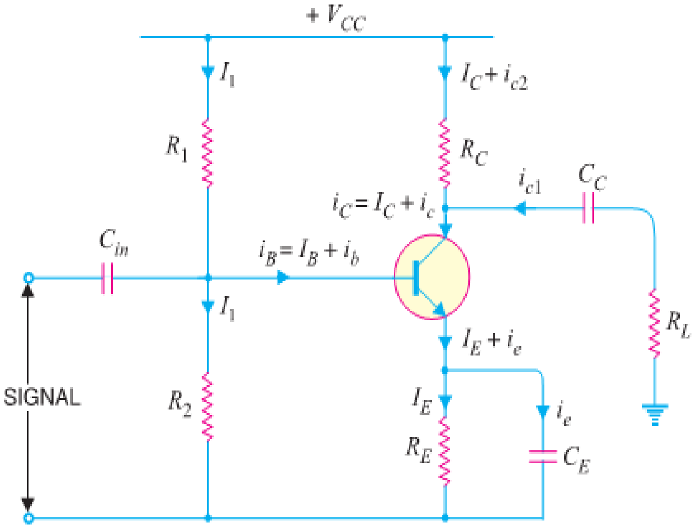
CHAPTER - 6

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

❖ D.C. AND A.C. EQUIVALENT CIRCUITS: -



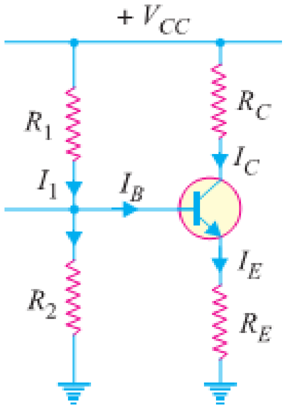
- Various circuit currents. It is useful to mention the various currents in the complete amplifier circuit. These are shown in the circuit of Fig.
- **(i) Base Current: -** When no signal is applied in the base circuit, D.C. base current I_B flows due to biasing circuit. When A.C. signal is applied, A.C. base current i_b also flows.
- Therefore, with the application of signal, Total Base Current i_B is given by: $\mathbf{i_B = I_B + i_b}$
- **(ii) Collector Current: -** When no signal is applied, a D.C. collector current I_C flows due to biasing circuit. When A.C. signal is applied, A.C. collector current i_c also flows.
- Therefore, the Total Collector Current i_C is given by: - $\mathbf{i_C = I_C + i_c}$

  Where $I_C = \beta\ I_B$ = zero signal collector current and $i_c = \beta\ i_b$ = collector current due to signal.
- **(iii) Emitter Current:-** When no 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. Therefore the Total Emitter Current is : - $\mathbf{i_E = I_E + i_e}$
- It is useful to keep in mind that: $I_E = I_B + I_C$ and $i_e = i_b + i_c$.
- But base current is usually very small, therefore, as a reasonable approximation, $I_E \approx I_C$ and $i_e \approx i_c$.

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

(a) Reduce all A.C. sources to zero.

(b) Open all the capacitors.



- Referring D.C. Equivalent Circuit

  D.C. Load $\mathbf{R_{DC} = R_C + R_E}$ & $V_{CC} = V_{CE} + I_C\ (R_C + R_E)$
- The maximum value of V_{CE} will occur when there is no collector current i.e. $I_C = 0$.

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

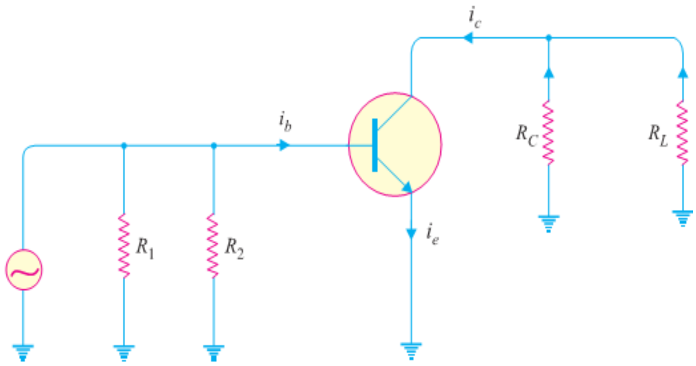
- The maximum collector current will flow when $V_{CE} = 0$.

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

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

(a) Reduce all D.C. sources to zero (i.e. $V_{CC} = 0$).

(b) Short all the capacitors.



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

$$\boxed{\therefore \quad \text{Total maximum } \textbf{collector-emitter voltage, } \mathbf{V_{CE\ MAX} = V_{CE} + I_C\ R_{AC}}}$$

- Maximum positive swing of A.C. collector current = V_{CE}/R_{AC}

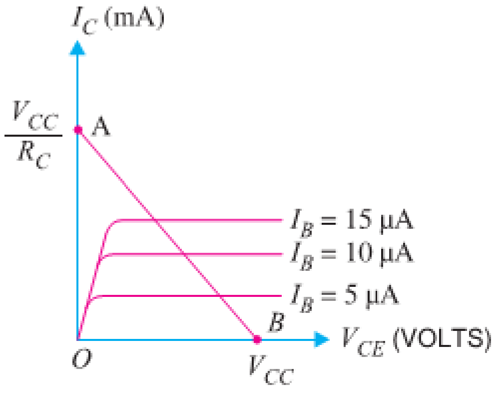
$$\boxed{\therefore \quad \text{Total maximum } \textbf{collector current, } \mathbf{I_{C\ MAX} = I_C + V_{CE}/R_{AC}}}$$

❖ LOAD LINE ANALYSIS: -

- In the transistor circuit analysis, it is generally required to determine the collector current for various collector-emitter voltages.
- One of the methods can be used to plot the output characteristics and determine the collector current at any desired collector-emitter voltage.
- However, a more convenient method, known as **load line method** can be used to solve such problems.
- This method is quite easy and is frequently used in the analysis of transistor applications.

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

- Consider a common emitter NPN transistor circuit where no signal is applied. Therefore, D.C. conditions prevail in the circuit. The output characteristics of this circuit are shown in Fig.



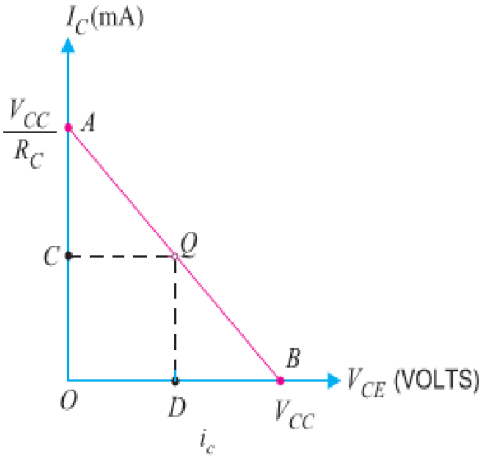
- The value of collector-emitter voltage V_{CE} at any time is given by ; $V_{CE} = V_{CC} - I_C R_C$ Or $I_C R_C = V_{CC} - V_{CE}$

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

  Or $I_C = (-1/R_C)\, V_{CE} + V_{CC}/R_C$ (≡ $Y = mX + C$)
- As V_{CC} and R_C are fixed values, therefore, it is a first degree equation and can be represented by a straight line on the output characteristics. This is known as **D.C. Load Line.**
- To add load line, we need two end points of the straight line. These two points can be located as under:

  (i) When the collector current $I_C = 0$, then collector-emitter voltage is maximum and is equal to V_{CC}

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



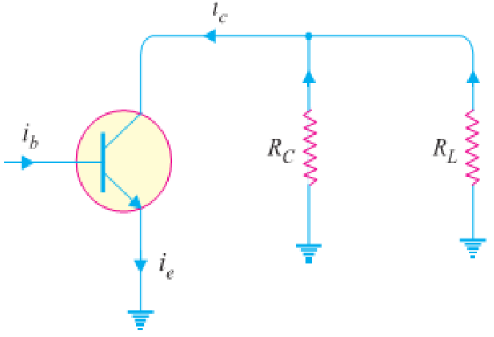
- This gives the first point B (OB $= V_{CC}$) on the collector-emitter voltage axis as shown in Fig.

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

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

  ∴ Max. $I_C = V_{CC}/R_C$
- This gives the second point A (OA $= V_{CC}/R_C$) on the collector current axis as shown in Fig.
- By joining these two points, **D.C. Load Line** AB is constructed.

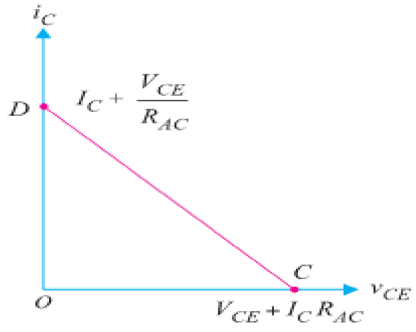
♣ **(II) A.C. LOAD LINE.** This is the line on the output characteristics of a transistor circuit which gives the values of i_C and v_{CE} when signal is applied.



- Referring back to the transistor amplifier shown in Fig., its A.C. equivalent circuit as far as output circuit is concerned is as shown in Fig.
- To add A.C. load line to the output characteristics, we again require two end points: –

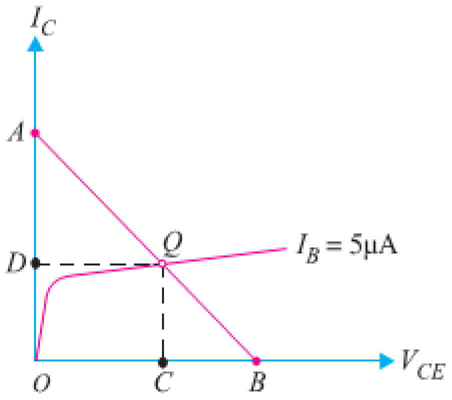
  1. One maximum collector-emitter voltage point **($V_{CE\ MAX}$)** and

  2. Other is maximum collector current point. **($I_{C\ MAX}$)**



- 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.
- Maximum collector current, $\mathbf{I_{C\ MAX} = I_C + V_{CE}/R_{AC}}$
- This locates the point D of A.C. load line on the collector-current axis.
- By joining points C and D, the **A.C. Load Line** CD is constructed.

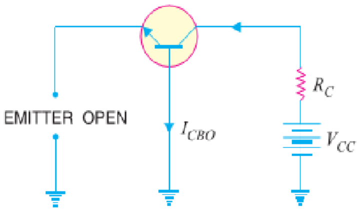
❖ OPERATING POINT: -



- 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 :

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

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

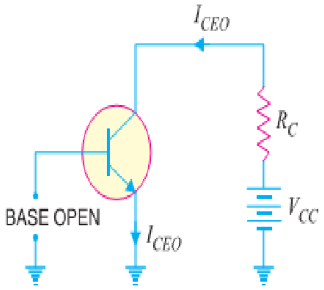


❖ THE LEAKAGE CURRENT:-

- The current is due to the movement of minority carriers is known as Leakage Current.
- In Common Base Connection of Transistor the leakage current $\mathbf{I_{CBO}}$ is the Collector-Base current with emitter open.
- Similarly, In Common Emitter Connection the leakage current $\mathbf{I_{CEO}}$ 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,



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

❖ MULTI STAGE 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.

