

❖ **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

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

➤ The maximum value of V_{CE} will occur when there is no collector current i.e. $I_C = 0$.

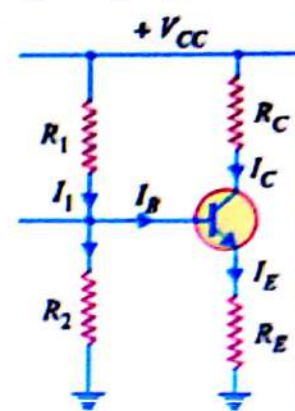
∴

$$\text{Maximum } V_{CE} = V_{CC}$$

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

∴

$$\text{Maximum } I_C = V_{CC} / (R_C + R_E)$$



❖ **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.

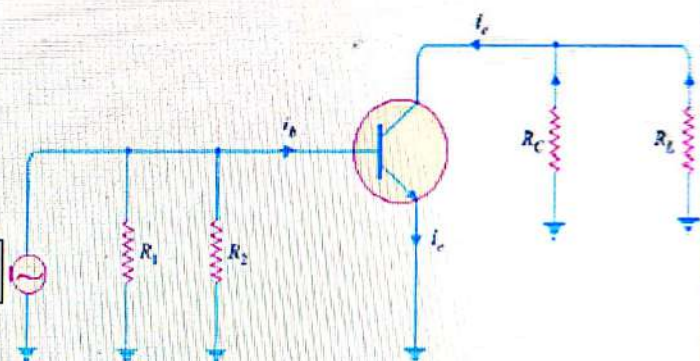
$$\text{A.C. load, } R_{AC} = (R_C R_L / (R_C + R_L))$$

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

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

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

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



❖ 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;

$$V_{CE} = V_{CC} - I_C R_C \quad \text{Or} \quad I_C R_C = V_{CC} - V_{CE}$$

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

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

- 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}

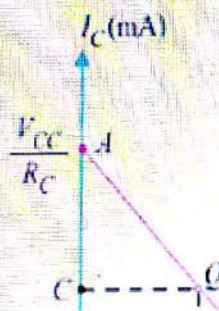
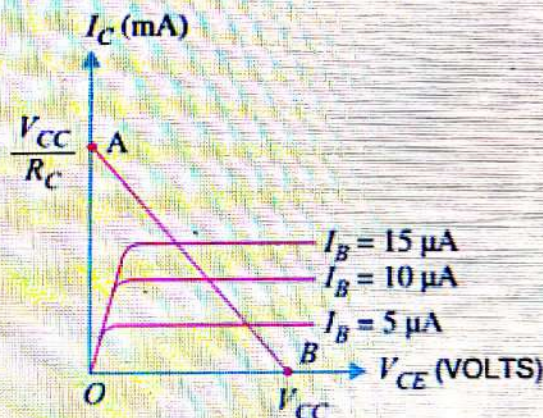
$$\text{i.e.} \quad \text{Max. } V_{CE} = V_{CC} - I_C R_C = V_{CC} \quad (\text{As } I_C = 0)$$

- 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

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

$$\therefore \quad \text{Max. } I_C = V_{CC}/R_C$$



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

➤ 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. $V_{CE} = V_{CC} - I_C R_C \text{ or } 0 = V_{CC} - I_C R_C$

$\therefore \text{Max. } I_C = V_{CC}/R_C$

➤ 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 ($V_{CE \text{ MAX}}$) and
2. Other is maximum collector current point. ($I_{C \text{ MAX}}$)

