GOVERNMENT POLYTECHNIC, DHENKANAL

LECTURE NOTES

Analog Electronics &OP-AMP

SEMESTER-4TH

PREPARED BY

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[CHAPTER-1]

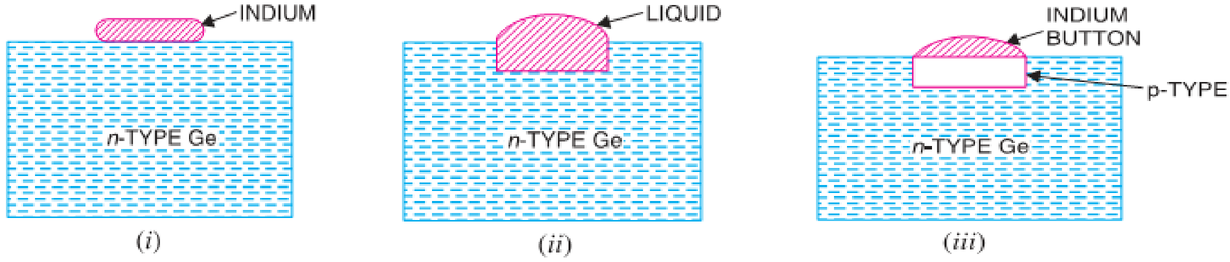
------------------- [DIODE&CIRCUITS] -------------------

CONSTRUCTION&WORKINGPRINCIPLEOFDIODE:-

- Whenap-typesemiconductorissuitablyjoinedton-typesemiconductor,thecontactsurfaceiscalled **PNJunction**.Mostsemiconductordevicescontainoneormore PN junctions.

Formation of PN junction.

- In actual practice, the characteristic properties of PN junction will not be apparent if a p-type block isjust brought in contact with n-type block. In fact, it is **fabricated** by special techniques.
- There are a numberoftechniquesforthefabrication ofPN-Junction: -
  - GrownJunction
  - AlloyJunction
  - DiffusedJunction
  - EpitaxialGrowth
  - PointcontractJunction.
- Butthe mostcommon method ofmakingPNjunction is called **Alloying**.

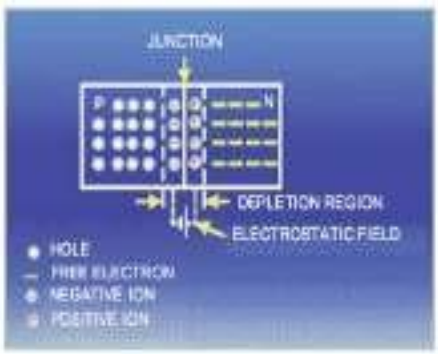


[FiguresofdifferentstagesofformationofPNjunctionbyAlloyingmethod]

- 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. Addition of indium overcomes the excess of electrons in the n-type germanium to such an extent that it creates a p-typeregion.Astheprocessgoeson,the remainingmoltenmixturebecomes increasinglyrichinindium.
- 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).

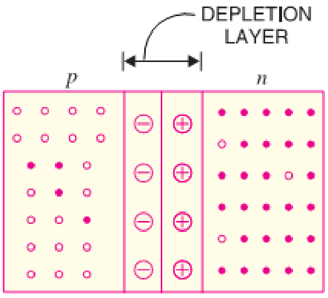
Properties of PN Junction.

- Toexplain PNjunction,considertwo typesofmaterials: -1)P-Type&2)N-Type.
- P-typesemiconductorhaving–iveacceptorionsand+ivechargedholes.N-typesemiconductorhaving +ivedonor ions&–ive free electrons.
- P-type has high concentration of holes and N-type has high concentration of electrons.
- So there is a tendency for the free electron to diffuse over p-side and holes to n-side. This 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.
- Similarlynegative charge establish on p-side of the junction.
- Whensufficientnoofdonorandaccepterionsgatheredatthe junction, further diffusion prevented. Because +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.

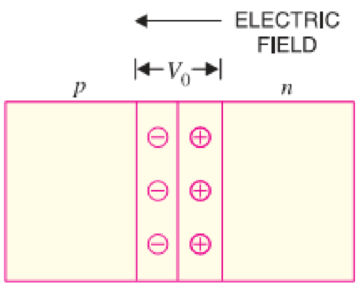


- Thus a barrier is set up against further movement of charge carriers is hole or electrons. This barrier is called as **Potential Barrier/ Junction Barrier (V_0)** and is of the order 0.1 to 0.3 volt. This prevents the respective majority carriers for crossing the barrier region. This region is known as **Depletion Layer**

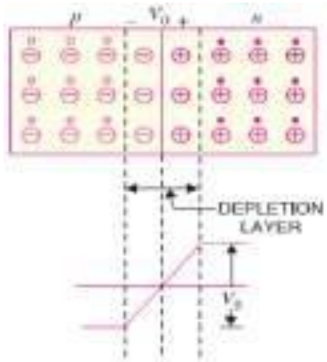
- The term depletion is due to the fact that near the junction, the region is depleted (i.e. emptied) ofcharge carries (free electrons and holes) due to diffusion across the junction.
- It may be noted that depletion layer is formed very quickly and is very thin compared to the n-region and the p-region.



(i)



(ii)



- 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 the fig above.
- 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 pn junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature.
- Thetypicalbarrierpotentialisapproximately: -ForSilicon,V_0 = 0.7V;ForGermanium, V_0 =0.3 V

❖ **<u>JunctionCapacitance:-</u>**

- When a PN junction isformed, a layerof positive and negative impurityions is formed on eitherside of the pn junction. This depletion layer acts as dielectric (non-conductive) medium between P-region and N-region. Therefore, these regions act as two plates of a capacitor separated by dielectric medium.
- The capacitance formed in this junction is called as Depletion Layer Capacitance or Space Charge Capacitance or Transition Region Capacitance or simple **Junction Capacitance.**

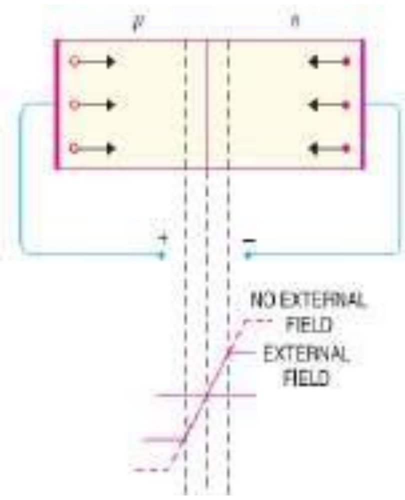
Applying D.C. Voltage Across PN Junction or Biasing a PN Junction

- In electronics,thetermbiasrefers tothe useofD.C.voltageto establishcertainoperatingconditionsfor an electronic device. In relation to a PN junction, there are following two bias conditions :

1.ForwardBiasing**2.**ReverseBiasing

❖ **<u>Forward Biasing</u>.** 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**.

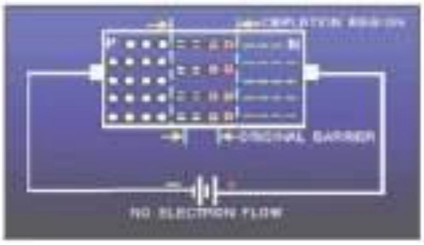
- To applyforward bias, connect positiveterminalofthebatteryto p-type and negative terminalto n-type as shown in Fig.



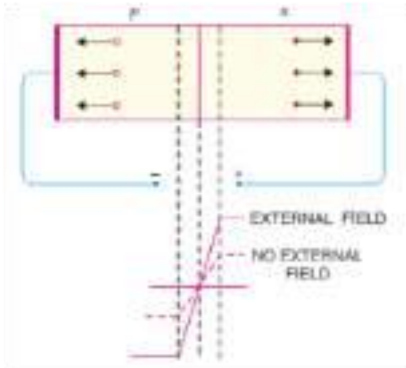
- The applied forward potential establishes an electric field which acts against the field due to potential barrier.
- Therefore,theresultantfieldisweakenedandthebarrierheightis reduced at the junction.
- As potential barrier voltage is very small (0.1 to 0.3 V), therefore, asmall forward voltage is sufficient to completelyeliminate thebarrier.
- 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.
- Thus,current flowsinthecircuit.Thisiscalled **ForwardCurrent**.
- WithforwardbiastoPNjunction,theimportantpointsare:-

(i) Thepotentialbarrierisreducedandatsomeforwardvoltagei.e. (0.1 to 0.3 V), it is eliminated altogether.
(ii) Thejunctionofferslowresistance(forwardresistance,R_f)tocurrent flow.
(iii) Currentflowsinthecircuitduetotheestablishmentoflowresistancepath.
(iv) Themagnitudeof currentdependsupontheappliedforwardvoltage.

❖ **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.**



- For reverse bias, connect -ve terminal of battery to p-type and +ve terminal to n-type as shown in Fig.
- 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.
- 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.



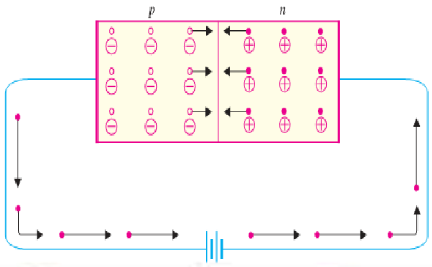
♣ Withreversebiasto PNjunction, Theimportant pointsare:

(i) Thepotential barrier isincreased.

(ii) ThejunctionoffersveryhighresistanceR$_r$)tocurrentflow.

(iii) Nocurrentflowsinthecircuitduetohighresistancepath.

- **Conclusion: -** From the above discussion, it follows that with reverse bias to the junction, a high resistance path is established and hence no current flow occurs.
- Whereas with forward bias to junction low resistance path is set up & hence current flows in the circuit.

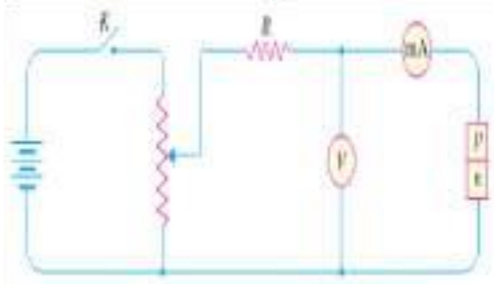


❖ **CurrentFlowinaForwardBiasedPNJunction:-**

- It concluded that in n-type region, current carried by free electrons whereas in p-type region, it is carried by holes. However, inexternal connecting wires, current is carried only by free electrons.

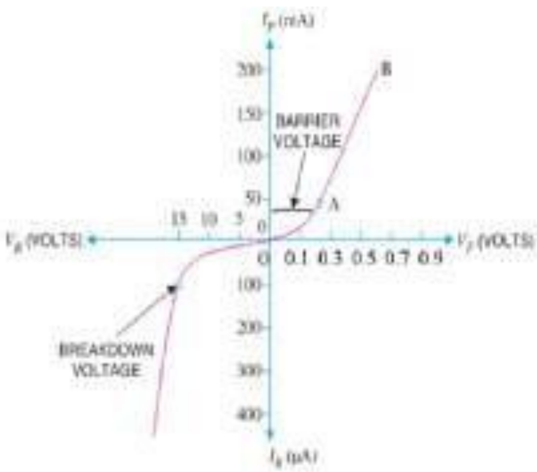
Volt-Ampere Characteristics of PN Junction:-

- 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.
- Thecharacteristicscanbestudiedunderthreeheads,namely:- **(1)**Zero externalvoltage, **(2)**ForwardBias **(3)**ReverseBias.



❖ **(i)Zeroexternalvoltage:-**Whentheexternalvoltageis zero,i.e.circuitisopenatK;thepotentialbarrieratthe junction does not permit current flow. Therefore, the circuit current is zero as indicated by point O in Fig.

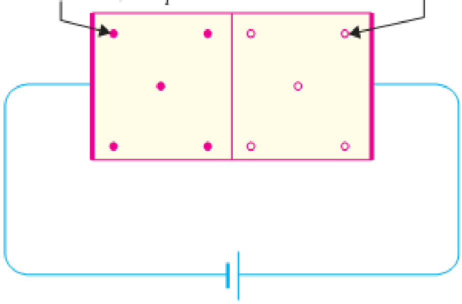
- **(ii)ForwardBias**:-Withforwardbiastothepnjunction i.e. p-type connected to positive terminal and n-type connected to negative terminal, the potential barrier is reduced. At some forward voltage (0.7 V for Si and 0.3 V for Ge), the potential barrier is altogether eliminated and current starts flowing 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 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. Because the external applied voltage is used up in overcoming the potential barrier.



- Once external voltage exceeds potential barrier voltage, the pn junction behaves like ordinaryconductor.
- Therefore, thecurrentrisesverysharplywith increasein external voltage(region ABon thecurve). The curve is almost linear.

❖ **(iii) Reverse Bias: -** With reverse bias to the pn junction i.e. p-type connected to negative terminal andn-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** (Is) 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. As shown in side Fig. to these minority carriers, the applied reverse bias appears as forward bias.



- Therefore,asmallcurrentflowsinthereverse direction. Ifreversevoltageis increasedcontinuously, thekineticenergyof electrons (minoritycarriers) 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 pn junction is due to the majority carriers produced by the impurity. However, reverse current is due to the minoritycarriers produced due to breakingof some co-valent bonds at room temperature.

❖ **ImportantTerms:-**

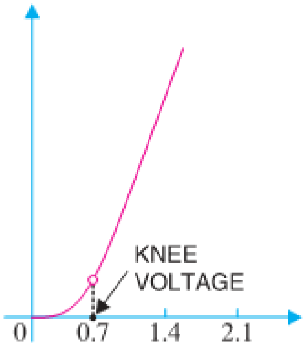
(i) Breakdown Voltage: - It is the minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current.

(ii) KneeVoltage: -The forwardvoltageatwhich thecurrentthroughthejunctionstartstoincrease rapidly.

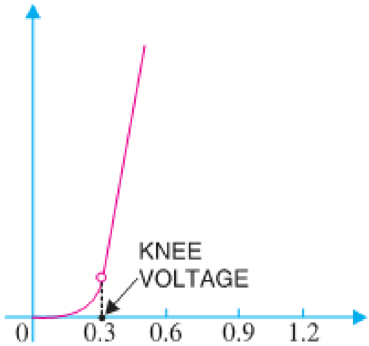
(iii) Peak inverse voltage (PIV):- It is the maximum reverse voltage that can be applied to the pn junction without damage to the junction. If the reverse voltage across the junction exceeds its PIV, the junction may be destroyed due to excessive heat. The peak inverse voltage is of particular importance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



SILICON



GERMANIUM

Other Type of DIODES: -

1.	ZenerDiode	**2.**	LightEmittingDiode	**3.**	Tunnel Diode	**4.**	PINDiodes
5.	Photo-Diode	**6.**	Varactor Diodes	**7.**	LaserDiodes	**8.**	Gunn Diodes
9.	Peltierdiodes	**10.**	Step RecoveryDiodes	**11.**	Schottky Diode	**12.**	SuperBarrierDiodes
13.	Optoisolator	**14.**	Point-contact diodes	**15.**	Avalanche diodes	**16.**	Constantcurrentdiodes

DIODE CURRENT EQUATION: -

- The Mathematical equation, which describes the forward and reverse characteristics of a semiconductor diode is called the diode current equation.
- Let I=ForwardorReverseDiodeCurrent, I_0
  = Reverse Saturation Current
  V=ExternalVoltage.(Itis+VeforForward Bias,-VeorReverseBias)
  η = A constant, whose value is equal to 1 for Ge diode and 2 for Si diode for relatively low valueofdiodecurrent(i.e.atorbelowthekneeofthecurve)andή=1 forGe&Sidiode for higher levels of diode current. (i. e. in the rapidly increasing section of the curve)
  V_T=Volt-equivalentoftemperature.Itsvalue isgiven bytherelationT/11,600, whereTistheabsolutetemperature.At roomtemperature(i.e. 300K), V_T=26vmV.
- Thecurrent equation for a forwardbiased diode isgiven bytherelation,

$$I=I_0(e^{V/\eta \cdot V_T}-1)$$

Weknowthatatroomtemperature,V_T=26mV=0.026V.SubstitutingthevalueofV$_T$intheabove equation it becomes,

$$I=I_0(e^{40V/\eta}-1)$$

- Thusdiodecurrentatorbelowthekneeof thecurveforGermanium andSiliconisgiven by

$I_{Ge}=I_0\ (e^{40V}-1)$ **[Asη= 1 forGe]** $I_{Si}=I_0\ (e^{20V}-1)$ **[Asη= 1for Si]**

- If the value of applied voltage is greater than unity (i.e. for the diode current in the rapid by increasing section of the curve) then the equation of diode current for Germanium or Silicon is given by

$I= I_0(e^{40V}-1)$ **[Asη=1for HigherValueof Voltage]**

- Thecurrentequationforareversebiaseddiodemaybeobtainedbychangingthesignoftheapplied voltage (V), i.e.

$$I= I_0(e^{-V/\eta \cdot V_T}-1)$$

- IftheValueofV>>V_T,thenthe term–V/η.V_T<< 1. ThereforeI= I_0.
- Thusthediodecurrentunderreversebiasisequaltothereversesaturationcurrentaslongasthe external voltage is below its break down value.

DIODE SPECIFICATION SHEET: -

- Allmanufactures of the semiconductor device provide data on specific diodes for the users to make proper utilization of the devices. This data could be a brief description limited to a one page or more than that. It includes the information arranged in table, graphs etc. The data is usually for : -
  - Forwardvoltage,V_F(AtaspecificCurrent&Temperature)
  - Maximum forwardcurrent,I_F(Ata specificTemperature)
  - ReversesaturationcurrentI$_R$orI$_O$(Ataspecific Voltage &Temperature)
  - ReverseVoltageRating[PIV,PRV,VRRMorV(BR)],Where,BR=Breakdownataspecific current & temperature.
  - Maximum powerdissipationlevelataparticular temperature.
  - Capacitance Value.
  - Reverserecoverytime,t_{rr}.
  - Operatingtemperaturerange.
- Beside this, depending on the type of diode being considered, more data may also be provided such as frequency range, noise level, switching time, thermal resistance level and peak repetitive values.
- Forthe application inmind, the significance ofthe data willusuallybe selfapparent.
- Ifthemaximumpowerordissipationratingisalso provided,itisunderstoodto beequal tothe produce

$$P_{Dmax}=V_D I_D$$

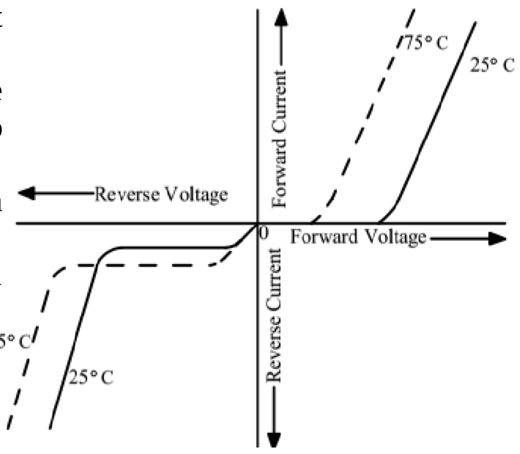
WhereI$_D$and V$_D$arethediodecurrentand voltage ataparticularpointof operation.

DIODEAPPLICATIONS:

- A PN junction diode has an important characteristic that it conducts well in forward direction andpoorly in reverse direction. This characteristic makes a diode very useful in a number of applications given below:
   1. AsRectifiersorPowerDiodesinD.C.powersupply.
   2. AsSignalDiodesincommunicationcircuits.
   3. AsZenerDiodesinvoltagestabilizingcircuits.
   4. AsVaractorDiodesinradioandTVreceivers.
   5. AsaSwitchin logiccircuitsused in computers

EFFECT OF TEMPERATURE OF DEPENDENCE OF JUNCTION DIODE:

- We have already discussed in the last article that the diode current is a function of temperature and the temperature appears in the denominator of the exponent term of the diode current equation (i.e., $V/\eta \cdot V_T$is equal to T/11600).
- It is thus obvious that with the increase in temperature, the exponent will reduce and hence the diode current should also decrease.
- However, it has been found that the variation of saturation current (I_0) is much greater than the exponential term.
- The above fact may be expressed in the form of a mathematical relation as given below:



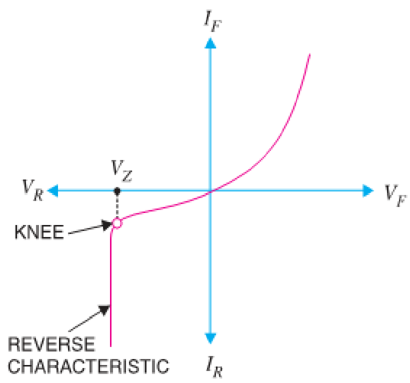
Let,I_{01}=Saturationcurrentattemp(T_1)forGeorSidiode, &I_{02} =Saturation current at some other temperature (T_2)

Then

$$I_{02}=I_{01}.2^{(T2-T1)}/10$$

- Asdiscussedinlastchapterthereversesaturationcurrent(I_0) willbe just about double in magnitude for every10ºC increase in temperature.
- Forexample, agermanium diode with anI_0in the order of1 or 2µA at 25ºChas a leakage current of 100µ A (= 0.1 mA) at a temperature of 100ºC.
- Current levels of this magnitude in the reverse bias region would certainly question our desired open-circuit condition in the reverse bias region.
- However,typicalvalues ofI_0forsilicondiodearemuchlowerthanthatofgermaniumforsimilarpower and current levels.
- Theincreasinglevel ofI_0withtemperature account forthelowerthreshold voltage asshown inFig.
- Duetothis reasonforwardcharacteristicat75°C isshown tothelefttothatofthecharacteristicat 25ºC.
- Asthetemperatureincreases,theforwardcharacteristicshiftsmoreandmoretotheleftofthe characteristic at 25ºC (i.e. become more and more "ideal").
- However,temperaturebeyondthenormaloperatingrangecanhaveaverydetrimentaleffectonthe diode's maximum power and current levels.
- We see in Fig., that in the reverse bias region, the breakdown voltage is increasing with the increase in temperature.

ZENER BREAK DOWN

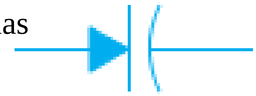


- It has already been discussed that when the reverse bias on a crystal diode is increased, a critical voltage, called **Breakdown Voltage** is reached where the reverse current increases sharply to a high value.
- The breakdown region is the knee of the reverse characteristic as shown in Fig. The satisfactory explanation of this breakdown of the junction was first given by the American scientist C. Zener.
- The breakdown voltage is also called **Zener Voltage** or **Zener Break Down** & the sudden increase in current is known as **Zener Current**.
- ThebreakdownorZenervoltagedependsupontheamountofdoping.
- If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of junction will occur at lower reverse voltage where as lightly doped diode has a higher breakdown voltage.

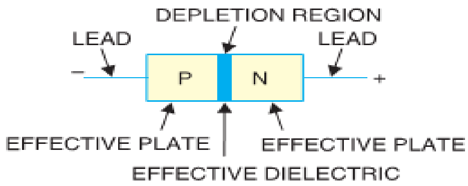
AVALANCHE BREAKDOWN: -

- Inthiscasetheincreasedreversevoltage increasestheamount of energyimparted to minoritycarriers.
- Asthereversevoltageisincreasedfurtherthe minoritycarriersacquiresalargeamountofenergy.
- WhenthesecarrierscollidewithSiorGeatoms,withinthecrystalstructure,theyimpartsufficient energy to break a covalent bond and generate additional carriers (electron-hole pair).
- These additional carriers pick up energy from the applied voltage and generates still more carriers. As a result of this, the reverse current increases rapidly.
- This cumulative process of carrier generation (multiplication) is known as **Avalanche Break down** orAvalanche **Multiplication**

❖ VARACTORDIODE



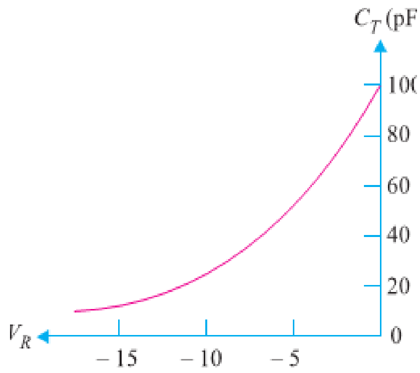
- A junction diode which acts as a variable capacitor under changing reverse bias is known as a **varactor diode**. It is also known as **Varicap** or **Voltcap.**
- Whenapn junction isformed, depletion layeriscreated in the junction area.
- Since there are no charge carriers within the depletion zone, the zone acts as an insulator.
- Thep-typematerialwithholes(+ivecharge)asmajoritycarriersandn-typematerialwithelectrons (−ive charge) as majority carriers act as charged plates.
- Thusthediode maybe considered asacapacitor withn-region andp-regionformingoppositelycharged plates and with depletion zone between them acting as a dielectric.
- Avaractor diode isspeciallyconstructed tohavehigh capacitanceunder reverse bias.
- Thevaluesofcapacitanceofvaractordiodesareinthepico farad (10^{-12} F) range.
- Innormaloperation,avaractordiodeisalwaysreverse biased.
- Thecapacitance ofvaractor diode isfoundas:



$$C_T = \varepsilon A / W_d$$

Where,

C_T= Total capacitance of the junction,A=Cross-sectionalareaofthejunction, ε=Permittivityofthesemiconductormaterial, Wd = Width of the depletion layer.



- When reverse voltage across a varactor diode is increased, the width Wd of the depletion layer increases. Therefore, the total junction capacitance C_T of the junction decreases.
- On the other hand, if the reverse voltage across the diode is lowered, the width Wd of the depletion layer decreases. Consequently, the total junction capacitance C_T increases.
- Itisusedas**VoltageVariableCapacitor,Voltage-ControlledTuning**

RECTIFIERS

❖ INTRODUCTION:-

✍For reasons associated with economics of generation and transmission, the electric power available is usuallyan A.C.Supply.Thesupplyvoltagevariessinusoidalandhasafrequencyof50 Hz.Itis usedfor lighting, heating and electric motors.

✍But there aremanyapplications (e.g. electroniccircuits)whereD.C. supplyis needed.Whensuch aD.C. Supply is required, the mains A.C. Supply is rectified by using *Crystal Diodes*.

✍The followingtworectifiercircuitscanbeused:-

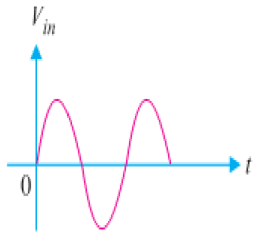
- (i)Half-wave rectifier(ii)Full-wave rectifier

HALF-WAVERECTIFIER:-

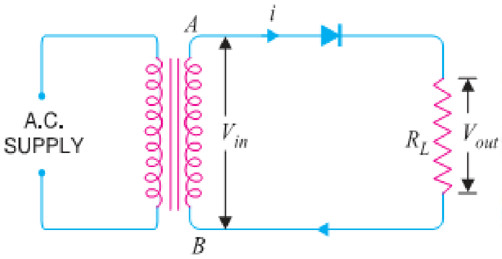
✍In half-wave rectification, the rectifier conducts current onlyduring the positive half-cycles of input A.C. Supply.