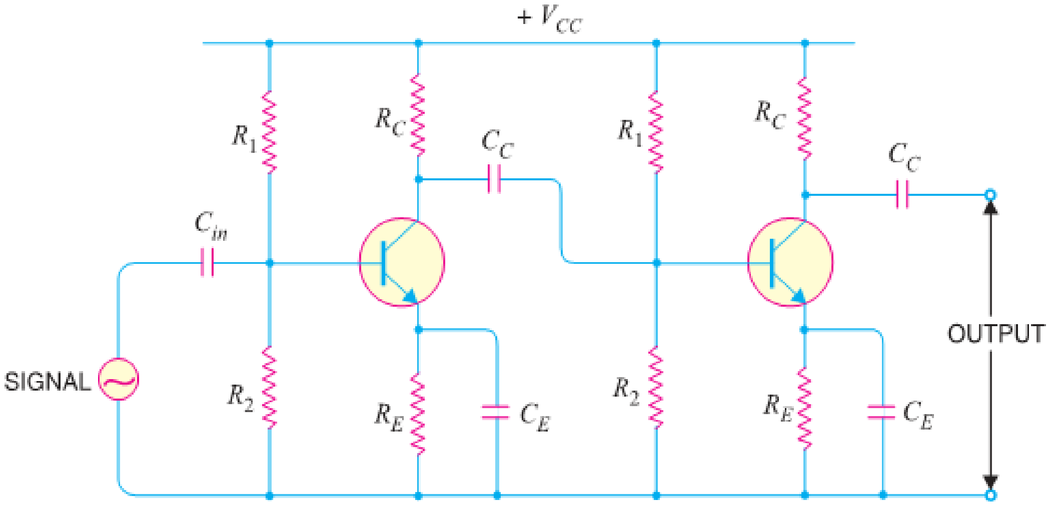
Name of coupling	*Name of multistage amplifier*
RC coupling	R-C coupled amplifier
Transformer coupling	Transformer coupled amplifier
Direct coupling	Direct coupled amplifier

IMPORTANT TERMS:-

- **Gain: -** The ratio of the output electrical quantity to the input one of the amplifier is called its gain.
- The gain of a multistage amplifier is equal to the product of gains of individual stages.
- **Frequency response: -** The curve between voltage gain and signal frequency of an amplifier is known as frequency response.
- **Decibel gain: -** Although the gain of an amplifier can be expressed as a number, yet great practical importance to assign it a unit.
- The unit assigned is bel or decibel (db). The common logarithm (log to the base 10) of power gain is known as bel power gain i.e. $\text{Power gain} = \log_{10} \frac{P_{out}}{P_{in}}\ bel$ (1 bel=10 db.)
- **Bandwidth: -** The range of frequency over which the voltage gain is equal to or greater than 70.7% of the maximum gain is known as **bandwidth**.
- From the fig. it is clear that for any frequency lying between f_1 and f_2, the gain is equal to or greater than 70.7% of the maximum gain.
- Therefore, $f_1 - f_2$ is the bandwidth. It may be seen that f_1 and f_2 are the limiting frequencies. The f_1 is called lower cut-off frequency and f_2 is known as upper cut-off frequency.

R-C COUPLED TRANSISTOR AMPLIFIER:-

- This is the most popular type of coupling because it is cheap and *provides excellent audio fidelity over a wide range of frequency*. It is usually employed for **voltage amplification**.
- Fig shows two stages of an RC coupled amplifier. A coupling capacitor C_C is used to connect the output of first stage to the base (i.e. input) of the second stage and so on.
- As the coupling from one stage to next is achieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are called ***Resistance - Capacitance coupled amplifiers***.
- The resistances R_1, R_2 and R_E form the *biasing* and *stabilization* network. The emitter bypass capacitor offers *low reactance path* to the signal. Without it, the voltage gain of each stage would be lost.
- The coupling capacitor C_C transmits A.C. signal but blocks D.C. This prevents D.C. interference between various stages and the shifting of operating point.



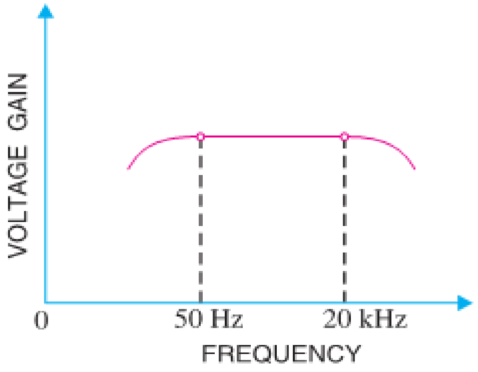
[Circuit Diagram of RC Coupled Transistor Amplifier]

- **OPERATION: -**
- When A.C. signal is applied to the base of the first transistor, it appears in the amplified form across its collector load R_C.
- The amplified signal developed across RC is given to base of next stage through coupling capacitor C_C. The second stage does further amplification of the signal.

- In this way, the cascaded (one after another) stages amplify the signal and the overall gain is considerably increased.
- It may be mentioned here that total gain is less than the product of the gains of individual stages.
- It is because when a second stage is made to follow the first stage, the effective load resistance of first stage is reduced due to the shunting effect of the input resistance of second stage.
- This reduces the gain of the stage which is loaded by the next stage

FREQUENCY RESPONSE 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 it is uniform over mid-frequency range (50 Hz to 20 kHz).
- This behaviour of the amplifier is briefly explained below:-
- **(i) At low frequencies** (< 50 Hz):- At this stage the reactance of coupling capacitor C_C is quite high and hence very small part of signal will pass from one stage to the next stage. Moreover, C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequencies. These two factors cause a falling of voltage gain at low frequencies.
- **(ii) At high frequencies** (> 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 reduce the voltage gain.
  Moreover, at high frequency, capacitive reactance of base-emitter junction is low which increases the base current. This reduces the current amplification factor β. Due to these two reasons, the voltage gain drops off at high frequency.



[Frequency Response Curve of RC Coupled Amp]

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

ADVANTAGES:-

(i) It has excellent frequency response. The gain is constant over the audio frequency range which is the region of most importance for speech, music etc.
(ii) It has lower cost since it employs resistors and capacitors which are cheap.
(iii) The circuit is very compact as the modern resistors and capacitors are small and extremely light.

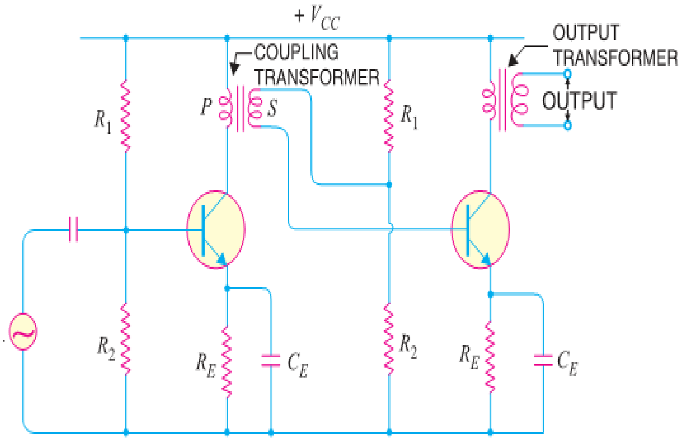
DISADVANTAGES:-

(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) They have the tendency to become noisy with age, particularly in moist climates.
(iii) Impedance matching is poor. It is because the output impedance of RC coupled amplifier is several hundred ohms whereas the input impedance of a speaker is only a few ohms. Hence, little power will be transferred to the speaker.

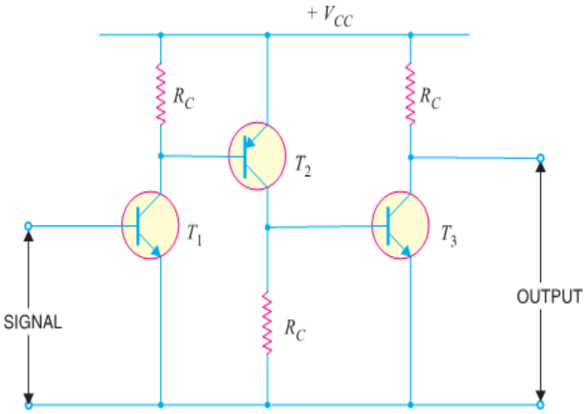
APPLICATIONS:-

- The RC coupled amplifiers have excellent audio fidelity over a wide range of frequency. Therefore, they are widely used as **voltage amplifiers** e.g. in the initial stages of public address system.
- If other type of coupling (e.g. transformer coupling) is employed in the initial stages, this results in frequency distortion which may be amplified in next stages.
- However, because of poor impedance matching, RC coupling is rarely used in the final stages.

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



(Transformer Coupled Transistor Amplifier)



(Direct Coupled Transistor Amplifier)

- ➢ **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 amplifying extremely low frequencies

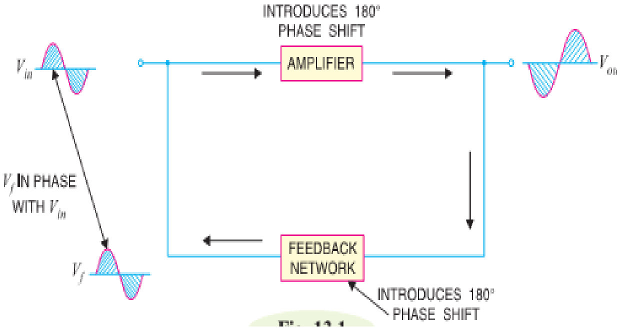
[FEED BACK AMPLIFIER]

❖ INTRODUCTION:-

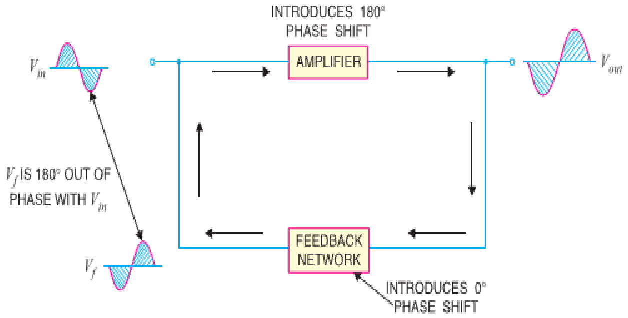
- ➢ A practical amplifier has a gain of nearly one million i.e. its output is one million times the input. Consequently, even a casual disturbance at the input will appear in the amplified form in the output.
- ➢ The noise in the output of an amplifier is undesirable and must be kept to as small a level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

❖ FEEDBACK:-

- ➢ The process of injecting a fraction of output energy of some device back to input is known as feedback.
- ➢ Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers viz Positive Feedback and Negative Feedback.
- **Positive Feedback**. When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback*. This is illustrated in Fig.
- ➢ Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage V_f to be in phase with the input signal V_{in}.
- ➢ The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability.



