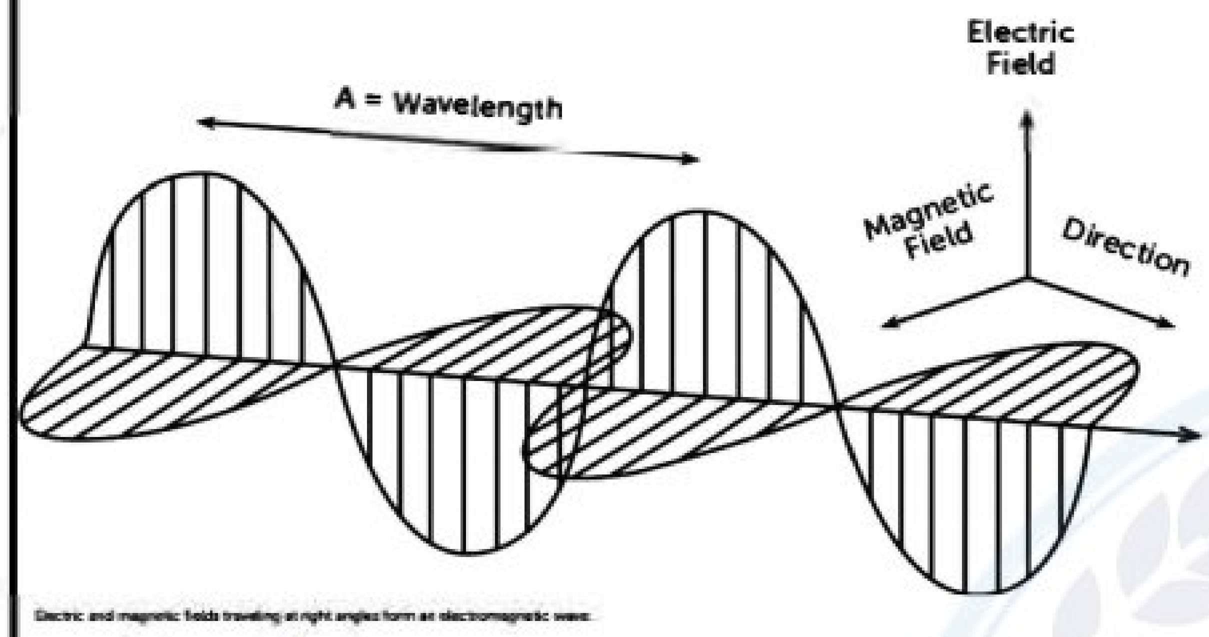
Chapter = 16

"Electromagnetic Waves and Electronics"

Electromagnetic Waves:

The moving electric field (arises from charge) and magnetic fields (arise from charge motion) combined together known as electromagnetic waves. OR

If an electric field and magnetic field is changing through any space or region, the two fields will propagate out of this region in the surrounding space. Such oscillating electric and magnetic field are known as electromagnetic waves.

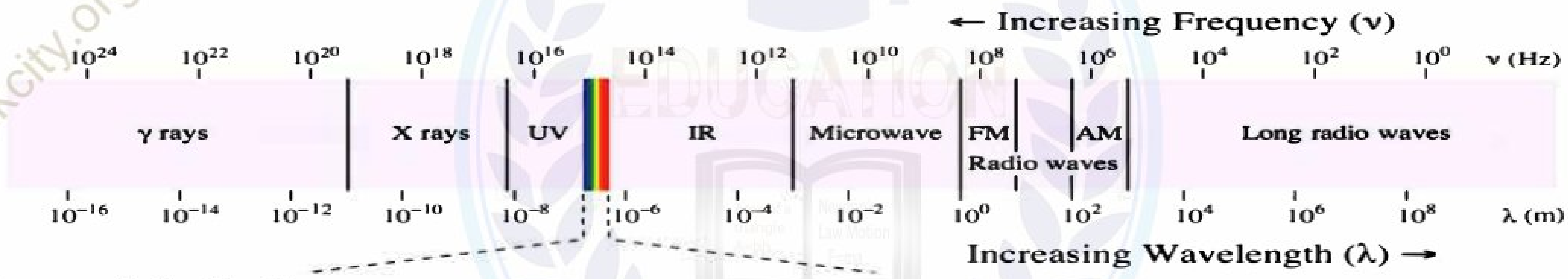


Properties:

In EM wave's electric field, magnetic field and direction of propagation are mutually perpendicular to each other.

Electromagnetic waves do not required medium to propagate. EM waves can pass through the vacuumed.

EM waves are transverse waves in which the particle motion is perpendicular to the direction of propagation.



Uses and Applications:

1. EM waves are used in communication and navigation.
2. Ariel, receiver sets detects the radio waves of EM Spectrum for several purposes.
3. Microwave oven, photocell, light sensing diodes uses the EM waves.
4. Electromagnetic waves are also used in crystallography, radiography.
5. A famous experiment photoelectric effect also uses the EM waves.
6. Treatment of cancer, detecting the flaws in metals, radiation detectors (e.g. Geiger counter).

Electromagnetic Spectrum:

Spectrum formed by electromagnetic radiation is known as electromagnetic spectrum.

Waves in Electromagnetic spectrum

1. Radio waves (large range of wavelength)
2. Microwaves (wavelengths from 1mm to 300 mm)
3. Infrared waves (mean value is 10 micrometer and are also called heat waves)

4. Visible waves (wavelength from 400 nm to 700 nm and are visible to normal human eye)
5. Ultraviolet waves (60 nm to 300 nm having very high frequencies and very short wavelengths)
6. Gamma rays (very short wavelengths even less than 10^{-11} m and very high frequencies)
7. The speed of Electromagnetic waves is give by

$$\boxed{c = \frac{1}{\sqrt{\epsilon_o \mu_o}}}$$

$$c = 2.998 \times 10^8 ms^{-1} = 3 \times 10^8 ms^{-1}$$

Information Carried By Electromagnetic Waves:

In the field of telecommunication it is common practice to send information by wireless mean to do it electromagnetic waves are used.

Modulation:

The superimposing of a low energy EM signal on a high frequency signal so that information can be transmitted is called Modulation.

Modulating Signal:

The low frequency signal that contain message to be transmitted is called modulating signal.

Carrier Signal:

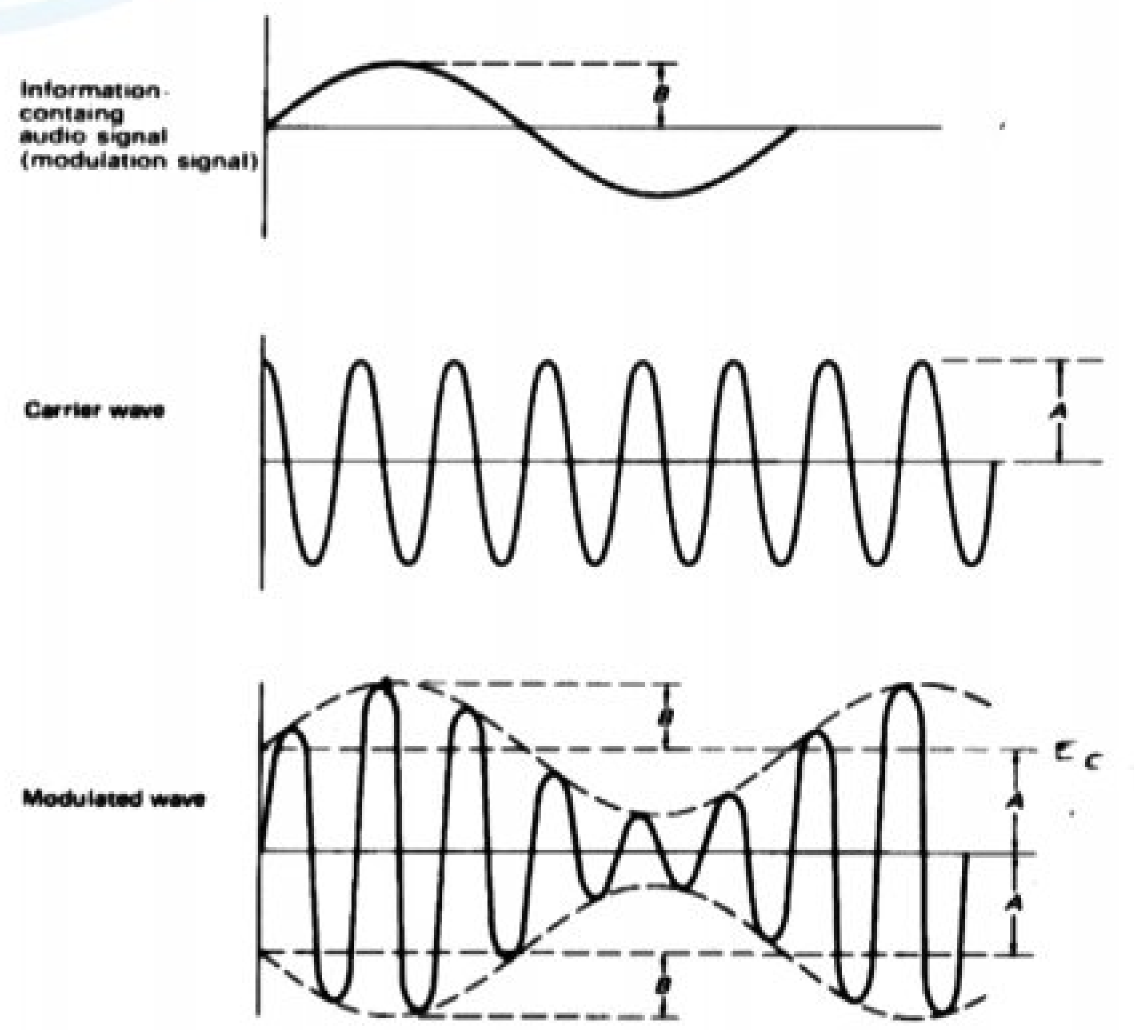
The high frequency signal on which modulating signal is super imposed is called carrier signal.

