ANALOGELECTRONICS
AND
OPAMP

[TH-2]

4RD SEM ELECTRICAL& ELECTRONICS ENGG.

Under SCTE&VT, Odisha

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CHAPTER-1

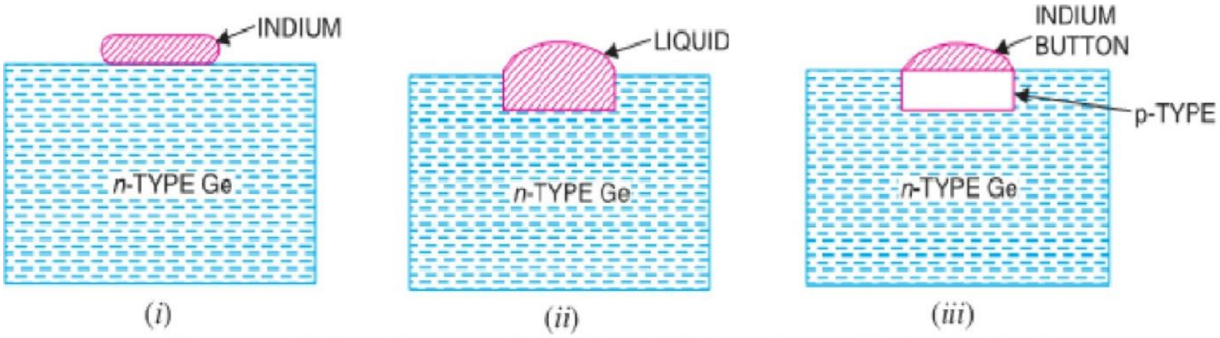
[P-NJUNCTIONDIODE]

❖ DEFINITION:-

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

❖ FORMATIONOFPNJUNCTION

- In actual practice, the characteristic properties ofPN junction will not be apparent ifa p-type block is just brought in contact with n-type block.
- It is fabricated by special techniques and one common method of making PN junction is called **Alloying**.



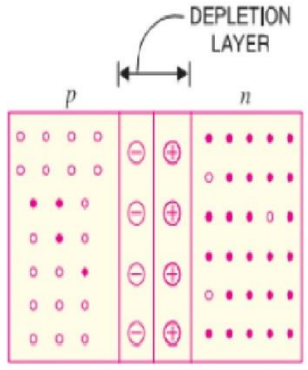
[Figures of different stages of formation of PN junction by Alloying method]

- In this method, a small block of indium (trivalent impurity) is placed on an n-type germaniums lab as shown in Fig (i). The system is then heated to a temperature of about 500ºC. The indium and some of the germanium melt to form a small puddle of molten germanium-indium mixture as shown in Fig (ii). The temperature is then lowered and puddle begins to solidify.
- Under proper conditions, the atoms of indium impurity will be suitably adjusted in the germanium slab to form a single crystal.
- The addition of indium overcomes the excess of electrons in the n-type germanium to such an extent that it creates a p-type region.
- As the process goes on, the remaining molten mixture becomes increasingly rich in indium. When all germanium has been re-deposited, the remaining material appears as indium but- ton which is frozen on to the outer surface of the crystallized portion as shown in Fig (iii).

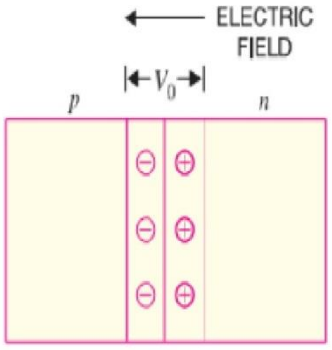
❖ PROPERTIES OF PN JUNCTION

- To explain PN junction,consider two types of materials: -
  1) P-Type-P-type semiconductor having –ive acceptor ions and +ive charge dholes.
  2) N-Type-N-type semiconductor having +ive donor ions and –ive free electrons.
- P-type has high concentration of holes & N-type has high concentration of electrons.
- The tendency for the free electron to diffuse over p-side and holes ton-side process is called **Diffusion.**

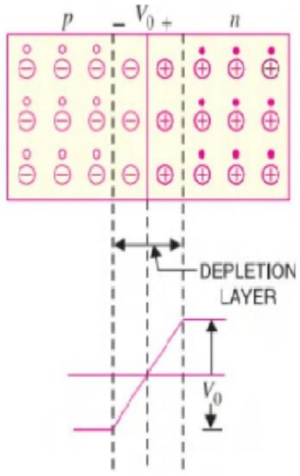
- When a free electron move across the junction from n-type to p-type, positive donor ions are removed by the force of electrons. Hence positive charge is built on the n-side of the junction. Similarly negative charge establish on p-side of the junction.
- When sufficient no of donor and accepter ions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



(i)



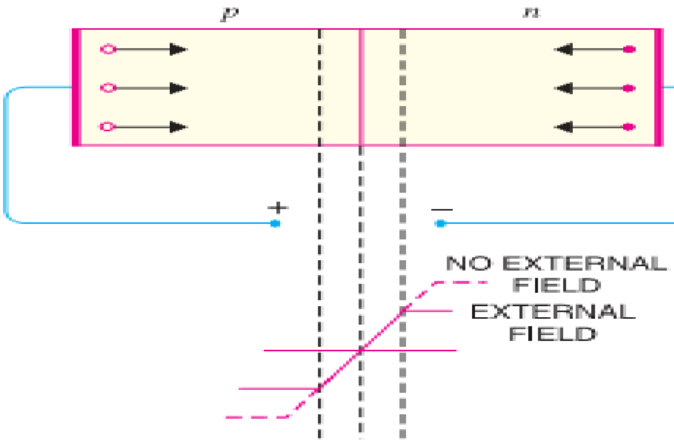
(ii)



- The electric field is a barrier to the free electrons in the n-region.
- There exists a potential difference across the depletion layer and is called barrier potential (V0). The barrier potential of a p-n junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature.
- The typical barrier potential is approximately:-ForSi,V_0=0.7V,ForGe,V_0=0.3V.

PN JUNCTION UNDER FORWARD BIASING

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



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

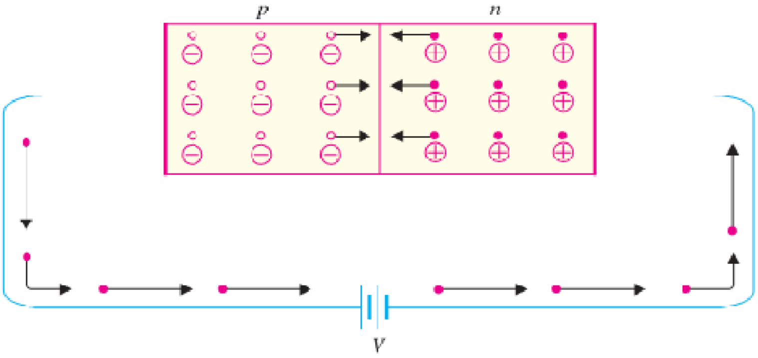
(i) The potential barrier is reduced and at some forward voltage (0.1 to 0.3 V), it is eliminated altogether.

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

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

❖ CURRENT FLOW IN A FORWARD BIASED PN JUNCTION:-

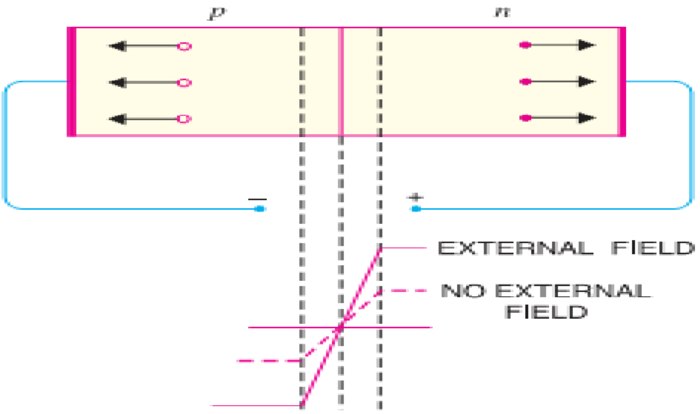
- It is concluded that inn-type region, current is carried by free electrons where as in p-type region, it is carried by holes. However, in the external connecting wires, the current is carried by free electrons.



❖ PN JUNCTION UNDER REVERSE BIASING

- When the external D.C.voltage applied to the junction is in such a direction that potential barrier is increased, it is called **Reverse Biasing.**
- To apply reverse bias, connect negative terminal of the battery top-type and positive terminal to n-type.

- It is clear that applied reverse voltage establishes an electric field which acts in the same direction as the field due to potential barrier.
- Therefore,theresultantfieldatthejunctionisstrengthenedandthebarrierheightis increased as shown in fig below .



- Theincreasedpotentialbarrierpreventstheflowofchargecarriersacrossthejunction.
- Thus,ahighresistancepathisestablishedfortheentirecircuitandhencethecurrent does not flow.
- WithreversebiastoPNjunction,thefollowingpointsareworthnoting:
  (i) Thepotentialbarrierisincreased.
  (ii)Thejunctionoffers veryhighresistance(ReverseResistanceR_r)tocurrentflow.
  (iii)Nocurrentflowsinthecircuitduetotheestablishmentofhighresistancepath.

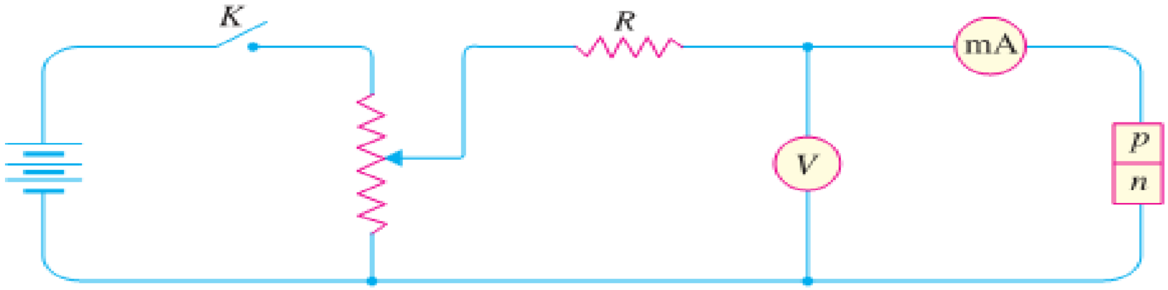
❖ VOLT-AMPERE CHARACTERISTICS OF PN JUNCTION:-

- Volt-ampere or V-I characteristic ofa pnjunction(also called a crystalor semiconductor diode) is the curve between voltage across the junction and the circuit current.
- Usually,voltageistakenalongx-axisandcurrentalongy-axis.Fig.showsthecircuit arrangement for determining the V-I characteristics of a pn junction.
- Thecharacteristicscanbestudiedunderthreeheadsnamely:
  1) Zeroexternalvoltage
  2) ForwardBias
  3) ReverseBias.

❖ ZERO EXTERNALVOLTAGE: -

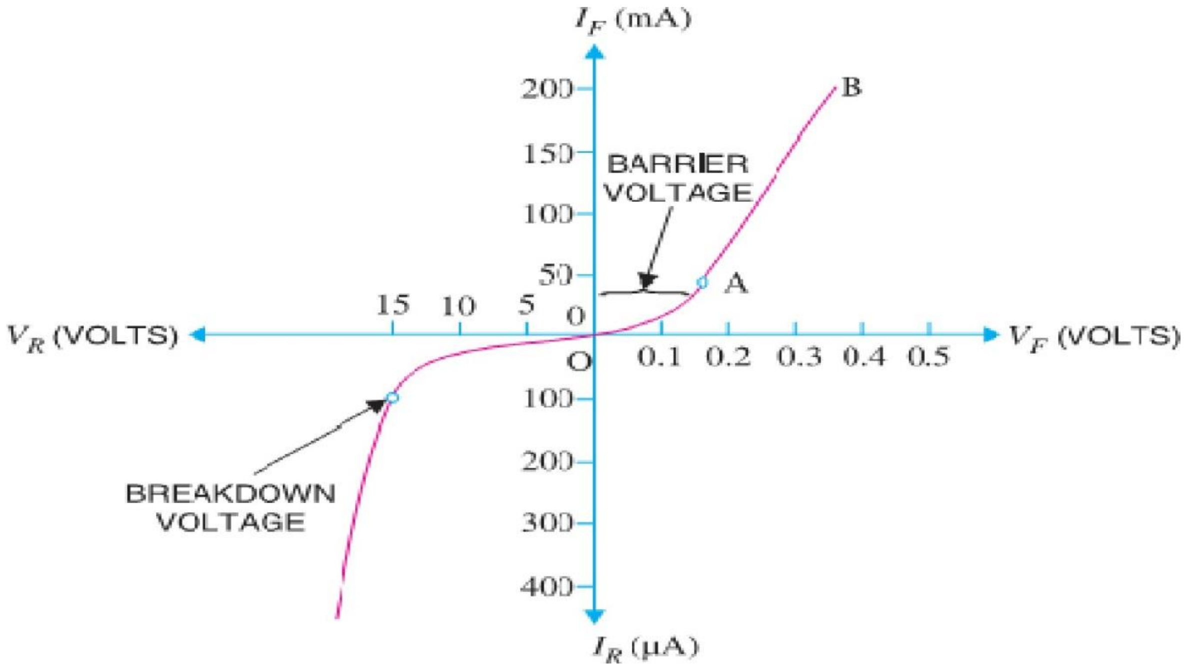
- Whentheexternalvoltageiszero,i.e.circuitisopenatK;thepotentialbarrieratthe junction does not permit current flow.

Therefore,thecircuitcurrentiszeroasindicatedbypointOinFig.



(II)FORWARD BIAS:-

- With forwardbias to thepnjunctioni.e.p-type connected to positiveterminaland n-type connected to negative terminal, the potential barrier is reduced.
- Atsomeforwardvoltage(0.7VforSiand0.3VforGe),thepotentialbarrieris altogether eliminated and current starts flowing in the circuit.
- Fromnowonwards,thecurrentincreaseswiththeincreaseinforwardvoltage.
- Thus, a risingcurve OBis obtained with forward bias as shownin Fig. Fromthe forward characteristic, it is seen that at first (region OA), the current increases very slowly andthe curve is non-linear.
- Itisbecausetheexternalappliedvoltageisusedupinovercomingthepotentialbarrier.
- However, once the external voltage exceeds the potential barrier voltage, the pn junction behaves like an ordinary conductor.
- Therefore, the current rises very sharply with increase in external voltage (region AB on the curve). Here the curve is almost linear.



(III)REVERSE BIAS:-

- Withreverse bias to thepnjunctioni.e.p-type connectedto negativeterminaland n-type connected to positive terminal, potential barrier at the junction is increased.
- Therefore,thejunctionresistancebecomesveryhighandpracticallynocurrentflows through the circuit.
- However, in practice, a very small current (of the order of μA) flows in the circuit with reverse bias as shown in the reverse characteristic.
- ThisiscalledReverseSaturationCurrent(I_s)andisduetotheminoritycarriers.
- It mayberecalledthat therearea few free electrons inp-type materialanda few holes in n-type material.
- These undesirable free electrons inp-type and holes in n-type are called minority carriers. Therefore, a small current flows in the reverse direction.

- If reverse voltage is increased continuously, the kinetic energy of electrons (minority carriers) maybecome high enoughto knock out electrons fromthe 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 maydestroy thejunction permanently.
- **Note:** -The forward current through a p-n junction is due to the majoritycarriers produced by the impurity.
- However, reverse current is due to the minority carriersproduced due to breaking of some covalent bonds at room temperature.

❖ IMPORTANT TERMS:-

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

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

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

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

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

❖ DCLOADLINE:-

- The line obtained by joining the maximum values of I_c and V_{ce} in the output characteristics of a CE configuration transistor is known as the DC Load Line.

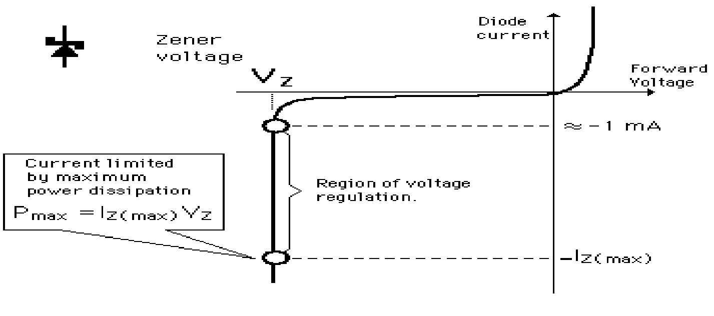
❖ PN JUNCTION BREAKDOWN:-

- Electricalbreakdownofsemiconductorcanoccurduetotwodifferentphenomena. Those two phenomena are

1. Zenerbreakdown
2. Avalanchebreakdown

❖ ZENER BREAKDOWN:-

- A properly doped crystal diode which has a sharp breakdown voltage is known as a **Zener Diode**.



- It has already been discussed that when the reverse bias on a crystal diode is increased, a critical voltage, called Breakdown Voltage is reached where the reverse current increases sharply to a high value.
- The breakdown region is the knee of the reverse characteristics as shown in Figure.
- The satisfactory explanation of this breakdown of the junction was first given by the American scientist C. Zener.
- The breakdown voltage is sometimes called Zener Voltage and the sudden increase in current is known as Zener Current. The breakdown or Zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage.
- On the other hand, a lightly doped diode has a higher breakdown voltage. Fig. shows the symbol of a Zener diode. It may be seen that it  is just like an ordinary diode except that the bar is turned into z-shape.

❖ PROPERTIES OF ZENER DIODE:-

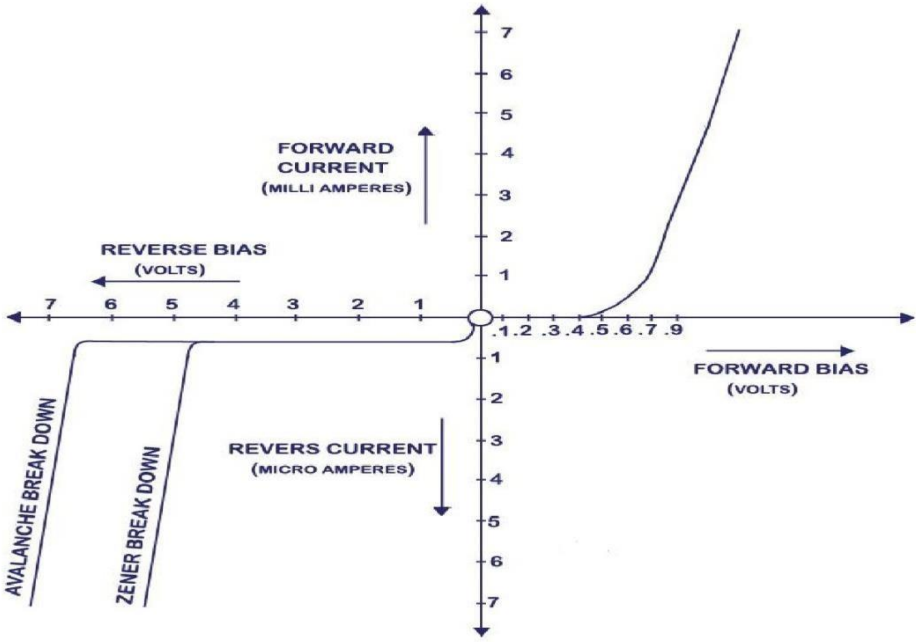
- The following points may be noted about the Zener diode:
- A Zener diode is like an ordinary diode except that it is properly doped to have a sharp breakdown voltage. A Zener diode is always reverse connected i.e. it is always reverse biased. A Zener diode has sharp breakdown voltage, called Zener voltage V_Z.
- When forward biased, its characteristics are just those of ordinary diode.
- The Zener diode is not immediately burnt just because it has entered the breakdown region. As long as the external circuit connected to the diode limits the diode current to less than burn out value, the diode will not burn out.
- Zener diode operated in this region will have a relatively constant voltage across it, regardless of the value of current through the device. This permits the Zener diode to be used as a **Voltage Regulator.**

➢ WORKING/OPERATION OF ZENER BREAKDOWN:-

- When the reverse voltage across the pn junction diode increases, the electric field across the diode junction increases (both internal & external).
- This results in a force of attraction on the negatively charged electrons at junction.
- This force frees electrons from its covalent bond and moves those free electrons to conduction band. When the electric field increases (with applied voltage), more and more electrons are freed from its covalent bonds.
- This results in drifting of electrons across the junction and electron hole recombination occurs. So a net current is developed and it increases rapidly with increase in electric field. Zener breakdown phenomena occurs in a pn junction diode with heavy doping & thin junction (means depletion layer width is very small).
- Zener breakdown does not result in damage of diode since current is only due to drifting of electrons, there is a limit to the increase in current as well.

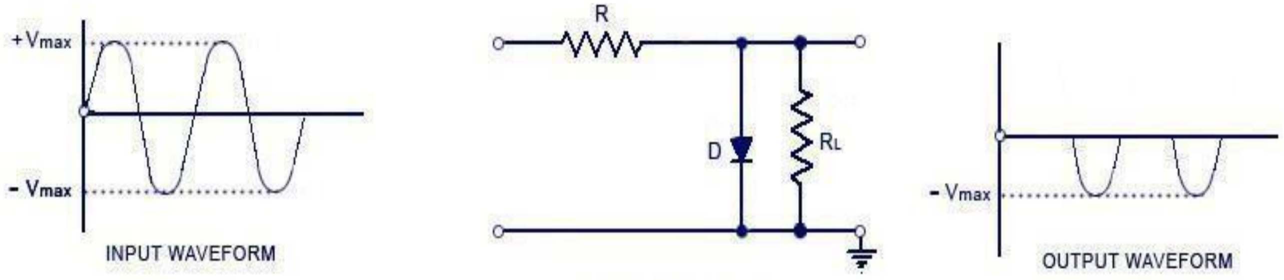
- **AVALANCHE BREAKDOWN:-**
- Avalanche breakdown occurs in a p-n junction diode which is moderately doped and has a thick junction (means its depletion layer width is high).
- Avalanche breakdown usually occurs when we apply a high reverse voltage across the diode (obviously higher than the zener breakdown voltage,say V_z).
- By increasing the applied reverse voltage, the electric field across junction will keep increasing. If applied reverse voltage is V_a and the depletion layer width is d, then the generated electric field can be calculated as $E_a = V_a/d$.
- This generated electric field exerts a force on the electrons at junction and it frees them from covalent bonds. These free electrons will gain acceleration and it will start moving across the junction with high velocity.
- This results in collision with other neighboring atoms. These collisions in high velocity will generate further free electrons. These electrons will start drifting and electron-hole pair recombination occurs across the junction. This results in net current which rapidly increases.

PN JUNCTION BREAKDOWN CHARACTERISTICS



- From the above fig we can see that avalanche breakdown occurs at a voltage (V_a) which is higher than zener breakdown voltage (V_z).
- It is because avalanche phenomena occurs in a diode which is moderately doped and junction width (say d) is high where as zener break down occurs in a diode with heavy doping and thin junction (here d is small).
- The electricfield thatoccurdue toappliedreverse voltage(sayV)canbecalculatedasE = V/d. So in a Zener breakdown, the electric field necessary to break electrons from covalent bond is achieved with lesser voltage than in avalanche breakdown due to thin depletion layer width.

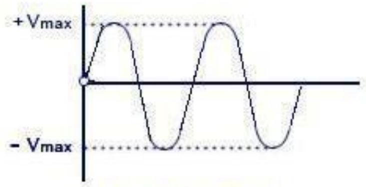
- In avalanche breakdown, the depletion layer width is higher and hence much more reverse voltage has to be applied to develop the same electric field strength (necessary enough to break electrons free).
- **CLIPPING CIRCUITS**
- Thecircuitwithwhichthewaveformisshapedbyremoving(orclipping)aportionofthe applied wave is known as a clipping circuit.
- Clippersfindextensive useinradar,digitalandotherelectronicsystems.
- Although several clipping circuitshavebeen developedtochangethewaveshape,we concentrate only on diode clippers.
- Theseclipperscanremovesignalvoltagesaboveorbelowaspecified level.
- Theimportantdiodeclippersare:-
    1. Positiveclipperandnegativeclipper
    2. Biasedpositiveclipperandbiasednegativeclipper
    3. Combinationclipper.
- **POSITIVE CLIPPER**
- Apositiveclipper isthatwhichremovesthepositivehalf-cyclesofthe inputvoltage.
- Thepositiveclipperisoftwotypes
    1. Positiveseriesclipper
    2. Positiveshuntclipper
- ThebelowFig.showsthetypicalcircuitofapositiveshuntclipperusingadiode.



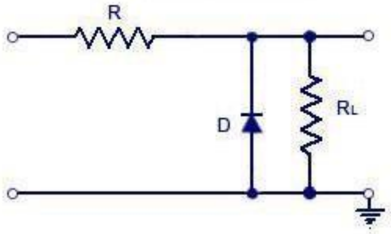
Positive Shunt Clipper

- Herethediodeiskeptinparallelwiththeload.
- During the positive half cycle, the diode ‘D’ is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily.
- This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the positive half cycles is zero.
- During the negative half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L
- Actually the circuit behaves as a voltage divider with an output voltage of $-[R_L/ R+ R_L] V_{max} \cong -V_{max}$(Taking or assuming when $R_L >> R$).

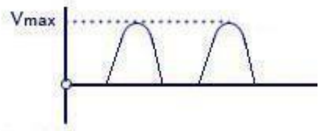
- **NEGATIVE CLIPPER**
- Anegativeclipperisthatwhichremovesthepositive half-cyclesoftheinput voltage. The negative clipper is of two types
  1. Negativeseriesclipper
  2. Negativeshuntclipper
- ThebelowFig.showsthetypicalcircuitofanegativeshuntclipperusingadiode.



INPUT WAVEFORM



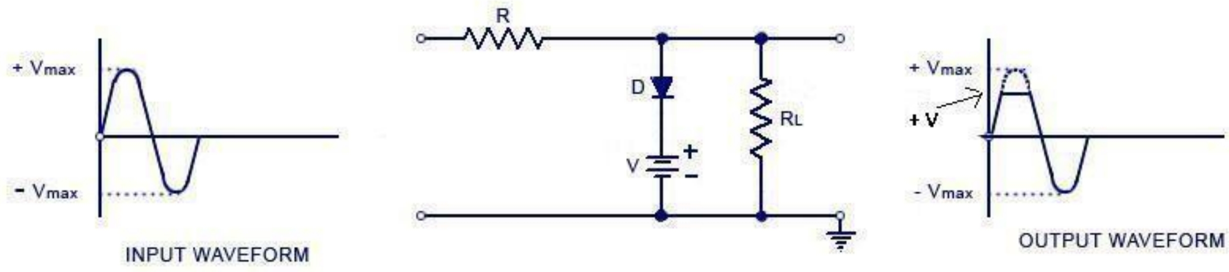
Negative Shunt Clipper



OUTPUT WAVEFORM

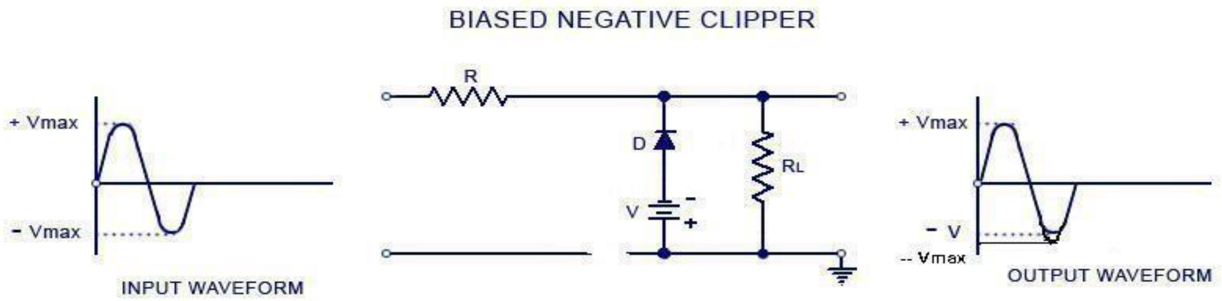
- During the negative half cycle, the diode ‘D’ is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily.
- This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the negative half cycles is zero.
- During the positive half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L
- Actually the circuit behaves as a voltage divider with an output voltage of $[R_L / R + R_L] V_{max} \cong V_{max}$(Taking or assuming when $R_L >> R$).
- **BIASED POSITIVE CLIPPER**
- When a small portion of the positive half cycle is to be removed, it is called a biased positive clipper.The circuit diagram and waveform is shown in the figure below.

BIASED POSITIVE CLIPPER

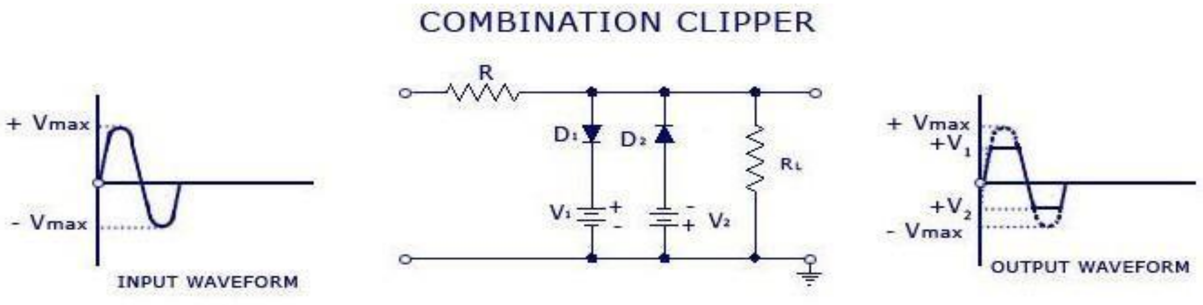


- During negative half cycle, when the input signal voltage is negative, the diode ‘D’ is reverse-biased. This causes it to act as an open-switch. Thus the entire negative halfcycle appears across the load, as illustrated by output waveform.
- During positive half cycle, when the input signal voltage is positive but does not exceed battery the voltage ‘V’, the diode ‘D’ remains reverse-biased and most of the input voltage appears across the output.

- When during the positive half cycle of input signal, the signal voltage becomesmore than the battery voltage V, the diode D is forward biased and so conducts heavily. The output voltage is equal to '+ V' and stays at '+ V' as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, 'V'.
- Thus a biased positive clipper removes input voltage when the input signal voltage becomes greater than the battery voltage.
- **BIASED NEGATIVE CLIPPER**
- When a small portion of the negative half cycle is to be removed, it is called a biased negative clipper. The circuit diagramand waveform is shown in the figure below.



- During positive half cycle, when the input signal voltage is positive, the diode 'D' is reverse-biased. This causes it to act as anopen-switch. Thus the entire positive halfcycle appears across the load, as illustrated by output waveform.
- During negative halfcycle, whenthe input signal voltage is negative but does not exceed battery the voltage 'V', the diode 'D' remains reverse-biased and most of the input voltage appears across the output.
- When during the negative half cycle of input signal, the signal voltage becomes more than the battery voltage V, the diode D is forward biased and so conducts heavily. The output voltage is equal to '-V' and stays at '-V' as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, 'V'.
- Thus a biased negative clipper removes input voltage when the input signal voltage becomes greater than the battery voltage.
- **COMBINATION CLIPPER:-**
- Combination clipper is employed when a portion of both positive and negative of each half cycle of the input voltage is to be clipped (or removed) using a biased positive and negative clipper together.The circuit for such a clipper is given in the figure below.