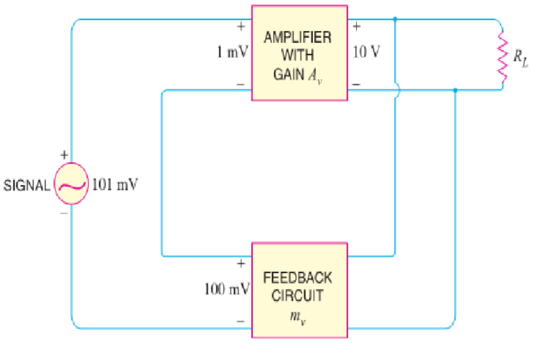
- Therefore, positive feedback is not often employed in amplifiers.
- One important use of positive feedback is in oscillators. If positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.
- **(ii) Negative Feedback.** When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig.
- As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage V_f is 180° out of phase with the input signal V_{in}.



- Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth & improved input and output impedances.
- It is due to these advantages that negative feedback is frequently employed in amplifiers.

❖ PRINCIPLES OF NEGATIVE VOLTAGE FEEDBACK IN AMPLIFIERS:-

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

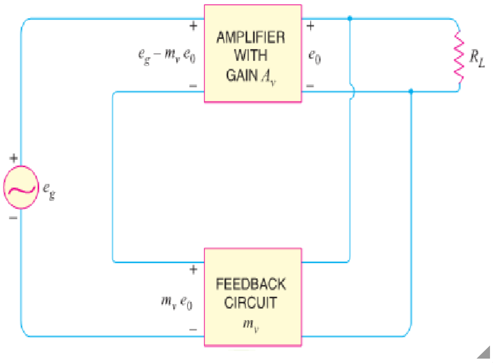


- As the feedback is negative, therefore, only 1 mV appears at the input terminals of the amplifier.
- Referring to Fig., we have,
  - ♣ Gain of amplifier without feedback, $A_v = (10\text{ V})/(1\text{ mV}) = 10{,}000$
  - ♣ Fraction of output voltage feedback, $m_v = (100\text{ mV})/10\text{V} = 0.01$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

❖ GAIN OF NEGATIVE VOLTAGE FEEDBACK AMPLIFIER:-

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

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



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

i.e. $(e_g - m_v e_0) A_v = e_0$ ➔ $A_v e_g - A_v m_v e_0 = e_0$

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

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

But 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.

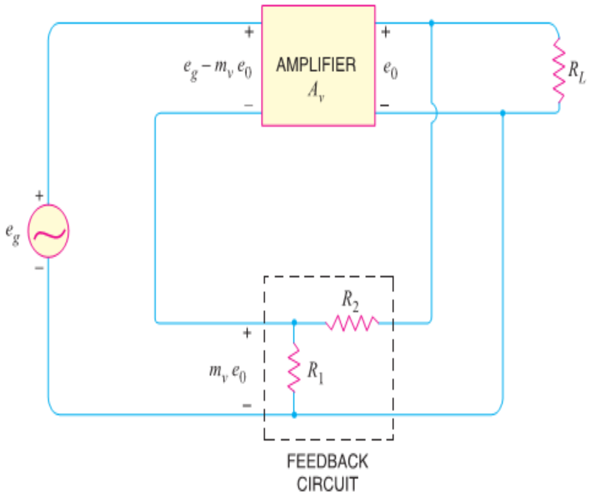
- The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.

♣ **(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 :

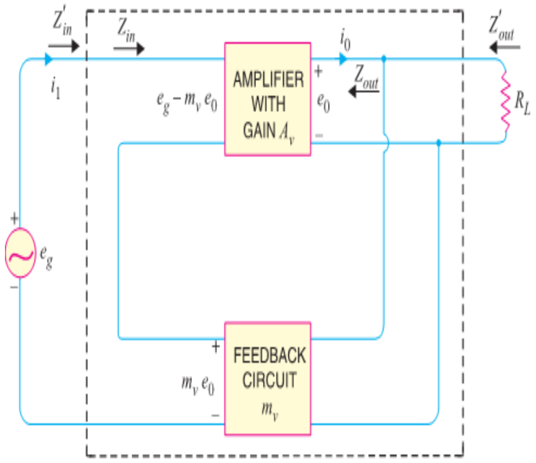
Voltage across R_1 = (——— e_0

Feedback fraction, m_v = —————— = ———

❖ INPUT & OUTPUT IMPEDANCE OF NEGATIVE FEEDBACK AMPLIFIER :-

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

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



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

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

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

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

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

Or — $= Z_{in} (1 + A_v m_v)$

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 :

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

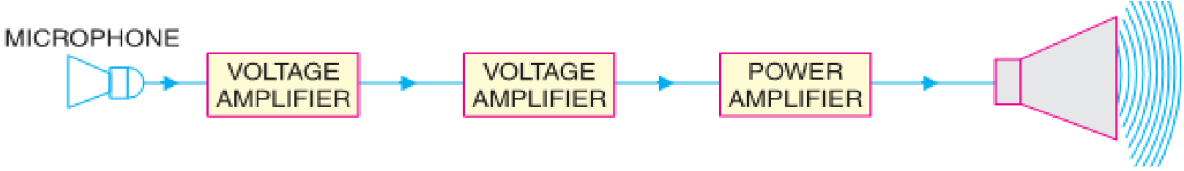
Where Z'_{out} = output impedance with negative voltage feedback
Z_{out} = output impedance without feedback

- ➢ 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 sufficient power is available to operate a loudspeaker or other output device.
- The first few stages in this multistage amplifier have the function of only voltage amplification. However, last stage is designed to provide maximum power. This final stage is known as power stage.



❖ Transistor Audio Power Amplifier: -

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

❖ DIFFERENCE BETWEEN VOLTAGE AND POWER AMPLIFIERS

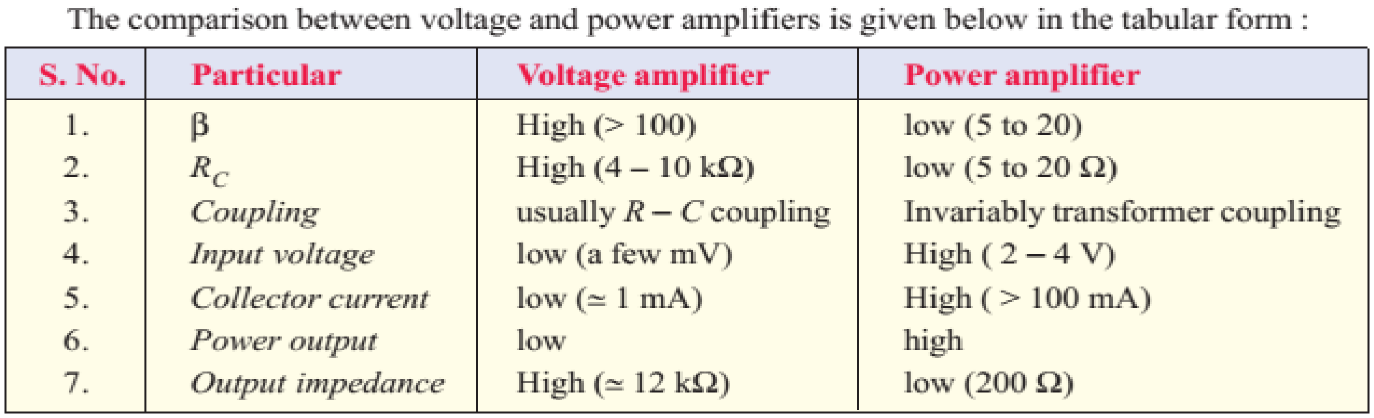
- The difference between the two types is really one of degree; it is a question of how much voltage and how much power.
- A voltage amplifier is designed to achieve maximum voltage amplification. It is, however, not important to raise the power level.
- On the other hand, a power amplifier is designed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

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

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

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

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



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

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

❖ PERFORMANCE QUANTITIES OF POWER AMPLIFIERS

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

Collector efficiency.

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

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

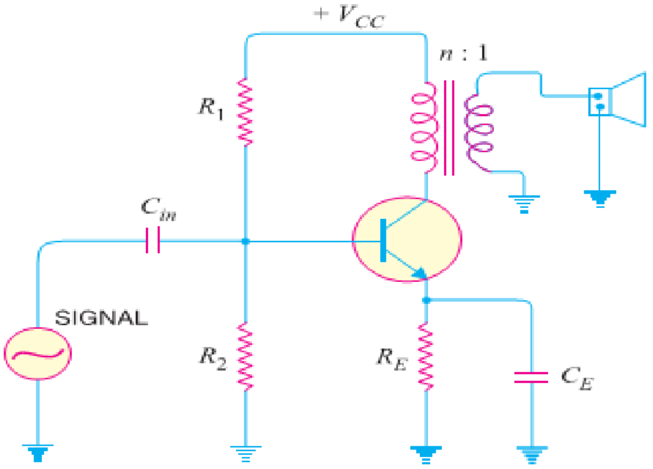
Power Dissipation Capability. The ability of a power transistor to dissipate heat is known as power dissipation capability.

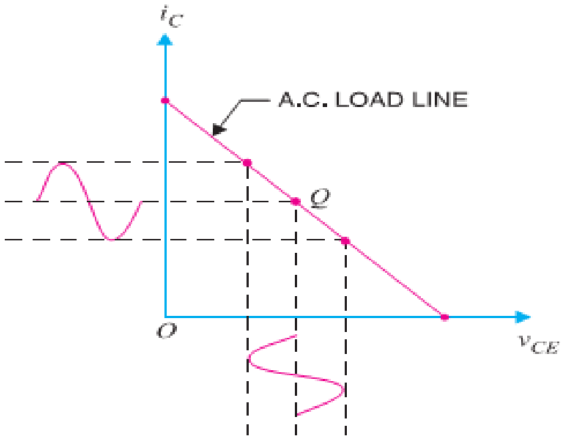
❖ CLASSIFICATION OF POWER AMPLIFIERS

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

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

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

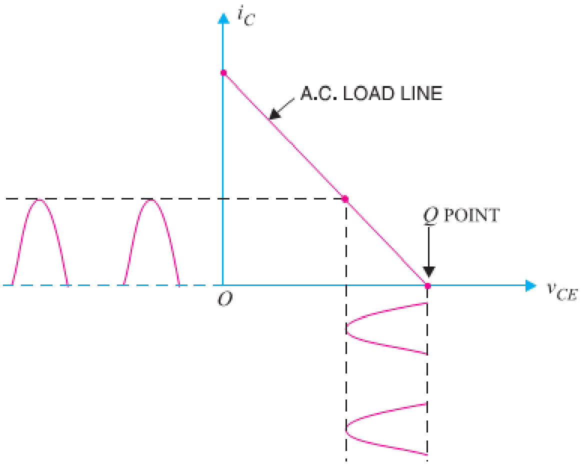




- The power amplifier must be biased in such a way that no part of the signal is cut off. Fig (i) shows circuit of class A power amplifier. Note that collector has a transformer as the load which is most common for all classes of power amplifiers.
- The use of transformer permits impedance matching,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

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

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



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

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

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

EXPRESSION FOR COLLECTOR EFFICIENCY

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

$$P_o = [(0.5\times0.707)\, v_{ce(p-p)}][(0.5\times0.707)\, i_{c(p-p)}] = \frac{V_{ce(p-p)} \times i_{c(p-p)}}{8}$$