✍Thenegativehalf-cyclesofA.C.Supplyissuppressedi.e.duringnegativehalf-cycles,nocurrentis conducted and hence no voltage appears across the load.

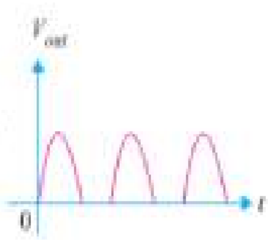
✍Therefore,currentalwaysflowsinonedirectionthroughtheloadthough aftereveryhalf-cycle



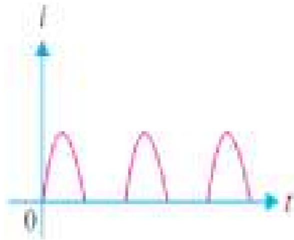
(InputWave form)



(Halfwave Rectifier Circuit)



(Outputvoltage wave)



(OutputCurrent)

Circuit Details: -

- Theabove Figshowsthe circuitwhereasinglecrystaldiodeactsasahalf-wave rectifier.
- TheA.C.SupplytoberectifiedisappliedinserieswiththediodeandloadresistanceR_L.Generally, A.C.Supplyisgiven througha transformer.
- The*use oftransformer*permitstwo advantages.
  - ✓ Firstly,itallowsustostep uporstep downtheA.C. inputvoltageasthesituation demands.
  - ✓ Secondly, the transformer isolates the rectifier circuit from power line and thus reduces the riskof electric shock.

OPERATION:-

- TheA.C. voltage acrossthe secondarywindingABchangespolaritiesaftereveryhalf-cycle.
- Duringthepositivehalf-cycleofinput A.C. voltage, endAbecomespositivew.r.t.end B. This makes the diode forward biased and hence it conducts current.
- During the negative half-cycle, end A is negative w.r.t. end B. Under this condition, the diode is reverse biased and it conducts no current.
- Therefore, current flows through the diode during positive half-cycles of input A.C. voltage only; it is blocked during the negative half-cycles. In this way, current flows through load R_L always in the same direction. Hence D.C. output is obtained across R_L.
- It may be noted that output across the load is *pulsating D.C*. These pulsations in the output are further smoothened with the help of filter circuits discussed later.

Disadvantages : -

(i) The pulsating current in the load contains alternating component whose basic frequency is equal tothe supply frequency.Therefore, an elaborate filtering is required to produce steady direct current.

(ii) TheA.C. supplydelivers power onlyhalf thetime.Therefore,the output islow.

❖ FULL-WAVERECTIFIER:-

- Infull-waverectification,currentflowsthroughtheloadinthesamedirectionforbothhalf-cyclesof input A.C. voltage.This can be achieved with two diodes working alternately.
- Forthepositivehalf- cycle ofinputvoltage,onediode suppliescurrent to the loadandforthenegative half-cycle, the other diode does so ; current being always in the same direction through the load.
- Therefore,afull-waverectifierutilizesbothhalf-cyclesofinput A.C.voltagetoproducethe D.C. output.
- The followingtwocircuitsarecommonlyused for full-wave rectification:-
  - ▪ **(i)**Centre-tap full-waverectifier **(ii)**Full-wavebridge rectifier

❖ CENTRE-TAPFULL-WAVERECTIFIER:-

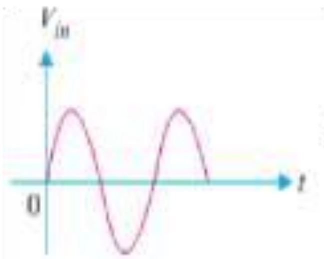
Circuit Details: -

- ThecircuitemploystwodiodesD_1andD_2asshowninFigbelow.Acentretappedsecondarywinding AB is used with two diodes connected so that each uses one half-cycle of input A.C. voltage.
- Inotherwords,diodeD_1utilizestheA.C.voltageappearingacrosstheupperhalf(OA)ofsecondary winding for rectification while diode D_2 uses the lower half winding OB.

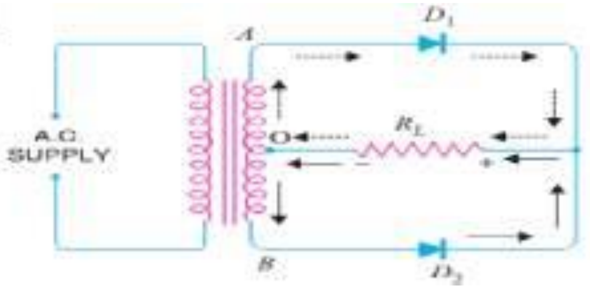
Circuit Operation: -

- Duringthepositivehalf-cycleofsecondaryvoltage,theendAofthesecondarywindingbecomespositive and end B negative. This makes the diode D_1 forward biased and diode D_2 reverse biased.
- Therefore,diodeD_1conductswhilediodeD_2does not.Theconventionalcurrentflowisthroughdiode D_1, load resistor R_L and the upper half of secondary winding as shown by the dotted arrows.
- Duringthe negative half-cycle,endAof thesecondarywindingbecomesnegative andend Bpositive.

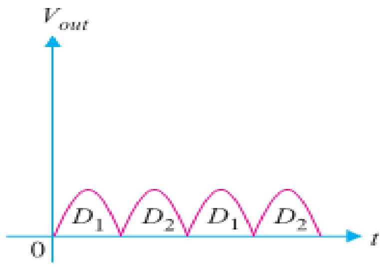
- Therefore,diodeD$_2$conductswhilediodeD$_1$does not.Theconventionalcurrentflowisthroughdiode D$_2$, load R$_L$& lower half winding shown by solid arrows.
- ItmaybeseenthatcurrentintheloadR$_L$isinthesamedirectionforbothhalf-cyclesofinputA.C. voltage. Therefore, D.C. is obtained across the load R$_L$.



(InputWave form)



(Centre-TapFull-WaveRectifier Circuit)



(Outputwaveform)

Advantages:-

(i) TheD.C.outputvoltageandloadcurrentvaluesaretwicethanthat ofahalfwaverectifier.
(ii) Theripple factorismuchless(0.482) thanthatofhalf rectifier (1.21).
(iii) Theefficiencyistwice(81.2%) thanthat of half wave rectifier(40.6%).

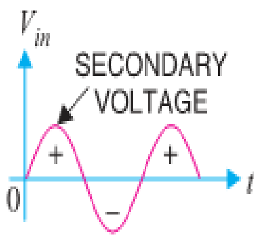
Disadvantages:-

(i) Itisdifficult tolocatethe centretapon thesecondarywinding.
(ii) TheD.C. output issmallaseach diodeutilizesonlyone-half ofthe transformer secondaryvoltage.
(iii) Thediodesusedmust havehighpeakinversevoltage.

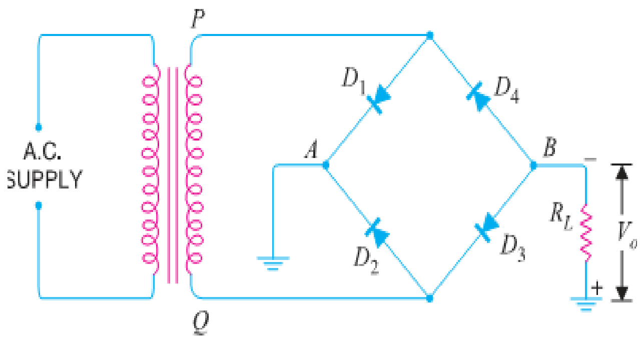
❖ FULL-WAVEBRIDGERECTIFIER:-

Circuit Details: -

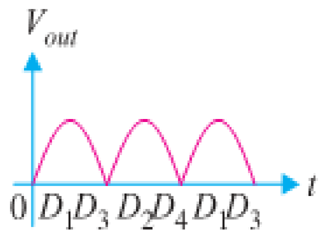
- Theneedfora centre tappedpowertransformeriseliminated inthe bridge rectifier.
- ItcontainsfourdiodesD$_1$,D$_2$,D$_3$ andD$_4$ connectedtoformbridgeasshowninFigbelow.
- TheA.C.supplytoberectifiedisappliedtothediagonallyoppositeendsofthebridgethroughthe transformer.
- Betweenothertwoendsofthe bridge,theload resistanceR$_L$is connected.



(InputWave Form)



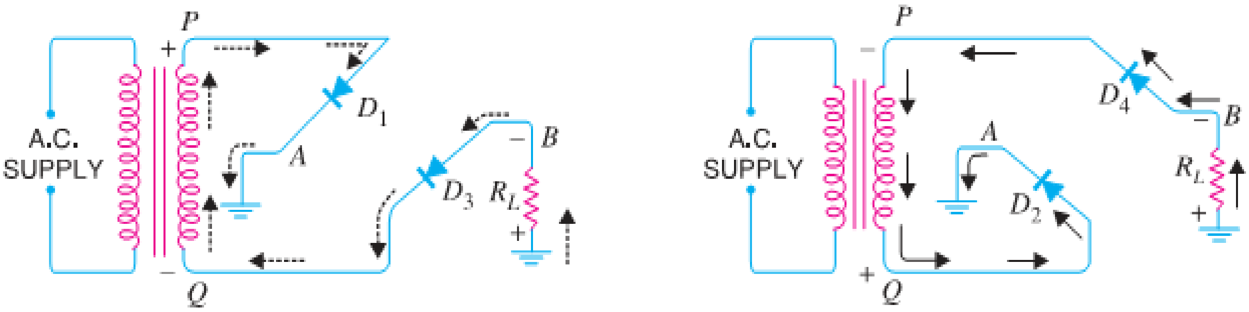
(Full-WaveBridgeRectifierCircuit)



(Outputwaveform)

CIRCUIT OPERATION :-

- Duringthe positive half-cycle of secondaryvoltage, the end P of the secondarywindingbecomes positive and end Q negative.
- ThismakesdiodesD$_1$andD$_3$forwardbiasedwhilediodesD2andD4 arereversebiased.
- Therefore, only diodes D$_1$ and D$_3$ conduct. These two diodes will be in series through the load R$_L$ as shown in Fig. below.The conventional current flow is shown by dotted arrows. It may be seen that current flows from A to B through the load R$_L$.
- During the negative half-cycle of secondary voltage, end P becomes negative and end Q positive.This makes diodes D$_2$and D$_4$ forward biased whereas diodes D$_1$ and D$_3$ are reverse biased.
- Therefore, only diodes D$_2$ and D$_4$ conduct.These two diodes will be in series through the load R$_L$ as shown in Fig. below. The current flow is shown by the solid arrows.
- It may be seen that again current flows from A to B through the load i.e. in the same direction as for the positive half-cycle. Hence, D.C. output is obtained across load R$_L$.



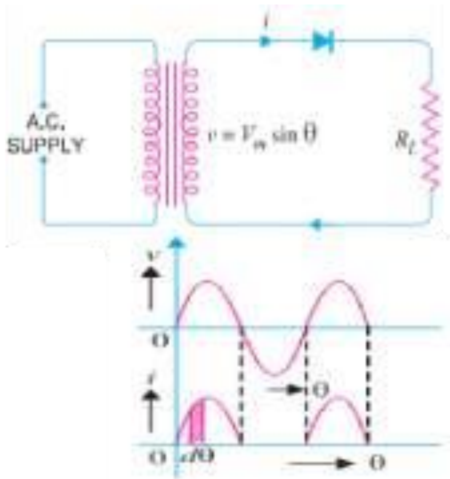
(Full-WaveBridgeRectifierCircuitin+veHalfCycle)(Full-WaveBridge RectifierCircuit-ve HalfCycle)

- **Advantages:-**
  (i) Theneedfor centre-tappedtransformeriseliminated.
  (ii) Theoutput istwicethatof the centre-tapcircuitfor thesame secondaryvoltage.
  (iii) ThePIVisone-halfthatofthecentre-tapcircuit (forsameD.C. output).
- **Disadvantages:-**
  (i) Itrequiresfourdiodes.(ii)Internalresistancesshigh.

Mathematical Derivation for Rectification Efficiency for HALF WAVE rectifier : -

Theratio ofd.c. power outputto theapplied inputa.c. power isknown asrectifierefficiencyi.e.,

$$\text{Rectifier efficiency, } \eta = \frac{\text{d.c. power output}}{\text{Input a.c. power}}$$



Considerahalf-wave rectifiershowninFig.

Let $v = V_m \sin\theta$ be the alternating voltage that appears across the secondary winding. Let r_f and R_L be the diode resistance and load resistance respectively.

The diode conducts during positive half-cycles of a.c. supply whileno current conduction takes place during negative half-cycles.

- **OUTPUTD.C.POWER:-**

Theoutputcurrentispulsatingdirectcurrent.Therefore,inordertofind D.C.power,averagecurrent hasto befound out.

$$\text{Average Value} = \frac{\text{Area Under The Curve Over a cycle}}{\text{Base}} = \int_0^\pi \frac{i\, d\theta}{2\pi}$$

$$I_{av} = I_{dc} = \frac{1}{2\pi}\int_0^\pi i\, d\theta = \frac{1}{2\pi}\int_0^\pi \frac{V_m \sin\theta}{r_f + R_L}\, d\theta = \frac{V_m}{2\pi(r_f+R_L)}\int_0^\pi \sin\theta\, d\theta = \frac{V_m \sin\theta}{r_f+R_L}[\ \ \cos\theta]_0^\pi$$

$$= \frac{V_m}{2\pi(r_f+R_L)} \times [(-\cos\pi) - (-\cos 0)] = \frac{V_m}{2\pi(r_f+R_L)} \times 2 = \frac{V_m}{(r_f+R_L)} \times \frac{1}{\pi} = \frac{I_m}{\pi} \qquad \left[\because I_m = \frac{V_m}{(r_f+R_L)}\right]$$

∴ D.C.Power, $P_{dc} = I_{dc}^2 \times R_L = \left(\frac{I_m}{\pi}\right)^2 \times R_L$

- **INPUTA.C.POWER:-**

TheA.C.powerinputis givenby: $P_{ac} = I_{rms}^2 (r_f + R_L)$ Forahalf-waverectifiedwave, $I_{rms} = I_m/2$ P_{ac} = ×

∴ $(r_f + (R_L))$ $\frac{I_m}{2}$

∴ Rectifierefficiency $= \frac{\text{d.c.output power}}{\text{a.c.input power}} = \left(\frac{(I_m/\pi)^2 \times R_L}{(I_m/2)^2 (r_f + R_L)}\right) = \frac{0.406 R_L}{r_f + R_L} = \frac{0.406 R_L}{1 + \frac{r_f}{R_L}}$

Theefficiencywillbemaximum if r_f isnegligibleascomparedto R_L.

∴ **Max. RectifierEfficiencyfor HALFWAVE Rectifier=40.6%**

Itshowsthatin half-waverectification,amaximum of40.6%ofa.c.poweris convertedintod.c.power.

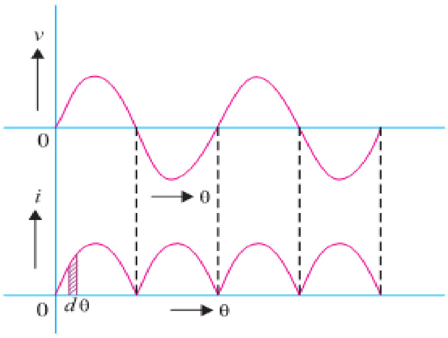
NOTE:- $I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i^2\, d\theta\right]^{1/2} = \left[\frac{1}{2\pi}\int_0^\pi I_m^2 \sin^2\theta\, d\theta + \frac{1}{2\pi}\int_\pi^{2\pi} 0\, d\theta\right]^{1/2} = \left[\frac{I_m^2}{2\pi}\int_0^\pi \frac{1-\cos 2\theta}{2}\, d\theta\right]^{1/2}$

$$= \left[\frac{I_m^2}{4\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^\pi\right]^{1/2} = \left[\frac{I_m^2}{4\pi}\left[\pi - 0 - \frac{\sin 2\pi}{2} + \sin 0\right]\right]^{1/2} = \left[\frac{I_m^2}{4\pi} \times \pi\right]^{1/2} = \left[\frac{I_m^2}{4}\right]^{1/2} = \frac{I_m}{2} \rightarrow I_{rms} = \frac{I_m}{2}$$

Similarly, $V_{rms} = V_m/2$ forHalfWaveand ForFull WaveRectifier $I_{rms} = I_m/\sqrt{2}$ and $V_{rms} = V_m/\sqrt{2}$

Mathematical Derivation for Rectification Efficiency for FULL WAVE Rectifier : -

- Fig.showstheprocessoffull-wave rectification.
- Let $v = V_m \sin\theta$ be the a.c. voltage to be rectified. Let rf and R_L bethe diode resistance and load resistance respectively.
- Obviously, the rectifier will conduct current through the load in the same direction for both half-cycles of input a.c. voltage. The instantaneous current *i* is given by :



$$i = \frac{v}{(rf + R_L)} = \frac{V_m \sin\theta}{(rf + R_L)}$$

❖ D.C.OUTPUTPOWER.

- The output current is pulsating direct current. Therefore, in order to find the d.c. power, average current has to be found out.For a full wave rectifier the average value or dc value can be found like half wave ,

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

∴ D.C.power output, $P_{dc} = I_{dc}^2 \times R_L = (\frac{2I_m}{\pi})^2 \times R_L$

❖ A.C.INPUTPOWER.

- The a.c.input power isgiven by:

$$P_{ac} = I_{rms}^2(rf + R_L)$$

Forafull-waverectified wave,wehave, $I_{rms} = I_m/\sqrt{2}$

$$\therefore \quad P_{ac} = (\frac{I_m}{\sqrt{2}})^2(rf + R_L)$$

∴ Full-waverectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2I_m/\pi)^2 R_L}{(\frac{I_m}{\sqrt{2}})^2(rf + R_L)} = \frac{8}{\pi^2} \times \frac{R_L}{(rf + R_L)} = \frac{0.812\, R_L}{rf + R_L} = \frac{0.812}{1 + \frac{rf}{R_L}}$$

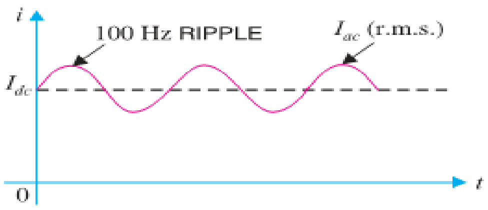
Theefficiencywillbe maximum if r_f isnegligibleascompared toR_L.

∴Maximumefficiency=81.2%

- Thisisdoubletheefficiencyduetohalf-waverectifier.Therefore,afull-waverectifieristwiceas effective as a half-wave rectifier.

RIPPLE FACTOR: -

- Theoutput ofarectifier consistsof ad.c.componentandan a.c.component(alsoknownasripple).
- Thea.c.componentisundesirableandaccountsforthepulsations in the rectifier output.
- Theeffectivenessofarectifierdependsuponthemagnitudeof a.c.componentintheoutput;thesmallerthiscomponent,the more effective is the rectifier.



- Ripplemean unwantedacsignalpresent intherectified output.
- TheratioofR.M.S.valueofA.C.componenttotheD.C.componentintherectifieroutputisknownas *ripplefactor*i.e.

$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c component}}{\text{value of d.c. component}} = \frac{I_{ac}}{I_{dc}}$$

❖ MathematicalAnalysis.

- Theoutput currentofarectifier contains d.c.aswellasa.c. component.
- Bydefinition,theeffective(i.e.r.m.s.)valueoftotalloadcurrentisgivenby: $I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$ Or $I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$
- DividingthroughoutbyI$_{dc}$, weget,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$ (ButI_{ac}/I_{dc}istheripple factor.)

$$\therefore \quad \text{Ripple factor} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{(\frac{I_{rms}}{I_{dc}})^2 - 1}$$

(i) **Forhalf-waverectification:-**

Inhalf-waverectification, $I_{rms}=I_m/2$; $I_{dc}= I_m/\pi$

∴ Ripplefactor $= \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1}$ **=1.21**

- Itisclearthata.c. componentexceedsthed.c.component inthe outputof ahalf-wave rectifier.
- Thisresultsingreaterpulsationsintheoutput.
- Therefore, half-waverectifierisineffectiveforconversion ofa.c.into d.c.

(ii) **Forfull-waverectification**:-

Infull-wave rectification, $I_{rms} =\frac{I_m}{\sqrt{2}}$; $I_{dc}=\frac{2I_m}{\pi}$

∴ Ripple factor $= \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1}$ **=0.48** i.e. $\frac{\text{effective a.c.component}}{\text{d.c.component}} = 0.48$

- Thisshowsthatintheoutputofafull-waverectifier,thed.c.componentismorethanthea.c. component. Consequently, the pulsations in the output will be less than in half-wave rectifier.
- Forthisreason,full-wave rectificationisinvariablyusedforconversion ofa.c.into d.c.

Peak Inverse Voltage (PIV) : -

- The maximum valueofreversevoltage occursat thepeakoftheinput cycle,whichisequalto V_m.
- Thismaximumreversevoltage iscalledpeak inversevoltage(PIV).ThusthePIVofdiode: -

a)ForHalfWave=V_m.,**b)**ForCenterTapped =2$V_m$and**c)**ForBridgeRectifier=V_m.

Transformer Utilization Factor (TUF) : -

- Itmaybedefinedastheratioofd.c.powerdeliveredtotheloadandthea.c.ratingofthetransformer secondary.

Thus, **TUF=P_{dc}/ P_{ac}**

- Forhalf wave rectifier,TUF=**0.287**;Centertapedrectifier,TUF=**0.693**;Bridgerectifier,TUF**=0.812**.
- The TUFisveryuseful in determiningtherating of atransformerto be used with rectifiercircuit.

Average Value of Voltage & Current for HALF WAVE Rectifiers: -

- If V_m= Maximum value of the a.c. input voltage, then the average or d.c. value of the output voltage and current is given by

$V_{dc}=V_m/\pi=0.318V_m$ and **$I_{dc}=I_m/\pi= 0.318I_m$**

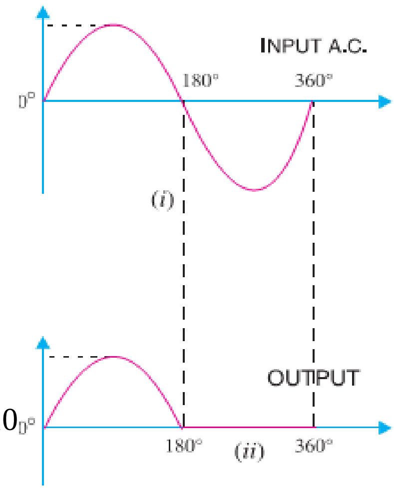
Average Value of Voltage & Current for FULL WAVE Rectifiers: -

- If V_m= Maximum value of the a.c. input voltage, then the average or d.c. value of the output voltage and current is given by

$V_{dc}=2V_m/\pi=0.636V_m$ and **$I_{dc}=2I_m/\pi = 0.636I_m$**

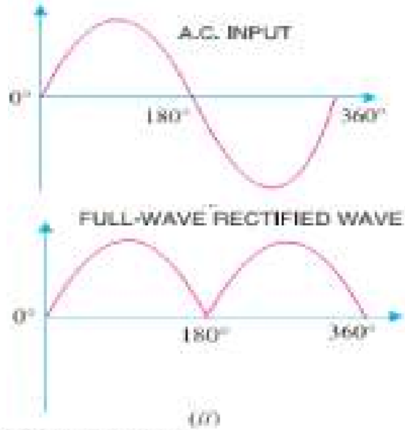
Output Frequency of Half Wave Rectifier: -

- Theoutputfrequencyofahalf-waverectifierisequaltotheinputfrequency(50Hz).Recallhowa complete cycle is defined.



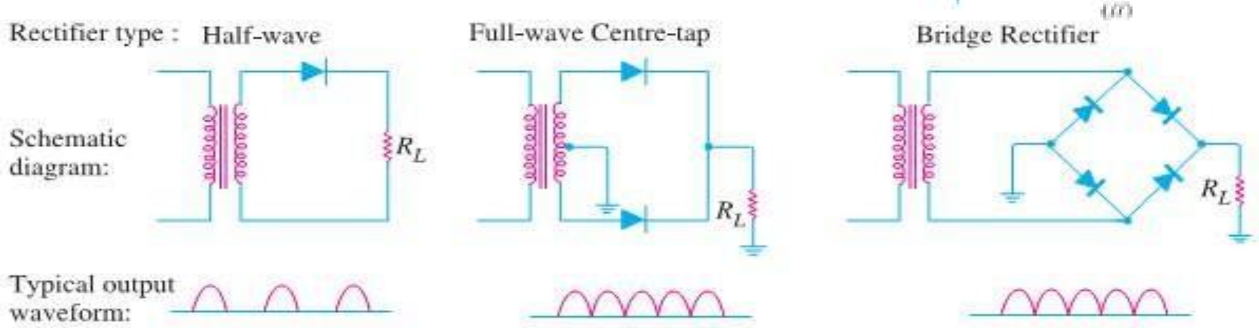
- A waveform has a complete cycle when it repeats the same wave patternover a given time.
- Thus in Fig. (i), the a.c. input voltage repeats the same wave pattern over 0° – 360°, 360° – 720° and so on.
- In Fig. (ii), the output waveform also repeats the same wave pattern over0° – 360°, 360° – 720° and so on.
- This means that when input a.c. completes one cycle, the output half wave rectified wave also completes one cycle.
- In other words, for the half wave rectifier the output frequency is equal to the input frequency i.e. **$f_{out} = f_{in}$**
- Forexample,iftheinputfrequencyofsinewaveappliedtoahalf-wave rectifier is 100 Hz, then frequencyof the output wave will also be 100 Hz.

✚ OutputFrequencyofFullWaveRectifier:-



- Theoutputfrequencyofafull-waverectifierisdoubletheinput frequency.
- Asawavehasa completecyclewhenitrepeatsthesame pattern.
- InFig. (i),theinput a.c.completesonecyclefrom0°– 360°.
- However, in Fig. (ii) full-wave rectified wave completes two cycles in this period.
- Therefore,output frequencyis twice theinput frequencyi.e. $\mathbf{f_{out}=2f_{in}}$
- For example, if the input frequency to a full-wave rectifier is 100 Hz, then the output frequency will be 200 Hz.

➢ COMPARISONOFRECTIFIERS:-



S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2f_{in}$	$2f_{in}$
6	Peak inverse voltage	V_m	$2V_m$	V_m

❖ FILTERCIRCUITS:-

- Generally, a rectifier is required to produce pure D.C. supply for using at various places in the electronic circuits.
- However,theoutputofarectifierhaspulsatingcharacteri.e.it containsA.C. andD.C. components.
- TheA.C.component isundesirable andmustbe keptawayfrom the load.
- Todoso,afiltercircuitisusedwhichremoves(orfiltersout)theA.C.componentandallowsonlythe D.C.component toreachthe load.
- A**filtercircuit**isadevicewhichremovestheA.C.componentofrectifieroutputbutallowstheD.C. component to reach the load.
- Afiltercircuitis generallya combinationofinductors(L)andcapacitors(C).
- ThefilteringactionofLandCdependsuponthebasicelectricalprinciples.
- Acapacitoroffersinfinitereactancetod.c.
- WeKnowthat$X_C=1/2\pi fC$.But forD.C., f=0.

