11

Multistage Transistor Amplifiers

INTRODUCTION

The output from a single stage amplifier is usually insufficient to drive an output device. Inther words, the gain of a single amplifier is inadequate for practical purposes. Conse quently, 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. It may be emphasised here that a practical amplifier is always a multistage amplifier. For example, in a transistor radio receiver, the number of amplification stages may be six or more. In this chapter, we shall focus our attention on the various multistage transistor amplifiers and their practical applications.

11.1 Multistage Transistor 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. Fig. 11.1 shows the block diagram of a 3-stage amplifier. Each stage consists of one transistor and associated circuitry and is coupled to the next stage through a coupling device. 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

Fig. 11.1

(*i*) In *RC* coupling, a capacitor is used as the coupling device. The capacitor connects the output of one stage to the input of the next stage in order to pass the a.c. signal on while blocking the d.c. bias voltages.

(*ii*) In transformer coupling, transformer is used as the coupling device. The transformer coupling provides the same two functions (*viz.* to pass the signal on and blocking d.c.) but permits in addition impedance matching.

(*iii*) In direct coupling or d.c. coupling, the individual amplifier stage bias conditions are so designed that the two stages may be directly connected without the necessity for d.c. isolation.

11.2 Role of Capacitors in Transistor Amplifiers

Regardless of the manner in which a capacitor is connected in a transistor amplifier, its behaviour towards d.c. and a.c. is as follows. *A capacitor blocks d.c. i.e. a capacitor behaves as an "open**" to d.c.* Therefore, for d.c. analysis, we can remove the capacitors from the transistor amplifier circuit. A capacitor offers reactance (= $1/2\pi fC$) to a.c. depending upon the values of f and C. In practical transistor circuits, the size of capacitors is so selected that they offer negligible (ideally zero) reactance to the range of frequencies handled by the circuits. Therefore, *for a.c. analysis, we can replace the capacitors by a short i.e. by a wire.* The capacitors serve the following two roles in transistor amplifiers :

1. As coupling capacitors
2. As bypass capacitors

1. As coupling capacitors. In most applications, you will not see a single transistor amplifier. Rather we use a multistage amplifier *i.e.* a number of transistor amplifiers are connected in series or cascaded. The capacitors are commonly used to connect one amplifier stage to another. When a capacitor is used for this purpose, it is called a *coupling capacitor.* Fig. 11.2 shows the coupling capacitors (C_{C1}; C_{C2} ; C_{C3} and C_{C4}) in a multistage amplifier. A coupling capacitor performs the following two functions :

(*i*) It blocks d.c. *i.e.* it provides d.c. isolation between the two stages of a multistage amplifier.

* The term *cascaded* means *connected in series.*

** $X_C = \dfrac{1}{2\pi fC}$. For d.c., $f = 0$ so that $X_C \rightarrow \infty$. Therefore, a capacitor behaves as an open to d.c.

(*ii*) It passes the a.c. signal from one stage to the next with little or no distortion.

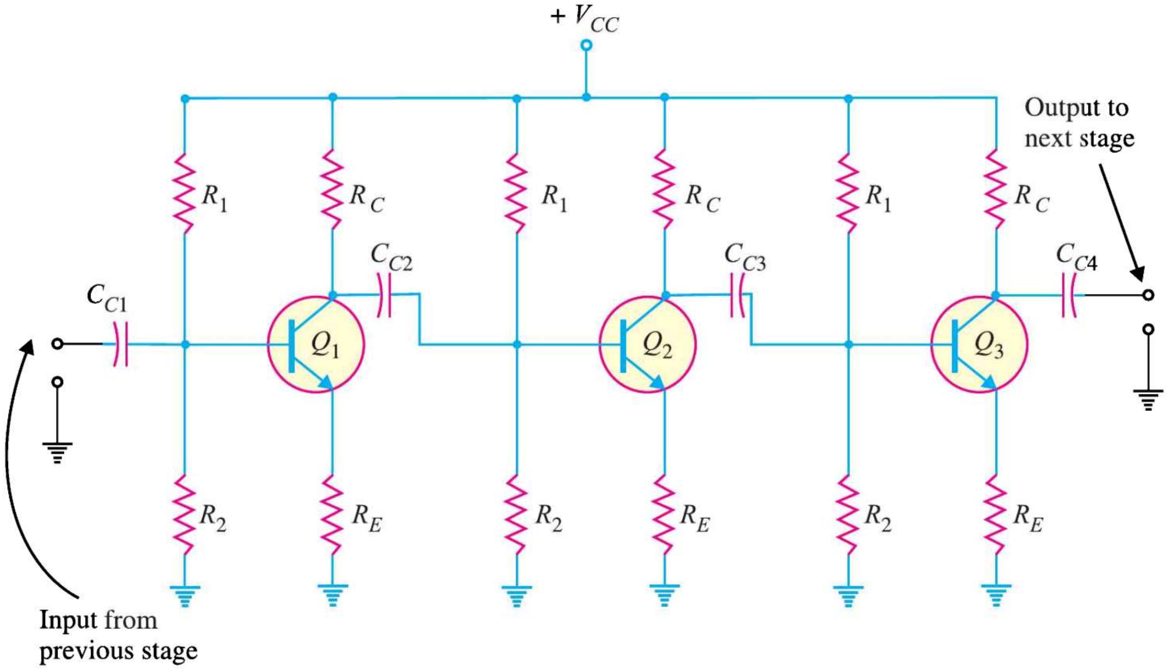


Fig. 11.2

2. As bypass capacitors. Like a coupling capacitor, a bypass capacitor also blocks d.c. and behaves as a short or wire (due to proper selection of capacitor size) to an a.c. signal. But it is used for a different purpose. A bypass capacitor is connected in parallel with a circuit component (*e.g.* resistor) to bypass the a.c. signal and hence the name. Fig. 11.3 shows a bypass capacitor C_E connected across the emitter resistance R_E. Since C_E behaves as a short to the a.c. signal, the whole of a.c. signal (i_e) passes through it. Note that C_E keeps the emitter at a.c. ground. Thus for a.c. purposes, R_E does not exist. We have already seen in the previous chapter that C_E plays an important role in determining the voltage gain of the amplifier circuit. If C_E is removed, the voltage gain of the amplifier is greatly reduced. Note that C_{in} is the coupling capacitor in this circuit.

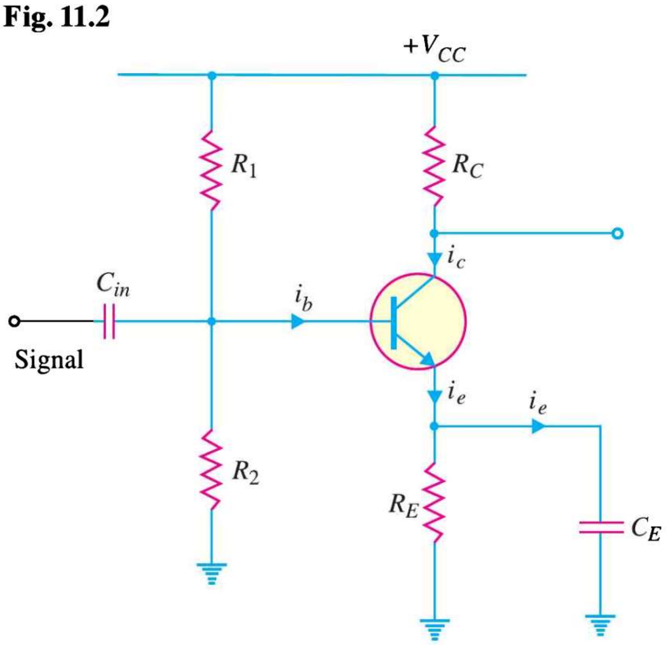


Fig. 11.3

11.3 Important Terms

In the study of multistage amplifiers, we shall frequently come across the terms *gain*, *frequency response*, *decibel gain* and *bandwidth*. These terms stand discussed below :

(*i*) **Gain.** *The ratio of the output *electrical quantity to the input one of the amplifier is called its* **gain.**

* Accordingly, it can be current gain or voltage gain or power gain.

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

$$^*G = G_1 \times G_2 \times G_3$$

It is worthwhile to mention here that in practice, total gain G is less than $G_1 \times G_2 \times G_3$ due to the loading effect of next stages.

(*ii*) Frequency response. The voltage gain of an amplifier varies with signal frequency. It is because reactance of the capacitors in the circuit changes with signal frequency and hence affects the output voltage. The curve between voltage gain and signal frequency of an amplifier is known as *frequency response*. Fig. 11.4 shows the frequency response of a typical amplifier. The gain of the amplifier increases as the frequency increases from zero till it becomes maximum at f_r, called *resonant frequency*. If the frequency of signal increases beyond f_r, the gain decreases.

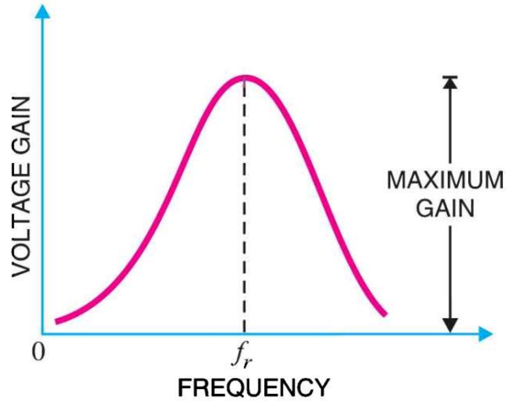


Fig. 11.4

The performance of an amplifier depends to a considerable extent upon its frequency response. While designing an amplifier, appropriate steps must be taken to ensure that gain is essentially uniform over some specified frequency range. For instance, in case of an audio amplifier, which is used to amplify speech or music, it is necessary that all the frequencies in the sound spectrum (*i.e.* 20 Hz to 20 kHz) should be uniformly amplified otherwise speaker will give a distorted sound output.

(*iii*) Decibel gain. Although the gain of an amplifier can be expressed as a number, yet it is of 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.*

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

$$1 \text{ bel} = 10 \textit{ db}$$

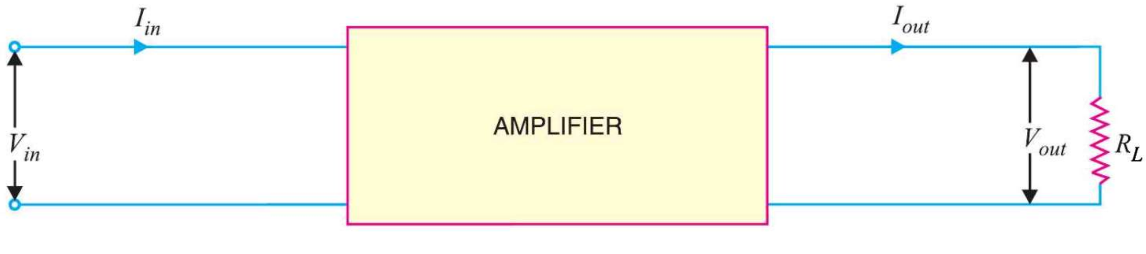


Fig. 11.5

* This can be easily proved. Suppose the input to first stage is V.

$$\text{Output of first stage} = G_1V$$

$$\text{Output of second stage} = (G_1V)\,G_2 = G_1G_2V$$

$$\text{Output of third stage} = (G_1G_2V)G_3 = G_1G_2G_3V$$

$$\text{Total gain, } G = \frac{\text{Output of third stage}}{V}$$

or

$$G = \frac{G_1\,G_2\,G_3\,V}{V} = G_1 \times G_2 \times G_3$$

$\therefore$ Power gain $= 10 \log_{10} \frac{P_{out}}{P_{in}}$ *db*

If the two powers are developed in the same resistance or equal resistances, then,

$$P_1 = \frac{V_{in}^2}{R} = I_{in}^2 R$$

$$P_2 = \frac{V_{out}^2}{R} = I_{out}^2 R$$

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

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

Advantages. The following are the advantages of expressing the gain in *db* :

(*a*) The unit *db* is a logarithmic unit. Our ear response is also logarithmic *i.e.* loudness of sound heard by ear is not according to the intensity of sound but according to the log of intensity of sound. Thus if the intensity of sound given by speaker (*i.e.* power) is increased 100 times, our ears hear a doubling effect ($\log_{10} 100 = 2$) *i.e.* as if loudness were doubled instead of made 100 times. Hence, this unit tallies with the natural response of our ears.

(*b*) When the gains are expressed in *db*, the overall gain of a multistage amplifier is the sum of gains of individual stages in *db*. Thus referring to Fig. 11.6,

$$\text{Gain as number} = \frac{V_2}{V_1} \times \frac{V_3}{V_2}$$

$$\text{Gain in } db = 20 \log_{10} \frac{V_2}{V_1} \times \frac{V_3}{V_2}$$

$$= 20 \log_{10} \frac{V_2}{V_1} + 20 \log_{10} \frac{V_3}{V_2}$$

$$= \text{1st stage gain in } db + \text{2nd stage gain in } db$$

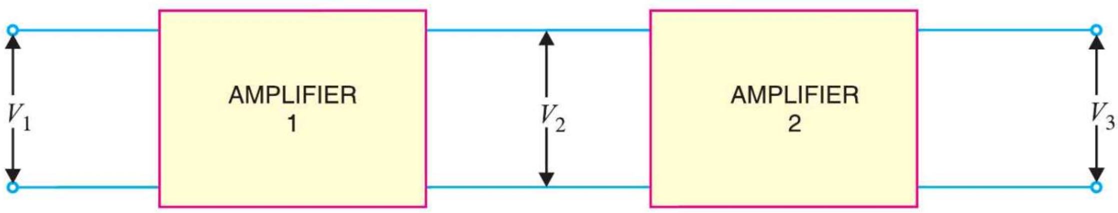


Fig. 11.6

However, absolute gain is obtained by multiplying the gains of individual stages. Obviously, it is easier to add than to multiply.

