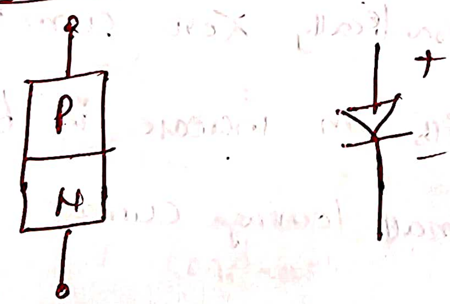
Q No. 8 (a).

(108)

Theory of PN-Junction diode

A PN junction is formed by joining p type and N type semiconductor together in very close contact. The term junction refers to the boundary interface where the two regions of the semiconductor meet. Diode is a two terminal electronic component that conducts electric current in only one direction. The crystal conducts conventional current in a direction from the p type side (anode) to the n-type side (cathode) but not in the opposite direction.

Symbol of PN junction



(*) Characteristics (V-I) and their temperature difference.

Forward bias

The application of forward bias voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented by V-I Chs curve is shown. is 'knee point' (or) cut in voltage.

Reverse bias

In reverse bias voltage at high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage.

However a very small leakage current does flow through the junction which can be measured in micro amperes (µA)

one final point if the reverse bias voltage V_r applied to the diode is increased to a sufficiently high current ~~enough~~ value, it will cause the PN junction to overheat and fail due to the avalanche effect around the junction.

this may cause the diode to become shorted and will result in the flow of maximum circuit current. and this shown as a step downward slope in the reverse static characteristic curve below.

Diode terminal characteristic equation for diode junction current.

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

Where $V_T = KT/q$:

V_D - Diode terminal voltage volts

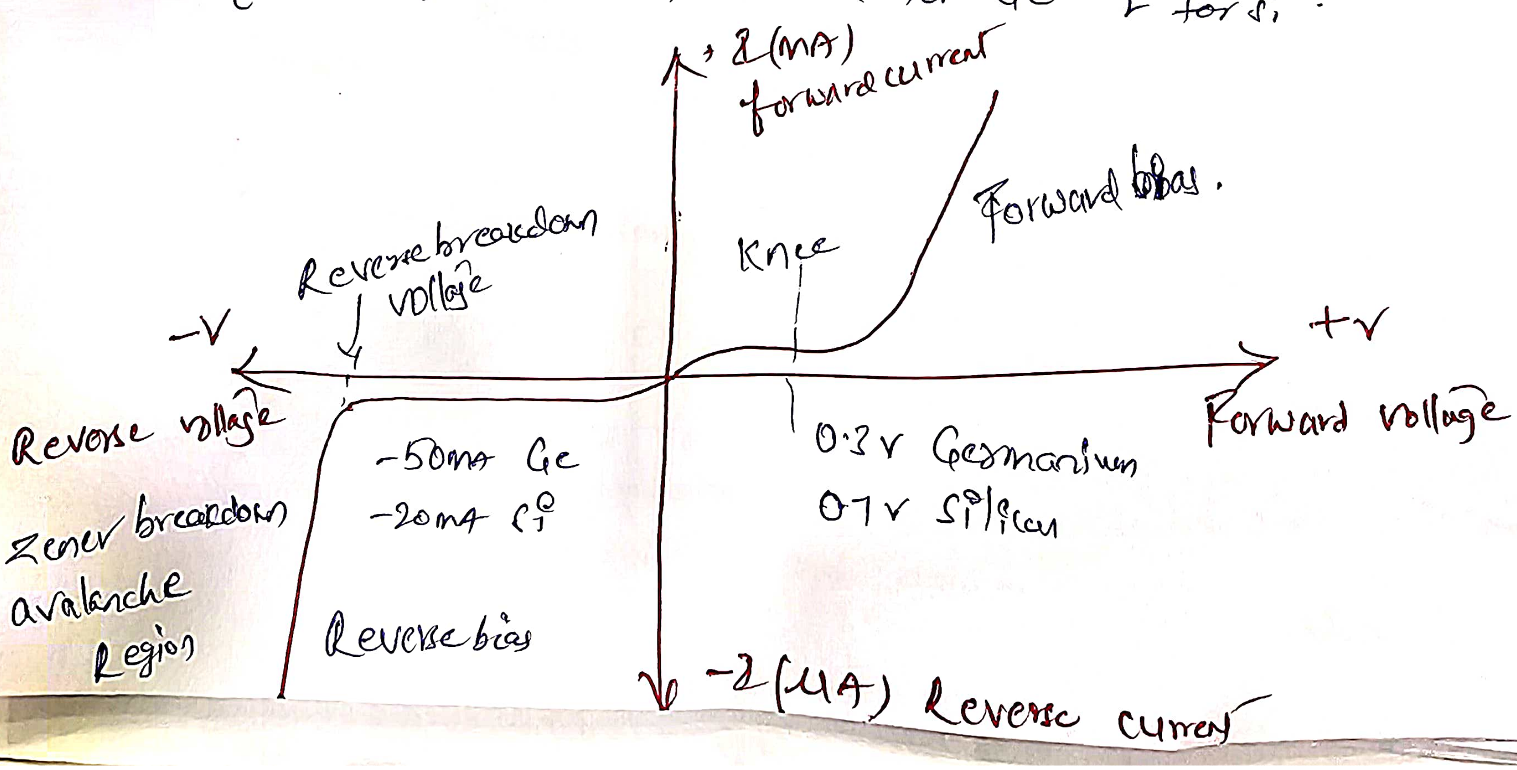
I_0 - Temperature dependant saturation current μA

