semiconductor is called P-type semiconductor.

* In P-type semiconductor majority charge carriers are holes and minority charge carriers are Electrons.



Table

* Comparision b/w Conductor, Semiconductor and Insulator.

Conductor	Semiconductor	Insulator.
A metal which is a good carrier of Electricity is called "conductor."	A metal having conductivity level b/w the Extremes of an insulator and conductor is known as "S.C."	poor conductor of Electricity is known as "Insulator."
It has "1" valency Electrons in its outermost orbit.	It has "4" valency Electrons in its outermost orbit.	It has "8" valency Electrons in its outermost orbit.
Resistance is very small.	Resistance is high	Resitance is very high
Conductivity is high.	conductivity is medium.	conductivity is Low. (negligible).
As Temparature increases resistance increases and it is +ve ~~pass~~ through Tempar coefficient	As Temp increases its resistance is decreases and it is negative Temparature coefficient.	Negative temparature coefficient.
Ex: metal, copper, Al, Ag etc.	Examples: Silicon, Germanium GaAs Etc.	Examples: Wood, plastic, Rubber, mica etc.
conductors are formed by metallic bonding.	S.C are formed by covalent bonding.	Insulators are formed by Ionic bonding.

* Mobility of Semiconductors

(8)

When some Electric field applied across through a material of Electrons with avarage velocity is called Drift velocity. respond by moving

$$V_d = \mu \times E$$

E = Electric field

$$\mu = \frac{V_d}{E}, \quad n_i = p = n.$$

→ The conductivity is proportional to the free electron. of material

→ In s.c the free Electrons lies b/w 10^7 & 10^{28} e/m^3

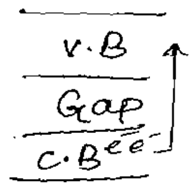
→ S.c acts as Insulator when V.B having Electrons and C.B is Empty. When we increase temparature Some of $\bar{e}$ greater the V.B aquires of thermal energy then $> G.E$ the $\bar{e}$ directly goes to the C.B.

$$J_n = n.\mu_n.q.E = \sigma_n E \text{ (conductivity of Electron)}$$

μ_n = Mobility of Electrons.

q = Charge of electron

E = Electric field.



The valency band it looses $\bar{e}$ and having holes (o).

$$J_p = P.\mu_p.q.E.$$

* The mobility of electron is defined as ratio of drift velocity to Electric field. i.e.) $\boxed{\mu = \frac{V_d}{E}}$

→ The current density due to the motion of the Electrons is given by

$$J_n = n\mu_n qE = \sigma_n E \rightarrow (1)$$

where μ_n = Mobility of Electrons

n = no. of Electrons per unit volume

E = Electric field.

q = charge of Electrons

→ The absence of electrons in valency band is represented by a small circle and is called "a hole".

→ The hole may serve as a carrier of Electricity whose effectiveness is comparable with the free Electrons.

→ The hole conduction current density is given by $J_p = p \cdot \mu_p \cdot q \cdot E = \sigma_p E$

where μ_p = hole mobility

p = no. of holes per unit volume

→ Hence the total current density J in a s.c is

$$J = (n\mu_n + p\mu_p) \cdot qE$$

$$= \sigma E.$$

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

→ For pure semi conductors the no. of free Electrons is equal to the no. of holes.

$\therefore n_i = p = n$.

→ Thus the total current density is $J = n_i(\mu_n + \mu_p) \cdot qE$

$$\boxed{J = n_i(\mu_n + \mu_p)qE}$$

Where $n = p = n_i$,

→ In the Intrinsic concentration of a s.c

* conductivity of a semiconductor

→ In pure sc the no. of holes is equal to the no. of Electrons.

→ Due to thermal agitation continueous to produ new Electron - hole pairs and the Electron. hole pair is created to charge carring particles a formed.

→ One is negative which is free Electron with mobility μ_n and the another one is positive ie the hole with mobility μ_p.

→ The Electrons and holes moving in opposite directions in an Electric field E but since they are opposite sign.

→ The current due to Each is the same direction.

→ Hence the total current density J with in the intrinsic semiconductor is given by

$$\boxed{J = J_n + J_p}$$

$$J = n(\mu_n) qE + p \cdot \mu_p \cdot qE$$

$$= qE\,(n\mu_n + p\mu_p)$$

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

$$= \sigma E \rightarrow (1)$$

Where J_n = Electron drift current density

J_p = hole drift current density.

→ Hence "σ" is the conductivity of a semi conductor which is equal to

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

→ The resistivity (ρ) of semiconductor is the resiprocal of the conductivity ie $\boxed{\rho = \frac{1}{\sigma}}$

→ for pure intrinsic s.c ie $n = p = n_i$ ie

$$J = n_i(\mu_n + \mu_p) q E.$$

→ The conductivity of Intrinsic s.c is

$$\sigma_i = q \cdot n_i \cdot (\mu_n + \mu_p)$$

→ Hence it is a clear the conductivity of an intrinsic s.c depends upon its intrinsic concentration (n_i) and mobility of Electron & holes.

→ conductivity of n and p type s.c

→ The conductivity of an intrinsic s.c

$$\sigma_i = q\, n_i (\mu_n + \mu_p)$$

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

→ for n-type semiconductors as $n >> p$ then the conductivity $\boxed{\sigma = q \cdot n \cdot \mu_n}$

→ For p-type s.c as $p >> n$ then the conductivity

$$\sigma = q \cdot n \cdot \mu$$

Problems

1. The mobility of free electrons and holes in pure germanium are 3800 and 1800 $cm^2/V\text{-}s$ the corresponding values for pure silicon are 1300 and 500 $cm^2/V\text{-}s$ respectively. Determine the values of intrinsic conductivity for both germanium and silicon. Assume intrinsic concentration $(n_i) = 2.5 \times 10^{13} cm^{-3}$ for Ge and $n_i = 1.5 \times 10^{10} cm^{-3}$ for Si.

Ans: The intrinsic conductivity for Ge $= q n_i(\mu_n + \mu_p)$

$$q = 1.602 \times 10^{-19} \text{ columobs}$$

$$= 1.602 \times 10^{-19} \times 2.5 \times 10^{13} cm^{-3} (3800 + 1800) = q$$

$$= 0.0224 \text{ siemens}/cm^2$$

The intrinsic conductivity for $si = q n_i(\mu_n + \mu_p)$

$$= 1.602 \times 10^{-19} \times 1.5 \times 10^{13} (1300 + 500) \quad p\text{-holes}$$

$$= 4.325 \times 10^{-6} \text{ Siemens}/cm^2$$

* Drift current and Diffusion current

The flow of charge ie current through a SC material are 2 types namely

1. Drift (current)
2. Diffusion (current).

The net current flows through a p-n junction diode also has a 2 components

1. Drift current
2. Diffusion current

Drift current (****)

* When an External Electricfield is applied across the semiconductor material the charge carriers attain certain drift velocity v_d which is equal to the product of mobility of charge carriers and applied Electricfield intensity 'E' ($v_d = \mu \times E$).

* The holes moves towards the -ve terminal of the battery and electrons move towards the +ve terminal of the battery and the combined effect of movement of charge carriers constitutes a current known as "Drift current".

(or)

* The "Drift current" is defined as the flow of electric current due to the motion of the charge carriers under the influence of an External electric field.

The Equation for the drift current density (J_n) due to the free Electrons is given by

$$J_n = n \cdot q \cdot \mu_n \cdot E \ A/cm^2$$

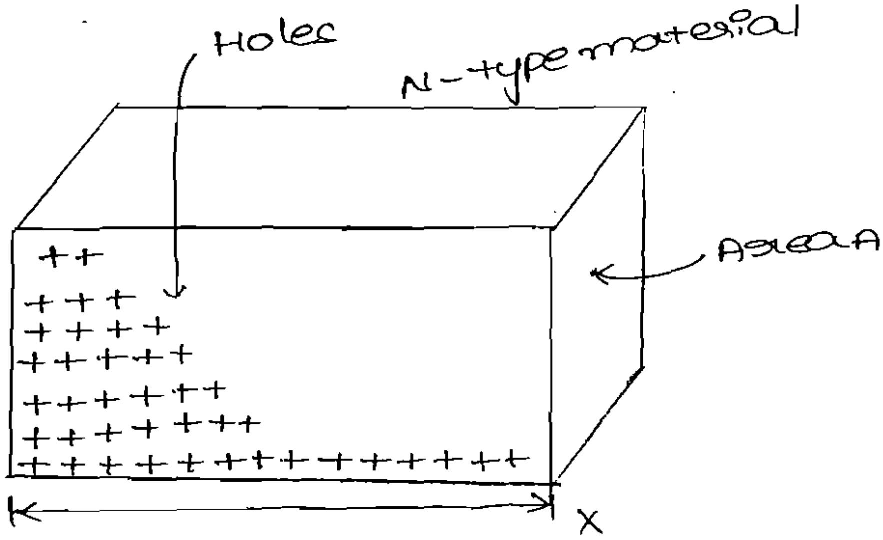
* The eqn for the drift current density (J_p) due to the free Electrons is given by

$$J_p = p \cdot q \cdot \mu_p \cdot E \ A/cm^2$$

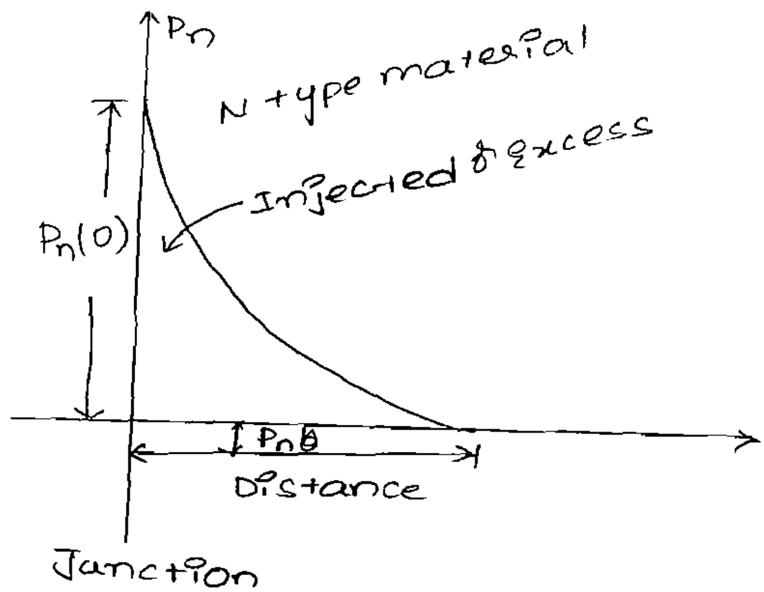
Diffusion current (****)

* It is possible for an Electric current to flow in a SC even in the abscence of applied voltage provided concentration gradient exists in the given material.

* A concentration gradient exists if the no. of either electrons & holes is grater in one reagion of semi conductor as compared to the rest of the region.



fig(a) Excess hole concentration.



fib(b) Resulting Diffusion current concentration

* A shown in fig(a) the hole concentration p(x) in a semiconductor bar varies from high value to low values
* Along the x-axis and is constant in y and z directions
* Diffusion current density due holes Jp is given by

$$J_p = -q\, D_p \frac{dp}{dx}\ A/cm^2$$

* Since hole density p(x) decrease with increasing x

As shown in fig (b) ie $\frac{dp}{dx}$ is negative (-ve).

* Diffusion current density due to the free Electron J_n is given by

$$J_n = q\, D_n \frac{dn}{dx} \; A/cm^2$$

Where $\frac{dp}{dx}$ and $\frac{dn}{dx}$ concentration gradient for Electrons and holes.

* Total Current

* the total current in a SC is the sum of drift and diffusion currents.

* therefore, for a p-type semiconductor the total current per unit area ie the total current density is given by

Drift current for p-type

$$J_p = p.q.\mu_p.E.$$

Diffusion current $J_p = -q \frac{dp}{dx} . D_p \; A/cm^2$

$$\therefore J_p = q\left(\mu_p p.E - D_p \frac{dp}{dx}\right)$$

For n-type SC the total current per unit area ie total current density is given by

Drift current $J_n = n.q.\mu_n.E$

$$J_p = -q\, D_n \frac{dn}{dx} \; A/cm^2$$

$$\therefore J_n = q\left(\mu_n n.E - D_n \frac{dn}{dx}\right)$$

*Charge densities in semiconductor

Under thermal equilibrium for any semiconductor the product of no. of holes and electrons is constant and is independent of the amount of donor and acceptor impurity doping. This relation is known as mass action law and is given by

$$\boxed{n \cdot p = n_i^2}$$

where n is no. of electrons per unit volume

p = no. of holes per unit volume

n_i = intrinsic conc. of S.C.

Charge densities in n-type and p-type semiconductor

Let ND be the law of mass action as given the relationship between free electron concentration and hole concentration.

⊕ → donor
⊖ → acceptor

→ Let N_D be the concentration of donor atoms in n-type semiconductor in order to maintain electric neutrality of the crystal we have

$$n_N = N_D + P_N$$

$$\boxed{n_N \approx N_D}$$

Where n_N and P_N are the electron hole concentration of n-type s.c.

The value of P_N is obtained from the relation of mass action law has

$$\boxed{P_N = \frac{n_i^2}{N_D}} \qquad \boxed{P_N = \frac{n_i^2}{n_N}}$$

→ which << n_N or N_D

milarly, p-type semiconductor we have

$P_p = N_A + n_p$

$\boxed{P_p \simeq N_A}$

Where N_A, P_p and n_p are the concentration of acceptor impurities, holes and electrons respectively in p-type s.c.

→ from mass action law,

$$\boxed{n_p = \frac{n_i^2}{P_p}}$$

$$\boxed{n_p = \frac{n_i^2}{N_A}}$$ Which << P_p & N_A.

Extrinsic conductivity (siemens/cm²) units

The conductivity of n-type s.c is given by

$\sigma_N = q \cdot n_N \mu_n = q N_D \cdot \mu_n$; Since $\boxed{n_N \simeq N_D}$

The conductivity of p-type s.c is given by

$\sigma_p = q \cdot P_p \mu_p = q \cdot N_A \cdot \mu_p$, since $\boxed{P_p \simeq N_A}$

The doping intrinsic s.c consider by α increases its conductivity.

Problems

Find the conductivity of silicon

1) In Intrinsic condition at room temperature of 300K

With donor impurity of 1 in 10^8.

Acceptor Impurity of 1 in 5×10^7.

With both the above impurities present simultaneously.

given that n_i for Si at 300K is 1.5×10^{10} cm^{-3}, $\mu_n = 1300$ cm²/V.s

$\mu_p = 500 cm^2/v\text{-}s$, no. of silicon atoms $/cm^3 = 5 \times 10^{22}$. (13)

1)a) $\sigma_i = q \cdot n_i (\mu_n + \mu_p)$

$= 1.67 \times 10^{-19} \times 1.5 \times 10^{10} (1300 + 500)$

$= 4.3254 \times 10^{-6} S\ cm$

(b) Number of silicon atoms

$= 5 \times 10^{22}$

$N_D = \frac{5 \times 10^{22}}{10^8} = 5 \times 10^{14} cm^{-3}$

$n \simeq N_D$

$P = \frac{n_i^2}{n} = \frac{n_i^2}{N_D} = \frac{(1.5 \times 10^{10})^2}{5 \times 10^{14}} = \frac{(1.5)^2 \times 10^{20}}{5 \times 10^{14}}$

$= 0.46 \times 10^6 cm^{-3}$

$P << n$ Hence p may be neglected. calculating conductivity

$\sigma = nq\mu_n$

$= N_D \cdot q \cdot \mu_n$

$= (5 \times 10^{14})(1.602 \times 10^{-19})(1300)$

$= 0.104\ S/cm$

(c) $N_A = \frac{5 \times 10^{22}}{5 \times 10^7}$

$= 10^{15} cm^{-3}$

further $P = N_A$

$n = \frac{n_i^2}{P} = \frac{n_i^2}{N_A}$

$= \frac{(1.5 \times 10^{10})^2}{10^{15}}$

$= 2.25 \times 10^5 cm^{-3}$

$P >> n$, n may be neglected

$\sigma = P \cdot q \cdot \mu_p = N_A \cdot q \cdot \mu_p$

$= (10^{15} \times 1.602 \times 10^{-19} \times 500)$

$= 0.08\ S/cm$

(d) $N_A' = N_A - N_D = 10^{15} - 5 \times 10^{14}$

$= 5 \times 10^{14} cm^{-3}$

$\sigma = N_A' \cdot q \cdot \mu_p$

$= (5 \times 10^{14})(1.602 \times 10^{-19}) 500$

$= 0.04\ S/cm$.

2) A sample of silicon at given temp in intrinsic S.C as a resistivity of $25 \times 10^4 \Omega/cm$ (Ω-cm). The sample is now doped to the extent of 4×10^{10} donar atoms/cm^3 and 10^{10} acceptor atoms/cm3. Find the total conduction current density if an Electric field of 4v/cm is applied across the sample given that mobility of Electrons (μ_n) = 1250 cm^2/v-s and Mobility of holes (μ_p) = 475 cm^2/v-s at the given temparature.

$$\sigma_i = q \cdot n_i (\mu_n + \mu_p)$$

$$= \frac{1}{25 \times 10^4}$$

$$\therefore n_i = \frac{\sigma_i}{q(\mu_n + \mu_p)}$$

$$= \frac{1}{(25 \times 10^4)(1.602 \times 10^{-19})(1250 + 4750)}$$

$$= 1.45 \times 10^{10} cm^{-3}$$

Net donor density $N_D = n$

$$= 4 \times 10^{10} - 10^{10} = 3 \times 10^{10} cm^{-3}$$

$$P = \frac{n_i^2}{N_D} = \frac{(1.45 \times 10^{10})^2}{3 \times 10^{10}} = 0.7 \times 10^{10} cm^{-3}$$

$$\sigma = q(n\mu_n + P\mu_p)$$

$$= (1.602 \times 10^{-19})(3 \times 10^{10} \times 1250 + 0.7 \times 10^{10} \times 475)$$

$$= 6.532 \times 10^{-6} S/cm$$

$\therefore$ Total conduction current density,

$$J = \sigma E$$

$$= 6.532 \times 10^{-6} \times 4$$

$$= 26.128 \times 10^{-6} A/cm^2$$

The current entering the volume at x is I and leaving at x+dx is I+dI, The no.of columbs/sec. (14)

(i) Decreases with in the volume = dI → (1)

→ Decredue to the recombination, no of columbs/ decreases with in the volume is given by

$$= (\text{charge on hole}) \times \left(\begin{array}{c}\text{holes/sec}\\ \text{per unit volume}\end{array}\right) \times (\text{volume})$$

$$= q \times P/\tau_p \times Adx = q\,Adx\,\frac{P}{\tau_p} \longrightarrow (2)$$

Let "g" is the rate at which Electron hole pair are generated by thermal generation per unit volume.

→ Due to this no.of columbs/sec increases with in the volume = (Charge on hole) x (Rate of combination) x (Volume)

$$= q \times g \times Adx = qg\,Adx \longrightarrow (3)$$

→ The total charge in no.of columbs/see is because of 3 factors as indicated by the equations 1,2,3.

→ The total charge in holes/unit volume per sec is $\frac{dP}{dt}$. Hence the total charge in columbs/sec with in the given volume = $q \cdot \frac{dp}{dt}$ (volume)

$$= q \cdot Adx \cdot \frac{dP}{dt} \longrightarrow (4)$$

→ According to Law of conservation of charges

$$q \cdot Adx\,\frac{dp}{dt} = qg\,Adx - q\,Adx\,\frac{P}{\tau_p} - dI \longrightarrow (5)$$

Note: the -ve sign indicate decrease while +ve indicates increase in no.of columbs/sec.

$$qA\,dx\frac{dp}{dt} = qA\,dx\left(g - \frac{p}{\tau_p}\right) - dI$$

$$\frac{dp}{dt} = \frac{-p}{\tau_p} + g - \frac{dI}{qA\,dx} \longrightarrow (8)$$

But current density $(J) = \frac{I}{A} \Rightarrow J = \frac{I}{A}$

$I = JA$ ie $dI = A\,dJ$ as A is constant.

Sub $dI = A\,dJ$ in (6)

$$\frac{dp}{dt} = \frac{-p}{\tau_p} + g - \frac{A\,dJ}{qA\,dx} \longrightarrow (7)$$

The total current density J is due to drift and diffusion currents.

$$J = \underbrace{-q\,D_p\frac{dp}{dx}}_{\text{Diffusion}} + \underbrace{pq\,\mu_p E}_{\text{Drift currents.}} \longrightarrow (8)$$

If the semiconductor is in the thermal Equilibrium and subjected to know external Electric field then whole density will attain a constant value P_o Under this condition $I=0$ ie $J=0$ and $\frac{dp}{dt}=0$ due to Equilibrium

Sub these values in Equ (7)

$$0 = -\frac{P_o}{\tau_p} + g - 0 \text{ ie } \boxed{g = \frac{P_o}{\tau_p}} \longrightarrow (9)$$

The equation (9) indicates thermal Equilibrium that is the rate at which wholes are thermally generated just equal to the rate at which holes are lost due to the recombination. Using equn (8), (9) in (7)

$$\frac{dp}{dt} = \frac{-p}{\tau_p} + \frac{P_o}{\tau_p} - \frac{d\left(-q\,D_p\frac{dp}{dx} + pq\,\mu_p E\right)}{qA\,dx}$$

$p << n$, p is neglected.

(15)

$\therefore \sigma = 2 N_D e \mu_n$

$= (1.602 \times 10^{-19})(4.2 \times 10^{22})(0.38)$

$= 2.554 \times 10^{3} S/m$

$\therefore$ resistivity $\rho = \frac{1}{\sigma}$

$= \frac{1}{2.554 \times 10^{3}}$

$= 0.392 \times 10^{-3}\ \Omega\text{-}m$

Resistance $R = \frac{\rho L}{A}$

$= \frac{0.392 \times 10^{-3} \times 5 \times 10^{-3}}{(5 \times 10^{-6})^2}$

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$= 78.4 K\Omega$

* Hall effect (****)

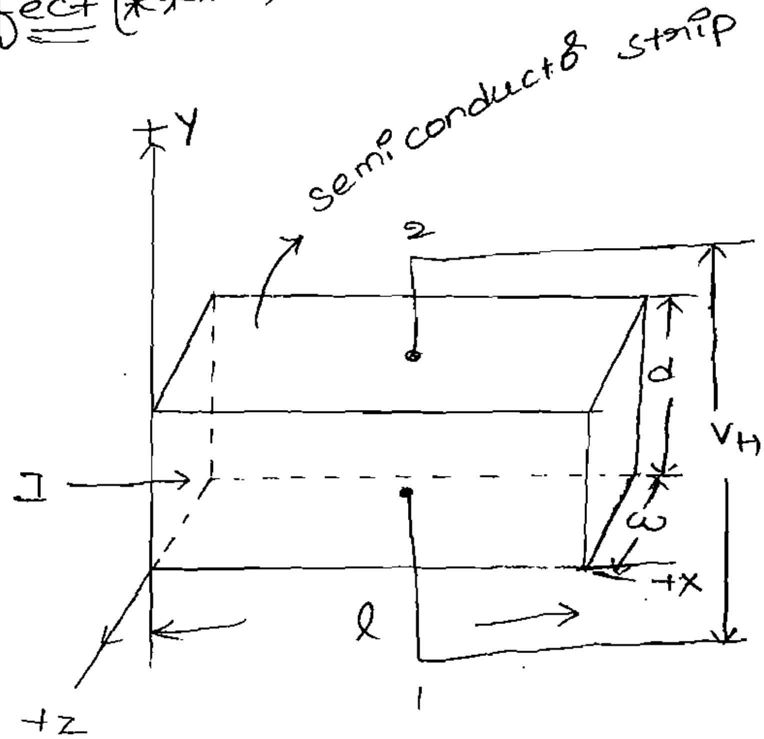


fig (a) Hall effect

(3) A semiconductor of pure germanium at 300K as a density of charge carriers 2.5X1019 /m³ it is doped with donor impurity atoms at the rate of one impurity atom every 106 atoms of germanium. all impurity atoms are supposed to be ionised the density of germanium atom is 4.2x1028 atoms/m³. Calculate the resistivity of the doped germanium if the electron mobility is 0.38 m/sec If the ge bar is 5x10⁻³m long and has a cross sectional area of $(5\times10^{-6})^2 m^2$. Determine its resistance and voltage drawn across the s.c bar for a current of 1 microamperes a flow through it.

Sol:- Density of added intensity atoms

$$N_D = \frac{4.2\times10^{28}}{10^6}$$

$$= 4.2\times10^{22}\ \text{atoms}/m^3$$

$$n \approx N_n$$

$$P = \frac{n_i^2}{n}$$

$$= \frac{n_i^2}{N_D}$$

$$= \frac{(2.5\times10^{19})^2}{4.2\times10^{22}}$$

$$\simeq 1.488\times10^{6}\ m^{-3}$$

$P << n$, P may be neglected.

$$\therefore \sigma = e N_D \mu_n$$

$$= (1.602\times10^{-19})(4.2\times10^{22})(0.38)$$

$$= 2.554\times10^{3}\ s/m$$

* If a metal or semiconductor carrying a current I is placed in a transverse magnetic field 'B', an Electric field 'E' is induced in the direction ⊥ to both current and magnetic field and this phenomenon is known as "Hall effect". (16)

* Consider a semiconductor strip carrying current 'I' as shown in fig(a) is the positive x-direction and 'B' is in the positive z-direction, a force will be exerted in the -ve y-direction on the current carriers.

* If a semiconductor is n-type so that the current is carried by electrons these electrons will be forced downward towards side 1 and in fig (a) and side 1 becomes negatively charged w.r.to side 2.

* Thus there exists a potential difference across the side 1 and side 2 this voltage is called "Hall voltage" denoted by "V_H".

* In the equilibrium condition the electric field intensity due to the hall effect must exert force on the carrier which just balances the force exerted by the magnetic field.

$$+qE = BqV$$

$$E = BV \longrightarrow (1)$$

Where q = Magnitude of the charge on the carrier

V = Drift speed.

Now $E = \frac{V_H}{d} \longrightarrow (2)$

$$V_H = E \cdot d \longrightarrow (2)$$

Where d = distance b/w the side 1 and side 2

* the current density J is given by

$$J = \frac{I}{wd} \; A/m^2 \longrightarrow (3)$$

* While the current density can be expressed in terms of charge density as

$$J = \rho v \longrightarrow (4)$$

Where ρ = charge density in cm/m³

v = speed in m/s

and

w = width of the strip in direction of B.

Equating Eqn (4) and (3), we get

$$\rho v = \frac{I}{wd} \Rightarrow v = \frac{I}{\rho wd}$$

$$\therefore V_H = Ed = Bv \cdot d$$

$$= B \cdot \frac{I}{\rho \cdot w\cancel{d}} \cdot \cancel{d}$$

$$\Rightarrow \boxed{V_H = \frac{BI}{\rho w}} \longrightarrow (5)$$

* Applications of Hall effect

→ Hall effect is used to determine wheather SC is n-type or ptype and to find out the carrier concentration.

→ To measuring the conductivity (σ) and mobility (μ) can be calculated.

* Measurement of Mobility and Conductivity

→ If the polarity of V_H is such that the surface +ve is -ve then carriers are electrons and we can write $\rho = n \cdot q \longrightarrow$ (6)

(17)

$p = p \cdot q \longrightarrow$ (7)

If side 2 is positive and we can write it as

$\rho = p \cdot q \longrightarrow$ (7)

* practically a constant R_H is called Hall coefficient is defined as

$$R_H = \frac{1}{n \cdot q} = \frac{1}{\rho} \longrightarrow (8)$$

Substitue Eqn (8) in Eq (5)

$$V_H = \frac{B I R_H}{w}$$

$$\boxed{R_H = \frac{V_H w}{B I}} \longrightarrow (9)$$

* the conductivity σ for Extrensic semiconducti is given by

$$\sigma = n \cdot q \cdot \mu$$

$$\sigma = \frac{\mu}{R_H}$$

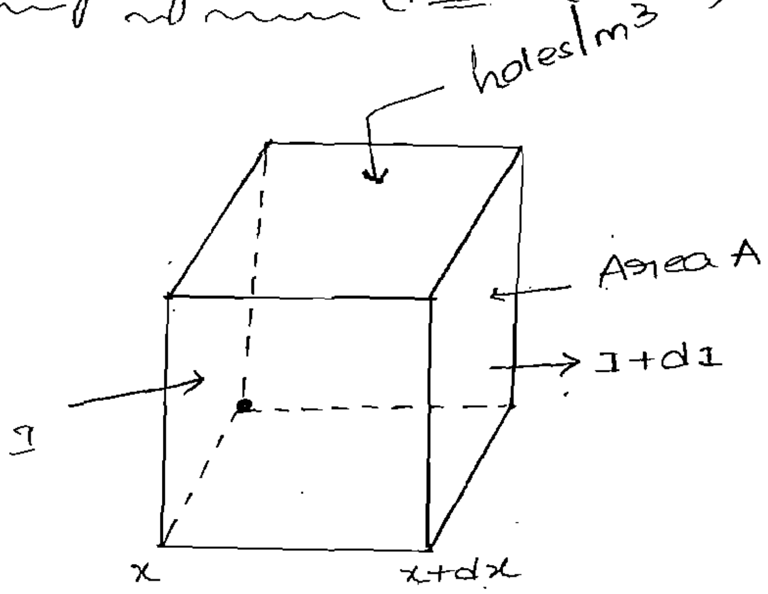
$$\boxed{\mu = \sigma R_H}$$

$$\boxed{\mu = \sigma \frac{V_H w}{B I}}$$

$$\sigma = \text{conductivity} = \frac{1}{\text{Resistivity}}$$

$$\boxed{\therefore \mu = \frac{1}{\text{Resitivity}} \times \frac{V_H w}{B I}}$$

25/01/18 *continuity Equation (Revise) (*****)



fig(a) Relating to the conservation of charge

τ_p → mean life time period of hole. P/τ_p

* The carrier concentration in the body of a sc is a function of time and distance mathematically a partial differential equation governs this functional relationship b/w carrier concentration, time and Distance (x) such an Equation is called "continuity Equation".

→ This equation based upon the fact that charge can be neither created nor destroyed.

→ consider the infinite simal element of volume of Area(A) and lenght dx as shown in fig(a) the average hole concentration is P.

→ If τ_p is mean life of time of the holes then P/τ_p Equal the holes/sec losted by recombination per unit volume.

→ In general the current will vary with distance within semiconductor if as indicated in fig(a).

$$\frac{dP}{dt} = \frac{1}{\tau_p}(P_0 - P) + \frac{1}{q}\left[q D_p \frac{d^2}{dx^2} P - \mu p \frac{d\,PE}{dx}\right]$$ (18)

$$\boxed{\frac{dp}{dt} = \frac{P_0 - P}{\tau_p} + D_p \frac{d^2 P}{dx^2} - \mu p \frac{dPE}{dx}} \longrightarrow (10)$$

This is called Equation of Conservation of charge & continuity Equation.

As holes in ~~Entire~~ n-type material are consider let us use the suffix n as concentration is a function of both time and distance. Let us use partial differentiation hence the final continuity Equation takes the form of

$$\boxed{\frac{\partial P_n}{\partial t} = \frac{(P_n - P_{n0})}{\tau_p} + D_p \frac{\partial^2 P_n}{\partial x^2} - \mu p \frac{\partial (P_n E)}{\partial x}} \longrightarrow (11)$$

Similarly the continuity Equation for Electrons in p-type material can be written as

$$\boxed{\frac{\partial n_p}{\partial t} = \frac{-(n_p - n_{p0})}{\tau_n} + D_n \frac{\partial^2 n_p}{\partial x^2} - \mu p \frac{\partial (n_p E)}{\partial x}} \longrightarrow (12)$$

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Concentration independent of distance and Electric field

$E = 0$

The Equation reduced as the concentration is not dependent on x and Electric field $E=0$ is

$$\boxed{\frac{dP_n}{dt} = \frac{-(P_n - P_{n0})}{\tau_p}}$$

where $\boxed{P_n - P_{n0} = K\, \exp^{-t/\tau_p}}$

Concentration independent of time and Electric field $E=0$

The Equation reduced as the concentration is not dependent on x and $E=0$

$$0 = -\frac{(P_n - P_{n0})}{\tau_p} + D_p \frac{\partial^2 P_n}{\partial x^2}$$

$$D_p \frac{\partial^2 P_n}{\partial x^2} = \frac{P_n - P_{n0}}{\tau_p}$$

$$\frac{\partial^2 P_n}{\partial x^2} = \frac{(P_n - P_{n0})}{D_p \tau_p}$$

$$= \frac{P_n - P_{n0}}{L_p^2}$$

Where $\sqrt{D_p \tau_p} = L_p =$ Diffusion Lenght of holes.

