Module -1

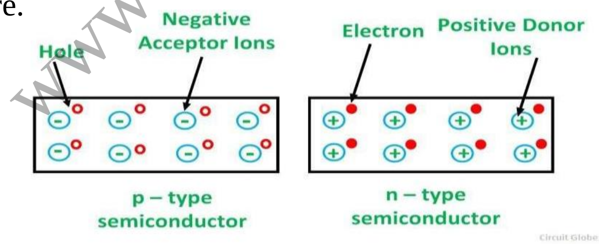
Semiconductor Diodes and Applications

junction diode, Equivalent circuit of a diode , Zener diode, Zener diode as a voltage regulator, Rectification-Half wave rectifier, Full wave rectifier, Bridge rectifier, capacitor filter circuit.
Photo diode, LED, Photocoupler
78XX series and 7805 Fixed IC voltage regulator

Introduction:

- Based on electrical properties, material are classified as,
  i. **Conductors (Metals):** Allows electric current to pass through it.
  ii. **Insulators:** Doesn't allow electric current to pass through it.
  iii. **Semiconductors:** Electrical conductivity is between that of conductor and insulator.
- Semiconductors are classified as,
  i. **Intrinsic:** Pure semiconductor
  ii. **Extrinsic:** Impure semiconductor, by adding impurity atoms to pure semiconductor
- The process of adding impurity atoms to a pure semiconductor is called **doping**.
- Extrinsic semiconductors are classified as,
  N-type: Which are obtained by adding pentavalent impurity atoms such as Arsenic, Antimony, Phosphors, etc,. In N-type semiconductor, current conduction is due to **electrons**, hence electrons are **majority charge carriers** and holes are minority charge carriers. Since donor impurity donates an electron it becomes positive ions and is shown in below figure.

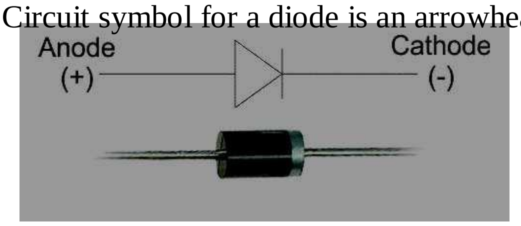
P-type: Which are obtained by adding trivalent impurity atoms such as Aluminum, Bronz etc,. In P-type semiconductor, current conduction is due to **holes**, hence holes are **majority charge carriers** and electrons are minority charge carriers. Since acceptor impurity has accepted electron it becomes negative ions and is shown in below figure.

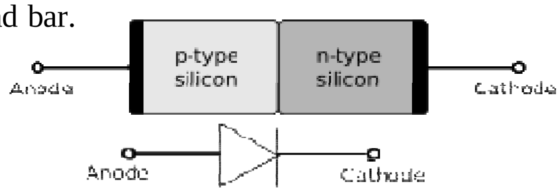


- The term diode refers to a two-electrode or two-terminal device. A semiconductor diode is simply a PN-junction with a connecting lead on each side.
- Diode is a one way device allowing current to flow from anode to cathode under forward bias, but behaving like a open circuit under reverse bias.
- Diode is used as a switch, ON during forward bias and OFF during reverse bias.

PN Junction Diode:

- A PN-junction provided with copper wire connecting leads becomes an electronic device known as **diode**, offering a low resistance when forward biased and high resistance reverse biased. Circuit symbol for a diode is an arrowhead and bar.





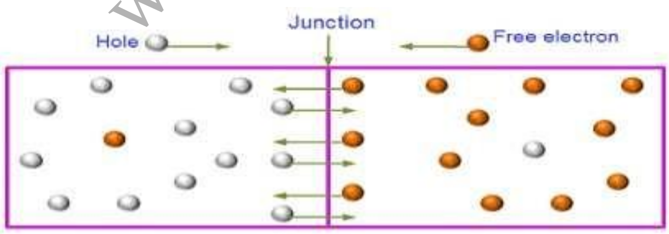
- The arrowhead indicates the conventional direction of current flow when the diode is forward biased (from the positive terminal through the device to the negative terminal).
- The **P-side** of the diode is always the positive terminal and is termed as **anode** and the **N-side** is always the negative terminal and is termed as **cathode**.
- A PN-junction diode can be destroyed when:
  (i) High level of forward current overheats the device.
  (ii) Large reverse voltage causes the junction to breakdown.

Types of Diodes: There are three types of diodes classified according to their forward current or reverse voltage carrying capacity.

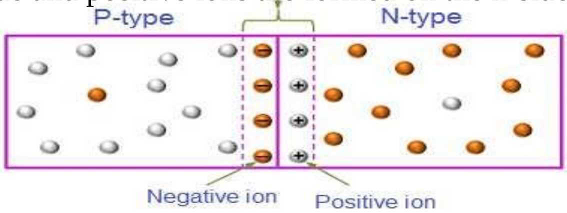
Diode:	Forward Current Capacity:	Reverse Voltage Capacity:
1. Low current diodes	Up to 100 mA	Up to 75 V
2. Medium current diodes	Up to 400 mA	Up to 200 V
3. High current diodes/Power diodes	Few amperes	Several hundreds of volts

P-N Junction:

- P-N junction is formed when a single crystal of semiconductor is added with acceptor impurity one side and donor impurity on the other side as shown in figure.
- Left side of the material is a P-type semiconductor having acceptor ions and positively charged holes. Right side is N-type having donor ions and free electrons.
- Since n-type has high concentration of electrons and p-type has high concentration of holes, there exists concentration gradient across the junction.
- Due to this, charge carriers move from high concentration area towards low concentration area to achieve uniform distribution of charge.
- In p-type excess holes move towards n-side, similarly electrons from n-side move towards p-side, this process is called **diffusion** and diffusion of charge carries takes place on either side as shown in figure.



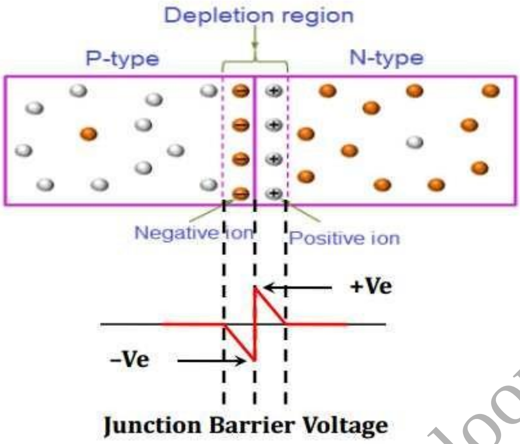
- When migrating electron diffuse into p-type and recombines with acceptor atoms on p-side, acceptor ion accepts this additional electron and becomes **negatively charged immobile ion** and hole disappears.
- When a hole diffuses into n-side they recombine with donor atom, this donor atom accepts additional hole and become **positively charged immobile ion** and electron disappears.
- The formation of immobile ions near the junction is as shown in figure. After diffusion, negative ions are formed on the p-side and positive ions are formed on the n-side.

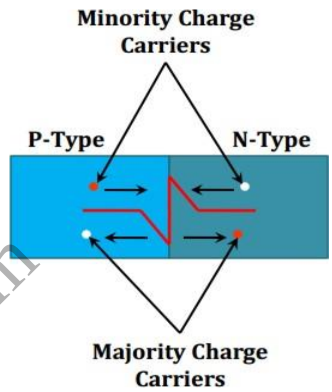


Depletion Region: $(1 \times 10^{-6}\ m)$

- In between immobile charges at the junction, there exists no charge carriers such a region is called **depletion region** or **space charge region**. It prevents further movement of electrons or holes across the junction.
- On n-side, the depletion region consists of donor impurity atoms have lost the free electrons associated with them, become positively charged.
- On p-side, the depletion region consists of acceptor impurity atoms, becomes negatively charged by loosing the hole associated with them.

Junction Barrier Voltage:

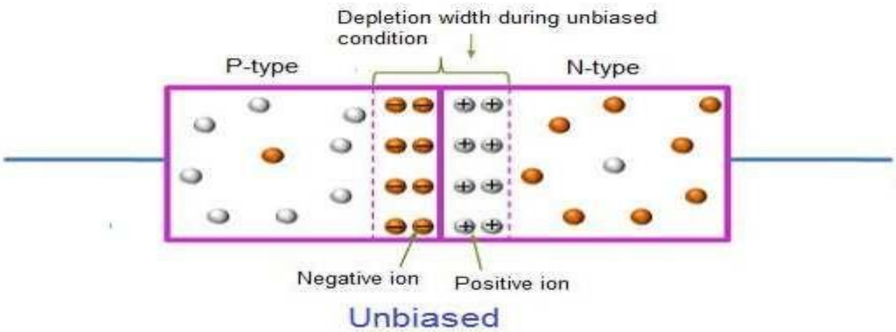




- The operation of PN junction is studied under three different cases: (i) Under no bias, (ii) Under forward bias, and (iii) Under reverse bias.

Under No Bias Condition:

- Under no bias condition, the positive charge on n-side repel the holes to cross from p to n side, negative charge on p-side repel free electrons to enter from n to p side.
- Thus a barrier is setup against further movement of charge carriers, this is called **potential barrier** or **junction barrier**. Potential barrier is of the order of 0.7 V for silicon and 0.3 V for germanium.
- The form of potential energy barrier against flow of electrons from n-side across the junction is shown in fig, the potential barrier of electron is negative due to the charge on an electron is negative.



- Similarly, there is a potential barrier against flow of holes from p-side across the junction, and the potential is positive due to charge on holes is positive.

Forward Biasing of P-N Junction:

- P-N junction is said to be forward biased, when the positive terminal of battery is connected to p-type and negative terminal to n-type as shown in fig.

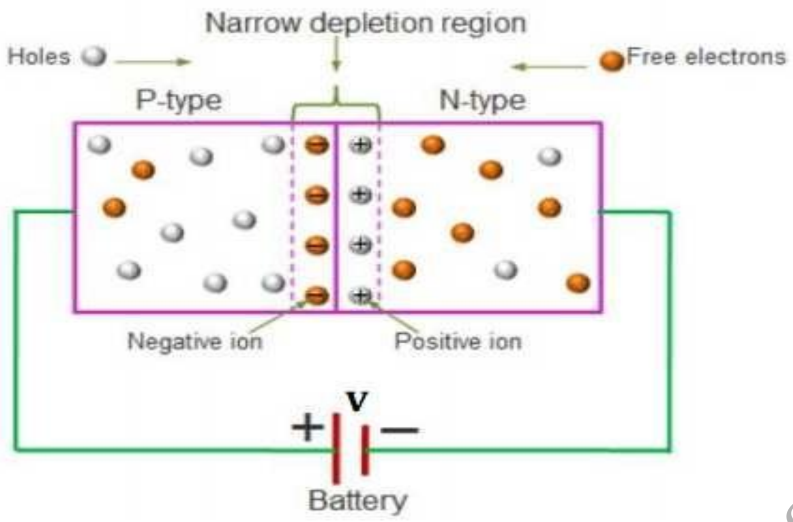


Fig: Forward Biased PN Junction Diode

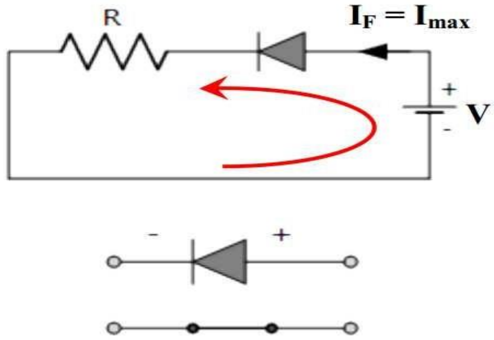


Fig: Circuit Diagram

- The application of forward bias will force electrons to move from n-side to p-side due to the negative polarity of the supply. Since these free electrons gain sufficient energy from supply they move into the p-side, but some electrons enter into depletion region and recombine. The majority of free electrons migrate into p-side and reduces the potential barrier.
- Similarly, forward bias will force holes to move from p-type to n-type due to the positive polarity of the supply. Since the holes in p-side acquire energy from supply and migrate to n-side reducing potential barrier.
- If the applied bias voltage (V) is progressively increased from zero, the barrier potential gets progressively decreases until it effectively disappears and charge carriers easily flow across the junction. Holes moves from left to right, and electrons moves from right to left, hence (I_n) resulting a large current known as (I_p)
- **forward current (I_F)** is the sum of electrons current and holes current
  .Therefore, Forward Current: $I_F = I_n + I_p$

Reverse Biasing of P-N Junction:

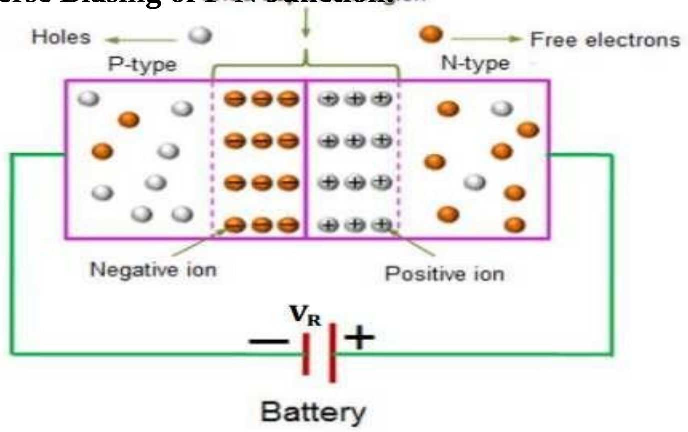


Fig: Reverse Biased PN Junction Diode

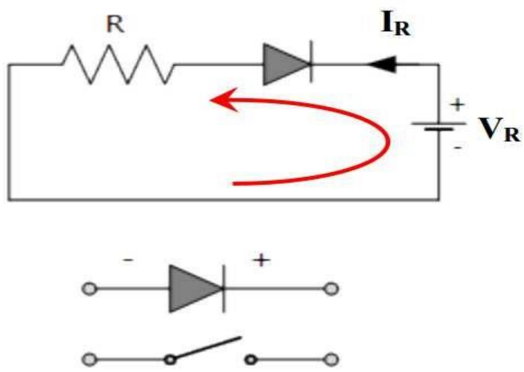
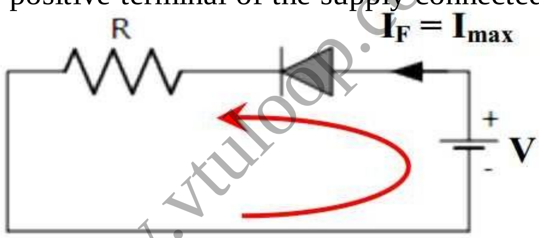


Fig: Circuit Diagram

- P-N junction is said to reverse biased when positive terminal of battery is connected to n-type and negative terminal of battery to p-type.
- On application of external bias V_R, holes from the p-side attracted to the negative terminal of battery and electrons in the n-side are attracted to the positive terminal of battery V_R.
- Since both the majority carriers move away from the junction, as a result the depletion layer gets widened. The wider the depletion layer, greater the difference in potential across the junction as shown in figure.
- When V_R is increased the barrier potential (V_B') also increases, but when barrier potential (V_B') is equal to supply potential V_R, then the barrier stops growing. When this happens, the majority carriers in n and p-type stop moving away from the junction creating an electric field.
- But some minority carriers recombine with majority carriers and when this happens, a very small magnitude of current I_O starts to flow in the electrical circuit in the direction opposite to conventional current hence called **reverse saturation current**.
- The magnitude of I_O is dependent only on junction temperature but independent of applied bias voltage V_R. For silicon it is less than 1 µA and for germanium it may exceed 10 µA.

