CONTENT GENERATION

[UNDER EDUSAT PROGRAMME]

FUNDAMENTAL ELECTRONIC DEVICES

[ETT 322]

3RD SEM CSE/IT, DIPLOMA ENGG.

Under SCTE&VT, Odisha

PREPARED BY: -

1. *Er. DEBI PRASAD PATNAIK*
   [Sr. Lecture, Dept of ETC, UCP ENGG. SCHOOL, Berhampur]

2. *Er. PARAMANANDA GOUDA*
   [Lecturer (PT), Dept of ETC, UCP ENGG. SCHOOL, Berhampur]

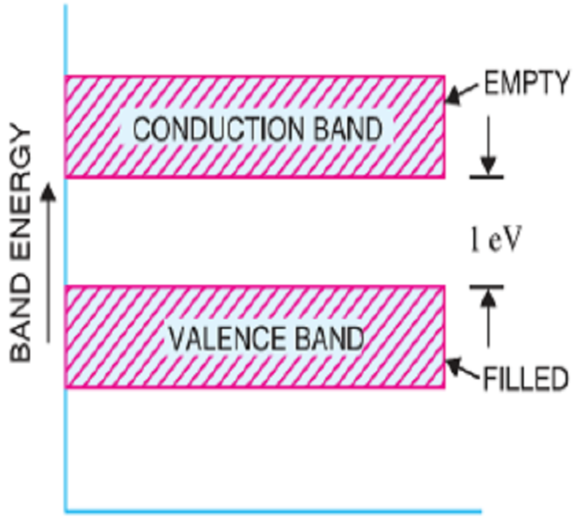
3. *Er. CHINMOY KUMAR PATTNAIK*
   [Lecturer (PT), Dept of ETC, UCP ENGG. SCHOOL, Berhampur]

[CHAPTER-1]

---------------------------------- [SEMICONDUCTOR THEORY] ----------------------------------

❖ SEMICONDUCTORS: -

- We know that some solids are good conductors of electricity while others are insulators. There is also an intermediate class of semiconductors.
- The difference in the behaviour of solids as regards their electrical conductivity can be beautifully explained in terms of energy bands.
- The electrons in the lower energy band are tightly bound to the nucleus and play no part in the conduction process.
- However, the valence and conduction bands are of particular importance for the electrical behaviour of various solids.
- Semiconductors are those substances whose electrical conductivity lies in between conductors and insulators e.g. germanium, silicon etc.



- In terms of energy band, the valence band is almost filled and conduction band is almost empty. The energy gap between valence and conduction bands is very small.
- Therefore, comparatively smaller electric field (smaller than insulators but much greater than conductors) is required to push the electrons from valence band to conduction band.
- In short, a semiconductor has:-

(a) Almost full valence band

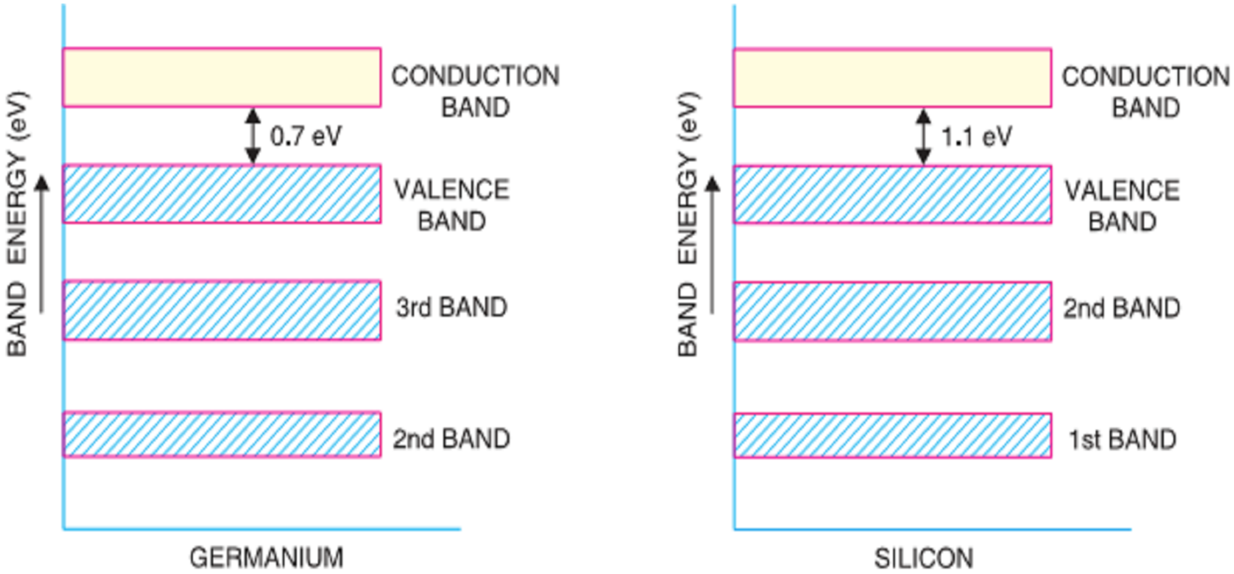
(b) Almost empty conduction band

(c) Small energy gap (≈1 eV) between valence and conduction bands.

- At low temperature, the valence band is completely full and conduction band is completely empty.
- Therefore, a semiconductor virtually behaves as an insulator at low temperatures.

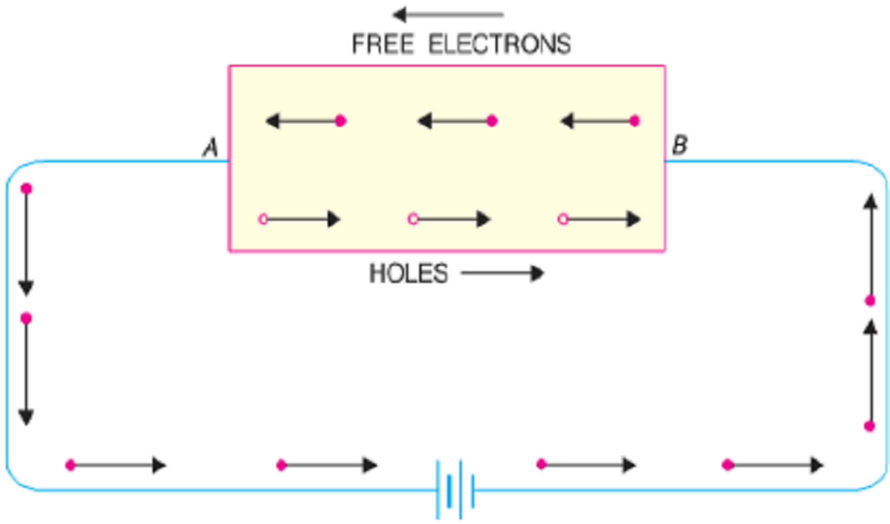
However, even at room temperature, some electrons (about one electron for 1010 atoms) cross over to the conduction band, imparting little conductivity to the semiconductor.

- As the temperature is increased, more valence electrons cross over to the conduction band and the conductivity increases.
- This shows that electrical conductivity of a semiconductor increases with the rise in temperature i.e. a semiconductor has negative temperature co-efficient of resistance.



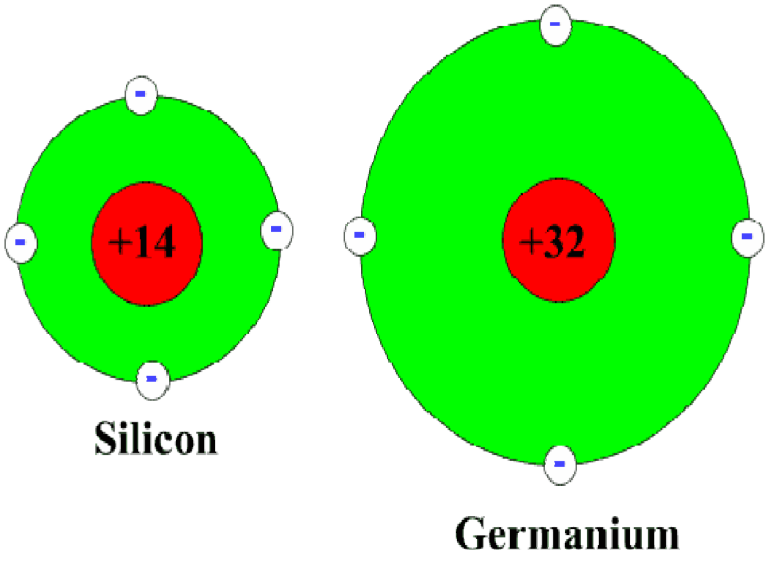
❖ CURRENT DUE TO CARRIERS IN SEMICONDUCTOR:-

- Under the influence of electric field, these free electrons will constitute electric current. It may be noted that each time a valence electron enters into the conduction band; a hole is created in the valence band.
- In an intrinsic semiconductor, even at room temperature, hole-electron pairs are created. When electric field is applied across an intrinsic semiconductor, the current conduction takes place by two processes, namely; by free electrons and holes as shown.



- The free electrons are produced due to the breaking up of some covalent bonds by thermal energy.
- At the same time, holes are created in the covalent bonds.
- Under the influence of electric field, conduction through the semiconductor is by both free electrons and holes.

❖ ATOMISTIC PICTURE OF SILICON & GERMANIUM



❖ ELECTRIC CURRENT IN SEMICONDUCTOR

- In general, the total current in a semiconductor is written as the sum of the electron and hole conduction currents and the electron and hole diffusion currents.

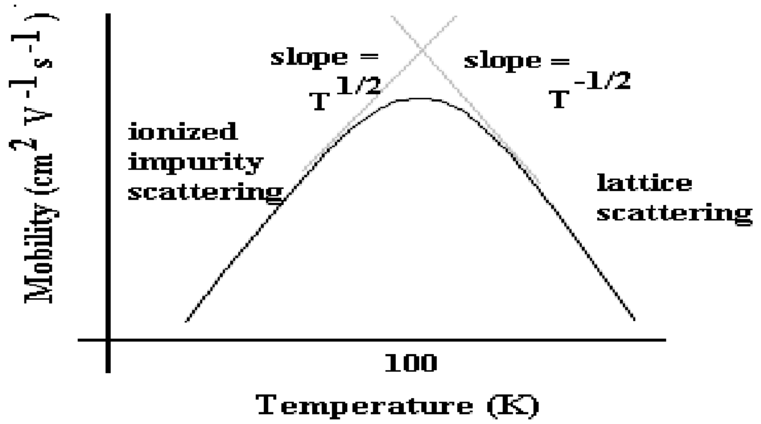
❖ FREE ELECTRON DENSITY IN SEMICONDUCTOR (J)

- The current density is defined as current over the cross sectional area.
- The electron density is the number of electrons in a unit volume, n = N/LA.

$I = \frac{qNv_d}{L} \longrightarrow J = \frac{I}{A} = \frac{qNv_d}{LA}$ Thus $J = qnv_d$.

ELECTRON MOBILITY IN SEMICONDUCTOR

- Mobility is a physical constant that describes the ease in which an electron can move through a material.
- The mobility is a function of temperature as well as the electric field.
- Thus, the speed of the electrons in the metal changes with temperature.



- The exact relationship between the change in mobility as a function of temperature is dependent on a number of material properties including the number of grain boundaries and how pure the metal is.

❖ **CLASSIFICATION OF SEMICONDUCTORS:-**

- Semiconductor is classified into two categories such as Intrinsic & Extrinsic Semiconductor.

❖ **PURE/INTRINSIC SEMICONDUCTOR: -**

- A semiconductor in an extremely pure form is known as an **Intrinsic Semiconductor**.

❖ **IMPURE/EXTRINSIC SEMICONDUCTOR: -**

- The intrinsic semiconductor has little current conduction capability at room temperature. To be useful, the pure semiconductor must be changed to significantly increase its conducting properties.
- This is achieved by adding a small amount of suitable impurity to a semiconductor. It is then called **Impurity** or **Extrinsic Semiconductor**.

❖ **DOPING**

- The process of adding impurities to a semiconductor is known as **doping**. Generally, for 108 atoms of semiconductor, one impurity atom is added.
- The purpose of adding impurity is to increase either the number of free electrons or holes in the semiconductor crystal.
- If a pentavalent impurity (having 5 valence electrons) is added to the semiconductor, a large number of free electrons are produced in the semiconductor.
- On the other hand, addition of trivalent impurity (having 3 valence electrons) creates a large number of holes in the semiconductor crystal.
- Depending upon the type of impurity added, extrinsic semiconductors are classified into:

  (i) n-type semiconductor **(ii)** p-type semiconductor
- Therefore, the total current inside the semiconductor is the sum of currents due to free electrons and holes.

❖ **EFFECT OF TEMPERATURE ON SEMICONDUCTORS:-**

- The electrical conductivity of a semiconductor changes appreciably with temperature variations. This is a very important point to keep in mind.

(i)AT ABSOLUTE ZERO:-

- At absolute zero temperature, all the electrons are tightly held by the semiconductor atoms. The inner orbit electrons are bound whereas the valence electrons are engaged in covalent bonding.
- At this temperature, the co-valent bonds are very strong and there are no free electrons. Therefore, the semiconductor crystal behaves as a perfect insulator.

- In terms of energy band description, the valence band is filled and there is a large energy gap between valence band and conduction band.
- Therefore, no valence electron can reach the conduction band to become free electron.
- It is due to the non-availability of free electrons that a semiconductor behaves as an insulator.

(ii)ABOVE ABSOLUTE ZERO: -

- When the temperature is raised, some of the covalent bonds in the semiconductor break due to the thermal energy supplied.
- The breaking of bonds sets those electrons free which are engaged in the formation of these bonds.
- The result is that a few free electrons exist in the semiconductor. These free electrons can constitute a tiny electric current if potential difference is applied across the semiconductor crystal.
- This shows that the resistance of a semiconductor decreases with the rise in temperature i.e. it has negative temperature coefficient of resistance.
- Thus, at room temperature, current through a semiconductor is too small to be of any practical value.
- As the temperature is raised, some of the valence electrons acquire sufficient energy to enter into the conduction band and thus become free electrons.

❖ HISTORY OF DEVELOPMENT OF SEMICONDUCTOR

1833: First Semiconductor Effect is Recorded

1874: Semiconductor Point-Contact Rectifier Effect is Discovered

1931: "The Theory Of Electronic Semi-Conductors" is Published

1940: Discovery of the *p-n* Junction

1958: Tunnel Diode Promises a High-Speed Semiconductor Switch

1961: Silicon Transistor Exceeds Germanium Speed

1965: Semiconductor Read-Only-Memory Chips Appear

[CHAPTER-2]

----------------- [THE PN JUNCTION IN FORWARD & REVERSED BIAS] -----------------

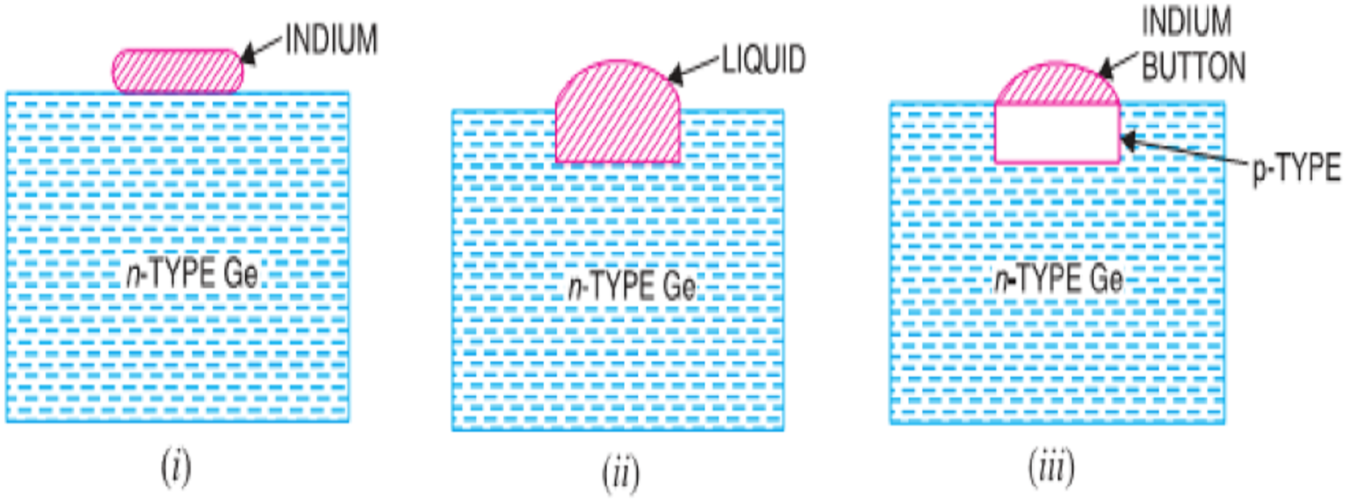
❖ **DEFINITION:-**

➢ When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called **p-n Junction**.

❖ **FORMATION OF PN JUNCTION**

➢ In actual practice, the characteristic properties of PN junction will not be apparent if a p-type block is just brought in contact with n-type block.

➢ It is fabricated by special techniques and one common method of making PN junction is called **Alloying**.



[Figures of different stages of formation of PN junction by Alloying method]

➢ In this method, a small block of indium (trivalent impurity) is placed on an n-type germanium slab as shown in Fig (i).

➢ The system is then heated to a temperature of about 500ºC.

➢ The indium and some of the germanium melt to form a small puddle of molten germanium-indium mixture as shown in Fig (ii).

➢ The temperature is then lowered and puddle begins to solidify.

➢ Under proper conditions, the atoms of indium impurity will be suitably adjusted in the germanium slab to form a single crystal.

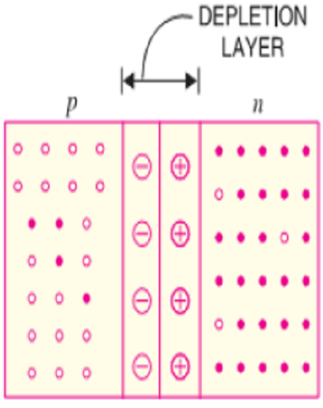
➢ The addition of indium overcomes the excess of electrons in the n-type germanium to such an extent that it creates a p-type region.

➢ As the process goes on, the remaining molten mixture becomes increasingly rich in indium.

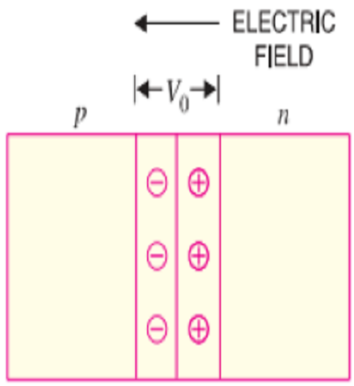
➢ When all germanium has been redeposited, the remaining material appears as indium button which is frozen on to the outer surface of the crystallized portion as shown in Fig (iii).

❖ PROPERTIES OF PN JUNCTION

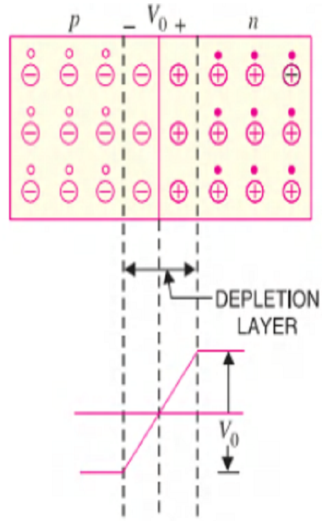
- To explain PN junction, consider two types of materials: -
  1) P-Type-P-type semiconductor having –ive acceptor ions and +ive charged holes.
  2) N-Type -N-type semiconductor having +ive donor ions and –ive free electrons.
- P-type has high concentration of holes & N-type has high concentration of electrons.
- The tendency for the free electron to diffuse over p-side and holes to n-side process is called **Diffusion.**
- When a free electron move across the junction from n-type to p-type, positive donor ions are removed by the force of electrons. Hence positive charge is built on the n-side of the junction. Similarly negative charge establish on p-side of the junction.
- When sufficient no of donor and accepter ions gathered at the junction, further diffusion is prevented.
- Since +ive charge on n-side repel holes to cross from p-side to n-side, similarly –ive charge on p-side repel free electrons to cross from n-type to p-type.
- Thus a barrier is set up against further movement of charge carriers is hole or electrons.
- This barrier is called as **Potential Barrier/ Junction Barrier (V0)** and is of the order 0.1 to 0.3 volt. This prevents the respective majority carriers for crossing the barrier region. This region is known as **Depletion Layer.**
- The term depletion is due to the fact that near the junction, the region is depleted (i.e. emptied) of charge carries (free electrons and holes) due to diffusion across the junction. It may be noted that depletion layer is formed very quickly and is very thin compared to the n region and the p-region.
- Once pn junction is formed and depletion layer created, the diffusion of free electrons stops.
- In other words, the depletion region acts as a barrier to the further movement of free electrons across the junction.
- The positive and negative charges set up an electric field as shown in fig below.



(i)



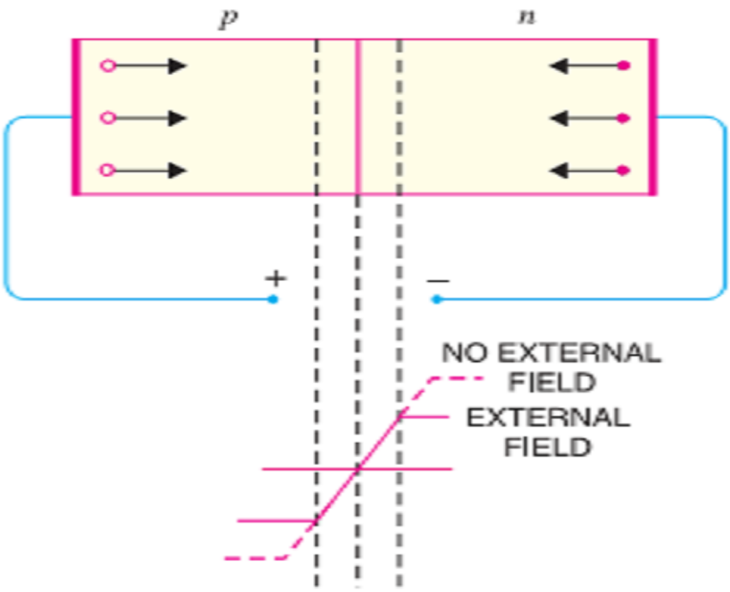
(ii)



- The electric field is a barrier to the free electrons in the n-region.
- There exists a potential difference across the depletion layer and is called **barrier potential (V_0).**
- The barrier potential of a p-n junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature.
- The typical barrier potential is approximately:-
- For silicon, $V_0 = 0.7$ V, For germanium, $V_0 = 0.3$ V.

❖ PN JUNCTION UNDER FORWARD BIASING

- When external D.C. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called Forward Biasing.
- To apply forward bias, connect positive terminal of the battery to p-type and negative terminal to n-type as shown in fig below.



- The applied forward potential establishes an electric field which acts against the field due to potential barrier.
- Therefore, the resultant field is weakened and the barrier height is reduced at the junction.
- As potential barrier voltage is very small (0.1 to 0.3 V), therefore, a small forward voltage is sufficient to completely eliminate the barrier.
- Once the potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit.
- Therefore, current flows in the circuit. This is called Forward Current.
- With forward bias to PN junction, the following points are worth noting :

(i) The potential barrier is reduced and at some forward voltage (0.1 to 0.3 V), it is eliminated altogether.

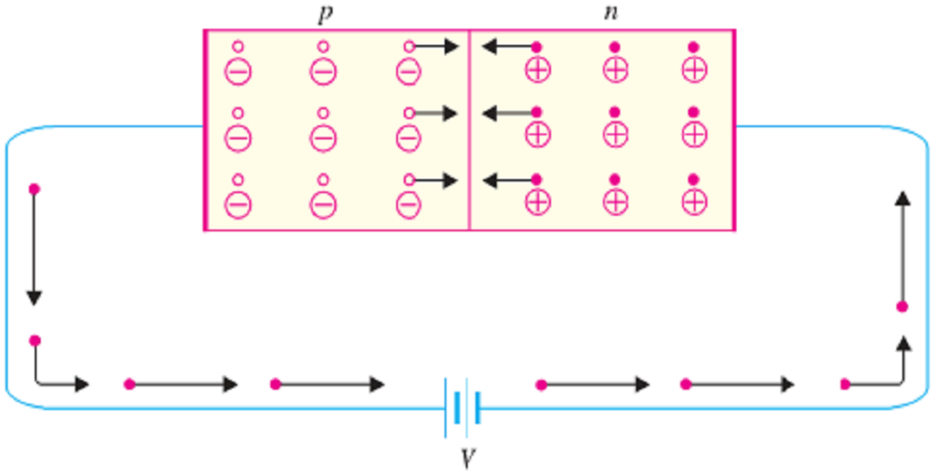
(ii) The junction offers low resistance (called forward resistance, R_f) to current flow.