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

IMPORTANT POINTS ABOUT CLASS-A POWER AMPLIFIER : -

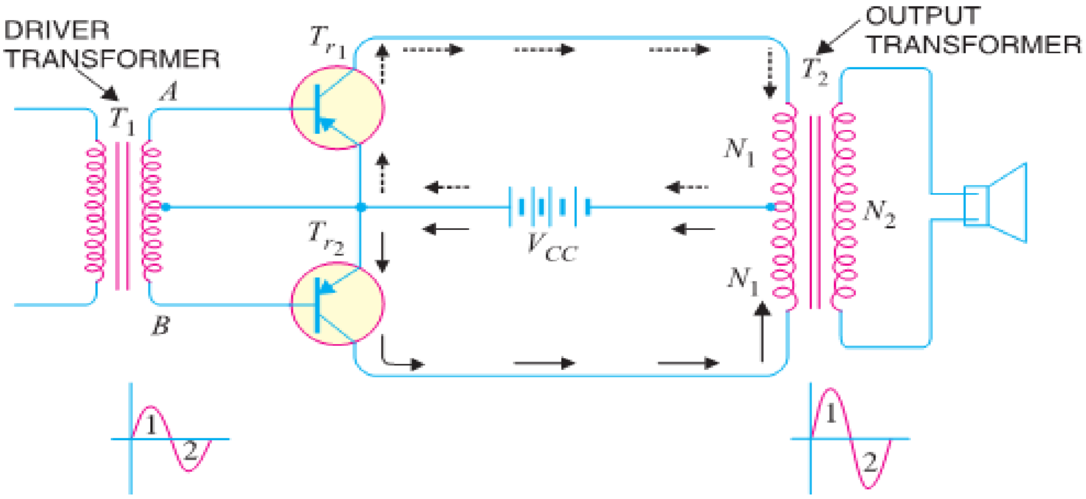
- **(i)** A Transformer coupled class A power amplifier has a maximum collector efficiency of 50% i.e., maximum of 50% d.c. supply power is converted into a.c. power output.
- In practice, the efficiency of such an amplifier is less than 50% (about 35%) due to power losses in the output transformer,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

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

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

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

PUSH-PULL AMPLIFIER : -



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

CIRCUIT OPERATION.

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

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

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

ADVANTAGES

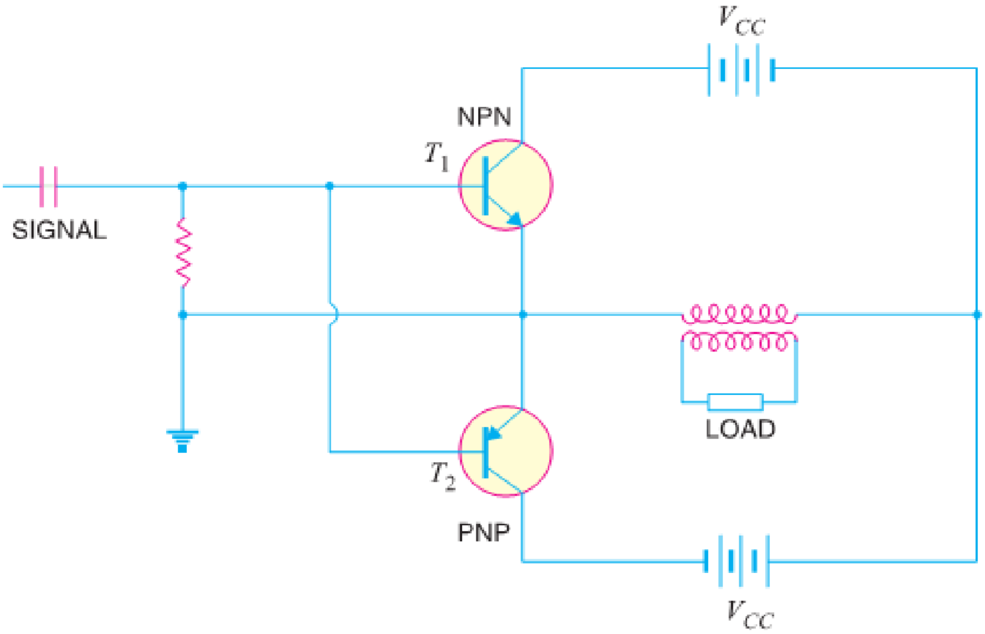
1) The efficiency of the circuit is quite high (≈ 75%) due to class B operation.
2) A high a.c. output power is obtained.

DISADVANTAGES

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

COMPLEMENTARY-SYMMETRY AMPLIFIER

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



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

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

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

HEAT SINK: -

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

[SINUSOIDAL OSCILLATOR]

INTRODUCTION TO OSCILLATOR: -

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

SINUSOIDAL OSCILLATORS:-

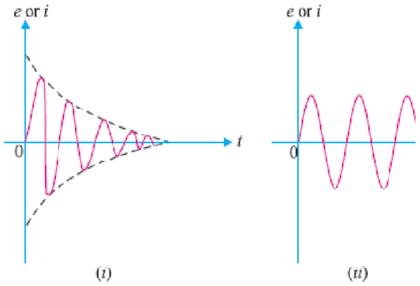
- An electronic device that generates sinusoidal oscillations of desired frequency is known as a **sinusoidal oscillator**. Although we speak of an oscillator as "generating" a frequency, it should be noted that it does not create energy, but merely acts as an energy converter.
- It receives D.C. energy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

ADVANTAGES

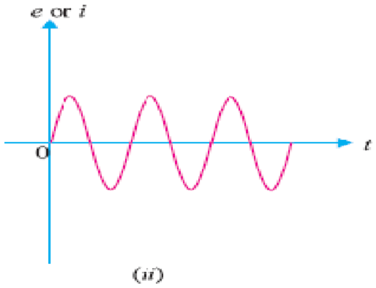
- Although oscillations can be produced by mechanical devices (e.g. alternators), but electronic oscillators have the following advantages:
- An oscillator is a non-rotating device. Consequently, there is little wear and tear and hence longer life.
- Due to the absence of moving parts, the operation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

TYPES OF SINUSOIDAL OSCILLATIONS:-

- Sinusoidal oscillations can be of two types viz **Damped Oscillations** and **Undamped Oscillations**.
- **(i) Damped Oscillations**: - The electrical oscillations whose amplitude goes on decreasing with time are called damped oscillations. Fig (i) Shows waveform of damped electrical oscillations.
- Obviously, the electrical system in which these oscillations are generated has losses and some energy is lost during each oscillation.
- Further, no means are provided to compensate for the losses and consequently the amplitude of the generated wave decreases gradually. It may be noted that frequency of oscillations remains unchanged since it depends upon the constants of the electrical system.

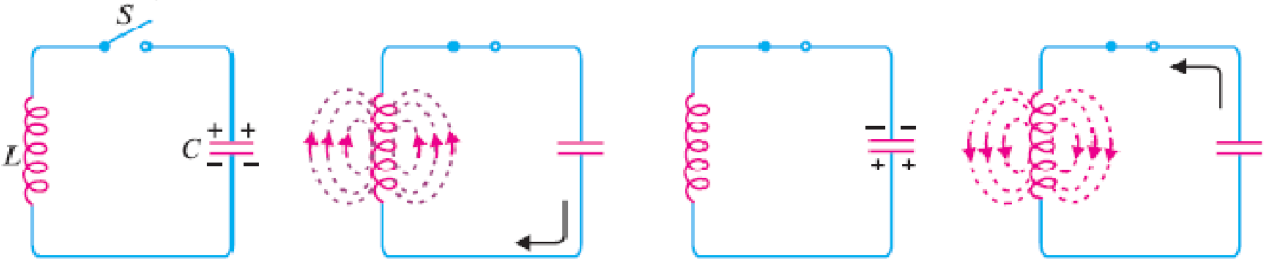


- **(ii) Undamped Oscillations**. The electrical oscillations whose amplitude remains constant with time are called undamped oscillations. Fig. (ii) Shows waveform of undamped electrical oscillations.
- Although the electrical system in which these oscillations are being generated has also losses, but 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: -

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

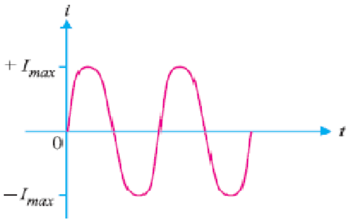


(i) *(ii)* *(iii)* *(iv)*

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

UNDAMPED OSCILLATIONS FROM TANK CIRCUIT:-

- As discussed before, a tank circuit produces damped oscillations. However, in practice, we need continuous undamped oscillations for the successful operation of electronics equipment.
- In order to make the oscillations in the tank circuit undamped, it is necessary to supply correct amount of energy to 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 of energy supplied should be such so as to meet the losses in the tank circuit & the a.c. energy removed from the circuit by the load.
- **(ii)** The applied energy should have the same frequency as tank circuit.
- **(iii)** The applied energy should be in phase with the oscillations set up in the tank circuit.
- If these conditions are fulfilled, the circuit will produce continuous undamped output as shown in 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:

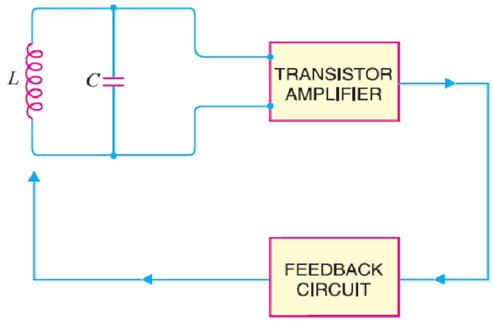
$$\boxed{\mathbf{m_v A_v = 1}}$$

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

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

ESSENTIALS OF TRANSISTOR OSCILLATOR: -

- Fig shows the block diagram of an oscillator. Its essential components are : -
- **Tank circuit**. It consists of inductance coil (L) connected in parallel with capacitor (C).
- The frequency of oscillations circuit depend upon the values of inductance of the coil and capacitance of the capacitor.
- **(ii) Transistor Amplifier.** The transistor amplifier receives D.C. power from the battery and changes it into a.c. power for supplying to the tank circuit.
- The oscillations occurring in the tank circuit are applied to the input of the transistor amplifier. Because of the amplifying properties of the transistor, we get increased output of these oscillations.



- This amplified output of oscillations is due to the D.C. power supplied by the battery.
- The output of the transistor can be supplied to the tank circuit to meet the losses.
- **(iii) Feedback Circuit**. The feedback circuit supplies a part of collector energy to the tank circuit in correct phase to aid the oscillations i.e. it provides positive feedback.