Characteristics of P-N junction:

- Consider the fig, where positive terminal of the supply connected to P-type and negative terminal of the supply to N-type.



- If the supply voltage (V) is very less compared to cut-in voltage (0.7 V for Silicon and 0.3 V for Germanium) of diode, the barrier potential (cut-in-voltage) blocks the movement of majority carriers and hence the forward current through the diode is very low (less than 100 µA).

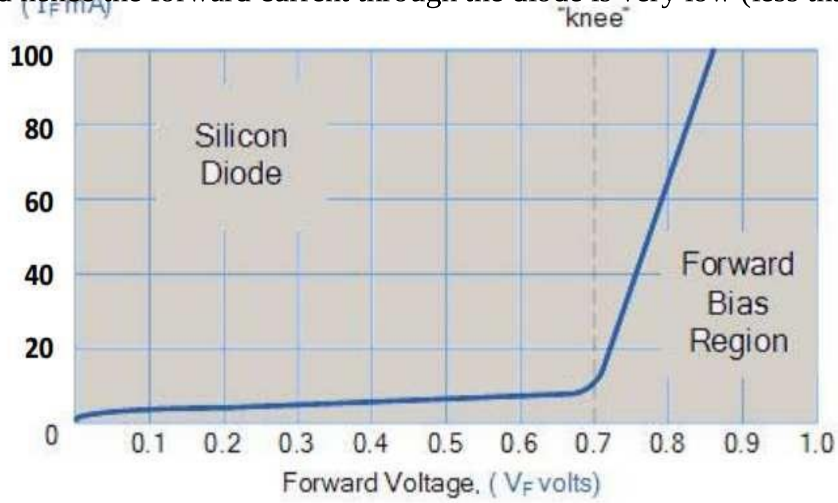


Fig: PN – Junction Forward Characteristics

- If the voltage V is greater than cut-in-voltage then the barrier potential reduces and I_F increases almost linearly.The relation between voltage and current is expressed mathematically by,

$$I_F = I_o\left(e^{V/\eta V_T} - 1\right) \text{ Ampere}$$

Where I_F is forward diode current

I_o is reverse saturation current V is applied voltage

V_T is thermal voltage

$$V_T = \frac{KT}{q} = \frac{T}{11600}$$

$$\frac{q}{K} = \frac{\text{Charge of an electron}}{\text{Boltzman Constant}} = \frac{1.6 \times 10^{-19}\ C}{1.38 \times 10^{-23}\ J/K} = 11600$$

Where T is absolute temperature in ^{O}K

At room temperature, T = 300 K, $V_T = \frac{300}{11600} = 26$ mV

η is constant which depends on physical construction of the device and also on operating conditions.

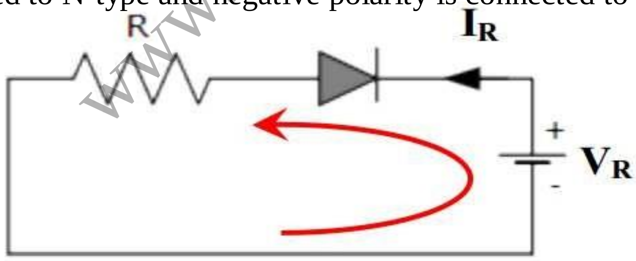
η = 2; for silicon (for small currents)

η = 1; for germanium (for large currents)

- When the applied voltage is greater than cut-in-voltage the forward current through the device increases exponentially and it can be limited by external resistor R, expressed mathematically as, $I_F = I_0 e^{V/\eta V_T}$
- Next, further increase in supply voltage V, the forward current increases almost linearly wrt V.

Reverse Characteristics of P-N Junction:

- An external potential (V_R) is applied to the PN junction such that the positive polarity of external potential (V_R) is connected to N-type and negative polarity is connected to P-type as in figure.



- Holes in P-type are attracted towards negative potential (V_R) and electrons in N-type are attracted towards positive potential, therefore depletion region gets widened.
- This effect causes to establish a greater barrier for majority carriers, so effectively reducing majority carriers flow to zero. But in turn the barrier promotes minority carriers to flow. The current which exists under reverse bias is called as **reverse saturation current (I_0)**.
- The current equation under reverse bias may be obtained as, $I_R = I_o\left(e^{-V_R/\eta V_T} - 1\right)$
- Since value of V_R is several time of V_T then $e^{-V_R/\eta V_T} << 1$, hence neglecting the exponential term. $I_R = -I_o$
- From the diode current equation it is clear that current through diode depends on temperature. The reverse saturation current doubles for every 10^{O} C.
- V-I characteristic is a plot of supply voltage with respect to current I_R.

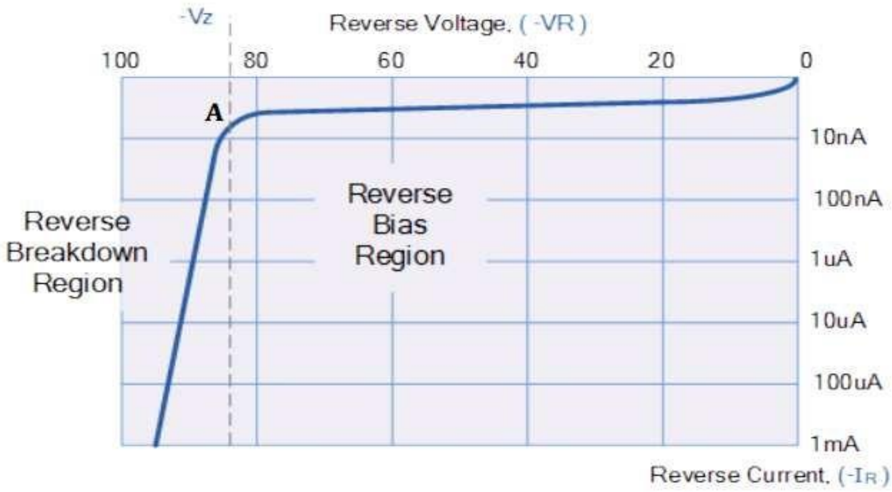
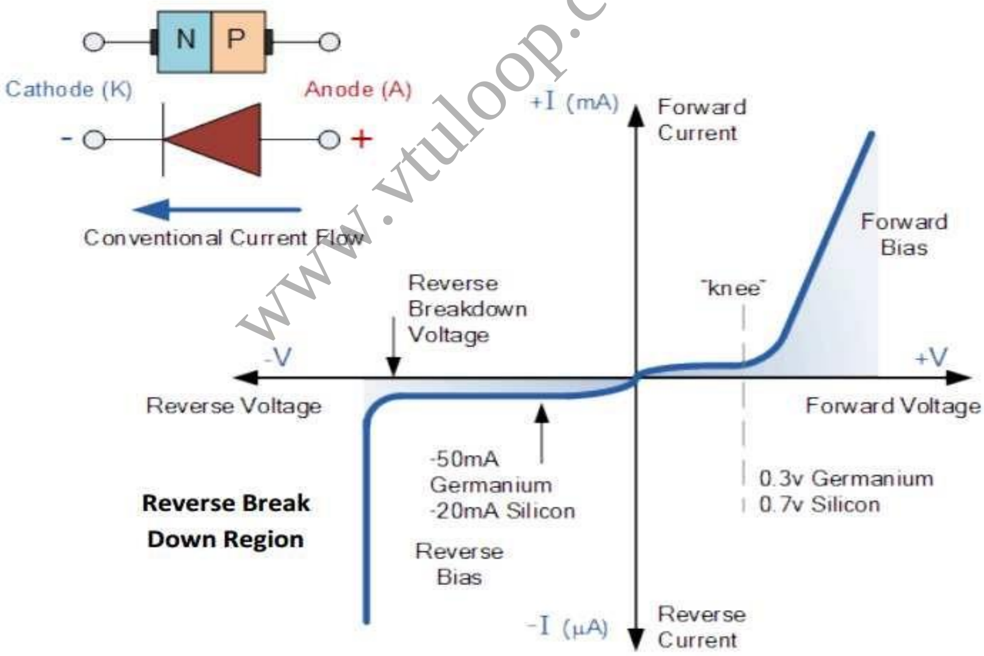


Fig: PN – Junction Reverse Characteristics

- At point A, reverse breakdown of the diode occurs and current increases sharply. This point is called as knee point.

V-I characteristics of Silicon and Germanium Diode:



- The forward and reverse characteristics of silicon and germanium shown in figure.
- Cut-in-voltage of germanium is 0.3V and silicon is 0.7V. The current through the device increases only when applied potential is higher than the cut-in-voltage.
- The reverse saturation current I_O is of the order of nA for silicon diode while it is of the order µA for germanium diode. Reverse breakdown voltage for Si diode (–75V) is higher than that of the Ge diode (–50V).

Diode Parameters:

The important diode parameters are:

i. **Knee Voltage / Forward Voltage (V_F):** Forward voltage drop at a given temperature is defined as the maximum forward voltage of the diode for a specific forward current, it is also given by the relation,

$$\text{Forward Voltage Drop}(V_F) = \frac{\text{Power Dissipated}}{\text{Forward dc Current}} = \frac{P_D}{I_F}$$

ii. **Maximum Forward Current $(I_{F_{max}})$:** Every diode has a maximum value of forward current that may be passed continuously through the diode safely is known as maximum forward current, if this value is exceeded, then the diode is destroyed due to excessive heat.

iii. **Reverse Saturation Current (I_R):** It is the maximum reverse current that flows through a reverse biased P-N junction at a given temperature, this current is only due to minority carriers, its value is <1µA for silicon and around 100 µA for germanium diodes.

iv. **Reverse Breakdown Voltage (V_{BR}):** It is the maximum reverse voltage applied at which the P-N junction breaks down and reverse current rises sharply. This critical value of voltage is known as **breakdown voltage**. Breakdown voltage is around 50V for Germanium diode and 75V for Silicon diode.

V **Power Dissipation (P_D):** The power dissipated in a diode for a given value of diode voltage (V_D) and current (I_D).

$$P_D = V_D \cdot I_D$$

v. **Static Resistance / dc Resistance:** It is the opposition offered by the P-N junction to the flow of dc current under forward bias, it is measured by taking a ratio of dc voltage across diode to the resulting dc current through it. It is given by,

$$R_{dc} = \frac{V_F}{I_F}$$

R_{dc} varies from 40Ω to 70Ω.

vi. **Dynamic Resistance / A.C Forward Resistance:** It is the opposition offered by the diode to the flow of changing (AC) forward current under forward bias, it is measured by taking a ratio of change in voltage across the diode to the change in current through it. The dynamic resistance is also known as incremental resistance or ac resistance.

$$r_d = \frac{\Delta V_F}{\Delta I_F}$$ At any temperature,

Where, I_F : Forward current

$$r_d = \frac{26\text{ mV}}{I_F}\left(\frac{T + 273°C}{298°C}\right)$$ T: Junction temperature

vii. **Peak inverse voltage:** It the maximum voltage that a diode can withstand in the reverse direction without breaking down. If this voltage is exceeded the diode may be destroyed. Diodes must have a peak inverse voltage rating that is higher than the maximum voltage that will be applied to them in a given application.

viii. **Maximum power rating:** It is defined as the maximum power that a diode can dissipate without damaging it is called maximum power rating. Usually, maximum power rating is specified by the manufacturer in its data sheet. The power dissipated at the junction is equal to the product of junction current and the voltage across the junction. If the power developed across the junction is more than the maximum power dissipated by it, the junction will be over-heated and may be destroyed.

ix. **Peak Inverse Voltage (PIV):** For a center tapped circuit, if any one diode doesn't conduct (during reverse bias) then the voltage appearing across it is the entire secondary voltage $V_m + V_m = 2V_m$. Thus diode used in center tapped rectifier should have high PIV ratings. It is defined as the maximum voltage that appears across diode during the non-conducting condition or under reverse bias.

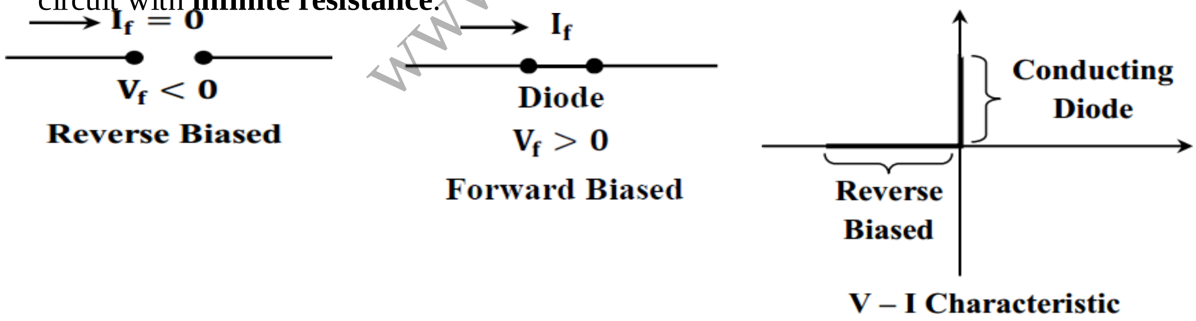
x. **Significance:** The PIV rating of the diode is given by manufacturer and diode should be operated below its PIV rating. If the maximum voltage across secondary transformer exceeds PIV rating of diode, then diode is damaged. For HWR under reverse bias condition, PIV = V_m.

