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Lecture Note on
ANALOG ELECTRONICS&LINEAR IC

Diploma 4th Semester

Vikash
Polytechnic

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[CHAPTER–1]

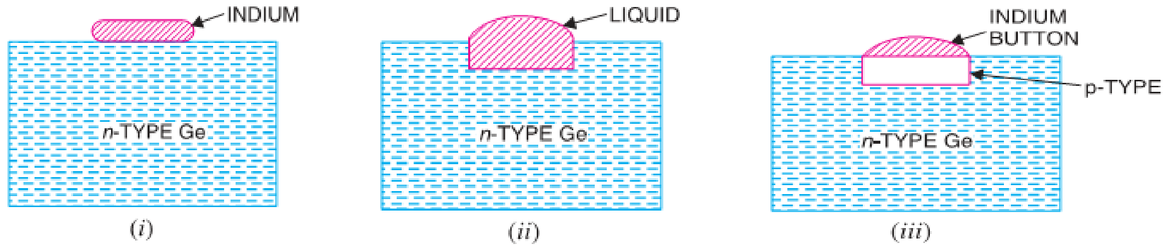
------------------ [DIODE,TRANSISTOR& ------------------
,CIRCUITS]

CONSTRUCTION&WORKINGPRINCIPLEOFDIODE:-

- Whenap-typesemiconductorissuitablyjoinedton-typesemiconductor,thecontactsurfaceiscalled **PNJunction**.MostsemiconductordevicescontainoneormorePNjunctions.

FormationofPNjunction.

- Inactualpractice,thecharacteristicpropertiesofPNjunctionwillnotbeapparentifap-typeblockis just brought in contact with n-type block.In fact, it is **fabricated** by special techniques.
- ThereareanumberoftechniquesforthefabricationofPN-Junction:-
  - GrownJunction
  - AlloyJunction
  - DiffusedJunction
  - EpitaxialGrowth
  - PointcontractJunction.
- ButthemostcommonmethodofmakingPNjunctioniscalled**Alloying**.

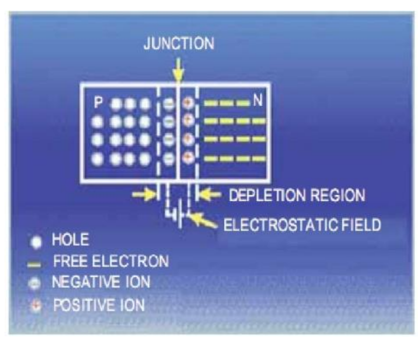


[FiguresofdifferentstagesofformationofPNjunctionbyAlloyingmethod]

- 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-indiummixture 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,theremainingmoltenmixturebecomesincreasingly richinindium.
- 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).

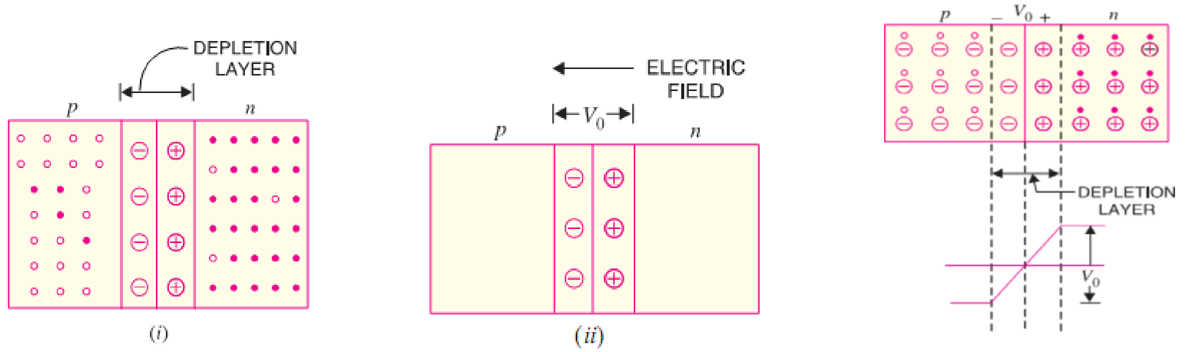
PropertiesofPNJunction.

- ToexplainPNjunction,considertwotypesofmaterials:-1)P-Type&2)N-Type.
- P-typesemiconductorhaving–iveacceptorionsand+ivechargedholes.N-typesemiconductorhaving +ivedonorions&–ivefreeelectrons.



- 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.
- Similarlynegativechargeestablishonp-sideofthejunction.
- Whensufficientnoofdonorandaccepterionsgatheredatthe junction,furtherdiffusionprevented.Because+ivechargeonn-siderepelholestocrossfromp-sideto n-side, similarly –ivecharge on p-side repel freeelectrons 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 **PotentialBarrier/JunctionBarrier(V_0)** and is of the order 0.1 to 0.3 volt. This prevents the respectivemajority carriersforcrossing thebarrierregion.Thisregionisknownas**DepletionLayer**

- Thetermdepletionisduetothefactthatnearthejunction,theregionisdepleted(i.e.emptied)of charge carries (free electrons and holes) due to diffusion across the junction.
- Itmaybenotedthatdepletionlayerisformedveryquicklyandisverythincomparedtothen-region and the p-region.
- Once pn junction is formed and depletion layer created, the diffusion of free electrons stops. In other



words,thedepletionregionactsasabarriertothefurthermovementoffreeelectronsacrossthe junction. The positive and negative charges set upan electric field as shown in the fig above.
- Theelectricfieldisabarriertothefreeelectronsinthen-region.Thereexistsapotentialdifference 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=0.3V

❖ **JunctionCapacitance:-**

- When a PN junction is formed, a layer of positive and negative impurity ions is formed on either side ofthepnjunction.Thisdepletionlayeractsasdielectric(non-conductive)mediumbetweenP-regionand N-region.Therefore,theseregionsactastwoplatesofa capacitorseparatedby dielectricmedium.
- The capacitance formed in this junction is called as Depletion Layer Capacitance or Space Charge Capacitance or Transition Region Capacitance or simple **JunctionCapacitance.**

ApplyingD.C.VoltageAcrossPNJunctionorBiasingaPNJunction

- In electronics, the term bias refers to the use of D.C. voltage to establish certain operating conditions foran electronic device.In relation to a PN junction, there are following two bias conditions :

1.ForwardBiasing**2.**ReverseBiasing

❖ **ForwardBiasing.** When externalD.C.voltageapplied tothe junction isinsuch a directionthat it cancels the potential barrier, thus permitting current flow, it is called **ForwardBiasing**.

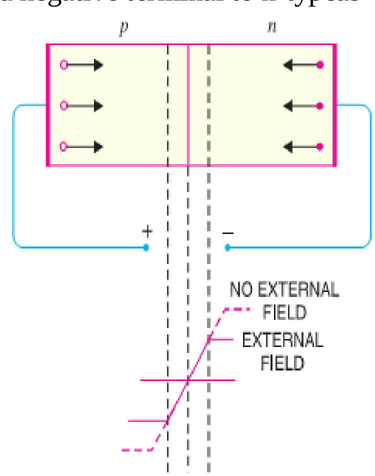
- To apply forward bias, connect positive terminal of the battery to p-typeand negative terminal to n-typeas shown in Fig.
- The appliedforward potential establishes anelectric field which actsagainst the field due to potential barrier.
- Therefore,theresultantfieldisweakenedandthebarrierheightis reduced at the junction.
- Aspotentialbarriervoltageisverysmall(0.1to0.3V),therefore,a small forward voltage is sufficient to completely eliminate the barrier.
- Once thepotentialbarrier iseliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit.
- Thus,currentflowsinthecircuit.ThisiscalledForward**Current**.
- WithforwardbiastoPNjunction,theimportantpointsare:-

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

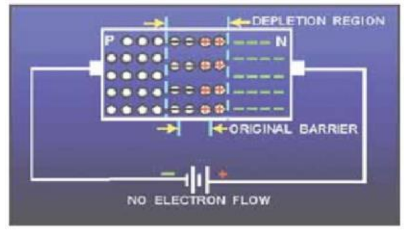
(ii) Thejunctionofferslowresistance(forwardresistance,R_f)tocurrentflow.

(iii) Currentflowsinthecircuitduetotheestablishmentoflowresistancepath.

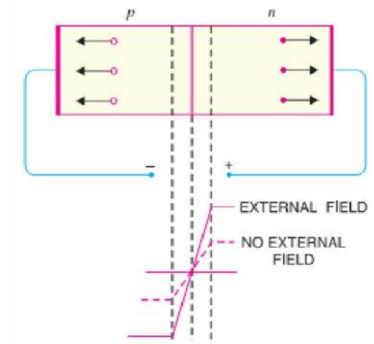
(iv) Themagnitudeofcurrentdependsupontheappliedforwardvoltage.



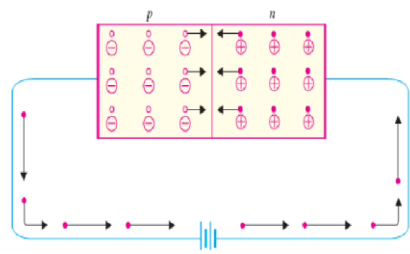
- **<u>ReverseBiasing</u>.** When the external D.C. voltage applied to the junction is in such a direction that potential barrier is increased, it is called **ReverseBiasing.**



  - 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 fieldwhich 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.



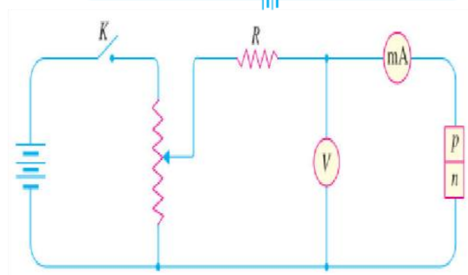
- ♣ WithreversebiastoPNjunction,Theimportantpointsare:
  - (i) Thepotentialbarrierisincreased.
  - (ii) ThejunctionoffersveryhighresistanceR$_r$)tocurrentflow.
  - (iii) Nocurrentflowsinthecircuitduetohighresistancepath.
  - **Conclusion:-** From the above discussion, it follows that with reverse bias to the junction, a high resistance path is established and hence no current flow occurs.
  - Whereaswithforwardbiastojunctionlowresistancepathissetup & hence current flows in the circuit.



- **CurrentFlowinaForwardBiasedPNJunction:-**
  - It concluded that in n-type region, current carried by free electrons whereasinp-typeregion,itiscarriedbyholes.However,in external connecting wires, current is carried only by free electrons.

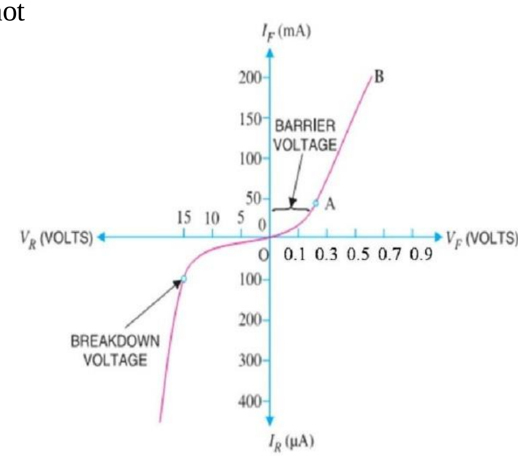
Volt-AmpereCharacteristicsofPNJunction:-

- 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)**Zeroexternalvoltage,**(2)**ForwardBias**(3)**ReverseBias.

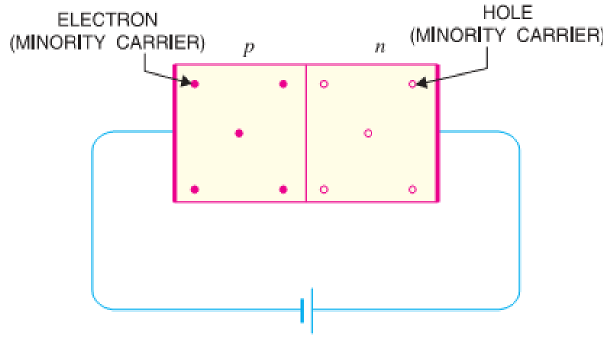
- **(i)Zeroexternalvoltage:-**Whentheexternalvoltageis zero,i.e.circuitisopenatK;thepotentialbarrieratthe junction does not permit current flow. Therefore, the circuit current is zero as indicated by point O in Fig.
  - **(ii)ForwardBias**:-Withforwardbiastothepnjunction i.e. p-type connected to positive 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 Vfor Ge), the potential barrier is altogether eliminated and currentstartsflowinginthecircuit.Fromnowonwards, 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 (regionOA),thecurrentincreasesveryslowlyandthe curve is non-linear. Because the external applied voltage is used up in overcoming the potential barrier.
  - Onceexternalvoltageexceedspotentialbarriervoltage,thepnjunctionbehaveslikeordinary conductor.
  - Therefore, the current rises very sharply with increase in external voltage (region AB on the curve). The curve is almost linear.

❖ **(iii)ReverseBias:-**Withreversebiastothepnjunctioni.e.p-typeconnectedtonegativeterminaland n-typeconnectedtopositiveterminal,potentialbarrieratthejunctionisincreased.Therefore,the junction resistance becomes very high and practically nocurrent flows through thecircuit.

- However,inpractice,averysmallcurrent(oftheorderofµA)flowsinthecircuitwithreversebiasas shown in the reverse characteristic.
- Thisiscalled**ReverseSaturationCurrent**(Is)and is due to the minority carriers.
- Itmay berecalledthattherearea fewfreeelectrons in p-type material and a few holes in n-type material.
- Theseundesirablefreeelectronsinp-typeandholes in n-type are called minority carriers. As shown insideFig.totheseminoritycarriers,theapplied reverse bias appears as forward bias.



- Therefore,asmallcurrentflowsinthereverse direction. If reverse voltage is increased continuously, the kinetic energy of electrons (minority carriers) may become high enough to knock out electrons from the semiconductor atoms.
- At this stage breakdown of the junction occurs, characterized by a sudden rise of reverse current and a sudden fall of the resistance of barrier region. This may destroy the junction permanently.
- **Note:-**Theforwardcurrentthroughapnjunctionisduetothemajoritycarriersproducedbythe impurity. However, reverse current is due to the minority carriers produced due to breaking of some co- valent bonds at room temperature.

❖ **ImportantTerms:-**

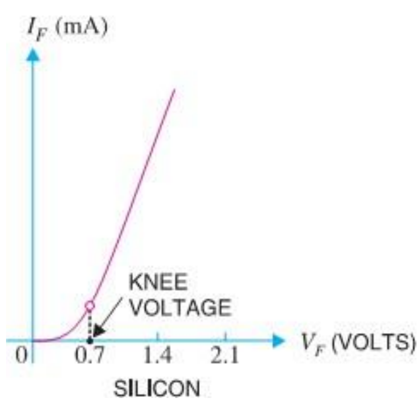
(i) BreakdownVoltage:- It is the minimum reverse voltage at which pn junction breaks down with suddenrise in reverse current.

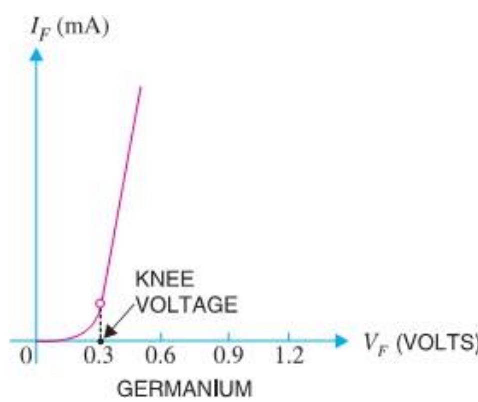
(ii) KneeVoltage:-Theforwardvoltageatwhichthecurrentthroughthejunctionstartstoincreaserapidly.

(iii) Peakinversevoltage(PIV):- It is the maximum reverse voltage that can be applied to the pn junction withoutdamagetothejunction.IfthereversevoltageacrossthejunctionexceedsitsPIV,thejunctionmay bedestroyedduetoexcessiveheat.Thepeakinversevoltageisofparticularimportanceinrectifierservice.

(iv) Maximumforwardcurrent:- It is the highest instantaneous forward current that a pn junction can conductwithoutdamagetothejunction.Manufacturer'sdatasheetusually specifiesthisrating.Ifthe forwardcurrentinapnjunctionismore thanthisrating,thejunctionwillbedestroyedduetooverheating.

(v) Maximumpowerrating:- 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





OtherTypeofDIODES:-

1.	ZenerDiode	**2.**	LightEmittingDiode	**3.**	TunnelDiode	**4.**	PINDiodes
5.	Photo-Diode	**6.**	VaractorDiodes	**7.**	LaserDiodes	**8.**	GunnDiodes
9.	Peltierdiodes	**10.**	StepRecoveryDiodes	**11.**	SchottkyDiode	**12.**	SuperBarrierDiodes
13.	Optoisolator	**14.**	Point-contactdiodes	**15.**	Avalanchediodes	**16.**	Constantcurrentdiodes

DIODECURRENTEQUATION:-

- The Mathematical equation, which describes the forward and reverse characteristics of a semiconductordiode is called the diode current equation.
- Let I = Forward or Reverse Diode Current,

  I_0 = Reverse Saturation Current

  V=ExternalVoltage.(Itis+VeforForwardBias,-VeorReverseBias)

  η = A constant, whose value is equal to 1 for Ge diode and 2 for Si diode for relatively low value of diode current (i.e. at or below the knee of the curve) and ή = 1 for Ge & Si diode for higher levels of diode current. (i. e. in the rapidly increasing section of the curve)

  V_T=Volt-equivalentoftemperature.ItsvalueisgivenbytherelationT/11,600, whereTistheabsolutetemperature.Atroomtemperature(i.e.300K),V_T=26vmV.
- Thecurrentequationforaforwardbiaseddiodeisgivenbytherelation,

Weknowthatatroomtemperature,V_T=26mV=0.026V.SubstitutingthevalueofV_Tintheabove equation it becomes,

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

- Thusdiodecurrentatorbelowthekneeofthecurveforgermaniumandsiliconisgivenby

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

- Ifthevalueofappliedvoltageisgreaterthanunity(i.e.forthediodecurrentintherapidbyincreasing section ofthecurve) thenthe equationofdiodecurrent forGermaniumor Silicon is given by

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

- Thecurrentequationforareversebiaseddiodemaybeobtainedbychangingthesignoftheapplied voltage (V), i.e.
- IftheValueofV>>V_T,thentheterm–V/η.V_T<<1.ThereforeI=I_0.
- Thusthediodecurrentunderreversebiasisequaltothereversesaturationcurrentaslongastheexternal voltage is below its break down value.

DIODESPECIFICATIONSHEET:-

- Allmanufactures of the semiconductor device provide data on specific diodes for the users to makeproperutilizationofthedevices.Thisdatacouldbeabriefdescriptionlimitedtoaonepageormore than that.It includes the information arranged in table, graphs etc. The datais usually for : -
  - Forwardvoltage,V_F(AtaspecificCurrent&Temperature)
  - Maximumforwardcurrent,I_F(AtaspecificTemperature)
  - Reversesaturationcurrent$I_R$orI_O(AtaspecificVoltage&Temperature)
  - ReverseVoltageRating[PIV,PRV,VRRMorV(BR)],Where,BR=Breakdownataspecific current & temperature.
  - Maximumpowerdissipationlevelataparticulartemperature.
  - CapacitanceValue.
  - Reverserecoverytime,t_{rr}.
  - Operatingtemperaturerange.
- Besidethis,dependingonthetypeofdiodebeingconsidered,moredatamayalsobeprovidedsuchas frequency range, noiselevel, switching time,thermal resistance levelandpeak repetitive values.
- Fortheapplicationinmind,thesignificanceofthedatawillusuallybeselfapparent.
- Ifthemaximumpowerordissipationratingisalsoprovided,itisunderstoodtobeequaltotheproduce

$$P_{Dmax}=V_DI_D$$

Where$I_D$and$V_D$arethediodecurrentandvoltageataparticularpointofoperation.

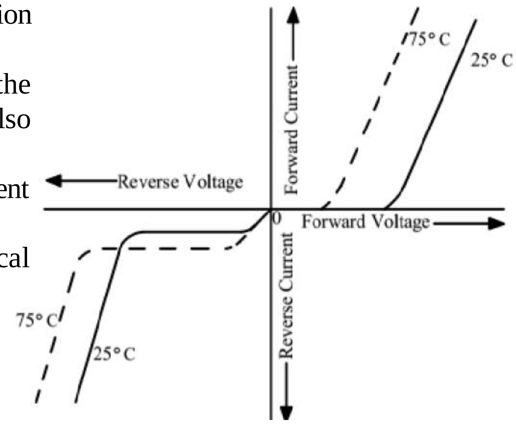
DIODEAPPLICATIONS:

➢ APNjunctiondiodehasanimportantcharacteristicthatitconductswellinforwarddirectionand poorly in reverse direction. This characteristic makes a diode very useful in a number of applicationsgiven below:

1. AsRectifiersorPowerDiodesinD.C.powersupply.
2. AsSignalDiodesincommunicationcircuits.
3. AsZenerDiodesinvoltagestabilizingcircuits.
4. AsVaractorDiodesinradioandTVreceivers.
5. AsaSwitchinlogiccircuitsusedincomputers

EFFECTOFTEMPERATUREOFDEPENDENCEOFJUNCTIONDIODE:

➢ We have already discussed in the last article that the diodecurrent is a function of temperature and the temperature appearsin 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 saturationcurrent (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} =Saturation current at temp (T_1) for Ge or Si diode,
&I_{02} =Saturation current at some other temperature (T_2)
Then

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

➢ Asdiscussedinlastchapterthereversesaturationcurrent(I_0) willbejustaboutdoubleinmagnitudeforevery10ºCincreaseintemperature.

➢ Forexample,agermaniumdiodewithanI_0intheorderof1or2µAat25ºChasaleakagecurrentof 100µ A (= 0.1 mA) at a temperature of 100ºC.

➢ Currentlevelsofthismagnitudeinthereversebiasregionwouldcertainlyquestionourdesiredopen- circuit condition in the reverse bias region.

➢ However, typical values of $I_0$for silicon diode are much lower than that of germanium for similar power and current levels.

➢ TheincreasinglevelofI_0withtemperatureaccountforthelowerthresholdvoltageasshowninFig.

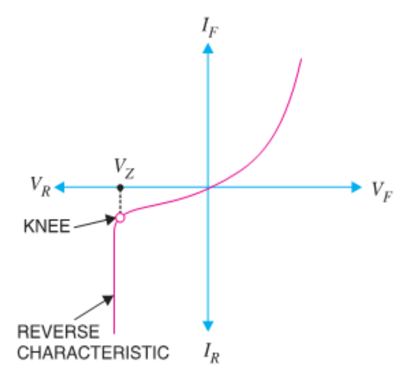
➢ Duetothisreasonforwardcharacteristicat75ºCisshowntothelefttothatofthecharacteristicat25ºC.

➢ Asthetemperatureincreases,theforwardcharacteristicshiftsmoreandmoretotheleftofthe characteristic at 25ºC (i.e. become more and more “ideal”).

➢ However,temperaturebeyondthenormaloperatingrangecanhaveaverydetrimentaleffectonthe diode’s maximum power and current levels.

➢ WeseeinFig.,thatinthereversebiasregion,thebreakdownvoltageisincreasingwiththeincreasein temperature.

ZENERBREAKDOWN



♣ It has already been discussed that when the reverse bias on a crystal diode is increased, a critical voltage, called **BreakdownVoltage** is reached where the reverse current increases sharply to a high value.

♣ Thebreakdownregionisthekneeofthereversecharacteristicas 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 **ZenerVoltage** or **ZenerBreakDown**& the sudden increase in current is known as **ZenerCurrent**.

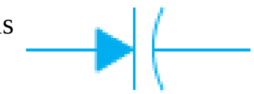
♣ ThebreakdownorZenervoltagedependsupontheamountofdoping.

♣ Ifthediodeisheavilydoped,depletionlayerwillbethinandconsequentlythebreakdownofjunction willoccur atlowerreversevoltage whereaslightly dopeddiodehasa higher breakdownvoltage.

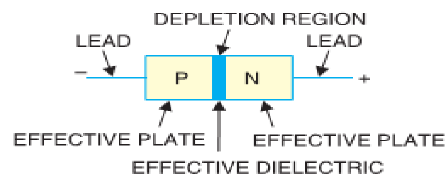
AVALANCHEBREAKDOWN:-

- Inthiscasetheincreasedreversevoltageincreasestheamountofenergyimpartedtominoritycarriers.
- Asthereversevoltageisincreasedfurtherthminoritycarriersacquiresalargeamountofenergy.
- WhenthesecarrierscollidewithSiorGeatoms,withinthecrystalstructure,theyimpartsufficient energy to break a covalent bond and generate additional carriers(electron-hole pair).
- Theseadditionalcarrierspickupenergy fromtheappliedvoltageandgeneratesstillmorecarriers.Asa result of this, the reverse current increases rapidly.
- Thiscumulativeprocessofcarriergeneration(multiplication)isknownas**AvalancheBreakdown**or Avalanche **Multiplication**

❖ VARACTORDIODE



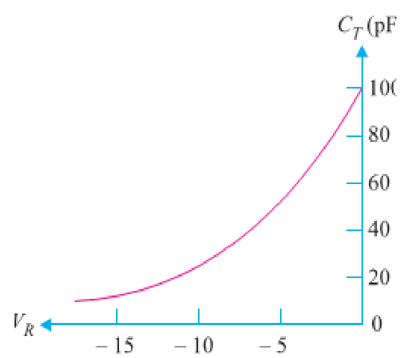
- A junction diode which acts as a variable capacitor under changing reverse bias is known as a **varactordiode**. It is also known as **Varicap** or **Voltcap.**
- Whenapnjunctionisformed,depletionlayeriscreatedinthejunctionarea.
- Sincetherearenochargecarrierswithinthedepletionzone,thezoneactsasan insulator.
- Thep-typematerialwithholes(+ivecharge)asmajoritycarriersandn-typematerialwithelectrons (−ive charge) as majority carriers act as charged plates.
- Thus the diode may be considered as a capacitor with n-region and p-region forming oppositely chargedplates and with depletion zone between them acting as a dielectric.
- Avaractordiodeisspeciallyconstructedtohavehighcapacitanceunderreversebias.
- Thevaluesofcapacitanceofvaractordiodesareinthepico farad (10^{-12} F) range.
- Innormaloperation,avaractordiodeisalwaysreversebiased.
- Thecapacitanceofvaractordiodeisfoundas:



$$C_T = \varepsilon A / W_d$$

Where,

C_T=Totalcapacitanceofthejunction, A= Cross-sectional area of the junction,
ε= Permittivity of the semiconductor material,
Wd = Width of the depletion layer.



- When reverse voltage across a varactor diode is increased, the widthWd of the depletion layer increases. Therefore, the total junction capacitance C_T of the junction decreases.
- Onthe other hand, if thereverse voltage across the diode islowered,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 isusually an A.C. Supply.The supply voltage varies sinusoidal and has a frequency of 50 Hz.It is used for lighting, heating and electric motors.
- But there are many applications (e.g. electronic circuits) where D.C. supply is needed.When such a D.C. Supply is required, the mains A.C. Supply is rectified by using *CrystalDiodes.*
- Thefollowingtworectifiercircuitscanbeused:-
  - (i)Half-waverectifier(ii)Full-waverectifier

HALF-WAVERECTIFIER:-

- In half-wave rectification,the rectifier conducts current only during the positive half-cycles of inputA.C.Supply.
- Thenegativehalf-cyclesofA.C.Supplyissuppressedi.e.duringnegativehalf-cycles,nocurrentisconducted and hence no voltage appears across the load.
- Therefore,currentalwaysflowsinonedirectionthroughtheloadthoughaftereveryhalf-cycle

(InputWaveform) (HalfwaveRectifierCircuit) (Outputvoltagewave)(OutputCurrent)

CircuitDetails:-

- TheaboveFigshowsthecircuitwhereasinglecrystaldiodeactsasahalf-waverectifier.
- TheA.C.SupplytoberectifiedisappliedinserieswiththediodeandloadresistanceR_L.Generally, A.C.Supplyisgiventhroughatransformer.
- The*useoftransformer*permitstwoadvantages.
  - ✓ Firstly,itallowsustostepuporstepdowntheA.C.inputvoltageasthesituationdemands.
  - ✓ Secondly,thetransformerisolatestherectifiercircuitfrompowerlineandthusreducestherisk of electric shock.

OPERATION:-

- TheA.C.voltageacrossthesecondarywindingABchangespolaritiesaftereveryhalf-cycle.
- During the positive half-cycle of input A.C. voltage, end A becomes positive w.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 *pulsatingD.C*. These pulsations in the output are further smoothened with the help of filter circuits discussed later.

Disadvantages: -

(i) Thepulsatingcurrentintheloadcontainsalternatingcomponentwhosebasicfrequencyisequalto thesupply frequency.Therefore,anelaborate filtering isrequiredtoproduce steady directcurrent.

(ii) TheA.C.supplydeliverspoweronlyhalfthetime.Therefore,theoutputislow.

❖ FULL-WAVERECTIFIER:-

- Infull-waverectification,currentflowsthroughtheloadinthesamedirectionforbothhalf-cyclesof input A.C. voltage.This can be achieved with two diodes working alternately.
- Forthepositivehalf-cycleofinputvoltage,onediodesuppliescurrenttotheloadandforthenegative half-cycle, the other diodedoes so ; currentbeing always inthesame directionthrough the load.
- Therefore,afull-waverectifierutilizesbothhalf-cyclesofinputA.C.voltagetoproducetheD.C.output.
- Thefollowingtwocircuitsarecommonlyusedforfull-waverectification:-
  - **(i)**Centre-tapfull-waverectifier **(ii)**Full-wavebridgerectifier

❖ CENTRE-TAPFULL-WAVERECTIFIER:-

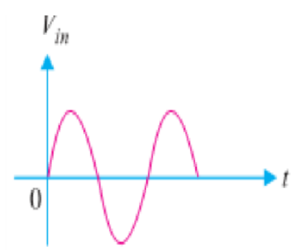
CircuitDetails:-

- ThecircuitemploystwodiodesD_1andD_2asshowninFigbelow.Acentretappedsecondarywinding AB is used with two diodes connected so that eachuses 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.

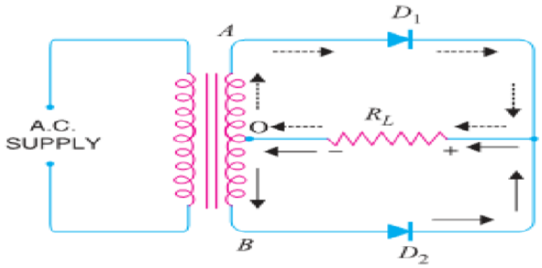
CircuitOperation:-

- Duringthepositivehalf-cycleofsecondaryvoltage,theendAofthesecondarywindingbecomes positiveandendB negative. ThismakesthediodeD_1forwardbiasedanddiodeD_2reverse biased.
- Therefore,diodeD_1conductswhilediodeD_2doesnot.Theconventionalcurrentflowisthroughdiode D_1,loadresistorR_L andtheupperhalfof secondary winding asshownby thedottedarrows.
- Duringthenegativehalf-cycle,endAofthesecondarywindingbecomesnegativeandendBpositive.

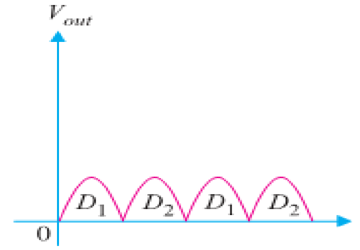
- Therefore,diodeD_2conductswhilediodeD_1doesnot.Theconventionalcurrentflowisthroughdiode D_2, load R_L& lower half winding shown by solid arrows.
- Itmaybeseenthatcurrentintheload$R_L$isinthesamedirectionforbothhalf-cyclesofinputA.C. voltage. Therefore, D.C. is obtained across the load R_L.



(InputWaveform)



(Centre-TapFull-WaveRectifierCircuit)



(Outputwaveform)

Advantages:-

(i) TheD.C.outputvoltageandloadcurrentvaluesaretwicethanthatofahalfwaverectifier.
(ii) Theripplefactorismuchless(0.482)thanthatofhalfrectifier(1.21).
(iii) Theefficiencyistwice(81.2%)thanthatofhalfwaverectifier(40.6%).

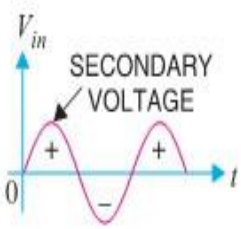
Disadvantages:-

(i) Itisdifficulttolocatethecentretaponthesecondarywinding.
(ii) TheD.C.outputissmallaseachdiodeutilizesonlyone-halfofthetransformersecondaryvoltage.
(iii) Thediodesusedmusthavehighpeakinversevoltage.

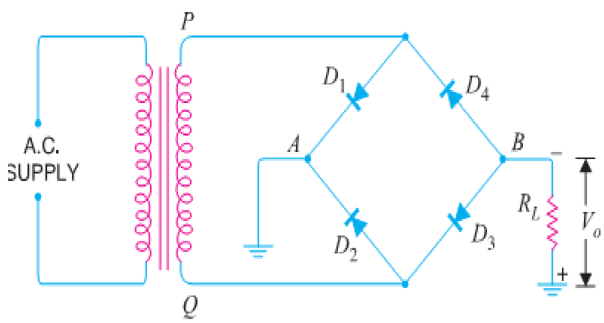
❖ FULL-WAVEBRIDGERECTIFIER:-

CircuitDetails:-

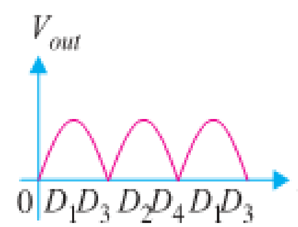
- Theneedforacentretappedpowertransformeriseliminatedinthebridgerectifier.
- ItcontainsfourdiodesD_1,D_2,D_3andD_4connectedtoformbridgeasshowninFigbelow.
- TheA.C.supplytoberectifiedisappliedtothediagonallyoppositeendsofthebridgethroughthe transformer.
- Betweenothertwoendsofthebridge,theloadresistance$R_L$isconnected.



(InputWaveForm)



(Full-WaveBridgeRectifierCircuit)



(Outputwaveform)

CIRCUITOPERATION :-

- During the positive half-cycle of secondary voltage, the end P of the secondary winding becomes positive and end Q negative.
- ThismakesdiodesD_1andD_3forwardbiasedwhilediodesD2andD4arereversebiased.
- Therefore,onlydiodesD_1andD_3conduct.Thesetwodiodeswillbeinseriesthroughtheload$R_L$as showninFig.below.Theconventionalcurrentflowisshownbydottedarrows.Itmaybeseenthat 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,onlydiodesD_2andD_4conduct.Thesetwodiodeswillbeinseriesthroughtheload$R_L$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.

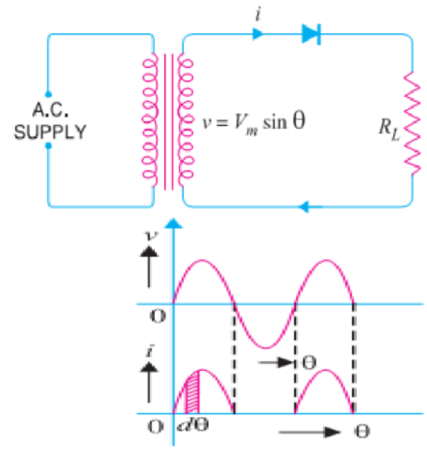
(Full-WaveBridgeRectifierCircuitin+veHalfCycle)(Full-WaveBridgeRectifierCircuit-veHalfCycle)

- **Advantages:-**
  (i) Theneedforcentre-tappedtransformeriseliminated.
  (ii) Theoutputistwicethatofthecentre-tapcircuitforthesamesecondaryvoltage.
  (iii) ThePIVisone-halfthatofthecentre-tapcircuit(forsameD.C.output).
- **Disadvantages:-**
  (i) Itrequiresfourdiodes.(ii)Internalresistanceshigh.

MathematicalDerivationforRectificationEfficiencyforHALFWAVErectifier:-

Theratioofd.c.poweroutputtotheappliedinputa.c.powerisknownasrectifierefficiencyi.e.,

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



Considerahalf-waverectifiershowninFig.

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.

Thediodeconductsduringpositivehalf-cyclesofa.c.supplywhile no current conduction takes place during negative half-cycles.

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

Theoutputcurrentispulsatingdirectcurrent.Therefore,inordertofind D.C.power,averagecurrenthastobefoundout.

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

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

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

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

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

The A.C. power input is given by : $P_{ac} = I_{rms}^2 (rf + R_L)$For a half-wave rectified wave,$\mathbf{I_{rms} = I_m/2}$ $\mathbf{P_{ac}} =$

∴ $\left(\frac{I_m}{2}\right)^2 \times (rf + R_L)$

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

Theefficiencywillbemaximumif$r_f$isnegligibleascomparedtoR_L.

∴ **Max.RectifierEfficiencyforHALFWAVERectifier=40.6%**

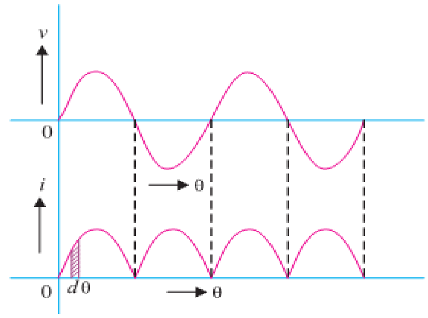
Itshowsthatinhalf-waverectification,amaximumof40.6%ofa.c.powerisconvertedintod.c.power.

NOTE:-$I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i^2\, d\theta\right]^{½} = \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\theta\, d\theta + \frac{1}{2\pi}\int_{\pi}^{2\pi} 0\, d\theta\right]^{½} = \left[\frac{I_m^2}{2\pi}\int_0^{\pi}\frac{1-\cos 2\theta}{2} d\theta\right]^{½}$

$$= \left[\frac{I_m^2}{4\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}\right]^{½} = \left[\frac{I_m^2}{4\pi}\left[\pi - 0 - \frac{\sin 2\pi}{2} + \sin 0\right]\right]^{½} = \left[\frac{I_m^2}{4\pi} \times \pi\right]^{½} = \left[\frac{I_m^2}{4}\right]^{½} = \frac{I_m}{2} \Rightarrow \mathbf{I_{rms}} = \frac{I_m}{2}$$

Similarlly,$\mathbf{V_{rms} = V_m/2}$forHalfWaveandForFullWaveRectifier$\mathbf{I_{rms} = I_m/\sqrt{2}}$and $\mathbf{V_{rms} = V_m/\sqrt{2}}$

Mathematical Derivation for Rectification Efficiency for FULL WAVE Rectifier:-



- Fig. shows the process of full-wave rectification.
- Let $v = V_m \sin\theta$ be the a.c. voltage to be rectified. Let rf and R_L be the 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. OUTPUT POWER.

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

❖ A.C. INPUT POWER.

- The a.c. input power is given by:

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

For a full-wave rectified wave, we have, $I_{rms} = I_m/\sqrt{2}$

∴ $P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (rf + R_L)$

∴ Full-wave rectification efficiency is

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

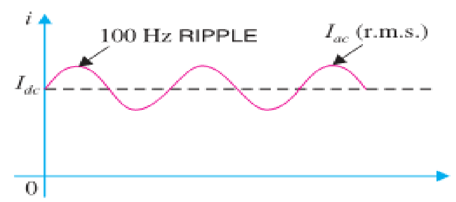
The efficiency will be maximum if r_f is negligible as compared to R_L.

∴ Maximum efficiency = 81.2%

- This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier.

RIPPLE FACTOR:-

- The output of a rectifier consists of a d.c. component and an a.c. component (also known as ripple).
- The a.c. component is undesirable and accounts for the pulsations in the rectifier output.
- The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output; the smaller this component, the more effective is the rectifier.
- Ripple mean unwanted ac signal present in the rectified output.



- The ratio of R.M.S. value of A.C. component to the D.C. component in the rectifier output is known as *ripple factor* i.e.

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

❖ Mathematical Analysis.

- The output current of a rectifier contains d.c. as well as a.c. component.
- By definition, the effective (i.e. r.m.s.) value of total load current is given by :

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2} \quad \text{Or} \quad I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

- Dividing throughout by I_{dc}, we get,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2}$$ (But I_{ac}/I_{dc} is the ripple factor.)

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

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

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

∴ Ripplefactor= $\sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2-1}$ =1.21.21

- Itisclearthata.c.componentexceedsthed.c.componentintheoutputofahalf-waverectifier.
- Thisresultsingreaterpulsationsintheoutput.
- Therefore,half-waverectifierisineffectiveforconversionofa.c.intod.c.

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

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

∴ Ripplefactor= $\sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2-1}$ =0.48.48 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-waverectificationisinvariablyusedforconversionofa.c.intod.c.

PeakInverseVoltage(PIV):-

- Themaximumvalueofreversevoltageoccursatthepeakoftheinputcycle,whichisequaltoV$_m$.
- Thismaximumreversevoltageiscalledpeakinversevoltage(PIV).ThusthePIVofdiode:-

a)For Half Wave = V_m,, **b)**For Center Tapped =2$V_m$and **c)** For Bridge Rectifier = V_m.

TransformerUtilizationFactor(TUF):-

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

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

- Forhalfwaverectifier,TUF=**0.287**;Centertapedrectifier,TUF=**0.693**;Bridgerectifier,TUF=**0.812**.
- TheTUFisveryusefulindeterminingtheratingofatransformertobeusedwithrectifiercircuit.