  ∴ $X_C=1/2\pi fC= 1/2\pi x0\ xC =\infty$(MeansCapacitor shows*infinite reactance*to DC)

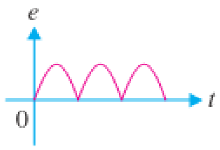
  ♣ ***Hence,aCapacitor doesnotallow d.c.topassthroughit.***

- WeknowX$_L=2\pi fL$.For d.c.,f=0

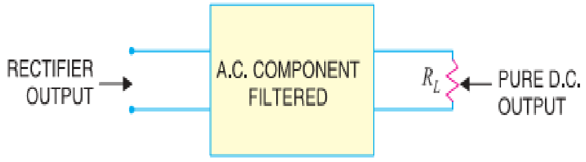
  ∴ $X_L=2\pi x0xL=0$(MeansInductor shows*zero reactance*toDC)

  ♣ ***HenceInductorpassesd.c.quitereadily.***

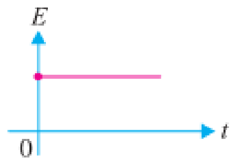
- *A Capacitor passes A.C. but does not pass D.C. at all. On the other hand, an Inductor opposes A.C. but allows D.C. to pass through it.*
- ItthenbecomesclearthatsuitablenetworkofLandCcaneffectivelyremovetheA.C.component, allowing the D.C. component to reach the load.



(PulsatingD.C)



(FilterCircuit)



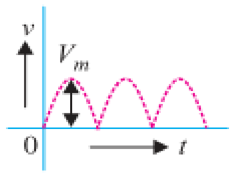
(Pure D.C)

➢ **TypesOfFilterCircuits:-**

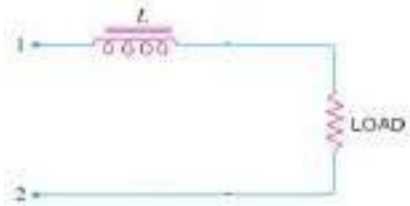
🙰There are different types of filter circuits according to their construction. The most commonly used filter circuits are : -

- ♣ <u>*InductiveFilterorSeries Inductor*</u>,
- ♣ <u>*CapacitorFilterorShunt Capacitor*</u>,
- ♣ <u>*ChokeInputFilterorLC Filter*</u>and
- ♣ <u>*CapacitorInputFilteror*π*-Filter*</u>.

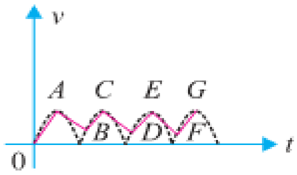
✓ **InductiveFilterOrSeriesInductor:-**



(Rectifiedoutput Pulsatingd.c)



(InductiveFilterCircuit)



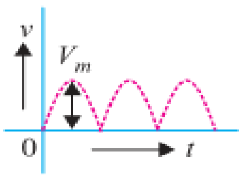
(Outputof Inductive Filter)

🙰Fig.(ii)ShowsatypicalInductivefiltercircuit.ItconsistsofanInductorLplacedacrosstherectifier output in series with load R_L.

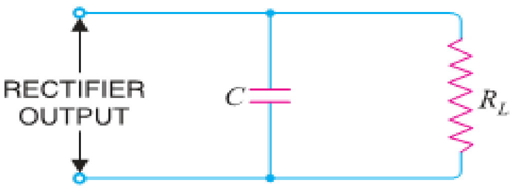
🙰Thechoke(Inductorwithironcore)offershighoppositiontothepassageofa.c.componentbutno opposition to the d.c. component.

🙰Theresultisthatmostofthea.c.componentappearsacrossthechokewhilewholeofd.c.component passes through the choke on its way to load. This results in the reduced pulsations at Load resistance R_L.

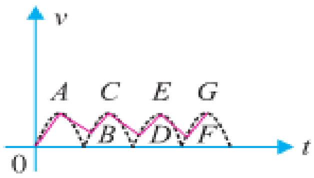
✓ **CapacitorFilterOrShunt Capacitor:-**



(RectifiedoutputPulsatingd.c)



(CapacitorFilterCircuit)



(OutputofCapacitor Filter)

🙰Fig.(ii)ShowsatypicalcapacitorfiltercircuitItconsistsofacapacitorCplacedacrosstherectifier output in parallel with load R_L.

🙰Thepulsatingdirectvoltageoftherectifierisappliedacrossthecapacitor.Astherectifiervoltage increases, it charges the capacitor and also supplies current to the load.

🙰Attheendofquartercycle[PointAinFig.(iii)],thecapacitorischargedtothepeakvalueV_m ofthe rectifier voltage.

🙰Now, the rectifier voltage starts to decrease. As this occurs, the capacitor discharges through the load and voltage across it decreases as shown by the line AB in Fig. (iii).

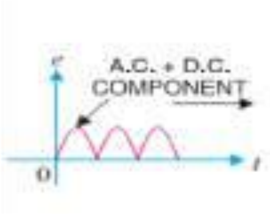
🙰The voltage across load will decrease onlyslightly because immediatelythe next voltage peak comes and recharges the capacitor.

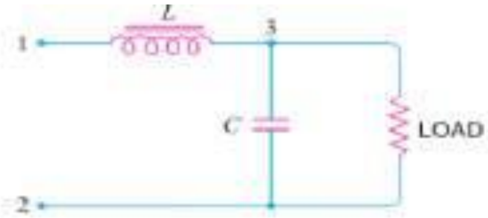
🙰This process is repeated again and again and the output voltage waveform becomes ABCDEFG. It maybe seen that very little ripple is left in the output.

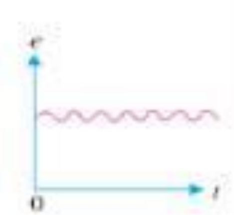
🙰Moreover,outputvoltageishigherasitremainssubstantiallynearthepeakvalueofrectifieroutput voltage.

🙰The capacitor filter circuit is extremelypopular because of its low cost, small size, little weight and good characteristics.

✓ **ChokeInputFilterOr LC Filter:-**



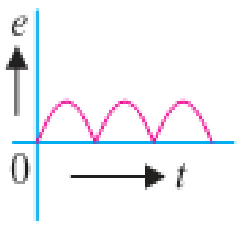


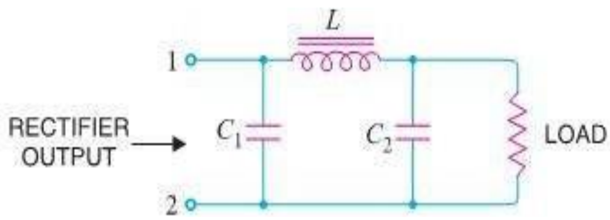


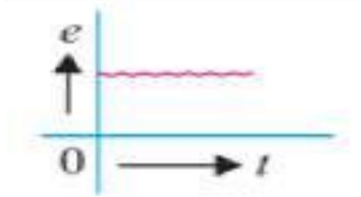
(Rectifiedoutput Pulsatingd.c) (ChokeInputFilterCircuit) (Outputof Choke InputFilter)

- Fig.showsatypicalchokeinputfiltercircuit.ItconsistsofachokeLconnectedinserieswiththe rectifier output and a filter capacitor C across the load.
- Only a single filter section is shown, but several identical sections are often used to reduce the pulsations as effectively as possible.
- Thepulsatingoutput oftherectifierisappliedacross terminals1and2ofthefilter circuit.
- As discussed before, the pulsating output of rectifier contains a.c. and d.c. components. The choke offers high opposition to the passage of a.c. component but negligible opposition to the d.c. component.
- Theresultisthatmostofthea.c.componentappearsacrossthechokewhilewholeofd.c.component passes through the choke on its way to load. This results in the reduced pulsations at terminal 3.
- Atterminal3,therectifieroutputcontainsd.c.componentandtheremainingpartofa.c.component which has managed to pass through the choke.
- Now,thelow reactanceoffiltercapacitorbypasses thea.c. component but prevents thed.c.componentto flow through it. Therefore, only d.c. component reaches the load.
- Inthisway,thefiltercircuithasfilteredoutthea.c.componentfromtherectifieroutput,allowing d.c. component to reach the load.

✓ **CapacitorInputFilterorπ-Filter:-**







(RectifiedoutputPulsatingd.c)(CapacitorInputorπ-FilterCircuit) (Outputofπ-Filter)

- Fig. shows a typical capacitor input filter or π-filter. It consists of a filter capacitor C_1connected across the rectifier output, a choke Lin series and another filter capacitor C_2connected across the load.
- Only one filter section is shown but several identical sections are often used to improve the smoothing action. The pulsating output from the rectifier is applied across the input terminals (i.e. terminals 1 & 2) of the filter.
- Thefilteringactionof thethree componentsvizC_1,LandC_2ofthisfilterisdescribedbelow:

  (a) The **filter capacitor C_1**offers low reactance to a.c. component of rectifier output while it offers infinite reactance to the d.c. component. Therefore, capacitor C_1 bypasses an appreciable amount of a.c. component while the d.c. component continues its journey to the choke L.

  (b) The**chokeL**offershighreactancetothea.c.componentbutitoffersalmostzeroreactancetothe d.c. component.Therefore,itallowsthe d.c.componenttoflow throughit,whiletheunbypassed a.c. component is blocked.

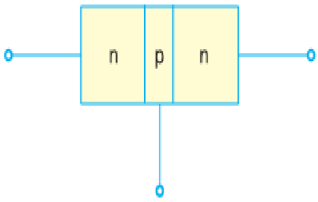
  (c) The **filter capacitor C_2**bypasses the a.c. component which the choke has failed to block. Therefore, only d.c. component appears across the load and that is what we desire

[CHAPTER-2]

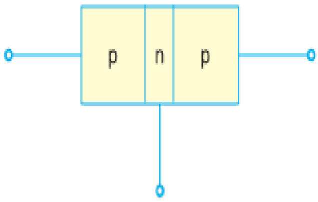
---------------------------[TRANSISTORSANDCIRCUITANALYSIS]------------------------

❖ **INTRODUCTION:-**

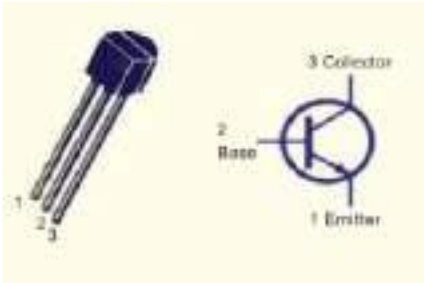
- When a third doped element is added to a crystal diode in such a way that two PN junctions are formed, the resulting device is known as a **Transistor**.
- This is a new type of electronics device which can able to amplify a weak signal in a fashion comparable and often superior to that realized by vacuum tubes.
- A transistor consists of two PN junctions formed by sandwiching either p-type or n-type semiconductor between a pair of opposite types. Hence Transistor is classified into two types, namely: -
  - **(i)**n-p-n transistor**(ii)**p-n-p transistor
- Ann-p-n transistoriscomposedoftwo n-typesemiconductorsseparatedbyathinsectionof p-type.
- However, a p-n-p transistor is formed bytwo p-sections separated by a thin section of n-type as shown in Figure below.



(i)



(ii)



❖ **NAMING:-**

- Atransistorhas*twopnjunctions*.Asdiscussedlater,onejunctionisforwardbiasedandtheotheris reverse biased.
- The*forwardbiasedjunction*hasalowresistancepathwhereasa*reversebiasedjunction*hasahigh resistance path.
- Theweaksignalisintroducedinthelowresistancecircuitandoutputistakenfromthehighresistance circuit. Therefore, a transistor transfers a signal from a low resistance to high resistance.
- Theprefix‘**trans**’meansthesignaltransferpropertyofthedevicewhile‘**istor**’classifiesitasasolid element in the same general family with resistors.

❖ **NAMINGTHETRANSISTOR TERMINALS:-**

- Atransistor(PNPorNPN)hasthreesectionsofdopedsemiconductors.
- The section on one sideisthe**emitter**and the section on the opposite sideisthe**collector**.
- Themiddlesection iscalledthe**base**andformstwojunctionsbetweentheemitterand collector.

(i)Emitter: -

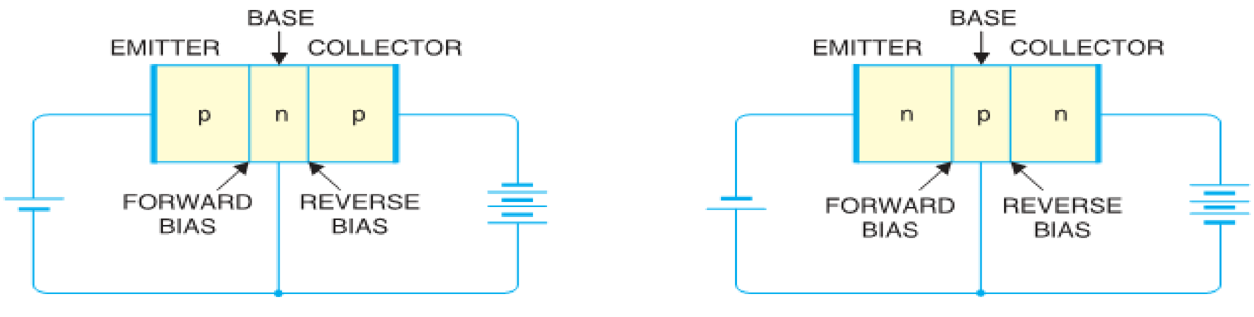
- Thesection ononesidethat*supplieschargecarriers*(electronsor holes)iscalledthe emitter.
- The emitterisalwaysforward biasedw.r.t. base so that it can supplyalarge numberofmajoritycarriers.
- The emitter (p-type) of PNP transistor is forward biased and supplies hole charges to its junction withthe base.Similarly the emitter (n-type) of NPN transistor has a forward bias and supplies free electrons to its junction with the base.

(ii) Collector:-

- Thesectionontheothersidethat*collectsthecharges*iscalledthecollector.Thecollectorisalways reverse biased. Its function is to remove charges from its junction with the base.
- Thecollector(p-type)ofPNPtransistorhasareversebiasandreceivesholechargesthatflowinthe output circuit. Similarly the collector (n-type) of NPN transistor has reverse bias & receives electrons.

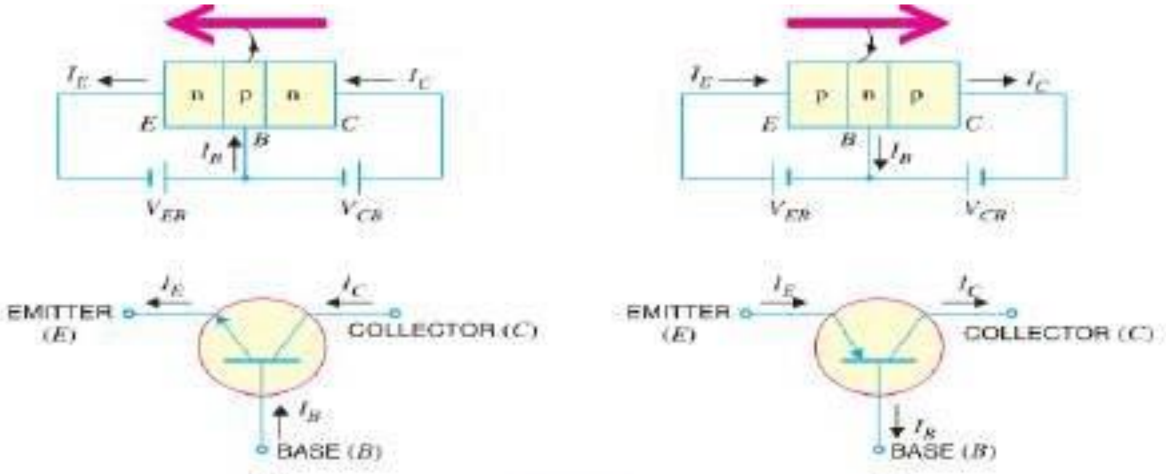
(iii)Base: -

- ThemiddlesectionwhichformstwoPN-junctionsbetweenemitter &collectoriscalledbase.
- Thebase-emitterjunctionisforwardbiased,allowinglowresistance fortheemitter circuit.
- Thebase-collectorjunctionisreversebiasedand provideshighresistanceinthecollector circuit.



(i) (ii)

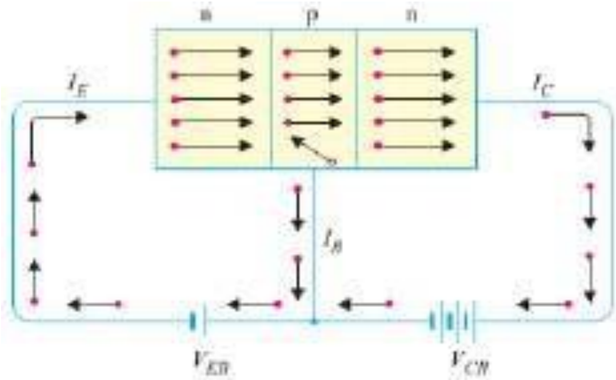
❖ TRANSISTORSYMBOL:-



(i) (ii)

❖ WORKINGOFNPNTRANSISTOR(NPN):-

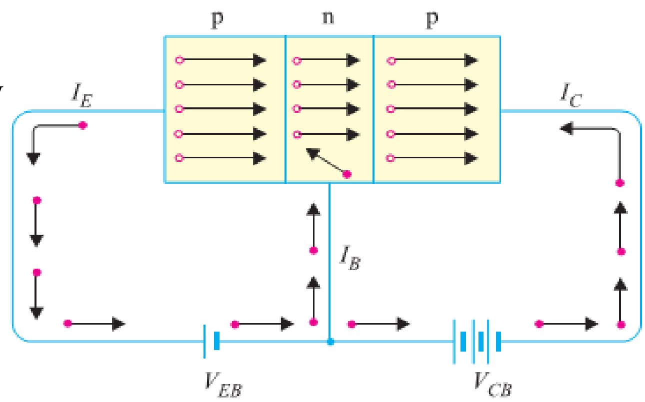
- TheNPNtransistorwithforwardbiasto emitter-basejunction &reversebiastocollector-base junction.
- The forward bias causes the electrons in the n-type emitter to flow towards the base.
- This constitutes the emitter current **I_E**.As these electrons flow through the p-type base, they tend to combine with holes.
- As the base is lightlydoped and verythin, therefore, only a few electrons (less than 5%) combine with holes to constitute base current **I_B**.
- The remainders (more than 95%) cross over into the collector region to constitute collector current **I_C**.



- Inthisway,almosttheentireemittercurrentflowsinthecollector circuit.
- It isclearthat emitter current isthesum of collectorand base currentsi.e.**$I_E = I_B + I_C$**

❖ WORKINGOFPNPTRANSISTOR(PNP):-

- Fig.showsthe basicconnectionofaPNPtransistor.
- Theforwardbiascausestheholesinthep-typeemitter to flow towards the base.
- ThisconstitutestheemittercurrentI$_E$.
- As these holes cross into n-type base, they tend to combine with the electrons.
- As the base is lightlydoped and verythin, therefore, only a few holes (less than 5%) combine with the electrons.Theremainder(morethan95%)crossinto the collectorregion to constitute collector current I$_C$.



- Inthisway,almosttheentireemittercurrentflowsinthecollector circuit.
- It may be noted that current conduction within PNP transistor is by holes. However, in the external connecting wires, the current is still by electrons

❖ TRANSISTOR CONNECTIONS:-

✍Therearethree leadsinatransistorsuchasemitter,baseandcollector terminals.

✍However, when a transistor is to be connected in a circuit, we require **four terminals**; two for the inputand two for the output.

✍This difficultyisovercomebymakingoneterminal ofitin commonto both inputandoutputterminals.

✍Theinput isfed between thiscommon terminaland oneoftheothertwo terminals.

✍The output isobtained between thecommonterminal andthe remainingterminal.

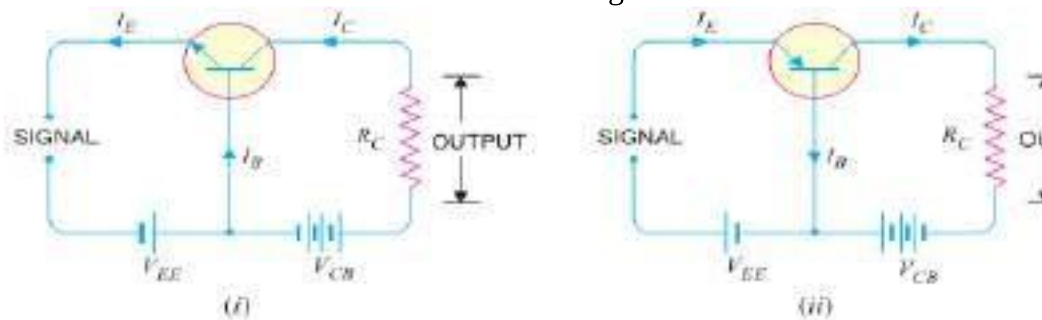
✍Soa transistorcan beconnected inacircuitin the followingways:-

(i) Common Baseconnection(**ii**) CommonEmitter connection(**iii**) CommonCollector connection

(i)Common Base Connection

Inthiscircuitarrangement,inputisappliedbetweenemitterandbaseandoutputistakenfrom collector and base.

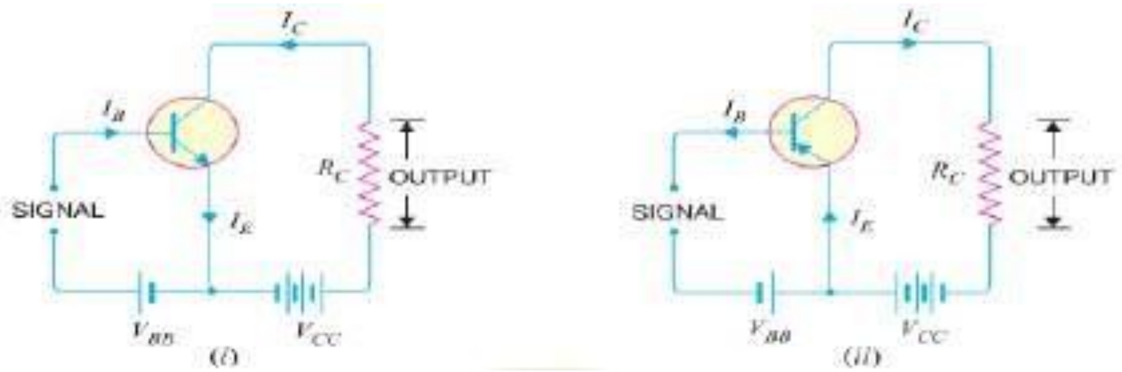
Here,baseofthetransistoriscommontobothinputandoutputcircuitsandhencethename **C**ommon**B**aseconnection.ACommonBaseNPNandPNP infigure below.



(ii) CommonEmitterConnection

In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter.

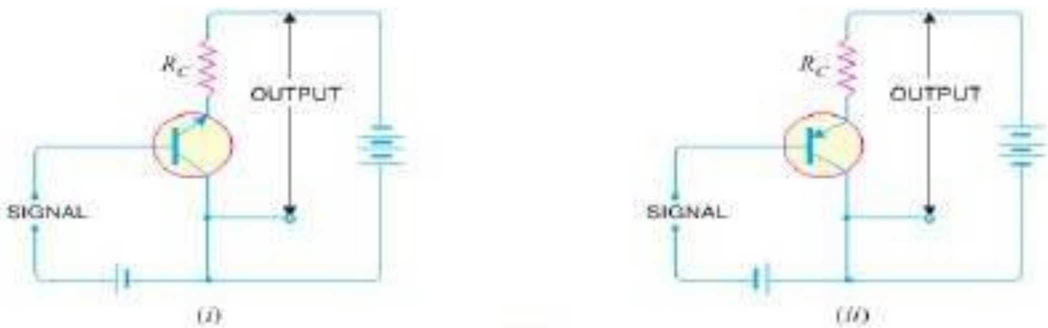
Here, emitter of the transistor is common to both input and output circuits and hence the name **C**ommon **E**mitter connection. A Common Emitter NPN and PNP transistor circuit is shown in figure below.



(iii) CommonCollectorConnection

In this circuit arrangement, input is appliedbetweenbaseand collector whileoutput is taken between the emitter and collector.

Here,collectorofthetransistoriscommontobothinputandoutputcircuitsandhencethename **C**ommon **C**ollectorconnection.ACommon CollectorNPNandPNP infigure below.



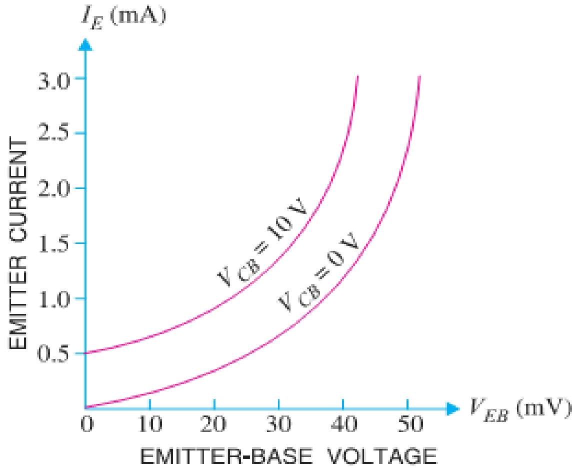
❖ TRANSISTOR CHARACTERISTICS:-

1) CharacteristicsofCommonBase Connection

- Thecompleteelectrical behavior ofatransistorcan bedescribedbystating theinterrelation ofthe various currents and voltages.
- These relationships can be conveniently displayed graphically and the curves thus obtained are known as the characteristics of transistor.
- Themostimportantcharacteristicsofcommonbaseconnectionare**inputcharacteristics**and**output characteristics**.

A) **Input Characteristics:-**

- It is the curve between emitter current I_E& emitter-base voltage V_{BE}at constant collector-base voltage V_{CB}.
- The emitter current is generally taken along y-axis and emitter-base voltage along x-axis. Fig. Shows the input characteristics of a typical transistor in CB arrangement.
- The following points may be noted from these characteristics :
  - ♣ The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. It means that input resistance is very small.
  - ♣ Theemittercurrentisalmostindependentofcollector-basevoltageV_{CB}.Thisleadstotheconclusionthat emittercurrent(andhencecollector current) isalmost independentofcollector voltage.



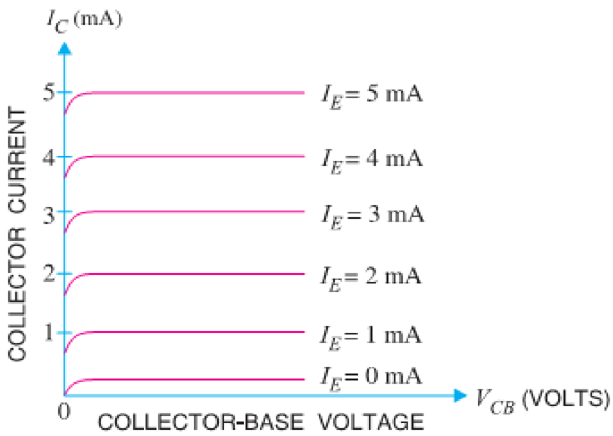
- **Input Resistance: -** It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}) i.e.

$$\text{Input resistance, } r_i = \frac{\Delta V_{BE}}{\Delta I_E} \text{ at constant } V_{CB}$$

- In fact, input resistance is the opposition offered to the signal current. As a verysmall $V_{EB}$is sufficient to producealarge flowofemittercurrentI_E,thus,inputresistance isquitesmall, oftheorder ofafewohms.