DIFFERENT TYPES OF TRANSISTOR OSCILLATORS:-

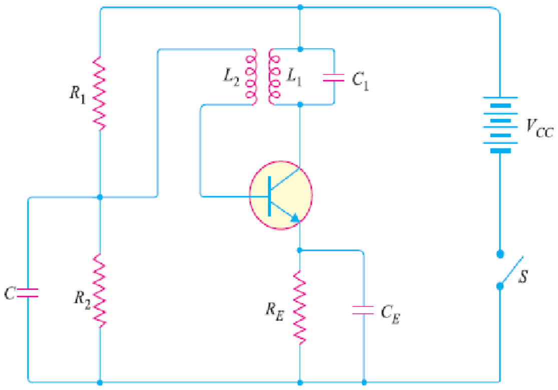
- A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it.
- All oscillators under different names have similar function i.e., they produce continuous undamped output. However, the major difference 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 :

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



- The feedback coil L_2 in the base circuit is magnetically coupled to the tank circuit coil L_1. In practice, L_1 and L_2 form the primary and secondary of the transformer respectively.
- The biasing is provided by potential divider arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations.
- **Circuit Operation**. When switch S is closed, collector current starts increasing and charges the capacitor C_1. When this capacitor is fully charged, it discharges through coil L_1, setting up oscillations of frequency determined by above equation.

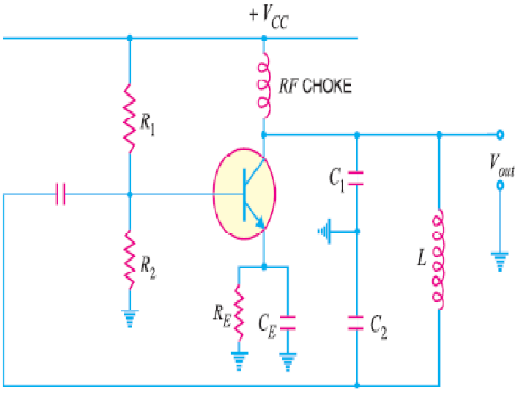
- These oscillations induce some voltage in coil L_2 by mutual induction. The frequency of voltage in coil L_2 is the same as that of tank circuit but its magnitude depends upon the number of turns of L_2 and coupling between L_1 and L_2.
- The voltage across L_2 is applied between base and emitter and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

❖ COLPITT'S OSCILLATOR:-

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

f = ——   Where **C_T =** ——

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

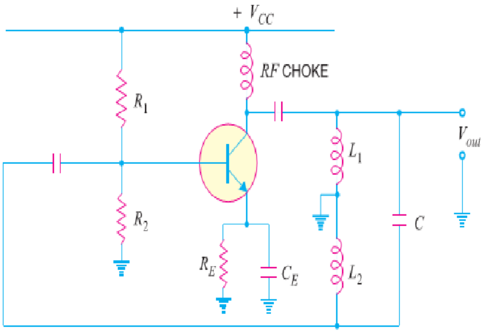


♣ **Circuit Operation.** When the circuit is turned on, the capacitors C_1 and C_2 are charged. The capacitors discharge through L, setting up oscillations of frequency determined by exp.(i).

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

❖ 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.

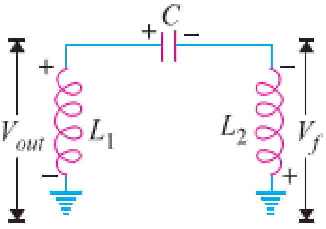


- The tank circuit is made up of L_1, L_2 and C. The frequency of oscillations is determined by the values of L_1, L_2 and C and is given by :

f = ——   ……….. (i)

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

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

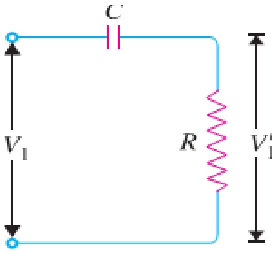


FEEDBACK CIRCUIT

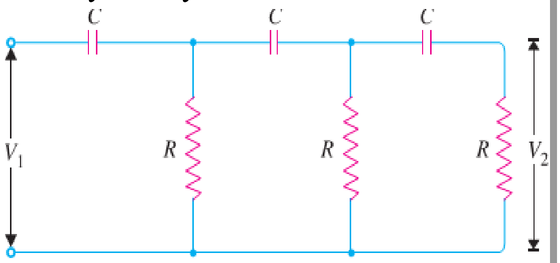
- The output voltage of the amplifier appears across L_1 and feedback voltage across L_2. The voltage across L_2 is 180° out of phase with the voltage developed across L_1 (V_{out}) as shown in Fig.
- It is easy to see that voltage feedback (i.e., voltage across L_2) to transistor provides positive feedback.
- 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 desirable feature of an oscillator is that it should feedback energy of correct phase to the tank circuit to overcome the losses occurring in it.
- In the oscillator circuits discussed so far, the tank circuit employed inductive (L) and capacitive (C) elements. In such circuits, a phase shift of 180º was obtained due to inductive or capacitive coupling and a further phase shift of 180º was obtained due to transistor properties.
- In this way, energy supplied to the tank circuit was in phase with the generated oscillations. The oscillator circuits employing L-C elements have two general drawbacks.
- **Firstly**, they suffer from frequency instability and poor waveform. **Secondly**, they cannot be used for very low frequencies because they become too much bulky and expensive.
- Good frequency stability and waveform can be obtained from oscillators employing resistive and capacitive elements. Such amplifiers are called R-C or phase shift oscillators and have the additional advantage that they can be used for very low frequencies.



- In a phase shift oscillator, a phase shift of 180º is obtained with a phase shift circuit instead of inductive or capacitive coupling.
- A further phase shift of 180º is introduced due to the transistor properties. Thus, energy supplied back to the tank circuit is assured of correct phase.
- **<u>Phase shift Circuit.</u>** A phase-shift circuit essentially consists of an R-C network. Fig (i) shows a single section of RC network. From the elementary theory of electrical engineering, it can be shown that alternating voltage V'_1across R leads the applied voltage V_1 by φº. The value of φ depends upon the values of R and C.



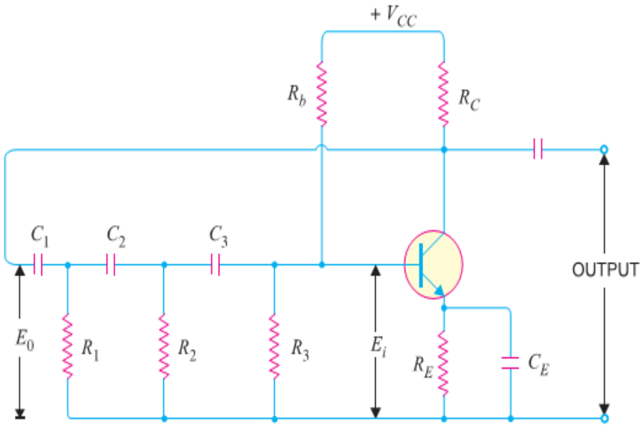
- If resistance R is varied, the value of φ also changes. If R were reduced to zero, V'_1 will lead V_1 by 90º i.e. φ= 90º.
- However, adjusting R to zero would be impracticable because it would lead to no voltage across R.
- Therefore, in practice, R is varied to such a value that makes V'_1 to lead V_1 by 60º.
- Fig (ii) shows the three sections of RC network. Each section produces a phase shift of 60º. Consequently, a total phase shift of 180º is produced i.e. voltage V_2 leads the voltage V_1 by 180º.

❖ PHASE SHIFT OSCILLATOR:-

- Fig. shows the circuit of a phase shift oscillator. It consists of a conventional single transistor amplifier and a RC phase shift network.
- The phase shift network consists of three sections R_1C_1, R_2C_2 and R_3C_3. At some particular frequency f_0, the phase shift in each RC section is 60º so that total phase-shift produced by the RC network is 180º.
- The frequency of oscillations is given by: $\boxed{\mathbf{f_0} = \frac{\quad}{\quad}}$ Where $R_1=R_2=R_3=\mathbf{R}$ & $C_1=C_2=C_3=\mathbf{C}$

♣ **<u>Circuit Operation.</u>** When the circuit is switched on, it produces oscillations of frequency determined by exp. (i). The output E_0 of the amplifier is fed back to RC feedback network.

- This network produces a phase shift of 180º and a voltage E_i appears at its output which is applied to the transistor amplifier.



- Obviously, the feedback fraction $m= E_i/E_0$. The feedback phase is correct. A phase shift of 180º is produced by the transistor amplifier.
- A further phase shift of 180º is produced by the RC network. As a result, the phase shift around the entire loop is 360º.

♣ **Advantages**

- It does not require transformers or inductors.
- It can be used to produce very low frequencies.
- The circuit provides good frequency stability.

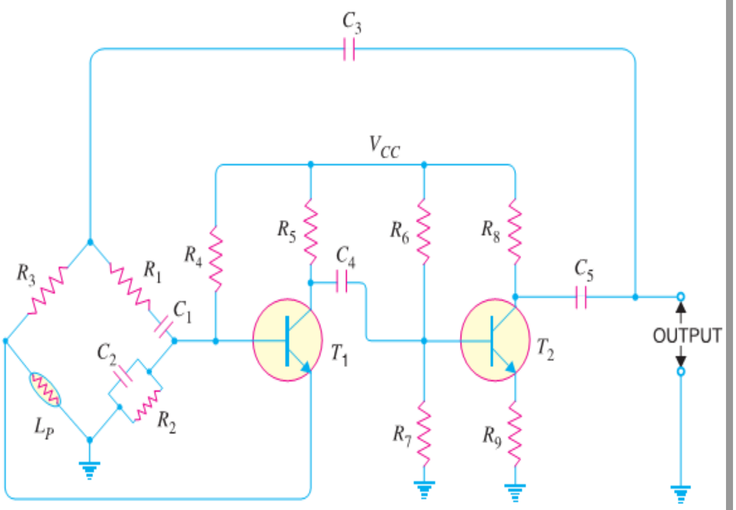
- **Disadvantages**
  - ✘ It is difficult for the circuit to start oscillations as the feedback is generally small.
  - ✘ The circuit gives small output.

❖ WIEN BRIDGE OSCILLATOR:-

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

$$\boxed{\mathbf{f} =}$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, then, $\mathbf{f} =$



- When the circuit is started, bridge circuit produces oscillations of frequency determined.
- 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 tend to increase, more current would provide more negative feedback.
- The result is that the output would return to original value.
- A reverse action would take place if the output tends to decrease.

- **Advantages**
  - **(i)** It gives constant output.
  - **(ii)** It works quite easily.
  - **(iii)** Overall gain is high due to two transistors.
  - **(iv)** The frequency of oscillations can be easily changed by using a potentiometer.
- **Disadvantages**
  - **(v)** It requires two transistors & large number of components.
  - **(vi)** It cannot generate very high frequencies.

❖ LIMITATIONS OF LC AND RC OSCILLATORS:-

- The LC and RC oscillators discussed so far have their own limitations. The major problem in such circuits is that their operating frequency does not remain strictly constant. There are two principal reasons for it viz.,
- (i) As the circuit operates, it will warm up. Consequently, the values of resistors and inductors, which are the frequency determining factors in these circuits, will change with temperature.
- This causes the change in frequency of the oscillator.
- (ii) If any component in the feedback network is changed, it will shift the operating frequency of the oscillator. However, in many applications, it is desirable and necessary to maintain the frequency constant with extreme low tolerances.