T - Absolute Temperature of p-N junction, K

K - Boltzmann's Constant 1.38×10^{-23} J/K

q - electron charge 1.6×10^{-19} c

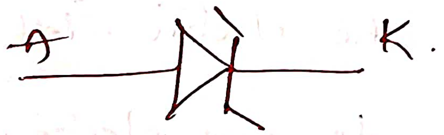
η = empirical constant 1 for Ge 2 for Si.



Zener diode characteristics

A zener diode not only allows current to flow from anode to cathode but also, in the reverse direction on reaching the zener voltage. Due to this zener diode is most commonly used semiconductor diodes. Zener diode is known as breakdown diode is a heavily doped device that is designed to operate in reverse direction. When the voltage across the terminals of a zener diode is reversed and the potential voltage reaches the zener voltage (knee voltage), the junction breaks down and the current flows in the reverse direction. This effect is known as zener effect.

Symbol



Avalanche break down in zener diode

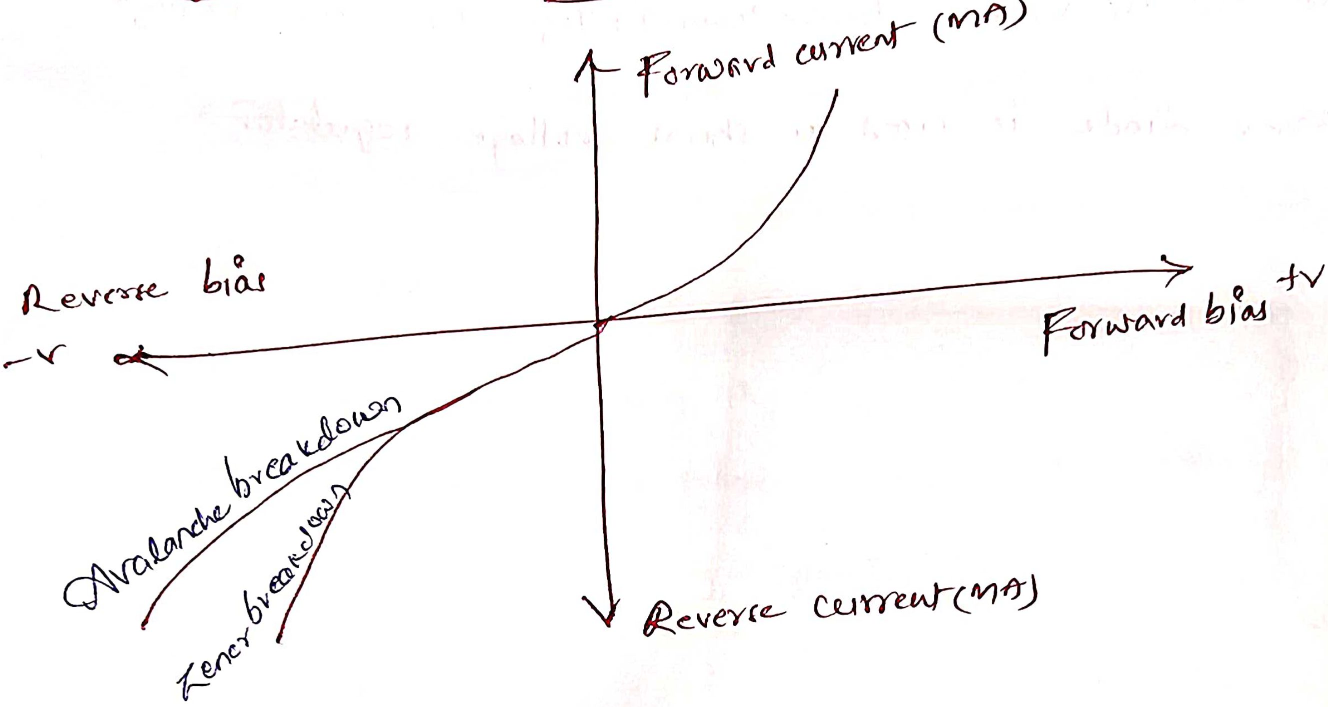
Avalanche breakdown occurs in normal diode and zener diode at high reverse voltage when a high value of reverse voltage is applied to the pn junction, the free electrons gain sufficient energy and accelerate at high velocities.