AverageValueofVoltage&CurrentforHALFWAVERectifiers:-

- IfV$_m$=Maximumvalueofthea.c.inputvoltage,thentheaverageord.c.valueoftheoutputvoltageand current is given by

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

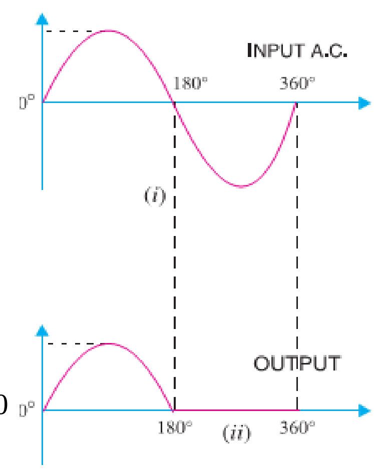
AverageValueofVoltage&CurrentforFULLWAVERectifiers:-

- IfV$_m$=Maximumvalueofthea.c.inputvoltage,thentheaverageord.c.valueoftheoutputvoltageand current is given by

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

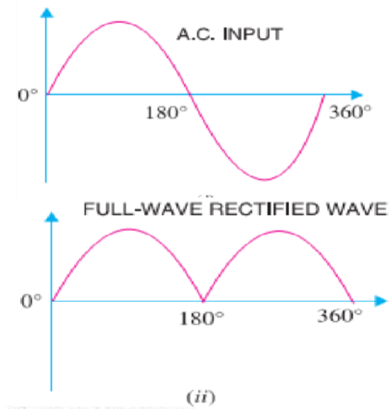
OutputFrequencyofHalfWaveRectifier:-

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



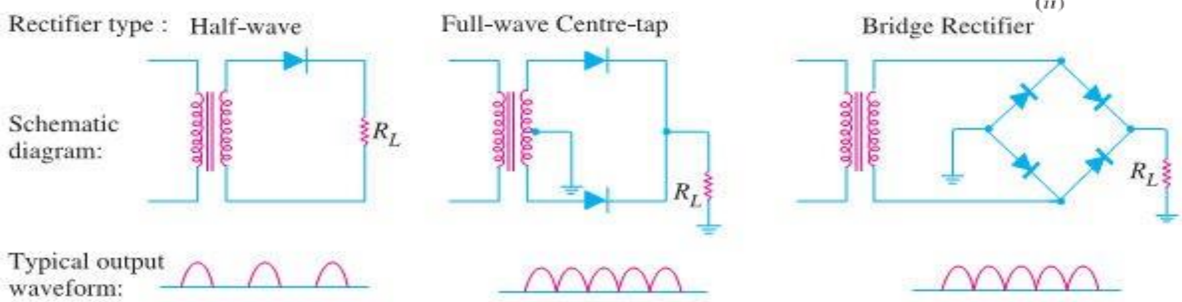
- Awaveformhasacompletecyclewhenitrepeatsthesamewavepattern over a given time.
- ThusinFig.(i),thea.c.inputvoltagerepeatsthesamewavepatternover 0° – 360°, 360° – 720° and so on.
- InFig.(ii),theoutputwaveformalsorepeatsthesamewavepatternover 0° – 360°, 360° – 720° and so on.
- This means that when input a.c. completes one cycle, the output half waverectified wave also completes one cycle.
- Inotherwords,for thehalfwaverectifiertheoutputfrequency isequalto the input frequency i.e. **$f_{out}=f_{in}$**
- Forexample,iftheinputfrequencyofsinewaveappliedtoahalf-wave rectifier is 100 Hz, then frequency of the output wave will also be 100 Hz.

Output Frequency of Full Wave Rectifier:-



- The output frequency of a full-wave rectifier is double the input frequency.
- As a wave has a complete cycle when it repeats the same pattern.
- In Fig. (i), the input a.c. completes one cycle from 0°–360°.
- However, in Fig. (ii) full-wave rectified wave completes two cycles in this period.
- Therefore, output frequency is twice the input frequency i.e. $\mathbf{f_{out}=2f_{in}}$
- For example, if the input frequency to a full-wave rectifier is 100Hz, then the output frequency will be 200 Hz.

- **COMPARISON OF RECTIFIERS:-**



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}	$2\,f_{in}$	$2\,f_{in}$
6	Peak inverse voltage	V_m	$2\,V_m$	V_m

- **FILTER CIRCUITS:-**

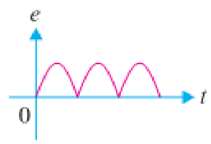
- Generally, a rectifier is required to produce pure D.C. supply for using at various places in the electronic circuits.
- However, the output of a rectifier has pulsating character i.e. it contains A.C. and D.C. components.
- The A.C. component is undesirable and must be kept away from the load.
- To do so, a filter circuit is used which removes (or filters out) the A.C. component and allows only the D.C. component to reach the load.
- A **filter circuit** is a device which removes the A.C. component of rectifier output but allows the D.C. component to reach the load.
- A filter circuit is generally a combination of inductors (L) and capacitors (C).
- The filtering action of L and C depends upon the basic electrical principles.
- A capacitor offers infinite reactance to d.c.
- We Know that $X_C=1/2\pi fC$. But for D.C., f=0.

  $\therefore X_C=1/2\pi fC=1/2\pi x0xC=\infty$ (Means Capacitor shows *infinite reactance* to DC)

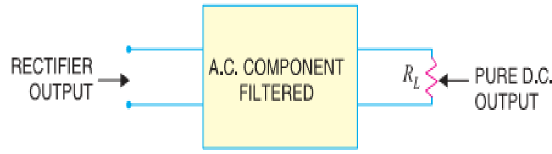
  - ***Hence, a Capacitor does not allow d.c. to pass through it.***
- We know $X_L=2\pi fL$. For d.c., f=0

  $\therefore$ $X_L=2\pi x0xL=0$ (Means Inductor shows *zero reactance* to DC)

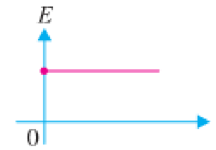
  - ***Hence Inductor passes d.c. quite readily.***
- *A Capacitor passes A.C. but does not pass D.C. at all. On the other hand, an Inductor opposes A.C. but allows D.C. to pass through.*
- It then becomes clear that suitable network of L and C can effectively remove the A.C. component, allowing the D.C. component to reach the load.



(PulsatingD.C)



(FilterCircuit)



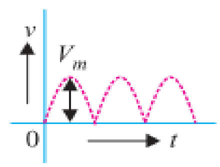
(PureD.C)

- **TypesOfFilterCircuits:-**

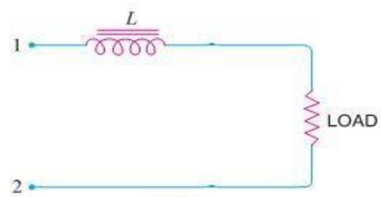
Therearedifferenttypesoffiltercircuitsaccordingtotheirconstruction.Themostcommonly usedfilter circuits are :
-

- *InductiveFilterorSeriesInductor*,
- *CapacitorFilterorShuntCapacitor*,
- *ChokeInputFilterorLCFilter*and
- *CapacitorInputFilterorπ-Filter*.

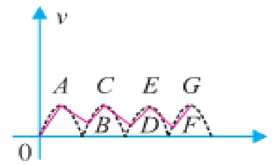
✓ **InductiveFilterOrSeriesInductor:-**



(RectifiedoutputPulsatingd.c)



(InductiveFilterCircuit)



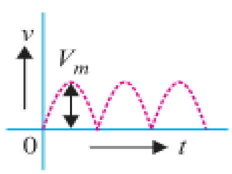
(OutputofInductiveFilter)

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

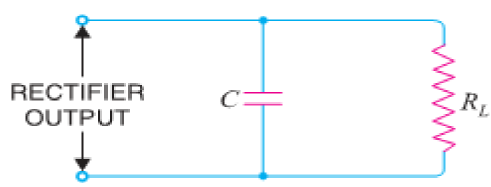
Thechoke(Inductorwithironcore)offershighoppositiontothepassageofa.c.componentbutno opposition to the d.c. component.

Theresultisthatmostofthea.c.componentappearsacrossthechokewhilewholeofd.c.component passesthroughthechokeonitsway toload.ThisresultsinthereducedpulsationsatLoadresistanceR_L.

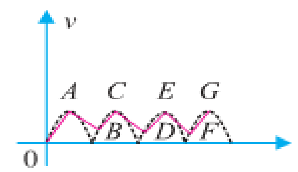
✓ **CapacitorFilterOrShuntCapacitor:-**



(RectifiedoutputPulsatingd.c)



(CapacitorFilterCircuit)



(OutputofCapacitorFilter)

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)],thecapacitorischargedtothepeakvalue$V_m$ofthe rectifier voltage.

Now, the rectifier voltage starts todecrease. As this occurs, the capacitordischarges through the load andvoltage across it decreases as shown by the line AB in Fig. (iii).

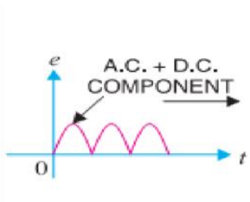
The voltage acrossload willdecrease only slightly because immediately the next voltage peak comes andrecharges the capacitor.

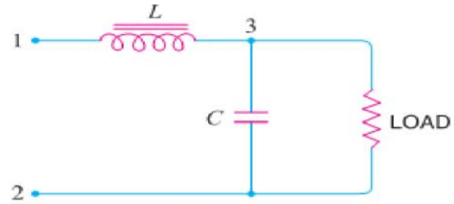
ThisprocessisrepeatedagainandagainandtheoutputvoltagewaveformbecomesABCDEFG.Itmay be seen that very little ripple is left in the output.

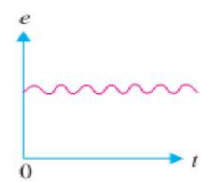
Moreover,outputvoltageishigherasitremainssubstantiallynearthepeakvalueofrectifieroutput voltage.

Thecapacitorfiltercircuitisextremely popularbecauseofitslowcost,smallsize, littleweightandgood characteristics.

✓ **ChokeInputFilterOrLCFilter:-**



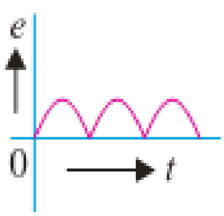


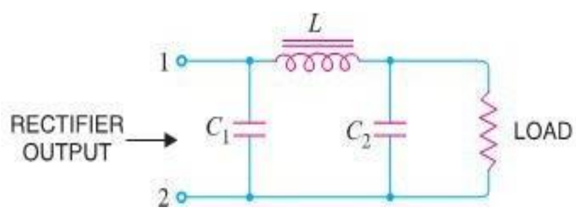


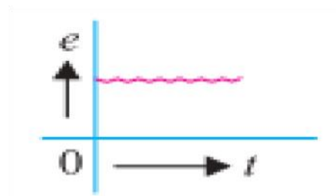
(RectifiedoutputPulsatingd.c) (ChokeInputFilterCircuit) (OutputofChokeInputFilter)

- Fig.showsatypicalchokeinputfiltercircuit.ItconsistsofachokeLconnectedinserieswiththerectifier output and a filter capacitor C across the load.
- Onlyasinglefiltersectionisshown,butseveralidenticalsectionsareoftenusedtoreducethepulsations as effectively as possible.
- Thepulsatingoutputoftherectifierisappliedacrossterminals1and2ofthefiltercircuit.
- Asdiscussedbefore,thepulsatingoutputofrectifiercontainsa.c.andd.c.components.Thechokeoffers high oppositionto the passage of a.c. componentbut negligibleoppositionto thed.c. component.
- Theresultisthatmostofthea.c.componentappearsacrossthechokewhilewholeofd.c.component passes through the chokeonitsway to load. This results in thereduced pulsations atterminal3.
- Atterminal3,therectifieroutputcontainsd.c.componentandtheremainingpartofa.c.component which has managed to pass through the choke.
- Now, the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component toflow through it. Therefore, only d.c. component reaches the load.
- Inthisway,thefiltercircuithasfilteredoutthea.c.componentfromtherectifieroutput,allowingd.c. component to reach the load.

✓ **CapacitorInputFilterorπ-Filter:-**







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

- Fig.showsatypicalcapacitorinputfilterorπ-filter.ItconsistsofafiltercapacitorC_1 connectedacross the rectifier output, achokeLinseries andanotherfilter capacitor C_2connected across theload.
- Only one filter section is shown but several identical sections are often used to improve the smoothing action.Thepulsatingoutputfromtherectifierisappliedacrosstheinputterminals(i.e.terminals1&2) of the filter.
- ThefilteringactionofthethreecomponentsvizC_1,LandC_2ofthisfilterisdescribedbelow:

  (a) The **filtercapacitorC_1**offers lowreactance toa.c.componentof rectifier outputwhile itoffers 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, it allows the d.c. component to flow through it, while the un bypassed a.c. component is blocked.

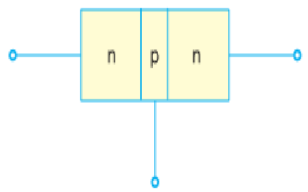
  (c) The **filtercapacitorC_2** bypasses the a.c. component which the choke has failed to block. Therefore, only d.c. component appears across the load and that is what we desire

[CHAPTER–2]

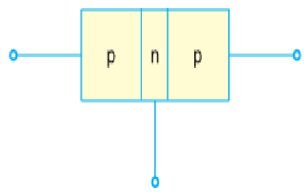
--------------------------[TRANSISTORSANDCIRCUITANALYSIS]------------------------

❖ INTRODUCTION:-

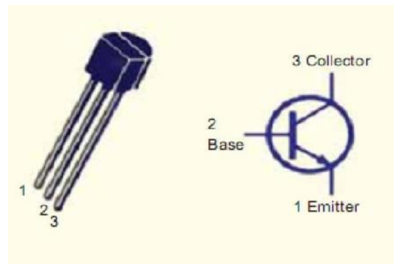
- WhenathirddopedelementisaddedtoacrystaldiodeinsuchawaythattwoPNjunctionsareformed, the resulting device is known as a **Transistor**.
- Thisisa new typeofelectronics devicewhichcanable toamplify a weaksignalinafashioncomparable and often superior to that realized by vacuum tubes.
- AtransistorconsistsoftwoPNjunctionsformedbysandwichingeitherp-typeorn-typesemiconductor between a pair of opposite types. Hence Transistor is classified into two types, namely:-
  - **(i)**n-p-ntransistor**(ii)**p-n-ptransistor
- Ann-p-ntransistoriscomposedoftwon-typesemiconductorsseparatedbyathinsectionofp-type.
- However, a p-n-ptransistorisformedby twop-sectionsseparatedby a thinsectionofn-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.

❖ NAMINGTHETRANSISTORTERMINALS:-

- Atransistor(PNPorNPN)hasthreesectionsofdopedsemiconductors.
- Thesectiononone sideisthe**emitter**andthesectionontheoppositesideisthe**collector**.
- Themiddlesectioniscalledthe**base**andformstwojunctionsbetweentheemitterandcollector.

(i)Emitter:-

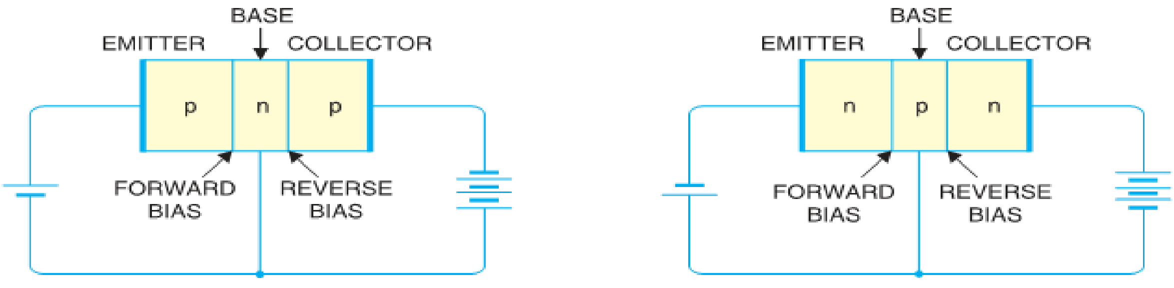
- Thesectiononone sidethat*supplieschargecarriers*(electronsorholes)iscalledtheemitter.
- Theemitterisalwaysforwardbiasedw.r.t.basesothatitcansupplyalargenumberofmajoritycarriers.
- Theemitter(p-type)ofPNPtransistorisforwardbiasedandsuppliesholechargestoitsjunctionwith thebase.Similarlytheemitter(n-type)ofNPNtransistorhasaforwardbiasandsuppliesfreeelectrons 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 outputcircuit.Similarly thecollector(n-type) ofNPNtransistorhasreversebias& receiveselectrons.

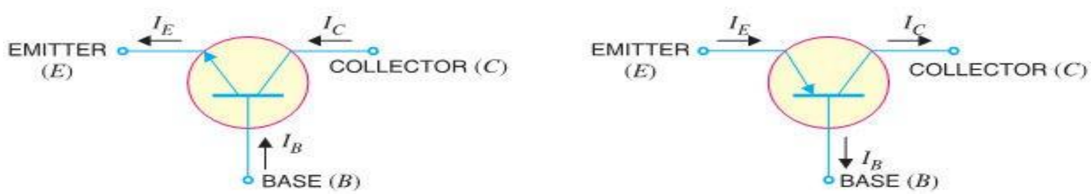
(iii)Base:-

- ThemiddlesectionwhichformstwoPN-junctionsbetweenemitter&collectoriscalledbase.
- Thebase-emitterjunctionisforwardbiased,allowinglowresistancefortheemittercircuit.
- Thebase-collectorjunctionisreversebiasedandprovideshighresistanceinthecollectorcircuit.



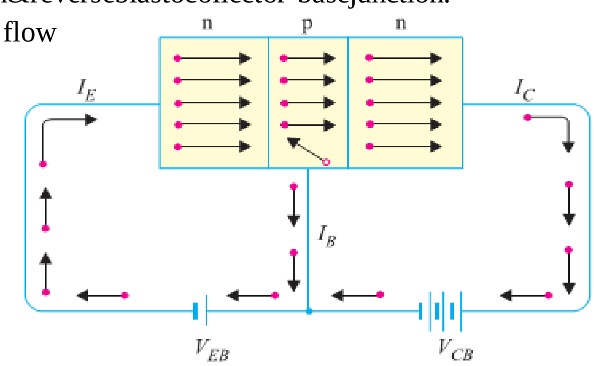
(i) (ii)

❖ **TRANSISTORSYMBOL:-**



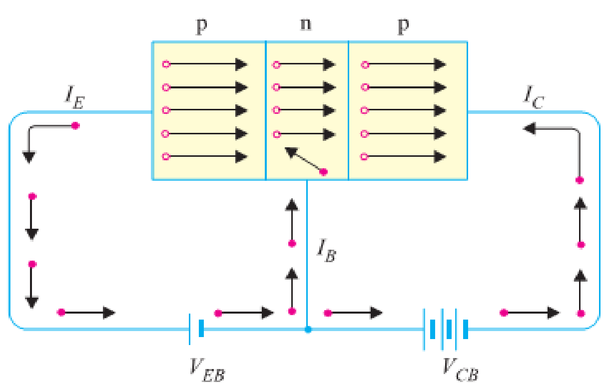
(i) (ii)

❖ **WORKINGOFNPNTRANSISTOR(NPN):-**



- TheNPNtransistorwithforwardbiastoemitter-basejunction&reversebiastocollector-basejunction.
- Theforwardbiascausestheelectronsinthen-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 lightly doped and very thin, 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,almosttheentireemittercurrentflowsinthecollectorcircuit.
- Itisclearthatemittercurrentisthesumofcollectorandbasecurrentsi.e.**$I_E=I_B+I_C$**

❖ **WORKINGOFPNPTRANSISTOR(PNP):-**



- Fig.showsthebasicconnectionofaPNPtransistor.
- Theforwardbiascausestheholesinthep-type emitter 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 lightly doped and very thin, therefore, only a few holes (less than 5%) combine with the electrons. The remainder (more than 95%) cross into the collector region to constitute collector current I_C.
- Inthisway,almosttheentireemittercurrentflowsinthecollectorcircuit.
- 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

❖ TRANSISTORCONNECTIONS:-

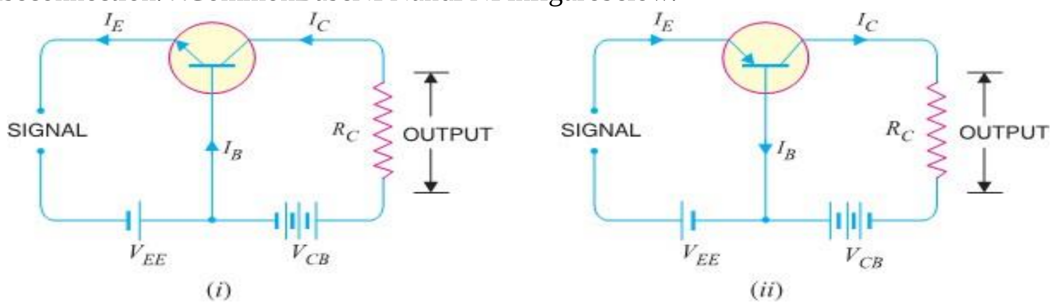
- Therearethreeleadsinatransistorsuchasemitter,baseandcollectorterminals.
- However,whenatransistoristobeconnectedinacircuit,werequire**fourterminals**;twofortheinput and two for the output.
- Thisdifficultyisovercomebymakingoneterminalofitincommontobothinputandoutputterminals.
- Theinputisfedbetweenthiscommonterminalandoneoftheothertwoterminals.
- Theoutputisobtainedbetweenthecommonterminalandtheremainingterminal.
- Soatransistorcanbeconnectedinacircuitinthefollowingways:-

(i) CommonBaseconnection(**ii**)CommonEmitterconnection(**iii**)CommonCollectorconnection

(i)CommonBaseConnection

Inthiscircuitarrangement,inputisappliedbetweenemitterandbaseandoutputistakenfrom collector and base.

Here,baseofthetransistoriscommontobothinputandoutputcircuitsandhencethename **C**ommon**B**aseconnection. ACommonBaseNPNandPNPinfigurebelow.

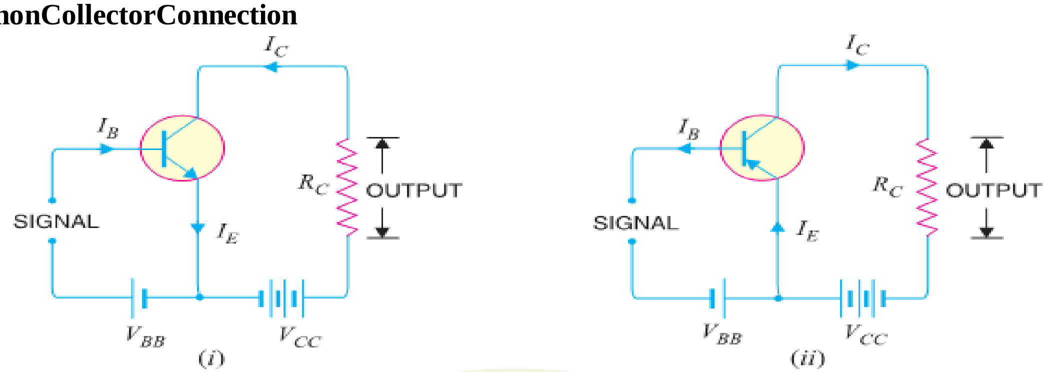


(ii) CommonEmitterConnection

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

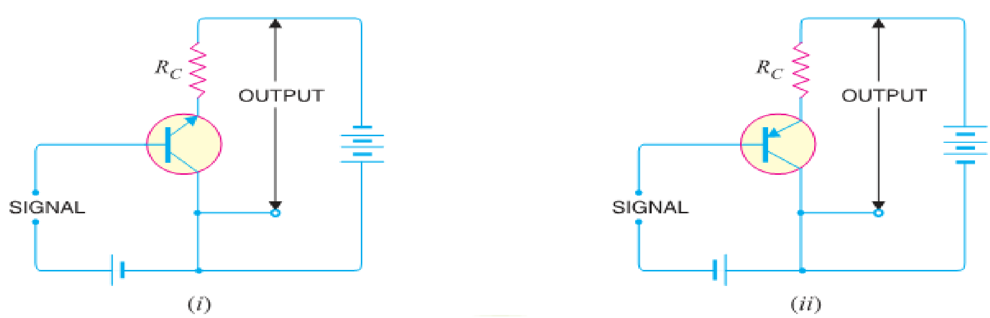
Here, emitter of the transistor is common to both input and output circuits and hence the name **C**ommon**E**mitter connection.ACommonEmitter NPNand PNPtransistorcircuitisshowninfigure below.

(iii) CommonCollectorConnection



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

Here,collectorofthetransistoriscommontobothinputandoutputcircuitsandhencethename **C**ommon**C**ollectorconnection.ACommonCollectorNPNandPNPinfigurebelow.

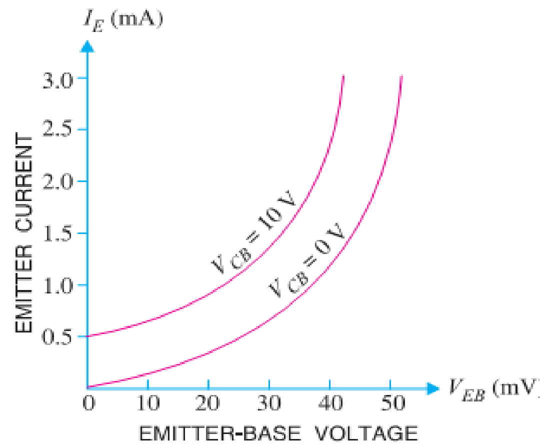


❖ TRANSISTORCHARACTERISTICS:-

1) CharacteristicsofCommonBaseConnection

- The complete electrical behavior of a transistor can be described by stating the interrelation of the variouscurrents and voltages.
- Theserelationshipscanbeconveniently displayedgraphically andthecurvesthusobtainedareknownas the characteristics of transistor.
- Themostimportantcharacteristicsofcommonbaseconnectionare**inputcharacteristics**and**outputcharacteristics**.

A) **InputCharacteristics:-**



- It is the curve between emitter current $\mathbf{I_E}$& emitter-base voltage $\mathbf{V_{BE}}$ at constant collector-base voltage $\mathbf{V_{CB}}$.
- 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 thatinput resistance is very small.
  - ♣ The emitter current is almost independent of collector-basevoltageV_{CB}.Thisleadstotheconclusionthat emittercurrent(andhencecollectorcurrent)isalmostindependentofcollectorvoltage.

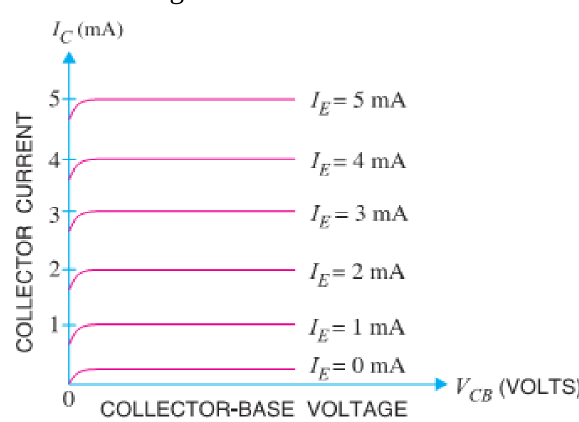
- **InputResistance:-** It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change inemitter current (ΔI_E) at constant collector-base voltage (V_{CB}) i.e.

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

- Infact,inputresistanceistheoppositionofferedtothesignalcurrent. Asavery smallV_{EB}issufficient to producealargeflowofemittercurrentI_E,thus,inputresistanceisquitesmall,oftheorderofafewohms.

B) **OutputCharacteristics:-**

- Itisthecurvebetweencollectorcurrent$\mathbf{I_C}$&collector-basevoltage$\mathbf{V_{BC}}$atconstantemittercurrent$\mathbf{I_E}$.
- Generally,collectorcurrentistakenalongy-axisandcollector-basevoltagealongx-axis.
- Thefig.showstheinputandoutputcharacteristicsofatypicaltransistorinCBarrangement.
- Thefollowingpointsmaybenotedfromcharacteristics:



  - ♣ 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 independentofV_{CB} anddependsuponI_E only.This is 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 producesonlyatinychangeincollectorcurrent.Thismeansthatoutputresistanceisveryhigh.

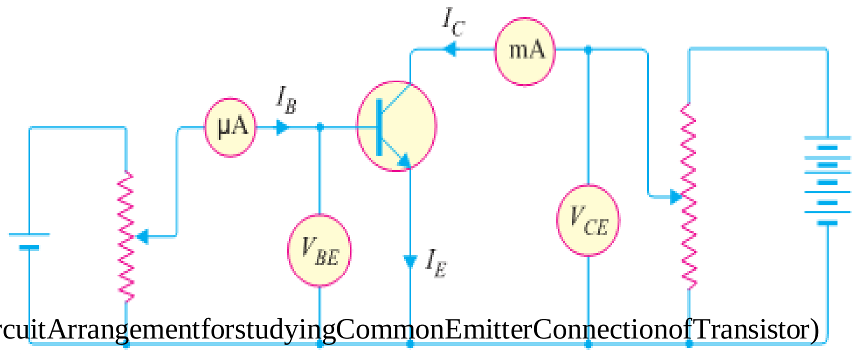
- **OutputResistance**: - It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current i.e.

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

- TheoutputresistanceofCBcircuitisveryhigh,oftheorderofseveraltensofkilo-ohms.

2) Characteristics of Common Emitter Connection:-

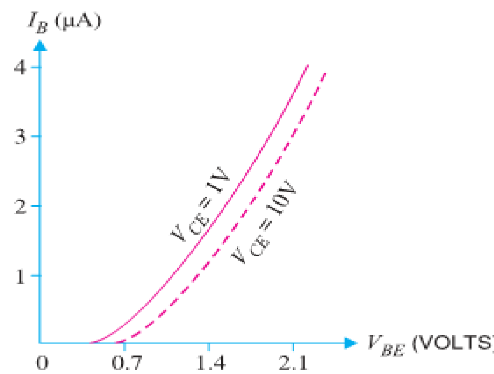
- The important characteristics of this circuit arrangement are the input characteristic and output characteristic.



(Circuit Arrangement for studying Common Emitter Connection of Transistor)

A) **Input Characteristics:-**

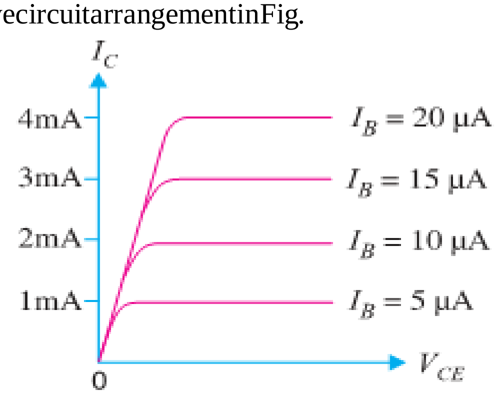
- It is the curve between base current IB & base-emitter voltage VBE at constant collector-emitter volt V_{CE}. The input characteristics of a CE connection can be determined by the circuit shown in Fig. Keeping V_{CE} constant (Let 10 V), note the base current I_B for various values of V_{BE}.



- 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.
- The following points may be noted from the characteristics:
  - The characteristic resembles that of a forward biased diode curve. This is expected since the base-emitter section of transistor is a diode and it is forward biased.
  - As compared to CB arrangement, I_B increases less rapidly with V_{BE}. Therefore, input resistance of a CE circuit is higher than that of CB circuit.
- **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) **Output Characteristics:-**

- It is the curve between collector current **I_C** and collector-emitter voltage **V_{CE}** at constant base current **I_B**.
- The output characteristics of CE circuit can be drawn with the help of above circuit arrangement in Fig.
- Keeping the base current I_B fixed at some value say, 5µA, 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 similar procedure, a family of output characteristics can be drawn as shown in Fig.
- The following points may be noted from the characteristics:
  - (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 called the 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 any value of V_{CE} above knee voltage, the collector current I_C is approximately equal 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_B i.e.

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

- Itmay benotedthatwhereastheoutputcharacteristicsofCBcircuitarehorizontal,they havenoticeable slope for the CE circuit.
- Therefore,outputresistanceofCEcircuitislessthanthatofCBcircuit.Itsvalueisoftheorderof50kΩ.

3) CharacteristicsofCommonCollectorConnection:-

- InaCommonCollectorcircuitconnectiontheloadresistorconnectedfromemittertoground,sothe collectortiedtogroundeventhoughthetransistorisconnectedinamannersimilartotheCEconnection.
- Hencethereisnoneedforasetofcommon-collectorcharacteristictochoosetheparametersofthecircuit. The output characteristic of the CC configuration is same as CE configuration.
- ForCCConnectiontheoutputcharacteristicareplotof**$I_E$versusV_{CE}**foraconstantvalueof**I_B**.
- Thereisanalmostunnoticeable changeintheverticalscaleof$I_C$oftheCE connectionif$I_C$isreplacedby I_E for CC connection. The input circuit of CC connection, the CE characteristic is sufficient to obtain the required information.
- HenceCommonCollectorcircuitconnectionisknownas**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).**

- 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,itsvaluerangesfrom20to500.

3) CommonCollectorConnection:-

In a common collector connection, the input current is the Emitter Current **I_B** and output current is the Emitter Current **I_E**.

Hencetheratioofchangeinemittercurrenttothechangeinbasecurrentat constantV_{CC}isknownascurrentamplificationfactorforCCConnectionandis denoted as γ **(Gamma).**

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

- Thiscircuitprovidesaboutthesamecurrentgainasthecommonemittercircuitas$\Delta I_E \approx \Delta I_C$.

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, $\beta = \frac{\alpha}{1-\alpha} = \alpha \times \frac{1}{1-\alpha} = \alpha \times \gamma$

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

$$\therefore \alpha = \frac{\beta}{1+\beta}$$

$$\therefore \beta = \frac{\alpha}{1-\alpha}$$

$$\therefore \gamma = \frac{1}{1-\alpha}$$

$$\therefore \quad \gamma - 1$$

$$\therefore \gamma = 1 + \beta$$

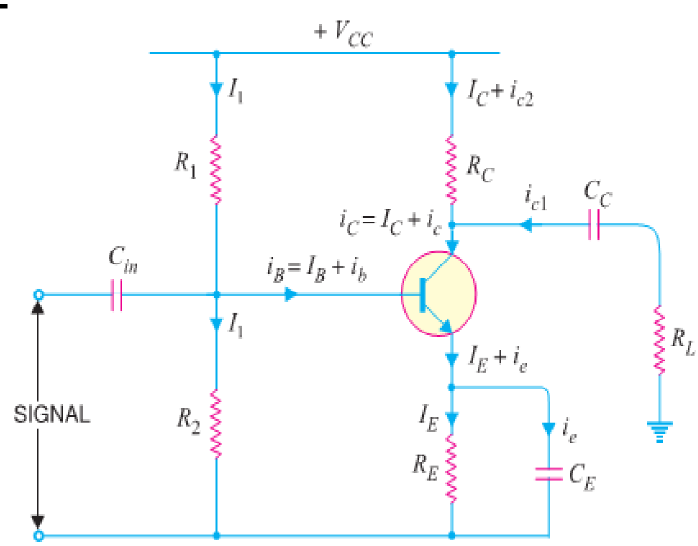
$$\therefore \beta = \gamma + 1$$

♣ **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**CommonEmitterCircuit**isthemostefficient.
- ♣ Itisusedinabout90to95percentofalltransistorapplications.
- ♣ Themainreasonsforthewidespreaduseofthiscircuitarrangementare: (i)Highcurrentgain. (ii)Highvoltageandpowergain.(iii)Moderateoutputtoinputimpedanceratio.

❖ D.C.ANDA.C.EQUIVALENTCIRCUITS:-



Various circuit currents. It is useful to mention the various currents in the complete amplifier circuit. These are shown in the circuit of Fig.

(i)BaseCurrent:- 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, with the application of signal, Total Base Current i_B is given by:$\mathbf{i_B=I_B+i_b}$

(ii)CollectorCurrent:- When no signal is applied, a D.C.collectorcurrentI_C flows due tobiasingcircuit.WhenA.C.signalisapplied, 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$i_c=\beta i_b$=collectorcurrentduetosignal.

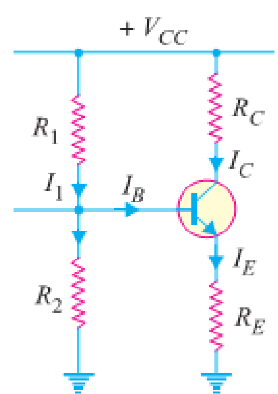
(iii)EmitterCurrent:-Whennosignalisapplied,aD.C.emittercurrent$I_E$flows.WhenA.C.signalis applied, A.C.Emitter Current $i_e$also flows. Therefore the TotalEmitter Currentis :- $\mathbf{i_E=I_E+i_e}$

Itisusefultokeepinmindthat:$I_E=I_B+I_C$and$i_e=i_b+i_c$.

Butbasecurrentisusuallyverysmall,therefore,asareasonableapproximation,$I_E \approx I_C$and$i_e \approx i_c$.

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

(a) ReduceallA.C.sourcestozero.
(b) Openallthecapacitors.



ReferringD.C.EquivalentCircuit

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

ThemaximumvalueofV_{CE}willoccurwhenthereisnocollectorcurrenti.e.I_C=0.

∴ **Maximum$V_{CE}=V_{CC}$**

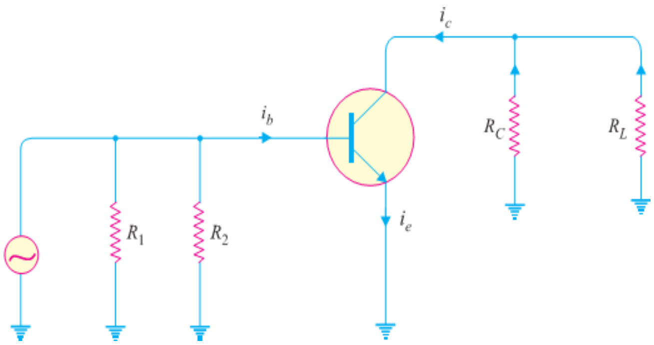
ThemaximumcollectorcurrentwillflowwhenV_{CE}=0.

∴ **Maximum$I_C=V_{CC}/(R_C+R_E)$**

❖ **A.C.EquivalentCircuit:-** In order to draw A.C. equivalent circuit, the following two steps are applied to the transistor circuit:

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

(b) Shortallthecapacitors.



Referring A.C. Equivalent circuit A.C. load equalto $R_C \| R_L$ i.e.

A.C.load,$\mathbf{R_{AC}=(R_C R_L/(R_C+R_L)}$

MaximumpositiveswingofA.C.collector- emitter voltage = $I_C \times R_{AC}$

∴ Totalmaximum**collector-emittervoltage,**$\mathbf{V_{CEMAX}=V_{CE}+I_C R_{AC}}$

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

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

❖ LOADLINEANALYSIS:-

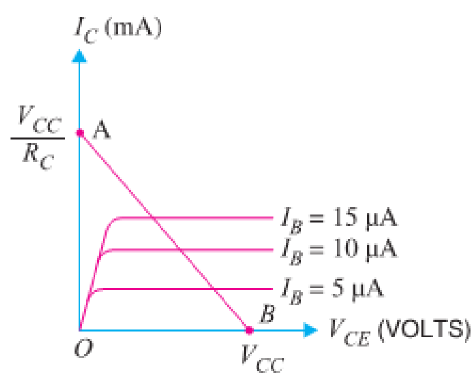
In the transistor circuit analysis, it is generally required to determine the collector current for various collector-emitter voltages.

Oneofthemethodscanbeusedtoplottheoutputcharacteristicsanddeterminethecollectorcurrentat any desiredcollector-emittervoltage.However,amoreconvenientmethod,knownas**loadlinemethod** can be used to solve such problems.

Thismethodisquiteeasyandisfrequentlyusedintheanalysisoftransistorapplications.

♣ **D.C.LOADLINE**:- Itisthe line onthe outputcharacteristics of a transistor circuitwhich 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 areshowninFig.



ThevalueofcollectorVemittervoltageV_{CE}atanytimeisgiven by ;

$V_{CE}= V_{CC}– I_C R_C$ Or $I_C R_C= V_{CC}- V_{CE}$

Or $I_C=V_{CC}/R_C-V_{CE}/ R_C$

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

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

Toaddloadline,weneedtwoendpointsofthestraightline. Thesetwopointscanbelocatedasunder:

(i) WhenthecollectorcurrentI_C=0,thencollector-emittervoltageismaximumandisequaltoV_{CC}

i.e. Max.$V_{CE}=V_{CC}–I_C R_C=V_{CC}$(As$I_C$=0)

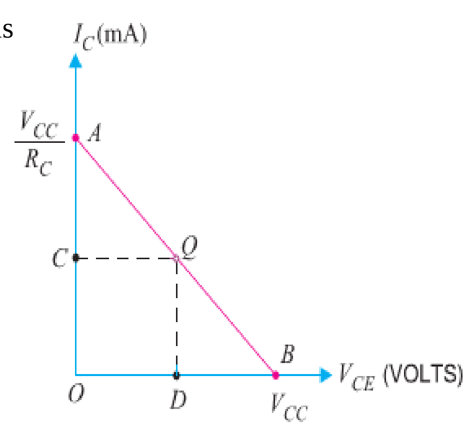
ThisgivesthefirstpointB(OB=V_{CC})onthecollector-emitter voltage axis as shown in Fig.

(ii) Whencollector-emittervoltageV_{CE} =0,thecollectorcurrent is maximum and is equal to V_{CC}/R_C

i.e. $V_{CE}=V_{CC}−I_C R_C$ or $0=V_{CC}−I_C R_C$

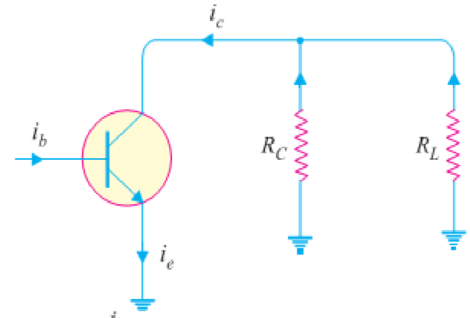
∴ Max.$I_C=V_{CC}/R_C$

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

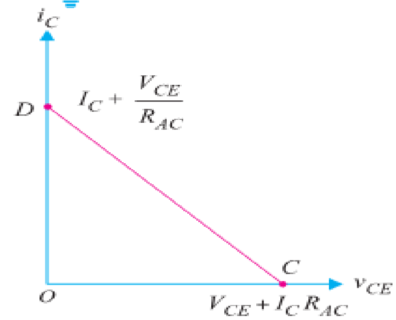


Byjoiningthesetwopoints,**D.C.LoadLine**ABisconstructed.

- **(II)A.C.LOADLINE.**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.



