Introduction

'A semiconductor is a material that is neither a good conductor nor a good insulator. In its purest form, it has few applications in electronics. When the characteristics of a pure semiconductor are altered through a process known as doping, many useful electronic devices can be developed.

A semiconductor material that has been subjected to the doping process is called an extrinsic material. The two types of extrinsic material are n-type & p-type materials.

The purest form of semiconductor is intrinsic material.

The three semiconductors used most frequently in the construction of electronic devices are Ge, Si and GaAs.

Adding impurities like antimony, arsenic & phosphorus (ie., pentavalent, which has five valence electrons) gives n-type material

Diffused impurities with five valence electrons are called donor atoms

In a n-type material, the electron is called majority carrier & hole the minority carrier.

Adding impurities like boron, gallium & indium (ie, trivalent which has three valence electrons) gives p-type material.

Diffused impurities with three valence electrons are called acceptor atoms.

In a p-type material, hole is majority carrier and electron is minority carrier.

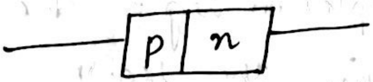
P-N JUNCTION DIODE

The first solid state electronic device called semiconductor diode or simply pn junction diode is constructed by joining p- and n-type semiconductor materials.

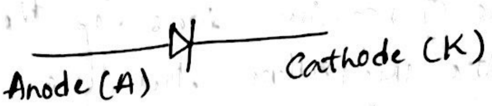
The doped regions meet to form a p-n junction.

Diodes are unidirectional devices that allow current to flow through them only in one direction.

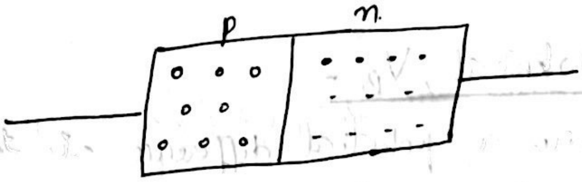
Basic Construction



Schematic symbol

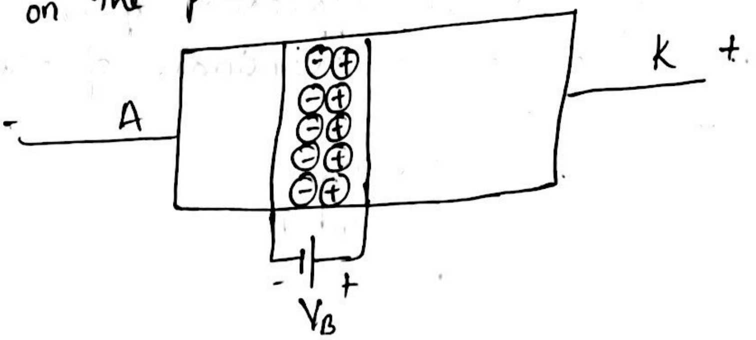


Internal distribution of charge



Depletion Zone –

At the instant the pn junction is formed, free e^-s on the n side migrate or diffuse across the junction to the p side. Once on p side, the free e^-s are minority current carriers. The life time of these free e^-s is short, however, ~~they~~ becoz they fall into holes shortly after crossing over to the p-side. When free e^- leaves the n side & falls into a hole on the p side, two ions are created, a positive ion & on the n side and a negative ion on the p-side.



As the process of diffusion continues, a barrier potential V_B is created and the diffusion of e⁻s from the n side to the p side stops. e's diffusing from the n side senses a large negative potential on the p side that repels them back to the n side. Similarly, holes from p side are repelled back to p-side by positive potential on the n-side.

This region of uncovered positive and negative ions is called the depletion region due to the depletion of free carriers in the region.

The positive & negative ions in the depletion region are fixed in the crystalline structure and are ∴ unable to move.

Barrier Potential, V_B -

Ions create a potential difference at the pn junction. This potential difference is called the barrier potential, V_B.

For Si $V_B = 0.7V$

Ge $V_B = 0.3V$

V_B cannot be measured externally with a voltmeter but it does exist at the pn junction.

V_B stops the diffusion of current carriers.

Bias -

Inorder to extract a response of a device, we need to bias.

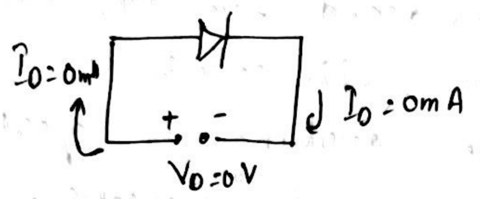
Bias refers to the application of an external voltage across the the two terminals of the device.