(iii) Current flows in the circuit due to the establishment of low resistance path. The magnitude of current depends upon the applied forward voltage.

❖ CURRENT FLOW IN A FORWARD BIASED PN JUNCTION:-

➢ It is concluded that in n-type region, current is carried by free electrons whereas in p-type region, it is carried by holes.

➢ However, in the external connecting wires, the current is carried by free electrons.



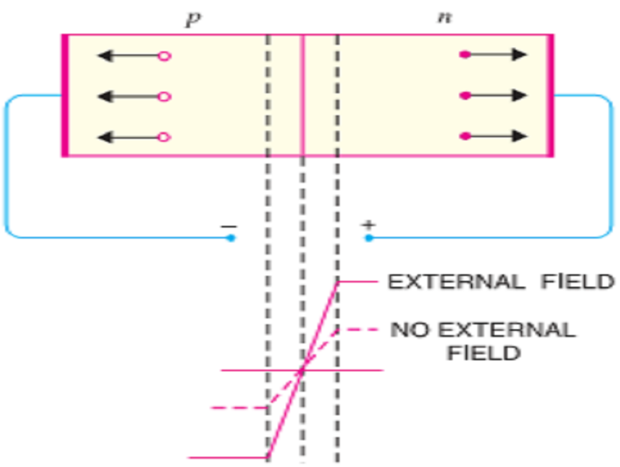
❖ PN JUNCTION UNDER REVERSE BIASING

➢ When the external D.C. voltage applied to the junction is in such a direction that potential barrier is increased, it is called **Reverse Biasing.**

➢ To apply reverse bias, connect negative terminal of the battery to p-type and positive terminal to n-type.

➢ It is clear that applied reverse voltage establishes an electric field which acts in the same direction as the field due to potential barrier.

➢ Therefore, the resultant field at the junction is strengthened and the barrier height is increased as shown in fig below .



➢ The increased potential barrier prevents the flow of charge carriers across the junction.

➢ Thus, a high resistance path is established for the entire circuit and hence the current does not flow.

➢ With reverse bias to PN junction, the following points are worth noting:

(i) The potential barrier is increased.

(ii)The junction offers very high resistance (Reverse Resistance R_r) to current flow.

(iii)No current flows in the circuit due to the establishment of high resistance path.

❖ VOLT-AMPERE CHARACTERISTICS OF PN JUNCTION:-

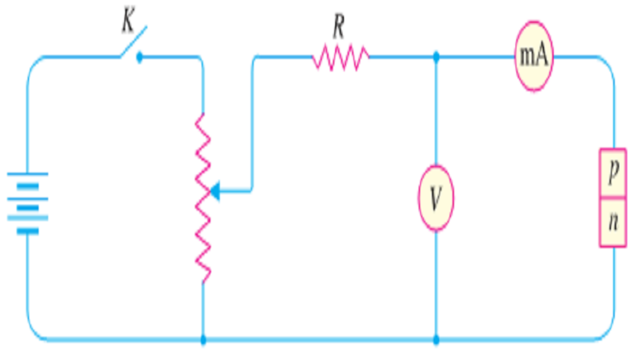
- Volt-ampere or V-I characteristic of a pn junction (also called a crystal or semiconductor diode) is the curve between voltage across the junction and the circuit current.
- Usually, voltage is taken along x-axis and current along y-axis. Fig. shows the circuit arrangement for determining the V-I characteristics of a pn junction.
- The characteristics can be studied under three heads namely:
  1) Zero external voltage
  2) Forward Bias
  3) Reverse Bias.

(I)ZERO EXTERNAL VOLTAGE: -

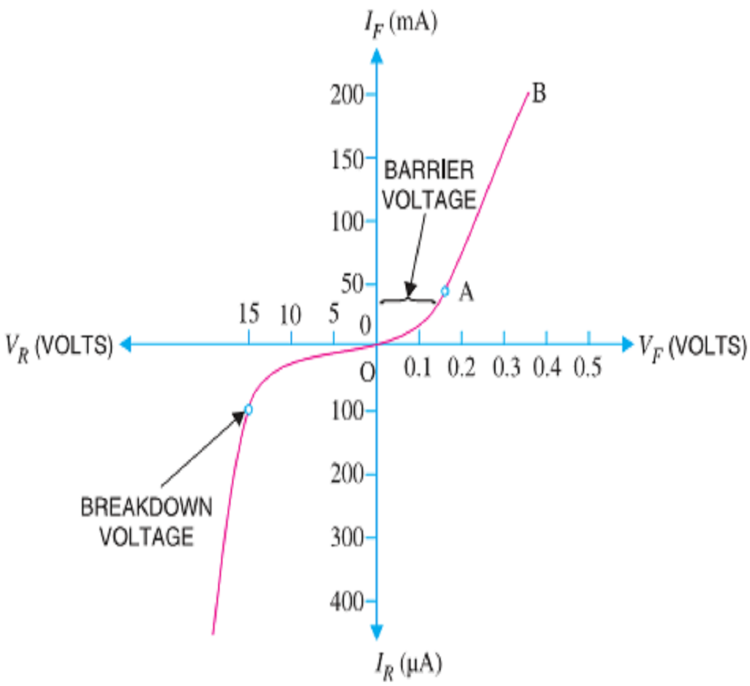
- When the external voltage is zero, i.e. circuit is open at K; the potential barrier at the junction does not permit current flow.

Therefore, the circuit current is zero as indicated by point O in Fig.

(II)FORWARD BIAS: -



- With forward bias to the pn junction i.e. p-type connected to positive terminal and n-type connected to negative terminal, the potential barrier is reduced.
- At some forward voltage (0.7 V for Si and 0.3 V for Ge), the potential barrier is altogether eliminated and current starts flowing in the circuit.
- From now onwards, the current increases with the increase in forward voltage.



- Thus, a rising curve OB is obtained with forward bias as shown in Fig. From the forward characteristic, it is seen that at first (region OA), the current increases very slowly and the curve is non-linear.
- It is because the external applied voltage is used up in overcoming the potential barrier.
- However, once the external voltage exceeds the potential barrier voltage, the pn junction behaves like an ordinary conductor.
- Therefore, the current rises very sharply with increase in external voltage (region AB on the curve). Here the curve is almost linear.

(III)REVERSE BIAS:-

- With reverse bias to the pn junction i.e. p-type connected to negative terminal and n-type connected to positive terminal, potential barrier at the junction is increased.
- Therefore, the junction resistance becomes very high and practically no current flows through the circuit.
- However, in practice, a very small current (of the order of μA) flows in the circuit with reverse bias as shown in the reverse characteristic.
- This is called Reverse Saturation Current (I_s) and is due to the minority carriers.
- It may be recalled that there are a few free electrons in p-type material and a few holes in n-type material.
- These undesirable free electrons in p-type and holes in n-type are called minority carriers.
- Therefore, a small current flows in the reverse direction.
- If reverse voltage is increased continuously, the kinetic energy of electrons (minority carriers) may become high enough to knock out electrons from the semiconductor atoms.
- At this stage breakdown of the junction occurs, characterized by a sudden rise of reverse current and a sudden fall of the resistance of barrier region.
- This may destroy the junction permanently.
- Note: -The forward current through a p-n junction is due to the majority carriers produced by the impurity.
- However, reverse current is due to the minority carriers produced due to breaking of some covalent bonds at room temperature.

❖ **IMPORTANT TERMS: -**

(i)**BREAKDOWN VOLTAGE**: - It is the minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current.

(ii)**KNEE VOLTAGE**: - It is the forward voltage at which the current through the junction starts to increase rapidly.

(iii) **PEAK INVERSE VOLTAGE (PIV)**:- It is the maximum reverse voltage that can be applied to the pn junction without damage to the junction. If the reverse voltage across the junction exceeds its PIV, the junction may be destroyed due to excessive heat. The peak inverse voltage is of particular importance in rectifier service.

(iv)**MAXIMUM FORWARD CURRENT**: - It is the highest instantaneous forward current that a pn junction can conduct without damage to the junction. Manufacturer's data sheet usually specifies this rating. If the forward current in a pn junction is more than this rating, the junction will be destroyed due to overheating.

(v) **MAXIMUM POWER RATING:** - It is the maximum power that can be dissipated at the junction without damaging it. The power dissipated at the junction is equal to the product of junction current and the voltage across the junction. This is a very important consideration and is invariably specified by the manufacturer in the data sheet.

[CHAPTER-3]

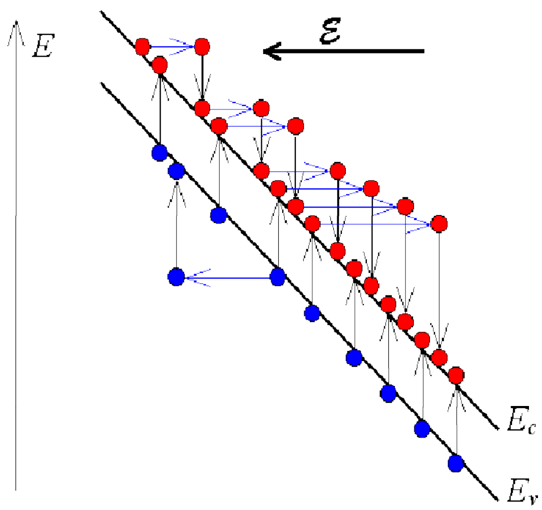
---------- [PHOTO DIODE, PHOTOTRANSISTORS & PNPN STRUCTURE] ----------

❖ INTRODUCTION

- Recombination of electrons and holes is a process by which both carriers annihilate each other: electrons occupy - through one or multiple steps - the empty state associated with a hole. Both carriers eventually disappear in the process.
- The energy difference between the initial and final state of the electron is released in the process. This leads to one possible classification of the recombination processes.
- In case of radiative recombination, this energy is emitted in the form of a photon where as in case of non-radiative recombination, it is passed on to one or more phonons.

❖ CARRIER GENERATION BY LIGHT IN A UNIFORM SEMICONDUCTOR

- The carriers can be generated in semiconductors by illuminating the semiconductor with light. The energy of the incoming photons is used to bring an electron from a lower energy level to a higher energy level.
- Carrier generation due to light absorption occurs if the photon energy is large enough to raise an electron from the valence band into an empty conduction band state, thereby generating one electron-hole pair.
- The photon energy needs to be larger than the bandgap energy to satisfy this condition E_{ph}, is larger than the bandgap energy, E_g.
- The photon is absorbed in this process and the excess energy, $E_{ph} - E_g$, is added to the electron and the hole in the form of kinetic energy.
- As the energy of the photon is given off to the electron, the photon no longer exists.
- Carrier generation or ionization due to a high-energy beam consisting of charged particles is similar except that the available energy can be much larger than the bandgap energy so that multiple electron-hole pairs can be formed.
- The high-energy particle gradually loses its energy and eventually stops.
- This generation mechanism is used in semiconductor-based nuclear particle counters.

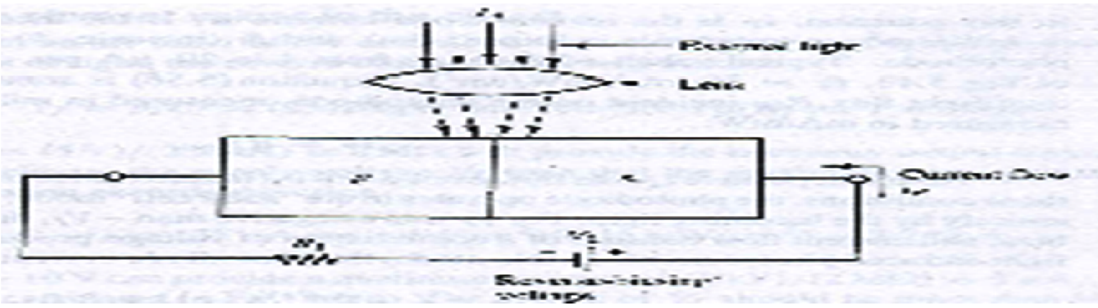


- As the number of ionized electron-hole pairs varies with the energy of the particle, one can also use such detector to measure the particle energy.
- Finally, there is a generation process called impact ionization.
- Impact ionization is caused by an electron/hole with an energy, which is much larger/smaller than the conduction/valence band edge.
- The detailed mechanism is illustrated with Fig

- The excess energy is given off to generate an electron-hole pair through a band-to-band transition.
- This generation process causes avalanche multiplication in semiconductor diodes under high reverse bias: As one carrier accelerates in the electric field it gains energy.
- The kinetic energy is given off to an electron in the valence band, thereby creating an electron-hole pair.
- The resulting two electrons can create two more electrons which generate four more causing an avalanche multiplication effect.
- Electrons as well as holes contribute to avalanche multiplication.

❖ **PN JUNCTION PHOTO DIODE FOR LIGHT DETECTION**

- Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device.
- A **photodiode** is a semiconductor device that converts light into current. The current is generated when photons are absorbed in the photodiode.
- This creates a region depleted of charge carriers that results in high impedance.
- The high impedance allows the construction of detectors using silicon and germanium to operate with high sensitivity at low temperatures.
- The photodiode functions using an illumination window as shown in Fig, which allows the use of light as an external input.



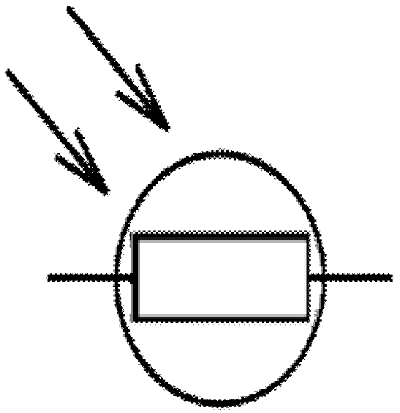
- Since light is used as an input, the diode is operated under reverse bias conditions. Under the reverse bias condition the current through the junction is zero when no light is present, this allows the diode to be used as a switch or relay when sufficient light is present.
- Photodiodes are mainly made from gallium arsenide instead of silicon because silicon creates crystal lattice vibrations called phonons when photons are absorbed in order to create electron-hole pairs.
- Gallium arsenide can produce electron-hole pairs without the slowly moving phonons; this allows faster switching between on and off states and GaAs also is more sensitive to the light intensity.
- Once charge carriers are produced in the diode material, the carriers reach the junction by diffusion.
- Important parameters for the photodiode include quantum efficiency, current and capacitance

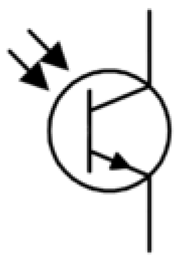
❖ PHOTOTRANSISTOR CONCEPT ONLY

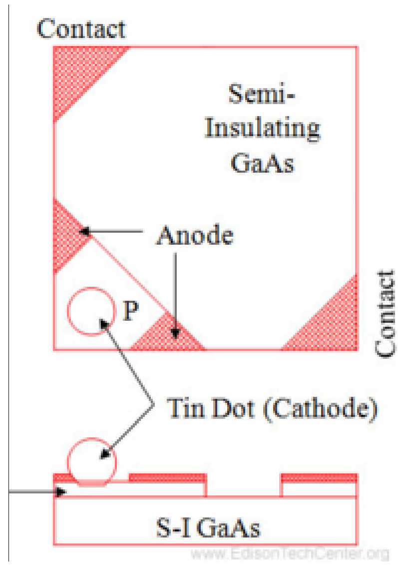
- A transistor that uses light rather than electricity to cause an electrical current to flow from one side to the other.
- It is used in a variety of sensors that detect the presence of light.
- Phototransistors combine a photodiode and transistortogether to generate more output cur rent than a photodiode by itself.

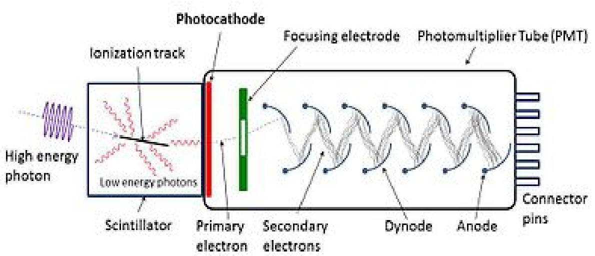
❖ MISCELLANEOUS PHOTO DETECTOR STRUCTURES

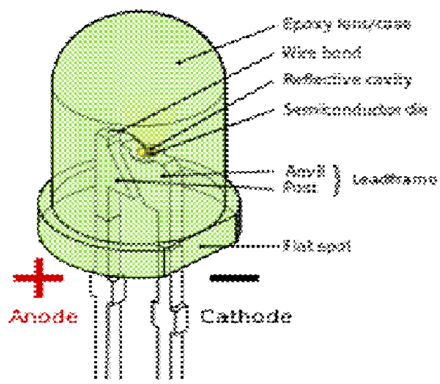
- Here are some of the Photo Detector Structures :-

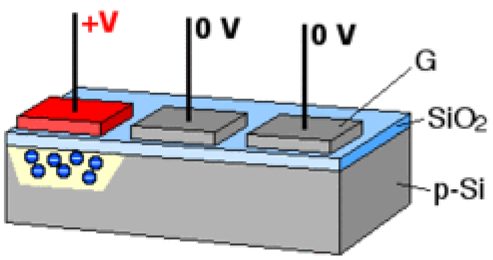










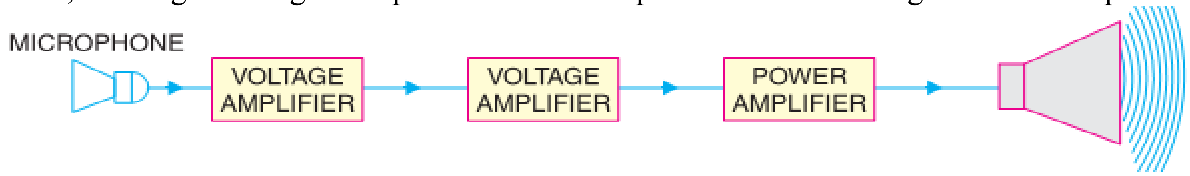


[CHAPTER-4]

[AUDIO POWER AMPLIFIERS]

❖ **INTRODUCTION:-**

- A practical amplifier always consists of a number of stages that amplify a weak signal until sufficient power is available to operate a loudspeaker or other output device.
- The first few stages in this multistage amplifier have the function of only voltage amplification. However, last stage is designed to provide maximum power. This final stage is known as power stage.



❖ **Transistor Audio Power Amplifier: -**

- A transistor amplifier which raises the power level of the signals having audio frequency range is known as transistor **Audio Power Amplifier**. Generally last stage of a multistage amplifier is the power stage.
- The power amplifier differs from all the previous stages in that here a concentrated effort is made to obtain maximum output power.
- A transistor that is suitable for power amplification is generally called a *power transistor*.

❖ **DIFFERENCE BETWEEN VOLTAGE AND POWER AMPLIFIERS**

- The difference between the two types is really one of degree; it is a question of how much voltage and how much power.
- A voltage amplifier is designed to achieve maximum voltage amplification. It is, however, not important to raise the power level.
- On the other hand, a power amplifier is designed to obtain maximum output power.

1) **Voltage Amplifier.** The voltage gain of an amplifier is given by : $\mathbf{A_v = \beta \times \frac{R_C}{R_{in}}}$

- In order to achieve high voltage amplification, the following features are incorporated in such amplifiers:
  - ♣ The transistor with high β(>100) is used in the circuit. i.e. Transistors are employed having thin base.
  - ♣ The input resistance R_{in} of transistor is sought to be quite low as compared to the collector load R_C.
  - ♣ A relatively high load R_C is used in the collector. To permit this condition, voltage amplifiers are always operated at low collector currents (≈ mA). If the collector current is small, we can use large R_C in the collector circuit

2) **Power Amplifier.** A power amplifier is required to deliver a large amount of power and as such it has to handle large current.

- In order to achieve high power amplification, the following features are incorporated in such amplifiers :
  - ♣ The size of power transistor is made considerably larger in order to dissipate the heat produced in the transistor during operation.
  - ♣ The base is made thicker to handle large currents. In other words, transistors with comparatively smaller β are used.
  - ♣ Transformer coupling is used for impedance matching.

The comparison between voltage and power amplifiers is given below in the tabular form :

S. No.	Particular	Voltage amplifier	Power amplifier
1.	β	High (> 100)	low (5 to 20)
2.	R_C	High (4 – 10 kΩ)	low (5 to 20 Ω)
3.	*Coupling*	usually $R - C$ coupling	Invariably transformer coupling
4.	*Input voltage*	low (a few mV)	High (2 – 4 V)
5.	*Collector current*	low (≃ 1 mA)	High (> 100 mA)
6.	*Power output*	low	high
7.	*Output impedance*	High (≃ 12 kΩ)	low (200 Ω)

❖ PERFORMANCE QUANTITIES OF POWER AMPLIFIERS

- The prime objective for a power amplifier is to obtain maximum output power. Since a transistor, like any other electronic device has voltage, current and power dissipation limits, therefore, the criteria for a power amplifier are : **Collector Efficiency, Distortion & Power Dissipation Capability**

Collector efficiency.

- The main criterion for a power amplifier is not the power gain rather it is the maximum a.c. power output. Now, an amplifier converts d.c. power from supply into a.c. power output.
- Therefore, the ability of a power amplifier to convert d.c. power from supply into a.c. output power is a measure of its effectiveness. This is known as *collector efficiency* and may be defined as under :
  - ♣ The ratio of a.c. output power to the zero signal power (i.e. d.c. power) supplied by the battery of a power amplifier is known as **collector efficiency**.

Distortion. The change of output wave shape from input wave shape of amplifier is called **Distortion**.

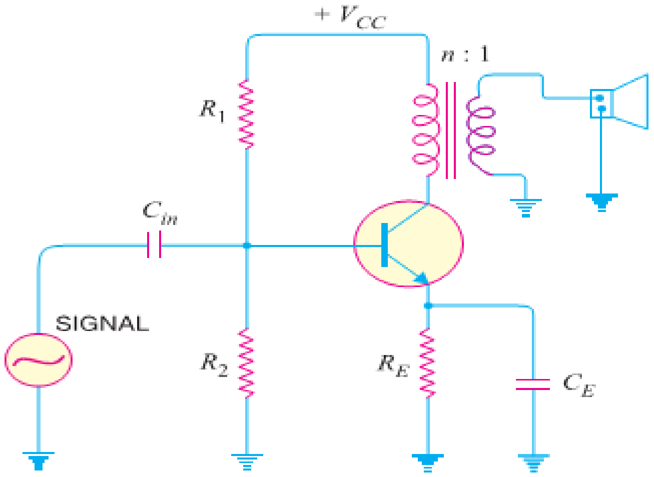
Power Dissipation Capability. The ability of a power transistor to dissipate heat is known as power dissipation capability.

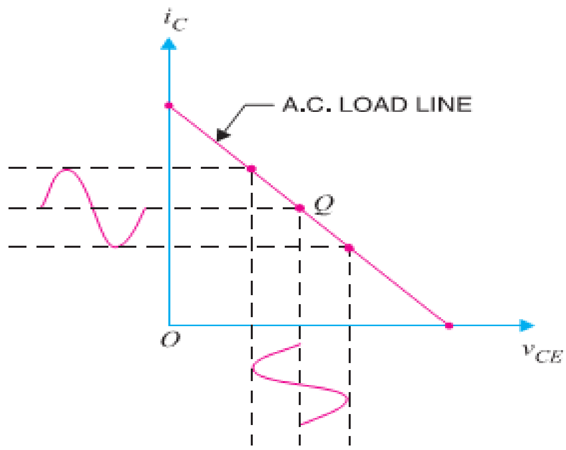
❖ CLASSIFICATION OF POWER AMPLIFIERS

- Transistor power amplifiers handle large signals. Many of them are driven by the input large signal that collector current is either cut-off or is in the saturation region during a large portion of the input cycle.
- Therefore, such amplifiers are generally classified according to their mode of operation i.e. the portion of the input cycle during which the collector current is expected to flow. On this basis, they are classified as

  (i) Class A power amplifier **(ii)** Class B power amplifier **(iii)** Class C power amplifier

CLASS A POWER AMPLIFIER. If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as *class A power amplifier*.