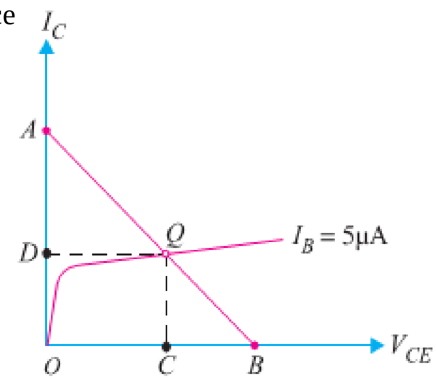
- Referring back to the transistor amplifier shown in Fig., its A.C. equivalentcircuitasfarasoutputcircuitisconcernedisas shown in Fig.
- To add A.C. load line to the output characteristics, we againrequire two end points: –
  1. Onemaximumcollector-emittervoltagepoint**(V_{CEMAX})**and
  2. Otherismaximumcollectorcurrentpoint.**(I_{CMAX})**
- Under the application of A.C. signal, these values are Maximum collector-emitter voltage, $\mathbf{V_{CEMAX}=V_{CE}+I_CR_{AC}}$.



- ThislocatesthepointCoftheA.C.loadlineonthecollector-emitter voltage axis.
- Maximumcollectorcurrent,$\mathbf{I_{CMAX}=I_C+V_{CE}/R_{AC}}$
- ThislocatesthepointDofA.C.loadlineonthecollector-currentaxis.
- ByjoiningpointsCandD,the**A.C.LoadLine**CDisconstructed.

❖ OPERATINGPOINT:-

- ThezerosignalvaluesofI$_C$andV$_{CE}$areknownasthe**Operatingpoint**.
- It is called operating point because the variations of I_C and V_{CE} take place about this point when signal is applied.
- It is also called quiescent (silent) point or **Q-Point** because it is the pointonI_C–V_{CE}characteristicwhenthetransistorissilenti.e.in the absence of the signal.
- Suppose in the absence of signal, the base current is 5μA. Then I_C andV_{CE}conditionsinthecircuitmustberepresentedbysome point on I_B = 5 μA characteristic.
- But$I_C$andV_{CE} conditionsinthe circuitshouldalsobe represented by some point on the d. c. load line AB.



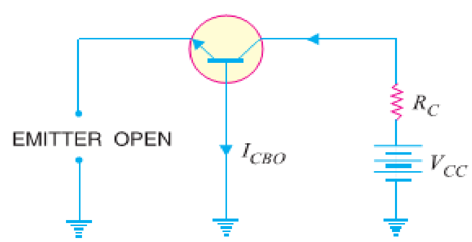
- ThepointQwheretheloadlineandthecharacteristicintersectis theonlypointwhichsatisfiesboththeseconditions.Therefore,thepointQdescribestheactualstateof affairsinthecircuitinthezerosignalconditionsandiscalledtheoperatingpoint.ReferringtoFig,forI_B =5μA,thezerosignalvaluesare:

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

- Itfollows,therefore,thatthezerosignalvaluesofI_C andV_{CE} (i.e.operatingpoint)aredeterminedbythe point where d.c. load line intersects at proper base current curve.

❖ THELEAKAGECURRENT:-

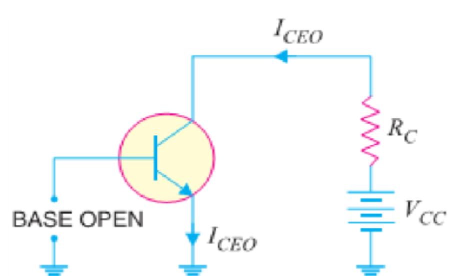
- The current is due to the movement of minority carriers is known as Leakage Current.
- InCommonBaseConnectionofTransistortheleakagecurrent $\mathbf{I_{CBO}}$istheCollector-Basecurrentwithemitteropen.



- Similarly,InCommonEmitterConnectiontheleakagecurrent $\mathbf{I_{CEO}}$istheCollector-EmitterCurrentwithopenBase.
- ExpressionforcollectorcurrentinCommonBaseConnectionis given by,

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

- Expression for collector current in Common Emitter Connection isgiven by,



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

❖ FAITHFULAMPLIFICATION:-

Theprocessofraisingthestrengthofaweaksignalwithoutanychangeinitsgeneralshapeisknownas *FaithfulAmplification*.Thekeyfactorforachievingfaithfulamplification:-

- (i)Properzerosignalcollectorcurrent
- (ii)Minimumproperbase-emittervoltage(V_{BE})atanyinstant
- (iii)Minimumpropercollector-emittervoltage(V_{CE})atanyinstant

❖ TRANSISTORBIASING:-

Theproperflowofzerosignalcollectorcurrentandthemaintenanceofpropercollector-emittervoltage during the passage of signal is known as *TransistorBiasing*.

Thefollowingarethemostcommonlyusedmethodsofobtainingtransistorbiasingfromonesourceof supply (i.e. V_{CC}):

- (i)BaseResistorMethod
- (ii)EmitterBiasMethod
- (iii)BiasingwithCollector-FeedbackResistor
- (iv)Voltage-DividerBias.

❖ STABILISATION:-

Theprocessofmakingoperatingpointindependentoftemperaturechangesorvariationsintransistor parameters is known as *Stabilization*.

❖ NEEDFORSTABILIZATION:-

Stabilizationoftheoperatingpointisnecessaryduetothe following reasons :

- (i)TemperaturedependenceofIC
- (ii)Individualvariations
- (iii)Thermalrunaway

Theself-destructionofanunsterilizedtransistorisknownas ***ThermalRunaway***.

❖ STABILITYFACTOR:-

TherateofchangeofcollectorcurrentI_Cw.r.t.thecollectorleakagecurrentI_{CO}[=I_{CEO}]atconstantβ and$I_B$iscalledstability factori.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.CalculatethevalueofIB.

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,determinethevalueofbasecurrent.

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

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,thecollectorcurrentis50μA.Findthetotalcollectorcurrent.Giventhatα=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.Thevoltagedropacross2kΩ resistancewhichisconnectedinthecollectoris2V.Findthebasecurrent.

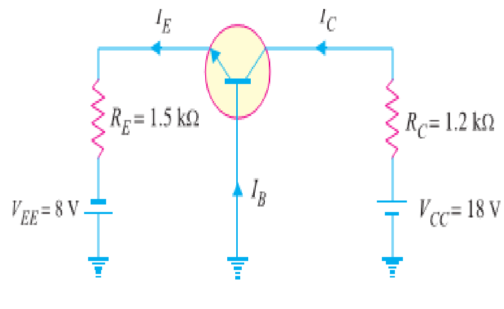
Solution: ThevoltagedropacrossR_C(=2kΩ)is2V. ∴ I_C=2V/2kΩ=1mA

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

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

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

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



ApplyingKirchhoff'svoltagelawtotheemitter-sideloop,weget,

$$V_{EE}=I_ER_E+V_{BE}$$

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

∴ $I_C \approx I_E$=**4.87mA**

Applying Kirchhoff's voltage law to the collector-side loop, we have,

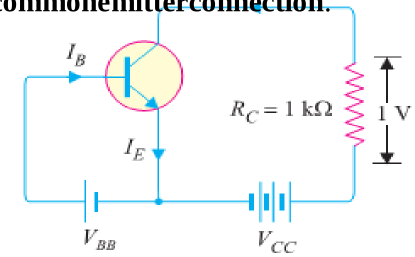
$V_{CC}=I_CR_C+V_{CB}$ ➔ $V_{CB}=V_{CC}-I_CR_C$= 18 V −4.87 mA ×1.2 kΩ = **12.16V**

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

Here β = 50, I_B = 20μA = 0.02 mA

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

7. Foratransistor,β =45andvoltagedropacross1kΩ whichisconnectedinthecollectorcircuitis1volt.Findthebasecurrentforcommonemitterconnection.



Solution: Fig.showstherequiredcommonemitterconnection.

ThevoltagedropacrossR$_C$(=1kΩ)is1volt.

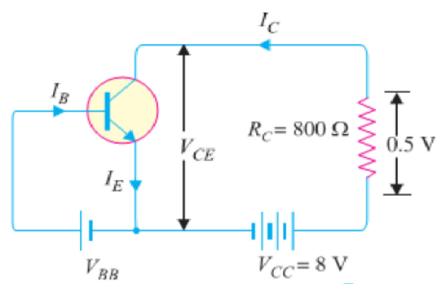
∴ $I_C=\frac{1\,V}{1\,K\Omega}$

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

8. Atransistorisconnectedincommonemitter(CE)configuration inwhichcollectorsupplyis8VandthevoltagedropacrossresistanceR$_C$connectedinthecollectorcircuitis0.5V.ThevalueofR$_C$=800Ω.Ifα=0.96,Determine:

(i) Collector-emittervoltage

(ii) Basecurrent



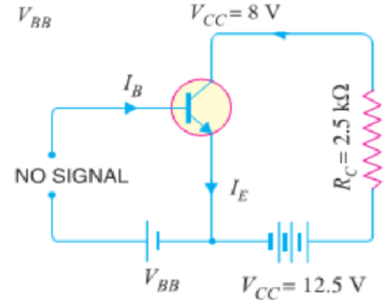
Solution: Fig. shows the required common emitter connection with Various values. (i) Collector-Emitter voltage,

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

(ii)ThevoltagedropacrossR$_C$(=800Ω)is0.5V.

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

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



9. ForthecircuitshowninFig.,DrawtheD.C.loadline.Solution:$V_{CE}=V_{CC}-I_CR_C$,WhenI_C=0➔$V_{CE}=V_{CC}$=**12.5V**

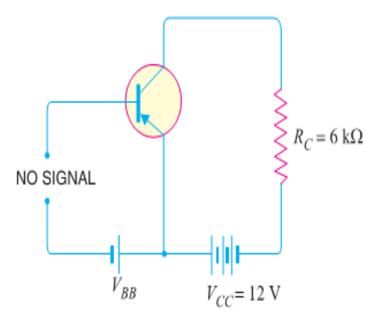
ThislocatesthepointBoftheloadlineoncollector–emittervoltageaxis.

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

ThislocatesthepointAoftheloadlineoncollectorcurrentaxis.

Byjoiningthesetwopoints,wegettheD.C.loadlineAB.

10. InthecircuitdiagramshowninFig.(i),ifV_{CC}=12VandR$_C$=6KΩ,drawthed.c.loadline.WhatwillbetheQpointifzerosignalbasecurrentis20μAandβ =50?



Solution: Thecollector–emittervoltageV_{CE}isgivenby:$V_{CE}=V_{CC}-I_CR_C$ 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.Byjoiningthesetwopoints,loadlineABisconstructed.

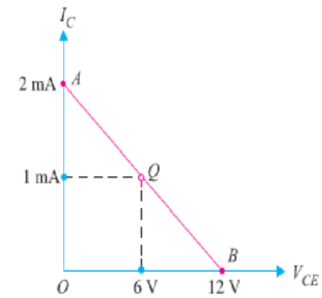
Zerosignalbasecurrent,I_B=20µA=0.02mACurrentamplificationfactor,β=50

∴ Zerosignalcollectorcurrent,$I_C=\beta I_B$=50×0.02=**1mA**

Zerosignalcollector–emittervoltageis$V_{CE}=V_{CC}-I_CR_C$=12–1mA×6kΩ=**6V**.

∴ Operatingpointis6V,1mA

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



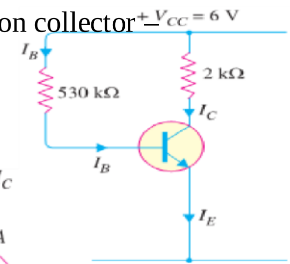
11. Fig.Showsthatasilicontransistorwithβ =100isbiasedbyBaseresistormethod.DrawD.C.theLoadLine&DetermineOperatingpoint.

Solution:V_{CC}=6V,R_B=530kΩ,R_C=2kΩ

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

When I_C = 0, V_{CE} = V_{CC} = **6V**. This locates the first point B (OB = 6V) of load line on collector – emittervoltageaxis as shown in Fig.(ii). When V_{CE}= 0,I_C= V_{CC}/R_C= 6V/2kΩ = **3mA.**

This locates the second point A (OA=3mA) of the load line on the collector current axis. By joining points A and B, D.C. Load Line AB is constructed.



OperatingpointQ. as it is silicon transistor, therefore, V_{BE} = 0.7V.

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

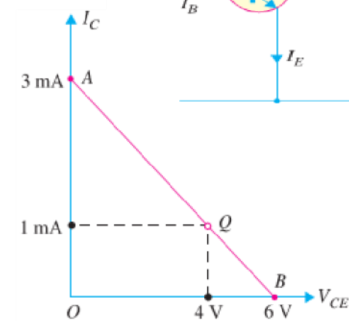
$I_BR_B+V_{BE}=V_{CC}$

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

∴Collectorcurrent,$I_C=\beta I_B$=100×10=1000µA=**1mA**

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

∴Operating point is (4V, 1mA.)Fig.(ii) Shows the operating point Q on the D.C. load line.Its co-ordinates are I_C = 1mA and V_{CE} = 4V.



12. ***Fig.showsasilicontransistorbiasedbyfeedbackresistormethod.Determinetheoperatingpoint.Giventhatβ =100.***

Solution:V_{CC}=20V, R_B=100kΩ, R_C=1 kΩ. Since it is silicon transistor, V_{BE}= 0.7V.

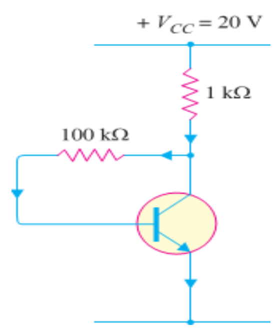
Assuming I_B to be in mA and using the relation,

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

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

Again$V_{CE}=V_{CC}-I_CR_C$=20–9.6mA×1kΩ=**10.4V**

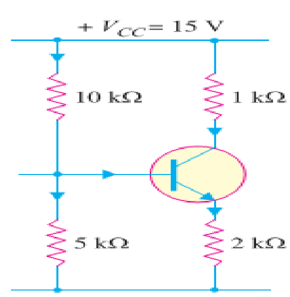
∴Q-Pointis(10.4V,9.6mA.)



13. Fig.showsthevoltagedividerbiasmethod.DrawtheD.C.LoadLineanddeterminetheoperatingpoint.Assumethetransistortobeofsilicon.

Solution:*D.C.LoadLine*. The collector-emitter voltage $V_{CE}$is given by:

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



- This locates the first point B (OB= 15V) of the load line on the collector-emittervoltageaxis. When V_{CE}= 0,I_C= V_{CC}/ (R_C+ R_E) = 15 V/ (1 + 2) kΩ=**5mA**
- 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:- For silicon Transistor, V_{BE} = 0.7 V

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

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

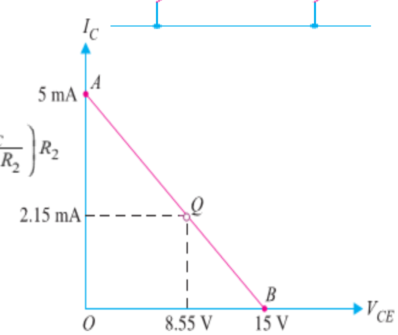
Voltage drop across $R_2=\left(\frac{V_{CC}}{R_1+R_2}\right)R_2$

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

∴Collectorcurrentis$I_C\approx I_E$=**2.15mA**

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

∴Operatingpointis(8.55V,2.15mA)isshowninFig.



❖ AMPLIFIER:-

✍Thedevicewhichincreasesthestrengthofaweaksignalisknownas*Amplifier*.Thiscanachievebyuse of Transistor.It may beclassified according tothenumber of stage of amplification, Such as:-

1) Singlestagetransistoramplifier.
2) Multistagetransistoramplifier.

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

✓ **MultistageTransistorAmplifier:-**Whenatransistorcircuitcontainingmorethanonestageof amplification is known as *MultistageTransistorAmplifier*.

❖ SINGLESTAGETRANSISTORAMPLIFIER:-

✍Asinglestagetransistoramplifierhasonetransistor,bias circuit and other auxiliary components.

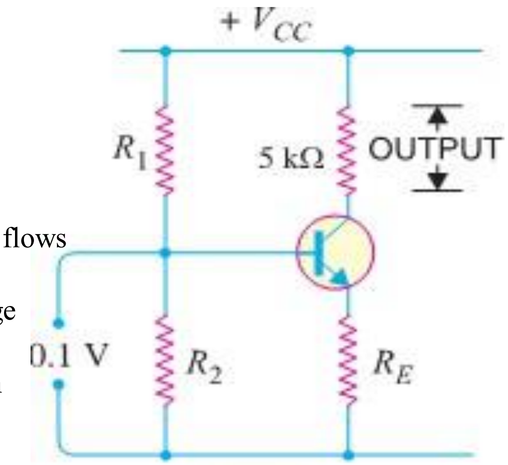
✍WhenaweakA.C.signalisgiventothebaseoftransistor,a small base current starts flowing.

✍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, alarge voltage appears across R_C.

✍Thus,aweaksignalappliedinthebasecircuitappearsin amplified form in the collector circuit.

✍Itisinthiswaythatatransistoractsasanamplifier.



[TransistorasanAmplifier]

❖ GraphicalDemonstrationofTransistorAmplifier:-

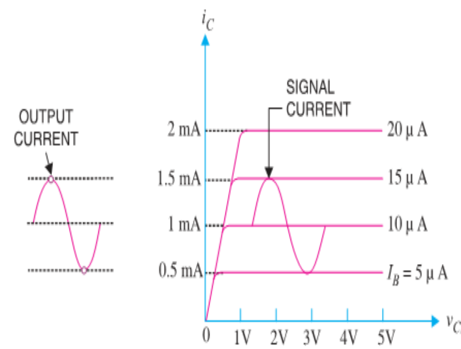
✍The function of transistor as an amplifier can also be explained graphically. The given Fig shows the output characteristics of a transistor in CE configuration.

✍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 firsthalf-cycle when base-emitter junction is more forward-biased.

✍However,theywilldecreaseinthesecondhalf-cyclewhenthe base-emitter junction is less forward biased.



✍Forexample,considerasinusoidalsignalwhichincreasesordecreasesthebasecurrentby5μAinthe 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 andhence collector current change continuously.

✍Inthefirsthalf-cyclepeakofthesignal,thebasecurrentincreasesto15μAandthecorresponding 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.

✍Forothervaluesofthesignal,thecollectorcurrentisinbetweenthesevaluesi.e.1.5mAand0.5mA.It is 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.

✍ThislargechangeincollectorcurrentflowsthroughcollectorresistanceR$_C$.Theresultisthatoutput signal is much larger than the input signal.Thus,the transistor has done amplification.

❖ MULTISTAGETRANSISTORAMPLIFIER:-

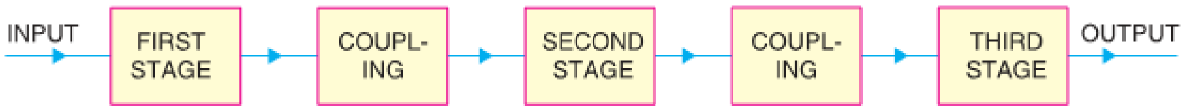
✍Theoutputfromasinglestageamplifierisusuallyinsufficienttodriveanoutputdevice.Inotherwords, the gain of a single amplifier is inadequate for practical purposes.

✍Consequently,additionalamplificationovertwoorthreestagesisnecessary.Toachievethis,theoutput of each amplifier stage is coupled in some way to the input of the next stage.

✍Theresultingsystemisreferredtoasmultistageamplifier.

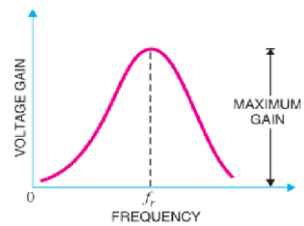
- Atransistorcircuitcontaining*morethanonestageofamplification*isknownas*multistagetransistoramplifier*.
- Inamultistageamplifier,anumberofsingleamplifiersareconnectedincascadearrangementi.e.output offirststageisconnectedtotheinputofthesecondstagethroughasuitablecoupling device andsoon.
- Thepurposeof**couplingdevice**(e.g.acapacitor,transformeretc.)is
  - (i)totransferA.C.outputofonestagetotheinputofthenextstageand
  - (ii)toisolatetheD.C.conditionsofonestagefromthenextstage.
- Thenameoftheamplifierisusuallygivenafterthetypeofcouplingused.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



- **IMPORTANTTERMS:-**

- **Gain:-**Theratiooftheoutputelectricalquantitytotheinputoneoftheamplifieriscalleditsgain.
- Thegainofamultistageamplifierisequaltotheproductofgainsofindividualstages.
- Forinstance,ifG_1,G_2andG_3aretheindividualvoltagegainsofathree-stageamplifier,thentotalvoltage gain G is given by: $G = G_1 \times G_2 \times G_3$
- **Frequencyresponse:-**Thecurvebetweenvoltagegainandsignalfrequency of an amplifier is known as frequency response.



- Thegainoftheamplifierincreasesasthefrequencyincreasesfromzerotillit becomes maximum at f_r, called resonant frequency.
- **Decibelgain:-**Althoughthegainofanamplifiercanbeexpressedasa number, yet great practical importance to assign it a unit.
- Theunitassignedisbelordecibel(db).Thecommonlogarithm(logtothebase10)ofpowergainis known as bel power gain i.e

$$\text{Power gain} = \log_{10} \frac{P_{out}}{P_{in}} \; bel$$

(1 bel=10 db.)

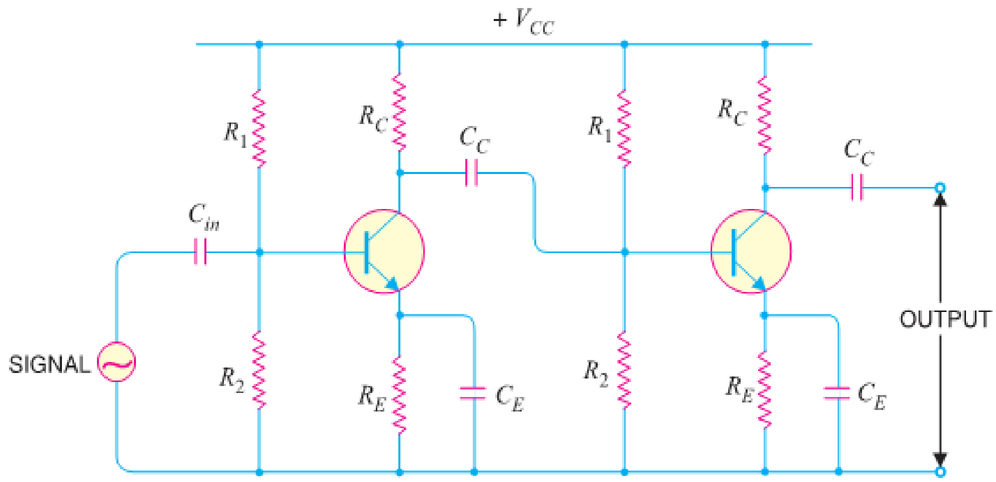
- Similarrlyvoltagegainandcurrentgainmaybedefinedasfollows:-

- **Bandwidth:-** The rangeof frequency over whichthe voltagegain isequalto 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 thelimitingfrequencies.The$f_1$iscalledlowercut-offfrequencyand$f_2$is known as upper cut-off frequency

- **<u>R-CCOUPLEDTRANSISTORAMPLIFIER:-</u>**

- Thisisthemostpopulartypeofcouplingbecauseitischeapand*providesexcellentaudiofidelityoverawiderangeoffrequency*.It is usually employed for **voltageamplification**.
- FigshowstwostagesofanRCcoupledamplifier.Acouplingcapacitor$C_C$isusedtoconnecttheoutput of first stage to the base (i.e. input) of the second stage and so on.
- Asthecouplingfromonestagetonextisachievedby acoupling capacitorfollowedby aconnectiontoa shunt resistor, therefore,suchamplifiers arecalled ***Resistance-Capacitancecoupledamplifiers***.

- 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.
- The coupling capacitor C_C transmits A.C. signal but blocks D.C. This prevents D.C. interference between various stages and the shifting of operating point.



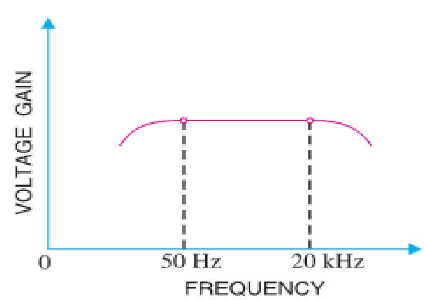
[Circuit Diagram of RC Coupled Transistor Amplifier]

- **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

FREQUENCY RESPONSE:

- Fig shows the frequency response of a typical RC coupled amplifier. It is clear that voltage gain drops off at low (< 50 Hz) and high (> 20 kHz) frequencies whereas it is uniform over mid-frequency range (50Hz 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 hence very small part of signal will pass from one stage to the 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** (>20kHz):- At this stage the reactance of C_C is very small and it behaves as a short circuit. These increases the loading effect of next stage and serves to reduce the voltage gain. Moreover, at high frequency, capacitive reactance of base-emitter junction is low which increases the base current. This reduces the current amplification factor β. Due to these two reasons, the voltage gain drops off at high frequency.



[Frequency Response Curve of RC Coupled Amp]

- **(iii) At mid-frequencies** (50Hz to 20kHz):- 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 the gain. 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) Ithasexcellentfrequency response.Thegainisconstantovertheaudiofrequency rangewhichisthe region of most importance for speech, music etc.
(ii) Ithaslowercostsinceitemploysresistorsandcapacitorswhicharecheap.
(iii) Thecircuitisverycompactasthemodernresistorsandcapacitorsaresmallandextremelylight.

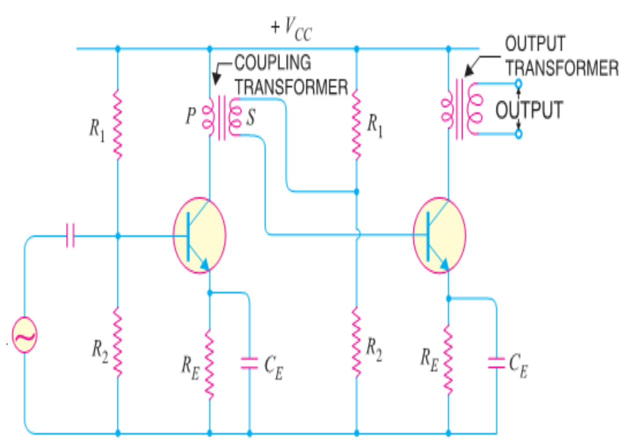
Disadvantages:-

(i) TheRCcoupledamplifiershavelowvoltageandpowergain.Itisbecausethelowresistance presentedbytheinputofeachstagetotheprecedingstagedecreasestheeffectiveloadresistance(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.

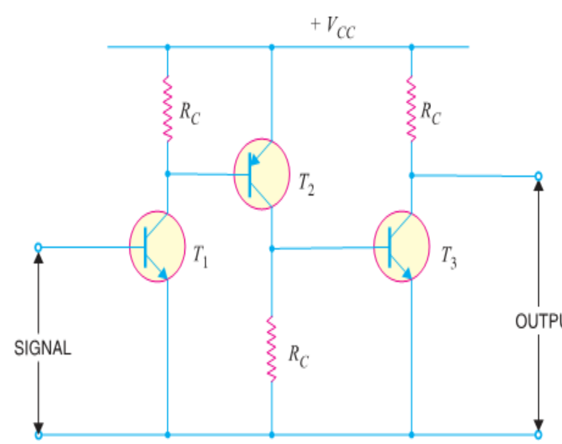
Applications:-

- The RCcoupled amplifiers have excellent audiofidelity overa widerangeof frequency.Therefore,they are widely used as **voltageamplifiers** e.g. in the initial stages of publicaddress system.
- Ifothertypeofcoupling(e.g.transformercoupling)isemployedintheinitialstages,thisresultsin frequency distortion which may be amplified in next stages.
- However,becauseofpoorimpedancematching,RCcouplingisrarelyusedinthefinalstages.

✓ **CircuitdiagramforOtherTypeofCouplingaregivenbelow:-**



(TransformerCoupledTransistorAmplifier)

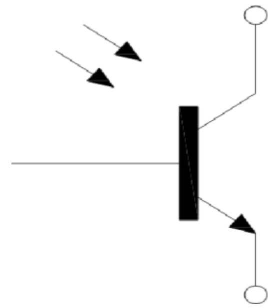


(DirectCoupledTransistorAmplifier)

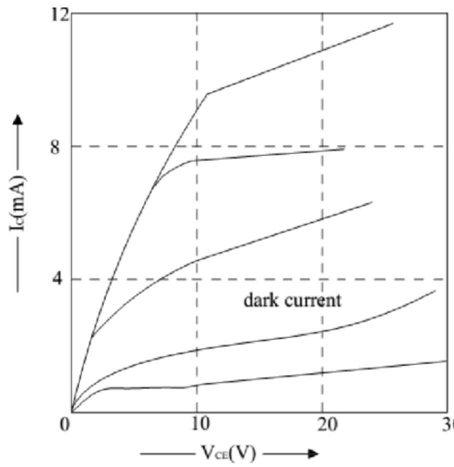
➤ **ComparisonofDifferentTypesofCoupling:-**

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:-



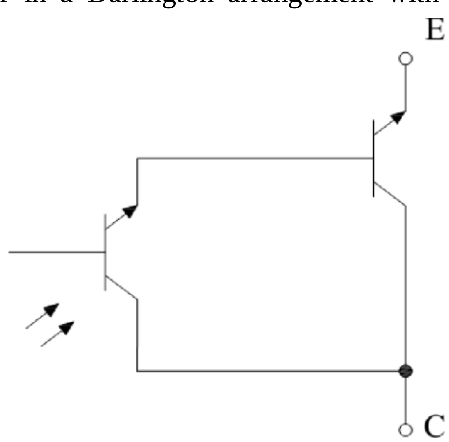
- It islight sensitive Transistorand issimilar to anordinary BJT except that it has no connection to the base terminal.Its operation is based on the photodiode that exits at CB junction.
- Insteadofthebasecurrent,theinputtothetransistorisprovidedintheform of light as shown in symbol.
- Silicon NPNs are 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.
- WhenthereisnoincidentlightontheCBjunction,thereisasmallthermallygeneratedcollector-to-emitterleakagecurrentI_{CEO} which, inthiscaseis called **darkcurrent** andis inthenA 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 certainvalue 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 responsetime. The photo transistor has the advantages of greatersensitivity and current capacity than photo diodes.
- However, photo diodes are faster of the two, switching in lessthan a nanosecond.

❖ PHOTODARLINGTON:-

- As shown in fig. a Photo Darlington consists of a photo transistor in a Darlington arrangement with a common transistor.



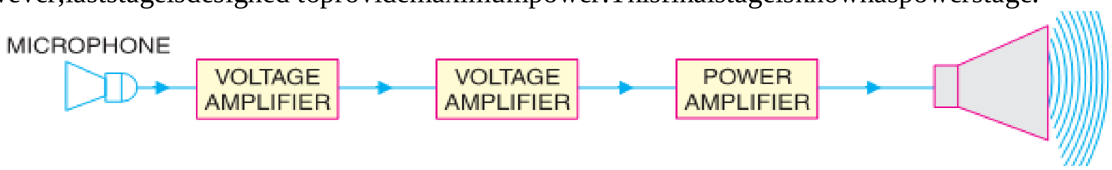
- It has a much greater sensitivity to incident radiant energy than a photo transistor because of higher current gain.
- However,itsswitchingtimeof50µsismuchlongerthanthe photo transistor (2µs) or the photo diode (1ns). Its circuit symbolis shown in fig.
- PhotoDarlingtonisusedinavarietyofapplicationsomeof which are given below.
- A *lightoperatedrelay* in which the photo transistor Q_1 drives the bipolar transistor Q_2. When sufficient light falls on Q_1 it is driven into saturation so that I_C is increased multiple. This collector current while passing through the relay coil energizes the relay.
- A*darkoperatedrelay*circuiti.e.oneinwhichrelayisdeenergizedwhenlightfallsonthephoto transistor.
- Suchrelaysareusedinmanyapplicationssuchas
  - **(i)** Automaticdooractivators
  - **(ii)** ProcessCounters
  - **(iii)** Variousalarmsystemsforsmokeorinterferencedetection.

[CHAPTER – 3]

[AUDIOPOWERAMPLIFIERS]

❖ INTRODUCTION:-

- Apracticalamplifieralwaysconsistsofanumberofstagesthatamplifyaweaksignaluntilsufficient power is available to operate a loudspeaker or other output device.
- Thefirstfewstagesinthismultistageamplifierhavethefunctionofonlyvoltageamplification. However,laststageisdesigned toprovidemaximumpower.Thisfinalstageisknownaspowerstage.



❖ TransistorAudioPowerAmplifier:-

- Atransistoramplifierwhichraisesthepower levelofthesignalshaving audiofrequency rangeisknown astransistor**AudioPowerAmplifier**.Generally laststage ofa multistageamplifier isthepowerstage.
- Thepoweramplifierdiffersfromallthepreviousstagesinthathereaconcentratedeffortismadeto obtain maximum output power.
- Atransistorthatissuitableforpoweramplificationisgenerallycalleda*powertransistor*.

❖ DIFFERENCEBETWEENVOLTAGEANDPOWERAMPLIFIERS

- Thedifferencebetweenthetwotypesisreallyoneofdegree;itisaquestionofhowmuchvoltageand how much power.
- Avoltageamplifierisdesignedtoachievemaximumvoltageamplification.Itis,however,notimportant to raise the power level.
- Ontheotherhand,apoweramplifierisdesignedtoobtainmaximumoutputpower.

1) **VoltageAmplifier.** Thevoltagegainofanamplifierisgivenby: $A_v = \beta \times \frac{R_c}{R_{in}}$

- Inordertoachievehighvoltageamplification,thefollowingfeaturesareincorporatedinsuchamplifiers:
  - ♣ Thetransistorwithhighβ(>100)isusedinthecircuit.i.e.Transistorsareemployedhavingthinbase.
  - ♣ TheinputresistanceR_{in}oftransistorissoughttobequitelowascomparedtothecollectorloadR_C.
  - ♣ A relatively highload$R_C$isused inthecollector. Topermitthiscondition,voltageamplifiersare alwaysoperatedatlowcollectorcurrents(≈mA).Ifthecollectorcurrentissmall,wecanuselarge R_C in the collector circuit

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

- Inordertoachievehighpoweramplification,thefollowingfeaturesareincorporatedinsuchamplifiers:
  - ♣ The size ofpower transistorismade considerably larger inorder todissipate theheatproducedinthe transistor during operation.
  - ♣ Thebaseismadethickertohandlelargecurrents.Inotherwords,transistorswithcomparatively smaller β are used.
  - ♣ Transformercouplingisusedforimpedancematching.

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)

❖ PERFORMANCEQUANTITIESOFPOWERAMPLIFIERS

- Theprimeobjectiveforapoweramplifieristoobtainmaximumoutputpower.Sinceatransistor,like any other electronic device has voltage, current and power dissipation limits, therefore, the criteria for a power amplifier are : **CollectorEfficiency,Distortion&PowerDissipationCapability**

Collectorefficiency.

- Themaincriterionforapoweramplifierisnotthepowergainratheritisthemaximuma.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 itseffectiveness.This is known as *collectorefficiency*and may bedefinedas 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 **collectorefficiency**.

Distortion. Thechangeofoutputwaveshapefrominputwaveshapeofamplifieriscalled**Distortion**.

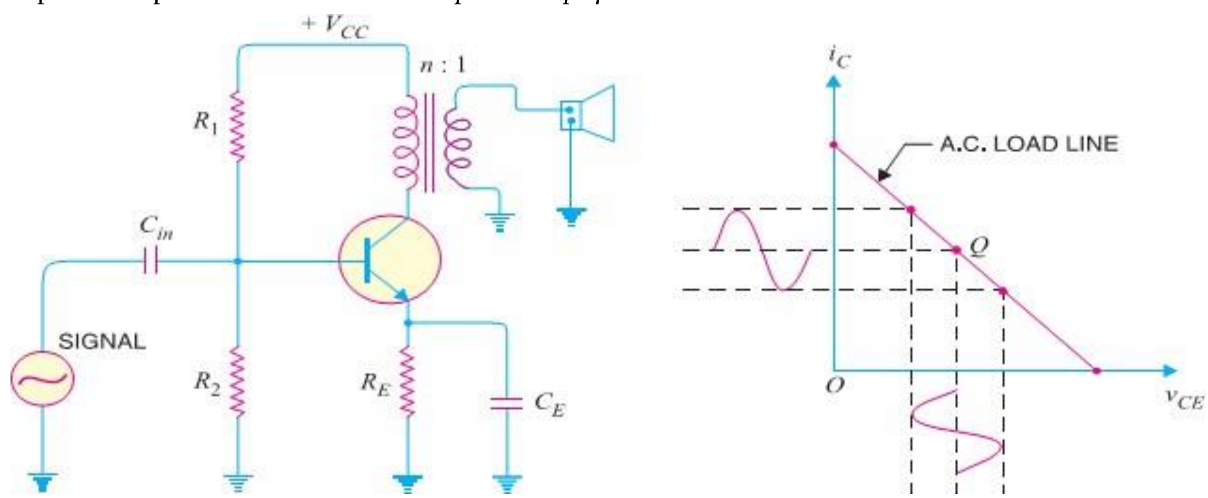
PowerDissipationCapability. The ability of a power transistor to dissipate heat is known as power dissipation capability.

❖ CLASSIFICATIONOFPOWERAMPLIFIERS

- Transistorpoweramplifiershandlelargesignals.Manyofthemaredrivenbytheinputlargesignalthat collectorcurrentiseithercut-off orisinthesaturationregionduringalargeportionoftheinputcycle.
- Therefore, such amplifiers are generally classified according to their mode of operation i.e. the portion oftheinputcycleduring whichthecollectorcurrentisexpectedtoflow.Onthisbasis,they are classifiedas

  (i) ClassApoweramplifier **(ii)**ClassBpoweramplifier**(iii)**ClassCpoweramplifier

CLASSAPOWERAMPLIFIER. If the collector current flows at all times during the full cycle of thesignal, the power amplifier is known as *classApoweramplifier*.

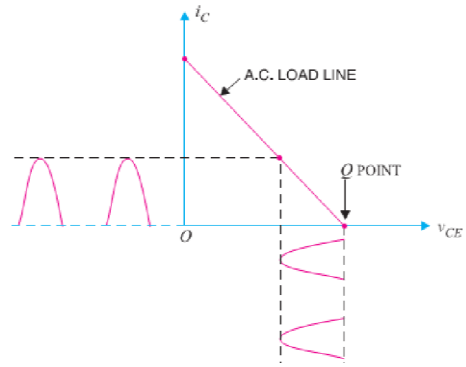


- Thepoweramplifiermustbebiasedinsuchawaythatnopartofthesignaliscutoff.Fig(i)shows circuitofclassApoweramplifier.Notethatcollectorhasatransformerastheloadwhichismost common for all classes of power amplifiers.
- The use of transformer permits impedance matching, resulting in the transference of maximum power tothe load e.g. loudspeaker.Fig (ii) shows the class A operation in terms of a.c. load line.
- TheoperatingpointQissoselectedthatcollectorcurrentflowsatalltimesthroughoutthefullcycleof the applied signal. As the output wave shape is exactly similar to the input wave shape, therefore, such amplifiers have least distortion.
- However,theyhavethedisadvantageoflowpoweroutputandlowcollectorefficiency(about35%).

CLASSBPOWERAMPLIFIER: - If the collector current flows only during the positive half-cycle ofthe input signal, it is called a *classBpoweramplifier*.

- Inclass B operation, the transistor bias is so adjusted that zero signal collector current is zero i.e. nobiasing circuit is needed at all.
- Duringthepositivehalf-cycleofthesignal,theinputcircuitisforwardbiasedandhencecollector currentflows.However,duringthenegativehalf-cycleofthesignal,theinputcircuitisreversebiased and no collector current flows.

- Fig.showstheclassBoperationintermsofa.c.loadline.
- TheoperatingpointQshallbelocatedatcollectorcutoffvoltage.
- ItiseasytoseethatoutputfromaclassBamplifierisamplified half-wave rectification.
- InaclassBamplifier,thenegativehalf-cycleofthesignaliscut off and hence a severe distortion occurs.
- However,classBamplifiersprovidehigherpoweroutputandcollector efficiency (50 − 60%).
- Such amplifiers are mostly used for power amplification in push-pull arrangement.



- Insuchanarrangement,2transistorsareusedinclassBoperation.Onetransistoramplifiesthepositive half cycle of the signal while the other amplifies the negative half-cycle.

CLASSCPOWERAMPLIFIER.Ifthecollectorcurrentflowsforlessthanhalf-cycleoftheinput signal, it is called *classCpoweramplifier*.

- InclassCamplifier,thebaseisgivensomenegativebiassothatcollectorcurrentdoesnotflowjust when the positive half-cycle of the signal starts.
- Suchamplifiersareneverusedforpoweramplification.However,theyareusedastunedamplifiersi.e. to amplify a narrow band of requencies near the resonant frequency.

