Module-1:

***Semiconductor Diodes: Introduction**, PN Junction diode, Characteristics and Parameters, Text 1: 2.1,2.2)*

***Diode Applications:** Introduction, Half Wave Rectification, Full Wave Rectification, Full Wave Rectifier Power Supply: Capacitor Filter Circuit, RC π filter (Text 1: 3.1,3.2,3.4,3.5)*

***Zener Diodes:** Zener Diode, Characteristics and Parameters, Zener Diode Voltage Regulator. (Text1:2.9, 3.7)*

Introduction:

- Materials are classified as 1. Conductors 2. Insulators and 3. Semiconductors based on electrical conductivity.
- The semiconductors classified into two types as follows:
  1. Intrinsic semiconductors
  2. Extrinsic semiconductors

The conductivity of an intrinsic semiconductor depends on the surrounding temperature. At room temperature, it exhibits a very low conductivity and is not suitable for electronic devices such as diodes and transistors.

Extrinsic semiconductors are semiconductors that are doped with specific impurities. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors. While adding impurities, a small amount of suitable impurity is added to pure material, increasing its conductivity by many times. Extrinsic semiconductors are also called impurity semiconductors or doped semiconductors. The process of adding impurities deliberately is termed as doping and the atoms that are used as an impurity are termed as dopants. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors.

The dopant added to the material is chosen such that the original lattice of the pure semiconductor is not distorted. Also, the dopants occupy only a few of the states in the crystal of the original semiconductor and it is necessary that the size of the dopant is nearly equal to the size of the semiconductor atoms.

Some Commonly Used Dopants:

While doping tetravalent atoms such as Si or Ge, two types of dopants are used, and they are:

- Pentavalent atoms: Atoms with valency 5; such as Arsenic (As), Phosphorous (Pi), Antimony (Sb), etc.
- Trivalent atoms: Atoms with valency 3; such as Indium (In), Aluminium (Al), Boron (B), etc.

The reason behind using these dopants is to have similar-sized atoms as the pure semiconductor. Both Silicon and Germanium atoms belong to the fourth group in the periodic table. Hence, the choice of dopants from the third and fifth group is more viable. This ensures that the size of the atoms is not very different from the fourth group. Therefore, the trivalent and pentavalent choices. These dopants give rise to two types of semiconductors as follows:

- n-type semiconductors
- p-type semiconductors

n-type Semiconductors:

When a tetravalent atom such as Si or Ge is doped with a pentavalent atom, it occupies the position of an atom in the crystal lattice of the Si atom. The four of the electrons of the pentavalent atom bond with the four neighbouring silicon atoms, and the fifth one remains weakly bound to the parent atom. As a result, the ionization energy required to set the fifth electron free is very low, and the electrons become free to move in the lattice of the semiconductor. Such semiconductors are termed as n-type semiconductors.

p-type Semiconductors:

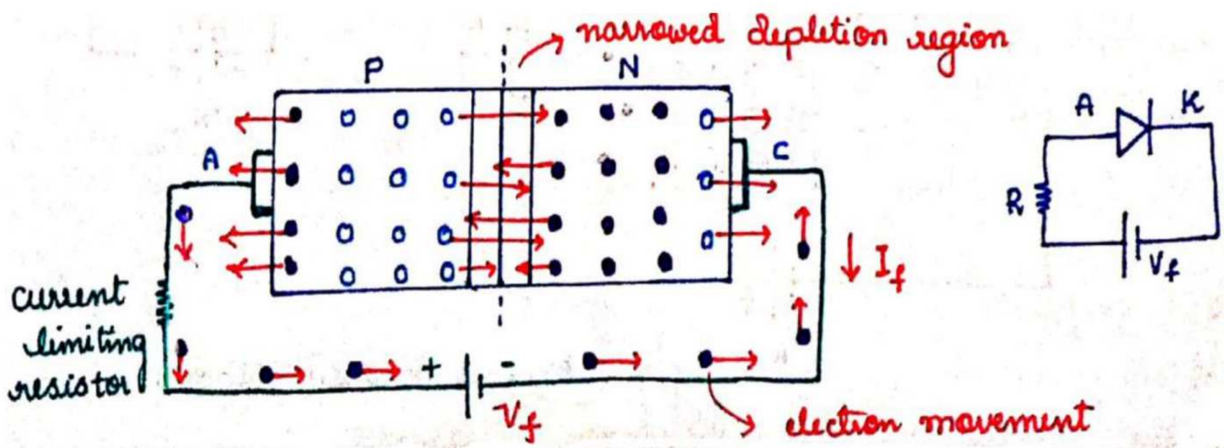
When a tetravalent atom such as Si or Ge is doped with a trivalent impurity such as Al, B, In, etc., the dopant atom has one less electron than the surrounding atoms of Si or Ge. Thus, the fourth atom of the tetravalent atom is free, and a hole or vacancy is generated in the trivalent atom. In such materials, the holes are the charge carriers, and such semiconductors are termed p-type semiconductors.

PN junction Diode:

3. When P-type and N-type semiconductors are placed in contact with one another, it forms a PN junction.
4. PN junction forms a popular semiconductor device called diode
5. A diode is a two terminal semiconductor device which conducts only in one direction offering a low resistance when forward biased and high resistance when reverse biased.