* Problems on Hall effect

1) A n-type silicon ball whose resistivity is $1000\,\Omega\text{-m}$ and width 1cm is used in the hall effect experiment if the current in the bar is $100\mu A$ and the hall voltage is 40mV. What is the intensity 'B' of the applied magnetic field. Assume μ_n(mobility of e^-) is $1300\,cm^2/v\text{-}s$.

Ans:- resistivity $= 1000\,\Omega\,/m \neq 100$

$d = 1cm = 10 \times 10^{-2}\ m^2/cm$

$I = 100\mu A$.

$V_H = 40mV$.

$\mu_n = 1300\ cm^2/v\text{-}S$

$$\boxed{\mu = \frac{1}{Resistivity} \times \frac{V_H w}{BI}}$$

(19)

$$1300 = \frac{1}{1000 \times 10^{2}} \times \frac{40 \times 10^{-3}}{10 \times 10^{-6} \times B}$$

$$B = \frac{10^{-3} \times 40 \times 10^{-3} \times 1 \times 10^{-2}}{1300 \times 10^{-2} \times 10 \times 10^{-6}}$$

$$\boxed{B = 0.3077\ wb/m^2}$$

(2) A n-type silicon ball whose resistivity 1000Ω-m and width 1cm is used hall effect Experiment if the current in the bar is 100μA and the hall voltage is 40mV. what is intensity 0.3077 wb/m² and also find out hall effect.

Ans:- Resistivity = 1000 Ω-m

$w = 1cm$

$V_H = 40mV = 40 \times 10^{-3} V$

$I = 10\mu A = 10 \times 10^{-6} A.$

$$\boxed{\sigma = \frac{1}{Resistivity} = \frac{1}{1000}}$$

$$R_H = \frac{40 \times 10^{-3} \times 1 \times 10^{-2}}{0.3077 \times 10 \times 10^{-6}}$$

$$= \frac{4}{0.3077} \times \frac{10^{-4}}{10^{-5}}$$

$$= \frac{40}{0.3077}$$

$$= 129.996$$

$$\boxed{\therefore R_H = 130}$$

3) The conductivity of N-type Sc is 10 simal/meter and Electron mobility is 50×10^{-4} $m^2/v\text{-}s$. Determine the electron concentration.

Ans:- conductivity = 10 simal/meter. (σ)

mobility = 50×10^{-4} $m^2/v\text{-}s$.

$$\boxed{\sigma = q \cdot n \cdot \mu n}$$

$$10 = q \cdot 1.602\times10\times50\times10^{-4}$$

$$q = \frac{10}{1.602\times10^{-19}\times50\times10^{-4}} = \frac{10^{23}}{8.01}$$

$$\boxed{q = 1.24\times10^{22} m^{-3}}$$

4) A current of 20amperes is passed through a thin metal strip which is subjected to a magnetic flux density of 1.2 web/m². The magnetic field is directed perpendicular to the current. The thickness of strip in the direction of magnetic field is 0.5mm. The hall voltage is 60volts. find the Electron density.

A: $I = 20A$

$B = 1.2\ web/m^2$

$V_H = 60$ volts

M.F = 0.5mm

$$\boxed{n = \frac{BI}{V_H \cdot q W}}$$

$$= \frac{1.2\times20}{60\times1.602\times10^{-19}\times0.5\times10^{-3}} = 5\times10^{21} m^3$$

$$= 4.993\times10^{21} m^3$$

(5) An Entire semiconductor has hall volt coefficient of $200cm^3$ and its conductivity is 10 simens/m. find its electron mobility.

Ans:-

$$\Rightarrow R_H = \frac{1}{nq} = \frac{1}{\rho}$$

$$R_H = 200cm^3$$

$$= 200 \times 10^{-6}$$

$$\Rightarrow \boxed{\mu = \sigma R_H}$$

$$= 10 \times 200 \times 10^{-6}$$

$$\boxed{\mu = 2000\ cm^2/V\text{-}s.}$$

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(6) Fermi Derac Function

→ In energy band diagram probability that energy level is occupied by an electron is given by fermi probability function denoted as F(E) it is given by the expression $F(E) = \frac{1}{1+e^{-(E-E_F)/KT}}$

Where K = Boltzman's constant in eV/°K.

T = Temparature in °K.

E_F = fermi level.

E = Energy level occupied by an electron in eV.

Fermi level in Intrinsic Semiconductor

Representation of fermi level in intrinsic semiconductor.

→ In Intrinsic semiconductor the probability of finding an electron in conduction band is zero.

→ The probability of finding a hole in valence is zero at 0°K ie T = 0°K.

→ Now, let E_c be the lowest Energy level in the conduction band while E_v be the highest Energy level in valency band.

→ As temperature increases equals no. of Electrons holes are generated. Hence probability of finding electron in conduction band and finding a hole in valency band is same.

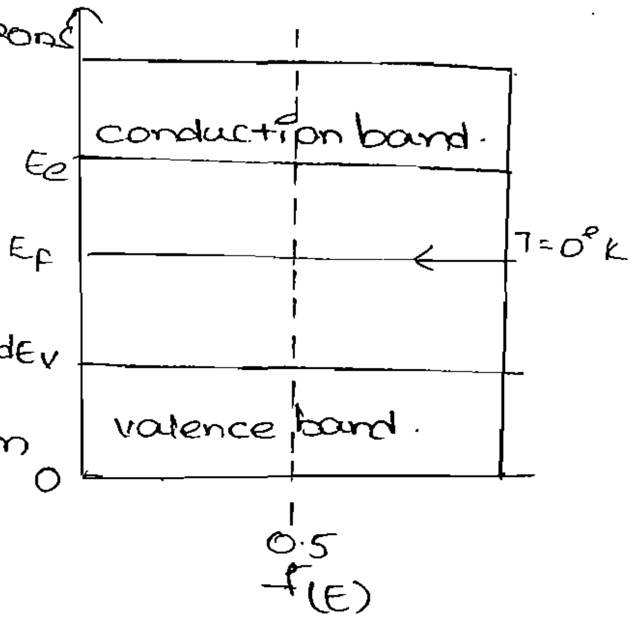
$$\boxed{\therefore E_F = \frac{E_C + E_V}{2}}$$

→ Thus in the Energy band diagram the fermi level the intrinsic semiconductor lies at the centre of the forbidden energy band.

→ The concentration of Electrons in the conduction is given by

$$n = N_c e^{-(E_C - E_F)/KT} \longrightarrow (1)$$

where N_c = effective density of Electrons in conduction band



→ The Concentration of holes in the valence band is given by

$$p = N_v e^{-(E_F - E_V)/KT} \longrightarrow (2)$$

where N_v = Effective density of holes in valency band

→ In Intrinsic semiconductor the $n = p = n_i$

So, Equating Eqn's (1) & (2)

$$N_c e^{-(E_c - E_F)/KT} = N_V e^{-(E_F - E_V)/KT}$$

$$\frac{N_c}{N_v} = \frac{e^{-(E_F - E_V)/KT}}{e^{-(E_C - E_F)/KT}}$$

$$\frac{N_C}{N_V} = e^{-(E_F+E_V+E_C-E_F)/KT} \longrightarrow (3)$$

Taking natural "log" on both sides.

$$\ln\frac{N_C}{N_V} = \frac{-2E_F+E_C+E_V}{KT}$$

$$E_F = \frac{E_C+E_V}{2} - \frac{KT}{2}\ln\frac{N_C}{N_V}$$ n=n

* In Intrensic Semiconductor $N_C = N_V$

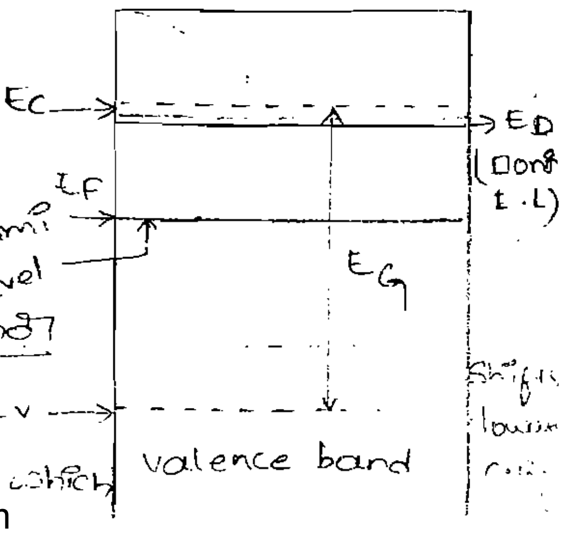
$$\boxed{\therefore E_F = \frac{E_C+E_V}{2}}$$

Fermi level in Extrensic semiconductor

→ In an Extrensic semiconductor it is not only the holes and Electrons which have charge but ionised impurity atoms (donor, acceptor) are also present and they too are charged. Let N_D be the Equal concentration of donor atoms. If p is the no. of holes in semiconductor then the total +ve charge density N_D+P. similarly if N_A is the concentration of acceptor ions and the no. of Electrons is 'n'. Then the total charge density is N_A+n.

* Since the semiconductor is Electrically neutral ie

$$\boxed{N_D+P = N_A+N}$$



→ * In N-type semiconductor donor impurity is added due to this large no. of Electrons get created in conduction band. The donor energy level corresponding to donor impurity gets introduced which is indicated as E_D and is very close to the conduction band gets below it.

* Concentration of Electrons is given as

$$\boxed{n = N_C \, e^{-(E_C - E_F)/KT}}$$

* In N-type material $n \simeq N_D$ so $N_D = N_C \cdot e^{-(E_C-E_F)/KT}$

$$\frac{N_D}{N_C} = e^{-(E_C - E_F)/KT}$$

Taking 'log' on both sides.

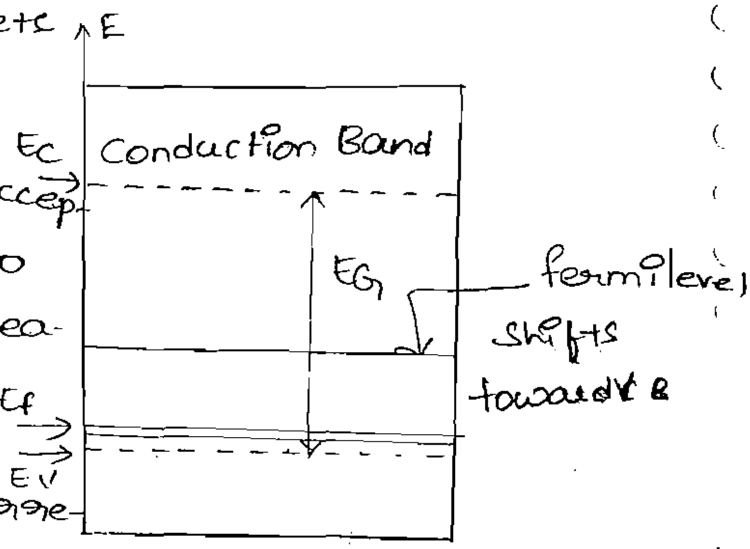
$$\ln \frac{N_D}{N_C} = -E_C + E_F / KT$$

$$\boxed{E_C - E_F = KT \ln \frac{N_C}{N_D}}$$

$$\boxed{E_F = E_C - KT \ln \frac{N_C}{N_D}}$$

* In N-type fermi level lies gets below the conduction band.

* In P-type Semiconductor acceptor impurity is added due to this large no. of holes are created in valency band.



* The acceptor Energy level corresponding to acceptor impurity gets introduced which is indicated as E_A and is very close to the valency band gets below it.

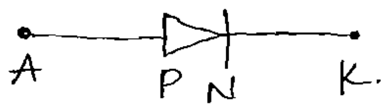
* Concentration of holes is given as $p = N_V e^{-(E_F - E_V)/KT}$

In p-type material $p \approx N_A$

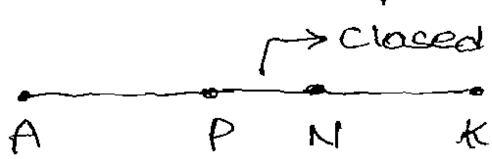
UNIT-2

①

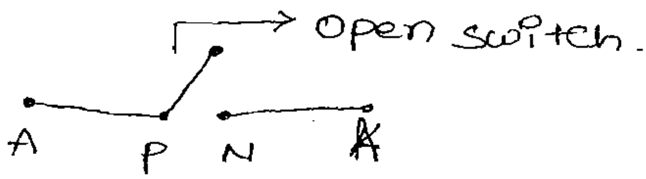
Ideal Diode



Diode acts as a switch either p-type or n-type material. In forward bias the switch is closed it is a perfect conductor and short circuit ie current is maximum and voltage is minimum [$I=\infty, V=0$].



In reverse bias the switch is opened it is a insulator the current is minimum voltage is maximum. ie [$I=0, V=\infty$].



In forward bias (the switch is) forward Resistance $R_f \simeq 0$ (few ohms)

In Reverse bias Reverse resistance $R_r \simeq \infty$ (mega ohms)

Applications

1. It is used as Regulator, automatic switch, rectifier, clipping, clamping circuits.

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Qualitative theory of P-N junction Diode or open circuit

· Junction of P-N junction Diode in equilibrium

$$N_A = N_V e^{-(E_F - E_V)/KT}$$

$$\frac{N_A}{N_V} = e^{-(E_F - E_V)/KT}$$

Taking 'ln' on B.S

$$\ln \frac{N_A}{N_V} = \frac{-E_F + E_V}{KT}$$

$$\ln \frac{N_A}{N_V} KT - E_V = -E_F$$

$$E_F = E_V + KT \ln \frac{N_V}{N_A}$$

with no applied voltage — Junction Diode

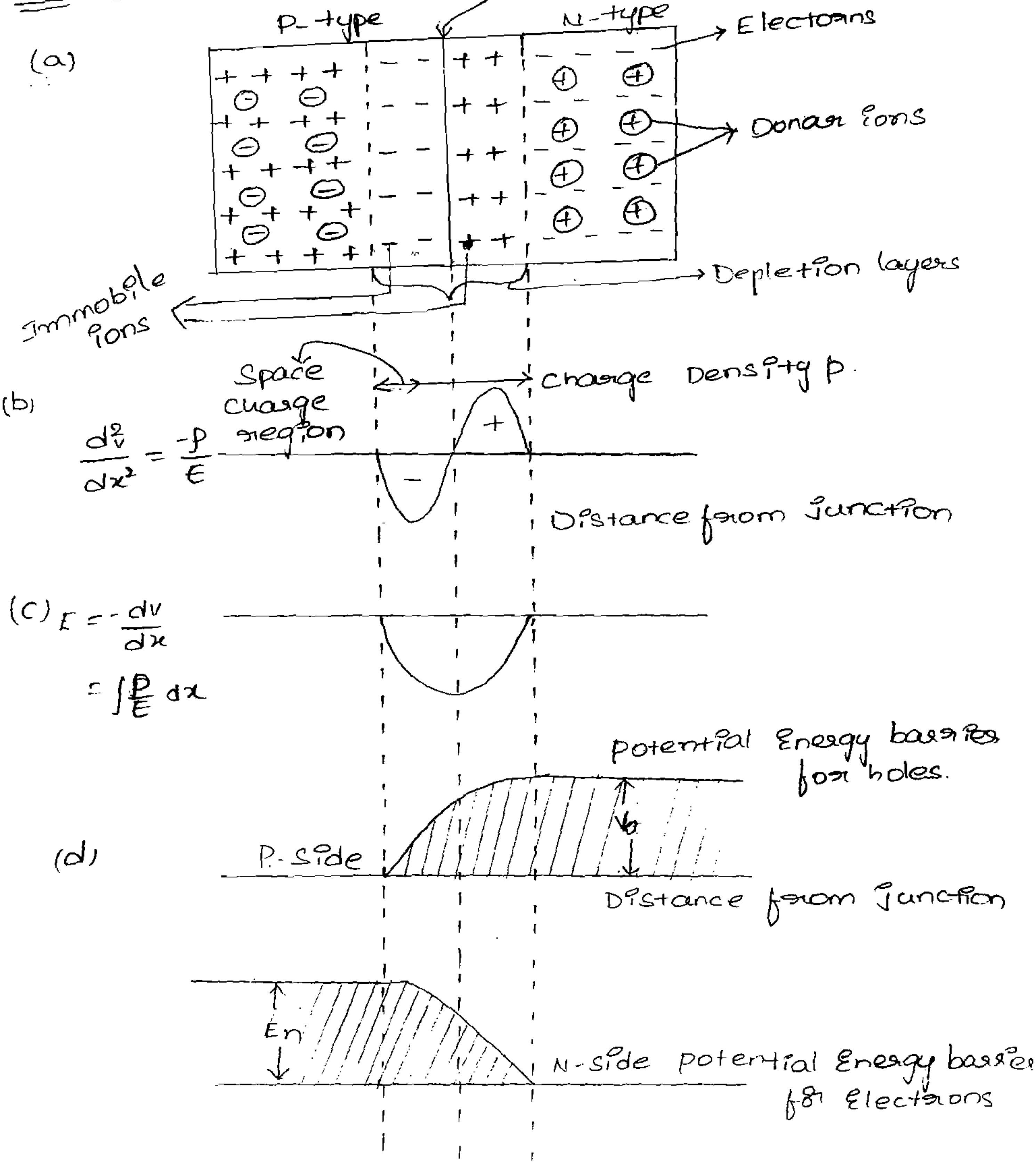


fig 1: A schematic diagram of PN junction including the charge density, Electric field intensity, potential energy barrier at the junction.

→ In a peace of semiconductor material if one half is p-type impurity and other half is doped with N-type P-N Junction is formed.

→ The plane dividing the two zones is called P-N junction.

→ As shown in fig 1 the n-type material has high concentration of electrons while p-type material has high concentration of holes.

→ Therefore, at the junction there is a tendency for free electrons to diffuse over to the p-side and holes to the n-side this process is called Diffusion.

→ As the free electrons move across the junction from n-type to p-type the Donar ions becomes positively charged hence a positive charge is built On the n side of the junction.

→ The free electrons that cross the junction uncover the negative acceptor ions by filling in the holes.

→ Therefore, the net negative charge is established in the p-side of the junction.

→ The net negative charge on p-side prevents further diffusion of electrons into the p-side similarly the net positive charge on the n-side repels the hole crossing from p-side to n-side. Thus a barrier is a set up near the junction which prevents free. thus movement of charge carriers Electrons & holes.

→ As a consequence of the induced Electric field across the deplection layer an electro static potential difference is established b/w p and n regions which is called the potential barrier, junction barrier, Diffusion potential (V_0). It is represented by

→ The magnitude of the contact potential V_0 varies with doping levels and temparature.

$V_0 = 0.3V$ | germanium   0.2 - 0.3

$V_0 = 0.7V$ | silicon.   0.6 - 0.7

1/7/16

Biasing

Forward Bias and Reverse Bias

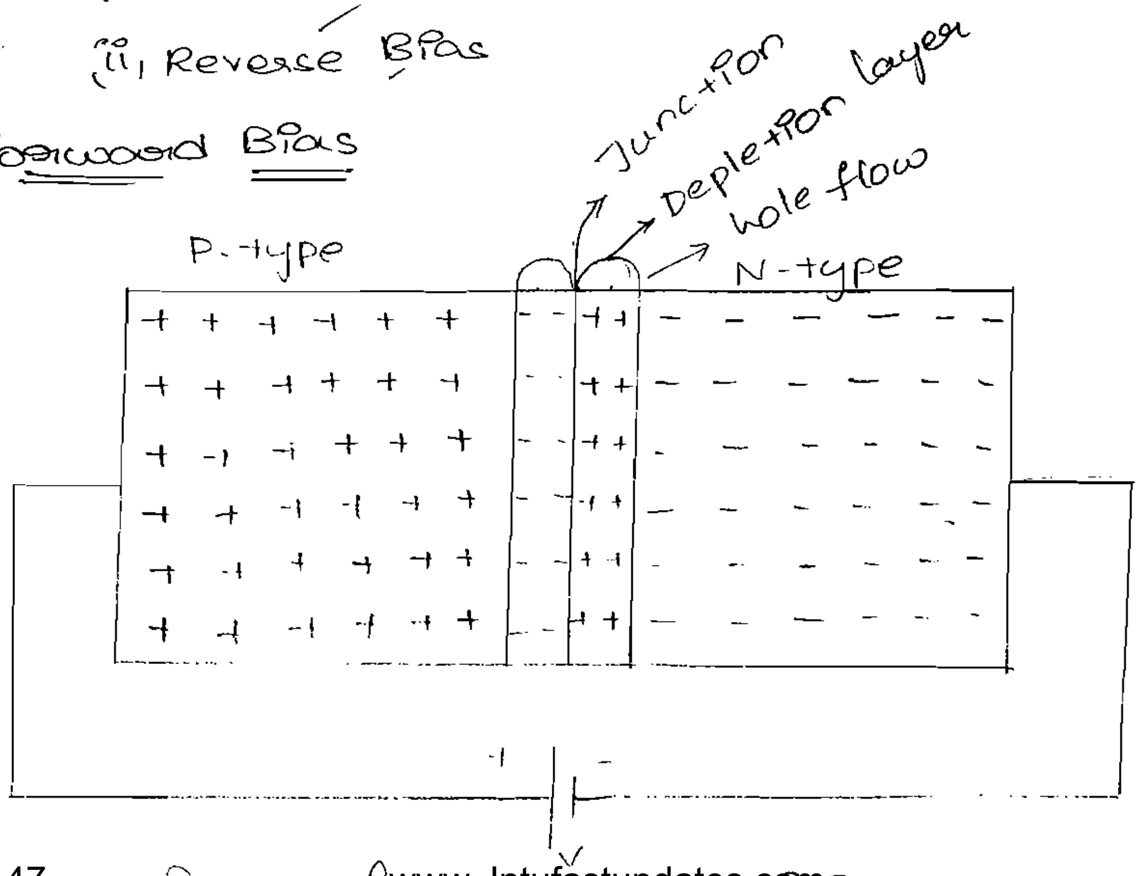
→ Appling a External signal to the circuit is known as Bias.

→ Biasing methos are 2-types.

(i) forward Bias

(ii) Reverse Bias

(i) forward Bias



- Figure forward Bias condition

→ When +ve terminal of the battery is connected to p-type and -ve terminal to the n-type of p-n junction Diode the bias applied is known as forward bias.

Operation

→ Under forward bias condition applied positive potential repels the holes in p-type region so that the holes moves towards the junction.

→ Under forward bias condition applied negative potential repels the electrons in n-type region so that the electrons move towards the junction.

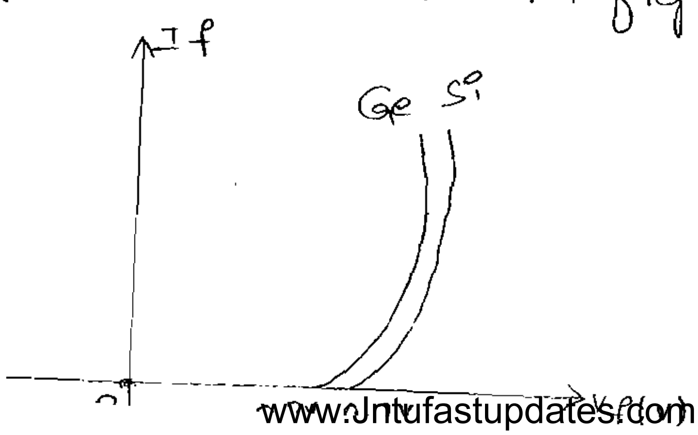
→ When the applied potential is more than the internal barrier potential the depletion region and internal potential barrier disappears so large current flows through the circuit

i.e. $V_f = 0$, $I_f = max$

V-I Characteristics of Diode

Under forward bias condition.

→ Under foward bias condition the V-I characteristic of a p-n junction as shown in fig (b)



Case (i)

→ As the forward voltage V_F is increased for ($V_F < V_0$) the forward current is almost zero (region OA)

→ Because the potential barrier prevents the holes from p-region and electrons from n-region to flow across the depletion region in the opposite direction.

Case (ii)

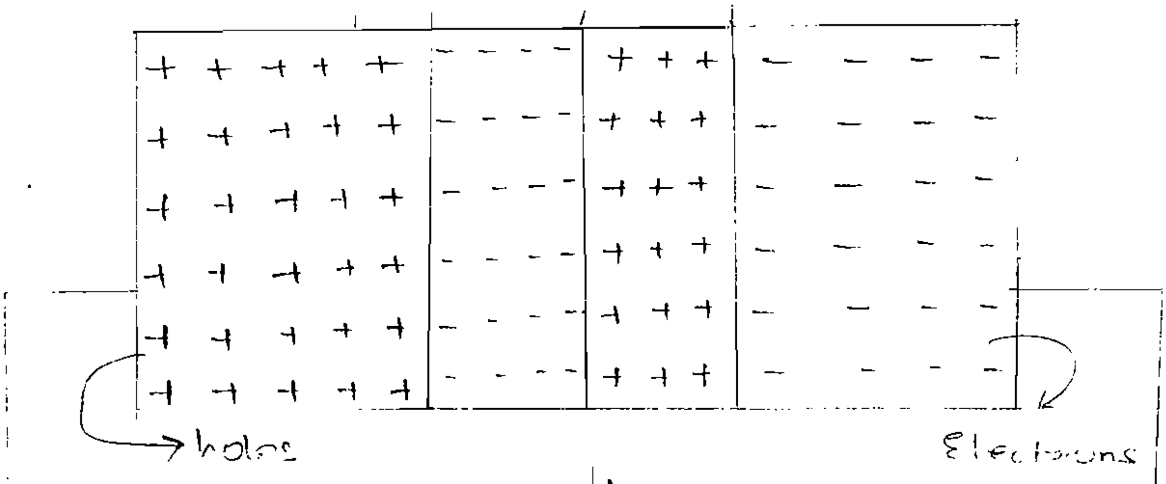
→ for $V_F > V_0$ the potential barrier of the junction completely disappears and hence the holes cross the junction from p-type to n-type and the electrons cross the junction in the opposite direction resulting large current flow in the external circuit.

→ At the "cut in voltage" the potential barrier is overcome and the current through the junction starts to increase rapidly. It is represented as V_γ.

* Cut in voltage for germanium = 0.3V

silicon = 0.7V

Reverse Bias



→ When the -ve terminal of the battery is connected to p-type and positive terminal of the battery is connected N-type then the bias is known as Reverse bias.

Operations

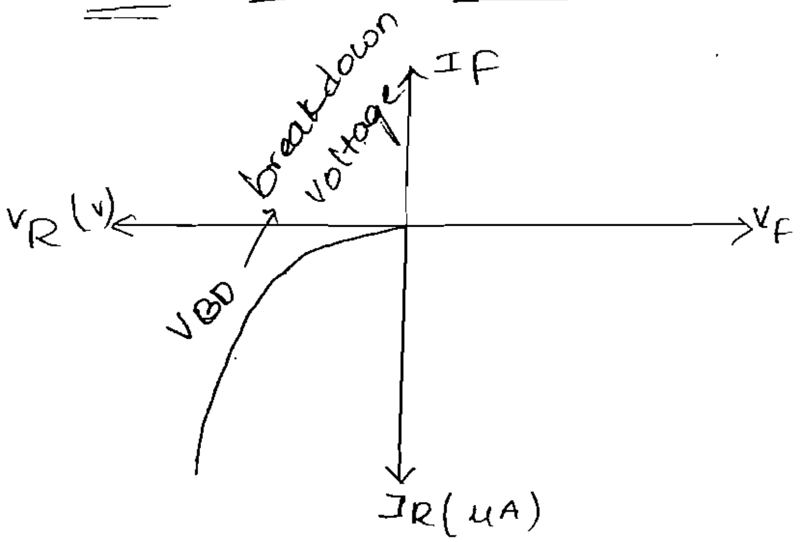
→ Under R.B.C, applied +ve potential attracts the Electrons in n-type region so that the Electrons moves away from the junction.

→ Under R.B.C, applied -ve potential attracts the holes in p-type region so that the holes moves away from the junction.

→ When the applied potential is more than the internal barrier potential and the width of the depletion layer increases.

V-I Characteristics of Diode

Under Reverse bias condition



fig(b) V-I characteristics of p-n junction diode under reverse bias condition.

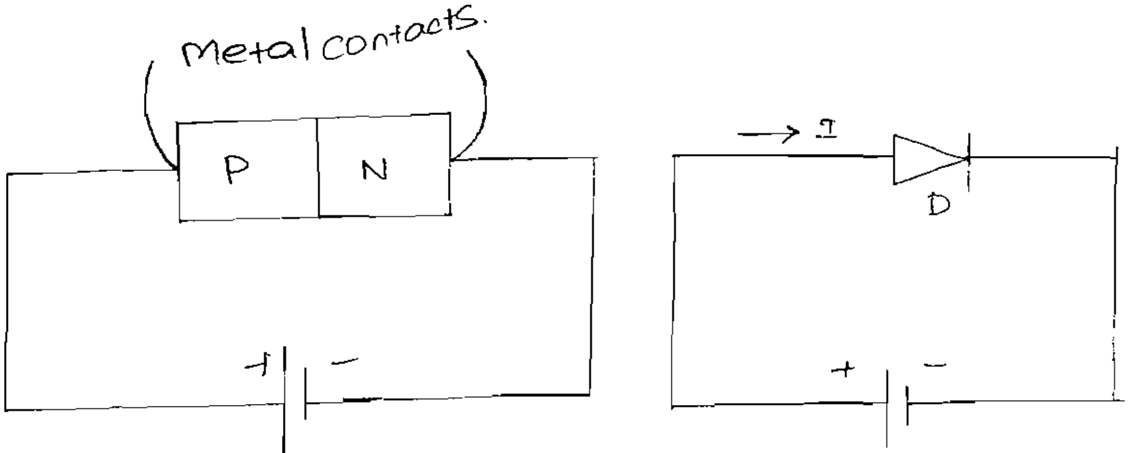
→ Under reverse bias condition thermally generated holes in the p-region are attracted toward the -ve terminal of the battery and Electrons in the n-region are attracted towards the +ve terminal of the battery.

→ The minority carriers Electrons in the p-region and holes in p-region vander over the junction and flow towards their majority charge carriers side giving rise to a small reverse current.

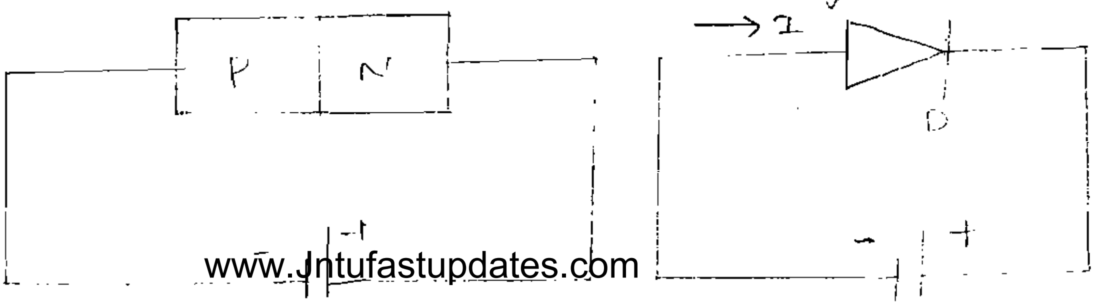
→ This current is known as Reverse saturation current (Io).

→ Therefore, theoritically no I current should flow through External circuit but in practise very small current of the order of a few micro amperes flows under reverse bias as shown in fig(b).

P-N Junction as a Diode



fig(a) F.B & R.B PN Junction Diode & its circuit symbols.