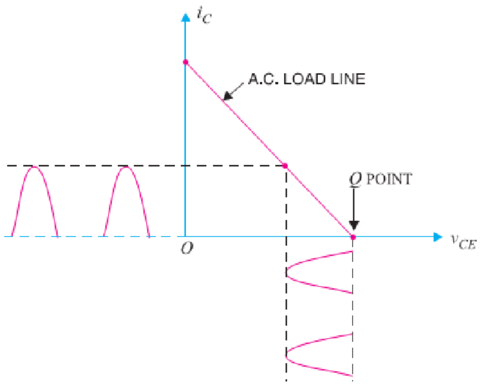




- The power amplifier must be biased in such a way that no part of the signal is cut off. Fig (i) shows circuit of class A power amplifier. Note that collector has a transformer as the load which is most common for all classes of power amplifiers.
- The use of transformer permits impedance matching, resulting in the transference of maximum power to the load e.g. loudspeaker. Fig (ii) shows the class A operation in terms of a.c. load line.
- The operating point Q is so selected that collector current flows at all times throughout the full cycle of the applied signal. As the output wave shape is exactly similar to the input wave shape, therefore, such amplifiers have least distortion.
- However, they have the disadvantage of low power output and low collector efficiency (about 35%).

CLASS B POWER AMPLIFIER: - If the collector current flows only during the positive half-cycle of the input signal, it is called a *class B power amplifier*.

- In class B operation, the transistor bias is so adjusted that zero signal collector current is zero i.e. no biasing circuit is needed at all.
- During the positive half-cycle of the signal, the input circuit is forward biased and hence collector current flows. However, during the negative half-cycle of the signal, the input circuit is reverse biased and no collector current flows.



- Fig. shows the class B operation in terms of a.c. load line.
- The operating point Q shall be located at collector cut off voltage.
- It is easy to see that output from a class B amplifier is amplified half-wave rectification.
- In a class B amplifier, the negative half-cycle of the signal is cut off and hence a severe distortion occurs.
- However, class B amplifiers provide higher power output and collector efficiency (50 − 60%).
- Such amplifiers are mostly used for power amplification in push-pull arrangement.
- In such an arrangement, 2 transistors are used in class B operation. One transistor amplifies the positive half cycle of the signal while the other amplifies the negative half-cycle.

CLASS C POWER AMPLIFIER. If the collector current flows for less than half-cycle of the input signal, it is called *class C power amplifier*.

- In class C amplifier, the base is given some negative bias so that collector current does not flow just when the positive half-cycle of the signal starts.
- Such amplifiers are never used for power amplification. However, they are used as tuned amplifiers i.e. to amplify a narrow band of requencies near the resonant frequency.

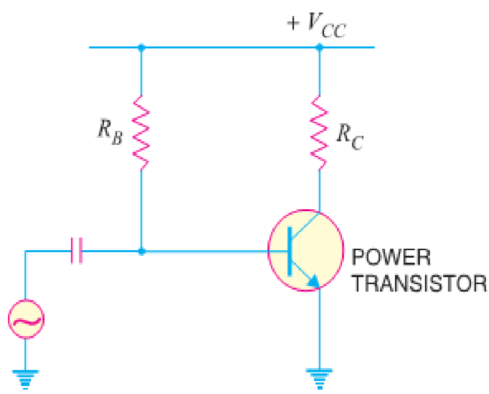
EXPRESSION FOR COLLECTOR EFFICIENCY

- For comparing power amplifiers, collector efficiency is the main criterion. The greater the collector efficiency, the better is the power amplifier.
- Now, Collector Efficiency, $\boldsymbol{\eta} = \frac{\text{a.c. power output}}{\text{d.c. power input}} = \frac{P_O}{P_{dc}}$
- Where $P_{dc} = V_{CC} I_C$ & $P_O = V_{CE} I_C$ in which V_{CE} is the r.m.s. value of signal output voltage and I_c is the r.m.s. value of output signal current.
- In terms of peak-to-peak values, the a.c. power output can be expressed as:

$P_o = [(0.5\times0.707)\, v_{ce(p-p)}][(0.5\times0.707)\, i_{c(p-p)}] = \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8}$ [As,0.5×0.707×0.5×0.707=0.125=**1/8**]

∴ **Collector η** $= \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8\, V_{CC}\, I_C}$

MAXIMUM COLLECTOR EFFICIENCY OF SERIES-FED CLASS A AMPLIFIER : -



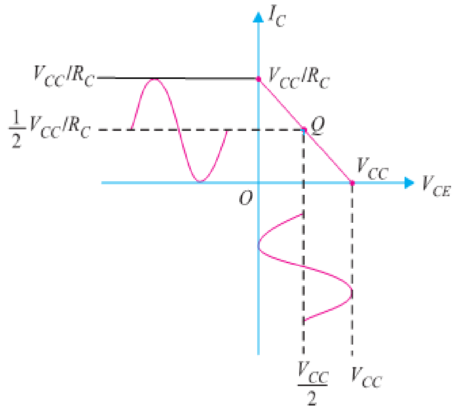
- Fig (i) shows a series fed class A amplifier. This circuit is seldom used for power amplification due to its poor collector efficiency.
- Nevertheless, it will help the reader to understand the class A operation. The d.c. load line of the circuit is shown in Fig. (ii).
- When an ac signal is applied to the amplifier, the output current and voltage will vary about the operating point Q.
- In order to achieve the maximum symmetrical swing of current and voltage (to achieve maximum output power), the Q point should be located at the centre of the dc load line.
- In that case, operating point is $I_C = V_{CC}/2R_C$ and $V_{CE} = V_{CC}/2$.

Maximum $v_{ce(p-p)} = V_{CC}$ Maximum $i_{c(p-p)} = V_{CC}/R_C$

Max. a.c. output power, $P_{o(max)} = \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8} = \frac{V_{CC} \times V_{CC}/R_C}{8} = \frac{V_{CC}^2}{8R_C}$

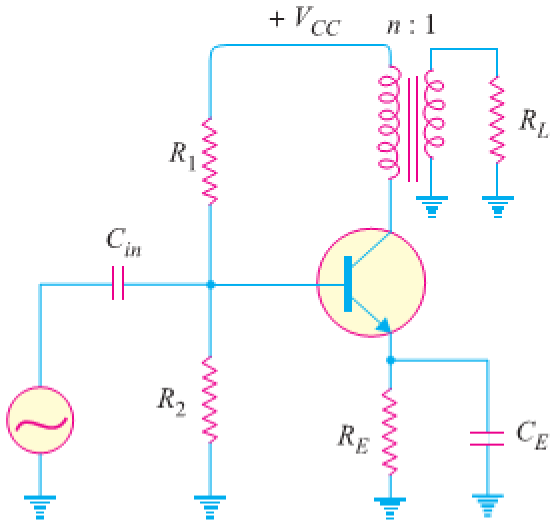
D.C. power supplied, $P_{dc} = V_{CC} I_C = V_{CC}\left(\frac{V_{CC}}{2R_C}\right) = \frac{V_{CC}^2}{2R_C}$

∴ Maximum collector $\eta = \frac{P_{O\,(max)}}{P_{dc}} \times 100 = \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} \times 100 =$ **25%**

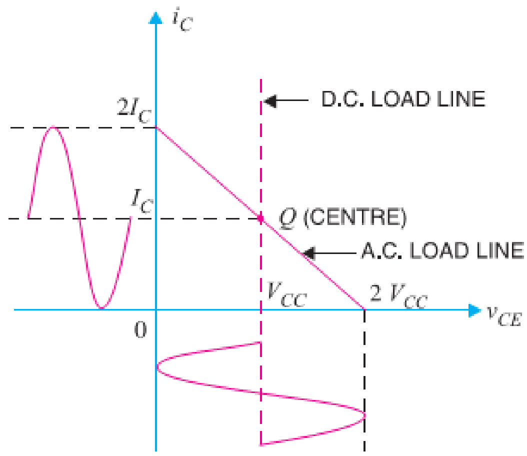


- Thus the maximum collector efficiency of a class A series-fed amplifier is 25%.
- In actual practice, collector efficiency is far less than this value.

Maximum Collector Efficiency Of Transformer Coupled Class A Power Amplifier : -



- In class A power amplifier, the load can be either connected directly in the collector or it can be transformer coupled.
- But Transformer coupled method is often preferred for two main reasons. **First,** transformer coupling permits impedance matching. **Secondly** it keeps the d.c. power loss small because of the small resistance of the transformer primary winding.
- Fig(i) shows a transformer coupled class A power amplifier.
- In order to determine maximum collector efficiency, refer to the output characteristics shown in Fig (ii).
- Under zero signal conditions, the effective resistance in the collector circuit is that of primary winding of Transformer.
- The primary resistance has a very small value and is assumed zero. Therefore, d.c. load line is a vertical line rising from V_{CC} as shown in Fig. (ii).



- When signal is applied, the collector current will vary about the operating point Q.
- In order to get maximum a.c. power output (Hence maximum collector η), the peak value of collector current due to signal alone should be equal to the zero signal collector current I_C.
- In terms of a.c. load line, the operating point Q should be located at the centre of a.c. load line.
- During the peak of the positive half-cycle of the signal, the total collector current is 2 I_C and $v_{ce} = 0$. During the negative peak of the signal, the collector current is zero and $v_{ce} = 2V_{CC}$.

∴ Peak-to-peak collector-emitter voltage is $v_{ce(p-p)} = 2V_{CC}$

Peak-to-peak collector current, $i_{c(p-p)} = 2\ I_C = \frac{V_{ce(p-p)}}{R'_L} = \frac{2V_{cc}}{R'_L}$

Where R'_L is the reflected value of load R_L and appears in primary of the transformer.

- If n ($= N_p/N_s$) is the turn ratio of the transformer, then, $R'_L = n^2 R_L$.
- d.c. power input, $P_{dc} = V_{CC}\ I_C = I^2_C R'_L$ (∵ $V_{CC} = I_C R'_L$)
- Max. a.c. output power, $P_{o(max)} = \frac{V_{ce(p-p)} \times i_{c(p-p)}}{8} = \frac{2V_{CC} \times 2I_C}{8} = \frac{1}{2} V_{CC}\ I_C = \frac{1}{2} I^2_C R'_L \ldots$ (i) (∵ $V_{CC} = I_C R'_L$)

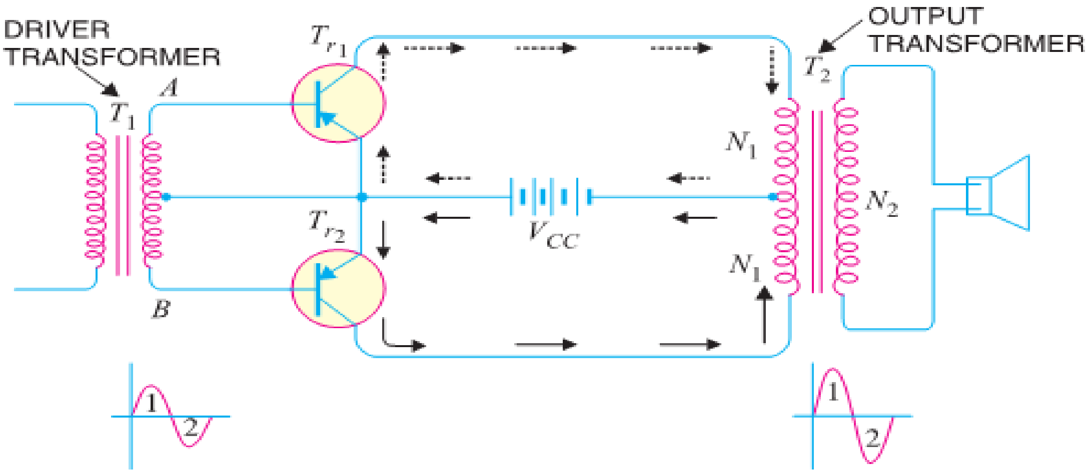
$$\therefore \quad \text{Max. Collector } \eta = \frac{P_{O\,(max)}}{P_{dc}} \times 100 = \frac{\left(\frac{1}{2}\right) I_C^2 R'_L}{I_C^2 R'_L} \times 100 = \mathbf{50\%}$$

IMPORTANT POINTS ABOUT CLASS-A POWER AMPLIFIER : -

- **(i)** A Transformer coupled class A power amplifier has a maximum collector efficiency of 50% i.e., maximum of 50% d.c. supply power is converted into a.c. power output.
- In practice, the efficiency of such an amplifier is less than 50% (about 35%) due to power losses in the output transformer, power dissipation in the transistor etc.
- **(ii)** The power dissipated by a transistor is given by : $P_{dis} = P_{dc} - P_{ac}$

  Where Pdc= available d.c. power & P_{ac} = available a.c. power
- So, In class A operation, Transistor must dissipate less heat when signal is applied therefore runs cooler.
- **(iii)** When no signal is applied to a class A power amplifier, $P_{ac} = 0$. ∴ P_{dis}= Pdc
- Thus in class A operation, maximum power dissipation in the transistor occurs under zero signal conditions.
- Therefore, the power dissipation capability of a power transistor (for class A operation) must be at least equal to the zero signal rating.
- **(iv)** When a class A power amplifier used in final stage, it is called single ended class A power amplifier.

PUSH-PULL AMPLIFIER : -



- The push-pull amplifier is a power amplifier and is frequently employed in the output stages of electronic circuits. It is used whenever high output power at high efficiency is required. Fig. shows the circuit of a push-pull amplifier.
- Two transistors T_{r1} and T_{r2} placed back to back are employed. Both transistors are operated in class B operation i.e. collector current is nearly zero in the absence of the signal.
- The centre tapped secondary of driver transformer T_1 supplies equal and opposite voltages to the base circuits of two transistors. The output transformer T_2 has the centre-tapped primary winding. The supply voltage V_{CC} is connected between the bases and this centre tap.
- The loudspeaker is connected across the secondary of this transformer.

CIRCUIT OPERATION.

- The input signal appears across the secondary AB of driver transformer. Suppose during the first half-cycle (marked 1) of the signal, end A becomes positive and end B negative.
- This will make the base-emitter junction of T_{r1} reverse biased and that of T_{r2} forward biased. The circuit will conduct current due to T_{r2} only and is shown by solid arrows.
- Therefore, this half-cycle of the signal is amplified by T_{r2} and appears in the lower half of the primary of output transformer. In the next half cycle of the signal, T_{r1} is forward biased whereas T_{r2} is reverse biased. Therefore, T_{r1} conducts and is shown by dotted arrows.
- Consequently, this half-cycle of the signal is amplified by T_{r1} and appears in the upper half of the output transformer primary. The centre-tapped primary of the output transformer combines two collector currents to form a sine wave output in the secondary.
- It may be noted here that push-pull arrangement also permits a maximum transfer of power to the Load through impedance matching. If R_L is the resistance appearing across secondary of output transformer, then resistance R'_L of primary shall become:

$$\mathbf{R'_L = \left(\frac{2N_1}{N_2}\right)^2 R_L}$$

Where N_1 = Number of turns between either end of primary winding and centre-tap
N_2 = Number of secondary turns

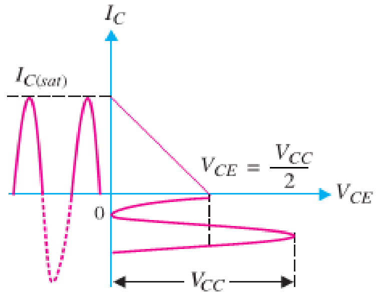
ADVANTAGES

1) The efficiency of the circuit is quite high (≈75%) due to class B operation.
2) A high a.c. output power is obtained.

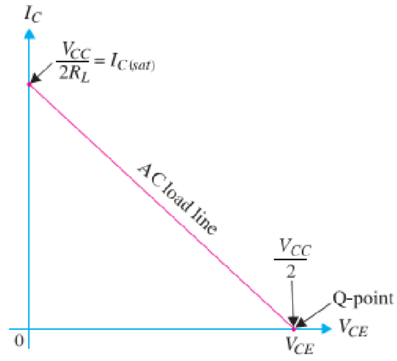
DISADVANTAGES

1) Two transistors have to be used.
2) It requires two equal and opposite voltages at the input. Therefore, push-pull circuit requires the use of driver stage to furnish these signals.
3) If the parameters of the two transistors are not the same, there will be unequal amplification of the two halves of the signal.
4) The circuit gives more distortion.
5) Transformers used are bulky and expensive.

MAXIMUM EFFICIENCY FOR CLASS B POWER AMPLIFIER



- We have already seen that a push-pull circuit uses two transistors working in class B operation. For class B operation, the Q-point is located at cut-off on both d.c. and a.c. load lines.
- For maximum signal operation, the two transistors in class B amplifier are alternately driven from cut-off to saturation. This is shown in Fig. (i). It is clear that a.c. output voltage has a peak value of V_{CE} and a.c. output current has a peak value of $I_{C(sat)}$.
- The same information is also conveyed through the a.c. load line for the circuit [See Fig. (ii)].



$\therefore$ Peak a.c. output voltage = V_{CE}

Peak a.c. output current = $I_{C(sat)} = \frac{V_{CE}}{R_L} = \frac{V_{CC}}{2R_L}$ $\quad (\because V_{CE} = \frac{V_{CC}}{2})$

- Maximum average a.c. output power $P_{o\ (max)}$ is the Product of r.m.s. values of a.c. output voltage and a.c. output current

$$= \frac{V_{CE}}{\sqrt{2}} \times \frac{I_{C(sat)}}{\sqrt{2}} = \frac{V_{CE} I_{C(sat)}}{2} = \frac{V_{CC}}{2} \times \frac{I_{C(sat)}}{2} = \frac{V_{CC} I_{C(sat)}}{4} \quad (\because V_{CE} = \frac{V_{CC}}{2})$$

$$\therefore \quad \mathbf{P_{o(max)} = 0.25\ V_{CC} I_{C(sat)}}$$

- The input d.c. power from the supply V_{CC} is $\mathbf{P_{dc} = V_{CC}\ I_{dc}}$
  Where I_{dc} is the average current drawn from the supply V_{CC}.
- Since the transistor is on for alternating half cycles, it effectively acts as a half-wave rectifier.

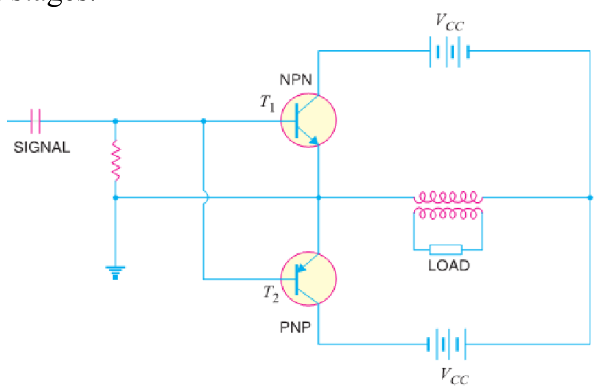
$$\therefore \quad I_{dc} = \frac{I_{C(sat)}}{\pi} \quad \rightarrow \quad P_{dc} = \frac{V_{CE} I_{C(sat)}}{\pi}$$

$$\therefore \quad \text{Max. Collector } \eta = \frac{P_{o\ (max)}}{P_{dc}} = \frac{0.25 V_{CC} I_{C(sat)}}{(V_{CC} I_{C\ (sat)})/\pi} \times 100 = 0.25\pi \times 100 = \mathbf{78.5\ \%}$$

- Thus the maximum collector efficiency of class B power amplifier is 78.5%. Recall that maximum collector efficiency for class A transformer coupled amplifier is 50%.

COMPLEMENTARY-SYMMETRY AMPLIFIER

- By complementary symmetry is meant a principle of assembling push-pull class B amplifier without requiring centre-tapped transformers at the input and output stages.



- Fig. shows the transistor push-pull amplifier using complementary symmetry. It employs one npn and one pnp transistor and requires no centre-tapped transformers.
- The circuit action is as follows. During the positive-half of the input signal, transistor T_1 (the npn transistor) conducts current while T_2(the pnp transistor) is cutoff.
- During the negative half-cycle of the signal, T_2 conducts while T_1 is cut off. In this way, npn transistor amplifies the positive half-cycles of the signal while the pnp transistor amplifies the negative half-cycles of the signal.
- Note that we generally use an output transformer (not centre-tapped) for impedance matching.

Advantages: - (1) This circuit does not require transformer. This saves on weight and cost.
(2) Equal and opposite input signal voltages are not required.

Disadvantages:- (1) It is difficult to get a pair of transistors (npn & pnp) having similar characteristics.
(2) We require both positive and negative supply voltages.

HEAT SINK: -

- As power transistors handle large currents, they always heat up during operation. Since transistor is a temperature dependent device, the heat must be dissipated to the surroundings to keep the temperature within allowed limits.
- Usually transistor is fixed on Aluminum metal sheet so that additional heat is transferred to the Al sheet.
- The metal sheet that serves to dissipate the additional heat from power transistor is known as **Heat Sink.**

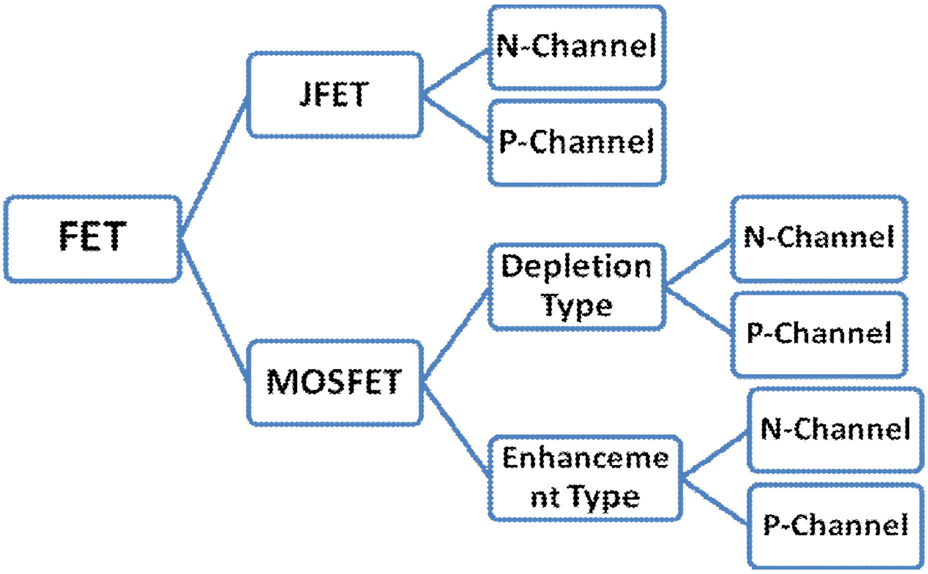
[CHAPTER-5]

--------------------------- [FIELD EFFECT TRANSISTOR (FET)] -------------------------

❖ INTRODUCTION: -

- In the previous chapters, we have discussed the circuit applications of an ordinary transistor. In this type of transistor, both holes and electrons play part in the conduction process. For this reason, it is sometimes called a **Bipolar Transistor.**
- The ordinary or bipolar transistor has two principal disadvantages. **First**, it has low input impedance because of forward biased emitter junction. **Secondly**, it has considerable noise level.
- Although low input impedance problem may be improved by careful design and use of more than one transistor, yet it is difficult to achieve input impedance more than a few mega ohms.
- The field effect transistor (FET) has, by virtue of its construction and biasing, large input impedance which may be more than 100 mega ohms.
- The FET is generally much less noisy than the ordinary or bipolar transistor. The rapidly expanding FET market has led many semiconductor marketing managers to believe that this device will soon become the most important electronic device, primarily because of its integrated-circuit applications.

❖ CLASSIFICATION OF FIELD EFFECT TRANSISTORS: -



❖ Other types of C-MOS also There Such as: -**CMOS, VMOS, LDMOS** etc.

❖ DIFFERENTIATION BETWEEN BJT & FET : -

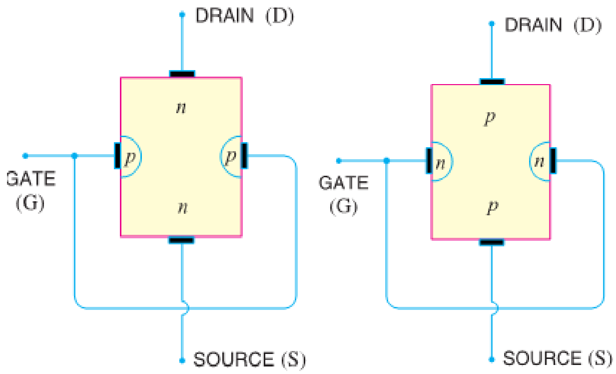
FET	BJT
✘ It means **Field Effect Transistor**	✘ Means **Bipolar Junction Transistor**
✘ Its three terminals are **Source, Gate & Drain**	✘ Its terminals are **Emitter, Base & Collector.**
✘ It is **Unipolar** devices i.e. Current in the device is carried either by electrons or holes.	✘ It is **Bipolar** devices i.e. Current in the device is carried by both electrons and holes.
✘ It is **Voltage controlled device.** i.e. Voltage at the gate or drain terminal controls the amount of current flowing through the devices.	✘ It is **Current controlled device.** i.e. Base Current controls the amount of collector current flowing through the devices.
✘ It has very High Input Resistance and Low Output Resistance.	✘ It has very Low Input Resistance and High Output Resistance.
✘ Low noisy operation	✘ High noisy operation
✘ It is Longer Life & High Efficiency.	✘ It is Shorter Life & Low Efficiency.
✘ It is much simpler to fabricate as IC and occupies less space on IC.	✘ It is comparatively difficult to fabricate as IC and occupies more space on IC then FET.
✘ It has Small gain bandwidth product.	✘ It has Large gain bandwidth product.
✘ It has higher switching speed.	✘ It has higher switching speed.