(*iv*) 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.**

* The human ear is not a very sensitive hearing device. It has been found that if the gain falls to 70.7% of maximum gain, the ear cannot detect the change. For instance, if the gain of an amplifier is 100, then even if the gain falls to 70.7, the ear cannot detect the change in intensity of sound and hence no distortion will be heard. However, if the gain falls below 70.7, the ear will hear clear distortion.

The voltage gain of an amplifier changes with frequency. Referring to the frequency response in Fig. 11.7, 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 former (f_1) is called *lower cut-off frequency* and the latter (f_2) is known as *upper cut-off frequency*. For distortionless amplification, it is important that signal frequency range must be within the bandwidth of the amplifier.

40 decibels phone

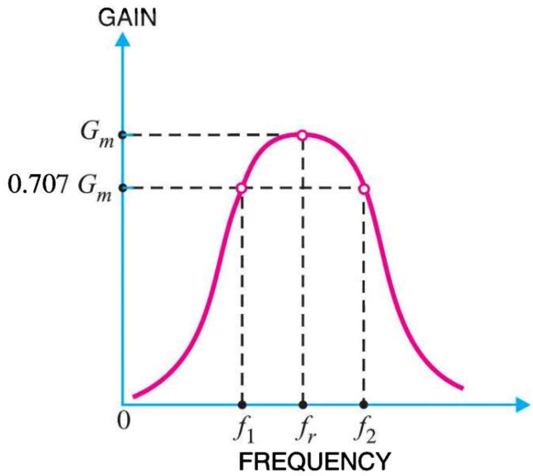


Fig. 11.7

The bandwidth of an amplifier can also be defined in terms of *db*. Suppose the maximum voltage gain of an amplifier is 100. Then 70.7% of it is 70.7.

∴ Fall in voltage gain from maximum gain

$$= 20 \log_{10} 100 - 20 \log_{10} 70.7$$

$$= 20 \log_{10} \frac{100}{70.7} \ db$$

$$= 20 \log_{10} 1.4142 \ db = 3 \ db$$

Hence **bandwidth** *of an amplifier is the range of frequency at the limits of which its voltage gain falls by 3 db from the maximum gain.*

The frequency f_1 or f_2 is also called *3-db frequency* or *half-power frequency.*

The 3-*db* designation comes from the fact that voltage gain at these frequencies is 3*db* below the maximum value. The term half-power is used because when voltage is down to 0.707 of its maximum value, the power (proportional to V^2) is down to $(0.707)^2$ or one-half of its maximum value.

Example 11.1. *Find the gain in db in the following cases :*

(i) Voltage gain of 30 *(ii) Power gain of 100*

Solution.

(*i*) Voltage gain $= 20 \log_{10} 30 \ db$ = **29.54 db**

(*ii*) Power gain $= 10 \log_{10} 100 \ db$ = **20 db**

Example 11.2. *Express the following gains as a number :*

(i) Power gain of 40 db *(ii) Power gain of 43 db*

Solution.

(*i*) Power gain = 40 *db* = 4 *bel*

If we want to find the gain as a number, we should work from logarithm back to the original number.

$$\therefore \quad P_1 = \frac{40\text{W}}{\text{antilog } 2.5} = \frac{40\text{W}}{3.16 \times 10^2} = \frac{40\text{W}}{316} = \mathbf{126.5\ mW}$$

(ii) $$\text{Voltage gain in } db = 20 \log_{10} \frac{V_2}{V_1} \quad \text{or} \quad 40 = 20 \log_{10} \frac{V_2}{V_1}$$

$$\therefore \quad \frac{V_2}{V_1} = \text{antilog } 2 = 100$$

Now $$V_2 = \sqrt{P_2 R} = \sqrt{40\text{W} \times 10\ \Omega} = 20\text{ V}$$

$$\therefore \quad V_1 = \frac{V_2}{100} = \frac{20\text{V}}{100} = \mathbf{200\ mV}$$

Example 11.10. *In an amplifier, the maximum voltage gain is 2000 and occurs at 2 kHz. It falls to 1414 at 10 kHz and 50 Hz. Find :*

(i) Bandwidth (ii) Lower cut-off frequency (iii) Upper cut-off frequency.

Solution.

(i) Referring to the frequency response in Fig. 11.8, the maximum gain is 2000. Then 70.7% of this gain is 0.707 × 2000 = 1414. It is given that gain is 1414 at 50 Hz and 10 kHz. As bandwidth is the range of frequency over which gain is equal or greater than 70.7% of maximum gain,

∴ Bandwidth = **50 Hz to 10 kHz**

(ii) The frequency (on lower side) at which the voltage gain of the amplifier is exactly 70.7% of the maximum gain is known as *lower cut-off frequency*. Referring to Fig. 11.8, it is clear that :

Lower cut-off frequency = **50 Hz**

(iii) The frequency (on the higher side) at which the voltage gain of the amplifier is exactly 70.7% of the maximum gain is known as *upper cut-off frequency*. Referring to Fig. 11.8, it is clear that:

Upper cut-off frequency = **10 kHz**

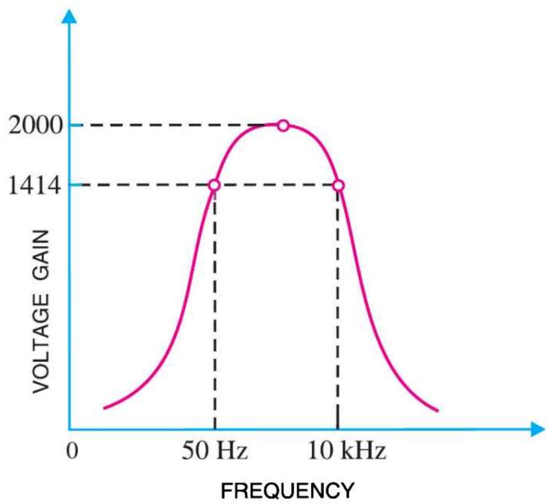


Fig. 11.8

Comments. As bandwidth of the amplifier is 50 Hz to 10 kHz, therefore, it will amplify the signal frequencies lying in this range without any distortion. However, if the signal frequency is not in this range, then there will be distortion in the output.

Note. The *db* power rating of communication equipment is normally less than 50 *db*.

11.4 Properties of db Gain

The power gain expressed as a number is called ordinary power gain. Similarly, the voltage gain expressed as a number is called ordinary voltage gain.

1. Properties of *db* power gain. The following are the useful rules for *db* power gain :

(i) Each time the ordinary power gain increases (decreases) by a factor of 10, the db power gain increases (decreases) by 10 db.

For example, suppose the ordinary power gain increases from 100 to 1000 (*i.e.* by a factor of 10).

$\therefore$ Increase in *db* power gain $= 10 \log_{10} 1000 - 10 \log_{10} 100$

$= 30 - 20 = 10$ *db*

This property also applies for the decrease in power gain.

(*ii*) *Each time the ordinary power gain increases (decreases) by a factor of 2, the db power gain increases (decreases) by 3 db.*

For example, suppose the power gain increases from 100 to 200 (*i.e.* by a factor of 2).

$\therefore$ Increase in *db* power gain $= 10 \log_{10} 200 - 10 \log_{10} 100$

$= 23 - 20 = 3$ *db*

2. Properties of db voltage gain. The following are the useful rules for *db* voltage gain :

(*i*) *Each time the ordinary voltage gain increases (decreases) by a factor of 10, the db voltage gain increases (decreases) by 20 db.*

For example, suppose the voltage gain increases from 100 to 1000 (*i.e.* by a factor of 10).

$\therefore$ Increase in *db* voltage gain $= 20 \log_{10} 1000 - 20 \log_{10} 100$

$= 60 - 40 = 20$ *db*

(*ii*) *Each time the ordinary voltage gain increases (decreases) by a factor of 2, the db voltage gain increases (decreases) by 6 db.*

For example, suppose the voltage gain increases from 100 to 200 (*i.e.* by a factor of 2).

$\therefore$ Increase in *db* voltage gain $= 20 \log_{10} 200 - 20 \log_{10} 100$

$= 46 - 40 = 6$ *db*

11.5 RC 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. 11.9 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 stabilisation 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.

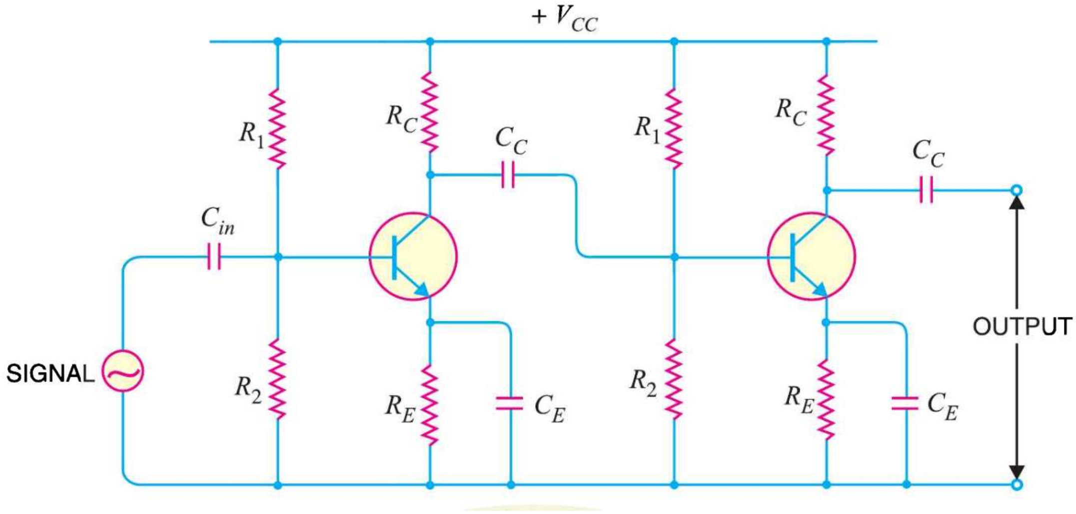


Fig. 11.9

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. 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. For instance, in a 3-stage amplifier, the gain of first and second stages will be reduced due to loading effect of next stage. However, the gain of the third stage which has no loading effect of subsequent stage, remains unchanged. The overall gain shall be equal to the product of the gains of three stages.

Frequency response. Fig.11.10 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), 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.

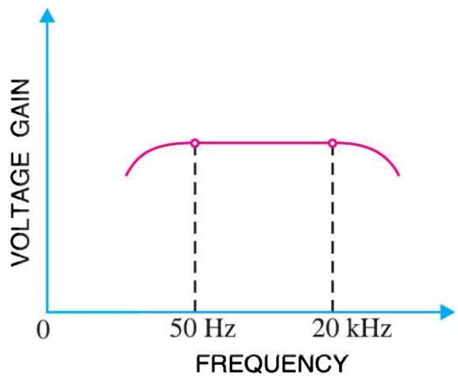


Fig. 11.10

(*ii*) *At high frequencies* (> 20 kHz), 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.

(*iii*) *At mid-frequencies* (50 Hz to 20 kHz), 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 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.


RC Coupled Amplifiers

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.

Note. When there is an even number of cascaded stages (2, 4, 6 etc), the output signal is not inverted from the input. When the number of stages is odd (1, 3, 5 etc.), the output signal is inverted from the input.

Example 11.11 *A single stage amplifier has a voltage gain of 60. The collector load R_C = 500 Ω and the input impedance is 1kΩ. Calculate the overall gain when two such stages are cascaded through R-C coupling. Comment on the result.*

Solution. The gain of second stage remains 60 because it has no loading effect of any stage. However, the gain of first stage is less than 60 due to the loading effect of the input impedance of second stage.

$$\therefore \quad \text{Gain of second stage} = 60$$

$$\text{Effective load of first stage} = R_C \parallel R_{in} = \frac{500 \times 1000}{500 + 1000} = 333\ \Omega$$

$$\text{Gain of first stage} = 60 \times 333/500 = 39.96$$

$$\text{Total gain} = 60 \times 39.96 = \mathbf{2397}$$

Comments. The gain of individual stage is 60. But when two stages are coupled, the gain is *not* $60 \times 60 = 3600$ as might be expected rather it is less and is equal to 2397 in this case. It is because the first stage has a loading effect of the input impedance of second stage and consequently its gain is reduced. However, the second stage has no loading effect of any subsequent stage. Hence, the gain of second stage remains 60.

Example 11.12. *Fig. 11.11 shows two-stage RC coupled amplifier. If the input resistance R_{in} of each stage is 1kΩ, find : (i) voltage gain of first stage (ii) voltage gain of second stage (iii) total voltage gain.*

Solution.

$$R_{in} = 1\ \text{k}\Omega\ ; \quad \beta = 100\ ; \quad R_C = 2\ \text{k}\Omega$$

(*i*) The first stage has a loading of input resistance of second stage.

$$\therefore \quad \text{Effective load of first stage, } R_{AC} = R_C \parallel R_{in} = \frac{2 \times 1}{2 + 1} = 0.66\ \text{k}\Omega$$

$$\therefore \quad \text{Voltage gain of first stage} = \beta \times R_{AC} / R_{in} = 100 \times 0.66/1 = \mathbf{66}$$

(*ii*) The collector of the second stage sees a load of only R_C (= 2 kΩ) as there is no loading effect of any subsequent stage.