Diode Approximations:

➢ The diode is approximated in three ways:
  i. Ideal diode approximation
  ii. Second approximation
  iii. Linear piecewise approximation or third approximation.

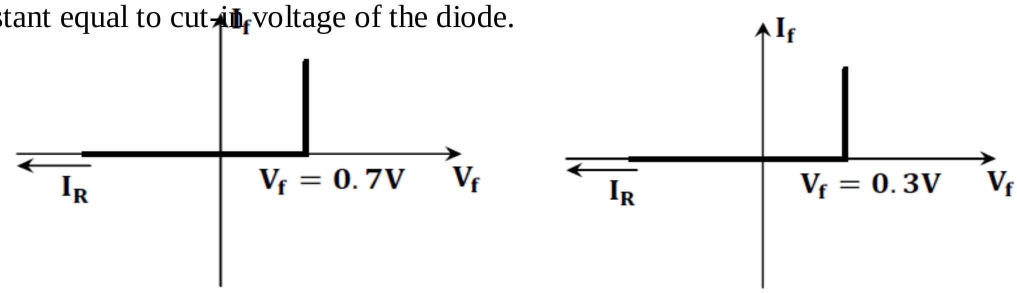
Ideal diode approximation:

➢ Ideal diode starts conducting when applied voltage V_f is just greater than zero. Drop across the conducting diode is also zero.
➢ A closed switch acts as short circuit with **zero resistance**, while an open switch acts as an open circuit with **infinite resistance**.



Second approximation:

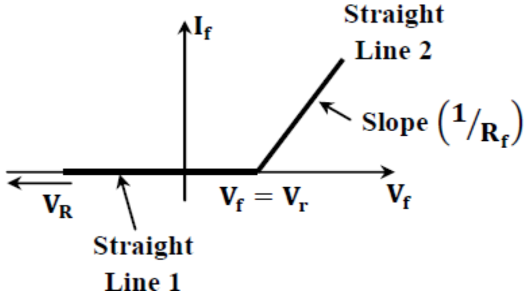
➢ If the supply voltage is much larger than the diode forward voltage drop V_f, then V_f is assumed constant equal to cut-in voltage of the diode.



(a) Silicon Diode (b) Germanium Diode

Linear piecewise approximation or third approximation:

- The approximation of characteristics with the help of pieces of straight line is called linear piecewise approximation.
- To obtain this approximation, $V_f = V_r$ (cut-in-voltage) is marked on a voltage axis and then a straight line is drawn with a slope equal to reciprocal of its dynamic forward resistance.
- Thus approximation consists of two straight line pieces, one horizontal and other with slope $\left({}^{1}/_{R_f}\right)$ as shown in figure.



Zener Diode :

- It is a special kind of **diode** which permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value – the breakdown voltage known as the **Zener** voltage. **Zener diodes** have a highly doped p-n junction.
- A diode which can be operated continuously in breakdown region without any damage being caused to it and operates in reverse bias condition is called **Zener Diode**.

Zener Diode As a Voltage Regulator:

- A zener diode can be used as a voltage regulator, since it maintains a constant output voltage even though the current through zener changes.
- The circuit is as shown in figure, consisting of an unregulated voltage source V_i connected to current limiting resistor R_S, a zener diode is in parallel with load resistor R_L.

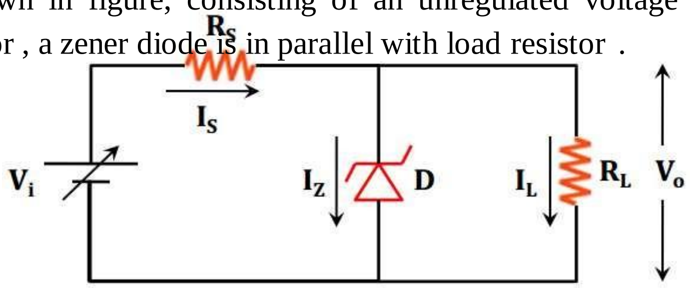


Fig: Zener Voltage Regulator

- The zener should be selected in such a way that the required regulated output voltage V_o should be equal to zener breakdown voltage.
- In order to work as a regulator the following conditions must be satisfied:
  1. Zener diode must be reverse biased.
  2. Input voltage must be greater than zener breakdown voltage.
  3. The load current should be less than $I_{z(max)}$

Regulator with no load:

- Generally in most of the electronic applications, it is required to supply a very low zener current to output. This circuit is usually employed as a voltage reference source that supplies only very low current. The resistor R_s is used to limit the zener diode current to desired value.

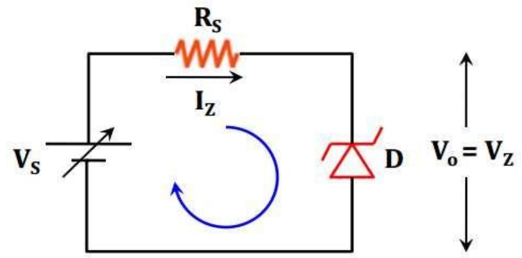


Fig: Regulator Circuit with No Load

Applying KVL to the loop,

$$V_s - I_z R_s - V_z = 0$$
$$\Rightarrow I_z R_s = V_s - V_z$$
$$\Rightarrow I_z = \frac{V_s - V_z}{R_s}$$

Minimum Zener Current: $I_{z(min)} = \dfrac{V_{s(min)} - V_z}{R_s}$

Maximum Zener Current: $I_{z(max)} = \dfrac{V_{s(max)} - V_z}{R_s}$

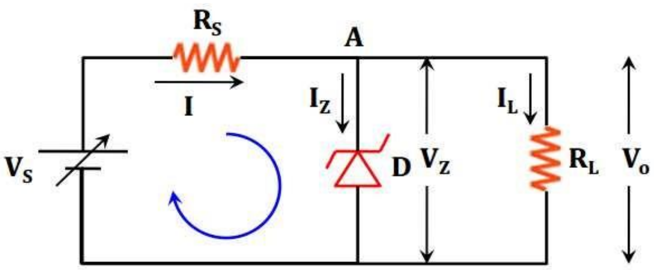
1. A zener diode has a breakdown voltage of 10V. It is supplied from a voltage source varying between 20-40V in series with resistance of 820Ω, using an ideal zener diode model obtain minimum and maximum zener currents.
   Solution: Given, Vz = 10V, $V_{s(min)}$ = 20V, $V_{s(min)}$ = 40V, R_s = 820 Ω

Minimum Zener Current: $I_{z(min)} = \dfrac{V_{s(min)} - V_z}{R_s} = \dfrac{20-10}{820} = 12.2\ mA$

Maximum Zener Current: $I_{z(max)} = \dfrac{V_{s(max)} - V_z}{R_s} = \dfrac{40-10}{820} = 36.6\ mA$

Regulator with Load (Loaded Regulator):

- Consider the circuit as shown in figure, the current through R_s is sum of I_L and I_z but care must be taken to ensure that $I_{z(min)}$ is greater to keep zener under breakdown region.



Applying KCL to node A,

$$I = I_z + I_L$$

Fig: Regulator Circuit with Load

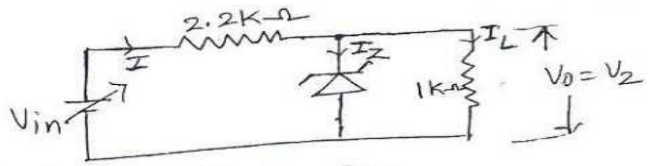
Applying KVL to loop,

$$V_s - IR_s - V_z = 0$$
$$\Rightarrow IR_s = V_s - V_Z$$
$$\Rightarrow I = \frac{V_s - V_z}{R_s}$$

Therefore, $I = I_z + I_L = \dfrac{V_s - V_z}{R_s}$

1. For a zener regulator shown in the Fig.Q.1(b), calculate the range of input voltage for which output will remain constant.

Fig.Q.1(b)



$V_z = 6.1V$, $I_{z_{min}} = 2.5$ mA, $I_{z_{max}} = 25mA$, $r_z = 0\Omega$.

Solution: Given, $V_z = 6.1V$, $I_{z(min)} = 2.5$ mA, $I_{z(max)} = 25$ mA,

$$I_L = \frac{V_Z}{R_L} = \frac{6.1}{1K\Omega} = 6.1mA$$

For $I_{z(min)}$ = 2.5 mA:
$I = I_{z(min)} + I_L = 2.5$ mA + 6.1 mA = 8.6 mA
$V_{in(min)} = IR_S + V_z = 8.6$ mA x 2.2 KΩ + 6.1 V = 25 V

For $I_{z(max)}$ = 25 mA:
$I = I_{z(max)} + I_L = 25$ mA + 6.1 mA = 31.1 mA
$V_{in(max)} = IR_S + V_z = 31.1$ mA x 2.2 KΩ + 6.1 V = 74.52 V

Hence Input Voltage Range is: **25V to 74.52V**

The voltage regulation can be done through two techniques

1. **Line regulation**

In this case, series resistance and load resistance are kept constant and it is assumed that all the variations in voltage arises due to fluctuations in input power supply. The regulated output voltage is achieved for input voltage above certain minimum level.
The percentage of regulation is given by $(\Delta V_o/\Delta V_{IN})*100$
Where V_o is the output voltage, V_{IN} is the input voltage and ΔV_o is the change in output voltage for a particular change in input voltage ΔV_{IN}.

2. **Load Regulation**

In this, the input voltage is fixed while the load resistance is varied. The constant output voltage is obtained as long as the load resistance is maintained above a minimum value.
The percentage of regulation is given by $(V_{NL}-V_{FL})/V_{NL}$ *100
Where V_{NL} is the voltage across the zener diode when no load is applied and V_{FL} is the full resistor voltage.

Rectification

- The most important applications of diodes are **rectification**: conversion of a sinusoidal ac waveform into single polarity half cycles.
  Rectifier: An electrical device used for rectification offers a low resistance to the current in one direction but a very high resistance to the current in the opposite direction. It is a circuit which converts **ac voltage** into **pulsating dc voltage**.
- Rectifier are classified into:
  i. Half wave rectifier
  ii. Full wave rectifier, which is further classified into:
     a. Centre tapped full wave rectifier
     b. Bridge rectifier
- **DC Power Supply:** Converts a sinusoidal ac waveform into dc by rectification and filtering.
  Filtering: It is a process, normally use large reservoir capacitor, which charges to peak input voltage to produce dc output. The capacitor partially discharges between the peaks of the rectified waveform, this result into ripple voltage on the output. The ripples can be reduced by using RC or LC filters.
- Specifications of power supply are: dc output voltage, load current, and ripple voltage. The performance of the power supply is defined in-terms of the output voltage stability, when input voltage or load current changes.

Half – Wave Rectifier:

- The rectifiers which conducts current or voltage only during one half cycle of ac input is called **half wave rectifier**. The below figure shows **half wave rectifier**, where single diode acts as a half wave rectifier. The AC input supply to be rectified is applied through transformer to diode D and series load resistor R_L.

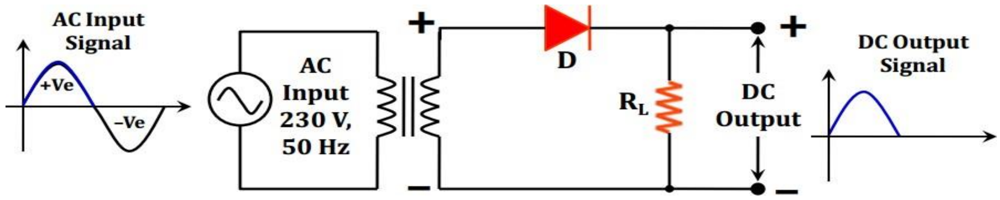


Fig: Half – Wave Rectifier Circuit

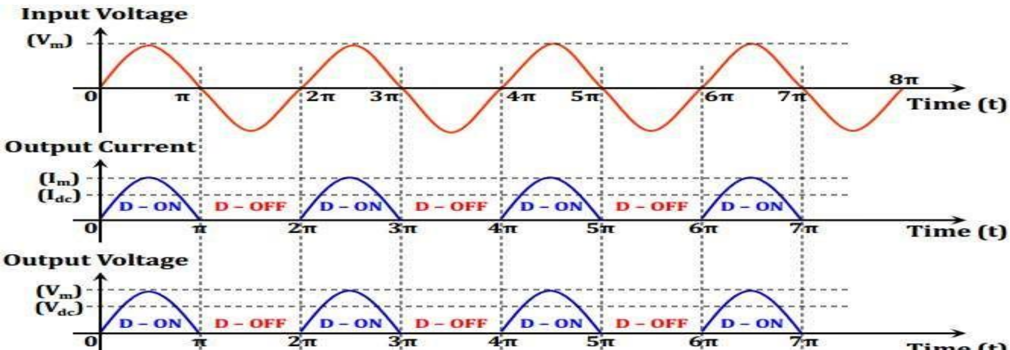


Fig: Waveform

- Input voltage V_i is a sinusoidal waveform it can be represented mathematically as,
- **During positive half cycle of V_i,** the diode is **forward biased** and acts as **short circuit**. The current flows through R_L and V_O follows V_i (Practically , where is voltage drop across the diode).

$$V_i = V_m \sin wt = V_m \sin\theta$$

$$V_o = V_i - V_F \qquad V_F$$

Output Voltage: $V_o = V_m \sin\theta \quad ; \text{for } 0 \le \theta \le \pi$

Output Current: $i = I_m \sin\theta \quad ; \text{for } 0 \le \theta \le \pi$

During negative half cycle of V_i, the diode is **reverse biased** and acts as **open circuit** and no current flows through R_L. Therefore no output voltage during this time. (Practically very small negative voltage levels produced by the diode reverse saturation current ( ). So I_R $V_o = -I_R R_L$

Output Voltage: $V_o = 0 \quad ; \text{for } \pi \le \theta \le 2\pi$

Output Current: $i = 0 \quad ; \text{for } \pi \le \theta \le 2\pi$

Maximum load current is give by,

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

Where

R_f : Forward resistance of a diode

R_s : Transformer secondary winding resistance

R_L : Load resistance

Advantages:

1. Only one diode is required.
2. Centre tap transformer is not required

Υ

Disadvantages:

1. Ripple factor is too high (= 1.21).
2. Efficiency of rectification is low (η = 40.6%).
3. DC saturation of transformer secondary winding takes place.
4. Transformer utilization factor is low.
5. AC supply delivers power only during half of the time, therefore output is low.