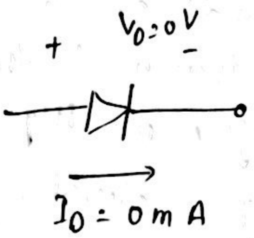
Three situation -

- No Bias
- Forward Bias
- Reverse Bias.

No Applied Bias (V = 0V).

Under no bias condition, any minority carriers (holes) in the n-type material within depletion region will pass quickly into the p-type material.



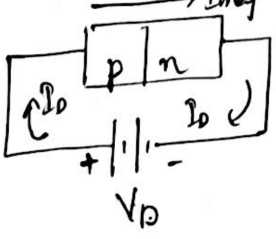


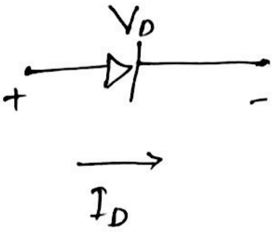
In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.

Forward Bias Condition ($V_D > 0V$);

A forward bias is established by applying the positive potential to the p-type & negative potential to the n-type material. The voltage source V_D must be large enough to overcome the internal barrier potential V_B. The forward bias potential, V_D will pressure the electrons in the n-type material & holes in the p-type material to recombine with the ions near the boundary & reduce the width of the depletion region. As the applied bias ↑se in magnitude, " " " will continue to ↓se in width until a large no. of e's can pass through the junction, resulting in an exponential rise in current.

$$\left.\begin{array}{l} \xleftarrow{I_s} \\ \xrightarrow{} I_{maj} \end{array}\right\} I_D = I_{maj} - I_s$$





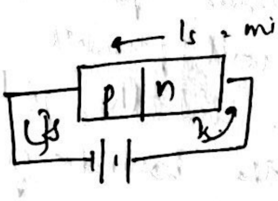
Reverse Bias Condition ($V_D < 0$ V)

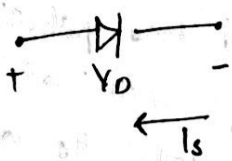
The +ve terminal is connected to n type & -ve terminal do the p-type material.

The no. of uncovered +ve ions in the depletion region of the n-type material will ↑se due to large no. of free e's drawn to the +ve potential of the applied voltage, V_D. ||ly the uncovered -ve ions will ↑se in p-type material. Therefore, this results in widening of the depletion region. resulting in great barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero.

The no. of minority carriers, entering the depletion region will not change, resulting in minority carrier flow.

The current that exists under reverse bias conditions is called the reverse saturation current & is represented by I_s.





PN JUNCTION DIODE EQUATION.

The general characteristics of a semiconductor diode is given by schockley's equ for FB & RB regions.

$$I_D = I_s \left[e^{V_D/\eta_k V_T} - 1\right]$$

I_s : reverse saturation current
V_D : applied FB voltage across the diode
n : ideality factor
(ranges b/w 1 and 2, usually $n = 1$)
V_T : thermal voltage

$$V_T = \frac{kT}{q}$$

k : Boltzman's const $= 1.38 \times 10^{-23}$ J/K
T : absolute temp in Kelvins $= 273 + t°C$
q : magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

$$I_D = I_s e^{V_D/nV_T} - I_s$$

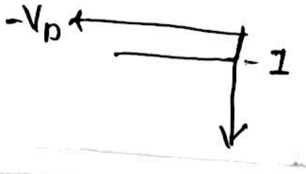
For $V_D > 0$ i.e., positive values of V_D
the first term increases exponentially & quickly
& " 2nd " can be ignored

$$\therefore I_D \cong I_s e^{V_D/nV_T} \quad (V_D = +ve)$$

For $V_D < 0$ i.e., negative values of V_D
the 1st term drops quickly below the level of I

$$\therefore I_D \approx -I_s \quad (V_D = -ve)$$

$\therefore$ For -ve values of V_D, I is essentially horizontal at the level of $-I_s$



for $V = 0$

$I_D = I_s(e^0 - 1) = I_s(1-1) = 0 \, mA.$

Volt - Ampere (V-I) Characteristics.

The V-I characteristics is described by equ of current of diode

$$I_D = I_s [e^{V/nV_T} - 1]$$

~~When voltage V is +ve and several times V_T~~

V-I characteristics curve is a plot of diode current I_D & diode voltage V_D. It includes I_D for both FB & RB voltages.

The upper right quadrant represents F.B condition & lower left quadrant R-B condition.