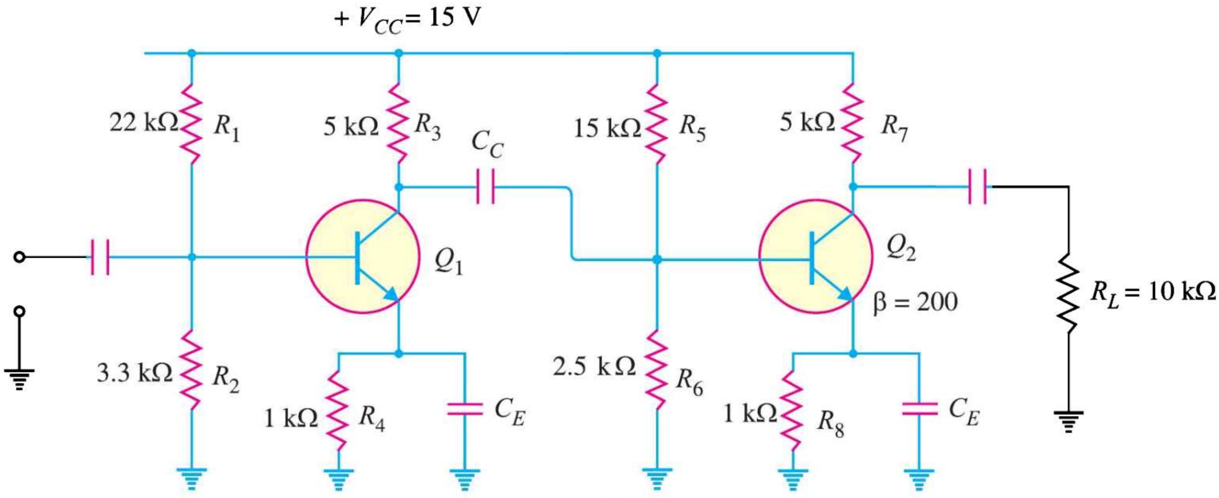


Fig. 11.14

$$\text{Voltage across } R_6 = \frac{V_{CC}}{R_5 + R_6} \times R_6 = \frac{15}{15 + 2.5} \times 2.5 = 2.14 \text{ V}$$

$$\text{Voltage across } R_8 = 2.14 - 0.7 = 1.44 \text{ V}$$

$$\text{Emitter current in } R_8, I_E = \frac{1.44 \text{ V}}{R_8} = \frac{1.44 \text{ V}}{1 \text{ k}\Omega} = 1.44 \text{ mA}$$

$$r'_e \text{ for second stage} = \frac{25 \text{ mV}}{I_E} = \frac{25 \text{ mV}}{1.44 \text{ mA}} = 17.4 \ \Omega$$

Similarly, it can be shown that r'_e for the first stage is 19.8 Ω .

$$Z_{in(base)} \text{ for second stage} = \beta \times r'_e \text{ for second stage} = 200 \times (17.4 \ \Omega) = 3.48 \text{ k}\Omega$$

$$\text{Input impedance of the second stage, } Z_{in} = R_5 \parallel R_6 \parallel Z_{in(base)}$$

$$= 15 \text{ k}\Omega \parallel 2.5 \text{ k}\Omega \parallel 3.48 \text{ k}\Omega = 1.33 \text{ k}\Omega$$

∴ Effective collector load for first stage is

$$R_{AC} = R_3 \parallel Z_{in} = 5 \text{ k}\Omega \parallel 1.33 \text{ k}\Omega = 1.05 \text{ k}\Omega$$

$$\text{Voltage gain of first stage} = \frac{R_{AC}}{r'_e \text{ for first stage}} = \frac{1.05 \text{ k}\Omega}{19.8 \ \Omega} = \mathbf{53}$$

***(ii)* Voltage gain of second stage.** The load R_L (= 10 kΩ) is the load for the second stage.

∴ Effective collector load for second stage is

$$R_{AC} = R_7 \parallel R_L = 5 \text{ k}\Omega \parallel 10 \text{ k}\Omega = 3.33 \text{ k}\Omega$$

$$\therefore \quad \text{Voltage gain of second stage} = \frac{R_{AC}}{r'_e \text{ for second stage}} = \frac{3.33 \text{ k}\Omega}{17.4 \ \Omega} = \mathbf{191.4}$$

***(iii)* Overall voltage gain.** Overall voltage gain = First stage gain × Second stage gain

= 53 × 191.4 = **10144**

11.6 Transformer-Coupled Amplifier

The main reason for low voltage and power gain of *RC* coupled amplifier is that the effective load (R_{AC}) of each stage is *decreased due to the low resistance presented by the input of each stage to the preceding stage. If the effective load resistance of each stage could be increased, the voltage and power gain could be increased. This can be achieved by transformer coupling. By the use of **im-

* The input impedance of an amplifier is low while its output impedance is very high. When they are coupled to make a multistage amplifier, the high output impedance of one stage comes in parallel with the low input impedance of next state. Hence effective load (R_{AC}) is decreased.

** The resistance on the secondary side of a transformer reflected on the primary depends upon the turn ratio of the transformer.

pedance-changing properties of transformer, the low resistance of a stage (or load) can be reflected as a high load resistance to the previous stage.

Transformer coupling is generally employed when the load is small. It is mostly used for power amplification. Fig. 11.15 shows two stages of transformer coupled amplifier. A coupling transformer is used to feed the output of one stage to the input of the next stage. The primary *P* of this transformer is made the collector load and its secondary *S* gives input to the next stage.

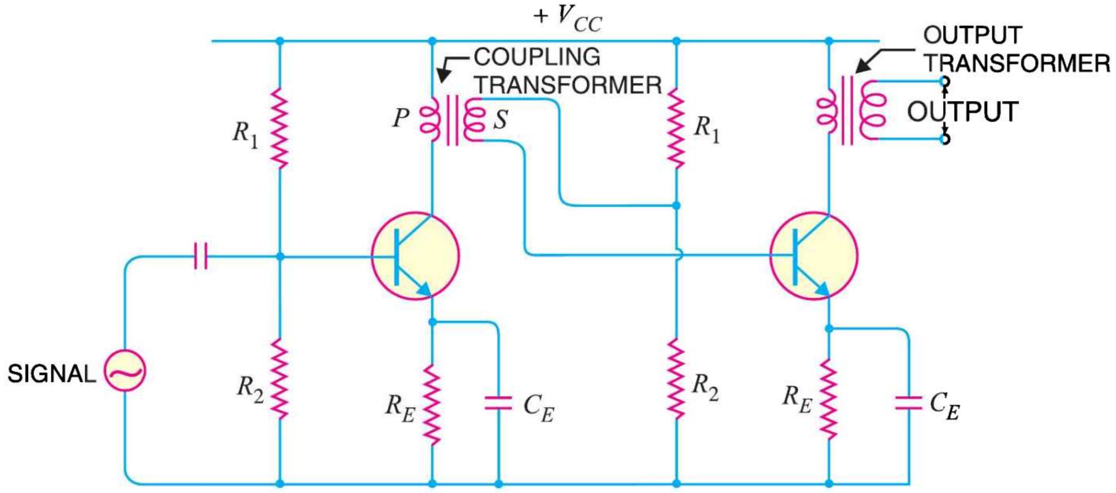


Fig. 11.15

Operation. When an a.c. signal is applied to the base of first transistor, it appears in the amplified form across primary *P* of the coupling transformer. The voltage developed across primary is transferred to the input of the next stage by the transformer secondary as shown in Fig.11.15. The second stage renders amplification in an exactly similar manner.

Frequency response. The frequency response of a transformer coupled amplifier is shown in Fig.11.16. It is clear that frequency response is rather poor *i.e.* gain is constant only over a small range of frequency. The output voltage is equal to the collector current multiplied by reactance of primary. At low frequencies, the reactance of primary begins to fall, resulting in decreased gain. At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence gain. It follows, therefore, that there will be disproportionate amplification of frequencies in a complete signal such as music, speech etc. Hence, transformer-coupled amplifier introduces *frequency distortion.*

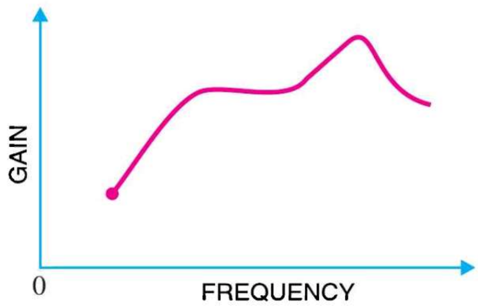


Fig. 11.16

It may be added here that in a properly designed transformer, it is possible to achieve a fairly constant gain over the audio frequency range. But a transformer that achieves a frequency response comparable to *RC* coupling may cost 10 to 20 times as much as the inexpensive *RC* coupled amplifier.

Advantages

(*i*) No signal power is lost in the collector or base resistors.

(*ii*) An excellent impedance matching can be achieved in a transformer coupled amplifier. It is easy to make the inductive reactance of primary equal to the output impedance of the transistor and inductive reactance of secondary equal to the input impedance of next stage.

(*iii*) Due to excellent impedance matching, transformer coupling provides higher gain. As a matter of fact, a single stage of properly designed transformer coupling can provide the gain of two stages of *RC* coupling.

Disadvantages

(*i*) It has a poor frequency response *i.e.*the gain varies considerably with frequency.

(*ii*) The coupling transformers are bulky and fairly expensive at audio frequencies.

(*iii*) Frequency distortion is higher *i.e.* low frequency signals are less amplified as compared to the high frequency signals.

(*iv*) Transformer coupling tends to introduce **hum* in the output.

Applications. Transformer coupling is mostly employed for *impedance matching*. In general, the last stage of a multistage amplifier is the *power stage.* Here, a concentrated effort is made to transfer maximum power to the output device *e.g.* a loudspeaker. For maximum power transfer, the impedance of power source should be equal to that of load. Usually, the impedance of an output device is a few ohms whereas the output impedance of transistor is several hundred times this value. In order to match the impedance, a step-down transformer of proper turn ratio is used. The impedance of secondary of the transformer is made equal to the load impedance and primary impedance equal to the output impedance of transistor. Fig. 11.17 illustrates the impedance matching by a step-down transformer. The output device (*e.g.* speaker) connected to the secondary has a small resistance R_L. The load R'_L appearing on the primary side will be:

$$^{**}R'_L = \left(\frac{N_P}{N_S}\right)^2 R_L$$

For instance, suppose the transformer has turn ratio $N_P : N_S :: 10 : 1$. If $R_L = 100\ \Omega$, then load appearing on the primary is :

$$R'_L = \left(\frac{10}{1}\right)^2 \times 100\ \Omega = 10\ \text{k}\Omega$$

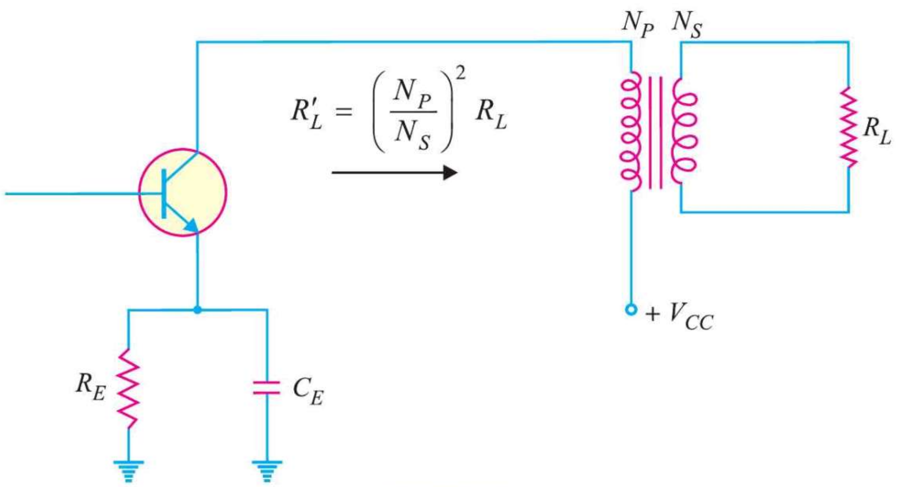


Fig. 11.17

* There are hundreds of turns of primary and secondary. These turns will multiply an induced e.m.f. from nearby power wiring. As the transformer is connected in the base circuit, therefore, the induced hum voltage will appear in amplified form in the output.

** Suppose primary and secondary of transformer carry currents I_P and I_S respectively. The secondary load R_L can be transferred to primary as R'_L provided the power loss remains the same *i.e.*,

$$I_P^2 R'_L = I_S^2 R_L$$

or $$R'_L = \left(\frac{I_S}{I_P}\right)^2 \times R_L = \left(\frac{N_P}{N_S}\right)^2 \times R_L \qquad \left(\because \frac{I_S}{I_P} = \frac{N_P}{N_S}\right)$$

Thus the load on the primary side is comparable to the output impedance of the transistor. This results in maximum power transfer from transistor to the primary of transformer. This shows that low value of load resistance (*e.g.* speaker) can be "stepped-up" to a more favourable value at the collector of transistor by using appropriate turn ratio.

Example 11.16. *A transformer coupling is used in the final stage of a multistage amplifier. If the output impedance of transistor is 1kΩ and the speaker has a resistance of 10Ω, find the turn ratio of the transformer so that maximum power is transferred to the load.*

Solution.

For maximum power transfer, the impedance of the primary should be equal to the output impedance of transistor and impedance of secondary should be equal to load impedance *i.e.*

$$\text{Primary impedance} = 1\ \text{k}\Omega = 1000\ \Omega$$

Let the turn ratio of the transformer be $n\ (= N_P/N_S)$.

$$\text{Primary impedance} = \left(\frac{N_P}{N_S}\right)^2 \times \text{Load impedance}$$

$$\therefore \quad \left(\frac{N_P}{N_S}\right)^2 = \frac{\text{Primary impedance}}{\text{Load impedance}}$$

$$\text{or} \quad n^2 = 1000/10 = 100$$

$$\therefore \quad n = \sqrt{100} = \mathbf{10}$$

A step-down transformer with turn ratio 10 : 1 is required.

Example 11.17. *Determine the necessary transformer turn ratio for transferring maximum power to a 16Ω load from a source that has an output impedance of 10 kΩ. Also calculate the voltage across the external load if the terminal voltage of the source is 10V r.m.s.*

Solution.