Full Wave Rectifiers:

- The rectifiers which conducts during both positive and negative half cycles of ac input is called **full wave rectifier**. In a full wave rectifiers, the current flows through the load for the entire cycle of input from 0 to 2π and are classified into two types:
  - i. Center tapped full wave rectifier
  - ii. Bridge rectifier

Center Tapped Full Wave Rectifier:

- It consists of two diodes D_1 and D_2 connected across center tap of secondary and load R_L as shown in figure. Input voltage is supplied from transformer with centre tapped secondary winding. It is essentially combination of two half-wave rectifier circuits, each supplied from one half of the transformer secondary.

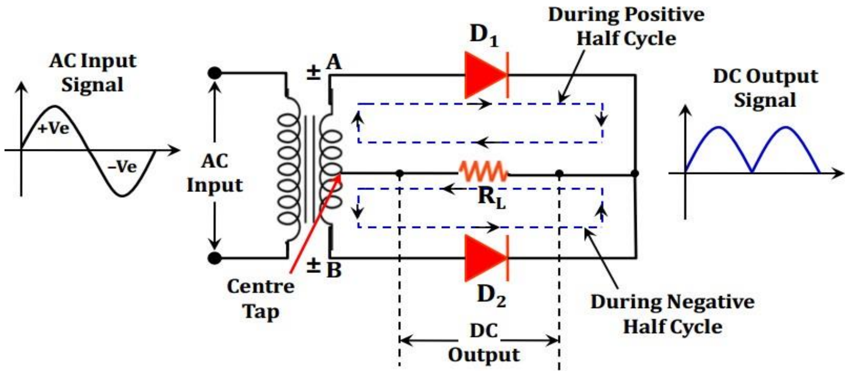


Fig: Centre Tapped Full Wave Rectifier Circuit

- **During positive half cycle** of ac input voltage, terminal A is positive and terminal B is negative, due to center tap transformer. The diode D_1 will be forward biased and hence conduct, while D_2 will be reverse biased and will not conduct. The diode D_1 supplies load current i.e., $i_L = i_{d1}$.
- **During negative half cycle** of ac input voltage, terminal A is negative and terminal B is positive, due to center tap transformer. The diode D_2 will be forward biased and hence conduct, while D_1 will be reverse biased and will not conduct. The diode D_2 supplies load current i.e., $i_L = i_{d2}$.
- Therefore, the current flows through load resistor (R_L) for both half cycles of ac input voltage. The output waveform is the combination of the two half cycles, that is continuous series of positive half-cycles of sinusoidal waveform.

Output Voltage: $V_o = V_i - V_F$

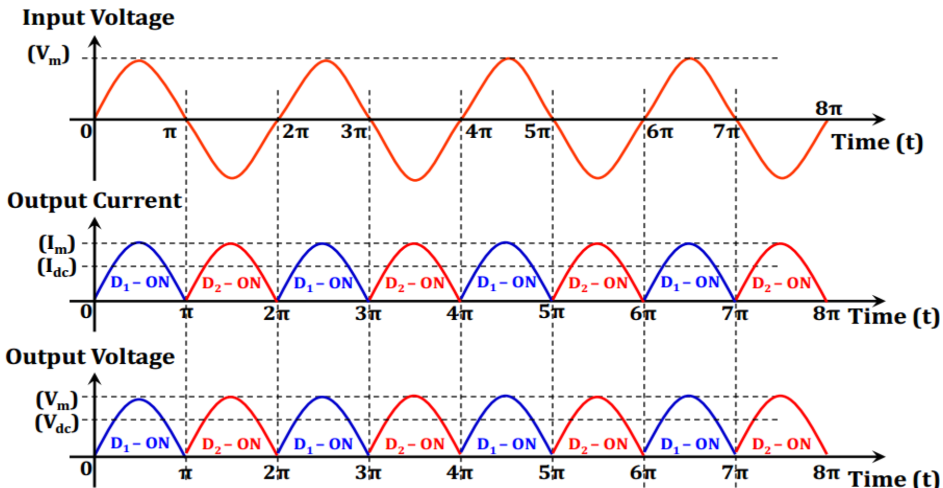


Fig: Waveform

Advantages:

1. Ripple factor is too high (γ = 0.48).
2. Efficiency of rectification is high (η = 81.2%).
3. No dc saturation of transformer secondary winding takes place.
4. DC output voltage and load current are twice compared to half rectifier.

Disadvantages:

1. It is expensive to manufacture a centre tapped transformer, which produces equal voltages on each half of secondary windings.
2. Difficult to locate the centre tap of secondary winding.
3. The output voltage is half of the secondary voltage.
4. Diodes have high peak inverse voltage, larger in size and costlier.
5. Peak inverse voltage of a diode is twice that of used in half wave rectifier.

Bridge Rectifier:

- The centre tapped transformer used is usually more expensive and requires more space than additional diodes. The most popular type of rectifier used in electronic power supplies are bridge rectifiers.

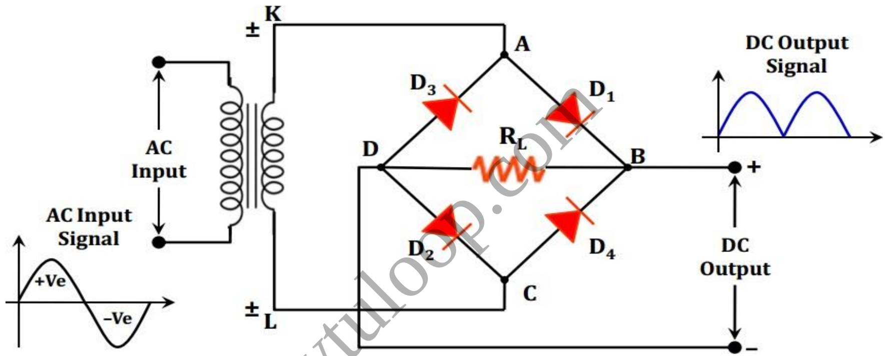


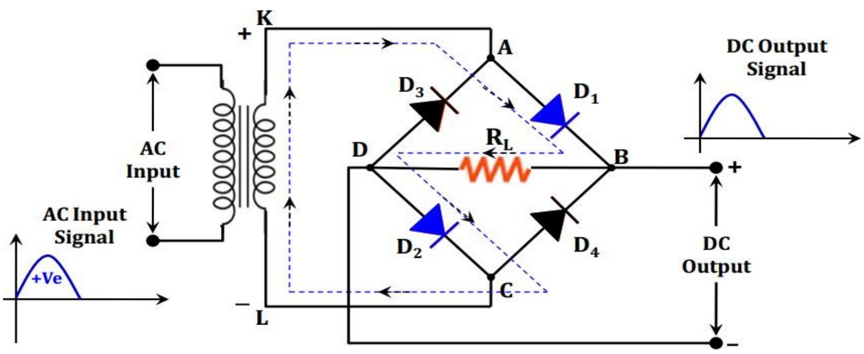
Fig: Bridge Rectifier Circuit

- It requires four identical diodes to form a bridge network. The circuit consists of four diodes D_1, D_2, D_3 and D_4 connected across secondary of transformer and load R_L.
- The secondary of transformer is connected to node points A & C and the load resistor (R_L) is connected to other node points B & D.
- The ac input terminals are connected to junction of D_1, D_3 and junction of D_2, D_4. The positive output terminal is at cathodes of D_1, D_4 and negative output terminal is at anodes of D_2, D_3.

  Let $V_i = V_m \sin \omega t$ be the instantaneous voltage appearing across the secondary.

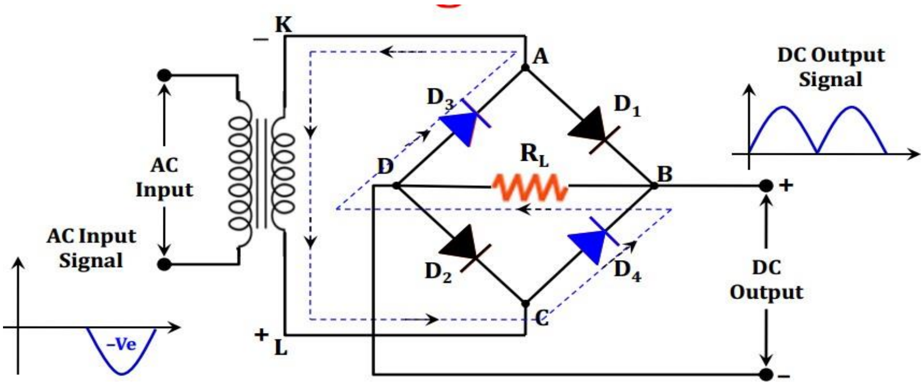
- **During the positive half cycle**, the point K is positive and L is negative, the diodes D_1 and D_2 are forward biased acts like closed switch. Whereas diodes D_3 and D_4 are reverse biased and acts like a open switch. Hence only two diodes D_1 and D_2 are conducts and allow the current to flow through R_L.

  Output Voltage: $V_o = V_i - 2V_F$



- **During the negative half cycle**, the point K is negative and L is positive, the diodes D_3 and D_4 are forward biased acts like closed switch. Whereas diodes D_1 and D_2 are reverse biased and acts as open switch. Hence only two diodes D_3 and D_4 are conducts and allow the current to flow through R_L.

Output Voltage: $V_o = V_i - 2V_F$



- It is observed that, during both half cycles of the input, the output polarity is always positive at the top of R_L and negative at the bottom. Both positive and negative half-cycles of the inputs are passed to the output, but negative half-cycles are inverted, so that output is a continuous series of positive half-cycles of sinusoidal voltage.
- The instantaneous value of current and voltage of transformer secondary is given by,

$$V = V_m \sin\theta \quad \& \quad i = I_m \sin\theta \quad \text{where } I_m = \frac{V_m}{R_s + R_f + R_L}$$

Advantages:

1. Transformer cost is less.
2. Peak inverse voltage of diode is one half of the diode used in centre tapped rectifier.
3. Centre tapped transformer is not required.
4. It can be used in applications, where floating output terminals are allowed.

Disadvantages:

1. It requires four diodes.
2. During each half cycle of ac input, two diodes that conducts are in series and therefore voltage drop in the internal resistance of rectifying unit will be twice as compared to centre tapped circuit.

DC or Average Current (I_{DC}) and Voltage (V_{DC}):

$$\text{Average Value} = \frac{\text{Area under the curve over the full cycle}}{\text{Time Period}}$$

For Half-Wave Rectifier:

Average Current (I_{DC}):

$$I_{DC} = \frac{\left[\int_0^{\pi} i.\,d\theta + \int_{\pi}^{2\pi} i.\,d\theta\right]}{2\pi}$$

Average Voltage (V_{DC}):

$$V_{dc} = I_{dc} R_L = \frac{I_m R_L}{\pi}$$

$$\text{; Substitute } I_m = \frac{V_m}{R_f + R_s + R_L}$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\theta \, . d\theta\right]$$

$$= \frac{I_m}{2\pi}[-\cos\theta]_0^{\pi}$$

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

$$= -\frac{I_m}{2\pi}[-1-1] = -\frac{I_m}{2\pi}[-2]$$

$$\mathbf{I_{DC} = \frac{I_m}{\pi} = 0.318\, I_m = 31.8\% I_m}$$

$$V_{dc} = \frac{V_m R_L}{\pi(R_f + R_s + R_L)}$$

; divide numerator and denominator by R_L

$$V_{dc} = \frac{V_m}{\pi\left(\frac{R_f + R_s}{R_L} + 1\right)}$$

If $R_L \gg R_f + R_s$, then $\frac{R_f + R_s}{R_L} \approx 0$

$$\mathbf{V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m = 31.8\%\, V_m}$$

Therefore, the average or DC value of load voltage / load current is 31.8% of the maximum ac input voltage or current.

For Full-Wave Rectifiers:

Average Current (I_{DC}):

$$I_{DC} = \frac{\left[\int_0^{\pi} i.d\theta + \int_{\pi}^{2\pi} i.d\theta\right]}{2\pi}$$

; by definite integral property it can be written as,

$$I_{DC} = \frac{1}{2\pi}\left[2\int_0^{\pi} i.d\theta\right] = \frac{1}{\pi}\left[\int_0^{\pi} I_m \sin\theta . d\theta\right]$$

$$= \frac{I_m}{\pi}[-\cos\theta]_0^{\pi} = -\frac{I_m}{\pi}[\cos\pi - \cos 0]$$

$$= -\frac{I_m}{\pi}[-1-1]\frac{-I_m}{\pi}(-2)$$

$$I_{DC} = \frac{\mathbf{2I_m}}{\pi} = \mathbf{0.636 I_m = 63.6\% I_m}$$

Average Voltage (V_{DC}):

$$V_{DC} = I_{DC}\, R_L = \frac{2I_m}{\pi} R_L$$

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

$$V_{DC} = \frac{2V_m R_L}{\pi(R_s + R_f + R_L)}$$

; divide numerator and denominator by R_L

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

If $R_L \gg R_s + R_f$, then $\frac{R_f + R_s}{R_L} \approx 0$

$$V_{DC} = \frac{\mathbf{2\,V_m}}{\pi} = \mathbf{0.636 V_m = 63.6\% V_m}$$

Therefore, the average or DC value of load voltage / load current is 63.6% of the maximum ac input voltage or current.

Root Mean Square Value of Load Current (I_{rms}) & Voltage (V_{rms}):

The effective value of the output is the rms value.