B) **OutputCharacteristics:-**

- It isthe curvebetweencollectorcurrentI_C&collector-basevoltageV_{BC}atconstantemittercurrent I_E.
- Generally,collectorcurrentistakenalongy-axisandcollector-basevoltagealongx-axis.
- Thefig.showstheinput andoutputcharacteristics ofatypicaltransistorinCB arrangement.
- The followingpointsmaybe notedfromcharacteristics:
  - ♣ The collector current I_C varies with V_{CB}only at very low voltages (<1V). The transistor is never operated in this region.
  - ♣ When the value of $V_{CB}$is raised above 1 − 2 V, the collector current becomes constant as indicated by straight horizontal curves. It means that now I_C is independent of V_{CB} and depends upon I_E only. Thisis consistent with the theory that the emitter current flows almost entirely to the collector terminal. The transistor is always operated in this region.
  - ♣ Averylargechangeincollector-basevoltage producesonlya tinychange incollectorcurrent.Thismeansthat outputresistanceisveryhigh.



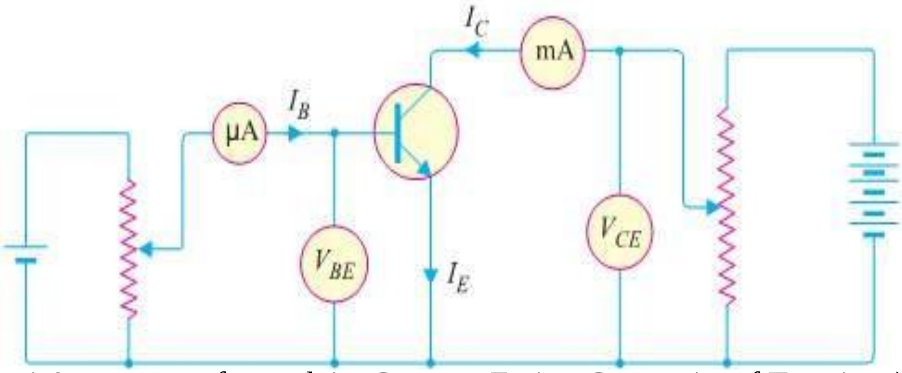
- **Output Resistance**: - It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current i.e.

$$\text{Output resistance, } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

- Theoutput resistanceofCBcircuit isveryhigh, ofthe orderof severaltensof kilo-ohms.

2) CharacteristicsofCommonEmitter Connection:-

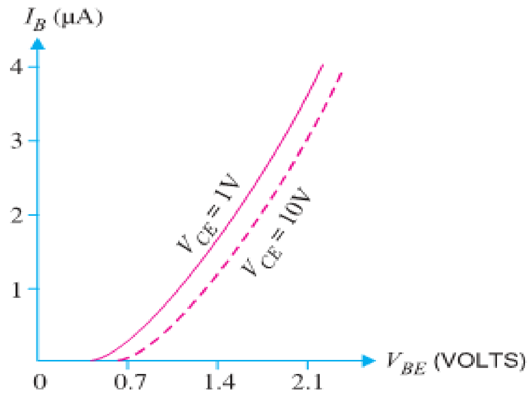
- The important characteristics of this circuit arrangement are the input characteristic and output characteristic.



(CircuitArrangementfor studyingCommonEmitterConnectionof Transistor)

A) **Input Characteristics:-**

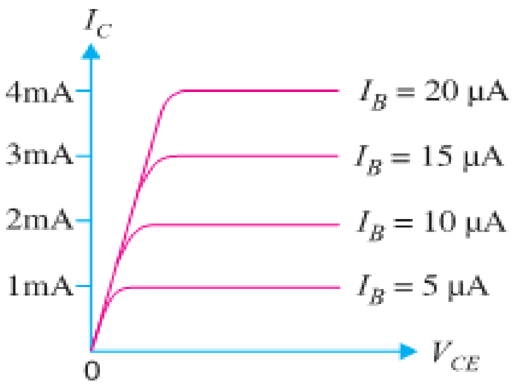
- It is the curve between base current IB & base-emitter voltage VBE at constant collector-emitter voltV_{CE}.Theinputcharacteristicsofa CEconnectioncanbe determinedbythe circuit shown in Fig. KeepingV_{CE}constant (Let 10 V), note the base current $I_B$for various values of V_{BE}.
- Then plot the readings obtained on the graph, taking $I_B$along y-axis and V_{BE} along x-axis. This gives the input characteristic at V_{CE}= 10V as shown in Fig.
- Thefollowingpointsmaybenotedfromthecharacteristics:
  - Thecharacteristicresemblesthatofaforwardbiaseddiode curve. This is expected since the base-emitter section of transistor is a diode and it is forward biased.
  - AscomparedtoCBarrangement,$I_B$increaseslessrapidly withV_{BE}.Therefore, inputresistanceof aCEcircuitishigherthan thatof CBcircuit.



- **Input Resistance: -** It is the ratio of change in base-emitter voltage (ΔV_{BE}) to the change in base current (ΔI_B) at constant V_{CE}.The value of input resistance for CE circuit is of the order of a few hundred ohms

B) **OutputCharacteristics:-**

- It isthe curvebetweencollectorcurrent**I_C**andcollector-emitter voltage **V_{CE}**at constantbasecurrent **I_B**.
- The outputcharacteristicsof CEcircuitcanbe drawnwiththe helpofabove circuitarrangementin Fig.
- Keeping the base current I_B fixed at some value say, 5 μA,note the collector current $I_C$for various values of V_{CE}.
- Then plot the readings on a graph, taking $I_C$along y-axis and V_{CE} along x-axis.
- This gives the output characteristic at I_B = 5 μA as shown in Fig. The test can be repeated for I_B= 10 μA to obtain the new output characteristic as shown in Fig.
- Following similarprocedure,a familyof output characteristics can be drawn as shown in Fig.



- The followingpoints maybe notedfromthecharacteristics:
  - (i) The collector current I_C varies with V_{CE} for V_{CE} between 0 and 1V only. After this, I_C becomes almost constant & independent of V_{CE}. This value of V_{CE} upto which I_C changes with V_{CE} is calledthe knee voltage (V_{knee}). The transistors are always operated in the region above knee voltage.
  - (ii) Above knee voltage, I_C is almost constant. However, a small increase in I_C with increasing V_{CE} is caused by the collector depletion layer getting wider and capturing a few more majority carriers before electron-hole combinations occur in the base area.
  - (iii)For anyvalueof V_{CE}aboveknee voltage, thecollectorcurrentI_C isapproximatelyequal to$\beta \times I_B$
- **Output Resistance: -** It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at constant I_Bi.e.

$$\text{Output resistance, } r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

- It may be noted that whereas the output characteristics of CB circuit are horizontal, they have noticeable slope for the CE circuit.
- Therefore,outputresistanceofCE circuitislessthanthat ofCB circuit.Itsvalueisof theorder of50 kΩ.

3) CharacteristicsofCommonCollector Connection:-

- InaCommonCollectorcircuitconnectiontheloadresistorconnectedfromemittertoground,sothe collector tied to ground even though the transistor is connected in a manner similar to the CE connection.
- Hencethereisnoneedforasetofcommon-collectorcharacteristictochoosetheparametersofthe circuit. The output characteristic of the CC configuration is same as CE configuration.
- ForCC Connectionthe outputcharacteristic areplot of**$I_E$versusV_{CE}**fora constant valueof**I_B**.
- Thereis analmost unnoticeablechangein theverticalscaleof I_C oftheCEconnection if I_C is replaced by I_E for CC connection. The input circuit of CC connection, the CE characteristic is sufficient to obtain the required information.
- HenceCommon Collectorcircuit connectionisknownas **EmitterFollower**.

❖ <u>CURRENTAMPLIFICATIONFACTORS</u>:-(Itistheratioofoutputcurrenttoinputcurrent)

1) CommonBaseConnection:-

In a common base connection, the input current is the Emitter Current **I_E**and output current is the Collector Current **I_C**.

Hence the ratio of change in collector current to the change in emitter current at constant collector-base voltage V_{CB} is known as current amplification factor for CB Connection and is denoted as **α (Alpha).**

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

- ♣ Practicalvaluesofαincommercialtransistorsrangefrom0.9to0.99.

2) CommonEmitterConnection:-

In a common emitter connection, the input current is the Base Current **I_B**and output current is the Collector Current **I_C**.

Hence ratio of change in collector current (I_C) to the change in base current (I_B) at constant collector-emitter voltage V_{CE} is known as current amplification factor for CE Connection and denoted as **β (Beta).**

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

- ♣ Usually,its valueranges from20to500.

3) CommonCollector Connection:-

In acommon collector connection, theinput currentis theEmitterCurrent **I_B**andoutput current is the Emitter Current **I_E**.

Hence the ratio of change in emitter current to the change in base current at constant V_{CC} is known as current amplification factor for CC Connection and is denoted as **γ (Gamma).**

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

- ♣ Thiscircuitprovidesaboutthesamecurrent gain asthecommonemittercircuitas$\Delta I_E \approx \Delta I_C$.

❖ RELATIONAMONGDIFFERENTCURRENTAMPLIFICATIONFACTORS:-

$$\Delta I_E = \Delta I_B + \Delta I_C$$

1) Relationbetweenαandβ:-

- ♣ As,$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} = \frac{\Delta I_C/\Delta I_E}{1-\Delta I_C/\Delta I_E} = \frac{\alpha}{1-\alpha}$ ➔ As,$\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{\Delta I_C}{\Delta I_B + \Delta I_C} = \frac{\Delta I_C/\Delta I_B}{1+\Delta I_C/\Delta I_B} = \frac{\beta}{1+\beta}$

2) Relationbetweenαandγ:-

- ♣ As,$\gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} = \frac{\Delta I_E/\Delta I_E}{1-\Delta I_C/\Delta I_E} = \frac{1}{1-\alpha}$ ➔As,$\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{\Delta I_E - \Delta I_B}{\Delta I_E} = \frac{\Delta I_E/\Delta I_B - 1}{\Delta I_E/\Delta I_B} = \frac{\gamma-1}{\gamma}$

3) Relationbetweenβandγ:-

- ♣ As,$\gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_B + \Delta I_C}{\Delta I_B} = \frac{\Delta I_B}{\Delta I_B} + \frac{\Delta I_C}{\Delta I_B} = 1 + \beta$➔As,$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_E - \Delta I_B}{\Delta I_B} = \frac{\Delta I_E}{\Delta I_B} - \frac{\Delta I_B}{\Delta I_B} = \gamma - 1$

4) Relationbetweenα,βandγ:-

- ♣ As, $\beta = \frac{\alpha}{1-\alpha} = \alpha X \frac{1}{1-\alpha} = \alpha x \gamma$

$$\therefore \beta = \alpha X \gamma$$

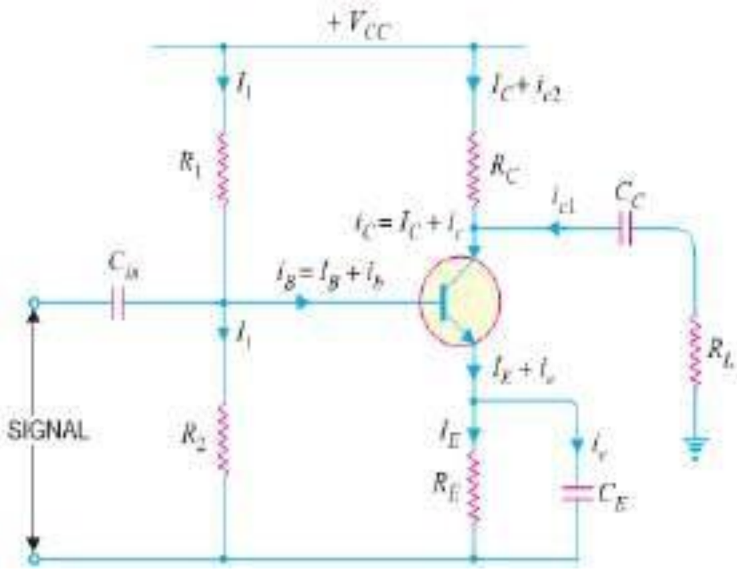
$\therefore \alpha = \frac{\beta}{1+\beta}$	$\therefore \beta = \frac{\alpha}{1-\alpha}$	$\therefore \gamma = \frac{1}{1-\alpha}$	∴ $\gamma - 1$	$\therefore \gamma = 1 + \beta$	$\therefore \beta = \gamma + 1$

♣ **COMPARISONOFTRANSISTORCONNECTIONS:-**

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

- ♣ Outofthethreetransistorconnections,the**Common EmitterCircuit**isthemost efficient.
- ♣ Itisusedin about90 to95 percent ofall transistor applications.
- ♣ Themainreasonsforthe widespreaduseofthis circuitarrangementare:
  (i)Highcurrent gain.(ii) Highvoltageandpower gain.(iii)Moderateoutputtoinputimpedance ratio.

❖ D.C.ANDA.C.EQUIVALENTCIRCUITS:-



✍Variouscircuitcurrents.Itisusefultomention the various currents in the complete amplifier circuit. These are shown in the circuit of Fig.

✍**(i) Base Current: -** When no signal is applied in the base circuit, D.C. base current $I_B$flows due to biasing circuit. When A.C. signal is applied, A.C. base current i_b also flows.

✍Therefore,withtheapplicationofsignal,Total Base Current $i_B$is given by:$\mathbf{i_B = I_B + i_b}$

✍**(ii) Collector Current: -** When no signal is applied, a D.C. collector current I_C flows due tobiasingcircuit.When A.C.signal isapplied, A.C.collectorcurrent$i_c$alsoflows.

✍Therefore, the Total Collector Current $i_C$is given by: -$\mathbf{i_C = I_C + i_c}$

Where $I_C = \beta\, I_B$=zerosignalcollectorcurrentand $i_c = \beta i_b$=collectorcurrent duetosignal.

✍**(iii) Emitter Current:-** When no signal is applied, a D.C. emitter current I_E flows. When A.C. signal isapplied, A.C. Emitter Current $i_e$also flows. Therefore the Total Emitter Current is : - $\mathbf{i_E = I_E + i_e}$

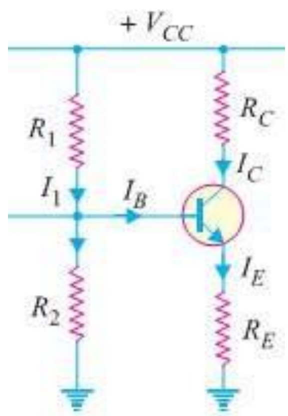
✍Itisusefulto keepinmindthat:$I_E = I_B + I_C$and$i_e = i_b + i_c$.

✍But basecurrent isusuallyverysmall,therefore,asa reasonableapproximation,$I_E \approx I_C$and$i_e \approx i_c$.

❖ **D.C.EquivalentCircuit:-**InordertodrawtheequivalentD.C.circuit,the following two steps are applied to the transistor circuit:-

(a) Reduce all A.C.sourcesto zero.

(b) Openallthe capacitors.



✍ReferringD.C. EquivalentCircuit

D.C.Load $\mathbf{R_{DC} = R_C + R_E}$ & $V_{CC} = V_{CE} + I_C(R_C + R_E)$

✍The maximumvalueof V_{CE}willoccurwhen thereisnocollector currenti.e.$I_C = 0$.

∴ **Maximum$\mathbf{V_{CE} = V_{CC}}$**

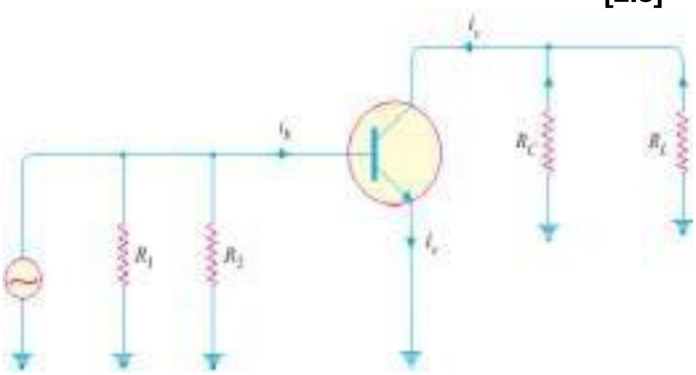
✍The maximum collector currentwillflowwhen$V_{CE} = 0$.

∴ **Maximum$\mathbf{I_C = V_{CC} / (R_C + R_E)}$**

❖ **<u>A.C.EquivalentCircuit</u>:-** InordertodrawA.C. equivalent circuit, the following two steps are applied to the transistor circuit:

(a) Reduce allD.C.sourcestozero(i.e. V_{CC}=0).

(b) Shortall the capacitors.



✍Referring A.C. Equivalent circuit A.C. load equal to R_C|| R_L i.e. A.C.load,**R_{AC}= (R_CR_L/ (R_C+R_L)**

✍Maximum positive swing of A.C. collector- emitter voltage = $I_C \times R_{AC}$

∴ Totalmaximum **collector-emittervoltage,V_{CEMAX}=V_{CE}+I_CR_{AC}**

✍MaximumpositiveswingofA.C.collectorcurrent = V_{CE}/R_{AC}

∴Totalmaximum**collectorcurrent,I_{CMAX}=I_C+V_{CE}/R_{AC}**

❖ <u>LOADLINEANALYSIS:-</u>

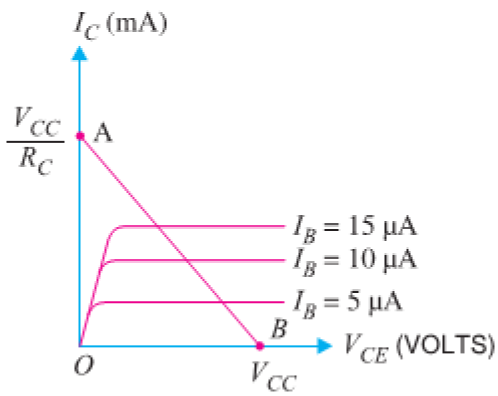
✍In the transistor circuit analysis, it is generally required to determine the collector current for various collector-emitter voltages.

✍One of the methods can be used to plot the output characteristics and determine the collector current at any desired collector-emitter voltage. However, a more convenient method, known as **load line method** can be used to solve such problems.

✍Thismethod isquite easyand isfrequentlyusedintheanalysisoftransistorapplications.

♣ **D.C. LOAD LINE**: - It is the line on the output characteristics of a transistor circuit which gives the values of I_C and V_{CE} corresponding to zero signal or D.C. conditions.

✍Consider a common emitter NPN transistor circuit where no signal is applied. Therefore, D.C. conditions prevailinthecircuit.Theoutputcharacteristicsofthiscircuit areshownin Fig.



✍The value of collector-emitter voltage V_{CE} at any time is given by ; V_{CE}= V_{CC}– I_C R_COrI_C R_C= V_{CC}- V_{CE}

OrI_C= V_{CC}/ R_C-V_{CE}/R_C

OrI_C=(-1/ R_C)V_{CE}+V_{CC}/R_C(≡ Y=mX+C)

✍As V_{CC} and R_C are fixed values, therefore, it is a first degree equation and can be represented bya straight line on the output characteristics. This is known as **D.C. Load Line.**

✍Toaddloadline,weneedtwoendpointsofthestraightline. Thesetwopointscanbelocatedas under:

(i) Whenthecollectorcurrent I_C=0,thencollector-emitter voltageismaximum andisequalto V_{CC}

i.e. Max.V_{CE}=V_{CC}–I_CR_C=V_{CC}(AsI_C=0)

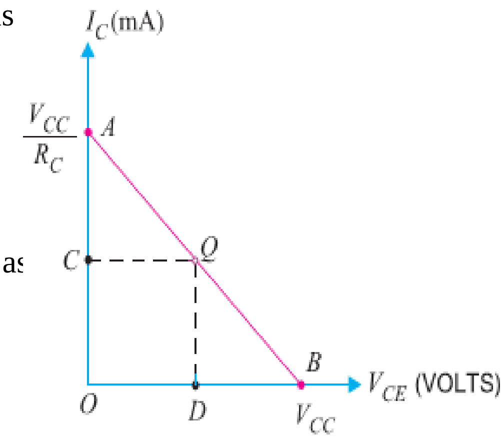
✍ThisgivesthefirstpointB(OB=V_{CC})onthecollector-emitter voltage axis as shown in Fig.

(ii) When collector-emitter voltage V_{CE}= 0, the collector current is maximum and is equal to V_{CC}/R_C

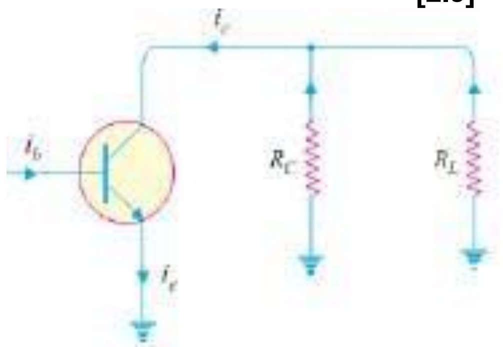
i.e. V_{CE}=V_{CC}– I_C $R_C$or0 =V_{CC}–I_CR_C

∴ Max. I_C= V_{CC}/R_C

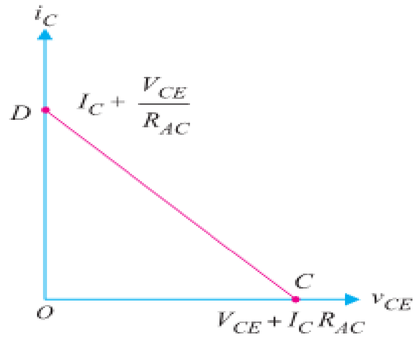
✍ThisgivesthesecondpointA(OA=V_{CC}/R_C)onthecollector current axis as shown in Fig.



✍Byjoiningthese two points, **D.C.LoadLine** ABis constructed.



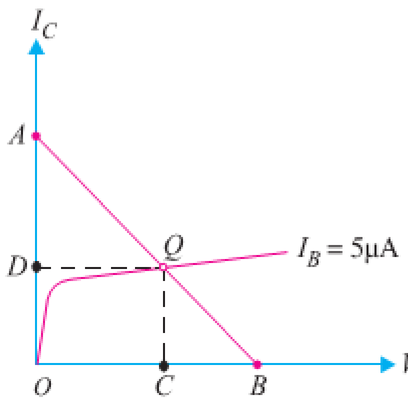
- **(II) A.C. LOAD LINE.** This is the line on the output characteristics of a transistor circuit which gives the values of i_C and v_{CE} when signal is applied.
- Referring back to the transistor amplifier shown in Fig., its A.C. equivalent circuit as far as output circuit is concerned is asshown in Fig.
- To add A.C. load line to the output characteristics, we again require two end points: –
  1. Onemaximum collector-emittervoltagepoint**(V_{CEMAX})**and
  2. Otherismaximum collectorcurrent point.**(I_{CMAX})**



- Under the application of A.C. signal, these values are Maximum collector-emitter voltage, $\mathbf{V_{CEMAX} = V_{CE} + I_C R_{AC}}$.
- This locates the point C of the A.C. load line on the collector-emitter voltage axis.
- Maximumcollector current,$\mathbf{I_{CMAX} = I_C + V_{CE}/R_{AC}}$
- This locatesthepointDofA.C.loadline onthecollector-current axis.
- ByjoiningpointsCandD,the**A.C.LoadLine**CDisconstructed.

❖ <u>OPERATINGPOINT:-</u>

- ThezerosignalvaluesofIcandVCEareknownasthe**Operatingpoint**.
- Itis calledoperatingpointbecausethevariationsofI_C andV_{CE}take place about this point when signal is applied.
- It is also called quiescent (silent) point or **Q-Point** because it is the point on I_C –V_{CE} characteristic when the transistor is silent i.e. in the absence of the signal.

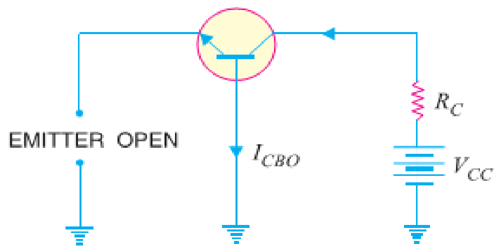


- Suppose in the absence of signal, the base current is 5μA. Then I_C and V_{CE} conditions in the circuit must be represented by somepoint on I_B = 5 μA characteristic.
- But I_C and V_{CE}conditions in the circuit should also be represented by some point on the d. c. load line AB.
- ThepointQwheretheloadlineandthecharacteristicintersectis the only point which satisfies both these conditions. Therefore, the point Q describes the actual state of affairsinthecircuitinthezerosignalconditionsandiscalledtheoperating point.ReferringtoFig,forI_B =5μA,thezerosignalvaluesare :

$$V_{CE} = OC \text{ volts} \qquad I_C = OD \text{ mA}$$

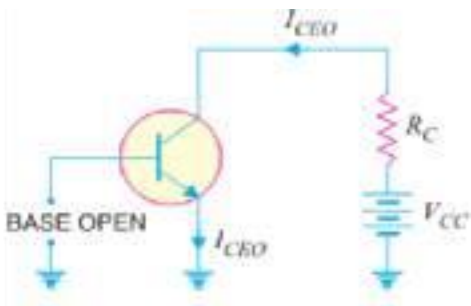
- It follows, therefore, that the zero signal values of $I_C$and V_{CE}(i.e. operating point) are determined by the point where d.c. load line intersects at proper base current curve.

❖ <u>THELEAKAGECURRENT</u>:-



- Thecurrentis dueto the movementofminoritycarriersis known as Leakage Current.
- InCommonBaseConnectionofTransistortheleakagecurrent $\mathbf{I_{CBO}}$istheCollector-Basecurrent withemitteropen.
- Similarly,InCommonEmitterConnectiontheleakagecurrent $\mathbf{I_{CEO}}$istheCollector-EmitterCurrent withopen Base.
- ExpressionforcollectorcurrentinCommonBaseConnectionis given by,

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$



- Expression for collector current in Common Emitter Connection is given by,

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad \text{Or} \quad I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

❖ FAITHFULAMPLIFICATION:-

✍Theprocessofraisingthestrengthofaweaksignalwithoutanychangeinitsgeneralshapeisknownas *FaithfulAmplification*. The keyfactor for achievingfaithful amplification: -

- ♣ (i)Properzerosignalcollector current
- ♣ (ii)Minimum proper base-emittervoltage (V_{BE}) atanyinstant
- ♣ (iii)Minimum propercollector-emitter voltage (V_{CE}) at anyinstant

❖ TRANSISTORBIASING:-

✍The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as *Transistor Biasing*.