❖ JUNCTION FIELD EFFECT TRANSISTOR (JFET) : -

- A junction field effect transistor is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes.
- In a JFET, the current conduction is either by electrons or holes and is controlled by means of an electric field between the gate electrode and the conducting channel of the device.
- The JFET has high input impedance and low noise level.

❖ CONSTRUCTIONAL DETAILS.

- A JFET consists of a p-type or n-type silicon bar containing two pn junctions at the sides as shown in Fig.
- The bar forms the conducting channel for the charge carriers. If the bar is of n-type, it is called n-channel JFET as shown in Fig (i) and if the bar is of p-type, it is called a p-channel JFET as shown in Fig (ii).
- The two pn junctions forming diodes are connected internally & a common terminal called **gate** is taken out.

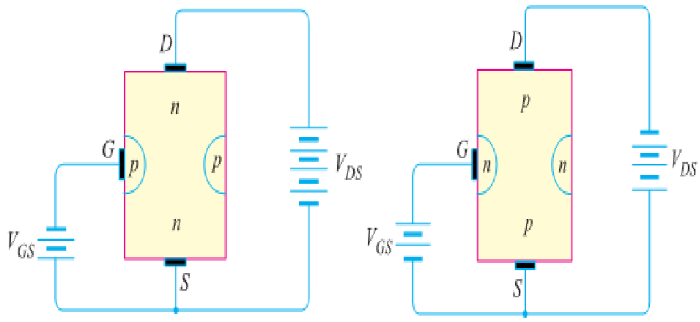


n-Channel JFET *p-Channel JFET*

- Other terminals are **source** and **drain** taken out from the bar as shown. Thus a JFET has essentially three terminals viz., Gate (G), Source (S) & Drain (D).

❖ JFET POLARITIES: -

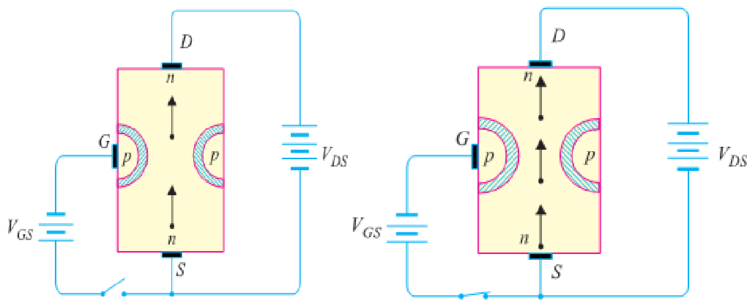
- Fig (i) shows n-channel JFET polarities whereas Fig (ii) shows the p-channel JFET polarities.
- Note that in each case, voltage between gate and source is such that the gate is reversing biased.
- This is the normal way of JFET connection.
- The drain & source terminals are interchangeable i.e., either end can be used as source and the other end as drain.



- The following points may be noted:
  - ♣ The input circuit (i.e. gate to source) of a JFET is reverse biased. This means that the device has high input impedance.
  - ♣ The drain is so biased w.r.t. source that drain current I_D flows from the source to drain.
  - ♣ In all JFETs, source current I_S is equal to the drain current i.e. $I_S = I_D$.

❖ WORKING PRINCIPLE OF JFET:-

- **Principle: -** Fig. shows the circuit of n-channel JFET with normal polarities. Note that the gate is reverse biased.
- The two pn junctions at the sides form two depletion layers. The current conduction by charge carriers (i.e. free electrons in this case) is through the channel between the two depletion layers and out of the drain.

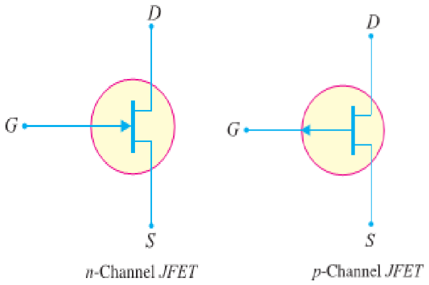


- The width and hence resistance of this channel can be controlled by changing the input voltage V_{GS}.
- The greater the reverse voltage V_{GS}, the wider will be the depletion layers and narrower will be the conducting channel. The narrower channel means greater resistance and hence source to drain current decreases. Reverse will happen should V_{GS} decrease.
- Thus JFET operates on the principle that width and hence resistance of the conducting channel can be varied by changing the reverse voltage V_{GS}.
- In other words, the magnitude of drain current (I_D) can be changed by altering V_{GS}.

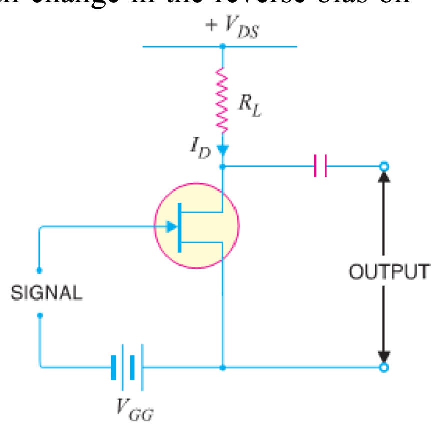
Working: - The working of JFET is as under :

- **(i)** When voltage V_{DS} is applied between drain & source terminals and voltage on the gate is zero [See the above Fig (i)], the two pn junctions at the sides of the bar establish depletion layers.
- The electrons will flow from source to drain through a channel between the depletion layers.
- The size of these layers determines width of the channel & hence the current conduction through the bar.
- **(ii)** When a reverse voltage V_{GS} is applied between the gate and source [See Fig (ii)], the width of the depletion layers is increased.
- This reduces the width of conducting channel, thereby increasing the resistance of n-type bar. Consequently, the current from source to drain is decreased.
- On the other hand, if the reverse voltage on the gate is decreased, the width of the depletion layers also decreases. This increases the width of the conducting channel and hence source to drain current.
- It is clear from the above discussion that current from source to drain can be controlled by the application of potential (i.e. electric field) on the gate.
- For this reason, the device is called field effect transistor. It may be noted that a p-channel JFET operates in the same manner as an n-channel JFET except that channel current carriers will be the holes instead of electrons and the polarities of V_{GS} and V_{DS} are reversed.

❖ JFET AS AN AMPLIFIER :-

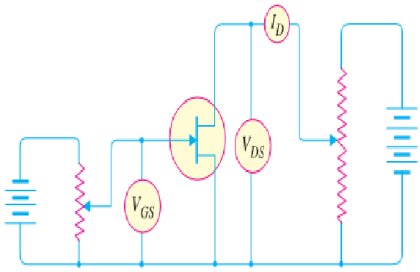


- Fig shows JFET amplifier circuit. The weak signal is applied between gate and source and amplified output is obtained in the drain-source circuit. For the proper operation of JFET, the gate must be negative w.r.t. source i.e., input circuit should always be reverse biased.
- This is achieved either by inserting a battery V_{GG} in the gate circuit or by a circuit known as biasing circuit.
- In the present case, we are providing biasing by the battery V_{GG}. A small change in the reverse bias on the gate produces a large change in drain current.

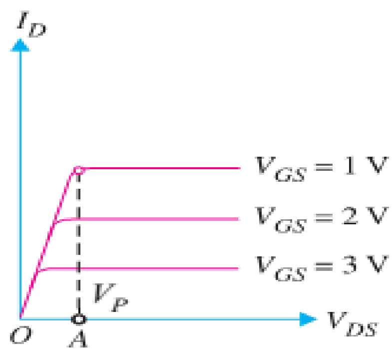


- This fact makes JFET capable of raising the strength of a weak signal. During the positive half of signal, the reverse bias on the gate decreases. This increases the channel width and hence the drain current.
- During the negative half-cycle of the signal, the reverse voltage on the gate increases. Consequently, the drain current decreases.
- The result is that a small change in voltage at the gate produces a large change in drain current.
- These large variations in drain current produce large output across the load R_L. In this way, JFET acts as an amplifier

❖ OUTPUT CHARACTERISTICS OF JFET



- The curve between drain current (I_D) and drain-source voltage (V_{DS}) of a JFET at constant gate source voltage (V_{GS}) is known as output characteristics of JFET.
- Fig shows circuit for determining output characteristics of JFET.
- Keeping V_{GS} fixed at some value, say 1V, the drain source voltage is changed in steps.
- Corresponding to each value of V_{DS}, the drain current I_D is noted.
- A plot of these values gives output characteristic of JFET at V_{GS}= 1V.
- Repeating similar procedure, output characteristics at other gate-source voltages can be drawn. Fig. shows a family of output characteristics.



The following points may be noted from the characteristics:

- **(i)** At first, the drain current I_D rises rapidly with drain-source voltage V_{DS} but then becomes constant.
- The drain-source voltage above which drain current becomes constant is known as pinch off voltage. Thus in Fig. OA is the pinch off voltage V_P.

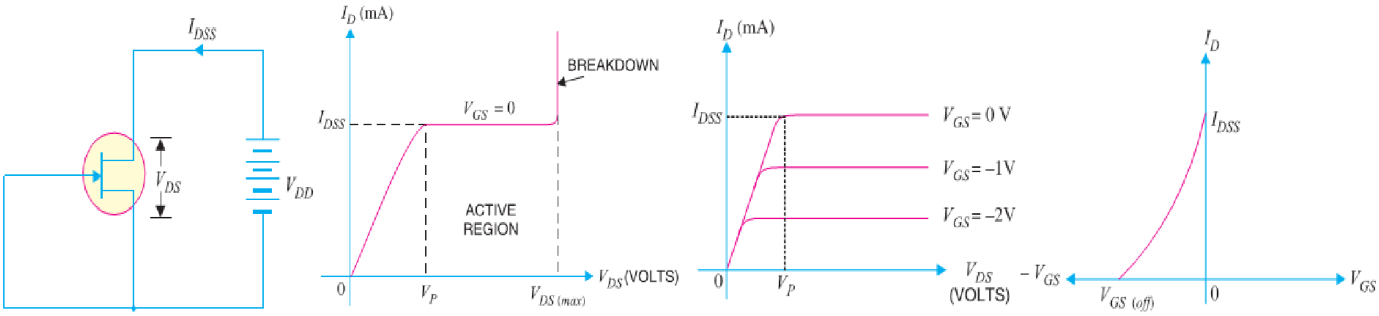
(ii) After pinch off voltage, channel width becomes so narrow that depletion layers almost touch each other.

- The drain current passes through the small passage between these layers.
- Thus increase in drain current is very small with V_{DS} above pinch off voltage.
- Consequently, drain current remains constant. The characteristics resemble that of a pentode valve.

SALIENT FEATURES OF JFET : -

- The following are some salient features of JFET:
  - **(i)** A JFET is a three-terminal voltage-controlled semiconductor device i.e. input voltage controls the output characteristics of JFET.
  - **(ii)** The JFET is always operated with gate-source pn junction reverse biased.
  - **(iii)** In a JFET, the gate current is zero i.e. I_G= 0A. **(iv)** Since there is no gate current, I_D= I_S
  - **(v)** The JFET must be operated between V_{GS} and V_{GS} (off). For this range of gate-to-source voltages, I_D will vary from a maximum of I_{DSS} to a minimum of almost zero.
  - **(vi)** As two gates are the same potential, both depletion layers widen or narrow by an equal amount.
  - **(vii)** The JFET is not subjected to thermal runaway when the temperature of the device increases.
  - **(viii)** The drain current I_D is controlled by changing the channel width.
  - **(ix)** Since JFET has no gate current, there is no β rating of the device. We can find drain current I_D

IMPORTANT TERMS : -



1. Shorted-Gate Drain Current (I_{DSS}): -

- It is the drain current with source short-circuited to gate (i.e. V_{GS} = 0) and drain voltage (V_{DS}) equal to pinch off voltage. It is sometimes called zero-bias current.

2. Pinch Off Voltage (V_P) : -

- It is the minimum drain-source voltage at which the drain current essentially becomes constant.

3. Gate-Source Cut Off Voltage V_{GS} (off): -

- It is the gate-source voltage where the channel is completely cut off and the drain current becomes zero.

PARAMETERS OF JFET: -

- Like vacuum tubes, a JFET has certain parameters which determine its performance in a circuit. The main parameters of JFET are: - **(i)** A.C. drain resistance **(ii)** Transconductance **(iii)** Amplification factor.
- **(i) A.C. Drain Resistance (r_d).** Corresponding to the a.c. plate resistance, we have a.c. drain resistance in a JFET. It may be defined as follows :
- It is the ratio of change in drain-source voltage (ΔV_{DS})to the change in drain current(ΔI_D) at constant gate-source voltage i.e.

$$\textbf{A.C. Drain Resistance, } r_d = \frac{\Delta V_{DS}}{\Delta I_D} \textbf{ at constant } V_{GS}$$

- For instance, if a change in drain voltage of 2 V produces a change in drain current of 0.02 mA, then, a.c. drain resistance, $r_d = \frac{2V}{0.02\ mA} = 100\ k\Omega$
- Referring to the output characteristics of a JFET in Fig., it is clear that above the pinch off voltage, the change in I_D is small for a change in V_{DS} because the curve is almost flat.
- Therefore, drain resistance of a JFET has a large value, ranging from 10 kΩ to 1 MΩ.
- **(ii) Transconductance (g_{fs}) : -**The control that the gate voltage has over the drain current is measured by transconductance g_{fs} & is similar to the transconductance g_m of the tube. It may be defined as follows :
- It is the ratio of change in drain current (ΔI_D) to the change in gate-source voltage(ΔV_{GS}) at constant drain-source voltage i.e.

$$\textbf{Transconductance, } g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}} \textbf{ at constant } V_{DS}$$

- The transconductance of a JFET is usually expressed either in mA/volt or micro mho. As an example, if a change in gate voltage of 0.1 V causes a change in drain current of 0.3 mA, then, Transconductance,
  ➔ $g_{fs} = \frac{0.3\text{ mA}}{0.1\text{ V}} = 3\text{mA/V} = 3\times10^{-3}$ A/V or mho or S(Siemens)$=3\times10^{-3} \times 10^{6}$ μ mho = 3000 μ mho (or μS)

♣ **(iii) <u>Amplification Factor</u> (μ).** It is the ratio of change in drain-source voltage (ΔV_{DS}) to the change in gate-source voltage(ΔV_{GS}) at constant drain current i.e.

$$\textbf{Amplification Factor, } \mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \textbf{ at constant } I_D$$

- Amplification factor of a JFET indicates how much more control the gate voltage has over drain current than has the drain voltage.
- For instance, if the amplification factor of a JFET is 50, it means that gate voltage is 50 times as effective as the drain voltage in controlling the drain current.

❖ RELATION AMONG JFET PARAMETERS: -

- The relationship among JFET parameters can be established as under :

We know $\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$

- Multiplying the numerator and denominator on R.H.S. by ΔI_D, we get,

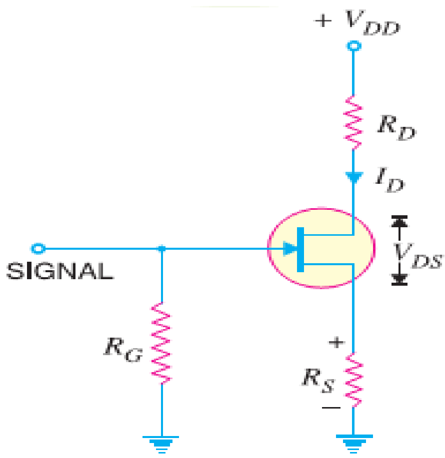
$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \times \frac{\Delta I_D}{\Delta I_D} = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}} \quad ➔ \quad \mu = r_d \times g_{fs}$$

➔ **Amplification Factor = A.C. Drain Resistance × Transconductance**

❖ JFET BIASING: -

- For the proper operation of n-channel JFET, gate must be negative w.r.t. source. This can be achieved either by inserting a battery in the gate circuit or by a circuit known as biasing circuit.
- The latter method is preferred because batteries are costly and require frequent replacement.
  1. Bias battery: - In this method, JFET is biased by a bias battery V_{GG}. This battery ensures that gate is always negative w.r.t. source during all parts of the signal.
  2. Biasing circuit: -The biasing circuit uses supply voltage V_{DD} to provide the necessary bias. Two most commonly used methods are **(i) Self-Bias (ii) Potential Divider Method**.

❖ SELF-BIAS FOR JFET : -



- Fig shows the self-bias method for n-channel JFET. The resistor RS is the bias resistor.
- The d.c. component of drain current flowing through R_S produces the desired bias voltage.

Voltage across R_S, $V_S = I_D R_S$

- Since gate current is negligibly small, the gate terminal is at d.c. ground i.e., $V_G = 0$.

$\therefore \quad V_{GS} = V_G - V_S = 0 - I_D R_S \quad$ or $\quad V_{GS} = - I_D R_S$

- Thus bias voltage V_{GS} keeps gate negative w.r.t. source.

Operating point: -

- The operating point (i.e., zero signals I_D & V_{DS}) can be easily determined. Since the parameters of the JFET are usually known, zero signal I_D can be calculated from the following relation :

$$I_D = I_{DSS}\left(1 - \frac{\Delta V_{GS}}{\Delta V_{GS(off)}}\right)^2$$

Also $\quad V_{DS} = V_{DD} - I_D (R_D + R_S)$

- Thus d.c. conditions of JFET amplifier are fully specified i.e. operating point for the circuit is (V_{DS}, I_D).

Also, $\quad R_S = \frac{|V_{GS}|}{|I_D|}$

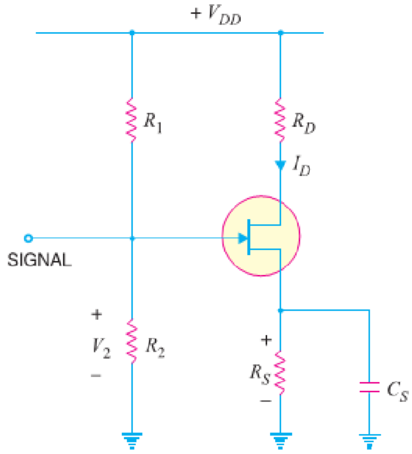
- Note that gate resistor R_G does not affect bias because voltage across it is zero.

- **Midpoint Bias: -** It is often desirable to bias a JFET near the midpoint of its transfer characteristic curve where $I_D = I_{DSS}/2$. When signal is applied, the midpoint bias allows a maximum amount of drain current swing between I_{DSS} and 0.
- It can be proved that when $V_{GS} = V_{GS(off)} / 3.4$, midpoint bias conditions are obtained for I_D.

$$I_D = I_{DSS}\left(1 - \frac{\Delta V_{GS}}{\Delta V_{GS(off)}}\right)^2 = I_{DSS}\left(1 - \frac{\Delta V_{GS(off)}/3.4}{\Delta V_{GS(off)}}\right)^2 = 0.5\ I_{DSS}$$

- To set drain voltage at midpoint ($V_D = V_{DD}/2$), select a value of R_D to produce the desired voltage drop.

JFET with Voltage-Divider Bias :-



- Fig shows potential divider method of biasing a JFET. This circuit is identical to that used for a transistor.
- The resistors R_1 and R_2 form a voltage divider across drain supply V_{DD}. The voltage V_2 (= V_G) across R_2 provides the necessary bias.

$$V_2 = V_G = \frac{V_{DD}}{R_1 + R_2} \times R_2$$

Now $\quad V_2 = V_{GS} + I_D R_S \quad$ Or $\quad \mathbf{V_{GS} = V_2 - I_D R_S}$

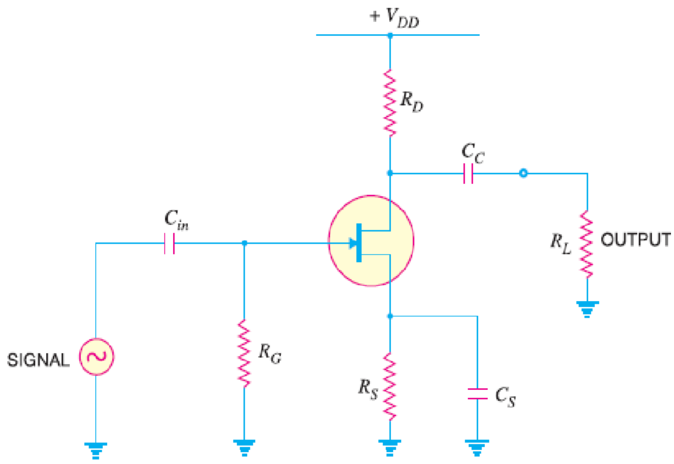
- The circuit is so designed that $I_D R_S$ is larger than V_2 so that V_{GS} is negative. This provides correct bias voltage. We can find the operating point as under:

$$I_D = \frac{V_2 - V_{GS}}{R_S} \quad \text{and} \quad V_{DS} = V_{DD} - I_D (R_D + R_S)$$

- Although the circuit of voltage-divider bias is a bit complex, yet the advantage of this method of biasing is that it provides good stability of the operating point.
- The input impedance Z_i of this circuit is given by ; $\quad Z_i = R_1 \| R2$

JFET Connections: -

- There are three leads in a JFET viz., source, gate and drain terminals. However, when JFET is to be connected in a circuit, we require four terminals; two for the input and two for the output.
- This difficulty is overcome by making one terminal of the JFET common to both input and output terminals. Accordingly, a JFET can be connected in a circuit in the following three ways:
  - Common Source connection
  - Common Gate connection
  - Common Drain connection
- The common source connection is the most widely used arrangement. It is because this connection provides high input impedance, good voltage gain and moderate output impedance.



COMMON SOURCE CONNECTION

- However, the circuit produces a phase reversal i.e., output signal is 180° out of phase with the input signal. Fig. shows a common source n-channel JFET amplifier.
- Note that source terminal is common to both input and output.

JFET Applications : -

- The high input impedance and low output impedance and low noise level make JFET far superior to the bipolar transistor. Some of the circuit applications of JFET are :
  - As a Buffer amplifier
  - As Phase-shift oscillators
  - As RF amplifier

Metal Oxide Semiconductor FET (MOSFET) :-

- The main drawback of JFET is that its gate must be reverse biased for proper operation of the device i.e.it can only have negative gate operation for n-channel and positive gate operation for p-channel.

- This means that we can only decrease the width of the channel (i.e. decrease the conductivity of the channel) from its zero-bias size.
- This type of operation is referred to as depletion-mode operation. Therefore, a JFET can only be operated in the depletion-mode.
- However, there is a field effect transistor (FET) that can be operated to enhance (or increase) the width of the channel (with consequent increase in conductivity of the channel) i.e. it can have enhancement-mode operation. Such a FET is called **MOSFET.**
- A field effect transistor (FET) that can be operated in the enhancement-mode is called a **MOSFET**.
- A MOSFET is an important semiconductor device & can be used in any of the circuits covered for JFET.
- However, a MOSFET has several advantages over JFET including high input impedance and low cost.

❖ TYPES OF MOSFETS :-

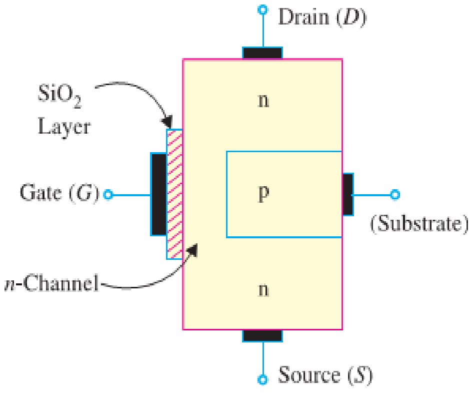
- There are two basic types of MOSFETs such as: -

1. Depletion-type MOSFET or D-MOSFET. The D-MOSFET can be operated in both the depletion mode and the enhancement-mode.
    - For this reason, a D-MOSFET is sometimes called **Depletion/Enhancement MOSFET**.

2. Enhancement-type MOSFET or E-MOSFET. The E-MOSFET can be operated only in enhancement mode. The manner in which a MOSFET is constructed determines whether it is D-MOSFET or E-MOSFET.