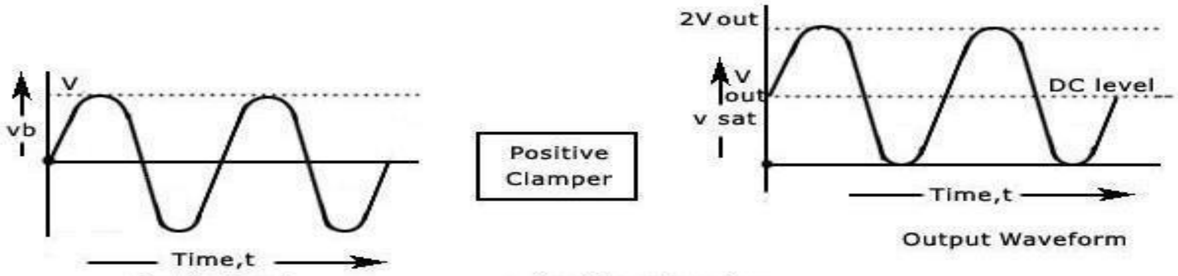


- For positive input voltage signal when input voltage exceeds battery voltage $+V_1$ diode D_1 conducts heavilywhile diode D_2 is reversed biased and so voltage $+V_1$ appears across the output.This output voltage $+V_1$ stays as long as input signal voltage exceeds $+V_1$.
- On the other hand for the negative input voltage signal, the diode D_1 remains reverse biased and diode D_2 conducts heavily only when input voltage exceeds battery voltageV_2 in magnitude.
- Thus during the negative half cycle the output stays at $-V_2$ so long as the input signal voltage is greater than $-V_2$.
- **APPLICATIONS OF CLIPPER:-**
- There are numerous clipper applications however, in general, clippers are usedto perform one of the following two functions:

(i) **CHANGING THE SHAPE OF WAVEFORM: -** Clippers can alter the shape of a waveform. For example, a clipper can be used to convert a sine wave into a rectangular wave, square wave etc. They can limit either the negative or positive alternation or both alternations of an a.c. voltage.

(ii) **CIRCUIT TRANSIENT PROTECTION:-** Transients can cause considerable damage to many types of circuits e.g., a digital circuit. In that case, a clipper diode can be used to prevent the transient form reaching that circuit.

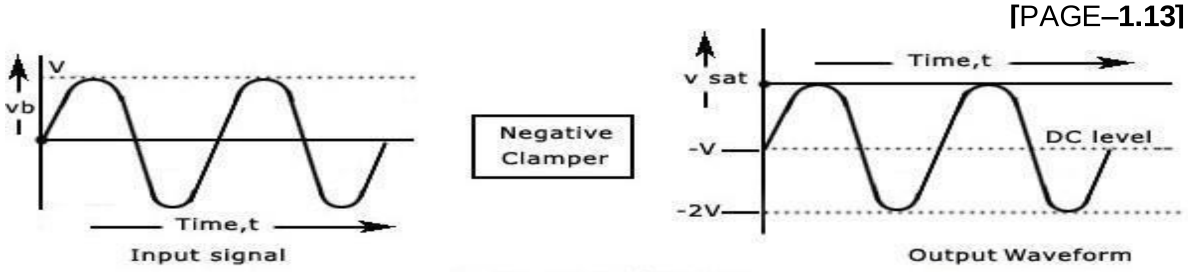
- **CLAMPER CIRCUITS:-**
- A clampingcircuitisusedtoplaceeitherthepositiveornegativepeakofasignalata desired level.The dc component is simply added or subtracted to/fromthe input signal.
- TheclamperisalsoreferredtoasanICrestorerandacsignallevelshifter.
- A clampcircuitaddsthe positiveor negative dccomponenttotheinputsignal so as to push it either on the positive side.
- Theclamperisoftwotypes :-
  1. Positiveclamper
  2. Negativeclamper
- The circuit will be called a positive clamper, when the signal is pushed upward side bythe circuit and the negative peak ofthe signal coincides with the zero level.



Input signal

Positive clamping

- Thecircuitwillbecalledanegativeclamper,whenthesignalispusheddownwardbythe circuit and the positive peak ofthe input signal coincides with the zero level.



Negative clamping

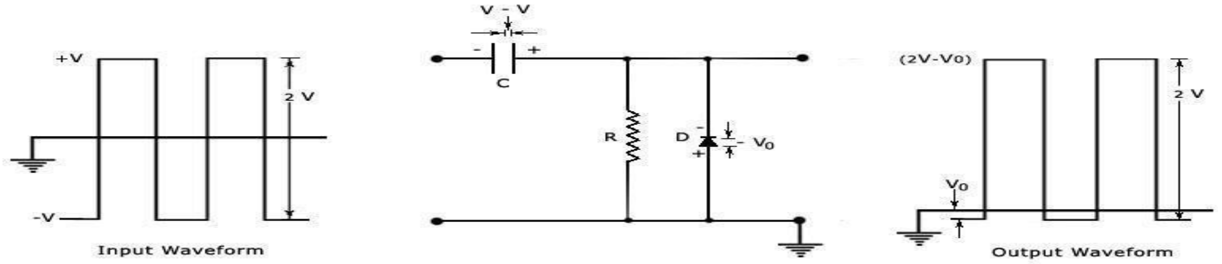
- For a clampingcircuit at least three components — a diode, a capacitorand a resistor are required. Sometimes an independent dc supply is also required to cause an additional shift. The important points regarding clamping circuits are:

1. The shape of the waveform will be the same, but its level is shifted either upward or downward,
2. There will be no change in the peak-to-peak or r.m.s value of the waveform due to the clamping circuit. Thus, the input waveform and output waveform will have the same peak-to-peak valuethat is,$2V_{max}$.This isshowninthe figureabove.It mustalsobe noted that same readings will be obtained in the ac voltmeter for the input voltage and the clamped output voltage.
3. There will be a change in the peak and average values of the waveform. In the figure shown above, the input waveform has a peak value of V_{max} and average value over a complete cycle is zero. The clamped output varies from 2 V_{max} and 0 (or 0 and $-2V_{max}$). Thus the peak value of the clamped output is $2V_{max}$ and average value is V_{max}.
4. ThevaluesoftheresistorRandcapacitorCaffectthewaveform.
5. The values for the resistor R and capacitor C should be determined from thetime constant equation of the circuit, t = RC. The values must be large enough to make sure that the voltage across capacitor C does not change significantly during the time interval the diode is non-conducting. In a good clamper circuit, the circuit time constant t = RC should be at least tentimes the time period of the input signal voltage. It is advantageous to first consider the condition under which the diode becomes forward biased.

❖ POSITIVE CLAMPER:-

- Consider a negative clamping circuit, a circuit that shifts the original signal in a vertical downward direction.

Positive Clamper

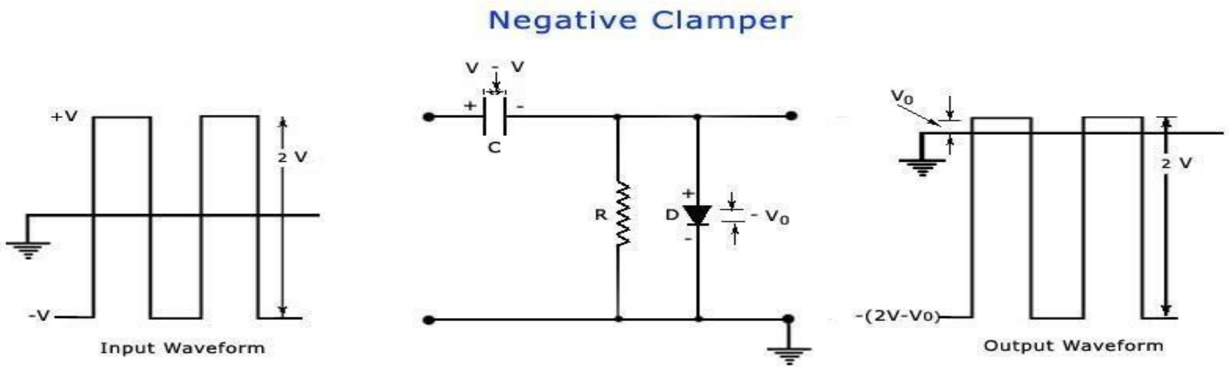


- The diode D will be forward biased and the capacitor C is charged with the polarity shown, when an input signal is applied.
- During the negative half cycle of input, the output voltage will be equal to the barrier potential ofthe diode, V_0 and capacitor is charged to $(V – V_0)$.

- Duringthepositivehalf cycle,thediodebecomesreverse-biasedandactsasanopen- circuit. Thus, there will be no effect on the capacitor voltage.
- The resistance R, being of very high value, cannot discharge C a lot during the positive portion of the input waveform.
- Thusduring positiveinput,the output voltagewill bethesum of theinputvoltageand capacitor voltage = $+V + (V — V_0) =+(2\ V – V_0)$.
- The value of the peak-to-peak output will be the difference of the negative and positive peak voltage levels is equal to $(2V\text{-}V_0) - V_0 = 2\ V$.

❖ NEGATIVE CLAMPER:-

- Consider a negative clamping circuit, a circuit that shifts the original signal in a vertical downward direction.



- ThediodeDwillbeforwardbiasedandthecapacitorCischargedwiththepolarity shown, when an input signal is applied.
- Duringthepositivehalfcycleofinput,theoutputvoltagewillbeequaltothebarrier potential ofthe diode, V_0 and capacitor is charged to $(V – V_0)$.
- During thenegativehalf cycle,thediodebecomesreverse-biasedandactsasan open- circuit. Thus, there will be no effect on the capacitor voltage.
- The resistance R, being of very high value, cannot discharge C a lot during the negative portion of the input waveform.
- Thus during negative input, the output voltage will be the sum of theinputvoltage andcapacitor voltage = $– V – (V — V_0) = – (2\ V – V_0)$.
- The value of the peak-to-peak output will be the difference of the negative and positive peak voltage levels is equal to $V_0 - [-(2V\text{-}V_0)] = 2\ V$.

❖ APPLICATIONS OF CLAMPER:-

- Clamping circuits are often used intelevisionreceivers as dc restorers inthe TV receiver They also find applications in storage counters, analog frequency meter, capacitance meter, divider and stair-case waveform generator.

CHAPTER-2

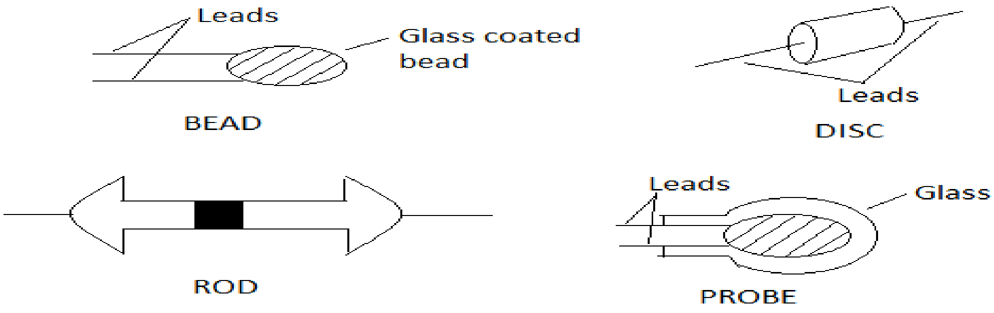
[SPECIAL SEMICONDUCTOR DEVICES]

❖ THERMISTOR

- ThermistoristhecontractionofthetermThermalResistor.
- It is generally composed of semiconductor materials. Most thermistors have a negative coefficient of temperature that is their resistance decreases with the increases of temperature.
- This high sensitivity to temperature changes makes thermistors extremely useful for precision temperature measurement, control and compensation.
- The temperature measurement of thermistor ranges from -60 0C to 150 0C and the resistance of thermistor ranges from 0.5Ω to 0.75MΩ. It exhibits highly non-linear characteristics of resistance versus temperature.

❖ CONSTRUCTION

- Thesethermistorsarecomposedofsinteredmixtureofmetallicoxidessuchas Manganese, Nickel, Cobalt, Copper, Iron and Uranium.
- Thesemaybeintheformofbeadsorrodsordiscs orprobes.
- The relation between resistance and absolute temperature of a thermistor can berepresented as
    - ♣ $R_{T1}=R_{T2}\exp[\beta(1/T1)-(1/T2)]$
    - ♣ WhereRT1=resistanceofthermistoratabsolutetemperatureT1K
    - ♣ R_{T2}=resistanceofthermistoratabsolutetemperatureT2K
    - ♣ Andβ=aconstantdependingonthematerialofthethermistor(usuallyit ranges from 3500 K to 4500 K).



[Different Types Of Thermistors]

❖ FEATURES

- Thesearecompact,ruggedandinexpensiveandhavegoodstabilitywhenproperlyaged.
- Measuring current is maintained at a value as low as possible so that self-heating of thermistors is avoided otherwise errors are introduced on account of changesof resistance caused by self-heating.

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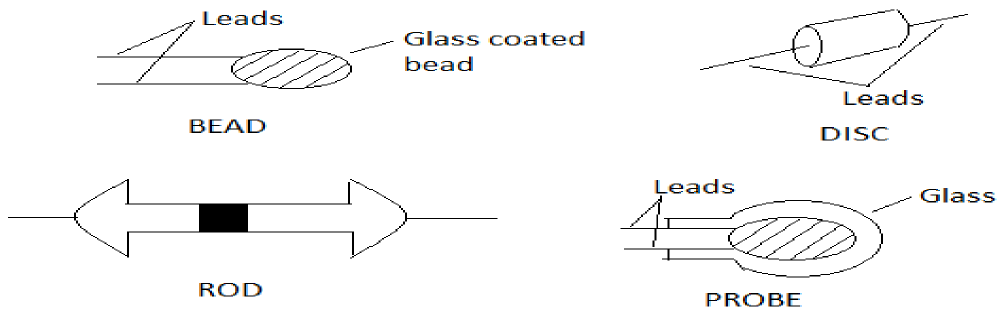

[Different Types Of Thermistors]

❖ FEATURES

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- Measuring current is maintained at a value as low as possible so that self-heating of thermistors is avoided otherwise errors are introduced on account of changesof resistance caused by self-heating.

- The upperoperating limit oftemperature for thermistor is dependentonphysicalchanges in the material.
- For thermistor the Response time can vary from fraction of second to minute depending on the size of detecting mass and thermal capacity of the thermistor.
- Responsetimevariesinverselywithdissipationfactor.

❖ APPLICATIONS

- Itisusedformeasurementandcontroloftemperatureandfortemperaturecompensation.
- Itisusedformeasurementofpowerathighfrequency.Itisalsousedforthermalconductivity.
- Thermistor is used for measurement oflevel, flow and pressure ofliquid, composition of gases and vaccum measurement. It is used for providing time delay.

❖ BARRETERS

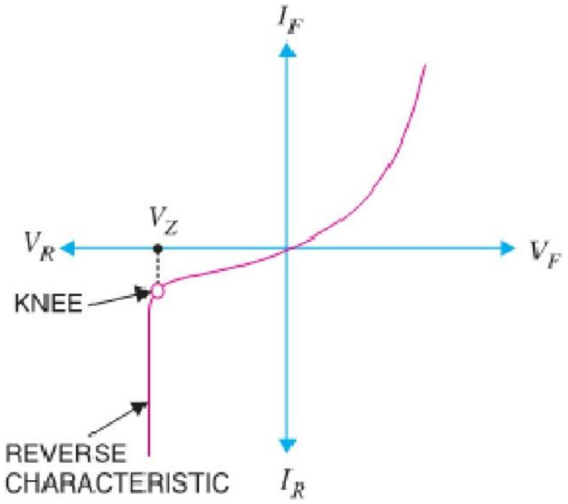
- Barretersaretheshortlengthwireswithfinediameterswithoperatingrangearound 1500C.

❖ SENSORS

- A **sensor** is a device that detects events or changes in quantities and provides a correspondingoutput,generallyasanelectricaloropticalsignal;forexample,a thermocouple converts temperature to an output voltage.
- Sensors are used in everyday objects such as touch-sensitive elevator buttons and lamps which dim or brighten by touching the base, besides innumerable applications of which most people are never aware.
- Withadvances in micro machineryand easyto use microcontroller platforms, the uses of sensors have expanded beyond the more traditionalfields of temperature, pressure or flow measurement.
- Moreover, analog sensors such as potentiometers and force-sensing resistors are still widely used. Applications include manufacturing and machinery, airplanesand aerospace, cars, medicine and robotics.
- A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes.
- For instance, ifthe mercury ina thermometer moves 1 cmwhenthe temperature changes by 1 °C, the sensitivity is 1 cm/°C .
- Sensors need to be designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages.
- Technologicalprogressallowsmoreandmoresensorstobemanufacturedon a microscopic scale as microsensors using MEMS technology.
- In most cases, a microsensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches.

ZENER DIODE:-

- Aproperlydopedcrystaldiodewhichhasasharpbreakdownvoltageisknownasa **ZenerDiode**.
- It has alreadybeen discussed that whenthe reverse bias ona crystal diode is increased, a critical voltage, called **Breakdown Voltage** is reached where the reverse current increases sharply to a high value.
- Thebreakdownregionisthekneeofthereversecharacteristicasshowninfig.



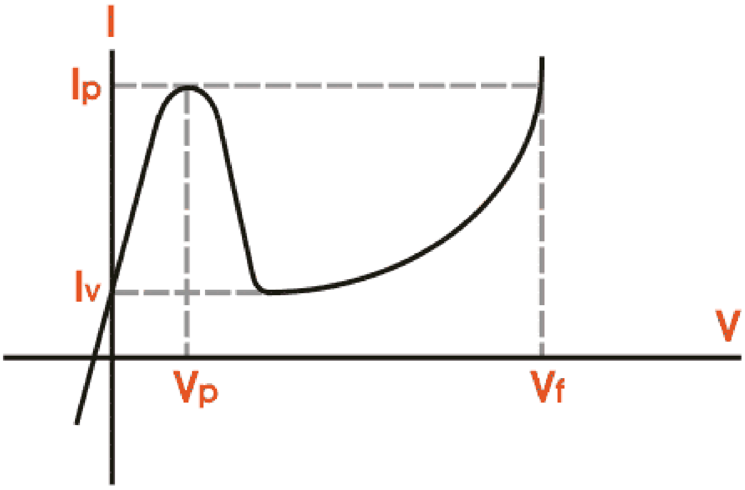
- The satisfactory explanation of this breakdown of the junction was first given by the American scientist C. Zener.
- The breakdown voltage is sometimes called **Zener Voltage** and the sudden increase in current is known as **Zener Current**.
- The breakdown or Zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage.
- Ontheotherhand,alightlydopeddiodehasahigherbreakdownvoltage.

- The given figure shows the symbol ofa Zener diode. It maybe seenthat it is just like an ordinary diode except that the bar is turned into z-shape.
  Thefollowingpointsmaybenotedaboutthezenerdiode:
  1. AZenerdiodeislikeanordinarydiodeexceptthatitisproperlydopedtohavea sharp breakdown voltage.
  2. AZenerdiodeisalwaysreverseconnectedi.e.itisalwaysreversebiased.
  3. AZenerdiodehassharpbreakdownvoltage,calledZenervoltage V_Z.
  4. Whenforwardbiased,itscharacteristicsarejustthoseofordinarydiode.
  5. The Zener diode is not immediately burnt just because it has entered the breakdownregion.
- As longas the externalcircuit connectedto the diode limits the diode current to less than burn out value, the diode will not burn out.

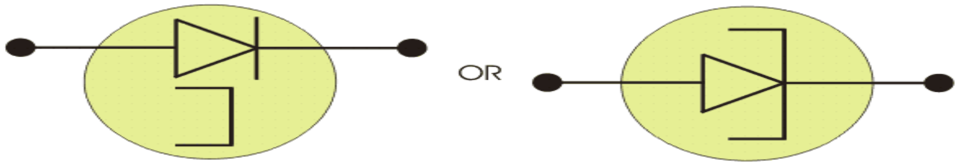
- Zener diode operated in this region will have a relatively constant voltage across it, regardless of the value of current through the device. This permits the Zener diode to be used as a **Voltage Regulator.**

❖ TUNNEL DIODE:-

- Under normal forward bias operation, as voltage begins to increase, electrons at first tunnel through the very narrow p–n junction barrier because filled electron states in the conduction band on the n-side become aligned with empty valence band hole states onthe p-side of the p-n junction.
- As voltageincreases furtherthesestatesbecome more misalignedandthecurrentdrops – this is called *negative resistance* because current decreases with increasing voltage.
- As voltage increases yet further, the diode begins to operate as a normal diode, where electrons travel by conduction across the p–n junction, and no longer by tunneling through the p–n junction barrier.
- Themostimportantoperatingregionforatunneldiodeisthenegativeresistanceregion.
- When used in the reverse direction, tunnel diodes are called **back diodes** (or **backward diodes**) and can act as fast rectifiers with zero offset voltage and extreme linearity for power signals (they have an accurate square law characteristic in the reverse direction).
- Under reverse bias, filled states on the p-side become increasingly aligned with empty states on the n-side and electrons now tunnel through the pn junction barrier in reverse direction.
- In a conventional semiconductor diode, conduction takes place while the p–n junction is forward biased and blocks current flow when the junction is reverse biased. This occurs up to a point known as the "reverse breakdown voltage" when conduction begins (often accompanied by destruction of the device).
- In the tunnel diode, the dopant concentrations in the p and n layers are increased to the pointwherethe **reversebreakdownvoltage** becomes **zero**andthediodeconductsinthe reverse direction.
- However, when forward-biased, an odd effect occurs called quantum mechanical tunnelling which gives rise toa regionwhere an*increase* in forward voltage isaccompanied by a *decrease* in forward current.
- Inthecurrentvoltagecharacteristics of **tunnel diode**, we can find a negative slope region when forward bias is applied.

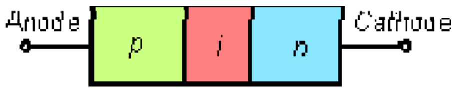


- Quantum mechanicaltunneling is responsible forthe phenomenonand thus this device is named as tunnel diode.
- The doping is very high so at absolute zero temperature the Fermi levels lies within the bias of the semiconductors. When no bias is applied any current flows through the junction.



- **PIN DIODE:-**

- The PIN diode can be shown diagrammatically as being a PN junction, but with an intrinsic layer between the PN and layers.
- The intrinsic layer of the PIN diode is a layer without doping, and as a result this increases the size of the depletion region - the region between the P and N layers where there are no majoritycarriers. This change inthe structure gives the PIN diode its unique properties.



BasicPINdiodestructure

- ThePINdiodeoperatesinexactlythesame wayasanormaldiode.
- The only real difference is that the depletion region, that normally exists between the P and N regions in an unbiased or reverse biased diode is larger.
- In anyPN junction, the P region contains holes asit has beendopedto ensure thatit has a predominance of holes.
- SimilarlytheNregionhasbeendopedtocontainexcess electrons.
- The region between the P and N regions contains no charge carriers as any holes or electrons combine As the depletion region has no charge carriers it acts as an insulator.
- Within a PIN diode the depletion region exists, but if the diode is forward biased, the carriers enter the depletion region (including the intrinsic region) and as the two carrier types meet, current starts to flow.
- When the diode is forward biased, the carrier concentration, i.e. holes and electrons is very much higher than the intrinsic level carrier concentration.
- Due to this high level injection level, the electric field extends deeply (almost the entire length) into the region.
- This electric field helps in speeding up of the transport of charge carriers from p to n region, whichresults in faster operationof the diode, making it a suitable device for high frequency operations.
- APINdiodeobeysthestandarddiodeequationforlowfrequencysignals.

Athigherfrequencies,thediodelookslikeanalmostperfect(verylinear,evenforlarge signals) resistor.

- Thereisalotofstoredchargeintheintrinsicregion.
- Atlowfrequencies,thechargecanberemovedandthediodeturnsoff.
- At higher frequencies, there is not enough time to remove the charge, so the diode never turns off.The PIN diode has a poor reverse recovery time.
- The high-frequencyresistance is inverselyproportionaltotheDCbiascurrentthrough the diode.
- APINdiode,suitablybiased,thereforeactsasavariableresistor.
- Thishigh-frequency resistancemay vary over awiderange(from 0.1 ohm to 10 kΩin some cases the useful range is smaller, though).
- The wide intrinsic regionalso means the diode will have a low capacitance whenreverse biased.
- InaPINdiode,thedepletionregionexistsalmostcompletelywithintheintrinsicregion.
- ThisdepletionregionismuchlargerthaninaPNdiode,andalmostconstant-size,independent of the reverse bias applied to the diode.
- Thisincreasesthevolumewhereelectron-holepairscanbegeneratedbyanincident photon.

PIN DIODE USES AND ADVANTAGES

- ThePINdiodeisusedinanumberofareasasaresultofitsstructureprovingsome properties which are of particular use.

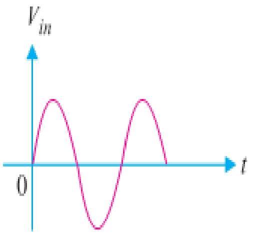
1. **HIGH VOLTAGE RECTIFIER:** The PIN diode can be used as a high voltage rectifier. The intrinsic region provides a greater separation between the PN and N regions, allowing higher reverse voltages to be tolerated.
2. **RF SWITCH:** The PIN diodemakes an ideal RF switch.Theintrinsiclayerbetweenthe Pand N regions increases the distance betweenthem. This also decreases the capacitance betweenthem, thereby increasing he levelof isolationwhenthe diode is reverse biased.
3. **PHOTODETECTOR:** As the conversion of light into current takes place within the depletion region of a photdiode, increasing the depletion region by addingthe intrinsic layer improves the performance by increasing he volume in which light conversion occurs.

CHAPTER-3

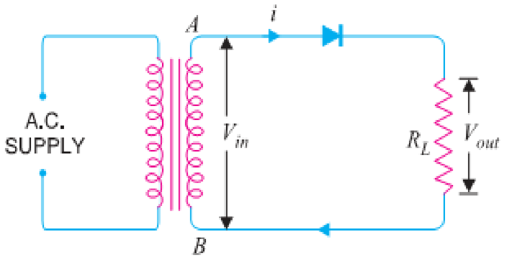
[RECTIFIERS]

❖ INTRODUCTION:-

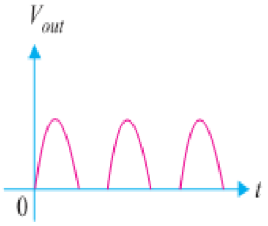
- For reasons associated with economics of generation and transmission, the electric power available is usually an A.C. Supply.The supply voltage varies sinusoidal and has a frequency of 50 Hz.It is used for lighting, heating and electric motors.
- But there are many applications (e.g. electronic circuits) where D.C. supply is needed. When such a D.C. Supply is required, the mains A.C. Supply is rectified by using *Crystal Diodes*.
- The following two rectifier circuits can be used:-
  - ♣ (i) Half-wave rectifier (ii) Full-wave rectifier
- **HALF-WAVE RECTIFIER:-**
- In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input A.C. Supply.
- The negative half-cycles of A.C. Supply is suppressed i.e. during negative half-cycles, no current is conducted and hence no voltage appears across the load.
- Therefore, current always flows in one direction through the load though after every half-cycle



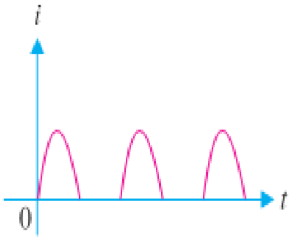
(Input Waveform)



(Halfwave Rectifier Circuit)



(Output voltage wave)



(Output Current)

Circuit Details: -

- The above Fig shows the circuit where a single crystal diode acts as a half-wave rectifier.
- The A.C. Supply to be rectified is applied in series with the diode and load resistance R_L. Generally, A.C. Supply is given through a transformer.
- The *use of transformer* permits two advantages.
  - ✓ Firstly, it allows us to step up or step down the A.C. input voltage as the situation demands.
  - ✓ Secondly, the transformer isolates the rectifier circuit from power line and thus reduces the risk of electric shock.

OPERATION:-

- The A.C. voltage across the secondary winding AB changes polarities after every half-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 *pulsating D.C.* These pulsations in the output are further smoothened with the help of filter circuits discussed later.

Disadvantages : -

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

(ii) The A.C. supply delivers power only half the time. Therefore, the output is low.

❖ FULL-WAVE RECTIFIER:-

- Infull-waverectification,currentflowsthrough theloadinthesamedirectionforbothhalf-cyclesof input A.C. voltage.This can be achieved with two diodes working alternately.
- For the positive half- cycle of input voltage, one diode supplies current to the load and for the negative half-cycle, the other diode does so ; current being always in the same direction through the load.
- Therefore,afull-waverectifierutilizesbothhalf-cyclesofinputA.C.voltagetoproducetheD.C.output.
- Thefollowingtwocircuitsarecommonlyusedforfull-waverectification: -

♣ **(i)**Centre-tapfull-waverectifier **(ii)**Full-wavebridge rectifier

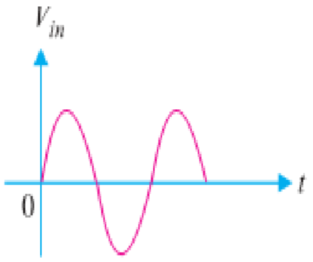
❖ CENTRE-TAPFULL-WAVE RECTIFIER:-

Circuit Details: -

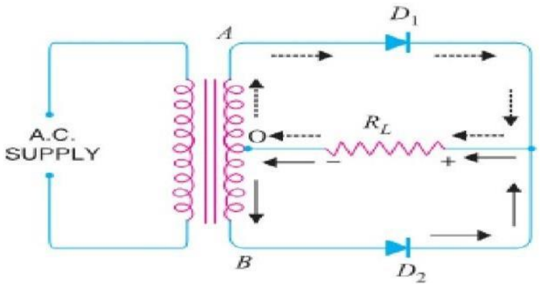
- The circuitemploys two diodes $D_1$and D_2as shown in Fig below. A centre tapped secondarywinding AB is used with two diodes connected so that each uses one half-cycle of input A.C. voltage.
- Inotherwords,diodeD_1utilizestheA.C.voltageappearingacrosstheupperhalf(OA)of secondary winding for rectification while diode D_2uses the lower half winding OB.

Circuit Operation: -

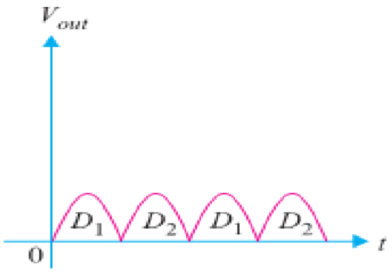
- Duringthepositivehalf-cycleofsecondaryvoltage,theendAofthesecondarywindingbecomes positive and end B negative. This makes the diode D_1forward biased and diode D_2reverse biased.
- Therefore, diode D_1conducts while diode D_2does not. The conventional current flow is through diode D_1, load resistor $R_L$and the upper half of secondary winding as shown bythe dotted arrows.
- Duringthenegativehalf-cycle,endAofthesecondarywinding becomesnegativeand endBpositive.
- Therefore, diode D_2conducts while diode D_1does not. The conventional current flow is through diode 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.outputvoltage andload currentvaluesaretwicethanthatofahalfwaverectifier.
(ii) Theripplefactorismuchless(0.482)thanthatofhalfrectifier(1.21).
(iii) Theefficiencyistwice(81.2%)thanthat ofhalfwaverectifier(40.6%).