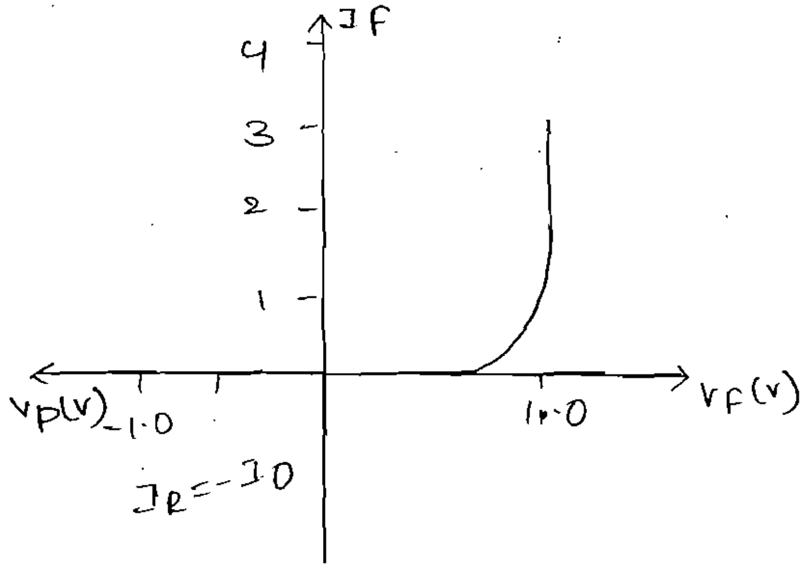
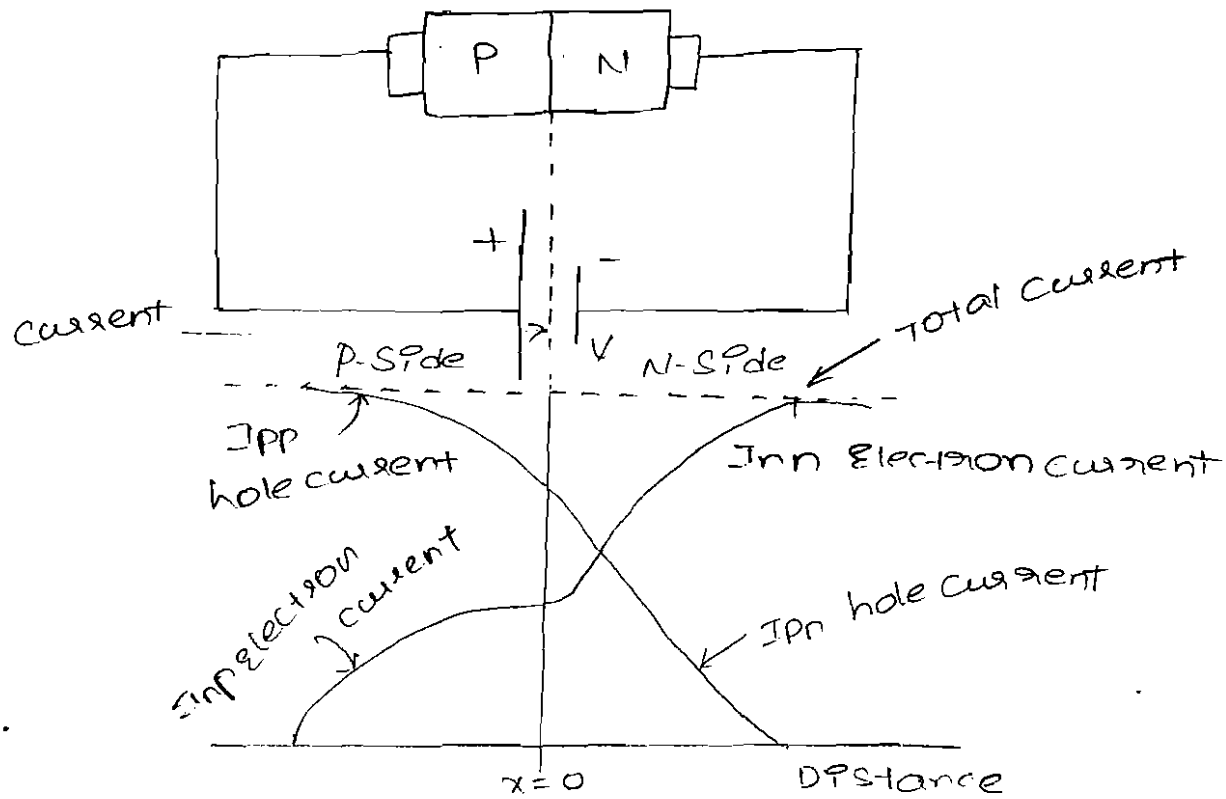


fig1(b):- Ideal V-I Characteristics of PN Junction

*P-N Junction as current component & current component of PN Junction Diode



-fig(c) The hole and Electron current components v/s distance in a PN Junction Diode The space charge region at the Junction is assumed to be negligible

→ figure(a) indicates when a forward bias is applied to a diode holes are injected into n-side and electrons into the p side the no.of injected minority carrier falls of exponentially with distance from the junction.

→ since the diffusion current of minority carriers is proportional to concentrating gradient. These current most also vary exponentially with the distance.

→ There are 2 minority currents I_{pn} and I_{np}.

→ $I_{pn}(x)$ represents the hole current in the n-type material and $I_{np}(x)$ represents the electron current in the p-type as a function of x.

→ Electrons crossing the junction at x=0 from right to left constitute a current in the same direction has hole crossing the junction from left to right.

→ Hence the total current I at x=0

$$I = I_{np}(0) + I_{pn}(0)$$

→ $I = I_{pp}(x) + I_{np}(x)$ from p-side at function x

→ $I = I_{nn}(x) + I_{pn}(x)$ from n-side at function x

* Diode Equation

* Law of Junction

→ It states that forward junction diode the injected hole concentration $P_n(0)$ in the n-region increases over thermal equilibrium value $P_n(0)$ P_{no} where

P_{no} = Thermal Equilibrium of hole concentration

P_{PO} : Thermal equilibrium of hole concentration of p side

$$P_{PO} = P_{no}\, e^{V_0/V_T} \longrightarrow (1)$$

Where V = applied forward bias voltage

V_0 = barrier potential

→ The barrier exists on both sides of the junction so the thermal equilibrium hole concentration is on n-side.

$$P_{PO} = P_n(0)\, e^{(V_0-V)/V_T} \longrightarrow (2)$$

Where $P_n(0)$ = injected hole concentration on n-side near the junction.

Equating equation (1) and (2).

$$P_{n0}\, e^{V_0/V_T} = P_n(0)\, e^{(V_0-V)/V_T}$$

$$\frac{P_{n0}}{P_n(0)} = \frac{e^{(V_0-V)/V_T}}{e^{V_0/V_T}}$$

$$P_{n0} = P_n(0) \cdot e^{\frac{V_0 - V - V_0}{V_T}}$$

$$\boxed{P_n(0) = P_{n0}\, e^{V/V_T}}$$

The total hole concentration in n-region that the junction varies with applied forward bias voltage V_f this is called "Law of junction".

$$P_n(0) = P_n(0) - P_{n0}$$

$$= P_{n0}\, e^{V/V_T} - P_{n0}$$

$$\boxed{P_n(0) = P_{n0}\left(e^{V/V_T} - 1\right)}$$

→ Now the difference b/w 2 concentrations at the junction under unbiased condition is called injected or excess concentration.

→ Now hole current crossing the junction from p-side to n-side is given by

$$I_{P_n}(0) = \frac{AeD_p P_n(0)}{L_p}$$

→ The Electron current crossing the junction from n-side to p-side is given by

$$I_{np}(0) = \frac{AeD_n n_p(0)}{L_n}$$

→ The total current $I = I_{P_n}(0) + \cancel{P} I_{np}(0)$

$$= \frac{AeD_p P_n(0)}{L_p} + \frac{AeD_n n_p(0)}{L_n}$$

$$= \frac{AeD_p P_{n0}(e^{V/V_T}-1)}{L_p} + \frac{AeD_n n_p(0)(e^{V/V_T}-1)}{L_n}$$

$$= (\cancel{A}e^{V/V_T}-1)\left[\frac{AeD_p P_{n0}}{L_p} + \frac{AeD_n n_p(0)}{L_n}\right]$$

$$I_0 = \frac{AeD_p P_{n0}}{L_p} + \frac{AeD_n n_p(0)}{L_n}$$

$$\boxed{I = I_0 [e^{V/V_T} - 1]}$$

→ For low level current $\eta = 1$ for Ge

$\eta = 2$ for Si

→ for high level current $\eta = 1$ for both Ge, Si.

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

Where A_e = Area of cross section of junction

D_p = diffusion constant for holes.

D_n = diffusion constant for Electrons.

Lp = diffusion lenght of holes

Ln = diffusion lenght of Electrons.

$$V_T \simeq \frac{KT}{q} = T/11{,}600$$

$$\boxed{V_T = \frac{T}{11{,}600}}$$

where T = Temparature of diode junction (^0K)

V_T = Thermal voltage = 26 mV. (milli = 10^{-3}).

q = Charge of Electron = 1.60×10^{-19} columbs.

K = constant

→ At room temparature 273+27 = 300°K.

V_T = 26mV

Problems

1. for a reverse bias to a Ge pn junction diode the Reverse Saturation current $I_0 = 0.3\mu A$ Determine the current flowing in the Diode when 0.15V forward bias is applied at room temparature.

Given $I_0 = 0.3 \times 10^{-6}$, $V_F = 0.15V$

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

$$I = I_0 (e^{40V_F} - 1)$$

$$= 0.3 \times 10^{-6} (e^{40 \times 0.15} - 1)$$

$$= 120.73 \mu A$$

95.H uA.

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2. The voltage across a silicon diode at room temparature 0.7V when 2mA current flows through it. If the voltage increases to 0.75V calculate the diode current assume V_t = 26mV.

T = 300k

Temparature Depends upon V-I Characteristics: (8)

Temparature depends upon current:-

We know that $I = I_0 \left(e^{V/nV_T} - 1\right)$

$$I_0 = K_1 T^2 \left(e^{\frac{-V_{G0}}{nV_t}} - 1\right) \text{ for Ge}$$

$$I_0 = K_2 T^{1.5} \left(e^{\frac{-V_{G0}}{nV_t}} - 1\right) \text{ for Si}$$

In general $I_0 = KT^m \left(e^{\frac{-V_{G0}}{nV_t}} - 1\right) \longrightarrow (1)$

Where k is constant independent of temparature

Where T = temparature in kelvin

M = constant

M = 2 for Ge

M = 1.5 for Si

$V_{GD} \approx 0.785°C$ for Ge

$\approx 1.21°C$ for Si

Apply natural log on equation 1 on B.S

$$\ln I_0 = \ln KT^m \left(\frac{-V_{G0}}{nV_t} - 1\right) \qquad e^{V/nV_T} \gg 1$$

$$\ln I_0 = \ln(K) + M\ln(T) - \frac{V_{G0}}{nV_t}$$

The above equation is differentiable with 't'

$$\frac{1}{I_0}\frac{dI_0}{dt} = M\left(\frac{1}{T}\right) - \frac{V_{G0}}{nV_T} \qquad \left[V_T = \frac{1 \times T}{q} = \frac{T}{11,600}\right]$$

$$\frac{1}{I_0} \cdot \frac{dI_0}{dt} = \left[\frac{M}{T} - \frac{V_{G0}}{n\frac{d}{dt}\left(\frac{11,600}{T}\right)}\right]$$

$$\frac{1}{I_0}\frac{dI_0}{dt} = \frac{M}{T} - \frac{V_{G0}}{n(11,600)(-1/T^2)}$$

$$= \frac{M}{T} - \frac{V_{G0}}{\eta}(11,600)\left(\frac{-1}{T^2}\right)$$

$$\frac{1}{I_0}\frac{dI_0}{dt} = \frac{M}{T} + \frac{V_{G0}}{\eta} \cdot \frac{11,600}{T \cdot T}$$

$$\frac{1}{I_0} \cdot \frac{dI_0}{dt} = \frac{M}{T} + \frac{V_{G0}}{\eta} \cdot \frac{1}{TV_T}$$

$$\frac{d}{dt}(\ln(I_0)) \approx 0.11/°C \text{ for Ge}$$

$$\approx 0.08/°C \text{ for Si.}$$

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* Resistance Levels 2M

As the operating point of Diode move from one region to another region the resistance of diode also change due to the non-linear shape of characteristics curve.

Diode Resistance

An ideal diode offers '0' resistance in forward bias and infinite resistance for reverse bias but in practise no resistance can act as ideal diode.

* Diode resistance are 2 types.

1. forward resistance.
2. Reverse Resistance.

1. Forward Resistance

→ Foward resistance canbe classified into 2 types

1. DC (or) Static Resistance.
2. AC (or) Dynamic Resistance.

DC (or) Static resistance

* It is defined as the ratio of DC voltage to DC current at any point on the characteristic curve.

$$R_f = \frac{V_{DC}}{I_{DC}}$$

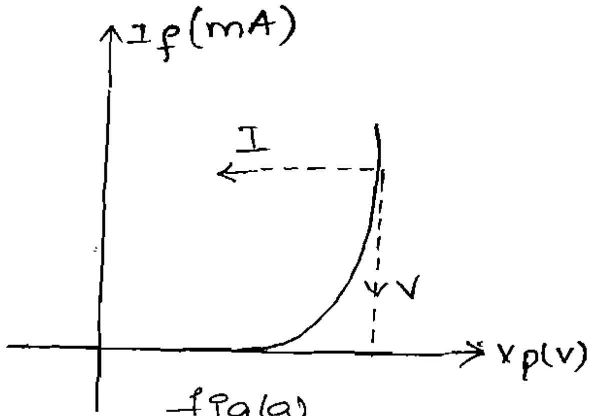


fig (a)

AC Resistance

* It is defined as the ratio of change in voltage to change in current at characteristics of diode. It is denoted by r_f (or)
* It is defined as the reciprocal of the slope of forward characteristics.

$$\text{ie } r_f = \frac{\Delta V}{\Delta I} \frac{(\text{change in voltage})}{(\text{change in current})}$$

(or)

$$r_f = \frac{1}{\text{slope of forward characteristics}}$$

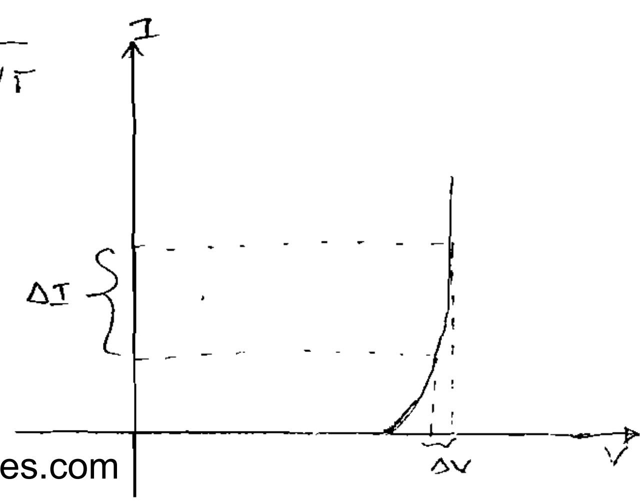
r_f is not constant value depends on applied voltage

We know that $I = I_0\left[e^{V/\eta V_T} - 1\right]$

$$I = I_0\left[e^{V/\eta V_T}\right] \quad \left[e^{V/\eta V_T} >> 1\right]$$

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

$$\frac{dI}{dV} = \frac{I}{\eta V_T}$$



2. Reverse Resistance

* The reverse resistance offered by the pn junction diode under reverse bias condition. It is very large when compared with forward resistance which is in the range of mega ohms which is denoted by R_r.

$$r_f = \frac{\Delta V}{\Delta I} = \frac{dV}{dI}.$$

We know that

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

$$I = I_0 e^{V/\eta V_T} - I_0.$$

$$g = \frac{1}{r_f} = \frac{dI}{dV}$$

$$g = \frac{d}{dV}\left[I_0\left(e^{V/\eta V_T} - 1\right)\right]$$

$$= I_0 e^{V/\eta V_T} \times \frac{1}{\eta V_T}$$

$$\frac{dI}{dV} = \frac{I}{\eta V_T} \qquad \boxed{R_r = \frac{\eta V_T}{I}}$$

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

Problem

1. For Germanium diode $I_0 = 2\mu A$ and the voltage 0.26 volts is applied: calculate forward and reverse dynamic resistance values at room temperature.

$= I_0(e^{3.846} - 1)$

$9 \times 10^{-7} = I_0 (45.805)$

$$I_0 = \frac{9 \times 10^{-7}}{45.805}$$

$I_0 = 0.196 \times 10^{-7}$

$$\boxed{I_0 = 1.96 \times 10^{-8} A}$$

4. When silicon Diode has reverse saturation of 2.5 uA at 300°K. find forward voltage for a forward current of 100mA.

$I = I_0 (e^{V/nV_T} - 1)$

$10 \times 10^{-3} = 2.5 \times 10^{-6} (e^{V/(2 \times 26 \times 10^{-3})} - 1)$

$$e^{V/0.052} = \frac{10 \times 10^{-3}}{2.5 \times 10^{-6}}$$

$= 4 \times 10^{3}$

$$\frac{V}{0.052} = 3.602$$

$$\boxed{V = 0.1873V}$$

$e^{V/0.052} = 4000$

Taking log

$$\frac{V}{0.052} = 3.602.$$

$V = 0.052 \times 3.602$

~~$V = 0.18$~~

$$\boxed{V = 0.1873V}$$

$V_{D1} = 0.7V$

current through Diode $= 2\times10^{-3}A$

$V_{D2} = 0.75V$

n- value

Si - 2

Ge - 1

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

$I_{D1} = I_0(e^{V_{D1}/\eta V_T} - 1)$

$\cancel{2\times10^{-3}} = I_0(e^{0.7/2\times26\times10^{-3}} - 1)$

$\cancel{2\times10^{-3}} = I_0(e^{\frac{0.7}{0.052}} - 1)$

$= 0.053 \cdot I_0$

$I_{D1} = I_0(e^{0.013\times10^{-3}} - 1)$

$2\times10^{-3} = I_0(e^{13.46} - 1)$

$\boxed{I_0 = 2.84\times10^{-9}}$

$I_{D2} = I_0(e^{V_{D2}/\eta V_T} - 1)$

$= 2.84\times10^{-9}[e^{0.75/2\times26\times10^{-3}} - 1]$

$\boxed{I_{D2} = 5.2306mA}$

3. The current flowing in a germanium in pn Junction diode $9\times10^{-7}A$ when the large reverse voltage is applied calculate the current flowing when 0.1V forward bias is applied.

A. $I = 9\times10^{-7}A$.

Germanium $\eta = 1$

$T = 300k$

$V = 0.1V$

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

$I = I_0\left(\frac{0.1}{e^{2\times26\times10^{-3}}} - 1\right)$

$9\times10^{-7} = I_0(0.003\times10^{3} \ldots)$

$$I = I_0 \left[e^{V/\eta V_T} + 1 \right]$$

$$= 2\times10^{-6} \left[e^{\frac{0.26}{1\times0.025}} \right]$$

$$= 2\times10^{-6} (e^{10.4})$$

$$\boxed{I = 0.065 A}$$

$$\frac{dI}{dV} = \frac{0.065}{(1)(0.025)}$$

$$\boxed{\therefore R_f = 2.6\,\Omega}$$

Reverse: $I = 2\times10^{-6} \left(e^{\frac{0.26}{(1)(0.025)}} - 1 \right)$

$$= 2\times10^{-6} (e^{10.4} - 1)$$

$$\boxed{I = 0.065 A}$$

$$R_r = \frac{(1)(0.025)}{0.065}$$

$$\boxed{\therefore R_r = 0.3846\,\Omega}$$

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* Diode capacitance

Diode capacitance are 2 type

1. Transistion capacitance (C_T)
2. Diffusion capacitance (C_D)

1. Transition capacitance (C_T)

→ Consider reverse bias PN Junction diode when the diode is reverse biased reverse current flows due to minority charge carriers.

→ Majority charge particles electrons in n-region and holes in p-region moves away from the junction the width of the depletion layer increases as reverse bias increases.

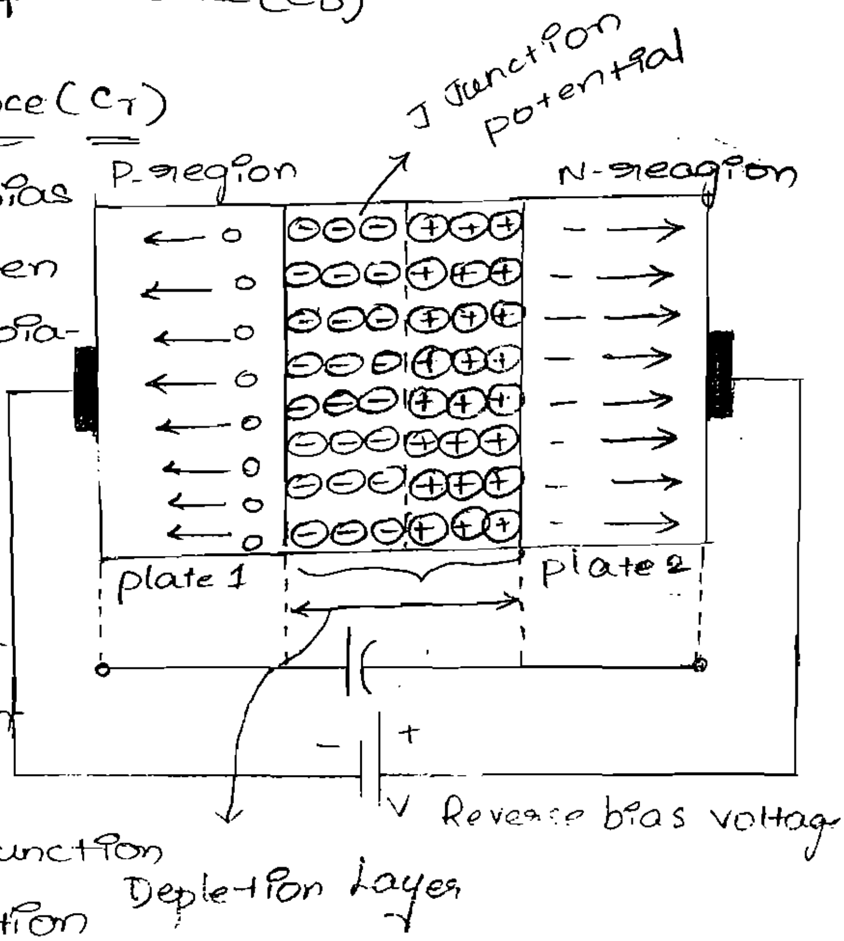


fig (a) PN Junction under Reverse bias condition

→ As the charged particles move away from the junction there exists a change in charge with respect to the applied reverse voltage.

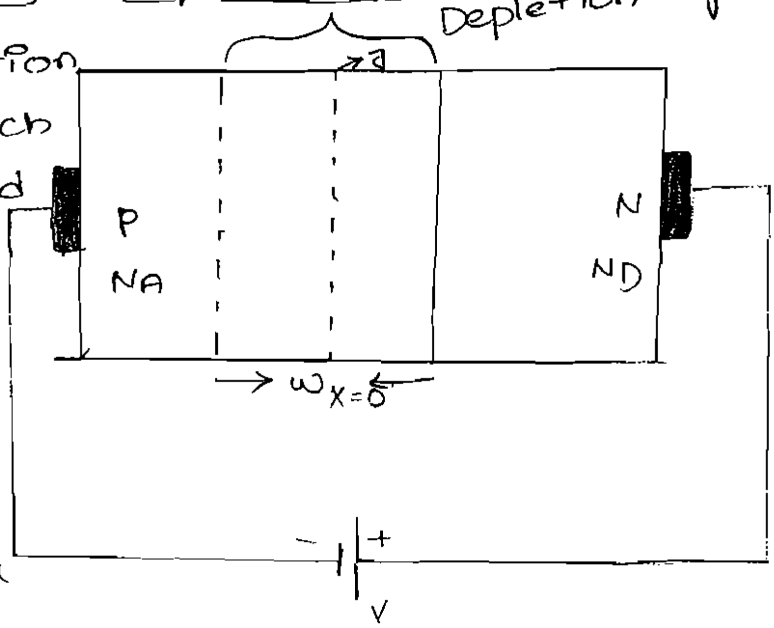
→ So change in charge 'dQ' with respect change in voltage 'dv' is nothing but capacitive effect.

→ Such a capacitance which comes into the picture under reverse bias condition is called transition capacitance & space charge capacitance & barrier capacitance & depletion layer capacitance and is denoted as C_T.

→ The magnitude of C_T is given by

$$C_T = \frac{dQ}{dV}$$

<u>Derivation of transition capacitance</u>



→ consider a PN junction diode the 2 sides which are not equally doped impurity added on one side is more than the other side.

→ Assume p-side is ~~heavily~~ light doped and n-side is heavily doped a depletion layer penetrates lightly doped side. The most of the depletion layer on p-side it is lightly doped as shown in fig(b).

fig(b) Uniqually Doped PN Junction.

→ It can be further assumed the concentration of

Hence width of the depletion layer increase with applied reverse bias voltage. ie $V_B \alpha \omega^2$

$\omega \alpha \sqrt{V_B}$

The total charge density of p-type material with area of junction A is given by

$$Q = eN_A \omega A -$$

No. of charged particle x charge on Each particle

above

Differentiate x Equation w.r.to V we get

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

$$= \left|\frac{d\omega}{dV}\right| eN_A \cdot A$$

$$= AeN_A \left|\frac{d\omega}{dA}\right| \longrightarrow (3)$$

differentiating the above Eqn (2) w.r.to V we get

$$1 = \left[\frac{eN_A 2\omega}{2\varepsilon}\right] \left|\frac{d\omega}{dV}\right|$$

$$\left|\frac{d\omega}{dV}\right| = \frac{\varepsilon}{eN_A \cdot \omega} \longrightarrow (4)$$

Sub eq (4) in (3) we get.

$$C_T = \left|\frac{dQ}{dV}\right| = AeN_A \frac{\varepsilon}{e \cdot N_A \omega}$$

$$= \frac{A\varepsilon}{\omega}$$

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

$$\boxed{C_T \alpha \frac{1}{\omega}}$$

acceptor impurity on p-side (NA) is much less ~~than~~ the donor impurity (ND) on N-side.

→ Hence the width of the depletion region on N-side is neglisable (small) compared to the width of the depletion layer on p-side.

→ Hence the entire depletion ~~regi~~ layer can be assumed to be on the p-side only.

The Relation between potential and charge density is given by poisancy equation as

$$\frac{d^2v}{dx^2} = \frac{eN_A}{\varepsilon} \longrightarrow (1)$$

Integrating equ (1)

$$\iint \frac{d^2v}{dx^2} = \iint \frac{eNA}{\varepsilon} d$$

$$\iint d^2v = \iint \frac{eNA}{\varepsilon} dx^2$$

$$v = eN_A \frac{x^2}{2\varepsilon}$$

At $x = \omega_p = \omega$, $v = v_B$

Where ω = width of the depletion layer.

v_B = Barrier voltage. So we can replace $v_B = v$, $x = \omega_p$

$$v_B = e\,NA \frac{\omega^2}{2\varepsilon} \longrightarrow (2)$$

Here $v_B = v_0 - v$

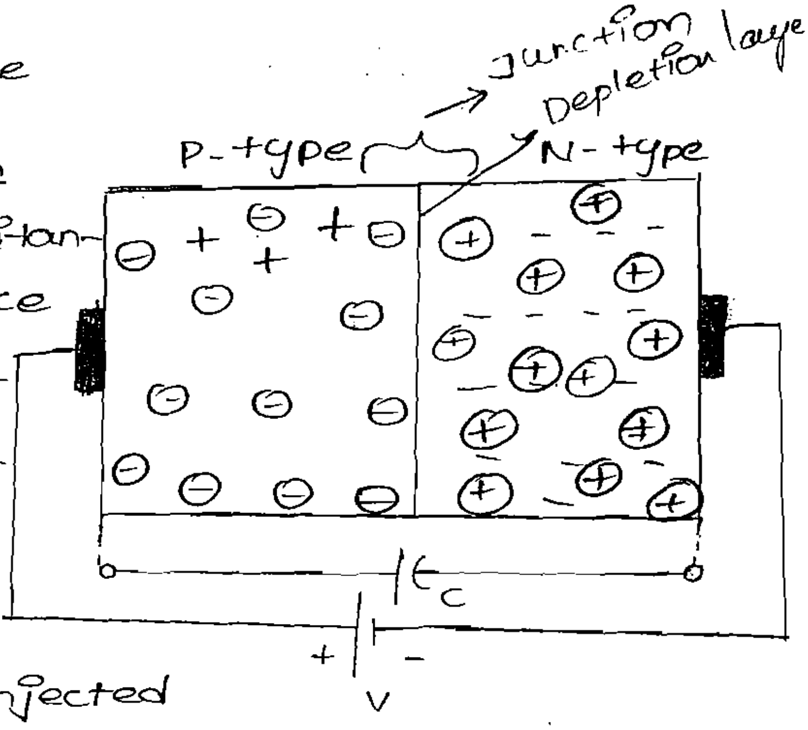
Where v = negative number of an applied reverse bias voltage

v_0 = contact potential.

As C_T increases the width of the depletion layer decreases.

* Diffusion capacitance

→ During forward bias condition other capacitance comes into Existance called Diffusion capacitance or Storage capacitance and denoted by "C_D."



→ It is also defined as the rate of change of injected Charge due to applied voltage forward bias voltage.

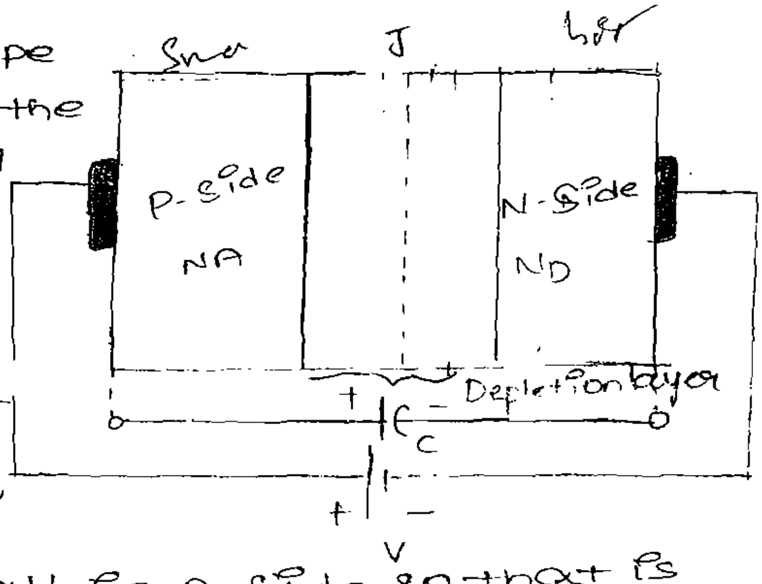
$$\boxed{C_D = \frac{dQ}{dV}}$$

Where dQ = change in the no. of minority carriers stored outside the depletion layer.

dV = change in voltage across the diode.

Derivation of Diffusion capacitance

→ Let us Assume the p-type material is one side of the diode is heavily doped in comparision with n-side since the holes moves from the P to N side. The hole current $I = I_{pI} P_n(0) + I_{n} P(0)$. So,



depletion layer is small in p-side so that is negligible.