there free electrons moving at high velocity collide with other atoms and knocks off more electrons. Due to this continous collision a large number of free electrons are generated as a result of electric current in the diode rapidly increases. This sudden increase in electric current may permanently destroy the normal diode. However a zener diode is designed to operate under avalanche breakdown and can sustain the sudden spike of current. Avalanche breakdown occurs in zener diodes with zener voltage greater than 6V.

Zener breakdown in zener diode

When the applied reverse bias voltage reaches closer to the zener voltage the electric field in the depletion region gets strong enough to pull electrons from their valence band. The valency electrons that gain sufficient energy from the strong ~~magnetic~~ electric field of the depletion region break free from the parent atom. At the zener breakdown region a small increase in the voltage results in the rapid increase of the electric current.

V-I characteristics of zener diode



Forward characteristics : First quadrant of graph represents forward characteristics of a zener diode. From the graph it is almost identical to the forward characteristics of pn junction diode.

Reverse characteristics : When a reverse voltage is applied to zener voltage a small reverse saturation current I_0 flows across the diode. This current is due thermally generated minority carriers. As the reverse voltage increases, at a certain value of reverse voltage the reverse current increases drastically and sharply.

this is an indication that the breakdown has occured.

We call this voltage breakdown voltage (or) zener voltage.

Zener diode is used as shunt voltage regulator.

BJT & NPN, PNP Transistors

* Two commonly employed methods for the fabrication of diodes transistors and their semiconductor devices are: (1) Grown type (2) Alloy type

Grown type

It is made by drawing a single crystal from a melt of silicon (or) Germanium whose impurity concentration is changed during the crystal drawing operation.

Alloy type

A thin wafer of n-type Germanium is taken. Two small dots of indium are attached to the wafer on both sides. The temperature is raised to a high value where indium melts, dissolves Germanium beneath it and forms a saturated solution. On cooling, indium crystallizes and changes Germanium to p-type. So a PNP transistor formed.

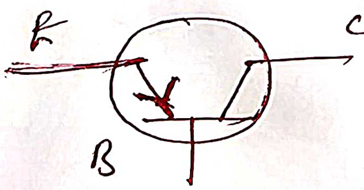
Grown type Junction Transistor

Grown type Junction transistors are manufactured through growing a crystal which is slowly pulled from the melt in the crystal growing furnace in fig.

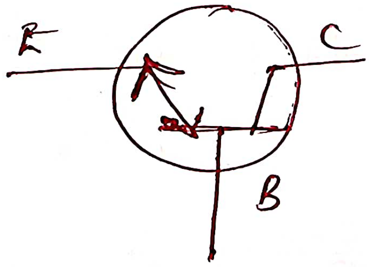
Purified polycrystalline semiconductor is kept in the chamber and heated in an atmosphere of N_2 and H_2 to prevent oxidation of seed crystal attached to the vertical shaft which is slowly ~~pulled~~ pulled at the rate of 1mm/4hrs (or) even less. The seed crystal is initially makes contact with the molten semiconductor. The crystal starts growing as the seed crystal is pulled. To get n-type impurities, to the molten polycrystalline solution impurities are added. Now the crystal that grows is n-type semiconductor. Then p-type impurities are added. So the crystal now is p-type. Hence the npn transistor is formed.