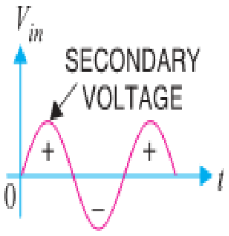
Disadvantages:-

(i) Itisdifficultto locatethe centretaponthesecondarywinding.
(ii) TheD.C.outputissmallaseachdiodeutilizesonlyone-halfofthetransformersecondaryvoltage.
(iii) Thediodesused musthavehighpeak inversevoltage.

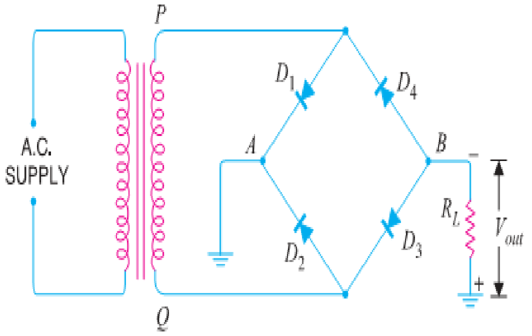
❖ FULL-WAVE BRIDGE RECTIFIER:-

Circuit Details: -

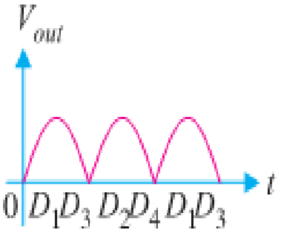
- Theneedforacentretappedpowertransformeriseliminatedinthebridge rectifier.
- ItcontainsfourdiodesD_1,D_2,D_3andD_4connectedtoformbridgeasshowninFig below.
- TheA.C.supplytoberectifiedisappliedtothediagonallyoppositeendsofthebridgethroughthe transformer.
- Betweenothertwoendsofthebridge,theload resistance$R_L$isconnected.



(InputWave Form)



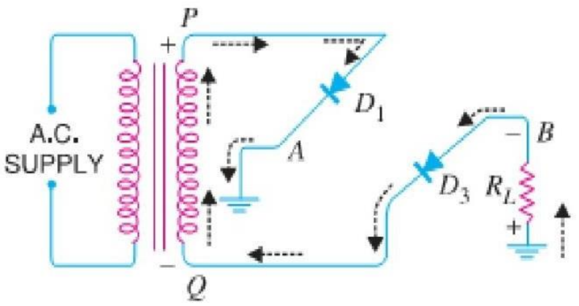
(Full-WaveBridgeRectifierCircuit)



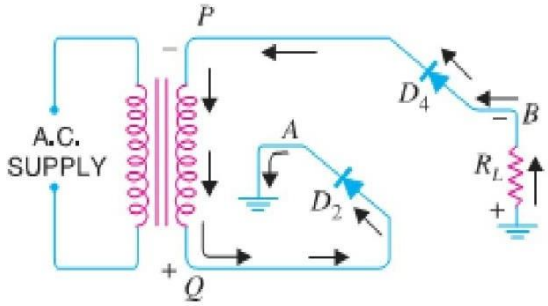
(Outputwaveform)

CIRCUIT OPERATION :-

- During the positive half-cycle of secondary voltage, the end P of thesecondary winding becomes positive and end Q negative.
- This makesdiodesD_1andD_3forwardbiasedwhilediodesD2andD4arereversebiased.
- Therefore, only diodes $D_1$and D_3conduct. These two diodes will be in series through the load $R_L$as shown in Fig. below. The conventional current flow is shown by dotted arrows. It may be seen that current flows from A to B through the load R_L.
- During the negative half-cycle of secondary voltage, end P becomes negative and end Q positive. This makes diodes D_2 and D_4forward biased whereas diodes $D_1$and $D_3$are reverse biased.
- Therefore, only diodes $D_2$and D_4conduct. These two diodes will be in series through the load $R_L$as shown in Fig. below. The current flow is shown by the solid arrows.
- It may be seen that again current flows from Ato 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) Theoutputistwicethat ofthecentre-tap circuitforthesamesecondaryvoltage.
  (iii) ThePIVisone-halfthatofthecentre-tapcircuit(forsameD.C.output).

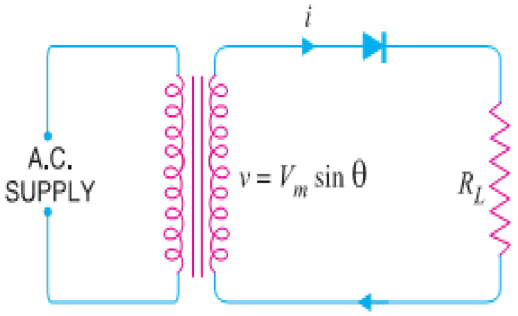
- **Disadvantages:-**

  (i) Itrequiresfourdiodes.(ii)Internalresistances high.

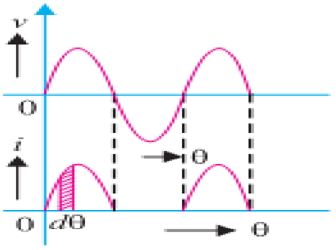
Mathematical Derivation for Rectification Efficiency for HALF WAVE rectifier :-

- Theratioofd.c.poweroutputtotheappliedinputa.c.powerisknownasrectifier efficiencyi.e.,

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



- ConsiderahalfwaverectifiershowninFig.
- Let $v = V_m \sin \theta$ be the alternating voltage that appears across the secondary winding. Let $r_f$and $R_L$be the diode resistance and load resistance respectively.
- The diode conducts during positive half-cycles of a.c. supply while no current conduction takes place during negative half-cycles.



- ❖ **OUTPUTD.C.POWER:-**
- ➢ Theoutputcurrentispulsatingdirectcurrent.Therefore,inordertofind D.C.power,averagecurrenthastobefoundout.

$$\text{AverageValue}=\frac{\text{AreaUnderTheCurve OveraCyCle}}{Base}=\frac{\int_0 i\,d\square}{2h}$$

$$I_{av}=I_{dc}=\frac{1}{2}\int_0 i\,d\square=\frac{1}{2}\int_0 \frac{V_{m}\sin\square}{rf+R_L}d\square=\frac{Vm}{2(rf+R_L)}\int_0 sik\theta\,d\square$$

$$=\frac{V_m\sin\square}{rf+R_L}[-\cos\square]_0=\frac{Vm}{2(rf+R_L)}\times[(-cos\pi)-(-\cos 0)]$$

$$=\frac{Vm}{2(rf+R_L)}\times 2=\frac{Vm}{(rf+R_L)}\times\frac{1}{h}=\frac{Im}{h}\left[\because I_m=\frac{Vm}{(rf+R_L)}\right]$$

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

- ❖ **INPUTA.C.POWER:-**
- ➢ TheA.C.powerinputisgivenby: $P_{ac}=I^2_{rms}(rf+R_L)$ Forahalf-waverectified wave, $\mathbf{I_{rms}=I_m/2}$

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

∴ Rectifierefficiency $=\frac{\text{d.C.outputpower}}{\text{a.C.inputpower}}=\frac{(I_{m}/\pi)^2\times R_L}{(I_m/2)^2(rf+R_L)}=\frac{0.406R_L}{rf+R_L}=\frac{0.406R_L}{rf+R_L}\;1+\frac{rf}{R_L}$

Theefficiencywillbemaximumifr$_f$ isnegligibleascomparedtoR$_L$.

∴ **Max.Rectifier Efficiency for HALF WAVE Rectifier= 40.6%**

- ➢ Itshowsthat inhalf-waverectification,maximumof40.6%ofa.c.powerisconvertedintod.c. power.

NOTE:- $I_{rms}=\left[\frac{1}{2}\int_0^{2} i^2 d\square\right]^{1/2}=\left[\frac{1}{2}\int_0^{m} I^2 sik^2\theta\,d\square+\frac{1}{2}\int^{2} 0\,d\square\right]^{1/2}=\left[\frac{I^2 m}{2}\int_0 \frac{1-cos2\theta}{2}d\square\right]^{1/2}$

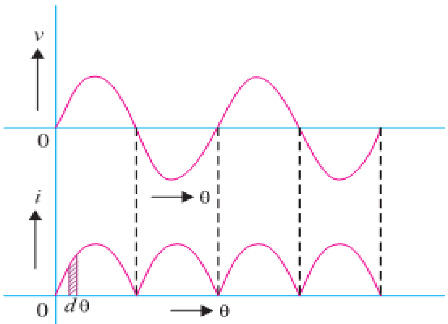
$=\left[\frac{I_m^2}{4}\left[\square-\frac{\sin2\square}{2}\right]_0\right]^{1/2}=\left[\frac{I_m^2}{4}\left[\pi-0-\frac{\sin2}{2}+\sin0\right]\right]^{1/2}=\left[\frac{I_m^2}{4}x\pi\right]^{1/2}=\left[\frac{I_m^2}{4}\right]^{1/2}=\frac{I_m}{2}$ ➔ $\mathbf{I_{rms}}=\frac{I_m}{2}$

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

Mathematical Derivation for Rectification Efficiency for FULL WAVE Rectifier :-

- ➢ Fig.showstheprocessoffull-waverectification.
- ➢ 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.**
- ➢ Theoutput current is pulsating direct current. Therefore, inorderto find the d.c. power, average current has to be found out.For afullwave rectifier the average value or dcvalue canbe found like halfwave,

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

∴D.C.poweroutput, $P_{dc}=I^2_{dc}\times R_L=\left(\frac{2Im}{\pi}\right)^2\times \mathbf{R_L}$

- ❖ **A.C.INPUT POWER.**
- ➢ Thea.c.inputpowerisgiven by: $P_{ac}=I^2_{rms}(rf+R_L)$

  Forafull-waverectifiedwave, wehave, $\mathbf{I_{rms}=I_m}/\sqrt{2}$ ∴ $\mathbf{P_{ac}}=\left(\frac{Im}{\sqrt{2}}\right)^2(rf+R_L)$

  ∴ Full-waverectificationefficiencyis

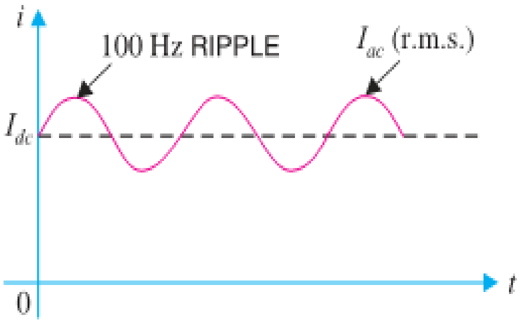
$$\eta=\frac{P_{dc}}{P_{ac}}=\frac{(2I_m/h)^2R_L}{\left(\frac{Im}{\sqrt{2}}\right)^2(rf+R)}=\frac{8}{h^2}\times\frac{R_L}{(rf+R_L)}=\frac{0.812R_L}{rf+R_L}=\frac{0.812}{1+\frac{rf}{R_L}}$$

Theefficiencywillbemaximumifr$_f$is negligibleascomparedtoR$_L$.∴Maximumefficiency= 81.2%

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

RIPPLE FACTOR: -

- Theoutputofarectifierconsistsofad.c.componentandana.c.component(alsoknownasripple).
- The a.c. component is undesirable and accounts for the pulsations in the rectifier output.
- The effectiveness of a rectifier dependsupon 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. componentin 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.

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

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

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

(i) For half-wave rectification: -

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

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

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

(ii) **For full-wave rectification**: -

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

∴ $$\text{Ripplefactor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/h}\right)^2 - 1} = \mathbf{0.48}$$ i.e. $\frac{\text{effeCtivea.C.Component}}{\text{d.C.Component}} = 0.48$

- This shows that inthe output ofa full-wave rectifier, the d.c. component is morethanthe a.c. component. Consequently, thepulsations intheoutput willbe lessthanin half-waverectifier.
- Forthisreason,full-waverectificationisinvariablyusedforconversionofa.c. intod.c.

Peak Inverse Voltage (PIV) : -

- ThemaximumvalueofreverseVoltage occursatthepeak oftheinputcycle,whichisequaltoV$_m$.
- Thismaximumreversevoltageiscalledpeakinversevoltage(PIV).ThusthePIVofdiode:-

a)ForHalfWave=V$_{m.,}$**b)**ForCenterTapped=2V$_m$and**c)**ForBridgeRectifier =V$_m$**.**

Transformer Utilization Factor (TUF) : -

- Itmay bedefinedastheratioof d.c.powerdelivered totheloadandthea.c.rating of thetransformer secondary.

Thus, $$\boxed{\mathbf{TUF = P_{dc}/ P_{ac}}}$$

- Forhalfwaverectifier,TUF=**0.287**;Centertapedrectifier,TUF=**0.693**;Bridge rectifier,TUF= **0.812**.
- TheTUFisveryusefulin determiningtheratingofatransformer to beused withrectifiercircuit.

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

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

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

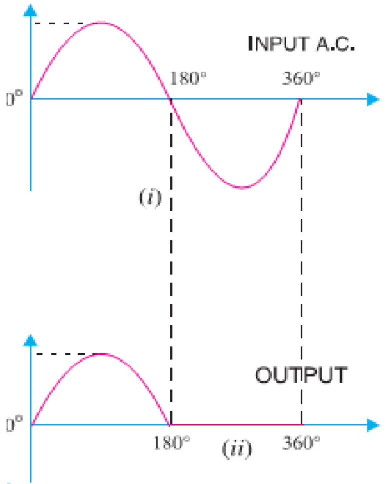
Average Value of Voltage & Current for FULL WAVE Rectifiers: -

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

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

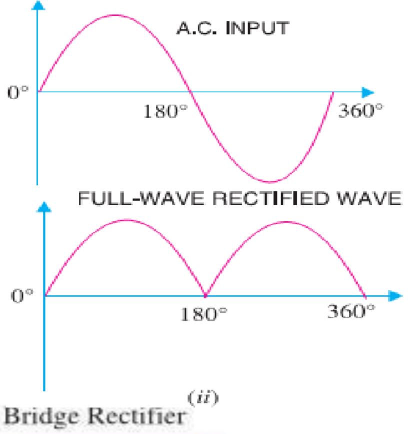
Output Frequency of Half Wave Rectifier: -

- The output frequency of a half-wave rectifier is equal to the input frequency (50Hz). Recall how a complete cycle is defined.
- A waveform has a complete cycle when it repeats the same wave pattern over a given time.
- Thus in Fig. (i), the a.c. input voltage repeats the same wave pattern over 0° – 360°, 360° – 720° and so on.
- In Fig. (ii), the output waveform also repeats the same wave pattern over 0° – 360°, 360° – 720° and so on.
- This means that when input a.c. completes one cycle, the output half wave rectified wave also completes one cycle.
- In other words, for the half wave rectifier the output frequency is equal to the input frequency i.e. $\mathbf{f_{out}= f_{in}}$
- For example, if the input frequency of sine wave applied to a half-wave rectifier is 100 Hz, then frequency of the output wave will also be 100 Hz.

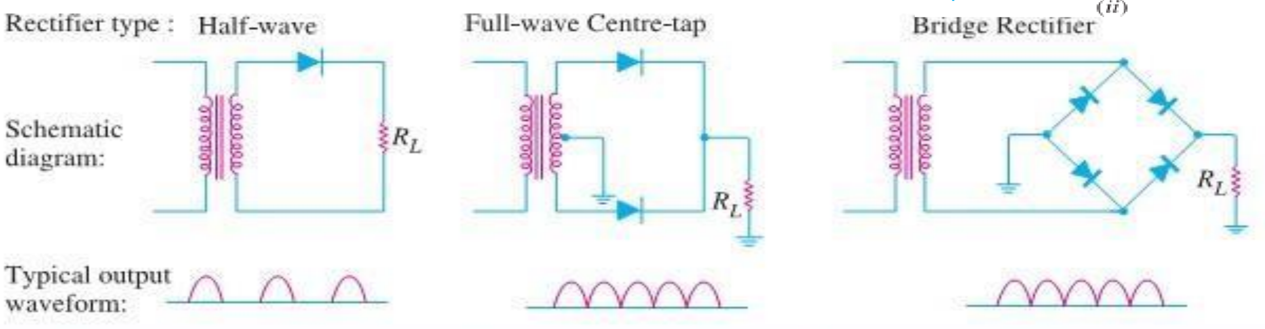


Output Frequency of Full Wave Rectifier: -

- 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 100 Hz, 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, arectifier isrequiredto producepureD.C. supplyfor usingat variousplaces inthe electronic circuits.
- However,theoutputofarectifierhaspulsatingcharacteri.e. itcontainsA.C. andD.C.components.
- TheA.C. componentisundesirableandmustbekeptawayfromtheload.
- Todoso,afiltercircuitisusedwhichremoves(orfiltersout)theA.C.componentandallowsonlythe D.C.component toreachtheload.
- A **filter circuit**isadevice whichremoves theA.C.componentof rectifieroutputbutallows theD.C. component to reach the load.
- Afilter circuitisgenerallyacombinationofinductors(L)andcapacitors(C).
- ThefilteringactionofLandCdependsuponthebasicelectricalprinciples.
- Acapacitoroffers infinite reactancetod.c.
- WeKnowthatX_C=1/2πfC.Butfor D.C.,f=0.

  ∴ X_C=1/2πfC = 1/2πx0 xC=∞(MeansCapacitorshows*infinitereactance*to DC)

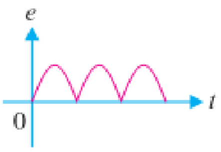
  ♣ ***Hence,a Capacitordoes notallowd.c.topassthroughit***.

- WeknowX$_L$=2πfL.Ford.c.,f= 0

  ∴ X_L=2πx0xL= 0(MeansInductorshows*zeroreactance*toDC)

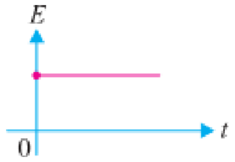
  ♣ ***HenceInductorpassesd.c.quitereadily.***

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



(PulsatingD.C)

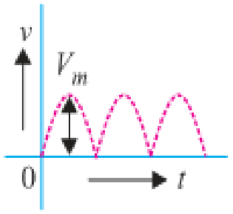
(FilterCircuit)



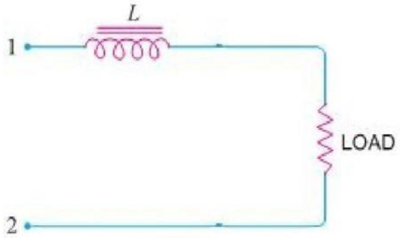
(PureD.C)

- **Types Of Filter Circuits:-**
- Thereare different typesoffiltercircuits accordingtotheir construction. The most commonlyused filter circuits are : -
  - ♣ *<u>InductiveFilterorSeries Inductor</u>*,
  - ♣ *<u>CapacitorFilterorShuntCapacitor</u>*,
  - ♣ *<u>ChokeInputFilterorLCFilter</u>*and
  - ♣ *<u>CapacitorInput Filterorπ-Filter</u>*.

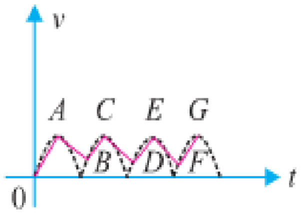
✓ Inductive Filter Or Series Inductor:-



(RectifiedoutputPulsatingd.c)



(InductiveFilterCircuit)

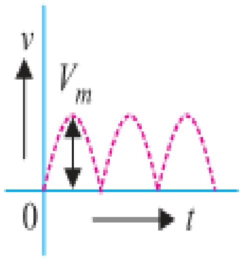


(OutputofInductiveFilter)

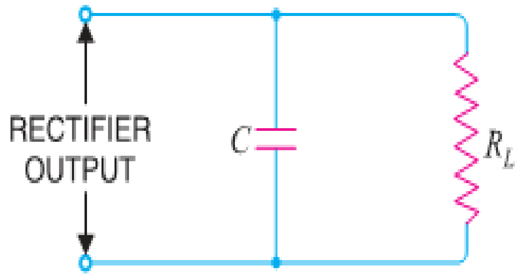
- Fig.(ii)Showsa typicalInductivefiltercircuit.Itconsists of an InductorL placedacrossthe rectifier output in series with load R_L.

- Thechoke(Inductorwithironcore)offershighoppositiontothepassageofa.c.componentbutno opposition to the d.c. component.
- The resultis thatmost of the a.c.componentappears across thechoke while whole of d.c.component passes throughthe chokeonits wayto load. This results inthe reduced pulsations at Loadresistance R_L.

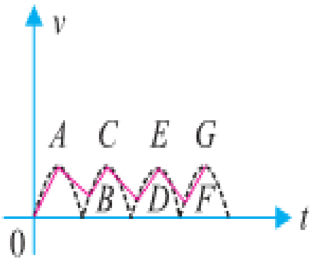
✓ **CapacitorFilterOrShunt Capacitor:-**



(RectifiedoutputPulsatingd.c)



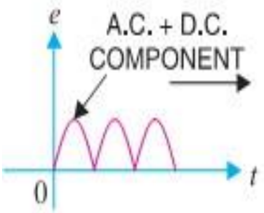
(CapacitorFilter Circuit)



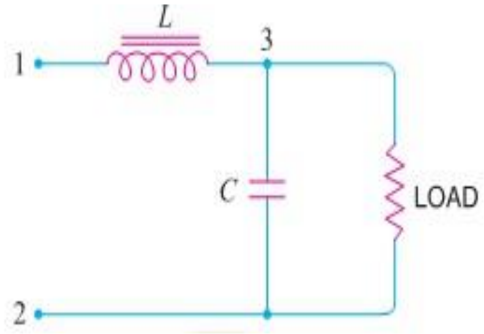
(OutputofCapacitorFilter)

- Fig.(ii)Showsa typical capacitorfiltercircuit.Itconsistsof acapacitorCplacedacrosstherectifier output in parallel with load R_L.
- Thepulsatingdirectvoltageoftherectifierisappliedacrossthecapacitor.Astherectifiervoltage increases, it charges the capacitor and also supplies current to the load.
- Attheendof quartercycle[PointAinFig.(iii)],thecapacitorischargedtothepeakvalueV_m of the rectifier voltage.
- Now, therectifiervoltagestarts todecrease.Asthisoccurs,thecapacitordischargesthrough theload and voltage across it decreases as shown bythe line AB in Fig. (iii).
- Thevoltageacrossloadwilldecreaseonly slightly becauseimmediately thenextvoltage peakcomes and recharges the capacitor.
- This process is repeated again and again and the output voltage waveform becomes ABCDEFG. It may be seen that very little ripple is left in the output.
- Moreover,outputvoltageishigherasitremainssubstantiallynearthepeakvalueofrectifieroutput voltage.
- Thecapacitor filtercircuit is extremelypopularbecauseofits lowcost, smallsize, littleweight and good characteristics.

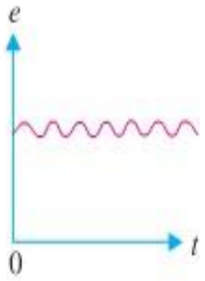
✓ **Choke Input Filter Or L C Filter:-**



(RectifiedoutputPulsatingd.c)



(ChokeInputFilterCircuit)

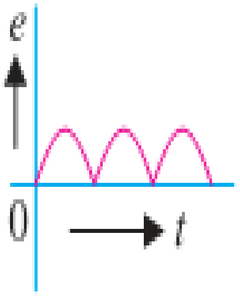


(OutputofChoke InputFilter)

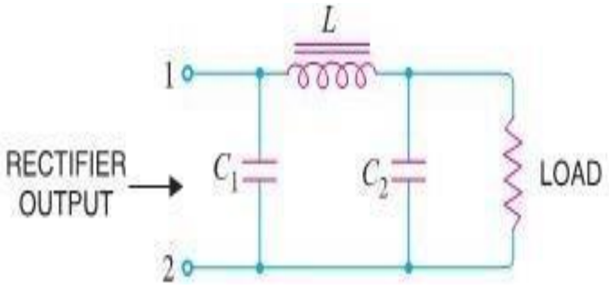
- Fig.showsatypicalchokeinputfiltercircuit.ItconsistsofachokeLconnectedinserieswiththe rectifier output and a filter capacitor C across the load.
- Onlyasingle filtersection isshown, but severalidenticalsectionsareoftenusedtoreducethepulsations as effectively as possible.
- Thepulsating outputoftherectifierisappliedacrossterminals1and2ofthefiltercircuit.
- Asdiscussed before, the pulsatingoutput ofrectifier containsa.c. and d.c. components. The chokeoffers high opposition to the passage of a.c. component but negligible opposition to the d.c. component.
- The resultis thatmost of the a.c.componentappears across thechoke while whole of d.c.component passes through the choke on its wayto load. This results in the reduced pulsations at terminal 3.

- Atterminal3,therectifieroutputcontainsd.c.componentandtheremainingpartofa.c.component which has managed to pass through the choke.
- Now,the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component to flow through it. Therefore, only d.c. component reaches the load.
- In this way, the filter circuithas filtered out the a.c. componentfrom the rectifier output, allowing d.c.component to reach the load.

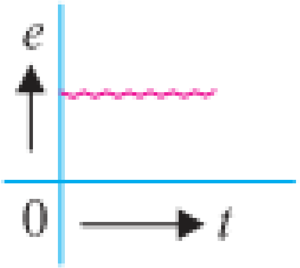
✓ **Capacitor Input Filter or π-Filter:-**



(RectifiedoutputPulsatingd.c)



(CapacitorInputor π-Filter Circuit)



(Outputofπ-Filter)

- Fig. shows a typicalcapacitor input filter or π-filter. It consists ofa filter capacitor C_1connected across the rectifier output, a choke Lin series and another filter capacitor C_2 connected across the load.
- Only one filter section is shown but several identical sections are often used to improve the smoothing action. The pulsating output fromthe rectifier is applied across the input terminals (i.e. terminals 1 &2) of the filter.
- ThefilteringactionofthethreecomponentsvizC_1, LandC_2ofthis filterisdescribedbelow:

  (a) The **filter capacitor C_1**offers low reactance to a.c. component of rectifier output while it offers infinite reactance tothe d.c. component. Therefore, capacitor C_1bypasses anappreciable amount of a.c. component while the d.c. component continues its journeyto 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**bypassesthe a.c. component whichthe choke has failed to block. Therefore, onlyd.c. component appears across the load and that is what we desire

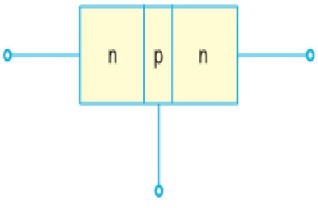
--❧- -ॐ---ALL THE BEST---☙---📖---ॐ---📖---❧---ALL THE BEST---ॐ- -☙---

CHAPTER-4

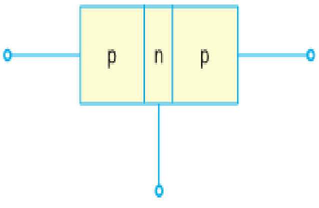
[TRANSISTORS]

INTRODUCTION:-

- Whena third doped element is added to a crystal diode in sucha waythat two PN junctions are formed, the resulting device is known as a **Transistor**.
- This isa newtypeofelectronics devicewhichcanableto amplifyaweak signalina fashioncomparable and often superior to that realized by vacuum tubes.
- A transistor consists of two PN junctions formed bysandwiching either p-type or n-type semiconductor 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-type semiconductors separatedbyathinsectionofp-type.
- However, ap-n-ptransistoris formed bytwo p-sectionsseparatedbyathinsectionofn-typeasshownin Figure below.



(i)



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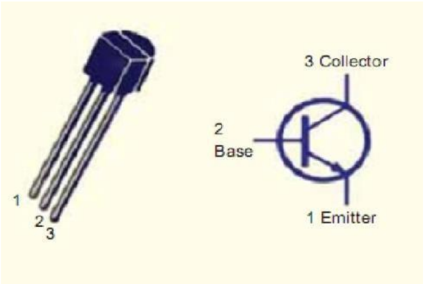


NAMING:-

- Atransistorhas*twopnjunctions*.Asdiscussedlater,onejunctionisforwardbiasedandtheotheris reverse biased.
- The*forwardbiasedjunction*hasalowresistancepathwhereasa*reversebiasedjunction*hasahigh resistance path.
- The weak signal is introduced in the low resistance circuit and output is taken from the high resistance circuit. Therefore, a transistor transfers a signal from a low resistance to high resistance.
- The prefix'**trans**'means the signal transferproperty of the device while '**istor**' classifiesitas a solid element in the same general family with resistors.

NAMING THE TRANSISTOR TERMINALS:-

- Atransistor(PNPorNPN)hasthree sections ofdopedsemiconductors.
- Thesectionononesideisthe**emitter**and thesectionontheoppositesideisthe **collector**.
- Themiddlesectioniscalledthe**base**andformstwojunctionsbetweentheemitter and collector.

(i) Emitter:-

- Thesectionononesidethat*supplieschargecarriers*(electronsorholes)iscalledtheemitter.
- The emitter is always forward biased w.r.t. base so that it can supplya largenumber of majoritycarriers.
- The emitter (p-type) of PNP transistor is forward biased and supplies hole charges to its junction with the base. Similarlythe emitter (n-type) ofNPN transistor has a forward bias and supplies free electrons to its junction with the base.

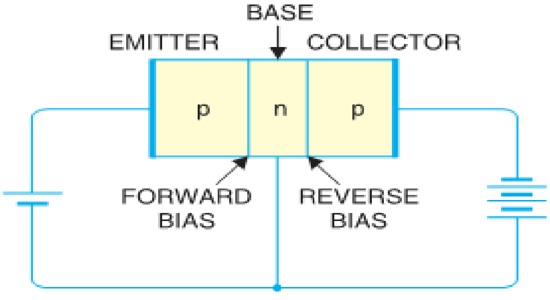
(ii) Collector:-

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

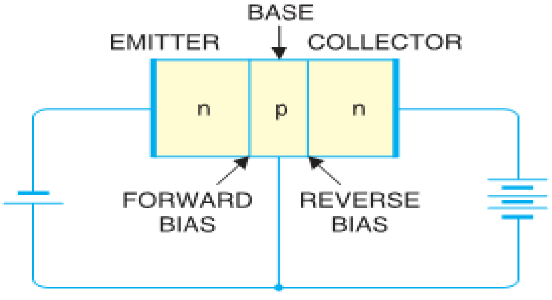
(iii)Base: -

- ThemiddlesectionwhichformstwoPN-junctionsbetweenemitter&collector iscalledbase.
- Thebase-emitterjunctionisforwardbiased,allowinglowresistancefortheemittercircuit.

✍Thebase-collectorjunctionisreversebiasedandprovideshighresistanceinthecollectorcircuit.