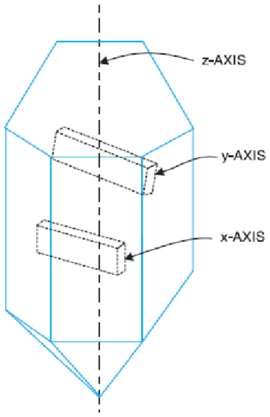
- It is apparent that if we employ LC or RC circuits, a change of temperature may cause the frequencies of adjacent broadcasting stations to overlap.
- In order to maintain constant frequency, piezoelectric crystals are used in place of LC or RC circuits. Oscillators of this type are called crystal oscillators.
- The frequency of a crystal oscillator changes by less than 0.1% due to temperature and other changes.
- Therefore, such oscillators offer the most satisfactory method of stabilizing the frequency and are used in great majority of electronic applications.

❖ PIEZOELECTRIC CRYSTALS:-

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

  The natural frequency f of a crystal is given by: $\mathbf{f} = \frac{K}{t}$ Where,

  K = Constant that depends upon the cut **&** **t** = Thickness of the crystal.



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

❖ WORKING OF QUARTZ CRYSTAL:-

- In order to use crystal in an electronic circuit, it is placed between two metal plates. The arrangement then forms a capacitor with crystal as the dielectric as shown in Fig.
- If an a.c. voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage. However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value.
- This natural frequency is almost constant. Effects of temperature change can be eliminated by mounting the crystal in a temperature-controlled oven as in radio and television transmitters.

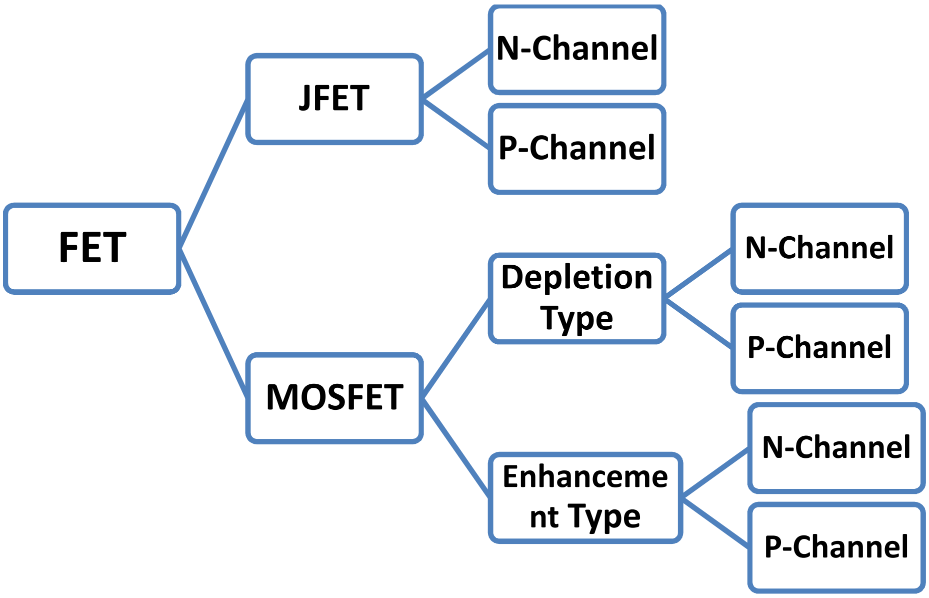
CHAPTER - 7

[FIELD EFFECT TRANSISTOR (FET)]

❖ INTRODUCTION: -

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

❖ CLASSIFICATION OF FIELD EFFECT TRANSISTORS: -



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

❖ DIFFERENTIATION BETWEEN BJT & FET : -

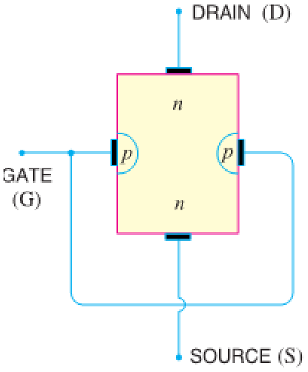
FET	BJT
✘ It means **Field Effect Transistor**	✘ Means **Bipolar Junction Transistor**
✘ Its three terminals are **Source, Gate & Drain**	✘ Its terminals are **Emitter, Base & Collector.**
✘ It is **Unipolar** devices i.e. Current in the device is carried either by electrons or holes.	✘ It is **Bipolar**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

JUNCTION FIELD EFFECT TRANSISTOR (JFET) : -

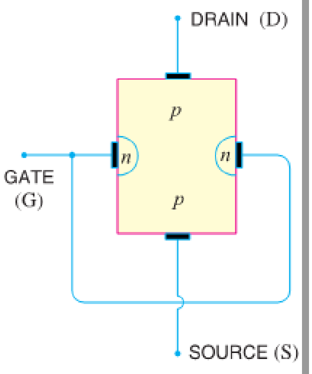
- A junction field effect transistor is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes.
- In a JFET, the current conduction is either by electrons or holes and is controlled by means of an electric field between the gate electrode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

CONSTRUCTIONAL DETAILS.

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



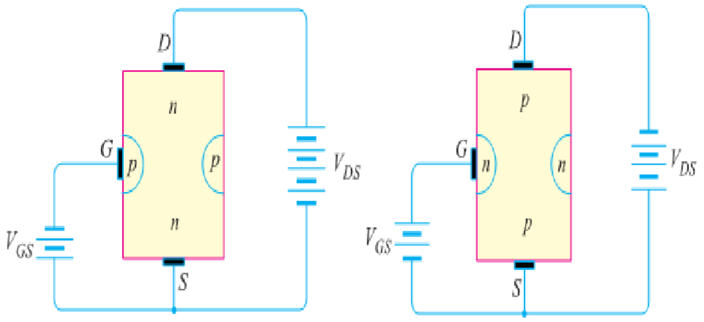
n-Channel JFET



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.
- This is the normal way of JFET connection.
- The drain & source terminals are interchangeable i.e., either end can be used as source and the other end as drain.

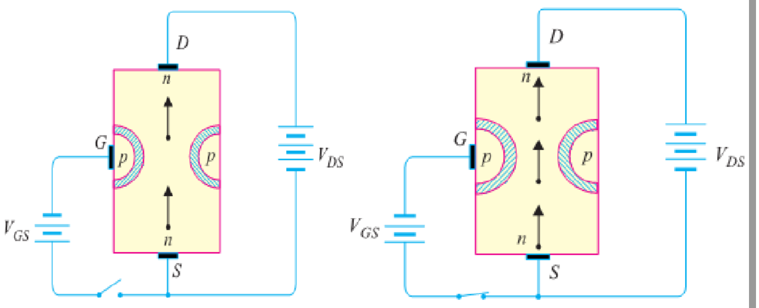


- The following points may be noted:
  - The input circuit (i.e. gate to source) of a JFET is reverse biased. This means that the device has high input impedance.
  - The drain is so biased w.r.t. source that drain current I_D flows from the source to drain.
  - In all JFETs, source current I_S is equal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

WORKING PRINCIPLE OF JFET:-

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

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



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

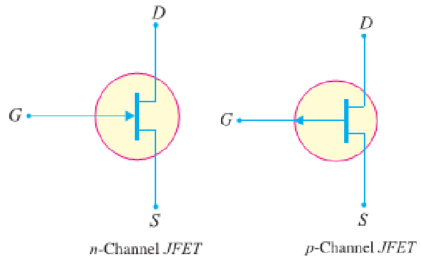
Working: - The working of JFET is as under :

- **(i)** When voltage V_{DS} is applied between drain & source terminals and voltage on the gate is zero [See the above Fig (i)], the two pn junctions at the sides of the bar establish depletion layers.
- The electrons will flow from source to drain through a channel between the depletion layers.

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

❖ JFET AS AN AMPLIFIER :-

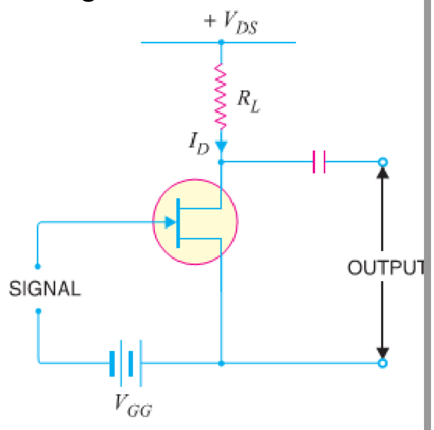
- Fig shows JFET amplifier circuit. The weak signal is applied between gate and source and amplified output is obtained in the drain-source circuit. For the proper operation of JFET, the gate must be negative w.r.t. source i.e., input circuit should always be reverse biased.
- This is achieved either by inserting a battery V_{GG} in the gate circuit or by a circuit known as biasing circuit.



n-Channel JFET p-Channel JFET

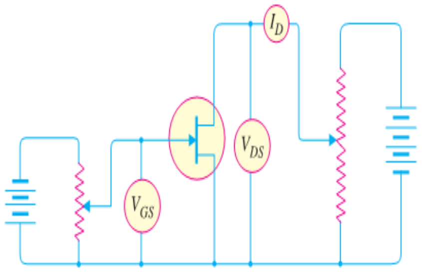
[Schematic Symbol of JFET]

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



❖ OUTPUT CHARACTERISTICS OF JFET

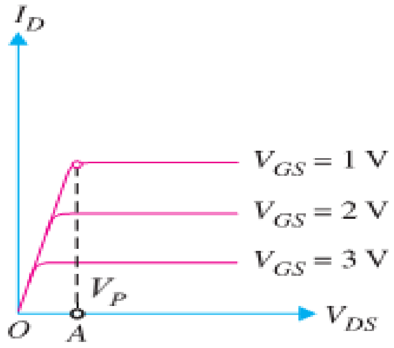
- The curve between drain current (I_D) and drain-source voltage (V_{DS}) of a JFET at constant gate source voltage (V_{GS}) is known as output characteristics of JFET.
- Fig shows circuit for determining output characteristics of JFET.
- Keeping V_{GS} fixed at some value, say 1V, the drain source voltage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



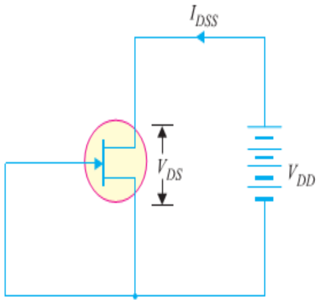
- Repeating similar procedure, output characteristics at other gate-source voltages can be drawn. Fig. shows a family of output characteristics.