EXPRESSIONFORCOLLECTOREFFICIENCY

- Forcomparingpoweramplifiers,collectorefficiencyisthemaincriterion.Thegreaterthecollector efficiency, the better is the power amplifier.
- Now, CollectorEfficiency,**η=** $\frac{\text{a.c. power output}}{\text{d.c. power input}} = \frac{P_O}{P_{dc}}$
- Where$P_{dc} = V_{CC}\, I_C$ & $P_O = V_{CE}\, I_C$inwhich $V_{CE}$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-peakvalues,thea.c.poweroutputcanbeexpressedas:

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

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

MAXIMUMCOLLECTOREFFICIENCYOFSERIES-FEDCLASSAAMPLIFIER:-

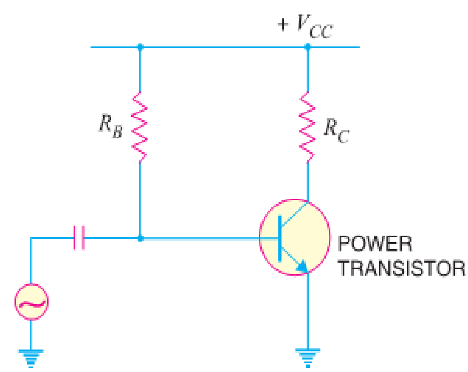
- Fig (i) shows a series fed class A amplifier. This circuit is seldom used for power amplification due to its poor collector efficiency.
- Nevertheless, it will help the reader to understand the class A operation. The d.c. load line of the circuit is shown in Fig. (ii).
- When an ac signal is applied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

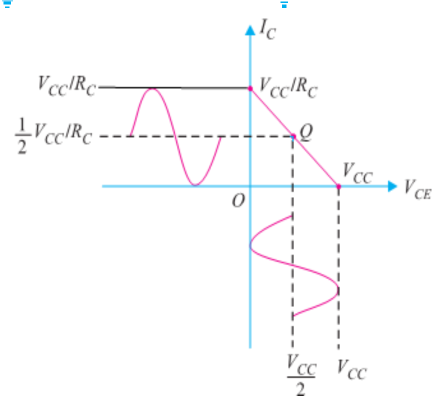
Maximum $v_{ce(p-p)} = V_{CC}$ Maximum $i_{c(p-p)}= V_{CC}/R_C$

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

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

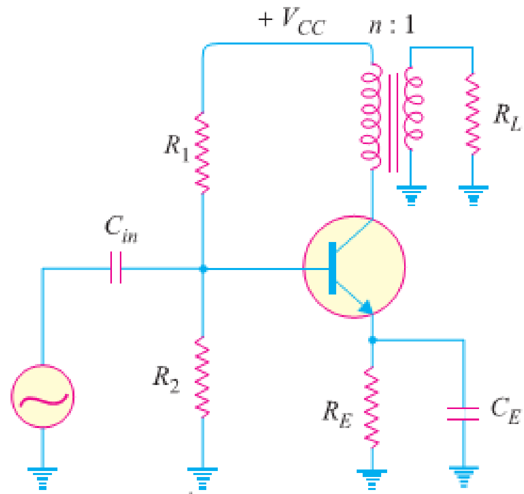
∴ Maximumcollectorη=$\frac{P_{O(max)}}{P_{dc}}\times100=\frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C}\times100=$**25%**



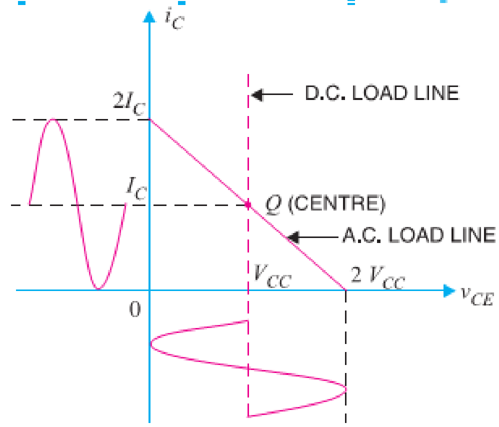


- ThusthemaximumcollectorefficiencyofaclassAseries-fedamplifier is 25%.
- Inactualpractice,collectorefficiencyisfarlessthanthisvalue.

MaximumCollectorEfficiencyOfTransformerCoupledClassAPowerAmplifier:-



- 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 mainreasons.**First,**transformercouplingpermits impedance matching. **Secondly** it keeps the d.c. power loss small because of the small resistance of the transformer primary winding.
- Fig(i)showsatransformercoupledclassApoweramplifier.
- 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.
- Theprimaryresistancehasaverysmallvalueandis assumedzero.Therefore,d.c.loadlineisaverticalline rising from V_{CC} as shown in Fig. (ii).
- Whensignalisapplied,thecollectorcurrentwillvary 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, thetotal collector current is 2 I_C and v_{ce} = 0. During the negative peak of the signal, the collector current is zero and v_{ce}= $2V_{CC}$.



∴Peak-to-peakcollector-emittervoltageis

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

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

WhereR′$_L$isthereflectedvalueofloadR$_L$andappearsinprimaryofthetransformer.

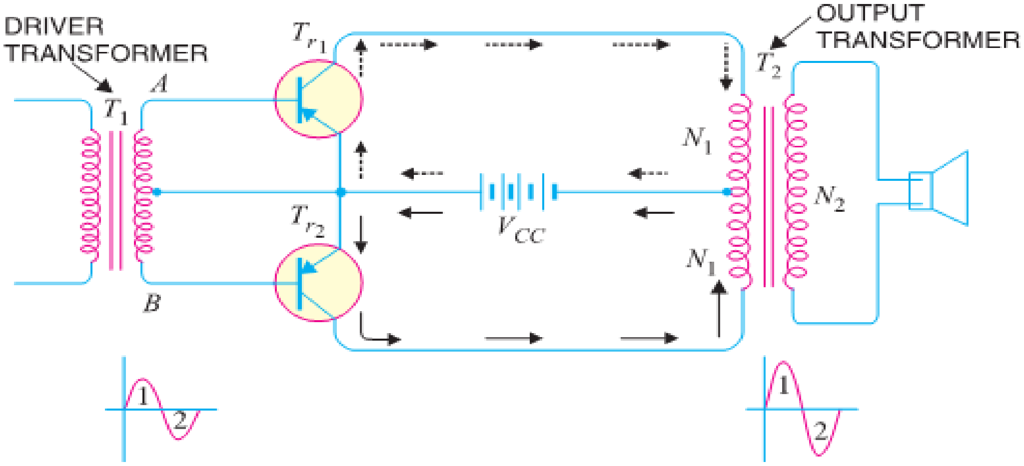
- Ifn(=N_p/N_s)istheturnratioofthetransformer,then, $R'_L=n^2R_L$.
- d.c.powerinput, $P_{dc}=V_{CC}I_C=I_C^2R'_L$ $(\because V_{CC}=I_CR'_L)$
- Max.a.c.outputpower, $P_{o(max)}=\frac{V_{ce(p-p)}\times i_{c(p-p)}}{8}=\frac{2V_{CC}\times 2I_C}{8}=\frac{1}{2}V_{CC}I_C=\frac{1}{2}I_C^2R'_L \ldots(i)(\because V_{CC}=I_CR'_L)$

∴ $$\text{Max.Collector}\eta=\frac{P_{o(max)}}{P_{dc}}\times 100=\frac{(\frac{1}{2})I_C^2R'_L}{I_C^2R'_L}\times 100=\mathbf{50\%}$$

IMPORTANTPOINTSABOUTCLASS-APOWERAMPLIFIER:-

- **(i)**ATransformercoupledclassApoweramplifierhasamaximumcollectorefficiencyof50%i.e., maximum of 50% d.c. supply power is converted into a.c. power output.
- Inpractice,theefficiencyofsuchanamplifierislessthan50%(about35%)duetopowerlossesinthe output transformer, power dissipation in the transistor etc.
- **(ii)**Thepowerdissipatedbyatransistorisgivenby: $P_{dis}=P_{dc}-P_{ac}$
  Where Pdc=availabled.c.power & P_{ac}=availablea.c.power
- So,InclassAoperation,Transistormustdissipatelessheatwhensignalisappliedthereforerunscooler.
- **(iii)**WhennosignalisappliedtoaclassApoweramplifier, $P_{ac}=0$.∴P_{dis}=Pdc
- ThusinclassAoperation,maximumpowerdissipationinthetransistoroccursunderzerosignal conditions.
- Therefore,thepowerdissipationcapabilityofapowertransistor(forclassAoperation)mustbeatleast equal to the zero signal rating.
- **(iv)**WhenaclassApoweramplifierusedinfinalstage,itiscalledsingleendedclassApoweramplifier.

PUSH-PULLAMPLIFIER:-



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

CIRCUITOPERATION.

- 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 circuitwill conduct current due to T_{r2} only and is shown by solid arrows.
- Therefore, this half-cycle of the signal is amplified by $T_{r2}$and appears in the lower half of the primary of outputtransformer.Inthenexthalfcycleofthesignal,T_{r1} isforwardbiasedwhereasT_{r2} isreverse 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 transformerprimary.Thecentre-tappedprimaryoftheoutputtransformercombinestwocollector 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 throughimpedancematching.IfR_L istheresistanceappearingacrosssecondary ofoutputtransformer, then resistance R'_L of primary shall become:

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

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

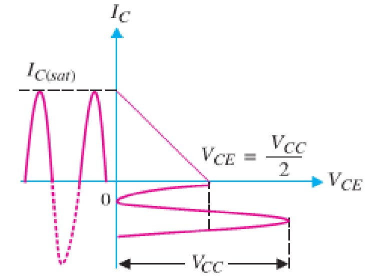
ADVANTAGES

1) Theefficiencyofthecircuitisquitehigh(≈75%)duetoclassBoperation.
2) Ahigha.c.outputpowerisobtained.

DISADVANTAGES

1) Twotransistorshavetobeused.
2) Itrequires two equal and opposite voltages at the input. Therefore, push-pull circuit requires the useof driver stage to furnish these signals.
3) Ifthe parameters of the two transistors are not the same, there will be unequal amplification of the two halves of the signal.
4) Thecircuitgivesmoredistortion.
5) Transformersusedarebulkyandexpensive.

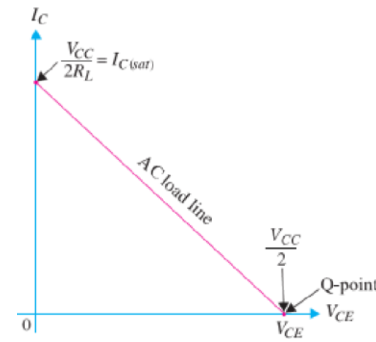
MAXIMUMEFFICIENCYFORCLASSBPOWERAMPLIFIER



- Wehavealreadyseenthatapush-pullcircuitusestwotransistors workinginclassBoperation.ForclassBoperation,theQ-pointis located at cut-off on both d.c. and a.c. load lines.
- Formaximumsignaloperation,thetwotransistorsinclassBamplifier arealternately drivenfromcut-off tosaturation.ThisisshowninFig.(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 $I_{C(sat)}$.
- Thesameinformationisalsoconveyedthroughthea.c.loadlineforthecircuit[SeeFig.(ii)].

∴ Peaka.c.outputvoltage=V_{CE}

Peaka.c.outputcurrent=$I_{C(sat)} = \frac{V_{CE}}{R_L} = \frac{V_{CC}}{2R_L}$ $\left(\because V_{CE} = \frac{V_{CC}}{2}\right)$



- Maximumaveragea.c.outputpower$P_{o(max)}$ istheProductofr.m.s. values of a.c. output voltage and a.c. output current

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

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

- Theinputd.c.powerfromthesupply$V_{CC}$is **$P_{dc} = V_{CC} I_{dc}$**

  WhereI_{dc}istheaveragecurrentdrawnfromthesupplyV_{CC}.
- Sincethetransistorisonforalternatinghalfcycles,iteffectivelyactsasahalf-waverectifier.

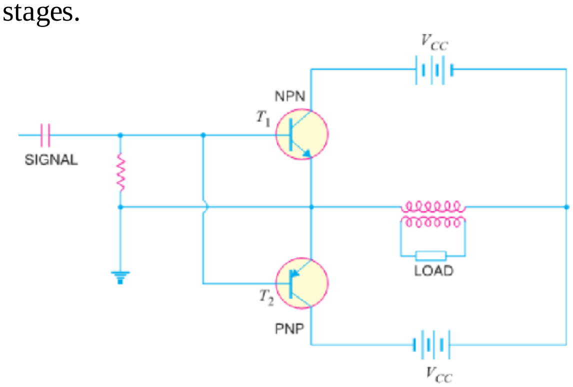
∴ $I_{dc} = \frac{I_{C(sat)}}{\pi}$ ➔ $P_{dc} = \frac{V_{CC} I_{C(sat)}}{\pi}$

∴ Max.Collectorη= $\frac{P_{o(max)}}{P_{dc}} = \frac{0.25 V_{CC} I_{C(sat)}}{(V_{CC} I_{C(sat)})/\pi} \times 100 = 0.25\pi \times 100 = \mathbf{78.5\%}$

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

COMPLEMENTARY-SYMMETRYAMPLIFIER

- 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 onepnp transistor and requires no centre-tapped transformers.
- Thecircuitactionisasfollows.Duringthepositive-half of the input signal, transistor T_1 (the npn transistor) conducts current while T_2(the pnp transistor) is cutoff.
- During the negative half-cycle of the signal, T_2 conducts whileT_1 iscutoff.Inthisway,npntransistoramplifies the positive half-cycles of the signal while the pnp transistor amplifies the negative half-cycles of the signal.



- Notethatwegenerallyuseanoutputtransformer(notcentre-tapped)forimpedancematching.

Advantages:-(1) Thiscircuitdoesnotrequiretransformer.Thissavesonweightandcost.

(2) Equalandoppositeinputsignalvoltagesarenotrequired.

Disadvantages:-(1) Itisdifficulttogetapairoftransistors(npn&pnp)havingsimilarcharacteristics.

(2) Werequirebothpositiveandnegativesupplyvoltages.

HEATSINK:-

- 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.
- UsuallytransistorisfixedonAluminummetalsheetsothatadditionalheatistransferredtotheAlsheet.
- Themetalsheetthatservestodissipatetheadditionalheatfrompowertransistorisknownas**HeatSink.**

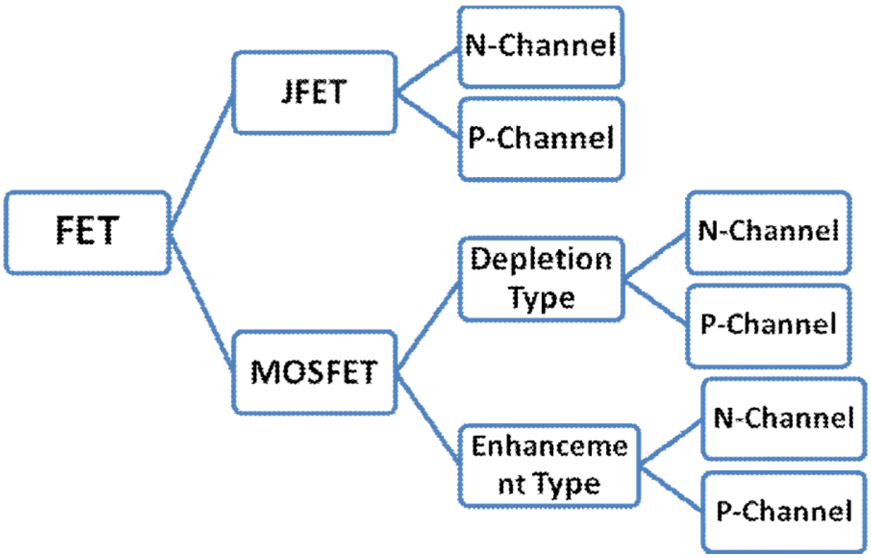
[CHAPTER–4]

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

❖ **INTRODUCTION:-**

- Inthepreviouschapters,wehavediscussedthecircuitapplicationsofanordinary transistor.Inthistype oftransistor,bothholesandelectronsplaypartintheconductionprocess.Forthisreason,itis sometimes called a **BipolarTransistor.**
- Theordinaryorbipolartransistorhastwoprincipaldisadvantages.**First**,ithaslowinputimpedance because of forward biased emitter junction. **Secondly**, it has considerable noise level.
- Althoughlowinputimpedanceproblemmaybeimprovedbycarefuldesignanduseofmorethanone transistor, yet it is difficult to achieve input impedance more than a few mega ohms.
- Thefieldeffecttransistor(FET)has,byvirtueofitsconstructionandbiasing,largeinputimpedance which may be more than 100 mega ohms.
- The FET is generally much less noisy than the ordinary or bipolar transistor. The rapidly expanding FET market has led many semiconductor marketing managers to believe that this device will soon become the most important electronic device, primarily because of itsintegrated-circuit applications.

❖ **CLASSIFICATIONOFFIELDEFFECTTRANSISTORS:-**



❖ OthertypesofC-MOSalsoThereSuchas:-**CMOS,VMOS,LDMOS**etc.

❖ **DIFFERENTIATIONBETWEENBJT&FET:-**

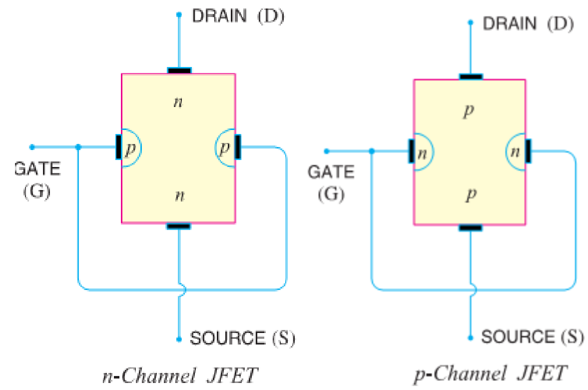
FET	BJT
✖ ItmeansFieldEffectTransistor	✖ MeansBipolarJunctionTransistor
✖ ItsthreeterminalsareSource,Gate&Drain	✖ ItsterminalsareEmitter,Base&Collector.
✖It is **Unipolar** devices i.e. Current in the device is carried either by electrons or holes.	✖It is **Bipolar** devices i.e. Current in the device is carried by both electrons and holes.
✖It is **Voltagecontrolleddevice.** i.e. Voltage at the gate or drain terminal controls the amount ofcurrentflowingthroughthedevices.	✖It is **Currentcontrolleddevice.** i.e. Base Current controls the amount of collector currentflowingthroughthedevices.
✖It has very High Input Resistance and Low Output Resistance.	✖It has very Low Input Resistance and High Output Resistance.
✖ Lownoisyoperation	✖ Highnoisyoperation
✖ ItisLongerLife&HighEfficiency.	✖ ItisShorterLife&LowEfficiency.
✖ It is much simpler to fabricate as IC and occupies less space on IC.	✖It is comparatively difficult to fabricate as IC and occupies more space on IC then FET.
✖ IthasSmallgainbandwidthproduct.	✖ IthasLargegainbandwidthproduct.
✖ Ithashigherswitchingspeed.	✖ Ithashigherswitchingspeed.

❖ JUNCTIONFIELDEFFECTTRANSISTOR(JFET):-

- Ajunctionfieldeffecttransistorisathreeterminalsemiconductordeviceinwhichcurrentconductionis by one type of carrier i.e., electrons or holes.
- In a JFET, the current conduction is either by electrons or holes and is controlled by means of an electricfield between the gate electrode and the conducting channel of the device.
- TheJFEThashighinputimpedanceandlownoiselevel.

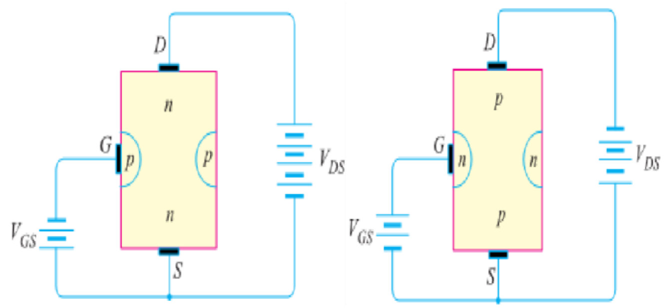
❖ CONSTRUCTIONALDETAILS.

- A JFET consists of a p-type or n-type silicon bar containing two pn junctions at the sides as shown in Fig.
- The bar forms the conducting channel for the charge carriers.If the bar is of n-type, it is called n-channelJFET as shown in Fig (i) and if the bar is of p-type, it is called a p-channel JFET as shown in Fig (ii).
- The two pn junctions forming diodes are connected internally & a common terminal called **gate** is taken out.
- Other terminals are **source** and **drain** taken out from the bar asshown.ThusaJFEThasessentially three terminals viz., Gate (G), Source (S) & Drain (D).



❖ 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.
- ThisisthenormalwayofJFETconnection.
- The drain & source terminals are interchangeable i.e.,eitherendcanbeusedassourceandthe other end as drain.

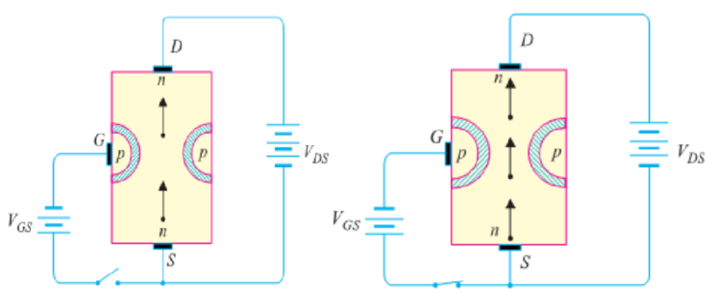


- Thefollowingpointsmaybenoted:
  - ♣ The input circuit (i.e. gate to source) of a JFET is reverse biased. This means that the device has high input impedance.
  - ♣ Thedrainissobiasedw.r.t.sourcethatdraincurrent$I_D$flowsfromthesourcetodrain.
  - ♣ InallJFETs,sourcecurrent$I_S$isequaltothedraincurrenti.e.$I_S=I_D$.

❖ WORKINGPRINCIPLEOFJFET:-

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

- The two pn junctions at the sides form two depletion layers. The current conduction by chargecarriers(i.e.freeelectronsinthis case) is through the channel between the two depletion layers and out of the drain.



- ThewidthandhenceresistanceofthischannelcanbecontrolledbychangingtheinputvoltageV_{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.
- ThusJFEToperatesontheprinciplethatwidthandhenceresistanceoftheconductingchannelcanbe varied by changing the reverse voltage V_{GS}.
- Inotherwords,themagnitudeofdraincurrent(I_D)canbechangedbyalteringV_{GS}.

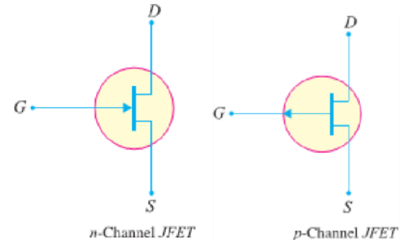
Working:-Theworking ofJFETisasunder:

- **(i)**WhenvoltageV_{DS}isappliedbetweendrain&sourceterminalsandvoltageonthegateiszero[See the above Fig (i)], the two pn junctions at the sides of the bar establish depletion layers.
- Theelectronswillflowfromsourcetodrainthroughachannelbetweenthedepletionlayers.

- Thesizeoftheselayersdetermineswidthofthechannel&hencethecurrentconductionthroughthebar.
- **(ii)**WhenareversevoltageV$_{GS}$ isappliedbetweenthegateandsource[SeeFig(ii)],thewidthofthe depletion layers is increased.
- Thisreducesthewidthofconductingchannel,therebyincreasingtheresistanceofn-typebar.Consequently, the current from source to drain is decreased.
- Ontheotherhand,ifthereversevoltageonthegateisdecreased,thewidthofthedepletionlayersalso decreases. This increasesthe width oftheconducting channel and hence source todrain current.
- Itisclearfromtheabovediscussionthatcurrentfromsourcetodraincanbecontrolledbythe application of potential (i.e. electric field) on the gate.
- For thisreason,the device is called field effect transistor.Itmay be notedthat a p-channel JFET operatesin the same manner as an n-channel JFET except that channel current carriers will be the holes instead of electrons and the polarities of V_{GS} and V_{DS} are reversed.

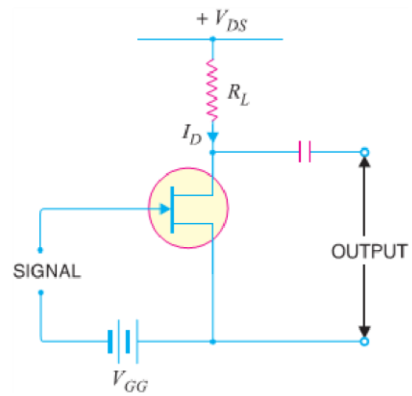
❖ JFETASANAMPLIFIER:-

- 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.,inputcircuitshouldalwaysbereversebiased.
- ThisisachievedeitherbyinsertingabatteryV$_{GG}$inthegatecircuitor byacircuitknownasbiasingcircuit.



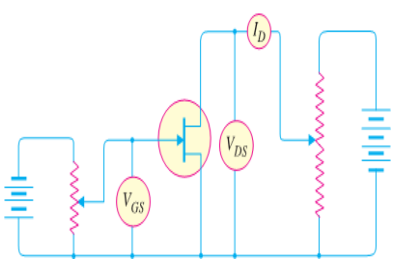
[SchematicSymbolofJFET]

- Inthepresentcase,weareprovidingbiasingbythebatteryV$_{GG}$.Asmallchangeinthereversebiason the gate produces a large change in drain current.
- This fact makes JFET capable of raising the strength of a weak signal. Duringthepositivehalfofsignal,thereversebiasonthegate decreases. This increases the channel width and hence the drain current.
- During the negative half-cycle of the signal, the reverse voltage on thegate increases. Consequently, the drain current decreases.
- The result is that a small change in voltage at the gate produces a largechange in drain current.
- Theselargevariationsindraincurrentproducelargeoutputacrossthe load R$_L$. In this way, JFET acts as an amplifier



❖ OUTPUTCHARACTERISTICSOFJFET

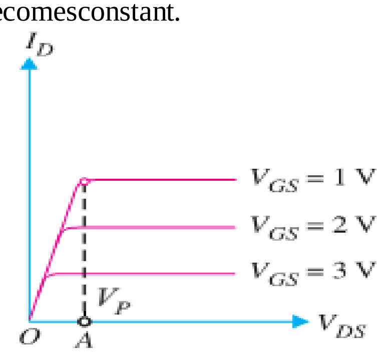
- The curve between drain current (I_D) and drain-source voltage (V_{DS}) ofa JFET at constant gate source voltage (V_{GS}) is known as output characteristics of JFET.
- FigshowscircuitfordeterminingoutputcharacteristicsofJFET.
- KeepingV$_{GS}$fixedatsomevalue,say1V,thedrainsourcevoltageis changed in steps.
- CorrespondingtoeachvalueofV$_{DS}$,thedraincurrentI$_D$isnoted.
- AplotofthesevaluesgivesoutputcharacteristicofJFETatV$_{GS}$=1V.



- Repeatingsimilarprocedure,outputcharacteristicsatothergate-sourcevoltagescanbedrawn.Fig.shows a family of output characteristics.

Thefollowingpointsmaybenotedfromthecharacteristics:

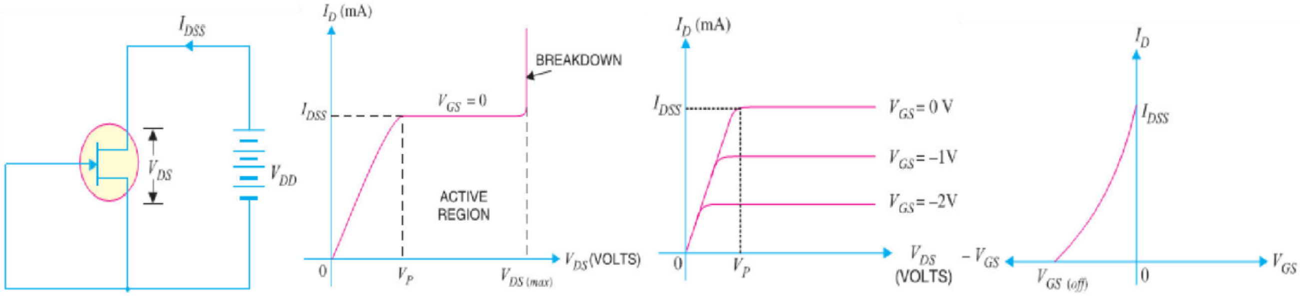
- **(i)**Atfirst,thedraincurrentI$_D$risesrapidlywithdrain-sourcevoltageV$_{DS}$butthenbecomesconstant.
- The drain-source voltage above which drain current becomes constant is known as pinch off voltage. Thus in Fig. OA is the pinch off voltage V_P.
- **(ii)**Afterpinchoffvoltage,thechannelwidthbecomessonarrowthat depletion layers almost touch each other.
- Thedraincurrentpassesthroughthesmallpassagebetweentheselayers.
- ThusincreaseindraincurrentisverysmallwithV$_{DS}$abovepinchoff voltage.
- Consequently,draincurrentremainsconstant.Thecharacteristics resemble that of a pentode valve.



SALIENTFEATURESOFJFET:-

- ThefollowingaresomesalientfeaturesofJFET:
  - **(i)** A JFET is a three-terminal voltage-controlled semiconductor device i.e. input voltage controls theoutput characteristics of JFET.
  - **(ii)**TheJFETisalwaysoperatedwithgate-sourcepnjunctionreversebiased.
  - **(iii)**InaJFET,thegatecurrentiszeroi.e.I_G=0A.**(iv)**Sincethereisnogatecurrent,I_D=I_S
  - **(v)** TheJFETmustbe operatedbetween V_{GS}andV_{GS}(off).For thisrangeofgate-to-sourcevoltages, I_D will vary froma maximum of I_{DSS} to a minimum of almost zero.
  - **(vi)**Astwogatesarethesamepotential,bothdepletionlayerswidenornarrowbyanequalamount.
  - **(vii)**TheJFETisnotsubjectedtothermalrunawaywhenthetemperatureofthedeviceincreases.
  - **(viii)**Thedraincurrent$I_D$iscontrolledbychangingthechannelwidth.
  - **(ix)**SinceJFEThasnogatecurrent,thereisnoβratingofthedevice.WecanfinddraincurrentI_D

IMPORTANTTERMS:-



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

- Itisthedraincurrentwithsourceshort-circuitedtogate(i.e.V_{GS}=0)anddrainvoltage(V_{DS})equalto pinch off voltage. It is sometimes called zero-bias current.

2. PinchOffVoltage(V_P):-

- Itistheminimumdrain-sourcevoltageatwhichthedraincurrentessentiallybecomesconstant.

3. Gate-SourceCutOffVoltageV_{GS}(off):-

- Itisthegate-sourcevoltagewherethechanneliscompletelycutoffandthedraincurrentbecomeszero.

PARAMETERSOFJFET:-

- Likevacuumtubes,aJFEThascertainparameterswhichdetermineitsperformanceinacircuit.The mainparametersofJFETare:-**(i)** A.C.drainresistance **(ii)**Transconductance **(iii)**Amplificationfactor.
- **(i)<u>A.C.DrainResistance</u>(r_d).**Correspondingtothea.c.plateresistance,wehavea.c.drainresistance in 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,$r_d = \frac{2V}{0.02\ mA} = 100k\Omega$
- Referringtotheoutputcharacteristicsofa JFETinFig.,itisclearthatabovethepinchoffvoltage,the change in $I_D$is small for a change in V_{DS}because the curve is almost flat.
- Therefore,drainresistanceofaJFEThasalargevalue,rangingfrom10kΩto1MΩ.
- **(ii)<u>Transconductance</u>(g_{fs}):-**Thecontrolthatthegatevoltagehasoverthedraincurrentismeasured by transconductanceg_{fs}&issimilartothetransconductance$g_m$ofthetube.Itmay bedefinedasfollows:
- Itistheratioofchangeindraincurrent(ΔI_D)tothechangeingate-sourcevoltage(ΔV_{GS})atconstant drain-source voltage i.e.

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

- ThetransconductanceofaJFETisusuallyexpressedeitherinmA/voltormicromho.Asanexample,if achangeingatevoltageof0.1V causesa changeindraincurrentof0.3mA,then,Transconductance,

➔$g_{fs} = \frac{0.3\ mA}{0.1\ V} = 3mA/V = 3\times10^{-3}$A/VormhoorS(Siemens)=$3\times10^{-3}\times10^{6}$µmho=3000µmho(orµS)

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

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

- AmplificationfactorofaJFETindicateshowmuchmorecontrolthegatevoltagehasoverdraincurrent than has the drain voltage.
- Forinstance,iftheamplificationfactorofaJFETis50,itmeansthatgatevoltageis50timesaseffective as the drain voltage in controlling the drain current.

RELATIONAMONGJFETPARAMETERS:-

- TherelationshipamongJFETparameterscanbeestablishedasunder:

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

- MultiplyingthenumeratoranddenominatoronR.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:-

- Fortheproperoperationofn-channelJFET,gatemustbenegativew.r.t.source.Thiscanbeachieved either by inserting a battery in thegate circuit or by acircuit known as biasing circuit.
- Thelattermethodispreferredbecausebatteriesarecostlyandrequirefrequentreplacement.

1. Biasbattery:- In this method, JFET is biased by a bias battery V_{GG}. This battery ensures that gate isalways negative w.r.t. source during all parts of the signal.

2. Biasingcircuit:-The biasing circuit uses supply voltage $V_{DD}$to provide the necessary bias. Two most commonly used methods are **(i)Self-Bias(ii)PotentialDividerMethod**.

SELF-BIASFORJFET:-

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

VoltageacrossR$_S$,$V_S=I_DR_S$

- Sincegatecurrentisnegligibly small,thegate terminalisatd.c. ground i.e., $V_G = 0$.

∴ $V_{GS}=V_G-V_S=0-I_DR_S$ or $V_{GS}=-I_DR_S$

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

Operatingpoint:-

- Theoperatingpoint(i.e.,zerosignalsI_D&V_{DS})canbeeasily determined.SincetheparametersoftheJFETareusuallyknown,zerosignalI_D canbecalculatedfrom the following relation :

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

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

- Thus d.c. conditions of JFET amplifier are fully specified i.e. operating point for the circuit is (V_{DS}, I_D).Also, $R_S=\frac{|V_{GS}|}{|I_D|}$
- NotethatgateresistorR$_G$doesnotaffectbiasbecausevoltageacrossitiszero.

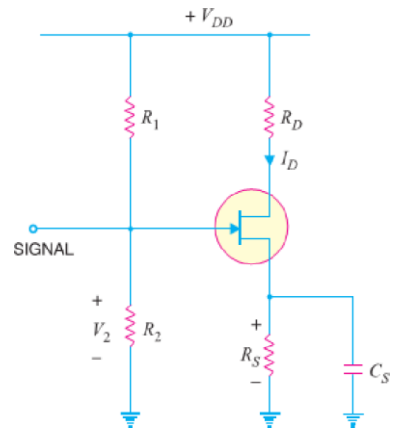
MidpointBias:- It is often desirable to bias a JFET near the midpoint of its transfer characteristic curve where $I_D = I_{DSS}/2$. When signal is applied, the midpoint bias allows a maximum amount of drain currentswing between I_{DSS} and 0.

- Itcanbeprovedthatwhen$V_{GS}=V_{GS(off)}/3.4$,midpointbiasconditionsareobtainedforI_D.

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

- Tosetdrainvoltageatmidpoint($V_D=V_{DD}/2$),selectavalueofR$_D$toproducethedesiredvoltagedrop.

- **JFETwithVoltage-DividerBias:-**



- FigshowspotentialdividermethodofbiasingaJFET.Thiscircuitis identical to that used for a transistor.
- TheresistorsR_1andR_2formavoltagedivideracrossdrainsupplyV_{DD}. The voltage V_2(= V_G) across R_2provides the necessarybias.

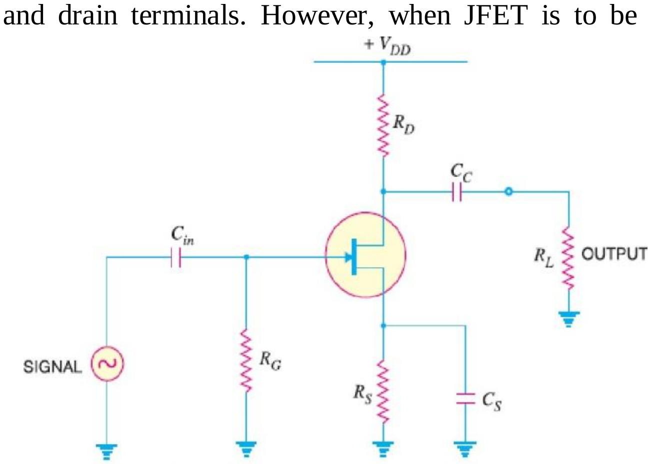
$$V_2=V_G=\frac{V_{DD}}{R_1+R_2}\times R_2$$

Now $V_2=V_{GS}+I_DR_S$ Or $\mathbf{V_{GS}=V_2-I_DR_S}$

- 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 advantageofthismethodofbiasingisthatitprovidesgoodstabilityoftheoperatingpoint.
- TheinputimpedanceZ$_i$ofthiscircuitisgivenby;$Z_i=R_1||R2$
- **JFETConnections:-**
- There are three leads in a JFET viz., source, gate and drain terminals. However, when JFET is to be connectedinacircuit,werequirefourterminals; twofortheinputandtwofortheoutput.



COMMON SOURCE CONNECTION

- Thisdifficultyisovercomebymakingone terminal of the JFET common to both input and output terminals. Accordingly, a JFET can be connected in a circuit in the following three ways:
  - CommonSourceconnection
  - 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.
- However,thecircuitproducesaphasereversali.e.,outputsignalis180°outofphasewiththeinput signal. Fig. shows a common source n-channel JFET amplifier.
- Notethatsourceterminaliscommontobothinputandoutput.

JFETApplications:-

- ThehighinputimpedanceandlowoutputimpedanceandlownoiselevelmakeJFETfarsuperiortothe bipolar transistor. Some of the circuit applications of JFET are :
  - AsaBufferamplifier
  - AsPhase-shiftoscillators
  - AsRFamplifier
- **MetalOxideSemiconductorFET(MOSFET):-**
- ThemaindrawbackofJFETisthatitsgatemustbereversebiasedforproperoperationofthedevice i.e.itcanonly have negativegateoperationfor n-channelandpositivegateoperationfor p-channel.
- Thismeansthatwecanonlydecreasethewidthofthechannel(i.e.decreasetheconductivityofthe channel) from its zero-bias size.
- Thistypeofoperationisreferredtoasdepletion-modeoperation.Therefore,aJFETcanonlybe operated in the depletion-mode.
- However,thereisafieldeffecttransistor(FET)thatcanbeoperatedtoenhance(orincrease)thewidth of the channel (with consequent increase in conductivity of the channel) i.e. it can have enhancement-mode operation. Such a FET is called **MOSFET.**
- Afieldeffecttransistor(FET)thatcanbeoperatedintheenhancement-modeiscalleda**MOSFET**.
- AMOSFETisanimportantsemiconductordevice&canbeusedinanyofthecircuitscoveredforJFET.

➢ However,aMOSFEThasseveraladvantagesoverJFETincludinghighinputimpedanceandlowcost.

❖ TYPESOFMOSFETS:-

➢ TherearetwobasictypesofMOSFETssuchas:-

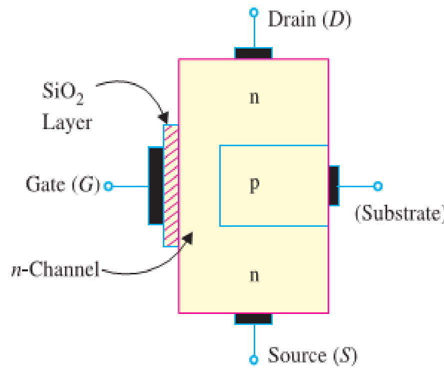
1. Depletion-typeMOSFETorD-MOSFET.TheD-MOSFETcanbeoperatedinboththedepletionmode and the enhancement-mode.
   - ➢ Forthisreason,aD-MOSFETissometimescalled**Depletion/EnhancementMOSFET**.

2. Enhancement-typeMOSFETorE-MOSFET. TheE-MOSFETcanbeoperatedonlyinenhancement mode.ThemannerinwhichaMOSFETisconstructeddetermineswhetheritisD-MOSFETorE-MOSFET.

❖ **D-MOSFET.**Figshowstheconstructionaldetailsofn-channelD-MOSFET.

➢ Itissimilarton-channelJFETexceptwiththefollowingmodifications/remarks:

➢ **(i)** The n-channel D-MOSFET is a piece of n-type material with ap-typeregion(called substrate) ontherightand an insulated gate on the left as shown in Fig.



n-Channel D-MOSFET

➢ 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 thinlayer of metal oxide (usually silicon dioxide, SiO_2) is depositedover 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 gateandotherplateisthechannelwithSiO_2asdielectric.RecallthatwehaveagatediodeinaJFET.

➢ **(iii)** It is a usual practice to connect the substrate to the source (S) internally so that a MOSFET has three terminals viz Source (S), Gate (G) and Drain (D).

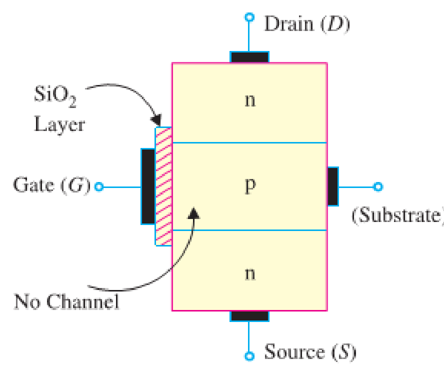
➢ **(iv)** Since the gate is insulated from the channel, we can apply either negative or positive voltage to thegate. Therefore, D-MOSFET can be operated in both depletion-mode and enhancement-mode. However, JFET can be operated only in depletion-mode.

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

➢ The E-MOSFET has no channel between source and drain unlike the D-MOSFET. Note that the substrate extends completely to the SiO_2 layer so that no channel exists.

➢ The E-MOSFET requires a proper gate voltage to form a channel (called induced channel). It is reminded that E-MOSFET can be operated only in enhancement mode.

➢ In short, the construction of E-MOSFET is quite similar to that of the D-MOSFET except for the absence of a channel between the drain and source terminals.



n-Channel E-MOSFET

❖ **WhythenameMOSFET?**

➢ Thereadermaywonderwhyisthedevicecalled MOSFET?

➢ Theanswerissimple.TheSiO_2layerisaninsulator.Thegateterminalismadeofametalconductor.

➢ Thus,goingfromgatetosubstrate,wehaveametaloxidesemiconductorandhencethenameMOSFET.

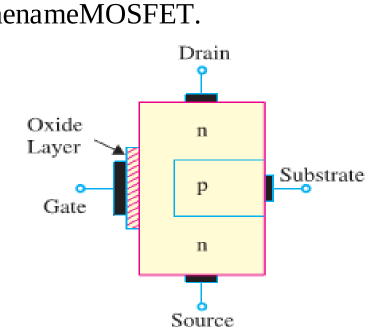
➢ Since the gate is insulated from the channel, the MOSFET is sometimes called **insulated-gateFET** (IGFET). However, this term is rarely used in place of the term MOSFET.