F.B region

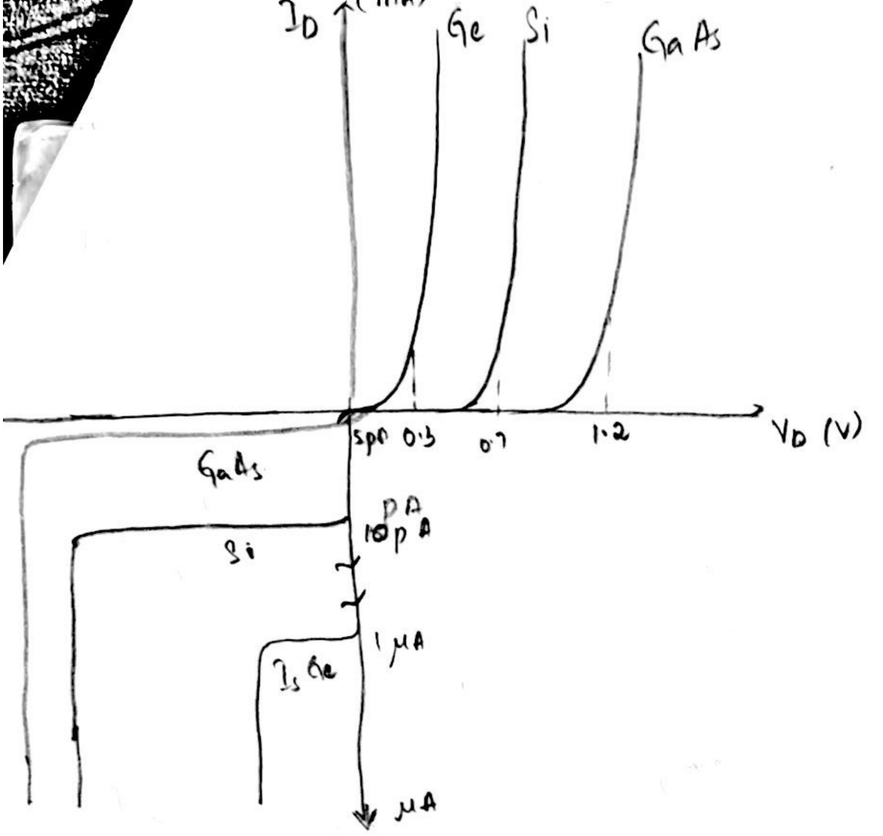
$V_D > 0V$, $I_D > 0 \, mA$.

Little diode current flows when the voltage V_D is less than the knee voltage, about (0.6V for Si) knee voltage. Beyond the knee voltage, I_D ↑ses sharply & exponentially.

R-B region

$V_D < 0V$ $I_D = -I_s$

for -ve values of V_D, I_D is essentially horizontal at the level of $-I_s$.



knee voltage (V_k)
V_k - Ge : 0.3
Si : 0.7
GaAs : 1.2

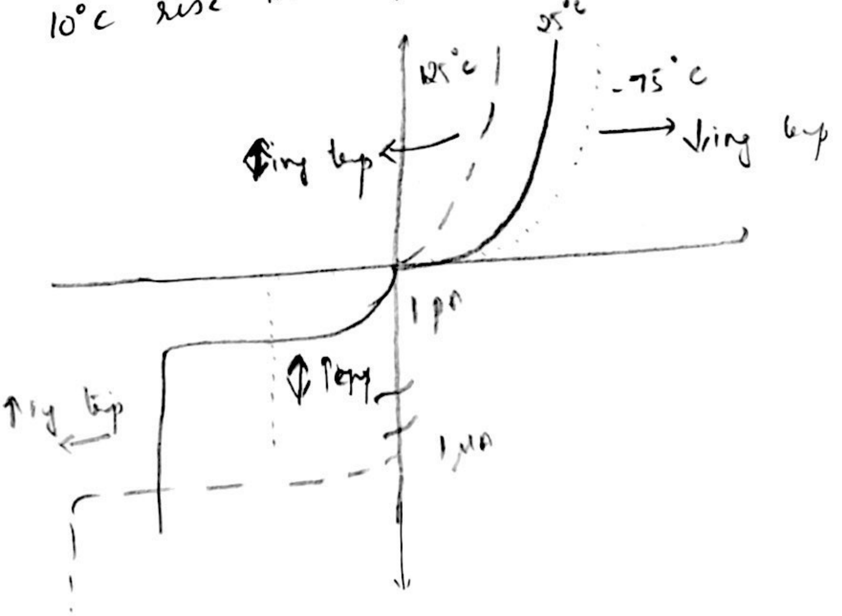
Zener Potential V_Z
For V_Z, there is a sharp change in char becoz of too -'ve voltage

TEMPERATURE EFFECT -

In F.B region, the characteristics of Si diode shift to left at a rate of 2.5 mV per °C ↑se in temp.