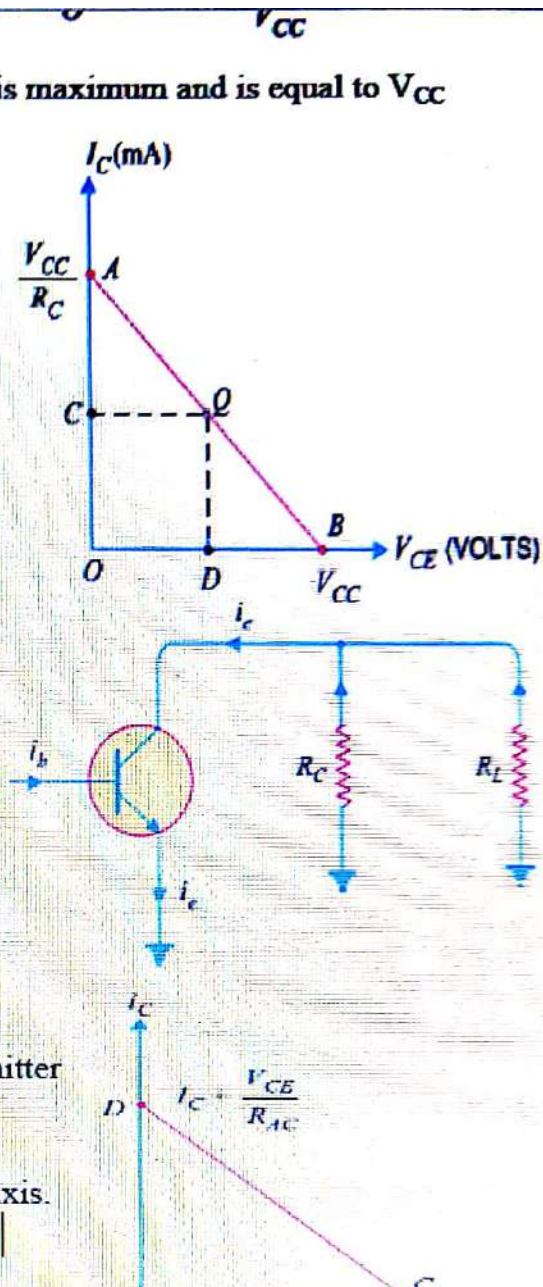
➤ Under the application of A.C. signal, these values are Maximum collector-emitter voltage, $V_{CE \text{ MAX}} = V_{CE} + I_C R_{AC}$.

➤ This locates the point C of the A.C. load line on the collector-emitter voltage axis.

➤ Maximum collector current, $I_{C \text{ MAX}} = I_C + V_{CE}/R_{AC}$

➤ This locates the point D of A.C. load line on the collector-current axis.

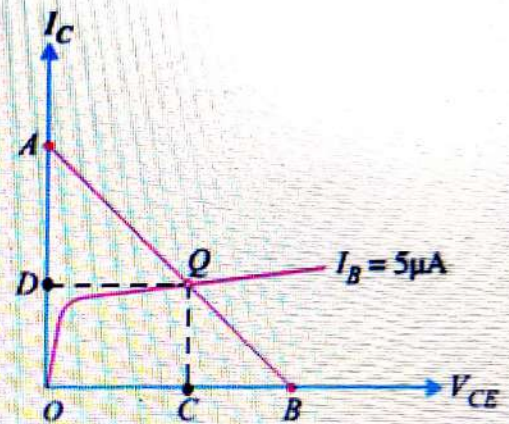
➤ By joining points C and D, the A.C. Load Line CD is constructed.



❖ 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 $5\mu A$. Then I_C and V_{CE} conditions in the circuit must be represented by some point on $I_B = 5\mu A$ 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 $I_B = 5\mu A$, the zero signal values are :

$$V_{CE} = OC \text{ volts} \quad I_C = OD \text{ mA}$$
- 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.