Modulated signal:

The signal obtain after the modulation is called modulated signal.

Types of Modulation:

AMPLITUDE MODULATION



There are following two (basic) types of (analog) modulation:

1) Amplitude Modulation.
2) Frequency Modulation.

Amplitude Modulation:

A type of modulation, in which amplitude of a carrier wave is modulated by an impose signal, usually at audio frequency. The variation in the amplitude of the carrier signal is proportional to the variation of the modulating signal while the frequency of the carrier remains constant.

Percentage Modulation:

In amplitude modulation it is common to calculate percentage of modulation (M).

Mathematically percentage modulation (A.M) can be expressed as

$$M = \frac{Amplitude\ of\ modulating\ signal\ (volts)}{Amplitude\ of\ carrier\ signal\ (volts)} \times 100$$

$$M = m_a \times 100$$

Here, m_a is called Modulation index and it may be defined as

"It is the ratio peak amplitude of modulating signal to the peak amplitude of carrier signal."

For modulation for error free purposes m_a should be less than or equal to 1.

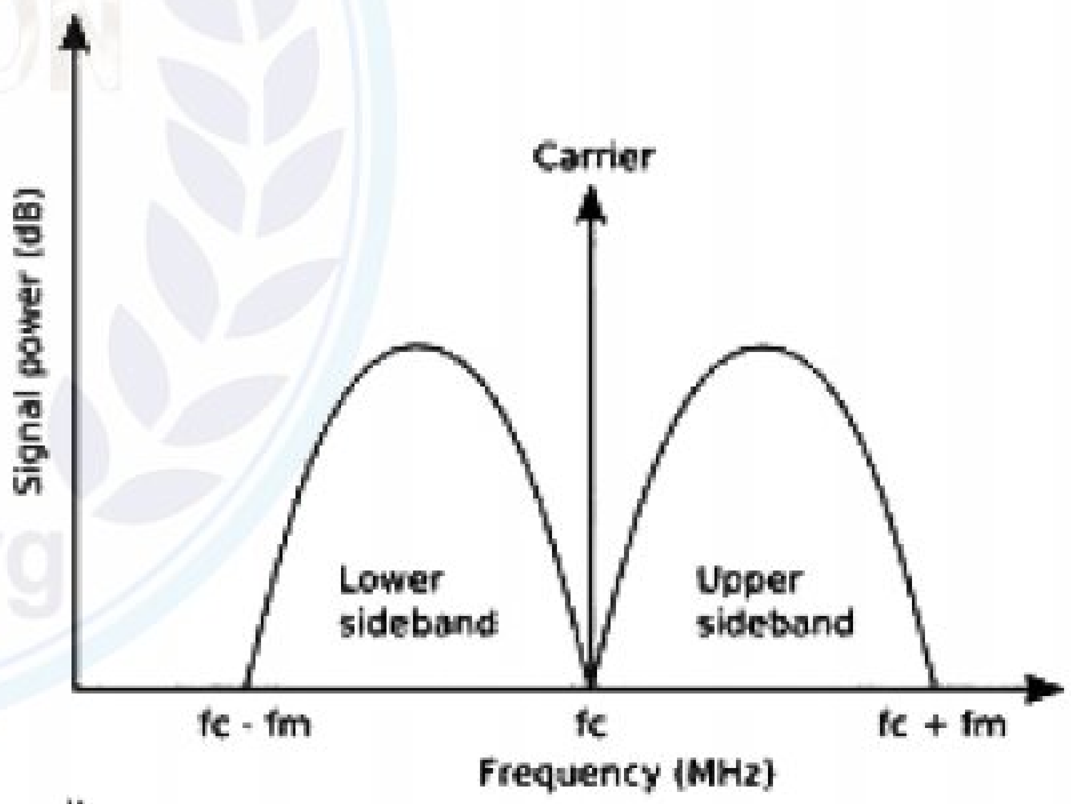
Application:

Amplitude modulation is used in variety of telecommunication application such as

1. Transmitting video signals in television transmission.
2. Armature AM radio.
3. Walky Talkies.

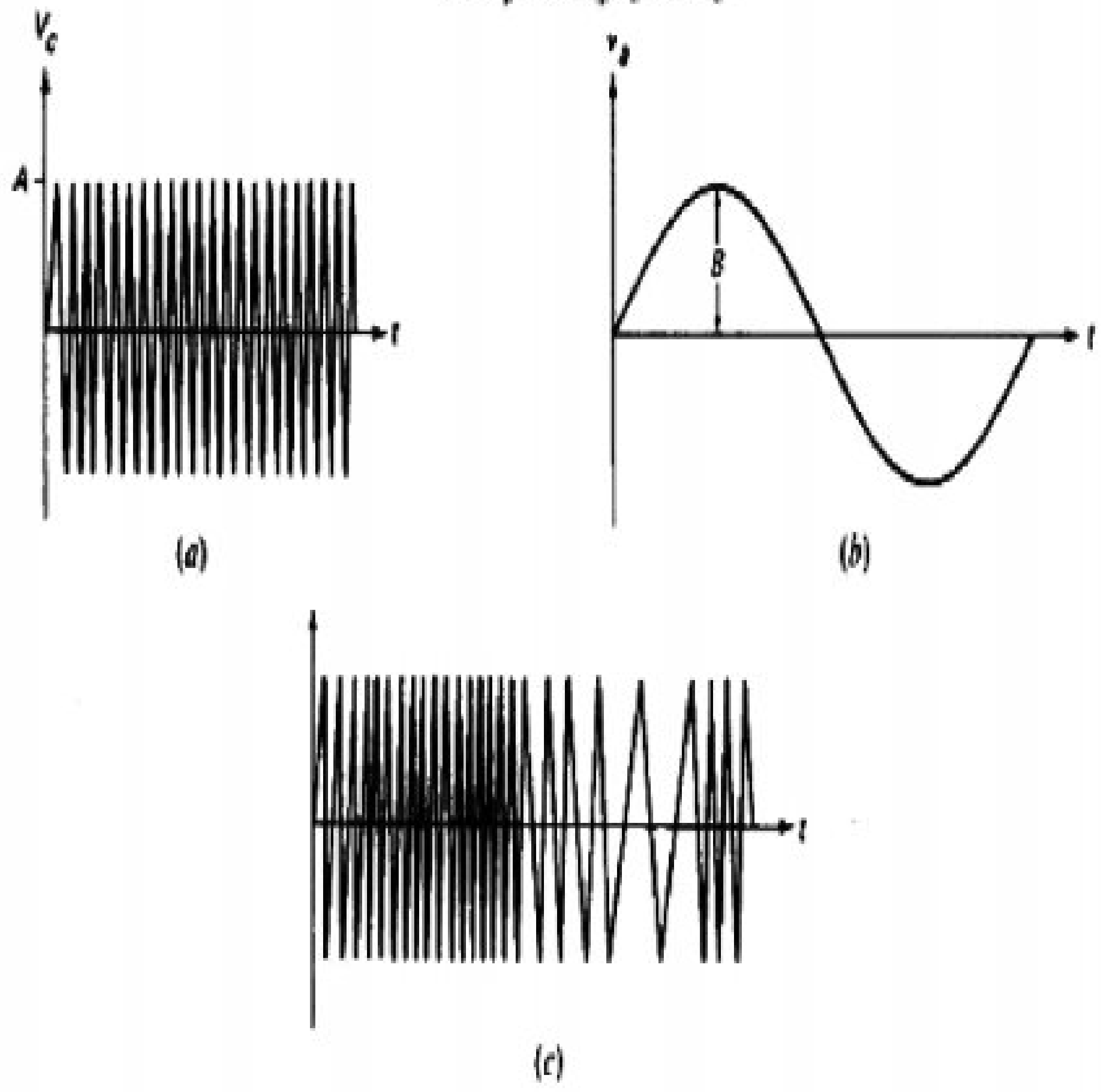
Sidebands:

In radio communications sidebands is a band of frequencies higher than or lower than the carrier frequency, containing power as a result of the modulation process.



Amplitude modulation of a carrier wave normally results in two mirror-image sidebands. The signal components above the carrier frequency constitute the upper sideband (USB), and those below the carrier frequency constitute the lower sideband (LSB). In conventional A.M transmission

Frequency Modulation:



A type of modulation in which in which a carrier wave is made to carry the information in a signal (audio or visual) by fluctuation in the frequency of the carrier wave. The variation in the frequency of the carrier signal is proportional to the frequency of the modulating signal while the amplitude of the carrier remains constant.