The reverse breakdown voltage of a semiconductor diode will ↑se or ↓se with temp depending on Zener potential.

In RB region, the reverse saturation current of Si diode doubles for every 10°C rise in temp



Applications of Diode.

One of imp app^n of diode is seen in rectifier ckts.
Rectifier is used to convert ac voltage to dc voltage with some ac components.
The dc source of power is an imp requirement in almost all electronic systems like TV, stereos & computers.
Large sgl diodes or rectifiers diodes (ex - IN4001) are used in ckts where the power line ac sgl is converted into dc sgl.
Ex of this is silicon p-n jn diodes with larger jn area which leads to a high transition capacitance & high power rating (>0.5W) of the diode. These work at lower power line freq (ex 50Hz in India & 60Hz in US)

PN junction Diode as Rectifier.

" " " is a 2 terminal device ie., polarity sensitive.
When the diode is FB, the diode conducts & allows current to flow through it without any resistance ie., Diode is ON
When the diode is RB, the diode doesnot conduct & no current flow through it ie., Diode is OFF.
Thus an ideal diode acts as a switch either open or closed depending upon the polarity of the voltage placed across it.
An ideal diode has zero resistance under FB &
infinite " " RB.

D·8

Rectifier used for converting a.c voltage into unidirectional voltage

Classification of rectifier is based upon the period of conduction

1) Half Wave Rectifier (HWR)

- The ckt consists of a power transformer T, which is step up or step down type. The primary of the transformer is connected to the 230V AC supply from which the rectifier derives the required electric power for the working.

HWR converts an ac voltage into a pulsating dc voltage using only one half of the applied a.c voltage. Hence named as HWR.

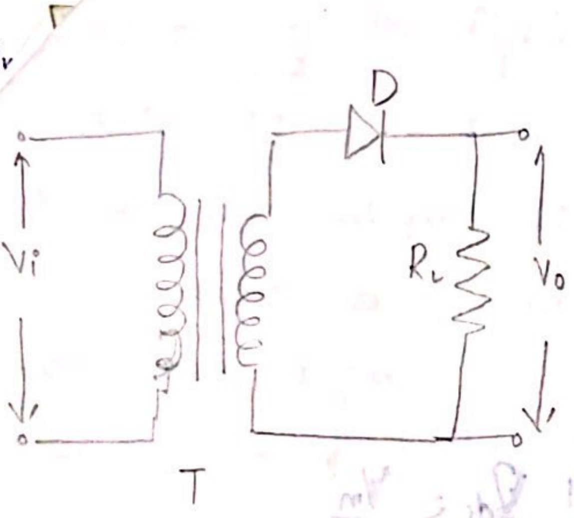
The diode D & load resistor R_L are in series with secondary winding of T.

During +'ve half cycles, D will conduct in the direction shown, since its anode is more +'ve than its cathode. This permits current I_D to flow as shown.

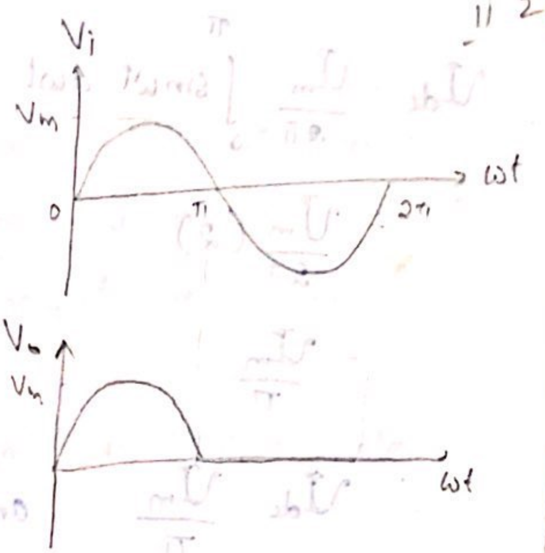
During -'ve half cycles, D will not conduct as its anode is negatively biased w.r.t cathode. ∴ I_D ceases to flow during -'ve half cycles.

The o/p is similar to i/p during +'ve half cycles but it is zero during -'ve half cycles. Thus o/p is a variable DC & not constant DC.