(*) Bipolar Junction Transistor (BJT)

The device in which conduction takes place due to two types of carriers, electrons and holes is called a Bipolar device. As p-n junctions exist in the construction of the device, it is a junction device. When there is transfer of resistance from input side which is forward biased (low resistance) to output side which is reverse biased (high resistance), it is a trans resistor (or) transistor device. There are two types of transistors NPN and PNP. In NPN transistor a p type silicon (Si) (or) Germanium (Ge) is sandwiched between two layers of n type silicon. The symbol for PNP transistor is shown in fig (a) and for NPN transistor is shown in fig.



PNP



NPN

The three sections of the transistor are Emitter, Base and Collector. If arrow mark is towards base it is PNP transistor.

If it is away then it is NPN transistor. The arrow mare on the emitter specifies the direction of current when the emitter base junction is forward biased. When PNP transistor is forward biased, holes are injected into the base so the holes move from emitter to base. The conventional current flows in the same direction as holes. So arrow ~~mark~~ mark is towards the base for PNP transistor. Similarly for NPN transistor, it is away. AC emitter current is represented as I_E, Base current as I_B and collector current as I_C. These currents are assumed to be positive when the currents flow into the transistor. V_{BE} refers to Emitter Base voltage. Emitter (E) voltage being measured with reference to base B. Similarly V_{BE} and V_{CE}.

principle of operation

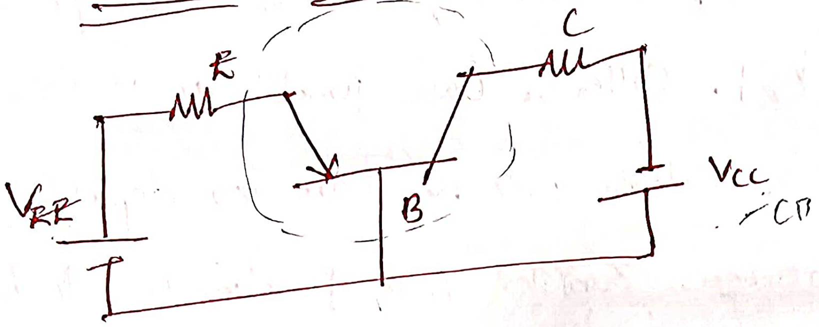


Fig shows a circuit for a pNp transistor. Emitter base junction is forward biased Collector base junction is reverse biased. Fig shows potential distribution along the transistor (x). When the transistor is open circuited there is no voltage applied. The potential barriers adjust themselves to a height V_0. V_0 will be few tenths of a volt. It is the barrier potential. So when the ~~potential~~ transistor is open circuited holes will not be injected into the collector. But when transistor bias voltages are applied emitter base junction is forward biased and the collector base junction is reverse biased. The base junction is increased, effective base width decreases. Since EB junction is forward biased in a pnp transistor the emitter base is lowered. So holes will be injected into the base. The injected holes diffused into the collector across a ntype material. When EB is forward biased Emitter base potential is increased by $|V_{EB}|$. Similarly collector base potential is reduced by $|V_{CB}|$. Collector base junction is reverse biased. So collector extends into the base (or) depletion region width increases. Emitter base junction is to be forward biased because the carriers must be injected and collector-base junction must be reverse biased, because the carriers must be attracted into the collector region. then only current flow results through the transistor

Q No. 7 (b)

(*) **Rectifiers**

P-N junction as Rectifier

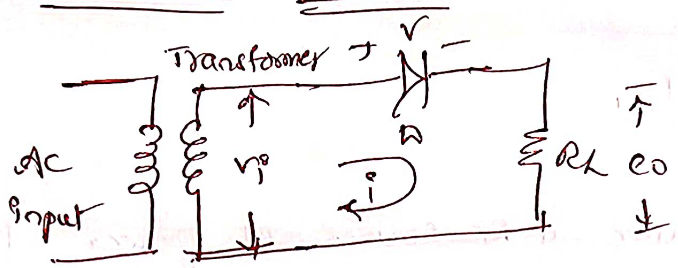
The electronic circuits require a DC source of power. For transistor A.C amplifier circuit for biasing DC supply is required. The input signal can be A.C and so the o/p signal will be amplified A.C. signal. But without biasing with DC supply, the circuit will not work. So more (or) less all electronic A-C instruments require DC power. To get this DC batteries can be used. But they will get dried quickly and replacing them every time is a costly. Hence it is economical to convert AC power into DC ~~each circuits their efficiency~~ etc.