Forward Biasing PN-Junction:

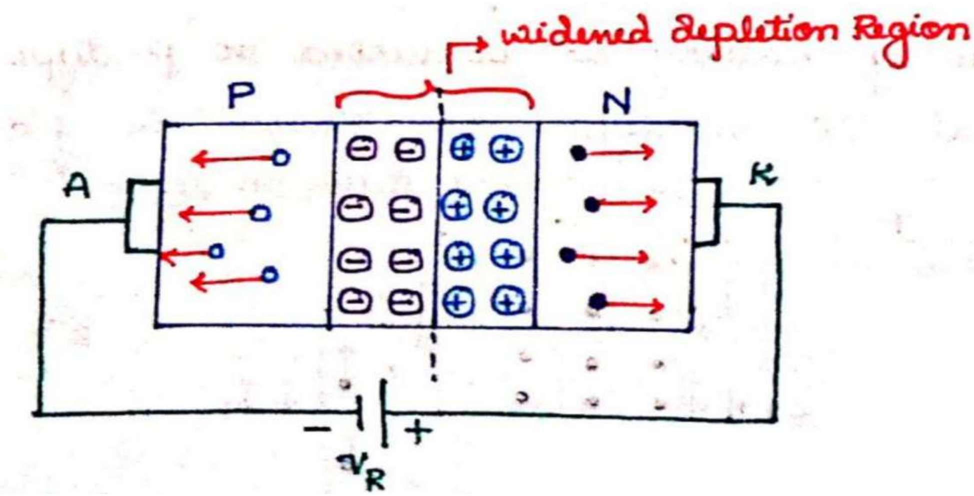
- PN Junction is said to be forward biased when the positive terminal of battery is connected to p-type and negative terminal of battery is connected to n-type as shown in the following figure.

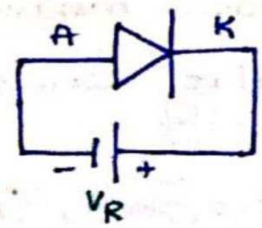


- If the applied voltage is less than the barrier potential, there will be no conduction
- When the applied voltage is more than the barrier potential, then the holes on p-side which are positively charged gets repelled from positive terminal and driven towards junction.
- Similarly the electrons on n-side which are negatively charged gets repelled from negative terminal and move towards the junction.
- This result in the reduction of barrier potential, hence resulting large current known as forward current starts flowing as shown in the above figure.

Reverse Biasing PN-Junction:

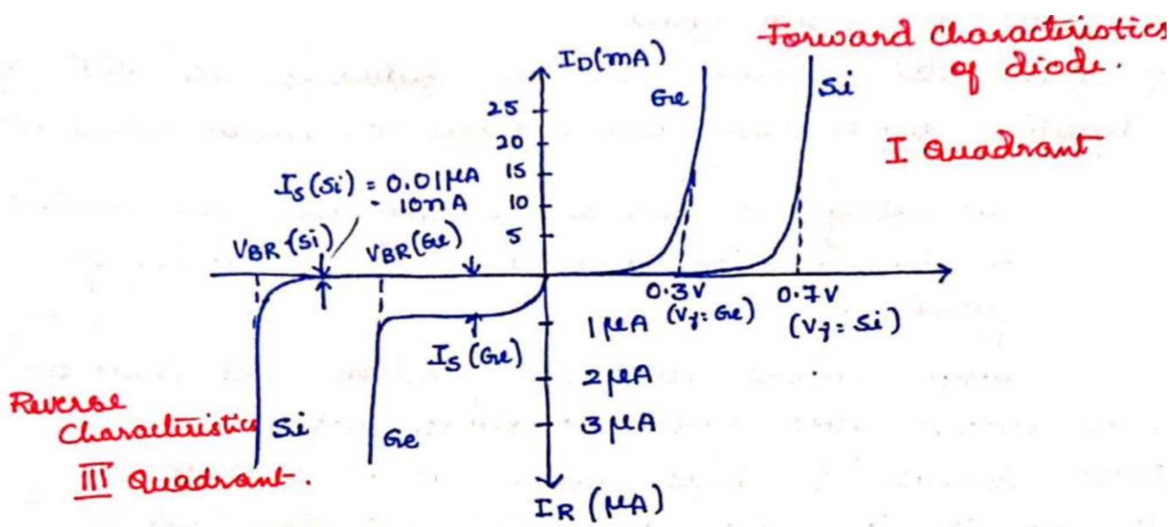
- PN Junction is said to be reverse biased when the positive terminal of battery is connected to n-type and negative terminal of battery is connected to p-type as shown in the following figure.





- When PN junction is reverse biased, then the holes on p-side of junction are attracted towards negative terminal and the electrons on n-side of junction are attracted towards positive terminal of battery.
- Thus holes on p-side and electrons on n-side move away from the junction thereby increase the barrier potential.
- If the barrier voltage is increased, majority charged carriers cannot cross the junction and there is no current flow across the junction.
- Minority charge carriers cross the junction and leads to a small current flow called reverse current as shown in the above figure.

V-I characteristics of diode:



Forward characteristics of diode:

- The positive terminal of battery is connected to p-type and negative terminal of battery is connected to n-type.

- If supply voltage is less than the cut in voltage (0.7V for Si and 0.3V for Ge) of diode, then forward current very low.
- If supply voltage is greater than the cut in voltage, then forward current increases linearly.

Reverse characteristics of diode:

- The positive terminal of battery is connected to n-type and negative terminal of battery is connected to p-type.
- Due to motion of minority carriers, a small reverse saturation current exists.
- At point A, reverse breakdown of diode occurs and current increases sharply.