2.



circuit diag of HWR.



i/p & o/p waveforms

Let i/p voltage be

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

o/p voltage is

$$V_o = V_m \sin\omega t \quad [0\ \pi]$$

$$= 0 \quad [\pi\ 2\pi]$$

Current equations

$$I_L = \frac{V_m}{R_L}\sin\omega t$$

$$= I_m \sin\omega t$$

Determination of DC value of the o/p voltage & current or Avg Value

Using fourier analysis

$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V_L\, d\omega t$$

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

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

For π to 2π
o/p is zero
no integ.

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

$$= \frac{V_m}{2\pi}(2)$$

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

$$\therefore V_{dc} = \frac{V_m}{\pi} \quad \text{and} \quad ||^{ly}\ V_{dc} = \frac{V_m}{\pi}$$

$$||^{ly}\ I_{dc} = \frac{V_m}{\pi(r_s + r_d + R_L)}$$

r_s → resistance of 2nd winding of the transformer

r_d → resistance of diode.

$$\therefore \boxed{V_{dc} = \frac{V_m}{\pi} \ , \ I_{dc} = \frac{V_m}{\pi(r_s + r_d + R_L)}} \text{ for HWR}$$

Determination of RMS value of the o/p voltage & current

RMS - root mean squared.

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

For π to 2π o/p is zero.

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

$$= \frac{V_m^2}{2\pi}\int_0^{\pi}\left[\frac{1-\cos 2\omega t}{2}\right]_0^{\pi} d\omega t$$

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

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

Determination of the Ripple Factor

Ripple Factor (γ) is a term associated with the amount of AC in the rectified DC voltage and current.

The ac component or fluctuating components in rectified o/p are called ripples.

Measure of the fluctuating components is ripple factor.

$\gamma = 0$ for pure DC.

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

From Fourier analysis

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

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

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

$$= \sqrt{\left[\frac{V_m/2}{V_m/\pi}\right]^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1}$$

$$= 1.21$$

$\therefore$ $\boxed{\gamma = 1.21}$ For HWR

Rectification Efficiency (η)

Rectifiers are AC to DC converters. Rectification efficiency is the ratio of DC power o/p to AC power i/p.

$$\eta = \frac{\text{DC power o/p}}{\text{AC power i/p}} \times 100\%$$

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

$$= \frac{I^2_{dc} R_L}{I^2_{rms} (R_L + r_s + r_f)}$$

$$= \left[\frac{I_m/\pi}{I_m/2}\right]^2 \cdot \left[\frac{R_L}{R_L + r_s + r_f}\right]$$

if $r_s + r_f << R_L$.

$$\frac{R_L}{R_L + r_s + r_f} \simeq 1$$

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

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

$$= .406$$

$$\therefore \boxed{\eta = 40\%}$$ for HWR

Form Factor.

Ratio of rms value to avg value.

$$FF = \frac{V_{rms}}{V_{dc}}$$

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

$$\boxed{FF = 1.57}$$

Peak Factor.

Ratio of peak value to the rms value.