For Half Wave Rectifies:

RMS value of load current (I_{rms}):

$$I_{rms} = \sqrt{\frac{\int_0^{\pi} i^2 . d\theta + \int_{\pi}^{2\pi} i^2 . d\theta}{2\pi}} \quad ; \text{Substitute } i = I_m \sin\theta$$

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\theta . d\theta} \qquad \text{WKT}, \sin^2\theta = \frac{1-\cos 2\theta}{2}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi}\frac{1-\cos 2\theta}{2} . d\theta} = \sqrt{\frac{I_m^2}{2\pi} x \frac{1}{2}\left[\int_0^{\pi} 1. d\theta - \int_0^{\pi}\cos 2\theta . d\theta\right]}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{4\pi}\left[[\theta]_0^{\pi} - \left[\frac{\sin 2\theta}{2}\right]_0^{\pi}\right]} = \sqrt{\frac{I_m^2}{4\pi}[\pi - 0]} = \sqrt{\frac{I_m^2\pi}{4\pi}}$$

$$I_{rms} = \frac{I_m}{2} = 0.5I_m = 50\%I_m$$

RMS value of load voltage (V_{rms}):

$$V_{rms} = I_{rms}\,R_L = \frac{I_m}{2}R_L \quad ;\text{substitute } I_m = \frac{V_m}{(R_f + R_s + R_L)}$$

$$V_{rms} = \frac{V_m \cdot R_L}{2(R_f + R_s + R_L)} \quad ;\text{divide numerator and denominator by } R_L$$

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

$$\text{If } R_L \gg R_f + R_s, \quad \text{then } \frac{R_f + R_s}{R_L} \approx 0$$

$$V_{rms} = \frac{V_m}{2} = \mathbf{0.5V_m}$$

For Full-Wave Rectifier:

RMS value of load current (I_{rms}):

$$I_{rms} = \sqrt{\frac{\left[\int_0^{\pi} i^2.d\theta + \int_{\pi}^{2\pi} i^2.d\theta\right]}{2\pi}}$$

; by definite integral property it can be written as,

$$I_{rms} = \sqrt{\frac{1}{2\pi}\left[2\int_0^{\pi} i^2.\,d\theta\right]} = \sqrt{\frac{1}{\pi}\left[\int_0^{\pi} I_m^2 \sin^2\theta.\,d\theta\right]} \qquad ;\text{substitute } \sin^2\theta = \frac{1 - \cos 2\theta}{2}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi}\left(\frac{1 - \cos 2\theta}{2}\right).d\theta} = \sqrt{\frac{I_m^2}{2\pi}\left[\int_0^{\pi} 1.d\theta - \int_0^{\pi} \cos 2\theta\,.\,d\theta\right]}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{2\pi}\left\{[\theta]_0^{\pi} - \left[\frac{\sin 2\theta}{2}\right]_0^{\pi}\right\}} = \sqrt{\frac{I_m^2}{2\pi}\left[\pi - \frac{1}{2}[\sin 2\pi - \sin 0]\right]} = \sqrt{\frac{I_m^2}{2}}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707I_m = 70.7\% \text{ of } I_m$$

RMS value of load voltage (V_{rms}):

$$V_{rms} = I_{rms}\,.R_L = \frac{I_m}{\sqrt{2}}\,.R_L \qquad ;\text{substitute } I_m = \frac{V_m}{(R_f + R_s + R_L)}$$

$$V_{rms} = \frac{V_m R_L}{\sqrt{2}(R_s + R_f + R_L)} \quad ;\text{divide numerator and denominator by } R_L$$

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

If $R_L \gg R_s + R_f$, then $\frac{R_f + R_s}{R_L} \approx 0$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707V_m = 70.7\% \text{ of } V_m$$

Efficiency of Rectification (η):

$$\eta = \frac{\text{DC Power Delivered to the load}}{\text{AC input power from the transformer secondary}} = \frac{P_{dc}}{P_{ac}}$$

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

$$\eta = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_s + R_L)} \text{ ; Divide Numerator \& Denominator by } R_L$$

$$\eta = \frac{I_{dc}^2}{I_{rms}^2 \left(\frac{R_f + R_s}{R_L} + 1\right)} \text{ ; If } R_L \gg R_s + R_f \text{ then } \frac{R_f + R_s}{R_L} \approx 0$$

$$\eta = \frac{I_{dc}^2}{I_{rms}^2}$$

For Half Wave Rectifier:

$$I_{dc} = \frac{I_m}{\pi} \text{ and } I_{rms} = \frac{I_m}{2}$$

$$\eta = \frac{\left(\frac{I_m}{\pi}\right)^2}{\left(\frac{I_m}{2}\right)^2} = \frac{\frac{I_m^2}{\pi^2}}{\frac{I_m^2}{4}} = \frac{I_m^2}{\pi^2} \times \frac{4}{I_m^2} = \frac{4}{\pi^2} = \mathbf{0.406 = 40}$$

Maximum Efficiency: $\eta = \mathbf{0.406 = 40.6\%}$

For Full Wave Rectifier:

$$I_{dc} = \frac{2I_m}{\pi} \text{ and } I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\eta = \frac{\left(\frac{2I_m}{\pi}\right)^2}{\left(\frac{I_m}{\sqrt{2}}\right)^2} = \frac{\frac{4I_m^2}{\pi^2}}{\frac{I_m^2}{2}} = \frac{4I_m^2}{\pi^2} \times \frac{2}{I_m^2} = \frac{8}{\pi^2} = \mathbf{0.812 = 81}$$

Maximum Efficiency: $\eta = \mathbf{0.812 = 81.2\%}$

Ripple Factor (ϒ):

- Rectifier converts AC power to DC power and is described quantitatively by a term called **ripple factor**.

$$\Upsilon = \frac{\text{rms value of AC component of output}}{\text{DC component of output}} = \frac{I_{ac}}{I_{dc}}$$

rms value of the ac component of current is given

$$I_{rms}^2 = I_{dc}^2 + I_{ac}^2 \Rightarrow I_{ac}^2 = I_{rms}^2 - I_{dc}^2 \Rightarrow I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

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

For Half - Wave Rectifier:

$$I_{rms} = \frac{I_m}{2} \text{ and } I_{dc} = \frac{I_m}{\pi}$$

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

$$= \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = \sqrt{(1.57)^2 - 1}$$

$$\Upsilon = 1.21 = 121\%$$

For Full Wave Rectifier:

$$I_{rms} = \frac{I_m}{\sqrt{2}} \text{ and } I_{dc} = \frac{2I_m}{\pi}$$

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

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = \sqrt{(1.11)^2 - 1}$$

$$\Upsilon = 0.482 = 48.2\%$$

Voltage Regulation:

It is the factor which tells about the change in dc output voltage as load changes from no load to full load condition.

$$\% \text{ Regulation} = \frac{V_{No\ Load} - V_{Full\ Load}}{V_{Full\ Load}} x\ 100$$

$$\% R = \frac{V_{NL} - V_{FL}}{V_{FL}} x\ 100$$

$$V_{NL} = V_{dc} \quad \text{and} \quad V_{FL} = I_{dc}R_L$$

$$\% R = \frac{V_{dc} - I_{dc}R_L}{I_{dc}R_L} x\ 100$$

For HWR;

$$V_{dc} = \frac{V_m}{\pi} \quad \text{and} \quad I_{dc} = \frac{I_m}{\pi}$$

$$I_{dc} = \frac{V_m}{\pi(R_f + R_s + R_L)}$$

$$\% R = \frac{\frac{V_m}{\pi} - \frac{V_m}{\pi(R_f + R_s + R_L)}R_L}{\frac{V_m}{\pi(R_f + R_s + R_L)}R_L} x\ 100 = \frac{\frac{V_m}{\pi}\left(1 - \frac{R_L}{R_f + R_s + R_L}\right)}{\frac{V_m}{\pi}\frac{R_L}{R_f + R_s + R_L}} = \frac{1 - \frac{R_L}{R_f + R_s + R_L}}{\frac{R_L}{R_f + R_s + R_L}} x\ 100$$

$$\% R = \frac{\frac{R_f + R_s + R_L - R_L}{R_f + R_s + R_L}}{\frac{R_L}{R_f + R_s + R_L}} x\ 100 = \frac{R_f + R_s}{R_L} x\ 100\%$$

R_f If $>> R_s$

$$\% R = \frac{R_f}{R_L} x\ 100\%$$

If $R_f = R_L$

$$\%R = 100\%$$

For FWR;

$$V_{dc} = \frac{2V_m}{\pi} \quad \text{and} \quad I_{dc} = \frac{2I_m}{\pi}$$

$$I_{dc} = \frac{2V_m}{\pi(R_f + R_s + R_L)}$$

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

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

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

If $R_f \gg R_s$

$$\% R = \frac{R_f}{R_L} \times 100\%$$

If $R_f = R_L$

$$\% R = 100\%$$

Form Factor:

It is defined as the ratio of RMS voltage across output to the average DC component.

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

Ripple factor expressed in-terms of form factor is,

$$\Upsilon = \sqrt{(FF)^2 - 1}$$

For HWR;

$$FF = \frac{\frac{I_m}{2}}{I_m/\pi} = \frac{\pi}{2} = 1.57$$

$$\Upsilon = \sqrt{(1.57)^2 - 1} = 1.21$$

For FWR;

$$FF = \frac{\frac{I_m}{\sqrt{2}}}{2I_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$\Upsilon = \sqrt{(1.11)^2 - 1} = 0.482$$

Transformer Utilization Factor:

Transformer utilization factor (TUF) of a rectifier circuit is defined as the ratio of the DC power available at the load resistor and the AC rating of the secondary coil of a **transformer**.

$$TUF = \frac{\text{DC power delivered to load}}{\text{AC power rating of transformer secondary}} = \frac{P_{dc}}{P_{ac(rated)}}$$

Rated Voltage of secondary transformer is: $V_{rms} = \frac{V_m}{\sqrt{2}}$

$$P_{ac(rated)} = V_{rms} \times I_{rms}$$

For Half Wave Rectifier:

RMS current flowing through the winding is: $I_{rms} = \frac{I_m}{2}$

$$P_{ac(rated)} = V_{rms} \times I_{rms} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2}$$

$$P_{dc} = I_{dc}^2 R_L \quad ;\text{Substitute } I_{dc} = \frac{I_m}{\pi}$$

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

$$TUF = \frac{P_{dc}}{P_{ac(rated)}} = \frac{\left(\frac{I_m^2}{\pi^2} R_L\right)}{\left(\frac{V_m}{\sqrt{2}} \frac{I_m}{2}\right)} \quad ;\text{substitute } I_m = \frac{V_m}{R_L}$$

$$TUF = \frac{\left(\frac{V_m^2}{\pi^2 R_L^2} R_L\right)}{\left(\frac{V_m}{\sqrt{2}} \frac{V_m}{2R_L}\right)} = \frac{V_m^2}{\pi^2 R_L} \times \frac{2\sqrt{2} R_L}{V_m^2} = \frac{2\sqrt{2}}{\pi^2} = 0.287 = 28.7\%$$

For Full Wave Rectifier:

RMS current flowing through the winding is : $I_{rms} = \frac{I_m}{\sqrt{2}}$

$$P_{ac(rated)} = V_{rms} \times I_{rms} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}$$

$$P_{dc} = I_{dc}^2 R_L \quad ;\text{Substitute } I_{dc} = \frac{2I_m}{\pi}$$

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

$$TUF = \frac{P_{dc}}{P_{ac(rated)}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}} \quad ;\text{substitute } I_m = \frac{V_m}{R_L}$$

$$TUF = \frac{\left(\frac{2V_m}{\pi R_L}\right)^2 R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{V_m}{\sqrt{2} R_L}} = \frac{\frac{4V_m^2}{\pi^2 R_L^2} R_L}{\frac{V_m^2}{2R_L}} = \frac{4V_m^2}{\pi^2 R_L} \times \frac{2R_L}{V_m^2} = \frac{8}{\pi^2} = 0.812 = 81.2\%$$

Comparison of Half wave rectifier, Full wave centre tapped and Bridge rectifier:

Sl. No:	Parameter:	Half-Wave Rectifier:	Full-Wave Centre Tapped Rectifier:	Bridge Rectifier:
1	Diodes:	1	2	4
2	Peak Inverse Voltage (PIV):	V_m	$2V_m$	V_m
3	Ripple Frequency:	f	2f	2f
4	Ripple Factor (γ):	$1.21 = 121\%$	$0.482 = 48.2\%$	$0.482 = 48.2\%$
5	Maximum Efficiency (η):	$0.406 = 40.6\%$	$0.812 = 81.2\%$	$0.812 = 81.2\%$
6	Average Current (I_{DC}):	$\frac{I_m}{} = 0.318\ I_m$	$\frac{2I_m}{} = 0.636I_m$	$\frac{2I_m}{} = 0.636I_m$
7	Average Voltage (V_{dc}):	$\frac{V_m}{} = 0.318\ V_m$	$\frac{2V_m}{} = 0.636V_m$	$\frac{2V_m}{} = 0.636V_m$
8	RMS Current (I_{rms}):	$\frac{I_m}{}$		
9	RMS Voltage (V_{rms}):	$\frac{V_m}{}$		
10	Voltage Regulation:			
11	Form Factor:	1.57	1.11	1.11
12	TUF:	$0.287 = 28.7\%$	$0.812 = 81.2\%$	$0.812 = 81.2\%$

1. A half wave rectifier uses a diode whose internal resistance is 30Ω to supply power to 1.1 KΩ load from 110V (rms) source of supply. Calculate: i) DC load voltage; ii) DC load current; iii) AC load current; iv) Percentage regulation.

Solution: Given $V_{rms} = 110V$, $R_L = 1.1\ K\Omega$, $R_f = 30\ \Omega$

$$V_{rms} = \frac{V_m}{\sqrt{2}} \Longrightarrow V_m = \sqrt{2}V_{rms} = \sqrt{2}\ x\ 110\ V = 155.56\ V$$

$$I_m = \frac{V_m}{R_f + R_s + R_L} = \frac{155.56\ V}{30\ \Omega + 0 + 1100\ \Omega} = 137.66\ mA$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{137.66\ mA}{\sqrt{2}} = 97.34\ mA$$

i) DC Load Voltage:

$$V_{dc} = \frac{V_m}{\pi} = 0.318\ V_m = 0.318\ x\ 155.56\ V = 49.46\ V$$

ii) DC Load Current:

$$I_{DC} = \frac{I_m}{\pi} = 0.318\ I_m = 0.318\ x\ 137.66\ mA = 43.77\ mA$$

AC Load Current:

$$I_{rms}^2 = I_{dc}^2 + I_{ac}^2 \Longrightarrow I_{ac}^2 = I_{rms}^2 - I_{dc}^2$$

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

$$I_{ac} = \sqrt{97.34^2 - 43.77^2} = 87\ mA$$

(i) Percentage Regulation:

$$\% R = \frac{R_f}{R_L} \times 100\% = \frac{30\ \Omega}{1100\ \Omega} \times 100 = 2.72\%$$

2. A full wave rectifier with a load of 1 KΩ. The ac voltage applied to the diode is 200-0-200 V, if diode resistance is neglected. Calculate: i) Average dc current; ii) Average dc voltage.