Diode parameters:

Cut-in voltage/Knee voltage: it is the forward voltage at which the diode starts conducting.

Breakdown voltage (V_{br}): It is the reverse voltage at which the diode breaks down with sudden rise in reverse current.

Peak inverse voltage (PIV): It is the maximum reverse voltage that can be applied to a p-n junction diode without causing any damage to the junction.

Reverse saturation current (I_r): It is the maximum reverse current produced due to the flow of majority carriers across the pn junction at a given temperature.

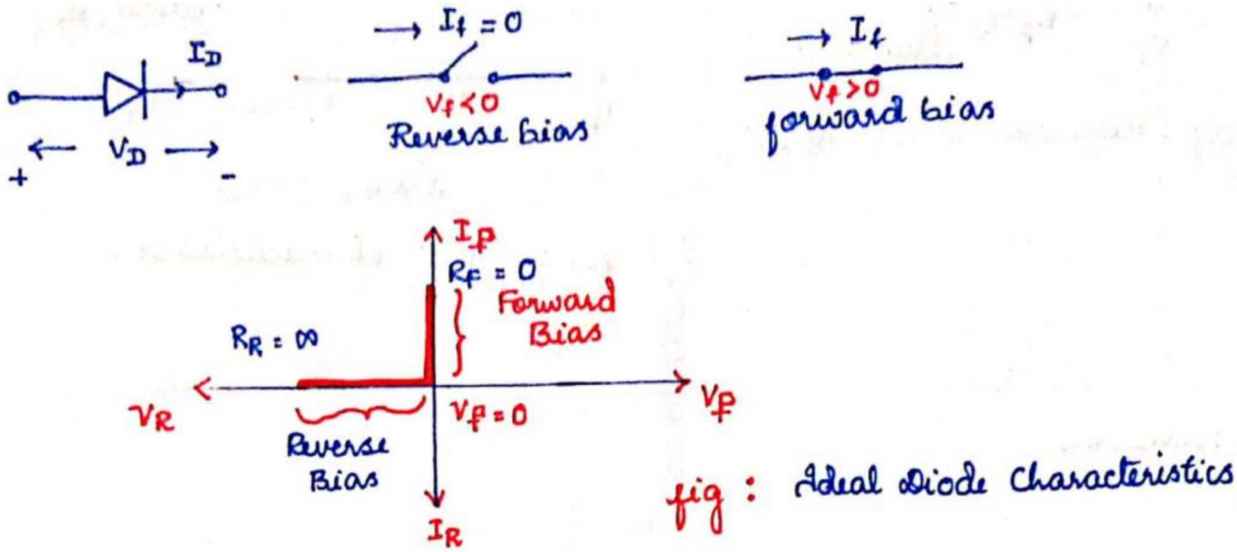
Maximum forward current (I_{fmax}): It is the maximum current a diode can allow under forward biased condition without any damage to it.

Maximum Power rating (**Power dissipation P_d**): It is the maximum power that can be dissipated at the junction without damaging it.

Equivalent circuit of diode (Diode approximation):

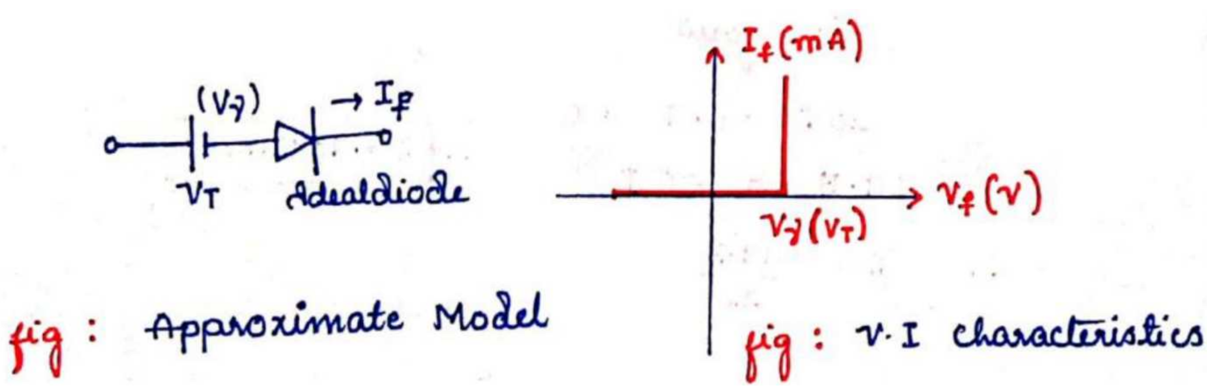
- There are three Equivalent circuit model of diode

1) Ideal diode model:



- An ideal diode offers zero forward resistance and infinite reverse resistance.
- The forward voltage drop is zero and reverse current is also zero.

2) Approximate model/Practical model:



- A practical diode offers zero forward resistance and infinite reverse resistance.
- The forward voltage drop is not zero.