$$PF = \frac{V_m}{V_{rms}}$$

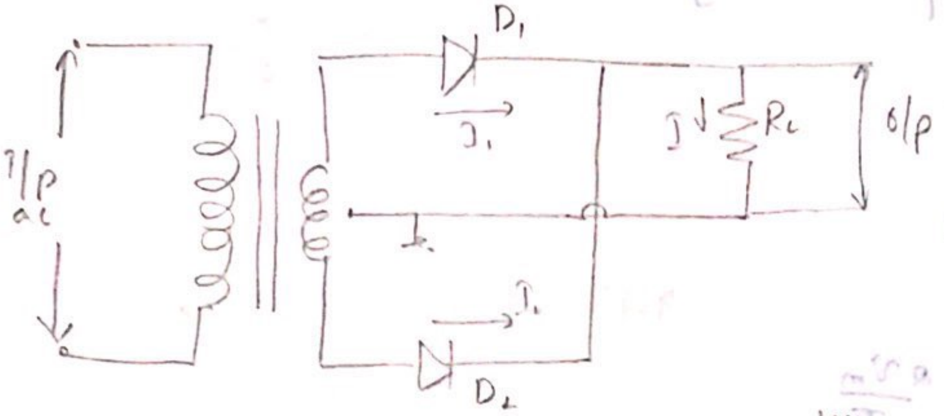
$$= \frac{V_m}{V_m/2} = 2$$

$$\boxed{PF = 2}$$

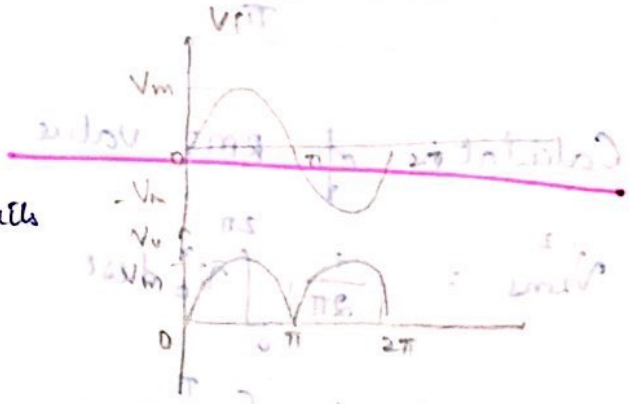
2) Full Wave Rectifier (FWR)

In this, both the half cycles of i/p wave are rectified hence named as FWR using 2 diodes D_1 and D_2.

A center-tapped transformer is used and FWR is also known as Center Tapped Rectifier



circuit diag of FWR



i/p & o/p waveform

During +ve half cycles, D_1 conducts and D_2 doesnot conduct and current I_1 flow through R_L as anode of D_1 is +ve.

During -ve half cycles, D_1 is OFF and D_2 is ON ie, current I_2 flow through R_L as shown in the fig

Let i/p be

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

o/p is

$$V_o = V_m \sin\omega t \qquad [0\ \pi]$$

$$= -V_m \sin\omega t \qquad [\pi\ \ 2\pi]$$

Calculation of DC Value / Avg Value.

$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V_o \, d\omega t$$

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

$$= \frac{V_m}{2\pi}\left\{ 2 + 2 \right\}$$

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

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

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

Calculation of RMS value.

$$V_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} V_o^2 \, d\omega t$$

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

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

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

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

Ripple Factor.

$$\gamma = \frac{V_{AC}}{V_{DC}}$$

$$= \sqrt{\frac{V^2_{rms}}{V^2_{dc}} - 1} = \sqrt{\left(\frac{V_m}{\sqrt{2}} \Big/ \frac{2V_m}{\pi}\right)^2 - 1}$$

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

$$= 0.481$$

$\therefore \boxed{\gamma = 0.481}$ for FWR

Efficiency.

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

$$= \frac{I^2_{dc}}{I^2_{rms}} \cdot \frac{R_L}{R_L + r_s + r_f}$$

$$= \frac{4V_m^2}{\pi} \cdot \frac{2}{V_m^2} \cdot\cdot \frac{R_L}{R_L + r_s + r_f} = \frac{8}{\pi^2}\left[\frac{R_L}{R_L + r_s + r_f}\right]$$

$$= 0.811 \frac{R_L}{R_L + r_s + r_f} \qquad r_s + r_f << R_L$$

$$\boxed{\eta = 81.1\%}$$

Form Factor:

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.1101$$

$$\boxed{FF = 1.11}$$

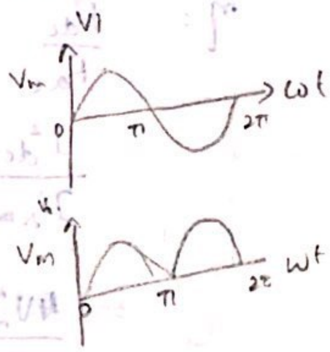
Peak Factor -

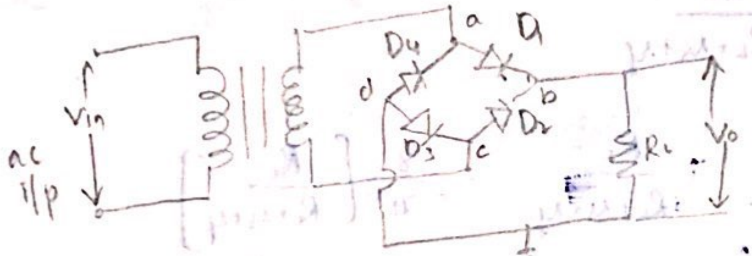
$$PF = \frac{V_m}{V_{rms}} = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2} = 1.414$$

$$\boxed{PF = 1.414}$$

Bridge Rectifier :