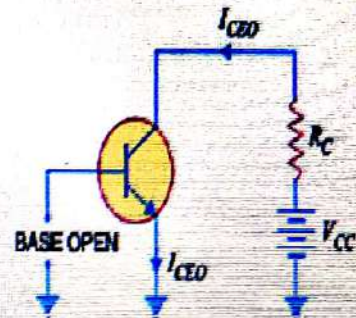
❖ THE LEAKAGE CURRENT:-

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

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

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

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



❖ 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

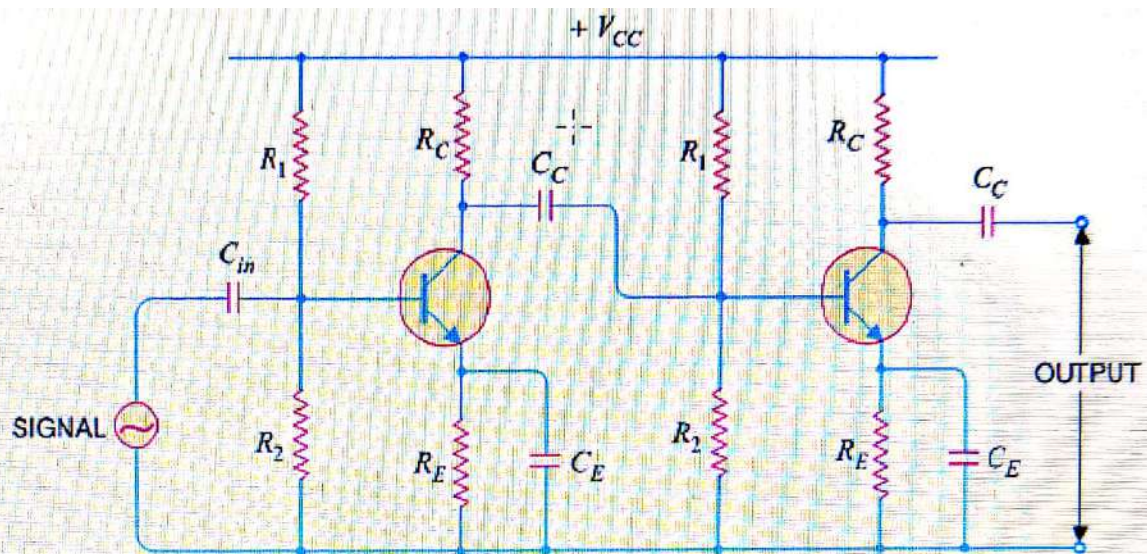
Name of multistage amplifier



➤ 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.

$$\text{Power gain} = \log_{10} \frac{P_{out}}{P_{in}} \text{ bel} \quad (1 \text{ bel} = 10 \text{ db.})$$
- **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 R_C is given to base of next stage through coupling capacitor C_C . The second stage does further amplification of the signal.

FREQUENCY RESPONSE R-C COUPLED TRANSISTOR AMPLIFIER:

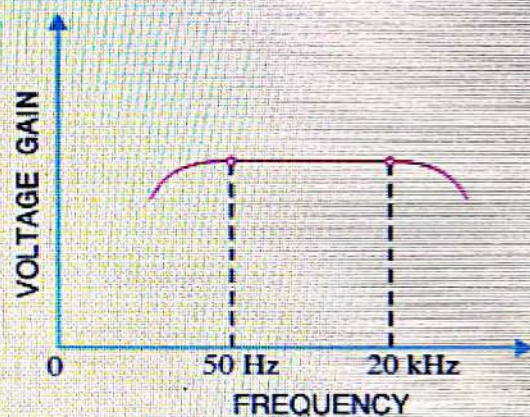
➤ Fig shows the frequency response of a typical RC coupled amplifier. It is clear that voltage gain drops off at low (< 50 Hz) and high (> 20 kHz) frequencies whereas it is uniform over mid-frequency range (50 Hz to 20 kHz).

➤ 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. This 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 C_C 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 very small.

✚ **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.

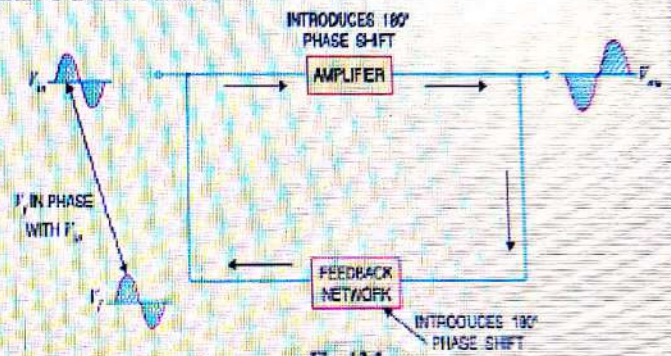
transistor amplifiers.