✍Thefollowing arethemostcommonly usedmethodsofobtaining transistorbiasing fromonesourceof supply (i.e. V_{CC}):

- ♣ (i)BaseResistorMethod
- ♣ (ii)EmitterBias Method
- ♣ (iii)Biasingwith Collector-Feedback Resistor
- ♣ (iv)Voltage-DividerBias.

❖ STABILISATION:-

✍Theprocessofmakingoperatingpointindependentoftemperaturechangesorvariationsintransistor parameters is known as *Stabilization*.

❖ NEEDFORSTABILIZATION:-Stabilizationoftheoperatingpointisnecessaryduetothe following reasons :

- ♣ (i)Temperature dependenceofIC
- ♣ (ii)Individual variations
- ♣ (iii)Thermal runaway

✍Theself-destruction ofan unsterilized transistorisknownas***Thermal Runaway***.

❖ STABILITYFACTOR:-

✍TherateofchangeofcollectorcurrentI_Cw.r.t.thecollectorleakagecurrentI_{CO}[=I_{CEO}]atconstantβ and$I_B$iscalledstability factor i.e.

$$\text{Stability factor, } S = \frac{dI_C}{dI_{CO}} \text{ at constant } I_B \text{ and } \beta$$

❖ SIMPLEPROBLEMSONTRANSISTOR:-

1. Inacommonbaseconnection,I_E=1mA,I_C=0.95mA.CalculatethevalueofI_B.

Solution: Using the relation, $I_E = I_B + I_C$

Or $1 = I_B + 0.95$ ∴ $I_B = 1 - 0.95 =$ **0.05mA**

2. Inacommonbaseconnection,currentamplificationfactoris0.9.Iftheemittercurrentis1mA, determine the value of base current.

Solution: Here, $\alpha = 0.9$, I_E=1mA

Now $\alpha = \frac{I_C}{I_E}$ Or $I_C = \alpha I_E = 0.9 \times 1 = 0.9$mA

Also $I_E = I_B + I_C$ ∴ Basecurrent, $I_B = I_E - I_C = 1 - 0.9 =$ **0.1mA**

3. Inacommonbaseconnection,theemittercurrentis1mA.Iftheemittercircuitisopen,the collector current is 50 µA. Find the total collector current. Given that α= 0.92.

Solution: Here,I_E=1mA, α=0.92, I_{CBO}=50µA

∴ Totalcollectorcurrent,$I_C = \alpha I_E + I_{CBO} = 0.92 \times 1 + 50 \times 10^{-3} = 0.92 + 0.05 =$ **0.97mA**

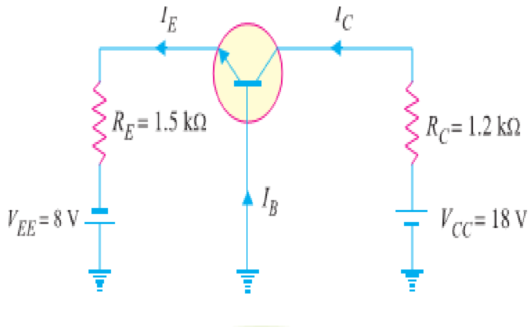
4. Inacommonbaseconnection,α=0.95.Thevoltagedropacross2kΩresistancewhichisconnected in the collector is 2V. Find the base current.

Solution: ThevoltagedropacrossR_C(=2kΩ)is2V. ∴ I_C=2V/2kΩ=1 mA

Now $\alpha = I_C/I_E$ ∴ $I_E = \frac{I_C}{\alpha} = \frac{1}{0.95} = 1.05$ mA

Usingthe relation,$I_E = I_B + I_C$ ∴ $I_B = I_E - I_C = 1.05 - 1 =$ **0.05 mA**

5. ForthecommonbasecircuitshowninFig.determineI_C&V_{CB}.AssumethetransistorisSilicon.



Solution: Since the transistor is of silicon, V_{BE}= 0.7V.

ApplyingKirchhoff'svoltagelawtothe emitter-sideloop,weget,

$$V_{EE}= I_E R_E+V_{BE}$$

Or $$I_E=\frac{V_{EE}-V_{BE}}{R_E}=\frac{8V-0.7V}{1.5\,K\Omega}= 4.87\text{mA}$$

$\therefore$ $I_C \approx I_E$=**4.87mA**

ApplyingKirchhoff'svoltagelawtothecollector-side loop, we have,

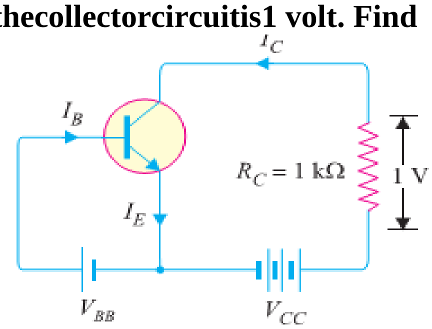
$V_{CC}=I_C R_C+V_{CB}$ ➔ $V_{CB}=V_{CC}-I_C R_C$= 18 V −4.87 mA ×1.2 kΩ = **12.16 V**

6. Calculate$I_E$inatransistorforwhichβ=50andI_B=20µA.

Solution: Here β = 50, I_B = 20µA = 0.02 mA

Now $\beta=\frac{I_C}{I_B}$ $\therefore$ $I_C=\beta I_B$=50×0.02=1mA;Usingtherelation,$I_E= I_B+ I_C$=0.02+1=**1.02mA**

7. Foratransistor,β=45 andvoltagedropacross1kΩwhichisconnectedinthecollectorcircuitis1 volt. Find the base current for common emitter connection.



Solution: Fig.showsthe requiredcommonemitterconnection.

ThevoltagedropacrossR_C(=1kΩ)is1volt.

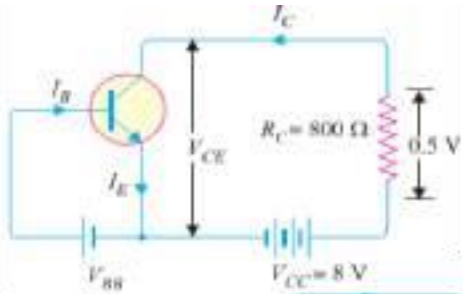
$\therefore$ $I_C=\frac{1\,V}{1\,K\Omega}$

Now $\beta=\frac{I_C}{I_B}$ $\therefore$ $I_B=\frac{I_C}{\beta}=\frac{1}{45}$=**0.022mA**

8. Atransistorisconnectedincommonemitter(CE)configuration inwhichcollectorsupplyis8VandthevoltagedropacrossresistanceR$_C$connectedinthecollector circuit is 0.5V. The value of R_C= 800 Ω. If α= 0.96, Determine :

(i) Collector-emittervoltage

(ii) Base current



Solution: Fig.showstherequiredcommonemitterconnectionwith Various values. (i) Collector-Emitter voltage,

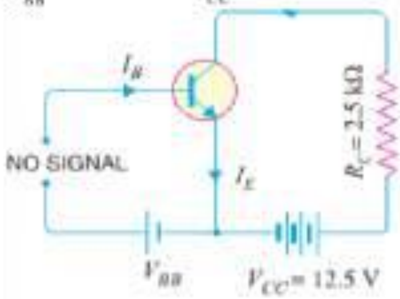
$$V_{CE}=V_{CC}-0.5 =8 -0.5=\mathbf{7.5\ V}$$

(ii)Thevoltage dropacrossR_C(=800 Ω)is0.5 V.

$\therefore$ $I_C=\frac{0.5\,V}{800\,\Omega}=\frac{5}{8}$mA=0.625 mA

Now$\beta=\frac{\alpha}{1-\alpha}=\frac{0.96}{1-0.96}$= 24 $\therefore$Basecurrent,$I_B=\frac{I_C}{\beta}=\frac{0.625}{24}$=**0.026mA**

9. For the circuit shown in Fig. , Draw the D.C. load line.



Solution:$V_{CE}=V_{CC}-I_C R_C$,WhenI_C=0➔$V_{CE}=V_{CC}$=**12.5V**

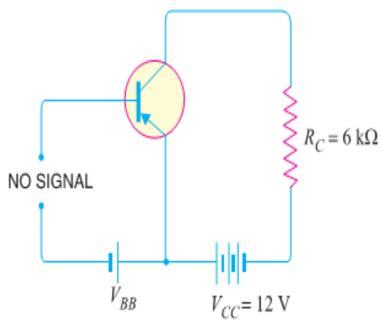
Thislocatesthe pointBof theloadline on collector– emittervoltageaxis.

WhenV_{CE}=0➔$I_C= V_{CC}/R_C$= 12.5V/2.5kΩ=**5mA**

Thislocatesthe pointAof theloadline oncollectorcurrent axis.

Byjoiningthese two points, weget the D.C. loadlineAB.

10. InthecircuitdiagramshowninFig.(i),ifV_{CC}=12VandR_C=6KΩ, draw the d.c. load line. What will be the Q point if zero signal base current is 20µA and β = 50?



Solution: Thecollector–emittervoltageV_{CE}isgivenby:$V_{CE}=V_{CC}-I_C R_C$ When I_C = 0, V_{CE} = V_{CC}= **12V.** This locates the point B of the load line.WhenV_{CE}=0, $I_C= V_{CC}/R_C$=12V/6kΩ=**2mA**.Thislocatesthe pointAofLoadLine. Byjoiningthese two points,load line ABisconstructed.

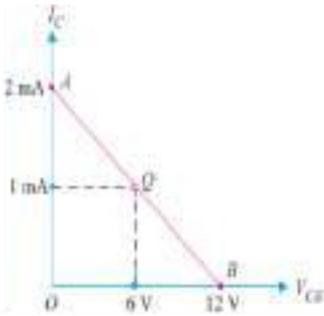
Zerosignalbase current,I_B=20 μA=0.02mACurrentamplificationfactor,β=50

∴ Zerosignalcollectorcurrent, I_C =βI_B=50×0.02 =**1mA**

Zerosignal collector– emittervoltage isV_{CE}=V_{CC}-$I_C R_C$=12–1mA×6 kΩ=**6V**.

∴ Operatingpoint is6V, 1mA

Fig. (ii)ShowstheQpoint.Itsco-ordinatesareI_C=1mAandV_{CE}=6V.



11. Fig.Showsthatasilicontransistorwithβ=100isbiasedbyBaseresistor method. Draw D.C. the Load Line & Determine Operating point.

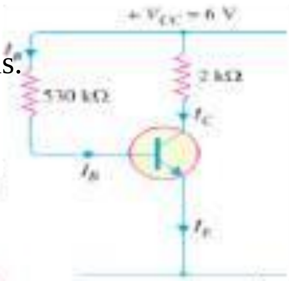
Solution:V_{CC} =6V, R_B= 530kΩ,R_C =2 kΩ

D.C. LoadLine. ReferringtoFig.(i),V_{CE}=V_{CC}- $I_C R_C$

WhenI_C=0,V_{CE}=V_{CC}=**6V**.ThislocatesthefirstpointB(OB=6V)ofloadlineoncollector– emitter voltage axis as shown in Fig. (ii). When V_{CE}= 0, I_C = V_{CC}/R_C = 6V/2 kΩ = **3 mA.**

ThislocatesthesecondpointA(OA=3mA)oftheloadlineonthecollector current axis.

By joining points A and B, D.C. Load Line AB is constructed.



OperatingpointQ.asitissilicontransistor,therefore,V_{BE}=0.7V.

Referring to Fig. (i), it is clear that:

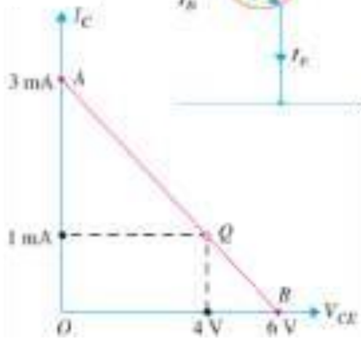
$I_B R_B + V_{BE} = V_{CC}$

Or $I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{(6-0.7)\,V}{530\ k\Omega}$ = 10μA

∴Collectorcurrent,I_C =βI_B=100×10=1000μA=**1mA**

Collector-emittervoltage, V_{CE}= V_{CC}–$I_C R_C$=6–1mA×2kΩ=6– 2=**4V**

∴Operatingpointis(4V,1mA.)Fig.(ii)ShowstheoperatingpointQon the D.C. load line.Its co-ordinates are I_C = 1mA and V_{CE} = 4V.

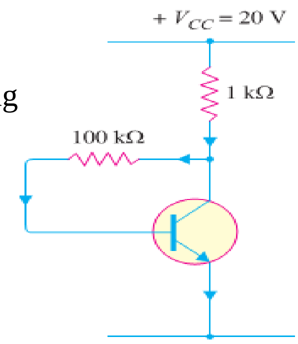


12. ***Fig.showsasilicontransistorbiasedbyfeedbackresistormethod.Determine the operating point. Given that β = 100.***

Solution:V_{CC}=20V,R_B=100kΩ,R_C=1kΩ.Sinceitissilicontransistor,V_{BE}=0.7V. Assuming I_B to be in mA and using the relation,

$R_B = \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B}$Or100 × I_B=20 – 0.7–100×I_B×1➔200I_B= 19.3

➔$I_B = \frac{19.3}{200}$=0.096mA ∴ Collectorcurrent, I_C=βI_B =100 ×0.096=**9.6mA**



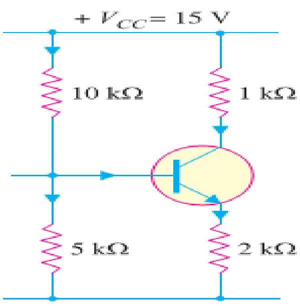
AgainV_{CE} =V_{CC}–$I_C R_C$=20– 9.6mA×1 kΩ =**10.4 V**

∴Q-Pointis(10.4V,9.6mA.)

13. Fig. shows the voltage divider bias method. Draw the D.C. Load Line anddetermine the operating point. Assume the transistor to be of silicon.

Solution:*D.C.LoadLine*.Thecollector-emittervoltageV_{CE}isgivenby:

V_{CE}=V_{CC}– I_C (R_C+ R_E) When I_C= 0, V_{CE} = V_{CC}= **15V.**



- ♣ This locates the first point B (OB= 15V) of the load line onthe collector-emitter voltage axis. When V_{CE}= 0, I_C= V_{CC}/ (R_C+ R_E) = 15 V/ (1 + 2) kΩ =**5 mA**
- ♣ This locates the second point A (OA=5mA) of the load line on collector current axis. By joining points A & B, the D.C. Load Line AB is constructed as in Fig.

OperatingPoint:-ForsiliconTransistor,V_{BE}=0.7V

Voltage across 5 kΩ is V_2= [V_{CC}/ (10+5)]*5

Voltage drop across $R_2 = \left(\frac{V_{CC}}{R_1 + R_2}\right) R_2$

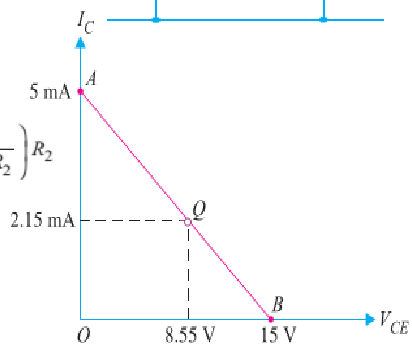
OrV_2= (15x5)/(10+5)=5 V

∴Emittercurrent,I_E=(V_2-V_{BE})/R_E=(5-0.7)/2kΩ=4.3/2kΩ=2.15mA

∴CollectorcurrentisI_C≈I_E=**2.15mA**

Collector-Emittervolt, V_{CE}=V_{CC}−I_C(R_C+ R_E) =15−2.15mA×3kΩ= **8.55V**

∴Operatingpointis (8.55V, 2.15 mA)is shownin Fig.



❖ AMPLIFIER:-

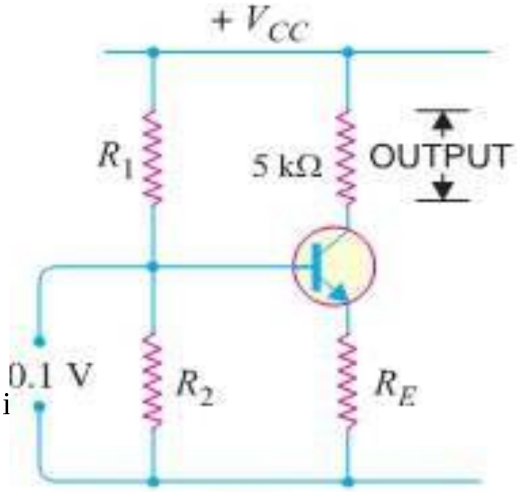
- The device which increases the strength of a weak signal is known as *Amplifier*. This can achieve by use of Transistor. It may be classified according to the number of stage of amplification, Such as:-
  - **1)** Singlestagetransistor amplifier.
  - **2)** Multistage transistoramplifier.

✓ **SingleStageTransistorAmplifier:-**Whenonlyonetransistorwithassociatedcircuitryisusedfor amplifying a weak signal, the circuit is known as *Single Stage Transistor Amplifier*.

✓ **MultistageTransistorAmplifier:-**Whenatransistorcircuitcontainingmorethanonestageof amplification is known as *Multi stage Transistor Amplifier*.

❖ SINGLESTAGETRANSISTOR AMPLIFIER:-

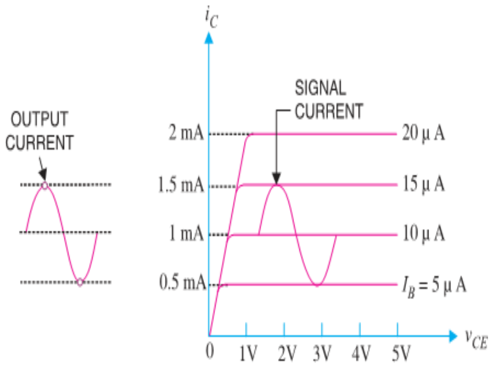
- Asinglestagetransistoramplifierhasonetransistor,bias circuit and other auxiliary components.
- WhenaweakA.C.signalisgiventothebaseoftransistor,a small base current starts flowing.
- Duetotransistoraction,amuchlarger(βtimesthebase current) current flows through the collector load R_C.
- As the value of R_C is quite high (usually 4-10 kΩ), therefore, a large voltage appears across R_C.
- Thus,aweaksignalappliedinthebasecircuitappearsinamplified form i the collector circuit.
- Itisin this waythatatransistoractsasan amplifier.



[TransistorasanAmplifier]

❖ GraphicalDemonstrationof Transistor Amplifier:-

- The function of transistor as an amplifier can also be explained graphically. The given Fig shows the output characteristics of a transistor in CE configuration.
- Suppose the zero signal base current is 10 µA i.e. this is the base current for which the transistor is biased by the biasing network.
- When an A.C. signal is applied to the base, it makes the base, say positive in the first half-cycle and negative in the second half cycle.
- Therefore, the base and collector currents will increase in the first half-cycle when base-emitter junction is more forward-biased.
- However,they willdecreaseinthesecondhalf-cyclewhenthe base-emitter junction is less forward biased.



- For example, consider a sinusoidal signal which increases or decreases the base current by 5 µA in the two half-cycles of the signal. It is clear that in the absence of signal, the base current is 10µA and the collector current is 1 mA. However, when the signal is applied in the base circuit, the base current and hence collector current change continuously.
- In the first half-cycle peak of the signal, the base current increases to 15 µA and the corresponding collector current is 1.5 mA. In the second half-cycle peak, the base current is reduced to 5 µA and the corresponding collector current is 0.5 mA.
- For other values of the signal, the collector current is in between these values i.e. 1.5 mA and 0.5 mA. Itis clear from above fig that 10 µA base current variation results in 1mA (1,000 µA) collector current variation i.e. by a factor of 100.
- This large change in collector current flows through collector resistance R_C.The result is that output signal is much larger than the input signal.Thus, the transistor has done amplification.

❖ MULTISTAGETRANSISTORAMPLIFIER:-

- The output from a single stage amplifier is usually insufficient to drive an output device. In other words, the gain of a single amplifier is inadequate for practical purposes.
- Consequently, additional amplification over two or three stages is necessary.To achieve this, the output of each amplifier stage is coupled in some way to the input of the next stage.
- Theresultingsystemisreferredto asmultistage amplifier.

- A transistor circuit containing *more than one stage of amplification* is known as *multistage transistor amplifier*.
- In a multistage amplifier, a number of single amplifiers are connected in cascade arrangement i.e. output of first stage is connected to the input of the second stage through a suitable coupling device and so on.
- The purpose of **coupling device** (e.g. a capacitor, transformer etc.) is
  - (i) to transfer A.C. output of one stage to the input of the next stage and
  - (ii) to isolate the D.C. conditions of one stage from the next stage.
- The name of the amplifier is usually given after the type of coupling used. e.g.

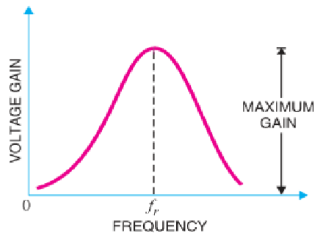
Name of coupling	*Name of multistage amplifier*
RC coupling	R-C coupled amplifier
Transformer coupling	Transformer coupled amplifier
Direct coupling	Direct coupled amplifier

❖ IMPORTANT TERMS:-

Gain: - The ratio of the output electrical quantity to the input one of the amplifier is called its gain.

- The gain of a multistage amplifier is equal to the product of gains of individual stages.
- For instance, if G_1, G_2 and G_3 are the individual voltage gains of a three-stage amplifier, then total voltage gain G is given by: $G = G_1 \times G_2 \times G_3$

Frequency response: - The curve between voltage gain and signal frequency of an amplifier is known as frequency response.



- The gain of the amplifier increases as the frequency increases from zero till it becomes maximum at f_r, called resonant frequency.

Decibel gain:- Although the gain of an amplifier can be expressed as a number, yet great practical importance to assign it a unit.

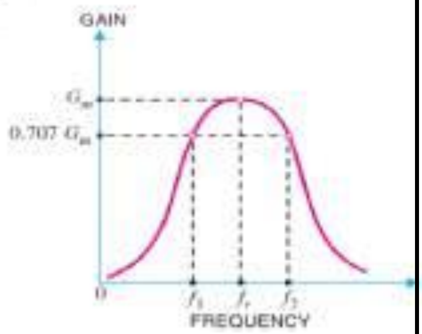
- The unit assigned is bel or decibel (db). The common logarithm (log to the base 10) of power gain is known as bel power gain i.e $\text{Power gain} = \log_{10} \frac{P_{out}}{P_{in}}\ bel$ (1 bel=10 db.)

Similarly voltage gain and current gain may be defined as follows:-

$$\text{Voltage gain in } db = 10 \log_{10} \frac{V_{out}^2 / R}{V_{in}^2 / R} = 20 \log_{10} \frac{V_{out}}{V_{in}}$$

$$\text{Current gain in } db = 10 \log_{10} \frac{I_{out}^2 R}{I_{in}^2 R} = 20 \log_{10} \frac{I_{out}}{I_{in}}$$

Bandwidth: - The range of frequency over which the voltage gain is equal to or greater than 70.7% of the maximum gain is known as **bandwidth**.

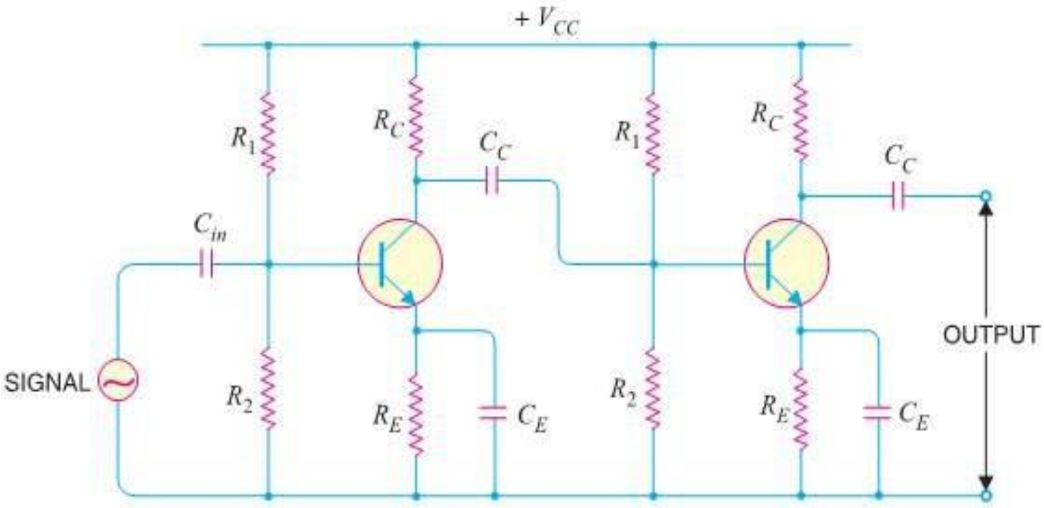


- From the fig. it is clear that for any frequency lying between f_1 and f_2, the gain is equal to or greater than 70.7% of the maximum gain.
- Therefore, $f_1 - f_2$ is the bandwidth. It may be seen that f_1 and f_2 are the limiting frequencies. The f_1 is called lower cut-off frequency and f_2 is known as upper cut-off frequency

❖ R-C COUPLED TRANSISTOR AMPLIFIER:-

- This is the most popular type of coupling because it is cheap and *provides excellent audio fidelity over a wide range of frequency*. It is usually employed for **voltage amplification**.
- Fig shows two stages of an RC coupled amplifier. A coupling capacitor C_C is used to connect the output of first stage to the base (i.e. input) of the second stage and so on.
- As the coupling from one stage to next is achieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are called ***Resistance - Capacitance coupled amplifiers***.

- The resistances R_1, R_2 and R_E form the *biasing* and *stabilization* network.The emitter bypass capacitor offers *low reactance path* to the signal.Without it, the voltage gain of each stage would be lost.
- Thecoupling capacitor C_C transmits A.C. signalbut blocks D.C. This prevents D.C. interference between various stages and the shifting of operating point.



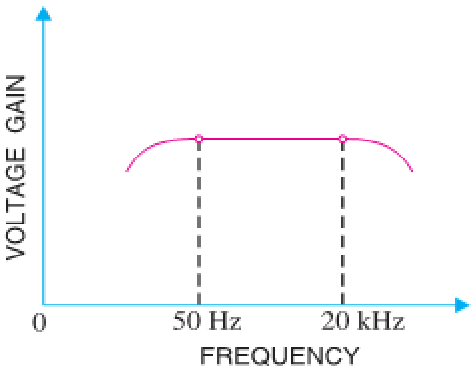
[CircuitDiagramofRCCoupledTransistorAmplifier]

- **Operation: -** When A.C. signal is applied to the base of the first transistor, it appears in the amplified form across its collector load R_C.The amplified signal developed across RC is given to base of next stage through coupling capacitor C_C.The second stage does further amplification of the signal.In this way, the cascaded (one after another) stages amplify the signal and the overall gain is considerably increased.