$I = I_{P_n}(0)$

→ The excess minority charge Q is existing on the n-side is given by

$$Q = L_p A_e P_n(0)$$

Where L_p = Diffusion of lenght of depletion layer

A_e = Area of cross section of Junction

Differentiating the above Eqn we get

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

$$= \frac{d}{dV}(L_p A_e P_n(0))$$

$$C_D = A_e L_p \frac{d}{dV}[P_n(0)] \longrightarrow (1)$$

We know that the diffusion whole current in n-side $I_{P_n}(x) = \frac{A_e D_p P_n(0) e^{-x/L_p}}{L_p}$

→ The hole current crossing the junction into the n-side with $x=0$ ie

$$I_{P_n}(0) = \frac{A_e D_p P_n(0)}{L_p}$$

$$\therefore I = \frac{A_e D_p P_n(0)}{L_p} \quad \text{(n side is neglisable).}$$

$$P_n(0) = \frac{I L_p}{A_e D_p}$$

Differentiating the above Eqn w.r.to V we get

$$\frac{d}{dV}[P_n(0)] = \frac{dI}{dV} \frac{L_p}{A_e D_p} \longrightarrow (2)$$

Substitute Equ (2) in Equ (1)

$$C_D = \cancel{Ae} L_P \frac{dI}{dV} \times \frac{L_P}{\cancel{Ae} D_P}$$

$$C_D = \frac{dI}{dV} \frac{L^2 P}{D_P}$$

$$C_D = g . \tau$$

where $\tau = \frac{L^2 P}{D_P}$

$$g = \frac{dI}{dV}$$

→ from Diode current Equation $g = \frac{I}{\eta \cdot V_T}$

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

where τ is the mean life time for holes and Electrons.//

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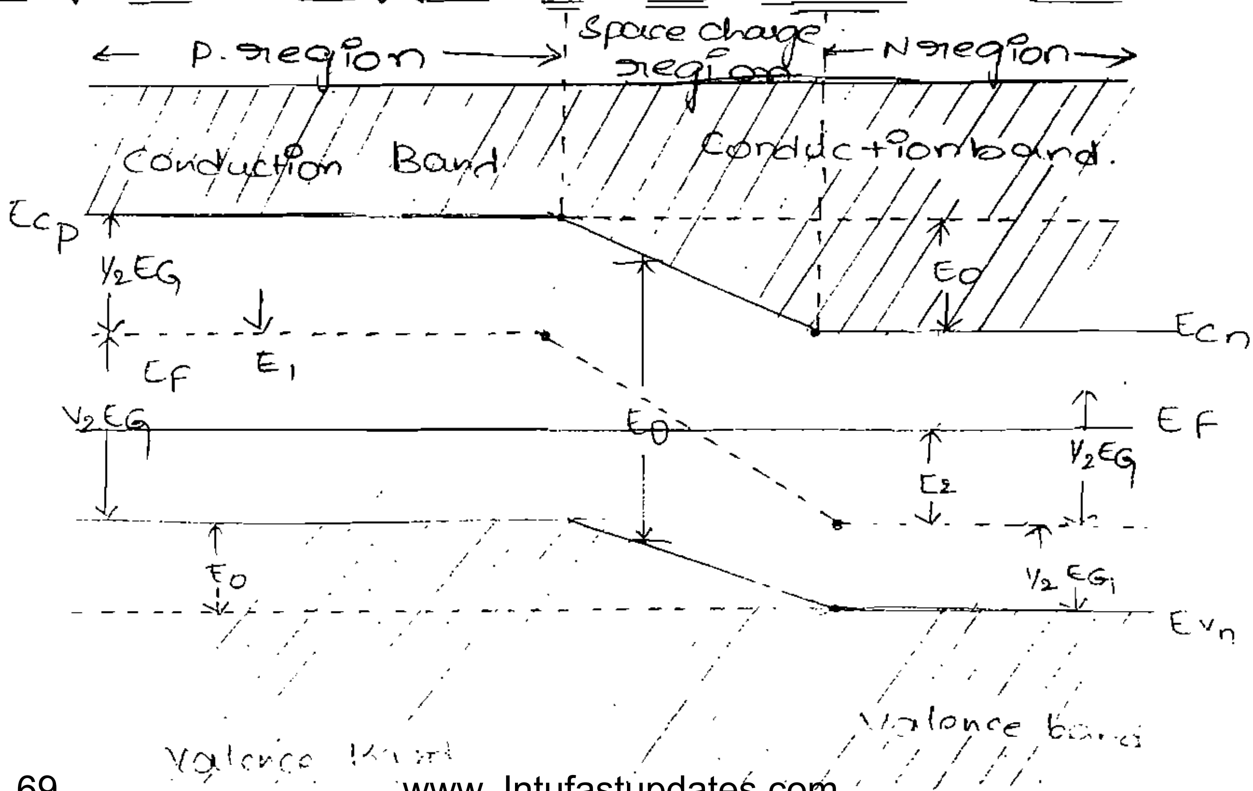
Energy band diagram of P-N Junction Diode



→ Consider a PN Junction diode in close physical contact at the Junction on atomic scale hence the energy band diagram of these two regions undergo relative shift to Equalize the fermi levels.

→ The fermi level E_F should be contact throughout the speciman at equilibrium the distribution of Electrons and holes in allowed energy states is dependent on the position of fermi levels.

Table -
Ideal vs practical →

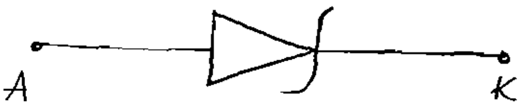
Ideal v/s Practical Characteristics:

S.NO.	Parameter	Symbol	Units	Ideal Diode	Practical Diode
1	forward resistance	R_f	Ohms(Ω)	Zero(0)	In the range of $10\Omega - 100\Omega$
2.	Reverse resistance	R_r	Ohms(Ω)	Infinity	In the range of $k\Omega$ - MegaΩ
3.	cut in voltage	V_γ	volts.	Zero.	for Ge - 0.3V silicon - 0.7V
4.	Total capacitance ($C_T + C_D$)	$C(C_T+C_D)$	faradays	zero.	Tipically 2 pico faradays
5.	Reverse recovery type	t_{rr}	Seconds	zero.	Tipically 4 nano Seconds
6.	Reverse breakdown voltage.	V_{BD}	Volts.	Infinity(∞)	Tipically 75V.
7.	Reverse current	I_r	Amperes	zero.	Tipically 100 micro Amperes.

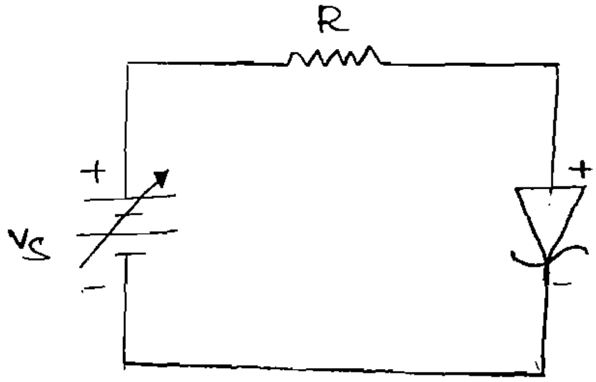
5

* Special Diodes

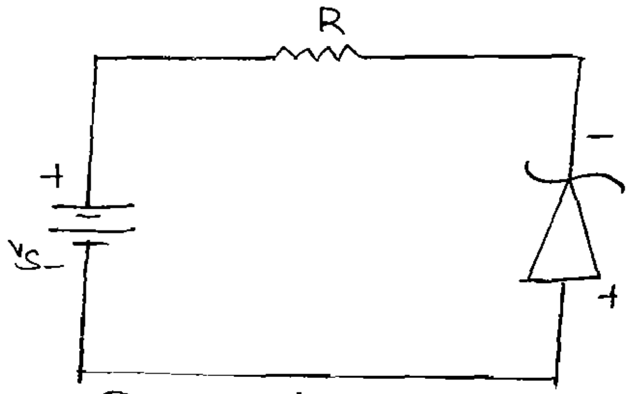
* 1. Zener Diode



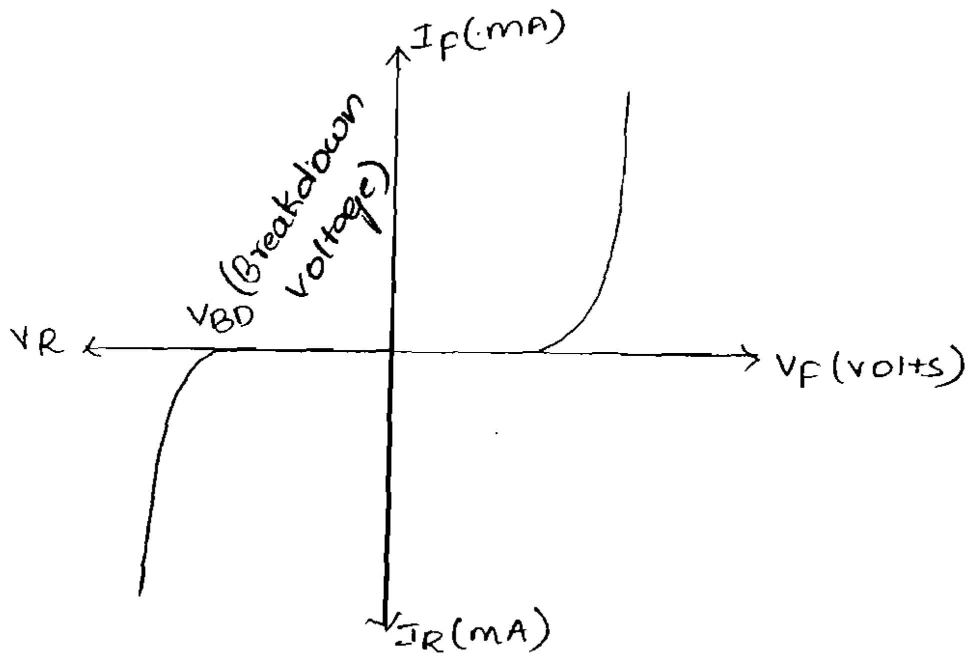
Symbol of Zener Diode.



Forward bias condition



Reverse bias condition



V-I Characteristics of Zener Diode

→ When reverse voltage reaches breakdown voltage in normal PN Junction diode the current through the junction and power decipated at the junction will be high such an operation is destructive and diode gets damaged.

→ Whereas diodes can be designed with adequate power decipation capabilities to operate in the breakdown voltage. One such a diode is known as 'Zerner Diode'.

→ Zerner Diode is a heavily doped than the ordinary diode from the V-I characteristics of zerner diode shown in above fig. It is found that the operation of zerner diode is same as the ordinary PN junction diode under forward bias condition.

→ Where as on under reverse bias condition breakdown of the junction occurs the breakdown voltage depends upon the amount of doping.

→ If a diode is heavily doped depletion layer will be thin and breakdown occurs at low reverse voltage is sharp. Whereas a lightly doped diode has higher breakdown voltage. (<6V)

→ The sharp increase in current under breakdown conditions are due to the following two mechanisms.

1. Avalanche breakdown. — thermal
2. zerner breakdown.

It is ~~used~~ act as a voltage regulator.

Zener diode Applications: (***) S.A

→ zener diode acts as a voltage regulator.

fig (a) symbol

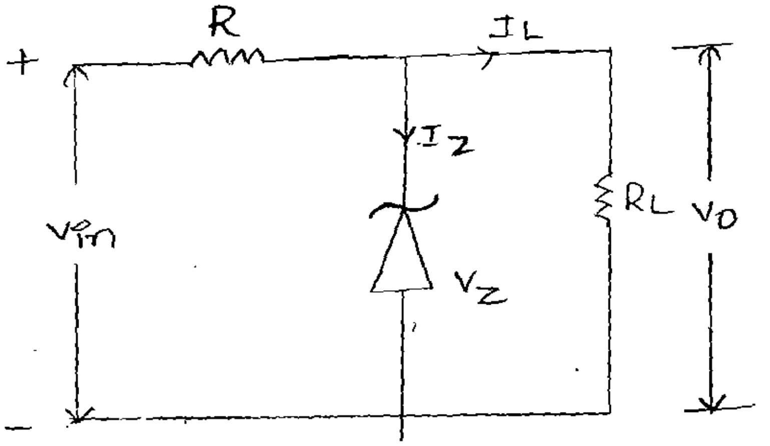


fig b As a voltage Regulator

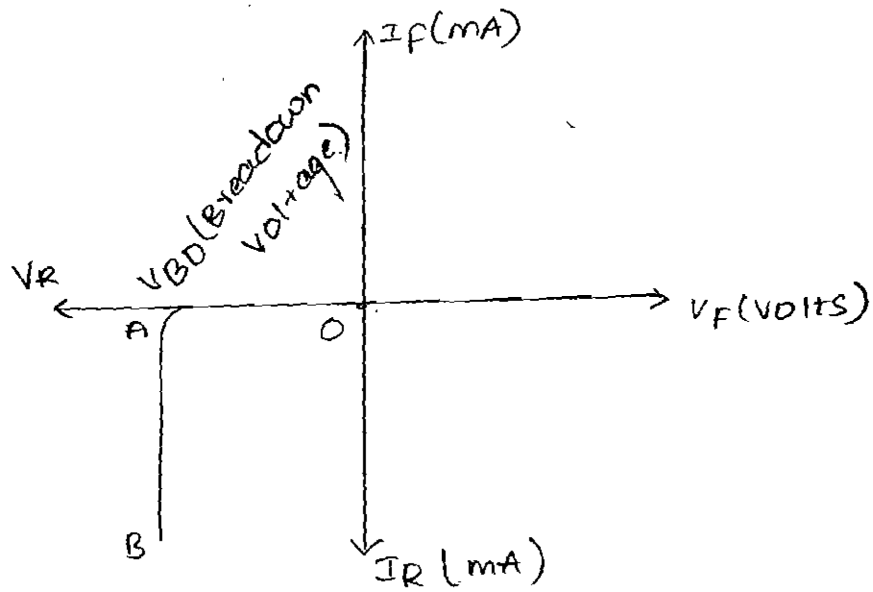


fig c V-I characteristics of Zener Diode for Reverse Bias Condition

→ zener characteristics shown in fig c under R. Bias condition the voltage across the diode remains constant and current through the diode increases as shown in region AB. Thus the voltage across zener diode serve as a reference voltage. Hence the diode can be used as voltage regulator.

→ In fig(b) it is required to provide constant voltage across load resistance (R_L) whereas its voltage may varying over a range as shown zener diode is reverse biased and as long as the input voltage does not fall below V_Z, the voltage across the diode will be constant and hence the load voltage will also be constant.

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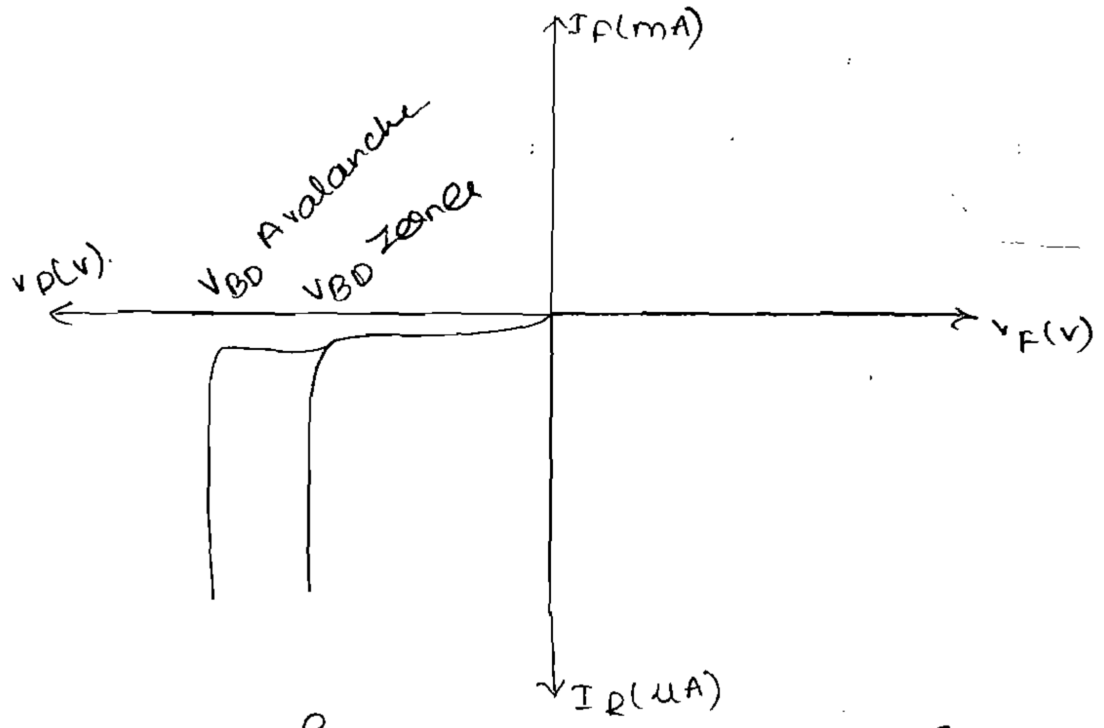
Breakdown Mechanism (S.A)(***)



fig(a) Breakdowns in PN Junction Diode.

→ Breakdown mechanisms

→ The diode enters the breakdown region, when the magnitude of the reverse voltage exceeds a threshold value ie specific to the particular diode called the "breakdown voltage".

→ The breakdown region for very small variation in voltage the current increases rapidly.

→ There are 2 types of breakdowns mechanisms.

1. Avalanche Breakdown
2. Zener Breakdown

1. Avalanche

→ In this mechanism thermally generated electron hole pairs gains energy from the external voltage is applied and breaks the covalent bonds to produce new electron hole pairs. This new electron pairs in-turn generates more electron hole pairs by disrupting ones bonds and the process continues cumulatively. This cumulative process is known as Avalanche breakdown.

→ It results in the flow of large reverse current and the diode finds itself in the region of Avalanche breakdown.

$$M = \frac{1}{1 - \left(\frac{V}{V_{BD}}\right)^n}$$

M = barrier multiplication factor

V = Applied reverse voltage.

V_{BD} = Reverse breakdown voltage.

n = Emperical Constant. for n-type Si is n = 4
for p-type Si n = 2.

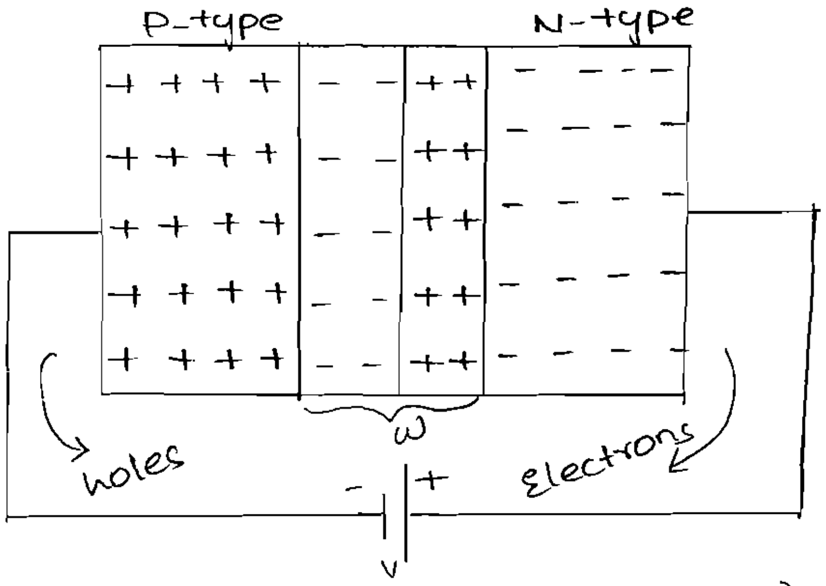
Zerner Breakdown

→ In this mechanism, electron hole pairs are generated by applying strong electric field because of the presence of strong electric field direct rupture of covalent bonds takes place.

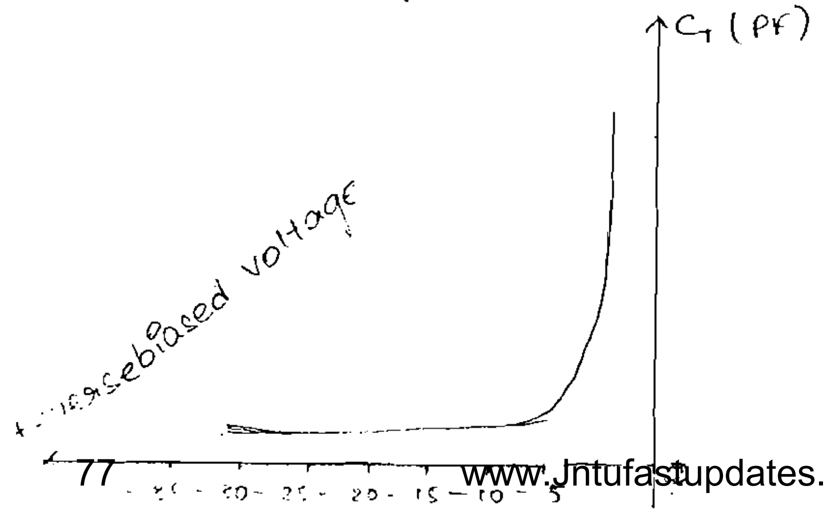
→ Due to this new electron hole pairs are generated the breakdown occuring due to application of strong electric field is known as "zerner breakdown."

*Varactor Diode

fig (a) Symbol of varactor



→ fig(b) : Depletion region in a reversebiased condition



fig(c) : Characteristics of varactor Diode

→ The varactor also called a varycap or Tunning or Voltage variable capacitor diode is also a junction diode with a small impurity doped at its junction.

→ When any diode is reverse biased a depletion layer is formed as shown in fig(b). When reverse bias voltage is increased the depletion layer width(ω) becomes wider.

→ When reverse bias voltage is decreased the depletion layer width(ω) becomes narrower. The depletion region is devoide of majority carriers and acts like an insulator preventing conduction between n and p region. of the diode, just like a di-electric which separates the two plates of a capacitor.

→ * The transition capacitance (C_T) Varies inversely to the reverse voltage as shown in fig(c) consequently an increase reverse bias voltage will result in an increase the depletion layer or region width and subsequent decreases in C_T.

→ At 'zero Volts' the varactor depletion region is small and the transition capacitance (C_T) is larger at approximately at 600PF.

→ When the reverse bias voltage across the varactor 15V the capacitance 300PF.

Applications of varactor Diode

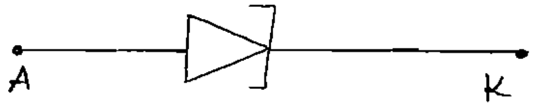
→ varactor diodes are used in FM radios, TV receivers AFC circuits and adjustable band pass filters.

→ In tuning of LC resonance circuit in microwave frequency multipliers and in very low noise microwave parametric amplifiers.

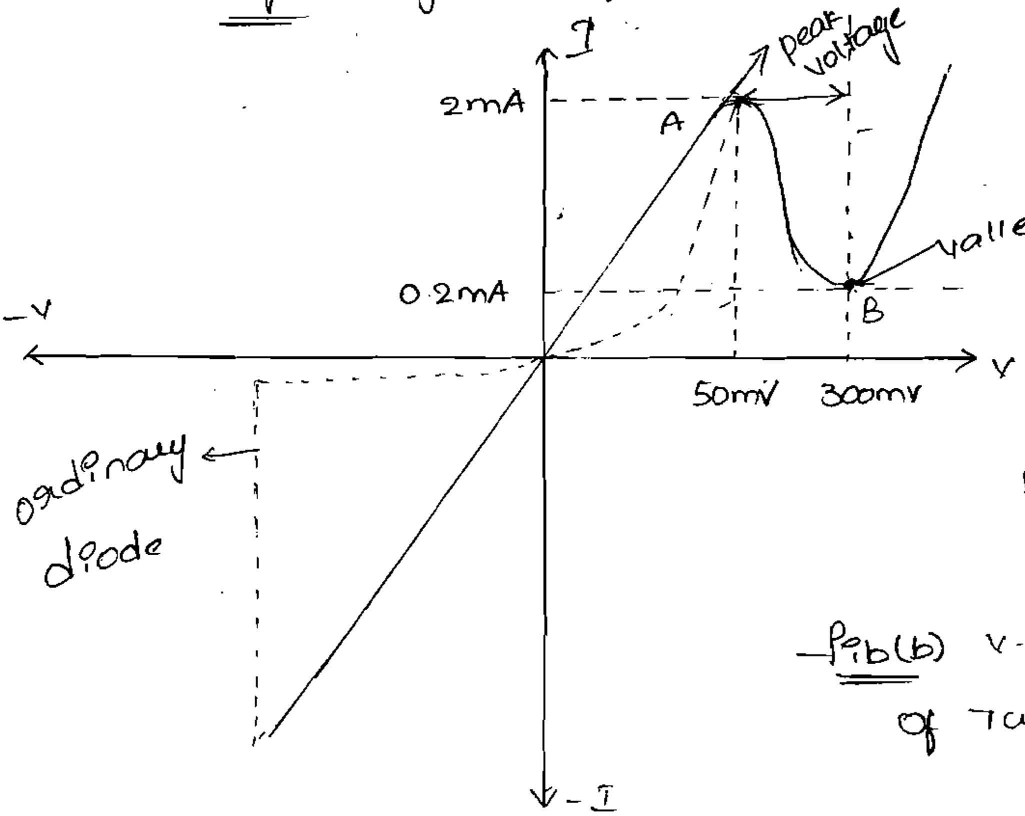
(19)

* Esaki/Tunnel Diode (Mid).

by Leo Isaki.



fig(a) Symbol of Tunnel Diode

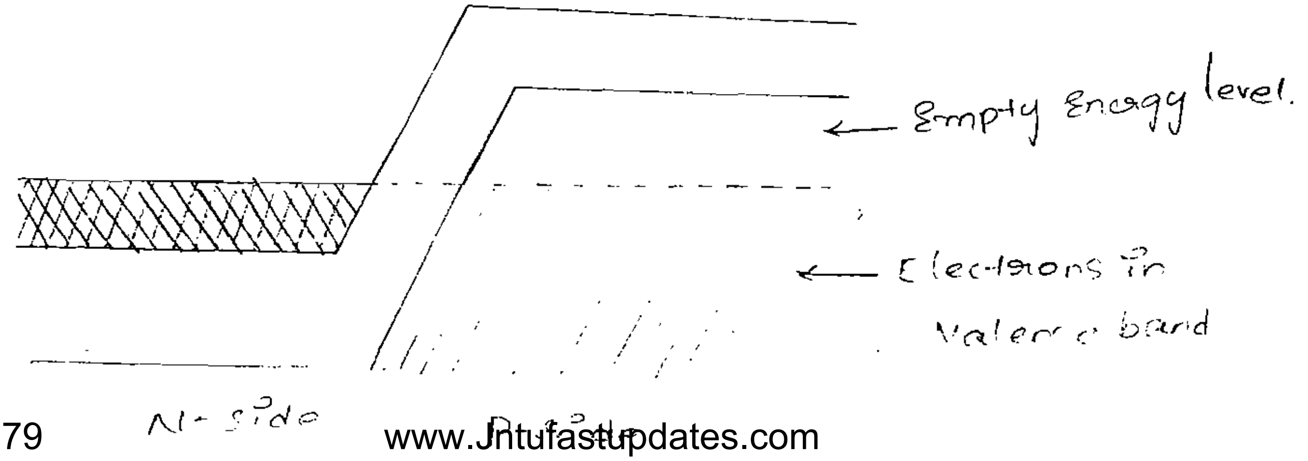


F.B↑ F.V↓

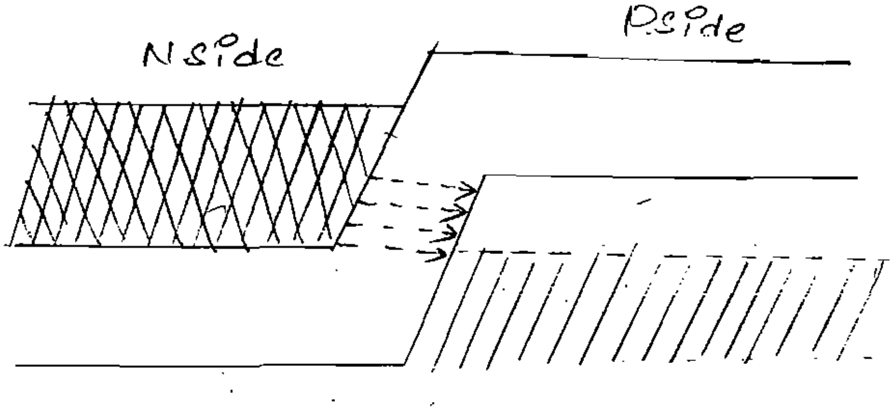
fig(b) V-I Characteristics of Tunnel Diode.

Energyband diagrams of Tunnel Diode.

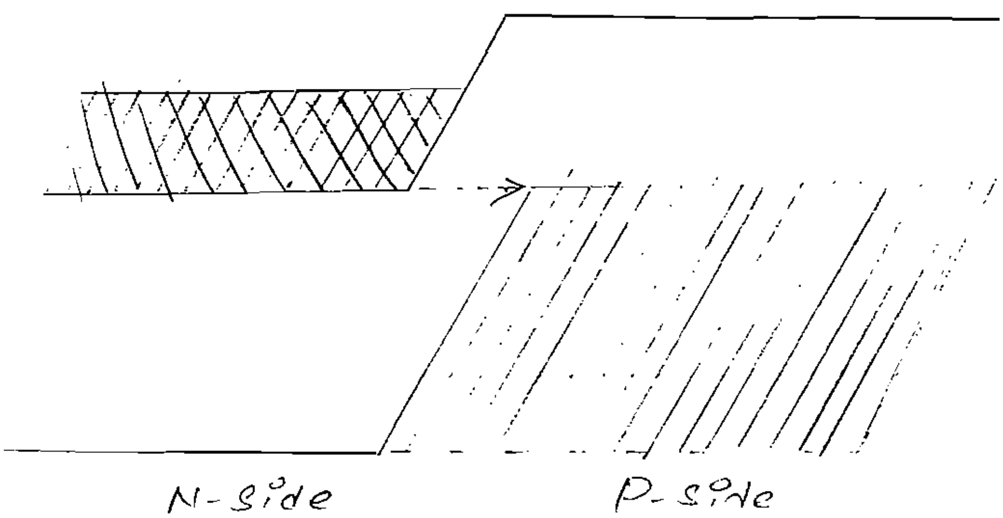
fig(c): zerobias voltage Electrons in conduction band.

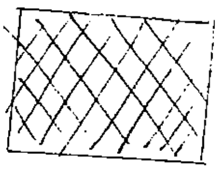


fig(d) peak voltage

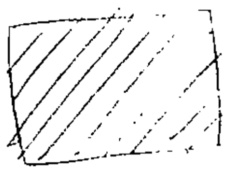


fig(e) valley voltage

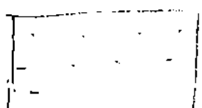




It Shows Energy States occupied by the Electrons in the conduction band.



It Shows Energy States occupied by the Electrons in the valency band.



Side of Junction

It Shows Energy [illegible] the Energy states

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(20)

→ A normal p-n junction has impurity concentration of about 1 part in 10^8 this much amount of 5 microns.

→ The diode in which the concentration of impurity atoms is greatly increased upto 1 part in 10^3 to get completely changed characteristics are called as "Tunnel diode".

→ These diodes are introduced by Leo Esaki. These diodes are also known as Esaki diodes.

→ In Tunnel diodes the doping level is very high the width of the depletion layer is very thin. So there is a large probability then the an electrons will penetrate through the barriers. This known as Tunneling of electrons. Hence this high impurity density pn junction devices are called Tunnel Diodes.

* The V-I characteristics for a typical germanium of tunnel diode.

→ It is seen that at first forward current raises sharply as applied voltage is increases, where it would have risen slowly for ordinary pn-junction diode.

→ Also reverse current is much larger for comparably back bias then in other diodes due to the thiness of p-n junction.

→ The interesting portion of the characteristics starts at the point on the curve ie the peak voltage

→ As the forward bias is increased beyond this ... drops and continous to draw until point B is reached this the voltage called valley voltage.

→ The V-I characteristics of Tunnel diode illustrates that it exibits dynamic resistance b/w A and B

→ Figure c,d,e shows Energy level diagram of the tunnel diode for 3 interesting bias level.

- When the bias is 'zero' these lines are at the same height unless energy is imparted to the electrons from some external source.

d) → When a small forward bias applied to the junction the energy level of the p-side is lower as compared with the N-side.

e) → When the forward bias is raised beyond this point tunneling with decreases as shown in fig(e).

Applications of Tunnel Diode

→ Tunnel diode is used as an ultra high speed switch with switching speed of order of nano seconds or pico seconds.

→ As logic memory storage device.

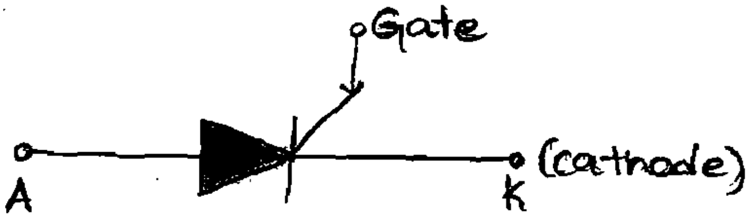
→ As microwave oscillator.

→ As Relaxation oscillator circuit.

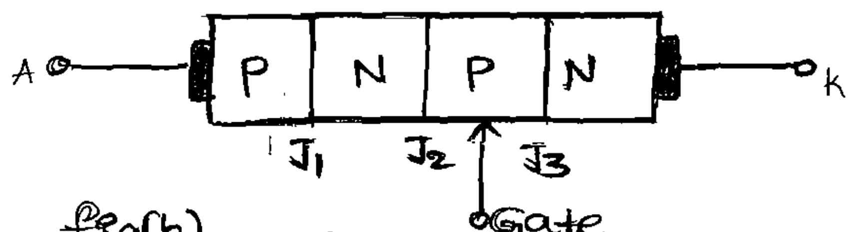
→ As an Amplifier.