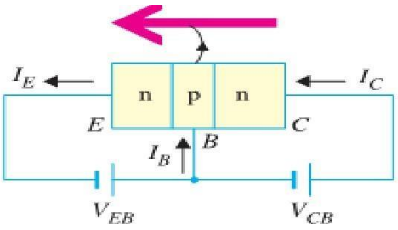


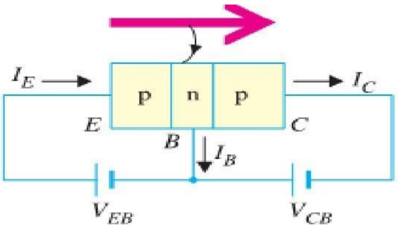
(i)

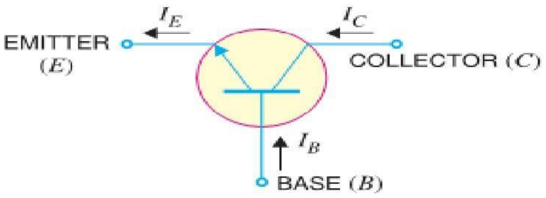


(ii)

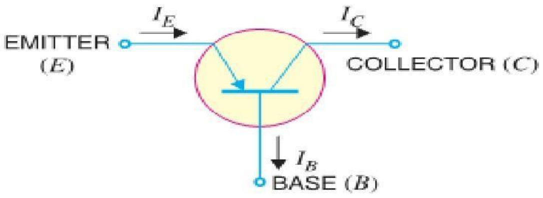
❖ TRANSISTORSYMBOL:-







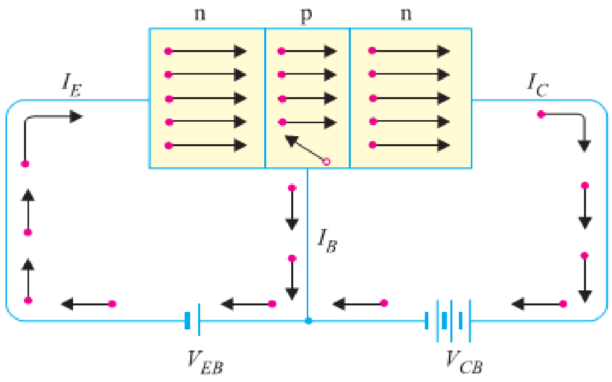
(i)



(ii)

❖ WORKINGN OF NPN TRANSISTOR(NPN):-

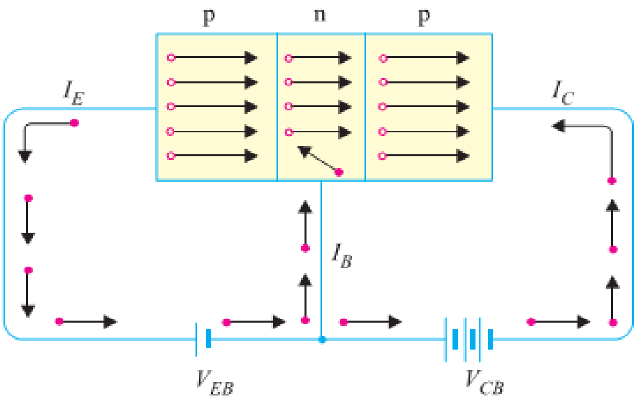
- TheNPNtransistorwithforward biastoemitter-basejunction&reversebiastocollector-basejunction.
- The forward bias causes the electrons in the n-type emitter to flow towards the base.
- This constitutes the emitter current **I_E**. As these electrons flow through the p-type base, they tend to combine with holes.
- As the base is lightlydoped and verythin, therefore, only a few electrons (less than 5%) combine with holes to constitute base current **I_B**.
- The remainders (more than95%) crossover into the collector region to constitute collector current **I_C**.
- In this way, almost the entire emitter current flowsin the collector circuit.



- Itisclearthat emittercurrentisthe sumofcollector andbasecurrentsi.e.**$I_E=I_B+I_C$**

❖ WORKING OF PNP TRANSISTOR (PNP):-

- Fig.showsthebasicconnectionofaPNPtransistor.
- The forward bias causes the holes in the p-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 lightlydoped and verythin, therefore, only a few holes (less than 5%) combine with the electrons. Theremainder (morethan 95%) crossinto the collectorregionto constitute collectorcurrent I$_C$.



- Inthisway,almosttheentireemittercurrentflows inthecollector circuit.

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

❖ TRANSISTOR CONNECTIONS:-

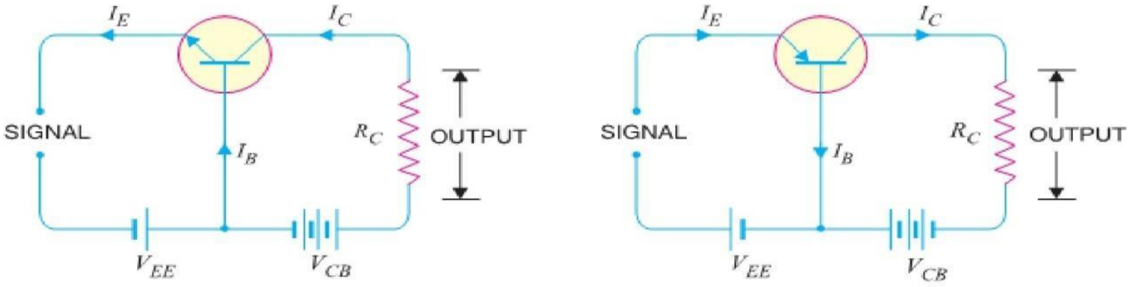
- There are three leads in a transistor such as emitter, base and collector terminals.
- However, when a transistor is to be connected in a circuit, we require **four terminals**; two for the input and two for the output.
- This difficulty is overcome by making one terminal of it in common to both input and output terminals.
- The input is fed between this common terminal and one of the other two terminals.
- The output is obtained between the common terminal and the remaining terminal.
- So a transistor can be connected in a circuit in the following ways:-

  (i) Common Base connection (**ii**) Common Emitter connection (**iii**) Common Collector connection

(i) Common Base Connection

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

Here, base of the transistor is common to both input and output circuits and hence the name **C**ommon **B**ase connection. A Common Base NPN and PNP in figure below.

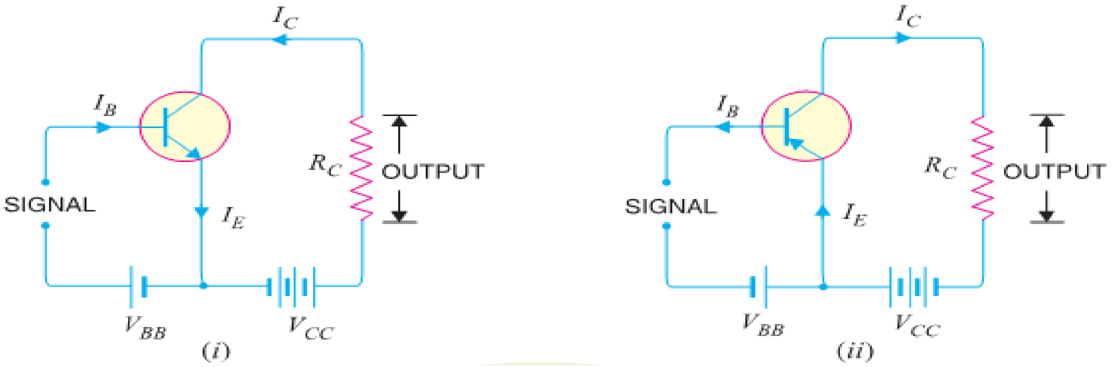


(i) (ii)

(ii) Common Emitter Connection

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

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

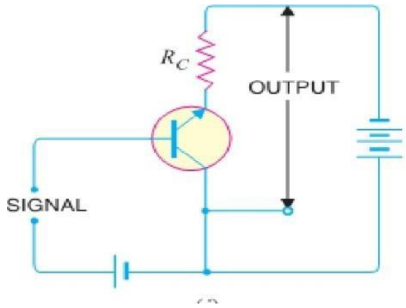


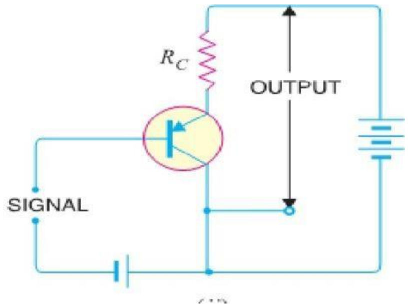
(i) (ii)

(iii) Common Collector Connection

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

Here, collector of the transistor is common to both input and output circuits and hence the name **C**ommon **C**ollector connection. A Common Collector NPN and PNP in figure below.



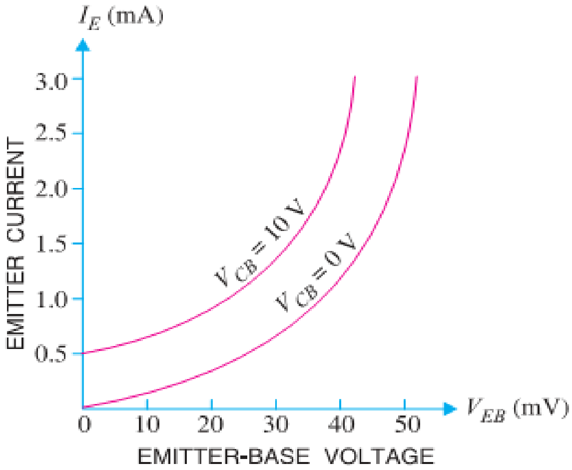


❖ TRANSISTOR CHARACTERISTICS:-

1) CharacteristicsofCommonBaseConnection

- Thecompleteelectricalbehaviorofatransistorcanbedescribedbystatingtheinterrelationofthe various currents and voltages.
- Theserelationships canbeconvenientlydisplayed graphicallyandthecurves thusobtained areknownas the characteristics of transistor.
- Themostimportantcharacteristics of common base connectionare **inputcharacteristics** and**output characteristics**.

A) Input Characteristics:-



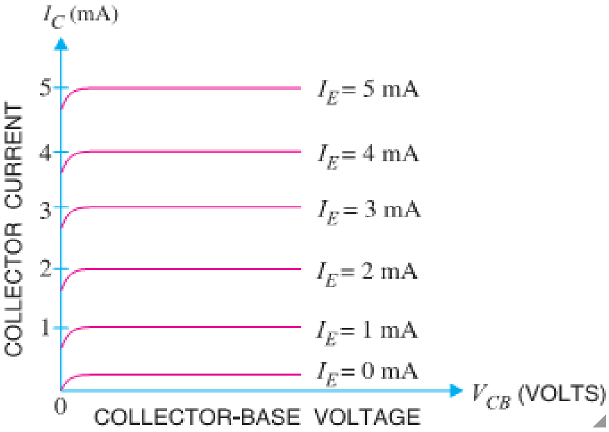
- It is the curve between emitter current **I_E**& emitter-base voltage **V_{BE}**at constant collector-base voltage **V_{CB}**.
- The emitter current is generally taken along y-axis and emitter-base voltage along x-axis. Fig. Shows the input characteristics of a typical transistor in CB arrangement.
- The following points may be noted from these characteristics :
  - ♣ The emitter current $I_E$increases rapidly with small increase in emitter-base voltage V_{EB}. It means that input resistance is very small.
  - ♣ The emitter current is almost independent of collector-basevoltageV_{CB}.Thisleadstotheconclusionthat emittercurrent(andhencecollectorcurrent)isalmostindependentofcollectorvoltage.
- **Input Resistance: -** It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}) i.e.

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

- Infact,input resistance istheoppositionoffered tothe signalcurrent.Asa verysmallV_{EB}issufficient to produce a large flow of emitter current I_E, thus, input resistance is quite small, of the order of afew ohms.

B) Output Characteristics:-

- Itisthecurvebetweencollector current**I_C**&collector-basevoltage**V_{BC}**atconstantemittercurrent**I_E**.
- Generally,collectorcurrentistakenalongy-axisandcollector-basevoltagealongx-axis.
- Thefig.showstheinputandoutputcharacteristicsofatypicaltransistorinCB arrangement.
- 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 independent of V_{CB} and depends upon I_E only. Thisis consistent with the theory that the emitter current



flowsalmostentirelytothecollectorterminal.Thetransistorisalwaysoperatedinthisregion.

- ♣ A very large change in collector-base voltage produces onlya tiny change in collector current. This means that output resistance is very high.

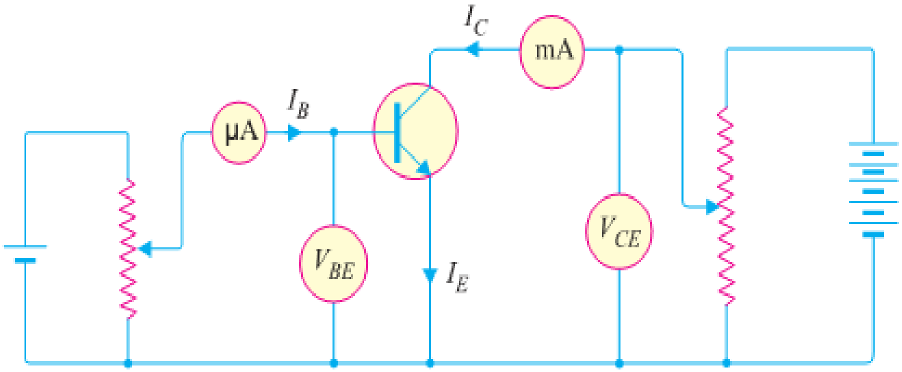
- **Output Resistance**: - It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting changein collector current (ΔI_C) at constant emitter current i.e.

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

- TheoutputresistanceofCBcircuitisveryhigh,oftheorderofseveraltensofkilo-ohms.

2) Characteristics of Common Emitter Connection:-

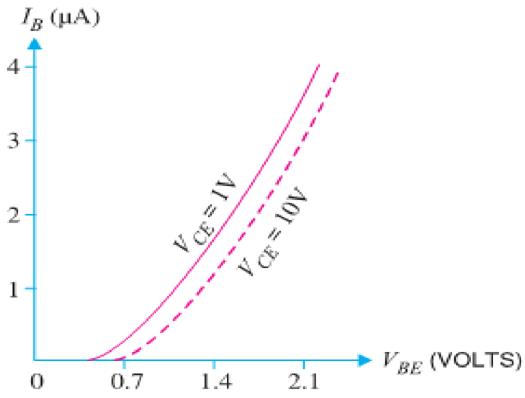
- The importantcharacteristics of this circuitarrangementare the input characteristic and output characteristic.



(Circuit ArrangementforstudyingCommonEmitterConnectionofTransistor)

A) Input Characteristics:-

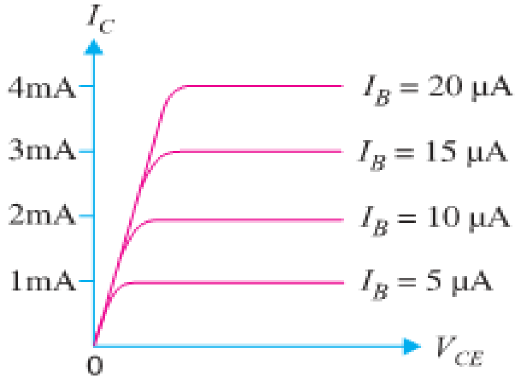
- It is the curve between base current IB & base-emitter voltage VBE at constant collector-emitter volt V_{CE}.TheinputcharacteristicsofaCE connectioncanbe determined bythecircuit showninFig. KeepingV_{CE}constant (Let 10 V), notethe base current I_B for various values of V_{BE}.
- Then plot the readings obtained on the graph, taking $I_B$along y-axis and V_{BE}along x-axis. This gives the input characteristic at V_{CE} = 10V as shown in Fig.
- Thefollowingpointsmaybenotedfromthecharacteristics:
  - ♣ 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 inbase-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: -

- Itisthecurvebetweencollectorcurrent**I_C**andcollector-emittervoltage**V_{CE}**atconstantbasecurrent**I_B**.
- TheoutputcharacteristicsofCEcircuitcanbedrawnwiththehelpofabovecircuitarrangementin Fig.
- Keeping the base current$I_B$fixed at some value say, 5 μA, note the collector current I_C for various values of V_{CE}.
- Then plot the readings on a graph, taking $I_C$along y-axis and V_{CE}along x-axis.
- This gives the output characteristic at I_B= 5 μA as shown in Fig. The test can be repeated for I_B= 10 μA to obtain the new output characteristic as shown in Fig.
- Following similar procedure, afamilyofoutput characteristics can be drawn as shown in Fig.



- Thefollowingpoints maybenotedfromthe 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)Forany value of V_{CE}above kneevoltage, the collectorcurrent$I_C$isapproximately equal toβ× I_B
- **Output Resistance: -** Itistheratioofchange incollector-emittervoltage(ΔV_{CE})tothechange in collector current (ΔI_C) at constant I_B i.e. $\text{Output resistance, } r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$
- It maybe notedthat whereas theoutput characteristics ofCB circuit are horizontal, theyhave noticeable slope for the CE circuit.
- Therefore,outputresistance ofCEcircuitislessthanthatCBcircuit.Itsvalueisoftheorderof50kΩ.

3) Characteristics of Common Collector Connection:-

- InaCommonCollectorcircuitconnectiontheloadresistorconnectedfromemittertoground,sothe collectortiedto groundeventhoughthetransistorisconnectedina manner similar totheCEconnection.
- Hencethereisnoneedforasetofcommon-collectorcharacteristictochoosetheparametersofthe circuit. The output characteristic of the CC configuration is same as CE configuration.
- For CCConnectiontheoutputcharacteristicareplotof**$I_E$versusV_{CE}**foraconstantvalueof**I_B**.
- There is an almost unnoticeable change in the vertical scale of $I_C$of the CE connection if $I_C$is replaced by $I_E$for CC connection.
- TheinputcircuitofCCconnection, theCEcharacteristicissufficienttoobtaintherequiredinformation.
- HenceCommonCollectorcircuitconnectionisknownas**EmitterFollower**.

CURRENT AMPLIFICATION FACTORS:-(Itistheratioofoutputcurrentto inputcurrent)

1) Common Base Connection:-

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).**

- Practicalvalues ofα incommercialtransistorsrangefrom0.9to0.99.

2) Common Emitter Connection:-

In acommon emitterconnection,theinputcurrentisthe Base Current**I_B**and outputcurrentisthe Collector Current **I_C**.

Henceratio ofchange incollector current(I_C)tothechange in basecurrent (I_B)at constant collector-emittervoltageV_{CE}isknownascurrentamplificationfactor for CEConnectionanddenotedas**β(Beta).**

- Usually,itsvalueranges from20to500.

3) Common Collector Connection:-

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

Hencetheratio ofchange inemittercurrenttothechange inbasecurrent atconstantV_{CC}isknownas current amplification factor for CC Connection and is denoted as **γ (Gamma).**

- Thiscircuitprovidesaboutthesamecurrentgainasthecommonemitter circuitas$\Delta I_E \approx \Delta I_C$.

$$\boxed{\alpha = \frac{\Delta I_C}{\Delta I_E}} \quad \boxed{\beta = \frac{\Delta I_C}{\Delta I_B}} \quad \boxed{\gamma = \frac{\Delta I_E}{\Delta I_B}}$$

❖ RELATION AMONG DIFFERENT CURRENT AMPLIFICATION FACTORS:-

$$\boxed{\Delta I_E=\Delta I_B+\Delta I_C}$$

1) Relation between αandβ:-

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

2) Relation between αandγ:-

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

3) Relation between βandγ:-

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

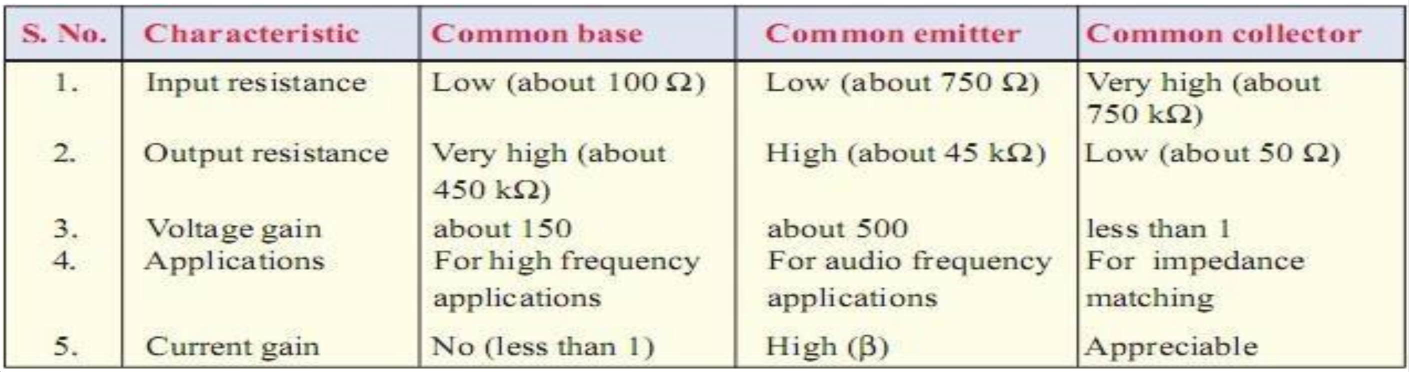
4) Relation betweenα, βand γ:-

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

$$\boxed{\therefore \beta=\alpha \times \gamma}$$

$$\boxed{\therefore \alpha=\frac{\beta}{1+\beta}}\quad\boxed{\therefore \beta=\frac{\alpha}{1-\alpha}}\quad\boxed{\therefore y=\frac{1}{1-\alpha}}\quad\boxed{\therefore \alpha=\frac{y-1}{y}}\quad\boxed{\therefore y=1+\beta}\quad\boxed{\therefore \beta=y+1}$$

❖ COMPARISON OF TRANSISTOR CONNECTIONS:-



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

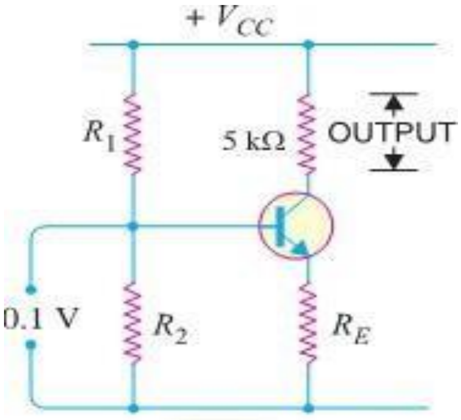
- ❖ Out of the three transistor connections, the **Common Emitter Circuit** is the most efficient.
- ❖ It is used in about 90 to 95 percent of all transistor applications.
- ❖ The main reasons for the widespread use of this circuit arrangement are: (i) High current gain. (ii) High voltage and power gain. (iii) Moderate output to input impedance ratio.

❖ AMPLIFIER:-

- ➢ The device which increases the strength of a weak signal is known as *Amplifier*. This can achieve by use of Transistor. It may be classified according to the number of stage of amplification, Such as:-
- ✓ **Single Stage Transistor Amplifier:-** When only one transistor with associated circuitry is used for amplifying a weak signal, the circuit is known as *Single Stage Transistor Amplifier*.
- ✓ **Multistage Transistor Amplifier:-** When a transistor circuit containing more than one stage of amplification is known as *Multi stage Transistor Amplifier*.

➢ SINGLE STAGE TRANSISTOR AMPLIFIER:-

- ➢ A single stage transistor amplifier has one transistor, bias circuit and other auxiliary components.
- ➢ When a weak A.C. signal is given to the base of transistor, a small base current starts flowing.
- ➢ Due to transistor action, a much larger (β times the base current) current flows through the collector load R_C.
- ➢ As the value of R_C is quite high (usually 4-10 kΩ), therefore, a large voltage appears across R_C.
- ➢ Thus, a weak signal applied in the base circuit appears in amplified form in the collector circuit.
- ➢ It is in this way that a transistor acts as an amplifier.



[Transistor as an Amplifier]

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CHAPTER-5

[TRANSISTORCIRCUITS]

TRANSISTOR BIASING:-

- Thebasicfunctionoftransistoristodoamplification.Theweaksignalisgiventothebaseofthe transistor and amplified output is obtained in the collector circuit.
- One important requirement during amplification is that onlythe magnitude ofthe signal should increase and there should be no change in signal shape.
- Thisincreaseinmagnitudeofthesignalwithoutanychangeinshapeisknownas***faithful amplification***.
- For this we have to provide inputcircuit (i.e. base-emitter junction) remains forward biased and output circuit (i.e. collector-base junction) remains reverse biased at all times.
- Toachieve faithfulamplificationthefollowingbasicconditionsmust be satisfied:-

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

- Thefulfillmentof thesewill ensurethattransistorworks over theactiveregion of the output characteristics.
- The proper flow of zero signal collector current and the maintenance ofproper collector-emitter voltage during the passage of signal is known as ***Transistor Biasing***.
- The basic purpose of transistor biasing is to keep the base-emitter junction properly forward biased and collector-base junction properly reverse biased during the application of signal.
- Thiscanbeachievedwithabiasbatteryorassociatingacircuitwithatransistor.
- The second method i.e. with a bias batteryor associating a circuit with a transistor is more efficient and is frequently employed.
- The circuit which provides transistor biasing is known as biasing circuit.The transistor biasing is very essential for the proper operation of transistor in any circuit.

✓ NEED OF TRANSISTOR BIASING:-

(i) Itshouldensureproperzero signalcollector current.
(ii) Itshouldensurethat V_{CE}doesnotfallbelow 0.5VforGetransistorsand1 VforSitransistors.
(iii) Itshouldensurethestabilizationofoperating point.

STABILISATION:-

- Theprocessofmakingoperatingpointindependentof temperaturechangesorvariationsintransistor parameters is known as *Stabilization*.

NEED FOR STABILIZATION:-

Stabilizationoftheoperatingpoint is necessaryduetothe following reasons :

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

- Theself-destructionofanunsterilizedtransistorisknownas***ThermalRunaway***.

STABILITY FACTOR :-

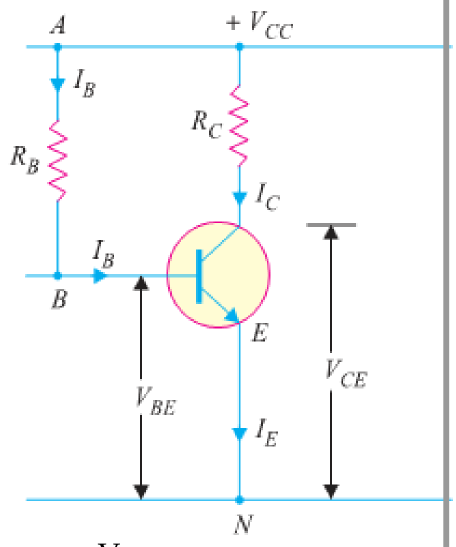
- Therate of change of collector current I_Cw.r.t. the collector leakage currentI_{CO} [= I_{CEO}] atconstant β and $I_B$is called stability factor i.e.

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

✓ METHODS OF TRANSISTOR BIASING:-

- Inthetransistor amplifier circuits drawnso far biasing was done withthe aid ofa batteryV_{BB}whichwas separate from the battery V_{CC}used in the output circuit. However, for simplicity and economy, it is desirable that transistor circuit should have a single source of supply the one in the output circuit (i.e. V_{CC}).
- The following are the most commonly used methods of obtaining transistor biasing from one source of supply:
  - **(i)** Baseresistormethod
  - **(ii)** Biasingwithcollector-feedbackresistor
  - **(iii)** Voltage-dividerbias
- In allthese methods, the same basic principle is employed i.e. required value ofbase current (and hence I_C) is obtained from V_{CC}in the zero signal conditions.
- ThevalueofcollectorloadR$_C$isselectedkeepinginviewthatV_{CE}shouldnotfallbelow0.5Vfor germanium transistors and 1V for silicon transistors.

❖ BASE RESISTOR METHOD:-



- In this method, a high resistance R_B(several hundred kΩ) is connected between the base and +ve end of supply for npn transistor and between base and negative end of supply for pnp transistor.
- Here, the required zero signal base current is *provided by V_{CC}*and it flows throughR_B. It is because now base ispositive w.r.t. emitter i.e. base-emitter junction is forward biased.
- The required value ofzero signalbase current I_B(and hence $I_C = \beta I_B$) can be madeto flow byselectingthepropervalue ofbaseresistorR_B.
- **Circuit analysis:-**

  It is required to find the value of $R_B$so that required collector current flows in the zero signal conditions.

  Let$I_C$betherequired zerosignalcollectorcurrent.

  $\therefore I_B = I_C/\beta$

  Consideringtheclosedcircuit ABENAandapplying Kirchhoff'svoltagelaw,weget, $V_{CC} = I_B R_B + V_{BE}$

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

  $R_B = \frac{V_{CC} - V_{BE}}{I_B}$ ………………………………………………………………… (i)

  As$V_{CC}$and$I_B$are known andV_{BE} canbeseenfrom thetransistormanual,therefore,valueofR_B can foundfromexp.(i).

  SinceV_{BE}isgenerallyquitesmallascompared toV_{CC},theformercanbeneglectedwith littleerror.

  ThusEquation(i)becomes, $R_B = \frac{V_{CC}}{I_B}$
- It may be noted that $V_{CC}$is a fixed known quantity and $I_B$is chosen atsome suitable value.Hence, $R_B$can always be found directly, and for this reason, this method is sometimes called **fixed-bias method**.
- **Advantages:**

  (i) ThisbiasingcircuitisverysimpleasonlyoneresistanceR$_B$isrequired.

  (ii) Biasingconditionscaneasilybesetandthecalculationsare simple.
- **Disadvantages:**

  (i) Thismethodprovidespoorstabilization.

  (ii) Thestabilityfactorisveryhigh.

❖ BIASING WITH FEEDBACK CIRCUIT:-

- In this method, one end of $R_B$is connected to the base and the other end to the collector. Here, the required zero signal base current is determined not by V_{CC}but by the *collector-base voltage V_{CB}*. It is clear that V_{CB}forward biasesthe base-emitter junction and hence base current $I_B$flows through R_B. This causes the zero signal collector current to flow in the circuit.

- **Circuit Analysis:-**

  TherequiredvalueofR$_B$neededtogivethezerosignalcurrentI$_C$canbedeterminedasfollows.

  Fromtheabovecircuitdiagram,$V_{CC} = I_C R_C + I_B R_B + V_{BE}$

$$R_B = \frac{V_{CC} - V_{BE} - I_C R_C}{I_B} = \frac{V_{CC} - V_{BE} - \beta\, I_B R_C}{I_B} \qquad (\because I_C = \beta\, I_B)$$

  Alternately,$V_{CE} = V_{BE} + V_{CB}$or$V_{CB} = V_{CE} - V_{BE}$

$$\therefore \qquad R_B = \frac{V_{CB}}{I_B} = \frac{V_{CE} - V_{BE}}{I_B}\,; \quad \text{where} \quad I_B = \frac{I_C}{\beta}$$

- **Advantages:-**

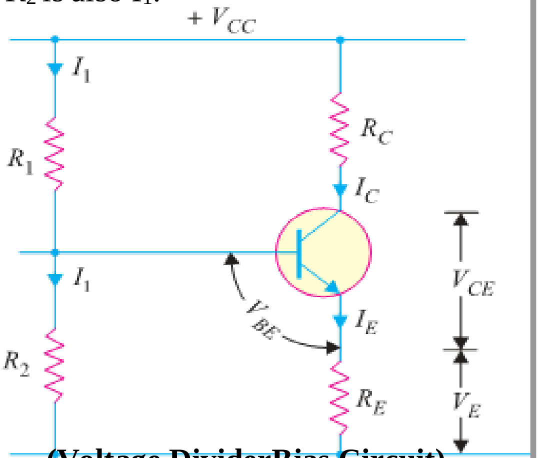
  (i) ItisasimplemethodasitrequiresonlyoneresistanceR$_B$.
  (ii) Thiscircuitprovidessomestabilizationoftheoperatingpointthanfixedbiasmethod.