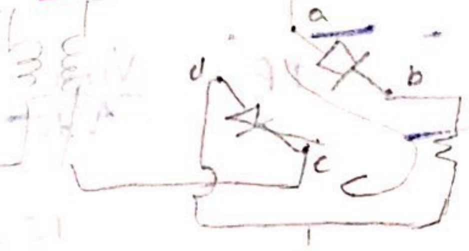
It is also FWR configuration
Two forms of FWR ckt are shown in the fig
The need of center tapped transformer in FWR is eliminated in this rectifier. It has 4 diodes connected to form a bridge. The a.c i/p voltage is applied to the diagonally opposite ends of the bridge. and load resistance is connected b/w the other 2 ends of the bridge





For the positive half cycles of i/p ac voltage, D_1 & D_3 are conducting whereas D_2 & D_4 are R.B. ∴ current i_1 flows through D_1 & D_3 & R_L

conduction path of current i_1 is a b R_L b d c Transformer a



for -ve half cycles D_2 and D_4 conducts whereas D_1 & D_3 are RB and current i_2 flows through D_2 D_4 & R_L.

conduction path of i_2 is c-b-R_L-d-a-transformer c

Comparison of Rectifiers.

	HWR	FWR	Bridge Rectifier
No. of Diodes	1	2	4
Avg Value (V_{dc})	V_m/π	$2V_m/\pi$	$2V_m/\pi$
RMS Value (V_{rms})	$V_m/2$	$V_m/\sqrt{2}$	$V_m/\sqrt{2}$
Ripple Factor (γ)	1.21	0.48	0.48
Efficiency (η)	40.6 %	81.1 %	81.1 %
Form Factor	1.57	1.11	1.11
Peak Factor	2	$\sqrt{2}$	$\sqrt{2}$
Output Freq.	f	$2f$	$2f$

Filters.

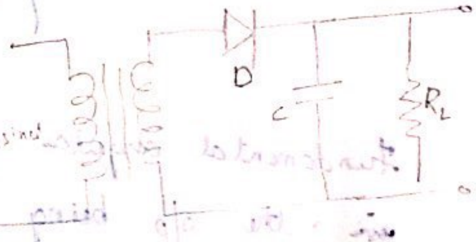
Filters are used to reduce the ripple or ac components present in the rectified DC o/p. Capacitors or Inductors are used as filters.

Types -

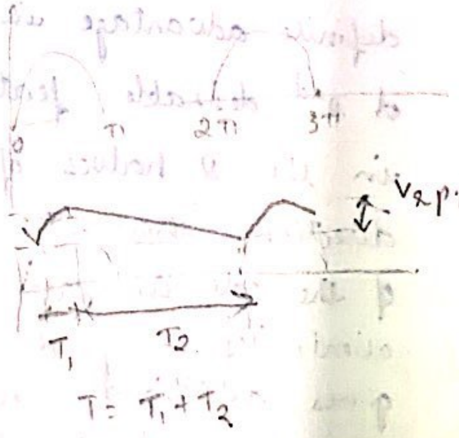
1) Capacitor Filter
2) Inductor "
3) L- Section (or) LC Filter.
4) π- Section (or) CLC "

1) Capacitor Filter

Filtering is effected by shunting the load with a capacitor. The action of the system depends upon the fact that the capacitor stores energy during the conduction period & delivers this energy to the load in non conducting period. In this way, the time during which the current passes through the load is prolonged & ∴ ripple is ↓ed.



For +ve half cycle, D conducts & charges the capacitor to the peak value of the i/p sgl. When the voltage across the capacitor C is $V_c = V_m$ then the voltage at the cathode of the diode is $+V_m$ which R B diode D for next half of +ve half cycle & full -ve half cycle.



In this duration capacitor discharges through R_L.

If high value of R_L is chosen, discharge duration can be prolonged to obtain smoother w/f.

Discharge continues till the voltage at the anode of diode exceeds the capacitor voltage during the next +ve ½ cycle.

$$\gamma = \text{Ripple Factor} : \frac{1}{2\sqrt{3} f C R_L}$$

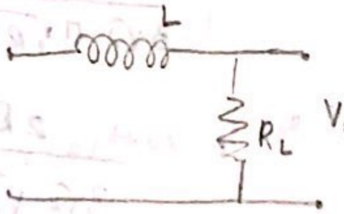
D 5

Inductor Filter or Choke Filter

The operation of inductor filter depends on the fundamental property of an " do oppose any change of current passing through it. Any sudden change in ckt with are smoothed out by an inductor.

The inductor or choke is placed in series with the load resistance R_L

Suppose that a choke i/p filter is applied to o/p of FWR



Inductor

$$\gamma = \frac{R_L}{3\sqrt{2}\,\omega L}$$

γ ↓se when L is ↑ed & R_L is ↓ed.