* Silicon controlled Rectifier/current control Rectifier (SCR)

(21)



fig(a) circuit symbol of SCR



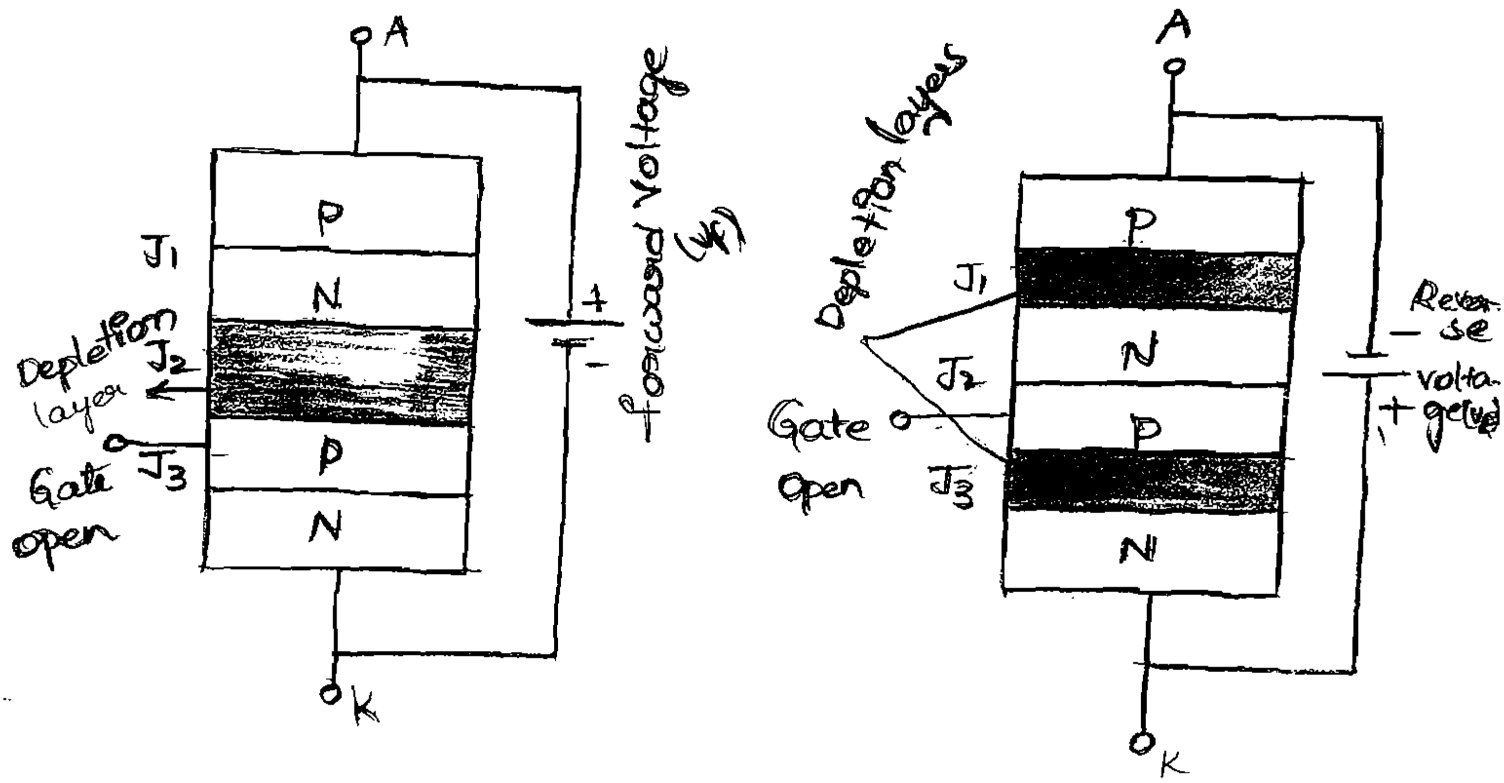
fig(b) Basic structure of SCR

Operation of SCR

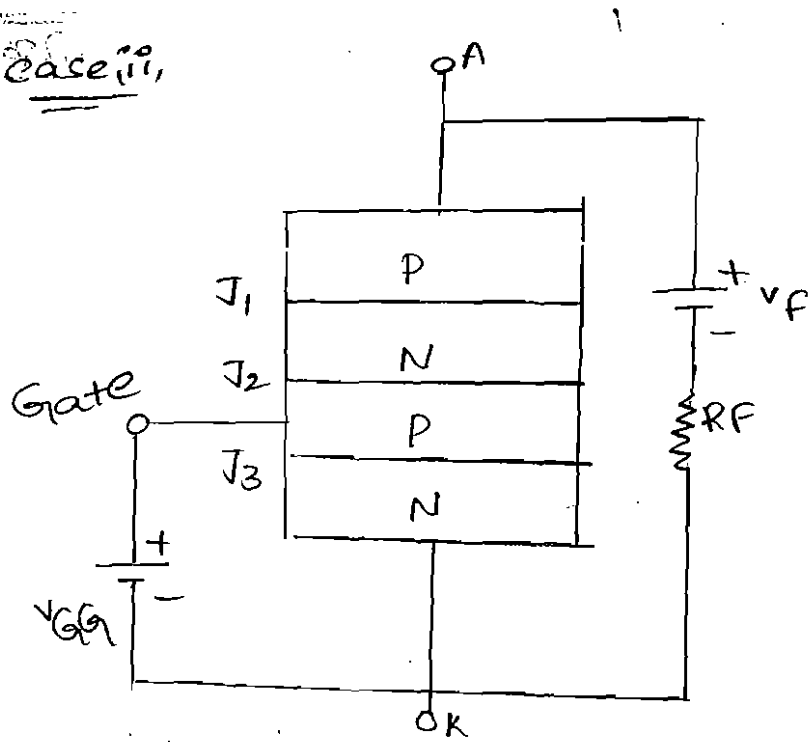
case (i) : Gate open

Forward blocking state

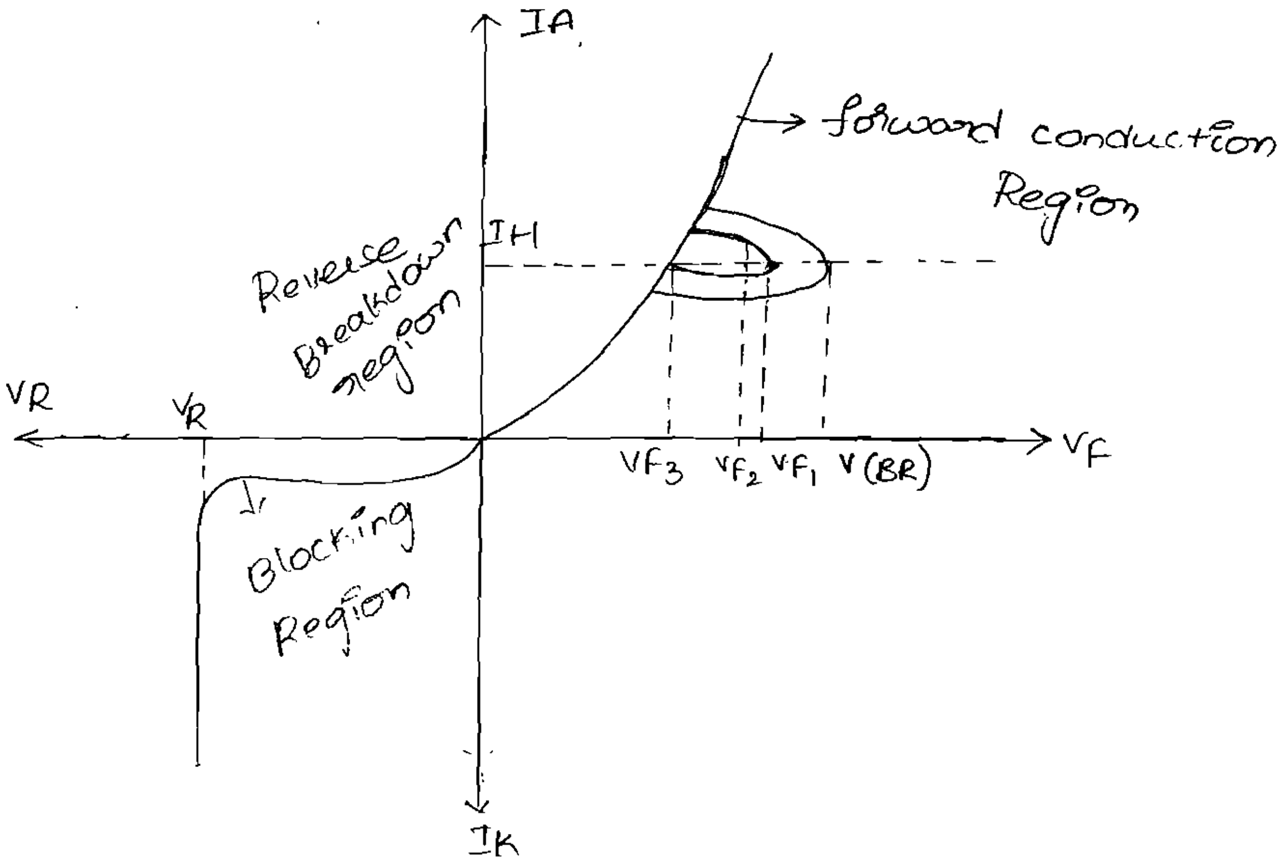
Reverse blocking state



Case iii,



SCR characteristics



→ The outer p layer acts as a anode and outer n layer as a cathode and inner p-layer acts as gate.

→ SCR is a 4 layer 3 terminal diode having 3 PN-junctions.

→ As reverse lekage current in silicon is very small compared to germanium so SCR is made of silicon.

→ In order to turn on SCR with the appliedtion of forward voltage some gate current has to flow through the device.

→ The SCR is depending upon gate current we can name SCR is current controlling devices.

→ Once if SCR is turned on when we can remove the voltage applied across the gate which is used to produce gate current.

Operation of SCR

→ ~~case~~ with gate open

→ In the above fig junction J_1 and J_3 are forward bias and J_2 is Reverse bias Even-though the forward voltage is applied to SCR as a gate terminal is opened. SCR will be in off state.

→ Only a small amount of reverse lekage current flows through the device the state of SCR is known as forward blocking state.

→ In the above fig the junction J_1 and J_3 are ~~FB~~ reverse bias and J_2 is ~~forward~~ bias (FB) because of the applied of reverse voltage to the SCR Eventhough J_2 forward biased as the gate is opened SCR will be in off state only.

→ A small amount of reverse leakage current flows through the device the state of SCR is known as Reverse blocking state.

NOTE:- If we Consider the forward blocking state of SCR & if we increase the forward voltage then the reverse bias applied to J_2 increases then a large reverse leakage current flows through the device the voltage at which there is a rapid increase in reverse leakage current is called "forward breakover voltage". (VBO)

Case(ii) :- Gate Closed

→ forward voltage is applied across anode & cathode +ve voltage is applied to gate. J_3 is forward biased so forward bias current I_{GG} flows across the junction J_3 then SCR will turn on as the width of the depletion region J_2 decreases.

→ As the depletion layer width reduces some current will cross the junction J_2 so the forward current of device(I_A) will be increased.

→ AS I_a increases the depletion region width further decreases increasing the carriers which crosses junction J_2, which again increases anode current. Hence increment in the current I_a takes place.

→ Once SCR is turn on gate looses its control in order to control this much high current I_a External resistor has tobe used.

Characteristics

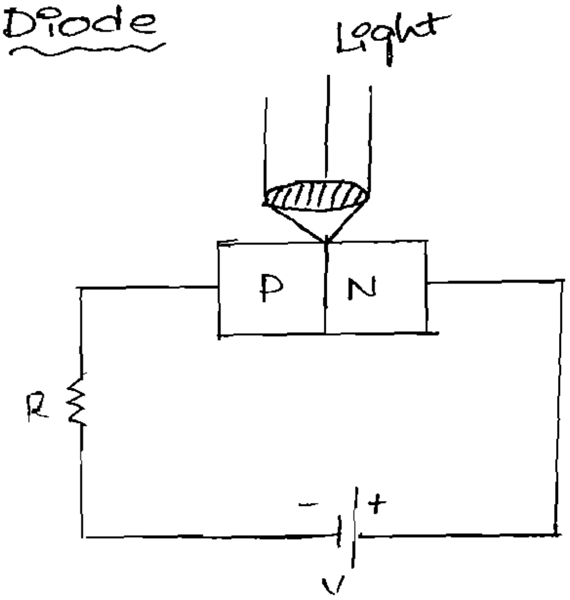
As shown in above figure, characteristics of SCR forward makeover voltage is that voltage about which the SCR enters the conduction region.

→ Holding current (I_H) is that value of current below which the SCR switches from the conduction state to forward blocking region.

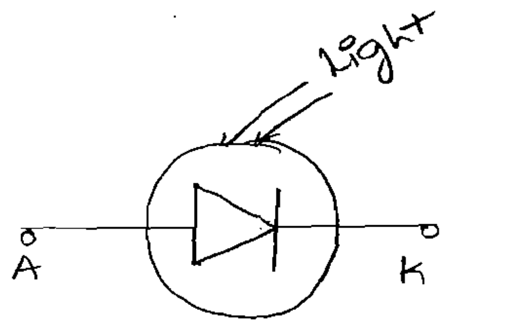
Application of SCR

1. It is used in water control.
2. It is used in heater control.
3. It is used in battery charges.
4. It is used in Inverters.
5. It is used in RPS (Regulated power supply).
6. It is used in Static switch.

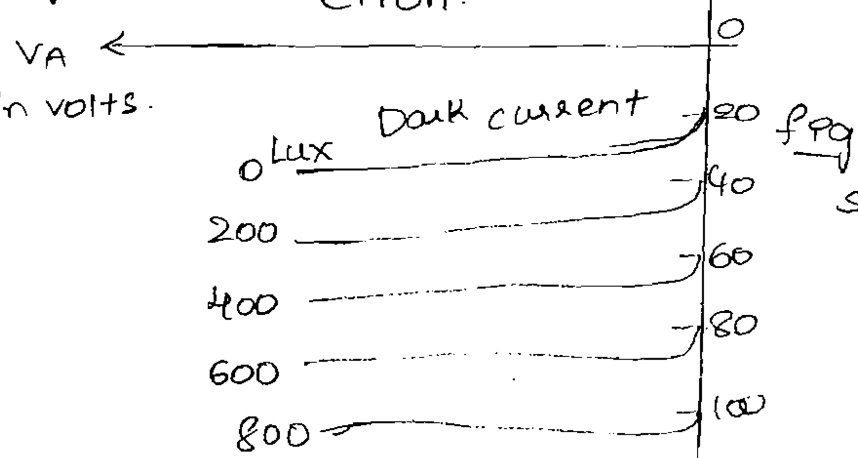
* Photo Diode



fig(a) photo Diode construction.



fig(b) symbol of photo Diode



fig(c) characteristics of photo Diode

→ Silicon photodiode is a light sensitive device & also called photo detector which converts light signals into Electrical signal.

→ The Diode is made of a semiconductor PN junction kept in a sealed plastic or glass casing the coverage designed that the light rays are allowed to fall on the surface across the junction the remaining sides of causing are painted to restrict the penetration of light rays.

→ A lense permits light to falls on the junction when light falls on the reverse biased PN photo diode junction, hole electron pairs are created of these hole electron pairs in a properly connected circuit results in current flow.

→ The magnitude of the photo current depends on the no. of charge carriers generated and hence on the illumination of the diode element.

→ The magnitude of the current under large reverse bias condition is

$$I = I_s + I_a\left[1 - e^{V/\eta V_T}\right]$$

where

I_s = Short circuit current

→ The characteristics of photo diode shown in fig(c) the reverse current increases in direct proportion to the level of illumination even when no light is applied there is a minimum ~~the~~ Reverse lekage current called Dark current flowing through device.

→ Germanium has higher dark current when silicon, but it also has high level of reverse current.

Applications of photo Diodes

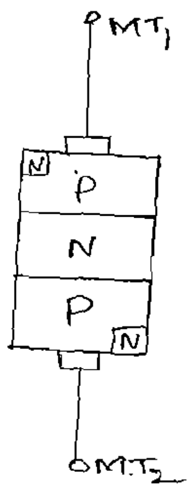
→ photodiodes are used as light detector, demodulator and Encoders.

→ They are used in optical communication system

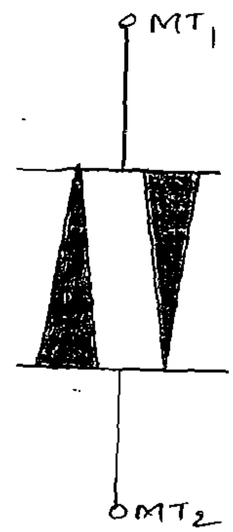
→ High speed counting & switching circuits.

→ sound track films & Electronic control circuits.

* DIAC (Diode AC switch).

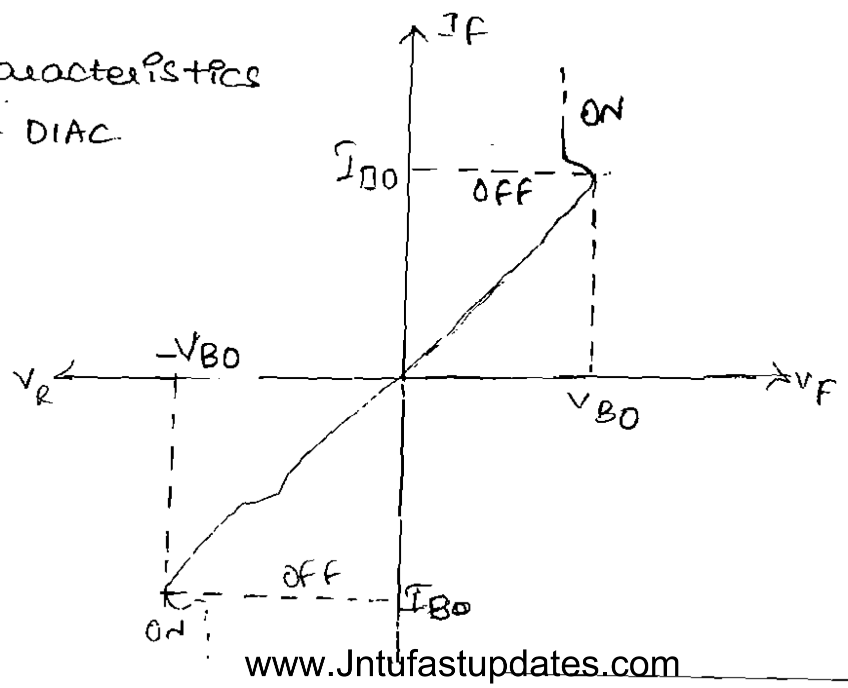


fig(a): DIAC Bias Structure



fig(b): DIAC circuit symbol

fig(c): Characteristics of DIAC



→ It is a 3 layer 2 terminal semiconductor device, MT_1 & MT_2 are the 2 main terminals which are interchangable it acts as a bidirectional diode.

→ It does not have any control terminals it has 2 junctions J_1 and J_2 the central layer is free from any connection with the terminals.

→ from fig(c) it act as a switch in both directions has doping levels at the 2 ends of the device. is the same, the DIAC has identical characteristics for both +ve and -ve half of an AC cycle

→ During +ve half cycle Empke MT_1 is +ve w.r.to MT_2 where as MT_2 is +ve w.r.to MT_1 in -ve half side.

→ And the voltage less than the breakover voltage a very small amount of current called the leakage current flows through the device and the device remains in the Off state.

→ When the voltage level reaches breakover voltage the device start conducting and wit exibits -ve resistance characteristics.

Applications

→ Light Dimming.

→ Motor ~~field~~ speed control.

→ heater control.

* UJT (Uni Junction Transistor)

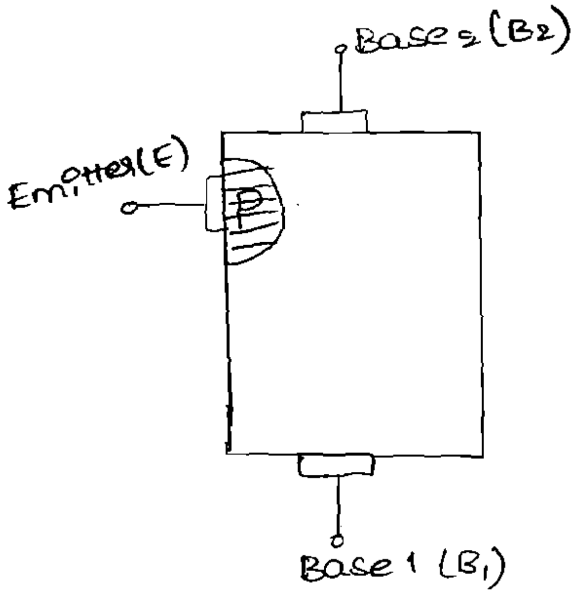
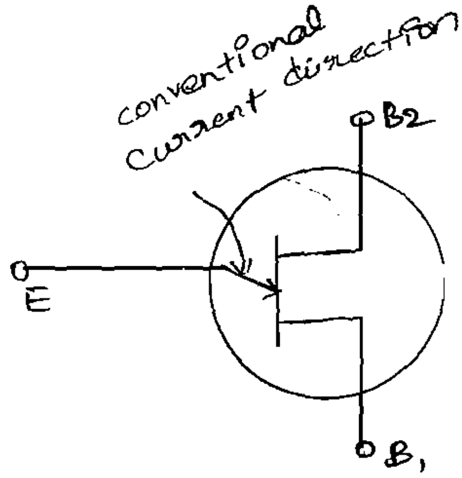
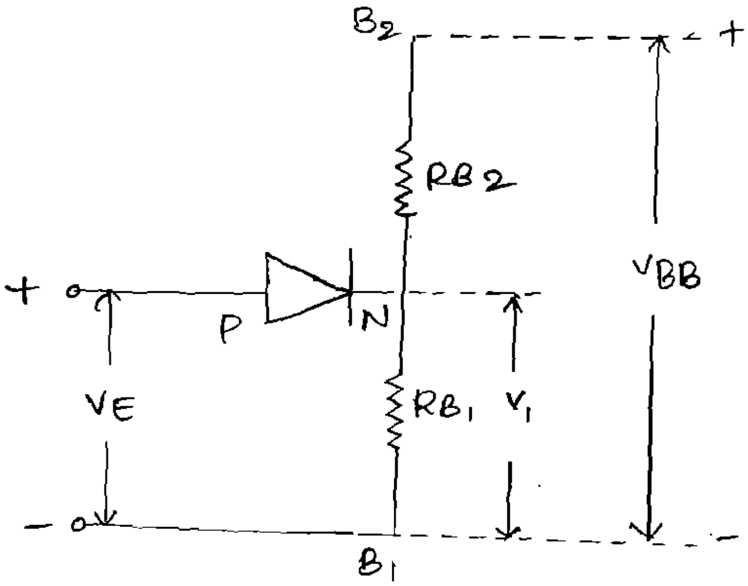


fig (a) : UJT Basic structure



fib (b):- UJT circuit symbol

N-type-RB



fig(c) UJT equivalent Circuit

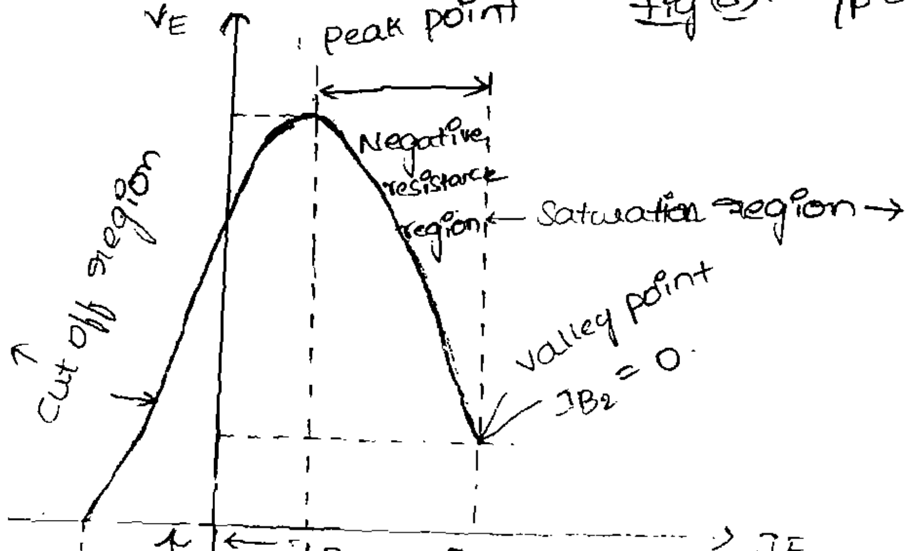


fig (d):- I/p characteristics of UJT

→ UJT is a 3 terminal devisc switching device. It has only one PN junction and 3 leads. It is commonly called as uni junction transistor

→ It consists of lightly doped N-type silicon bar with a heavily doped p-type materials alloyed to its one side closer to B_2 for producing single PN junction.

→ The circuit symbol of UJT has shown in fig(b) Here the Emitter lead is drawn at angle to the vertical and the arrow indicates the direction of the conventional current.

Operation of UJT

→ Referring to fig(c) the interbase resistance b/w B_2 & B_1 of the silicon bar is $R_{BB} = R_{B_1} + R_{B_2}$.

→ With Emitter terminal open if voltage V_{BB} is applied b/w the 2 bases a voltage gradient is Established along the N type bar.

→ The voltage drop across R_{B_1} is given by $B_1 = \eta V_{BB}$

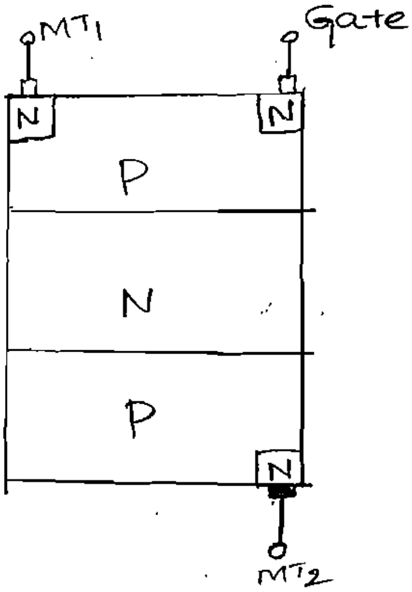
where intrensic stand off ratio $\eta = \frac{R_{B_1}}{R_{B_1} + R_{B_2}}$

Where $\eta \simeq 0.56 - 0.75$

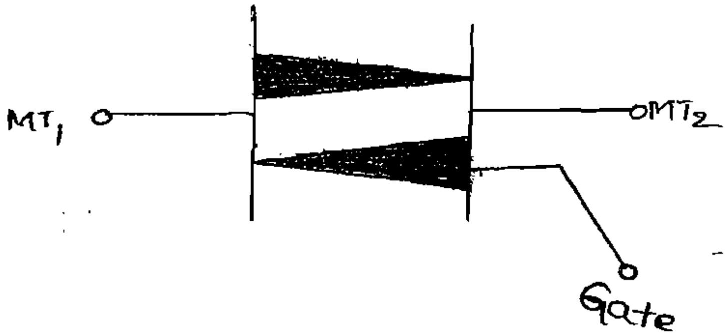
This voltage V_1 reverse biases the PN junction and Emitter current is cut off but small lekage current flows from B_2 to Emitter due to minority carriers.

→ If possibletive voltage V_{BE} is applied to the Emitter the PN junction will remind reverse biase biased long as $V_E < V_1$

*TRIAC (Triode AC Switch).

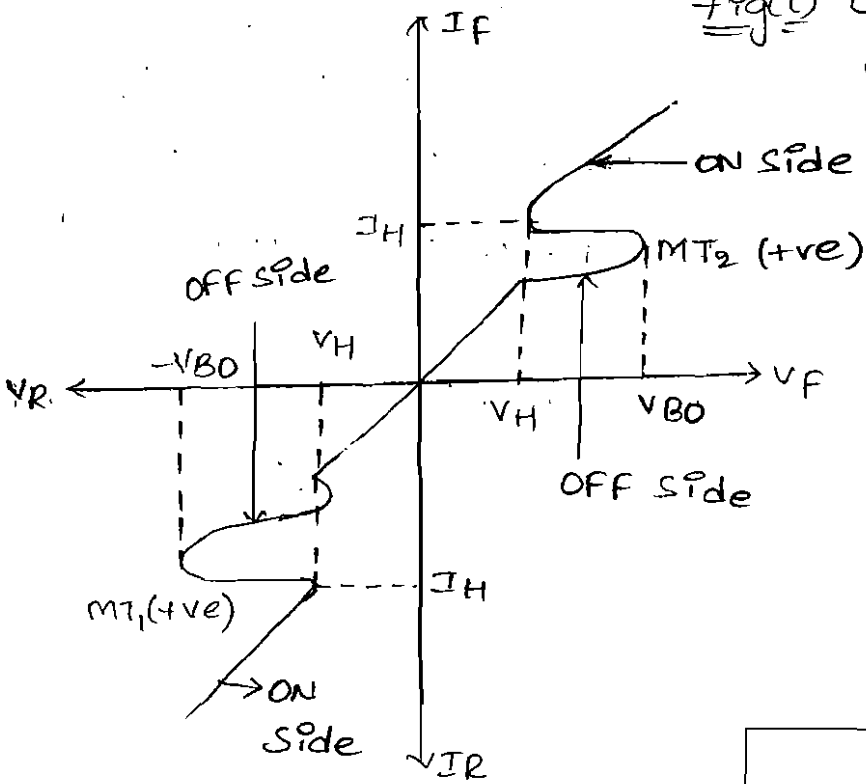


fig(a): TRIAC Basic Structure

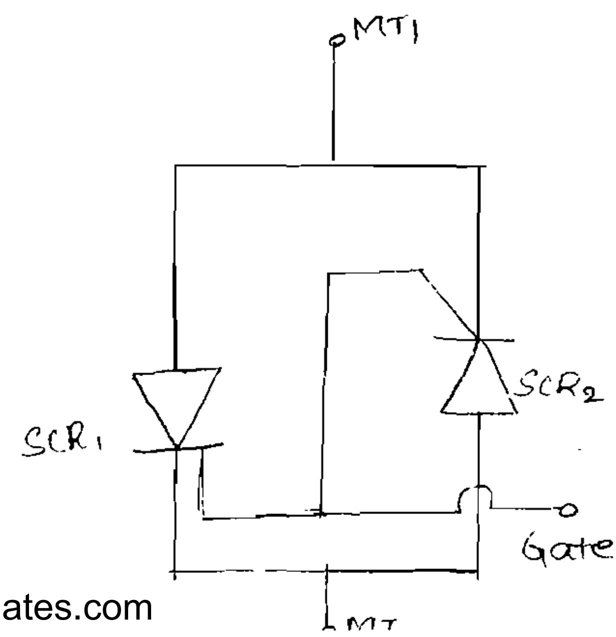


fig(b) TRIAC circuit symbol.

fig(c) Characteristics of TRIAC



fig(d) Equivalent circuit



→ If V_E Exceeds V_1 by the cut in voltage V_γ the diode becomes forward bias so Emitter current I_E is increased and limited by V_E.

→ The device is now in ON state.

→ The -ve voltage is applied to the Emitter PN junction remains reverse biased and the Emitter current is cut off the device is in OFF state.

Characteristics

→ The peak point P the diode is reverse biased and hence the region to the left of peak point is called cut-off region.

→ At P the peak voltage $V_B = \eta V_{BB} + V_\gamma$

→ The diode starts conducting and holes are injected into n layer. Hence resistance decreases there by decreasing V_E for the ~~decreases~~ increase in I_E.

→ There is -ve resistance region from peak point to valley point.

→ The region to the right of the valley point is called saturation region. The valley point the resistance changes from -ve to +ve.