Solution: Given V_{rms} = 200 V, R_L = 1 KΩ,

$$V_m = \sqrt{2}V_{rms} = \sqrt{2} \times 200 = 282.84\ V$$

$$I_m = \frac{V_m}{R_f + R_s + R_L} = \frac{282.84}{1000} = 282.84\ mA$$

(i) Average dc current:

$$I_{DC} = \frac{2I_m}{\pi} = 0.636 I_m = 0.636 \times 282.84\ mA = 179.88\ mA$$

(ii) Average dc voltage:

$$V_{DC} = \frac{2V_m}{\pi} = 0.636 V_m = 0.636 \times 282.84\ V = 179.88\ V$$

3. A single phase full – wave rectifier supplies a power to a 1 KΩ load. The AC voltage applied to the diode is 300 – 0 – 300 V. If diode resistance is 25Ω and that of the transformer secondary is negligible. Determine average load current, average load voltage and rectification efficiency.

Solution: Given V_{rms} = 300 V, R_L = 1 KΩ, R_f = 25 Ω

$$V_m = \sqrt{2}V_{rms} = \sqrt{2} \times 300 = 424.26\ V$$

$$I_m = \frac{V_m}{R_f + R_s + R_L} = \frac{424.26}{25 + 1000} = 414\ mA$$

Average Load Current:

$$I_{DC} = \frac{2I_m}{\pi} = 0.636 I_m = 0.636 \times 414\ mA = 263.25\ mA$$

Average Load Voltage:

$$V_{DC} = \frac{2V_m}{\pi} = 0.636 V_m = 0.636 \times 424.26\ V = 270\ V$$

Rectification Efficiency:

$$\eta = \frac{8}{\pi^2} \times \frac{R_L}{(R_f + R_s + R_L)} = 0.812 \times \frac{1000\Omega}{(30\Omega + 0 + 1000\Omega)} = 0.7883 = 78.83\%$$

4. A half wave rectifier from a supply 230 V 50 Hz with step down transformer ratio 3:1 to a resistive load of 10 KΩ. The diode forward resistance is 75 Ω and transformer secondary is 10 Ω. Calculate the DC current, DC voltage, efficiency and ripple factor.

Solution: Given $N_1 : N_2 = 3 : 1$, V_P = 230 V, R_L = 10 KΩ, R_f = 75 Ω and R_s = 10 Ω

$$\frac{N_1}{N_2} = \frac{V_P}{V_S} \Rightarrow N_1 V_S = N_2 V_P \Rightarrow V_S(rms) = \frac{N_2}{N_1} V_P = \frac{1}{3} V_P = \frac{230}{3} = 76.66V$$

$$V_m = \sqrt{2} \times V_S(rms) = \sqrt{2} \times 76.66 = 108.41\ V$$

$$I_m = \frac{V_m}{(R_f + R_s + R_L)} = \frac{108.41}{(75 + 10 + 10K)} = 10.75\ mA$$

$$I_{dc} = \frac{I_m}{\pi} = 0.318I_m = 0.318 \text{ x } 10.75 \text{ mA} = 3.418 \text{ mA}$$

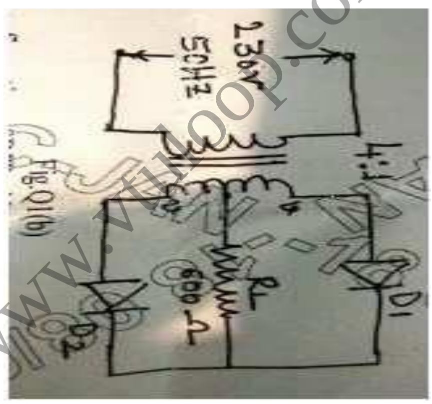
$$V_{dc} = \frac{V_m}{\pi} = 0.318V_m = 0.318 \text{ x } 108.41 = 34.47 \text{ V}$$

$$\eta = \frac{4}{\pi^2} \text{x} \frac{R_L}{(R_f + R_s + R_L)} = 0.406 \text{ x } \frac{10K}{75 + 10 + 10K} = 0.4025 = 40.25\%$$

$$I_{rms} = \frac{V_{rms}}{(R_f + R_s + R_L)} = \frac{76.66}{(75 + 10 + 10K)} = 7.6 \text{ mA}$$

$$\Upsilon = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{7.6 \text{ mA}}{3.418 \text{ mA}}\right)^2 - 1} = 1.22$$

4. The input voltage applied to the primary of a 4:1 step down transformer of a full wave centre tap rectifier is 230 V, 50 Hz is the load resistance of 600 Ω and forward resistance is 20 Ω. Determine the following for circuit shown in Fig. Q1(b).
   i) dc power output
   ii) Rectification efficiency
   iii) PIV



Solution: Given $N_1 : N_2 = 4 : 1$, $V_P = 230$ V, $R_L = 600$ Ω, $R_f = 20$ Ω

$$\frac{N_1}{N_2} = \frac{V_P}{V_S} \Rightarrow N_1V_S = N_2V_P \Rightarrow V_S(\text{rms}) = \frac{N_2}{N_1}V_P = \frac{1}{4}V_P = \frac{230}{4} = 57.5 \text{ V}$$

$$V_m = \sqrt{2} \text{ x } V_S(\text{rms}) = \sqrt{2} \text{ x } 57.5 = 81.31 \text{ V}$$

$$I_m = \frac{V_m}{(R_f + R_s + R_L)} = \frac{181.31}{(20 + 0 + 600)} = 131.15 \text{ mA}$$

$$I_{dc} = \frac{2I_m}{\pi} = 0.636I_m = 0.636 \text{ x } 131.15 \text{ mA} = 83.415 \text{ mA}$$

i) dc power output:

$$P_{dc} = {I_{dc}}^2R_L = (83.415 \text{ x } 10^{-3})^2 \text{ x } 600 = 4.17 \text{ W}$$

ii) Rectification efficiency:

$$\eta = \frac{8}{\pi^2} \text{x} \frac{R_L}{(R_f + R_s + R_L)} = 0.8105 \text{ x } \frac{600}{20 + 0 + 600} = 0.7844 = 78.44\%$$

iii) PIV:

$$PIV = 2V_m = 2 \text{ x } 81.31 = 162.62 \text{ V}$$

5. If the input voltage for a bridge rectifier is 50 V and each diode has a forward resistance of 25Ω. Find the current through a load resistance of 2950Ω and the dc voltage.

Solution: Given V_m = 50 V, R_L = 2950 Ω, R_f = 25 Ω

Current through a load resistance:

$$I_m = \frac{V_m}{(R_f + R_s + R_L)} = \frac{50}{(25 + 0 + 2950)} = 16.8 \text{ mA}$$

dc voltage:

$$V_{dc} = \frac{2V_m}{\pi} = 0.636 \text{ x } 50 = 31.83 \text{ V}$$

6. A sinusoidal wave of V_i = 600 sin 30t is applied to a half wave rectifier. The load resistance is 2 KΩ and forward resistance of the diode is 60 Ω. Find:
   (i) DC current through the diode
   (ii) AC or rms value of current through the circuit
   (iii) DC output voltage
   (iv) AC power input
   (v) DC power output
   (vi) Rectifier efficiency

Solution: Given V_i = 600 sin 30t = V_m sin wt, R_L = 2 KΩ, R_f = 60 Ω

(i) $I_{DC} = \frac{I_m}{\pi}$ and $I_m = \frac{V_m}{R_f+R_s+R_L} = \frac{V_m}{R_f+R_L} = \frac{600}{60+2x10^3} = 291.2\text{mA}$

$$I_{DC} = \frac{I_m}{\pi} = \frac{291.2\text{mA}}{\pi} = 92.71 \text{ mA}$$

(ii) $I_{rms} = \frac{I_m}{2} = \frac{291.2\text{mA}}{2} = 145.6 \text{ mA}$

(iii) DC output voltage: $V_{DC} = I_{DC} \text{ x } R_L = 92.71 \text{ mA x } 2 \text{ K}\Omega = 185.4 \text{ V}$

(iv) AC power input: $P_{ac} = I_{rms}^2 (R_f + R_L) = (145.6 \text{ mA})^2 (60\,\Omega + 2 \text{ K}\Omega) = 43.67 \text{ W}$

(v) DC power output: $P_{dc} = I_{dc}^2 (R_L) = (92.71 \text{ mA})^2 (2 \text{ K}\Omega) = 17.1 \text{ W}$

(vi) Rectifier efficiency:

$$\eta = \frac{P_{dc}}{P_{ac}} \text{ x } 100 = \frac{17.1 \text{ W}}{43.67 \text{ W}} \text{ x } 100 = 39.3\%$$

7. The input to the full wave rectifier is V(t) = 200 sin 50t. If R_L is 1 KΩ and forward resistance is 50 Ω. Find:
   (i) DC current through the circuit
   (ii) The AC (rms) value of current through the circuit
   (iii) The DC output voltage
   (iv) The AC power input
   (v) The DC power output
   (vi) Rectifier efficiency

Solution: Given V(t) = 200 sin 50t = V_m sin wt, R_L = 1 KΩ, R_f = 50 Ω,

(i) and

$$I_{DC} = \frac{2I_m}{\pi} \quad I_m = \frac{V_m}{R_f+R_s+R_L} = \frac{V_m}{R_f+R_L} = \frac{200}{60+1x10^3} = 0.190 \text{ A}$$

$$I_{DC} = \frac{2I_m}{\pi} = \frac{20.190}{\pi} = 0.120 \text{ A}$$

(ii) $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.190}{\sqrt{2}} = 0.134\ A$

(iii)DC output voltage: $V_{DC} = I_{DC} \times R_L = 0.120\ A \times 1\ K\Omega = 120\ V$

(iv)AC power input: $P_{ac} = I_{rms}^2\,(R_f + R_L) = (0.134\ A)^2(1\ K\Omega + 50\ \Omega) = 18.85\ W$

(v) DC power output: $P_{dc} = I_{dc}^2\,(R_L) = (0.120\ A)^2(1\ K\Omega) = 14.4\ W$

(vi)Rectifier efficiency:

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{14.4\ W}{18.85\ W} \times 100 = 79.39\%$$

Filters:

- The rectified output is not direct voltage, to convert it into direct voltage (dc voltage), a **smoothing circuit** or **filter** must be employed.
- The device which removes ac component (ripple) from the rectified output (pulsating dc which contains ac and dc components) is called **filter**.
- **Filter** may be defined as a device which removes AC component of the rectifier output but allows the DC component to reach the load.

OR:

It is a circuit, which converts pulsating output of the rectifier into a steady DC level.

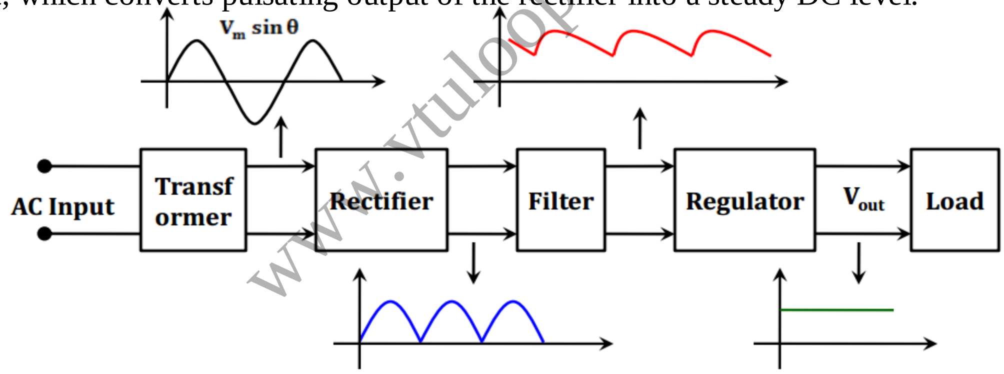


Fig: Components of Typical Power Supply

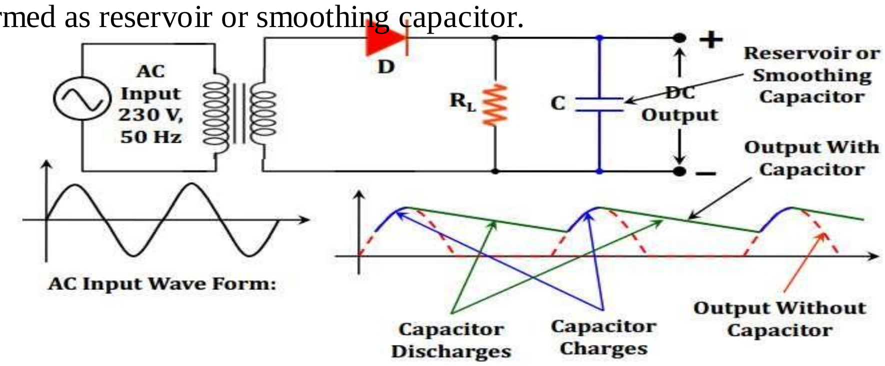
- Filter circuit is generally a combination of Inductors (L) and Capacitors (C).