3) Piecewise linear model:

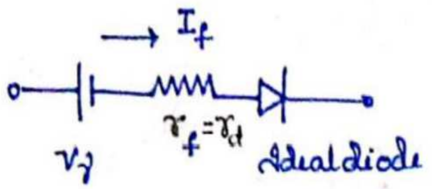


fig : Piecewise Linear Model

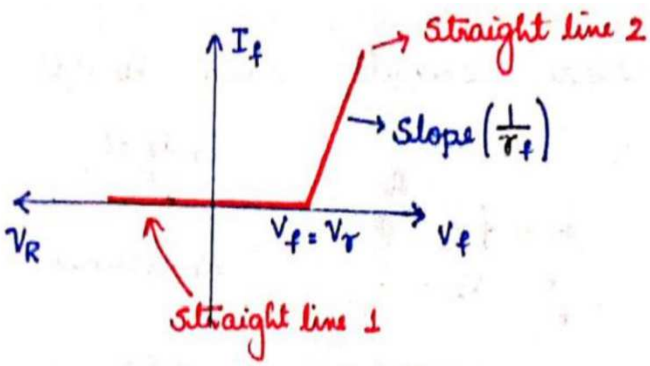


fig : V-I characteristics.

- When the forward characteristics of a diode is straight-line approximation then it is called piecewise linear characteristics.

Rectifier:

- An electrical device used to convert ac voltage into pulsating dc voltage.
- Rectifiers are classified into 2 categories depending on period of condition
    1. Half wave rectifier
    2. Full wave rectifier –which is further classified into
        a) Center tapped full wave rectifier
        b) Bridge rectifier

Half-wave rectifier:

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

Circuit Diagram

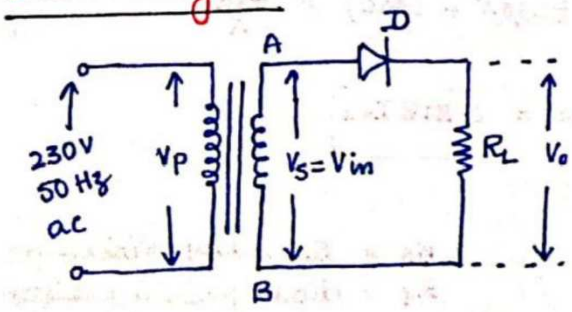


fig : circuit diagram

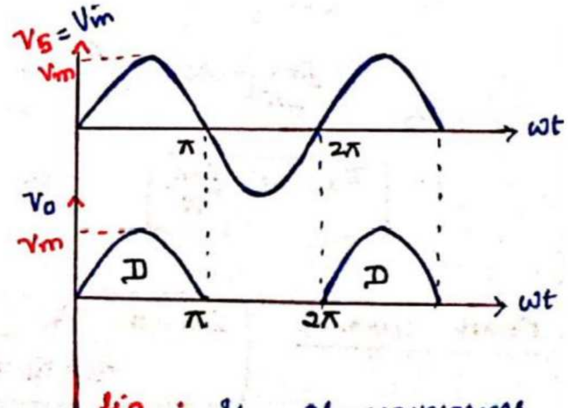


fig : i/p - o/p waveforms

Operation:

- During positive half cycle of supply voltage, diode is said to be forward biased and acts as a short circuit and current flows through R_L. Therefore V_0 = +V_{in}
- During negative half cycle of supply voltage, diode is said to be reverse biased and acts as an open circuit, no current flows through R_L. Therefore V_0 = 0.

Full wave rectifier:

- Full wave rectifier converts both the half cycles of input ac signal to pulsating dc.
- It consists of two diodes as shown in figure.
- Center tapping in the secondary of the transformer is done to obtain two equal voltages but of opposite phase.