- **Disadvantages:-**

  (i) Thecircuitdoesnotprovidegoodstabilization.
  (ii) Thiscircuitprovidesanegativefeedbackwhichreducesthegainoftheamplifier.
  (iii) Thiswillreduce thebasecurrentandhencecollectorcurrent.

❖ VOLTAGE DIVIDER BIAS METHOD:-

- This is the most widely used method of providing biasing and stabilization to a transistor.In this method,tworesistancesR$_1$and R$_2$are connectedacross thesupply voltage V$_{CC}$and*providebiasing*. The emitter resistance R$_E$*provides stabilization*. The name ‘‘voltage divider’’ comes from the voltage divider formed by R$_1$and R$_2$. The voltage drop across R$_2$forward biases the base- emitter junction. This causes the base current and hence collector current flows in the zero signal conditions.
- **Circuit analysis:-**
- Suppose thatthe currentflowing through resistance R$_1$is I$_1$.As base currentI$_B$is verysmall,therefore, it can be assumed with reasonable accuracythat current flowing through R$_2$ is also I$_1$.



(Voltage DividerBias Circuit)

(i) Collectorcurrent I$_C$:-

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

$\therefore$ Voltage across resistance R_2 is

$$V_2 = \left(\frac{V_{CC}}{R_1 + R_2}\right) R_2$$

ApplyingKirchhoff'svoltagelawtothebasecircuit $V_2 = V_{BE} + V_E = V_{BE} + I_E R_E$

$$I_E = \frac{V_2 - V_{BE}}{R_E}\,; \qquad I_C = \frac{V_2 - V_{BE}}{R_E}\,; \qquad \text{Since } I_E \simeq I_C$$

- Thus IC in this circuit is almost independent of transistor parameters and hence good stabilization is ensured. Due to this reason the potential divider bias has become universal method for providing transistor biasing.

(ii) Collector-emitter voltage(V$_{CE}$):-

Applying Kirchhoff's voltage law to the collector side,

$V_{CC} = I_C R_C + V_{CE} + I_E R_E = I_C R_C + V_{CE} + I_C R_E$ (As$I_C \simeq I_E$)

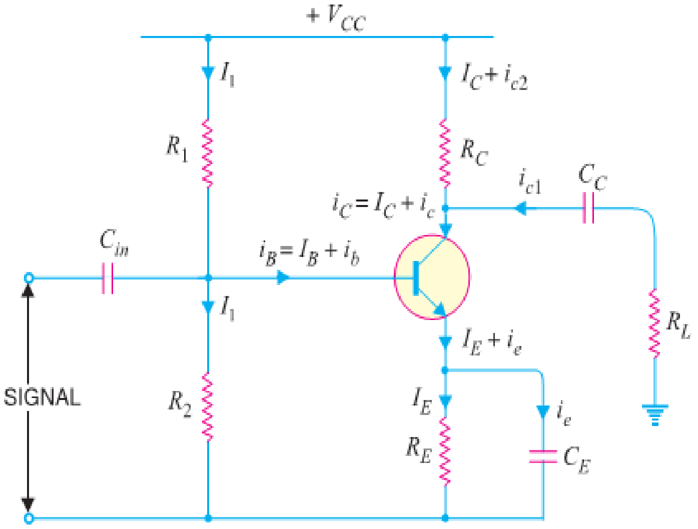
So, $V_{CC} = I_C(R_C + R_E) + V_{CE} \Rightarrow V_{CE} = V_{CC} - I_C(R_C + R_E)$

- **Advantages: -**
- Inthiscircuit,excellent stabilizationisprovidedbyR$_E$.ConsidertheFollowingEquation, $V_2 = V_{BE} + I_C R_E$
- Suppose the collector current I$_C$increases due to rise in temperature. This will cause the voltage drop across emitter resistance R$_E$to increase.

CHAPTER-6

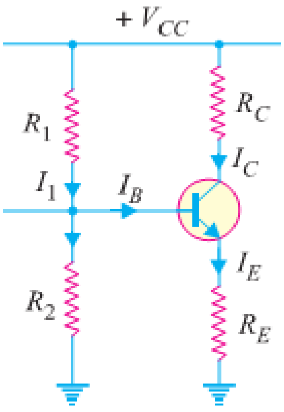
----------------------[TRANSISTOR AMPLIFIERS & OSCILLATORS--------------------

❖ D.C.ANDA.C.EQUIVALENT CIRCUITS:-



- 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) Base Current: -** When no signal is applied in thebase circuit, D.C. base current $I_B$flows dueto biasingcircuit. WhenA.C. signalisapplied, 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) Collector Current: -** When no signal is applied, a D.C. collector current $I_C$flows due to biasingcircuit. WhenA.C. signalisapplied, A.C. collector current i_c also flows.
- Therefore, the TotalCollector Current $i_C$is given by: -$\mathbf{i_C = I_C + i_c}$

  Where$I_C = \beta I_B$=zerosignalcollectorcurrent and$i_c = \beta i_b$=collectorcurrentduetosignal.
- **(iii) Emitter Current:-** Whenno signal is applied, a D.C. emitter current $I_E$flows. When A.C. signal is applied, A.C. Emitter Current i_e also flows. Thereforethe TotalEmitter Current is : - $\mathbf{i_E = I_E + i_e}$
- 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.Equivalent Circuit**:-InordertodrawtheequivalentD.C.circuit,the following two steps are applied to the transistor circuit:-

(a) ReduceallA.C.sourcestozero.

(b) Openallthecapacitors.

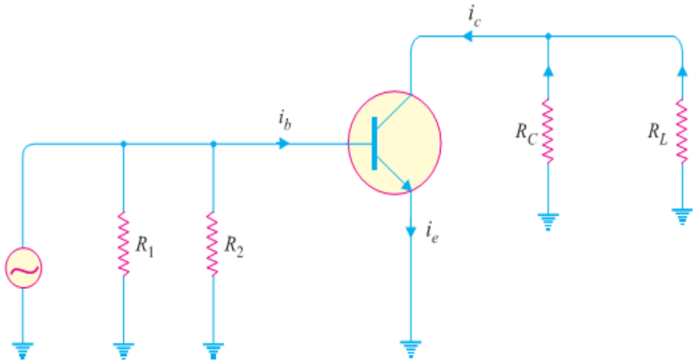
- ReferringD.C.EquivalentCircuit

  D.C.Load $\mathbf{R_{DC} = R_C + R_E}$ & $V_{CC} = V_{CE} + I_C(R_C + R_E)$
- Themaximum valueofV_{CE} willoccur whenthereisnocollectorcurrenti.e.I_C=0.

$$\therefore \quad \boxed{\textbf{Maximum}\, \mathbf{V_{CE} = V_{CC}}}$$

- Themaximumcollector currentwillflowwhenV_{CE}=0.

$$\therefore \quad \boxed{\textbf{Maximum}\, \mathbf{I_C = V_{CC}/(R_C + R_E)}}$$



❖ **A.C.Equivalent Circuit**:-Inorderto drawA.C. equivalent circuit, the following two steps are applied to the transistor circuit:

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

(b) Short allthecapacitors.

- Referring A.C. Equivalent circuit A.C. load equal to $R_C \parallel R_L$ i.e. $\boxed{\text{A.C.load, } \mathbf{R_{AC} = (R_C R_L/(R_C + R_L)}}$
- Maximum positive swing ofA.C. collector-emitter voltage = $I_C \times R_{AC}$

$$\boxed{\therefore \text{Totalmaximum}\textbf{collector-emittervoltage, } \mathbf{V_{CE\,MAX} = V_{CE} + I_C R_{AC}}}$$

- Maximumpositiveswingof A.C.collectorcurrent=V_{CE}/R_{AC}

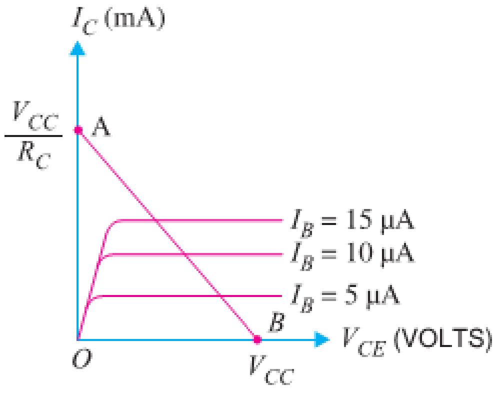
$$\boxed{\therefore \text{Totalmaximum}\textbf{collectorcurrent,}\mathbf{I_{CMAX} = I_C + V_{CE}/R_{AC}}}$$

❖ LOAD LINE ANALYSIS:-

- Inthetransistorcircuitanalysis,itisgenerally requiredtodeterminethecollectorcurrentforvarious collector-emitter voltages.
- One of the methods can be used to plot the output characteristics and determine the collector current at any desired collector-emitter voltage.
- However,amoreconvenientmethod,knownas**load line method**canbeusedtosolvesuchproblems.
- Thismethodisquiteeasyandisfrequentlyusedin theanalysisoftransistorapplications.

♣ **D.C.LOADLINE**:-Itis theline on the outputcharacteristics of a transistorcircuitwhich gives the values of $I_C$and V_{CE}corresponding to zero signal or D.C. conditions.

- ConsideracommonemitterNPNtransistorcircuit where no signalisapplied.Therefore,D.C.conditions prevailinthecircuit.Theoutputcharacteristicsof thiscircuit areshowninFig.



- The value of collector-emitter voltage V_{CE}at any time is given 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$I_C = (-1/R_C)V_{CE} + V_{CC}/R_C (\equiv Y = mX + C)$
- As $V_{CC}$and $R_C$are fixed values, therefore, it is a first degree equation and can be represented bya straight line onthe output characteristics. This is known as **D.C. Load Line.**
- To add load line, we need two end points of the straight line. These two points can be located as under:

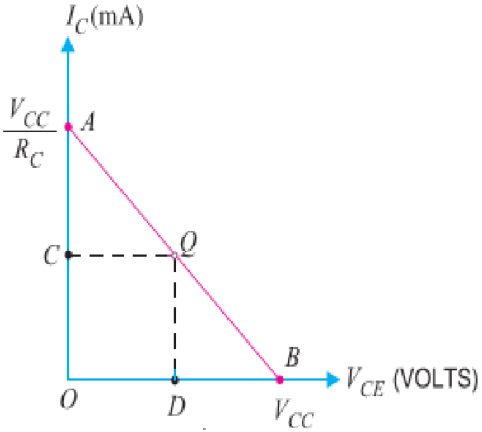
  (i) Whenthecollectorcurrent I_C=0,thencollector-emittervoltage ismaximumandisequalto V_{CC}

  i.e. Max.$V_{CE} = V_{CC} - I_C R_C = V_{CC}$ (AsI_C =0)
- ThisgivesthefirstpointB(OB=V_{CC})on thecollector-emitter voltage axis as shown in Fig.

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

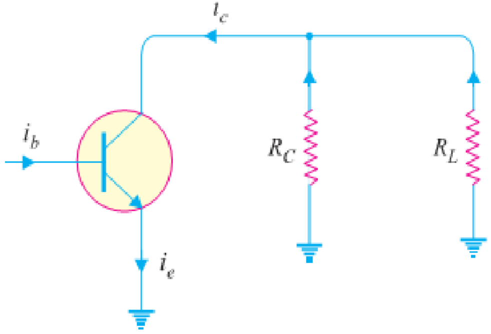
  i.e. $V_{CE} = V_{CC} - I_C R_C$or0=$V_{CC} - I_C R_C$

  ∴ 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. LOAD LINE.** This is the line on the output characteristics of a transistor circuit which gives the values of $i_C$and v_{CE} when signal is applied.

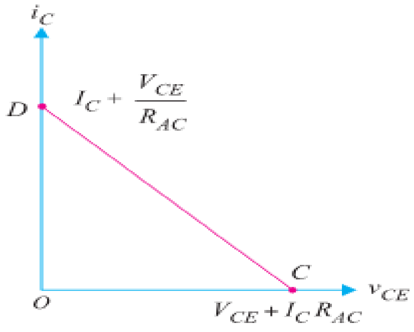
- Referring back to the transistor amplifier shown in Fig., its A.C. equivalent circuit as far as output circuit is concernedisas shown in Fig.



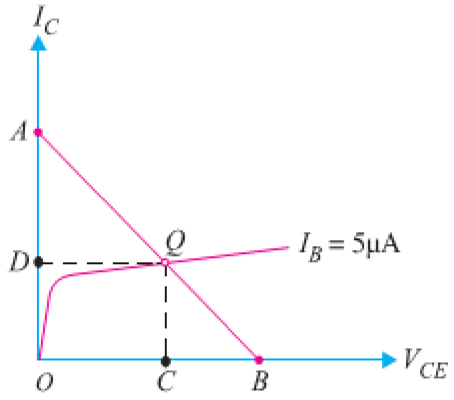
- To add A.C. load line to the output characteristics, we again require two end points: –

  1. Onemaximumcollector-emittervoltagepoint**($V_{CE MAX}$)**and

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

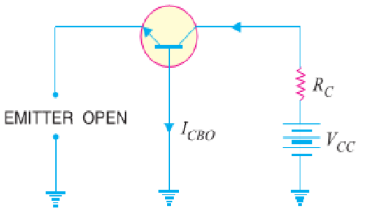


❖ OPERATING POINT:-

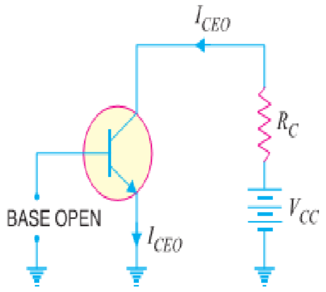


- The zero signal values of I_C and V_{CE} are known as the **Operating point**.
- It is called operating point because the variations of I_C and V_{CE} take place about this point when signal is applied.
- It is also called quiescent (silent) point or **Q-Point** because it is the point on $I_C – V_{CE}$ characteristic when the transistor is silent i.e. in the absence of the signal.
- Suppose in the absence of signal, the base current is 5μA. Then I_C and V_{CE} conditions in the circuit must be represented by some point on I_B = 5 μA characteristic.
- But I_C and V_{CE} conditions in the circuit should also be represented by some point on the d. c. load line AB.
- The point Q where the load line and the characteristic intersect is the only point which satisfies both these conditions. Therefore, the point Q describes the actual state of affairs in the circuit in the zero signal conditions and is called the operating point. Referring to Fig, for I_B = 5 μA, the zero signal values are :

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



❖ THE LEAKAGE CURRENT:-



- The current is due to the movement of minority carriers is known as Leakage Current.
- In Common Base Connection of Transistor the leakage current **I_{CBO}** is the Collector-Base current with emitter open.
- Similarly, In Common Emitter Connection the leakage current **I_{CEO}** is the Collector-Emitter Current with open Base.
- Expression for collector current in Common Base Connection is given by,

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

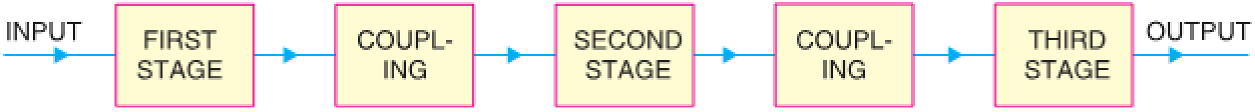
- Expression for collector current in Common Emitter Connection is given by,

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

❖ MULTISTAGE TRANSISTOR AMPLIFIER:-

- The output from a single stage amplifier is usually insufficient to drive an output device. In other words, the gain of a single amplifier is inadequate for practical purposes.
- Consequently, additional amplification over two or three stages is necessary. To achieve this, the output of each amplifier stage is coupled in some way to the input of the next stage.
- The resulting system is referred to as multistage amplifier.
- A transistor circuit containing *more than one stage of amplification* is known as *multistage transistor amplifier*.
- In a multistage amplifier, a number of single amplifiers are connected in cascade arrangement i.e. output of first stage is connected to the input of the second stage through a suitable coupling device and so on.
- The purpose of **coupling device** (e.g. a capacitor, transformer etc.) is
  - (i) to transfer A.C. output of one stage to the input of the next stage and
  - (ii) to isolate the D.C. conditions of one stage from the next stage.
- The name of the amplifier is usually given after the type of coupling used. e.g.

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

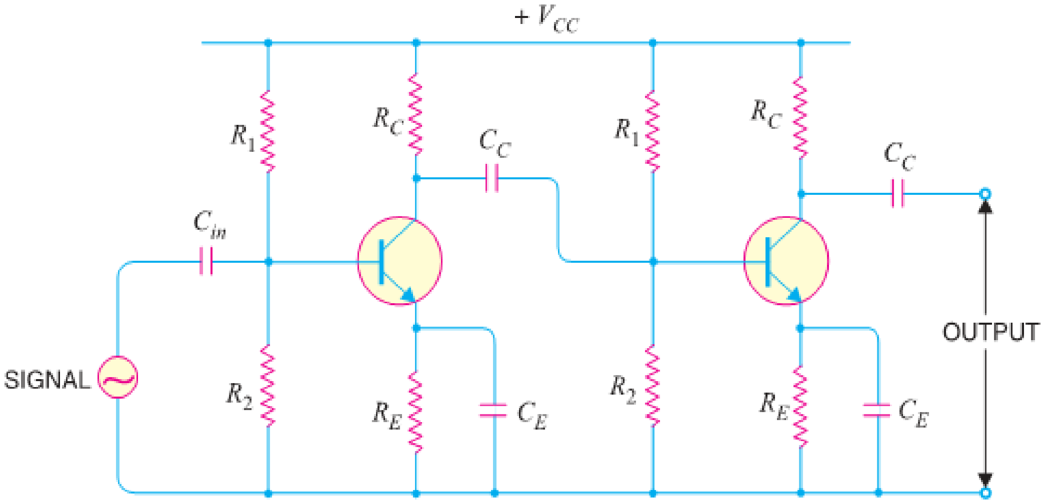


IMPORTANTTERMS:-

- **Gain: -** The ratiooftheoutputelectricalquantityto theinput one ofthe amplifieris calledits gain.
- Thegainofamultistageamplifierisequaltotheproductofgainsofindividual stages.
- **Frequencyresponse: -** The curve between voltage gain and signal frequency of an amplifier is known as frequency response.
- **Decibelgain:-**Althoughthegainofanamplifiercanbeexpressedasanumber,yetgreatpractical importance to assign it a unit.
- Theunitassignedisbelordecibel (db).Thecommonlogarithm(logtothebase10)of powergainis known as bel power gain i.e $\text{Power gain} = \log_{10} \frac{P_{out}}{P_{in}}\ bel$ (1 bel=10 db.)
- **Bandwidth:-** The range of frequency overwhich the voltage gain is equal to orgreater than 70.7% of the maximum gain is known as **bandwidth**.
- Fromthe fig. it is clear that for anyfrequencylyingbetween$f_1$and f_2, the gain is equaltoor greaterthan 70.7% of the maximum gain.
- Therefore,f_1-f_2isthebandwidth.Itmay beseenthat$f_1$and$f_2$arethelimitingfrequencies.The$f_1$is called lower cut-off frequency and $f_2$is known as upper cut-off frequency.

R-CCOUPLED TRANSISTOR AMPLIFIER:-

- This is the most popular type ofcoupling because it is cheap and*provides excellent audiofidelityover a wide range of frequency*. It is usually employed for **voltage amplification**.
- Fig shows two stagesofanRC coupled amplifier. Acoupling capacitor $C_C$is used to connect theoutput of first stage to the base (i.e. input) of the second stage and so on.
- Asthecoupling fromonestageto next is achieved byacouplingcapacitor followed bya connectionto a shunt resistor, therefore, such amplifiers are called ***Resistance - Capacitance coupled amplifiers***.
- Theresistances R_1, $R_2$and $R_E$formthe *biasing*and *stabilization* network. Theemitter bypass capacitor offers *lowreactance path* to the signal.Without it, the voltage gain ofeach stage would be lost.
- Thecouplingcapacitor C_C transmits A.C. signalbut blocks D.C. This prevents D.C.interference between various stages and the shifting of operating point.



[CircuitDiagramofRCCoupled Transistor Amplifier]

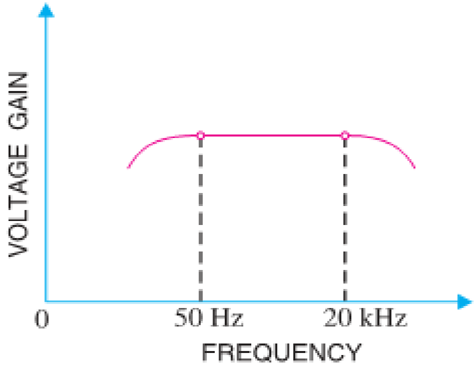
OPERATION: -

- 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 amplifythe signal and the overall gain is considerably increased.
- Itmaybementioned herethattotalgainislessthantheproductofthegainsofindividualstages.
- 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 ofthe input resistance of second stage.
- Thisreducesthegainofthestagewhich isloaded bythe nextstage

FREQUENCY RESPONSE R-C COUPLED TRANSISTOR AMPLIFIER:

- 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 itis uniform overmid-frequency range (50 Hz to 20 kHz).
- Thisbehaviouroftheamplifierisbrieflyexplainedbelow:-
- **(i) At low frequencies** (< 50 Hz):- At this stage the reactance ofcoupling capacitor $C_C$is quite high and henceverysmallpartofsignalwillpassfromonestagetothe next stage. Moreover, $C_E$cannot shunt the emitter resistance $R_E$effectively because of its large reactance at low frequencies. These two factors cause a falling of voltage gain at low frequencies.
- **(ii) At high frequencies** (> 20 kHz):-At this stage the reactance of $C_C$is very small and it behaves as a short circuit. These increases the loading effect of next stage and serves to reducethe voltage gain.
  Moreover,at high frequency,capacitive reactance of base-emitterjunctionislowwhichincreasesthebasecurrent.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** (50 Hz to 20 kHz):- At this stage the voltage gain of the amplifier is constant. Theeffect ofcoupling capacitor inthis frequencyrange is suchso as tomaintainauniform 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 canceleach other, resulting in a uniform gain at mid-frequency.

ADVANTAGES:-

(i) It has excellent frequencyresponse. The gain is constant overthe audio frequencyrangewhichis the region of most importance for speech, music etc.

(ii) Ithaslowercostsinceitemploysresistorsandcapacitorswhichare cheap.

(iii) Thecircuitisverycompactasthemodernresistorsandcapacitorsaresmallandextremelylight.

DISADVANTAGES:-

(i) The RC coupled amplifiers have low voltage and power gain. It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (R_{AC}) and hence the gain.

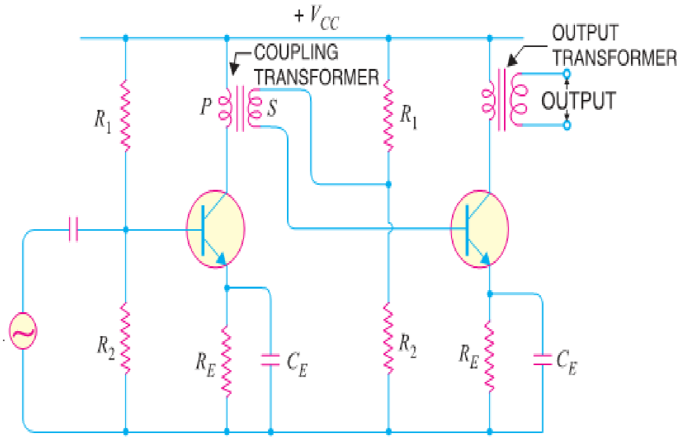
(ii) Theyhavethetendencytobecomenoisywithage,particularlyin moistclimates.

(iii) Impedance matching is poor. It is because the output impedance ofRC coupled amplifier is several hundred ohms whereas the input impedance ofa speaker is only a few ohms. Hence, little power will be transferred to the speaker.

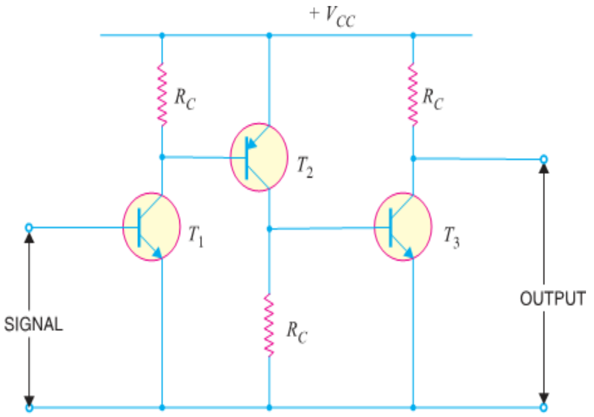
APPLICATIONS:-

- TheRCcoupledamplifiershaveexcellent audio fidelityoverawiderangeoffrequency. Therefore, they are widely used as **voltage amplifiers** e.g. in the initial stages ofpublic address system.
- Ifothertypeofcoupling(e.g.transformercoupling)isemployedintheinitialstages,thisresultsin frequency distortion which may be amplified in next stages.
- However,becauseofpoorimpedancematching,RCcouplingisrarelyusedinthefinalstages.

✓ CIRCUIT DIAGRAM FOR OTHER TYPE OF COUPLING ARE GIVEN BELOW:-



(TransformerCoupledTransistorAmplifier)



(DirectCoupledTransistorAmplifier)

➢ Comparison of Different Types of Coupling:-

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

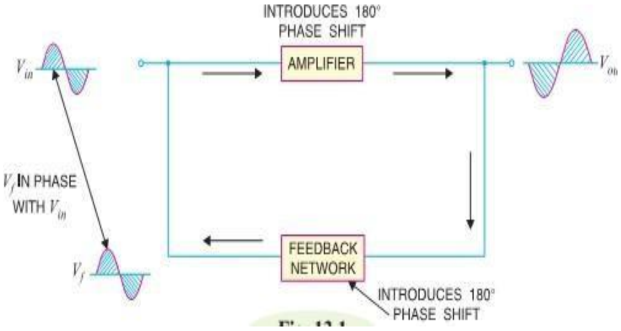
[FEEDBACKAMPLIFIER]

❖ INTRODUCTION:-

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

❖ FEEDBACK:-

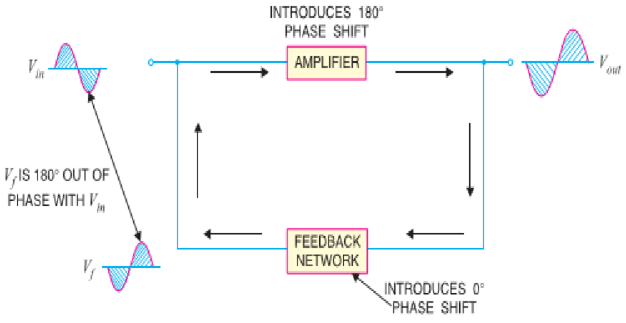
- ➢ Theprocessofinjecting afractionofoutput energyofsomedeviceback toinputisknownasfeedback.
- ➢ Depending upon whether the feedback energyaids oropposes the input signal, there aretwo basic types of feedback in amplifiers viz Positive Feedback and Negative Feedback.



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

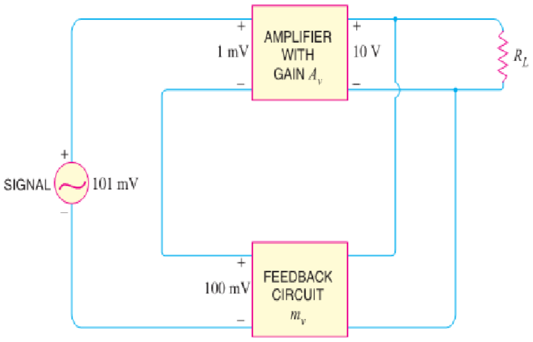
- ➢ Both amplifier and feedback network introducea phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage $V_f$to be in phase with the input signal V_{in}.
- ➢ Thepositivefeedbackincreasesthegainofthe amplifier.However,ithasthedisadvantagesofincreaseddistortionandinstability.

- Therefore,positive feedback isnotoftenemployedinamplifiers.
- One important useofpositive feedback is inoscillators. Ifpositive feedback is sufficiently large, it leads to oscillations.As a matter of fact, an oscillator is a device thatconverts d.c. power into a.c. power of any desired frequency.



- **(ii) Negative Feedback.** When the feedback energy (voltage or current) is out of phase with theinput signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig.
- As you can see, the amplifier introducesa phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage $V_f$is 180° out of phase with the input signal V_{in}.
- Negative feedback reduces the gain ofthe amplifier. However, the advantages ofnegative feedback are: reduction in distortion, stability in gain, increased bandwidth & improved input and output impedances.
- Itisduetotheseadvantagesthatnegativefeedbackis frequentlyemployedinamplifiers.

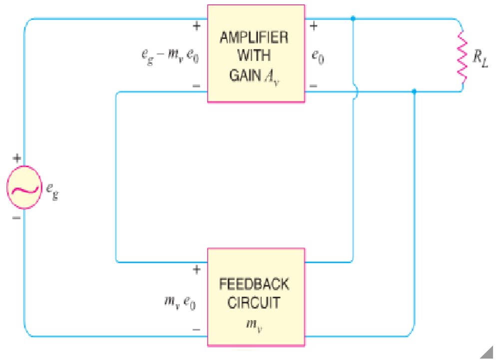
PRINCIPLES OF NEGATIVE VOLTAGE FEEDBACK IN AMPLIFIERS:-



- A feedback amplifier has main two parts such as an amplifier and a feedback circuit.
- The feedback circuit usually consists ofresistorsand returns a fraction of output energy back to the input.
- Fig. shows the principles of negative voltage feedback in an amplifier. Typical values have been assumed to make the treatment more illustrative.
- The output of the amplifier is 10 V. The fraction $m_v$of this output i.e.100 mV is feedback to the input where it is applied in series with the input signal of 101 mV.
- Asthefeedbackisnegative,therefore,only1mVappearsattheinputterminalsoftheamplifier.
- ReferringtoFig., wehave,
    - Gainofamplifierwithoutfeedback,A_v=(10V)/(1mV)=10,000
    - Fractionofoutputvoltage feedback,m_v=(100mV)/10V=0.01
    - Gainofamplifierwithnegativefeedback,A_{vf}=10V/101mV=100
- Thefollowingpointsare worthnoting:-

- 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 only100.
- 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 only1 mV.
- Inanegativevoltagefeedbackcircuit,thefeedbackfraction$m_v$isalwaysbetween0and1.
- Thegainwithfeedbackissometimescalled**closed-loopgain**whilethegainwithoutfeedbackiscalled ***open-loopgain***.Thesetermscomefromthefactthatamplifierandfeedbackcircuits forma "loop".
- Whenloopis "opened"bydisconnectingfeedbackcircuitfromI/P,amplifier'sgain**A_v**,[open-loopgain]
- Whentheloopis "closed"byconnectingthefeedbackcircuit,gaindecreasesto**A_{vf}**["closed-loop"gain]

GAIN OF NEGATIVE VOLTAGE FEEDBACK AMPLIFIER:-



- ConsiderthenegativevoltagefeedbackamplifiershowninFig.
- Thegainoftheamplifier without feedbackis**A_v**.
- Negative feedback is then applied by feeding a fraction **m_v** of the output voltage **e_0**back to amplifier input.
- Therefore,theactual inputtotheamplifieristhesignalvoltage**e_g** minus feedback voltage **m_v e_0** i.e.,

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

➔ $e_0 + A_v m_v e_0 = A_v e_g$ ➔

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

$e_0(1 + A_v m_v) = A_v e_g$ But $\mathbf{e_0/e_g}$ is the voltage gain of the amplifier with feedback.