❖ **D-MOSFET.** Fig shows the constructional details of n-channel D-MOSFET.

- It is similar to n-channel JFET except with the following modifications/remarks :
- **(i)** The n-channel D-MOSFET is a piece of n-type material with a p-type region (called substrate) on the right and an insulated gate on the left as shown in Fig.
- The free electrons (Q it is n-channel) flowing from source to drain must pass through the narrow channel between the gate and the p-type region (i.e. substrate).
- **(ii)** Note carefully the gate construction of D-MOSFET. A thin layer of metal oxide (usually silicon dioxide, SiO_2) is deposited over a small portion of the channel.
- A metallic gate is deposited over the oxide layer. As SiO_2 is an insulator, thus gate is insulated from the channel. Note that the arrangement forms a capacitor. One plate of this capacitor is the gate and other plate is the channel with SiO_2 as dielectric. Recall that we have a gate diode in a JFET.

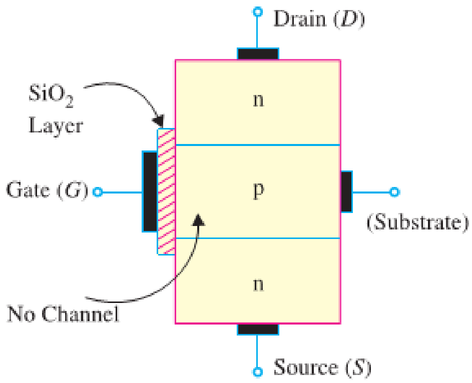


n-Channel D-MOSFET

- **(iii)** It is a usual practice to connect the substrate to the source (S) internally so that a MOSFET has three terminals viz Source (S), Gate (G) and Drain (D).
- **(iv)** Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate. Therefore, D-MOSFET can be operated in both depletion-mode and enhancement-mode. However, JFET can be operated only in depletion-mode.

❖ **E-MOSFET**. Fig shows the constructional details of n-channel E-MOSFET. Its gate construction is similar to that of D-MOSFET.

- The E-MOSFET has no channel between source and drain unlike the D-MOSFET. Note that the substrate extends completely to the SiO_2 layer so that no channel exists.
- The E-MOSFET requires a proper gate voltage to form a channel (called induced channel). It is reminded that E-MOSFET can be operated only in enhancement mode.
- In short, the construction of E-MOSFET is quite similar to that of the D-MOSFET except for the absence of a channel between the drain and source terminals.

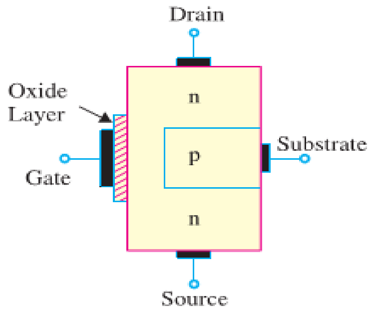


n-Channel E-MOSFET

❖ Why the name MOSFET ?

- The reader may wonder why is the device called MOSFET?

- The answer is simple. The SiO_2 layer is an insulator. The gate terminal is made of a metal conductor.
- Thus, going from gate to substrate, we have a metal oxide semiconductor and hence the name MOSFET.
- Since the gate is insulated from the channel, the MOSFET is sometimes called **insulated-gate FET** (IGFET). However, this term is rarely used in place of the term MOSFET.



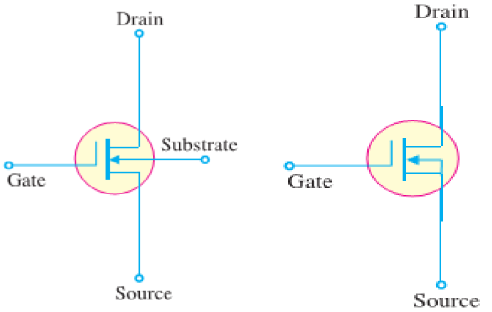
n-Channel D-MOSFET
(i)

❖ Symbols for D-MOSFET

There are two types of D-MOSFETs such as

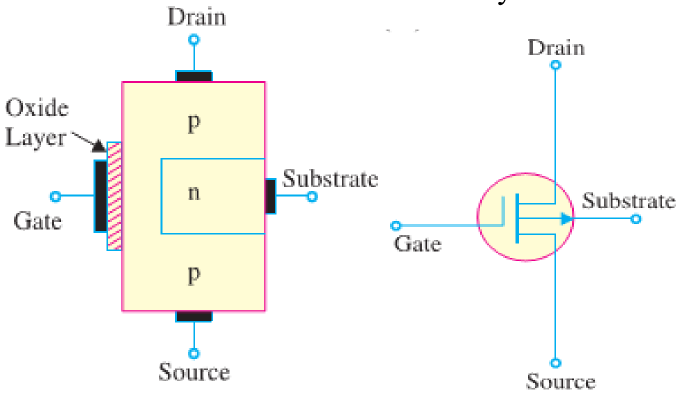
(i) n-channel D-MOSFET and **(ii)** p-channel D-MOSFET

- **(i) N-Channel D-MOSFET**. Fig (i) shows the various parts of n-channel D-MOSFET.
- The p-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side.
- Electrons flowing from source (when drain is positive w.r.t. source) must pass through this narrow channel.
- The symbol for n-channel D-MOSFET is shown in Fig (ii).
- The gate appears like a capacitor plate. Just to the right of the gate is a thick vertical line representing the channel.
- The drain lead comes out of the top of the channel and the source lead connects to the bottom.
- The arrow is on the substrate and points to the n-material; therefore we have n-channel D-MOSFET.
- It is a usual practice to connect substrate to source internally as shown in Fig. (iii).
- This gives rise to a three-terminal device.



Symbol *(ii)*   Symbol *(iii)*

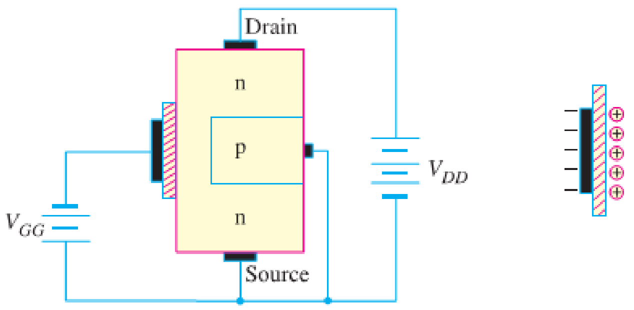
- **(ii) P-Channel D-MOSFET.** Fig (i) shows the various parts of p-channel D-MOSFET.
- The n-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side.
- The conduction takes place by the flow of holes from source to drain through this narrow channel.
- The symbol for p-channel D-MOSFET shown in Fig (ii). It is a usual practice to connect the substrate to source internally.
- This results in a three-terminal device schematic symbol is shown in Fig(iii).



p-Channel D-MOSFET *(i)*   Symbol *(ii)*   Symbol *(iii)*

❖ Circuit Operation of D-MOSFET

- Fig (i) shows the circuit of n-channel D-MOSFET. The gate forms a small capacitor. One plate of this capacitor is the gate and the other plate is the channel with metal oxide layer as the dielectric.



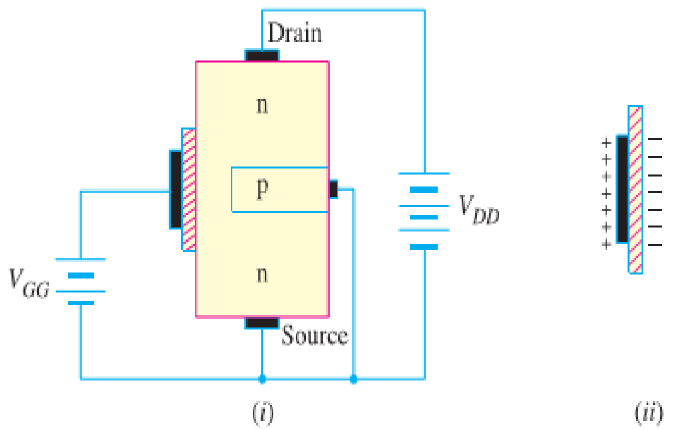
(i)   *(ii)*

- When gate voltage is changed, the electric field of the capacitor changes which in turn changes the resistance of the n-channel.
- Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate.
- The negative-gate operation is called **Depletion Mode** whereas positive gate operation is known as **Enhancement Mode**.

♣ **Depletion Mode**. Fig (i) shows depletion-mode operation of n-channel D-MOSFET. Since gate is negative, it means electrons are on the gate as shown is Fig (ii).

- These electrons repel the free electrons in the n-channel, leaving a layer of positive ions in a part of the channel as shown in Fig (ii).
- In other words, we have depleted (i.e. emptied) the n-channel of some of its free electrons. Therefore, lesser number of free electrons are made available for current conduction through the n- channel.
- This is the same thing as if the resistance of the channel is increased. The greater the negative voltage on the gate, the lesser is the current from source to drain.
- Thus by changing the negative voltage on the gate, we can vary the resistance of the n-channel and hence the current from source to drain.
- Note that with negative voltage to the gate, the action of D-MOSFET is similar to JFET.
- Because the action with negative gate depends upon depleting (i.e. emptying) the channel of free electrons, the negative-gate operation is called depletion mode.

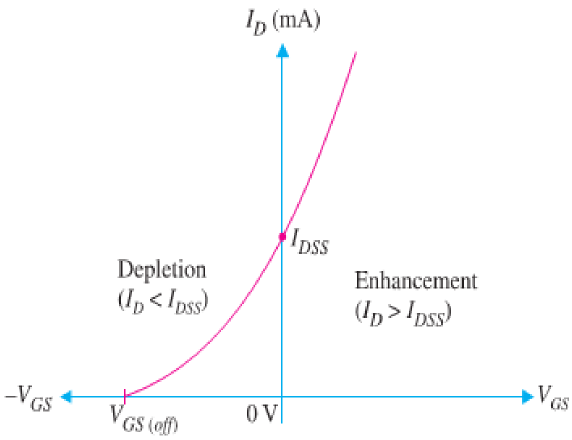
♣ **(ii) Enhancement Mode.** Fig (i) shows enhancement-mode operation of n-channel D-MOSFET. Again, the gate acts like a capacitor.



- Since the gate is positive, it induces negative charges in the n-channel as shown in Fig (ii).
- These negative charges are the free electrons drawn into the channel.
- Because these free electrons are added to those already in the channel, the total number of free electrons in the channel is increased.
- Thus a positive gate voltage enhances or increases the conductivity of the channel.
- The greater the positive voltage on the gate, greater the conduction from source to drain.
- Thus by changing the positive voltage on the gate, we can change the conductivity of the channel.
- The main difference between D-MOSFET and JFET is that we can apply positive gate voltage to D-MOSFET and still have essentially zero current.
- Because the action with a positive gate depends upon enhancing the conductivity of the channel, the positive gate operation is called enhancement mode.

♣ **The following points may be noted about D-MOSFET operation: -**

- **(i)** In D-MOSFET, source to drain current is controlled by electric field of capacitor formed at the gate.
- **(ii)** The gate of JFET behaves as a reverse-biased diode whereas the gate of a D-MOSFET acts like a capacitor. For this reason, it is possible to operate D-MOSFET with positive or negative gate voltage.
- **(iii)**As the gate of D-MOSFET forms a capacitor, therefore, negligible gate current flows whether positive or negative voltage is applied to the gate.
- For this, the input impedance of D-MOSFET is very high, ranging from 10,000 MΩ to 10, 000, 00 MΩ.
- **(iv)** The extremely small dimensions of the oxide layer under the gate terminal result in a very low capacitance and the D-MOSFET has, therefore, a very low input capacitance.
- This characteristic makes the D-MOSFET useful in high-frequency applications.

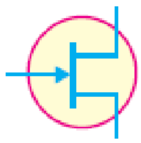
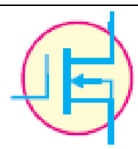
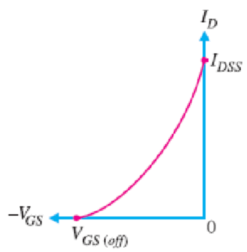
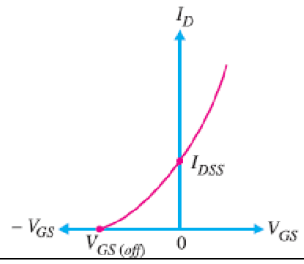


❖ D-MOSFET Transfer Characteristic : -

- Fig shows the transfer characteristic curve (or transconductance curve) for n-channel D-OSFET.
- The behaviour of this device can be beautifully explained with the help of this curve as under :-
- **(i)** The point on the curve where $V_{GS} = 0$, $I_D = I_{DSS}$. It is expected because I_{DSS} is the value of I_D when gate and source terminals are shorted i.e. $V_{GS} = 0$.
- (ii) As V_{GS} goes negative, I_D decreases below value of I_{DSS} till I_D reaches zero when $V_{GS} = V_{GS(off)}$ just as with JFET.
- **(iii)**When V_{GS} is positive, I_D increases above the value of I_{DSS}. The maximum allowable value of I_D is given on the data sheet of D-MOSFET.
- Note that the transconductance curve for the D-MOSFET is very similar to the curve for a JFET.
- Because of this similarity, the JFET and the D-MOSFET have the same transconductance equation viz.

$$\mathbf{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2}$$

❖ D-MOSFET Vs JFET: -

SN	Parameters	JFETs	D-MOSFETs
1	Symbol		
2	Transconductance Curve		
3	Modes of operation:	Depletion only	Depletion and enhancement
4	Commonly Used bias circuits:	**(1)** Gate bias; **(2)** Self bias; **(3)** Voltage-divider bias;	**(1)** Gate bias; **(2)** Self bias; **(3)** Voltage-divider bias; **(4)** Zero bias
5	Advantages:	Extremely high input impedance.	**(1)** Higher input impedance than a comparable *JFET*. **(2)** Can operate in both modes (Depletion and Enhancement).
6	Disadvantages:	**(1)**Bias instability; **(2)** Can operate only in depletion mode.	**(1)** Bias instability. **(2)** More sensitive to changes in temperature than the *JFET*.

[CHAPTER-6]

[FEED BACK AMPLIFIER]

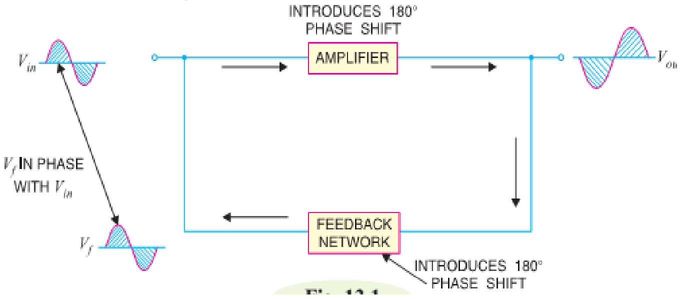
❖ INTRODUCTION:-

- A practical amplifier has a gain of nearly one million i.e. its output is one million times the input. Consequently, even a casual disturbance at the input will appear in the amplified form in the output.
- The noise in the output of an amplifier is undesirable and must be kept to as small a level as possible. The noise level in amplifiers can be reduced considerably by the use of negative feedback i.e. by injecting a fraction of output in phase opposition to the input signal.
- The object of this chapter is to consider the effects and methods of providing negative feedback in transistor amplifiers.

❖ FEEDBACK:-

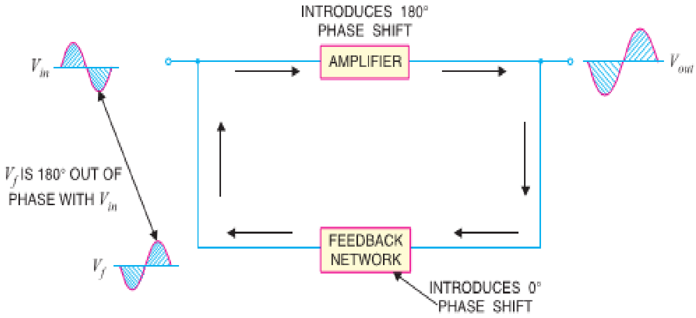
- The process of injecting a fraction of output energy of some device back to the input is known as **feedback.** Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers viz Positive Feedback and Negative Feedback.

Positive Feedback. When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback*. This is illustrated in Fig.



- Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage V_f to be in phase with the input signal V_{in}.
- The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is not often employed in amplifiers.
- One important use of positive feedback is in oscillators. If positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.

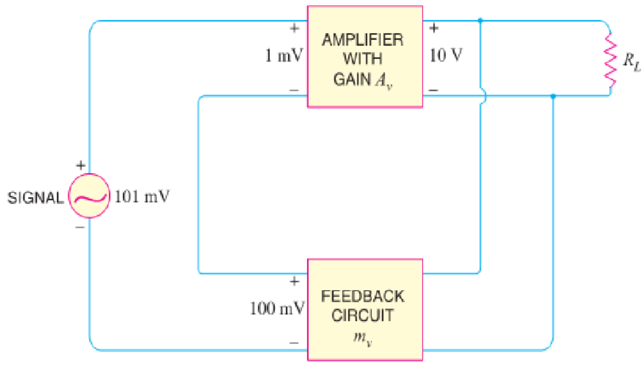
(ii) Negative Feedback. When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig.



- As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage V_f is 180° out of phase with the input signal V_{in}.
- Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances.
- It is due to these advantages that negative feedback is frequently employed in amplifiers.

❖ PRINCIPLES OF NEGATIVE VOLTAGE FEEDBACK IN AMPLIFIERS:-

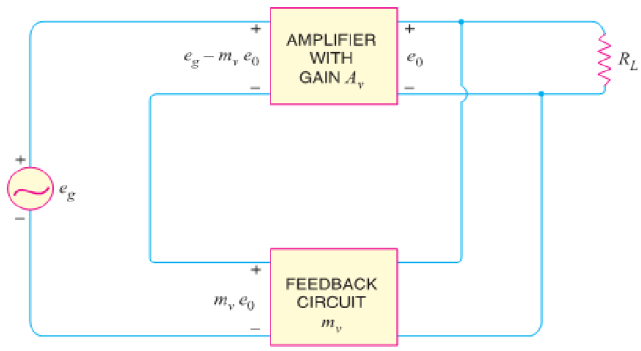
- A feedback amplifier has main two parts such as an amplifier and a feedback circuit.
- The feedback circuit usually consists of resistors and returns a fraction of output energy back to the input.
- Fig. shows the principles of negative voltage feedback in an amplifier. Typical values have been assumed to make the treatment more illustrative.
- The output of the amplifier is 10 V. The fraction m_v of this output i.e.100 mV is feedback to the input where it is applied in series with the input signal of 101 mV.



- As the feedback is negative, therefore, only 1 mV appears at the input terminals of the amplifier.
- Referring to Fig., we have,
    - Gain of amplifier without feedback, $A_v = (10\ V)/(1\ mV) = 10{,}000$
    - Fraction of output voltage feedback, $m_v = (100\ mV)/10V = 0.01$
    - Gain of amplifier with negative feedback, $A_{vf} = 10V/101mV = 100$
- The following points are worth noting:-
- When negative voltage feedback is applied, the gain of the amplifier is reduced. Thus, the gain of above amplifier without feedback is 10,000 whereas with negative feedback, it is only 100.
- When negative voltage feedback is employed, the voltage actually applied to the amplifier is extremely small. In this case, the signal voltage is 101 mV and the negative feedback is 100 mV so that voltage applied at the input of the amplifier is only 1 mV.
- In a negative voltage feedback circuit, the feedback fraction m_v is always between 0 and 1.
- The gain with feedback is sometimes called **closed-loop gain** while the gain without feedback is called ***open-loop gain***. These terms come from the fact that amplifier and feedback circuits form a "loop".
- When loop is "opened" by disconnecting feedback circuit from I/P, amplifier's gain $\mathbf{A_v}$,[open-loop gain]
- When the loop is "closed" by connecting the feedback circuit, gain decreases to $\mathbf{A_{vf}}$ ["closed-loop" gain]

GAIN OF NEGATIVE VOLTAGE FEEDBACK AMPLIFIER:-

- Consider the negative voltage feedback amplifier shown in Fig.



- The gain of the amplifier without feedback is $\mathbf{A_v}$.
- Negative feedback is then applied by feeding a fraction $\mathbf{m_v}$ of the output voltage $\mathbf{e_0}$ back to amplifier input.
- Therefore, the actual input to the amplifier is the signal voltage $\mathbf{e_g}$ minus feedback voltage $\mathbf{m_v\, e_0}$ i.e.,

Actual input to amplifier = $(e_g - m_v e_0)$

The output e_0 must be equal to the input voltage $(e_g - m_v e_0)$ multiplied by gain A_v of the amplifier i.e.

$(e_g - m_v e_0)\, A_v = e_0$ ➔ $A_v e_g - A_v\, m_v\, e_0 = e_0$

➔ $e_0 + A_v\, m_v\, e_0 = A_v e_g$ ➔ $e_0\,(1 + A_v\, m_v) = A_v e_g$

$$\frac{e_0}{e_g} = \frac{A_v}{1 + A_v m_v}$$

- But $\mathbf{e_0/e_g}$ is the voltage gain of the amplifier with feedback.

∴ Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

- It may be seen that the gain of the amplifier without feedback is A_v. However, when negative voltage feedback is applied, the gain is reduced by a factor $1 + A_v\, m_v$.
- It may be noted that negative voltage feedback does not affect the current gain of the circuit.

ADVANTAGES OF NEGATIVE VOLTAGE FEEDBACK:-

- The following are the advantages of negative voltage feedback in amplifiers:-
- **Gain Stability**. An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

- For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product $A_v m_v$ much greater than unity. Therefore, in the above relation, 1 can be neglected as compared to $A_v m_v$ and the expression becomes:

$$A_{vf} = \frac{A_v}{A_v\, m_v} = \frac{1}{m_v}$$

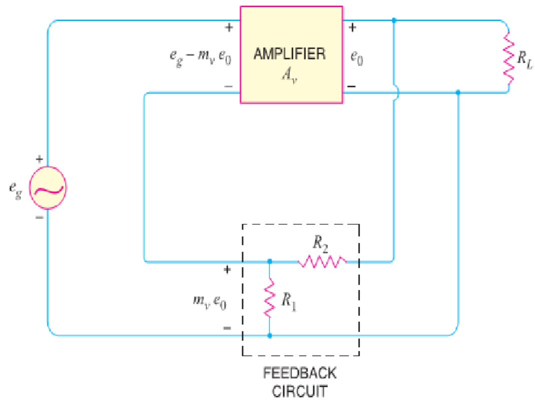
- It may be seen that the gain now depends only upon feedback fraction m_v i.e., on the characteristics of feedback circuit.

- As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.
- **(ii) Reduces non-linear Distortion.** A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers. It can be proved mathematically that:

$D_{vf} = \frac{D}{1 + A_v\, m_v}$ Where D=distortion in amplifier without feedback & D_{vf}=distortion with negative feedback

- Thus by applying negative voltage feedback to an amplifier, distortion is reduced by a factor $\mathbf{1 + A_v\, m_v}$.
- **(iii)Improves Frequency Response**. As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is independent of signal frequency. The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.
- **(iv)Increases Circuit Stability.** The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude. This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilized or accurately fixed in value. This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason. This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.
- **(v) Increases input impedance and decreases output impedance.** The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching.

❖ FEEDBACK CIRCUIT:-



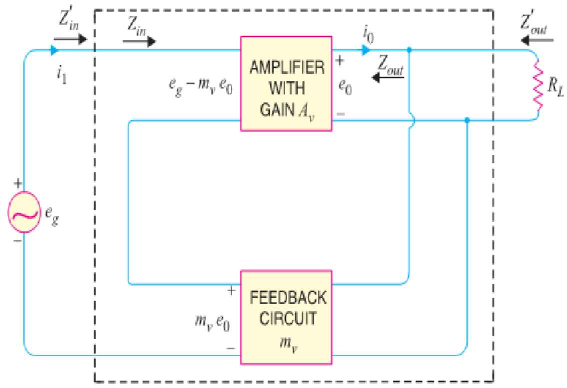
- The function of the feedback circuit is to return a fraction of the output voltage to the input of the amplifier.
- Fig. shows the feedback circuit of negative voltage feedback amplifier. It is essentially a potential divider consisting of resistances R_1 and R_2.
- The output voltage of the amplifier is fed to this potential divider which gives the feedback voltage to the input.
- Referring to Fig. it is clear that :

Voltage across $R_1 = \left(\frac{R_1}{R_1 + R_2}\right) e_0$

Feedback fraction, $m_v = \frac{\text{Voltage across } R_1}{e_0} = \frac{R_1}{R_1 + R_2}$

❖ INPUT & OUTPUT IMPEDANCE OF NEGATIVE FEEDBACK AMPLIFIER :-

- **(a) Input impedance.** The increase in input impedance with negative voltage feedback can be explained by referring to Fig. Suppose the input impedance of the amplifier is Z_{in} without feedback and Z'_{in} with negative feedback. Let us further assume that input current is i_1.