Reactance of Capacitor: $X_C = \frac{1}{2\pi fC}$

Reactance of Inductor: $X_L = 2\pi fL$

Half Wave Rectifier with Capacitor Filter:

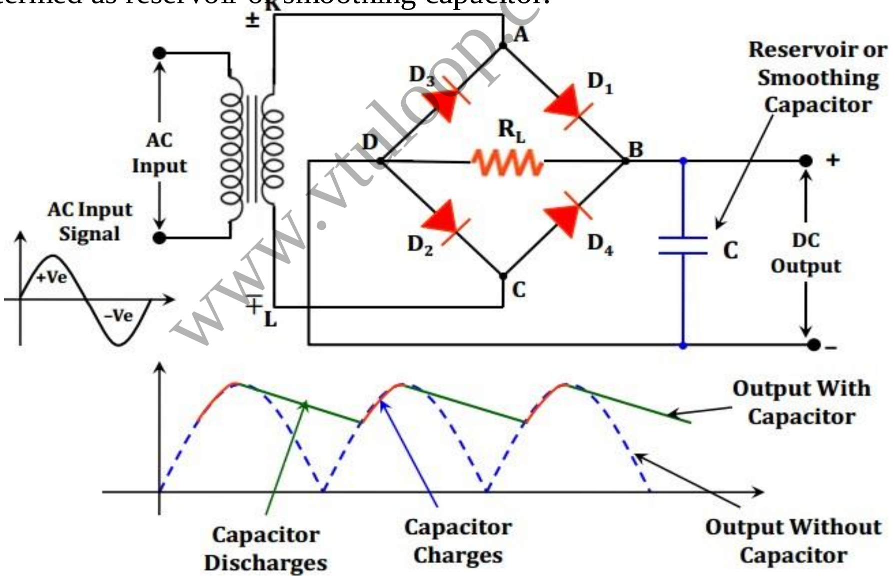
- The below figure shows a half-wave rectifier circuit with capacitor (C) and load resistor (R_L). The capacitor is termed as reservoir or smoothing capacitor.



- **During the positive quarter cycle** of the input signal. Diode is forward biased, this charges the capacitor C to peak value of input V_m. Practically, capacitor voltage is $V_C = V_m - V_F$
- When the input voltage at anode falls below V_m, diode becomes **reverse biased**, because the capacitor voltage at the cathode is remains equal to V_m. Then, there is no capacitor charging current, and the capacitor begins to discharge through the load resistor (R_L), hence the capacitor voltage falls slowly.
- The diode remains reverse biased in:
  (i) Rest of the positive half-cycle,
  (ii) Negative half-cycle,
  (iii) First part of the positive half-cycle again, until the input voltage (V_i) becomes greater than the capacitor voltage (V_C).
- When V_i becomes greater than V_C, diode becomes forward biased again and capacitor recharges to V_m, and the same cycle repeats.

Full Wave Rectifier with Capacitor Filter:

- The below figure shows a full-wave rectifier circuit with capacitor (C) and load resistor (R_L). The capacitor is termed as reservoir or smoothing capacitor.



- **During the positive quarter cycle** of the input signal, diodes D_1 & D_2 are forward biased, hence current flows through load resistor R_L, this charges the capacitor C to peak value of input V_m. Practically, capacitor voltage is $V_C = V_m - 2V_F$
- When the input voltage at anodes of D_1 & D_2 falls below V_m, diodes becomes **reverse biased**, because the capacitor voltage at the cathodes is remains equal to V_m. Then, there is no capacitor charging current, and the capacitor begins to discharge through the load resistor (R_L), hence the capacitor voltage falls slowly.
- The diode remains reverse biased in:
  (i) Rest of the positive half-cycle,
  (i) First part of the negative half-cycle, until the input voltage (V_i) becomes greater than the capacitor voltage (V_C).

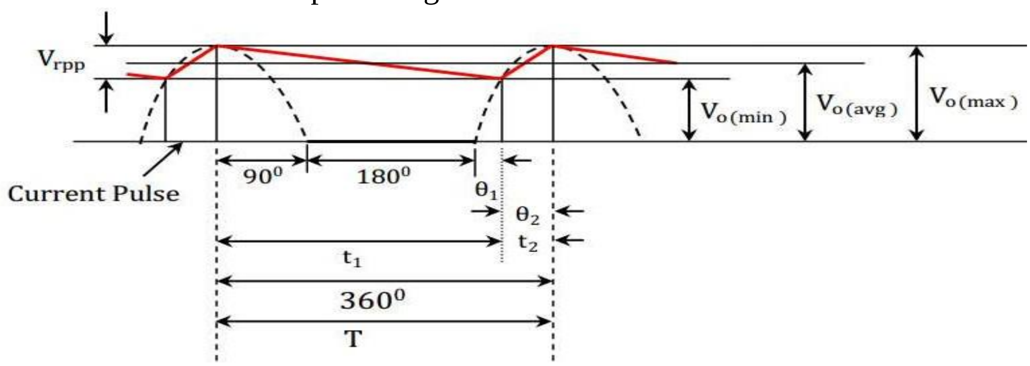
- **During the negative quarter cycle** of the input signal, when V_i becomes greater than V_C, diodes D_3 & D_4 are forward biased, hence current flows through load resistor R_L, this charges the capacitor C to peak value of input V_m.
- When the input voltage at anodes of D_3 & D_4 falls below V_m, diodes becomes **reverse biased**, because the capacitor voltage at the cathodes is remains equal to V_m. Then, there is no capacitor charging current, and the capacitor begins to discharge through the load resistor (R_L), hence the capacitor voltage falls slowly.
- The diode remains reverse biased in:
  (i) Rest of the negative half-cycle,
  (ii) First part of the positive half-cycle, until the input voltage (V_i) becomes greater than the capacitor voltage (V_C).
- During the next positive quarter cycle, when V_i becomes greater than V_C, diodes D_1 & D_2 are forward biased, and the same cycle repeats.

Ripple Amplitude and Capacitance:

- The amplitude of the ripple voltage is affected by:
  (i) Load current,
  (ii) Capacitor value and
  (iii) Capacitor discharge time.
- The discharge time depends upon the frequency of the ripple waveform, which is same as the ac input frequency in case of a half-wave rectifier.
- With a constant load current, the ripple amplitude is inversely proportional to the capacitance: the largest capacitance produces the smallest ripple.
- The ripple amplitude can be calculated from: (i) Capacitor value, (ii) Load current and (iii) Capacitor discharge time.

For half wave rectifier with capacitor filter:

- Consider the below circuit output voltage waveform.



The waveform quantities are as follows:

$V_{o(avg)}$: Average dc output voltage

$V_{o(min)}$: Minimum output voltage

$V_{o(max)}$: Maximum output voltage

V_{rpp} : Ripple voltage peak – to – peak amplitude

T : Time period of the ac input waveform

t_1 : Capacitor discharge time

t_2 : Capacitor charge time

θ_1 : Phase angle of input wave form zero to $V_{o(min)}$

θ_2 : Phase angle of input wave form $V_{o(min)}$ to $V_{o(max)}$

From figure, because the input wave is sinusoidal,

$$V_{o(min)} = V_{o(max)} \sin\theta_1 \implies \theta_1 = \sin^{-1}\left(\frac{V_{o(min)}}{V_{o(max)}}\right)$$

Also from figure, $\theta_2 = 90^0 - \theta_1$

Time period, $T = \frac{1}{f}$

Where f is the frequency of input waveform.

The input waveform goes through a 360^0 phase angle during time T, which gives the time per degree as,

$$t/\text{degree} = \frac{T}{360^0}$$

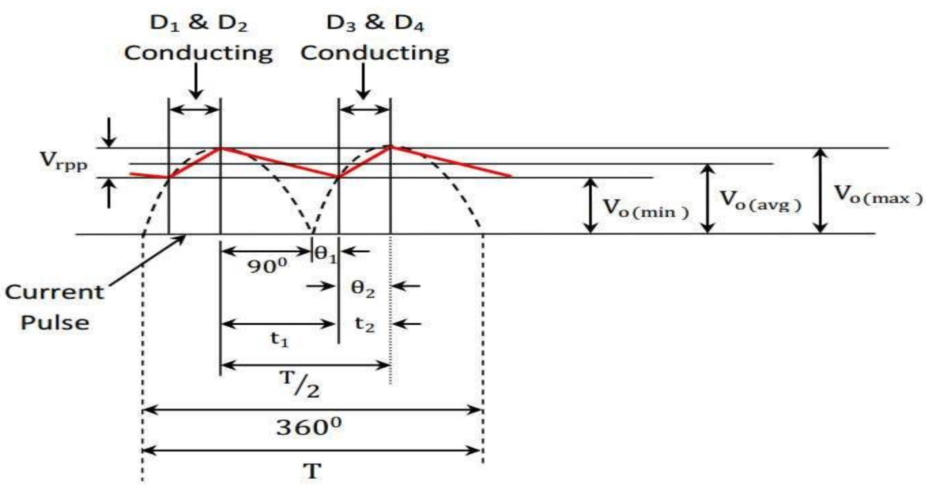
So, $t_2 = \theta_2 \times \frac{T}{360^0} = \frac{\theta_2 T}{360^0}$ and $t_1 = T - t_2$

Taking the current as constant quantity,

$$C = \frac{I_L\, t_1}{V_{rpp}}$$

For full wave rectifier with capacitor filter:

➢ Consider the below circuit output voltage waveform.



From figure,

$$\theta_1 = \sin^{-1}\left(\frac{V_{o(min)}}{V_{o(max)}}\right) \quad \text{and} \quad \theta_2 = 90^0 - \theta_1$$

$$t_2 = \frac{\theta_2 T}{360^0} \quad \text{and} \quad t_1 = \left(\frac{T}{2}\right) - t_2$$

$$C = \frac{I_L\, t_1}{V_{rpp}}$$

Expression for Ripple Factor(γ):

- The amount of charge lost by the capacitor during the interval t_1 $Q_{discharge} = I_{dc} t_1$
- This charge is replaced during a short interval t_2 During which the voltage across the capacitor changes by an amount equal to peak-to-peak voltage of ripple V_{rpp}.

Therefore, $\therefore Q_{charge} = CV_{rpp}$

$$Q_{charge} = Q_{discharge} \Rightarrow CV_{rpp} = I_{dc} t_1 \Rightarrow V_{rpp} = \frac{I_{dc} t_1}{C}$$

Let us consider half wave rectifier with C – filter.

$$t_1 + t_2 = T \text{ and } t_2 \ll t_1 \text{ Therefore, } t_1 \approx T$$

$$V_{rpp} = \frac{I_{dc} T}{C} \quad \text{WKT, } T = \frac{1}{f}$$

$$V_{rpp} = \frac{I_{dc}}{f\,C} \text{ - - - - - (1)}$$

RMS value of ripple voltage is given by,

$$V_{r,rms} = \frac{V_{rpp}}{2\sqrt{3}} \Rightarrow V_{rpp} = 2\sqrt{3}\, V_{r,rms} \text{ and } I_{dc} = \frac{V_{dc}}{R_L}$$

Substitute in Eqn:(1)

$$2\sqrt{3} \text{ x } V_{r,rms} = \frac{V_{dc}}{f\,C\,R_L}$$

$$\Rightarrow \frac{V_{r,rms}}{V_{dc}} = \frac{1}{2\sqrt{3}\, f\,C\,R_L}$$

$$\gamma = \frac{V_{r,rms}}{V_{dc}} = \frac{1}{2\sqrt{3}\, f\,C\,R_L} \quad \text{; Ripple factor in HWR with C filter}$$

For Full Wave Rectifier with C filter,

$$t_1 + t_2 = \frac{T}{2} \text{ and } t_2 \ll t_1 \text{ Therefore, } t_1 \approx \frac{T}{2} = \frac{1}{2f}$$

$$V_{rpp} = \frac{I_{dc} t_1}{C}$$

$$V_{rpp} = \frac{I_{dc}}{2fC} \text{ - - - - (2)}$$

rms value of ripple voltage is given by,

$$V_{r,rms} = \frac{V_{rpp}}{2\sqrt{3}} \Rightarrow V_{rpp} = 2\sqrt{3}\, V_{r,rms} \text{ and } I_{dc} = \frac{V_{dc}}{R_L}$$

Substitute in Eqn:(2)

$$2\sqrt{3} \text{ x } V_{r,rms} = \frac{V_{dc}}{2f\,C\,R_L} \Rightarrow \frac{V_{r,rms}}{V_{dc}} = \frac{1}{4\sqrt{3}\, f\,C\,R_L}$$

Therefore, $\gamma = \frac{V_{r,rms}}{V_{dc}} = \frac{1}{4\sqrt{3}\, f\,C\,R_L}$; Ripple factor in FWR with C filter

DC Output Voltage:

For HWR with C – filter:

$$V_{dc} = V_m - \frac{V_{rpp}}{2} = V_m - \frac{I_{dc}}{2fC} \quad ; \text{Substitute } I_{dc} = \frac{V_{dc}}{R_L}$$

$$V_{dc} = V_m - \frac{V_{dc}}{2fCR_L}$$

$$V_{dc} + \frac{V_{dc}}{2fR_LC} = V_m \Rightarrow V_{dc}\left[1 + \frac{1}{2fR_LC}\right] = V_m \Rightarrow \mathbf{V_{dc}} = \frac{\mathbf{V_m}}{\mathbf{1 + \frac{1}{2fCR_L}}}$$

For FWR with C – filter:

$$V_{dc} = V_m - \frac{V_{rpp}}{2} = V_m - \frac{I_{dc}}{2 \times 2fC} \quad ; \text{Substitute } I_{dc} = \frac{V_{dc}}{R_L}$$

$$V_{dc} = V_m - \frac{V_{dc}}{4fCR_L}$$

$$V_{dc} + \frac{V_{dc}}{4fCR_L} = V_m \Rightarrow V_{dc}\left[1 + \frac{1}{4fCR_L}\right] = V_m \Rightarrow \mathbf{V_{dc}} = \frac{\mathbf{V_m}}{\mathbf{1 + \frac{1}{4fCR_L}}}$$

1. In a FWR with a capacitor filter the load current from the circuit operating from 230V 50Hz supply is 10mA. Estimate the value of capacitor required to keep the ripple factor less than 1%.