∴ Voltage gain with negative feedback is

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

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

❖ ADVANTAGES OF NEGATIVE VOLTAGE FEEDBACK:-

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

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

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

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

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

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

♣ **(ii) Reduces non-linear Distortion.** A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers.

It can be proved mathematically that:

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

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

- Thus by applying negative voltage feedback to an amplifier, distortion is reduced by a factor $\mathbf{1 + A_v m_v}$.

♣ **(iii) Improves Frequency Response**. As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is independent of signal frequency.

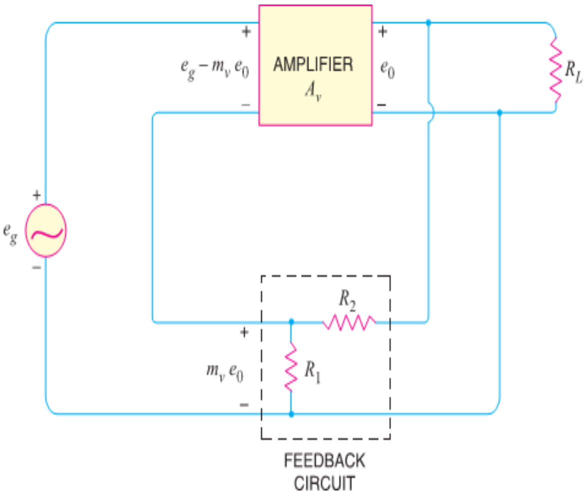
- The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.

♣ **(iv) Increases Circuit Stability.** The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude.

- This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilized or accurately fixed in value.
- This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason.
- This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable.
- The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.

♣ **(v) Increases input impedance and decreases output impedance.** The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching.

❖ FEEDBACK CIRCUIT:-



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

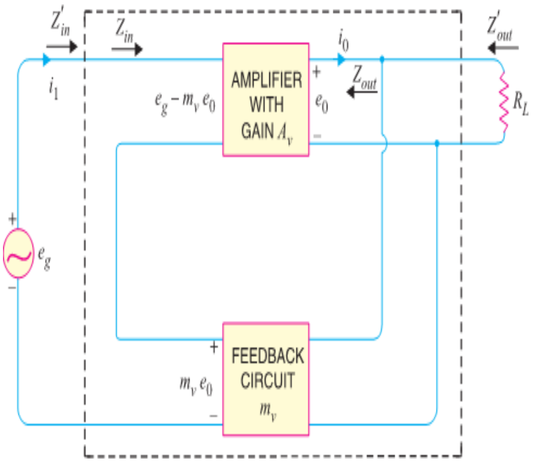
Voltage across R_1 = (——— e_0

Feedback fraction, m_v = ——————— = ———

❖ INPUT& OUTPUT IMPEDANCE OF NEGATIVE FEEDBACKA MPLIFIER:-

♣ **(a) Input impedance.** The increase in input impedance with negative voltage feedback can be explained by referring to Fig.

- Suppose the input impedance of the amplifier is Z_{in} without feedback and Z'_{in} with negative feedback. Let us further assume that input current is i_1.
- Referring to Fig., we have,



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

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

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

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

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

— $= Z_{in} (1 + A_v m_v)$

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

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

- It is clear that by applying negative voltage feedback, the input impedance of the amplifier is increased by a factor $1 + A_v m_v$. As $A_v m_v$ is much greater than unity.
- Therefore, input impedance is increased considerably. This is an advantage, since the amplifier will now present less of a load to its source circuit.

♣ **(b) Output impedance.** Following similar line, we can show that output impedance with negative voltage feedback is given by :

$$\boxed{\therefore \mathbf{Z'_{out}} = \text{———}}$$

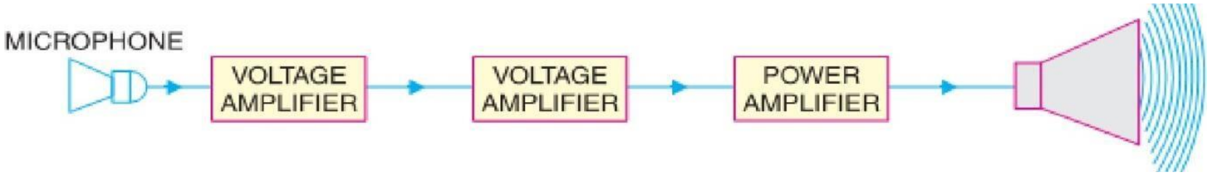
Where Z'_{out} = output impedance with negative voltage feedback
Z_{out} = output impedance without feedback

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

[AUDIO POWER AMPLIFIERS]

❖ INTRODUCTION:-

- ➢ A practical amplifier always consists of a number of stages that amplify a weak signal until sufficientpower is available to operate a loudspeaker or other output device.
- ➢ The first few stages in this multistage amplifierhavethe function ofonlyvoltage amplification. However, last stageisdesignedtoprovidemaximumpower.This finalstageisknownaspowerstage.



❖ Transistor Audio Power Amplifier:-

- ➢ Atransistor amplifier whichraises the powerlevel ofsignals having audio frequencyrange is known as transistor **Audio Power Amplifier**. Generally last stage of a multistage amplifier is the power stage.
- ➢ Thepoweramplifierdiffersfrom allthepreviousstagesinthathereaconcentratedeffortismadeto obtain maximum output power.
- ➢ Atransistorthatissuitableforpoweramplificationisgenerallycalleda*powertransistor*.

❖ DIFFERENCE BETWEEN VOLTAGE AND POWER AMPLIFIERS

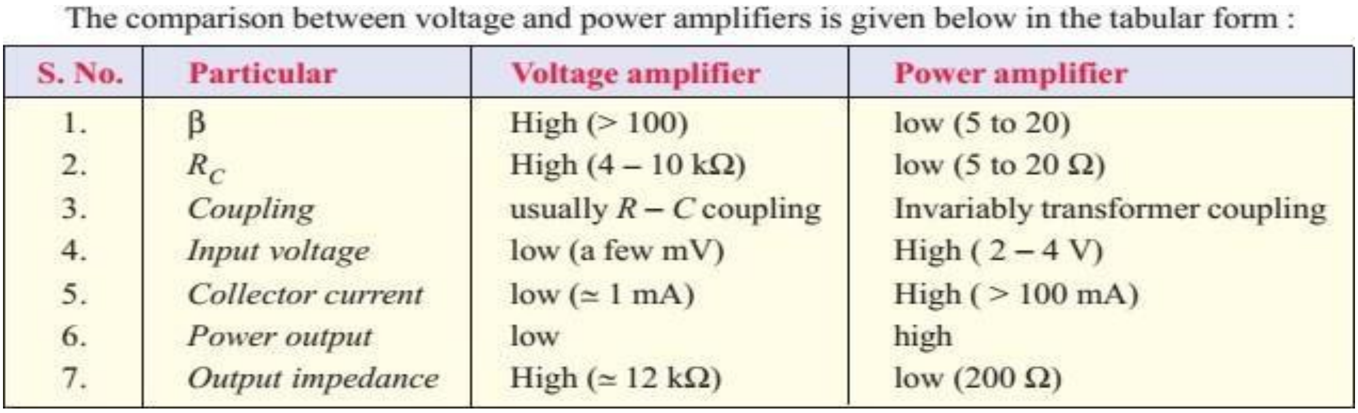
- ➢ The difference between the two types is reallyone of degree; itis a question of how much voltage and how much power.
- ➢ A voltage amplifier is designed to achieve maximum voltage amplification. It is, however, not important to raise the power level.
- ➢ Ontheother hand,apower amplifierisdesignedtoobtainmaximumoutput power.

1) VoltageAmplifier. Thevoltage gainofanamplifierisgiven by: $A_v = \beta \times \frac{R_C}{R_{in}}$

- ➢ In order to achieve high voltage amplification, the following features are incorporated insuch amplifiers:
  - ♣ The transistor with high β(>100) is used in the circuit. i.e.Transistorsareemployed having thin base.
  - ♣ TheinputresistanceR_{in}oftransistorissoughttobequitelowascomparedtothecollectorloadR_C.
  - ♣ A relatively high load $R_C$is used in the collector. To permit this condition, voltage amplifiers are always operated at low collector currents (≈ mA). If the collector current is small, we can use large $R_C$in the collector circuit

2) Power Amplifier.A power amplifieris required to deliver alarge amount of power and as such ithas to handle large current.

- ➢ Inordertoachievehighpoweramplification,thefollowingfeaturesareincorporatedinsuchamplifiers:
  - ♣ Thesize ofpowertransistor is madeconsiderablylarger inorder to dissipatethe heat produced inthe transistor during operation.
  - ♣ Thebaseismadethickertohandlelargecurrents.Inotherwords,transistorswithcomparatively smaller β are used.
  - ♣ Transformercouplingisused forimpedance matching.



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

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

❖ PERFORMANCE QUANTITIES OF POWER AMPLIFIERS

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

Collector efficiency.

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

Distortion. The change ofoutput wave shape from inputwave shape ofamplifieris called**Distortion**.

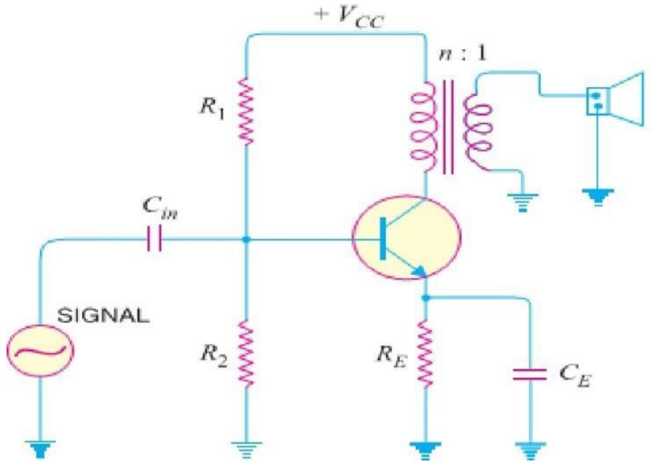
Power Dissipation Capability. The ability of a power transistor to dissipate heat is known as power dissipation capability.

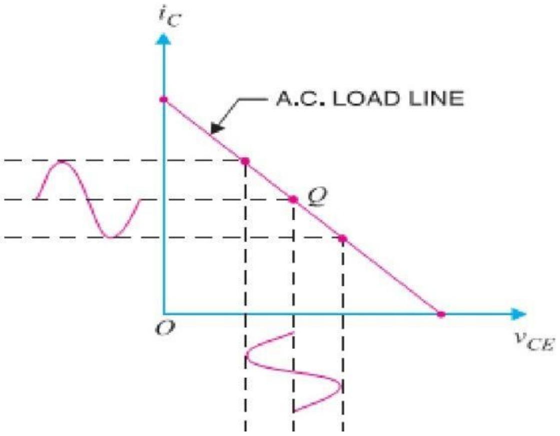
❖ CLASSIFICATION OF POWER AMPLIFIERS

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

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

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

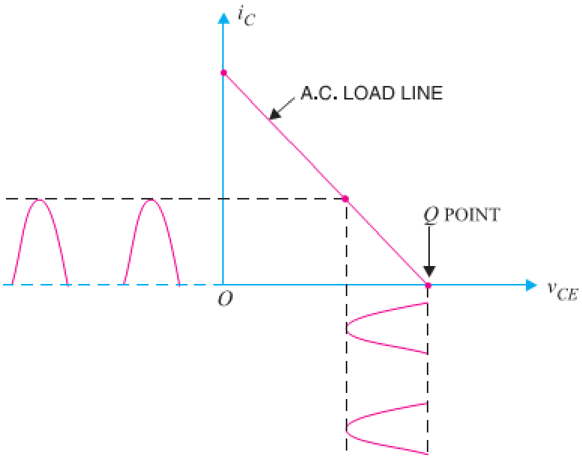




- The power amplifier must be biased in such a way that no part of the signal is cut off. Fig (i) shows circuit of class A power amplifier. Note that collector has a transformer as the load which is most common for all classes of power amplifiers.
- Theuseoftransformer permits impedance matching, resulting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

CLASS B POWER AMPLIFIER:- Ifthecollectorcurrentflowsonlyduringthepositive half-cycleof the input signal, it is called a *class B power amplifier*.

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



- Fig. showstheclassBoperationintermsofa.c.loadline.
- The operating point Q shall be located at collector cut off voltage.
- Itiseasytoseethatoutputfromaclass Bamplifieris amplified half-wave rectification.
- Inaclass Bamplifier, thenegativehalf-cycleofthesignal is cut off and hence a severe distortion occurs.
- However, class B amplifiers provide higher power output and collector efficiency (50 – 60%).
- Such amplifiers aremostly usedforpoweramplification in push-pull arrangement.
- Insuchanarrangement,2transistorsareusedinclassB operation.Onetransistoramplifiesthepositivehalfcycleofthesignalwhiletheotheramplifiesthe negative half-cycle.

CLASS C POWER AMPLIFIER.If the collector currentflowsforless thanhalf-cycle of theinput signal, it is called *class C power amplifier*.

- InclassCamplifier,thebaseisgivensomenegativebiassothatcollectorcurrentdoesnotflowjust when the positive half-cycle of the signal starts.
- Suchamplifiers are never used for power amplification. However, theyare used as tuned amplifiers i.e. to amplifya narrow band of frequencies near the resonant frequency.

EXPRESSION FOR COLLECTOR EFFICIENCY

- Forcomparingpoweramplifiers,collectorefficiencyisthemaincriterion.Thegreaterthecollector efficiency, the better is the power amplifier.
- Now, CollectorEfficiency, $\boldsymbol{\eta} = \frac{\text{a.C.poweroutput}}{\text{d.C.powerinput}} = \frac{PO}{P_{dc}}$
- 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: $P_o = [(0.5\times0.707)\, v_{ce(p-p)}][(0.5\times0.707)\, i_{c(p-p)}] = \frac{V_{ce(p-p)}\times i_{c(p-p)}}{8}$

$$\therefore \quad \textbf{Collector}\,\boldsymbol{\eta} = \frac{V_{ce(p-p)}\times i_{c(p-p)}8}{V_{cc}I_c}$$

IMPORTANT POINTS ABOUT CLASS-A POWER AMPLIFIER : -

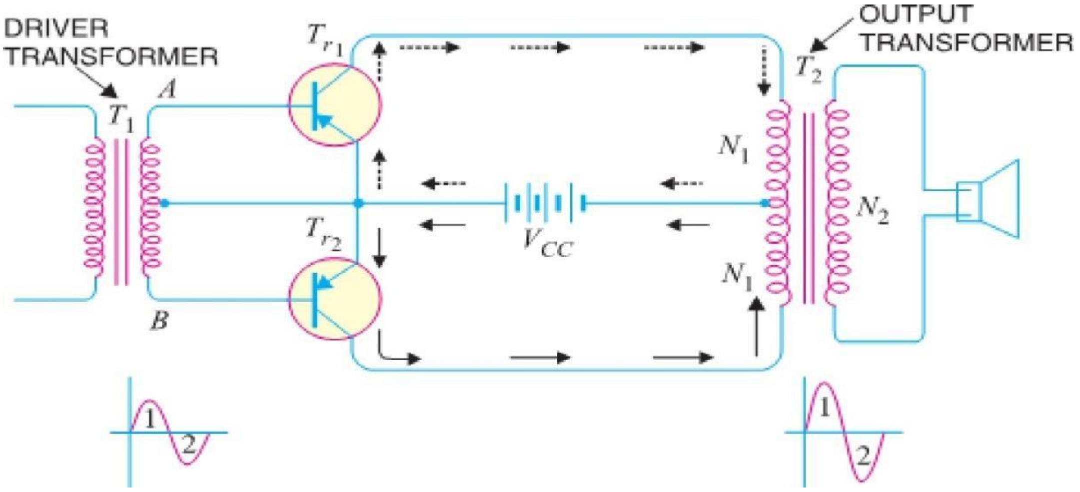
- **(i)**ATransformercoupledclassApoweramplifierhasamaximumcollectorefficiencyof50%i.e., maximum of 50% d.c. supply power is converted into a.c. power output.
- In practice, the efficiency of such an amplifier is less than 50% (about 35%) dueto power losses in the output transformer, power dissipation in the transistor etc.
- **(ii)**The powerdissipatedbyatransistorisgivenby:

$$P_{dis} = P_{dc} - P_{ac}$$

Where P_{dc}=availabled.c.power
& P_{ac}= available a.c. power

- So,InclassAoperation,Transistormustdissipatelessheatwhensignalisappliedthereforerunscooler.
- **(iii)**Whennosignalisappliedto a classApoweramplifier,$P_{ac}=0. \therefore P_{dis}=P_{dc}$
- ThusinclassAoperation,maximumpowerdissipationinthetransistoroccursunderzerosignal conditions.
- Therefore, the power dissipation capabilityofa power transistor (for class Aoperation) must be at least equal to the zero signal rating.
- **(iv)**WhenaclassApoweramplifierusedinfinalstage,itiscalledsingleendedclassApower amplifier.

PUSH-PULL AMPLIFIER: -



- The push-pull amplifier is a power amplifier and is frequently employed in the output stages of electronic circuits. It is used whenever high output power at high efficiency is required. Fig. shows the circuit of a push-pull amplifier.
- Two transistors $T_{r1}$and T_{r2}placed back to back are employed. Both transistors are operated in class B operation i.e. collector current is nearly zero in the absence of the signal.
- The centre tapped secondary of driver transformer T_1supplies equal and opposite voltages to the base circuitsoftwotransistors.The outputtransformer T_2hasthe centre-tapped primarywinding. The supply voltage V_{CC} is connected between the bases and this centre tap.
- The loudspeakerisconnected acrossthesecondaryofthis transformer.

CIRCUIT OPERATION.

- The input signal appears across the secondary AB of driver transformer. Suppose during the first half-cycle (marked 1) of the signal, end A becomes positive and end B negative.
- Thiswill make the base-emitterjunctionofT_{r1}reverse biased and that ofT_{r2}forward biased. The circuit will conduct current due to T_{r2} onlyand is shown by solid arrows.
- Therefore,this half-cycleofthesignalisamplified byT_{r2}andappears inthe lower halfoftheprimaryof output transformer. In the next half cycle of the signal, $T_{r1}$is forward biased whereas $T_{r2}$is reverse biased. Therefore, T_{r1} conducts and is shown by dotted arrows.
- Consequently, this half-cycle ofthe signal isamplified by$T_{r1}$and appears in theupper halfoftheoutput transformer primary. The centre-tapped primary of the output transformer combines two collector currents to form a sine wave output in the secondary.
- It may be noted here that push-pullarrangement also permits a maximumtransfer ofpower to the Load through impedance matching. If $R_L$is the resistance appearing across secondary of output transformer, then resistance R'_L of primary shall become:

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

Where N_1 =Numberofturnsbetweeneitherend ofprimarywindingandcentre-tap N_2 = Number of secondary turns

ADVANTAGES

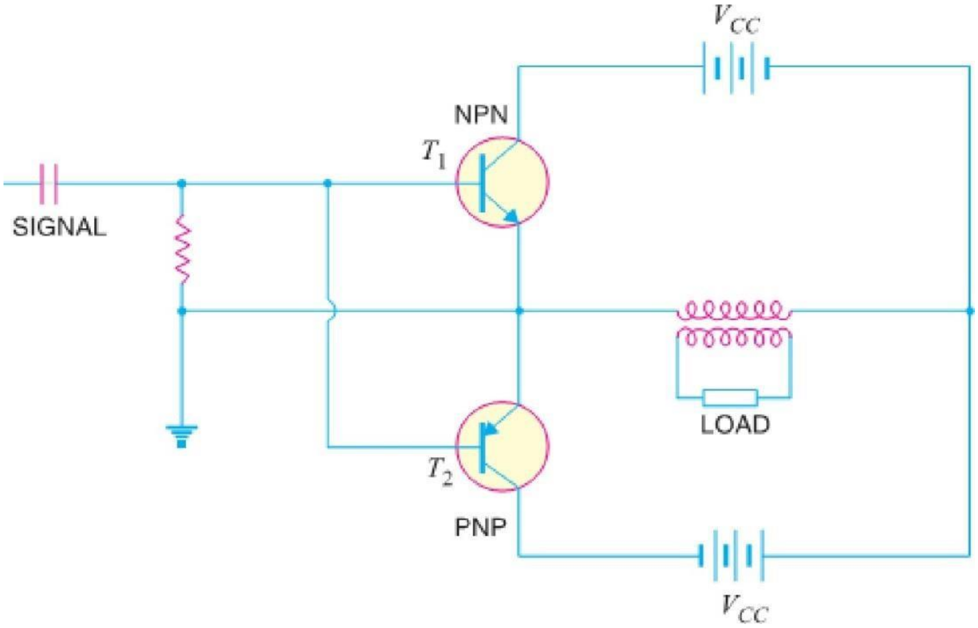
1) Theefficiencyofthecircuitis quitehigh(≈75%)duetoclassBoperation.
2) Ahigha.c.output power is obtained.

DISADVANTAGES

1) Twotransistorshavetobeused.
2) Itrequirestwoequalandoppositevoltagesatthe input.Therefore, push-pullcircuit requirestheuse of driver stage to furnish these signals.
3) Iftheparametersofthetwotransistorsarenotthesame, therewillbeunequalamplificationofthe two halves of the signal.
4) Thecircuitgivesmoredistortion.
5) Transformersusedarebulkyandexpensive.

COMPLEMENTARY-SYMMETRY AMPLIFIER

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



- Fig. shows the transistor push-pull amplifier using complementary symmetry. It employs one npn and one pnp transistor and requires no centre-tapped transformers.
- The circuit action is as follows. During the positive-half of the input signal, transistor T_1(the npn transistor) conducts current while T_2(the pnp transistor) is cutoff.
- During the negative half-cycle of the signal, T_2conducts while $T_1$is cut off. In this way, npn transistor amplifies the positive half-cycles of the signal while the pnp transistor amplifies the negative half-cycles of the signal.
- Notethatwegenerallyuseanoutputtransformer(not centre-tapped)forimpedancematching.

Advantages: - (1) This circuitdoesnot require transformer. This savesonweight and cost.
(2) Equaland oppositeinputsignalvoltagesarenotrequired.

Disadvantages: -(1) Itis difficulttogeta pairof transistors (npn & pnp)havingsimilar characteristics.
(2) Werequirebothpositiveandnegativesupplyvoltages.

HEAT SINK: -

- As power transistors handle large currents, they always heat up during operation. Since transistor is a temperature dependent device, the heat must be dissipated to the surroundings to keep the temperature within allowed limits.
- UsuallytransistorisfixedonAluminummetalsheet sothat additionalheatistransferredtotheAl sheet.
- The metal sheet that serves to dissipate the additional heat from power transistor isknown as **HeatSink.**

[SINUSOIDAL OSCILLATOR]

❖ INTRODUCTION TO OSCILLATOR: -

- ➢ Manyelectronicdevicesrequireasourceofenergyat aspecific frequency which mayrange froma few Hz to several MHz. This is achieved byan electronic device called an oscillator.
- ➢ Oscillators are extensivelyused in electronic equipment. For example, in radio and television receivers, oscillators are used to generate high frequencywave (called carrier wave) in the tuning stages.
- ➢ Audio frequency and radiofrequency signals are required for the repair of radio, television and other electronic equipment. Oscillators are also widely used in radar, electronic computers andother electronic devices. Oscillators can produce sinusoidal or non-sinusoidal (e.g. square wave) waves.

❖ SINUSOIDAL OSCILLATORS:-

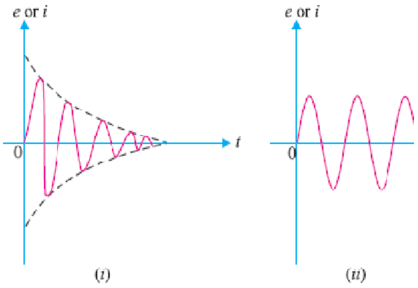
- ➢ An electronic device that generates sinusoidal oscillations of desired frequency is knownasa **sinusoidaloscillator**. Although we speak of an oscillator as “generating” a frequency, it should be noted that it does not create energy, but merely acts as an energy converter.
- ➢ ItreceivesD.C.energyandchangesitintoA.C.energyofourdesiredfrequency.
- ➢ The frequency of oscillations depends upon the constants of the device. It may be mentioned here that although an alternator produces sinusoidal oscillations of 50Hz, it cannot be called an oscillator.
- ➢ **Firstly**,Analternatorisamechanicaldevicehavingrotatingpartswhereasanoscillatorisanon- rotating electronic device.
- ➢ **Secondly**,AnalternatorconvertsMechanicalEnergyintoA.C.Energywhileanoscillatorconverts D.C.EnergyintoA.C.energy.
- ➢ **Thirdly**,An alternatorcannotproduce high frequency oscillations whereas an oscillatorcan produce oscillations ranging from a few Hz to several MHz.

❖ ADVANTAGES

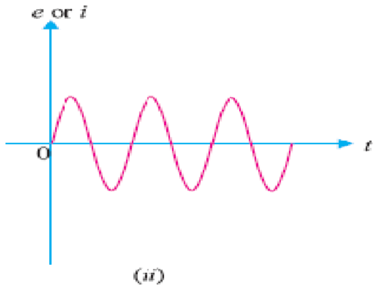
- ➢ Although oscillationscan beproducedby mechanicaldevices(e.g.alternators),butelectronic oscillators have the following advantages:
- ♣ Anoscillatorisanon-rotatingdevice.Consequently,there islittlewear andtearandhence longerlife.
- ♣ Dueto the absenceofmoving parts,theoperationofanoscillatoris quite silent.
- ♣ Anoscillatorcanproducewavesfromsmall(20Hz)to extremelyhigh frequencies(>100 MHz).
- ♣ Thefrequencyofoscillationscanbeeasilychanged whendesired.
- ♣ Ithasgoodfrequencystabilityi.e.frequencyoncesetremainsconstantfor considerableperiodoftime.
- ♣ Ithasveryhighefficiency.

❖ TYPES OF SINUSOIDAL OSCILLATIONS:-

- ➢ Sinusoidaloscillationscanbeoftwotypesviz**DampedOscillations**and**UndampedOscillations**.
- ♣ **(i)Damped Oscillations**: - The electrical oscillations whose amplitude goes on decreasing with time arecalleddampedoscillations.Fig(i)Showswaveformofdamped electricaloscillations.
- ➢ Obviously, the electrical system in which these oscillations are generated has losses and some energy is lost during each oscillation.
- ➢ Further, no means are provided to compensate for the losses and consequentlytheamplitudeofthegeneratedwave decreasesgradually. It may be noted that frequency of oscillationsremainsunchanged since it depends upon the constants of the electrical system.

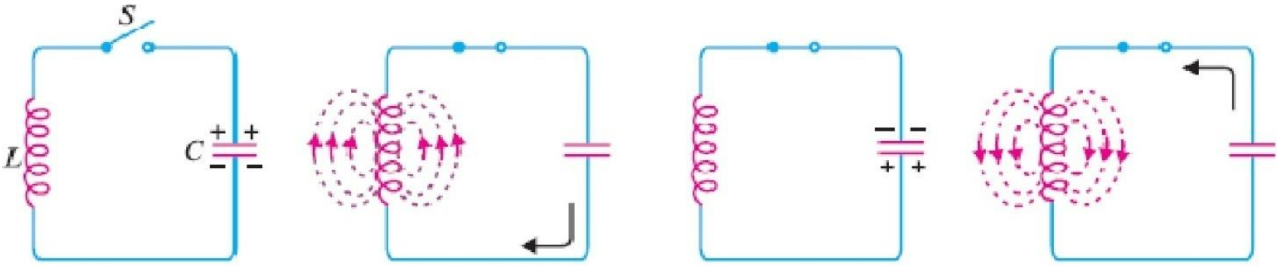


- ♣ **(ii) Undamped Oscillations**. The electrical oscillations whose amplitude remains constant with time are called undamped oscillations. Fig. (ii) Shows waveform of undamped electricaloscillations.
- ➢ Although the electrical system in which these oscillations are being generated has also losses, but now right amount of energy is being supplied to overcome the losses.
- ➢ Consequently, amplitude of generated wave remains constant. It should be emphasized that an oscillator is required to produce undamped electrical oscillations for utilizing in various electronics equipment.



OSCILLATORY CIRCUIT:-

- Acircuitwhichproduceselectricaloscillationsof any desiredfrequencyisknownasan **Oscillatory Circuit** or **Tank Circuit**.
- A simple oscillatory circuitconsists of a capacitor(C) andinductance coil (L)in parallel as shown in Fig. This system can produce electrical oscillations of frequency determined bythe values of L and C.
- Tounderstand howthiscomesabout,supposethecapacitor ischarged fromad.c. sourcewithapolarity as shown in Fig. (i).

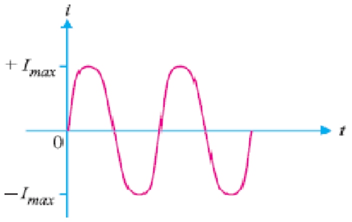


(*i*) (*ii*) (*iii*) (*iv*)

- **(i)** In the position shown in Fig (i), the upper plate of capacitor has deficit of electrons and the lower plate has excess of electrons. Therefore, there is a voltage across the capacitor and the capacitor has electrostatic energy.
- **(ii)**WhenswitchSisclosed asshown inFig (ii), the capacitorwilldischarge throughinductance 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 willbe maximumwhenthe capacitoris fullydischarged. At this instant, electrostatic energyiszero but because electron motion isgreatest (i.e. maximum current),the magnetic field energy around the coil is maximum. This is shown in Fig (ii).
- Obviously, the electrostatic energy across the capacitor is completely converted into magnetic field energy around the coil.
- **(iii)**Oncethecapacitorisdischarged,themagneticfieldwillbegintocollapseandproduceacounter e.m.f.AccordingtoLenz's law,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 beginstodischarge; current now flowing in the opposite direction.
- Fig (iv) shows capacitor fully discharged and maximum current flowing. The sequence of charge and discharge results in alternating motion of electrons or an oscillating current.
- The energy is alternately stored in the electric field of the capacitor (C) and the magnetic field of the inductance coil (L). This interchange ofenergy between L and C is repeated over and again resulting in the production of oscillations.