- Referring to Fig., we have,

$e_g - m_v e_0 = i_1 Z_{in}$

Now $e_g = (e_g - m_v\, e_0) + m_v\, e_0$

$= (e_g - m_v e_0) + A_v\, m_v\, (e_g - m_v e_0)$ $[\because e_0 = A_v\, (e_g - m_v e_0)]$

$= (e_g - m_v e_0)\,(1 + A_v m_v)$

$= i_1 Z_{in}\,(1 + A_v\, m_v)$ $[\because e_g - m_v\, e_0 = i_1 Z_{in}]$

Or $\frac{e_g}{i_1} = Z_{in}\,(1 + A_v\, m_v)$

But $\frac{e_g}{i_1} = Z'_{in}$, the input impedance of the amplifier with negative voltage feedback.

$$\therefore\ \mathbf{Z'_{in} = Z_{in}\,(1 + A_v\, m_v)}$$

- It is clear that by applying negative voltage feedback, the input impedance of the amplifier is increased by a factor $1 + A_v m_v$. As $A_v m_v$ is much greater than unity.
- Therefore, input impedance is increased considerably. This is an advantage, since the amplifier will now present less of a load to its source circuit.
- **(b) Output impedance.** Following similar line, we can show that output impedance with negative voltage feedback is given by :

$$\therefore \ Z'_{out} = \frac{Z_{out}}{1 + A_v m_v}$$

Where Z'_{out} = output impedance with negative voltage feedback
Z_{out} = output impedance without feedback

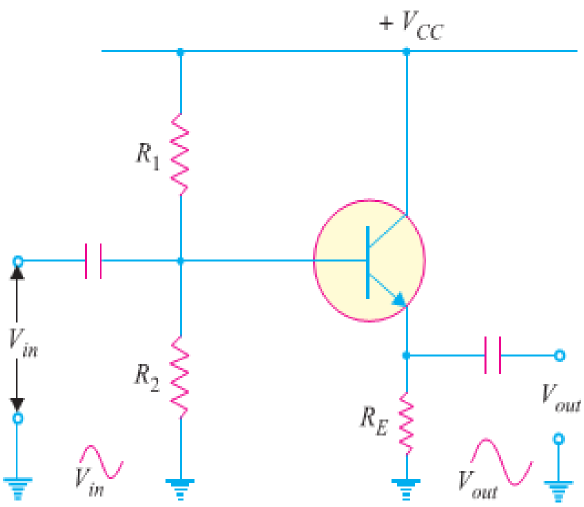
- It is clear that by applying negative feedback, the output impedance of the amplifier is decreased by a factor $1 + A_v m_v$.
- This is an added benefit of using negative voltage feedback.
- With lower value of output impedance, the amplifier is much better suited to drive low impedance loads.

EMITTER FOLLOWER:-

- It is a negative current feedback circuit. The emitter follower is a current amplifier that has no voltage gain. Its most important characteristic is that it has high input impedance and low output impedance.
- This makes it an ideal circuit for impedance matching.

Circuit Details.

- Fig. shows the circuit of an emitter follower. As we can see, it differs from the circuitry of a conventional CE amplifier by the absence of *collector load* and *emitter bypass capacitor*.
- The emitter resistance R_E itself acts as the load and a.c. output voltage (V_{out}) is taken across R_E.
- The biasing is generally provided by voltage-divider method or by base resistor method.
- The following points are worth noting about the emitter follower:
  - **(i)** There is neither collector resistor in the circuit nor there is emitter bypass capacitor.
  - **(ii)** These are the two circuit recognition features of the emitter follower.
  - **(iii)** Since the collector is at ac ground, this circuit is also known as common collector (CC) amplifier.



- **Operation.** The input voltage is applied between base and emitter and the resulting a.c. emitter current produces an output voltage $i_e R_E$ across the emitter resistance.
- This voltage opposes the input voltage, thus providing negative feedback.
- Clearly, it is a negative current feedback circuit since the voltage feedback is proportional to the emitter current i.e., output current.
- It is called **emitter follower** because the output voltage follows the input voltage.

Characteristics.

- The major characteristics of the emitter follower are:-
  - **(i)** No voltage gain. In fact, the voltage gain of an emitter follower is close to 1.
  - **(ii)** Relatively high current gain and power gain.
  - **(iii)** High input impedance and low output impedance.
  - **(iv)** Input and output ac voltages are in phase.

APPLICATIONS

- The emitter follower has the following principal applications:
  - (i) To provide current amplification with no voltage gain.
  - (ii) Impedance matching.

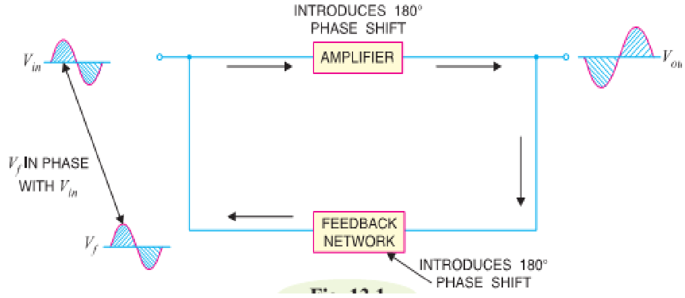
[CHAPTER-7]

[SINUSOIDAL OSCILLATOR]

❖ **FEEDBACK:-**

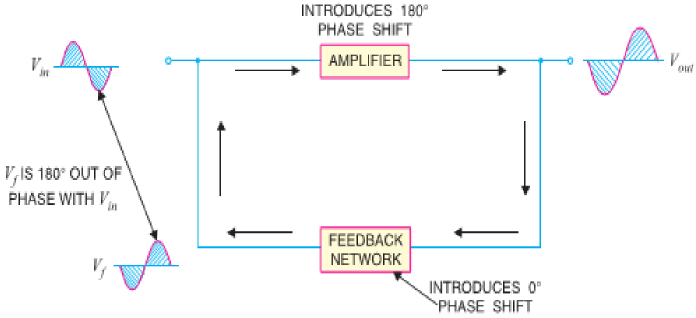
- The process of injecting a fraction of output energy of some device back to the input is known as feedback.
- Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers viz Positive Feedback and Negative Feedback.

Positive Feedback. When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback*. This is illustrated in Fig.



- Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage V_f to be in phase with the input signal V_{in}.
- The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is not often employed in amplifiers.
- One important use of positive feedback is in oscillators. If positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.

(ii) Negative Feedback. When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig.

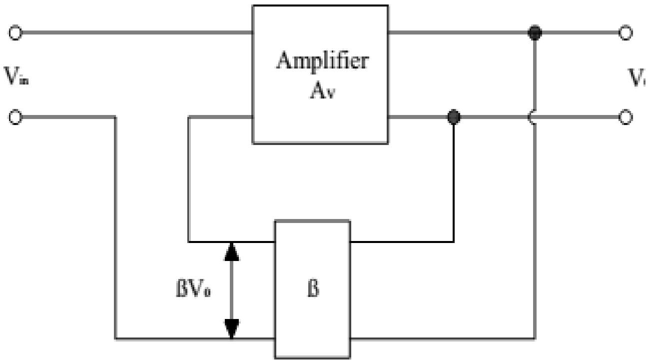


- As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage V_f is 180° out of phase with the input signal V_{in}.
- Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances.

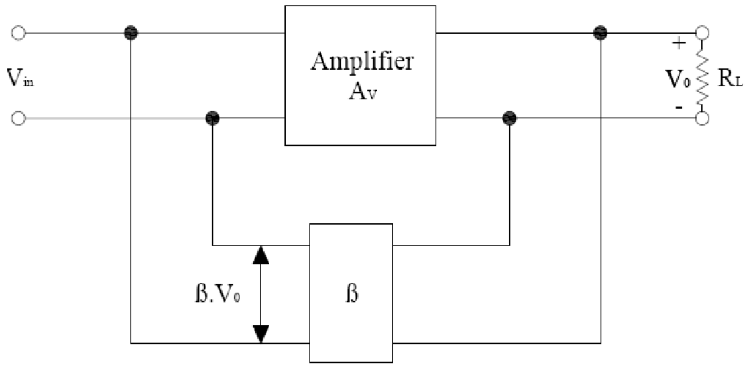
❖ It is due to these advantages that negative feedback is frequently employed in amplifiers.

❖ **<u>Types Of Feedback Connections</u>: -**

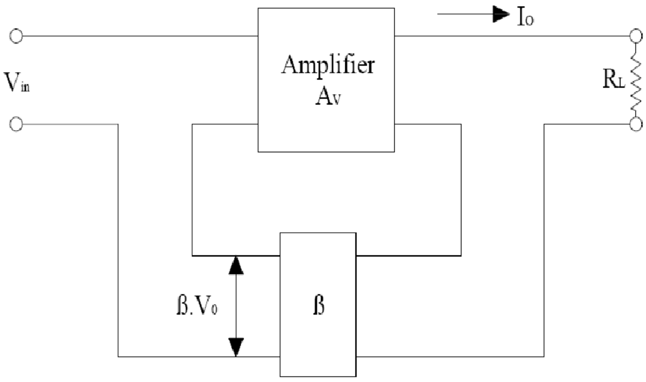
- There are four basic types of connecting the feedback signal from an amplifier output to its input : -
  - ♣ Voltage-Series feedback connection.
  - ♣ Voltage-Shunt feedback connection.
  - ♣ Current-Series feedback connection.
  - ♣ Current-Shunt feedback connection.
- It means that both voltage and current can be feedback to the input either in series or parallel.
- In the feedback connection types, the term **'voltage'** refers to connecting the output voltage as input to the feedback network.
- The term **'current'** refers to tapping off some output current through the feedback network.
- The term '**series**' refers to connecting the feedback signal in series with the input signal voltage.
- The term '**shunt**' refers to connecting the feedback signal in shunt (parallel) with an input current source.
- It has been observed that the series feedback connections tend to increase the input resistance, while the shunt feedback connection tends to decrease the input resistance.
- Moreover, the voltage feedback will tend to decrease the output resistance.
- As a matter of fact, higher input resistance and lower output resistance is desired for most cascade amplifiers.
- Both of these characteristic are obtained by using the voltage – series feedback connection.



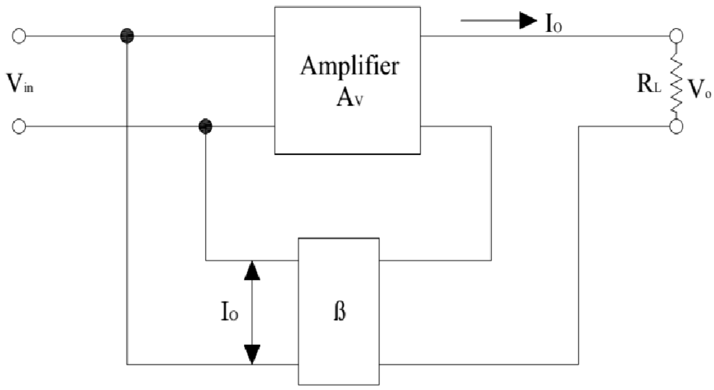
Feedback Network
[Voltage - Series Feedback Connection]



Feedback Network
[Voltage - Shunt Feedback Connection]



Feedback Network
[Current - Series Feedback Connection]



Feedback Network
[Current - Shunt Feedback Connection]

❖ **ADVANTAGES OF NEGATIVE VOLTAGE FEEDBACK:-**

- The following are the advantages of negative voltage feedback in amplifiers:-
- ♣ **(i) Gain Stability**. An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

- For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product $A_v m_v$ much greater than unity. Therefore, in the above relation, 1 can be neglected as compared to $A_v m_v$ and the expression becomes:

$$A_{vf} = \frac{A_v}{A_v\, m_v} = \frac{1}{m_v}$$

- It may be seen that the gain now depends only upon feedback fraction m_v i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.
- ♣ **(ii) Reduces non-linear Distortion.** A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers. It can be proved mathematically that:

$$D_{vf} = \frac{D}{1 + A_v\, m_v}$$

Where D = distortion in amplifier without feedback
D_{vf} = distortion in amplifier with negative feedback

- Thus by applying negative voltage feedback to an amplifier, distortion is reduced by a factor **$1 + A_v\, m_v$**.
- ♣ **(iii)Improves Frequency Response**. As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is independent of signal frequency.
- The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.

- **(iv)Increases Circuit Stability.** The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude.
- This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilized or accurately fixed in value.
- This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason.
- This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.
- **(v) Increases input impedance and decreases output impedance.** The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching.

INTRODUCTION TO OSCILLATOR,

- Many electronic devices require a source of energy at a specific frequency which may range from a few Hz to several MHz. This is achieved by an electronic device called an oscillator.
- Oscillators are extensively used in electronic equipment. For example, in radio and television receivers, oscillators are used to generate high frequency wave (called carrier wave) in the tuning stages.
- Audio frequency and radiofrequency signals are required for the repair of radio, television and other electronic equipment. Oscillators are also widely used in radar, electronic computers and other electronic devices. Oscillators can produce sinusoidal or non-sinusoidal (e.g. square wave) waves.

SINUSOIDAL OSCILLATORS:-

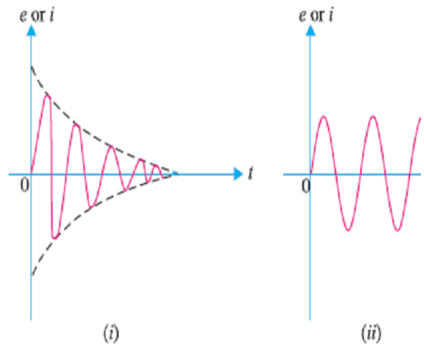
- An electronic device that generates sinusoidal oscillations of desired frequency is known as a **sinusoidal oscillator**. Although we speak of an oscillator as "generating" a frequency, it should be noted that it does not create energy, but merely acts as an energy converter.
- It receives D.C. energy and changes it into A.C. energy of our desired frequency.
- The frequency of oscillations depends upon the constants of the device. It may be mentioned here that although an alternator produces sinusoidal oscillations of 50Hz, it cannot be called an oscillator.
- **Firstly**, An alternator is a mechanical device having rotating parts whereas an oscillator is a non-rotating electronic device. **Secondly**, An alternator converts Mechanical Energy into A.C. Energy while an oscillator converts D.C. Energy into A.C. energy. **Thirdly**, An alternator cannot produce high frequency oscillations whereas an oscillator can produce oscillations ranging from a few Hz to several MHz.

ADVANTAGES

- Although oscillations can be produced by mechanical devices (e.g. alternators), but electronic oscillators have the following advantages:
- An oscillator is a non-rotating device. Consequently, there is little wear and tear and hence longer life.
- Due to the absence of moving parts, the operation of an oscillator is quite silent.
- An oscillator can produce waves from small (20 Hz) to extremely high frequencies (> 100 MHz).
- The frequency of oscillations can be easily changed when desired.
- It has good frequency stability i.e. frequency once set remains constant for a considerable period of time.
- It has very high efficiency.

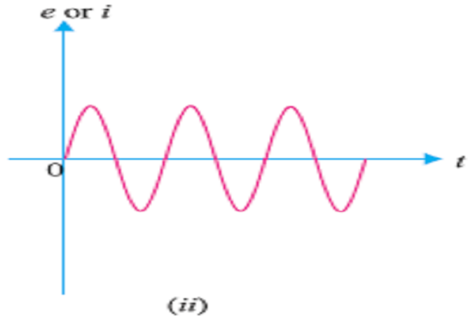
TYPES OF SINUSOIDAL OSCILLATIONS:-

- Sinusoidal oscillations can be of two types viz **Damped Oscillations** and **Undamped Oscillations**.
- **(i) Damped Oscillations**: - The electrical oscillations whose amplitude goes on decreasing with time are called damped oscillations. Fig (i) Shows waveform of damped electrical oscillations.



- Obviously, the electrical system in which these oscillations are generated has losses and some energy is lost during each oscillation.
- Further, no means are provided to compensate for the losses and consequently the amplitude of the generated wave decreases gradually. It may be noted that frequency of oscillations remains unchanged since it depends upon the constants of the electrical system.

♣ **(ii) Undamped Oscillations**. The electrical oscillations whose amplitude remains constant with time are called undamped oscillations. Fig. (ii) Shows waveform of undamped electrical oscillations.

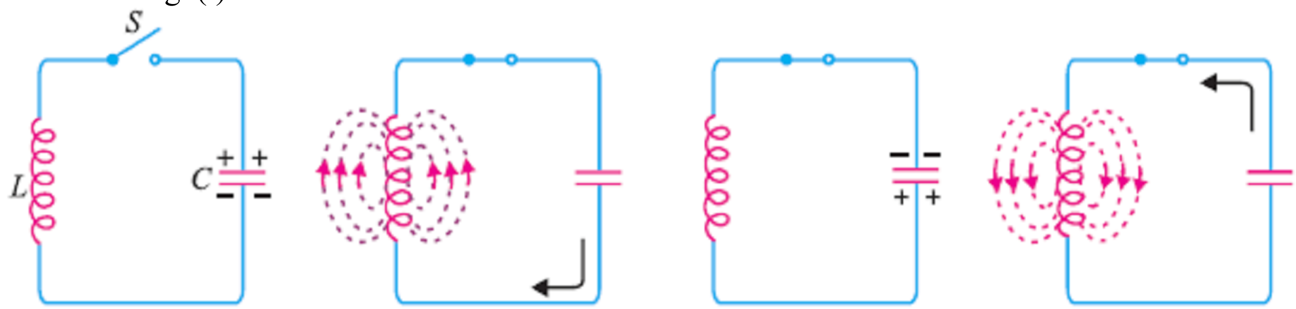


(ii)

- Although the electrical system in which these oscillations are being generated has also losses, but now right amount of energy is being supplied to overcome the losses.
- Consequently, the amplitude of the generated wave remains constant. It should be emphasized that an oscillator is required to produce undamped electrical oscillations for utilizing in various electronics equipment.

❖ **OSCILLATORY CIRCUIT: -**

- A circuit which produces electrical oscillations of any desired frequency is known as an **Oscillatory Circuit** or **Tank Circuit**.
- A simple oscillatory circuit consists of a capacitor (C) and inductance coil (L) in parallel as shown in Fig. This system can produce electrical oscillations of frequency determined by the values of L and C.
- To understand how this comes about, suppose the capacitor is charged from a d.c. source with a polarity as shown in Fig. (i).

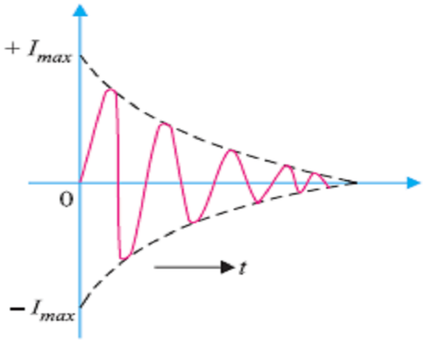


(i) (ii) (iii) (iv)

- **(i)** In the position shown in Fig (i), the upper plate of capacitor has deficit of electrons and the lower plate has excess of electrons. Therefore, there is a voltage across the capacitor and the capacitor has electrostatic energy.
- **(ii)** When switch Sis closed as shown in Fig (ii), the capacitor will discharge through inductance and the electron flow will be in the direction indicated by the arrow.
- This current flow sets up magnetic field around the coil. Due to the inductive effect, the current builds up slowly towards a maximum value.
- The circuit current will be maximum when the capacitor is fully discharged. At this instant, electrostatic energy is zero but because electron motion is greatest (i.e. maximum current), the magnetic field energy around the coil is maximum. This is shown in Fig (ii).
- Obviously, the electrostatic energy across the capacitor is completely converted into magnetic field energy around the coil.
- **(iii)** Once the capacitor is discharged, the magnetic field will begin to collapse and produce a counter e.m.f. According to Lenz's law, the counter e.m.f. will keep the current flowing in the same direction.
- The result is that the capacitor is now charged with opposite polarity, making upper plate of capacitor negative and lower plate positive as shown in Fig (iii).
- **(iv)** After the collapsing field has recharged the capacitor, the capacitor now begins to discharge; current now flowing in the opposite direction.
- Fig (iv) shows capacitor fully discharged and maximum current flowing. The sequence of charge and discharge results in alternating motion of electrons or an oscillating current.
- The energy is alternately stored in the electric field of the capacitor (C) and the magnetic field of the inductance coil (L). This interchange of energy between L and C is repeated over and again resulting in the production of oscillations.

♣ WAVEFORM.

- If there were no losses in the tank circuit to consume the energy, the interchange of energy between L and C would continue indefinitely.
- In a practical tank circuit, there are resistive and radiation losses in the coil and dielectric losses in the capacitor. During each cycle, a small part of the originally imparted energy is used up to overcome these losses.
- The result is that the amplitude of oscillating current decreases gradually and eventually it becomes zero when all the energy is consumed as losses.
- Therefore, the tank circuit by itself will produce damped oscillations as shown in Fig.



♣ Frequency of oscillations.

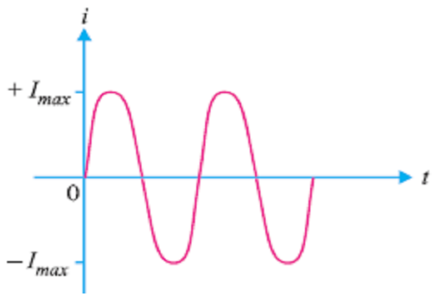
- The frequency of oscillations in the tank circuit is determined by the constants of the circuit viz Land C.
- The actual frequency of oscillations is the resonant frequency (or natural frequency) of the tank circuit given by :

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

- It is clear that frequency of oscillations in the tank circuit is inversely proportional to L and C. This can be easily explained.
- If a large value of capacitor is used, it will take longer for the capacitor to charge fully and also longer to discharge. This will lengthen the period of oscillations in the tank circuit, or equivalently lower its frequency.
- With a large value of inductance, the opposition to change in current flow is greater and hence the time required to complete each cycle will be longer.
- Therefore, the greater the value of inductance, the longer is the period or the lower is the frequency of oscillations in the tank circuit.

❖ UNDAMPED OSCILLATIONS FROM TANK CIRCUIT:-

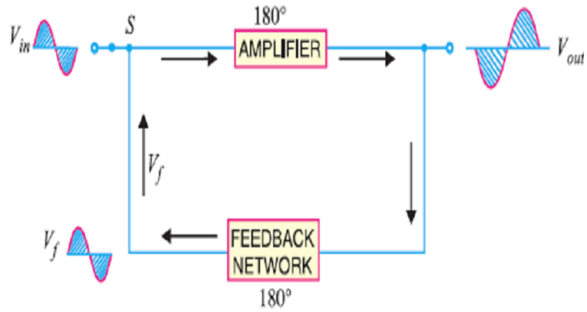
- As discussed before, a tank circuit produces damped oscillations. However, in practice, we need continuous undamped oscillations for the successful operation of electronics equipment.
- In order to make the oscillations in the tank circuit undamped, it is necessary to supply correct amount of energy to the tank circuit at the proper time intervals to meet the losses.
- Thus referring back to Fig of tank circuit, any energy which would be applied to the circuit must have a polarity conforming to the existing polarity at the instant of application of energy.
- If the applied energy is of opposite polarity, it would oppose the energy in the tank circuit, causing stoppage of oscillations.
- Therefore, in order to make the oscillations in the tank circuit undamped, the following conditions must be fulfilled :



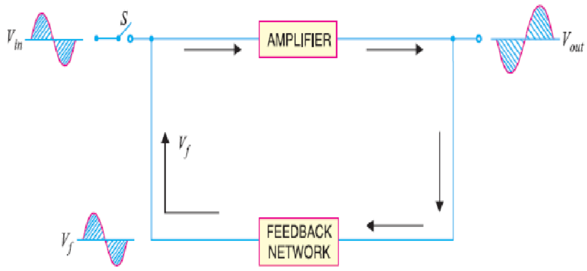
- ♣ **(i)** The amount of energy supplied should be such so as to meet the losses in the tank circuit and the a.c. energy removed from the circuit by the load.
  - ✘ For instance, if losses in LC circuit amount to 5 mW and a.c. output being taken is 100 mW, then power of 105 mW should be continuously supplied to the circuit.
- ♣ **(ii)** The applied energy should have the same frequency as that of the oscillations in the tank circuit.
- ♣ **(iii)** The applied energy should be in phase with the oscillations set up in the tank circuit i.e. it should aid the tank circuit oscillations.
- ♣ If these conditions are fulfilled, the circuit will produce continuous undamped output as shown in Fig.