Applications

1. Sawtooth wave generator
2. Pulse generator.
3. Switching timing circuit.
4. Phase control circuits.

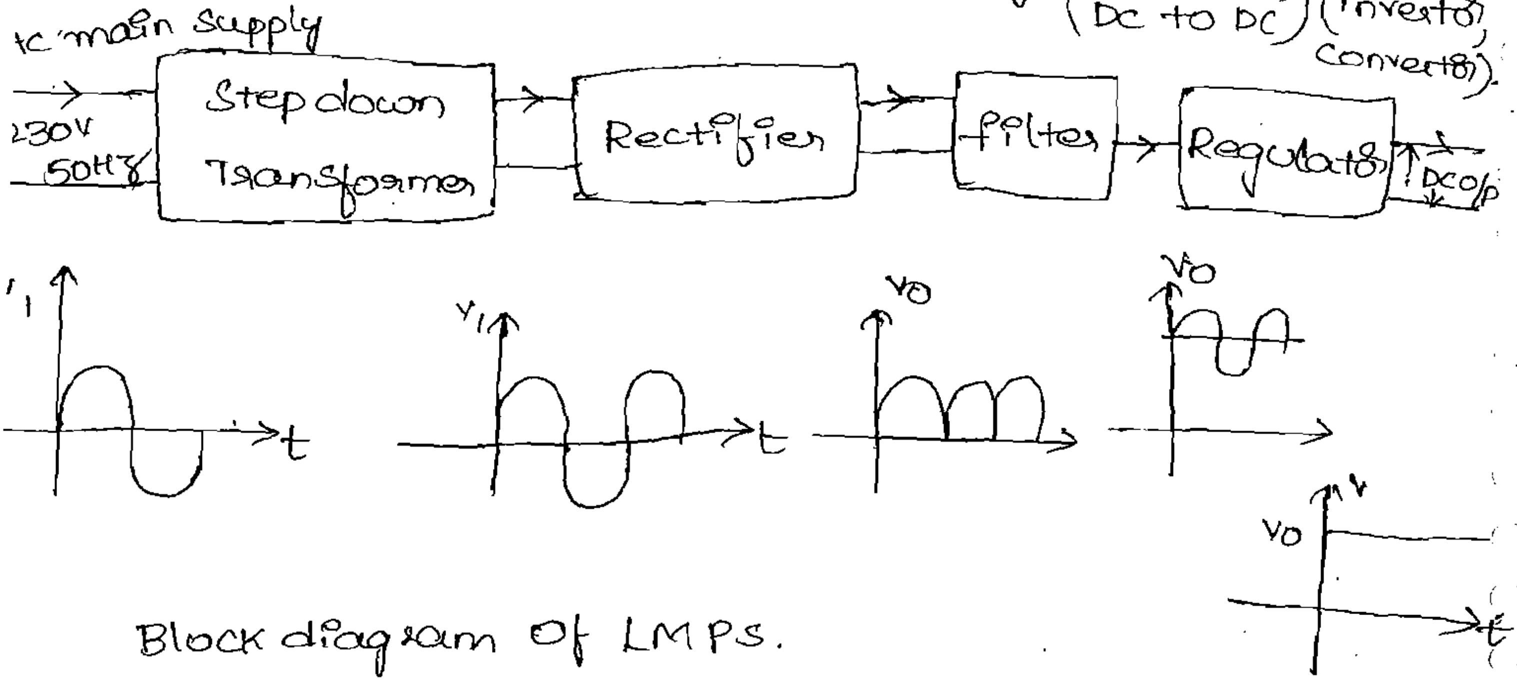
9/7/16

UNIT-3

Rectifiers & filters

→ LMPS - Linear Mode power supply (Ac to Dc). Converter

→ SMPS - Switch mode power supply (Dc to Ac) (Dc to DC) (inverter, converter).



Block diagram Of LMPS.

PN Junction Diode

→ A PN junction is a 2-terminal device. ie polarity sensitive.

→ When the diode is forward biased the diode conducts and allows current to flows through it without any resistance. ie the diode is ON.

→ When the diode is reverse biased the diode does not conducts no current flows through it that is diode is off.

→ Thus an ideal diode acts as a Switch either open or closed depending upon the polarity of the voltage across it.

→ The ideal diode has zero resistance forward bias and infinite resistance for Reverse bias.

Rectifier

→ Rectifier is an Electronic device which converts Ac voltage into pulsating DC voltage (uni directional voltage).

→ It utilises uni directional conduction device like p-n junction diode & vaccum diode.

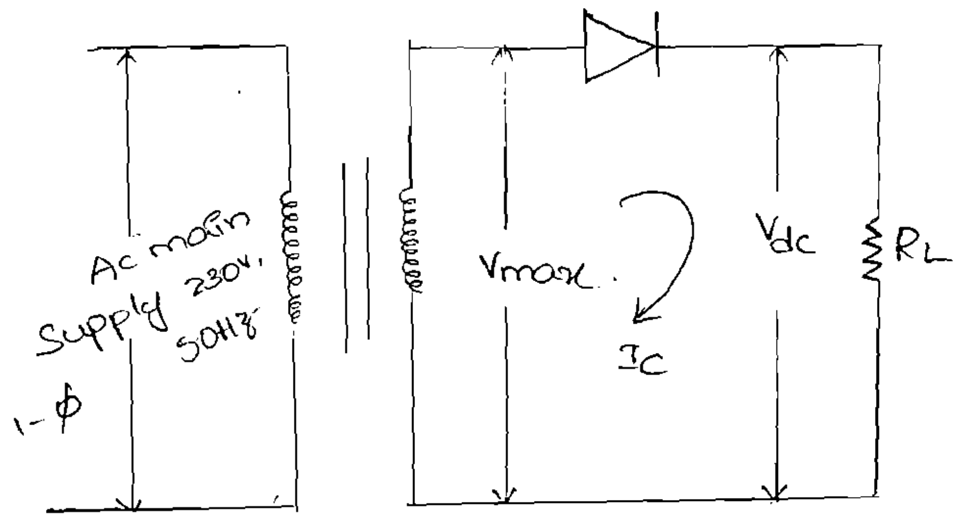
→ It is classified depending upon the period of conduction has

(i) Halfwave Rectifier

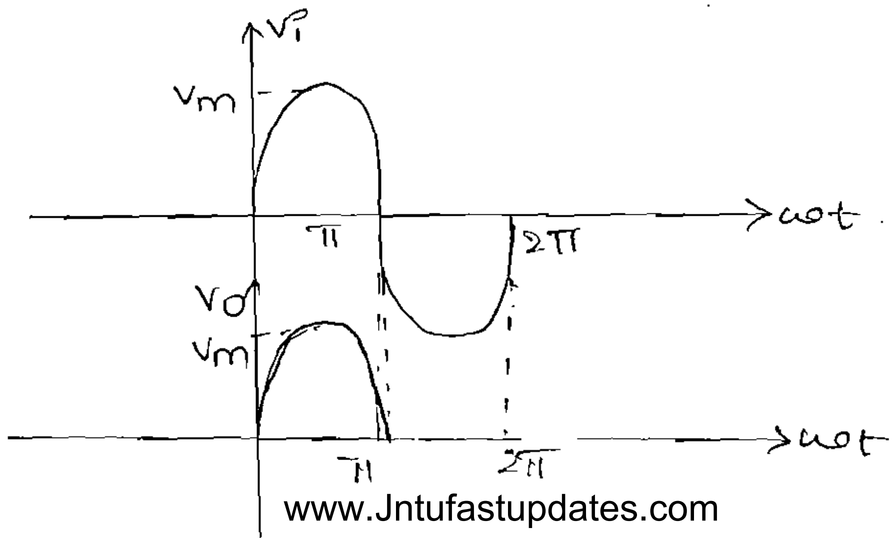
(ii) Fullwave Rectifier.

(iii) Bridge.

(i) Half wave Rectifier



fig(a): Basic Structure of HWR



$$= \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \, dt + \int_{\pi}^{2\pi} V_m \sin\omega t \, dt.$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi} + 0$$ (∵ As no voltage flows through -ve half of ac i/p voltage).

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

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

$$= \frac{V_m}{\pi}.$$

Similarly $I_{dc} = \frac{I_m}{\pi}$.

→ Applying Kichoff's Law, we can write

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

Where V_m = Voltage across the secondary of the transformer.

R_f = forward resistance of diode.

R_s = Resistance of secondary winding of Transformer (Sheet resistance).

* **RMS Value** (Root Mean Square).

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T (V_0)^2 d(\omega t)}$$

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

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

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t + 0}$$

S.O.B.S

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

$$= \frac{V_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2} d(\omega t)$$

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

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

$$= \frac{V_m^2}{4\pi}\left[(\pi - 0) - \cancel{\sin 2\pi}(0-0)\right]$$

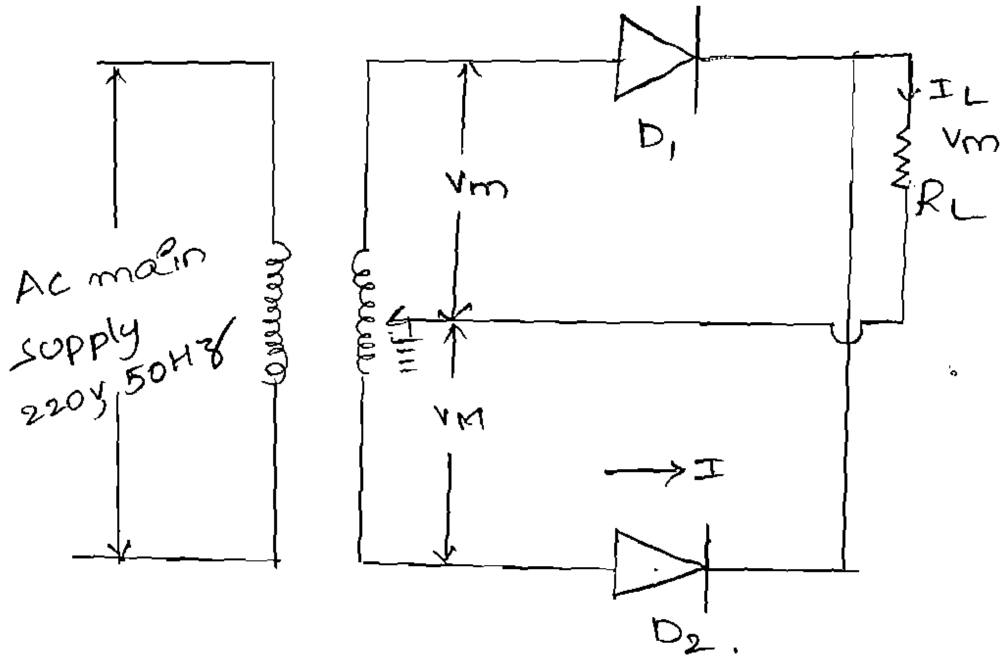
$$= \frac{V_m^2}{4\cancel{\pi}} \times \cancel{\pi}$$

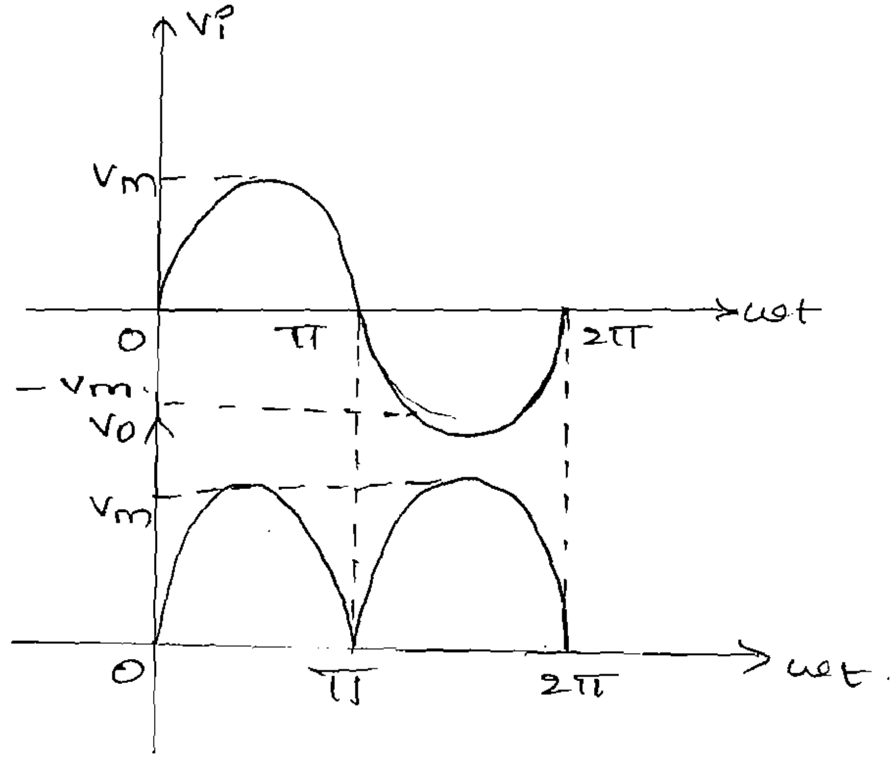
$$= \frac{V_m^2}{4}$$

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

Similarly $I_{RMS} = \frac{I_m}{2}$.

Full wave Rectifier





Operation

Case(i)

→ During +ve half of the i/p signal the anode of the diode D_1 becomes more +ve at the same time the anode of the Diode D_2 becomes -ve. Hence D_1 conducts and D_2 does not conducts.

→ the load current (current) flows through D_1 the voltage drop across R_L will be equal to the i/p voltage.

Case (ii)

→ During -ve half of the i/p signal the Anode of Diode D_1 becomes more -ve at the same time the anode of the Diode D_2 becomes +ve Hence D_2 conducts and D_2 does not conducts.

→ The load recurrent flows through D_2 the voltage drop across R_L will be equal to the i/p voltage.

$$V_0 = V_m \sin\omega t \quad 0 \le \omega t \le \pi$$

$$= -V_m \sin\omega t \quad \pi \le \omega t \le 2\pi$$

Avarage & DC voltage.

$$V_{Avg} = \frac{1}{T}\int_0^T V_m \sin\omega t \, d\omega t$$

$$= \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\omega t \, d\omega t$$

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

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

$$= \frac{1}{2\pi}\left[V_m(2) + V_m[2]\right] = \frac{1}{\cancel{2}\pi}[\cancel{4}^{2} V_m]$$

$$\boxed{V_{Avg} = \frac{2V_m}{\pi}} \quad \text{similarly} \quad \boxed{I_{Avg} = \frac{2I_m}{\pi}}$$

RMS value

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T (V_0)^2 \, d\omega t} = \sqrt{\frac{1}{T}\int_0^T V_m^2 \sin^2\omega t \, d\omega t}$$

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

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

$$= \sqrt{\frac{V_m^2}{2\pi}\left(\frac{1}{2}\left(\omega t - \frac{\sin \omega t}{2}\right)_0^{\pi} + \frac{1}{2}\left(\omega t - \frac{\sin 2\omega t}{2}\right)_{\pi}^{2\pi}\right)}$$

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

$$= \sqrt{\frac{V_m^2}{2\pi}\left[\frac{\pi}{2} + \frac{\pi}{2}\right]}$$

$$= \sqrt{\frac{V_m^2}{2\cancel{\pi}} \times \cancel{\pi}}$$

$$= \sqrt{\frac{V_m^2}{2}}$$

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

Similarly $I_{RMS} = \frac{I_m}{\sqrt{2}}$

* Performance Characteristics HWR.

1. Ripple factor
2. Efficiency.
3. Form factor
4. Peak factor
5. Percentage of Regulation
6. Peak Inverse Voltage (PIV) (SHImp)
7. Transformer utilization factor (TUF).

1. Ripple factor

→ It is defined as the ratio of RMS value of Ac component present in output to the avarage value (or) dc voltage.

→ It is denoted as γ.

$$\gamma = \frac{\text{RMS of value of Ac component}}{\text{Dc voltage or Avarage value}}$$

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

$$V_{rms} = \sqrt{V_{ac}^2 + V_{dc}^2}$$

$$V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$$\frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}}$$

$$\gamma = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - \frac{V_{dc}^2}{V_{dc}^2}}$$

$$= \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1}$$

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

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

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

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

Full wave rectifier (Ripple factor).

$$V_{rms} = \sqrt{V_{ac}^2 + V_{dc}^2}$$

$$V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$$\frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}}$$

$$= \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - \frac{V_{dc}^2}{V_{dc}^2}}$$

$$= \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1}$$

$$\frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{\left(\frac{2V_m}{\pi}\right)^2} = \frac{\frac{1}{2}}{\frac{4}{\pi^2}} = \sqrt{\frac{\pi^2}{16} - 1}$$

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

$$= \sqrt{\frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{\left(\frac{2V_m}{\pi}\right)^2} - 1} = \sqrt{\frac{\frac{1}{2}}{\frac{4}{\pi^2}} - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$= 0.48$$

$$= \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1}$$

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

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

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

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

Full wave rectifier (Ripple factor)

$$V_{rms} = \sqrt{V_{ac}^2 + V_{dc}^2}$$

$$V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$$\frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}}$$

$$= \sqrt{\frac{V_{rms}^2}{V^2_{dc}} - \frac{V_{dc}^2}{V^2_{dc}}}$$

$$= \sqrt{\frac{V_{rms}^2}{V^2_{dc}} - 1}$$

$$\frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{\left(\frac{2V_m}{\pi}\right)^2} = \frac{\frac{1}{\cancel{2}}}{\frac{4}{\pi^2}} = \frac{1}{2} \times \frac{\pi^2}{4} = \sqrt{\frac{\pi^2}{\cancel{1}8} - 1}$$

$$= \sqrt{\frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{\left(\frac{2V_m}{\pi}\right)^2} - 1} = \sqrt{\frac{\frac{1}{2}}{4/\pi^2} - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$= 0.48 \,//$$

2. Efficiency

→ It is defined as the ratio of o/p dc power to input ac power.

→ It is denoted as η.

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

$P_{dc} = I_{dc} \cdot V_{dc}$.

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

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

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

Where $I_m = \dfrac{V_m}{R_f + R_c + R_s}$

$$P_{dc} = \left(\frac{\frac{V_m}{R_f + R_c + R_s}}{\frac{\pi}{1}}\right)^2 \cdot R_L$$

$$P_{dc} = \left(\frac{V_m}{\pi(R_f + R_c + R_s)}\right)^2 R_L$$

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

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 (R_f + R_L + R_s)$$

$$\eta = \frac{\left(\frac{V_m}{\pi(R_f + R_c + R_s)}\right)^2 \cdot R_L}{\left(\frac{I_m}{2}\right)^2 (R_f + R_L + R_s)}$$

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

$$= \frac{\left(\frac{I_m}{\pi}\right)^2 \cdot R_L}{\left(\frac{I_m}{2}\right)^2 (R_f+R_L+R_s)}$$

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

$$= \frac{4}{\pi^2} \cdot \frac{R_L}{R_f+R_L+R_s}$$

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

$$\eta = \frac{0.405}{\left(1+\frac{R_f+R_s}{R_L}\right)}$$

Now $\frac{R_f+R_s}{R_L} < 1$

so $\eta = 0.405$ $\qquad \therefore \% \eta = 0$

$\% \eta = 40.5\%$

* Form factor

→ It is defined as the ratio of RMS value to the avarage value.

$$\text{form factor} = \frac{V_{rms}}{V_{dc}}$$

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

full wave rectifier = $\dfrac{V_{rms}}{V_{dc}}$

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

$$= \frac{\pi}{2} \times 1/\sqrt{2}$$

$$= \frac{\pi}{2\sqrt{2}} = 1.1107.$$

Efficiency

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

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

$$P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L + R_s)$$

$$\frac{P_{dc}}{P_{ac}} = \frac{4\cancel{I_m^2}}{\pi^2} R_L \times \frac{2}{\cancel{I_m^2}(R_f + R_L + R_s)}$$

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

$$= \frac{8}{\pi^2} \cdot \frac{R_L}{R_L\left[1 + \left(\frac{R_f + R_s}{R_L}\right)\right]}$$

$$= \frac{8}{\pi^2}$$

$$\eta = 0.8105$$

$$\% \eta = 81.05 .$$

3/8/16

Peak factor (halfwave)

→ It is defined as peak factor the ratio of peak value to RMS value.

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{RMS values}}$$

$$= \frac{\cancel{V_m}}{\frac{\cancel{V_m}}{2}} = 2.$$

full wave rectifier

$$\frac{V_m}{V_{Rms}} = \frac{\cancel{V_m}}{\frac{\cancel{V_m}}{\sqrt{2}}} = \sqrt{2} = 1.4142.$$

halfwave

$$\text{Regulation} = \frac{V_{noload} - V_{full\,load}}{V_{full\,load}}$$

$$\boxed{V_{dc} = V_{NL} = \frac{V_m}{\pi}} \quad \left[I_m = \frac{V_m}{R_f + R_L}\right]$$

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

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

$$V_{FL} = \frac{V_m}{\pi(R_f + R_L)} \cdot R_L$$

$$V_{FL} = \frac{V_m(R_L + R_f - R_f)}{\pi(R_f + R_L)}$$

3/8/16

Peak factor (halfwave)

→ It is defined as peak factor the ratio of peak value to RMS value.

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{RMS values}}$$

$$= \frac{\cancel{V_m}}{\frac{\cancel{V_m}}{2}} = 2.$$

full wave rectifier

$$\frac{V_m}{V_{Rms}} = \frac{\cancel{V_m}}{\frac{\cancel{V_m}}{\sqrt{2}}} = \sqrt{2} = 1.4142.$$

halfwave

$$\text{Regulation} = \frac{V_{noload} - V_{full\,load}}{V_{full\,load}}$$

$$\boxed{V_{dc} = V_{NL} = \frac{V_m}{\pi}} \quad \left[I_m = \frac{V_m}{R_f + R_L} \right]$$

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

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

$$V_{FL} = \frac{V_m}{\pi (R_f + R_L)} \cdot R_L$$

$$V_{FL} = \frac{V_m (R_L + R_f - R_f)}{\pi (R_f + R_L)}$$

$$= \frac{V_m(\cancel{R_L}+R_F)}{\pi(\cancel{R_L}+R_F)} - \frac{V_m}{\pi}\cdot\frac{R_F}{(R_F+R_L)}$$

$$\boxed{V_{FL} = \frac{V_m}{\pi} - \frac{V_m}{\pi}\cdot\frac{R_F}{R_F+R_L}}$$

$$\text{Regulation} = \frac{\cancel{\frac{V_m}{\pi}} - \cancel{\frac{V_m}{\pi}} + \frac{V_m}{\pi}\cdot\frac{R_F}{R_F+R_L}}{\frac{V_m}{\pi} - \frac{V_m}{\pi}\cdot\frac{R_F}{R_F+R_L}}$$

$$= \frac{\cancel{\frac{V_m}{\pi}}\cdot\frac{R_F}{R_F+R_L}}{\cancel{\frac{V_m}{\pi}}\left[1-\frac{R_F}{R_F+R_L}\right]}$$

$$= \frac{\frac{R_F}{R_F+R_L}}{1-\frac{R_F}{R_F+R_L}} = \frac{\frac{R_F}{\cancel{R_F+R_L}}}{\frac{\cancel{R_F}+R_L-\cancel{R_F}}{\cancel{R_F+R_L}}}$$

$$\boxed{\text{Regulation} = \frac{R_F}{R_L}}$$

$$\boxed{\%\text{ of Regulation} = \frac{R_F}{R_L}\times 100}$$

full wave

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

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

$$V_{FL} = \frac{I_m}{\pi} \times R_L$$

$$V_{FL} = \frac{V_m}{\pi(R_F+R_L)} \cdot R_L$$

$$V_{FL} = \frac{V_m(R_L+R_F-R_F)}{\pi(R_L+R_F)}$$

$$= \frac{V_m(R_L+\cancel{R_F})}{\pi(R_L\cancel{+R_F})} - \frac{V_m}{\pi} \cdot \frac{R_F}{R_F+R_L}$$

$$V_{FL} = \frac{2V_m}{\pi} - \frac{2V_m}{\pi} \cdot \frac{R_F}{R_F+R_L}$$

$$\text{Regulation} = \frac{\frac{2V_m}{\pi} - \frac{2V_m}{\pi} + \frac{2V_m}{\pi} \cdot \frac{R_F}{R_F+R_L}}{\frac{2V_m}{\pi} - \frac{2V_m}{\pi} \cdot \frac{R_F}{R_F+R_L}}$$

$$= \frac{\frac{\cancel{V_m}}{\cancel{\pi}} \cancel{+} \frac{2V_m}{\pi} \cdot \frac{R_F}{R_F+R_L}}{\frac{2V_m}{\pi} - \frac{2V_m}{\pi} \cdot \frac{R_F}{R_F+R_L}}$$

$$\times\left(= \frac{\cancel{V_m}}{\cancel{\pi}}\left[1+\frac{R_F}{R_F+R_L}\right] \Big/ \frac{\cancel{V_m}}{\cancel{\pi}}\left[1-\frac{R_F}{R_F+R_L}\right]\right)$$

* Transformer utilization factor

→ It indicates how much the transformer is utilised in the circuit is called transformer utilisation factor.

TUF is defined as the ratio of dc power delivering to the load to AC rating of transformer secondary

$$TUF = \frac{P_{dc}}{P_{ac}} \times \frac{1}{(\text{rated})}$$

$$= \frac{P_{dc}}{P_{ac}(\text{rated})}$$

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

$$P_{ac}(\text{rated}) = V_{ac}(\text{rated}) \times I_{ac}(\text{rated})$$

$$= V_{RMS} \times I_{RMS}$$

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

[∵ In the Half wave rectifier circuit the rated voltage of the Transformer secondary is $\frac{V_m}{\sqrt{2}}$ but the actual RMS current flowing through the winding is $\frac{I_m}{2}$ not $\frac{I_m}{\sqrt{2}}$]

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

$$TUF = \frac{\frac{I_m^2}{\pi^2} \cdot R_L}{\frac{V_m I_m}{2\sqrt{2}}}$$

$$= \frac{I_m^{\cancel{2}}}{\pi^2} \cdot R_L \times \frac{2\sqrt{2}}{V_m \cancel{I_m}} = \frac{I_m}{\pi^2} \cdot R_L \times \frac{2\sqrt{2}}{V_m}$$

$$= \frac{I_M R_L}{\pi^2 V_{max}} \times \frac{2\sqrt{2}}{V_M}$$

$$= \frac{\cancel{I_m}}{\pi^2} \cdot R_L \times \frac{2\sqrt{2}}{\cancel{I_m}(R_L+R_F)} \quad \left[\because V_M = I_m(R_L+R_F)\right]$$

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

$$= \frac{2\sqrt{2}}{\pi^2} \times \frac{R_L}{R_L+R_F}$$

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

$$T_0 \boxed{TUF = 0.286} \text{ (half wave)}$$

full wave

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

→ The primary of the transformer is feeding to half ~~p~~ wave rectifiers seperately is two half wave rectifiers work independently of each other but feed a common load. we have already derived the TUF for half wave rectifier circuit to be equal to 0.286.

TUF for primary winding = 2 × TUF for HWR

$$= 2 \times 0.286$$

$$= 0.573$$

→ The average TUF for full wave rectifier will be TUF of primary + TUF of secondary.

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

$$= \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}}$$

$$= \frac{4I_m^{\cancel{2}}}{\pi^2} \cdot R_L \times \frac{2}{V_m \cdot \cancel{I_m}}$$

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

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

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

$$= 0.81$$

$$\boxed{\therefore TUF = 0.81}$$

(full wave).

$$\text{Average} = \frac{\text{TUF of primary} + \text{TUF of secondary}}{2}$$

$$= \frac{0.81 + 0.57}{2}$$

$$= 0.69$$

Advantage of HWR

→ It is simple and low cost rectifier circuit.

Disadvantages

→ Ripple factor is high. ($\gamma = 1.21$)

→ Low Efficiency (40.5%)

→ Low TUF it means the transformer is not folly utilized. (0.28%)

→ Poor Regulation.

Advantage of FWR

→ Ripple factor is low

→ The O/P voltage and transformer Efficiency is higher.

→ Higher TUF and better Regulation than HWR.

Disadvantages

→ PIV is high.

→ In the circuit we are using 2 diodes and bulk transformer is needed

Problems on HWR

1) A HWR having resistive load of 1000Ω rectifies an alternating voltage of 325 volts. peak value and the diode has forward resistance of 100Ω. Calculate i) Peak, Average, RMS value of current.

ii) DC power output

iii) AC input power.

iv) Efficiency of the rectifier.

Sol:- Given data $R_L = 1000\Omega$

$V_M = 325$ volts

$R_F = 100\Omega$

Peak value of current $I_M = \dfrac{V_M}{R_F + R_L}$

$= \dfrac{325}{1000+100}$

$= 0.295$

$I_M = 295.45$ mA.

(I_{dc})

Average current $= \dfrac{I_m}{\pi}$

$= \dfrac{295.45}{\pi}$

$(I_{dc}) = 94.04$ mA

RMS value of current $(I_{RMS}) = \dfrac{I_m}{2}$

$= \dfrac{295.45}{2}$

$= 147.725$ mA

ii) Dc power output

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

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

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

$$= (94.04)^2 \cdot 1000 \times 10^{-6}$$

$$= 8.845 \text{ watts.}$$

iii) Ac input power

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

$$= (147.725)^2 (1000 + 100) \times 10^{-6}$$

$$= 24 \text{ watts.}$$

iv) Efficiency $(\eta) = \frac{P_{dc}}{P_{ac}}$

$$= \frac{8.845}{24} \times 100$$

$$= 36.85 \%$$

2) A HWR has load of $3.5k\Omega$ with the diode resistance & secondary coil resistance together have a resistance of 800Ω & the input voltage has a signal voltage of peak value 240V. Calculate

i) Peak, average, Rms value of current

ii) Dc power output iii) Ac power input iv) Efficiency (η)

Sol:- Given data $R_L = 3.5K\Omega = 3500\Omega$ $I_m = \frac{V_m}{R_L+R_s+R_f}$

$V_m = 240V$

$R_f + R_s = 800\Omega$

Peak value of current $= I_m = \frac{V_m}{R_L+R_f+R_s}$

$= \frac{240}{3.5K\Omega + 800\Omega}$

$= \frac{240}{3500+800}$

$= 0.055A.$

Average value $= \frac{I_m}{\pi} = \frac{0.0558}{\pi}$

$= 0.01776A.$

RMS value of current $I_{rms} = \frac{I_m}{2} = \frac{0.0558}{2}$

$= 0.0279A.$

ii) DC power output $= V_{dc} \cdot I_{dc}$

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

$= (I_{dc})^2 \cdot R_L$

$= (0.01776)^2 \cdot 3500$

$= 1.1039$ watts.

iii) AC power input

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

$$= (0.0279)^2 (800+3500)$$

$$= 3.347 \text{ watts}$$

iv) Efficiency $(\eta) = \frac{P_{dc}}{P_{ac}}$

$$= \frac{1.1039}{3.347} \times 100$$

$$= 32.98\%$$

3) An AC supply of 220V is applied to a HWR circuit through a transformer with turns ratio of 10:1 find i) DC output voltage

ii) PIV

Assume the diode

Sol:- Given data

The transformer secondary voltage $N_1 : N_2$

10 : 1

stepdown

primary AC supply $= \frac{220}{10} = 22V$ (secondary voltage)

Maximum value of secondary voltage $V_m = \sqrt{2} \times 22$

$= 31.17V$

i) DC output voltage $(V_{dc}) = \frac{V_m}{\pi} = \frac{31.11}{\pi} = 9.90$

ii) PIV of the Diode $\simeq V_m \simeq 3x1.11V$

4) A halfwave Rectifier used to supply 24V DC to a resistive load of 500Ω and the diode has forward resistance of 50Ω. calculate the maximum value of Ac voltage required at the input.

$R_L = 500\Omega,\ R_f = 50\Omega$

$V_{dc} = 24$

$I_{dc} = \frac{V_{dc}}{R_L} = \frac{24}{500} = 4.8mA$

maximum value of load current $I_m = \pi \times I_{dc}$

$= 48 \times \pi$

$= 15.07\ mA.$

∴ Ac voltage required at the input,

$V_m = I_m \times (r_f + R_L)$

$= 150.7 \times (500 + 500 \times 10^{-3})$

$= 150.7 \times (500 \times 10^{-3})$

$V_m = 82.938V$

Problems on FWR

1) A fullwave rectifier delivers 50watts to a Load of 200Ω with the Ripple factor 1%. calculate the Ac Ripple voltage across the Load.