UNDAMPED OSCILLATIONS FROM TANK CIRCUIT:-

- Asdiscussedbefore, atankcircuit producesdampedoscillations. However, inpractice, weneed continuous undamped oscillations for the successful operation of electronics equipment.
- In order to make the oscillations in the tank circuitundamped, itis necessaryto supplycorrect amount of energyto tank circuit at proper time intervals to meet the losses.
- Therefore, in order to make the oscillations in the tank circuit undamped, the following conditions must be fulfilled :



- **(i)** The amount ofenergysupplied should be suchso as to meet the losses inthe tank circuit & the a.c. energyremoved fromthe circuit bythe load.
- **(ii)**Theappliedenergyshouldhave thesamefrequencyastank circuit.
- **(iii)**Theappliedenergyshouldbeinphasewiththeoscillationssetupinthetankcircuit.
- Iftheseconditionsarefulfilled, thecircuitwillproducecontinuousundamped outputasshownin Fig.

✍Therefore, the amplifier will produce sinusoidal output with no external signal source. The following points may be noted carefully :

- A transistor amplifier with proper positive feedback will work as an oscillator.
- The circuit needs only a quick trigger signal to start the oscillations.
- Once the oscillations have started, no external signal source is needed.
- In order to get continuous undamped output from the circuit, the following condition must be met:

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

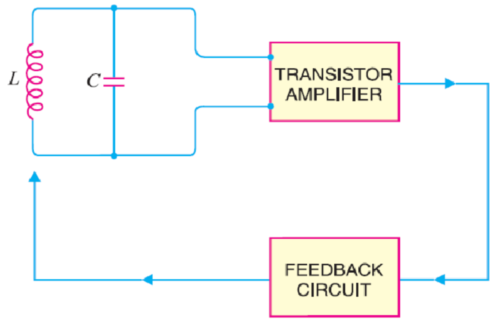
Where **A_v**=Voltage Gain of Amplifier without Feedback and **m_v** =Feedback Fraction

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

❖ ESSENTIAL SOFT TRANSISTOR OSCILLATOR:-

✍Fig shows the block diagram of an oscillator. Its essential components are:-

- **Tank circuit**. It consists of inductance coil (L) connected in parallel with capacitor (C).



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

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

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

✍This amplified output of oscillations is due to the D.C. power supplied by the battery.

✍The output of the transistor can be supplied to the tank circuit to meet the losses.

- **(iii) Feedback Circuit**. The feedback circuit supplies a part of collector energy to the tank circuit in correct phase to aid the oscillations i.e. it provides positive feedback.

❖ DIFFERENT TYPES OF TRANSISTOR OSCILLATORS:-

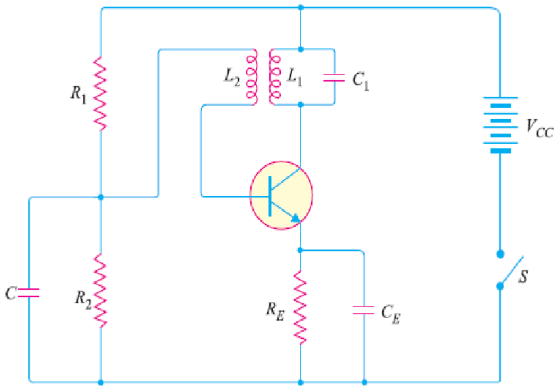
✍A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it.

✍All oscillators under different names have similar function i.e., they produce continuous undamped output. However, the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses.

✍The following are the transistor oscillators commonly used at various places in electronic circuits:

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

❖ TUNED COLLECTOR OSCILLATOR:-



✍Fig shows circuit of tuned collector oscillator. It contains tuned circuit L_1- C_1 in the collector and hence the name.

✍The frequency of oscillations depends upon the values of L_1 and C_1 and is given by :

$$\boxed{f = \frac{\quad}{\quad}}$$

✍The feedback coil L_2 in the base circuit is magnetically coupled to the tank circuit coil L_1. In practice, L_1 and L_2 form the primary and secondary of the transformer respectively.

✍The biasing is provided by potential divider arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations.

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

✍These oscillations induce some voltage in coil L_2 by mutual induction. The frequency of voltage in coil L_2 is the same as that of tank circuit but its magnitude depends upon the number of turns of L_2 and coupling between L_1 and L_2.

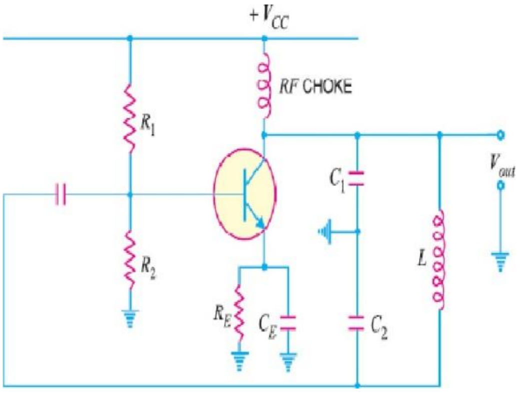
✍The voltage across L_2 is applied between base and emitter and appears in the amplified form in the collector circuit, thus overcoming the losses occurring in the tank circuit.

✍The number of turns of L_2 and coupling between L_1 and L_2 are so adjusted that oscillations across L_2 are amplified to a level just sufficient to supply losses to the tank circuit.

✍It may be noted that the phase of feedback is correct i.e. energy supplied to the tank circuit is in phase with the generated oscillations. A phase shift of 180° is created between the voltages of L_1 and L_2 due to transformer action.

✍A further phase shift of 180° takes place between base-emitter and collector circuit due to transistor properties. As a result, the energy feedback to the tank circuit is in phase with the generated oscillations.

❖ COLPITT'S OSCILLATOR:-



✍Fig shows a Colpitt's oscillator. It uses two capacitors and placed across a common inductor L and the centre of the two capacitors is tapped.

✍The tank circuit is made up of C_1, C_2 and L. The frequency of oscillations is determined by the values of C_1, C_2 and L and is given by ;

f= —— Where **C_T=** ——

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

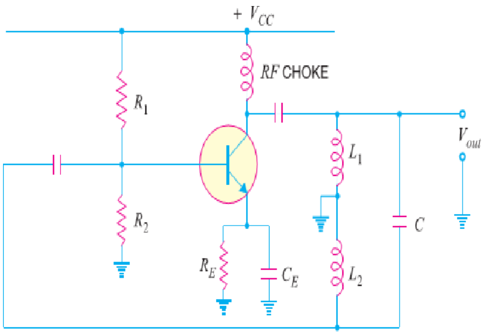
♣ **<u>Circuit Operation.</u>** When the circuit is turned on, the capacitors C_1 and C_2 are charged. The capacitors discharge through L, setting up oscillations of frequency determined by exp.(i).

✍Output voltage of the amplifier appears across C_1 and feedback voltage is developed across C_2. The voltage across it is 180° out of phase with the voltage developed across C_1 (V_{out}) as shown in Fig.

✍It is easy to see that voltage feedback (voltage across C_2) to the transistor provides positive feedback.

✍A phase shift of 180° is produced by transistor and a further phase shift of 180° is produced by C_1– C_2 voltage divider. In this way, feedback is properly phased to produce continuous undamped oscillation.

❖ HARTLEY OSCILLATOR:-

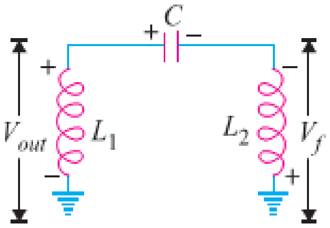


✍The Hartley oscillator is similar to Colpitt's oscillator with minor modifications. Instead of using tapped capacitors, two inductors L_1 and L_2 are placed across a common capacitor C and the centre of the inductors is tapped as shown in Fig.

✍The tank circuit is made up of L_1, L_2 and C. The frequency of oscillations is determined by the values of L_1, L_2 and C and is given by :

f= —— ………… (i)

Where **L_T=L_1+L_2+2M** & M=Mutual inductance between L_1 & L_2



FEEDBACK CIRCUIT

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

✍The output voltage of the amplifier appears across L_1 and feedback voltage across L_2. The voltage across L_2 is 180° out of phase with the voltage developed across L_1 (V_{out}) as shown in Fig.

✍It is easy to see that voltage feedback (i.e., voltage across L_2) to transistor provides positive feedback.

✍A phase shift of 180° is produced by the transistor & further phase shift of 180° is produced by L_1–L_2 voltage divider. In this way, feedback is properly phased to produce continuous undamped oscillations.

❖ PRINCIPLE OF PHASE SHIFT OSCILLATORS:-

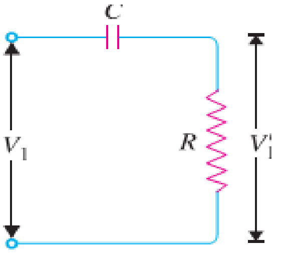
✍One desirablefeature ofan oscillator is that it should feedback energy of correct phase to the tank circuit to overcome the losses occurring in it.

✍In the oscillator circuits discussed so far, the tank circuit employed inductive (L) and capacitive (C) elements.In such circuits, a phase shiftof 180° was obtained due toinductive or capacitive coupling and a further phase shift of 180° was obtained due to transistor properties.

✍In this way, energy supplied to the tank circuit was in phase with the generated oscillations. The oscillator circuits employing L-C elements have two general drawbacks.

✍**Firstly**, they suffer from frequency instability and poor waveform. **Secondly**, they cannot be used for very low frequencies because theybecome too much bulky and expensive.

✍Good frequency stability and waveform can be obtained from oscillators employing resistive and capacitive elements. Such amplifiers are called R-C or phase shift oscillators and have the additional advantage that they can be used for very low frequencies.



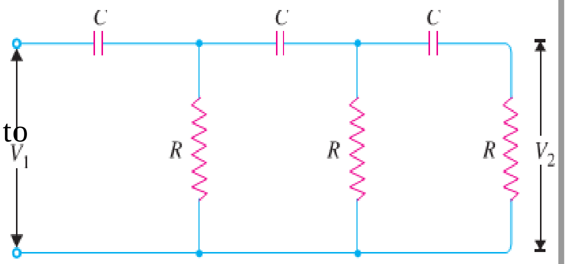
✍In a phase shift oscillator, a phase shift of 180° is obtained with a phase shift circuit instead of inductive or capacitive coupling.

✍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.

✍**Phase shift Circuit.**A phase-shift circuit essentially consists of an R-C network. Fig (i) shows a single section of RC network. From the elementary theory of 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 by90° i.e. φ= 90°.

✍However,adjustingRto zerowouldbeimpracticable because it would lead to no voltage across R.



✍Therefore,inpractice,Risvariedto suchavaluethatmakesV'_1toleadV_1by60°.

✍Fig(ii)showsthethreesectionsofRCnetwork.Eachsectionproducesaphaseshiftof60°. Consequently, atotalphaseshiftof180° isproducedi.e. voltage V_2leadsthevoltage V_1by180°.

❖ PHASE SHIFT OSCILLATOR:-

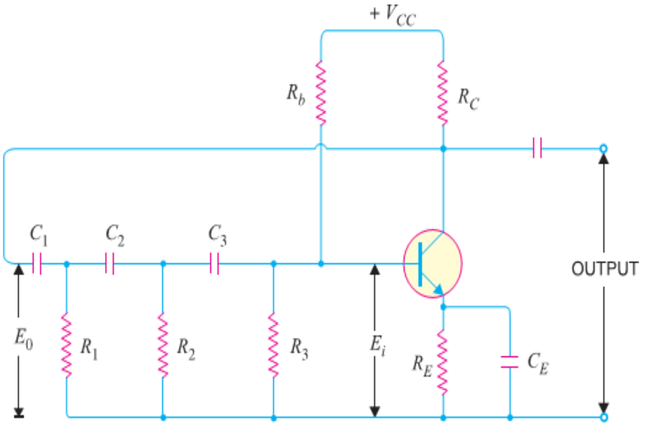
✍Fig. shows the circuit of a phase shift oscillator. It consists of a conventional single transistor amplifier and a RC phase shift network.

✍The phase shiftnetwork consists of three sections R_1C_1, R_2C_2 and R_3C_3. At some particular frequencyf_0, the phaseshiftineachRCsection is60°sothattotalphase-shiftproduced bytheRCnetworkis180°.

✍Thefrequencyofoscillationsis givenby: $\boxed{f_0 = \frac{}{}}$ Where$R_1=R_2=R_3=$**R**&$C_1=C_2=C_3=$**C**

♣ **Circuit Operation.**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 networkproduces aphase shift of180° and avoltage $E_i$appears at itsoutput which is appliedtothe transistor amplifier.



✍Obviously, the feedback fraction m= E_i/E_0. The feedback phase is correct. A phase shift of 180° is produced by the transistor amplifier.

✍A further phase shift of180° isproduced bythe RC network. As a result, the phase shift around the entire loop is 360°.

♣ **Advantages**

- ✘It doesnot requiretransformers orinductors.
- ✘Itcanbe usedto produceverylow frequencies.
- ✘Thecircuitprovidesgoodfrequencystability.

♣ Disadvantages

✗Itisdifficultforthecircuittostartoscillationsasthefeedbackisgenerallysmall.

✗Thecircuitgivessmalloutput.

❖ WIEN BRIDGE OSCILLATOR:-

✍The Wien-bridge oscillator is the standard oscillator circuit for all frequencies in the range of 10 Hz to about 1 MHz. It is the most frequently used type of audio oscillator as the output is free from circuit fluctuations and ambient temperature.

✍Fig. shows the circuit of Wien bridge oscillator. It is essentially a two-stage amplifier with R-C bridge circuit. The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and tungsten lamp L_p.

✍Resistances $R_3$and $L_p$are used to stabilize the amplitude of the output. The transistor T_1serves as an oscillator and amplifier while the other transistor T_2 serves as an inverter (to produce 180° phase shift).

✍The circuit uses positive and negative feedbacks. The positive feedback is through R_1C_1, $C_2R_2$to the transistor T_1. The negative feedback is through the voltage divider to the input of transistor T_2.

✍The frequencyof oscillations is determined by the series element $R_1C_1$and parallel element $R_2C_2$of the bridge.

f= ——————

IfR$_1$=R$_2$=RandC$_1$=C$_2$=C, then, **f=** ———

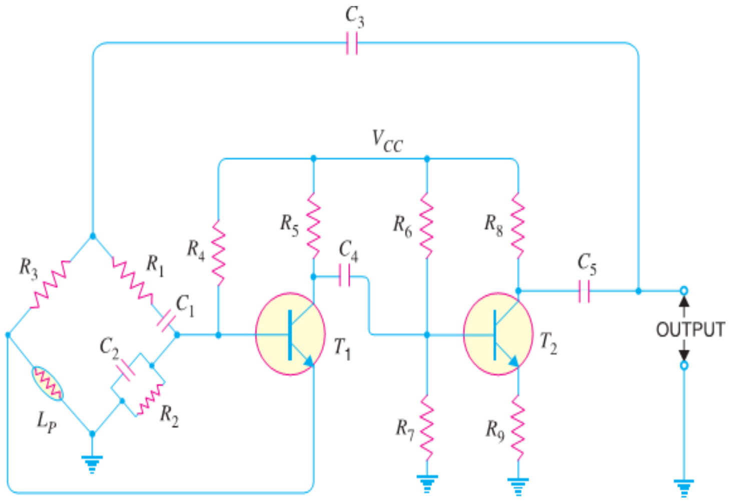
✍When the circuit is started, bridge circuit produces oscillations of frequencydetermined.

✍The two transistors produce a total phase shift of 360° 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 tendto increase, more current would provide more negative feedback.

✍The result is that the output would return to original value.



✍Areverseactionwouldtakeplaceiftheoutputtends to decrease.

♣ Advantages

(i) Itgivesconstant output.
(ii) Itworksquite easily.
(iii) Overallgain ishighdueto twotransistors.
(iv) Thefrequencyofoscillationscanbe easilychanged byusinga potentiometer.

♣ Disadvantages

(v) Itrequirestwotransistors&largenumberofcomponents.
(vi) Itcannotgenerateveryhigh frequencies.

❖ LIMITATIONS OF LC AND RC OSCILLATORS:-

✍The LC and RC oscillators discussed so far have their own limitations. The major problem in such circuits is that their operating frequency does not remain strictly constant. There are two principal reasons for it viz.,

♣ (i) As the circuitoperates, itwillwarm up. Consequently, the values of resistors and inductors, which are the frequencydetermining factors in these circuits, will change with temperature.

♣ Thiscausesthechangein frequencyoftheoscillator.

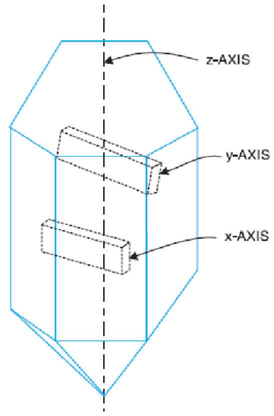
✍(ii) If any component in the feedback network is changed, it will shift the operating frequency of the oscillator. However, in many applications, it is desirable and necessary to maintain the frequency constant with extreme low tolerances.

- It is apparent thatif we employ LC or RC circuits,a change of temperature maycause the frequencies of adjacent broadcasting stations to overlap.
- Inordertomaintainconstantfrequency,piezoelectriccrystalsareusedinplaceofLCorRCcircuits. Oscillatorsofthistypearecalledcrystaloscillators.
- The frequencyofacrystaloscillatorchangesbylessthan0.1%duetotemperatureandotherchanges.
- Therefore, such oscillators offer the most satisfactory method of stabilizing the frequencyand are used in great majority of electronic applications.

❖ PIEZOELECTRIC CRYSTALS:-

- Certain crystalline materials, namely, *Rochelle salt, quartz and tourmaline* exhibit the **piezoelectric effect** i.e., when we apply an a.c. voltage across them, they vibrate at the frequency of the applied voltage. Conversely, when they are compressed or placed under mechanical strain to vibrate, they produce an a.c. voltage.
- Such crystals which exhibit piezoelectric effect are called **piezoelectric crystals**. Of the various piezoelectric crystals, **quartz** is most commonlyused as it is inexpensive & readilyavailable in nature.
- **Quartz Crystal**. Quartz crystals are generally used in crystal oscillators because of their great mechanical strength and simplicity of manufacture.
- The natural shape of quartz crystal is hexagonal as shown in Fig. The three axes are shown: the z-axis is called the optical axis, the x-axis is called the electrical axis and y-axis is called the mechanical axis.
- Quartz crystal can be cutin different ways. Crystal cut perpendicular to the x- axis is called **x-cut crystal** whereas that cut perpendicular to y-axis is called **y- cut crystal**. The piezoelectric properties of a crystal depend upon its cut.
- **Frequency ofCrystal.** Eachcrystalhasanaturalfrequencylikea pendulum. The natural frequencyfofacrystalisgivenby:$f=\frac{K}{t}$ Where,

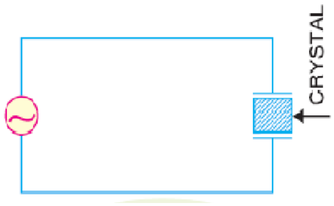
  K=Constantthatdepends uponthe cut**&t**=Thicknessofthecrystal.



- Itisclearthat frequencyis inverselyproportionaltocrystalthickness. Thethinner thecrystal, the greater is its natural frequency and vice-versa.
- However, extremelythincrystalmaybreakbecauseofvibrations. Thisputsalimit tothefrequency obtainable. In practice, frequencies between 25 kHz to 5 MHz have been obtainedwithcrystals.

❖ WORKING OF QUARTZ CRYSTAL:-

- In order to use crystal in an electronic circuit, it is placedbetweentwo metal plates. The arrangement then forms a capacitor with crystal as the dielectric as shown in Fig.



- If an a.c. voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage. However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value.
- This naturalfrequency is almost constant. Effectsoftemperature change can be eliminated bymounting the crystal in a temperature-controlled oven as in radio and television transmitters.

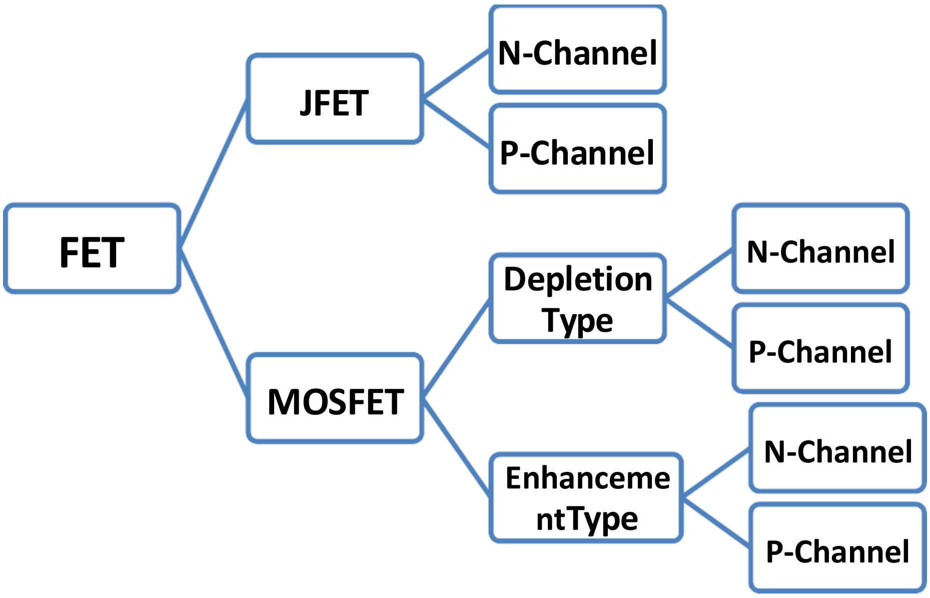
CHAPTER-7

[FIELD EFFEC TTRANSISTOR(FET)]

❖ INTRODUCTION:-

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

❖ CLASSIFICATION OF FIELD EFFECT TRANSISTORS:-



- ❖ OthertypesofC-MOSalso There Suchas: -**CMOS,VMOS,LDMOS**etc.

❖ DIFFERENTIATION BETWEEN BJT & FET:-

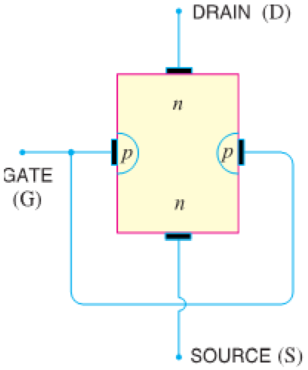
FET	BJT
✖ Itmeans**FieldEffectTransistor**	✖ Means**BipolarJunction Transistor**
✖ Itsthreeterminals are**Source,Gate & Drain**	✖ Itsterminals are**Emitter,Base& Collector.**
✖ It is **Unipolar** devices i.e. Current in the deviceiscarriedeitherbyelectronsorholes.	✖ Itis**Bipolar**devicesi.e.Current inthedevice is carried by both electrons and holes.
✖ Itis**Voltagecontrolleddevice.**i.e.Voltageat the gate or drain terminal controls the amount of current flowing through the devices.	✖ Itis**Currentcontrolleddevice.** i.e.Base Current controls the amount of collector current flowing through the devices.
✖ IthasveryHighInput ResistanceandLow Output Resistance.	✖ IthasveryLowInputResistanceandHigh Output Resistance.
✖ Lownoisyoperation	✖ Highnoisyoperation
✖ ItisLongerLife &HighEfficiency.	✖ ItisShorterLife&LowEfficiency.
✖ ItismuchsimplertofabricateasICand occupies less space on IC.	✖ ItiscomparativelydifficulttofabricateasIC and occupies more space on IC then FET.
✖ IthasSmallgainbandwidthproduct.	✖ IthasLargegainbandwidthproduct.
✖ Ithashigherswitchingspeed.	✖ Ithashigherswitchingspeed.

❖ JUNCTION FIELD EFFECT TRANSISTOR(JFET):-

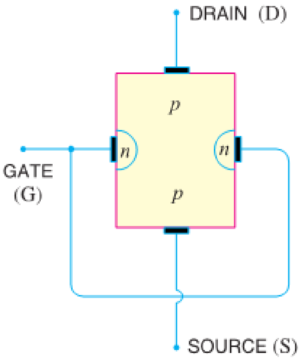
- Ajunctionfieldeffecttransistorisathreeterminalsemiconductordevice in whichcurrent conductionis by one type of carrier i.e., electrons or holes.
- InaJFET,thecurrentconductioniseitherbyelectronsorholesandiscontrolledbymeansofan electric field between the gate electrode and the conducting channel of the device.
- TheJFEThashighinputimpedanceandlownoise level.

❖ CONSTRUCTIONAL DETAILS.

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



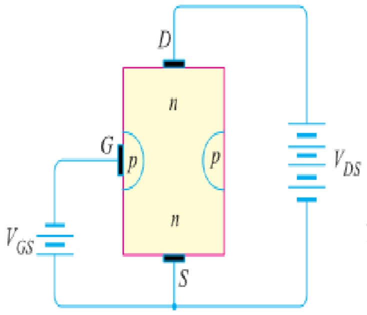
n-Channel JFET

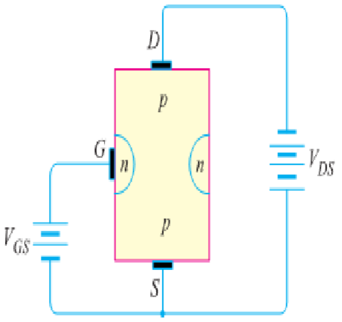


p-Channel JFET

❖ JFET POLARITIES:-

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



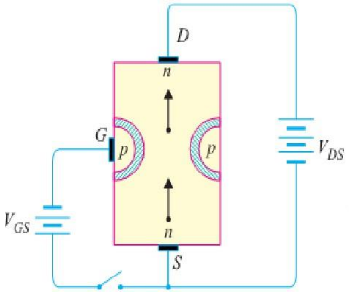


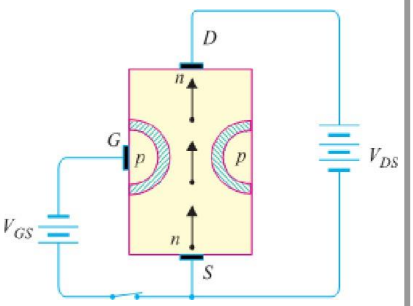
- Thefollowingpointsmaybenoted:
  - ♣ Theinput circuit (i.e.gatetosource)ofaJFET is reverse biased.Thismeansthatthedevicehas high input impedance.
  - ♣ Thedrainissobiasedw.r.t. sourcethatdraincurrent$I_D$flows fromthesourcetodrain.
  - ♣ InallJFETs,sourcecurrent$I_S$isequaltothedraincurrenti.e.I_S=I_D.

❖ WORKING PRINCIPLE OF JFET:-

Principle: - Fig. shows the circuit of n-channelJFETwithnormalpolarities.Note that the gate is reverse biased.

- The two pn junctions at the sides form two depletion layers. The current conduction by charge carriers (i.e. free electrons inthiscase) is through the channel between the two depletion layers and out of the drain.



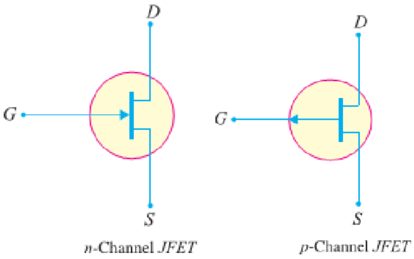


- Thewidthandhence resistanceofthischannelcanbecontrolled bychangingtheinputvoltageV_{GS}.
- The greater the reverse voltage V_{GS}, the wider will be the depletion layers and narrower will be the conducting channel. The narrower channel means greater resistance and hence source to drain current decreases. Reverse will happen should V_{GS} decrease.
- Thus JFET operates on the principle that width and hence resistance of the conducting channel can be varied by changing the reverse voltage V_{GS}.
- Inotherwords,themagnitudeofdraincurrent(I_D)can bechangedbyaltering V_{GS}.

Working:-The working of JFET is as under :

- **(i)** When voltage $V_{DS}$is applied between drain & source terminals and voltage on the gate is zero [See the above Fig (i)], the two pn junctions at the sides ofthe bar establish depletion layers.
- Theelectronswillflowfromsourcetodrainthroughachannelbetweenthedepletionlayers.

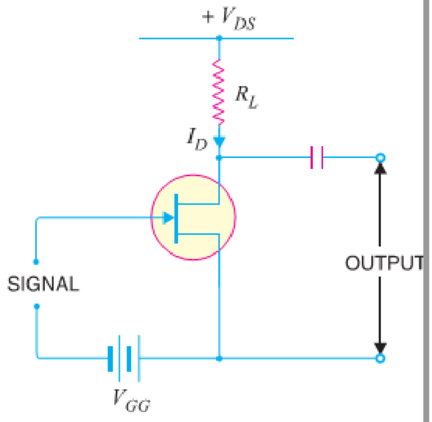
- Thesizeoftheselayersdetermineswidthofthechannel &hencecurrentconductionthroughthebar.
- **(ii)** When a reverse voltage $V_{GS}$is applied between the gate and source [See Fig (ii)], the width of the depletion layers is increased.
- This reduces the width of conducting channel, thereby increasing the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



[SchematicSymbolofJFET]

❖ JFET AS AN AMPLIFIER:-

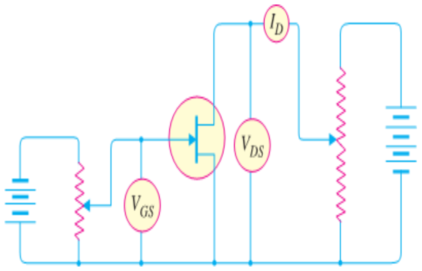
- Fig shows JFET amplifier circuit. The weak signal is applied between gate and source and amplified output is obtained in the drain-source circuit.FortheproperoperationofJFET,thegatemustbenegative w.r.t.sourcei.e.,input circuitshouldalwaysbereversebiased.
- ThisisachievedeitherbyinsertingabatteryV_{GG}inthegatecircuitor byacircuitknownasbiasingcircuit.
- In the present case, we are providing biasing by the battery V_{GG}. A small change in the reverse bias on the gate produces a large change in drain current.



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

❖ OUTPUT CHARACTERISTICS OF JFET

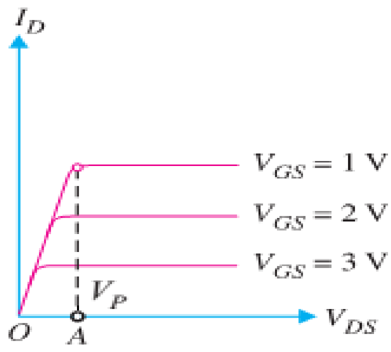
- Thecurve betweendraincurrent (I_D)anddrain-sourcevoltage(V_{DS}) of a JFET at constant gate source voltage (V_{GS}) is known as output characteristics of JFET.
- FigshowscircuitfordeterminingoutputcharacteristicsofJFET.
- Keeping V_{GS}fixed at some value, say 1V, the drain source voltage is changed in steps.
- CorrespondingtoeachvalueofV_{DS},thedraincurrentI_D isnoted.
- AplotofthesevaluesgivesoutputcharacteristicofJFETatV_{GS}=1V.