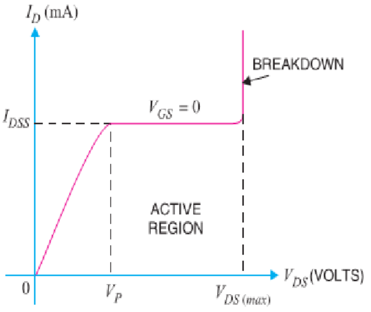
The following points may be noted from the characteristics:

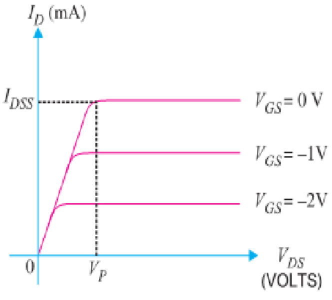
- **(i)** At first, the drain current I_D rises rapidly with drain-source voltage V_{DS} but then becomes constant.
- The drain-source voltage above which drain current becomes constant is known as pinch off voltage. Thus in Fig. OA is the pinch off voltage V_P.
- **(ii)** After pinch off voltage, the channel width becomes so narrow that depletion layers almost touch each other.
- The drain current passes through the small passage between these layers.
- Thus increase in drain current is very small with V_{DS} above pinch off voltage.
- Consequently, drain current remains constant. The characteristics resemble that of a pentode valve.

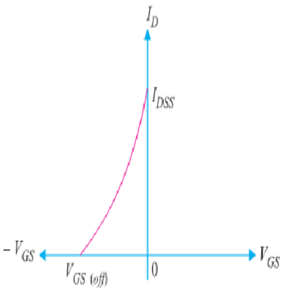


IMPORTANT TERMS : -









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

♣ **(ii) <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,

➔ $g_{fs} = \frac{0.3\text{ mA}}{0.1\text{ V}} = 3\text{mA/V} = 3\times10^{-3}$ A/V or mho or S(Siemens)$=3\times10^{-3} \times 10^{6}\ \mu$ mho = 3000 μ mho (or μS)

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

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

- 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: -

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

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

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

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

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

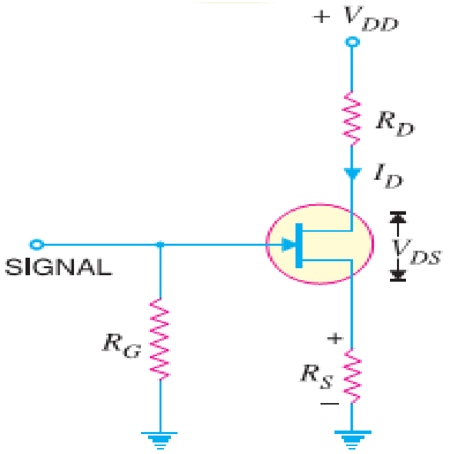
JFET BIASING: -

- For the proper operation of n-channel JFET, gate must be negative w.r.t. source. This can be achieved either by inserting a battery in the gate circuit or by a circuit known as biasing circuit.
- The latter method is preferred because batteries are costly and require frequent replacement.

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

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

SELF-BIAS FOR JFET : -



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

Voltage across R_S, $V_S = I_D R_S$

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

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

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

Operating point: -

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

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

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

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

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

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

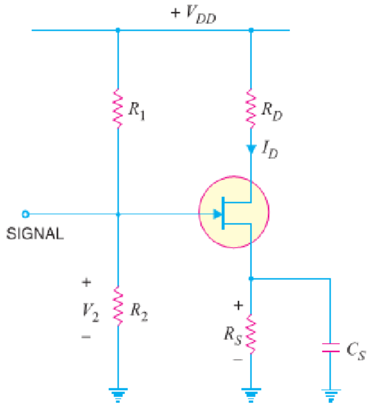
Midpoint Bias: - It is often desirable to bias a JFET near the midpoint of its transfer characteristic curve where $I_D = I_{DSS}/2$. When signal is applied, the midpoint bias allows a maximum amount of drain current swing between I_{DSS} and 0.

- It can be proved that when $V_{GS} = V_{GS\,(off)} / 3.4$, midpoint bias conditions are obtained for I_D.

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

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

JFET with Voltage-Divider Bias :-



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

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

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

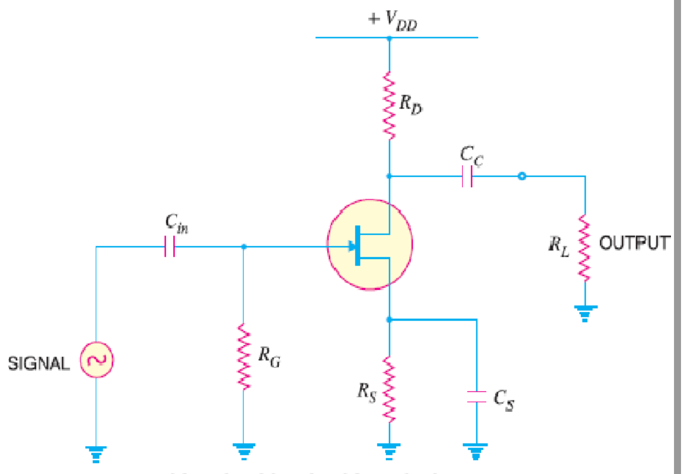
- The circuit is so designed that $I_D R_S$ is larger than V_2 so that V_{GS} is negative. This provides correct bias voltage. We can find the operating point as under:

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

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

JFET Connections: -

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



COMMON SOURCE CONNECTION

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

JFET Applications : -

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

CHAPTER - 8

OPERATIONAL AMPLIFIERS

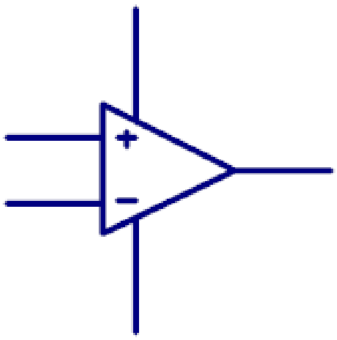
❖ INTRODUCTION

The operational amplifier is an extremely efficient and versatile device. Its applications span the broad electronic industry filling requirements for signal conditioning, special transfer functions, analog instrumentation, analog computation, and special systems design. The analog assets of simplicity and precision characterize circuits utilizing operational amplifiers.

❖ OP-AMP BASICS

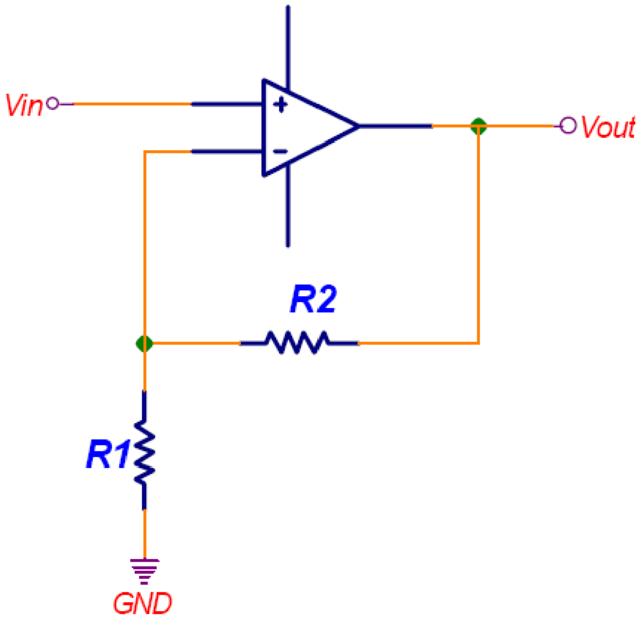
Operational amplifiers are convenient building blocks that can be used to build amplifiers, filters, and even an analog computer. Op-amps are integrated circuits composed of many transistors & resistors such that the resulting circuit follows a certain set of rules. The most common type of op-amp is the voltage feedback type and that's what we'll use.

The schematic representation of an op-amp is shown to the left. There are two input pins (non-inverting and inverting), an output pin, and two power pins. The ideal op-amp has infinite gain. It amplifies the voltage difference 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).



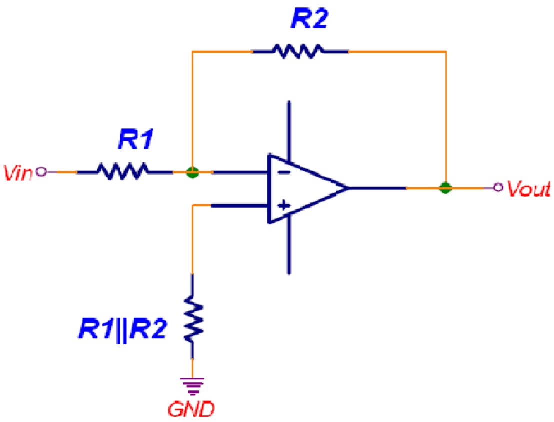
❖ NON-INVERTING AMPLIFIER:

No current flows into the input, **Rin** = ∞ The output adjusts to bring Vin- to the same voltage as Vin+. Therefore Vin- = Vin and since no current flows into Vin- the same current must flow through R1 & R2. Vout is therefore VR1 + VR2 = Vin- + IR2 = Vin- + (Vin/R1)R2.



❖ INVERTING AMPLIFIER

Because no current flows into the input pins there can't be any voltage drop across the R1 ‖ R2. Vin+ is therefore at 0V(this is called a virtual ground). The output will adjustsuch that Vin- is at zero volts. This makes **Rin = R1** (not ∞)**.** The current through R1 & R2 have to be the same since no current goes into the input pins.
Therefore I = Vin/R1. Vout = Vin+ - IR2 = 0 - (Vin/R1)R2. Therefore **Vout = -Vin(R2/R1)**

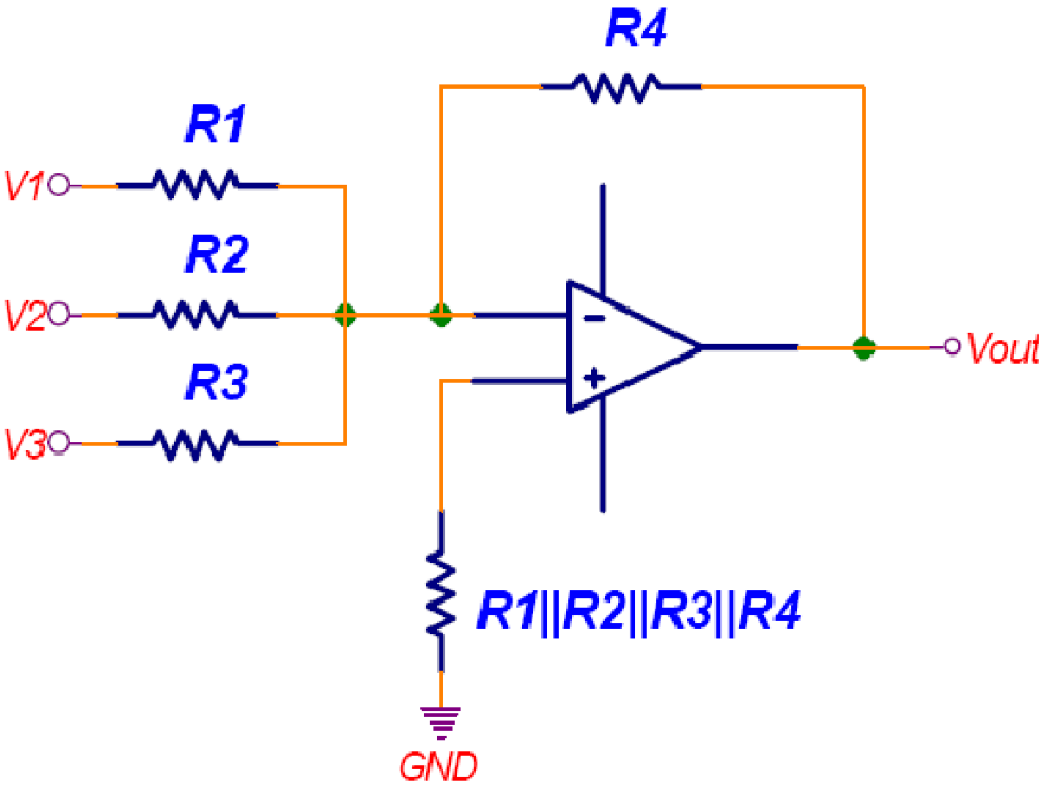


❖ SUMMING AMPLIFIER:

Since Vin- is a virtual ground adding V2 and R2 (and V3 & R3) doesn't change the current flowing through R1 from V1. Each input contributes to the output using the following equation:

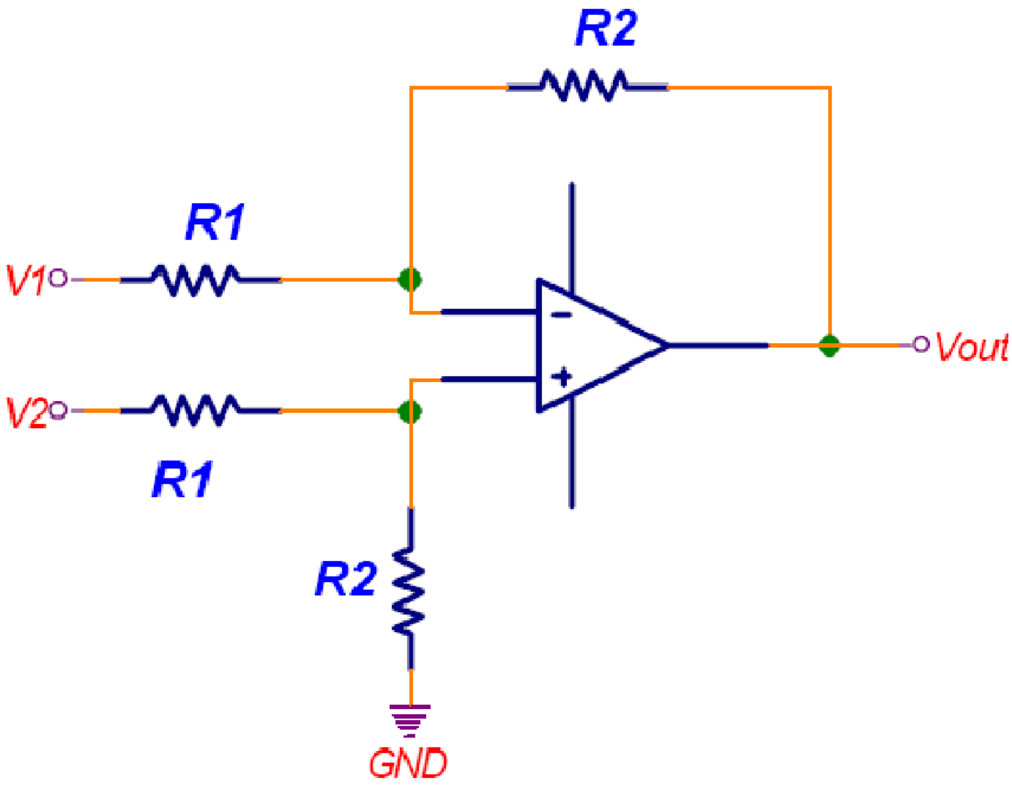
Vout = -V1(R4/R1) - V2(R4/R2) - V3(R4/R3).

The input impedance for the V1 input is still R1, similarly V2's input impedance is R2 and V3's is R3. Most of the time the parallel combination of R1-R4 isn't used and Vin+ is grounded.



❖ DIFFERENCE AMPLIFIER:

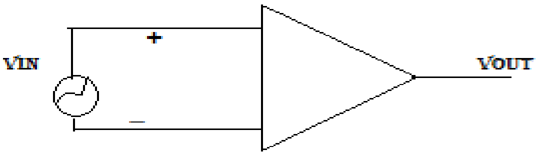
You can work out the gain as before using the two rules (no current flows into the inputs, and the output will adjust to bring Vin- to Vin+). The result is **Vout = 2(V2-V1)*(R2/R1).** Also, **Rin(-) = R1, Rin(+) = R1 + R2**.



❖ COMMON-MODE OP- AMP

These type of op-amp have common mode voltage to both terminals.

It means without connecting the same voltage at both the terminal we may connect one voltage or either inverting or non-inverting terminal and other is connected with short to that voltage.



❖ COMMON MODE REJECTION RATIO

Common mode rejection ratio which is defined as the ratio of differential gain to common mode

CMRR = A_d / A_{cm}

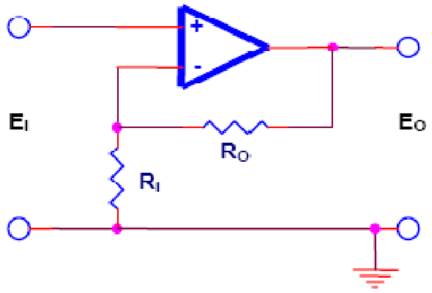
$A_d = V_0 / V_d$, $A_{cm} = V_0 / V_{cm}$

As the gain is generally high so CMRR is used to express as a logarithmic gain 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:

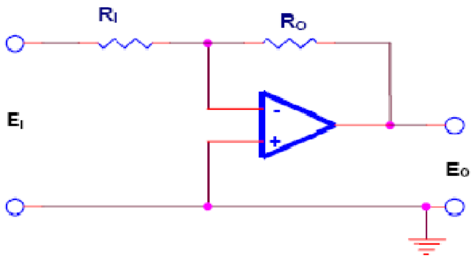
$$E_I = \frac{R_I}{R_I + R_O} \cdot E_O$$

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

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



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

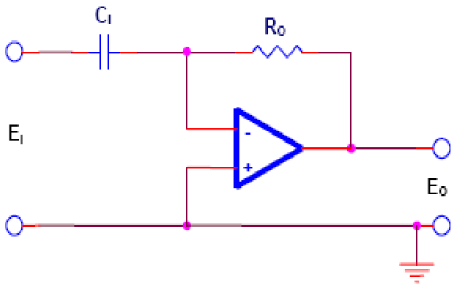
Figure 17. Inverting Amplifier

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.

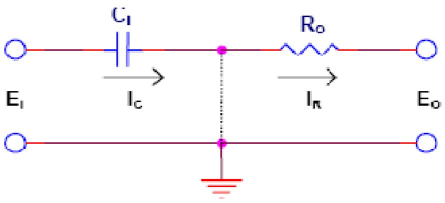


Figure 23. An Intuitive Picture of the Differentiator

Since the inverting input is at ground potential:

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

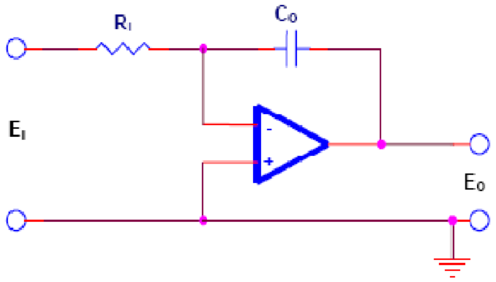
so that:

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

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

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



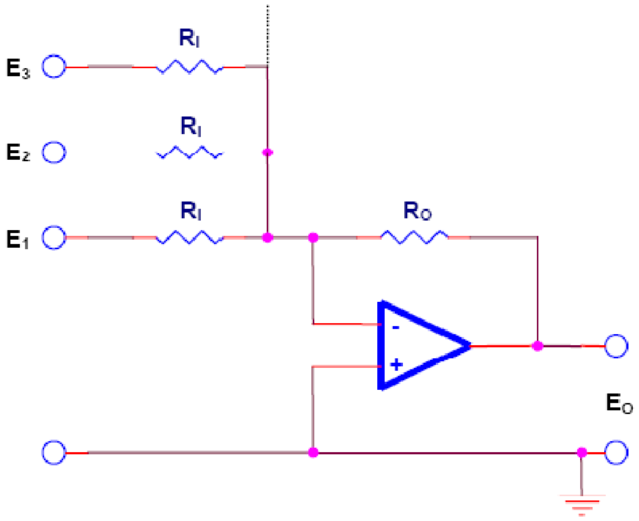
$$E_O = \frac{-1}{R_I C_O} \quad E_I dt$$

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.

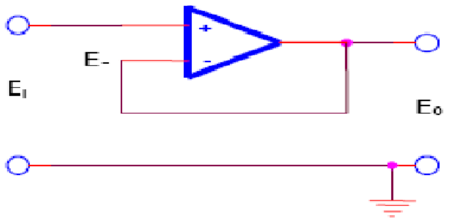


$$E_O = \frac{-R_O}{R_I}(E_1 + E_2 + E_3 + \ldots)$$

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:

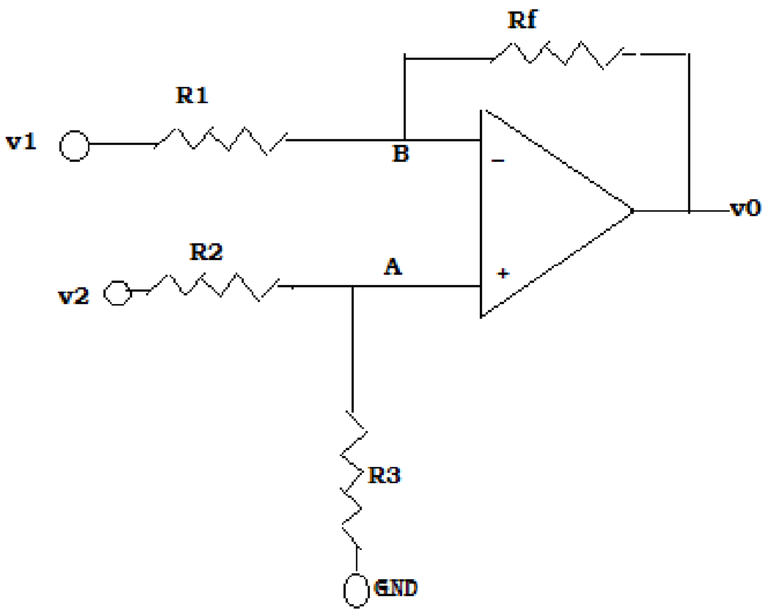
$$E_I-\frac{E_O}{A}=E_O$$

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

$$E_O=E_I$$

❖ VOLTAGE SUBSTRACTOR

- ➢ Generally Subtraction of signals are being performed by substracting one signal from another signal. These types of subtractor are always used in analog signals.



Voltage across terminal A can be found by using 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 analysis 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 $RF = R1 = R2 = R3 = 1\ K\Omega$

The output voltage V0 becomes

$$V0 = V2 - V1$$

SLEW RATE

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

$S.R = \Delta V0 / \Delta T\ (V/\mu s)$

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