❖ POSITIVE FEEDBACK AMPLIFIER — OSCILLATOR:-

- A transistor amplifier with proper positive feedback can act as an oscillator i.e., it can generate oscillations without any external signal source.



- Fig shows a transistor amplifier with positive feedback. Remember that a positive feedback amplifier is one that produces a feedback voltage (V_f) that is in phase with the original input signal.
- As we can see, this condition is met in the circuit shown in Fig. A phase shift of 180° is produced by the amplifier and a further phase shift of 180° is introduced by feedback network.
- Thus, the signal is shifted by 360° and fed to the input i.e., feedback voltage is in phase with the input signal.



- **(i)** We note that the circuit shown in Fig is producing oscillations in the output. However, this circuit has an input signal. This is inconsistent with our definition of an oscillator i.e., an oscillator is a circuit that produces oscillations without any external signal source.
- **(ii)** When we open the switch S of Fig (i), we get the circuit shown in Fig (ii).This means the input signal (V_{in}) is removed. However, V_f (which is in phase with original signal) is still applied to the input signal.
- The amplifier will respond to this signal in the same way that it did to V_{in} i.e., V_f will be amplified and sent to the output. The feedback network sends a portion of the output back to the input.
- Therefore, the amplifier receives another input cycle and another output cycle is produced. This process will continue so long as the amplifier is turned on.
- Therefore, the amplifier will produce sinusoidal output with no external signal source. The following points may be noted carefully :
  - ♣ A transistor amplifier with proper positive feedback will work as an oscillator.
  - ♣ The circuit needs only a quick trigger signal to start the oscillations.
  - ♣ Once the oscillations have started, no external signal source is needed.
  - ♣ In order to get continuous undamped output from the circuit, the following condition must be met:

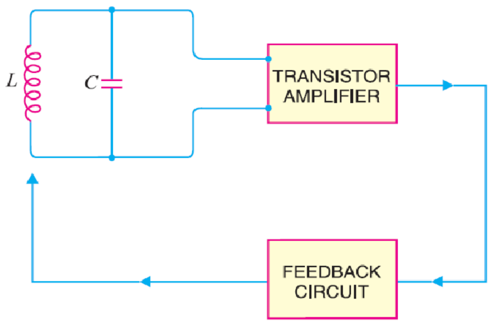
$$\mathbf{m_v A_v = 1}$$

Where $\mathbf{A_v}$ = Voltage Gain of Amplifier without Feedback and $\mathbf{m_v}$ = Feedback Fraction

  - ♣ This relation is called **Barkhausen Criterion**.

❖ ESSENTIALS OF TRANSISTOR OSCILLATOR: -

- Fig shows the block diagram of an oscillator. Its essential components are : -
- ♣ **Tank circuit**. It consists of inductance coil (L) connected in parallel with capacitor (C).



- The frequency of oscillations circuit depend upon the values of inductance of the coil and capacitance of the capacitor.
- ♣ **(ii) Transistor Amplifier.** The transistor amplifier receives D.C. power from the battery and changes it into a.c. power for supplying to the tank circuit.
- The oscillations occurring in the tank circuit are applied to the input of the transistor amplifier. Because of the amplifying properties of the transistor, we get increased output of these oscillations.
- This amplified output of oscillations is due to the D.C. power supplied by the battery.
- The output of the transistor can be supplied to the tank circuit to meet the losses.
- ♣ **(iii) Feedback Circuit**. The feedback circuit supplies a part of collector energy to the tank circuit in correct phase to aid the oscillations i.e. it provides positive feedback.

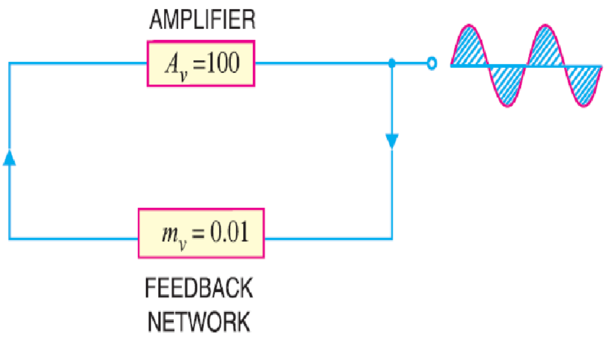
❖ EXPLANATION OF BARKHAUSEN CRITERION:-

- Barkhausen criterion is that in order to produce continuous undamped oscillations at the output of an amplifier, the positive feedback should be such that: **$m_vA_v = 1$**
- Once this condition is set in the positive feedback amplifier, continuous undamped oscillations can be obtained at the output immediately after connecting the necessary power supplies.

♣ **(i) Mathematical Explanation.** The voltage gain of a positive feedback amplifier is given by;

$$A_{vf} = \frac{A_V}{1 - A_V m_V} \quad \Rightarrow \quad \text{If } m_vA_v = 1, \quad \text{then } A_{vf} \to \infty.$$

- We know that we cannot achieve infinite gain in an amplifier. So what does this result infer in physical terms? It means that a vanishing small input voltage would give rise to finite (i.e., a definite amount of) output voltage even when the input signal is zero.
- Thus once the circuit receives the input trigger, it would become an oscillator, generating oscillations with no external signal source.
- **(ii) Graphical Explanation**. Let us discuss the condition m_vA_v = 1graphically. Suppose the voltage gain of the amplifier without positive feedback is 100.
- In order to produce continuous undamped oscillations, $m_vA_v = 1$ or $m_v \times 100 = 1$ or $m_v = 0.01$.
- This is illustrated in Fig. Since the condition $m_vA_v = 1$ is met in the circuit shown in Fig, it will produce sustained oscillations.



- Suppose the initial triggering voltage is 0.1V peak. Starting with this value, circuit ($A_v = 100$; $m_v = 0.01$) will progress as follows.

Cycle	V_{in}	V_{out}	V_f
1.	0.1Vpk	10Vpk	0.1Vpk
2.	0.1Vpk	10Vpk	0.1Vpk

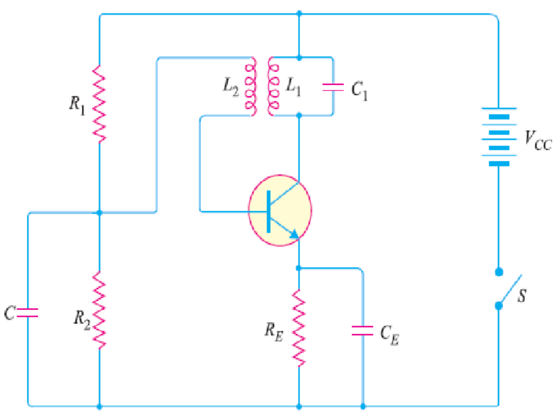
- The same thing will repeat for 3rd, 4th cycles and so on. Note that during each cycle, $V_f = 0.1$Vpk and $V_{out} = 10$ Vpk. Clearly, the oscillator is producing continuous undamped oscillations.
- The relation $m_v\ A_v = 1$ holds good for true ideal circuits. However, practical circuits need an m_vA_v product that is slightly greater than 1. This is to compensate for power loss (in resistors) in the circuit.

❖ DIFFERENT TYPES OF TRANSISTOR OSCILLATORS:-

- A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it.
- All oscillators under different names have similar function i.e., they produce continuous undamped output. However, the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses.
- The following are the transistor oscillators commonly used at various places in electronic circuits:

(i) Tuned Collector Oscillator (ii) Colpitt's Oscillator
(iii) Hartley Oscillator (iv) Phase Shift Oscillator
(v) Wien Bridge Oscillator (vi) Crystal Oscillator

❖ TUNED COLLECTOR OSCILLATOR:-



- Fig shows circuit of tuned collector oscillator. It contains tuned circuit L_1 - C_1 in the collector and hence the name.
- The frequency of oscillations depends upon the values of L_1 and C_1 and is given by :

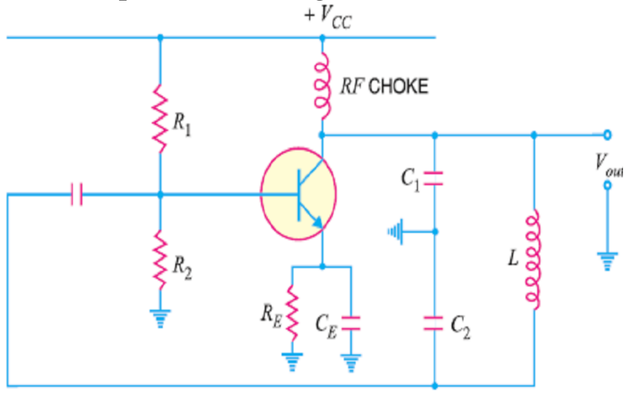
$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

- The feedback coil L_2 in the base circuit is magnetically coupled to the tank circuit coil L_1. In practice, L_1 and L_2 form the primary and secondary of the transformer respectively. The biasing is provided by potential divider arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations.

♣ **Circuit Operation**. When switch S is closed, collector current starts increasing and charges the capacitor C_1. When this capacitor is fully charged, it discharges through coil L_1, setting up oscillations of frequency determined by above equation.

- These oscillations induce some voltage in coil L_2 by mutual induction. The frequency of voltage in coil L_2 is the same as that of tank circuit but its magnitude depends upon the number of turns of L_2 and coupling between L_1 and L_2.
- The voltage across L_2 is applied between base and emitter and appears in the amplified form in the collector circuit, thus overcoming the losses occurring in the tank circuit.
- The number of turns of L_2 and coupling between L_1 and L_2 are so adjusted that oscillations across L_2 are amplified to a level just sufficient to supply losses to the tank circuit.
- It may be noted that the phase of feedback is correct i.e. energy supplied to the tank circuit is in phase with the generated oscillations. A phase shift of 180º is created between the voltages of L_1 and L_2 due to transformer action.
- A further phase shift of 180º takes place between base-emitter and collector circuit due to transistor properties. As a result, the energy feedback to the tank circuit is in phase with the generated oscillations.

❖ COLPITT'S OSCILLATOR:-



- Fig shows a Colpitt's oscillator. It uses two capacitors and placed across a common inductor L and the centre of the two capacitors is tapped.
- The tank circuit is made up of C_1, C_2 and L. The frequency of oscillations is determined by the values of C_1, C_2 and L and is given by ;

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

Where $C_T = \frac{C_1 C_2}{C_1 + C_2}$

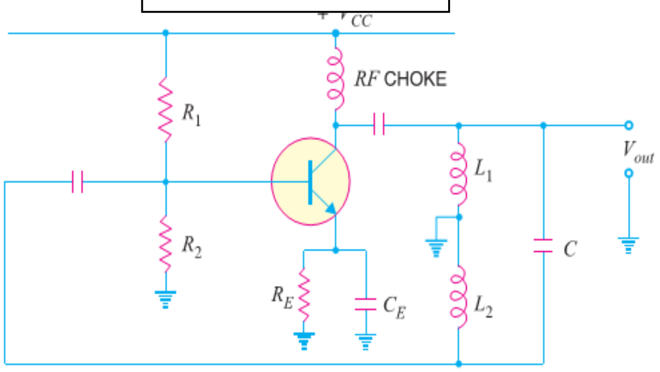
✡ Note that $C_1 - C_2 - L$ is also the feedback circuit that produces a phase shift of 180°.

♣ **Circuit Operation.** When the circuit is turned on, the capacitors C_1 and C_2 are charged. The capacitors discharge through L, setting up oscillations of frequency determined by exp.(i).

- Output voltage of the amplifier appears across C_1 and feedback voltage is developed across C_2. The voltage across it is 180° out of phase with the voltage developed across C_1 (V_{out}) as shown in Fig.
- It is easy to see that voltage feedback (voltage across C_2) to the transistor provides positive feedback.
- A phase shift of 180° is produced by transistor and a further phase shift of 180° is produced by $C_1 - C_2$ voltage divider.
- In this way, feedback is properly phased to produce continuous undamped oscillation.
- **Feedback fraction m_v.** The amount of feedback voltage in Colpitt's oscillator depends upon feedback fraction m_v of the circuit. For this circuit, Feedback fraction,

$$m_v = \frac{V_f}{V_{out}} = \frac{X_{c2}}{X_{c1}} = \frac{C_1}{C_2}$$

❖ HARTLEY OSCILLATOR:-



- The Hartley oscillator is similar to Colpitt's oscillator with minor modifications. Instead of using tapped capacitors, two inductors L_1 and L_2 are placed across a common capacitor C and the centre of the inductors is tapped as shown in Fig.
- The tank circuit is made up of L_1, L_2 and C. The frequency of oscillations is determined by the values of L_1, L_2 and C and is given by :

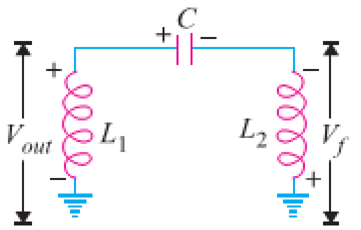
$$f = \frac{1}{2\pi\sqrt{CL_T}} \quad \ldots\ldots\ldots\ldots \text{(i)}$$

Where $L_T = L_1 + L_2 + 2M$ & M= mutual inductance between L_1 and L_2

✡ Note that $L_1 - L_2 - C$ is also the feedback network that produces a phase shift of 180°.

♣ **Circuit Operation**. When the circuit is turned on, the capacitor is charged. When this capacitor is fully charged, it discharges through coils L_1 and L_2 setting up oscillations of frequency determined by equ (i).

- The output voltage of the amplifier appears across L_1 and feedback voltage across L_2. The voltage across L_2 is 180° out of phase with the voltage developed across L_1 (V_{out}) as shown in Fig.
- It is easy to see that voltage feedback (i.e., voltage across L_2) to the transistor provides positive feedback.
- A phase shift of 180° is produced by the transistor and a further phase shift of 180° is produced by $L_1 - L_2$ voltage divider.
- In this way, feedback is properly phased to produce continuous undamped oscillations.



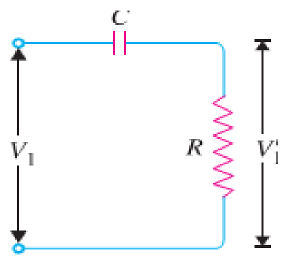
FEEDBACK CIRCUIT

- **Feedback fraction m_v.** In Hartley oscillator, the feedback voltage is across L_2 and output voltage is across L_1.

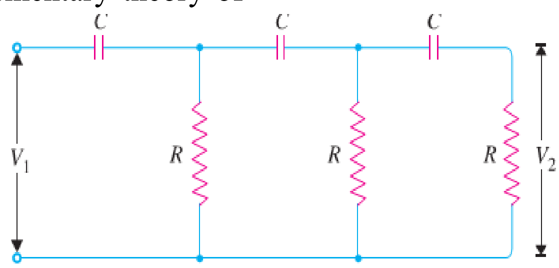
$$m_v = \frac{V_f}{V_{out}} = \frac{X_{L2}}{X_{L1}} = \frac{L_1}{L_2}$$

❖ **PRINCIPLE OF PHASE SHIFT OSCILLATORS:-**

- One desirable feature of an oscillator is that it should feedback energy of correct phase to the tank circuit to overcome the losses occurring in it.
- In the oscillator circuits discussed so far, the tank circuit employed inductive (L) and capacitive (C) elements. In such circuits, a phase shift of 180º was obtained due to inductive or capacitive coupling and a further phase shift of 180º was obtained due to transistor properties.
- In this way, energy supplied to the tank circuit was in phase with the generated oscillations. The oscillator circuits employing L-C elements have two general drawbacks.
- **Firstly**, they suffer from frequency instability and poor waveform. **Secondly**, they cannot be used for very low frequencies because they become too much bulky and expensive.
- Good frequency stability and waveform can be obtained from oscillators employing resistive and capacitive elements. Such amplifiers are called R-C or phase shift oscillators and have the additional advantage that they can be used for very low frequencies.
- In a phase shift oscillator, a phase shift of 180º is obtained with a phase shift circuit instead of inductive or capacitive coupling.
- A further phase shift of 180º is introduced due to the transistor properties. Thus, energy supplied back to the tank circuit is assured of correct phase.



- **Phase shift Circuit.** A phase-shift circuit essentially consists of an R-C network. Fig (i) shows a single section of RC network. From the elementary theory of electrical engineering, it can be shown that alternating voltage V'_1across R leads the applied voltage V_1 by φº. The value of φ depends upon the values of R and C.
- If resistance R is varied, the value of φ also changes. If R were reduced to zero, V'_1 will lead V_1 by 90º i.e. φ= 90º.
- However, adjusting R to zero would be impracticable because it would lead to no voltage across R.



- Therefore, in practice, R is varied to such a value that makes V'_1 to lead V_1 by 60º.
- Fig (ii) shows the three sections of RC network. Each section produces a phase shift of 60º. Consequently, a total phase shift of 180º is produced i.e. voltage V_2 leads the voltage V_1 by 180º.

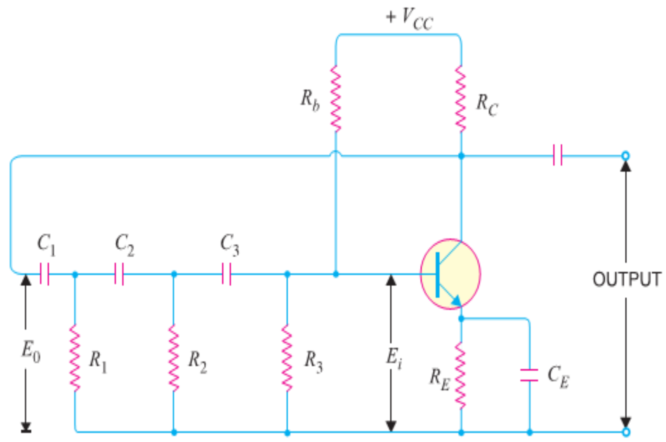
❖ **PHASE SHIFT OSCILLATOR:-**

- Fig. shows the circuit of a phase shift oscillator. It consists of a conventional single transistor amplifier and a RC phase shift network.
- The phase shift network consists of three sections R_1C_1, R_2C_2 and R_3C_3. At some particular frequency f_0, the phase shift in each RC section is 60º so that the total phase-shift produced by the RC network is 180º.
- The frequency of oscillations is given by:

$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$

Where $R_1 = R_2 = R_3 = \mathbf{R}$ & $C_1 = C_2 = C_3 = \mathbf{C}$

- **Circuit Operation.** When the circuit is switched on, it produces oscillations of frequency determined by exp. (i). The output E_0 of the amplifier is fed back to RC feedback network.
- This network produces a phase shift of 180º and a voltage Ei appears at its output which is applied to the transistor amplifier.
- Obviously, the feedback fraction m= E_i/E_0. The feedback phase is correct. A phase shift of 180º is produced by the transistor amplifier.
- A further phase shift of 180º is produced by the RC network. As a result, the phase shift around the entire loop is 360º.



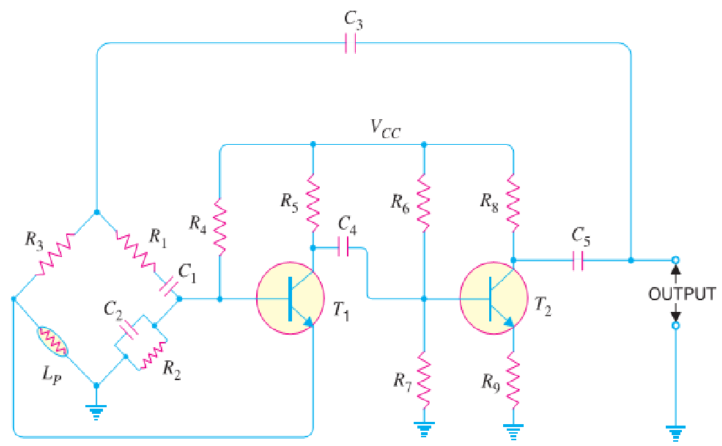
- **Advantages**
  - It does not require transformers or inductors.
  - It can be used to produce very low frequencies.
  - The circuit provides good frequency stability.
- **Disadvantages**
  - It is difficult for the circuit to start oscillations as the feedback is generally small.
  - The circuit gives small output.

WIEN BRIDGE OSCILLATOR:-

- The Wien-bridge oscillator is the standard oscillator circuit for all frequencies in the range of 10 Hz to about 1 MHz. It is the most frequently used type of audio oscillator as the output is free from circuit fluctuations and ambient temperature.
- Fig. shows the circuit of Wien bridge oscillator. It is essentially a two-stage amplifier with R-C bridge circuit. The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and tungsten lamp L_p.
- Resistances R_3 and L_p are used to stabilize the amplitude of the output. The transistor T_1 serves as an oscillator and amplifier while the other transistor T_2 serves as an inverter (to produce 180º phase shift).
- The circuit uses positive and negative feedbacks. The positive feedback is through R_1C_1, C_2R_2 to the transistor T_1. The negative feedback is through the voltage divider to the input of transistor T_2.
- The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

$$f = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, then, $f = \frac{1}{2\pi RC}$



- When the circuit is started, bridge circuit produces oscillations of frequency determined.
- The two transistors produce a total phase shift of 360º so that proper positive feedback is ensured.
- The negative feedback in the circuit ensures constant output. This is achieved by the temperature sensitive tungsten lamp L_p. Its resistance increases with current.
- Should the amplitude of output tend to increase, more current would provide more negative feedback.
- The result is that the output would return to original value.
- A reverse action would take place if the output tends to decrease.
- **Advantages**

  (i) It gives constant output. **(ii)** It works quite easily. **(iii)** Overall gain is high due to two transistors. **(iv)**The frequency of oscillations can be easily changed by using a potentiometer.
- **Disadvantages**

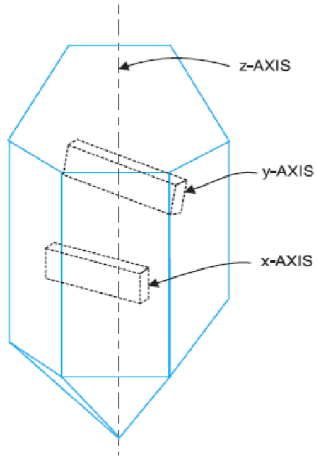
(i) It requires two transistors & large number of components. **(ii)** It cannot generate very high frequencies.

LIMITATIONS OF LC AND RC OSCILLATORS:-

- The LC and RC oscillators discussed so far have their own limitations. The major problem in such circuits is that their operating frequency does not remain strictly constant. There are two principal reasons for it viz.,
- (i) As the circuit operates, it will warm up. Consequently, the values of resistors and inductors, which are the frequency determining factors in these circuits, will change with temperature.
- This causes the change in frequency of the oscillator.
- (ii) If any component in the feedback network is changed, it will shift the operating frequency of the oscillator.
- However, in many applications, it is desirable and necessary to maintain the frequency constant with extreme low tolerances.
- It is apparent that if we employ LC or RC circuits, a change of temperature may cause the frequencies of adjacent broadcasting stations to overlap.
- In order to maintain constant frequency, piezoelectric crystals are used in place of LC or RC circuits. Oscillators of this type are called crystal oscillators.
- The frequency of a crystal oscillator changes by less than 0.1% due to temperature and other changes.
- Therefore, such oscillators offer the most satisfactory method of stabilizing the frequency and are used in great majority of electronic applications.

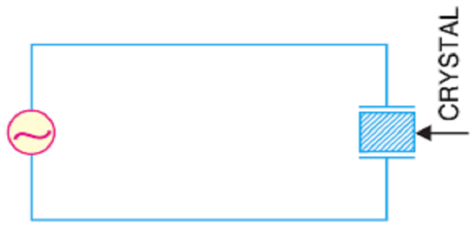
PIEZOELECTRIC CRYSTALS:-

- Certain crystalline materials, namely, *Rochelle salt, quartz and tourmaline* exhibit the **piezoelectric effect** i.e., when we apply an a.c. voltage across them, they vibrate at the frequency of the applied voltage. Conversely, when they are compressed or placed under mechanical strain to vibrate, they produce an a.c. voltage.
- Such crystals which exhibit piezoelectric effect are called **piezoelectric crystals**. Of the various piezoelectric crystals, **quartz** is most commonly used as it is inexpensive and readily available in nature.