Rectifier is a circuit which offers low (impedance) resistance to the current in one direction and high resistance in the opposite direction.

Rectifier converts sinusoidal signal into unidirectional flow and not pure DC

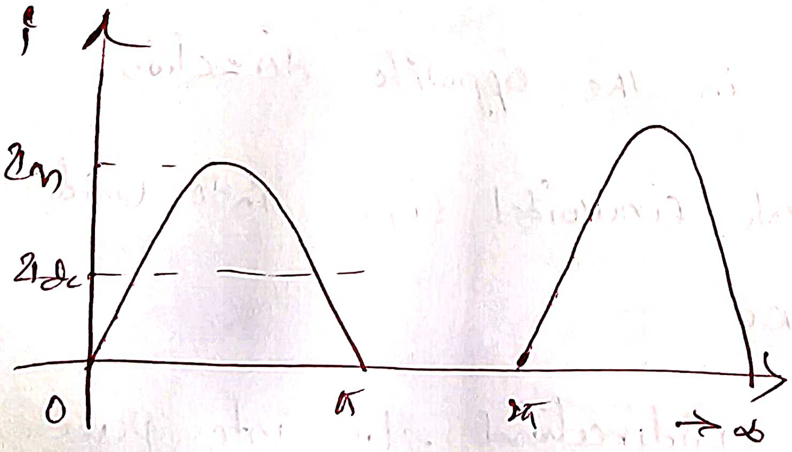
Filter converts unidirectional flow into pure DC.

Half wave Rectifier



- A basic circuit for rectification is shown in fig. The rectifying devices are semiconductor diodes for low voltage signals and vacuum diodes for high voltage signals.

- AC input is normally the AC main supply. Since the voltage is 230V. and such a high voltage cannot be applied to the semiconductor diode, step down transformer should be used. If large DC voltage is required vacuum diodes should be used. output voltage is taken across (R_L) load resistor. Since peak value of AC signal is much larger than V_γ, we neglect V_γ. The output waveform for half-wave rectifier is shown below.



$i = I_m \sin \alpha$

$\alpha = \omega t \quad 0 \le \alpha \le \pi$

$i = 0 \quad \pi \le \alpha \le 2\pi$

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

Half wave rectified o/p.

R_f - is forward resistance R_L - is load resistance.

→ what happens if DC ammeter connected in rectifier o/p circuit

The ammeter reads average value.

$$I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin \omega t \, d\omega t = \frac{I_m}{2\pi}\left[-\cos \omega t\right]_0^{\pi}$$

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

→ what happens if AC ammeter is connected in rectifier output circuit

AC ammeter reads RMS or Effective value.

Effective value or RMS value of an AC quantity is the equivalent DC value which produces the same heating effect as the alternating current.

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

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{2\pi} \sin^2 \omega t \, d\omega t}$$

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

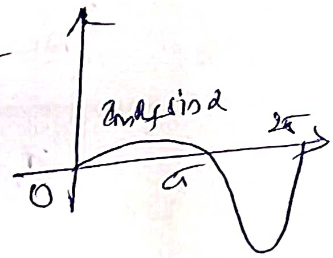
$$= \frac{I_m}{\sqrt{2\pi}}\sqrt{\left.\frac{\omega t}{2}\right|_0^{2\pi} + \left.\frac{\sin 2\omega t}{4}\right|_0^{2\pi}}$$

$$= \frac{I_m \sqrt{\pi}}{\sqrt{2}\sqrt{2\pi}} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

(*) peak inverse voltage

For the diode rectifier circuit shown in fig. during positive half cycle the diode conducts. the forward resistance of the diode R_f will be small.

the average value across load $V = i \times R_f$



$i = I_m \sin\alpha \qquad 0 \le \alpha \le \pi$

$V = I_m R_f \sin\alpha \qquad 0 \le \alpha \le \pi$

Since R_f is small the voltage during +ve half cycle small. during negative half cycle diode will not conduct current through circuit is zero but the voltage across secondary is $V = V_m \sin\alpha$

$\pi \le \alpha \le 2\pi$

DC voltage read by DC voltmeter is average value

$$V_{DC} = \frac{1}{2\pi}\left[\int_0^{\pi} I_m R_f \sin\alpha \, d\alpha + \int_{\pi}^{2\pi} V_m \sin\alpha \, d\alpha\right]$$

$$= \frac{1}{2\pi}\left[(2) I_m R_f - (2) I_m (R_f + R_L)\right]$$

$\because$ $V_m = I_m (R_f + R_L)$

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

If we connect CRO across a diode.