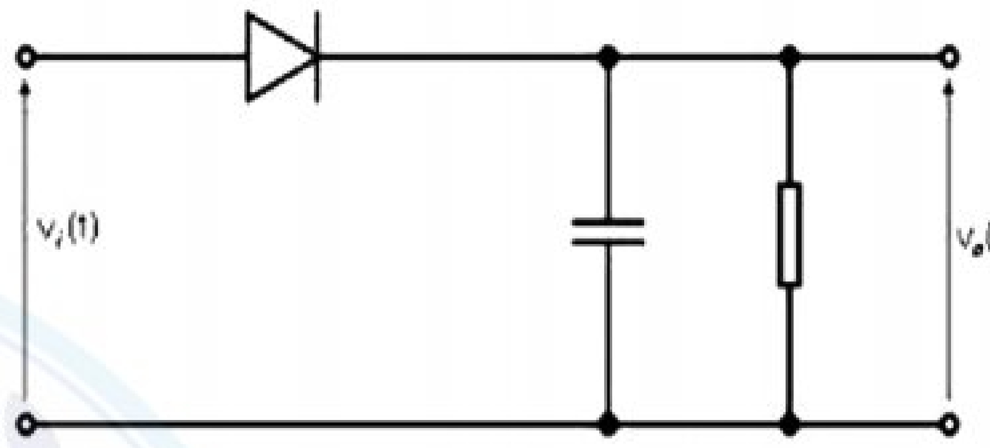
Application:

Frequency modulation is used in variety of telecommunication application such as

- Transmitting Audio signals in television transmission.
- Commercial FM radio.
- Cellular communication.

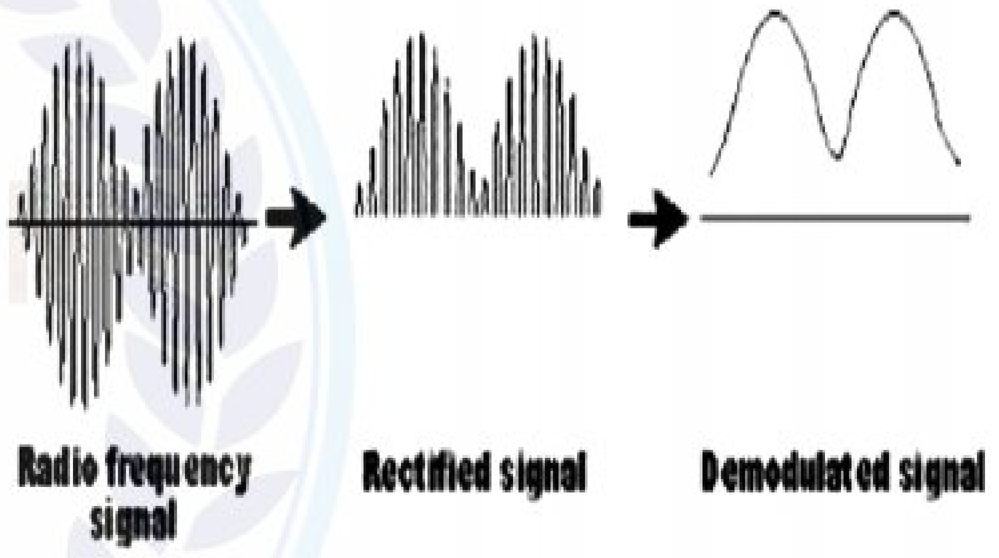
Reception of Electromagnetic signals:

Electromagnetic waves carrying the modulated carrier signal are received at the receiving end with help of an antenna and then Demodulated to obtain the message signal.



Demodulation:

Signal processing process use to extract out the message from the modulated carrier signal is called demodulation.



Demodulator:

The circuit used to demodulate the Modulated carrier signal is called Demodulator.

Construction:

A simple Demodulator circuit for A. M waves is shown in figure. It consists of a Rectifier diode, capacitor with High capacitance and a high value resistance.

Working:

Working of the demodulator circuit is as follows:

1. Amplitude modulated electromagnetic wave is received at antenna.
2. the voltage signal induced into the antenna by EM radiation is fed to the rectifier diode
3. The diode acts as a non linear device and produces a totally positive signal at its output.
4. This varying positive voltage is fed to a capacitor which acts as a low pass filter and joins peak voltage of each cycle with peak of next cycle and hence produced message signal containing information.

Solid State Physics:

Solid state physics is the branch of physics that deals with the structure and properties of solids.

Two types of solids are 1. Crystalline & 2. Amorphous

Crystalline:

Crystalline state of solids is characterized by regular or periodic arrangement of atoms or molecules. Most of the solids are crystalline in nature. E.g. diamond, sodium chloride

Non Crystalline (Amorphous):

Non crystalline state of solids is characterized by disordered arrangement of atoms or molecules. E.g. is glass, carbon

Properties of Crystal:

1. A crystal has sharp melting point.
2. It is incompressible.
3. It has definite shape.
4. It has characteristic latent heat of fusion.
5. It consists of identical blocks. These identical blocks are the smallest volume of the crystal and called unit cell.

Valance Band:

The outer most shell of the electrons in every element is called valance band. Electrons in valance band are not free to the applied electric field. Electrons in the valance band are bounded to the atom.

Conducting Band:

Next to the valance band is the conduction band. Electrons in this band are free to the applied electric field.

Forbidden Band:

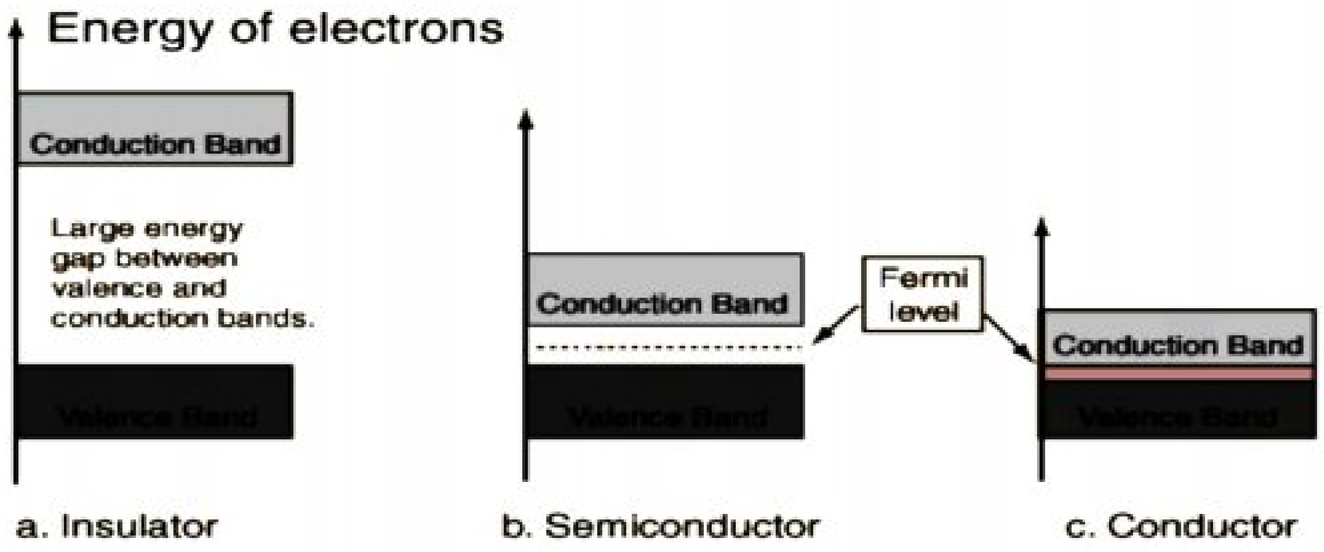
The band which is lies between the conduction band and valance band is called forbidden band. Electrons cannot lies in this band it is forbidden.

As far as concerning the band theory the substances are dividing into three categories.

1. Conductors
2. Semi-Conductors
3. Insulators

Conductors:

There is no forbidden band in the conductors and the valance band and the conduction band are overlap. Electrons from the valance band can easily jumps to the valance band when it is subjected to the electric field.



The resistance of conductors increases with the increase in temperature. E.g. are copper, gold

Semi-Conductors:

The forbidden band of very small width exists between the valance band and conduction band of semi-conductors. E.g. are silicon and germanium.

The resistance of semi-conductors decreases with the increase in temperature.

Insulators:

A very wide energy gap exists between the valance band and conduction band of the insulator. Electrons in the valance band cannot jumps to the conduction band when electric field is applied to the insulator. E.g. is wood, rubber, plastic. The resistance remains same with the increase in temperature.

Intrinsic Semiconductors:

1. The pure semiconductors are called "intrinsic semi-conductors".
2. These intrinsic semi-conductors located in the group 4 of the periodic table. E.g. are silicon and germanium.
3. They have 4 valance electrons.
4. The number of charge carriers is determined by the properties of the material itself.

Extrinsic Semi-Conductors:

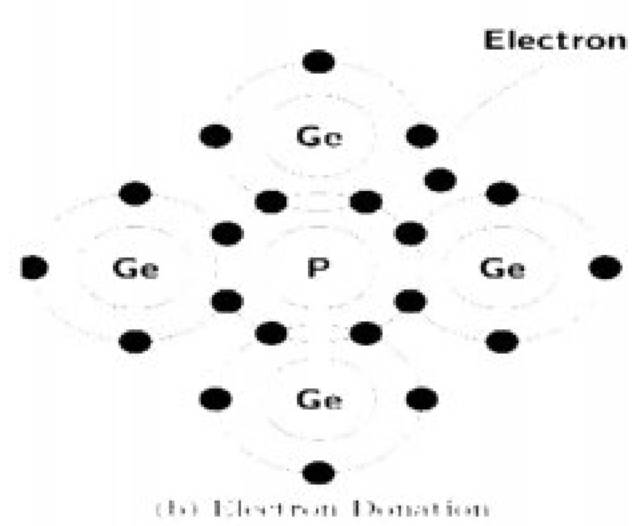
1. Doped semiconductors or impure semiconductors are called "extrinsic semi-conductors".
2. Extrinsic semiconductor formed when a small amount of impurity from group 3 or group 5 of the periodic table is added to the silicon or germanium (intrinsic semiconductors).
3. There are two types of extrinsic semiconductors. N-type & P-type
4. The number of charge carriers is determined by the doping level.