❖ FEEDBACK:-

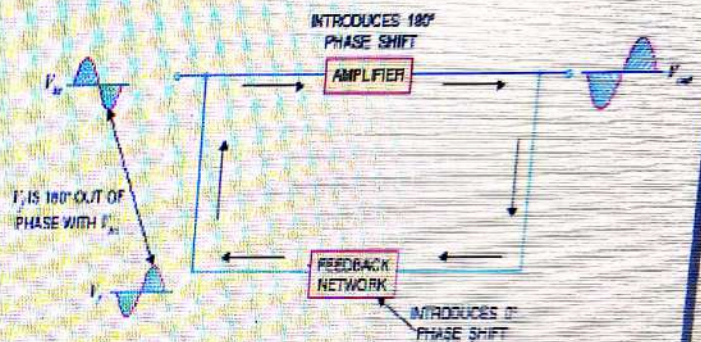
- The process of injecting a fraction of output energy of some device back to input is known as feedback.
- Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers viz Positive Feedback and Negative Feedback.

✚ **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.

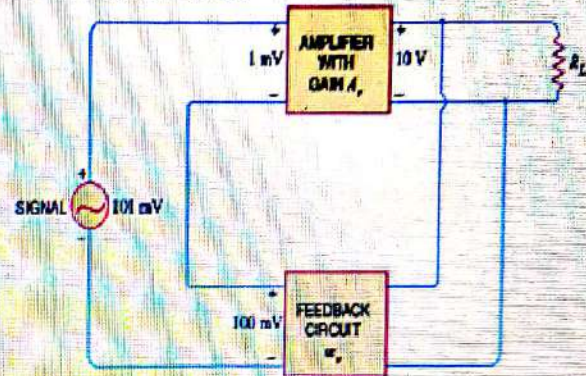


- Therefore, positive feedback is not often employed in amplifiers.
- One important use of positive feedback is in oscillators. If positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired 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,

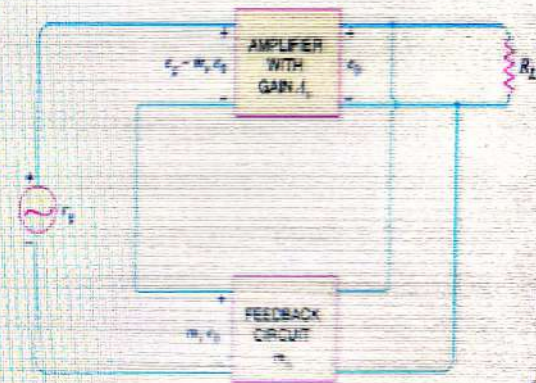


- ♣ Gain of amplifier without feedback, $A_v = (10 \text{ V}) / (1 \text{ mV}) = 10,000$
- ♣ Fraction of output voltage feedback, $m_v = (100 \text{ mV}) / 10 \text{ V} = 0.01$
- ♣ Gain of amplifier with negative feedback, $A_{vf} = 10 \text{ V} / 101 \text{ mV} = 100$
- The following points are worth 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 A_v [open-loop gain]
- ♣ When the loop is "closed" by connecting the feedback circuit, gain decreases to 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 A_v .
- Negative feedback is then applied by feeding a fraction m_v of the output voltage e_0 back to amplifier input.
- Therefore, the actual input to the amplifier is the signal voltage e_g minus feedback voltage $m_v e_0$ i.e.,

$$\text{Actual input to amplifier} = (e_g - m_v e_0)$$



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

i.e.

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

→

$$A_v e_g - A_v m_v e_0 = e_0$$

→

$$e_0 + A_v m_v e_0 = A_v e_g$$

→

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

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

But e_0/e_g is the voltage gain of the amplifier with feedback.

∴ Voltage gain with negative feedback is

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

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

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

❖ ADVANTAGES OF NEGATIVE VOLTAGE FEEDBACK:-

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

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

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

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

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

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

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

It can be proved mathematically that:

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

Where

D = distortion in amplifier without feedback

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

Where

D = distortion in amplifier without feedback

D_{vf} = distortion in amplifier with negative feedback

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