For maximum power transfer, the impedance of the primary should be equal to the output impedance of the source.

$$\text{Primary impedance, } R'_L = 10\ \text{k}\Omega = 10{,}000\ \Omega$$

$$\text{Load impedance, } R_L = 16\ \Omega$$

Let the turn ratio of the transformer be $n\ (= N_P/N_S)$.

$$\therefore \quad R'_L = \left(\frac{N_P}{N_S}\right)^2 R_L$$

$$\text{or} \quad \left(\frac{N_P}{N_S}\right)^2 = \frac{R'_L}{R_L} = \frac{10{,}000}{16} = 625$$

$$\text{or} \quad n^2 = 625$$

$$\text{or} \quad n = \sqrt{625} = \mathbf{25}$$

$$\text{Now} \quad \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$\therefore \quad V_S = \left(\frac{N_S}{N_P}\right) \times V_P = \frac{1}{25} \times 10 = \mathbf{0.4\ V}$$

Example 11.18. *The output resistance of the transistor shown in Fig. 11.18 is 3kΩ. The primary of the transformer has a d.c. resistance of 300 Ω and the load connected across secondary is 3Ω. Calculate the turn ratio of the transformer for transferring maximum power to the load.*

Solution.

$$\text{D.C. resistance of primary, } R_P = 300\ \Omega$$

$$\text{Load resistance, } R_L = 3\ \Omega$$

Example 11.20. *In the above example, find the number of primary and secondary turns. Given that core section of the transformer is such that 1 turn gives an inductance of 10μH.*

Solution.

We know that inductance of a coil is directly proportional to the square of number of turns of the coil *i.e.*

$$L \propto N^2$$

or $$L = K N^2$$

Now $$L = 10\,\mu H = 10^{-5}\text{ H}, \quad N = 1 \text{ turn}$$

∴ $$10^{-5} = K(1)^2$$

or $$K = 10^{-5}$$

$$\text{Primary inductance} = K N_P^2$$

or $$8 = 10^{-5} N_P^2$$

∴ $$\text{Primary turns, } N_P = \sqrt{8 \times 10^5} = \mathbf{894}$$

Similarly, $$\text{Secondary turns, } N_S = \sqrt{2 \times 10^5} = \mathbf{447}$$

11.7 Direct-Coupled Amplifier

There are many applications in which extremely low frequency (< 10 Hz) signals are to be amplified *e.g.* amplifying photo-electric current, thermo-couple current etc. The coupling devices such as capacitors and transformers cannot be used because the electrical sizes of these components become very large at extremely low frequencies. Under such situations, one stage is *directly* connected to the next stage without any intervening coupling device. This type of coupling is known as *direct coupling*.

Circuit details. Fig. 11.19 shows the circuit of a three-stage direct-coupled amplifier. It uses *complementary transistors. Thus, the first stage uses ***npn*** transistor, the second stage uses ***pnp*** transistor and so on. This arrangement makes the design very simple. The output from the collector of first transistor T_1 is fed to the input of the second transistor T_2 and so on.

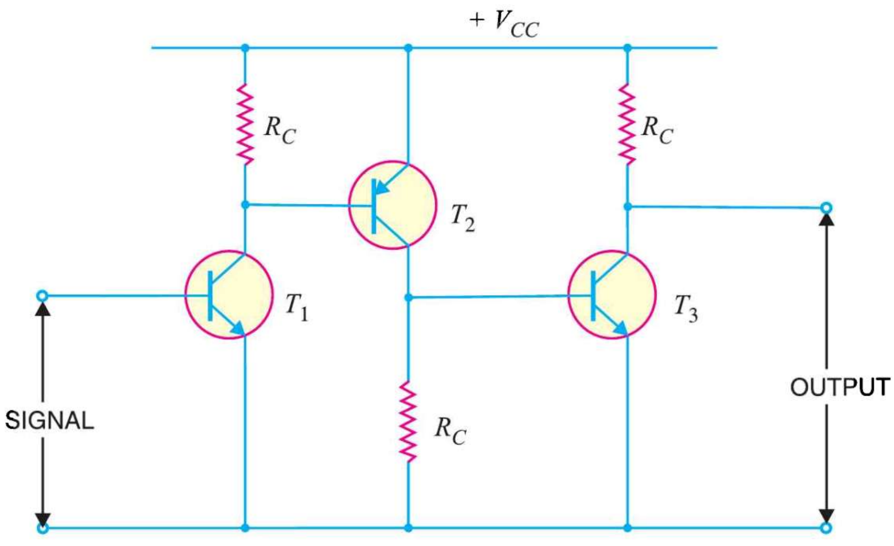


Fig. 11.19

* This makes the circuit stable w.r.t. temperature changes. In this connection (*i.e., npn* followed by *pnp*), the direction of collector current increase β, when the temperature rises, is opposite for the two transistors. Thus the variation in one transistor tends to cancel that in the other.

The weak signal is applied to the input of first transistor T_1. Due to transistor action, an amplified output is obtained across the collector load R_C of transistor T_1. This voltage drives the base of the second transistor and amplified output is obtained across its collector load. In this way, direct coupled amplifier raises the strength of weak signal.

Advantages

(*i*) The circuit arrangement is simple because of minimum use of resistors.

(*ii*) The circuit has low cost because of the absence of expensive coupling devices.

Disadvantages

(*i*) It cannot be used for amplifying high frequencies.

(*ii*) The operating point is shifted due to temperature variations.

Example 11.21. *Fig. 11.20 shows a direct coupled two-stage amplifier. Determine (i) d.c. voltages for both stages (ii) voltage gain of each stage and overall voltage gain.*

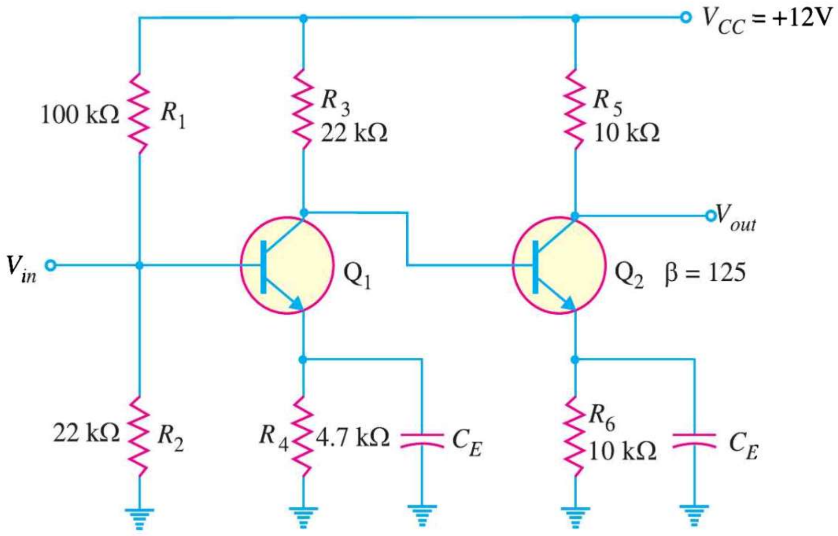


Fig. 11.20

Solution. Note that direct-coupled amplifier has no coupling capacitors between the stages.

(*i*) **D.C. voltages.** We shall now determine the d.c. voltages for both the stages following the established procedure.

First stage

$$\text{D.C. current thro' } R_1 \text{ and } R_2 = \frac{V_{CC}}{R_1 + R_2} = \frac{12\text{V}}{100 \text{ k}\Omega + 22 \text{ k}\Omega} = 0.098 \text{ mA}$$

$$\text{D.C. voltage across } R_2 = 0.098 \text{ mA} \times R_2 = 0.098 \text{ mA} \times 22 \text{ k}\Omega = \mathbf{2.16V}$$

This is the d.c. voltage at the base of transistor Q_1.

$$\text{D.C. voltage at the emitter, } V_{E1} = 2.16 - V_{BE} = 2.16\text{V} - 0.7\text{V} = \mathbf{1.46V}$$

$$\text{D.C. emitter current, } I_{E1} = \frac{V_{E1}}{R_4} = \frac{1.46\text{V}}{4.7 \text{ k}\Omega} = 0.31 \text{ mA}$$

$$\text{D.C. collector current, } I_{C1} = 0.31 \text{ mA} \quad (\because I_{C1} \simeq I_{E1})$$

$$\text{D.C. voltage at collector, } V_{C1} = V_{CC} - I_{C1} R_3$$

$$= 12\text{V} - 0.31 \text{ mA} \times 22 \text{ k}\Omega = \mathbf{5.18V}$$

Second stage

$$\text{D.C. base voltage} = V_{C1} = \mathbf{5.18V}$$

$$\text{D.C. emitter voltage, } V_{E2} = V_{C1} - V_{BE} = 5.18\text{V} - 0.7\text{V} = \mathbf{4.48V}$$

(*v*) The capacitances of the components of a transistor amplifier are usually larger than the corresponding components of the tube amplifier.

MULTIPLE-CHOICE QUESTIONS

1. A radio receiver has .... of amplification.
   (*i*) one stage (*ii*) two stages
   (*iii*) three stages
   (*iv*) more than three stages
2. *RC* coupling is used for .... amplification.
   (*i*) voltage (*ii*) current
   (*iii*) power (*iv*) none of the above
3. In an *RC* coupled amplifier, the voltage gain over mid-frequency range ....
   (*i*) changes abruptly with frequency
   (*ii*) is constant
   (*iii*) changes uniformly with frequency
   (*iv*) none of the above
4. In obtaining the frequency response curve of an amplifier, the ....
   (*i*) amplifier level output is kept constant
   (*ii*) amplifier frequency is held constant
   (*iii*) generator frequency is held constant
   (*iv*) generator output level is held constant
5. An advantage of *RC* coupling scheme is the ....
   (*i*) good impedance matching
   (*ii*) economy
   (*iii*) high efficiency (*iv*)none of the above
6. The best frequency response is of .... coupling.
   (*i*) *RC* (*ii*) transformer
   (*iii*) direct (*iv*) none of the above
7. Transformer coupling is used for .... amplification.
   (*i*) power (*ii*) voltage
   (*iii*) current (*iv*) none of the above
8. In an *RC* coupling scheme, the coupling capacitor C_C must be large enough ....
   (*i*) to pass d.c. between the stages
   (*ii*) not to attenuate the low frequencies
   (*iii*) to dissipate high power
   (*iv*) none of the above
9. In *RC* coupling, the value of coupling capacitor is about ....
   (*i*) 100 pF (*ii*) 0.1 μF
   (*iii*) 0.01 μF (*iv*) 10 μF
10. The noise factor of an ideal amplifier expressed in *db* is ....
    (*i*) 0 (*ii*) 1
    (*iii*) 0.1 (*iv*) 10
11. When a multistage amplifier is to amplify d.c. signal, then one must use .... coupling.
    (*i*) *RC* (*ii*) transformer
    (*iii*) direct (*iv*) none of the above
12. .... coupling provides the maximum voltage gain.
    (*i*) *RC* (*ii*) transformer
    (*iii*) direct (*iv*) impedance
13. In practice, voltage gain is expressed ....
    (*i*) in *db* (*ii*) in volts
    (*iii*) as a number (*iv*) none of the above
14. Transformer coupling provides high efficiency because ....
    (*i*) collector voltage is stepped up
    (*ii*) d.c. resistance is low
    (*iii*) collector voltage is stepped down
    (*iv*) none of the above
15. Transformer coupling is generally employed when load resistance is ....
    (*i*) large (*ii*) very large
    (*iii*) small (*iv*) none of the above
16. If a three-stage amplifier has individual stage gains of 10 *db*, 5 *db* and 12 *db*, then total gain in *db* is ....
    (*i*) 600 *db* (*ii*) 24 *db*
    (*iii*) 14 *db* (*iv*) 27 *db*
17. The final stage of a multistage amplifier uses ....
    (*i*) *RC* coupling
    (*ii*) transformer coupling
    (*iii*) direct coupling
    (*iv*) impedance coupling

18. The ear is not sensitive to........
- (*i*) frequency distortion
- (*ii*) amplitude distortion
- (*iii*) frequency as well as amplitude distortion
- (*iv*) none of the above

19. *RC* coupling is not used to amplify extremely low frequencies because ....
- (*i*) there is considerable power loss
- (*ii*) there is hum in the output
- (*iii*) electrical size of coupling capacitor becomes very large
- (*iv*) none of the above

20. In transistor amplifiers, we use .... transformer for impedance matching.

(*i*) step up (*ii*) step down
(*iii*) same turn ratio (*iv*) none of the above

21. The lower and upper cut off frequencies are also called .... frequencies.

(*i*) sideband (*ii*) resonant
(*iii*) half-resonant
(*iv*) half-power

22. A gain of 1,000,000 times in power is expressed by ....

(*i*) 30 *db* (*ii*) 60 *db*
(*iii*) 120 *db* (*iv*) 600 *db*

23. A gain of 1000 times in voltage is expressed by ....

(*i*) 60 *db* (*ii*) 30 *db*
(*iii*) 120 *db* (*iv*) 600 *db*

24. 1 *db* corresponds to .... change in power level.

(*i*) 50% (*ii*) 35%
(*iii*) 26% (*iv*) 22%

25. 1 *db* corresponds to .... change in voltage or current level.

(*i*) 40% (*ii*) 80%
(*iii*) 20% (*iv*) 25%

26. The frequency response of transformer coupling is ....

(*i*) good (*ii*) very good
(*iii*) excellent (*iv*) poor

27. In the initial stages of a multistage amplifier, we use ....
- (*i*) *RC* coupling
- (*ii*) transformer coupling
- (*iii*) direct coupling
- (*iv*) none of the above

28. The total gain of a multistage amplifier is less than the product of the gains of individual stages due to ....
- (*i*) power loss in the coupling device
- (*ii*) loading effect of next stage
- (*iii*) the use of many transistors
- (*iv*) the use of many capacitors

29. The gain of an amplifier is expressed in *db* because ....
- (*i*) it is a simple unit
- (*ii*) calculations become easy
- (*iii*) human ear response is logarithmic
- (*iv*) none of the above

30. If the power level of an amplifier reduces to half, the *db* gain will fall by ....

(*i*) 0.5 *db* (*ii*) 2 *db*
(*iii*) 10 *db* (*iv*) 3 *db*

31. A current amplification of 2000 is a gain of ....

(*i*) 3 *db* (*ii*) 66 *db*
(*iii*) 20 *db* (*iv*) 200 *db*

32. An amplifier receives 0.1 W of input signal and delivers 15 W of signal power. What is the power gain in *db* ?

(*i*) 21.8 *db* (*ii*) 14.6 *db*
(*iii*) 9.5 *db* (*iv*) 17.4 *db*

33. The power output of an audio system is 18 W. For a person to notice an increase in the output (loudness or sound intensity) of the system, what must the output power be increased to ?