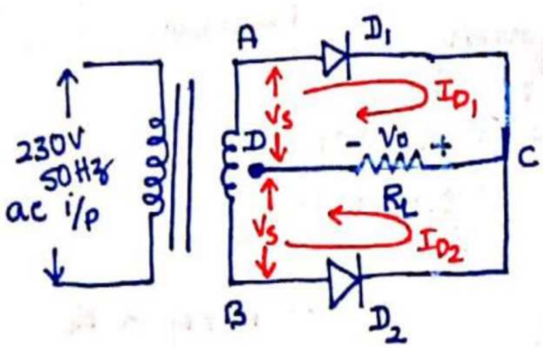


fig: circuit diagram

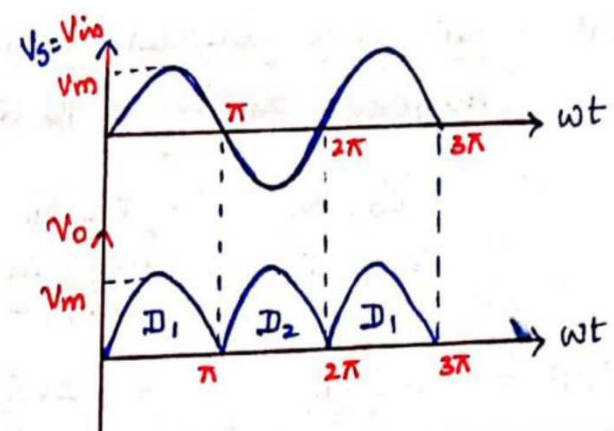


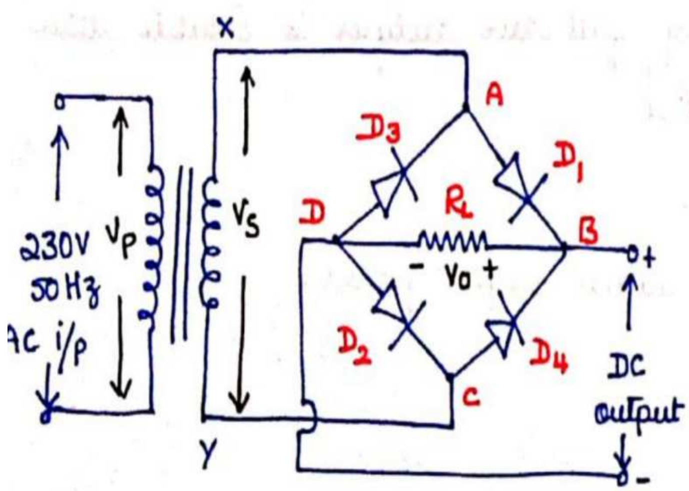
fig : i/p - o/p waveforms

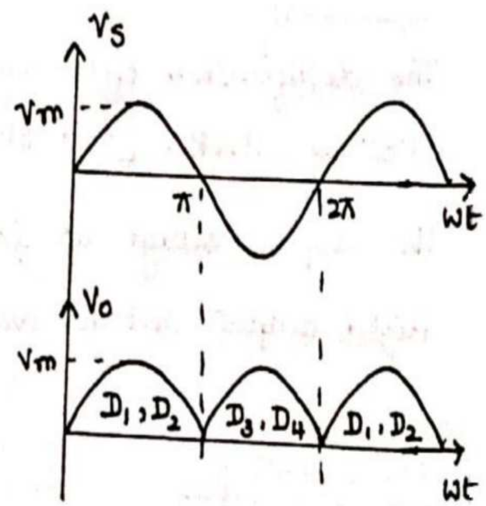
Operation:

- During positive half cycle of supply voltage, terminal A is positive and terminal B is negative due to center tap transformer. Diode D1 will be forward biased and hence conduct, while D_2 will be reverse biased and will not conduct. As D_1 conducts, current flows through the path A-D_1-C- R_L-D. Therefore $V_0 = +V_{in}$.
- During negative half cycle of supply voltage, terminal A is negative and terminal B is positive due to center tap transformer. Diode D_1 will be reverse biased, while D_2 will be forward biased and hence conduct. As D2 conducts, current flows through the path B-D2-C- R_L-D. Thus current keeps on flowing through R_L.

Full wave bridge rectifier:

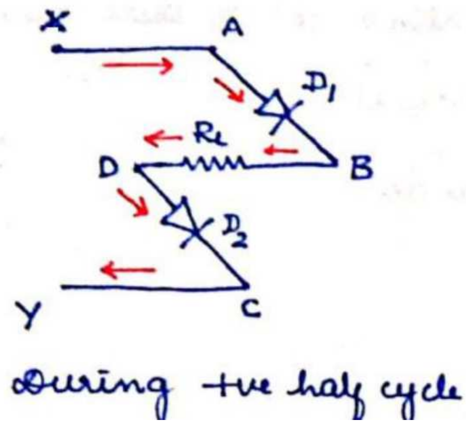
- It is most popular rectifier.
- It requires four identical diodes to form a bridge network. The circuits consists of four diodes D1, D2, D3 and D4 connected across secondary of transformer and load R_L.
- The secondary of transformer is connected to node points A and C and the load resistor(R_L) is connected to other node points B and D.

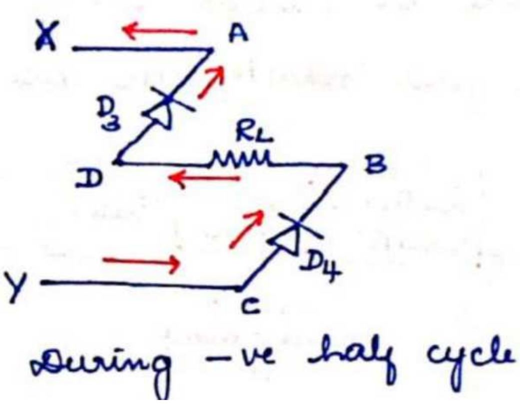




Operation:

- During the positive half cycle, the point X is positive and Y is negative. Diodes D_1,D_2 are forward biased acts like closed switch and D3,D4 are reverse biased and acts like a open switch and current flows through R_L through the path X-A-B-R_L-D-C-Y as shown below.

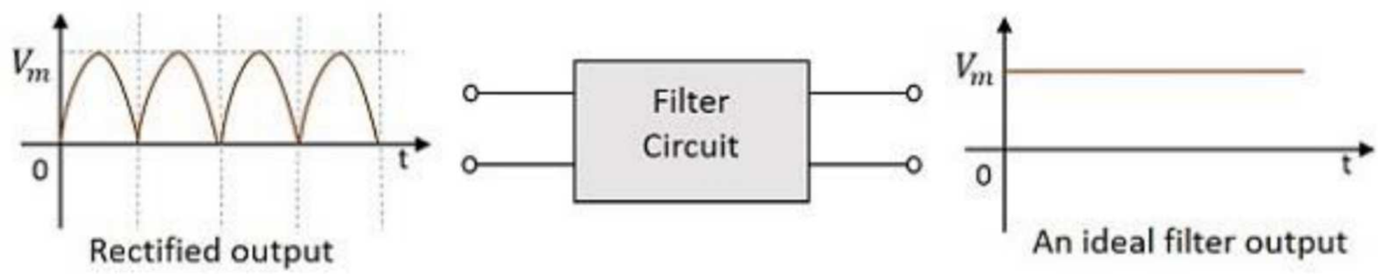




- During the negative half cycle, the point X is negative and Y is positive. Diodes D_1, D_2 are reverse biased and D3,D4 are forward biased and current flows through R_L through the path Y-C-D4-B-R_L-D-D3-A-X as shown above.

Filter circuit:

- A filter circuit blocks the ac component present in the rectified output and allows the dc component to reach the load.
- The following figure shows the functionality of a filter circuit.