❖ **SymbolsforD-MOSFET**

TherearetwotypesofD-MOSFETssuchas

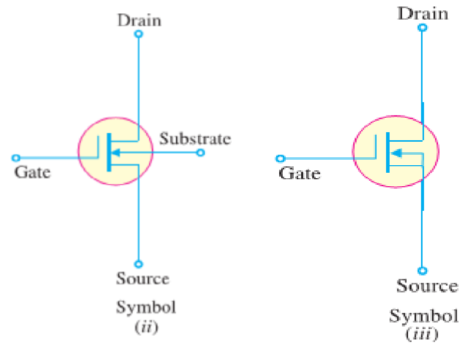
(i)n-channelD-MOSFETand**(ii)**p-channelD-MOSFET

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

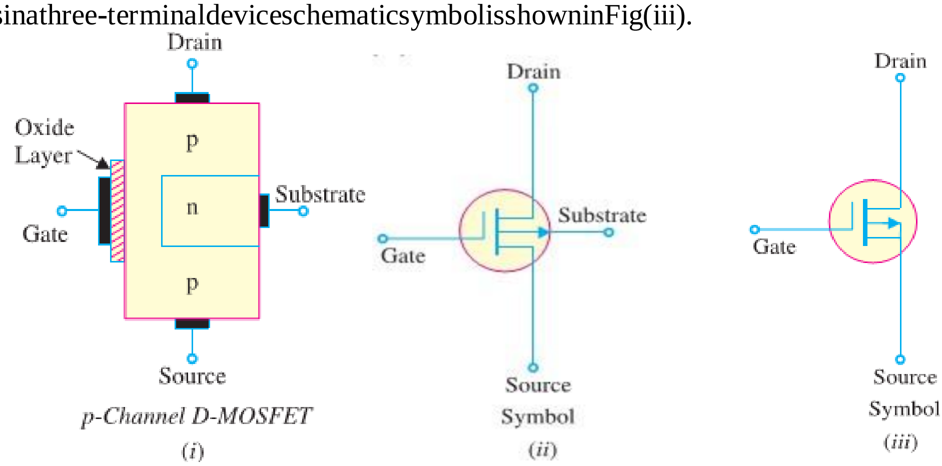


n-Channel D-MOSFET
(i)

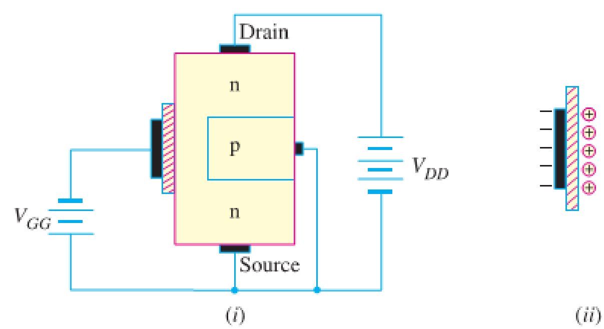
- Thep-typesubstrateconstrictsthechannelbetweenthesourceanddrainsothatonlyasmallpassage remains at the left side.
- Electronsflowingfromsource(whendrainispositivew.r.t.source)mustpassthroughthisnarrowchannel.
- Thesymbolforn-channelD-MOSFETisshowninFig(ii).
- Thegateappearslikeacapacitorplate.Justtotherightofthe gate is a thick vertical line representing the channel.
- Thedrainleadcomesoutofthetopofthechannelandthesource 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 asshown in Fig. (iii).
- Thisgivesrisetoathree-terminaldevice.



- **(ii)P-ChannelD-MOSFET.**Fig(i)showsthevariouspartsofp-channelD-MOSFET.
- The n-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side.
- Theconductiontakesplacebytheflowofholesfromsourcetodrainthroughthisnarrowchannel.
- The symbol for p-channel D-MOSFET shown in Fig (ii). It is a usual practice to connect the substrate to source internally.
- Thisresultsinathree-terminaldeviceschematicsymbolisshowninFig(iii).



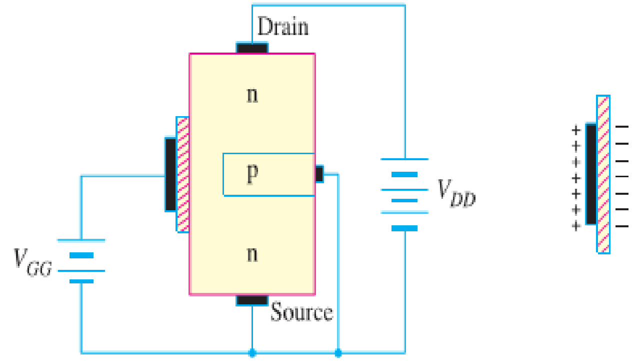
❖ CircuitOperationofD-MOSFET



- Fig (i) shows the circuit of n-channel D-MOSFET.The gate forms a small capacitor. One plate of this capacitor is the gate and the other plate is the channel with metal oxide layer as the dielectric.
- Whengatevoltageischanged,theelectricfieldof the capacitor changes which in turn changes the resistance of the n-channel.
- Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate.
- 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).
- Theseelectronsrepelthefreeelectronsinthen-channel,leavingalayerofpositiveionsinapartofthe channel as shown in Fig (ii).
- Inotherwords,wehavedepleted(i.e.emptied)then-channelofsomeofitsfreeelectrons.Therefore, lesser number of free electronsaremade availablefor currentconductionthrough then- channel.

- This is the same thing as if the resistance of the channel is increased. Thegreater the negative voltage onthe gate, the lesser is the current from source to drain.
- Thusbychangingthenegativevoltageonthegate,wecanvarytheresistanceofthen-channeland hence the current from source to drain.
- Notethatwithnegativevoltagetothegate,theactionofD-MOSFETissimilartoJFET.
- Becausetheactionwithnegativegatedependsupondepleting(i.e.emptying)thechanneloffree electrons, the negative-gate operation is called depletion mode.

♣ **(ii)EnhancementMode.** Fig (i) shows enhancement-mode operationofn-channelD-MOSFET.Again, the gate acts like a capacitor.



(i) (ii)

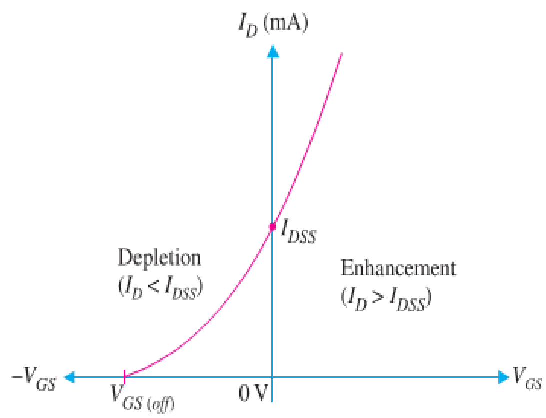
- Sincethegateispositive,itinducesnegative charges in the n-channel as shown in Fig (ii).
- Thesenegativechargesarethefreeelectronsdrawn into the channel.
- Because these free electrons are added to those already in the channel, the total number of free electrons in the channel is increased.
- Thus a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

♣ **ThefollowingpointsmaybenotedaboutD-MOSFEToperation:-**

- **(i)**InD-MOSFET,sourcetodraincurrentiscontrolledbyelectricfieldofcapacitorformedatthegate.
- **(ii)**ThegateofJFETbehavesasareverse-biaseddiodewhereasthegateofaD-MOSFETactslikea capacitor.Forthisreason,itispossibletooperate D-MOSFETwithpositiveornegativegate voltage.
- **(iii)**AsthegateofD-MOSFETformsacapacitor,therefore,negligiblegatecurrentflowswhether positive or negative voltage is applied to the gate.
- Forthis,theinputimpedanceofD-MOSFETisveryhigh,rangingfrom10,000MΩto10,000,00MΩ.
- **(iv)**Theextremelysmalldimensionsoftheoxidelayerunderthegateterminalresultinaverylow capacitance and the D-MOSFET has, therefore, a very low input capacitance.
- ThischaracteristicmakestheD-MOSFETusefulinhigh-frequencyapplications.

❖ D-MOSFETTransferCharacteristic:-

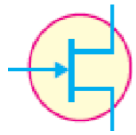
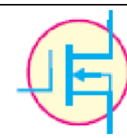
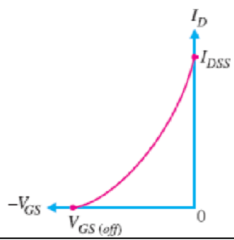
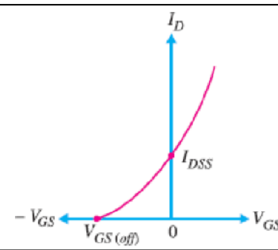
- Figshowsthetransfercharacteristiccurve(ortransconductancecurve)forn-channelD-OSFET.
- The behaviour of this device can be beautifully explained with the help of this curve as under :-
- **(i)** The point on the curve where $V_{GS} = 0$, $I_D = I_{DSS}$. It is expected because I_{DSS} is the value of I_D when gate and source terminals are shorted i.e. $V_{GS}= 0$.
- (ii)AsV_{GS}goesnegative,$I_D$decreasesbelowvalueofI_{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.
- NotethatthetransconductancecurvefortheD-MOSFET is very similar to the curve for a JFET.



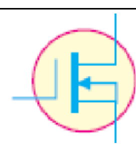
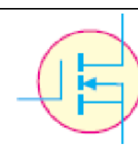
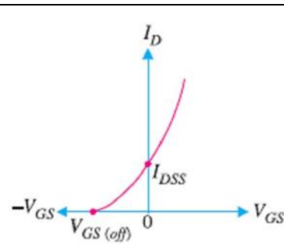
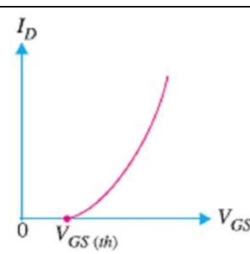
- Becauseofthissimilarity,theJFETandtheD-MOSFEThavethesametransconductanceequationviz.

$$\frac{V_{GS}}{V_{GS(off)}}$$

❖ D-MOSFETVsJFET:-

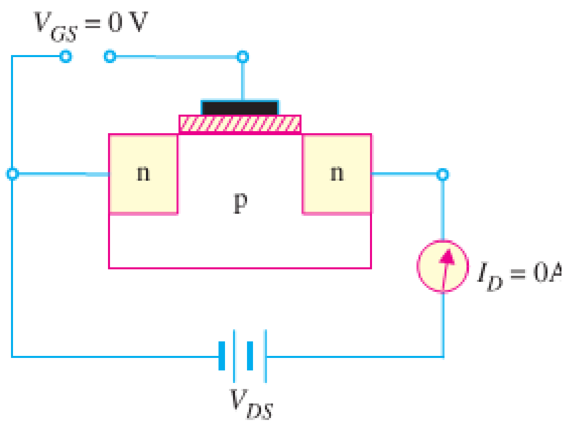
SN	Parameters	JFETs	D-MOSFETs
1	Symbol		
2	Transconductance Curve		
3	Modesof operation:	Depletiononly	Depletionandenhancement
4	Commonly Used bias circuits:	**(1)** Gatebias; **(2)** Selfbias; **(3)** Voltage-dividerbias;	**(1)** Gatebias; **(2)** Selfbias; **(3)** Voltage-dividerbias; **(4)** Zerobias
5	Advantages:	Extremelyhighinputimpedance.	**(1)** Higher input impedance than a comparable *JFET*. **(2)** Can operate in both modes (Depletion and Enhancement).
6	Disadvantages:	**(1)** Bias instability; **(2)** Can operate only in depletion mode.	**(1)** Biasinstability. **(2)** More sensitive to changes in temperature than the *JFET*.

❖ Tablebelowsummarizesmanyofthecharacteristicsof D-MOSFETsand E-MOSFETs:-

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

❖ **E-MOSFET:-**

- TwothingsareworthnotingaboutE-MOSFET.
- First, E-MOSFET operates only in the enhancement mode and has no depletion mode.
- Secondly,theE-MOSFEThasnophysicalchannel 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 thedevice starts conducting.
- TheminimumvalueofV$_{GS}$ofproperpolaritythatturns on E-MOSFET is called **Thresholdvoltage** [$V_{GS(th)}$].
- The n-channel device requires positive V_{GS} ($\geq V_{GS(th)}$) &thep-channeldevicerequiresnegativeV_{GS}($\geq V_{GS(th)}$).

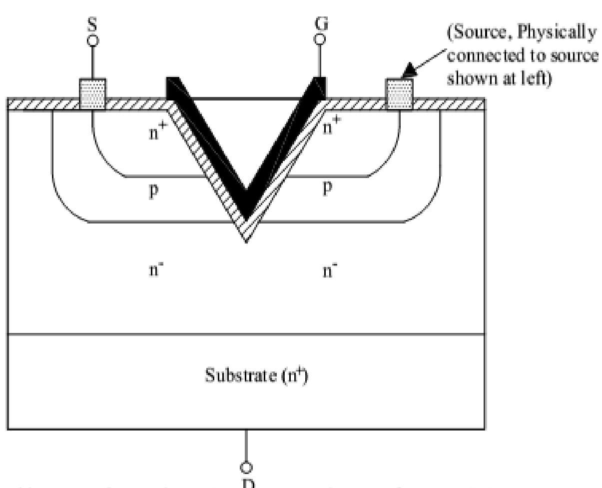


❖ **PowerMOSFETs:-**

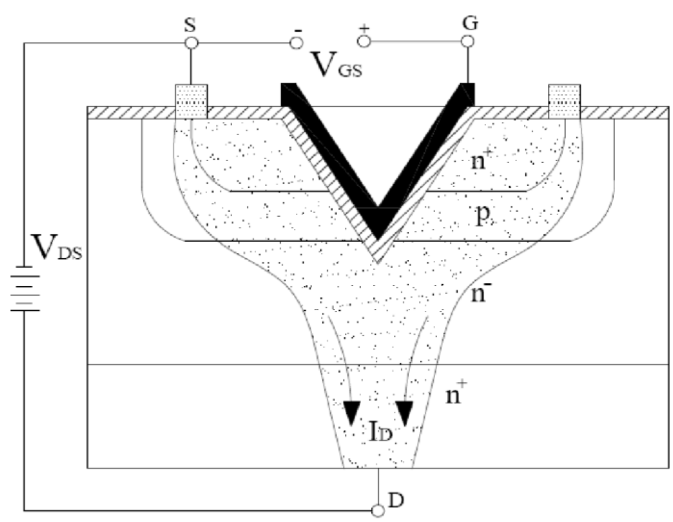
- Withtheadvancementoftechnology,theengineershaveproducedawidevariety ofMOSEFTsthatare designed specifically for high current, high voltage and high power applications.
- SomeExamplesofPowerMOSFETareVMOS,LDMOSetc.

❖ **VMOS[V-GroveMOSFETorVerticalMOSFET]:-**

- OneofthemajordisadvantagesofatypicalMOSFETisthereducedpowerhandlinglevelascompared 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]

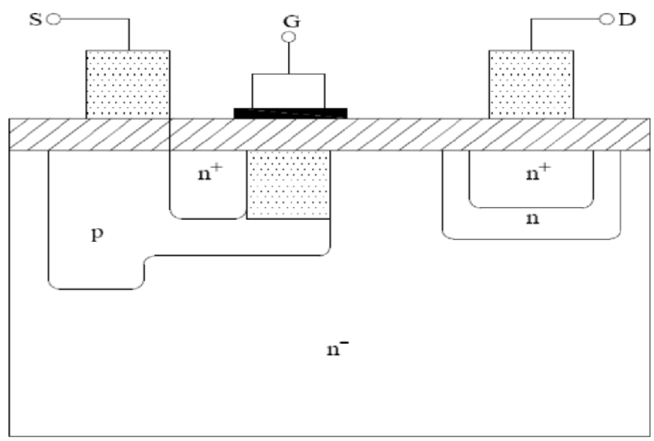
- Asseenfromthisfigure,alltheelementsoftheplanarMOSFETarepresentintheverticalmetal-oxide silicon FET(orsimply VMOS) the metallicsurfaceconnectionto the terminals of the device.
- The vertical-MOSEFT (or simple VMOS) is a component designed to handle much larger drain currentsthan the standard MOSEFT.
- ThecurrenthandlingcapabilityoftheVMOSisaresultofitsphysicalconstructionwhichisillustrated in Fig.Asseen fromthis figure, the component gas materials that are labelled as P,$N^+$and N^-.
- TheN^-materiallabelsindicatedifferencesindopinglevels.
- Alsonoticethatthereisnophysicalchannelconnectingthesource(attop)andthedrain(atbottom). Thus VMOS is an *enhancementtype* MOSEFT.
- WithV-shapedgate,alargerchannelisformedbyapositivegatevoltage.
- Withalargechannel,thedeviceiscapableofhandlinglargeamountofdraincurrent.
- TheOperationofVMOSisillustratedinFig.

VMOSOperation:-

- Whenapositivegatevoltageisappliedtothedevice,anN-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.
- AnotheradvantagesofusingVMOSidthefactitisnotsusceptibletothermalrunaway.
- TheVMOShasapositivetemperaturecoefficient,meansthattheresistanceofthecomponentincreases when temperature increases.
- Thusanincreaseintemperaturewillcauseadecreaseindraincurrent.
- TheVMOSdevicecanbefabricatedwithmorethanoneV-grovetoincreaseamountofdraincurrent and some other performance characteristics.

❖ LDMOS:-

- TheLDMOS(i.e.LateralDoubleDiffusedMOSFET) is another type of power MOSFET.
- This MOSFET uses a very small channel region andaheavilydopedN-typeregion(N^+)to obtain 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-typematerial 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 and the 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 $r_{d(ON)}$.



LDMOS

- Withalowchannelresistance,theLDMOSdevicecanhandleveryhighamountofcurrentwithout generating and damaging amount of heat.
- TheLDMOShastypicalvaluesof$r_{d(ON)}$thatareintherangeof2Ωorless.
- Withthislowvaluechannelresistance,itistypicallycapableofhandlingcurrentashighas20A.

❖ C-MOS:-

- C-MOSmeanscomplementaryMOS.Thesearemostlyusedinthefieldofdigitalelectronicsto manufacture logic gates and many other synchronous and asynchronous circuits.
- ThelogicgatesincludesAND,OR&NOTgatesandtheirvariouscombinations.
- Thesynchronouscircuitincludesflip-flops,counters,memories,A/DandD/Aconverters.
- Theasynchronouscircuitincludescombinationsoflogicgatessuchasdecoders,encoders,multiplexers and de-multiplexers etc.
- ACMOSlogiccircuitconsistsofcombinationsofNMOS&PMOSdevices.

[CHAPTER–5]

------------------- [FEEDBACKAMPLIFIER] -----------------

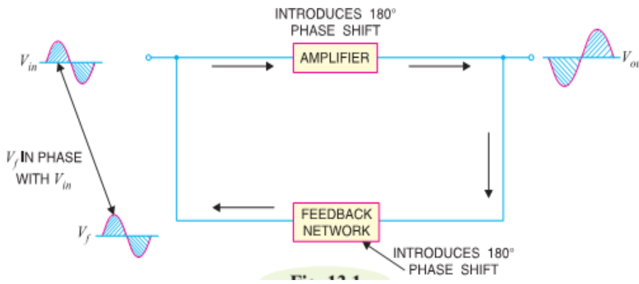
❖ INTRODUCTION:-

- Apracticalamplifierhasagainofnearlyonemillioni.e.itsoutputisonemilliontimestheinput. Consequently,evenacasualdisturbanceattheinputwillappearintheamplifiedformintheoutput.
- The noise in the output of an amplifier is undesirable and must be kept to as small a level as possible. The noise level in amplifiers can be reduced considerably by the use of negative feedback i.e. by injecting a fraction of output in phase opposition to the input signal.
- Theobjectofthischapteristoconsidertheeffectsandmethodsofprovidingnegativefeedbackin transistor amplifiers.

❖ FEEDBACK:-

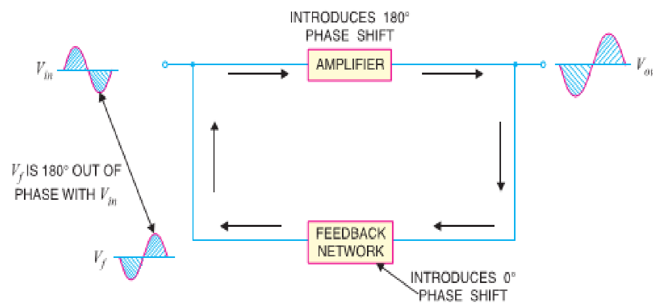
- Theprocessofinjectingafractionofoutputenergyofsomedevicebacktotheinputisknownas **feedback.** Depending upon whether the feedback energy aids or opposes the input signal, there are twobasic types of feedback in amplifiers vizPositive Feedbackand Negative Feedback.

PositiveFeedback. When the feedback energy (voltage or current) is in phase with the inputsignal and thus aids it, it is called *positivefeedback*. This is illustrated in Fig.



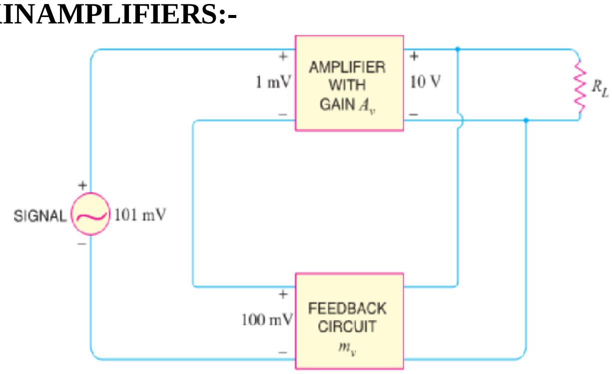
- Both amplifier and feedback network introduce a phaseshiftof180°.Theresultisa360°phase shiftaroundtheloop,causingthefeedback voltage V_f to be in phase with the input signal V_{in}.
- The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability.Therefore, positive feedback is not often employed in amplifiers.
- Oneimportantuseofpositivefeedbackisinoscillators.Ifpositivefeedbackissufficientlylarge,itleads 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)NegativeFeedback. When the feedback energy (voltage or current) is out of phase withthe input signal and thus opposes it, it is called *negativefeedback*. This is illustrated in Fig.



- As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback networkissodesignedthatitintroducesno phaseshift(i.e.,0°phaseshift).Theresultisthat thefeedbackvoltage$V_f$is180°outofphasewiththeinputsignalV_{in}.
- Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reductionindistortion,stability ingain,increasedbandwidthandimprovedinputandoutputimpedances.
- Itisduetotheseadvantagesthatnegativefeedbackisfrequentlyemployedinamplifiers.

❖ PRINCIPLESOFNEGATIVEVOLTAGEFEEDBACKINAMPLIFIERS:-



- 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 feedbackin an amplifier. Typical values have been assumed to make the treatment more illustrative.
- The output of the amplifier is 10 V. The fraction m_v of this output i.e.100 mV is feedback to the input where it is applied in series with the input signal of 101 mV.
- Asthefeedbackisnegative,therefore,only1mVappearsattheinputterminalsoftheamplifier.

Referring to Fig., we have,

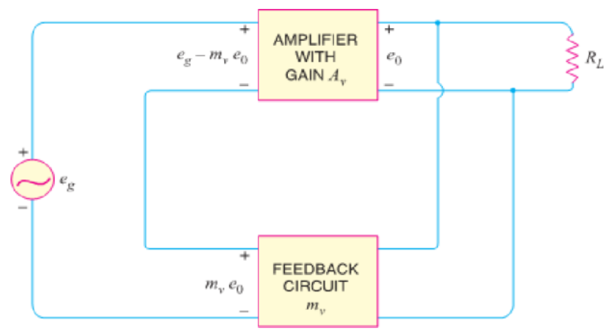
- Gain of amplifier without feedback, $A_v = (10\ V)/(1\ mV) = 10,000$
- Fraction of output voltage feedback, $m_v = (100\ mV)/10V = 0.01$
- Gain of amplifier with negative feedback, $A_{vf} = 10V/101mV = 100$

The following points are worth noting:-

- When negative voltage feedback is applied, the gain of the amplifier is reduced. Thus, the gain of above amplifier without feedback is 10,000 whereas with negative feedback, it is only 100.
- When negative voltage feedback is employed, the voltage actually applied to the amplifier is extremely small. In this case, the signal voltage is 101 mV and the negative feedback is 100 mV so that voltage applied at the input of the amplifier is only 1 mV.
- In a negative voltage feedback circuit, the feedback fraction m_v is always between 0 and 1.
- The gain with feedback is sometimes called **closed-loop gain** while the gain without feedback is called ***open-loop gain***. These terms come from the fact that amplifier and feedback circuits form a "loop".
- When loop is "opened" by disconnecting feedback circuit from I/P, amplifier's gain $\mathbf{A_v}$, [open-loop gain]
- When the loop is "closed" by connecting the feedback circuit, gain decreases to $\mathbf{A_{vf}}$ ["closed-loop" gain]

GAIN OF NEGATIVE VOLTAGE FEEDBACK AMPLIFIER:-

Consider the negative voltage feedback amplifier shown in Fig.



The gain of the amplifier without feedback is $\mathbf{A_v}$.

Negative feedback is then applied by feeding a fraction $\mathbf{m_v}$ of the output voltage $\mathbf{e_0}$ back to amplifier input.

Therefore, the actual input to the amplifier is the signal voltage $\mathbf{e_g}$ minus feedback voltage $\mathbf{m_v e_0}$ i.e.,

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

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

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

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

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

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

∴ Voltage gain with negative feedback is

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

It may be seen that the gain of the amplifier without feedback is A_v. However, when negative voltage feedback is applied, the gain is reduced by a factor $1 + A_v m_v$.

It may be noted that negative voltage feedback does not affect the current gain of the circuit.

ADVANTAGES OF NEGATIVE VOLTAGE FEEDBACK:-

The following are the advantages of negative voltage feedback in amplifiers:-

- **Gain Stability**. An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

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

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

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

It may be seen that the gain now depends only upon feedback fraction m_v i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.

- **(ii)Reducesnon-linearDistortion.** Alargesignalstagehasnon-lineardistortionbecauseitsvoltage gainchangesatvariouspointsinthecycle.Thenegativevoltagefeedbackreducesthenonlinear distortion in large signal amplifiers. It can be proved mathematically that:

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

Where D=distortioninamplifierwithoutfeedback
D_{vf}=distortioninamplifierwithnegativefeedback

Thusbyapplyingnegativevoltagefeedbacktoanamplifier,distortionisreducedbyafactor **$1+A_v m_v$**.

- **(iii)ImprovesFrequencyResponse**. As feedback is usually obtained through a resistive network,therefore,voltagegainoftheamplifieris independentofsignalfrequency.Theresultis thatvoltagegain oftheamplifierwillbesubstantiallyconstantoverawiderangeofsignalfrequency.Thenegative voltage feedback, therefore, improves the frequency response of the amplifier.
- **(iv)IncreasesCircuitStability.** Theoutputofanordinaryamplifieriseasilychangedduetovariations inambient temperature, frequency and signalamplitude.Thischanges thegain of the amplifier,resulting indistortion.However,byapplyingnegativevoltagefeedback,voltagegainoftheamplifierisstabilized or accurately fixed in value. This can be easily explained. Suppose the output of a negative voltagefeedbackamplifierhasincreasedbecauseoftemperaturechangeorduetosomeotherreason.This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.
- **(v)Increasesinputimpedanceanddecreasesoutputimpedance.** The negative voltage feedback increasestheinputimpedance anddecreasestheoutputimpedance ofamplifier.Suchachangeis profitable in practice as the amplifier can then serve the purpose of impedance matching.

FEEDBACKCIRCUIT:-

The function of the feedback circuit is to return a fraction of the output voltage to the input of the amplifier.

Fig. shows the feedback circuit of negative voltage feedback amplifier. It is essentially a potential divider consisting of resistances R_1 and R_2.

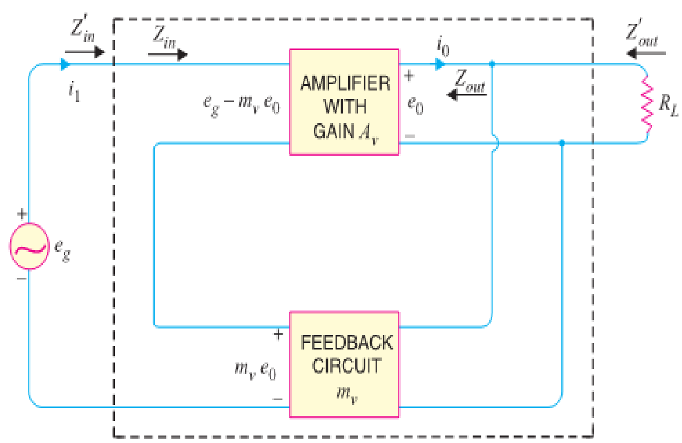
The output voltage of the amplifier is fed to this potential divider which gives the feedback voltage to the input.

Referring to Fig. it is clear that : Voltage across $R_1 = \left(\frac{R_1}{R_1 + R_2}\right) e_0$

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

INPUT&OUTPUTIMPEDANCEOFNEGATIVEFEEDBACKAMPLIFIER:-

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



ReferringtoFig.,wehave, $e_g - m_v e_0 = i_1 Z_{in}$

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

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

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

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

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

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

- Itisclearthatbyapplyingnegativevoltagefeedback,theinputimpedanceoftheamplifierisincreased by a factor 1 + $A_v m_v$. As $A_v m_v$ is much greater than unity.
- Therefore,inputimpedanceisincreasedconsiderably.Thisisanadvantage,sincetheamplifierwillnow present less of a load to its source circuit.

♣ **(b)Outputimpedance.**Followingsimilarline,wecanshowthatoutputimpedancewithnegative voltage feedback is given by :

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

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

- Itisclearthatbyapplyingnegativefeedback,theoutputimpedanceoftheamplifierisdecreasedbya factor 1 + $A_v m_v$.
- Thisisanaddedbenefitofusingnegativevoltagefeedback.
- Withlowervalueofoutputimpedance,theamplifierismuchbettersuitedtodrivelowimpedanceloads.

❖ EMITTERFOLLOWER:-

- Itisanegativecurrentfeedbackcircuit.Theemitterfollowerisacurrentamplifierthathasnovoltage gain.Its mostimportantcharacteristicis that ithas high input impedanceandlowoutputimpedance.
- Thismakesitanidealcircuitforimpedancematching.

♣ CircuitDetails.

- Fig.shows the circuit of an emitter follower. Aswe can see, it differs from the circuitry of a conventionalCE amplifier by the absence of *collectorload* and *emitterbypasscapacitor*.
- TheemitterresistanceR$_E$itselfactsastheloadanda.c.outputvoltage(V_{out})istakenacrossR$_E$.
- Thebiasingisgenerallyprovidedbyvoltage-dividermethodorbybaseresistormethod.
- Thefollowingpointsareworthnotingabouttheemitterfollower:
  - **(i)** Thereisneithercollectorresistorinthecircuitnorthereisemitterbypasscapacitor.
  - **(ii)** Thesearethetwocircuitrecognitionfeaturesoftheemitterfollower.
  - **(iii)** Since the collector is at ac ground, this circuit is also known as common collector (CC) amplifier.

♣ **Operation.**The input voltage is applied between baseand emitter and the resulting a.c. emitter current produces an output voltage $i_e R_E$ across the emitter resistance.

- This voltage opposes the input voltage, thus providing negative feedback.
- Clearly, it is a negative current feedback circuit since the voltage feedback is proportional to the emitter current i.e., output current.
- It is called **emitterfollower** because the output voltage follows the input voltage.

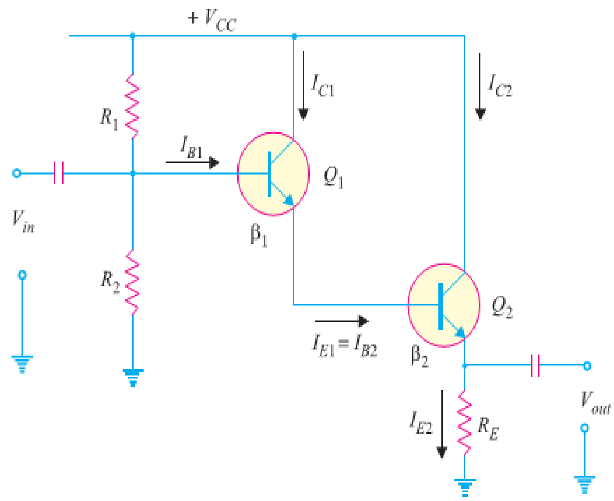
♣ Characteristics.

- Themajorcharacteristicsoftheemitterfollowerare:-
  - **(i)** Novoltagegain.Infact,thevoltagegainofanemitterfolloweriscloseto1.
  - **(ii)** Relativelyhighcurrentgainandpowergain.
  - **(iii)** Highinputimpedanceandlowoutputimpedance.
  - **(iv)** Inputandoutputacvoltagesareinphase.

♣ APPLICATIONS

- Theemitterfollowerhasthefollowingprincipalapplications:
  - (i) Toprovidecurrentamplificationwithnovoltagegain.
  - (ii) Impedancematching.

❖ DARLINGTONAMPLIFIER:-



- Sometimes, the current gain and input impedance ofan emitter follower are insufficient to meet the requirement.
- Inordertoincreasetheoverallvaluesofcircuit currentgain(A_i)andinputimpedance,two transistors are connected in series in emitter follower configuration as shown in Fig.
- Suchacircuitiscalled**Darlingtonamplifier**.
- Note that emitter of first transistor is connected to the base of the second transistor and the collectorterminals of the two transistors are connectedtogether.
- The result is that emitter current of the first transistoris the base current of the second transistor.
- Therefore, the current gain of the pair is equal toproduct of individual current gains i.e.

$I_{E1} = \beta_1 I_{B1} \quad (\because I_{E1} \simeq I_{C1})$

Now I_{E1} is the base current of Q_2 *i.e.* $I_{E1} = I_{B2}$.

Now $I_{E2} = \beta_2 I_{B2} = \beta_2 I_{E1} = \beta_2 \beta_1 I_{B1}$

$\therefore$ Overall current gain, $\beta = \frac{I_{E2}}{I_{B1}} = \frac{\beta_1 \beta_2 I_{B1}}{I_{B1}} = \beta_1 \beta_2$

$$\beta=\beta_1\beta_2$$

- Notethathighcurrentgainisachievedwitha minimum use of components. The biasing analysis is similar to that for one transistor except that two V_{BE}drops are to be considered.
- ThusreferringtoFig.,

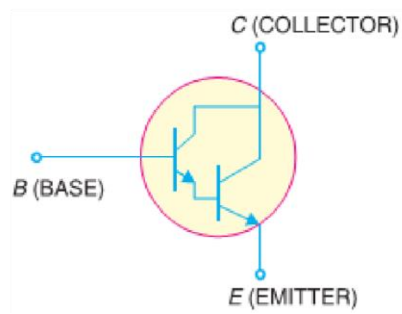
VoltageacrossR$_2$, $V_2=\frac{V_{CC}}{R_1+R_2}\times R_2$

VoltageacrossR$_E$, $V_E=V_2-2V_{BE}$

CurrentthroughR$_E$, $I_{E2}=\frac{V_2-2V_{BE}}{R_E}$

- Sincethetransistorsaredirectlycoupled,$I_{E1}=I_{B2}$.Now$I_{B2}=I_{E2}/\beta_2$.

$\therefore \quad I_{E1}=\frac{I_{E2}}{\beta_2}$



- In practice, the two transistors are put inside single transistor housingand three terminals E, B and C are brought out as shown in Fig.
- Thisthreeterminaldeviceisknownasa**Darlingtontransistor**.
- TheDarlingtontransistoractslikeasingletransistorthathashighcurrentgainandhighinputimpedance.

♣ **Characteristics.**ThefollowingaretheimportantcharacteristicsofDarlingtonamplifier:

(i) Extremelyhighinputimpedance(MΩ).
(ii) Extremely high current gain (several thousands).
(iii)Extremely low output impedance (a few Ω).

- SincethecharacteristicsoftheDarlingtonamplifierarebasicallythesameasthoseoftheemitter follower, the two circuits are used for similar applications.
- Whenyouneedhigherinputimpedanceandcurrentgainand/orloweroutputimpedancethanthe standard emitter follower can provide, you use a Darlington amplifier.
- Darlingtontransistorsarecommonlyavailable.Likestandardtransistors,theyhaveonlythreeterminals but they have much higher values of current gain and input impedance.

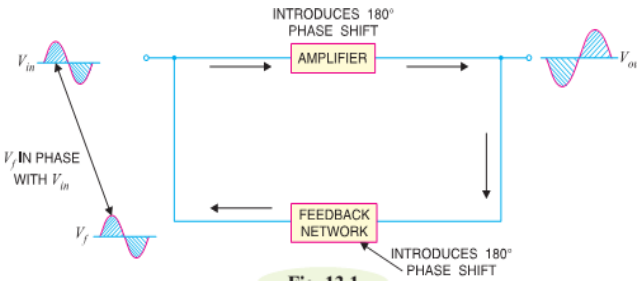
[CHAPTER–6]

------------------- [SINUSOIDALOSCILLATOR] -----------------

❖ **FEEDBACK:-**

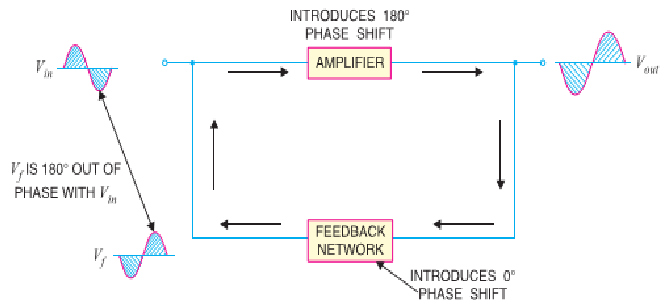
- Theprocessofinjectingafractionofoutputenergyofsomedevicebacktotheinputisknownas feedback.
- Dependinguponwhetherthefeedbackenergyaidsoropposestheinputsignal,therearetwobasictypes of feedback in amplifiers viz Positive Feedback and Negative Feedback.

PositiveFeedback. When the feedback energy (voltage or current) is in phase with the inputsignal and thus aids it, it is called *positivefeedback*. This is illustrated in Fig.



- Both amplifier and feedback network introduce a phaseshiftof180°.Theresultisa360°phase shiftaroundtheloop,causingthefeedback voltage V_f to be in phase with the input signal V_{in}.
- The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability.Therefore, positive feedback is not often employed in amplifiers.
- Oneimportantuseofpositivefeedbackisinoscillators.Ifpositivefeedbackissufficientlylarge,itleads 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)NegativeFeedback. When the feedback energy (voltage or current) is out of phase withthe input signal and thus opposes it, it is called *negativefeedback*. This is illustrated in Fig.

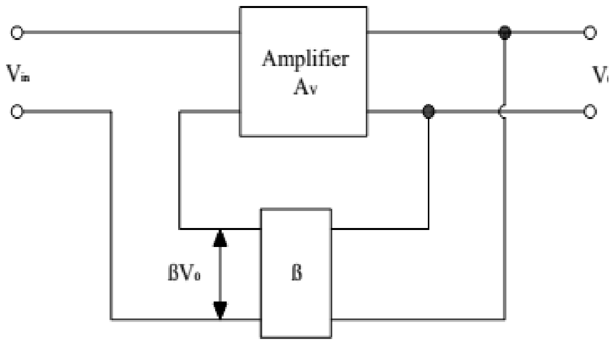


- As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback networkissodesignedthatitintroducesno phaseshift(i.e.,0°phaseshift).Theresultisthat thefeedbackvoltage$V_f$is180°outofphasewiththeinputsignalV_{in}.
- Negativefeedbackreducesthegainoftheamplifier.However,theadvantagesofnegativefeedbackare: reductionindistortion,stability ingain,increasedbandwidthandimprovedinputandoutputimpedances.

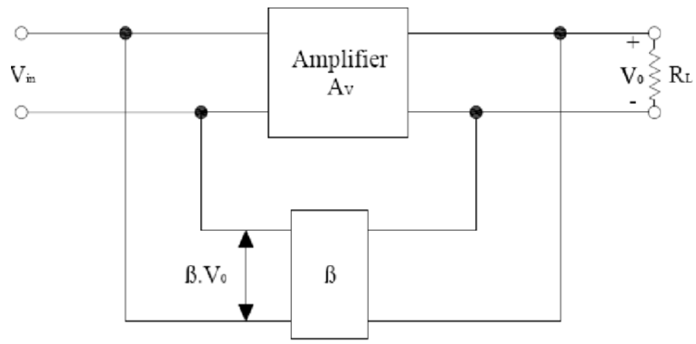
❖ Itisduetotheseadvantagesthatnegativefeedbackisfrequentlyemployedinamplifiers.

❖ **<u>TypesOfFeedbackConnections</u>:-**

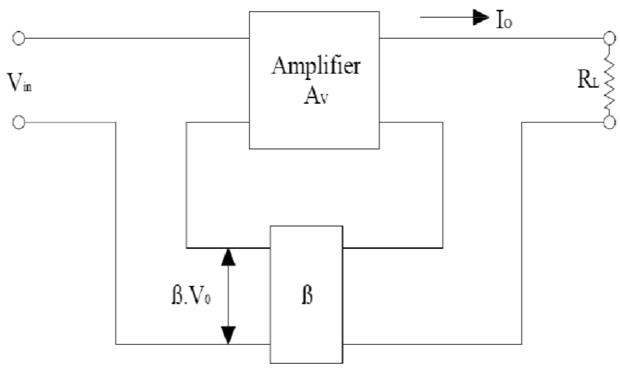
- Therearefourbasictypesofconnectingthefeedbacksignalfromanamplifieroutputtoitsinput:-
  - ♣ Voltage-Seriesfeedbackconnection.
  - ♣ Voltage-Shuntfeedbackconnection.
  - ♣ Current-Seriesfeedbackconnection.
  - ♣ Current-Shuntfeedbackconnection.
- Itmeansthatbothvoltageandcurrentcanbefeedbacktotheinputeitherinseriesorparallel.
- Inthefeedbackconnectiontypes,theterm**'voltage'**referstoconnectingtheoutputvoltageasinputto the feedback network.
- Theterm**'current'**referstotappingoffsomeoutputcurrentthroughthefeedbacknetwork.
- Theterm'**series'**referstoconnectingthefeedbacksignalinserieswiththeinputsignalvoltage.
- Theterm'**shunt'**referstoconnectingthefeedbacksignalinshunt(parallel)withaninputcurrentsource.
- Ithasbeenobservedthattheseriesfeedbackconnectionstendtoincreasetheinputresistance,whilethe shunt feedback connection tends to decrease the input resistance.
- Moreover,thevoltagefeedbackwilltendtodecreasetheoutputresistance.
- Asamatteroffact,higherinputresistanceandloweroutputresistanceisdesiredformostcascade amplifiers.
- Bothofthesecharacteristicareobtainedbyusingthevoltage–seriesfeedbackconnection.