Sol:- Given data $P_{dc} = 50$ watts

$$R_L = 200\,\Omega$$

$$\eta = \frac{V_{ac}}{V_{dc}} = 1$$

$$\gamma = 0.01$$

$$V_{dc}^2 = P_{dc} \cdot R_L$$

$$V_{dc} = \sqrt{P_{dc} \cdot R_L}$$

$$= \sqrt{50 \times 200} = \sqrt{10{,}000}$$

$$V_{dc} = 100$$

$$\frac{V_{ac}}{V_{dc}} = 0.01$$

$$V_{ac} = 0.01 \times 100$$

$$\boxed{V_{ac} = 1}$$

2) A FWR has center tansferred of 100v - 0 - 100v and Each one of the diode is rated at $I_{max} = 400$ mA and $I_{Avg} = 150$mA. Determine i) value of Load resistor that gives the largest DC power o/p.

ii) DC Load Voltage & current.

iii) PIV of Each Diode

Ans:- We know that the maximum value of current flowing through the diode should not exceed 80% of its rated current

$$I_{max} = 0.8 \times 400 = 320 mA.$$

The maximum value of secondary voltage

$$V_m = \sqrt{2} \times 100$$
$$= 141.4V.$$

∴ The value of load resistor that gives the largest dc power output = $R_L = \frac{V_{max}}{I_{max}}$

$$= \frac{141.4}{320 \times 10^{-3}}$$
$$= 441.8\Omega$$

ii) $V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 141.4}{\pi}$

$$= 90.01$$

$I_{dc} = \frac{V_{dc}}{R_L} = \frac{90.01}{441.8} = 0.2037$

iii) PIV of each Diode $= 2 \times 141.4$

$$= 282.8.$$

****

3) A 220V, 60Hz voltage is applied to primary of 5:1 (stepdown), centre tapped transformer uses in a full wave rectifier having a load of 9800Ω. If the diode resistance and secondary

coil resistance together has a resistance of 1000Ω. Determine i) Dc voltage across the Load

ii) Dc current flowing through the Load

iii) Dc power delivered to the Load.

iv) PIV across Each Diode

v) Ripple voltage & its frequency.

vi) Rectification Efficiency.

The voltage across the two Ends of secondary voltage from center tapping to one $= \frac{230}{5} = 46V$.

End, $V_{rms} = \frac{46}{2} = 23V$.

a) The dc voltage across the load, $V_{dc} = \frac{2V_m}{\pi}$

$$= \frac{2 \times 23 \times \sqrt{2}}{\pi}$$

$$= 20.7V$$

b) The dc current flowing through the load

$$I_{dc} = \frac{V_{dc}}{R_f + R_c + R_s} = \frac{20.7}{1000} = 20.7mA$$

c) The dc power delivered to the load

$$P_{dc} = (I_{dc})^2 \times R_L = (20.7m)^2 \times 900$$

$$= 0.386W$$

d) PIV across Each diode $= 2V_m$

$$= 2(23\sqrt{2}) = 65V$$

e) Ripple voltage

$$V_{rms} = \sqrt{(V_{rms})^2 - (V_{dc})^2}$$

$$= \sqrt{(23)^2 - (20.7)^2} = 10.05V$$

frequency of Ripple voltage $= 2\times 60 = 120Hz$.

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

$$= \frac{(V_{dc})^2/R_L}{(V_{rms})^2/R_L} = \frac{(V_{dc})^2}{(V_{rms})^2}$$

$$= \frac{(20.7)^2}{(23)^2}$$

$$= 0.81.$$

$\therefore \% \eta = 0.81 \times 100 = 81\%$

5.

Comparing i/p voltage to $v_m \sin(\omega t+\phi)$, $\phi = 90°$.

$V_m = 100V$, $R_L = 5k\Omega$

$$I_m = \frac{V_m}{R_L+R_f+R_s} = \frac{200}{5\times 10^3} = 40mA.$$

$$I_{Rms} = \frac{I_m}{2} = \frac{40}{2} = 20mA.$$

$$I_{DC} = \frac{I_m}{\pi} = 12.7324mA.$$

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

$$= \sqrt{\frac{(20)^2}{(12.73)^2} - 1}$$

$\eta = 1.21$

$$TUF = \frac{\text{DC power output}}{\text{AC power rating of transformer}}$$

$$= \frac{I_{DC}^2 R_L}{\left(\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{2}\right)}$$

$$= \frac{(12.73 \times 10^{-3})^2 (5 \times 10^3)}{\left(\frac{200}{\sqrt{2}}\right)\left(\frac{40 \times 10^{-3}}{2}\right)}$$

$$= 0.2865$$

$P_{ac} = I_{Rms}^2 R_L = (20 \times 10^{-3})^2 \times 5 \times 10^2 = 2W$

$P_{dc} = I_{DC}^2 R_L = (12.73)^2 5 \times 10^{-3} = 0.8105W.$

$$\% \eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{0.8105}{2} \times 100 = 40.52\%$$

$I_{DC} = 100mA$

$R_L = 250\Omega$

$V_{DC} = \text{DC o/p voltage} = I_{DC} \cdot R_L$

$= 100 \times 10^{-3} \times 250 = 25V$

$PIV = V_m = \pi \cdot V_{DC} = \pi \times 25 = 78.53V$

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

$\therefore I_{DC} = \frac{I_m}{\pi} = \frac{V_m}{\pi \cdot R_L}$ i.e. $100 \times 10^{-3} = \frac{V_m}{\pi \times 250}$.

$V_m = 78.53V$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{78.53}{\sqrt{2}} = 55.36V.$$

Given

$R_f = 20\Omega,\ R_L = 1K\Omega$

$V_{DC} = 55.4V$

$$I_{DC} = \frac{V_{DC}}{R_L} = \frac{55.4}{1\times10^3} = 55.4mA.$$

$$I_{DC} = \frac{2I_m}{\pi} \text{ ie } I_m = \frac{\pi \times 55.4\times10^{-3}}{2} = 87.02mA.$$

i) $I_{rms} = \dfrac{I_m}{\sqrt{2}} = \dfrac{87.02}{\sqrt{2}} = 61.53mA.$

ii) Average voltage across Each diode $= I_{DC}\cdot R_f$

$= 1.108V$

iii) $\gamma = \sqrt{\dfrac{(I_{rms})^2}{(I_{DC})^2} - 1}$

$= \sqrt{\dfrac{(61.53)^2}{(55.4)^2} - 1}$

$= 0.483.$

iv) $I_x = \frac{V_x}{R_f + R_L} \Rightarrow V_m = I_m(R_f + R_L)$

$= 87.02 \times 10^{-3}(1000+20) + 1.108$

$= 89.878.$

$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{89.87}{\sqrt{2}} = 63.548\,V$

$V_{DC} = 5V,\ I_{DC} = 200mA.$

$V_{DC} = I_{DC} \cdot R_L$ ie $R_L = 25\Omega$

Let R_f = Diode forward resistance $= 2\Omega$

R_s = half secondary transformer resistance $= 5\Omega$

$I_m = \frac{(V_m - 0.7)}{R_f + R_L + R_s}$ and $I_{DC} = \frac{2I_m}{\pi}$, Si drop = 0.7V

$\frac{\pi}{2} \times 200 \times 10^{-3} = \frac{V_m - 0.7}{2+25+5}$

$V_m = 10.753$

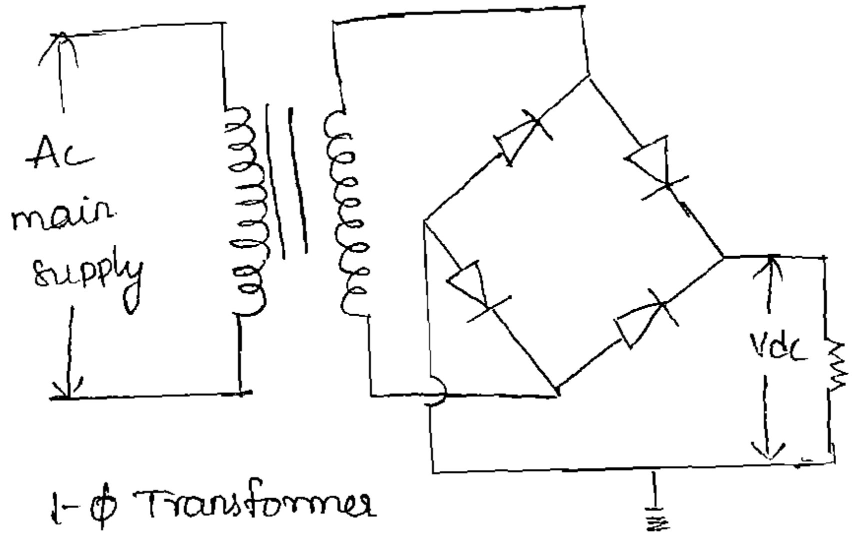
$V_{rms} = \frac{V_m}{\sqrt{2}} = 7.603V.$

$\frac{V_{p(rms)}}{V_{s(rms)}} = \frac{N_1}{N_2}$ where $V_{prms} = 230V$

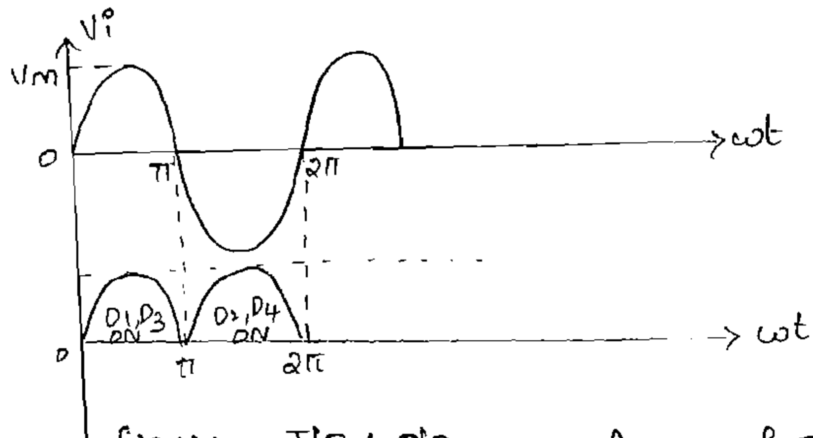
$\frac{230}{7.603} = \frac{N_1}{N_2} \Rightarrow N_1 : N_2 = 30.25 : 1$

where N_2 is the no. of turns of half secondary.

Bridge Rectifier:



fig(a) Basic structure of Bridge Rectifier



fig(b): I/P & O/P wave forms of Bridge Rectifiers

The need for centre tapped transformer in a full wave rectifier is eliminated in the bridge rectifier

→ The bridge rectifier has four diodes connected to form a bridge

→ The AC input voltage is applied to diagonally opposite ends of the bridge

→ The load resistance is connected b/w another 2 ends of the bridge

case(i): 1. for +ve half cycle of i/p AC voltage diode D_1 & D_3 conducts where as D_4 & D_2 doesnot conducts

2. The conducting diodes will be in series through load resistance R_L so load current flows through R_L

Case (ii):

1. for -ve halfcycle of the i/p AC voltage diode D2 & D4 conducts where as D1 & D3 doesnot conduct

2. The conducting diodes will be in series to load resistance R_L so load current flows through R_L

3. The bi-directional wave is converted into uni-directional.

PIV of bridge rectifier is Vm and TUF is 0.81

Advantages:

1. The PIV across each diode is Vm
hence the voltage rating of diode can be less

2. centre tapped transformer is not required

3. TUF is high

Disadvantages: 1. More no. of diodes are used.

Compourisions Of Rectifiers:

Parameter	H·W·R	F·W·R	Bridge Rectifier
no.of diodes	1	2	4
V_{DC}	V_m/π	$2V_m/\pi$	$2V_m/\pi$
V_{rms}	$V_m/2$	$V_m/\sqrt{2}$	$V_m/\sqrt{2}$
I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
PIV	V_m	$2V_m$	V_m
TUF	0.286	0.69	0.81
Efficiency	40.8%	81%	81%
Ripple factor	1.21	0.48	0.48
form factor	1.57	1.11	1.11
peak factor	2	$\sqrt{2}$	$\sqrt{2}$
% Regulation	$\frac{R_f}{R_L} \times 100$	$\frac{R_f}{R_L} \times 100$	$\frac{R_f}{R_L} \times 100$
o/p frequency	f	$2f$	$2f$

* Harmonic components in a Rectifier circuit

→ Harmonic means a sinusoidal component of a periodic waveform which is an integral multiple of fundamental frequency the o/p current eqn in rectifier circuit can be represented by using fourier series expansion ie

$$\boxed{i = I_M\left[\frac{1}{\pi} + \frac{1}{2}\sin\omega t - \frac{2}{\pi}\sum_{K=2,4,6}\frac{\cos\omega t.K}{(K+1)(K-1)}\right]}$$

→ A full wave rectifier consists of 2 halfwave rectifier circuits one circuit conducts during one half cycle and second circuit conducts during second half cycle the currents are related by the expression.

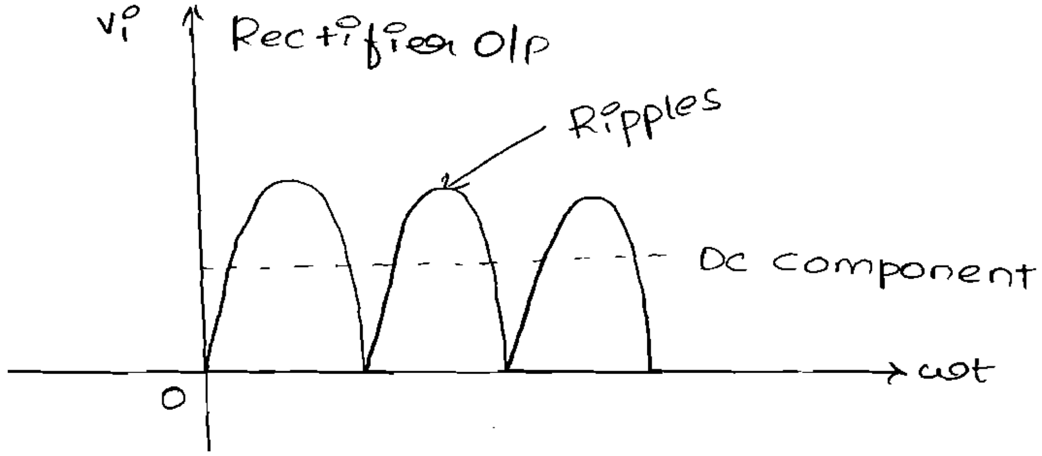
wot
1-21

$$\boxed{i = I_M\Bigg[\underbrace{\frac{2}{\pi}}_{DC} - \overbrace{\frac{4}{\pi}\sum_{K=2,4,6}\frac{\cos K\omega t}{(K+1)(K-1)}}^{AC}\Bigg]}$$

* Filters

→ The rectifier o/p contains DC components & AC components so in order to get a smooth DC o/p we require an extra circuit we requi. b/w rectifier o/p and load.

→ filters are used to minimize the undesirable AC ie Ripple leaving only DC component to appear at the o/p.



*Types Of filter

***1. capacitor filter

2. Inductor filter

3. LRC filter & L section filter

4. CLC filter & π section filter

5. Multiple L section filter.

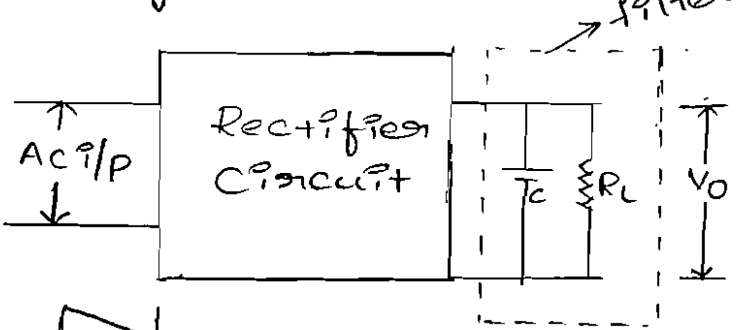
6. Multiple π section filter.

1. capacitor filter

→ Reactance of capacitance

→ for Ac signals $X_C = \frac{1}{2\pi f_C}$ (X_C is Low) (Short circuit)

→ for Dc signals $X_C = \frac{1}{0} = \infty$ (open circuit).

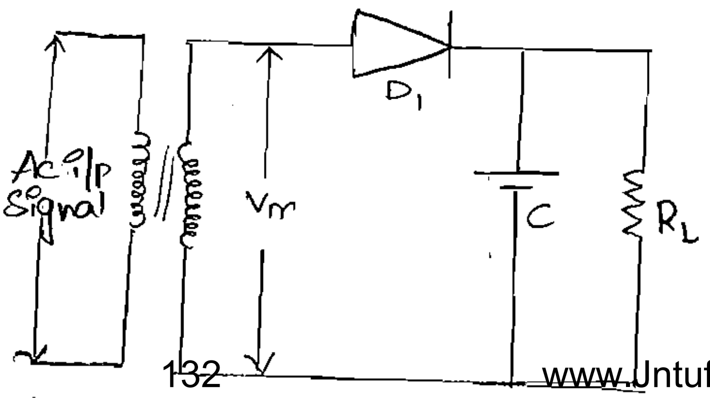


HW with CF

Rectifier - pulsating Dc Ac & Dc

capacitor - block Dc allows the Ac ground s.c

Ac leaves Dc same



fig(a): Basic structure of HWR.

inductor :- Allows Dc blocks the Ac

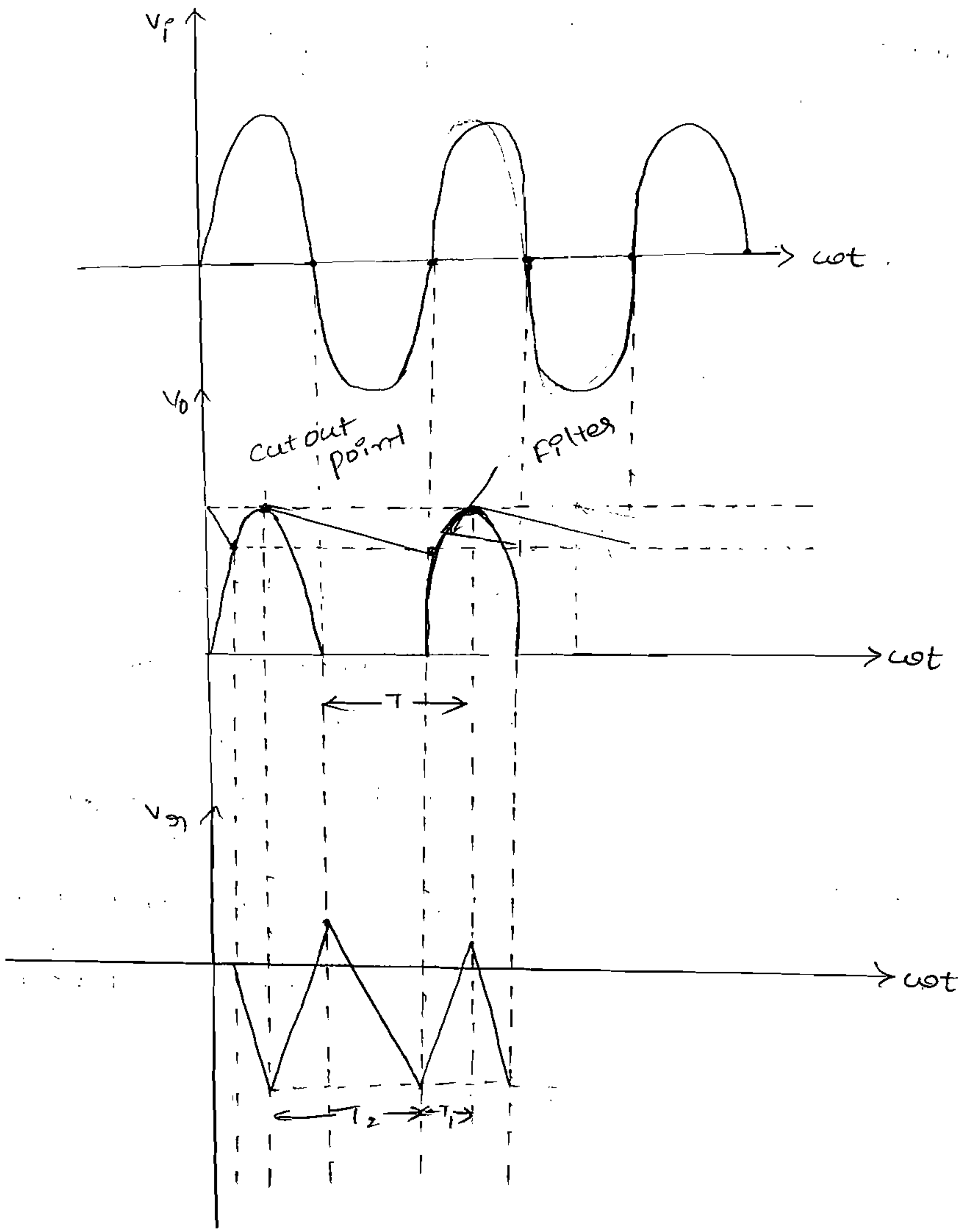


fig (b): The i/p & o/p wave forms of HWR with capacitor filter

→ Let t_1 is the capacitor charging time period

t_2 is the capacitor discharging time period

→ The total time period is $T = t_1 + t_2$ ($t_2 >> t_1$)

is the total T.P.

→ Let V_R be the ripple components (AC component) of magnitude of the triangular waveform.

→ The RMS value of triangular wave is

$$\boxed{V_{RMS} = \frac{V_R}{2\sqrt{3}}}$$

→ The capacitor charge during charging time period

$$C = \frac{Q}{V}$$

$$Q = CV.$$

$$Q_{charge} = C \times V_r \longrightarrow (1)$$

→ The charge lost by the capacitor during discharge time period $i = Q/t$.

$$Q_{discharge} = I_{dc} \cdot T_2 \longrightarrow (2)$$

→ At steadystate Q charge = Q discharge.

$$C \times V_r = I_{dc} \times T_2$$

$$V_r = \frac{I_{dc} \times T_2}{C} \qquad I_{dc} = \frac{V_{dc}}{R_L}$$

$$V_{rms} = \frac{V_r}{2\sqrt{3}} \Rightarrow V_r = V_{rms} \cdot 2\sqrt{3}$$

$$C \cdot V_{rms} \cdot 2\sqrt{3} = I_{dc} \cdot T_2.$$

$$C \cdot V_{rms} \cdot 2\sqrt{3} = \frac{V_{dc}}{R_L} \cdot T_2.$$

$$\frac{V_{rms}}{V_{dc}} = \frac{1}{2\sqrt{3}\cdot C\cdot R_L} \times T_2$$

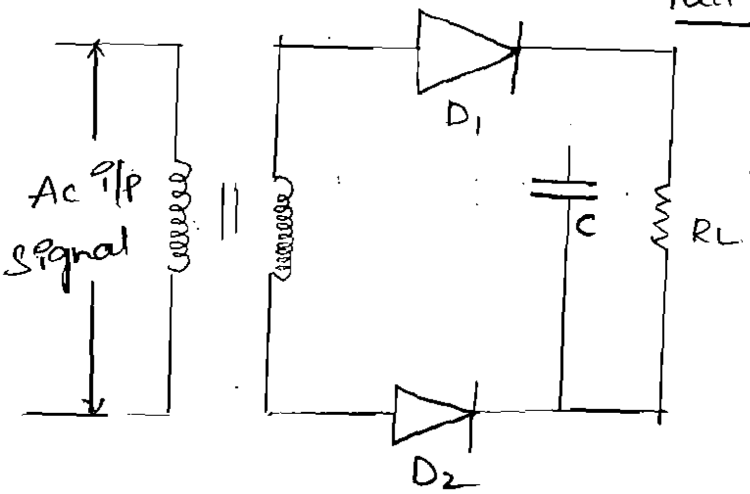
$f = \frac{1}{T_2}$

$T_2 = 1/f$

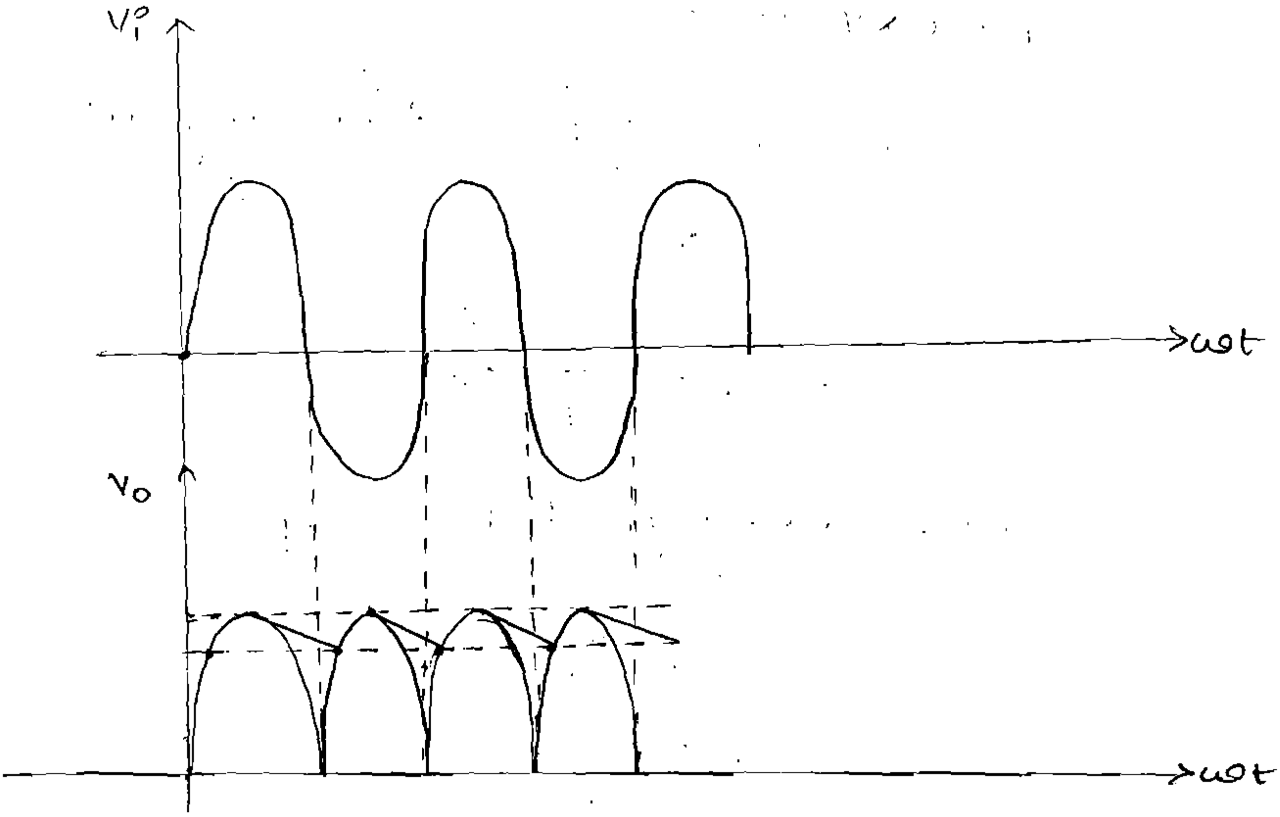
$$\boxed{\frac{V_{rms}}{V_{dc}} = \frac{1}{2\sqrt{3}\, f_C \cdot R_L}}$$

(γ)

Full wave Rectifier



fig(a): Basic Structure Of FWR



ωt

$$Q_{discharge} = I_{dc} \cdot T_2 \rightarrow (2)$$

At Study State $Q_{charge} = Q_{discharge}$

$$CV_O = I_{dc} \cdot T_2$$

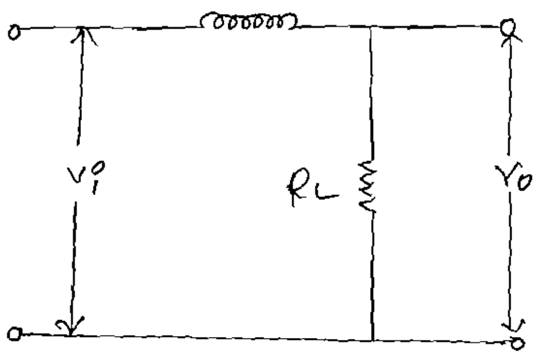
$$CV_{rms} 2\sqrt{3} = I_{dc} \cdot T_2$$

$$2\sqrt{3} CV_{rms} = \frac{V_{dc}}{R_2} \cdot T_2$$

$$T_2 = \frac{1}{2f}$$

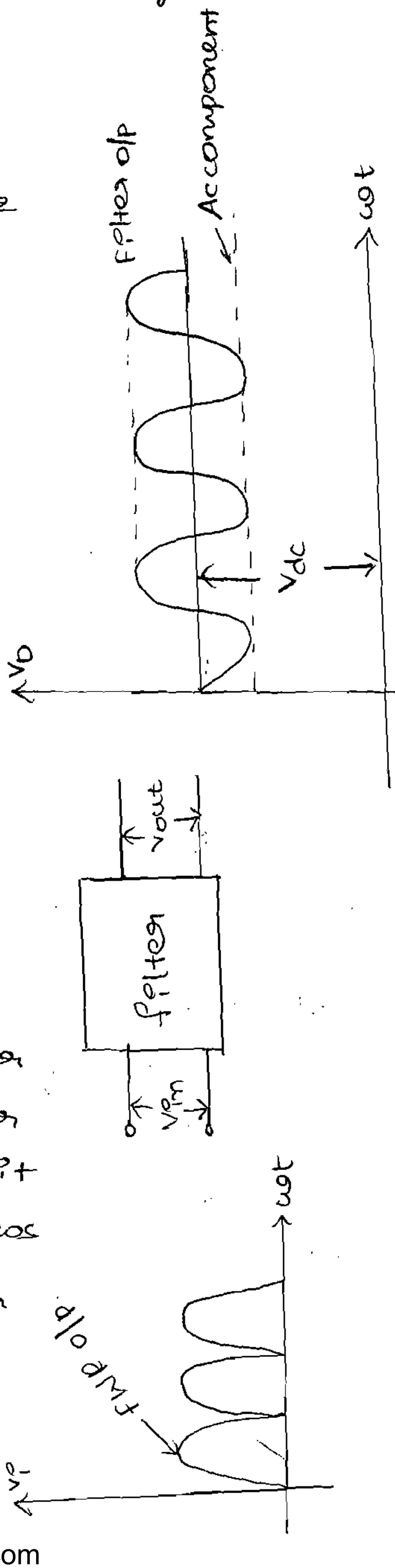
$$\frac{V_{rms}}{V_{dc}} = \frac{1}{4\sqrt{3} f C R_L}$$

*Inductor filter



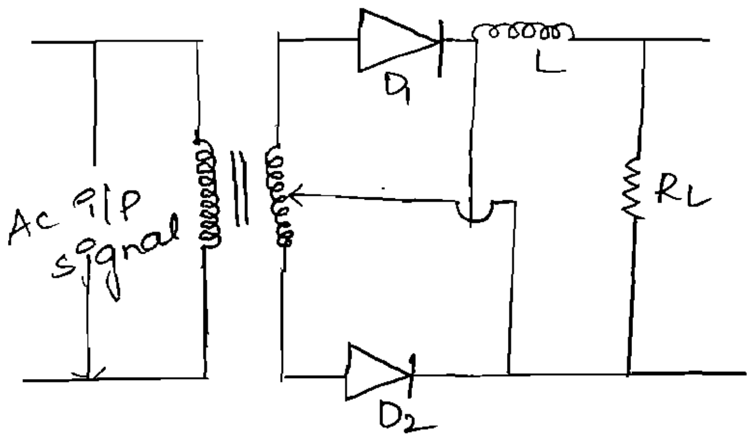
fig(a): Inductor filter.

→ fig(b) shows inductor filter when the o/p of the rectifier passes through an inductor it blocks AC component and allows only the DC component to reach the load.