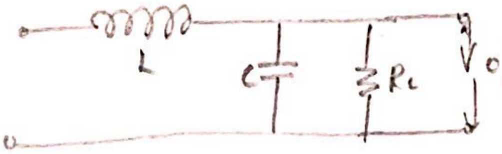
∴ Inductor filter is more effective only when the load current is high (ie, small R_L)

Larger 'L' value, smaller is 'γ' value.

3. LC Filter - / L-Section Filter:

In inductor filter $r \propto R_L$ & in capacitor filter $r \propto 1/R_L$

∴ if these 2 filters a combined to form LC filter or L-section filter



If the value of inductance is ↑ed, it will ↑se the time of conduction but at some critical value of inductance, one diode, either D_1 or D_2 in FWR, will always be conducting.

$$\boxed{\gamma = \frac{\sqrt{2}}{3}\,\frac{X_c}{X_L}}$$

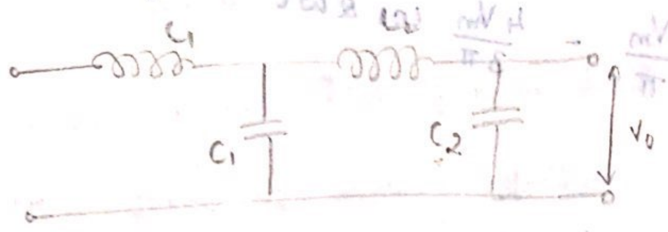
$$X_C = \frac{1}{2\omega C}$$

$$= \frac{\sqrt{2}}{3}\left(\frac{1}{4\omega^2 LC}\right)$$

$$X_L = 2\omega L$$

4) Multiple LC filter.

Better filtering is achieved using 2 or more L-section filters



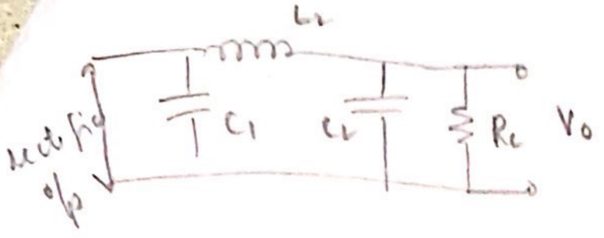
$$\gamma = \frac{\sqrt{2}}{3}\,\frac{X_{C1}}{X_{L1}}\,\frac{X_{C2}}{X_{L2}}$$

For n - LC filter

$$\gamma = \frac{\sqrt{2}}{3}\left[\frac{X_c}{X_L}\right]^2$$

5) π - or CLC filter -

In multiple section LC filter, there is drop across the element L1 which is undesirable in some cases. By removing inductor L1 the ckt can be modified into π or CLC filter which avoids the drop across L1, The CLC filter becomes a combination of a capacitor filter & choke filter Hence no longer ripple factor is ~~in~~ independent of RL



$$\gamma = \sqrt{2}\,\frac{X_{C_1}}{R_L}\,\frac{X_{C_2}}{X_{L_2}}$$

Application of Zener Diode -

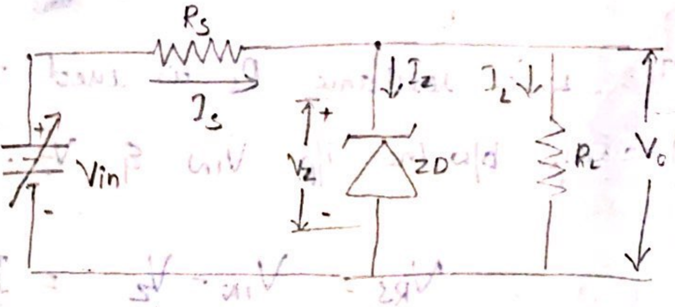
Zener diodes are des special pn junction diodes with adequate power dissipation capabilities to operate in the breakdown region whic can be employed as voltage reference or constant voltage devices. in the electronic ckts.

It provides constant o/p voltage in its breakdown region though Current is varying.

Used to minimize the voltage fluctuation of dc power supply obtained by the rectifier - filter combination.

∴ Zener is also known as Voltage Regulator

A simple zener voltage regulator ckt is shown here where



ZD is placed in ||el to R_L and V_{IN}

A series resistance R_s is in series with source & the load.

ZD - Zener diode
R_L - load resistance
Vin - Source voltage
V_Z - Zener ..
R_s - Series Resistance

V_{in} is a variable DC voltage.