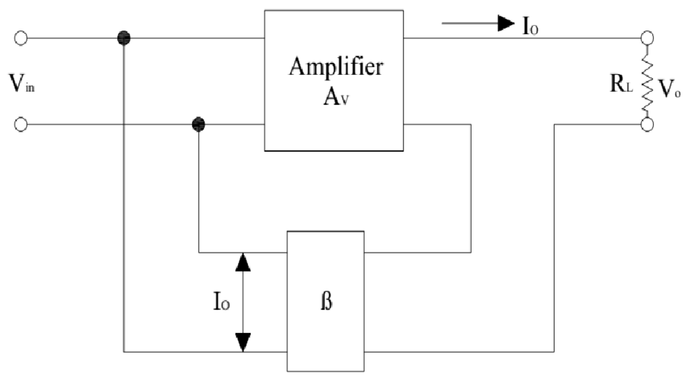
Feedback Network
[Voltage - Series Feedback Connection]



Feedback Network
[Voltage - Shunt Feedback Connection]



Feedback Network
[Current - Series Feedback Connection]



Feedback Network
[Current - Shunt Feedback Connection]

❖ ADVANTAGESOFNEGATIVEVOLTAGEFEEDBACK:-

Thefollowingaretheadvantagesofnegativevoltagefeedbackinamplifiers:-

- **(i)GainStability**.Animportantadvantageofnegativevoltagefeedbackisthattheresultantgainofthe amplifier can bemade independent oftransistorparameters or the supply voltage variations.

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

For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product $A_v m_v$muchgreaterthanunity.Therefore,intheaboverelation,1canbeneglectedascomparedto$A_v m_v$ and the expression becomes:

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

It may be seen that the gain now depends only upon feedback fraction m_v i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffectedbychangesintemperature,variationsintransistorparametersandfrequency.Hence,thegain of the amplifier is extremely stable.

- **(ii)Reducesnon-linearDistortion.**Alargesignalstagehasnon-lineardistortionbecauseitsvoltage gainchangesatvariouspointsinthecycle.Thenegativevoltagefeedbackreducesthenonlinear distortion in large signal amplifiers. It can be proved mathematically that:

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

Where D=distortioninamplifierwithoutfeedback
D_{vf}=distortioninamplifierwithnegativefeedback

Thusbyapplyingnegativevoltagefeedbacktoanamplifier,distortionisreducedbyafactor**$1+A_v m_v$**.

- **(iii)ImprovesFrequencyResponse**.Asfeedbackisusuallyobtainedthrougharesistivenetwork, therefore, voltage gain of the amplifier is independent of signal frequency.

Theresultisthatvoltagegainoftheamplifierwillbesubstantiallyconstantoverawiderangeofsignal frequency.The negativevoltagefeedback,therefore,improvesthefrequency response oftheamplifier.

- **(iv)IncreasesCircuitStability.**Theoutputofanordinaryamplifieriseasilychangedduetovariations in ambient temperature, frequency and signal amplitude.

This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilized or accurately fixed in value.

This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason.

Thismeansmorenegativefeedbacksincefeedbackisbeinggivenfromtheoutput.Thistendstooppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.

(v)Increasesinputimpedanceanddecreasesoutputimpedance. The negative voltage feedback increasestheinputimpedanceanddecreasestheoutputimpedanceofamplifier.Suchachangeis profitable in practice as the amplifier can then serve the purpose of impedance matching.

INTRODUCTIONTOOSCILLATOR,

Many electronic devices require a source of energy at a specific frequency which may range from a few Hz to several MHz. This is achieved by an electronic device called an oscillator.

Oscillatorsareextensivelyusedinelectronicequipment.Forexample,inradioandtelevisionreceivers, oscillators are usedtogenerate high frequency wave(calledcarrierwave) inthetuning stages.

Audio frequency and radiofrequency signals are required for the repair of radio, television and other electronic equipment. Oscillators are also widely used in radar, electronic computers and other electronic devices. Oscillatorscan produce sinusoidal or non-sinusoidal (e.g. square wave) waves.

SINUSOIDALOSCILLATORS:-

An electronic device that generates sinusoidal oscillations of desired frequency is known as a **sinusoidaloscillator**. Although we speak of an oscillator as “generating” a frequency, it should be noted that it does not create energy, but merely acts as an energy converter.

ItreceivesD.C.energyandchangesitintoA.C.energyofourdesiredfrequency.

The frequency of oscillations depends upon the constants of the device. It may be mentioned here that although analternator produces sinusoidal oscillations of 50Hz, itcannotbecalledanoscillator.

Firstly, An alternator is a mechanical device having rotating parts whereas an oscillator is a non-rotating electronic device. **Secondly**, An alternator converts Mechanical Energy into A.C. Energy while anoscillator converts D.C. Energy into A.C. energy. **Thirdly**, An alternator cannot produce high frequency oscillationswhereasanoscillatorcanproduce oscillationsranging froma fewHzto several MHz.

ADVANTAGES

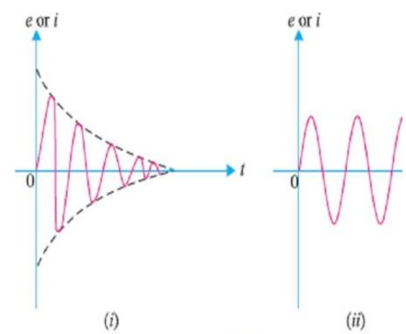
Although oscillations can be produced by mechanical devices (e.g. alternators), but electronicoscillatorshave the following advantages:

- Anoscillatorisanon-rotatingdevice.Consequently,thereislittlewearandtearandhencelongerlife.
- Duetotheabsenceofmovingparts,theoperationofanoscillatorisquitesilent.
- Anoscillatorcanproducewavesfromsmall(20Hz)toextremelyhighfrequencies(>100MHz).
- Thefrequencyofoscillationscanbeeasilychangedwhendesired.
- Ithasgoodfrequencystabilityi.e.frequencyoncesetremainsconstantforaconsiderableperiodoftime.
- Ithasveryhighefficiency.

TYPESOFSINUSOIDALOSCILLATIONS:-

Sinusoidaloscillationscanbeoftwotypesviz**DampedOscillations**and**UndampedOscillations**.

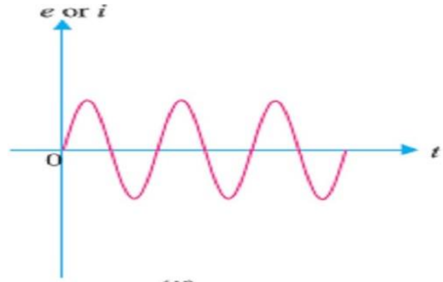
- **(i)DampedOscillations**:-Theelectricaloscillationswhose amplitudegoesondecreasingwithtimearecalleddamped oscillations. Fig (i) Shows waveform of damped electrical oscillations.



Obviously, the electrical system in which these oscillations aregenerated has losses and some energy is lost during each oscillation.

Further, no means are provided to compensate for the losses and consequently the amplitude of the generated wave decreases gradually.Itmaybenotedthatfrequencyofoscillationsremainsunchanged since it depends upon the constants of the electrical system.

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

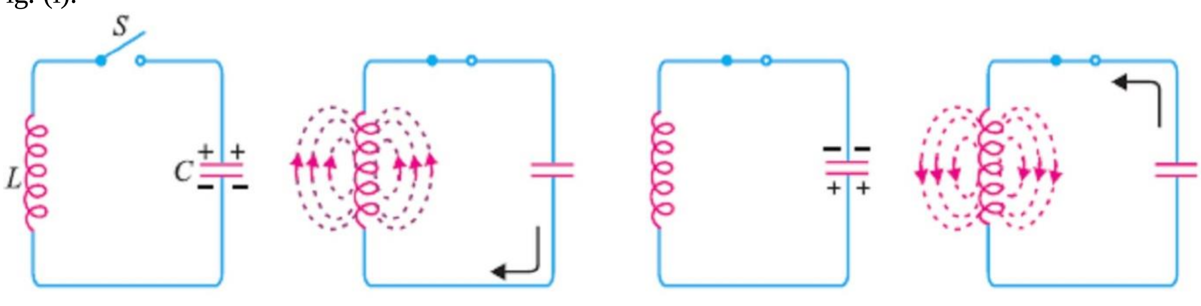


(ii)

- Althoughtheelectricalsysteminwhichtheseoscillationsare beinggeneratedhasalsolosses,butnowrightamountofenergy is being supplied to overcome the losses.
- Consequently, the amplitude of the generated wave remains constant.Itshouldbeemphasizedthatanoscillatorisrequiredto produceundampedelectricaloscillationsforutilizinginvariouselectronicsequipment.

❖ **OSCILLATORYCIRCUIT:-**

- Acircuitwhichproduceselectricaloscillationsofanydesiredfrequencyisknownasan**OscillatoryCircuit** or **TankCircuit**.
- Asimpleoscillatorycircuitconsistsofacapacitor(C)andinductancecoil(L)inparallelasshownin Fig.Thissystemcanproduce electricaloscillationsoffrequency determinedby thevaluesofL andC.
- Tounderstandhowthiscomesabout,supposethecapacitorischargedfromad.c.sourcewithapolarity as shown in Fig. (i).



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

- **(i)**InthepositionshowninFig(i),theupperplateofcapacitorhasdeficitofelectronsandthelower plate has excess of electrons. Therefore, there is a voltage across the capacitor and the capacitor has electrostatic energy.
- **(ii)** When switch Sis closed as shown in Fig (ii), the capacitor will discharge through inductance and the electron flow will be in the direction indicated by the arrow.
- This current flow sets up magnetic field around the coil. Due to the inductive effect, the current builds up slowly towards a maximum value.
- The circuit current will be maximum when the capacitor is fully discharged. At this instant, electrostatic energy is zero but because electron motion is greatest (i.e. maximum current), the magnetic field energy around the coil is maximum. This is shown in Fig (ii).
- Obviously,theelectrostaticenergyacrossthecapacitoriscompletelyconvertedintomagneticfield energy around the coil.
- **(iii)**Oncethecapacitorisdischarged,themagneticfieldwillbegintocollapseandproduceacounter e.m.f.AccordingtoLenz'slaw,thecountere.m.f.willkeepthecurrentflowinginthesamedirection.
- The result is that the capacitor is now charged with opposite polarity, making upper plate of capacitor negative and lower plate positive as shown in Fig (iii).
- **(iv)** After the collapsing field has recharged the capacitor, the capacitor now begins to discharge; current now flowing in the opposite direction.
- Fig (iv) shows capacitor fully discharged and maximum current flowing. The sequence of charge and discharge results in alternating motion of electrons or an oscillating current.
- The energy is alternately stored in the electric field of the capacitor (C) and the magnetic field of the inductancecoil(L).Thisinterchangeofenergy betweenL andCisrepeatedoverandagainresulting in the production of oscillations.

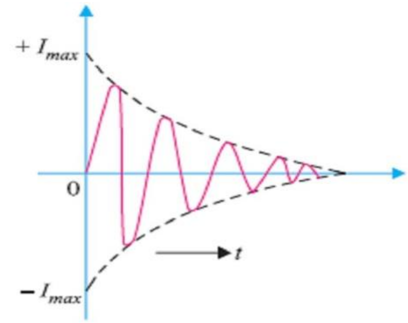
♣ **WAVEFORM.**

✍Iftherewerenolossesinthetankcircuittoconsumetheenergy,theinterchangeofenergybetweenL and C would continue indefinitely.

✍Ina practicaltankcircuit,therearereresistiveandradiationlossesin the coil and dielectric losses in the capacitor. During each cycle, a small part of the originally imparted energy is used up to overcome these losses.

✍The result is that the amplitude of oscillating current decreases gradually and eventually it becomes zero when all the energy is consumed as losses.

✍Therefore, the tank circuit by itself will produce damped oscillationsas shown in Fig.



♣ **Frequencyofoscillations.**

✍ThefrequencyofoscillationsinthetankcircuitisdeterminedbytheconstantsofthecircuitvizLandC.

✍The actual frequency of oscillations is the resonant frequency (or natural frequency) of the tank circuitgiven by :

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

✍ItisclearthatfrequencyofoscillationsinthetankcircuitisinverselyproportionaltoLandC.Thiscan be easily explained.

✍If a large value of capacitor is used, it will take longer for the capacitor to charge fully and also longer to discharge. This will lengthen the period of oscillations in the tank circuit, or equivalently lower its frequency.

✍With a large value of inductance, the opposition to change in current flow is greater and hence the time required to complete each cycle will be longer.

✍Therefore, the greater the value of inductance, the longer is the period or the lower is the frequency of oscillations in the tank circuit.

❖ **UNDAMPEDOSCILLATIONSFROMTANKCIRCUIT:-**

✍Asdiscussedbefore,atankcircuitproducesdampedoscillations.However,inpractice,weneed continuous undamped oscillations for the successful operation of electronics equipment.

✍In order to make the oscillations in the tank circuit undamped, it is necessary to supply correct amount ofenergy to the tank circuit at the proper time intervals to meet the losses.

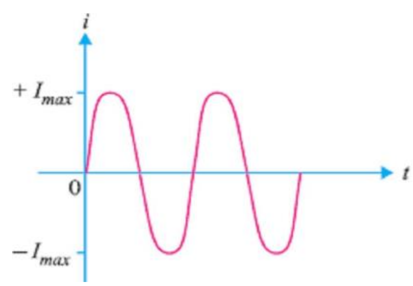
✍ThusreferringbacktoFigoftankcircuit,anyenergywhichwouldbeappliedtothecircuitmusthavea polarity conforming to the existing polarity at the instant of application of energy.

✍Iftheappliedenergyisofoppositepolarity,itwouldopposetheenergyinthetankcircuit,causing stoppage of oscillations.

✍Therefore,inordertomaketheoscillationsinthetankcircuit undamped, the following conditions must be fulfilled :

♣ **(i)** The amount of energy supplied should be such so as to meet the lossesinthetankcircuitandthea.c.energyremovedfromthe circuit by the load.

✘For instance, if losses in LC circuit amount to 5 mW and a.c. output being taken is 100 mW, then power of 105 mW should be continuously supplied to the circuit.



♣ **(ii)**Theappliedenergyshouldhavethesamefrequencyasthatoftheoscillationsinthetankcircuit.

♣ **(iii)** The applied energy should be in phase with the oscillations set up in the tank circuit i.e. it should aidthe tank circuit oscillations.

♣ Ifthesecconditionsarefulfilled,thecircuitwillproducecontinuousundampedoutputasshowninFig.

❖ **POSITIVEFEEDBACKAMPLIFIER—OSCILLATOR:-**

Atransistoramplifierwithproperpositivefeedbackcanactasanoscillatori.e.,itcangenerate oscillations without any external signal source.

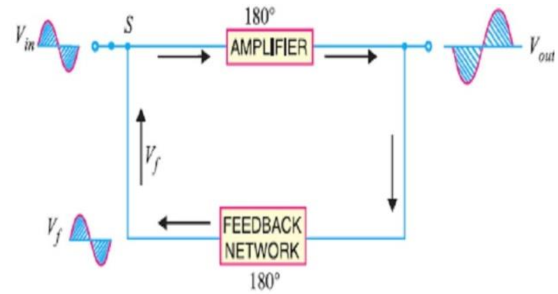
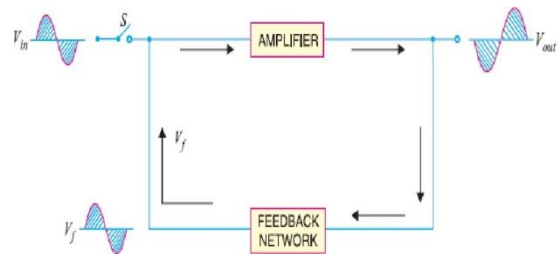


Fig shows a transistor amplifier with positive feedback. Remember that a positive feedback amplifier is one that produces a feedback voltage (V_f) that is in phase with the original input signal.

Aswecansee,thisconditionismetinthecircuitshown in Fig. A phase shift of 180° is produced by the amplifier andafurtherphaseshiftof180°isintroducedby feedback network.

Thus,thesignalisshiftedby360°andfedtotheinput i.e., feedback voltage is in phase with the input signal.



(i) We note that the circuit shown in Fig is producing oscillations in the output. However, this circuit has an input signal. This is inconsistent with our definition of an oscillator i.e., an oscillator is a circuit that produces oscillations without any external signal source.

(ii) WhenweopentheswitchSofFig(i),wegetthe circuitshowninFig(ii).Thismeanstheinputsignal(V_{in})isremoved.However,V_f (whichisinphase with original signal) is still applied to the input signal.

TheamplifierwillrespondtothissignalinthesamewaythatitdidtoV_{in} i.e.,V_f willbeamplifiedand sent to the output. The feedback network sendsaportion of the output back to the input.

Therefore,theamplifierreceivesanotherinputcycleandanotheroutputcycleisproduced.Thisprocess will continue so long as the amplifier is turned on.

Therefore,theamplifierwillproducesinusoidaloutputwithnoexternalsignalsource.Thefollowing points may be noted carefully :

- Atransistoramplifierwithproperpositivefeedbackwillworkasanoscillator.
- Thecircuitneedsonlyaquicktriggersignaltostarttheoscillations.
- Oncetheoscillationshavestarted,noexternalsignalsourceisneeded.
- Inordertogetcontinuousundampedoutputfromthecircuit,thefollowingconditionmustbemet:

$$mA=1$$

WhereA_v=VoltageGainofAmplifierwithoutFeedback and m_v=FeedbackFraction

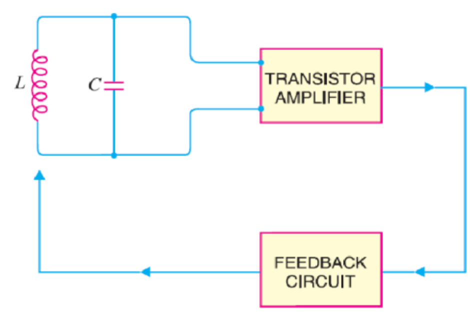
- Thisrelationiscalled**BarkhausenCriterion**.

❖ **ESSENTIALSOFTRANSISTOROSCILLATOR:-**

Figshowstheblockdiagramofanoscillator.Itsessentialcomponentsare:-

- **Tankcircuit**.Itconsistsofinductancecoil(L)connectedinparallelwithcapacitor(C).

The frequency of oscillations circuit depend upon the values of inductance of the coil and capacitance of the capacitor.



- **(ii)Transistor Amplifier.**Thetransistoramplifierreceives D.C. power from the battery and changes it into a.c. power for supplying to the tank circuit.

The oscillations occurring in the tank circuit are applied to the input of the transistor amplifier. Because of the amplifying properties of the transistor, we get increased output of these oscillations.

ThisamplifiedoutputofoscillationsisduetotheD.C.powersuppliedbythebattery.

Theoutputofthetransistorcanbesuppliedtothetankcircuittomeetthelosses.

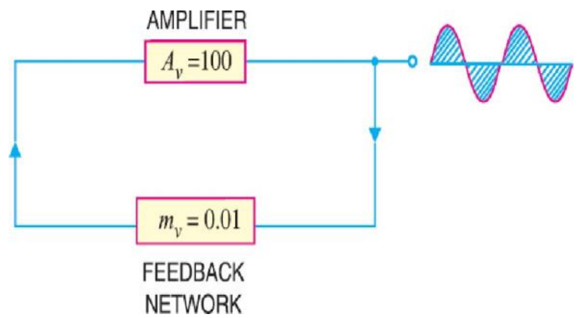
- **(iii)FeedbackCircuit**.The feedback circuit supplies a part of collector energy to the tankcircuit incorrect phase to aid the oscillations i.e. it provides positive feedback.

❖ EXPLANATIONOFBARKHAUSENCRITERION:-

- Barkhausencriterionisthatinordertoproducecontinuousundampedoscillationsattheoutputofan amplifier, the positive feedback should be such that: **$m_v A_v = 1$**
- Oncethisconditionissetinthepositivefeedbackamplifier,continuousundampedoscillationscanbe obtained at the output immediately after connecting the necessary power supplies.
- **(i)MathematicalExplanation.**Thevoltagegainofapositivefeedbackamplifierisgivenby;

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

- We know that we cannot achieve infinite gain in an amplifier. So what does this result infer in physical terms? It means that a vanishing small input voltage would give rise to finite (i.e., a definite amount of) output voltage even when the input signal is zero.
- Thusoncethecircuitreceivestheinputtrigger,itwouldbecomeanoscillator,generatingoscillations with no external signal source.
- **(ii)GraphicalExplanation**.Letusdiscussthe condition $m_v A_v = 1$graphically. Suppose the voltagegain of the amplifier without positive feedback is 100.



- In order to produce continuous undamped oscillations, $m_v A_v = 1$ or $m_v \times 100 = 1$ or $m_v = 0.01$.
- ThisisillustratedinFig.Sincetheconditionm$_v$A$_v$ =1 is met in the circuit shown in Fig, it will produce sustained oscillations.
- Supposetheinitialtriggeringvoltageis0.1Vpeak. Startingwiththisvalue,circuit(A_v=100;m_v=0.01)willprogressasfollows.

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

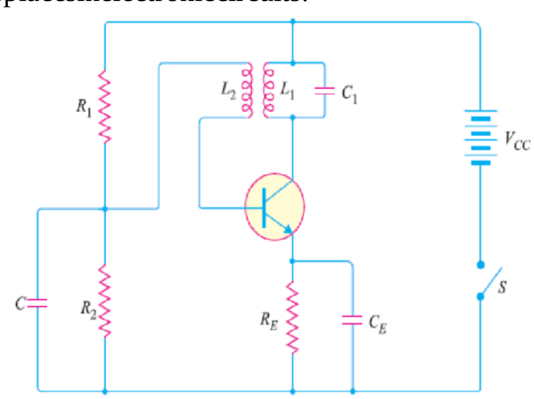
- Thesamethingwillrepeatfor3rd,4thcyclesandsoon.Notethatduringeachcycle,V_f =0.1Vpkand V_{out} = 10 Vpk. Clearly, the oscillator is producing continuous undamped oscillations.
- Therelation$m_v A_v$ =1holdsgoodfortrueidealcircuits.However,practicalcircuitsneedan$m_v A_v$ productthatisslightly greaterthan1.Thisistocompensatefor powerloss(inresistors) inthecircuit.

❖ DIFFERENTTYPESOFTRANSISTOROSCILLATORS:-

- A transistor can work as an oscillator to produce continuous undamped oscillations of any desiredfrequency if tank and feedback circuits are properly connected to it.
- Alloscillatorsunderdifferentnameshavesimilarfunctioni.e.,theyproducecontinuousundamped output. However, the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses.
- Thefollowingarethetransistoroscillatorscommonlyusedatvariousplacesinelectroniccircuits:

(i)TunedCollectorOscillator(ii)Colpitt'sOscillator
(iii)HartleyOscillator (iv)PhaseShiftOscillator
(v)WienBridgeOscillator (vi)CrystalOscillator

❖ TUNEDCOLLECTOROSCILLATOR:-



- Fig shows circuit of tuned collector oscillator. It contains tuned circuit L_1 - C_1in the collector and hence the name.
- The frequency of oscillations depends upon the values of L_1 and C_1 and is given by :

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

- ThefeedbackcoilL$_2$inthebasecircuitismagnetically coupledtothetankcircuitcoilL$_1$.Inpractice,L$_1$andL$_2$formthe primary andsecondary of the transformer respectively.The biasing is provided by potential divider arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations.

- **<u>CircuitOperation</u>**.WhenswitchSisclosed,collectorcurrentstartsincreasingandchargesthe capacitor C_1. When this capacitor is fully charged, it discharges through coil L_1, setting up oscillations of frequency determined by above equation.
- TheseoscillationsinducesomevoltageincoilL_2 bymutualinduction.Thefrequencyofvoltageincoil L_2 isthesame asthatof tankcircuitbutitsmagnitudedependsuponthenumber ofturnsof L_2 and coupling between L_1 and L_2.
- The voltageacrossL_2 isappliedbetweenbaseandemitterandappearsintheamplifiedforminthe collector circuit, thus overcoming the losses occurring in the tank circuit.
- The number of turns of $L_2$and coupling between $L_1$and $L_2$are so adjusted that oscillations across $L_2$are amplified to a level just sufficient to supply losses to the tank circuit.
- Itmaybenotedthatthephaseoffeedbackiscorrecti.e.energysuppliedtothetankcircuitisinphase with the generated oscillations. A phase shift of 180° is created between the voltages of $L_1$and L_2due to transformer action.
- A further phase shift of 180° takes place between base-emitter and collector circuit due to transistor properties.Asaresult,theenergy feedbacktothetankcircuitisinphase withthegeneratedoscillations.

COLPITT'SOSCILLATOR:-

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

$$f = \frac{1}{2\pi\sqrt{LC_T}} \qquad \text{Where} \quad C_T = \frac{C_1 C_2}{C_1 + C_2}$$

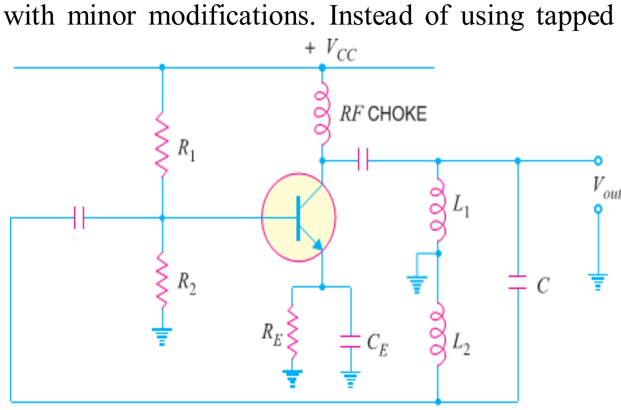
✡Notethat**C_1-C_2-L**isalsothefeedbackcircuitthatproducesaphaseshiftof180°.

- **<u>CircuitOperation.</u>**Whenthecircuitisturnedon,thecapacitorsC_1 andC_2 arecharged.Thecapacitors discharge through L, setting up oscillations of frequency determined by exp.(i).
- OutputvoltageoftheamplifierappearsacrossC_1andfeedbackvoltageisdevelopedacrossC_2.The voltageacross itis 180°out of phase withthevoltagedeveloped acrossC_1(V_{out}) as shown in Fig.
- Itiseasytoseethatvoltagefeedback(voltageacrossC_2)tothetransistorprovidespositivefeedback.
- Aphaseshiftof180°isproducedbytransistorandafurtherphaseshiftof180°isproducedbyC_1-C_2 voltage divider.
- Inthisway,feedbackisproperlyphasedtoproducecontinuousundampedoscillation.
- **Feedbackfractionm$_v$.**TheamountoffeedbackvoltageinColpitt'soscillatordependsuponfeedback fraction m_v of the circuit. For this circuit, Feedback fraction,

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

HARTLEYOSCILLATOR:-

- The Hartley oscillator is similar to Colpitt's oscillator with minor modifications. Instead of using tapped capacitors,twoinductorsL_1andL_2areplaced across a common capacitor C and the centre of the inductors is tapped as shown in Fig.



- The tank circuit is made up of L_1, L_2 and C. The frequencyofoscillationsisdeterminedbythe values of L_1, L_2 and C and is given by :

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

Where**$L_T=L_1+L_2+2M$**

HereM=mutualinductancebetweenL_1andL_2

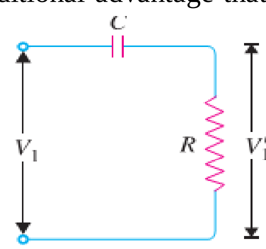
✡NotethatL_1-L_2-Cisalsothefeedbacknetworkthatproducesaphaseshiftof180°.

- ♣ **CircuitOperation**. When the circuit is turned on, the capacitor is charged. When this capacitor is fully charged,itdischargesthroughcoilsL_1andL_2setting uposcillationsoffrequency determinedby equ(i).
- TheoutputvoltageoftheamplifierappearsacrossL_1andfeedback voltage across L_2. The voltage across L_2 is 180° out of phase with the voltage developed across L_1 (V_{out}) as shown in Fig.
- It is easy to see that voltage feedback (i.e., voltage across L_2) to the transistor provides positive feedback.
- Aphaseshiftof180°isproducedbythetransistorandafurtherphase shift of 180° is produced by $L_1 - L_2$ voltage divider.
- In this way, feedback is properly phased to produce continuous undamped oscillations.
- **Feedbackfractionm$_v$.** In Hartley oscillator, the feedback voltage is across L_2 and output voltage is across L_1.

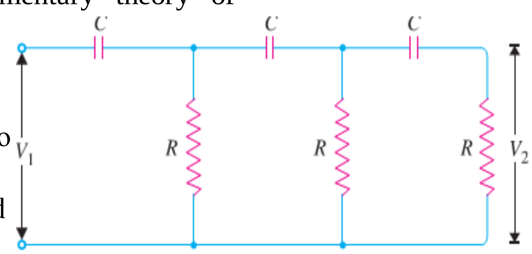
$$m_v = \frac{V_f}{V_{out}} = \frac{X_{L2}}{X_{L1}} = \frac{L_1}{L_2}$$

❖ PRINCIPLEOFPHASESHIFTOSCILLATORS:-

- One desirablefeature ofanoscillatoristhatitshouldfeedbackenergy ofcorrectphasetothetankcircuit to overcome the losses occurring in it.
- In the oscillator circuits discussed so far, the tank circuit employed inductive (L) and capacitive (C) elements.Insuchcircuits,aphaseshiftof180°wasobtainedduetoinductiveorcapacitivecouplingand a further phase shift of 180° was obtained due to transistor properties.
- Inthisway,energysuppliedtothetankcircuitwasinphasewiththegeneratedoscillations.The oscillator circuits employing L-C elements have two general drawbacks.
- **Firstly**,theysufferfromfrequencyinstabilityandpoorwaveform.**Secondly**,theycannotbeusedfor very low frequencies because they become too much bulky and expensive.
- Goodfrequencystabilityandwaveformcanbeobtainedfromoscillatorsemployingresistiveand capacitive elements. Such amplifiers are called R-C or phase shift oscillators and have the additional advantage that they can be used for very low frequencies.



- Inaphaseshiftoscillator,aphaseshiftof180°isobtainedwithaphaseshift circuit instead of inductive or capacitive coupling.
- A further phase shift of 180° is introduced due to the transistor properties. Thus, energy supplied back to the tank circuit is assured of correct phase.
- **PhaseshiftCircuit.** A phase-shift circuit essentially consists of an R-C network. Fig (i) shows a single section of RC network.From the elementary theory of electricalengineering,itcanbeshownthatalternating voltage V'_1across R leads the applied voltage V_1 by φ°. The value of φ depends upon the values of R and C.



- IfresistanceRisvaried,thevalueofφalsochanges.IfR were reduced to zero, V'_1 will lead V_1 by 90° i.e. φ= 90°.
- However,adjustingRtozerowouldbeimpracticablebecause it would lead to no voltage across R.
- Therefore,inpractice,RisvariedtosuchavaluethatmakesV'_1toleadV_1by60°.
- Fig(ii)showsthethreesectionsofRCnetwork.Eachsectionproducesaphaseshiftof60°. Consequently,atotalphaseshiftof180°isproducedi.e.voltageV_2leadsthevoltageV_1by180°.

❖ PHASESHIFTOSCILLATOR:-

- Fig.showsthecircuitofaphaseshiftoscillator.Itconsistsofaconventionalsingletransistoramplifier and a RC phase shift network.
- Thephase shiftnetworkconsistsofthree sectionsR_1C_1, R_2C_2andR_3C_3.At someparticularfrequency f_0, thephaseshiftineachRCsectionis60°sothatthetotalphase-shiftproducedbytheRCnetworkis180°.
- Thefrequencyofoscillationsisgivenby:

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

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

- **CircuitOperation.** When the circuit is switched on, it produces oscillations of frequency determined byexp. (i). The output $E_0$of the amplifier is fed back to RC feedback network.
- This network producesa phase shift of180ºand avoltage Ei appears at itsoutput which is applied to the transistor amplifier.
- Obviously,thefeedbackfractionm=E_i/E_0.Thefeedbackphaseiscorrect.Aphaseshiftof180ºisproduced by the transistor amplifier.
- Afurtherphaseshiftof180ºisproducedbythe RC network. As a result, the phase shift around the entire loop is 360º.

Advantages

- Itdoesnotrequiretransformersorinductors.
- Itcanbeusedtoproduceverylowfrequencies.
- Thecircuitprovidesgoodfrequencystability.

Disadvantages

- It is difficult for the circuit to start oscillations as the feedback is generally small.
- Thecircuitgivessmalloutput.

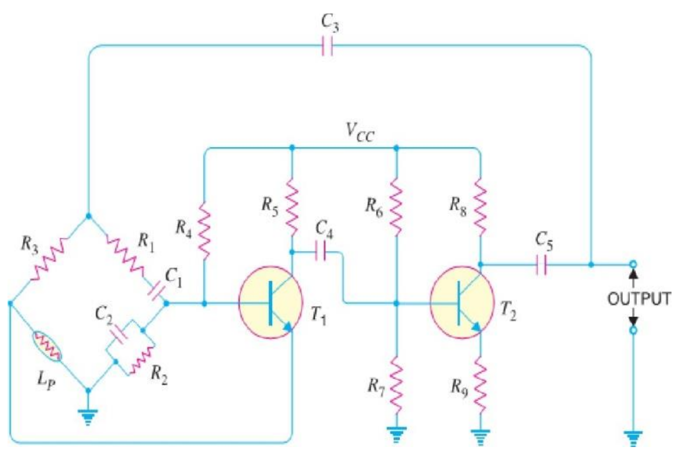
WIENBRIDGEOSCILLATOR:-

- The Wien-bridge oscillator is the standard oscillator circuit for all frequencies in the range of 10 Hz toabout 1 MHz. It is the most frequently used type of audio oscillator as the output is free from circuit fluctuations and ambient temperature.
- Fig. shows the circuit of Wien bridge oscillator. It is essentially a two-stage amplifier with R-C bridge circuit. The bridge circuithas the arms R_1C_1, R_3, R_2C_2 and tungsten lampL_p.
- Resistances R_3 and L_p are used to stabilize the amplitude of the output. The transistor T_1 serves as an oscillatorandamplifierwhiletheothertransistorT_2servesasaninverter(toproduce180ºphase shift).
- The circuit uses positive and negative feedbacks. The positive feedback is through R_1C_1, C_2R_2 to the transistorT_1. The negativefeedback is through thevoltagedivider to the inputof transistorT_2.
- The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

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

IfR_1=R_2=RandC_1=C_2=C,then,

$$f= \frac{1}{2\pi\,RC}$$



- Whenthecircuitisstarted,bridgecircuit produces oscillations of frequency determined.
- The two transistors produce a total phase shift of 360º so that proper positive feedback is ensured.
- The negative feedback in the circuit ensures constant output. This is achieved by the temperature sensitive tungsten lamp L_p. Its resistance increases with current.
- Should the amplitude of output tend to increase, more current would provide more negative feedback.
- Theresultisthattheoutputwouldreturntooriginal value.
- Areverseactionwouldtakeplaceiftheoutputtendstodecrease.

Advantages

(i) Itgivesconstantoutput.**(ii)**Itworksquiteeasily.**(iii)**Overallgainishighduetotwotransistors.
(iv) Thefrequencyofoscillationscanbeeasilychangedbyusingapotentiometer.

Disadvantages

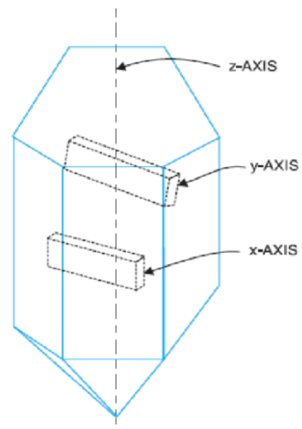
(i) Itrequirestwotransistors&largenumberofcomponents.**(ii)**Itcannotgenerateveryhighfrequencies.

❖ **LIMITATIONSOFLCANDRCOSCILLATORS:-**

- TheLCandRCoscillatorsdiscussedsofarhavetheirownlimitations.Themajorprobleminsuch circuitsisthattheiroperatingfrequencydoesnotremainstrictlyconstant.Therearetwoprincipal reasons for it viz.,
- ♣ (i) As the circuit operates, it will warm up. Consequently, the values of resistors and inductors, which are the frequency determining factors in these circuits, will change with temperature.
- ♣ Thiscausesthechangeinfrequencyoftheoscillator.
- ♣ (ii)Ifanycomponentinthefeedbacknetworkischanged,itwillshifttheoperatingfrequencyofthe oscillator.
- However,inmanyapplications,itisdesirableandnecessarytomaintainthefrequencyconstantwith extreme low tolerances.
- It isapparent that ifwe employ LC orRCcircuits, a change of temperature may cause thefrequencies of adjacent broadcasting stations to overlap.
- Inordertomaintainconstantfrequency,piezoelectriccrystalsareusedinplaceofLCorRCcircuits. Oscillatorsofthistypearecalledcrystaloscillators.
- Thefrequencyofacrystaloscillatorchangesbylessthan0.1%duetotemperatureandotherchanges.
- Therefore, such oscillators offer the most satisfactory method of stabilizing the frequency and are used ingreat majority of electronic applications.

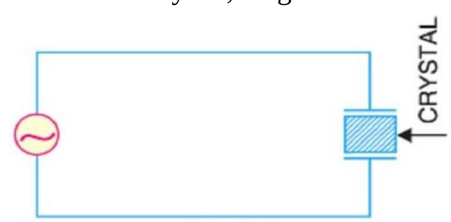
❖ **PIEZOELECTRICCRYSTALS:-**

- Certaincrystallinematerials,namely,*Rochellesalt*,*quartzandtourmaline*exhibitthe**piezoelectriceffect**i.e.,when weapplyana.c.voltageacrossthem,theyvibrateatthefrequencyoftheapplied voltage.Conversely,whentheyarecompressedorplacedundermechanicalstraintovibrate,they produce an a.c. voltage.
- Such crystals which exhibit piezoelectric effect are called **piezoelectriccrystals**. Of the various piezoelectriccrystals,**quartz**ismostcommonlyusedasitisinexpensiveand readilyavailableinnature.



- **QuartzCrystal**.Quartzcrystalsaregenerallyusedincrystaloscillators because of their great mechanical strength and simplicity of manufacture.
- Thenaturalshapeofquartzcrystalishexagonalasshowninfig.Thethree axes are shown: the z-axis is called the optical axis, the x-axis is called the electrical axis and y-axis is called the mechanical axis.
- Quartz crystal can be cut in different ways. Crystal cut perpendicular to the x-axisiscalled**x-cutcrystal**whereasthatcutperpendiculartoy-axisiscalled **y-cutcrystal**. The piezoelectric properties of a crystal depend upon its cut.
- **FrequencyofCrystal.**Eachcrystalhasanaturalfrequencylikeapendulum. Thenaturalfrequencyfofacrystalisgivenby:$f=\frac{K}{t}$Where,

  K=Constantthatdependsuponthecut**&t**=Thicknessofthecrystal.
- It is clear thatfrequency is inversely proportionalto crystalthickness. Thethinner the crystal, thegreateris its natural frequency and vice-versa.
- However,extremelythincrystalmaybreakbecauseofvibrations. This puts a limit to the frequency obtainable. In practice, frequencies between 25 kHz to 5 MHz have been obtained with crystals.

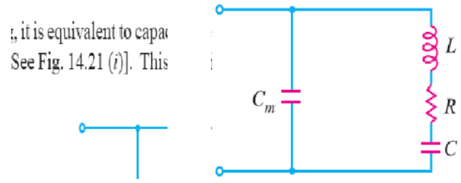


❖ **WORKINGOFQUARTZCRYSTAL:-**

- Inordertousecrystalinanelectroniccircuit,itisplacedbetween twometalplates.Thearrangementthenformsacapacitorwithcrystalasthedielectricasshowninfig.
- If an a.c. voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage.However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value.
- Thisnaturalfrequency isalmostconstant.Effects oftemperature change canbeeliminatedby mounting the crystal in a temperature-controlled oven as in radio and television transmitters.

❖ **EquivalentCircuitofCrystal:-**

Althoughthecrystalhaselectromechanicalresonance,wecanrepresentthecrystalactionbyan equivalent electrical circuit.



(i)Whenthecrystalisnotvibrating,itisequivalentto capacitance C_m because it has two metal plates separated by a dielectric [See Fig (i)].

Thiscapacitanceisknownas**mountingcapacitance**.

(ii)Whenacrystalvibrates,itisequivalenttoR–L–Cseries circuit. Therefore, the equivalent circuit of a vibrating crystal is R– L– C series circuit shunted by the mounting capacitance C_m as shown in Fig (ii).

C_m=mountingcapacitance**&**R–L–C=electricalequivalentofvibrationalcharacteristicofthecrystal

❖ **TRANSISTORCRYSTALOSCILLATOR:-**

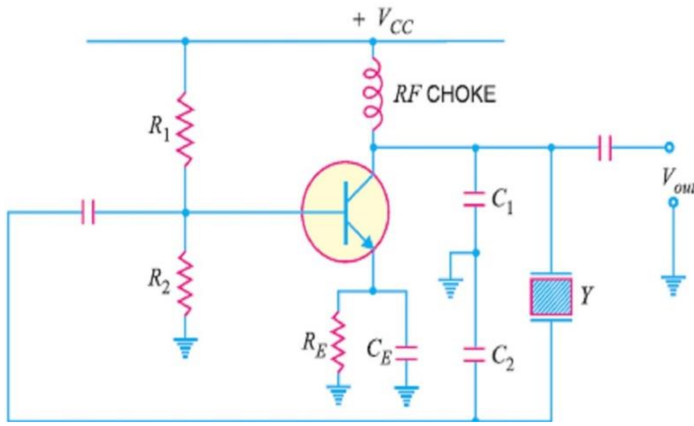


Fig. shows the transistor crystal oscillator. NotethatitisaCollpit'soscillator modified to act as a crystal oscillator.

The only change is the addition of thecrystal (Y) in the feedback network. The crystal will act as a parallel-tuned circuit.

As we can see in this circuit that instead of Fig. resonance caused by L and (C_1 + C_2), we have the parallel resonance of thecrystal. At parallel resonance, theimpedance of the crystal is maximum.

Thismeansthatthereisamaximum voltagedropacrossC_1.Thisinturnwillallowthemaximumenergytransferthroughthefeedback network at f_p.