(*i*) 14.2 W (*ii*) 11.6 W
(*iii*) 22.68 W (*iv*) none of the above

34. The output of a microphone is rated at – 52 *db*. The reference level is 1 V under specified sound conditions. What is the output voltage of this microphone under the same sound conditions ?

(*i*) 1.5 mV (*ii*) 6.2 mV
(*iii*) 3.8 mV (*iv*) 2.5 mV

35. *RC* coupling is generally confined to low power applications because of ....
(*i*) large value of coupling capacitor
(*ii*) low efficiency
(*iii*) large number of components
(*iv*) none of the above

36. The number of stages that can be directly coupled is limited because ....
(*i*) changes in temperature cause thermal instability
(*ii*) circuit becomes heavy and costly
(*iii*) it becomes difficult to bias the circuit
(*iv*) none of the above

37. The purpose of RC or transformer coupling is to ....
(*i*) block a.c.
(*ii*) separate bias of one stage from another
(*iii*) increase thermal stability
(*iv*) none of the above

38. The upper or lower cut off frequency is also called .... frequency.
(*i*) resonant (*ii*) sideband
(*iii*) 3 *db* (*iv*) none of the above

39. The bandwidth of a single stage amplifier is .... that of a multistage amplifier.
(*i*) more than (*ii*) the same as
(*iii*) less than (*iv*) data insufficient

40. The value of emitter capacitor C_E in a multi-stage amplifier is about ....
(*i*) 0.1 μF (*ii*) 100 pF
(*iii*) 0.01 μF (*iv*) 50 μF

Answers to Multiple-Choice Questions

1. (*iv*)	**2.** (*i*)	**3.** (*ii*)	**4.** (*iv*)	**5.** (*ii*)
6. (*iii*)	**7.** (*i*)	**8.** (*ii*)	**9.** (*iv*)	**10.** (*i*)
11. (*iii*)	**12.** (*ii*)	**13.** (*i*)	**14.** (*ii*)	**15.** (*iii*)
16. (*iv*)	**17.** (*ii*)	**18.** (*i*)	**19.** (*iii*)	**20.** (*ii*)
21. (*iv*)	**22.** (*ii*)	**23.** (*i*)	**24.** (*iii*)	**25.** (*i*)
26. (*iv*)	**27.** (*i*)	**28.** (*ii*)	**29.** (*iii*)	**30.** (*iv*)
31. (*ii*)	**32.** (*i*)	**33.** (*iii*)	**34.** (*iv*)	**35.** (*ii*)
36. (*i*)	**37.** (*ii*)	**38.** (*iii*)	**39.** (*i*)	**40.** (*iv*)

Chapter Review Topics

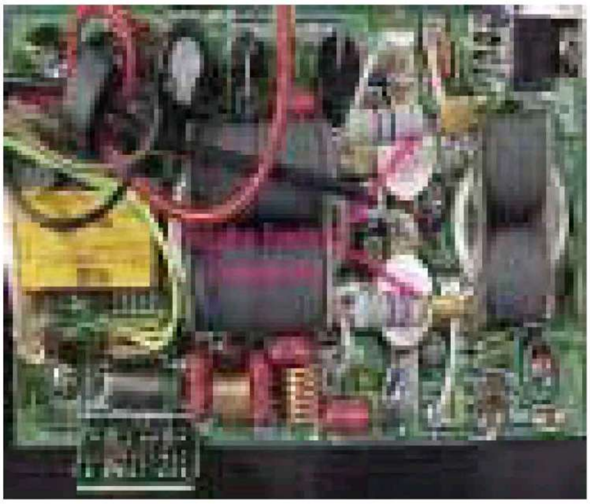
1. What do you understand by multistage transistor amplifier ? Mention its need.
2. Explain the following terms : (*i*) Frequency response (*ii*) Decibel gain (*iii*) Bandwidth.
3. Explain transistor *RC* coupled amplifier with special reference to frequency response, advantages, disadvantages and applications.
4. With a neat circuit diagram, explain the working of transformer-coupled transistor amplifier.
5. How will you achieve impedance matching with transformer coupling ?
6. Explain direct coupled transistor amplifier.

Problems

1. The absolute voltage gain of an amplifier is 73. Find its decibel gain. **[37db]**
2. The input power to an amplifier is 15mW while output power is 2W. Find the decibel gain of the amplifier. **[21.25db]**
3. What is the *db* gain for an increase of power level from 12W to 24W ? **[3 db]**
4. What is the *db* gain for an increase of voltage from 4mV to 8mV ? **[6 db]**
5. A two-stage amplifier has first-stage voltage gain of 20 and second stage voltage gain of 400. Find the total decibel gain. **[78 db]**

13

Amplifiers with Negative Feedback



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. There is a strong tendency in amplifiers to introduce *hum* due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its 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.

13.1 Feedback

The process of injecting a fraction of output energy of *some device back to the input is known as* **feedback**.

The principle of feedback is probably as old as the invention of first machine but it is only some 50 years ago that feedback has come into use in connection with electronic circuits. It has been found very useful in reducing noise in amplifiers and making amplifier operation stable. 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.*

(*i*) 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. 13.1. 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}.

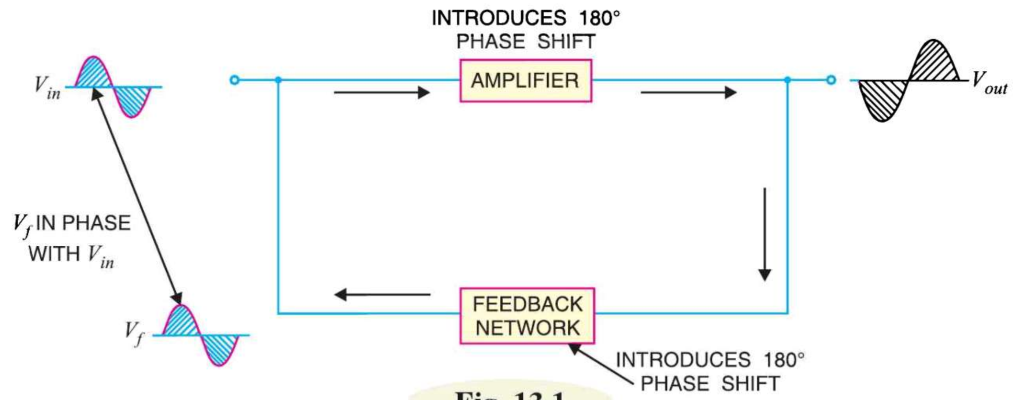


Fig. 13.1

The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is seldom employed in amplifiers. One important use of positive feedback is in oscillators. As we shall see in the next chapter, 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. 13.2. 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}.

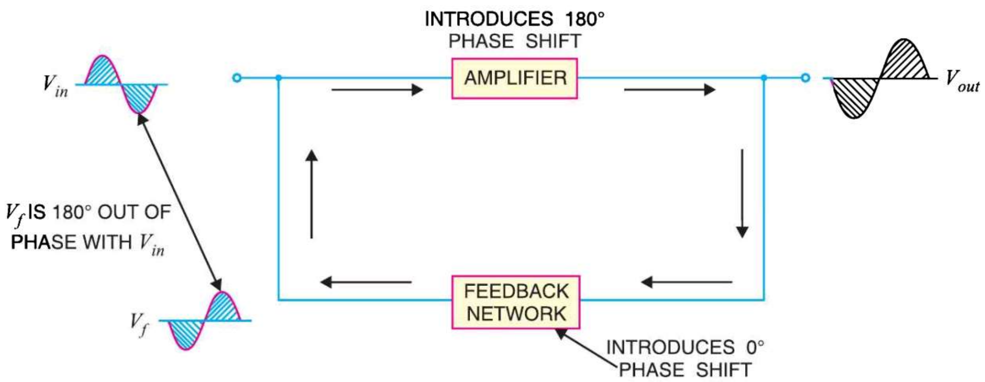


Fig. 13.2

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

13.2 Principles of Negative Voltage Feedback In Amplifiers

A feedback amplifier has two parts viz 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. 13.3 *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 fedback 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. 13.3, we have,

$$\text{Gain of amplifier without feedback, } A_v = \frac{10 \text{ V}}{1 \text{ mV}} = 10,000$$

Fig. 13.3

$$\text{Fraction of output voltage fedback, } m_v = \frac{100 \text{ mV}}{10 \text{ V}} = 0.01$$

$$\text{Gain of amplifier with negative feedback, } A_{vf} = \frac{10 \text{ V}}{101 \text{ mV}} = 100$$

The following points are worth noting :

(i) 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.

(ii) 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.

(iii) In a negative voltage feedback circuit, the feedback fraction m_v is always between 0 and 1.

(iv) 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 the loop is "opened" by disconnecting the feedback circuit from the input, the amplifier's gain is A_v, the "open-loop" gain. When the loop is "closed" by connecting the feedback circuit, the gain decreases to A_{vf}, the "closed-loop" gain.

* Note that amplifier and feedback circuits are connected in *series-parallel*. The inputs of amplifier and feedback circuits are in *series* but the outputs are in *parallel*. In practice, this circuit is widely used.

** Since with negative voltage feedback the voltage gain is decreased and current gain remains unaffected, the power gain A_p $(= A_v \times A_i)$ will decrease. However, the drawback of reduced power gain is offset by the advantage of increased bandwidth.

13.3 Gain of Negative Voltage Feedback Amplifier

Consider the negative voltage feedback amplifier shown in Fig. 13.4. 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.*,

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

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

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

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

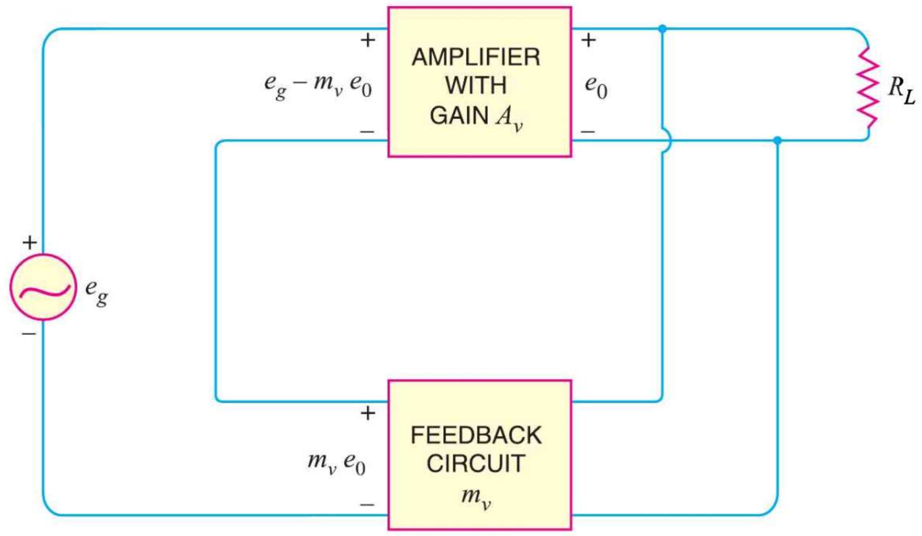


Fig. 13.4

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.

Example 13.1. *The voltage gain of an amplifier without feedback is 3000. Calculate the voltage gain of the amplifier if negative voltage feedback is introduced in the circuit. Given that feedback fraction m_v = 0.01.*

Solution. $A_v = 3000, \quad m_v = 0.01$

∴ Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v} = \frac{3000}{1 + 3000 \times 0.01} = \frac{3000}{31} = \mathbf{97}$$

Example 13.2. *The overall gain of a multistage amplifier is 140. When negative voltage feedback is applied, the gain is reduced to 17.5. Find the fraction of the output that is fedback to the input.*

Solution. $A_v = 140, \quad A_{vf} = 17.5$

Let m_v be the feedback fraction. Voltage gain with negative feedback is

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

or $$17.5 = \frac{140}{1 + 140\, m_v}$$

or $$17.5 + 2450\, m_v = 140$$

$\therefore$ $$m_v = \frac{140 - 17.5}{2450} = \mathbf{\frac{1}{20}}$$

Example 13.3. *When negative voltage feedback is applied to an amplifier of gain 100, the overall gain falls to 50.*

(*i*) *Calculate the fraction of the output voltage fedback.*

(*ii*) *If this fraction is maintained, calculate the value of the amplifier gain required if the overall stage gain is to be 75.*

Solution.

(*i*) Gain without feedback, $A_v = 100$

Gain with feedback, $A_{vf} = 50$

Let m_v be the fraction of the output voltage fedback.

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

or $$50 = \frac{100}{1 + 100\, m_v}$$

or $$50 + 5000\, m_v = 100$$

or $$m_v = \frac{100 - 50}{5000} = \mathbf{0.01}$$

(*ii*) $A_{vf} = 75 \;; \quad m_v = 0.01 \;; \quad A_v = ?$

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

or $$75 = \frac{A_v}{1 + 0.01\, A_v}$$

or $$75 + 0.75\, A_v = A_v$$

$\therefore$ $$A_v = \frac{75}{1 - 0.75} = \mathbf{300}$$

Example 13.4. *With a negative voltage feedback, an amplifier gives an output of 10 V with an input of 0.5 V. When feedback is removed, it requires 0.25 V input for the same output. Calculate (i) gain without feedback (ii) feedback fraction m_v.*

Solution.

(*i*) Gain without feedback, $A_v = 10/0.25 = \mathbf{40}$

(*ii*) Gain with feedback, $A_{vf} = 10/0.5 = 20$

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

or $$20 = \frac{40}{1 + 40\, m_v}$$

or $$20 + 800\, m_v = 40$$

or $$m_v = \frac{40 - 20}{800} = \mathbf{\frac{1}{40}}$$

Example 13.5. *The gain of an amplifier without feedback is 50 whereas with negative voltage feedback, it falls to 25. If due to ageing, the amplifier gain falls to 40, find the percentage reduction in stage gain (i) without feedback and (ii) with negative feedback.*

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

or $$25 = \frac{50}{1 + 50\, m_v}$$

or $$m_v = 1/50$$

(*i*) **Without feedback.** The gain of the amplifier without feedback is 50. However, due to ageing, it falls to 40.