Doping:

The process of addition of impurity to a pure semiconductor is called doping.

N-type Semiconductor:

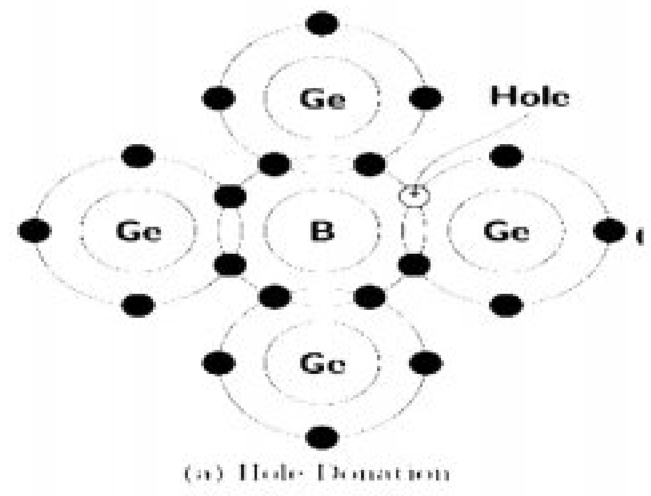
1. When extremely small amount of pentavalent substance (e.g. arsenic (As) or phosphors (P) located in group 5 of the periodic table) are added to the germanium or silicon crystal (group 4 element), "n-type semiconductor" is formed.
2. The process of doping in this case is called donor doping.
3. Donor doping donate electrons. As excess electrons are achieved in each covalent bonding.
4. Majority charge carriers are electrons while minority charge carriers are holes.



5. Negative charge carriers are available in N-type semiconductor.

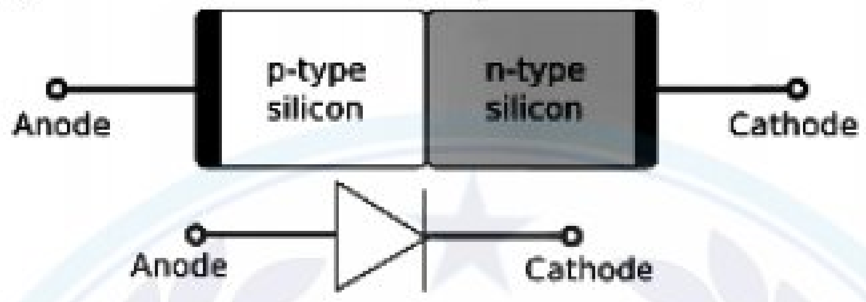
P-type Semiconductor:

1. When extremely small amount of trivalent substance (e.g. boron (B) or aluminum (Al) located in the group 3 of the periodic table) are added to the germanium or silicon crystal (group 4 elements), "p-type semiconductor" is formed.
2. The process of doping in this case is called accepter doping.
3. Accepter doping accept electrons. As excess hole are created in each covalent bonding.
4. Majority charge carriers are holes while minority charge carriers are electrons.
5. Positive charge carriers are available in P-type semiconductor.



PN-Junction Diode

When both p-type semiconductor and n-type semiconductors joined together then PN-junction is formed.



It is also called junction diode, PN-junction diode or simply diode. OR

If a crystal of germanium or silicon is doped in such a way that half is doped with a trivalent impurity and the other half is doped with a pentavalent impurity, then a PN-junction is formed.

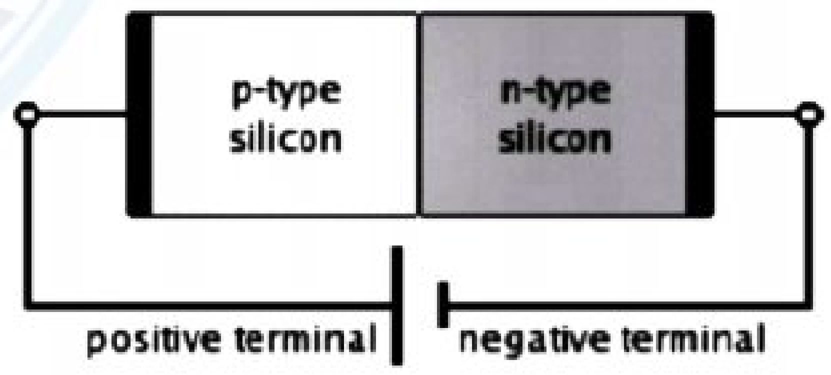
The PN –junction is extremely thin of the order of micrometer.

Biasing

The application of electric potential across a semiconductor diode is called biasing.

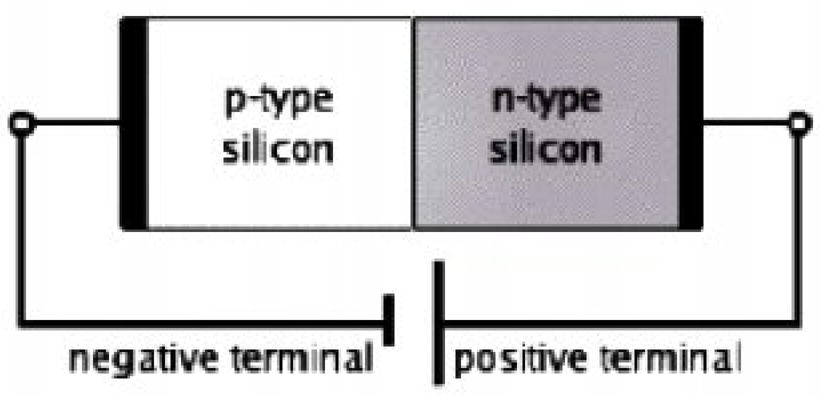
Forward Biasing:

1. In forward biasing positive terminal of a battery is attached with the p type layer of PN-junction and negative terminal of a battery is attached with the n type layer of PN-junction.
2. The applied forward potential establishes an electric field which reduces the height of the potential barrier at the junction.
3. The junction resistance is very low becomes almost zero.
4. Considerable amount of current flows due to the majority charge carriers.
5. Forward Biasing permits the flow of current through PN-junction diode.



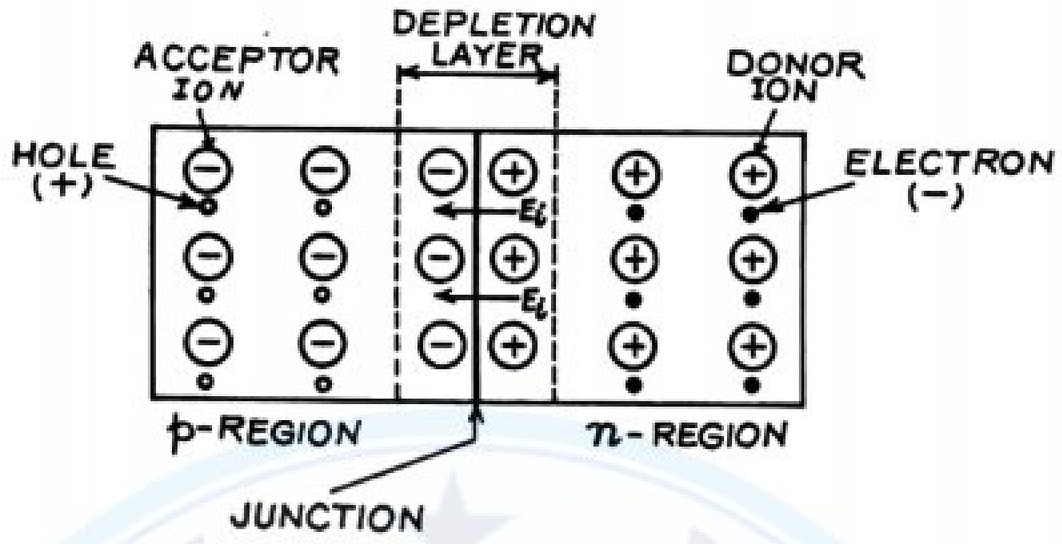
Reverse Biasing:

1. In Reverse biasing negative terminal of a battery is attached with the p type layer of PN-junction and positive terminal of a battery is attached with the n type layer of PN-junction.
2. The applied reverse potential establishes an electric barrier which increases the height of the potential barrier at the junction.
3. The junction resistance becomes very high.
4. A very small amount of current flows due to the minority charge carriers.
5. Reverse Biasing does not permit the flow of current.



Formation of the Potential barrier in PN-Junction:

In PN-Junction diode holes are majority charge carriers in p-side of the junction and electrons are majority charge carriers in the n-side of the junction. When diffusion of these electrons and holes take place across the junction the positive charge (due to the positive ions) developed at the n-side of the junction and negative charge (due to the negative ions) developed at the p-side of the junction. These newly formed positive and negative ions give an electric field which prevents the majority charge carriers flow across the junction is called "depletion region". Potential difference due to this electric field is setup at the junction which is called "potential barrier" or "junction barrier". This junction barrier is small in forward biasing and large in reverse biasing.



Rectifier:

The device which is used to convert alternating current into direct current is known as rectifier. In most application of the electronics diode is uses as a rectifier so called diode rectifier.