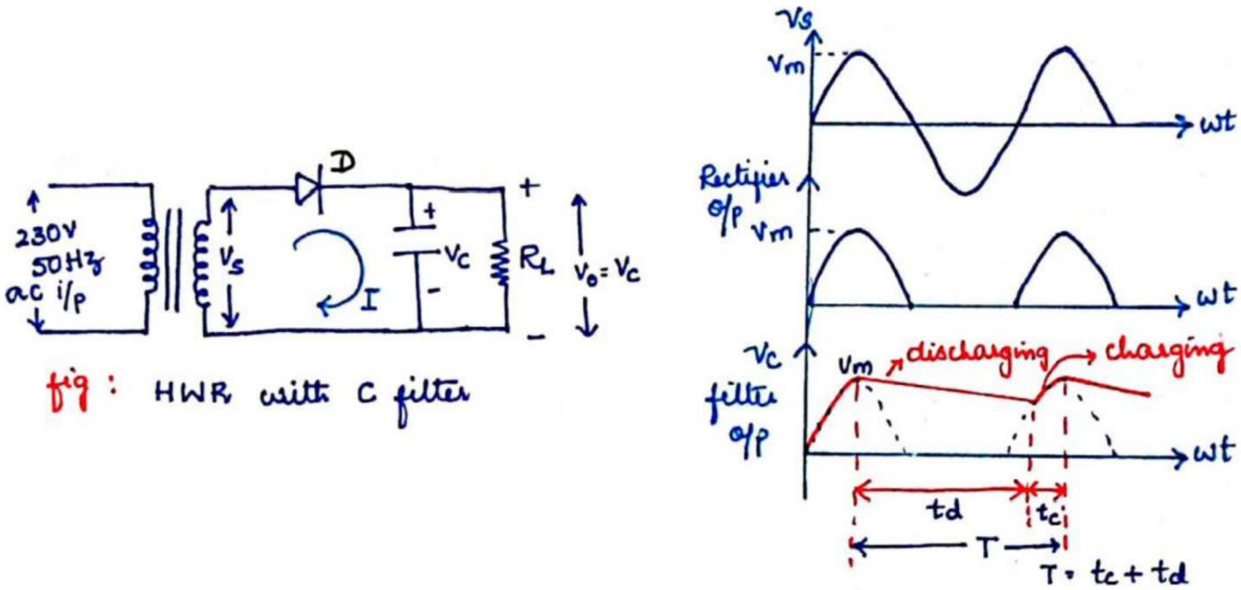
- Filters are the circuits which converts pulsating dc to pure dc.
- Capacitor and inductor are used in filter circuits.
- Filter circuit are connected between rectifier and load.
- Most popular used filters are capacitor and RC filter.

Capacitor Filter circuit:

- In capacitor filter circuit, capacitor is connected parallel with the output of the rectifier in a linear power supply.
- Capacitor increases the dc voltage and decreases the ripple voltage components of the output.

Half wave rectifier with capacitor filter:

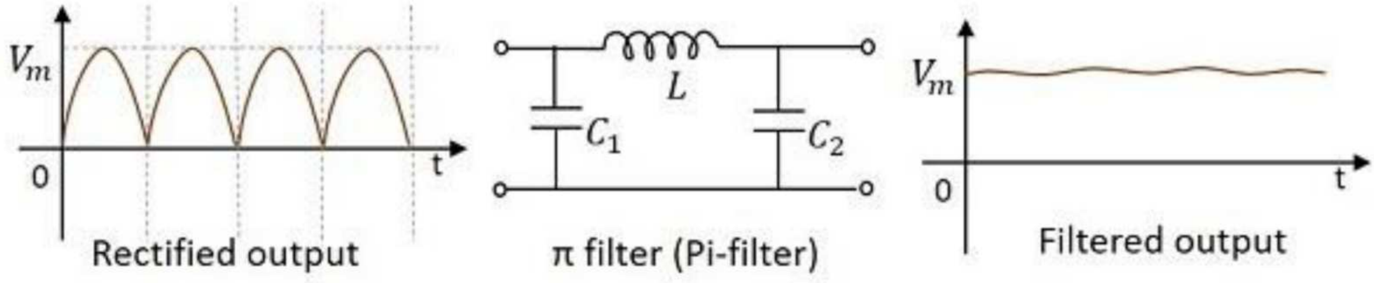
- Half wave rectifier with capacitor filter is as shown in figure.



- During positive half cycle of input, diode is forward biased and capacitor charges to a peak value Vm as shown in the above figure.
- When input starts decreasing below its peak value, capacitor will be fully charged and holds the charge until the input ac supply to the rectifier reaches the negative half cycle.
- During negative half cycle of input, diode gets reverse biased and blocks the current through it. During this non-conduction period, Vs is less than Vc so the capacitor discharges through R_L until V_c is less than V_s. this cycle repeats producing a very smooth dc voltage.
- Time required by the capacitor is very small to charge while its discharging time is very large, ripple in the output gets reduced.

LC Pi-filter:

This is another type of filter circuit which is very commonly used. It has capacitor at its input and hence it is also called as a Capacitor Input Filter. Here, two capacitors and one inductor are connected in the form of π shaped network. A capacitor in parallel, then an inductor in series, followed by another capacitor in parallel makes this circuit. If needed, several identical sections can also be added to this, according to the requirement. The figure below shows a circuit for π filter.