It may be mentioned here that total gain is less than the product of the gains of individual stages.It is because when a second stage is made to follow the first stage, the effective load resistance of first stage is reduced due to the shunting effect of the input resistance of second stage.This reduces the gain of the stage which is loaded by the next stage

- **FREQUENCYRESPONSE:**

- Fig shows the frequency response of a typical RC coupled amplifier.It is clear that voltage gain dropsoffat low (<50 Hz) and high (> 20 kHz) frequencies whereas it is uniform overmid-frequencyrange (50 Hz to 20 kHz).This behaviour of the amplifier is briefly explained below:-
- **(i) At low frequencies** (< 50 Hz):- At this stage the reactance of coupling capacitor C_C is quite high and henceverysmallpartofsignalwillpassfromonestagetothe next stage. Moreover, C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequencies. These two factors cause a falling of voltage gain at low frequencies.
- **(ii) At high frequencies** (> 20 kHz):-At this stage the reactance of C_C is very small and it behaves as a short circuit.These increasestheloadingeffectofnextstage andservestoreducethe voltage gain. Moreover,athighfrequency,capacitivereactanceofbase-emitterjunctionislowwhichincreasesthebasecurrent.This reduces the current amplificationfactor β.Due to these two reasons, the voltagegain drops off athighfrequency.



[Frequency Response Curve of RC Coupled Amp]

- **(iii) At mid-frequencies** (50 Hz to 20 kHz):- At this stage the voltage gain of the amplifier is constant. The effect of coupling capacitor in this frequency range is such so as to maintain a uniform voltage gain. Thus, as the frequency increases in this range, reactance of CC decreases which tends to increase thegain.However, at the same time, lower reactance means higher loading of first stage and hence lower gain.These two factors almost cancel each other, resulting in a uniform gain at mid-frequency.

Advantages:-

(i) It has excellent frequency response.The gain is constant over the audio frequency range which is the region of most importance for speech, music etc.
(ii) Ithaslowercostsinceitemploysresistorsandcapacitorswhicharecheap.
(iii) Thecircuitisverycompactasthemodernresistorsandcapacitorsare smallandextremelylight.

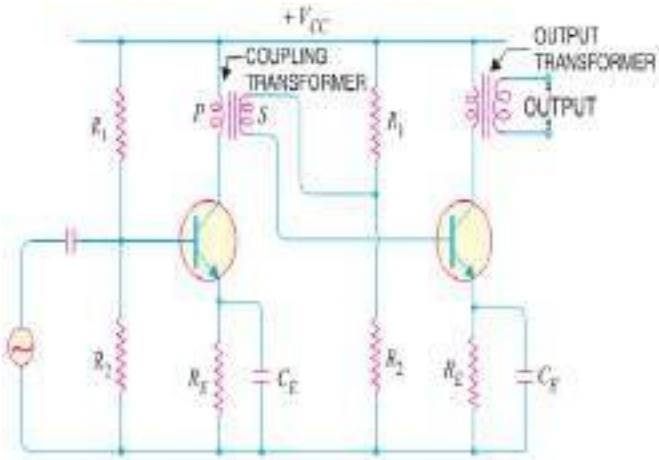
Disadvantages:-

(i) The RC coupled amplifiers have low voltage and power gain.It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (R_{AC}) and hence the gain.
(ii) Theyhavethetendencytobecomenoisywithage,particularlyinmoistclimates.
(iii) Impedance matching is poor.It is because the output impedance of RC coupled amplifier is several hundred ohms whereas the input impedance of a speaker is only a few ohms. Hence, little power will be transferred to the speaker.

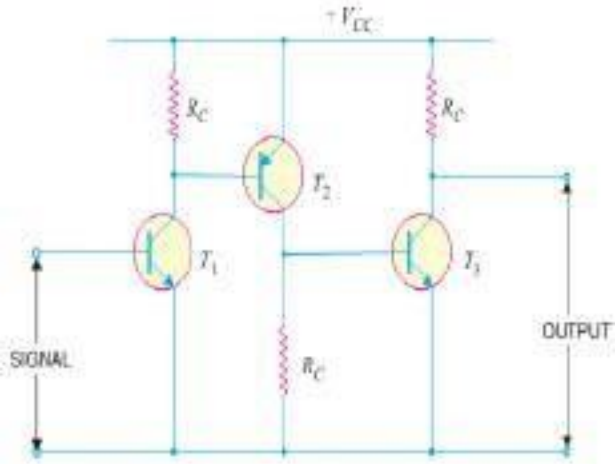
Applications:-

- The RC coupled amplifiers have excellent audio fidelityover a wide range of frequency.Therefore, they are widely used as **voltage amplifiers** e.g. in the initial stages of public address system.
- Ifothertypeofcoupling(e.g.transformercoupling)isemployedintheinitialstages,thisresultsin frequency distortion which may be amplified in next stages.
- However, becauseof poor impedancematching, RCcouplingisrarelyusedin the final stages.

✓ **CircuitdiagramforOtherTypeofCouplingaregiven below:-**



(TransformerCoupledTransistorAmplifier)

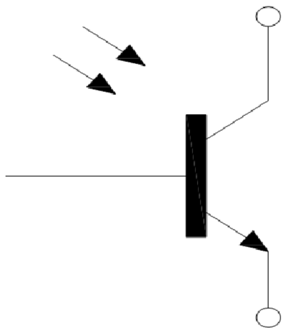


(DirectCoupledTransistorAmplifier)

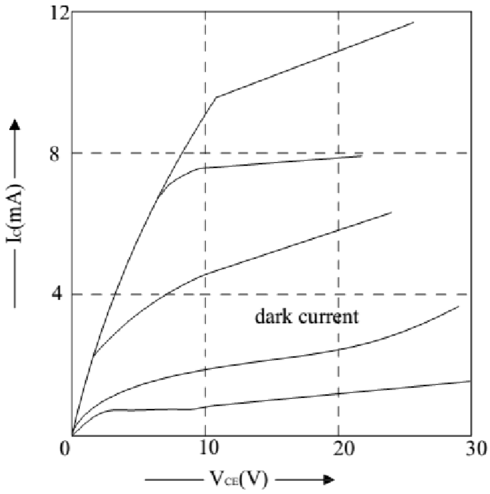
➢ **ComparisonofDifferentTypesof Coupling:-**

S. No	Particular	*RC* coupling	Transformer coupling	Direct coupling
1.	*Frequency response*	Excellent in the audio frequency range	Poor	Best
2.	*Cost*	Less	More	Least
3.	*Space and weight*	Less	More	Least
4.	*Impedance matching*	Not good	Excellent	Good
5.	*Use*	For voltage amplification	For power amplification	For amplifiying extremely low frequencies

❖ PHOTOTRANSISTOR:-



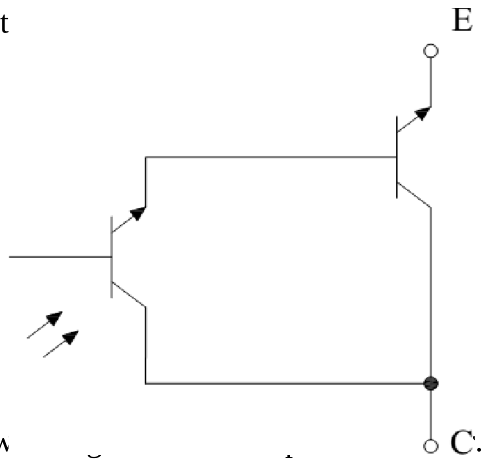
- It is light sensitive Transistor and is similar to an ordinary BJT except that it has no connection to the base terminal. Its operation is based on the photo diode that exits at CB junction.
- Instead of the base current, the input to the transistor is provided in the formof light as shown in symbol.
- Silicon NPNs are mostly used as photo Transistor. The device is usually is packed in a TO-type can with a lens on top although it is sometimes encapsulated in clear plastic.
- When there is no incident light on the CB junction, there is a small thermally generated collector-to-emitter leakage current I_{CEO} which, in this case is called **dark current** and is in the nA range.
- When light is incident on the CB junction, a base current I_λ is produced which is directly proportional to the light intensity. Hence, collector current $I_C=\beta I_\lambda$.
- Typical collector characteristic curve of a photo transistor are shown in fig. each individual curves corresponds to a certain value of light intensity expressed in mW/cm^2. As seen I_C increases with light intensity.



- The phototransistor has applications similar to those of a photo diode. Their main differences are in the current and response time. The photo transistor has the advantages of greater sensitivity and current capacity than photo diodes.
- However, photo diodes are faster of the two, switching in less than a nanosecond.

❖ PHOTODARLINGTON:-

- Asshowninfig.aPhotoDarlingtonconsistsofaphototransistorinaDarlingtonarrangementwitha common transistor.
- It has a much greater sensitivityto incident radiant energy than a phot transistor because of higher current gain.
- However, its switching time of 50µs is much longer than the photo transistor (2µs) or the photo diode (1ns). Its circuit symbol is shown in fig.



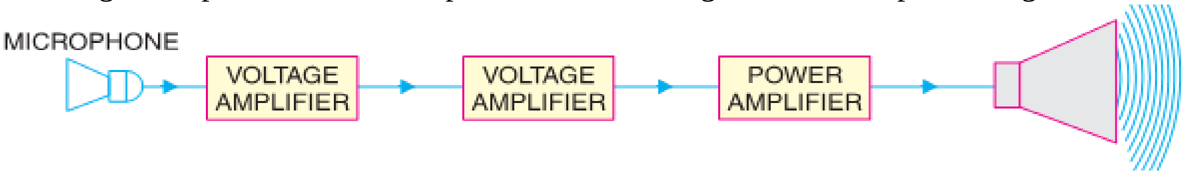
- Photo Darlington is used in a variety of application some of which are given below.
- A*light operated relay*in whichthephoto transistorQ_1 drivesthe bipolartransistorQ_2.WhensufficientlightfallsonQ_1itisdriven into saturation so that I_C is increased multiple. This collector current while passing through the relay coil energizes the relay.
- A *dark operated relay* circuit i.e. one in which relay is deenergized w
- Suchrelaysare usedinmanyapplications such as
  - **(i)** Automatic door activators
  - **(ii)** ProcessCounters
  - **(iii)** Variousalarmsystemsforsmokeorinterferencedetection.

[CHAPTER-3]

[AUDIOPOWERAMPLIFIERS]

❖ INTRODUCTION:-

- Apracticalamplifieralwaysconsistsofanumberofstagesthatamplifyaweaksignaluntilsufficient power is available to operate a loudspeaker or other output device.
- Thefirstfewstagesinthismultistageamplifierhavethefunctionofonlyvoltageamplification. However, last stage is designed to provide maximum power.This final stage is known as power stage.



❖ TransistorAudioPowerAmplifier:-

- A transistor amplifier which raises the power level of the signals having audio frequencyrange is known as transistor **Audio Power Amplifier**. Generally last stage of a multistage amplifier is the power stage.
- Thepoweramplifierdiffersfromallthepreviousstagesinthathereaconcentratedeffortismadeto obtain maximum output power.
- Atransistor that issuitableforpower amplification isgenerallycalled a*power transistor*.

❖ DIFFERENCEBETWEENVOLTAGEANDPOWERAMPLIFIERS

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

1) **Voltage Amplifier.** Thevoltagegain ofan amplifierisgiven by: $A_v = \beta \times \frac{R_c}{R_{in}}$

   - Inordertoachievehigh voltage amplification,thefollowingfeaturesareincorporatedinsuchamplifiers:
     - ♣ Thetransistorwithhighβ(>100) isusedinthecircuit. i.e.Transistorsare employedhavingthin base.
   - ♣ TheinputresistanceR$_{in}$oftransistor issoughttobequitelowascomparedtothecollector loadR$_C$.
   - ♣ 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 largeR$_C$ in the collector circuit

2) **Power Amplifier.** A power amplifieris required to delivera large amount of powerand as such it has to handle large current.

- Inordertoachievehigh poweramplification,thefollowingfeaturesareincorporatedinsuchamplifiers:
  - ♣ The size of power transistor is made considerably larger in order to dissipate the heat produced in the transistor during operation.
  - ♣ Thebaseismadethickertohandlelargecurrents.Inotherwords,transistorswithcomparatively smaller β are used.
  - ♣ Transformercouplingisused forimpedance 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)

❖ PERFORMANCEQUANTITIESOFPOWER 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**.

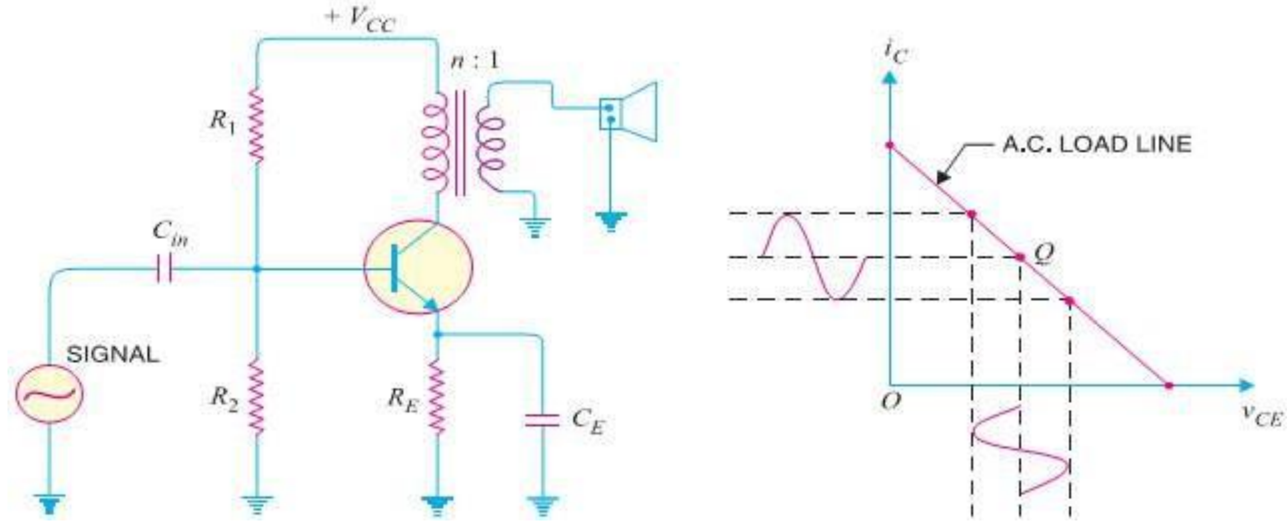
Power Dissipation Capability. The ability of a power transistor to dissipate heat is known as power dissipation capability.

❖ CLASSIFICATIONOFPOWERAMPLIFIERS

- 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,suchamplifiersaregenerallyclassified accordingtotheirmodeofoperationi.e.theportionof theinputcycleduringwhichthecollector currentisexpectedtoflow.Onthisbasis,theyareclassifiedas

(i) ClassApoweramplifier **(ii)**ClassBpower amplifier**(iii)** ClassCpower amplifier

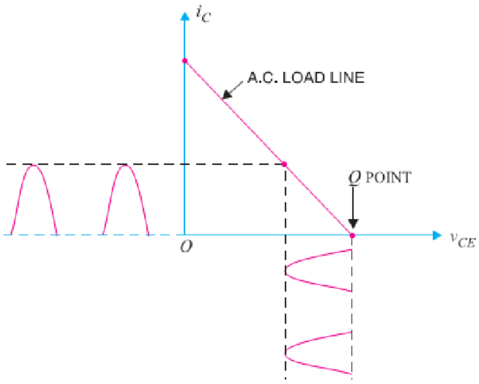
CLASS APOWERAMPLIFIER. If the collectorcurrentflows atall timesduring thefull cycle ofthe signal, the power amplifier is known as *class A power amplifier*.



- 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,theyhave thedisadvantage oflowpoweroutput and lowcollector efficiency(about 35%).

CLASS B POWER AMPLIFIER: - If the collector current flows onlyduring 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 collectorcurrent flows.However, during the negative half-cycle of the signal, the input circuit is reverse biased and no collector current flows.



- Fig.showstheclassBoperation intermsofa.c.load line.
- TheoperatingpointQshallbe locatedatcollectorcutoff voltage.
- It is easy to see that output from a class B amplifier is amplifiedhalf-wave rectification.
- In a class B amplifier, the negative half-cycle of the signal is cut off and hence a severe distortion occurs.
- However,classBamplifiersprovidehigherpoweroutputand 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.

CLASSCPOWERAMPLIFIER.Ifthecollectorcurrentflowsforlessthanhalf-cycleoftheinput signal, it is called *class C power amplifier*.

- InclassCamplifier,thebaseisgivensomenegativebiassothatcollectorcurrentdoesnotflowjust 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.

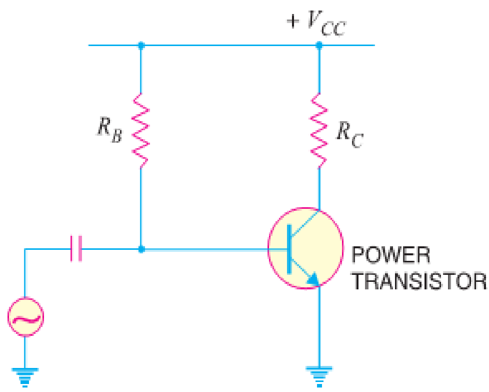
EXPRESSION FOR COLLECTOR EFFICIENCY

- Forcomparingpoweramplifiers,collectorefficiencyisthemaincriterion.Thegreaterthecollector efficiency, the better is the power amplifier.
- Now, CollectorEfficiency, $\eta = \frac{\text{a.c. power output}}{\text{d.c. power input}} = \frac{P_O}{P_{dc}}$
- 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.
- Intermsofpeak-to-peak values,thea.c.poweroutputcanbeexpressed 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** $\eta = \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8\, V_{cc}\, I_c}$

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



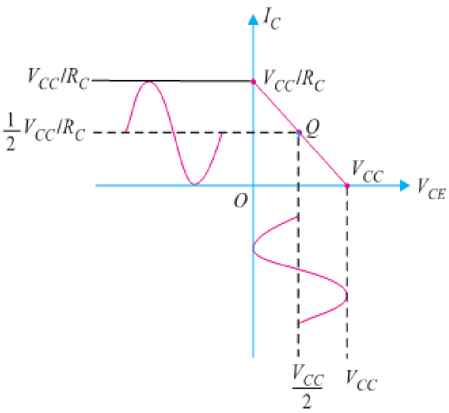
- Fig (i) shows aseries fed class A amplifier. This circuit is seldom used for power amplification due to its poor collector efficiency.
- Nevertheless, it will help the reader to understand the class A operation. The d.c. load line of the circuit is shown in Fig. (ii).
- When an ac signal is applied 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.
- Inthatcase,operatingpointis $I_C=V_{CC}/2R_C$ 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, $P_{o(max)} = \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8} = \frac{V_{CC} \times V_{CC}/R_C}{8} = \frac{V_{CC}^2}{8R_C}$

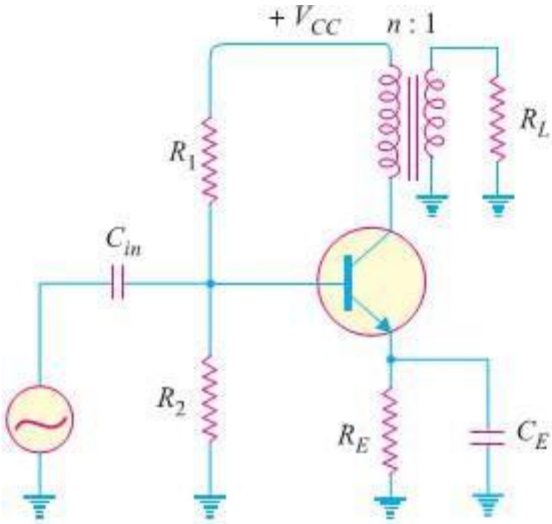
D.C.powersupplied, $P_{dc} = V_{CC} I_C = V_{CC}\left(\frac{V_{CC}}{2R_C}\right) = \frac{V_{CC}^2}{2R_C}$

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

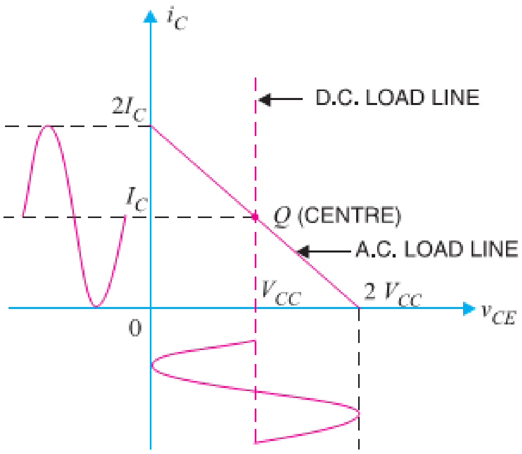


- ThusthemaximumcollectorefficiencyofaclassAseries-fed amplifier is 25%.
- In actualpractice, collectorefficiencyisfarlessthanthis value.

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 permitsimpedance matching. **Secondly** it keeps the d.c. power loss small because of the small resistance of the transformer primary winding.
- Fig(i)showsatransformercoupled classApoweramplifier.
- 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 thesignal, the collectorcurrent iszero and v_{ce}= $2V_{CC}$.

  ∴Peak-to-peakcollector-emittervoltage is

  $$v_{ce(p-p)} = 2V_{CC}$$

  Peak-to-peakcollectorcurrent, $i_{c(p-p)} = 2\,I_C = \frac{v_{ce(p-p)}}{R'_L} = \frac{2V_{CC}}{R'_L}$

  WhereR′$_L$isthereflected value ofload $R_L$andappearsin primaryof the transformer.
- If $n(=N_p/N_s)$istheturnratioof thetransformer,then, $R'_L = n^2 R_L$.
- d.c.powerinput, $P_{dc} = V_{CC}\,I_C = I_C^2 R'_L$ $(\because V_{CC} = I_C R'_L)$
- Max. a.c. output power, $P_{o(max)} = \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8} = \frac{2V_{CC} \times 2I_C}{8} = \frac{1}{2} V_{CC} I_C = \frac{1}{2} I_C^2 R'_L$ …(i) $(\because V_{CC} = I_C R'_L)$

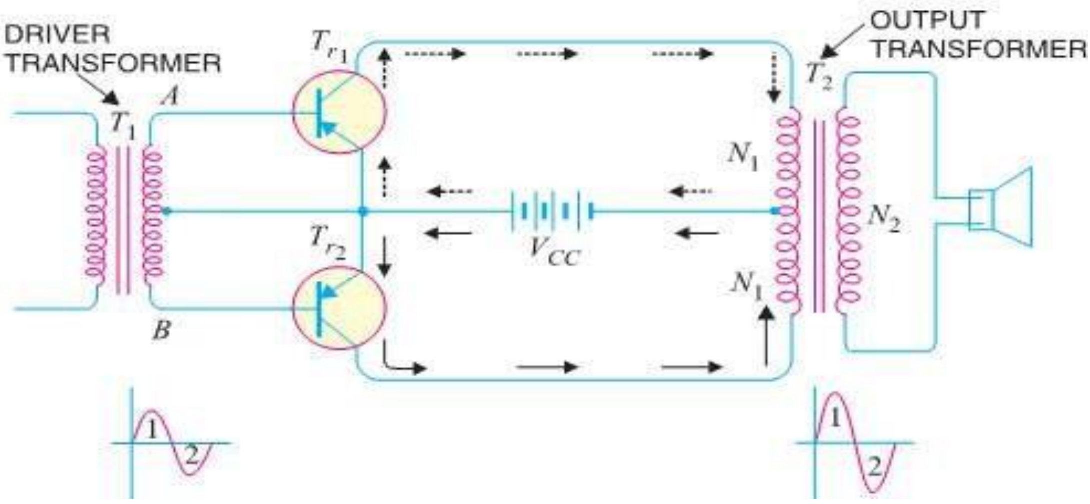
  ∴ Max. Collector $\eta = \frac{P_{O(max)}}{P_{dc}} \times 100 = \frac{\left(\frac{1}{2}\right) I_C^2 R'_L}{I_C^2 R'_L} \times 100 =$ **50%**

IMPORTANT POINTS ABOUT CLASS-A POWER AMPLIFIER : -

- **(i)**ATransformercoupledclassApoweramplifierhasamaximumcollectorefficiencyof50%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 theoutput transformer, power dissipation in the transistor etc.
- **(ii)**Thepowerdissipatedbya transistor isgiven by: $P_{dis} = P_{dc} - P_{ac}$

  Where Pdc=availabled.c.power & P_{ac}= availablea.c. power
- So,InclassAoperation,Transistormustdissipatelessheatwhensignalis appliedthereforeruns cooler.
- **(iii)**When no signal isapplied toa classApoweramplifier, P_{ac}=0.∴P_{dis}=Pdc
- ThusinclassAoperation,maximumpowerdissipationinthetransistoroccursunderzerosignalconditions.
- Therefore, the power dissipation capability of a power transistor (for class A operation) must be at least equal to the zero signal rating.
- **(iv)**WhenaclassApoweramplifierusedinfinalstage,itiscalledsingleendedclassApower amplifier.

PUSH-PULL AMPLIFIER : -



- The push-pull amplifier is a power amplifier and is frequently employed in the output stages ofelectronic 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_2has the centre-tapped primary winding. The supply voltage $V_{CC}$is connected between the bases and this centre tap.
- Theloudspeakerisconnectedacrossthesecondaryofthis 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 primaryof 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:

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

Where N_1=Numberofturnsbetweeneitherendofprimarywindingandcentre-tap N_2 = Number of secondary turns

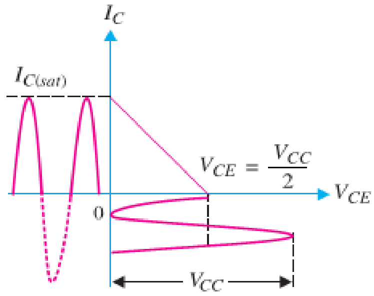
ADVANTAGES

1) Theefficiencyof thecircuit isquitehigh (≈75%) due to classB operation.
2) Ahigha.c. outputpowerisobtained.

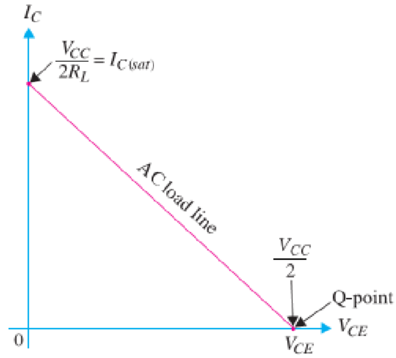
DISADVANTAGES

1) Twotransistorshaveto beused.
2) Itrequirestwoequalandoppositevoltagesattheinput.Therefore,push-pullcircuitrequirestheuse of driver stage to furnish these signals.
3) Iftheparametersofthetwotransistorsarenotthesame,therewillbeunequalamplificationofthe two halves of the signal.
4) Thecircuit givesmore distortion.
5) Transformersused arebulkyandexpensive.

MAXIMUM EFFICIENCY FOR CLASS B POWER AMPLIFIER



- We have already seen that a push-pull circuit uses two transistorsworking in class B operation. For class B operation, the Q-point islocated at cut-off on both d.c. and a.c. load lines.
- For maximum signal operation, the two transistors in class B amplifierare 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 $I_{C(sat)}$.
- Thesameinformationisalsoconveyedthroughthe a.c.loadlineforthe circuit[SeeFig. (ii)].