Solution: Given $V_i = 230V, 50Hz \text{ and } I_{dc} = I_L = 10mA$

$$\Upsilon = \frac{1}{4\sqrt{3}\, f\, C\, R_L} \Rightarrow C = \frac{1}{4\sqrt{3}\, f\, \Upsilon\, R_L}$$

$$V_{dc} = I_{dc} R_L \Rightarrow R_L = \frac{V_{dc}}{I_{dc}} \text{ and } V_{dc} = \frac{2V_m}{\pi}$$

$$V_m = \sqrt{2} V_{rms} = \sqrt{2} \times 230 = 325.27\ V$$

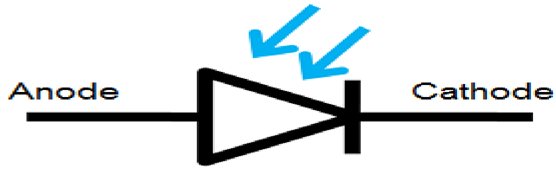
$$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 325.27}{\pi} = 207$$

$$R_L = \frac{V_{dc}}{I_{dc}} = \frac{207}{10 \times 10^{-3}} = 20.7\ K\Omega$$

$$C = \frac{1}{4\sqrt{3}\, f\, \Upsilon\, R_L} = \frac{1}{4\sqrt{3} \times 50 \times 10 \times 10^{3}} = 0.29\ \mu F$$

Photodiode

A photodiode is one type of light detector, used to convert the light into current or voltage based on the mode of operation of the device. It comprises of optical filters, built-in lenses and also surface areas. These diodes have a slow response time when the surface area of the photodiode increases. Photodiodes are alike to regular semiconductor diodes, but that they may be either visible to let light reach the delicate part of the device. Several diodes intended for use exactly as a photodiode will also use a PIN junction somewhat than the usual PN junction.



Photodiode symbol

Some photodiodes will look like a light emitting diode. They have two terminals coming from the end. The smaller end of the diode is the cathode terminal, while the longer end of the diode is the anode terminal. See the following schematic diagram for the anode and cathode side. Under forward bias condition, conventional current will flow from the anode to the cathode, following the arrow in the diode symbol. Photocurrent flows in the reverse direction.

The types of the photodiodes can be classified based on its construction and functions as follows.

- PN Photodiode
- Schottky Photo Diode
- PIN Photodiode
- Avalanche Photodiode

These diodes are widely used in the applications where the detection of the presence of light, color, position, intensity is required. The main features of these diodes include the following.

- The linearity of the diode is good with respect to incident light
- Noise is low.
- The response is wide spectral
- Rugged mechanically
- Light weight and compact
- Long life

Light Definitions and units

As per quantum theory, light is in the form of photons and each photon delivers an energy packet to the surface on which it falls.

$$W=hf \text{ joules}$$

Where h=Planck's constant ($6.624*10^{-34}$ joule seconds)

f= frequency of light of light waves in Hz

The frequency of light is directly related to its wavelength as $f=v/\lambda$

Where v=velocity of light ($3*10^{8}$ m/s)

λ =wavelength in meters

Units of wavelength are angstrom (A^{o}) or micrometer(μm)

$1A^{o}=10^{-10}m, 1\mu m=10^{-6}m$

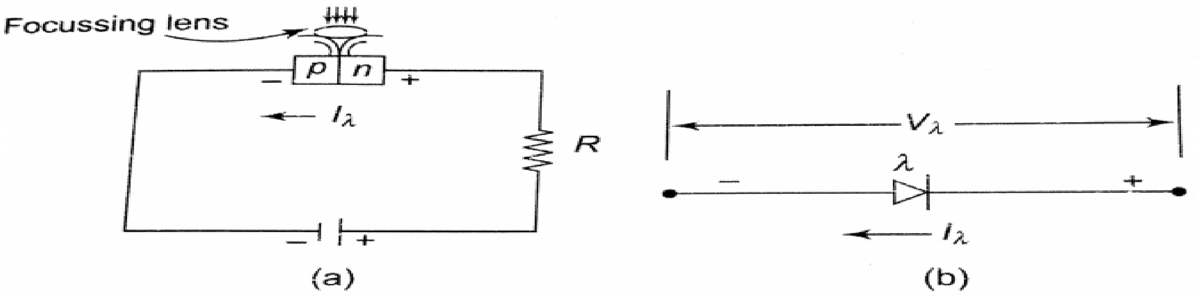
Intensity of light is measured in units of luminous flux incident on unit area.Units of luminous flux are lumens where $1lm=1.496*10^{-10}W$

Practical unit of intensity of light is

$1lm/ft^{2}$,called foot candle(f_c)$=1.609*10^{-9}W/m^{2}$

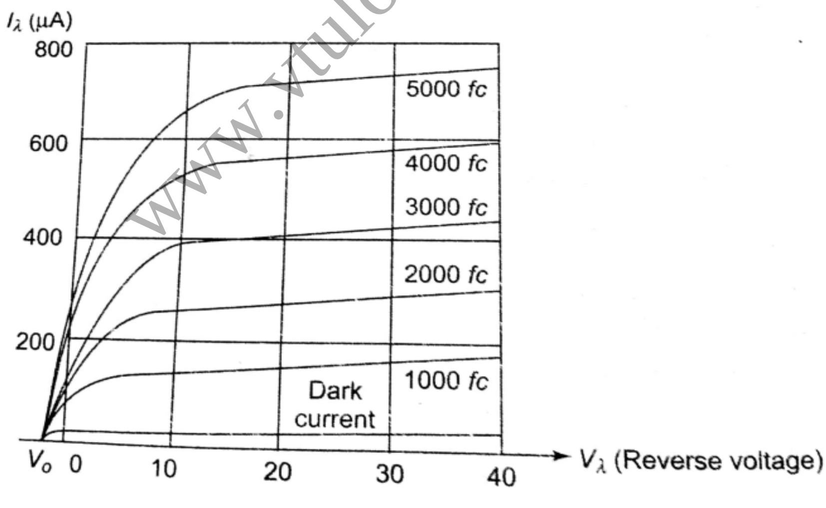
Photodiode Operation

A photodiode is a PN junction (silicon/germanium) operates in reverse bias region as shown in fig. The reverse saturation current I_λ (µA) is limited by the availability of thermally generated minority carrier. As light is made to impinge on the junction, the light photons impact energy to the valence electrons causing more electron hole pairs to be released. As a result, the concentration of minority carriers increases and so does the current I_λ .The symbol of a photodiode is drawn in fig.



Fig(a)Photodiode in Reverse bias Fig(b)Symbol

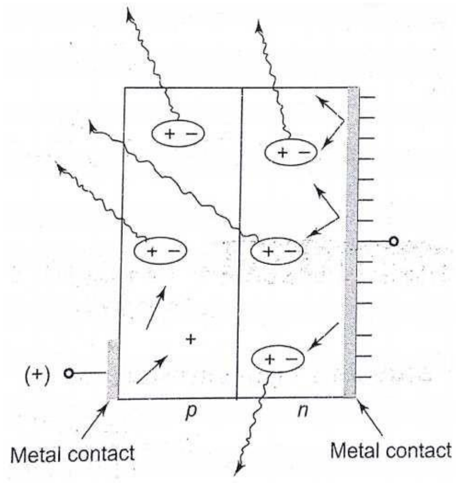
The VI characteristics for various values of light intensity (f_c)are drawn in fig.The dark current characteristic corresponding to no light impingement (I_λ=I_s).By examining the characteristics it is found that at a certain V_λ(say 20 V),I_λ increases almost linearly with f_c



VI Characteristics of photodiode

Light Emitting Diode

In a forward biased PN junction ,diode recombination of electrons and holes takes place at the junction and within the body of the crystal,particularly at the location of a crystal defect.Upon capture of a free electron by a hole,the electron goes into a new state and its kinetic energy is given off as heat and as light photons.In a silicon diode,most of this energy given off as heat but in other materials such as gallium arsenide(GaAs)or gallium phosphide(GaP),sufficient number of photons(light)are generated so as to create a visible source.This process of light emission in PN junction of such materials is illustrated in fig,and is known as electroluminescence.



Light emission in PN junction

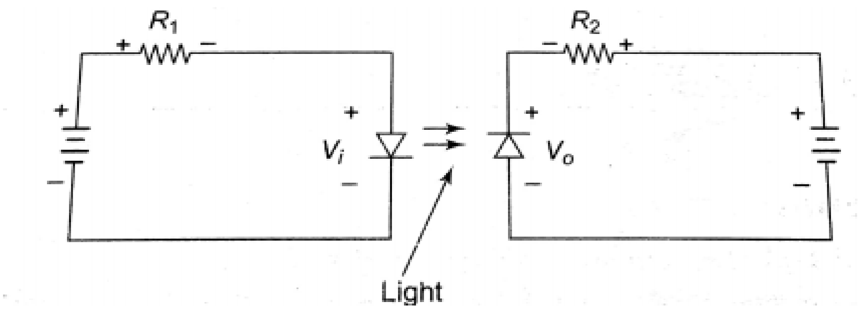
The metal contact of P-material made much small to permit the emergence of maximum number of photons so that in an LED,the light lumens generated per watt of electric power is high. Intensity of light increases almost linearly with forward current,depending on the material used.
The voltage levels of LEDs are 1.7V to 3.3V which is compatible with the solid state circuits. The response time is short(only a few nanoseconds)and light contrast is good.
LEDs emits light red, green, orange or blue

Applications

LEDs find several display applications, particularly in 8-segment display of numbers 0 to 9.These are now being used in LED TV's.

Photocoupler

It is a package of anLED and photodiode whereas circuits are electrically isolated as shown in fig.The LED is forward biased and the photodiode is reverse biased.The output is available across R_2



The key advantage of the photocoupler is the electrical isolation between two circuits. It is employed to couple circuits whose voltage level may differ by several thousand volts.

78XX series voltage regulator

The 78XX series (where XX=05,06,08,10,12,15,18 or 24) is the typical three Voltage regulators. The 7805 produces an output an output +5V,the 7806 produces +6V,the 7808 produces +8V,and so on, upto 7824,which produces an output of +24V.

Figure shows the functional block diagram for the 78XX series.A built in reference voltage V_{ref} drives the non inverting input of an amplifier.A voltage divider consisting of $R_1'$and R_2' samples the output voltage and returns a feedback voltage to the inverting input of a high gain amplifier.The output voltage is given by

$$V_{out}=((R_1'+R_2')/R_1')*V_{ref}$$

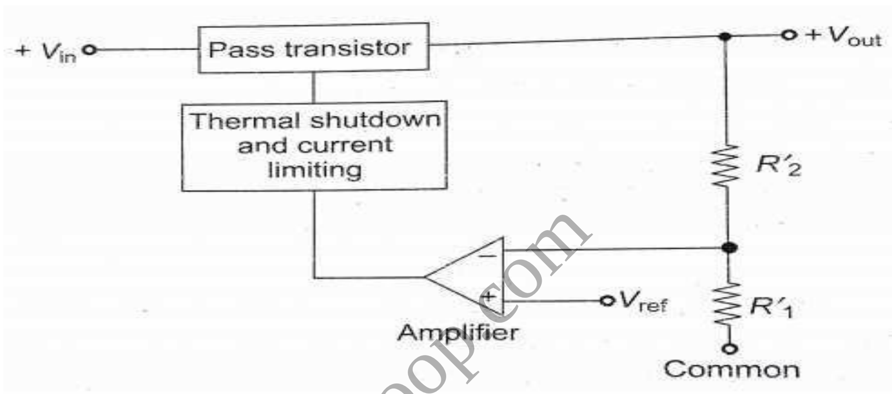


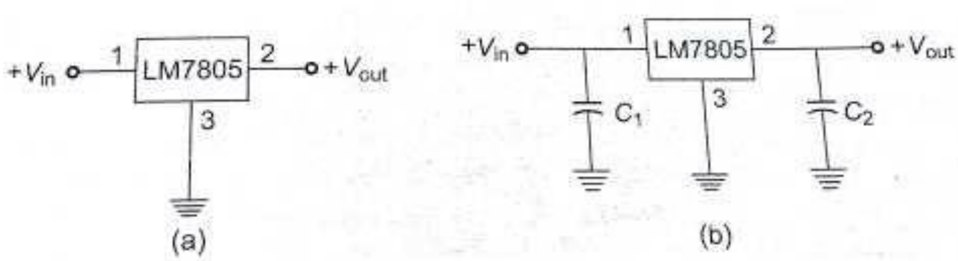
Fig: Functional Block Diagram of Three Terminal IC Regulator

The primes attached to $R_1'$and R_2' indicate that these resistors are inside the IC itself, rather than being external resistors. These resistors are factory trimmed to get the different output voltages (5 to 15 V)in the 78XX series. The tolerance of the output voltage is ±4%.

The LM 78XX includes a pass transistor that can handle 1A of load current, provided that adequate heat sinking is used. Also included are thermal shutdown and current limiting.

Thermal shutdown means that the chip will shut itself off when the internal temperature becomes too high, around 175ºC.This is a precaution against excessive power dissipation, which depends on the ambient temperature type of heat sinking and other variables. Because of thermal shutdown and current limiting, devices in the 78XX series are almost indestructible.

7805 Fixed Voltage Regulator



Fig(a) Using 7805 for voltage regulation   Fig(b)Input capacitor prevents oscillations and output capacitor improves frequency response

Fig(a) shows an LM7805 connected as a fixed voltage voltage regulator. Pin 1 is the input, Pin 2 is the output and Pin 3 is ground. The LM7805 has an output voltage of +5V and a maximum load current of 1A.The typical load regulation is 10mV for a load current between 5mA and 1.5A.The typical line regulation is 3mV for an input voltage of 7 to 25V.It also as a ripple rejection of 80dB,which means it will reduce the input ripple by a factor of 10,000.With in an output resistance of approximately 0.01Ω,the LM7805 is a very stiff voltage source to all loads within its current rating.

When an IC is more than 6 from the filter capacitor of the unregulated power supply, the inductance of the connecting wire may produce oscillations inside IC. This is why manufacturers recommend using a bypass capacitor C_1 on Pin1(Fig b).To improve the transient response of the regulated output voltage ,a bypass capacitor C_2 is sometimes used on Pin 2.Typical values for either bypass capacitor from 0.1 to 1µF.The data sheet of the 78XX series suggests 0.22µF for the input capacitor and 0.1µF for the output capacitor.

Any regulator in the 78XX series has a drop out voltage of 2 to 3 V, depending on the output voltage.This means that the input voltage must be atleast 2 to 3 V greater than output voltage.Otherwise,the chip stops regulating.Also ,there is a maximum input voltage because of excessive power dissipation.For instance,the LM7805 will regulate over an input range of approximately 8 to 20V.The data sheet for the 78XX series gives the minimum and maximum input voltages for the other preset output voltages.