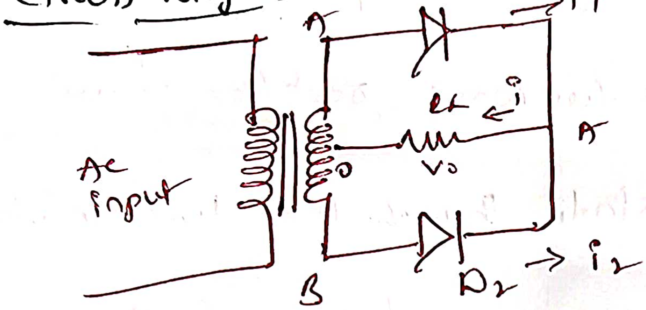
the diode is being subjected to a maximum voltage of V_m.

It occurs when diode is not conducting. Hence it is called peak inverse voltage

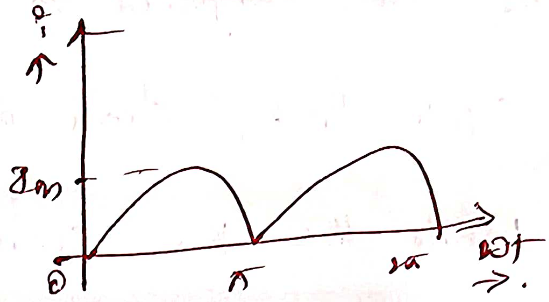
Q.No. 8 (b).

Full Wave Rectifier

Circuit Diagram



o/p waveform



- Full wave rectifier consists of two diodes D_1 and D_2 and centre tapped transformer.
- During the +ve half cycle D_1 conducts and the current through D_2 is zero. During -ve half cycle D_2 conducts and the current through D_1 is zero. A centre tapped transformer is used.

The total current i flows through the load resistance R_L and the output voltage v_0 is taken across R_L.

For full wave rectifier circuit I_{DC} = twice that of half wave rectifier circuit $\therefore I_{DC} = \frac{2I_m}{\pi}$

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

A centre tapped transformer is essentially to get full wave rectification. So there is a phase shift of 180°, because of centre tapping. So diode D_1 is forward biasing during the input cycle of 0 to π, D_2 is forward biased during the period π to 2π. since the input D_2 has a phase shift of $180°$, compared to the input to D_1. so positive half cycle for D_2 starts at a full wave rectifier circuit

while the DC current starts through the load resistance R_L is twice that of the half wave rectifier circuit.

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

<u>peak inverse voltage</u> : With reference to full wave rectifier circuit during -ve half cycle D_1 is not conducting and D_2 is conducting. Hence maximum voltage across R_L is V_m, since voltage is also present between A and O of the transformer the total voltage across $D_1 = V_m + V_m = 2V_m$.

✱ Ripple factor of Half wave rectifier and Fullwave Rectifier

Ripple factor γ = $\dfrac{\text{Rms value of ripple current}}{\text{Average value of DC current}}$

$$\gamma = \frac{I'_{rms}}{I_{DC}}$$

Total current $I = I_{DC} + I'(\text{ripple})$ $\Rightarrow$ $\boxed{I'_{ripple} = I - I_{DC}}$

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I - I_{DC})^2\, d\alpha}$$

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}\left[I^2 - 2I\cdot I_{DC} + I_{DC}^2\right] d\alpha}$$

$\frac{1}{2\pi}\int_0^{2\pi} i^2\, d\alpha$ = square of rms value by definition

$\frac{1}{2\pi}\int_0^{2\pi} i\, d\alpha$ = Average value of DC value I_{DC}

$$= \sqrt{(I_{rms})^2 - 2I_{DC}^2 + I_{DC}^2}$$

$$I'_{rms} = \sqrt{(I_{rms})^2 - I_{DC}^2}$$

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

For half wave rectifier $\gamma = \sqrt{\left[\dfrac{I_m \times \pi}{2 \times I_m}\right]^2 - 1}$

$$= \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = \underline{1.21}$$

For full wave rectifier

$$\gamma = \sqrt{\frac{I_{rms}^2 - I_{DC}^2}{I_{DC}^2}}$$

$$= \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.482$$