∴ Peak a.c. output voltage = V_{CE}

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

- 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

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

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

- Theinput d.c. powerfrom the supply$V_{CC}$is **$P_{dc} = V_{CC} I_{dc}$**
  WhereI_{dc}istheaverage currentdrawn fromthesupplyV_{CC}.
- Sincethe transistor ison foralternatinghalfcycles, iteffectivelyactsasa half-wave rectifier.

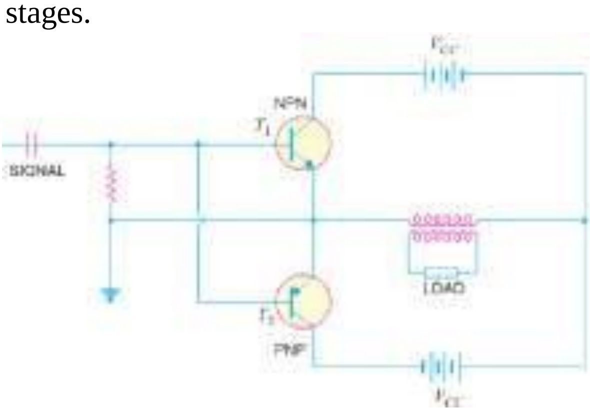
∴ $I_{dc} = \frac{I_{C(sat)}}{\pi} \rightarrow P_{dc} = \frac{V_{CC} I_{C(sat)}}{\pi}$

∴ 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 pnptransistorandrequiresnocentre-tappedtransformers.



- 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_2conducts 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.
- Notethatwegenerallyuse anoutputtransformer(notcentre-tapped)forimpedance matching.

Advantages: - (1) This circuit does not require transformer. This saves on weight and cost.
(2) Equalandoppositeinputsignalvoltagesarenot required.

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

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.
- Usuallytransistorisfixedon Aluminum metalsheet sothat additionalheatistransferredto theAl sheet.
- Themetal sheetthat servestodissipatethe additionalheat from powertransistor isknownas **Heat Sink.**

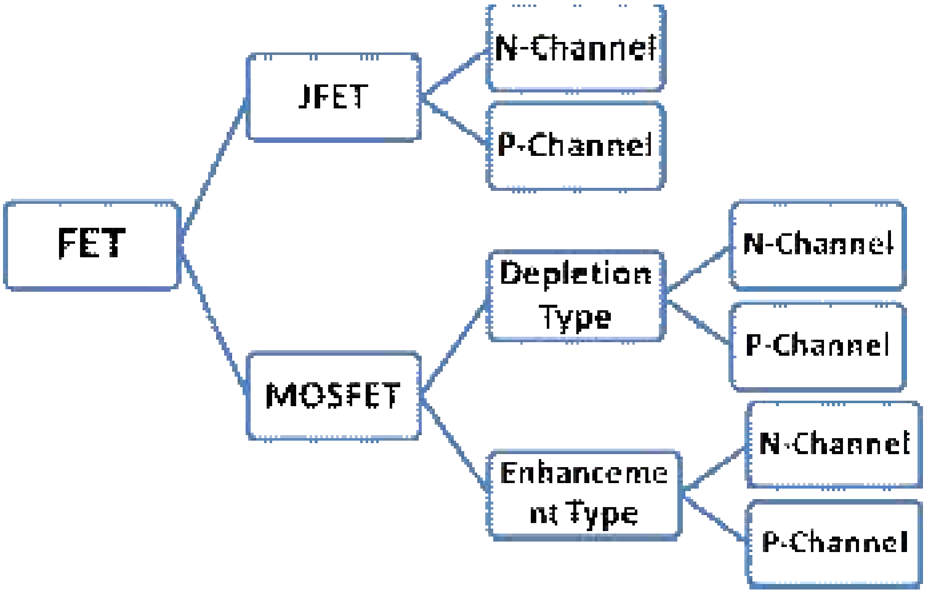
[CHAPTER-4]

---------------------------[FIELDEFFECTTRANSISTOR(FET)]-------------------------

❖ INTRODUCTION:-

- In the previous chapters, we have discussed the circuit applications of an ordinarytransistor. In this type of transistor, both holes and electrons play part in the conduction process. For this reason, it issometimes 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 generallymuch less noisythan the ordinary or bipolar transistor. The rapidly expanding FET markethas ledmanysemiconductormarketingmanagerstobelievethatthisdevicewillsoonbecomethe most important electronic device, primarily because of its integrated-circuit applications.

❖ CLASSIFICATIONOFFIELDEFFECTTRANSISTORS:-



- ❖ OthertypesofC-MOSalsoThereSuch as:-**CMOS,VMOS,LDMOS** etc.

❖ DIFFERENTIATION BETWEENBJT &FET :-

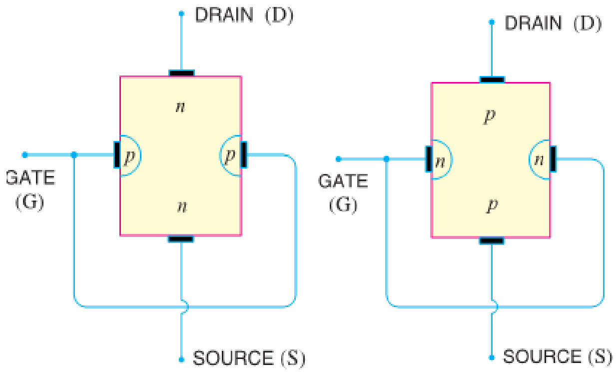
FET	BJT
✖ ItmeansF**ieldEffect Transistor**	✖ Means**BipolarJunctionTransistor**
✖ Itsthreeterminalsare**Source, Gate&Drain**	✖ Itsterminalsare**Emitter,Base& Collector.**
✖Itis**Unipolar**devicesi.e.Currentinthedevice is carried either by electrons or holes.	✖Itis**Bipolar**devicesi.e.Currentinthedevice is carried by both electrons and holes.
✖Itis **Voltagecontrolled device.**i.e.Voltage at thegateordrainterminalcontrolstheamount of current flowing through the devices.	✖Itis**Currentcontrolleddevice.**i.e.Base Currentcontrolstheamountofcollector current flowing through the devices.
✖IthasveryHighInputResistanceandLow Output Resistance.	✖IthasveryLow InputResistanceandHigh Output Resistance.
✖ Lownoisyoperation	✖ Highnoisyoperation
✖ Itis LongerLife&High Efficiency.	✖ ItisShorter Life&Low Efficiency.
✖ ItismuchsimplertofabricateasICand occupies less space on IC.	✖Itiscomparativelydifficulttofabricateas IC and occupies more space on IC then FET.
✖ IthasSmallgainbandwidthproduct.	✖ IthasLargegainbandwidthproduct.
✖ Ithashigherswitchingspeed.	✖ Ithashigherswitchingspeed.

❖ JUNCTIONFIELDEFFECTTRANSISTOR(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 eitherbyelectrons or holes and is controlled bymeans of an electric field between the gate electrode and the conducting channel of the device.
- TheJFEThashighinputimpedance andlownoiselevel.

❖ CONSTRUCTIONAL DETAILS.

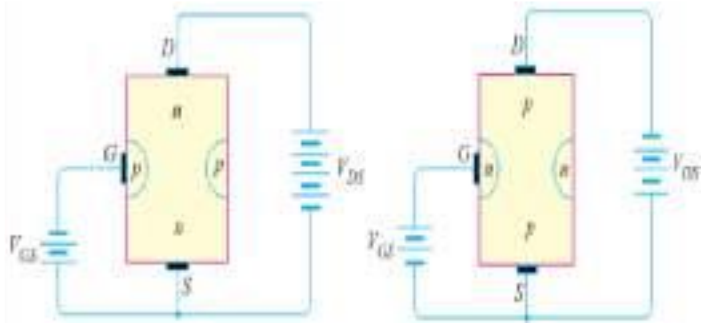
- A JFET consists of a p-type or n-type silicon bar containingtwopnjunctionsatthesidesasshown inFig.
- The bar forms the conducting channel for the charge carriers. If the bar is of n-type, it is called n-channel JFET as shown in Fig (i) and if the bar is of p-type, it is called a p-channel JFET as shown in Fig (ii).
- The two pn junctions forming diodes are connected internally&a commonterminalcalled**gate**istakenout.
- Otherterminals are**source**and**drain**takenout fromthe bar as shown. Thus a JFET has essentially three terminals viz., Gate (G), Source (S) & Drain (D).



n-Channel JFET *p-Channel JFET*

❖ JFETPOLARITIES:-

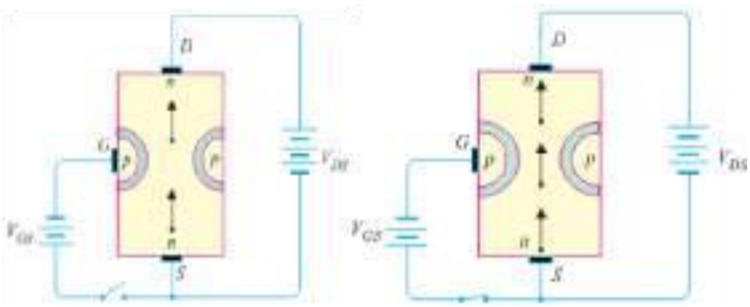
- Fig (i) shows n-channel JFET polarities whereas Fig (ii) shows the p-channel JFET polarities.
- Note that in each case, voltage between gate and source is such that the gate is reversing biased.
- Thisisthe normalwayof JFETconnection.
- Thedrain&sourceterminalsareinterchangeable i.e., either end can be used as source and the other end as drain.



- Thefollowingpoints maybe noted:
  - ♣ Theinputcircuit(i.e. gatetosource)ofaJFETis reversebiased.Thismeansthatthedevicehas high input impedance.
  - ♣ Thedrainissobiasedw.r.t.sourcethatdrain current $I_D$flowsfromthesourceto drain.
  - ♣ InallJFETs,sourcecurrent $I_S$isequaltothedrain currenti.e.I_S=I_D.

❖ WORKINGPRINCIPLEOFJFET:-

Principle: - Fig. shows the circuit of n-channel JFET with normal polarities. Note that the gate is reverse biased.



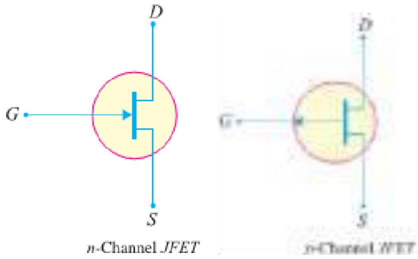
- The two pn junctions at the sides form two depletion layers. The current conduction by charge carriers (i.e. free electrons in thiscase) is through the channel between the two depletion layers and out of the drain.
- Thewidth andhenceresistanceofthis channel can becontrolled bychangingtheinput voltage 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}.
- Inother words,the magnitudeofdraincurrent (I_D) can be changed byalteringV_{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.
- Theelectronswillflowfromsourcetodrainthrougha channelbetweenthedepletion layers.

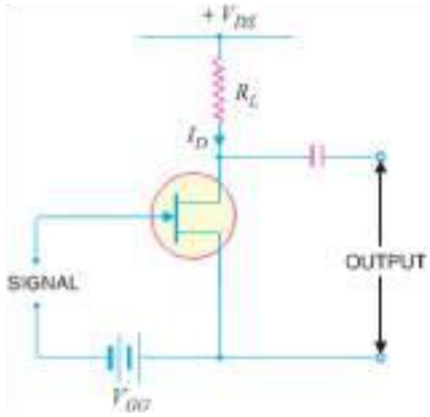
- Thesizeoftheselayersdetermineswidthofthechannel&hence thecurrentconductionthroughthebar.
- **(ii)** When a reverse voltage $V_{GS}$is applied between the gate and source [See Fig (ii)], the width of the depletion layers is increased.
- This reduces the width of conducting channel, thereby increasing 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 theapplication of potential (i.e. electric field) on the gate.
- Forthis reason, thedeviceiscalledfieldeffecttransistor. It maybenoted thatap-channelJFEToperates in thesamemanneras an n-channelJFETexcept that channelcurrentcarriers will betheholes instead of electrons and the polarities of $V_{GS}$and V_{DS} are reversed.

JFETASANAMPLIFIER:-



[SchematicSymbolof JFET]

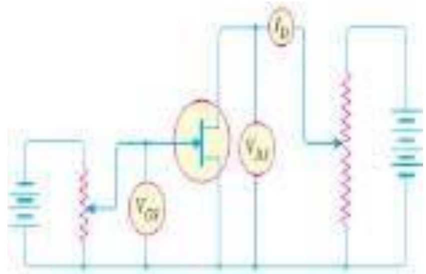
- Fig shows JFET amplifier circuit. The weak signal is applied between gate and source and amplified output is obtained in the drain-source circuit.FortheproperoperationofJFET,thegatemustbenegative w.r.t.sourcei.e.,input circuitshould alwaysbe reverse biased.
- ThisisachievedeitherbyinsertingabatteryV$_{GG}$inthegatecircuitor byacircuitknown asbiasingcircuit.
- 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 gatedecreases.Thisincreasesthechannelwidthandhencethedraincurrent.
- 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

OUTPUTCHARACTERISTICSOFJFET

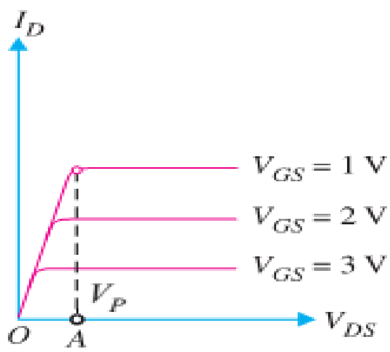
- Thecurvebetweendraincurrent(I_D)anddrain-sourcevoltage(V_{DS})of a JFET at constant gate source voltage (V_{GS}) is known as output characteristics of JFET.
- Figshowscircuitfordeterminingoutputcharacteristicsof JFET.



- Keeping V_{GS} fixed at some value, say 1V, the drain source voltage is changed in steps.
- CorrespondingtoeachvalueofV$_{DS}$,thedraincurrentI$_D$is noted.
- Aplotofthesevaluesgivesoutputcharacteristic ofJFETatV$_{GS}$= 1V.
- Repeatingsimilarprocedure,outputcharacteristicsatothergate-sourcevoltagescanbedrawn.Fig. shows a family of output characteristics.

The following points may be noted from the characteristics:

- **(i)**At first,thedrain current I$_D$risesrapidlywithdrain-sourcevoltageV$_{DS}$but thenbecomes constant.
- Thedrain-sourcevoltage abovewhichdrain current becomes constant is known aspinchoffvoltage.Thusin Fig. OAisthe pinch offvoltage V_P.

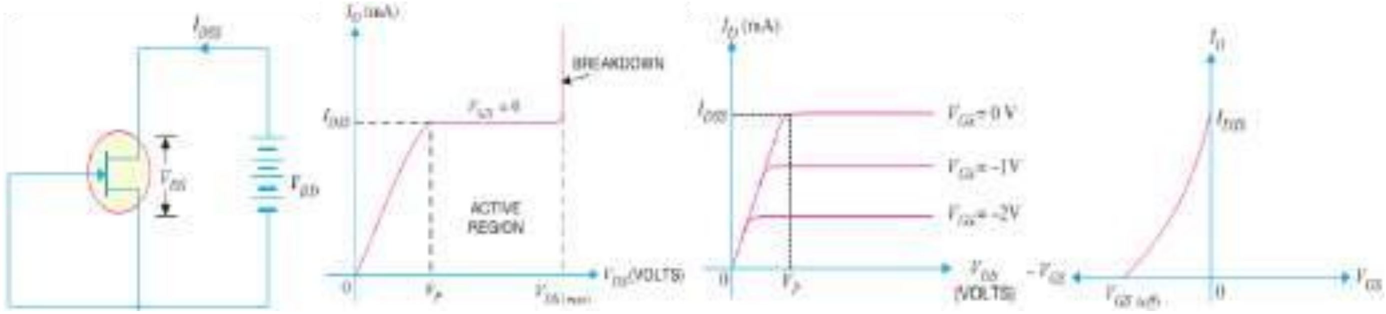


- **(ii)** After pinch off voltage, the channel width becomes so narrow thatdepletion layers almost touch each other.
- Thedraincurrentpassesthroughthesmallpassagebetweentheselayers.
- Thusincreaseindraincurrentisvery smallwithV$_{DS}$abovepinchoff voltage.
- Consequently,draincurrentremainsconstant.Thecharacteristicsresemble that of a pentode valve.

SALIENT FEATURES OF JFET : -

- Thefollowingaresomesalientfeaturesof JFET:
  - **(i)** A JFET is a three-terminal voltage-controlled semiconductor device i.e. input voltage controls the output characteristics of JFET.
  - **(ii)**TheJFETisalwaysoperatedwithgate-sourcepnjunctionreversebiased.
  - **(iii)** InaJFET,the gate currentiszeroi.e. I_G= 0A. **(iv)**Sincethereisnogatecurrent, I_D=I_S
  - **(v)**The JFETmust beoperated betweenV_{GS} and V_{GS} (off). Forthis range of gate-to-source voltages, I_D will vary from a maximum of I_{DSS} to a minimum of almost zero.
  - **(vi)**Astwogatesarethesamepotential,both depletionlayerswiden ornarrowbyanequal amount.
  - **(vii)**TheJFETisnot subjected to thermalrunawaywhen thetemperatureof the device increases.
  - **(viii)**Thedrain current $I_D$iscontrolled bychangingthe channel width.
  - **(ix)**SinceJFEThasnogatecurrent, there isno β ratingof the device.Wecan finddrain currentI_D

IMPORTANTTERMS:-



1. Shorted-GateDrainCurrent(I_{DSS}):-

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

2. PinchOff Voltage(V_P):-

- Itistheminimum drain-sourcevoltage atwhichthedraincurrentessentiallybecomes constant.

3. Gate-SourceCutOff VoltageV_{GS}(off):-

- Itisthe gate-sourcevoltagewherethe channeliscompletelycutoffandthedraincurrentbecomeszero.

PARAMETERSOFJFET:-

- Likevacuumtubes,aJFEThascertainparameterswhichdetermineitsperformanceinacircuit.The main parameters of JFET are: - **(i)** A.C. drain resistance **(ii)** Transconductance **(iii)** Amplification factor.
- **(i) <u>A.C. Drain Resistance</u> (r_d).** Corresponding to the a.c. plate resistance, we have a.c. drain resistancein a JFET. It may be defined as follows :
- Itistheratioofchangeindrain-sourcevoltage(ΔV_{DS})tothechangeindraincurrent(ΔI_D)atconstant gate-source voltage i.e.

$$\textbf{A.C.DrainResistance,}r_d = \frac{\Delta V_{DS}}{\Delta I_D} \textbf{ atconstant} V_{GS}$$

- Forinstance,ifachangeindrainvoltageof2Vproducesachangeindraincurrentof0.02mA,then, a.c.drainresistance,$r_d = \frac{2\text{ V}}{0.02\text{ mA}}$=100kΩ
- Referring to the output characteristics of a JFET in Fig., it is clear that above the pinch off voltage, thechange in $I_D$is small for a change in V_{DS}because the curve is almost flat.
- Therefore,drain resistanceof aJFEThasa large value, rangingfrom 10 kΩto 1 MΩ.
- **(ii) <u>Transconductance</u> (g_{fs}) : -**The control that the gate voltage has over the drain current is measured bytransconductanceg_{fs}&issimilartothetransconductance $g_m$ofthetube. Itmaybedefinedas follows:
- Itistheratioofchangeindraincurrent(ΔI_D)tothechangeingate-sourcevoltage(ΔV_{GS})atconstant drain-source voltage i.e.

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

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

- **(iii) Amplification Factor (μ).**It is theratio of changein drain-source voltage (ΔV_{DS})to thechangein gate-source voltage(ΔV_{GS}) at constant drain current i.e.

$$\textbf{AmplificationFactor},\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \textbf{ atconstant} I_D$$

- Amplification factor of a JFET indicates how much more control the gate voltage has over drain current than has the drain voltage.
- Forinstance,iftheamplificationfactorofaJFETis50,itmeansthatgatevoltageis50timesas effective as the drain voltage in controlling the drain current.

❖ RELATIONAMONGJFETPARAMETERS:-

- TherelationshipamongJFETparameterscanbe establishedasunder:

Weknow $\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$

- Multiplyingthe numerator and denominator onR.H.S. byΔI_D, weget,

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

➔AmplificationFactor=A.C.DrainResistance×Transconductance

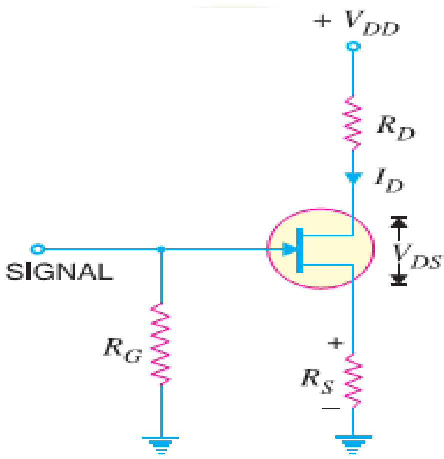
❖ JFETBIASING: -

- For the proper operationof n-channel JFET, gatemustbe negative w.r.t. source. Thiscan be achievedeither by inserting a battery in the gate circuit or by a circuit known as biasing circuit.
- Thelattermethod ispreferredbecausebatteriesarecostlyandrequirefrequent replacement.

1. Bias battery:- Inthis method,JFETisbiasedbyabiasbatteryV_{GG}.Thisbatteryensuresthatgateis always negative w.r.t. source during all parts of the signal.

2. Biasingcircuit:-ThebiasingcircuitusessupplyvoltageV_{DD}toprovidethenecessarybias.Two most commonly used methods are **(i) Self-Bias (ii) Potential Divider Method**.

❖ SELF-BIASFORJFET:-



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

VoltageacrossRs,$V_S = I_D R_S$

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

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

- ThusbiasvoltageV$_{GS}$keepsgatenegativew.r.t. source.

Operating point: -

- Theoperatingpoint(i.e.,zerosignalsI_D&V_{DS})canbeeasily determined. Since the parameters of the JFET are usually known, zero signal $I_D$can be calculated fromthe following relation :

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

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

- Thusd.c.conditionsofJFETamplifierarefullyspecifiedi.e.operatingpointforthecircuitis(V_{DS}, I_D). Also,

$$R_S = \frac{|V_{GS}|}{|I_D|}$$

- NotethatgateresistorR$_G$doesnotaffectbiasbecausevoltageacrossitiszero.

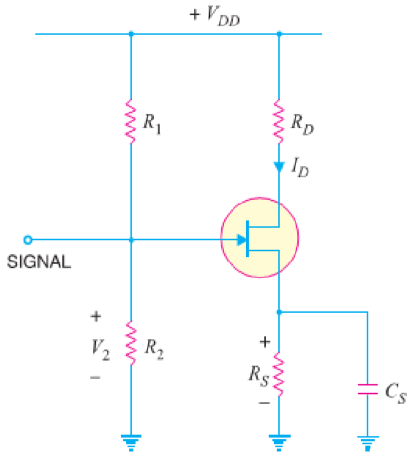
MidpointBias:-Itisoftendesirabletobias aJFETnearthemidpointofitstransfercharacteristiccurve where $I_D = I_{DSS}/2$. When signal is applied, the midpoint bias allows a maximum amount of drain current swing between I_{DSS} and 0.

- Itcanbeproved thatwhen$V_{GS} = V_{GS(off)}/3.4$,midpoint biasconditionsareobtainedforI_D.

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

- Toset drainvoltage atmidpoint($V_D = V_{DD}/2$), selecta valueofR$_D$toproduce thedesiredvoltage drop.

❖ JFETwithVoltage-DividerBias:-



- Fig shows potential divider method of biasing a JFET. This circuit isidentical to that used for a transistor.
- TheresistorsR$_1$andR$_2$formavoltagedivideracrossdrainsupplyV$_{DD}$. 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 $V_2 = V_{GS} + I_D R_S$ Or $\mathbf{V_{GS} = V_2 - I_D R_S}$

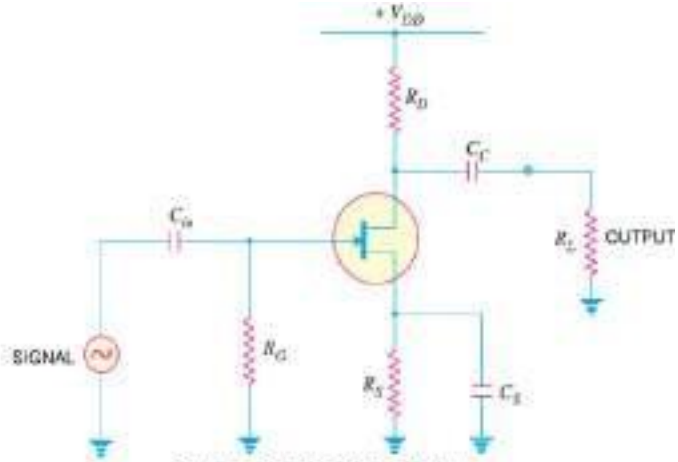
- The circuit is so designed that I_D R_S is larger than V_2 so that V_{GS} is negative. This provides correct bias voltage. We can find the operating point as under:

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

- Althoughthecircuitofvoltage-dividerbiasisabitcomplex,yetthe advantageof thismethodofbiasingisthatit providesgood stabilityof theoperatingpoint.
- Theinput impedanceZ$_i$ofthiscircuit isgivenby;$Z_i = R_1 || R2$

❖ JFETConnections:-

- There are three leads in a JFET viz., source, gate and drain terminals. However, when JFET is to be connectedinacircuit,werequirefourterminals; two forthe input and twoforthe output.
- This difficulty is overcome by making oneterminal 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 Sourceconnection
  - ♣ CommonGateconnection
  - ♣ CommonDrainconnection
- 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,thecircuitproducesaphasereversali.e.,outputsignalis180°outofphasewiththeinput signal. Fig. shows a common source n-channel JFET amplifier.
- Notethat sourceterminaliscommonto both inputand 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 :
  - ♣ AsaBufferamplifier
  - ♣ AsPhase-shift oscillators
  - ♣ AsRF amplifier

❖ MetalOxideSemiconductorFET(MOSFET):-

- The main drawback of JFET is that its gate must be reverse biased for proper operation of the devicei.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 beoperated in the depletion-mode.
- However, there is a field effect transistor (FET) that can be operated to enhance (or increase) the widthof the channel (with consequent increase in conductivity of the channel) i.e. it can have enhancement- mode operation. Such a FET is called **MOSFET.**
- Afield effect transistor(FET)that canbeoperated inthe enhancement-mode iscalled a **MOSFET**.
- AMOSFETisan important semiconductordevice &can beusedin anyofthe circuitscovered for JFET.

- However,aMOSFETthas several advantagesover JFET includinghigh input impedanceand lowcost.