Notethatfeedbackispositive.Aphaseshiftof180°isproducedbythetransistor.Afurtherphaseshift of 180° is produced by the capacitor voltage divider.

Thisoscillatorwilloscillateonlyatf_p.Eventhesmallestdeviationfrom$f_p$willcausetheoscillatortoact asaneffectiveshort.Consequently,wehaveanextremely stableoscillator.

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

♣ **Advantages**

✘Theyhaveahighorderoffrequencystability.

✘Thequalityfactor(Q)ofthecrystalisveryhigh.

♣ **Disadvantages**

✘Theyarefragileandconsequentlycanonlybeusedinlowpowercircuits.

✘Thefrequencyofoscillationscannotbechangedappreciably.

[CHAPTER–7]

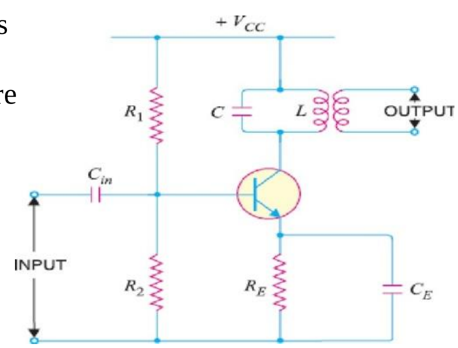
[TUNEDAMPLIFIER]

❖ INTRODUCTION

- Mostoftheaudioamplifierswehavediscussedintheearlierchapterswillalsoworkatradiofrequencies *i.e*.above50kHz.
- However, they suffer from two major drawbacks. **First,** they become less efficient at radio frequency. **Secondly,**suchamplifiershavemostlyresistiveloadsandconsequentlytheirgainisindependentof signal frequency over a large bandwidth.
- In other words,an audioamplifier amplifies a wide band of frequencies equally welland does notpermit the selection of a particular desiredfrequency while rejecting all other frequencies.
- However, sometimes it is desired that an amplifier should be selective *i.e*. it should select a desiredfrequency or narrow band of frequencies for amplification.
- For instance, radio and television transmission are carried on a specific radio frequency assigned to the broadcasting station.Theradioreceiverisrequiredtopickupandamplify theradiofrequency desired while discriminating all others.
- To achieve this, the simple resistive load is replaced by a parallel tunedcircuit whose impedance stronglydepends upon frequency.
- Such a tuned circuit becomes very selective and amplifies very strongly signals of resonant frequency and narrow band on either side.
- Thus,theuseoftunedcircuitsinconjunctionwithatransistormakespossibletheselectionandefficient amplification of aparticular desiredradio frequency. Suchan amplifier is calleda ***tunedamplifier***.
- Inthischapter,weshallfocusourattentionontransistortunedamplifiersandtheirincreasing applications in high frequency electronic circuits.

❖ <u>TUNEDAMPLIFIERS</u>

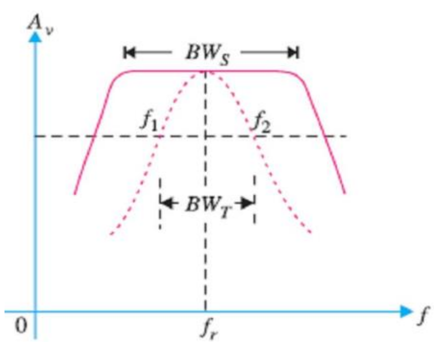
- *Amplifierswhichamplifyaspecificfrequencyornarrowbandoffrequenciesarecalled**tunedamplifiers.***
- Tunedamplifiersaremostlyusedfortheamplificationofhighorradiofrequencies.
- Itisbecauseradiofrequenciesaregenerallysingleandthetuned circuit permits their selection and efficient amplification.
- Tunedamplifiersarewidelyusedinradioandtelevisioncircuits where they are called upon to handle radio frequencies.
- Fig.showscircuitofasimpletransistortunedamplifier.Here, instead of load resistor, a parallel tuned circuit in the collector.



- Theimpedanceofthistunedcircuitstronglydependsupon frequency.Itoffersaveryhighimpedanceat*resonantfrequency* and very small impedance at all other frequencies.
- Ifthesignalhasthesamefrequencyastheresonantfrequencyof *LC*circuit,largeamplificationwillresultduetohighimpedanceof*LC*circuitatthisfrequency.
- When signals of many frequencies are present at the input of tuned amplifier, it will select and strongly amplify the signals of resonant frequency while rejecting all others.
- Therefore, such amplifiers are very useful in radio receivers to select the signal from one particular broadcasting station when signals ofmany other frequencies are present atthereceivingaerial.

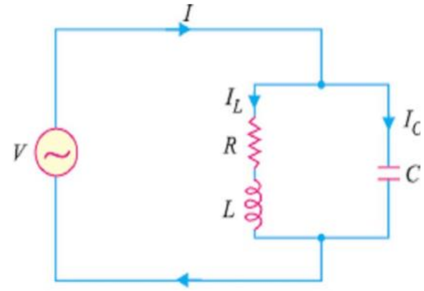
❖ DIFFERENCEBETWEENTUNEDAMPLIFIERSANDOTHERAMPLIFIERS:-

- Wehaveseenthatamplifiers(*e.g*.,voltageamplifier,power amplifier *etc*.) provide the constant gain over a limited band of frequencies *i.e*., from lower cut-off frequency f_1 to upper cut-off frequency f_2. Now bandwidth of the amplifier, $BW = f_2 - f_1$.
- Thedifferenceisthattunedamplifiersaredesignedtohave specific, usually narrow bandwidth. This is explained in the Fig.

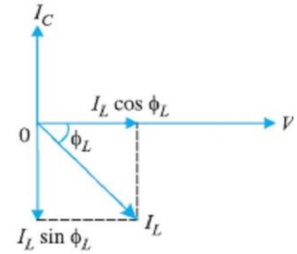


- NotethatBW_Sisthebandwidthofstandardfrequencyresponse while BW_T is the bandwidth of the tuned amplifier.
- Inmanyapplications,thenarrowerthebandwidthofatunedamplifier,thebetteritis.

❖ ANALYSISOFPARALLELTUNEDCIRCUIT:-



- Aparalleltunedcircuitconsistsofacapacitor*C*andinductor*L* connectedinparalleltoeachotherwithrespecttoasupplysource.
- Fig. shows a parallel resonant circuit connected across an ac supply source of variable frequency.
- HeretheresistanceRrepresentsthecoilresistance.Itsvalueis usually very small and the order of few ohms and hence it can be neglected as compare to the impedance of the resonance circuits.
- Now consider the frequency of the ac supply to be varied suitably. As a result of this, the circuit will encounter different impedance at different frequencies.

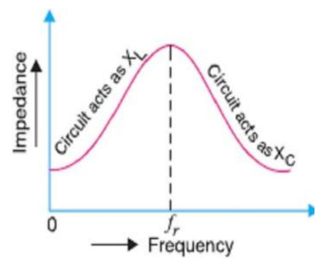


- As the frequency is increased the inductive reactance [X_L] is also increased andthe capacitive reactance [X_C] is increased. There is a certain frequency of the applied ac voltage at which the inductive reactance is equal to the capacitive reactance. This frequency is called **resonancefrequency.** It is designated by **f_0.**
- The frequency at which parallel resonance occurs (*i.e.* reactive component of circuit current becomes zero) is called the ***resonantfrequency*f_0**.
- Atresonantfrequency,thecircuitissaidtobeinelectricalresonance.Under resonanceconditiontheimpendenceof theresonantcircuitsbecomes maximumand the linecurrent(i.e. the current drawn from the source) is minimum.
- Theexpressionforresonancefrequencymaybeobtainedfromthecondition,

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

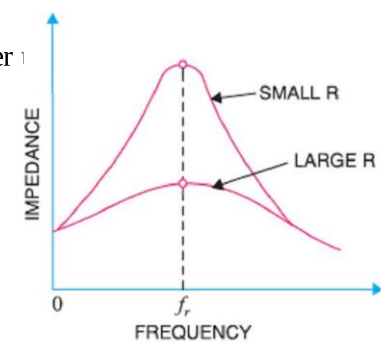
- IfvalueofinductanceisHenry&thecapacitanceisfaradsHertzthentheresonancefrequencyisHertz.

❖ RESONANCECURVE:-



- It is a curve, which shows the variation of **circuitimpedance** (or circuitcurrent) with the change in **frequency** of the applied voltage.
- Fig.showsthevariationofcircuitimpedance(Z_p)withchangeinfrequency of the applied voltage.
- Fromthefigitisclearthattheimpedanceismaximumattheresonanceand isequaltoL/CR.If thefrequency ischanged above orbelowtheresonance, the value of impedance decreases rapidly.
- If$f_1$and$f_2$arethelower&highercutofffrequenciesthenBandwidth**BW=f_2-f_1**.

❖ SHARPNESSOFRESONANCE:-



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

SharpnessofResonance=BandWidth/Resonantfrequency

$=BW/f_0=f_2-f_1/f_0=1/Q_0$

- WhereQ_0iscalledthequalityfactororQ-Factor.
- Theratioofinductivereactanceandresistanceofthecoilatresonance,therefore,becomesameasureof the quality of the tuned circuit.
- This is called quality factor and may be defined as under : The ratio of *inductivereactanceofthecoilatresonancetoitsresistanceisknownas***qualityfactorQ***i.e.* **$Q=X_L/R=2\pi fL/R$**
- The quality factor *Q* of a parallel tuned circuit is very important as the sharpness of resonance curve and henceselectivity ofthecircuitdependsuponit.Highervalueof*Q*,moretheselectiveofthetunedcircuit.
- The smaller the resistance of coil, the sharper is the resonance curve. This is due to the fact that a small resistance consumes less power and draws a relatively small line current.
- Fig.showstheeffectofresistance*R*ofthecoilonthesharpnessoftheresonancecurve.Itisclearthat when resistance is small, the resonance curve is very sharp. However, if the coil has large resistance, the resonancecurveislesssharp.Sowhere highselectivity isdesired,the value of*Q*shouldbevery large.

- ❖ **ADVANTAGESOFTUNEDAMPLIFIERS:-**

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

(*i*)Smallpowerloss.(*ii*)Highselectivity.(*iii*)Smallercollectorsupplyvoltage.

- ❖ **<u>SINGLETUNEDAMPLIFIER</u>:-**

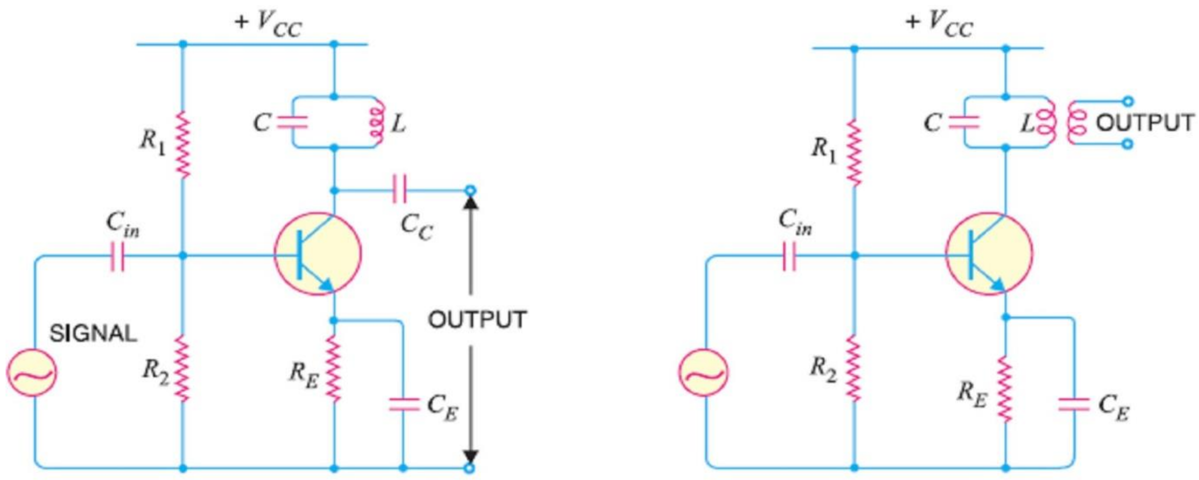
Asingletunedamplifierconsistsofatransistoramplifiercontainingaparalleltunedcircuitasthe collectorload.Thevaluesofcapacitanceandinductanceofthetunedcircuitaresoselectedthatits resonant frequency is equal to the frequency to be amplified.

Theoutputfromasingletunedamplifiercanbeobtainedeither**(*a*)**byacouplingcapacitor$C_C$asshown in Fig (i) or **(*b*)** by a secondary coil as shown in Fig (*ii*).

Fig(i)isalsocalledassingletunedvoltageamplifierusingCapacitiveCoupledwhereasfig(ii)iscalled as single tuned voltage amplifier using Inductive Coupled.

Boththesecircuitsconsistofatransistoramplifierandatunescircuitastheload.Thevaluesof capacitance (C) and Inductance (L) of the tunes circuits are selected in such a way that the resonant frequency of the tunes circuit is equal to the frequency to be selected and amplified.

TheresistorsR$_1$,R$_2$ and R$_E$arecalledbiasing resisters.Theseresistorsprovidethed.c.operating current and voltage for the transistor.



(*i*) (*ii*)

- ❖ **OPERATION.**

Thehighfrequencysignali.e.radiofrequencysignaltobeamplifiedisgiventotheinputoftheamplifier.

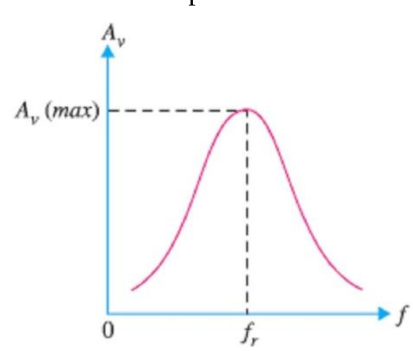
Theresonantfrequencyofparalleltunedcircuitismadeequaltothefrequency ofthesignalbychanging the value of *C*.

Undersuchconditions,thetunedcircuitwillofferveryhighimpedancetothesignalfrequency.Hencea large output appears across the tuned circuit.

Incasetheinputsignaliscomplexcontainingmanyfrequencies,onlythatfrequencywhichcorresponds to the resonant frequency of the tuned circuit will be amplified.

Allotherfrequencieswillberejectedbythetunedcircuit.Inthisway,atunedamplifierselectsand amplifies the desired frequency.

- ❖ **FrequencyResponseofSingleTunedVoltageAmplifiers:-**



Attheresonantfrequency,theimpedanceoftheparallelresonant circuit is very high and is purely resistive.

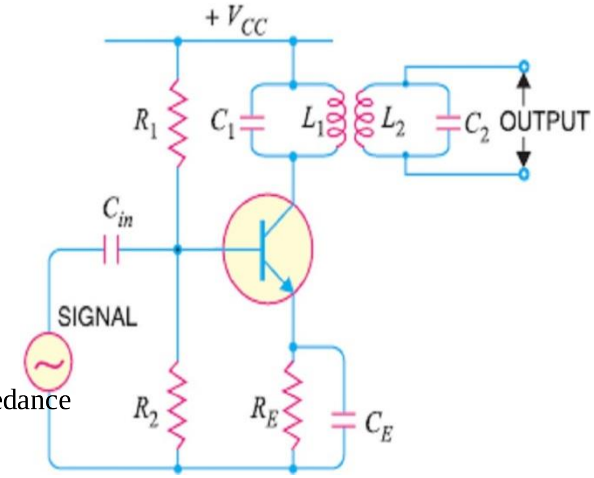
Therefore, when the circuit is tuned to resonant frequency, the voltageacross R$_L$ is maximum.

- ❖ Inotherwords,thevoltagegainismaximumatf$_r$.However,above and below the resonant frequency, the voltage gain decreases rapidly.
- ❖ Thehigherthe*Q*ofthe circuit,thefasterthegaindropsoffoneither side of resonance.

❖ LIMITATIONSOFSINGLETUNEDAMPLIFIER:-

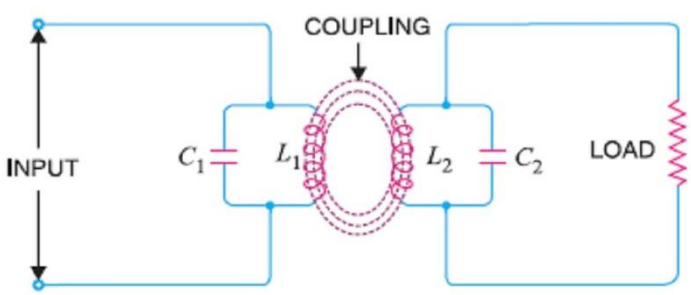
- Thetunedvoltageamplifier,incommunicationreceiver,isusedtoselectthedesiredcarrierfrequency and amplifying thecomplete band of frequencies around the selected carrier frequency.
- Inotherword,tunedamplifiersarerequiredtobehighselectivity.Butthehighselectivityrequiresa tuned circuit with a high Q-factor.
- Wealsoknowthatahigh-Qcircuitwillgiveahighvoltagegain.But,atthesametime,itwillgive reduces bandwidth (Because band width is reciprocal to the Q-factor).
- Itmeansthatatunedatunedvoltageamplifierwithreducedbandwidthmaynotbeabletoamplify equally the complete band of the transmitted signal.
- Inotherwords,narrowbandwidthorsmallerpassbandoftheamplifierwillresultinapoorreproduction of the audio signal.
- Itisthemajorlimitationofasingletunedvoltageamplifier&isovercomebyusingdoubletunedcircuit.

❖ <u>DOUBLETUNEDAMPLIFIER</u>:-

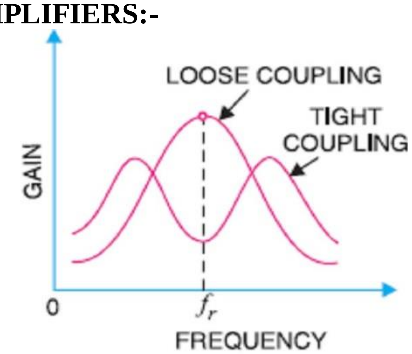


- Figshowsthecircuitofadoubletunedamplifier.
- It consists of a transistor amplifier containing two tuned circuits;one(L_1C_1)inthecollectorandtheother(L_2C_2) in the output as shown.
- TheresistorsR$_1$,R$_2$andR$_E$areusedtoprovided.c. current and voltage for transistor operation.
- Thehighfrequencysignaltobeamplifiedisappliedto the input terminals of the amplifier.
- TheresonantfrequencyoftunedcircuitL_1C_1ismadeequal to the signal frequency.
- Under such conditions, the tuned circuit offers very highimpedance to the signal frequency.
- Hence,largeoutputappearsacrossthetunedcircuitL_1C_1.
- TheoutputfromthistunedcircuitistransferredtothesecondtunedcircuitL_2C_2throughmutual induction. Double tuned circuits are extensively used for coupling the various circuits of radio andtelevision receivers.

❖ FREQUENCYRESPONSEOFDOUBLETUNEDVOLTAGEAMPLIFIERS:-



(*i*)



(*ii*)

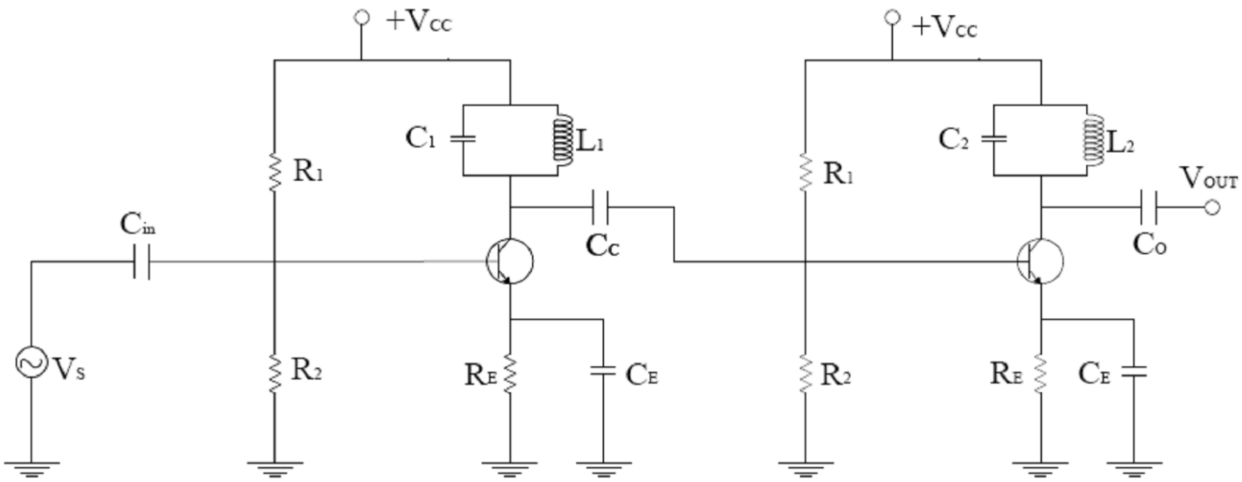
- Thefrequencyresponseofadoubletunedcircuitdependsuponthedegreeofcoupling*i.e.*uponthe amount of mutual inductance between the two tuned circuits.
- WhencoilL_2iscoupledtocoilL_1[SeeFig.(*i*)],aportionofloadresistanceiscoupledintotheprimary tank circuit L_1C_1 and affects the primary circuit in exactly the same manner as though a resistor had been added in series with the primary coil L_1.
- Whenthecoilsarespacedapart,alltheprimary coilL_1fluxwillnotlinkthesecondary coilL_2.Thecoils are said to have ***loosecoupling***.
- Undersuchconditions,theresistancereflectedfromtheload(*i.e*.secondarycircuit)issmall.The resonance curve will be sharp and the circuit Q is high as shown in Fig. (*ii*).
- Whentheprimaryandsecondarycoilsareveryclosetogether,theyaresaidtohave***tightcoupling***. Undersuchconditions,thereflectedresistancewillbelargeandthecircuit$Q$islower.
- Twopositionsofgainmaxima,oneaboveandtheotherbelowtheresonantfrequency,areobtained.

❖ BANDWIDTHOFDOUBLE–TUNEDCIRCUIT:-

- Ifyou refer to the frequency responseof double-tuned circuitshown inFig. (*ii*), itisclear that bandwidth increases with the degree of coupling.
- Obviously,thedeterminingfactorinadoubletunedcircuitisnot*Q*butthecoupling.Foragiven frequency, the tighter the coupling, the greater is the bandwidth. $\mathbf{BW_{dt}=kf_r}$
- Thesubscript*dt*isusedtoindicatedouble-tunedcircuit.Here*k*iscoefficientofcoupling.
  - ✡ItProvides**HighSelectivity**,**HighGain**andrelatively**LargeBandWidth**totunedcircuit.

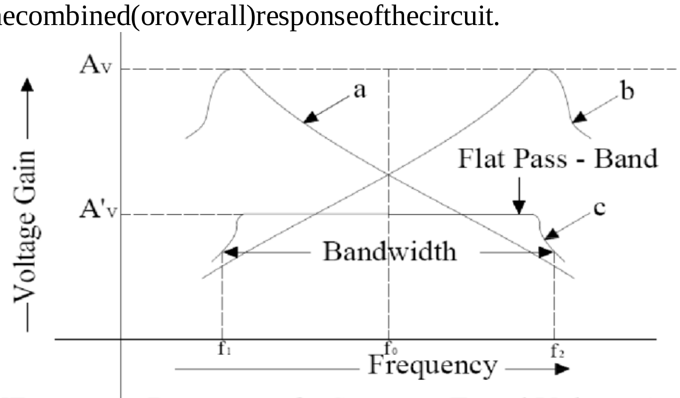
❖ <u>STAGGER-TUNEDVOLTAGEAMPLIFIER</u>:-

- Ithasbeenobservedthatiftwoormoretunedcircuits,whicharesynchronouslytunedarecascaded,the overall bandwidth decreases.
- However,ifthedifferenttunedcircuitswhicharecascaded,aretunedtoslightlydifferentfrequencies,it is possible to obtain an increased bandwidth with aflat pass band with steep sides.
- Thistechniqueisknownas**Stagger-Tuning**.



[Two-Stage Stagger Tuned Voltage Amplifier]

- TheaboveFigshowsatwostagetunedvoltageamplifier.Thestaggertuninginthiscircuit,maybe achieved by resonating thetuned circuit$L_1C_1$and$L_2C_2$to slightly differentfrequencies.
- Thefigurebelowshowsthefrequencyresponseofastagger-tunedamplifier.Inthisfigure,curve**‘a’** showsthegainversesfrequencyresponseoftheL_1C_1tunedcircuit.
- Similarlythecurve‘b’showsthegainversesfrequencyresponseoftheL2C2tunedcircuit.
- Thecurve**‘c’**indicatesthecombined(oroverall)responseofthecircuit.



[Frequency Responce of a Stagger - Tuned Voltage Amplifier]

- Itisclearfromthiscircuitthattheamplifierhasagreaterbandwidthandflatterpass-band.Ithasbeen found that more the passband and stepper will bethe gain fall-off outside the pass band.
- Itisnotedthatbecauseofstagger-tuning,thereisalossofvoltagegain(GainreducesfromA$_v$toA\`$_v$).
- Ifanoptimumstager-tuningisemployed,theresponsecurveoftheamplifierisveryclosetoa rectangular response curve. Such a response is known as **ButterworthResponse.**

[CHAPTER – 8]

[COMMONAPPLICATIONOFDIODE,TRANSISTOR&WAVESHAPINGCIRCUIT]

❖ **INTRODUCTION**

- Wehaveseenthatdiodescanbeusedasrectifiers.Apartfromthis,diodeshavemanyotherapplications.
- However,weshallconfineourselvestothefollowingtwoapplicationsofdiodes:-

(i) Asa**Clipper** **(ii)**Asa**Clamper**

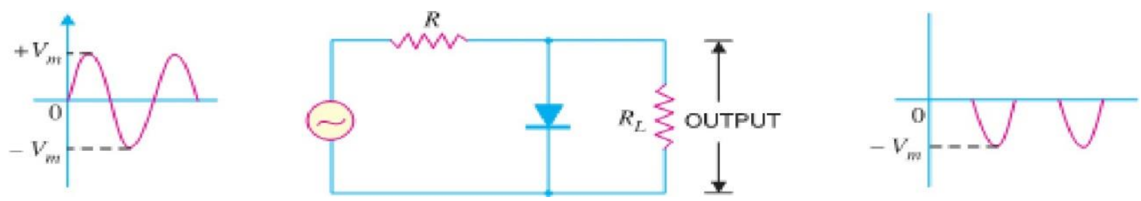
- A**clipper**(orlimiter)isusedtoclipofforremoveaportionofana.c.signal.Thehalf-waverectifieris basically a clipper that eliminates one of the alternations of an a.c. signal.
- A**clamper**(ordcrestorer)isusedtorestoreorchangethedcreferenceofanacsignal.Forexample, you may have a 10 V ppac signal that varies equally above and below 2 V dc.

❖ **<u>CLIPPINGCIRCUITS</u>:-**

- Thecircuitwithwhichthewaveformisshapedbyremoving(orclipping)aportionoftheappliedwave is known as a **clippingcircuit.**
- Clippersfindextensiveuseinradar,digitalandotherelectronicsystems.Althoughseveralclipping circuitshave beendevelopedtochangethewaveshape,weshallconfineourattentiontodiodeclippers.
- Theseclipperscanremovesignalvoltagesaboveorbelowaspecifiedlevel.
- Theimportantdiodeclippersare**(i)Positive**Clipper**(ii)Biased**Clipper**(iii)Combination**Clipper.

♣ **POSITIVECLIPPER:-**

- A positive clipper is that which removes the positive half-cycles of the input voltage.Fig. shows thetypical circuit of a positive clipper using a diode.



- Asshown,theoutputvoltagehasallthepositivehalf-cyclesremovedorclippedoff.
- The circuit action is as follows**:-** During the positive half-cycle of the input voltage, the diode is forward biased and conducts heavily.
- Therefore,thevoltageacrossthediode(whichbehavesasashort)andhencetheoutputvoltageacross the load R is zero.Hence output voltage during positive half-cycles is zero.
- Duringthenegativehalf-cycleoftheinputvoltage,thediodeisreversebiasedandbehavesasanopen.
- Inthiscondition,thecircuitbehavesasavoltagedividerwithanoutputgivenby:

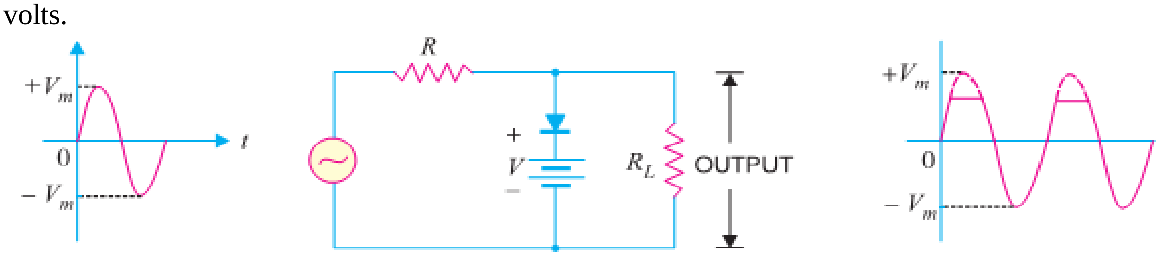
$$\text{Output voltage} = -\frac{R_L}{R + R_L} V_m$$

Generally,$R_L$ismuchgreaterthanR. **∴Outputvoltage=-V_m**

- Itmaybenotedthatifitisdesiredtoremovethenegativehalf-cycleoftheinput,theonly thingtobe done is to reverse the polarities of the diode in the circuit shown in Fig. Such a clipper is then called a **negativeclipper**.

♣ **(ii)BIASEDCLIPPER:-**

- Sometimes it is desired to remove a small portion of positive or negative half-cycle of the signal voltage. For this purpose, biased clipper is used.Fig. shows the circuit of a biased clipper using a diode with a battery of V volts.



- Withthepolaritiesofbattery shown,aportionofeachpositivehalf-cyclewillbeclipped.However,the negativehalf-cycleswillappearassuchacrosstheload.Sucha clipper iscalled***biasedpositiveclipper***.

✍Thecircuitactionisasfollows**:-**Wheninputvoltageisgreaterthan+V,thediodebehavesasashort and the output equals +V. The outputwillstay at+V solongastheinput voltageisgreater than +V.

✍Duringtheperiodtheinputvoltageislessthan+V,thediodeisreversebiasedandbehavesasanopen.

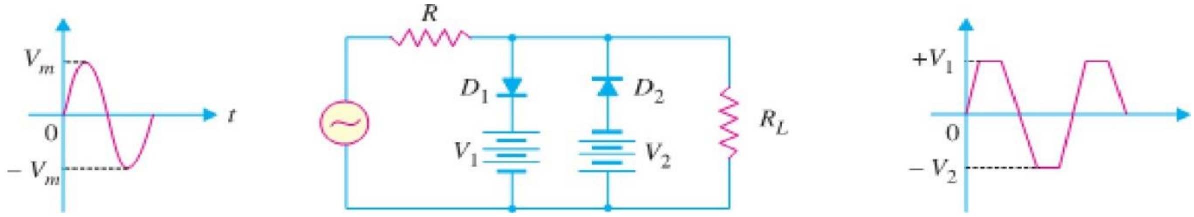
✍Therefore,mostoftheinputvoltageappearsacrosstheoutput.Inthisway,thebiasedpositiveclipper removes input voltage above +V.

✍Duringthenegativehalf-cycleoftheinputvoltage,thedioderemainsreversebiased.Therefore,almost entire negative half-cycle appears across the load.

✍Ifitisdesiredtoclipaportionofnegativehalf-cyclesofinputvoltage,theonlythingtobedoneisto reverse the polarities of diodeor battery. Sucha circuitis then called a **biasednegativeclipper**.

♣ **(iii)COMBINATIONCLIPPER:-**

✍Itisacombinationof*biasedpositive*and*negativeclippers*.Withacombinationclipper,aportionof bothpositiveand negative half-cycles of input voltage can beremovedor clipped as shown in Fig.



✍The circuit action is as follows**:-** When positive input voltage is greater than $+V_1$, diode D_1 conducts heavily whilediodeD_2 remainsreversebiased.Therefore,a voltage $+V_1$ appearacrossthe load.This output stays at $+V_1$ so long as the input voltage exceeds $+V_1$

✍Ontheotherhand,duringthenegativehalf-cycle,thediodeD_2willconductheavilyandtheoutputstays at $-V_2$ so long as the input voltage is greater than $-V_2$.

✍Notethat$+V_1$and$-V_2$arelessthan$+V_m$and$-V_m$respectively.

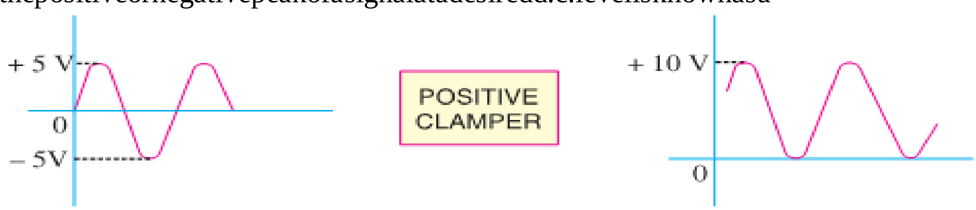
✍Between $+V_1$ and $-V_2$ neither diode is on. Therefore, in this condition, most of the input voltage appears acrosstheload.Itisinterestingtonotethatthisclippingcircuitcangivesquarewaveoutputif$V_m$is much greater than the clipping levels.

♣ **APPLICATIONSOFCLIPPERS**

✍**(i)**Changingtheshapeofawaveform**(ii)**Circuittransient(SuddenriseofVoltageorCurrent)protection

❖ **CLAMPINGCIRCUITS:-**

✍Acircuitthatplaceseitherthepositiveornegativepeakofasignalatadesiredd.c.levelisknownasa **clampingcircuit.**



✍Aclampingcircuit(oraclamper)essentiallyaddsad.c.componenttothesignal.Fig.showsthekey idea behind clamping. The input signal is a sinewave having a peak-to-peak value of 10V.

✍Theclamperaddsthed.c.componentandpushesthesignalupwardssothatthenegativepeaksfallon the zero level.Asyou can see, the waveform nowhas peak values of +10V and 0 V.

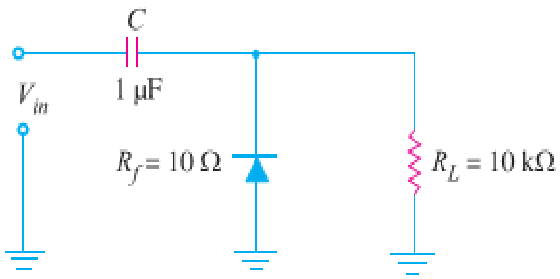
✍Itmay beseenthattheshapeoftheoriginalsignalhasnotchanged;onlythereisverticalshiftinthe signal.Suchaclamperiscalleda**positiveclamper**.The**negativeclamper**doesthereversei.e.it pushes the signal downwards so that the positive peaks fall on the zero level.

✍Thefollowingpointsmaybenotedcarefully:

✍**(i)** The clamping circuit **doesnotchangethepeak-to-peakorr.m.s.value** of the waveform. ThusreferringtoFig.above,theinputwaveformandclampedoutputhavethesamepeak-to-peakvaluei.e., 10Vinthiscase.Ifyoumeasuretheinputvoltageandclampedoutputwithana.c.voltmeter,the readings will be the same.

✍**(ii)**Aclampingcircuit**changesthepeakandaveragevalues**ofawaveform.Thusintheabovecircuit, it is easy to see that input waveform has a peak value of 5 V and average value over a cycle is zero.The clamped outputvariesbetween 10 V and0V.Thusthepeak value is 10 Vand average value is 5 V.

♣ **BASICIDEAOFACLAMPER**



✍Aclampingcircuitshouldnotchangepeak-to-peak value of the signal; it should only change the dc level.

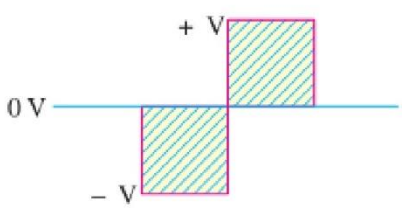
✍Todoso,aclampingcircuitusesacapacitor,together with a diode and a load resistor R.

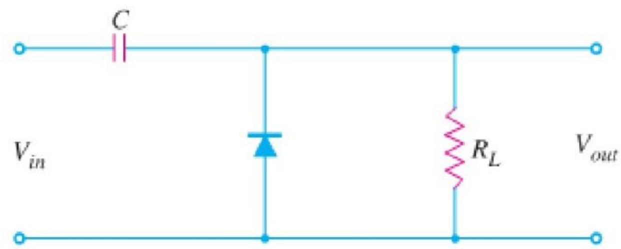
✍Fig.showsthecircuitofa*positiveclamper*.

✍Theoperationofaclamperisbasedontheprinciple that charging time of a capacitor is made very small as compared to its discharging time.

♣ **POSITIVECLAMPER:-**

✍Fig.showsthecircuitofapositiveclamper.Theinputsignalisassumedtobeasquarewavewithtime period T. The clamped output is obtained across R_L.



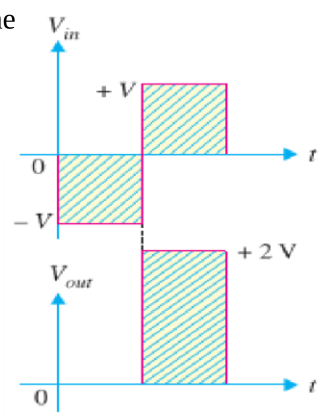


✍Thecircuitdesignincorporatestwomainfeatures.

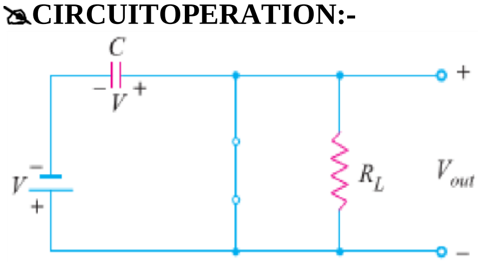
✍**Firstly**,thevaluesofCand$R_L$aresoselectedthattimeconstantτ=CR_Lisverylarge.

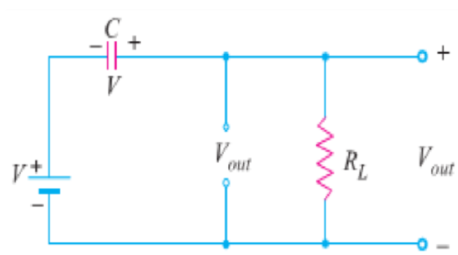
✍Thismeansthatvoltageacrossthecapacitorwillnotdischarge significantly during the interval the diode is non-conducting.

✍**Secondly**,R_LCtimeconstantisdeliberatelymademuchgreaterthanthe time period T of the incoming signal.



✍**CIRCUITOPERATION:-**





✍**(i)** During the negative half-cycle of the input signal, the diode is forward biased. Therefore, the diode behavesasashortasshowninFig(i).Thechargingtimeconstant(=CR_f,whereR_f=forwardresistance of the diode) is very small so that the capacitor will charge to V volts very quickly.

✍So,duringthisinterval,theoutputvoltageisdirectlyacrosstheshortcircuit.Therefore,**V_{out}=0.**

✍**(ii)**Whentheinputswitchesto+Vstate(i.e.,positivehalf-cycle),thediodeisreversebiasedand behaves as an open as shown in Fig (ii).

✍Sincethedischargingtimeconstant(=CR_L)ismuchgreaterthanthetimeperiodoftheinputsignal,the capacitor remains almostfully charged to V voltsduring the off time of the diode.

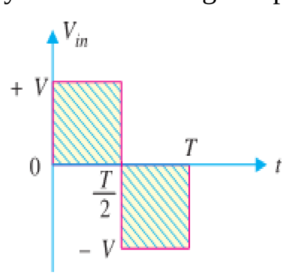
✍ApplyingKirchhoff'svoltagelawinFig(ii)totheinputloop,wehave,V+V−V_{out}=0**orV_{out}=2V**

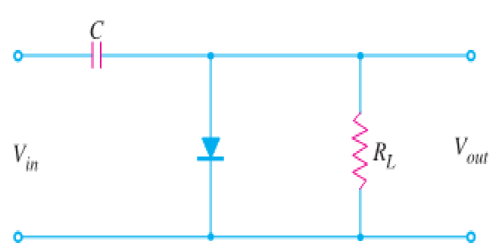
✍TheresultingwaveformisshowninFig.(iii)Itisclearthatitisapositivelyclampedoutput.Thatisto say theinputsignalhasbeenpushedupwardby Vvoltssothatnegativepeaksfallonthezerolevel.

♣ **NEGATIVECLAMPER:-**

✍Fig. shows the circuit of a negative clamper. The clamped output is taken across R_L.

✍Note that only change from the positive clamper is that the connections of diode are reversed.

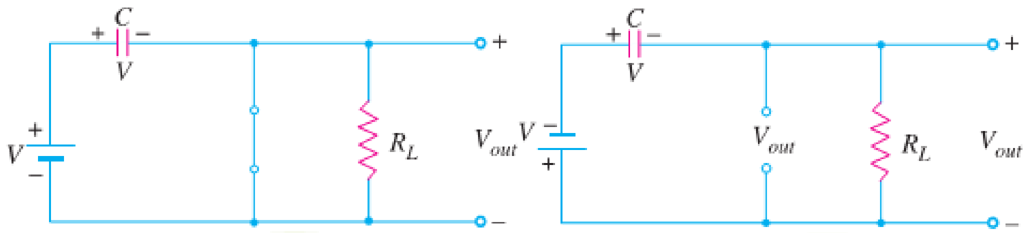




CIRCUITOPERATION:-

(i) Duringthepositivehalf-cycleoftheinputsignal,thediodeisforwardbiased. Therefore,thediodebehavesasashortasshowninFig(i).

Thechargingtimeconstant(=CR_f)isverysmallsothatthecapacitorwillcharge toVvoltsveryquickly.Itiseasytoseethatduringthisinterval,theoutput voltage is directly across the short circuit. Therefore, **Vout=0**.



(ii) Whentheinputswitchesto–Vstate(i.e.,negativehalf-cycle),thediodeisreversebiasedandbehaves as an open as shown in Fig (ii).