Types of Rectifier:

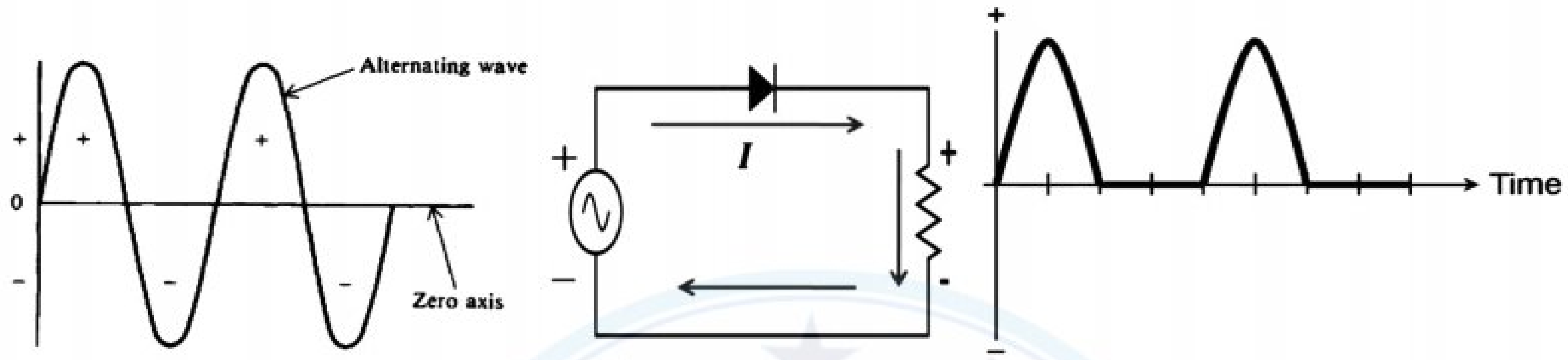
1. Half wave rectifier 2. Full wave rectifier

Half wave rectification:

Such type of rectification in which unidirectional current flows in the output load resistance only for the positive half cycle of the input AC voltage is called half wave rectification.

Construction:

It consists of semiconductor diode (PN-Junction) D and resistance R which is connected in series. The output is taken across the load resistance R. In this circuit DC current is obtained only for the positive half cycle of the input AC current that's why it is called half wave rectifier.



Working:

During the positive half cycle of the input AC voltage the anode (p-side) of the diode is positive with respect to the cathode (n-side) of the diode so the diode becomes forward bias and permits the flow of current and positive pulse is obtained across the output resistance R. During the negative half cycle of the input AC cycle the anode (p-side) of the diode is negative with respect to the cathode (n-side) of the diode so the diode becomes reverse bias and does not permits the flow of current and so that zero volt is appear across the load resistance R. Unidirectional output current is obtained for every positive half cycle of the input AC voltage.

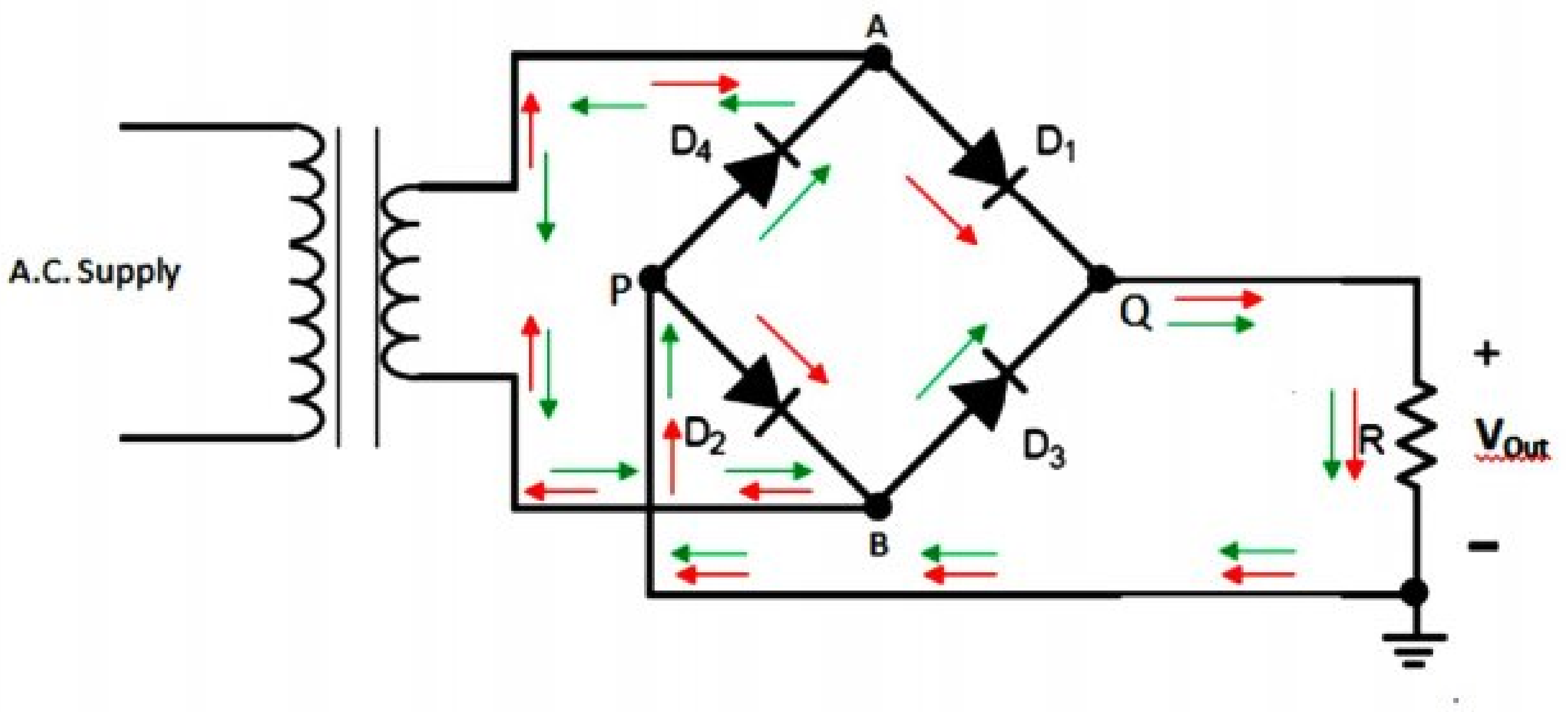
Full wave rectification:

Such type of rectification in which output current flows in the same direction for the positive and negative half cycle of the input AC voltage is called full wave rectification.

Construction:

It consists of 4 semiconductor diodes and load resistance R. Semiconductor diodes are connected in bridge type arrangement. The output is taken across the load resistance R.

In this circuit unidirectional DC current is obtained for both positive half and negative half cycle of the input AC voltage that's why it is called full wave rectifier.



Working

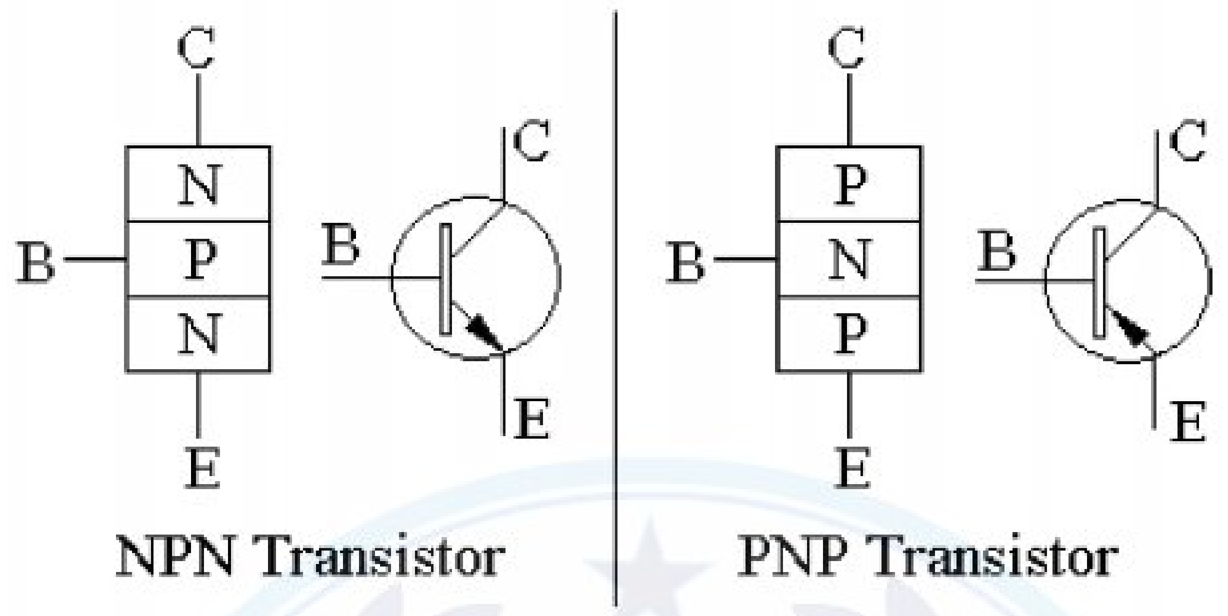
During the positive half cycle the terminal A of the bridge is positive with respect to the terminal B. The diodes D_1 and D_2 become forward biased and the current flows through the circuit and positive pulse appear on the load resistance. During the negative half cycle the terminal A of the bridge is negative with respect to the terminal B. The diodes D_3 and D_4 become forward biased and the current flows through the circuit and positive pulse appear on the output load resistance. Thus unidirectional pulsating DC output current is obtained for both positive and negative half of the input AC cycle.

Transistor

A transistor consists of two junctions. One junction acts as forward biased, so it transfer the charge while the second junction is reverse biased so it resists the flow of charge. OR

A transistor is a semiconductor which consists of a thin central layer of one type of semiconductor material sandwiched between two relatively thick pieces of the other types.

Transistor has three regions emitter, base and collector. Transistor is a semiconductor device which can amplify both current and voltage.