- **Quartz Crystal**. Quartz crystals are generally used in crystal oscillators because of their great mechanical strength and simplicity of manufacture.
- The natural shape of quartz crystal is hexagonal as shown in Fig. The three axes are shown: the z-axis is called the optical axis, the x-axis is called the electrical axis and y-axis is called the mechanical axis.
- Quartz crystal can be cut in different ways. Crystal cut perpendicular to the x-axis is called **x-cut crystal** whereas that cut perpendicular to y-axis is called **y-cut crystal**. The piezoelectric properties of a crystal depend upon its cut.
- **Frequency of Crystal.** Each crystal has a natural frequency like a pendulum.
  The natural frequency f of a crystal is given by: $\mathbf{f} = \frac{K}{t}$ Where,

  K = Constant that depends upon the cut **&** **t** = Thickness of the crystal.
- It is clear that frequency is inversely proportional to crystal thickness. The thinner the crystal, the greater is its natural frequency and vice-versa.
- However, extremely thin crystal may break because of vibrations. This puts a limit to the frequency obtainable. In practice, frequencies between 25 kHz to 5 MHz have been obtained with crystals.



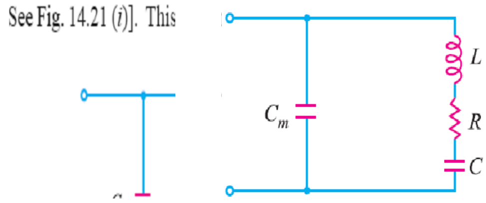
WORKING OF QUARTZ CRYSTAL:-

- In order to use crystal in an electronic circuit, it is placed between two metal plates. The arrangement then forms a capacitor with crystal as the dielectric as shown in Fig.
- If an a.c. voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage. However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value.

- This natural frequency is almost constant. Effects of temperature change can be eliminated by mounting the crystal in a temperature-controlled oven as in radio and television transmitters.

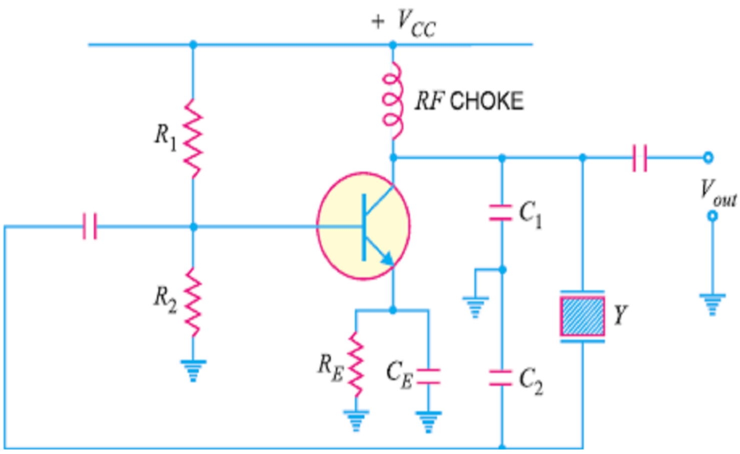
❖ Equivalent Circuit of Crystal:-

- Although the crystal has electromechanical resonance, we can represent the crystal action by an equivalent electrical circuit.



- (i) When the crystal is not vibrating, it is equivalent to capacitance C_m because it has two metal plates separated by a dielectric [See Fig (i)].
- This capacitance is known as **mounting capacitance**.
- (ii) When a crystal vibrates, it is equivalent to R–L– C series circuit. Therefore, the equivalent circuit of a vibrating crystal is R– L– C series circuit shunted by the mounting capacitance C_m as shown in Fig (ii).
  C_m = mounting capacitance **&** R–L–C = electrical equivalent of vibrational characteristic of the crystal

❖ TRANSISTOR CRYSTAL OSCILLATOR:-



- Fig. shows the transistor crystal oscillator. Note that it is a Collpit's oscillator modified to act as a crystal oscillator.
- The only change is the addition of the crystal (Y) in the feedback network. The crystal will act as a parallel-tuned circuit.
- As we can see in this circuit that instead of Fig. resonance caused by L and ($C_1 + C_2$), we have the parallel resonance of the crystal. At parallel resonance, the impedance of the crystal is maximum.
- This means that there is a maximum voltage drop across C_1. This in turn will allow the maximum energy transfer through the feedback network at f_p.
- Note that feedback is positive. A phase shift of 180° is produced by the transistor. A further phase shift of 180° is produced by the capacitor voltage divider.
- This oscillator will oscillate only at f_p. Even the smallest deviation from f_p will cause the oscillator to act as an effective short. Consequently, we have an extremely stable oscillator.

$$Q\text{-factor of crystal} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

♣ **Advantages**
- ✖ They have a high order of frequency stability.
- ✖ The quality factor (Q) of the crystal is very high.

♣ **Disadvantages**
- ✖ They are fragile and consequently can only be used in low power circuits.
- ✖ The frequency of oscillations cannot be changed appreciably.

[CHAPTER-8]

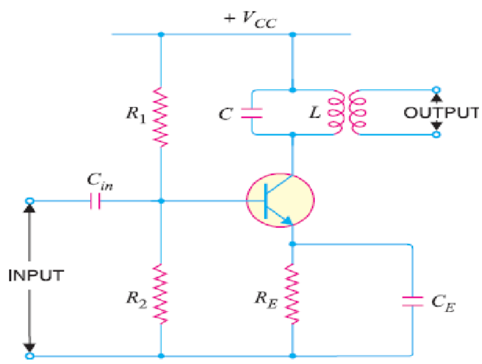
------------------------------------ [TUNED AMPLIFIER] ------------------------------------

❖ INTRODUCTION

- Most of the audio amplifiers we have discussed in the earlier chapters will also work at radio frequencies *i.e.* above 50 kHz.
- However, they suffer from two major drawbacks. **First,** they become less efficient at radio frequency. **Secondly,** such amplifiers have mostly resistive loads and consequently their gain is independent of signal frequency over a large bandwidth.
- In other words, an audio amplifier amplifies a wide band of frequencies equally well and does not permit the selection of a particular desired frequency while rejecting all other frequencies.
- However, sometimes it is desired that an amplifier should be selective *i.e.* it should select a desired frequency or narrow band of frequencies for amplification.
- For instance, radio and television transmission are carried on a specific radio frequency assigned to the broadcasting station. The radio receiver is required to pick up and amplify the radio frequency desired while discriminating all others.
- To achieve this, the simple resistive load is replaced by a parallel tuned circuit whose impedance strongly depends upon frequency.
- Such a tuned circuit becomes very selective and amplifies very strongly signals of resonant frequency and narrow band on either side.
- Thus, the use of tuned circuits in conjunction with a transistor makes possible the selection and efficient amplification of a particular desired radio frequency. Such an amplifier is called a ***tuned amplifier***.
- In this chapter, we shall focus our attention on transistor tuned amplifiers and their increasing applications in high frequency electronic circuits.

❖ TUNED AMPLIFIERS

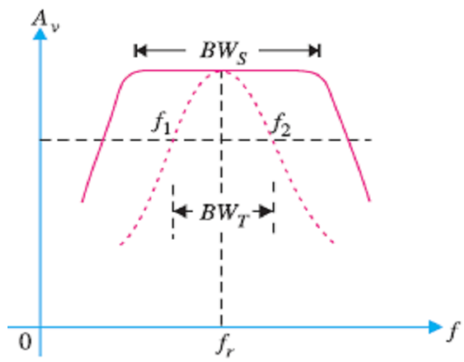
- *Amplifiers which amplify a specific frequency or narrow band of frequencies are called* ***tuned amplifiers.***
- Tuned amplifiers are mostly used for the amplification of high or radio frequencies.
- It is because radio frequencies are generally single and the tuned circuit permits their selection and efficient amplification.
- Tuned amplifiers are widely used in radio and television circuits where they are called upon to handle radio frequencies.
- Fig. shows circuit of a simple transistor tuned amplifier. Here, instead of load resistor, a parallel tuned circuit in the collector.
- The impedance of this tuned circuit strongly depends upon frequency. It offers a very high impedance at *resonant frequency* and very small impedance at all other frequencies.



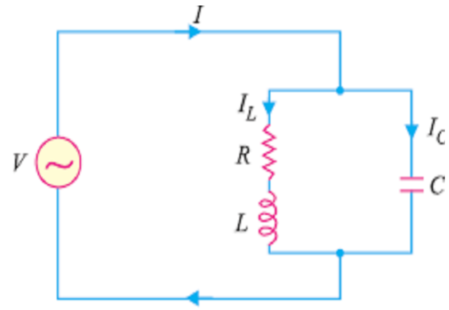
- If the signal has the same frequency as the resonant frequency of *LC* circuit, large amplification will result due to high impedance of *LC* circuit at this frequency.
- When signals of many frequencies are present at the input of tuned amplifier, it will select and strongly amplify the signals of resonant frequency while rejecting all others.
- Therefore, such amplifiers are very useful in radio receivers to select the signal from one particular broadcasting station when signals of many other frequencies are present at the receiving aerial.

❖ DIFFERENCE BETWEEN TUNED AMPLIFIERS AND OTHER AMPLIFIERS : -

- We have seen that amplifiers (*e.g.*, voltage amplifier, power amplifier *etc.*) provide the constant gain over a limited band of frequencies *i.e.*, from lower cut-off frequency f_1 to upper cut-off frequency f_2. Now bandwidth of the amplifier, $BW = f_2 - f_1$.
- The difference is that tuned amplifiers are designed to have specific, usually narrow bandwidth. This is explained in the Fig.

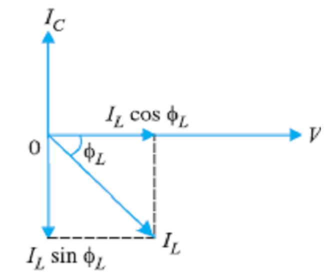


- Note that BW_S is the bandwidth of standard frequency response while BW_T is the bandwidth of the tuned amplifier.
- In many applications, the narrower the bandwidth of a tuned amplifier, the better it is.



❖ ANALYSIS OF PARALLEL TUNED CIRCUIT : -

- A parallel tuned circuit consists of a capacitor *C* and inductor *L* connected in parallel to each other with respect to a supply source.
- Fig. shows a parallel resonant circuit connected across an ac supply source of variable frequency.
- Here the resistance R represents the coil resistance. Its value is usually very small and the order of few ohms and hence it can be neglected as compare to the impedance of the resonance circuits.
- Now consider the frequency of the ac supply to be varied suitably. As a result of this, the circuit will encounter different impedance at different frequencies.

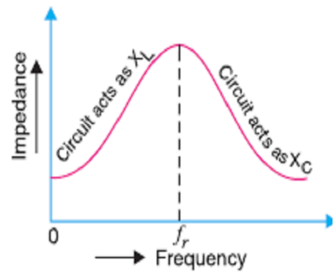


- As the frequency is increased the inductive reactance [X_L] is also increased and the capacitive reactance [X_C] is increased. There is a certain frequency of the applied ac voltage at which the inductive reactance is equal to the capacitive reactance. This frequency is called **resonance frequency.** It is designated by $\mathbf{f_0}$**.**
- The frequency at which parallel resonance occurs (*i.e.* reactive component of circuit current becomes zero) is called the ***resonant frequency*** $\mathbf{f_0}$.
- At resonant frequency, the circuit is said to be in electrical resonance. Under resonance condition the impendence of the resonant circuits becomes maximum and the line current (i.e. the current drawn from the source) is minimum.
- The expression for resonance frequency may be obtained from the condition,

$$X_L = X_C \quad \rightarrow \quad 2\pi f_0 L = \frac{1}{2\pi f_0 C} \quad \rightarrow \quad f_0^2 = \frac{1}{4\pi^2 LC} \quad \rightarrow \quad \boxed{\mathbf{f_0 = \frac{1}{2\pi\sqrt{LC}}}}$$

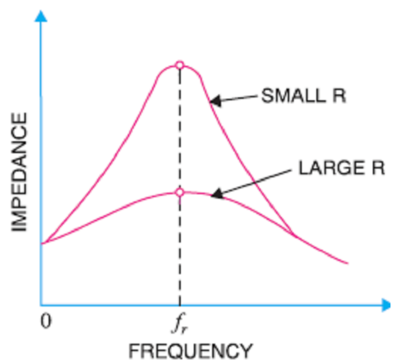
- If value of inductance is Henry & the capacitance is farads Hertz then the resonance frequency is Hertz.

❖ RESONANCE CURVE : -



- It is a curve, which shows the variation of **circuit impedance** (or circuit current) with the change in **frequency** of the applied voltage.
- Fig. shows the variation of circuit impedance (Z_p) with change in frequency of the applied voltage.
- From the fig it is clear that the impedance is maximum at the resonance and is equal to L/CR. If the frequency is changed above or below the resonance, the value of impedance decreases rapidly.
- If f_1 and f_2 are the lower & higher cutoff frequencies then Band width $\mathbf{BW=f_2\text{-}f_1}$.

❖ SHARPNESS OF RESONANCE: -



- The resonance curve of a resonant circuit is required to be as sharp as possible in order to provide a high selectivity.
- The sharp resonance curve means that the impedance falls off rapidly as the frequency is varied above and below the resonant frequency.
- Mathematically the sharpness of a resonance curve is defined as ratio of the bandwidth of the circuit to its resonant frequency. i.e.

Sharpness of Resonance = Band Width / Resonant frequency

$= BW/f_0 = f_2\text{-}f_1 / f_0 = 1 / Q_0$

- Where Q_0 is called the quality factor or Q-Factor.
- The ratio of inductive reactance and resistance of the coil at resonance, therefore, becomes a measure of the quality of the tuned circuit.
- This is called quality factor and may be defined as under : The ratio of *inductive reactance of the coil at resonance to its resistance is known as* **quality factor Q** *i.e.* $\mathbf{Q = X_L/R = 2\pi fL/R}$

- The quality factor *Q* of a parallel tuned circuit is very important as the sharpness of resonance curve and hence selectivity of the circuit depends upon it. Higher value of *Q*, more the selective of the tuned circuit.
- The smaller the resistance of coil, the sharper is the resonance curve. This is due to the fact that a small resistance consumes less power and draws a relatively small line current.
- Fig. shows the effect of resistance *R* of the coil on the sharpness of the resonance curve. It is clear that when resistance is small, the resonance curve is very sharp. However, if the coil has large resistance, the resonance curve is less sharp. So where high selectivity is desired, the value of *Q* should be very large.

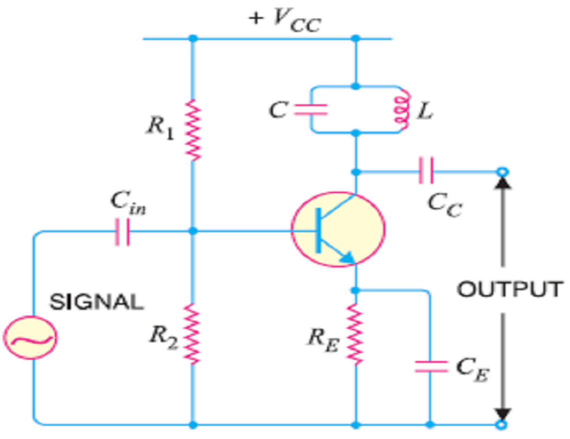
❖ ADVANTAGES OF TUNED AMPLIFIERS: -

- In high frequency applications, it is generally required to amplify a single frequency, rejecting all other frequencies present. For such purposes, tuned amplifiers are used. These amplifiers use tuned parallel circuit as the collector load and offer the following advantages :

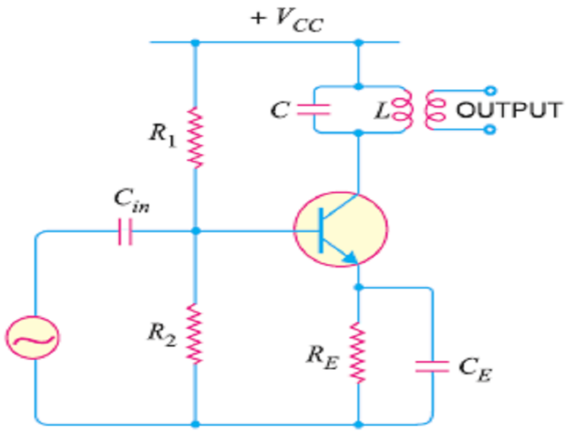
  (*i*) Small power loss. (*ii*) High selectivity. (*iii*) Smaller collector supply voltage.

❖ SINGLE TUNED AMPLIFIER : -

- A single tuned amplifier consists of a transistor amplifier containing a parallel tuned circuit as the collector load. The values of capacitance and inductance of the tuned circuit are so selected that its resonant frequency is equal to the frequency to be amplified.
- The output from a single tuned amplifier can be obtained either **(*a*)** by a coupling capacitor C_C as shown in Fig (i) or **(*b*)** by a secondary coil as shown in Fig (*ii*).
- Fig (i) is also called as single tuned voltage amplifier using Capacitive Coupled where as fig (ii) is called as single tuned voltage amplifier using Inductive Coupled.
- Both these circuits consist of a transistor amplifier and a tunes circuit as the load. The values of capacitance (C) and Inductance (L) of the tunes circuits are selected in such a way that the resonant frequency of the tunes circuit is equal to the frequency to be selected and amplified.
- The resistors R_1, R_2 and R_E are called biasing resisters. These resistors provide the d.c. operating current and voltage for the transistor.



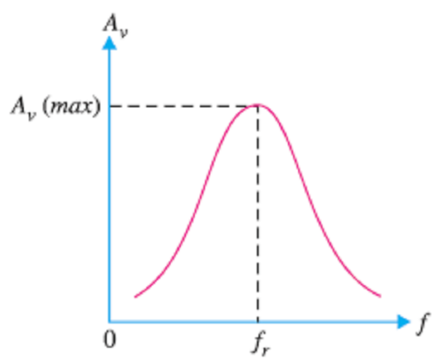
(*i*)



(*ii*)

❖ OPERATION.

- The high frequency signal i.e. radio frequency signal to be amplified is given to the input of the amplifier.
- The resonant frequency of parallel tuned circuit is made equal to the frequency of the signal by changing the value of *C*.
- Under such conditions, the tuned circuit will offer very high impedance to the signal frequency. Hence a large output appears across the tuned circuit.
- In case the input signal is complex containing many frequencies, only that frequency which corresponds to the resonant frequency of the tuned circuit will be amplified.
- All other frequencies will be rejected by the tuned circuit. In this way, a tuned amplifier selects and amplifies the desired frequency.



❖ **Frequency Response of Single Tuned Voltage Amplifiers : -**

- At the resonant frequency, the impedance of the parallel resonant circuit is very high and is purely resistive.
- Therefore, when the circuit is tuned to resonant frequency, the voltage across R_L is maximum.

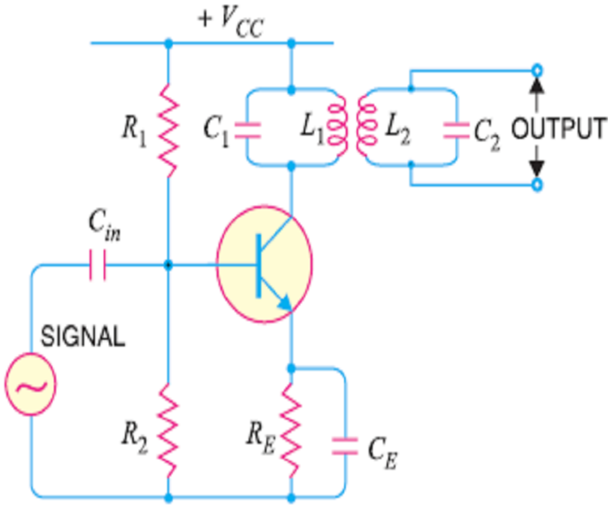
❖ In other words, the voltage gain is maximum at f_r. However, above and below the resonant frequency, the voltage gain decreases rapidly.

❖ The higher the *Q* of the circuit, the faster the gain drops off on either side of resonance.

❖ **LIMITATIONS OF SINGLE TUNED AMPLIFIER: -**

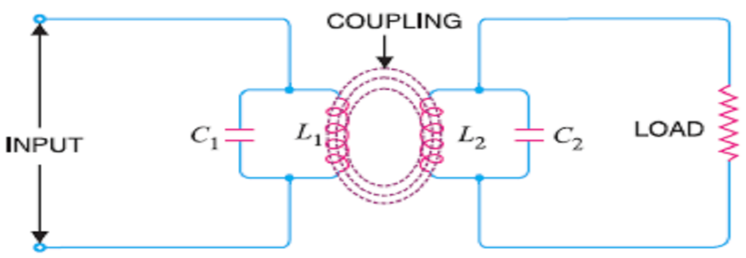
- The tuned voltage amplifier, in communication receiver, is used to select the desired carrier frequency and amplifying the complete band of frequencies around the selected carrier frequency.
- In other word, tuned amplifiers are required to be high selectivity. But the high selectivity requires a tuned circuit with a high Q-factor.
- We also know that a high-Q circuit will give a high voltage gain. But, at the same time, it will give reduces bandwidth (Because band width is reciprocal to the Q-factor).
- It means that a tuned a tuned voltage amplifier with reduced band width may not be able to amplify equally the complete band of the transmitted signal.
- In other words, narrow band width or smaller pass band of the amplifier will result in a poor reproduction of the audio signal.
- It is the major limitation of a single tuned voltage amplifier & is overcome by using double tuned circuit.

❖ **<u>DOUBLE TUNED AMPLIFIER</u> : -**

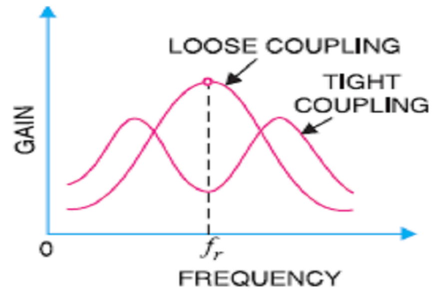


- Fig shows the circuit of a double tuned amplifier.
- It consists of a transistor amplifier containing two tuned circuits; one (L_1C_1) in the collector and the other (L_2C_2) in the output as shown.
- The resistors R_1, R_2 and R_E are used to provide d.c. current and voltage for transistor operation.
- The high frequency signal to be amplified is applied to the input terminals of the amplifier.
- The resonant frequency of tuned circuit L_1C_1 is made equal to the signal frequency.
- Under such conditions, the tuned circuit offers very high impedance to the signal frequency.
- Hence, large output appears across the tuned circuit L_1C_1.
- The output from this tuned circuit is transferred to the second tuned circuit L_2C_2 through mutual induction. Double tuned circuits are extensively used for coupling the various circuits of radio and television receivers.

❖ **FREQUENCY RESPONSE OF DOUBLE TUNED VOLTAGE AMPLIFIERS : -**



(*i*)



(*ii*)

- The frequency response of a double tuned circuit depends upon the degree of coupling *i.e.* upon the amount of mutual inductance between the two tuned circuits.

- When coil L_2 is coupled to coil L_1 [See Fig. (*i*)], a portion of load resistance is coupled into the primary tank circuit L_1C_1 and affects the primary circuit in exactly the same manner as though a resistor had been added in series with the primary coil L_1.
- When the coils are spaced apart, all the primary coil L_1 flux will not link the secondary coil L_2. The coils are said to have ***loose coupling***.
- Under such conditions, the resistance reflected from the load (*i.e.* secondary circuit) is small. The resonance curve will be sharp and the circuit Q is high as shown in Fig. (*ii*).
- When the primary and secondary coils are very close together, they are said to have ***tight coupling***. Under such conditions, the reflected resistance will be large and the circuit Q is lower.
- Two positions of gain maxima, one above and the other below the resonant frequency, are obtained.

❖ **BANDWIDTH OF DOUBLE–TUNED CIRCUIT: -**

- If you refer to the frequency response of double-tuned circuit shown in Fig. (*ii*), it is clear that bandwidth increases with the degree of coupling.
- Obviously, the determining factor in a double tuned circuit is not Q but the coupling. For a given frequency, the tighter the coupling, the greater is the bandwidth. $\mathbf{BW_{dt} = k\ f_r}$
- The subscript *dt* is used to indicate double-tuned circuit. Here *k* is coefficient of coupling.
  - It Provides **High Selectivity**,
  - **High Gain** and
  - Relatively **Large Band Width** to tuned circuit.

----ALL THE BEST ----ALL THE BEST ----

PREPARED BY: -

1. Er. DEBI PRASAD PATNAIK
   [Sr. Lecture, Dept of ETC, UCP ENGG. SCHOOL, Berhampur]

2. Er. PARAMANANDA GOUDA
   [Lecturer (PT), Dept of ETC, UCP ENGG. SCHOOL, Berhampur]

3. Er. CHINMOY KUMAR PATTNAIK
   [Lecturer (PT), Dept of ETC, UCP ENGG. SCHOOL, Berhampur]