Sincethedischargingtimeconstant(=CR_L)ismuchgreaterthanthetimeperiodoftheinputsignal,the capacitor almost remainsfully charged to V voltsduring the off time of the diode.

ApplyingKirchhoff'svoltagelawtotheinputloopinFig(ii)➔ $-V-V-V_{out}=0$ **or** $V_{out}=-2V$

TheresultingwaveformisshowninFig(iii).Notethattotalswingoftheoutputsignalisequaltothe total swing of the input signal.

♣ **APPLICATIONSOFCLIPPERS**

- ✓ ClampercircuitisusedTVreceivertorestoretheoriginald.c.referencesignaltothevideosignal,
- ✓ Usedtoproducedcvoltagemultipleofpeakacinputvoltagei.e.knownas**VoltageMultiplier.**

❖ <u>VOLTAGEMULTIPLIER</u>

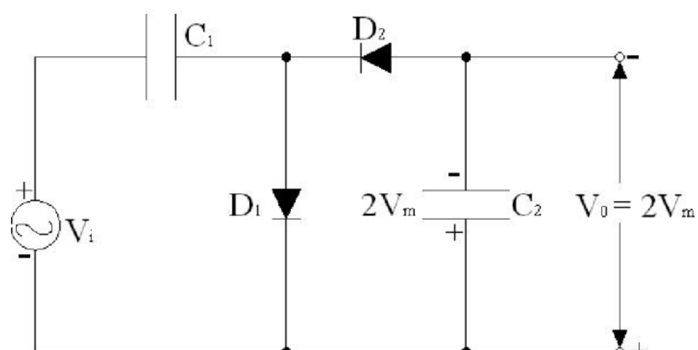
Voltagemultiplierisacircuit,whichproducesanoutputdcvoltagewhosevalueismultipleofpeakac input voltage (i.e. $2V_m$, $3V_m$, $4V_m$& so on).

Suchcircuitsareusedaspowersupplyforhighvoltage/lowcurrentdevicelikeCRO.

♣ VOLTAGEDOUBLER:-

A voltage multiplier, whose output dc voltage is double the peak ac input voltage, is called a **VoltageDoubler.**Fig shows the circuit, of a half-wave voltage doubler.

Inthiscircuit,eachsectionofadiodeandcapacitor(sayD_1andC_1orD_2andC_2)iscalleda*peakrectifier*.The operation of the circuit may be explained as given below:



During the positive half-cycle of the inputsignal, the diode D_1 conducts (and diode D_2 is cut-off), charging the capacitor C_1 up to thepeak rectified voltage (i.e., V_m).

Duringthenegativehalf-cycle,diode,$D_1$is cut-off and diode D_2 conducts charging capacitor C_2.

It may be noted that during negative half-cycle the voltage across capacitor C_1 is in series with the input voltage.Therefore the total voltage presented to capacitor C_2 is equal to $2V_m$.

Asaresultofthis,thecapacitorC_2ischargedtoavoltageof$2V_m$duringthenegativehalf-cycle.

Onnextpositivehalf-cycle,thediodeD_2innon-conducting&capacitorwilldischargethroughtheload.

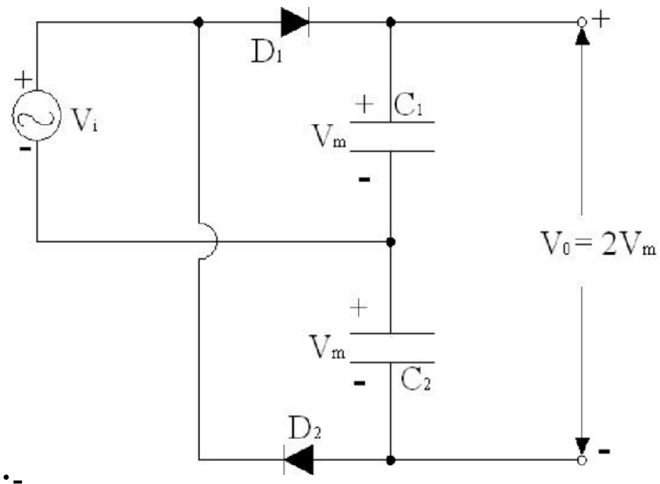
IfnoloadisconnectedacrosscapacitorC_2,bothcapacitorsstaychargedattheirfullvalues(i.e.,$C_1$to V_m and C_2 to $2V_m$).

ItmaybenotedthatboththediodesD_1andD_2haveapeakinversevoltage(PIV)of$2V_m$each.

Fig(ii)showsanothervoltagedoublercircuitknownasfull-wavevoltagedoubler.

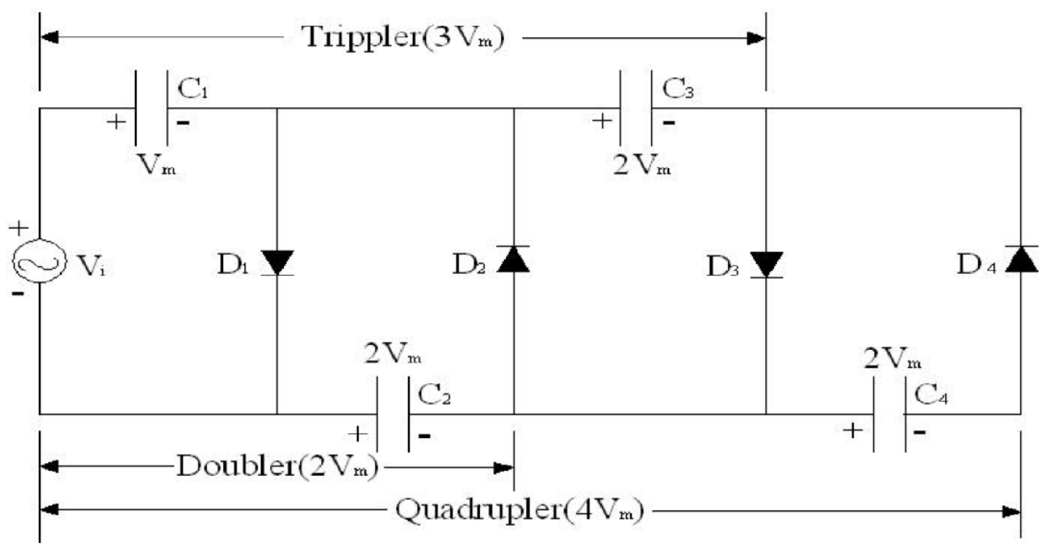
Inthiscircuitduring,thepositivehalfcycleofa.c.inputvoltage,diodeD_1conductschargingcapacitor C_1 to a peak voltage V_m with polarity as shown in the fig.

- The diode D_2 is cut-off at this time. During the negative half-cycle the diode D_2 conducts (while D_1 is at cut-off) charging capacitor C_2 to V_m.
- If there is no load connected across the output,then the output voltage is equal to $2V_m$.
- Howeveriftheloadisconnected,thenthe voltage would be less then $2V_m$.
- Thepeakinversevoltage(PIV)acrosseach diode, in a full-wave voltage doubler, is equal to $2V_m$.
- The full-wave voltage doubler has an advantage overaconventialcenter-tappedfull-wave rectifier that it does not require any center-tapped transformer.



♣ VOLTAGETRIPPLERANDQUADRUPLER:-

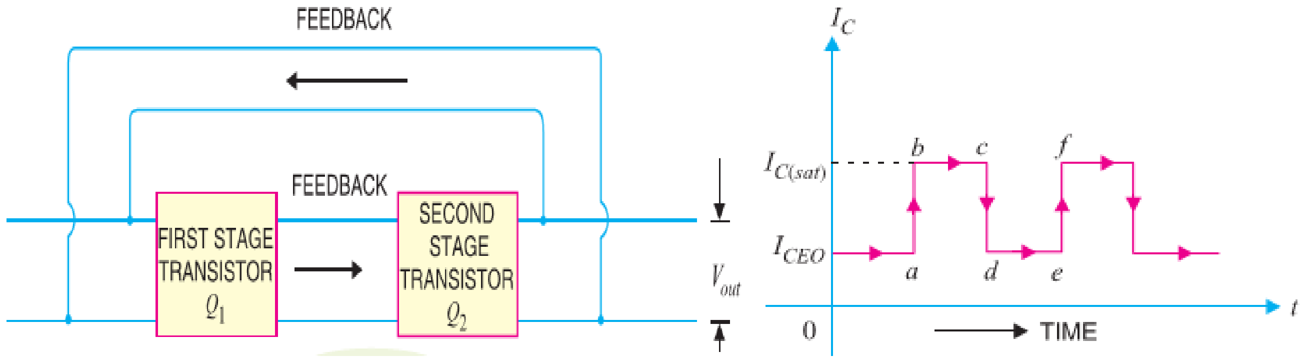
- Fig.showstheextensionofahalf-wavevoltagedoubler.Thiscircuitdevelopsanoutputvoltageequalto 3 and 4 times the peak input voltage.
- It is obvious from the pattern of the circuit connection as to how additional diodes and capacitors may beconnected for the amount of voltage multiplication.



- But it has been observed that if we increase the voltage multiplication beyond four, the regulation is verypoor.It isbecause of this fact, that voltage multipliers are not used in low-voltage supplies.
- TheoperationofthevoltageTriplerandquadruplercircuitmaybeunderstoodfromthefact,thatduring the first positive half-cycle, the capacitor C_1charges through diode $D_1$to apeakvoltage V_m.
- Duringthenegativehalf-cycle,capacitorC_2chargesthroughdiodeD_2totwicethepeakvoltage$2V_m$ developed by the sum of the voltage across capacitor C_1 and the input signal.
- During the second positive half-cycle, the diode D_3conductsand the voltage across capacitor C_2charges the capacitor C_3 to the same $2V_m$ peak voltage
- Duringthenegativehalf-cycle,diodesD_2andD_4conductallowingcapacitorC_3tochargecapacitor$C_4$to the same $2V_m$ peak voltage.
- Itisevidentfromfig.thatthevoltageacrosscapacitor$C_2$is$2V_m$,across$C_1$and$C_3$is$3V_m$andacrossC_2 and C_4 is $4V_m$.
- Itmeansthatthevoltagequadruplercircuitcanprovidethreedifferentvoltagesi.e.$2V_m$,$3V_m$,$4V_m$.
- Itwillbeinterestingtoknowthatifweuseadditionalsectionofdiodeandcapacitorwiththevoltage quadrupler circuit, then each capacitor will be charged to $2V_m$.
- Thepeakinversevoltageforeachdiodeinthecircuitisequalto$2V_m$.

❖ MULTIVIBRATORS:-

- An electronic circuit that generates square waves (or other non-sinusoidal such as rectangular, saw-tooth waves) is known as a **multivibrator.**
- A multivibrator is a switching circuit which depends for operation on positive feedback.It is basically a two-stage amplifierwith outputof one feedback tothe input of the other asshown in Fig (i).



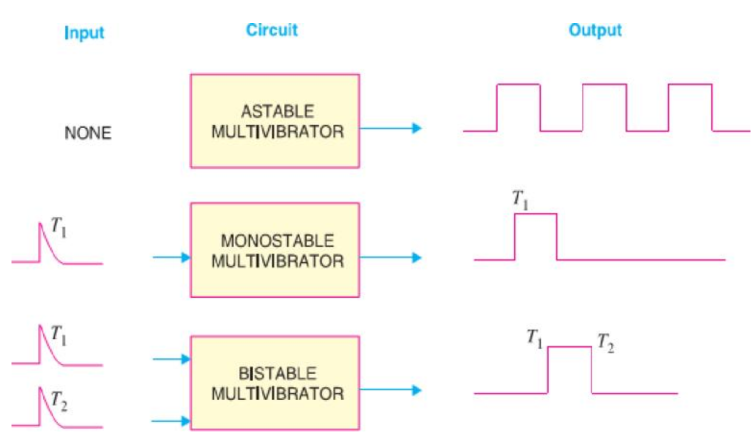
- The name multivibrator is derived from the fact that a square wave actually consists of a large number of (Fourier series analysis) sinusoidal of different frequencies.
- Thecircuitoperatesintwostates(vizONandOFF)controlledbycircuitconditions.Eachamplifier stagesuppliesfeedbacktotheotherinsuchamannerthatwilldrivethetransistorofonestageto saturation (ON state) and the other to cut off (OFF state).
- After a certain time controlled by circuit conditions, the action is reversed i.e. saturated stage is driven to cutoffandthecutoffstageisdriventosaturation.Theoutputcanbetakenacrosseitherstageandmay be rectangular or square wave depending upon the circuit conditions.
- Fig (ii)showstheblockdiagramofa multivibrator.Itisa two-stageamplifier with100%positive feedback. Suppose output is taken across the transistor Q_2. At any particular instant, one transistor is ON and conducts I_C (sat) while the other is OFF. Suppose Q_2 is ON and Q_1 is OFF.
- ThecollectorcurrentinQ$_2$willbeI$_C$(sat)asshowninFig(ii).Thisconditionwillprevailforatime(bc in this case) determined by circuit conditions.
- After this time, transistor Q_2 is cut off and Q_1 is turned ON. The collector current in Q_2 is now I_{CEO} as shown. The circuit will stay in this condition for a time de. Again Q_2 is turned ON and $Q_1$is driven to cut off. In this way, the output will be a square wave.

♣ TYPESOFMULTIVIBRATORS:-

- Amultivibratorisbasicallyatwo-stageamplifierwithoutputofonefeedbacktotheinputoftheother.
- At any particular instant,one transistor is ON and the other is OFF.Aftera certain time depending upon the circuit components, the stages reverse their conditions.
- Theconductingstagesuddenlycutsoffandthenon- conducting stage suddenly starts to conduct.
- Thetwopossiblestatesofamultivibratorare:

	ON	OFF
First State	Q_1	Q_2
Second State	Q_2	Q_1

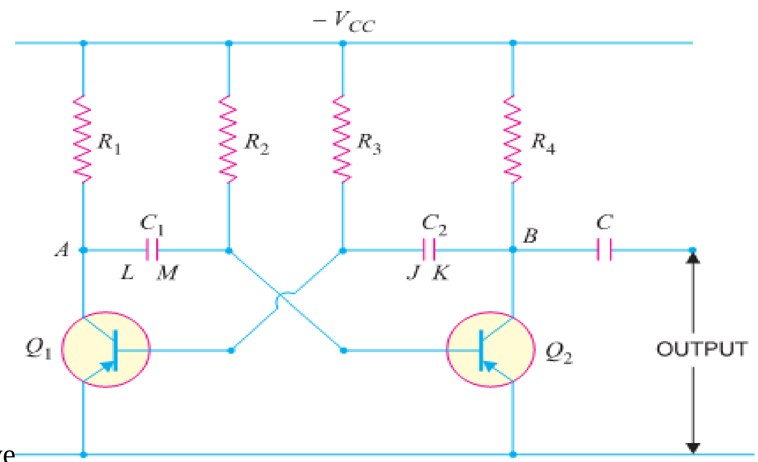
- Dependinguponthemannerinwhichthetwostages interchange their states, the multivibrators are classified as :-
  - ✓ Astableorfreerunningmultivibrator
  - ✓ Monostableorone-shotmultivibrator
  - ✓ Bi-stableorflip-flopmultivibrator
- Fig.showstheinput/outputrelationsfor the three types of multivibrators.
- **(i)**Theastableorfreerunning multivibrator alternates automatically between the two states and remains in each for a time dependent upon the circuit constants.
- Thus it is just an oscillator since it requires no external pulse for its operation.



- Of course, it does require a source of d.c. power. Because it continuously produces the square-wave output, it is often referred to as a free running multivibrator.
- **(ii)** The monostable or one-shot multivibrator has one state stable and one quasi-stable (i.e. half-stable) state. The application of input pulse triggers the circuit into its quasi-stable state, in which it remains for a period determined by circuit constants.
- After this period of time, the circuit returns to its initial stable state, the process is repeated upon the application of each trigger pulse.
- Since the monostable multivibrator produces a single output pulse for each input trigger pulse, it is generally called one-shot multivibrator.
- **(iii)** The bistable multivibrator has both the two states stable. It requires the application of an external triggering pulse to change the operation from either one state to the other.
- Thus one pulse is used to generate half-cycle of square wave and another pulse to generate the next half-cycle of square wave. It is also known as a **flip-flop multivibrator** because of the two possible states it can assume.

❖ **<u>TRANSISTOR ASTABLE MULTIVIBRATOR</u>**

- A multivibrator which generates square waves of its own (i.e. without any external triggering pulse) is known as an **astable** or **free running multivibrator.**
- The astable multivibrator has no stable state. It switches back and forth from one state to the other, remaining in each state for a time determined by circuit constants.
- In other words, at first one transistor conducts (i.e. ON state) and the other stays in the OFF state for some time.
- After this period of time, the second transistor is automatically turned ON and the first transistor is turned OFF.
- Thus the multivibrator will generate a square wave output of its own.



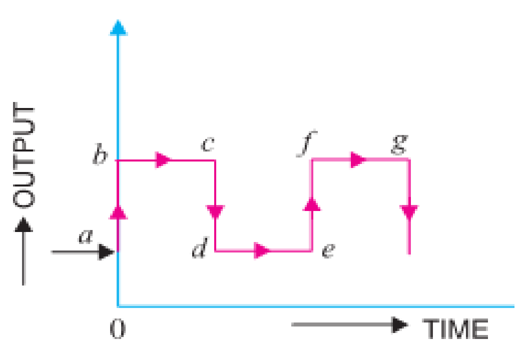
- The width of the square wave and its frequency will depend upon the circuit constants.

❖ **CIRCUIT DETAILS:-** Fig. shows the circuit of a typical transistor astable multivibrator using two identical transistors Q_1 and Q_2.

- The circuit essentially consists of two symmetrical CE amplifier stages, each providing a feedback to the other. Thus *collector loads* of the two stages are equal i.e. $R_1 = R_4$ and the *biasing resistors* are also equal i.e. $R_2 = R_3$.
- The output of transistor Q_1 is coupled to the input of Q_2 through C_1 while the output of Q_2 is fed to the input of Q_1 through C_2. The square wave output can be taken from Q_1 or Q_2.

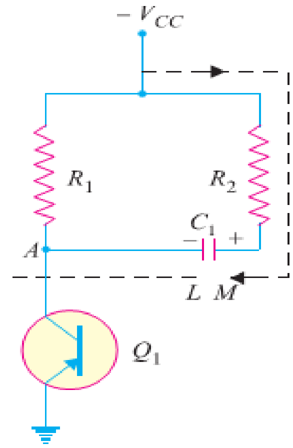
❖ **CIRCUIT OPERATION:-** When V_{CC} is applied, collector currents start flowing in Q_1 and Q_2. In addition, the coupling capacitors C_1 and C_2 also start charging up.

- As the characteristics of no two transistors (i.e. β, V_{BE}) are exactly alike, therefore, one transistor, say Q_1, will conduct more rapidly than the other.
- The rising collector current in Q_1 drives its collector more and more positive. The increasing positive output at point A is applied to the base of transistor Q_2 through C_1.
- This establishes a reverse bias on Q_2 and its collector current starts decreasing. As the collector of Q_2 is connected to the base of Q_1 through C_2, therefore, base of Q_1 becomes more negative i.e. Q_1 is more forward biased.



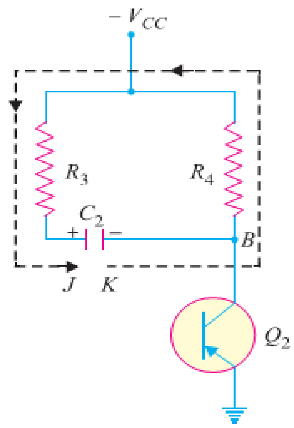
- This further increases the collector current in Q_1 and causes a further decrease of collector current in Q_2. This series of actions is repeated until the circuit drives Q_1 to saturation and Q_2 to cutoff.

- These actions occur very rapidly and may be considered practicallyinstantaneous.TheoutputofQ$_1$(ONstate)isapproximatelyzeroandthatof Q_2 (OFF state) is approximately V_{CC}.
- Thisisshownby abinaboveFig.WhenQ$_1$isatsaturationandQ$_2$iscutoff, the full voltage V_{CC} appears across R_1 and voltage across R_4 will be zero.
- ThechargesdevelopedacrossC$_1$andC$_2$aresufficienttomaintainthe saturation and cut off conditions at $Q_1$and Q_2 respectively. This condition is represented by time interval bc in Fig.
- However,thecapacitorswillnotretainthechargesindefinitely butwill dischargethroughtheirrespectivecircuits.ThedischargepathforC$_1$,with plate L negative and Q_1 conducting, is LAQ$_1$V$_{CC}$R$_2$M as shown in Fig. (i).



(i)

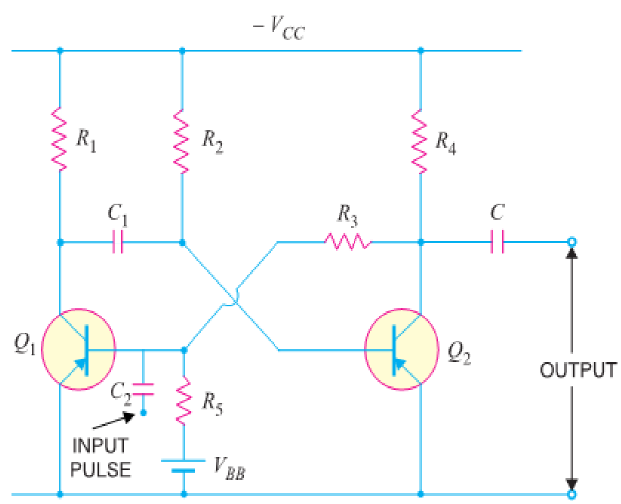
- The discharge path for C_2, with plate K negative and Q_2 cut off, is KBR$_4$R$_3$J as shown in Fig (ii). As theresistance of the discharge path for C_1 is lower thanthat of C_2, therefore, C_1 will discharge more rapidly.
- As C_1 discharges, the base bias at Q_2 becomes less positive and at a time determined by R_2 and C_1, forward bias is re-established at Q_2. This causes the collector current to start in Q_2.
- The increasing positive potential at collector of Q_2 is applied to the base of Q_1 throughthecapacitorC$_2$.HencethebaseofQ$_1$willbecomemorepositivei.e. Q_1 is reverse biased.
- ThedecreaseincollectorcurrentinQ$_1$sendsanegativevoltagetothebaseof Q_2 through C_1, thereby causing further increase inthe collector current of Q_2.
- Withthissetofactionstakingplace,Q$_2$isquicklydriventosaturationandQ$_1$ to cut off. This condition is represented by cd in Fig. The period of time during which Q_2 remains at saturation and Q_1 at cut off is determined by C_2 and R_3.



(ii)

❖ <u>TRANSISTORMONOSTABLEMULTIVIBRATOR</u>

- Amultivibratorinwhichonetransistorisalwaysconducting(i.e.intheON state)andtheotherisnon-conducting(i.e.intheOFFstate)iscalleda**monostablemultivibrator**
- A monostable multivibrator has only one state stable. Inotherwords,ifonetransistorisconductingand theotherisnon-conducting,thecircuitwillremain in this position.
- Itis only with theapplication ofexternal pulsethat the circuit will interchange the states.
- However, after a certain time, the circuit will automatically switch back to the original stable state and remains there until another pulse is applied.
- Thus a monostable multivibrator cannot generate squarewavesofitsownlikeanastable multivibrator. Only external pulse will cause it to generate the square wave.



❖ CIRCUITDETAILS:-

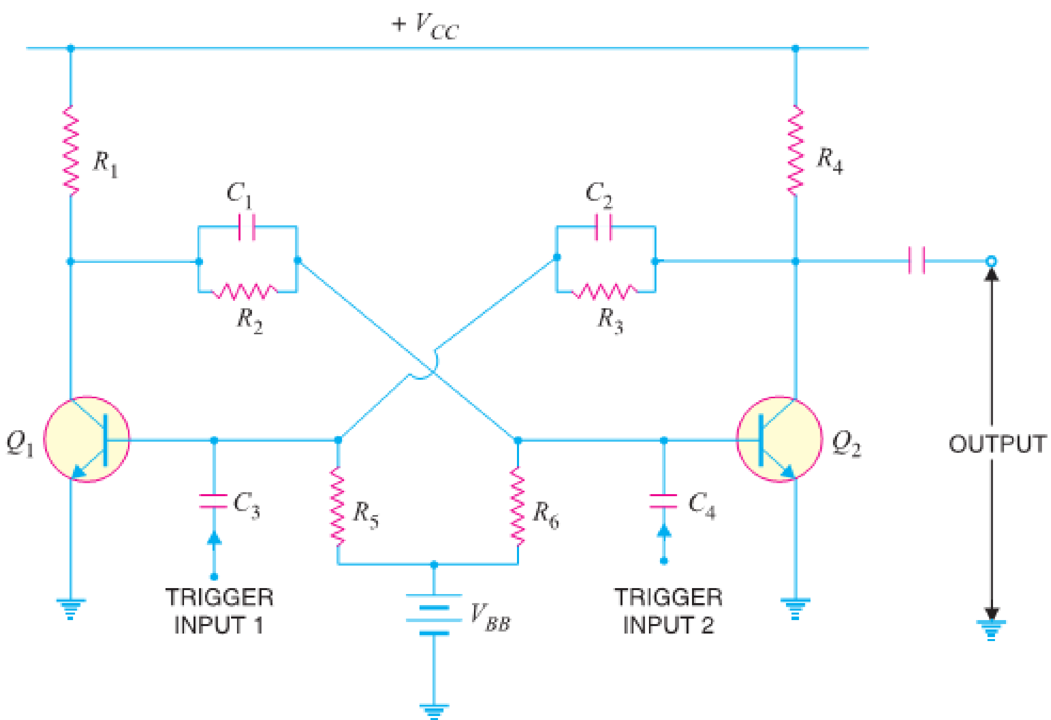
- Fig.showsthecircuitofatransistormonostable multivibrator.ItconsistsoftwosimilartransistorsQ$_1$andQ$_2$withequalcollectorloadsi.e.R$_1$=R$_4$.
- ThevaluesofV$_{BB}$ andR$_5$aresuchastoreversebiasQ$_1$andkeepitatcutoff.ThecollectorsupplyV$_{CC}$ and R_2 forward bias Q_2 and keep it at saturation.
- TheinputpulseisgiventhroughC$_2$toobtainthesquarewave.AgainoutputcanbetakenfromQ$_1$orQ$_2$.

❖ CIRCUITOPERATION:-

- With the circuit arrangement shown, Q_1 is at cutoff and Q_2 is at saturation. This is the stable state for thecircuit and it will continue to stay in this state until a triggering pulse is applied at C_2.
- When a negative pulse of short duration and sufficient magnitude is applied to the base of Q_1 through C_2,the transistor Q_1 starts conducting and positive potential is established at its collector.

- The positive potential at the collector of Q_1 is coupled to the base of Q_2 through capacitor C_1. Thisdecreases the forward bias on Q_2 and its collector current decreases.
- TheincreasingnegativepotentialonthecollectorofQ$_2$isappliedtothebaseofQ$_1$throughR$_3$.This further increases the forward bias on Q_1 and hence its collector current.
- With this set of actions taking place, $Q_1$is quickly driven to saturation and Q_2 to cut off.With Q_1 at saturation and Q_2 at cut off, the circuit will come back to the original stage (i.e. Q_2 at saturation and Q_1 at cut off) after some time as explained in the following discussion.
- ThecapacitorC$_1$(chargedtoapproximatelyV$_{CC}$)dischargesthroughthepathR$_2$V$_{CC}$Q$_1$.AsC$_1$ discharges, it sends a voltage to the base of Q_2 to make it less positive.
- Thisgoesonuntilapointisreachedwhenforwardbiasisre-establishedonQ$_2$andcollectorcurrent starts to flow in Q_2.
- ThestepbystepeventsalreadyexplainedoccurandQ$_2$isquicklydriventosaturationandQ$_1$tocutoff.
- Thisis the stable state for the circuitand itremainsinthiscondition until another pulse causes the circuitto switch over the states.

❖ <u>TRANSISTORBISTABLEMULTIVIBRATOR:-</u>



- Amultivibratorwhichhasboththestatesstableiscalleda**BistableMultivibrator.**
- Thebistablemultivibratorhasboththestatesstable.Itwillremaininwhicheverstateithappenstobe until a trigger pulse causes it to switch to the other state.
- Forinstance,supposeatanyparticularinstant,transistorQ$_1$isconductingandtransistorQ$_2$isatcutoff. Iflefttoitself,thebistablemultivibratorwillstayinthispositionforever.
- However, if an external pulse is applied to the circuit in such a way that Q_1 is cut off and Q_2 is turned on,the circuit will stay in the new position.
- Anothertriggerpulseisthenrequiredtoswitchthecircuitbacktoitsoriginalstate.

❖ CIRCUITDETAILS:-

- Circuitdetails.Fig.showsthecircuitofatypicaltransistorbistablemultivibrator.
- ItconsistsoftwoidenticalCEamplifierstageswithoutputofonefedtotheinputoftheother.
- Thefeedbackiscoupledthroughresistors(R$_2$,R$_3$)shuntedbycapacitorsC$_1$andC$_2$.
- ThemainpurposeofcapacitorsC$_1$andC$_2$istoimprovetheswitchingcharacteristicsofthecircuitby passing the high frequency components of the square wave.
- This allows fast rise and fall times and hence distortion less square wave output. The output can be takenacross either transistor.

❖ **OPERATION:-**

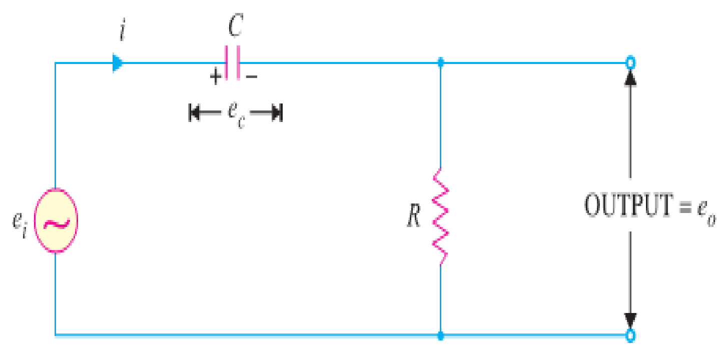
- When V_{CC} is applied, one transistor will start conducting slightly ahead of the other due to some differences in the characteristics of the transistors.
- This will drive one transistor to saturation and the other to cut off in a manner described for the astable multivibrator.
- Assume that Q_1 is turned ON and Q_2 is cut OFF. If left to itself, the circuit will stay in this condition. In order to switch the multivibrator to its other state, a trigger pulse must be applied.
- A negative pulse applied to the base of Q_1 through C_3 will cut it off or a positive pulse applied to the base of Q_2 through C_4 will cause it to conduct.
- Suppose a negative pulse of sufficient magnitude is applied to the base of Q_1 through C_3.
- This will reduce the forward bias on Q_1 and cause a decrease in its collector current and an increase in collector voltage.
- The rising collector voltage is coupled to base of Q_2 where it forward biases base-emitter junction of Q_2.
- This will cause an increase in its collector current and decrease in collector voltage.
- The decreasing collector voltage is applied to the base of Q_1 where it further reverse biases the base- emitter junction of Q_1 to decrease its collector current.
- With this set of actions taking place, Q_2 is quickly driven to saturation and Q_1 to cut off.
- The circuit will now remain stable in this state until a negative trigger pulse at Q_2 (or a positive trigger pulse at Q_1) changes this state.

❖ DIFFERENTIATING CIRCUIT:

- A circuit in which output voltage is directly proportional to the derivative of the input is known as a **Differentiating Circuit.**

i.e. **Output ∝ d/dt(Input)**

- A differentiating circuit is a simple RC series circuit with output taken across the resistor R.
- The circuit is suitably designed so that output is proportional to the derivative of the input.
- Thus if a d.c. or constant input is applied to such a circuit, the output will be zero. It is because the derivative of a constant is zero.
- Fig shows a typical differentiating circuit. The output across R will be the derivative of the input.



- It is important to note that merely using voltage across R does not make the circuit a differentiator; it is also necessary to set the proper circuit values.
- In order to achieve good differentiation, the following two conditions should be satisfied:
  - ♣ The time constant RC of the circuit should be much smaller than the time period of the input wave.
  - ♣ The value of X_C should be 10 or more times larger than R at the operating frequency.
- Fulfilled these conditions, the output across R in Fig. will be the derivative of the input.

Let e_i be the input alternating voltage and let i be the resulting alternating current.

The charge q on the capacitor at any instant is $q = Ce_c$

$$\text{Now} \quad i = \frac{dq}{dt} = \frac{dq}{dt} = \frac{d}{dt}(Ce_c)$$

$$i = C.\frac{de_c}{dt}$$

- Since the capacitive reactance is very much larger than R, the input voltage can be considered equal to the capacitor voltage with negligible error i.e. $e_c = e_i$

$$\therefore \quad i = C.\frac{de_i}{dt}$$

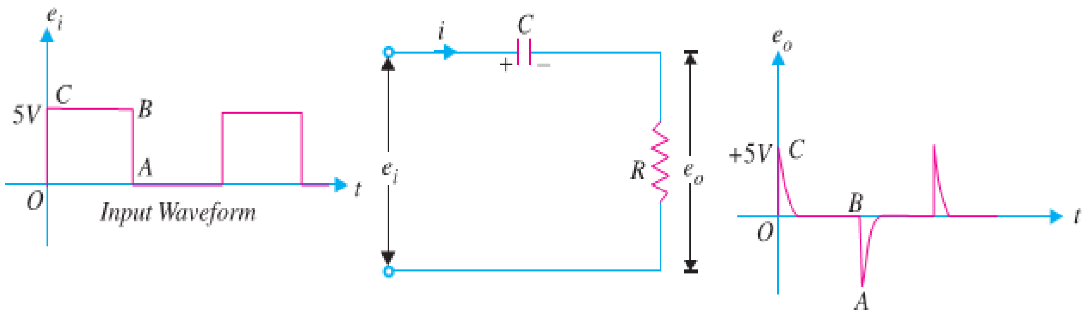
- Output voltage, $e_o = iR = RC.\frac{d}{dt}e_i \Rightarrow e_o \propto \frac{d}{dt}(e_i)$

➔ **Output Voltage ∝ d/dt(Input Voltage)**

❖ **OUTPUTWAVEFORMS:-**

✍Theoutputwaveformfromadifferentiatingcircuitdependsuponthetimeconstantandshapeofthe input wave. Three important cases will be considered.

✍**(i)Wheninputisasquarewave:-** In this case, output will consist of sharp narrow pulses as shown in Fig. During the OC part of input wave, its amplitude changes abruptly and hence the differentiated wave will be a sharp narrow pulse as shown in Fig.



✍However,duringtheconstantpartCBoftheinput,theoutputwillbezerobecausederivativeofaconstant is zero.Let us look at the physical explanation of this behavior of the circuit.

✍SincetimeconstantRCofthecircuitisverysmallw.r.t.timeperiodofinputwaveandX_C>>R,the capacitorwillbecome fully chargedduring theearly part of each half-cycleof the input wave.

✍Duringtheremainderpartofthehalf-cycle,theoutputofthecircuitwillbezerobecausethecapacitor voltage (e_c) neutralizes the input voltage and there can be nocurrent flow through R.

✍Thus we shallget sharppulse at the output during the start of each half-cycle of input wave whilefor the remainder part of the half-cycle of input wave, the output will be zero.

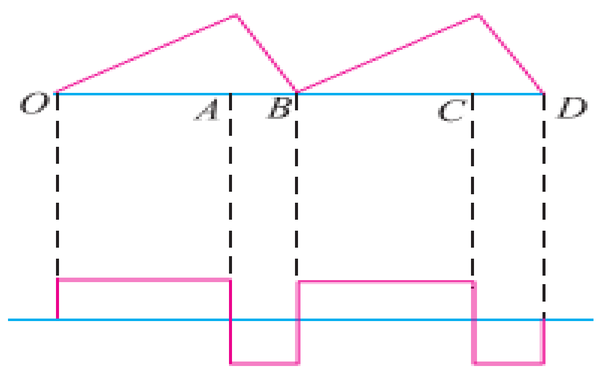
✍Inthisway,a symmetrical outputwavewithsharppositive and negative peaks isproduced. Suchpulses are used in many waysin electroniccircuits e.g.in television transmitters and receivers, in multivibratorsto initiate action etc.

✍**(ii)Wheninputisatriangularwave:-**Whentheinputfedtoadifferentiatingcircuitisatriangular wave, the output will be a rectangular wave as shown in Fig.

✍DuringtheperiodOAoftheinputwave,its amplitude changes at a constant rate and, therefore,the differentiated wave has a constant value for each constant rate of change.

✍DuringtheperiodABoftheinputwave,thechange is less abrupt so that the output will be a very narrow pulse of rectangular form.

✍Thuswhenatriangularwaveisfedtoa differentiating circuit, the output consists of a succession of rectangular waves of equal or unequal durationdependingupontheshapeoftheinputwave.



✍**(iii)Wheninputisasinewave.**Asinewaveinput becomesacosinewaveandacosinewaveinputbecomesaninvertedsinewaveattheoutput.

❖ **APPLICATIONSOFDIFFERENTIATINGCIRCUIT:-**

♣ Togenerateaseriesofnarrowpulsesfromrectangularorsquarewaves.

♣ Togenerateastepfromarampinput.

♣ Togenerateasquarewavefromtriangularwaveinputs.

❖ **<u>INTEGRATINGCIRCUIT</u>:-**

✍Acircuitinwhichoutputvoltageisdirectlyproportionaltotheintegraloftheinputisknownasan **IntegratingCircuit.**

i.e. **Output**$\int$**(Input)**

✍AnintegratingcircuitisasimpleRCseriescircuitwithoutputtakenacrossthecapacitorCasshownin Fig.It may be seen thatR and C of the differentiating circuit have changed places.

- Inorderthatthecircuitrendersgoodintegration,thefollowingconditionsshouldbefulfilled:
- ♣ ThetimeconstantRCofthecircuitshouldbeverylargeascomparedtothetimeperiodofinputwave.
- ♣ ThevalueofRshouldbe10ormoretimeslargerthan X_C.
- Let e_i betheinputalternatingvoltageandletibetheresultingalternatingcurrent.
- SinceRisvery largeascomparedtocapacitivereactance X_C ofthecapacitor,itisreasonabletoassume that voltage across R (i.e. e_R) is equal to the input voltage i.e.

$$\mathbf{e_i = e_R} \quad , \quad \text{Also } i = \frac{e_R}{R} = \frac{e_i}{R}$$

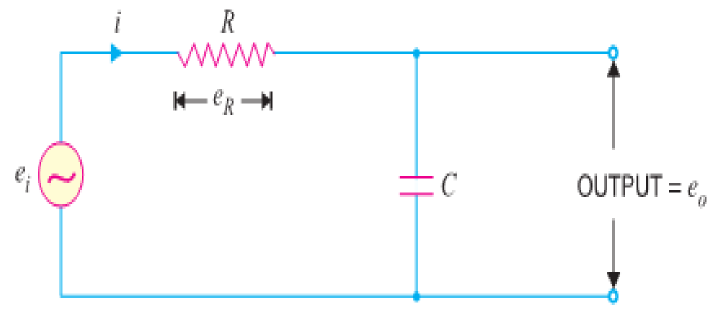
- Thechargeqonthecapacitoratanyinstantis $\mathbf{q = \int i\,dt} = \int \frac{e_i}{R} dt$
- Outputvoltage, $e_o = \frac{q}{C} = \frac{\int \frac{e_i}{R} dt}{C}$

$$= \frac{1}{RC} \int e_i\,dt$$

$$= \text{constant} \times \int e_i\,dt$$

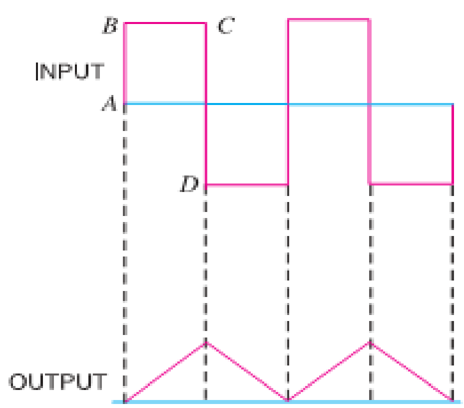
$$\Rightarrow e_o \propto \int e_i\,dt$$

$$\therefore \textbf{ Output voltage} \propto \int \textbf{Input}$$

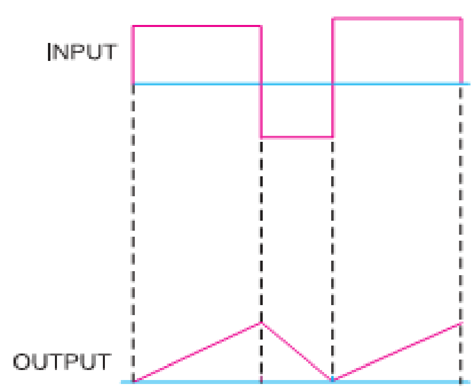


❖ OUTPUTWAVEFORMS:-

- Theoutputwaveformfromanintegratingcircuitdependsupontimeconstantandshapeoftheinput wave. Two important cases will be discussed:
- **(i)Wheninputisasquarewave:-**Whentheinputfedtoanintegratingcircuitisasquarewave,the output will be a triangular wave as shown in Fig. (i).
- Asintegrationmeanssummation,therefore,outputfromanintegratingcircuitwillbethesumofallthe input waves at any instant.
- ThissumiszeroatAandgoesonincreasingtillitbecomesmaximumatC.Afterthis,thesummation goes on decreasing to the onset of negative movement CD of the input.
- **(ii)Wheninputisrectangularwave:-**Whentheinputfedtoanintegratingcircuitisarectangular wave, the output will be a triangular wave as shown in Fig. (ii).



(i)



(ii)

❖ APPLICATIONSOFINTEGRATINGCIRCUIT:-

- ♣ Toperformmathematicalintegrationinanalogcomputers.
- ♣ Togenerateatriangularwavefromasquarewaves.
- ♣ Togenerateasawtoothwavefromarectangularwave.

- **Differentiator**isanRCcircuitwithaninputappliedtotheCapacitorandoutputtakenacrossResistor.
- **Integrator**isanRCcircuitwithaninputappliedtotheResistorandoutputtakenacrossCapacitor.
- **TimeConstant**istheproductofR&C.