Emitter:

The emitter has greater concentration of impurity. It acts like a source of charges in the transistor. It is smaller than collector in size.

Base:

The central region is known as base. Generally the base is very thin of the order of 10^{-6} m as compared to emitter and collector.

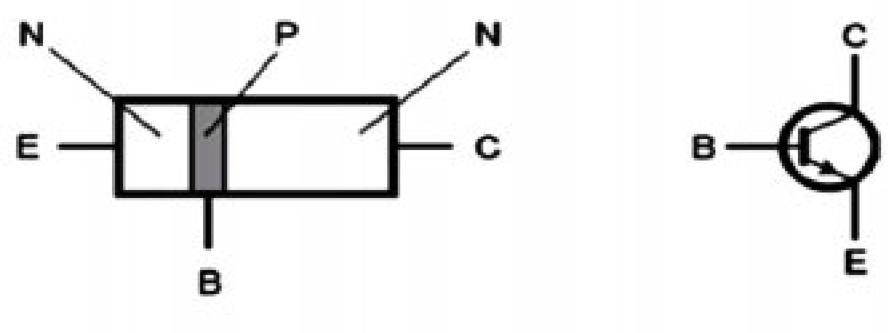
Collector:

The region to the right of the base is called collector. The collector has less concentration of impurity as compared to emitter. The collector is larger in size than emitter.

$$I_E = I_C + I_B$$

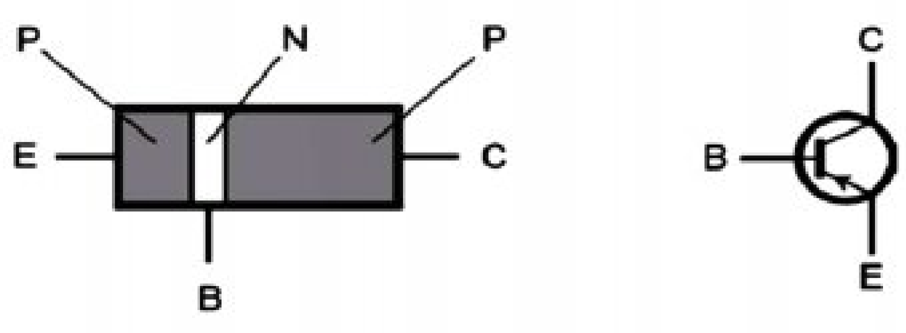
NPN Transistor:

In n-p-n transistor p-type material is sandwiched between two n-type materials. It is known as n-p-n transistor.



PNP Transistor:

In p-n-p transistor n-type material is sandwiched between two p-type materials. It is known as p-n-p transistor.



Advantages:

1. Transistors operate on low voltages so they do not require huge voltages.
2. They are exceedingly small and light.
3. They produce little heat.

Uses of Transistors:

1. Transistor can be used as an amplifier to amplify the input signal.
2. Transitory can be used as a switching device for ON/OFF.
3. Transistors are now widely using in radio, telecommunications, computers, television, telephones and cell phones for different purposes.

Limitations:

1. Power heating capability is limited to few watts.
2. Frequency response is limited.

AMPLIFIER:

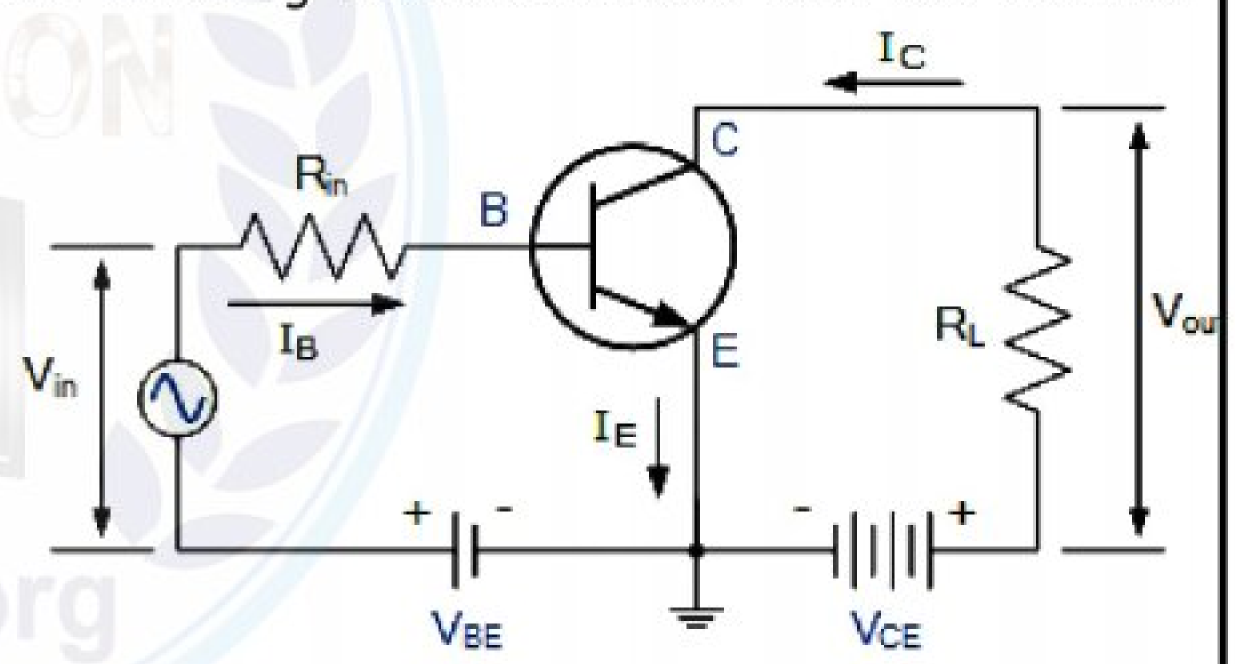
Amplifier is a circuit or device that can raises the strength of a weak signal. The factor by which an amplifier increases the strength of a weak signal is called gain of an amplifier.

Transistor as an Amplifier:

A transistor can be used to amplify a weak signal. The transistor has following relation between base and collector current.

$$I_C = \alpha I_B$$

Where α is called the gain of the transistor.



Now if we apply a small voltage across the base emitter junction, this voltage allows a small base current to flow inside the base region resulting in large collector current to flow in collector. Now, if we connect a large resistance R_C at collector. Collector current will cause a large voltage to build across $\mathbf{R_C}$. Hence, small voltage applied at BE junction is converted into large voltage across $\mathbf{R_C}$.

Effect of temperature on semiconductor:

The semiconductor have negative temperature coefficient i.e. the resistance of semiconductor decreases with the increase in temperature for a specified range. As the temperature increases the impurities start to ionize and if sufficient thermal energy is acquired by them, electron hole pairs are created due to the bond breaking and conductivity increases.

Characteristics of EM waves:

Rectifier: (Text Book):

A device which converts alternating current voltage into pulsating direct current voltage is called a rectifier. The following two types of rectification can be obtained using a diode

1. Half wave rectification
2. Full wave rectification

A semiconductor diode, also known as crystal diodes, can be used for rectification purposes.

Half Wave Rectifier (Text Book):

In half wave rectification, the rectifier conducts current only during the positive half cycles of input ac voltage. The negative half cycles of a.c. supply are suppressed i.e. during negative half cycles, no current is conducted and hence no voltage appears across the load in the external circuit.

Construction:

Figure shows the circuit where a single diode acts as a half wave rectifier. The a.c. signal to be rectified is applied in series with the diode and load resistance R_L. The dc output is obtained across the load R_L. Generally a.c. supply is given through the transformer. The use of transformer has two advantages.

1. It allows us to step up or step down the ac input voltage.
2. Transformer isolate the rectifier circuit from power line and the reduces the risk of electric shock.

Working:

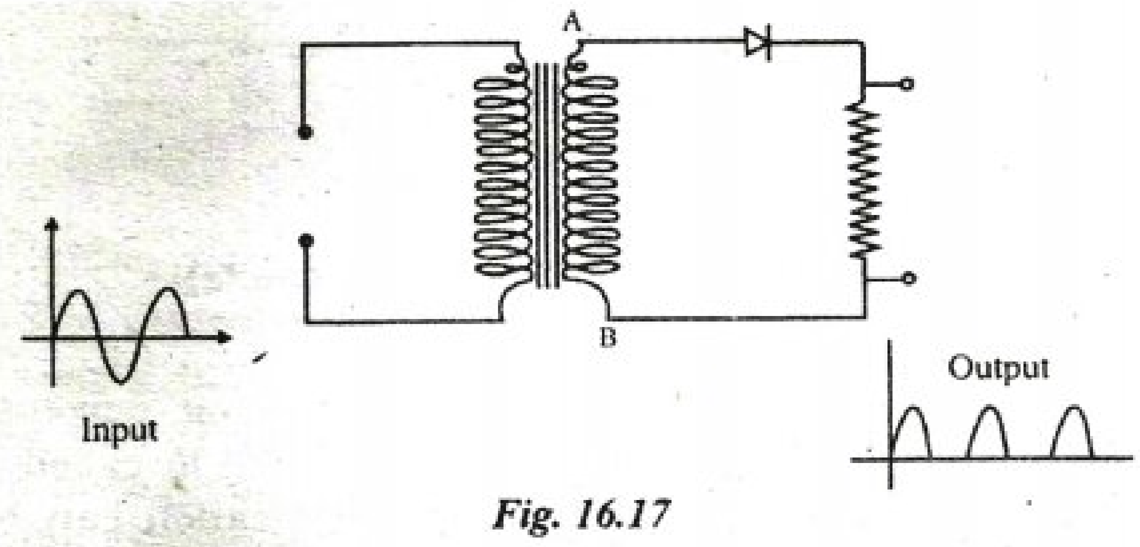


Fig. 16.17

The AC voltage across the secondary winding AB changes polarities after every half cycle. During the positive half cycle of input a.c. voltage at A becomes positive with respect to end B. This makes the diode forward biased and hence it conducts current. During the negative half cycle A is negative with respect to the end B and this makes the diode reverse biased and it conducts no current, therefore the current flows through the diode during the positive half cycle of input a.c. voltage and it is blocked during the negative half cycles. In this way current flows through load always in the same direction. Hence dc output is obtained across the load resistor R_L.