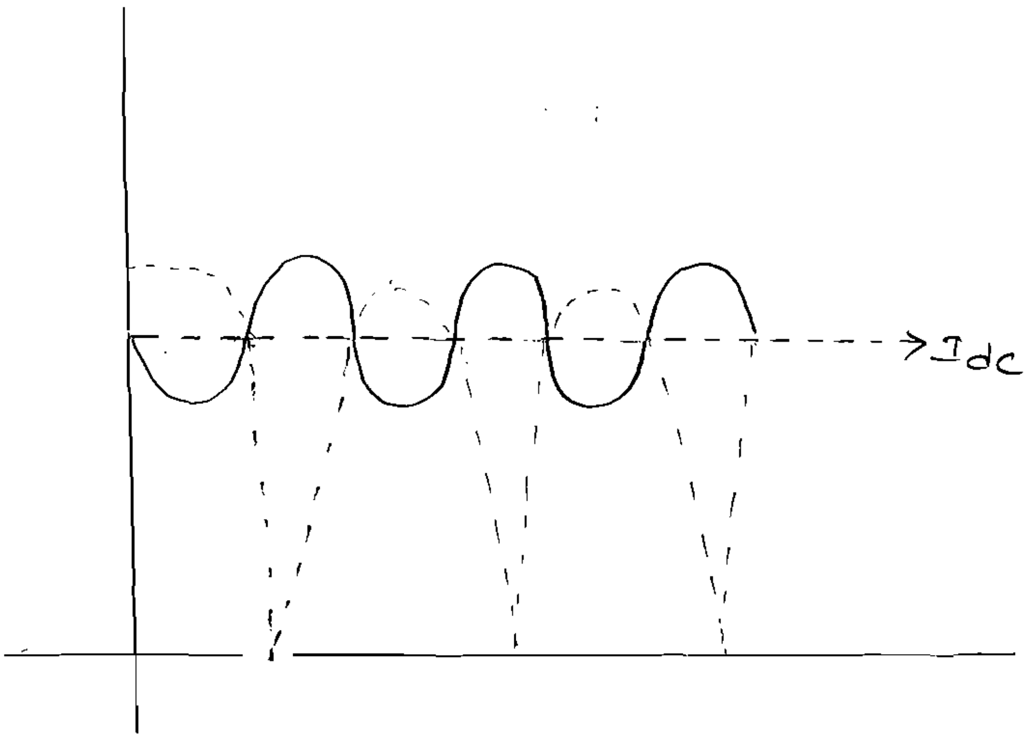


fig(b): concept of inductor filter

→ FWR With Inductor Filter



fig(a):



→ The fourier series for the load current for the full wave rectifier

$$I \simeq I_M\left[\frac{2}{\pi} - \frac{4}{\pi}\sum_{K=2,4,6} \frac{\cos K\omega t}{(K+1)(K-1)}\right]$$

Write 2,4,6.

$$I = I_M\left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t\right] \rightarrow (1)$$

Neglecting higher order harmonic terms we get

$$I_L = \frac{2I_M}{\pi} - \frac{4I_M}{3\pi}\cos 2\omega t \rightarrow (2)$$

Neglecting diode forward resistance we can write DC component of current.

$$I_{dc} = \frac{2I_m}{\pi} \quad \text{(dc component)}$$

$$V_{dc} = I_{dc} \cdot R_L, \; V_m = I_m R_L \Rightarrow I_m = \frac{V_M}{R_L}$$

$$I_{dc} = \frac{2V_m}{\pi \cdot R_L}$$

→ The second harmonic component Ac component or Ripple component and can be written as

$$I_M = \frac{V_M}{Z} \quad [\text{Ac component}]$$

Z = Impedence $= R_L + j2X_L$

$$Z = R_L + j2X_L \; [X_L = 2X_L]$$

$$\therefore Z = \sqrt{R_L^2 + 4\omega^2 L^2}$$

$$I_M = \frac{V_M}{\sqrt{R_L^2 + 4\omega^2 L^2}} \rightarrow (3)$$

Substitute (3) in (2)

$$I_L = \frac{4V_m}{3\pi\sqrt{R_L^2 + 4\omega^2 L^2}} \cos 2\omega t.$$

Expression for Ripple factor

$$\text{Ripple factor} = \frac{I_{rms}}{I_{dc}}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$ for Ac component present in I_L.

AC in $I_{rms} = \dfrac{4V_m}{3\sqrt{2}\,\pi\sqrt{R_L^2+4\omega^2L^2}}$

$$\text{Ripple factor}\,(\gamma) = \frac{I_{rms}}{I_{dc}}$$

$$= \frac{\dfrac{\cancel{4}^{2}V_m}{3\sqrt{2}\,\cancel{\pi}\sqrt{R_L^2+4\omega^2L^2}}}{\dfrac{\cancel{2}\cdot \cancel{V_m}}{\cancel{\pi}R_L}}$$

$$= \frac{2R_L}{3\sqrt{2}\sqrt{R_L^2+4\omega^2L^2}}$$

$$= \frac{2\cancel{R_L}}{3\sqrt{2}\cdot\cancel{R_L}\sqrt{1+\dfrac{4\omega^2L^2}{R_L^2}}}$$

$$= \frac{2}{3\sqrt{2}\sqrt{1+\dfrac{4\omega^2L^2}{R_L^2}}}$$

If $\dfrac{4\omega^2L^2}{R_L^2} >> 1$ then simplified expression for

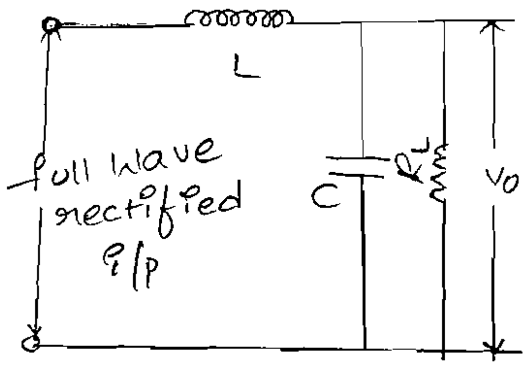
$$\gamma = \frac{R_L}{3\sqrt{2}\,\omega L}$$

→ Initially no load condition R_L and hence $\dfrac{4\omega^2L^2}{R_L^2} = 0$

so $\dfrac{2}{3\sqrt{2}} = 0.47$

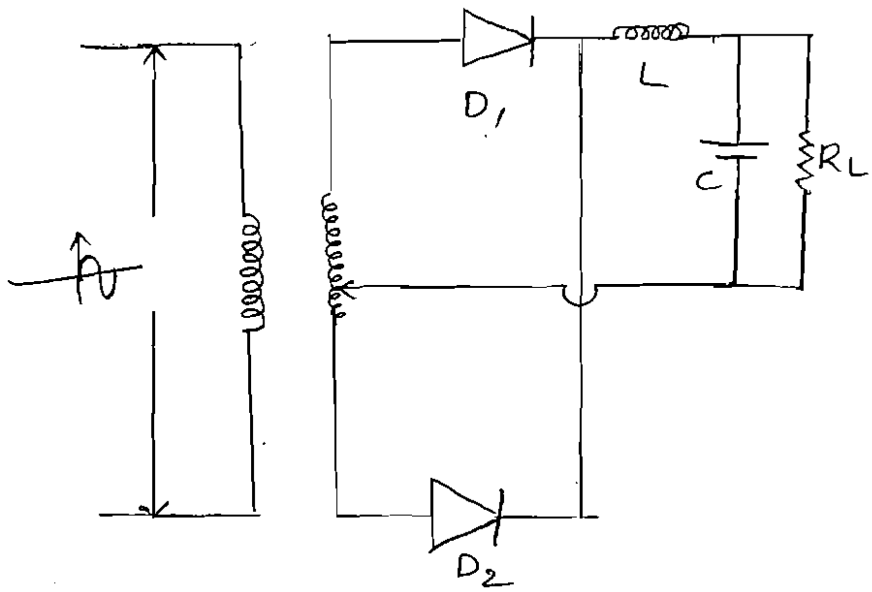
→ This is slightly less than the value of 0.48 it is clear that the inductor filter should only be used where R_L is consistantly small.

** L-section filter or Lc filter (contd) 10/8/16



fig(a): Lc filter

FWR with Lc filter.



fig(b): Basic structure of fwr with Lc filter.

→ From fourier series the o/p voltage can be expressed as $V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t$.

The DC output voltage $V_{dc} = \frac{2V_m}{\pi}$

$$I_{rms} = \frac{4V_m}{3\pi\sqrt{2}} \times \frac{1}{X_L} \Rightarrow \frac{\sqrt{2}\cdot\sqrt{2}\cdot(2V_m)}{3\pi\sqrt{2}} \times \frac{1}{X_L}$$

$$= \frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{1}{X_L}$$

$$= \frac{\sqrt{2}}{3} \cdot \frac{V_{dc}}{X_L}$$

→ this current flowing through X_C the reactance of capacitance causes the ripple voltage in the

Output.

$$\boxed{V_{rms} = \frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{X_C}{X_L}}$$

The ripple factor $\gamma = \frac{V_{rms}}{V_{dc}}$

$$= \frac{\frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{X_C}{X_L}}{\frac{2V_m}{\pi}}$$

$$= \frac{\frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{\frac{1}{2\omega C}}{2\omega L}}{\frac{2V_m}{\pi}} \quad \left(\because X_C = \frac{1}{2\omega C}, X_L = 2\omega L\right)$$

$$= \frac{\frac{\sqrt{2}}{3} \cancel{V_{dc}} \cdot \frac{1}{4\omega^2 LC}}{\cancel{V_{dc}}}$$

$$= \frac{\sqrt{2}}{3} \times \frac{1}{4\omega^2 LC}$$

inductor higher order ripples capacitor removes small AC ripple.

→ If frequency $f = 50H$, $C = mf$ and L is henrys

$$\boxed{\therefore \gamma = 1.19H / LC}$$

→ In this filter the inductor removes all high frequencies ripple components and capacitor removes all remaining AC ripple components hence the resulting in smooth DC. O/P.

→ The ripple factor directly proportional to the load resistance R_L in the inductor filter and inversely proportional to the capacitor filter.

$\gamma \propto \sqrt{2} \cdot R_L \rightarrow$ inductor

$\gamma \propto \frac{1}{R_L} \rightarrow$ capacitor.

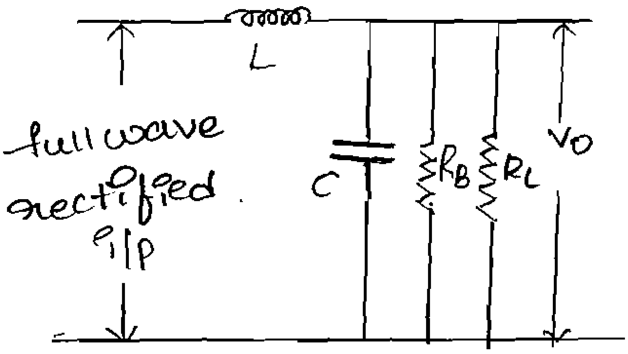
→ If these 2 filters are (compared) combined as L section filter as shown in fig(a).

→ The Rf will be independent of R_L.

→ If the value of the inductance is increased it will increases.

→ At some critical value of inductance one diode either D_1 or D_2 in full wave rectifier will always be conducting.

* Bleeder Resistor



fig(a): Bleeder Resistor

→ It was assumed in the analysis given above that for a critical value of inductor either of the diode is always conducting ie current does not fall to zero the incoming current consists of 2 components.

1. $I_{dc} = \frac{V_{dc}}{R_L}$

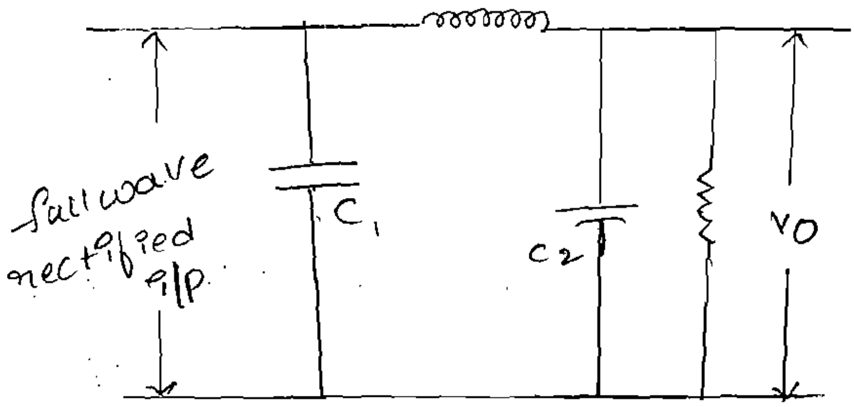
2. A sinusoidal varying components with peak value of $\frac{4V_m}{3\pi} \times \frac{1}{X_L}$

We know that for LC filter. $I_{rms} = \frac{\sqrt{2}}{3} \times \frac{V_{dc}}{X_L}$

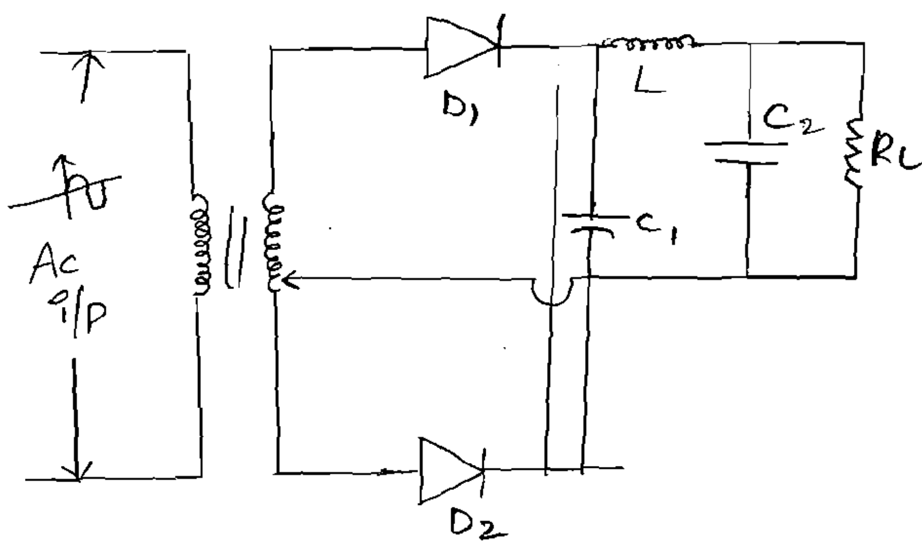
→ It should be noted that the condition is

$$\boxed{X_L \geq \frac{2}{3} R_L}$$

* π section filter & CLC filter



fig(a):- π section & CLC filter.



fig(b): FWR with π section filter

$$\gamma = \sqrt{2} \cdot \frac{X_{C_1}}{R_L} \cdot \frac{X_{C_2}}{X_L}$$

Where $X_{C_1} = \frac{1}{2\omega C_1}$, $X_{C_2} = \frac{1}{2\omega C_2}$, $X_L = 2\omega L$.

$$\gamma = \frac{\sqrt{2} \cdot \left(\frac{1}{2\omega C_1}\right) \cdot \left(\frac{1}{2\omega C_2}\right)}{R_L \cdot 2\omega L} = \frac{\sqrt{2}}{8\omega^3 L C_1 C_2 R_L}$$

If C_1 & C_2 are Expressed in μf & $\omega = 2\pi f$
$f = 50Hz$ then.

$$\gamma = \frac{\sqrt{2}}{8(2\pi \times 50)^3 \times (C_1 \times 10^{-6} \times C_2 \times 10^{-6} \times L \times R_L)}$$

$$\boxed{\gamma = \frac{5700}{LC_1C_2R_L}}$$

2.48050×10^{6}

11/8/16

→ fig(a) shows the CLC filter which basically consists of a capacitor filter followed by an LC filter.

→ This filter Offers a fairly smooth output and it is Characterized by an highly peak diode current and poor regulation.

Problems on Bridge Rectifier

* In a bridge rectifier the transformer is connected to 220V, 60Hz mains and the turns ratio of the stepdown transformer is 11:1. Assume the diode is ideal. Find i) V_{dc}
ii) I_{dc}
iii) PIV (2003).

Ans:- Given i/p voltage = 220V, 60Hz

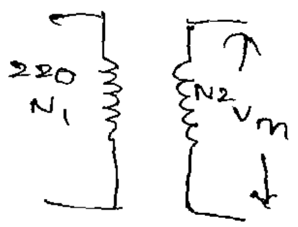
Turn ratio = 11:1

i) V_{dc}

To find the voltage across the load $V_{dc} = \frac{2V_m}{\pi}$

$V_m = \sqrt{2}\, V_{rms}$ secondary.

$V_{rms\ secondary} = \dfrac{V_{rms\ primary}}{\text{Turns ratio}}$



$= \dfrac{200V}{11}$

$= 18.18V$

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

$= \sqrt{2} \times 18.18$

$V_m = 25.71V$

$$\boxed{V_{dc} = \frac{2 \times V_m}{\pi} = \frac{2 \times 25.71V}{\pi} = 16.36V}$$

ii) To find $I_{dc} = \dfrac{V_{dc}}{R_L}$

Assume $R_L = 600\Omega$

$$\boxed{I_{dc} = \frac{16.36V}{600\Omega} = 27.2mA.}$$

iii) To find PIV for bridge rectifier is V_m

$$\boxed{\therefore V_m = 25.7V}$$

*

2) A Bridge rectifier uses four identical diodes having forward resistance of 5Ω and the secondary voltage is 30V. Determine the DC o/p Voltage for $I_{dc} = 200mA$ and the value of the o/p ripple voltage. (2004, 2009).

3) (c)

Ans :- Given transformer secondary resistance = 5Ω

$V_{rms} = 30V$

$I_{dc} = 200mA$

The diode forward resistance $r_f = 2 \times 5\Omega = 10\Omega$

w.k.T

$$V_{dc} = \frac{2V_m}{\pi} = I_{dc}(r_f + r_s).$$

$$V_m = \sqrt{2} \cdot V_{rms} = \sqrt{2} \times 30V.$$

$$V_{dc} = \frac{2 \times \sqrt{2} \times 30}{\pi} = 200 \times 10^{-3}(10+5) = 24V$$

$$\text{Ripple factor} = \frac{\text{rms value of the output}}{\text{average.}}$$

$$* \; 0.48 = \frac{\text{rms value of ripple at the output}}{24.}$$

Hence, rms value of ripple at the output

$= 0.48 \times 24 = 11.52V$

— o —

* Problems on filters

1) Calculate the value of capacitance to use in a capacitor filter connected to a full wave rectifier operating at a standard aircraft power frequency of 400Hz if the ripple factor is 10%. for a load of 500Ω.

Ans:- We know that the ripple factor for capacitor filter is $1/4\sqrt{3} f_c R_L$

$$\gamma = \frac{1}{4\sqrt{3} \times 400 \times C \times 500}$$

$$0.1 = \frac{1}{4\sqrt{3} \times 400 \times C \times 500} = \frac{1}{4\sqrt{3} \times 400 \times 0.1 \times 500}$$

$$\boxed{\therefore C = 7.2 \mu F}$$

2) A fwR voltage of 18V, peak is applied across 500μF filter. calculate the RF and DC voltage if the load takes a current of 100mA.

3) A 15-0-15 Volts ideal ~~voltage~~ transformer is used with a fw circuit with diodes having forward drop of 1V the load resistance of 100Ω and a capacitor of 10,000 μF is used as a filter across the load resistance. Calculate DC load current and voltage

4) Design a filter for fw circuit with LC filter to provide an output voltage of 10V with a load current of 200mA and the ripple is limited to 2%.

Ans:- The effective load resistance $R_L = \frac{V}{I}$

$= \frac{10V}{200\times10^{-3}}$

$R_L = 50\Omega$

We know that the ripple factor $= \gamma = \frac{1.194}{LC}$

$LC = \frac{1.194}{0.02}$ $\qquad \gamma = \frac{2}{100} = 0.02$

$= 59.7$

critical value of $L = \frac{R_L}{3\omega} = \frac{R_L}{3\times2\pi f}$ $\quad f = 50,60Hz$

$= \frac{50}{3\times2\times\pi\times50}$

$= \frac{1}{6\pi}$

$= 53.05\,mH.$

ving

4) In full x LC filter as $L = 10H$, $c = 100\mu F$ and $R_L = 500\Omega$ calculate I_{dc}, V_{dc}, ripple factor for an i/p of $v_i = 30\sin(100\pi t)V$.

5) Design a CLC or π section filter for $V_{dc} = 10V$, $I_L = 200mA$ and ripple factor $\gamma = 2\%$.

Ans:- Given data is $V_{dc} = 10V$

$I_L = 200mA.$

$\gamma = \frac{2}{100} = 0.02.$

$R_L = \frac{V}{I} = \frac{10}{200\times10^{-3}} = 50\Omega$

We know that Ripple factor $\gamma = \frac{2}{100} = 0.02$

$$\gamma = \frac{5700}{LC_1C_2R_L} \Rightarrow \frac{5700}{10 \times C^2 \times 50} = 0.02$$

$$\boxed{C = 23.87}$$

$11.4 = 0.02C^2$

$\frac{57}{C^2} = 0.02$

If we assume $L = 10H$, $C_1 = C_2 = C$.

$C^2 = \frac{11.4}{0.02}$ $\quad 0.02C^2 = 57$

$C^2 = 2850$

$C = \sqrt{2850}$

$C^2 = 570$

$C = \sqrt{570} = 23.87$

5) A FWR supplies a load ~~regulatance~~ regulating 300V at 200mH calculate the transformer secondary voltage i) A capacitor i/p. filter using capacitor of 10mF

ii) A choke i/p filter using a choke of 10H and a capacitance of 10mF.

4) Design a CLC & π section filter for $V_{dc} = 10V$.

$I_L = 200mA$, ripple factor $= 2\%(0.02)$

$$R_L = \frac{V}{I} = \frac{V}{200 \times 10^{-3}} = 50\Omega$$

$$\gamma = \frac{5700}{LC_1C_2R_L}$$

$$\gamma LC_1C_2 = \frac{5700}{50} = 114.$$

If we assume $L = 10H$, $C_1 = C_2 = C$.

$$0.02\, LC_1C_2 = 114$$

$$0.02 \times 10C^2 = 114$$

$$C^2 = \frac{114}{0.2}$$

$$\boxed{C = 23.87F}$$

Given $V_{dc} = 300V$, $I_{dc} = 200mA$

a. for the capacitor filter with C = 10 μF.

$$V_{dc} = V_m - \frac{I_{dc}}{4fC}$$

$$300 = V_m - \frac{200\times10^{-3}}{4\times50\times10\times10^{-6}} = V_m - 100$$

$V_m = 400\,V$ (p-p).

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 282.84\,V.$$

b) for the choke, i.e. LC filter with L = 10 H, C = 10 μF.

$$V_{dc} = \frac{2V_m}{\pi} \Rightarrow 300 = \frac{2V_m}{\pi}$$

$V_m = 471.23\,V$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 333.21\,V.$$

2Sol:- $V_m = 18\,V$, $C = 500\,\mu F$ and $I_{dc} = 100\,mA$

$$V_{dc} = V_m - \frac{I_{dc}}{4fC} = 18 - \frac{100\times10^{-3}}{4\times50\times500\times10^{-6}} = 17\,V.$$

$$V_{rms} = \frac{I_{dc}}{4\sqrt{3}fC} = \frac{100\times10^{-3}}{4\sqrt{3}\times50\times500\times10^{-6}} = 0.577\,V.$$

$$\gamma = \frac{V_{r.rms}}{V_{dc}} = \frac{0.577}{17}\times100 = 3.39\%$$

3Sol:- Given transformer secondary voltage = 15-0-15 V_{rms}

Diode forward drop = 1 V, $R_L = 100\,\Omega$, $C = 10{,}000\,\mu F$

W.K.T $V_{dc} = V_m - \frac{V_{r,p-p}}{2} = V_m - \frac{I_{dc}}{4fC}$.

$$V_{dc} = V_m - \frac{V_{dc}}{R_L 4fC} \quad \left[\because I_{dc} = \frac{V_{dc}}{R_L}\right]$$

Simplifying we get $V_{dc} = \left[\frac{4fR_LC}{4fR_LC+1}\right]V_m$.

W.K.T $V_m = V_{rms}\times\sqrt{2} = 15\times\sqrt{2}$

$$\therefore V_{dc} = \left[\frac{4\times50\times100\times10000\times10^{-6}}{4\times50\times100\times10000\times10^{-6}+1}\right] 15\times\sqrt{2} = 21.105V.$$

considering the given voltage drop of 1 volts to diode.

$$V_{dc} = 21.105 - 1 = 20.105V.$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{20.105}{100} = 0.20105A.$$

5 sol:- $v_i = V_m \sin\omega t$

$$v_i = 30 \sin(100\pi t)V$$

comparing the i/p with $v_i = V_m \sin\omega t$

$$V_m(\text{secondary}) = V_m = 30V.$$

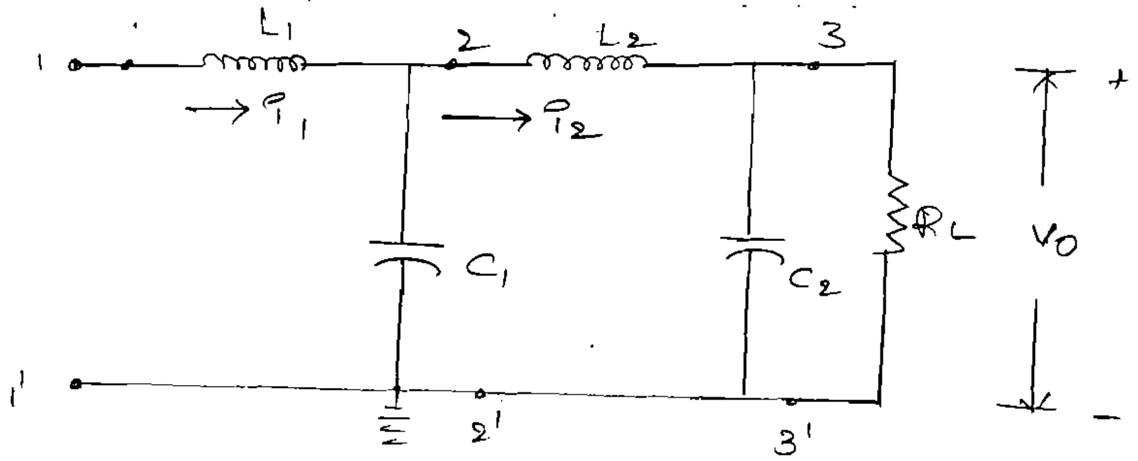
$$V_{dc} = \frac{2V_m}{\pi} = \frac{2\times30}{\pi} = 19.0985.$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{19.0985}{500} = 0.03819A = 38.19mA$$

$$\gamma = \frac{1}{6\sqrt{2}\omega^2 LC} = \frac{1}{6\sqrt{2}\times(100\pi)^2\times10\times100\times10^{-6}} = 1.194\times10^{-3}$$

Multiple L-section filter

The filtering level can be improved by using two & more L-section filters in series as shown in fig(a) It is assumed that the reactance of all the inductances are much larger than the reactance of the capacitors and the reactance of the last capacitor is small compared with the resistance of the load.



fig(a). A multiple (two section) L-section filter

→ The impedance b/w 3 & 3' is X_{C2} and the impedence between 2 & 2' is X_{C1} and the impedance.

→ The alternating current i_1 through L_1 is given by $I_1 = \frac{\sqrt{2}}{3} \cdot \frac{V_{dc}}{X_{L1}}$

→ The AC voltage across C_1 is given by

$$V_{22'} \simeq I_1 X_{C1}$$

→ The alternating current i_2 through L_2 is given by

$$I_2 = \frac{V_{22'}}{X_{L2}}$$

→ The AC voltage across C_2 and hence across the load is given by.

$$V_{33'} \simeq I_1 \cdot \frac{X_{C2} X_{C1}}{X_{L2}} \simeq \frac{\sqrt{2}}{3} V_{dc} \cdot \frac{X_{C2}}{X_{L2}} \cdot \frac{X_{C1}}{X_{L1}}$$

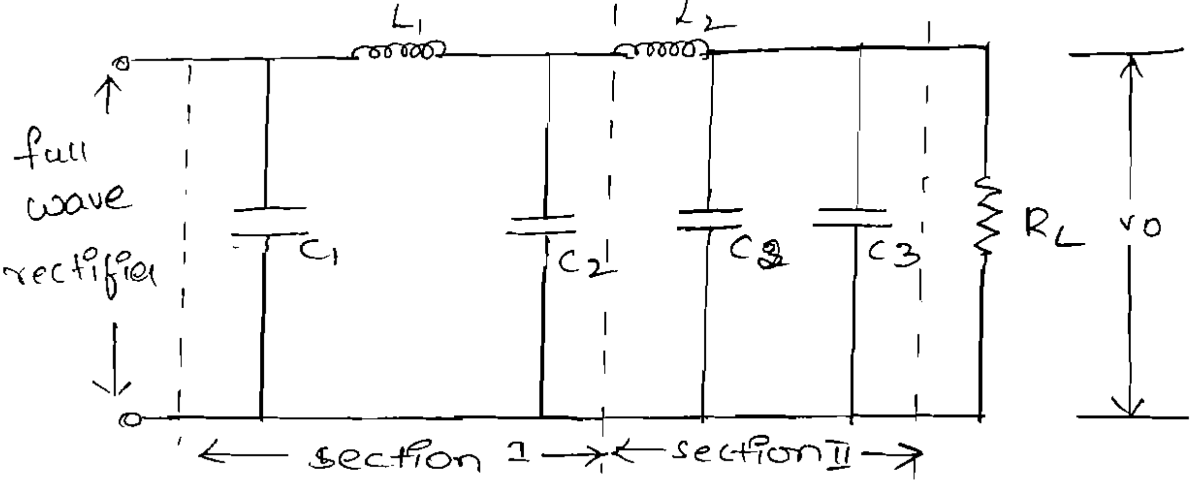
→ The ripple factor is obtaining by dividing the above equation by V_{dc}

$$\gamma \simeq \frac{\sqrt{2}}{3} \times \frac{X_{C1}}{X_{L1}} \cdot \frac{X_{C2}}{X_{L2}}$$

for example the ripple factor of multiple L-section filter $\gamma_n = \frac{\sqrt{2}}{3}\left(\frac{X_C}{X_L}\right)^n = \frac{\sqrt{2}}{3} \cdot \frac{1}{(16\pi^2 f^2 LC)^n}$

Where 'n' is the no. of similar 'L' section.

Multiple 'π' section



fig(a): Multiple π-section filter.

In order to obtain pure DC at the output more no.of π-sections may be used in series such a filter using more than one π section as shown in fig(a) is called multiple π-section filter.

The ripple factor for multiple π-section filter is given by $\gamma = \gamma_2 \cdot \frac{X_{C_1}}{R_L} \cdot \frac{X_{C_2}}{X_{L_1}} \cdot \frac{X_{C_3}}{X_{L_2}} \cdots \frac{X_{C_n}}{X_{L(n-1)}}$

Where n is the no.of π-sections.

Comparision of filters

S.NO.	Name.	formula of Ripple factor.	value of ripple factor.
1.	HWR with capacitive filter	$\gamma = \frac{1}{2\sqrt{3} f C R_L}$	$\gamma = 0.09$ (If $f = 50Hz$, $C = 100\mu F$ and $R_L = 3k\Omega$)
2.	FWR with capacitive filter.	$\gamma = \frac{1}{4\sqrt{3} f C R_L}$	$\gamma = 0.0086$ (If $f = 50Hz$, $C = 100\mu F$, $R_L = 3k\Omega$)
3.	Induction filter	$\gamma = \frac{2}{3\sqrt{2}\sqrt{1+\frac{4\omega^2 L^2}{R^2}}}$	$\gamma = 0.47$
4.	L-section filter	$\gamma = \frac{\sqrt{2}}{3} \cdot \frac{1}{4\omega^2 LC} \left(\frac{1}{6\sqrt{2}\omega^2 LC}\right)$	$\gamma = 1.194/LC$ $\gamma = 0.02626$ (If $f = 50Hz$, $L = 1000mH$, $C = 50\mu F$)
5.	Multiple L-section filter	$\gamma = \frac{\sqrt{2}}{3\omega^4 L_1 L_2 C_1 C_2}$	$\gamma = 0.019$ (If $L_1 = L_2 = 1mH$, $C_1 = C_2 = 50\mu f$, $f = 50Hz$)
6.	π-section filter	$\gamma = \frac{\sqrt{2}}{8\omega^3 L C_1 C_2 R_L}$	$\gamma = 5.54 \times 10^{-4}$ (If $L = 10H$, $C_1 = C_2 = 16\mu f$, $R_L = 4k\Omega$)
7.	Multiple π-section filter	$\gamma = \sqrt{2} \cdot \frac{X_{C1}}{R_L} \cdot \frac{X_{C2}}{X_{C1}} \cdots \frac{X_{Cn}}{X_{L(n-1)}}$	