∴ $$\text{\%age reduction in stage gain} = \frac{50 - 40}{50} \times 100 = \mathbf{20\%}$$

(*ii*) **With negative feedback.** When the gain without feedback was 50, the gain with negative feedback was 25. Now the gain without feedback falls to 40.

∴ $$\text{New gain with negative feedback} = \frac{A_v}{1 + A_v\, m_v} = \frac{40}{1 + (40 \times 1/50)} = 22.2$$

∴ $$\text{\%age reduction in stage gain} = \frac{25 - 22.2}{25} \times 100 = \mathbf{11.2\%}$$

Example 13.6. *An amplifier has a voltage amplification A_v and a fraction m_v of its output is fedback in opposition to the input. If $m_v = 0.1$ and $A_v = 100$, calculate the percentage change in the gain of the system if A_v falls 6 db due to ageing.*

Solution. $$A_v = 100, \quad m_v = 0.1, \quad A_{vf} = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{100}{1 + 100 \times 0.1} = 9.09$$

$$\text{Fall in gain} = 6db$$

Let A_{v1} be the new absolute voltage gain without feedback.

Then, $$20 \log_{10} A_v/A_{v1} = 6$$

or $$\log_{10} A_v/A_{v1} = 6/20 = 0.3$$

or $$\frac{A_v}{A_{v1}} = \text{Antilog } 0.3 = 2$$

or $$A_{v1} = A_v/2 = 100/2 = 50$$

∴ $$\text{New } A_{vf} = \frac{A_{v1}}{1 + A_{v1}\, m_v} = \frac{50}{1 + 50 \times 0.1} = 8.33$$

$$\text{\% age change in system gain} = \frac{9.09 - 8.33}{9.09} \times 100 = \mathbf{8.36\%}$$

$$= \frac{1000 \times 900}{100 + 900} = 900$$

$$\therefore \quad A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{900}{1 + 900 \times (1/50)} = \mathbf{47.4}$$

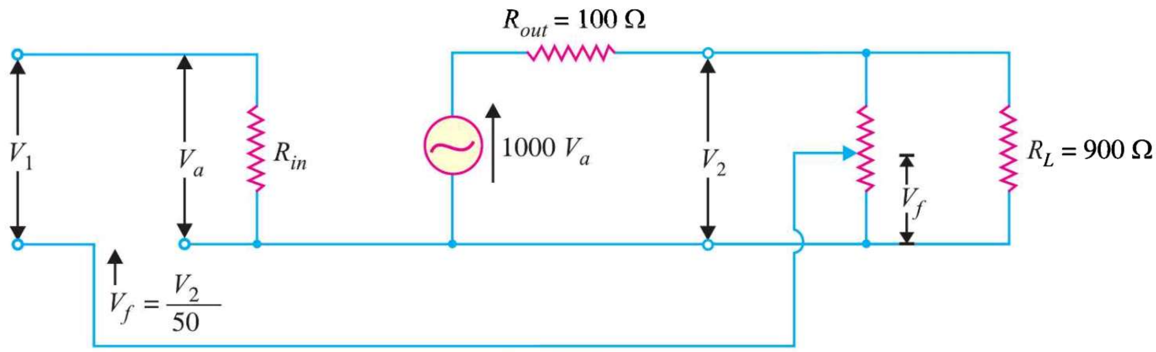


Fig. 13.5

Example 13.10. *An amplifier is required with a voltage gain of 100 which does not vary by more than 1%. If it is to use negative feedback with a basic amplifier the voltage gain of which can vary by 20%, determine the minimum voltage gain required and the feedback factor.*

Solution.

$$100 = \frac{A_v}{1 + A_v\, m_v}$$

or $$100 + 100\, A_v\, m_v = A_v \qquad \text{... } (i)$$

Also $$99 = \frac{0.8\, A_v}{1 + 0.8\, A_v\, m_v}$$

or $$99 + 79.2\, A_v\, m_v = 0.8\, A_v \qquad \text{...}(ii)$$

Multiplying eq (*i*) by 0.792, we have,

$$79.2 + 79.2\, A_v\, m_v = 0.792\, A_v \qquad \text{... } (iii)$$

Subtracting [(*ii*) – (*iii*)], we have,

$$19.8 = 0.008\, A_v \quad \therefore \quad A_v = \frac{19.8}{0.008} = \mathbf{2475}$$

Putting the value of A_v (= 2475) in eq. (*i*), we have,

$$100 + 100 \times 2475 \times m_v = 2475$$

$$\therefore \quad m_v = \frac{2475 - 100}{100 \times 2475} = \mathbf{0.0096}$$

13.4 Advantages of Negative Voltage Feedback

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

(*i*) 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 non-linear 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

It is clear that 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 stabilised 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.

***(a)* Input impedance.** The increase in input impedance with negative voltage feedback can be explained by referring to Fig. 13.6. 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. 13.6, we have,

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

Now

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

* $A_{vf} = 1/m_v$. Now m_v depends upon feedback circuit. As feedback circuit consists of resistive network, therefore, value of m_v is unaffected by change in signal frequency.

or $$\frac{e_g}{i_1} = Z_{in}(1 + A_v m_v)$$

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

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

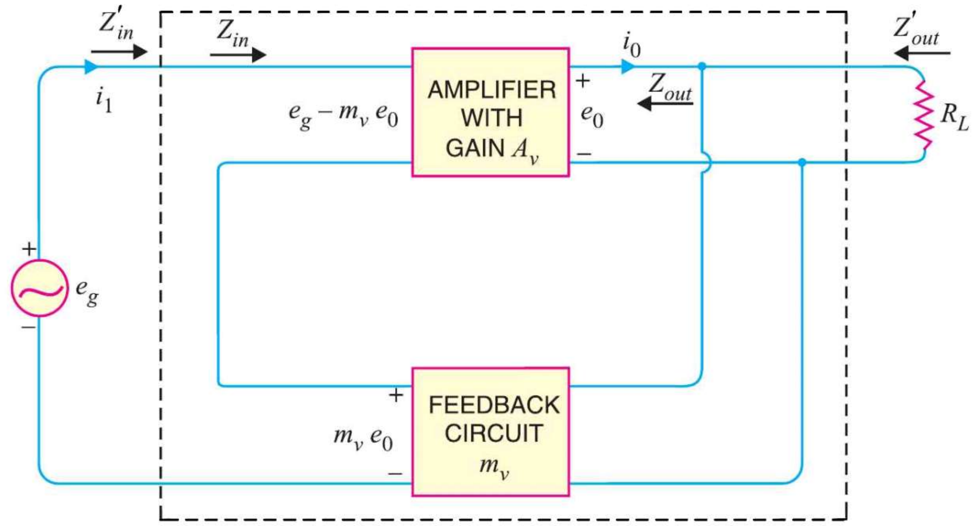


Fig. 13.6

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 :

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

where Z'_{out} = output impedance with negative voltage feedback

Z_{out} = output impedance without feedback

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.

13.5 Feedback Circuit

The function of the feedback circuit is to return a fraction of the output voltage to the input of the amplifier. Fig. 13.7 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. 13.7, it is clear that :

$$\text{Voltage across } R_1 = \left(\frac{R_1}{R_1 + R_2}\right) e_0$$

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

Example 13.15. *The current gain of an amplifier is 200 without feedback. When negative current feedback is applied, determine the effective current gain of the amplifier. Given that current attenuation m_i = 0.012.*

Solution. $$A_{if} = \frac{A_i}{1 + m_i\ A_i}$$

Here $A_i = 200\ ;\quad m_i = 0.012$

$\therefore$ $$A_{if} = \frac{200}{1 + (0.012)\ (200)} = \mathbf{58.82}$$

13.8 Effects of Negative Current Feedback

The negative current feedback has the following effects on the performance of amplifiers :

(*i*) Decreases the input impedance. The negative current feedback decreases the input impedance of most amplifiers.

Let Z_{in} = Input impedance of the amplifier without feedback

Z'_{in} = Input impedance of the amplifier with negative current feedback

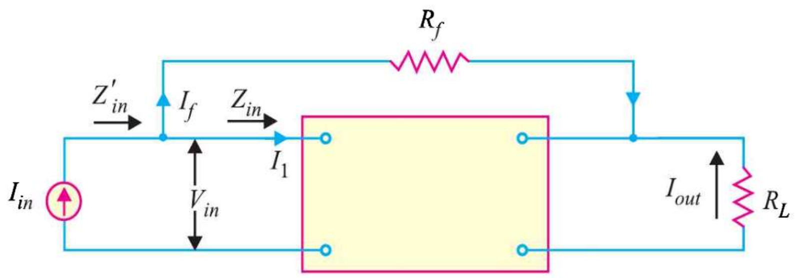


Fig. 13.11

Referring to Fig. 13.11, we have,

$$Z_{in} = \frac{V_{in}}{I_1}$$

and $$Z'_{in} = \frac{V_{in}}{I_{in}}$$

But $V_{in} = I_1\ Z_{in}$ and $I_{in} = I_1 + I_f = I_1 + m_i\,I_{out} = I_1 + m_i A_i I_1$

$\therefore$ $$Z'_{in} = \frac{I_1\ Z_{in}}{I_1 + m_i\ A_i\ I_1} = \frac{Z_{in}}{1 + m_i\ A_i}$$

or $$Z'_{in} = \frac{Z_{in}}{1 + m_i\ A_i}$$

Thus the input impedance of the amplifier is decreased by the factor $(1 + m_i A_i)$. Note the primary difference between negative current feedback and negative voltage feedback. Negative current feedback *decreases* the input impedance of the amplifier while negative voltage feedback *increases* the input impedance of the amplifier.

(*ii*) Increases the output impedance. It can be proved that with negative current feedback, the output impedance of the amplifier is increased by a factor $(1 + m_i A_i)$.

$$Z'_{out} = Z_{out}\,(1 + m_i\ A_i)$$

where Z_{out} = output impedance of the amplifier without feedback

Z'_{out} = output impedance of the amplifier with negative current feedback

The reader may recall that with negative voltage feedback, the output impedance of the amplifier is decreased.

***(iii)* Increases bandwidth.** It can be shown that with negative current feedback, the bandwidth of the amplifier is increased by the factor $(1 + m_i\, A_i)$.

$$BW' = BW\,(1 + m_i\, A_i)$$

where BW = Bandwidth of the amplifier without feedback

BW' = Bandwidth of the amplifier with negative current feedback

Example 13.16. *An amplifier has a current gain of 240 and input impedance of 15 kΩ without feedback. If negative current feedback (m_i = 0.015) is applied, what will be the input impedance of the amplifier ?*

Solution. $$Z'_{in} = \frac{Z_{in}}{1 + m_i\, A_i}$$

Here Z_{in} = 15 kΩ ; A_i = 240 ; m_i = 0.015

$$\therefore \quad Z'_{in} = \frac{15}{1 + (0.015)\,(240)} = \mathbf{3.26\ k\Omega}$$

Example 13.17. *An amplifier has a current gain of 200 and output impedance of 3 kΩ without feedback. If negative current feedback (m_i = 0.01) is applied; what is the output impedance of the amplifier ?*

Solution. $$Z'_{out} = Z_{out}\,(1 + m_i\, A_i)$$

Here Z_{out} = 3 kΩ ; A_i = 200 ; m_i = 0.01

$$\therefore \quad Z'_{out} = 3[1 + (0.01)\,(200)] = \mathbf{9\ k\Omega}$$

Example 13.18. *An amplifier has a current gain of 250 and a bandwidth of 400 kHz without feedback. If negative current feedback (m_i = 0.01) is applied, what is the bandwidth of the amplifier?*

Solution. $$BW' = BW\,(1 + m_i\, A_i)$$

Here BW = 400 kHz ; m_i = 0.01 ; A_i = 250

$$\therefore \quad BW' = 400[1 + (0.01)\,250] = \mathbf{1400\ kHz}$$

13.9 Emitter Follower

It is a negative current feedback circuit. The emitter follower is a current amplifier that has no voltage gain. Its most important characteristic is that it has high input impedance and low output impedance. This makes it an ideal circuit for impedance matching.

Circuit details. Fig. 13.12 shows the circuit of an emitter follower. As you can see, it differs from the circuitry of a conventional *CE* amplifier by the absence of collector load and emitter bypass capacitor. The emitter resistance R_E itself acts as the load and a.c. output voltage (V_{out}) is taken across R_E. The biasing is generally provided by voltage-divider method or by base resistor method. The following points are worth noting about the emitter follower :

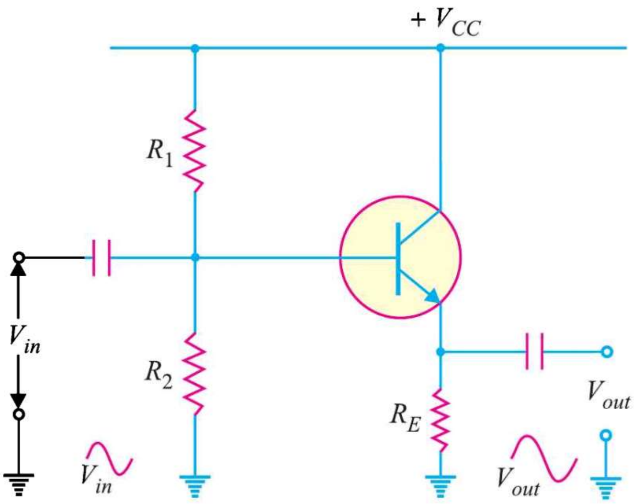


Fig. 13.12

(*i*) There is neither collector resistor in the circuit nor there is emitter bypass capacitor. These are the two circuit recognition features of the emitter follower.