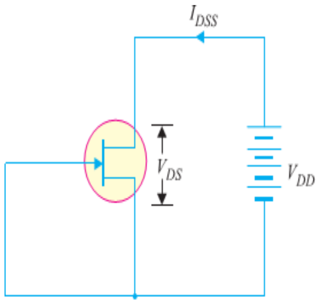
- Repeatingsimilarprocedure,outputcharacteristicsatothergate-sourcevoltagescanbedrawn.Fig. shows a family of output characteristics.

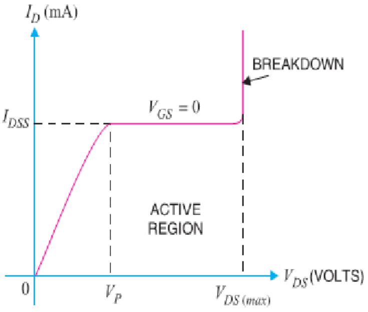
The following points may be noted from the characteristics:

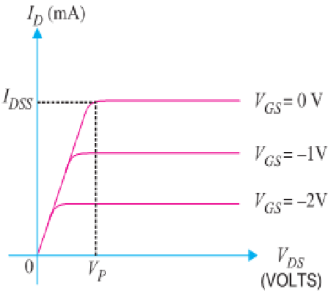
- **(i)**Atfirst,thedraincurrentI_D risesrapidlywithdrain-sourcevoltageV_{DS}butthenbecomesconstant.
- Thedrain-sourcevoltage abovewhichdraincurrent becomesconstant is knownaspinchoffvoltage. Thusin Fig. OAisthe pinchoffvoltageV_P.
- **(ii)** After pinch off voltage, the channel width becomes so narrow thatdepletion layers almost touch each other.
- Thedraincurrentpassesthroughthesmallpassagebetweentheselayers.
- Thusincreasein drain currentisvery small withV_{DS}above pinch off voltage.
- Consequently,draincurrentremainsconstant.Thecharacteristics resemble that of a pentode valve.

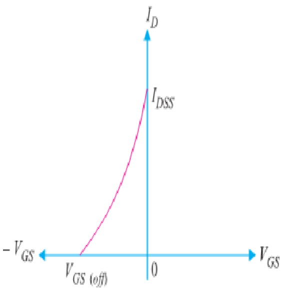


IMPORTANT TERMS : -









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

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

2. Pinch Off Voltage (V_P):-

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

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

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

❖ PARAMETERS OF JFET:-

- Like vacuum tubes, a JFET has certain parameters which determine its performance in a circuit. The main parameters of JFET are: -**(i)** A.C. drain resistance **(ii)** Transconductance **(iii)** Amplification factor.

♣ **(i) <u>A.C. Drain Resistance</u> (r_d).** Corresponding to the a.c. plate resistance, we have a.c. drain resistance in a JFET. It may be defined as follows :

- It is the ratio of change in drain-source voltage (ΔV_{DS}) to the change in drain current (ΔI_D) at constant gate-source voltage i.e.

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

- For instance, if a change in drain voltage of 2V produces a change in drain current of 0.02mA, then, a.c. drain resistance, $r_d = \frac{2V}{0.02mA} = 100$ kΩ
- Referring to the output characteristics of a JFET in Fig., it is clear that above the pinch off voltage, the change in I_D is small for a change in V_{DS} because the curve is almost flat.
- Therefore, drain resistance of a JFET has a large value, ranging from 10 kΩ to 1 MΩ.

♣ **(ii) <u>Transconductance</u> (g_{fs}) : -**The control that the gate voltage has over the drain current is measured by transconductance g_{fs} & is similar to transconductance g_m of the tube. It may be defined as follows: -

- It is the ratio of change in drain current (ΔI_D) to the change in gate-source voltage (ΔV_{GS}) at constant drain-source voltage i.e.

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

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

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

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

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

❖ RELATION AMONG JFET PARAMETERS:-

- TherelationshipamongJFET parameterscanbeestablishedasunder :

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

- MultiplyingthenumeratoranddenominatoronR.H.S.byΔI_D,weget,

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

➔AmplificationFactor=A.C.Drain Resistance×Transconductance

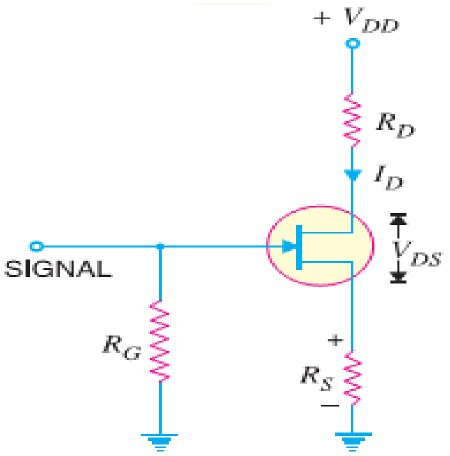
❖ JFET BIASING:-

- For the proper operation of n-channel JFET, gate must be negative w.r.t. source. This can be achieved either byinserting a batteryin the gate circuit or bya circuit known as biasing circuit.
- Thelattermethodispreferredbecausebatteriesarecostlyandrequirefrequentreplacement.

  1. BiasBattery: -Inthis method, JFET is biasedbyabias batteryV_{GG}. This batteryensuresthat gateis always negative w.r.t. source during all parts of the signal.

  2. Biasingcircuit:-Thebiasingcircuit usessupplyvoltage$V_{DD}$to providethe necessarybias.Two most commonlyused methods are **(i) Self-Bias (ii) Potential Divider Method**.

❖ SELF-BIAS FOR JFET:-



- Figshowstheself-biasmethodforn-channelJFET.Theresistor RS is the bias resistor.
- The d.c.component ofdraincurrent flowingthrough$R_S$produces the desired bias voltage.

$$\text{Voltage across } R_S, V_S = I_D R_S$$

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

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

- ThusbiasvoltageV_{GS}keepsgatenegativew.r.t.source.

Operating point: -

- Theoperatingpoint(i.e.,zerosignalI_D&V_{DS})canbeeasily determined. Since the parameters of the JFET are usuallyknown, zero signal I_D can be calculated from the following relation :

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

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

- Thusd.c.conditionsofJFETamplifierare fullyspecified i.e.operatingpoint forthecircuit is(V_{DS}, I_D). Also,

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

- NotethatgateresistorR$_G$doesnotaffectbiasbecausevoltage acrossitis zero.

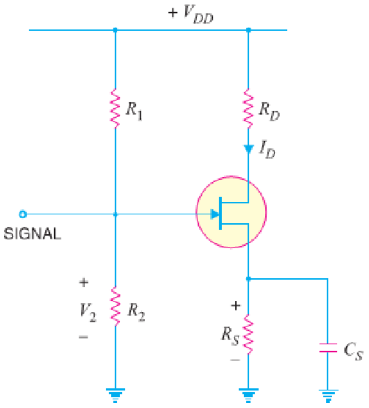
Midpoint Bias: - It is often desirable to bias a JFET near the midpoint of its transfer characteristic curvewhere$I_D = I_{DSS}/2$.Whensignalisapplied,the midpoint biasallowsa maximumamountofdrain current swing between I_{DSS} and 0.

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

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

- Tosetdrainvoltageatmidpoint($V_D = V_{DD}/2$),selectavalueof$R_D$to produce the desired voltage drop.

❖ JFET with Voltage-Divider Bias:-



- FigshowspotentialdividermethodofbiasingaJFET.Thiscircuitis identical to that used for a transistor.
- The resistors $R_1$and R_2 form a voltage divideracross drain supply V_{DD}.The voltage V_2 (= V_G) across R_2 provides the necessary bias.

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

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

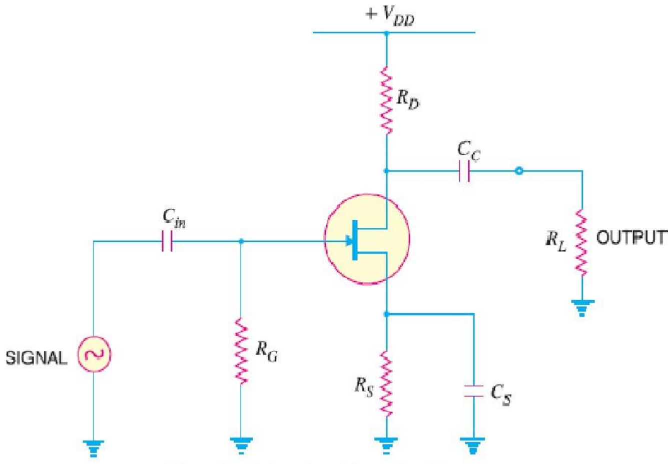
- The circuit is so designed that $I_D R_S$ is larger than V_2 so that V_{GS} is negative. This provides correct bias voltage. We can find the operating point as under:

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

- Althoughthecircuit ofvoltage-dividerbiasisabit complex, yet theadvantageofthis methodofbiasing is that it provides good stability of the operating point.
- The inputimpedance$Z_i$ofthiscircuitisgivenby; $Z_i = R_1 \| R2$

JFET Connections:-

- TherearethreeleadsinaJFETviz.,source,gateanddrainterminals.However,whenJFETistobe connectedinacircuit,werequirefourterminals; twofortheinputandtwoforthe output.
- This difficulty is overcome by makingone 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 commonsource connection is the most widely used arrangement. It is because this connection provides high input impedance, good voltage gain and moderate output impedance.



COMMON SOURCE CONNECTION

- However,thecircuitproducesaphasereversali.e.,outputsignalis180°outofphasewiththeinput signal. Fig. shows a common source n-channel JFET amplifier.
- Notethatsourceterminaliscommonto bothinput and output.

JFET Applications : -

- The high input impedance and low output impedance and low noise level make JFET far superior tothe bipolar transistor. Some of the circuit applications of JFET are :
  - AsaBufferamplifier
  - AsPhase-shiftoscillators
  - AsRFamplifier

CHAPTER-8

OPERATIONAL AMPLIFIERS

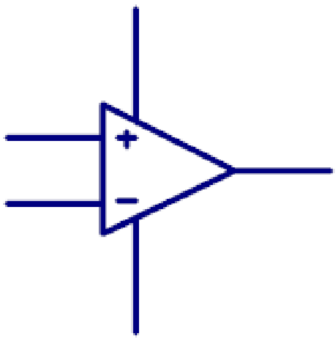
❖ INTRODUCTION

Theoperationalamplifier isanextremelyefficientand versatiledevice.Its applicationsspanthebroad electronic industry filling requirements for signal conditioning, special transfer functions, analog instrumentation, analog computation, and special systems design. The analog assets ofsimplicity and precision characterize circuits utilizing operational amplifiers.

❖ OP-AMP BASICS

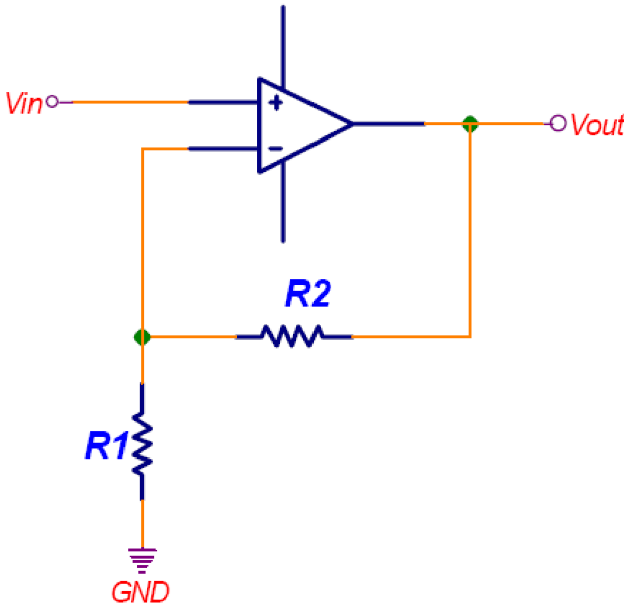
Operationalamplifiersare convenient building blocksthat canbe used to build amplifiers, filters, and even ananalogcomputer.Op-ampsare integratedcircuitscomposedofmanytransistors&resistors suchthatthe resulting circuit follows a certain set ofrules. The most common type ofop-amp is the voltage feedback type and that's what we'll use.

The schematic representation ofan op-amp is shown to the left. There are twoinput pins(non-invertingand inverting),anoutputpin,andtwopower pins.Theidealop-amphasinfinitegain.It amplifiesthevoltagedifference between the two inputs and that voltage appears at the output. Without feedback this op-amp would act like a comparator (i.e. when the non-inverting input is at a higher voltage than the inverting input the output will be high, when the inputs are reversed the output will be low).



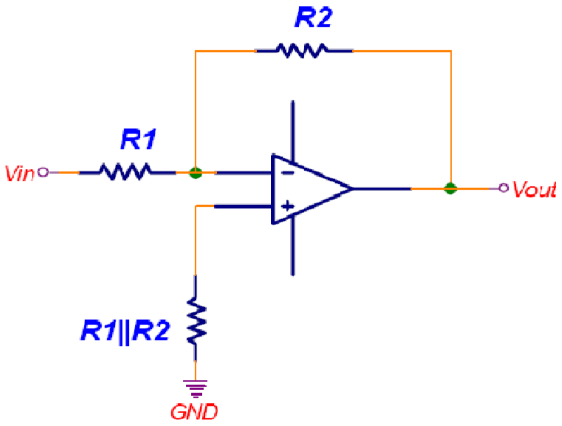
❖ NON-INVERTING AMPLIFIER:

No current flows into the input, **Rin** = ∞ The output adjusts to bring Vin- to the same voltage as Vin+. ThereforeVin-=Vinandsince no currentflowsintoVin-thesamecurrent must flowthroughR1&R2. Vout is therefore VR1 + VR2 = Vin- + IR2 = Vin- + (Vin/R1)R2.



❖ INVERTING AMPLIFIER

Becausenocurrent flows intothe inputpinstherecan’tbeanyvoltagedropacrossthe R1‖ R2. Vin+ is therefore at 0V(this is called a virtual ground). The output will adjustsuch that Vin- isatzerovolts.This makes **Rin=R1**(not∞)**.**ThecurrentthroughR1&R2have tobe the same since no current goes into the input pins.
ThereforeI=Vin/R1.Vout=Vin+-IR2=0-(Vin/R1)R2.Therefore**Vout=-Vin(R2/R1)**

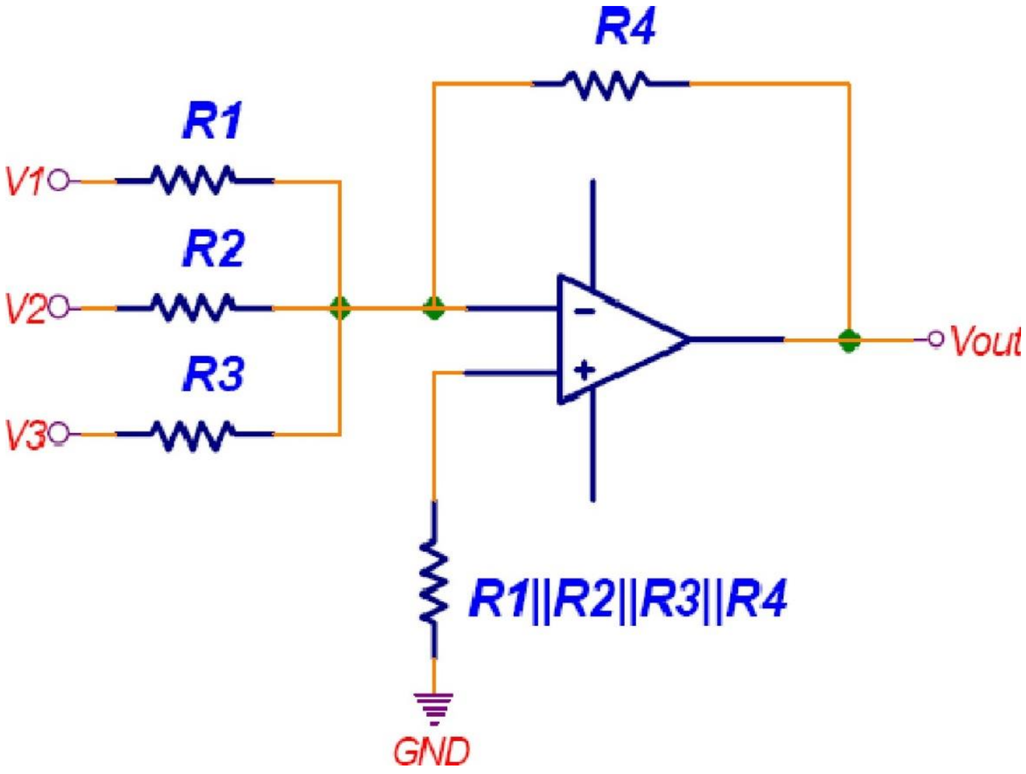


❖ SUMMING AMPLIFIER:

SinceVin- isavirtualgroundaddingV2andR2(andV3&R3)doesn't changethecurrent flowingthrough R1 from V1. Each input contributes to the output using the following equation:

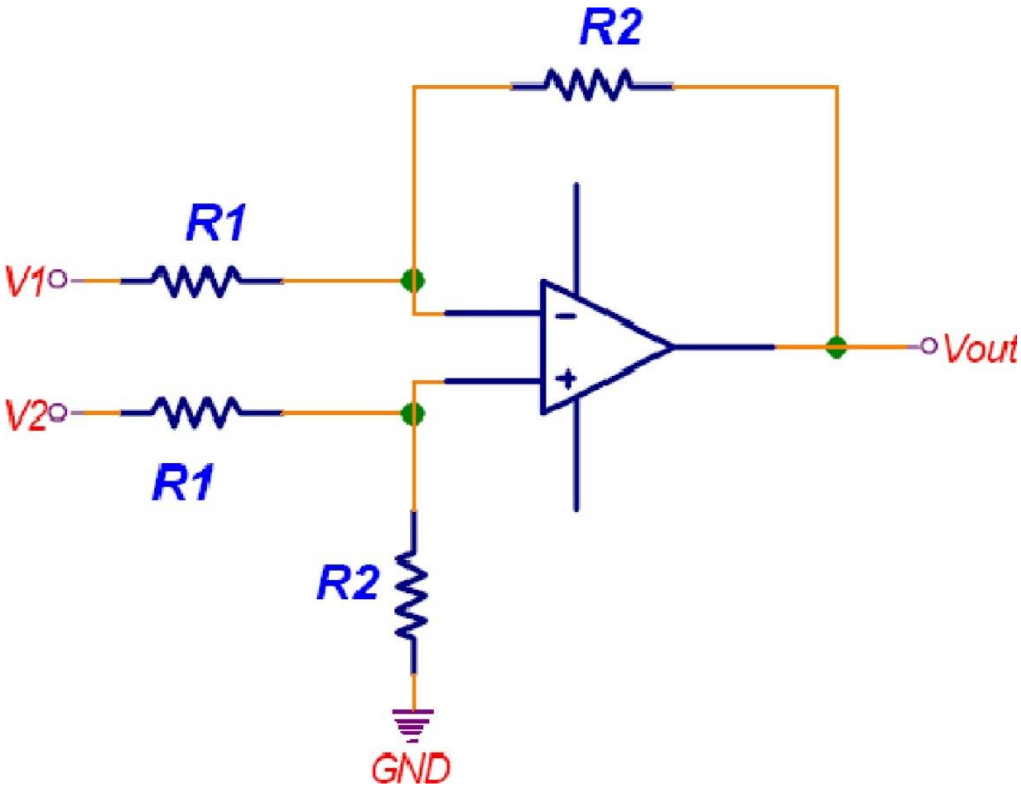
Vout=-V1(R4/R1)-V2(R4/R2)- V3(R4/R3).

The input impedance fortheV1input isstillR1,similarlyV2'sinput impedance isR2andV3'sisR3.Most of the time the parallel combination of R1-R4 isn't used and Vin+ is grounded.



❖ DIFFERENCE AMPLIFIER:

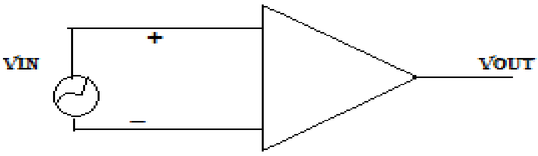
You can work out the gain as before using the two rules (no current flows into the inputs, andtheoutputwilladjusttobringVin-to Vin+).Theresult is **Vout=2(V2-V1)*(R2/R1).** Also,**Rin(-) = R1, Rin(+) = R1 + R2**.



❖ COMMON-MODEOP-AMP

Thesetypeofop-amphavecommonmodevoltagetobothterminals.

Itmeanswithout connectingthesamevoltageatboththeterminalwe mayconnectonevoltageoreither inverting or non-inverting terminal and other is connected with short to that voltage.



❖ COMMON MODE REJECTION RATIO

Commonmoderejectionratio whichisdefinedastheratio ofdifferentialgaintocommonmode CMRR = A_d/A_{cm}

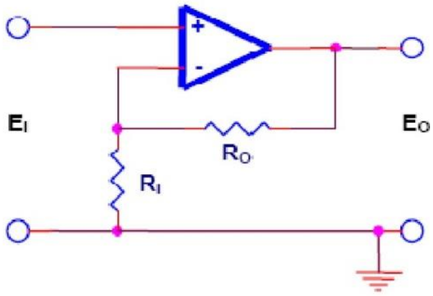
$A_d=V_0/V_d$,$A_{cm}=V_0/V_{cm}$

Asthegainisgenerallyhighso CMRRisusedtoexpressasa logarithmicgain function CMRRR=

20log A_d/A_{cm}

❖ OPERATIONAL-AMPLIFIER WITH FEEDBACK

Non-Inverting Amplifier



$$E_O = \left(1 + \frac{R_O}{R_I}\right) \cdot E_I$$

The same voltage must appear at the inverting and non-inverting inputs, so that:

$$(E-) = (E+) = E_I$$

From the voltage division formula:

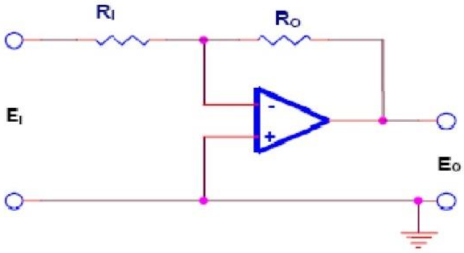
$$E_I = \frac{R_I}{R_I + R_O} \cdot E_O$$

$$\frac{E_O}{E_I} = \frac{R_I + R_O}{R_I} = 1 + \frac{R_O}{R_I}$$

The input impedance of the non-inverting amplifier circuit is infinite since no current flows into the inverting input. Output impedance is zero since output voltage is ideally independent of output current. Closed loop gain is $1 + \frac{R_O}{R_I}$ hence can be any desired value above unity.

Such circuits are widely used in control and instrumentation where non-inverting gain is required.

INVERTING AMPLIFIER



$$\frac{E_O}{E_I} = \frac{-R_O}{R_I}$$

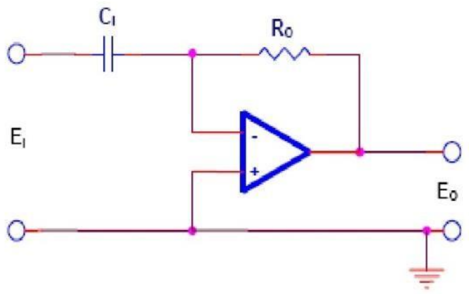
Figure 17. Inverting Amplifier

The inverting amplifier appears in figure 17. This circuit and its many variations form the bulk of commonly used operational amplifier circuitry. Single ended input and output versions were first used, and they became the basis of analog computation. Today's modern differential input amplifier is used as an inverting amplifier by grounding the non-inverting input and applying the input signal to the inverting input terminal.

Since the amplifier draws no input current and the input voltage approaches zero when the feedback loop is closed (the two summing point restraints), we may write:

$$\frac{E_I}{R_I} = \frac{E_O}{R_O} = 0$$

Differentiator



$$E_O = -R_O C_I \frac{dE_I}{dt}$$

Figure 22. Differentiator Circuit

Using a capacitor as the input element to the inverting amplifier, figure 22, yields a differentiator circuit. Consideration of the device in figure 23 will give a feeling for the differentiator circuit.

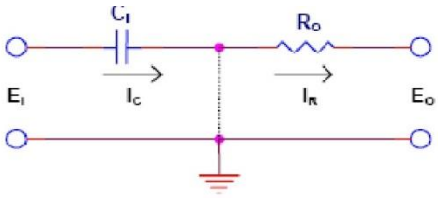


Figure 23. An Intuitive Picture of the Differentiator

Since the inverting input is at ground potential:

$$I_C = C_I \frac{dE_I}{dt}, \text{ and } I_C - I_R = 0$$

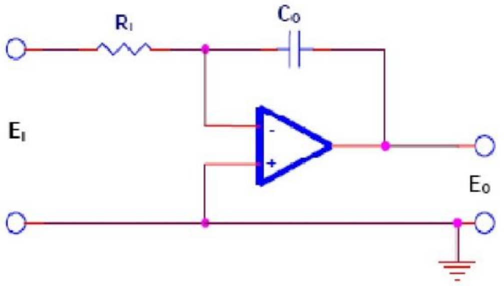
so that:

$$C_I \frac{dE_I}{dt} + \frac{E_O}{R_O} = 0$$

$$E_O = -R_O C_I \frac{dE_I}{dt}$$

It should be mentioned that of all the circuits presented in this section, the differentiator is the one that will operate least successfully with real components. The capacitive input makes it particularly susceptible to random noise and special techniques will be discussed later for remedying this effect.

Integrator



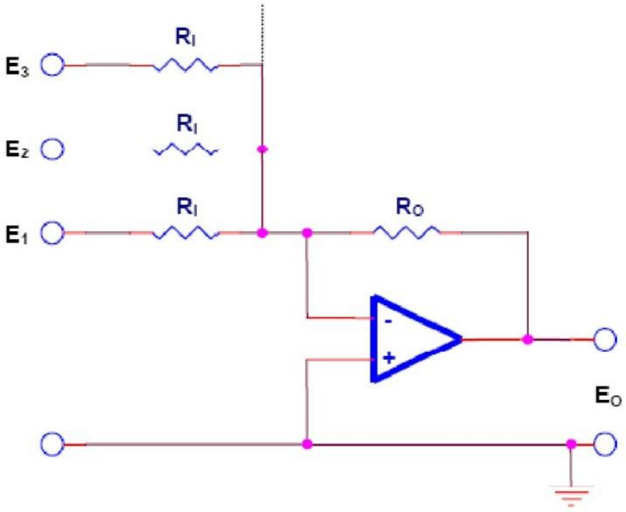
$$E_O = \frac{-1}{R_I C_O} \; E_I dt$$

Figure 21. Integrator Circuit

If a capacitor is used as the feedback element in the inverting amplifier, shown in figure 21, the result is an integrator. An intuitive grasp of the integrator action may be obtained from the statement under the section, “Current Output,” that current through the feedback loop charges the capacitor and is stored there as a voltage from the output to ground. This is a voltage input current integrator.

Voltage Adder

In a great many practical applications the input to the inverting amplifier is more than one voltage. The simplest form of multiple inputs is shown in figure 24.

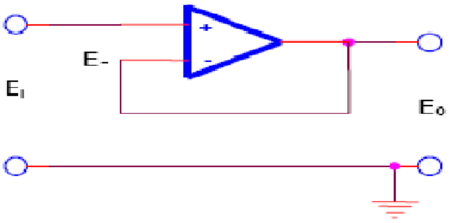


$$E_O = \frac{-R_O}{R_I}\left(E_1 + E_2 + E_3 + \ldots\right)$$

Figure 24. Voltage Adding Circuit

Current in the feedback loop is the algebraic sum of the current due to each input. Each source, E_1, E_2, etc., contributes to the total current, and no interaction occurs between them. All inputs “see” R_I as the input impedance, while gain is $\frac{-R_O}{R_I}$. Direct voltage addition may be obtained with $R_O = R_I$.

THE VOLTAGE FOLLOWER



Let the voltage at the inverting input with respect to the non-inverting input be E-.

By Kirchoff's voltage law:

$$(E-)+E_I=E_O$$

But by definition:

$$E_O=-A(E-)$$

where A is the gain of the operational amplifier

Then:

$$(E-)=\frac{-E_O}{A}$$

And substituting:

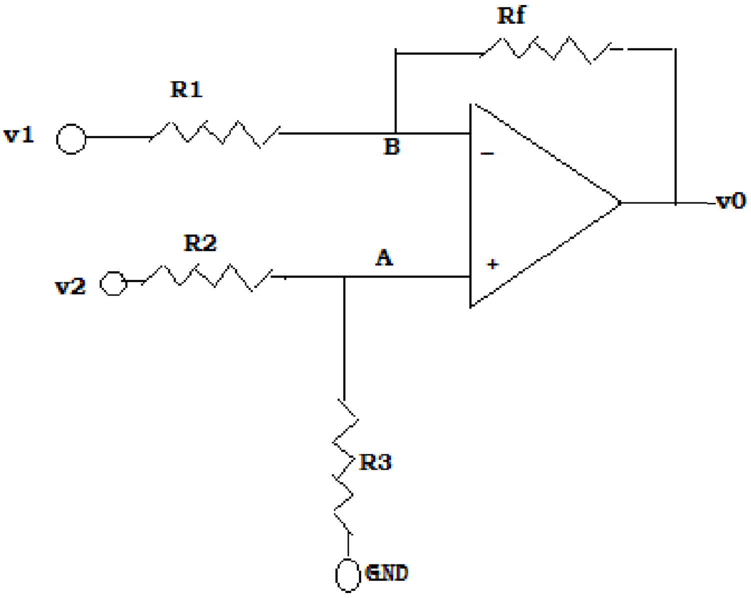
$$E_I-\frac{E_O}{A}=E_O$$

Letting A go to infinity, $\frac{E_O}{A}$ approaches zero, and:

$$E_O=E_I$$

❖ VOLTAGE SUBSTRACTOR

- ➢ GenerallySubtractionofsignalsare beingperformedbysubstractingonesignalfromanothersignal. These types of subtractor are always used in analog signals.



Voltage across terminal A can be found byusing voltage division rule and we know that voltage across A is equals to the B so $VA = VB$

$VA=V2 .R2/R2+R3=VB$

Applying nodal analys is in terminal B the equation becomes

$(VB - V1)/R1 + (VB-V0) / RF = 0$

$VB/R1+(VB/RF-V1/R1)=V0/RF$ VB

$(1/R1 + 1/RF) -V1/R1 = V0/RF$

But we know that$VB=V2.R2/ R2+R3$

$(V2.R2/R2+R3)[(RF+R1)/R1.RF] -V1/R1=V0/RF$ (V2

.R2/ R2+R3) [(RF+ R1)/R1] – V1. RF/R1 = V0 V0=

$(V2 .R2/ R2+R3) [1+ RF/R1] - (V1. RF)/ R1$

If we put $RF= R1=R2=R3= 1K\Omega$

The output voltage V0 becomes

$$V0=V2-V1$$

SLEWRATE

It is the ratio of change in output voltage to change in time

$S.R =\Delta V0/\Delta T$ (V/µs)