Full Wave Rectifier (Text Book):

In full wave rectification, current flows through the load in the same direction for both half cycles of input a.c. voltage. The can be achieved with two diodes working alternately.

Construction:

The circuit employees two diodes D_1 and D_2 as shown in figure. A center tapped secondary winding AB is used with two diodes connected so that each uses one half cycle of input a.c. voltage. D_1 utilizes the a.c. voltage appearing across the upper half OA of secondary winding for rectification while diode D_2 uses the lower half winding OB.

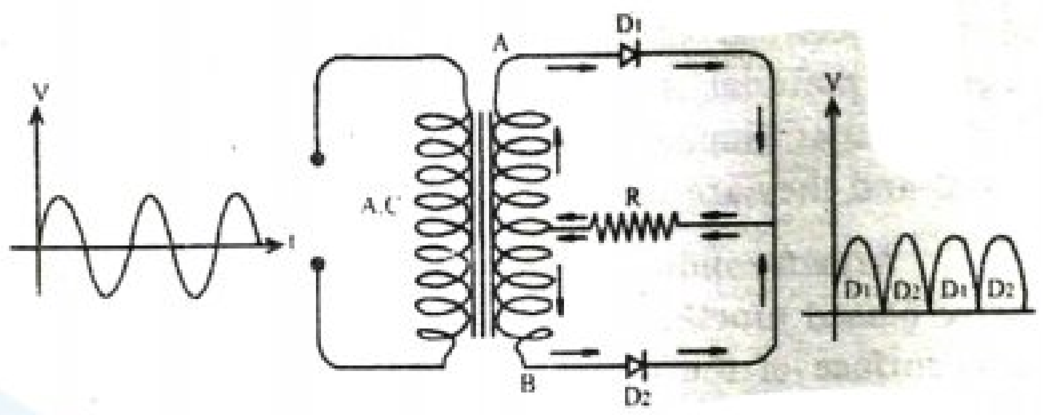


Fig. 16.18

Working:

During the positive half cycle of secondary voltage, the end A of secondary winding becomes positive and end B negative. This makes the diode D_1 forward biased and diode D_2 reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. The conventional current flow is through diode D_1, load resistor R_L and the upper half of the secondary winding, as shown in figure. During the negative half cycle, end A of the secondary winding becomes negative and end B positive. Therefore diode D_2 conducts while diode D_1 does not. The conventional current flows is through diode D_2, load resistor R_L and lower half winding as shown in figure. Therefore current flows through load resistance for both half cycles of input a.c. voltage.

Full wave rectification:

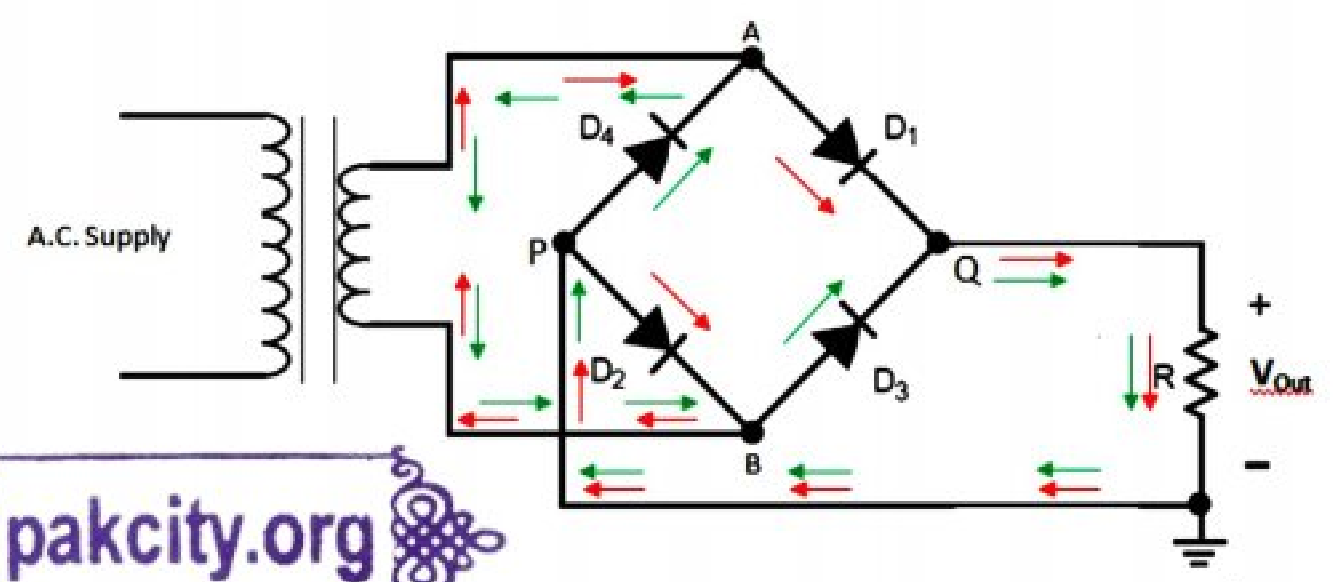
Such type of rectification in which output current flows in the same direction for the positive and negative half cycle of the input AC voltage is called full wave rectification.

Construction:

It consists of 4 semiconductor diodes and load resistance R. Semiconductor diodes are connected in bridge type arrangement. The output is taken across the load resistance R.

In this circuit unidirectional DC current is obtained for both positive half and negative half cycle of the input AC voltage that's why it is called full wave rectifier.

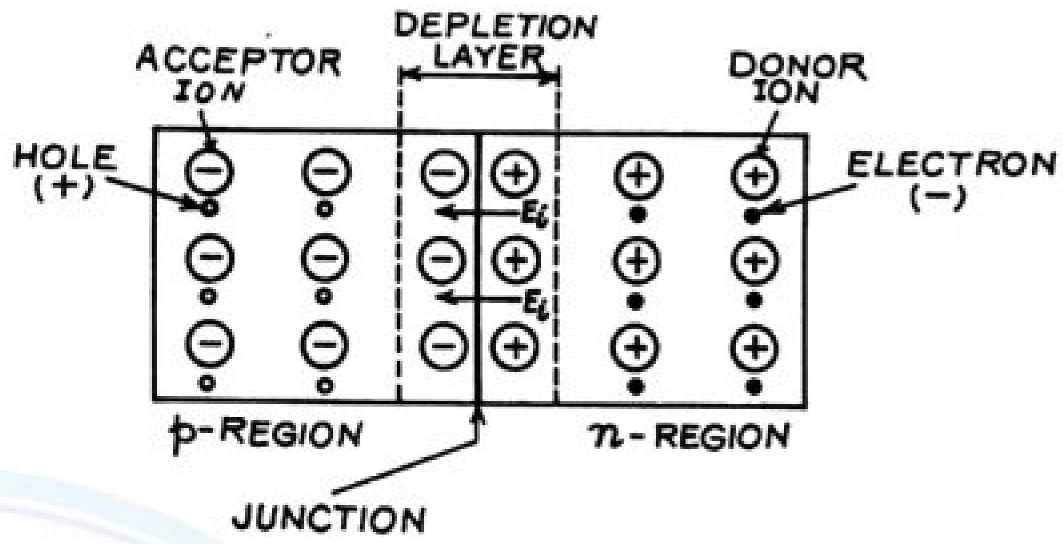
Working



During the positive half cycle the terminal A of the bridge is positive with respect to the terminal B. The diodes D_1 and D_2 become forward biased and the current flows through the circuit and positive pulse appear on the load resistance. During the negative half cycle the terminal A of the bridge is negative with respect to the terminal B. The diodes D_3 and D_4 become forward biased and the current flows through the circuit and positive pulse appear on the output load resistance. Thus unidirectional pulsating DC output current is obtained for both positive and negative half of the input AC cycle.

Formation of the Potential barrier in PN-Junction:

In PN-Junction diode holes are majority charge carriers in p-side of the junction and electrons are majority charge carriers in the n-side of the junction. When diffusion of these electrons and holes take place across the junction the positive charge (due to the positive ions) developed at the n-side of the junction and negative charge (due to the negative ions) developed at the p-side of the junction. These newly formed positive and negative ions give an electric field which prevents the majority charge carriers flow across the junction is called "depletion region". Potential difference due to this electric field is setup at the junction which is called "potential barrier" or "junction barrier". This junction barrier is small in forward biasing and large in reverse biasing.