(*ii*) Since the collector is at *ac* ground, this circuit is also known as *common collector* (*CC*) *amplifier.*

Operation. The input voltage is applied between base and emitter and the resulting a.c. emitter current produces an output voltage $i_e R_E$ across the emitter resistance. This voltage opposes the input voltage, thus providing negative feedback. Clearly, it is a negative current feedback circuit since the voltage fedback is proportional to the emitter current *i.e.*, output current. It is called emitter follower because the output voltage follows the input voltage.

Characteristics. The major characteristics of the emitter follower are :

(*i*) No voltage gain. In fact, the voltage gain of an emitter follower is close to 1.

(*ii*) Relatively high current gain and power gain.

(*iii*) High input impedance and low output impedance.

(*iv*) Input and output *ac* voltages are in phase.

13.10 D.C. Analysis of Emitter Follower

The d.c. analysis of an emitter follower is made in the same way as the voltage divider bias circuit of a CE amplifier. Thus referring to Fig. 13.12 above, we have,

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

$$\text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{V_2 - V_{BE}}{R_E}$$

$$\text{Collector-emitter voltage, } V_{CE} = V_{CC} - V_E$$

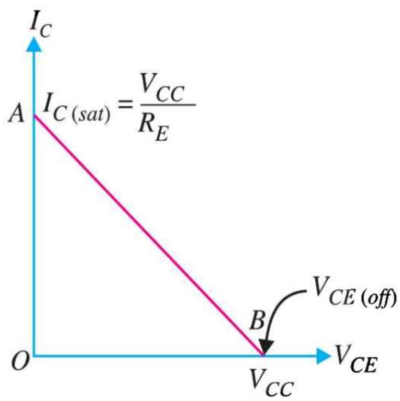


Fig. 13.13

D.C. Load Line. The d.c. load line of emitter follower can be constructed by locating the two end points *viz.*, $I_{C(sat)}$ and $V_{CE(off)}$.

(*i*) When the transistor is saturated, $V_{CE} = 0$.

$$\therefore \quad I_{C(sat)} = \frac{V_{CC}}{R_E}$$

This locates the point *A* ($OA = V_{CC}/R_E$) of the d.c. load line as shown in Fig. 13.13.

(*ii*) When the transistor is cut off, $I_C = 0$. Therefore, $V_{CE(off)} = V_{CC}$. This locates the point *B* ($OB = V_{CC}$) of the d.c. load line.

By joining points *A* and *B*, d.c. load line *AB* is constructed.

Example 13.19. *For the emitter follower circuit shown in Fig. 13.14 (i), find V_E and I_E. Also draw the dc load line for this circuit.*

Solution.

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{18}{16 + 22} \times 22 = 10.42 \text{ V}$$

$$\text{Voltage across } R_E,\ V_E = V_2 - V_{BE} = 10.42 - 0.7 = \mathbf{9.72\ V}$$

$$\text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{9.72 \text{ V}}{910\ \Omega} = \mathbf{10.68\ mA}$$

If these conditions are fulfilled, the circuit will produce continuous undamped output as shown in Fig. 14.4.

14.5. Positive Feedback Amplifier — Oscillator

A transistor amplifier with *proper* positive feedback can act as an oscillator *i.e.*, it can generate oscillations without any external signal source. Fig. 14.5 shows a transistor amplifier with positive

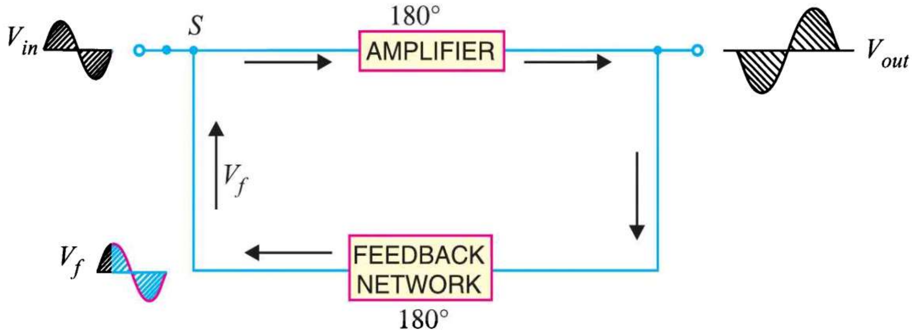


Fig. 14.5

feedback. Remember that a positive feedback amplifier is one that produces a feedback voltage (V_f) that *is in phase* with the original input signal. As you can see, this condition is met in the circuit shown in Fig. 14.5. A phase shift of 180° is produced by the amplifier and a further phase shift of 180° is introduced by feedback network. Consequently, the signal is shifted by 360° and fed to the input *i.e.*, feedback voltage is in phase with the input signal.

Positive Feedback Amplifier

(*i*) We note that the circuit shown in Fig. 14.5 is producing oscillations in the output. However, this circuit has an input signal. This is inconsistent with our definition of an oscillator *i.e.*, an oscillator is a circuit that produces oscillations without any external signal source.

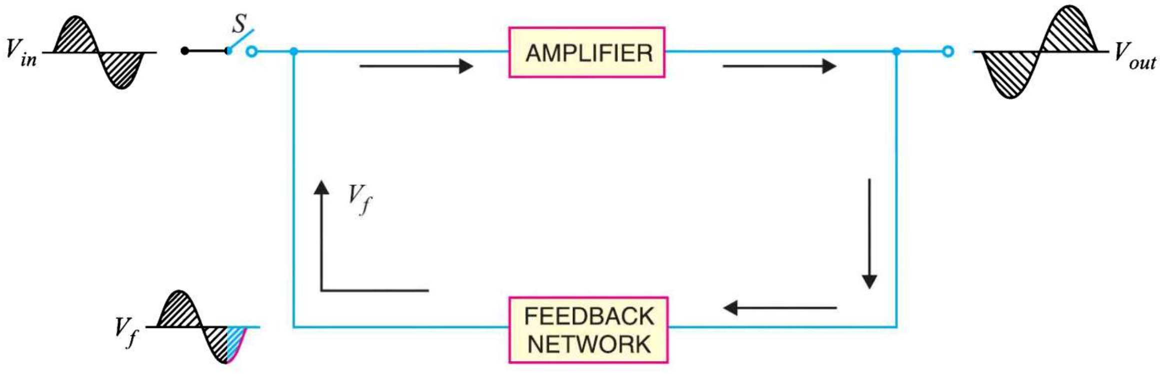


Fig. 14.6

(*ii*) When we open the switch *S* of Fig. 14.5, we get the circuit shown in Fig. 14.6. This means the input signal (V_{in}) is removed. However, V_f (which is in phase with the original signal) is still applied to the input signal. The amplifier will respond to this signal in the same way that it did to V_{in} *i.e.*, V_f will be amplified and sent to the output. The feedback network sends a portion of the output back to the input. Therefore, the amplifier receives another input cycle and another output cycle is produced. This process will continue so long as the amplifier is turned on. Therefore, the amplifer will produce sinusoidal output with no external signal source. The following points may be noted carefully :

(a) A transistor amplifer with proper *positive* feedback will work as an oscillator.

(b) The circuit needs only a quick trigger signal to start the oscillations. Once the oscillations have started, no external signal source is needed.

(c) In order to get continuous undamped output from the circuit, the following condition must be met :

$$m_v A_v = 1$$

where A_v = voltage gain of amplifer without feedback

m_v = feedback fraction

This relation is called *Barkhausen criterion*. This condition will be explained in the Art. 14.7.

14.6 Essentials of Transistor Oscillator

Fig. 14.7 shows the block diagram of an oscillator. Its essential components are :

(i) Tank circuit. It consists of inductance coil (*L*) connected in parallel with capacitor (*C*). The frequency of oscillations in the circuit depends 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.

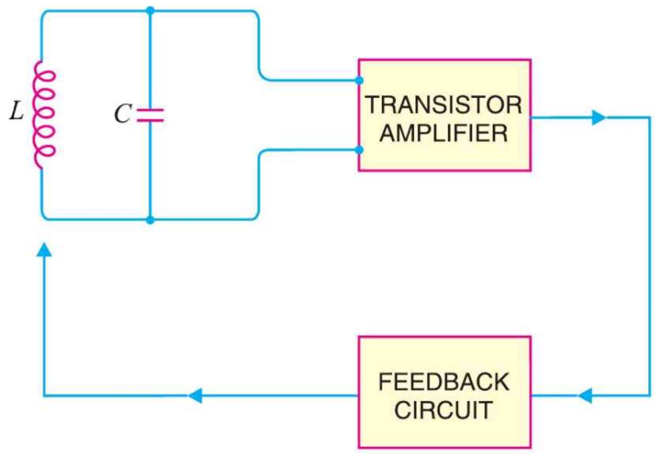


Fig. 14.7

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.

14.7 Explanation of Barkhausen Criterion

Barkhausen criterion is that in order to produce continuous undamped oscillations at the output of an amplifier, the positive feedback should be such that :

$$m_v A_v = 1$$

Once this condition is set in the positive feedback amplifier, continuous undamped oscillations can be obtained at the output immediately after connecting the necessary power supplies.

receiver makes use of an LC tuned circuit with L_1 = 58.6 μH and C_1 = 300 pF. Calculate the frequency of oscillations.

Solution.

$$L_1 = 58.6\ \mu\text{H} = 58.6 \times 10^{-6}\ \text{H}$$

$$C_1 = 300\ \text{pF} = 300 \times 10^{-12}\ \text{F}$$

Frequency of oscillations,
$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

$$= \frac{1}{2\pi\sqrt{58.6 \times 10^{-6} \times 300 \times 10^{-12}}}\ \text{Hz}$$

$$= 1199 \times 10^{3}\ \text{Hz} = \mathbf{1199\ kHz}$$

Example 14.2. *Find the capacitance of the capacitor required to build an LC oscillator that uses an inductance of L_1 = 1 mH to produce a sine wave of frequency 1 GHz (1 GHz = 1 × 10^{12} Hz).*

Solution.

Frequency of oscillations is given by ;

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

or
$$C_1 = \frac{1}{L_1 (2\pi f)^2} = \frac{1}{(1 \times 10^{-3})(2\pi \times 1 \times 10^{12})^2}$$

$$= 2{\cdot}53 \times 10^{-23}\ \text{F} = \mathbf{2{\cdot}53 \times 10^{-11}\ pF}$$

The LC circuit is often called *tuned circuit* or *tank circuit.*

14.10 Colpitt's Oscillator

Fig. 14.10 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 ;

$$f = \frac{1}{2\pi\sqrt{LC_T}} \quad \text{....}(i)$$

where
$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

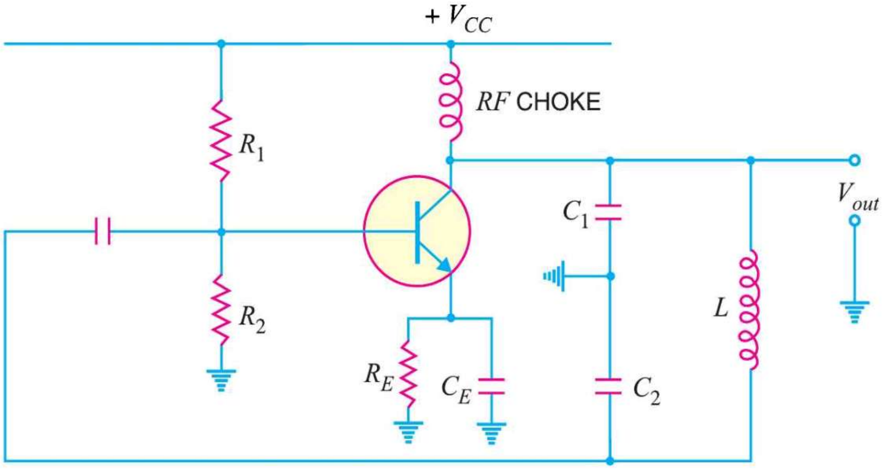


Fig. 14.10

*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*). The 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. 14.11. It is easy to see that voltage fedback (voltage across C_2) to the transistor provides positive feedback. A phase shift of 180° is produced by the 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.

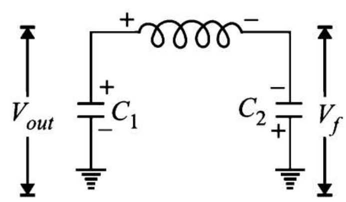


Fig. 14.11

Feedback fraction m_v. The amount of feedback voltage in Colpitt's oscillator depends upon feedback fraction m_v of the circuit. For this circuit,

$$\text{Feedback fraction, } m_v = \frac{V_f}{V_{out}} = \frac{X_{c2}}{X_{c1}} = \frac{C_1}{C_2}^{***}$$

or

$$m_v = \frac{C_1}{C_2}$$

Example 14.3. *Determine the (i) operating frequency and (ii) feedback fraction for Colpitt's oscillator shown in Fig. 14.12.*

Solution.

(*i*) **Operating Frequency.** The operating frequency of the circuit is always equal to the resonant frequency of the feedback network. As noted previously, the capacitors C_1 and C_2 are in series.

$$\therefore \quad C_T = \frac{C_1 C_2}{C_1 + C_2} = \frac{0.001 \times 0.01}{0.001 + 0.01} = 9.09 \times 10^{-4}\ \mu\text{F}$$

$$= 909 \times 10^{-12}\ \text{F}$$

$$L = 15\ \mu\text{H} = 15 \times 10^{-6}\ \text{H}$$

$$\therefore \quad \text{Operating frequency, } f = \frac{1}{2\pi\sqrt{LC_T}}$$

$$= \frac{1}{2\pi\sqrt{15 \times 10^{-6} \times 909 \times 10^{-12}}}\ \text{Hz}$$

$$= 1361 \times 10^3\ \text{Hz} = \mathbf{1361\ kHz}$$

(*ii*) **Feedback fraction**

$$m_v = \frac{C_1}{C_2} = \frac{0.001}{0.01} = \mathbf{0.1}$$

* The RF choke decouples any ac signal on the power lines from affecting the output signal.

** Referring to Fig. 14.11, it is clear that C_1 and C_2 are in series. Therefore, total capacitance C_T is given by;

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

*** Referring to Fig. 14.11, the circulating current for the two capacitors is the same. Futher, capacitive reactance is inversely proportional to capacitance.