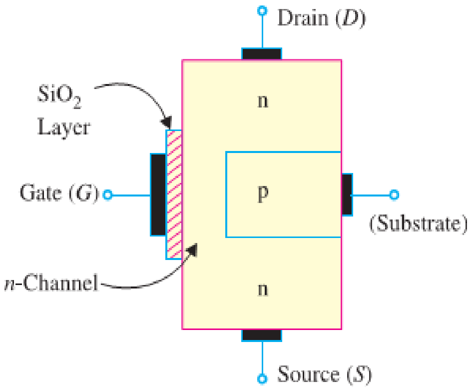
❖ TYPESOFMOSFETS:-

- Therearetwobasictypes ofMOSFETssuchas:-

1. Depletion-type MOSFET or D-MOSFET. The D-MOSFET can be operated in both the depletion mode and the enhancement-mode.
    - Forthisreason,aD-MOSFETissometimescalled**Depletion/Enhancement MOSFET**.

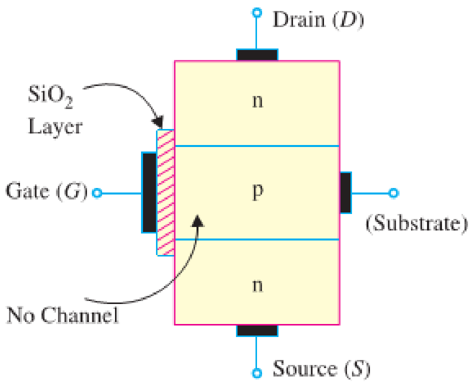
2. Enhancement-type MOSFET or E-MOSFET. The E-MOSFET can be operated only in enhancementmode.Themanner in which aMOSFETisconstructed determines whether it isD-MOSFETor E-MOSFET.

- ❖ **D-MOSFET.**Figshowstheconstructionaldetailsofn-channelD-MOSFET.
- Itissimilarton-channel JFETexceptwiththefollowingmodifications/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 arrangementformsacapacitor.Oneplateofthiscapacitoristhe gateand otherplateisthechannel with SiO_2 asdielectric. Recallthat wehaveagatediode in aJFET.



n-Channel D-MOSFET

- **(iii)** It is ausual practice to connectthesubstrateto thesource(S)internallyso that aMOSFET 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 theD-MOSFET.Notethatthesubstrateextendscompletelytothe SiO_2layer 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-MOSFETis quite similarto thatof the D-MOSFET except for the absence of a channel between the drain and source terminals.



n-Channel E-MOSFET

❖ WhythenameMOSFET?

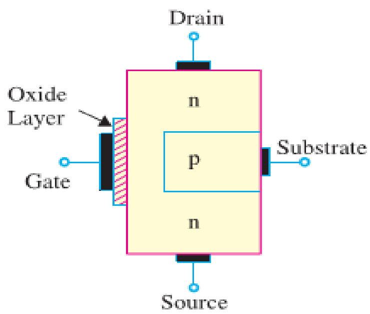
- Thereader maywonderwhyisthe device calledMOSFET?
- Theanswer is simple.TheSiO_2layerisaninsulator. The gateterminalismadeof ametalconductor.
- Thus,goingfromgatetosubstrate,wehaveametal oxide semiconductorand hence thename MOSFET.
- Since the gate is insulated from the channel, the MOSFET is sometimes called **insulated-gate FET** (IGFET). However, this term is rarely used in place of the term MOSFET.

❖ SymbolsforD-MOSFET

TherearetwotypesofD-MOSFETssuchas

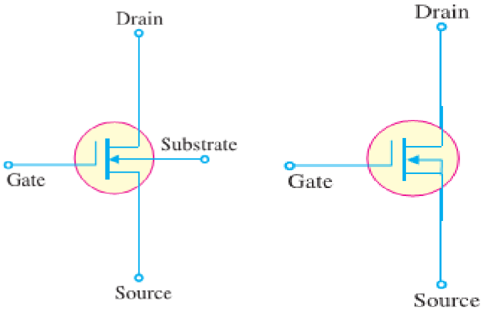
(i)n-channelD-MOSFETand**(ii)**p-channelD-MOSFET

- **(i) N-Channel D-MOSFET**.Fig (i) shows the various parts of n-channel D-MOSFET.



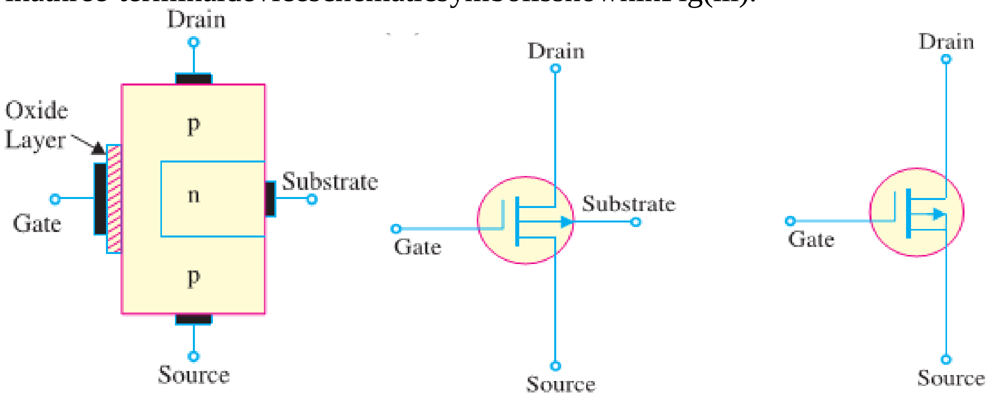
n-Channel D-MOSFET
(i)

- Thep-typesubstrateconstrictsthechannelbetweenthesourceanddrainsothatonlyasmallpassage remains at the left side.
- Electronsflowingfromsource(whendrainispositivew.r.t.source)mustpassthroughthisnarrow channel.
- Thesymbol forn-channel D-MOSFETisshownin Fig (ii).
- The gate appearslike acapacitor plate. Just to the right ofthegate is a thick vertical line representing the channel.
- Thedrainleadcomesoutofthetopofthechannelandthe source lead connects to the bottom.
- Thearrowisonthesubstrateandpointstothen-material;therefore we have n-channel D-MOSFET.
- It is a usual practice to connect substrate to source internally as shown in Fig. (iii).
- Thisgivesrisetoathree-terminaldevice.



Symbol (ii) Symbol (iii)

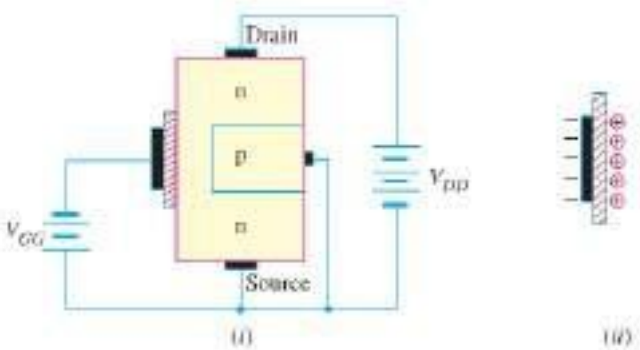
- **(ii)P-ChannelD-MOSFET.**Fig(i)showsthevariouspartsofp-channelD-MOSFET.
- Then-typesubstrateconstrictsthechannelbetweenthesourceanddrainsothatonlyasmallpassage remains at the left side.
- Theconductiontakesplacebytheflowofholesfrom sourcetodrain throughthisnarrow channel.
- Thesymbolforp-channelD-MOSFETshowninFig(ii).Itisausualpracticetoconnectthesubstrateto source internally.
- Thisresults inathree-terminaldeviceschematicsymbolisshowninFig(iii).



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

❖ CircuitOperationofD-MOSFET

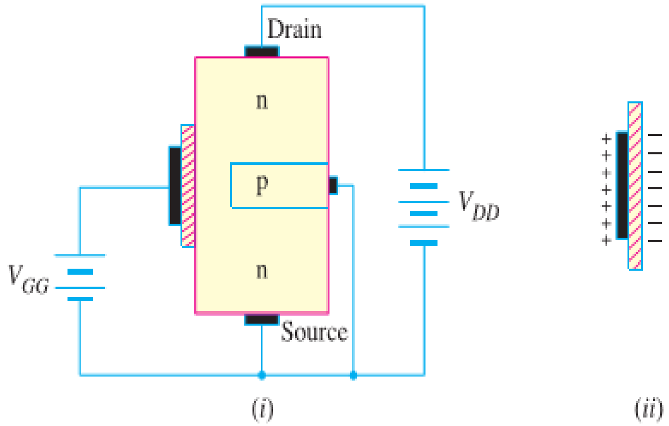
- Fig (i) shows the circuit of n-channel D-MOSFET. The gate forms a small capacitor. One plate of this capacitoris thegate andtheotherplateis thechannel with metal oxide layer as the dielectric.
- When gate voltage is changed, the electric field ofthe capacitor changes which in turn changes the resistance of the n-channel.
- Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate.



- Thenegative-gateoperationiscalled**DepletionMode**whereaspositivegateoperationisknownas **EnhancementMode**.
- ♣ **DepletionMode**.Fig(i)showsdepletion-modeoperationofn-channelD-MOSFET.Sincegateis 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).
- Inotherwords,we havedepleted(i.e.emptied) the n-channelof someofitsfree 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.
- Thusbychangingthenegativevoltageonthegate,wecanvarytheresistanceofthen-channeland hence the current from source to drain.
- Notethat with negativevoltage to the gate, theaction ofD-MOSFETissimilarto JFET.
- Becausetheactionwithnegativegatedependsupondepleting(i.e.emptying)thechanneloffreeelectrons, 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.



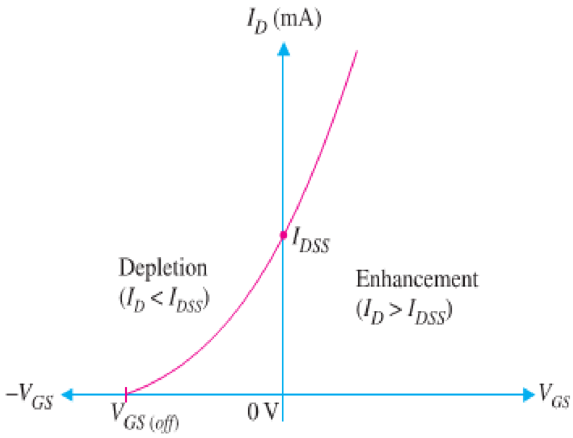
- Since the gate is positive, it induces negative charges in the n-channel as shown in Fig (ii).
- These negative charges are the free electronsdrawn into the channel.
- Because these free electrons are added to those already in the channel, the total number of free electrons in the channel is increased.
- Thus a positive gate voltage enhances or increases the conductivity of the channel.
- Thegreaterthepositivevoltageonthegate, greater the conduction from source to drain.
- Thus by changing the positive voltage on the gate, we can change the conductivity of the channel.
- ThemaindifferencebetweenD-MOSFETandJFETisthatwecanapplypositivegatevoltagetoD- MOSFET and still have essentially zero current.
- Becausetheactionwithapositivegatedependsuponenhancingtheconductivityofthechannel,the positive gate operation is called enhancement mode.

♣ **ThefollowingpointsmaybenotedaboutD-MOSFEToperation:-**

- **(i)**InD-MOSFET, sourceto draincurrent iscontrolled byelectricfieldofcapacitorformedatthegate.
- **(ii)**ThegateofJFETbehavesasareverse-biaseddiodewhereasthegateofaD-MOSFETactslikea capacitor. For this reason, it is possible to operate D-MOSFET with positive or negative gate voltage.
- **(iii)**AsthegateofD-MOSFETformsacapacitor,therefore,negligiblegatecurrentflowswhether positive or negative voltage is applied to the gate.
- Forthis, the inputimpedanceofD-MOSFETisveryhigh,rangingfrom 10,000 MΩto10, 000, 00 MΩ.
- **(iv)**Theextremelysmalldimensionsoftheoxidelayerunderthegateterminalresultinaverylow capacitance and the D-MOSFET has, therefore, a very low input capacitance.
- Thischaracteristicmakes theD-MOSFETusefulinhigh-frequencyapplications.

❖ D-MOSFETTransferCharacteristic: -

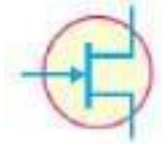
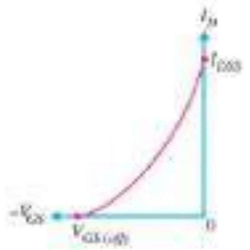
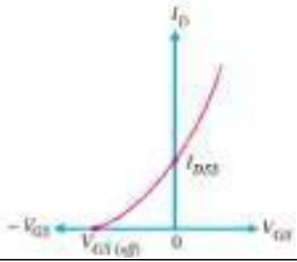
- Figshowsthetransfercharacteristiccurve(ortransconductancecurve)for n-channel D-OSFET.
- The behaviour of this device can be beautifully explained with the help of this curve as under :-
- **(i)** The point on the curve where V_{GS} = 0, I_D = I_{DSS}. It is expected because I_{DSS} is the value of 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.



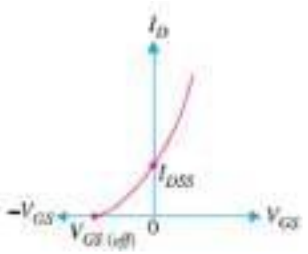
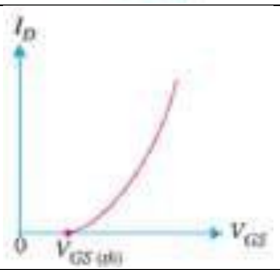
- Becauseofthissimilarity,theJFETandtheD-MOSFEThavethesametransconductanceequation viz.

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

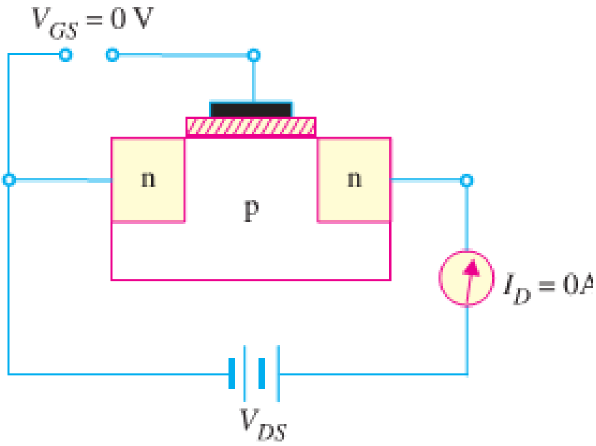
❖ D-MOSFETVsJFET:-

SN	Parameters	JFETs	D-MOSFETs
1	Symbol		
2	Transconductance Curve		
3	Modes of operation:	Depletiononly	Depletionandenhancement
4	Commonly Usedbiascircuits:	**(1)** Gate bias; **(2)** Self bias; **(3)** Voltage-dividerbias;	**(1)** Gate bias; **(2)** Self bias; **(3)** Voltage-dividerbias; **(4)** Zerobias
5	Advantages:	Extremelyhigh input impedance.	**(1)** Higherinputimpedancethan a comparable *JFET*. **(2)** Canoperateinboth modes (DepletionandEnhancement).
6	Disadvantages:	**(1)** Bias instability; **(2)** Can operateonlyindepletionmode.	**(1)** Biasinstability. **(2)** Moresensitivetochangesin temperature than the *JFET*.

❖ Tablebelowsummarizesmanyofthecharacteristicsof D-MOSFETsandE-MOSFETs: -

SN	Parameters	D-MOSFETs	E-MOSFETs
1	Symbol		
2	Transconductance Curve		
3	ModesofOperation:	EnhancementandDepletion	EnhancementOnly
4	Commonly Usedbiascircuits:	**(1)** Gate bias; **(2)** Self bias; **(3)** Voltage-dividerbias; **(4)** Zerobias.	**(1)** Gate bias; **(2)** Voltage-dividerbias; **(3)** Drain-feedbackbias.

❖ E-MOSFET:-



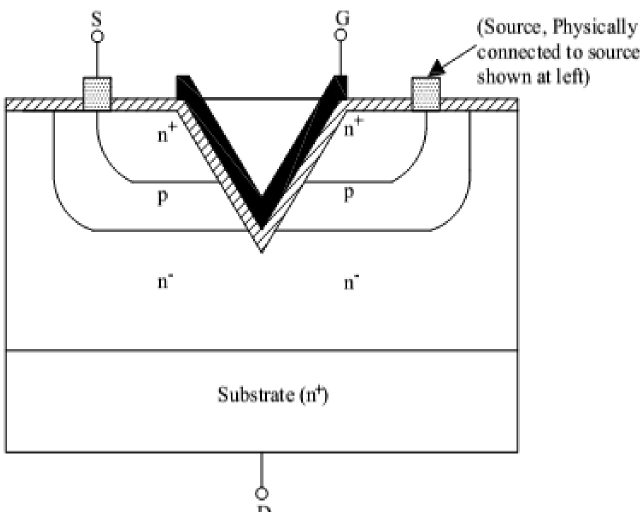
- Twothingsareworth notingabout E-MOSFET.
- First, E-MOSFET operates only in the enhancement mode and has no depletion mode.
- Secondly, the E-MOSFET has no physical channel from source to drain because the substrate extends completely to the SiO_2 layer [See Fig (i)].
- It is only by the application of V_{GS} (gate-to-source voltage) of proper magnitude and polarity that the device starts conducting.
- TheminimumvalueofV_{GS}ofproperpolaritythatturns on E-MOSFET is called **Threshold voltage** [$V_{GS(th)}$].
- The n-channel device requires positive V_{GS} ($\geq V_{GS(th)}$)&thep-channeldevicerequiresnegativeV_{GS}($\geq V_{GS(th)}$).

❖ PowerMOSFETs:-

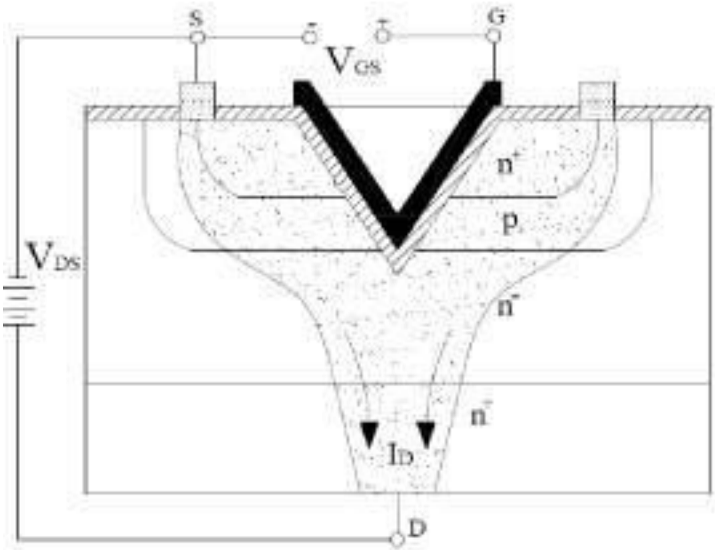
- With the advancement of technology, the engineers have produced a wide variety of MOSEFTs that are designed specifically for high current, high voltage and high power applications.
- SomeExamplesofPowerMOSFETareVMOS, LDMOSetc.

❖ VMOS[V-GroveMOSFETorVerticalMOSFET]:-

- One of the major disadvantages of a typical MOSFET is the reduced power handling level as compared to BJT transistors. The power handling level of a typical MOSFET is less than 1W.
- ThisdrawbackoftheMOSFETcanbeovercomebychangingtheconstructionmodefromoneofthe planer nature to one with a vertical structure as shown in Fig.



Illustrating the Construction of VMOS



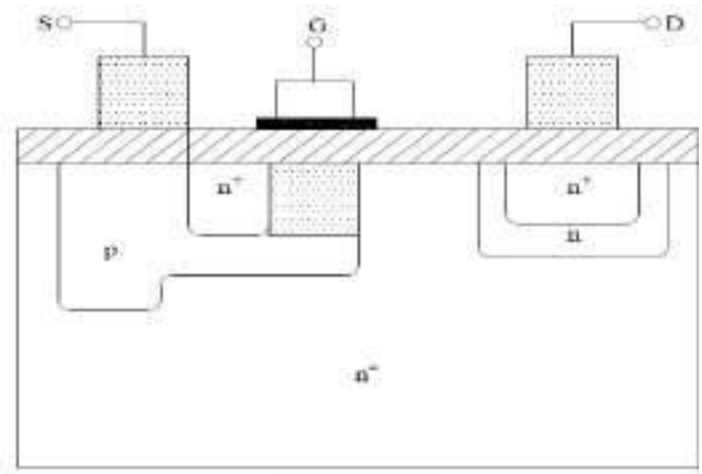
[Illustrating VMOS Operation]

- As seen from this figure, all the elements of the planar MOSFET are present in the vertical metal-oxide silicon FET (or simply VMOS) the metallic surface connection to the terminals of the device.
- The vertical-MOSEFT (or simple VMOS) is a component designed to handle much larger drain currents than the standard MOSEFT.
- The current handling capability of the VMOS is a result of its physical construction which is illustratedin Fig.As seen from this figure, the component gas materials that are labelled as P, N^+ and N^-.
- TheN^-materiallabelsindicatedifferencesindopinglevels.
- Alsonoticethatthereisnophysicalchannelconnectingthesource(attop)andthedrain(atbottom). Thus VMOS is an *enhancement type* MOSEFT.
- WithV-shapedgate,a largerchannelis formed byapositivegate voltage.
- Withalarge channel,thedeviceiscapableofhandlinglarge amountofdrain current.
- TheOperationofVMOSisillustratedinFig.

VMOS Operation: -

- WhenapositivegatevoltageisappliedtothedeviceanN-typechannelformsintheP-typeregions. This effective channel connects the source to the drain.
- Asseenfromthefiguretheshapeofthegatecausesawiderchanneltoformthaniscreatedinthe standard MOSFET. Hence, the amount of drain current is much higher for this component.
- Moreover,theVMOScanexhibitahighertransconductanceandalowerturn-onresistancethanthe conventional planer MOSFET.
- AnotheradvantagesofusingVMOSidthe factit isnot susceptible tothermal runaway.
- The VMOS has a positive temperature coefficient, means that the resistance of the component increases when temperature increases.
- Thusanincreaseintemperaturewillcause adecreaseindrain current.
- TheVMOSdevicecanbefabricatedwithmorethanoneV-grovetoincreaseamountofdraincurrent and some other performance characteristics.

❖ LDMOS:-



LDMOS

- TheLDMOS(i.e.LateralDoubleDiffused MOSFET) is another type of power MOSFET.
- This MOSFET uses a very small channel region and a heavily doped N-type region (N^+) toobtain a high drain current and low channel resistance [$r_{d(ON)}$].
- FigshowsthebasicconstructionofLDMOS.
- As seen from this figure, the narrow channel (Shaded region) is made up of the P-type material that lies between the N^- Substrate (lightly doped) and the N^+ (heavily doped) source region.
- Since only the N-type material lies between the channel andthe drain, the effective length of the channel is externally short. This coupled with the N-type material in channel-to-drain path provides an extremely low value of $r_{d(ON)}$.
- Withalowchannelresistance,theLDMOSdevicecanhandleveryhighamountofcurrentwithout generating and damaging amount of heat.
- TheLDMOShastypicalvaluesof$r_{d(ON)}$thatareintherangeof2Ωorless.
- Withthislowvaluechannel resistance,it istypicallycapableof handlingcurrent ashighas20 A.

❖ C-MOS:-

- C-MOSmeanscomplementaryMOS.Thesearemostlyusedinthefieldofdigitalelectronicsto manufacture logic gates and many other synchronous and asynchronous circuits.
- ThelogicgatesincludesAND,OR&NOTgates andtheirvariouscombinations.
- Thesynchronouscircuitincludesflip-flops,counters,memories,A/DandD/A converters.
- The asynchronous circuit includes combinations of logic gates such as decoders, encoders, multiplexers and de-multiplexers etc.
- ACMOSlogiccircuitconsistsofcombinationsofNMOS&PMOSdevices.

[CHAPTER-5]

[FEEDBACK AMPLIFIER]

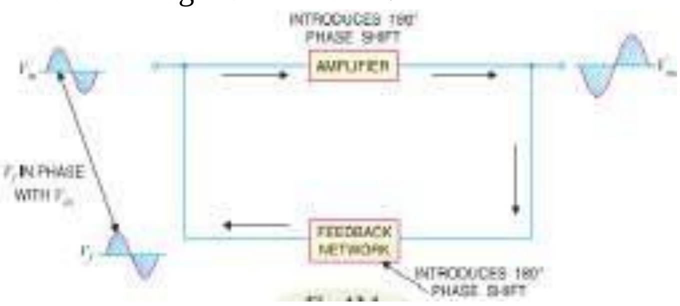
❖ INTRODUCTION:-

- Apracticalamplifierhasagainofnearlyonemillioni.e.itsoutputisonemilliontimestheinput. Consequently,evena casualdisturbance at theinputwill appearin theamplifiedform inthe output.
- Thenoiseintheoutputofan amplifierisundesirableand mustbekeptto assmallalevel aspossible.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:-

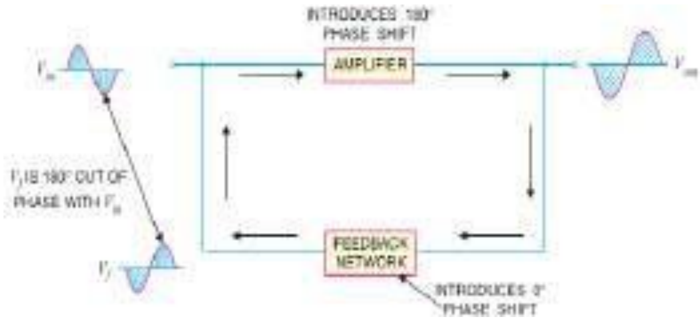
- The process of injecting a fraction of output energy of some device back to the input is known as **feedback.** Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers viz Positive Feedback and Negative Feedback.

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° phaseshift around the loop, causing the feedbackvoltage $V_f$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.

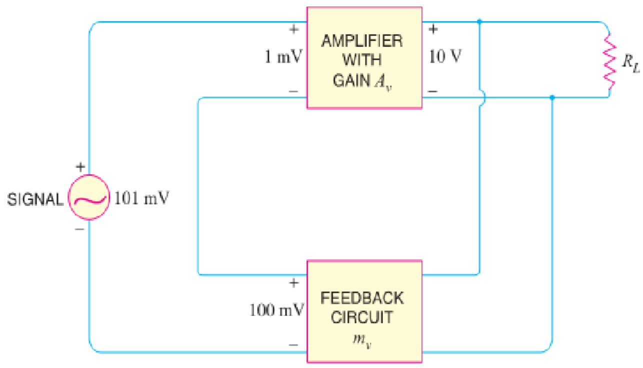
(ii) Negative Feedback. When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig.



- 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 nophaseshift(i.e.,0°phaseshift).Theresultisthat thefeedback voltage $V_f$is180°out of phasewith the inputsignal V_{in}.
- Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stabilityin gain, increased bandwidth and improved input and output impedances.
- Itisduetothese advantagesthatnegativefeedbackisfrequentlyemployed in amplifiers.

❖ PRINCIPLESOFNEGATIVE VOLTAGEFEEDBACKIN 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.100mVis feedbacktotheinput whereit is applied in series with the input signal of 101 mV.



- Asthefeedbackisnegative,therefore, only1mVappearsattheinputterminalsofthe amplifier.