Working of a Pi filter

In this circuit, we have a capacitor in parallel, then an inductor in series, followed by another capacitor in parallel.

- Capacitor C1 − This filter capacitor offers high reactance to dc and low reactance to ac signal. After grounding the ac components present in the signal, the signal passes to the inductor for further filtration.
- Inductor L − This inductor offers low reactance to dc components, while blocking the ac components if any got managed to pass, through the capacitor C1.
- Capacitor C2 − Now the signal is further smoothened using this capacitor so that it allows any ac component present in the signal, which the inductor has failed to block.

Zener diode characteristics:

- Forward characteristics of zener diode is same as that of ordinary diode.
- When the reverse voltage across the zener diode is greater than Vz, the breakdown takes place, then reverse current increases rapidly.
- Under reverse biased condition there is a small leakage current of order of nA flowing through the diode initially but after certain voltage, breakdown occurs and the current increases at a constant voltage.

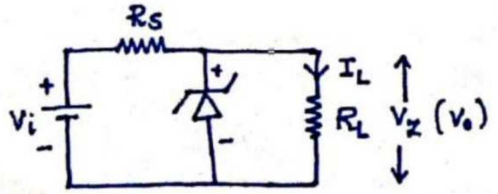


fig : Zener Diode Circuit

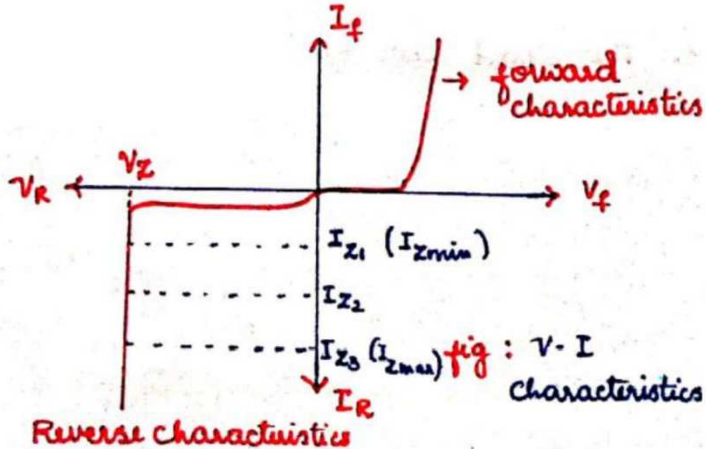


fig : V-I Characteristics

1.3 Voltage regulators

- Voltage regulator is a circuit that maintains a constant d.c output voltage irrespective of variations in the input line voltage or in the load.
- Voltage regulator is one of the important application of a Zener diode.
- A zener diode can be used as a voltage regulator, since it maintains a constant output voltage even though the current through zener changes.

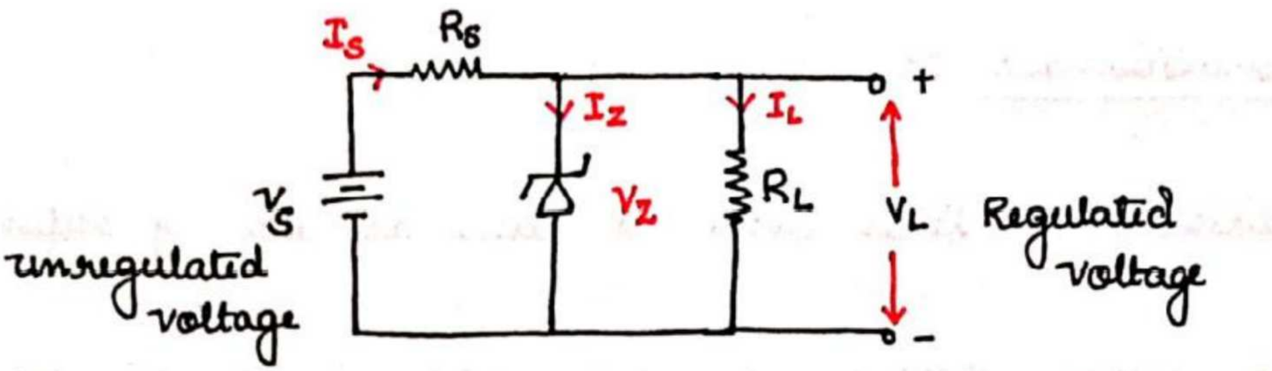
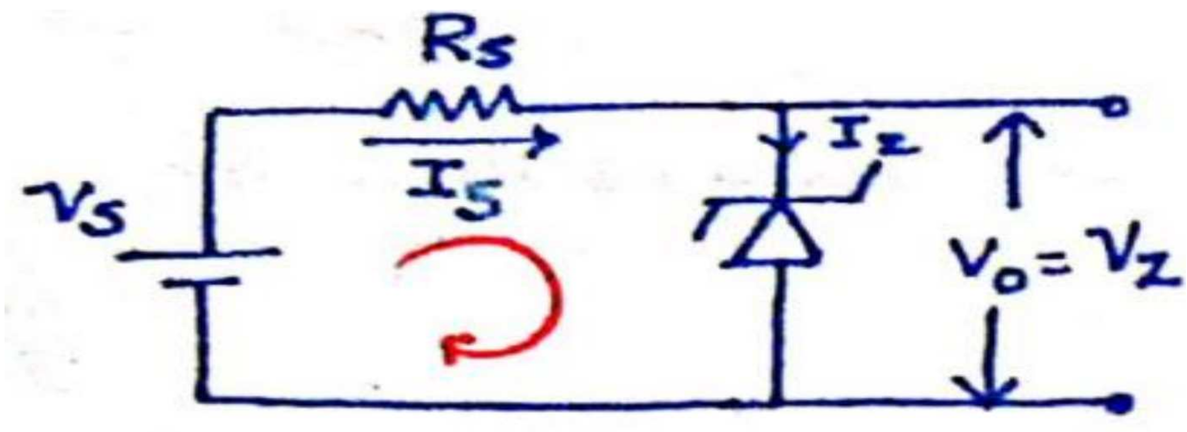