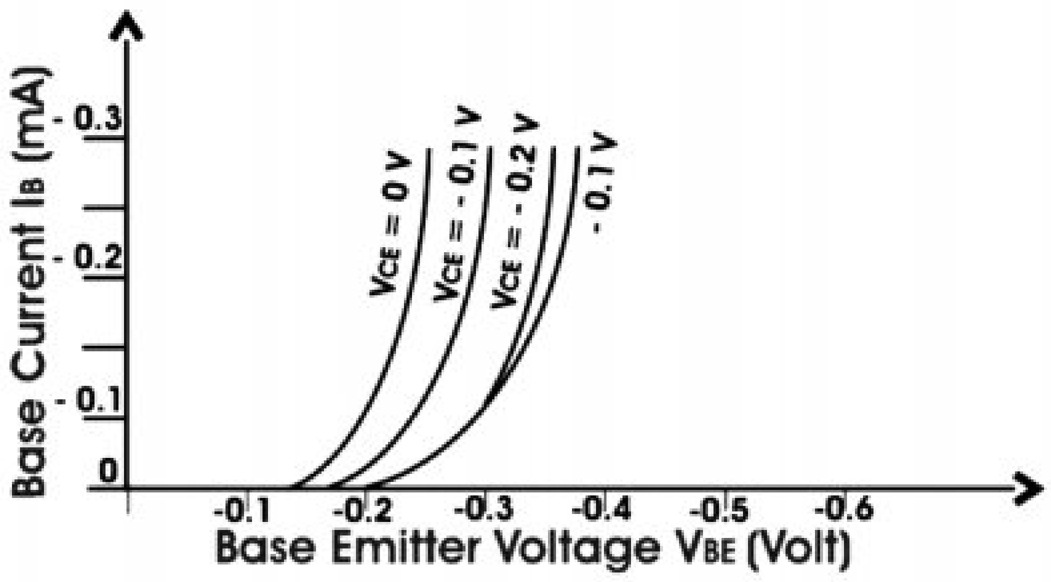
Characteristics Curves:

The characteristic contains two curves i.e. input characteristic and output characteristic.

Input Characteristics:

It gives the relationship between input voltage & input current

1. I_B (Base Current) is the input current, V_{BE} (Base – Emitter Voltage) is the input voltage for CE (Common Emitter) mode. So, the input characteristics for CE mode will be the relation between I_B and V_{BE} with V_{CE} as parameter.
2. The typical CE input characteristics are similar to that of a forward biased of p – n diode. But as V_{CB} increases the base width decreases
3. The characteristics curves is represented as,



Out Put Characteristics:

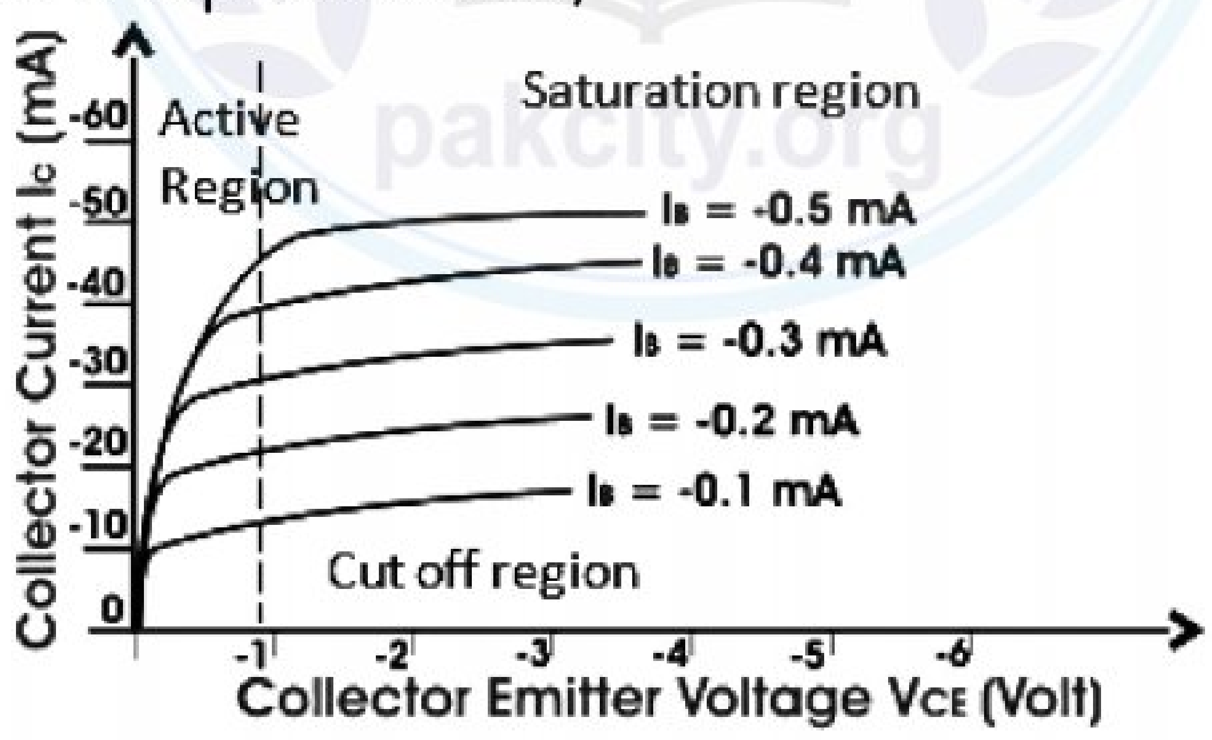
It gives the relationship between voltage & current in output circuit.

1. Output characteristics for CE mode is the curve or graph between collector current (I_C) and collector – emitter voltage (V_{CE}) when the base current I_B is the parameter.
2. CE transistor has also three regions named

1. **Active region:**
   The active region has collector region reverse biased and the emitter junction forward biased.

2. **Cut-off regions:**
   For cut-off region the emitter junction is slightly reverse biased and the collector current is not totally cut-off.

3. **Saturation region:**
   For saturation region both the collector and the emitter junction are forward biased.
   The characteristics curves is represented as,



AMPLIFIER:

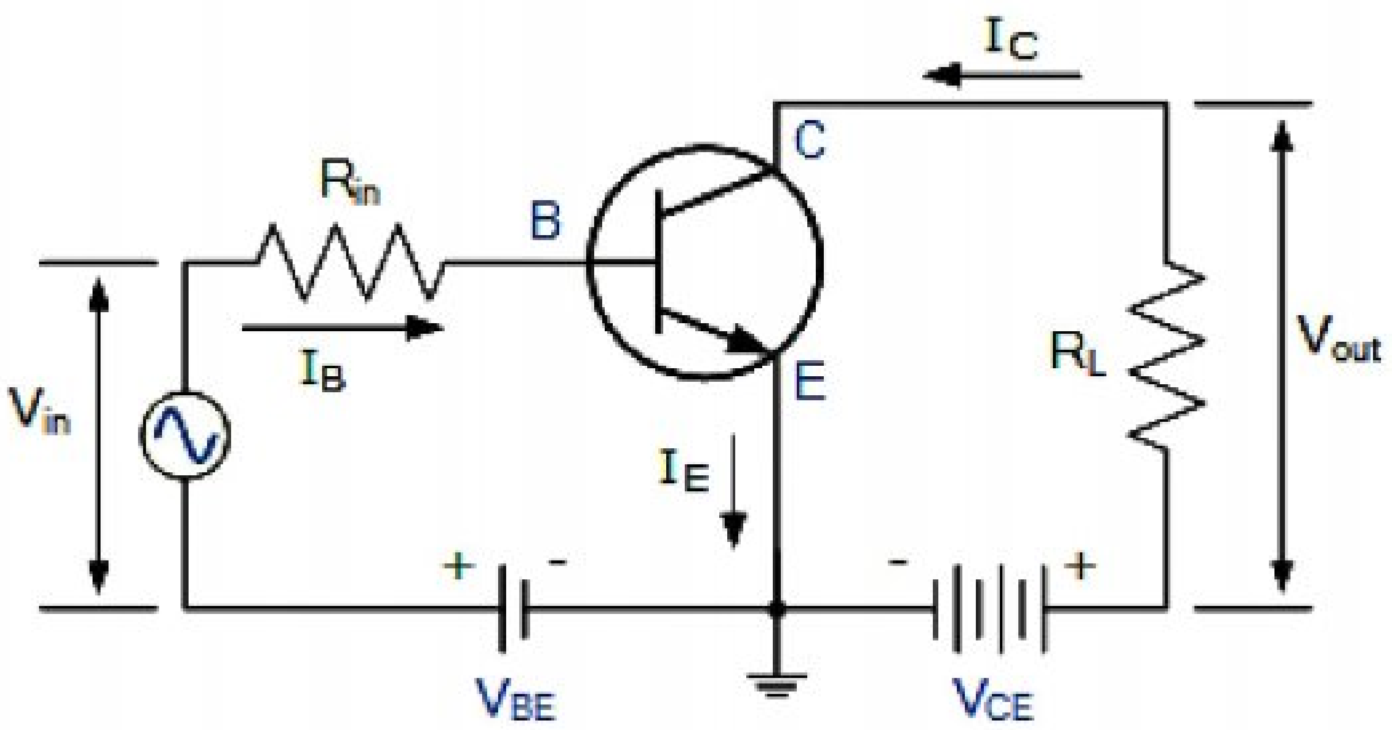
Amplifier is a circuit or device that can raises the strength of a weak signal. The factor by which an amplifier increases the strength of a weak signal is called gain of an amplifier.

Transistor as an Amplifier:

A transistor can be used to amplify a weak signal. The transistor has following relation between base and collector current.

$$I_C = \alpha I_B$$

Where α is called the gain of the transistor.



Now if we apply a small voltage across the base emitter junction, this voltage allows a small base current to flow inside the base region resulting in large collector current to flow in collector. Now, if we connect a large resistance R_C at collector. Collector current will cause a large voltage to build across $\mathbf{R_C}$. Hence, small voltage applied at BE junction is converted into large voltage across $\mathbf{R_C}$.