fig : Zener Diode as a Voltage Regulator

- The above figure shows the zener diode as voltage regulator, zener is connected in parallel with the load, therefore the circuit is also known as shunt regulator.
- A resistance R_s is connected in series with zener to limit current in the circuit. Through R_s is also known as series current limiting resistor.

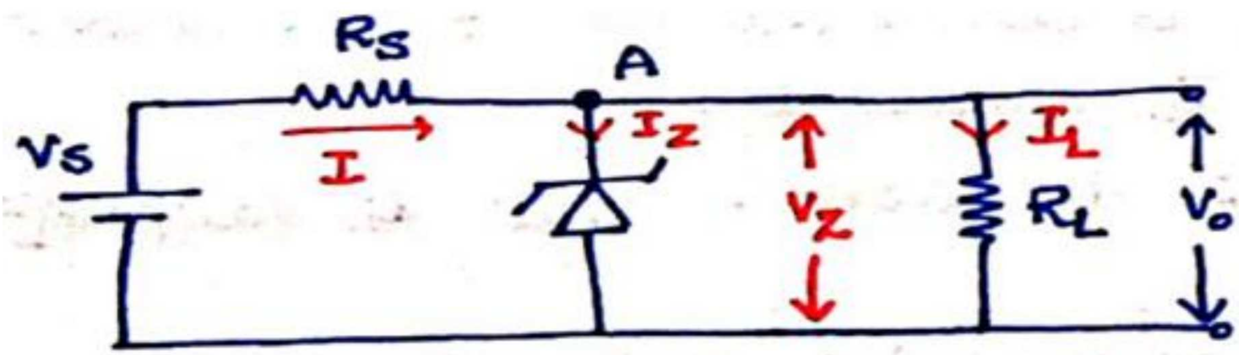
Regulator with no load:

- The resistor R_s is used to limit the zener diode current to desired value.



Regulator with load:

- Consider the circuit as shown in fig, the current through Rs is sum of load current and zener current, but care must be taken to ensure that Iz(min) is greater to keep zener under breakdown region.



- Zener to work as voltage regulator, the following conditions must be satisfied.
  (a) Zener diode must be reverse biased.
  (b) Input voltage must be greater than zener breakdown voltage.
- The load current should be less than Iz(max).
- R_S is included to limit the zener current to a safe value when the load is disconnected.
- When a load (R_L) is connected, the zener current (I_Z) will fall as current is diverted into the load resistance (it is usual to allow a minimum current of 2 mA to 5 mA in order to ensure that the diode regulates).
- The output voltage (V_Z) will remain at the Zener voltage until regulation fails at the point at which the potential divider formed by R_S and R_L produces a lower output voltage that is less than V_Z.

- The ratio of R_S to R_L is thus important.
- Regulated output V_Z is given by:

$$V_Z = V_{IN}\ X\ \frac{R_L}{R_L + R_S}$$

where VIN is the unregulated input voltage.

- Thus the maximum value for R_S can be calculated from:

$$R_{S(max)} = R_L \times \left[\frac{V_{IN}}{V_Z} - 1\right]$$

- The power dissipated in the zener diode will be given by PZ = IZ × VZ, hence the minimum value for RS can be determined from the off-load condition when:

$$R_{S(min)} = \frac{V_{IN} - V_Z}{I_Z} = \frac{V_{IN} - V_Z}{\left(\frac{P_{Z\,max}}{V_Z}\right)} = \frac{(V_{IN} - V_Z) \times V_Z}{P_{Z\,max}}$$

where P_Z max. is the maximum rated power dissipation for the zener diode.

Problems:

Example: A 5 V zener diode has a maximum rated power dissipation of 500 mW. If the diode is to be used in a simple regulator circuit to supply a regulated 5 V to a load having a resistance of 400 Ω, determine a suitable value of series resistor for operation in conjunction with a supply of 9 V.

<u>Given</u>

$V_Z = 5V$

$V_{IN} = 9V$

$R_L = 400\Omega$

$P_{Z\,max} = 500mW = 0.5W$

$$R_{S\,max} = R_L \times \left(\frac{V_{IN}}{V_Z} - 1\right)$$

$$= 400 \times \left(\frac{9}{5} - 1\right)$$

$$\boxed{R_{S\,max} = 320\,\Omega}$$

$$R_{S\,min} = \frac{V_{IN} V_Z - V_Z^2}{P_{Z\,max}}$$

$$= \frac{(9 \times 5) - 5^2}{0.5}$$

$$\boxed{R_{S\,min} = 40\,\Omega}$$

Hence suitable value for R_S would be 150Ω (roughly midway between two extreams)

1) Determine the peak output voltage and current for a bridge rectifier circuit when the secondary RMS voltage is 30V and the diode forward drop is 0.7V.

2) A diode with V_F=0.7V is connected as a half wave rectifier. The load resistance is 500Ω and the secondary RMS voltage is 22V. Determine the peak output voltage and the peak load current.