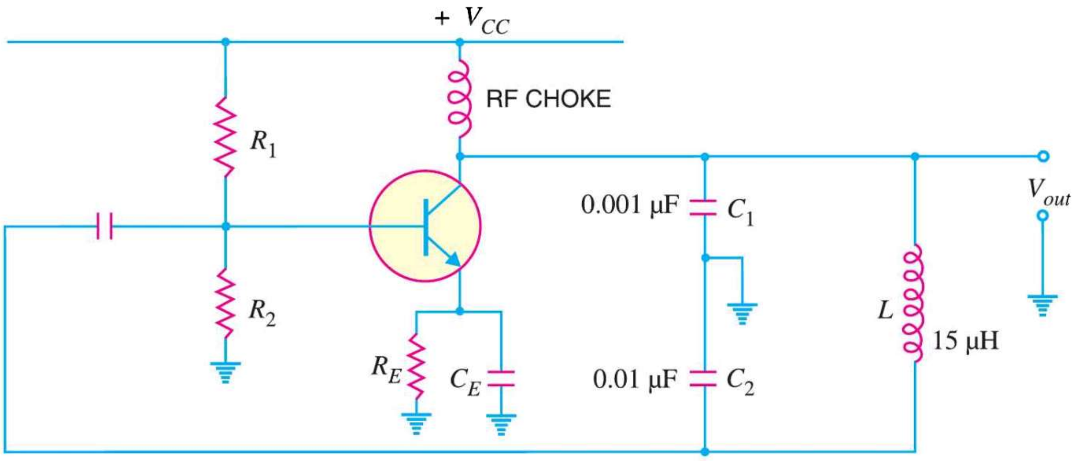


Fig. 14.12

Example 14.4. *A 1 mH inductor is available. Choose the capacitor values in a Colpitts oscillator so that f = 1 MHz and m_v = 0.25.*

Solution.

Feedback fraction, $m_v = \dfrac{C_1}{C_2}$

or $0.25 = \dfrac{C_1}{C_2}$ $\quad\therefore\; C_2 = 4C_1$

Now $f = \dfrac{1}{2\pi\sqrt{LC_T}}$

or $C_T = \dfrac{1}{L(2\pi f)^2} = \dfrac{1}{(1\times 10^{-3})\,(2\pi\times 1\times 10^6)^2} = 25.\,3\times 10^{-12}\,\text{F}$

$= 25.3$ pF

or $\dfrac{C_1C_2}{C_1 + C_2} = 25.3$ pF $\quad\left[\because C_T = \dfrac{C_1C_2}{C_1 + C_2}\right]$

or $\dfrac{C_2}{1 + \dfrac{C_2}{C_1}} = 25.3$

or $\dfrac{C_2}{1+4} = 25.3$ $\quad\therefore\; C_2 = 25.3 \times 5 = \mathbf{126.5\ pF}$

and $C_1 = C_2/4 = 126.5/4 = \mathbf{31.6\ pF}$

14.11 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. 14.13. 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 :

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

where $L_T = L_1 + L_2 + 2M$

Here M = mutual inductance between L_1 and L_2

Note that $L_1 - L_2 - C$ is also the feedback network that produces a phase shift of 180°.

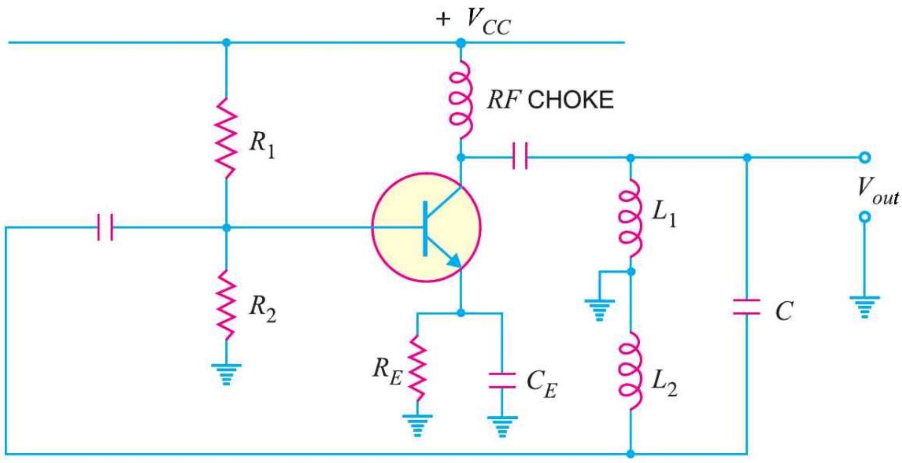


Fig. 14.13

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 *exp. (*i*). The output voltage of the amplifier appears across L_1 and feedback voltage across L_2. The voltage across L_2 is 180° out of phase with the voltage developed across L_1 (V_{out}) as shown in Fig. 14.14. It is easy to see that voltage fedback (*i.e.*, voltage across L_2) to the transistor provides positive feedback. A phase shift of 180° is produced by the transistor and a 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.

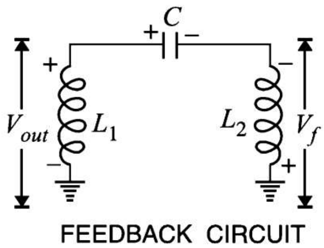


Fig. 14.14

Feedback fraction m_v. In Hartley oscillator, the feedback voltage is across L_2 and output voltage is across L_1.

$$\therefore \quad \text{Feedback fraction, } m_v = \frac{V_f}{V_{out}} = \frac{X_{L_2}}{X_{L_1}} = {}^{**}\frac{L_2}{L_1}$$

$$\text{or} \quad m_v = \frac{L_2}{L_1}$$

Example 14.5. *Calculate the (i) operating frequency and (ii) feedback fraction for Hartley oscillator shown in Fig. 14.15. The mutual inductance between the coils, M = 20 μH.*

Solution.

(*i*) $L_1 = 1000\ \mu H\ ;\ L_2 = 100\ \mu H\ ;\ M = 20\ \mu H$

$$\therefore \quad \text{Total inductance, } L_T = L_1 + L_2 + 2M$$

$$= 1000 + 100 + 2 \times 20 = 1140\ \mu H = 1140 \times 10^{-6} H$$

$$\text{Capacitance, } C = 20\ pF = 20 \times 10^{-12}\ F$$

* Referring to Fig. 14.14, it is clear that L_1 and L_2 are in series. Therefore, total inductance L_T is given by : $L_T = L_1 + L_2 + 2M$

** Referring to Fig. 14.14, the circulating current for the two inductors is the same. Further, inductive reactance is directly proportional to inductance.

Example 14.9. *In the Wien bridge oscillator shown in Fig. 14.18, $R_1 = R_2 = 220\ k\Omega$ and $C_1 = C_2 = 250\ pF$. Determine the frequency of oscillations.*

Solution.

$$R_1 = R_2 = R = 220\ \text{k}\Omega = 220 \times 10^3\ \Omega$$

$$C_1 = C_2 = C = 250\ \text{pF} = 250 \times 10^{-12}\ \text{F}$$

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

$$= \frac{1}{2\pi \times 220 \times 10^3 \times 250 \times 10^{-12}}\ \text{Hz}$$

$$= \mathbf{2892\ Hz}$$

14.15 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. For example, the frequency tolerance for a broadcasting station should not exceed 0.002% *i.e.* change in frequency due to any reason should not be more than 0.002% of the specified frequency. The broadcasting stations have frequencies which are quite close to each other. In fact, the frequency difference between two broadcasting stations is less than 1%. 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 stabilising the frequency and are used in great majority of electronic applications.

14.16 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 because it is inexpensive and readily available in nature.

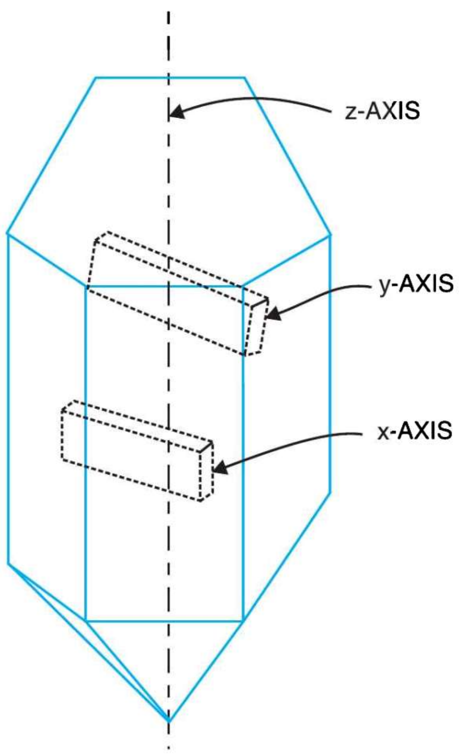


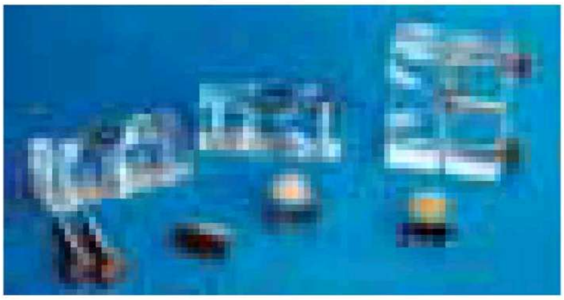
Fig. 14.19

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. 14.19. 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 :

$$f = \frac{K}{t}$$

where K is a constant that depends upon the cut and t is the 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.



Piezoelectric Crystals

14.17 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. 14.20. 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.

Fig. 14.20

14.18 Equivalent Circuit of Crystal

Although the crystal has electromechanical resonance, we can represent the crystal action by an equivalent electrical circuit.

(*i*) When the crystal is not vibrating, it is equivalent to capacitance C_m because it has two metal plates separated by a dielectric [See Fig. 14.21 (*i*)]. This capacitance is known as *mounting capacitance*.

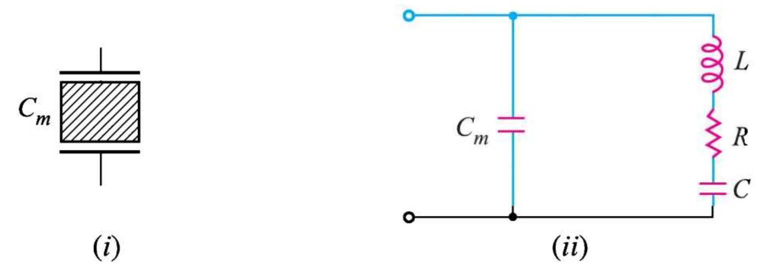
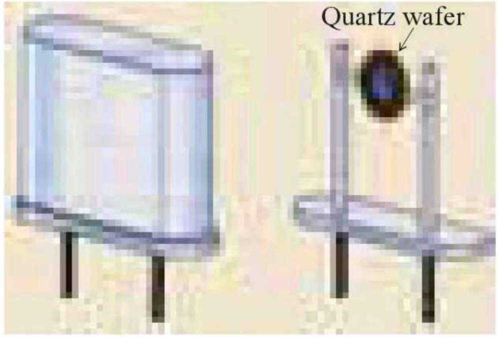


Fig. 14.21

(*ii*) When a crystal vibrates, *it is equivalent to $R - L - C$ series circuit. Therefore, the equivalent circuit of a vibrating crystal is $R - L - C$ series circuit shunted by the mounting capacitance C_m as shown in Fig. 14.21 (*ii*).



A quartz crystal

C_m = mounting capacitance

$R–L–C$ = electrical equivalent of vibrational characteristic of the crystal

Typical values for a 4 MHz crystal are :

L = 100 mH ; R = 100 Ω

C = 0.015 pF ; C_m = 5 pF

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

$$= \frac{1}{100}\sqrt{\frac{100 \times 10^{-3}}{0.015 \times 10^{-12}}} = 26{,}000$$

Note that Q of crystal is very high. The extremely high Q of a crystal leads to frequency **stability.

14.19 Frequency Response of Crystal

When the crystal is vibrating, its equivalent electrical circuit is as shown in Fig. 14.22 (*i*). The capacitance values of C and C_m are relatively low (less than 1 pF for C and 4–40 pF for C_m). Note that the value of C is much lower than that of C_m.

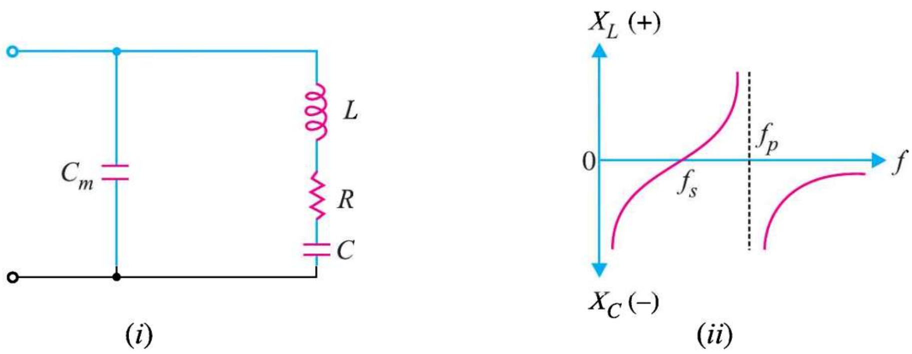


Fig. 14.22

(*i*) At low frequencies, the impedance of the crystal is controlled by extremely high values of X_{C_m} and X_C. In other words, at low frequencies, the impedance of the network is high and capacitive as shown in Fig. 14.22 (*ii*).

(*ii*) As the frequency is increased, $R - L - C$ branch approaches its resonant frequency. At some definite frequency, the reactance X_L will be equal to X_C. The crystal now acts as a series-

* When the crystal is vibrating , L is the electrical equivalent of crystal mass, C is the electrical equivalent of elasticity and R is electrical equivalent of mechanical friction.

** When Q is high, frequency is primarily determined by L and C of the crystal. Since these values remain fixed for a crystal, the frequency is stable. However, in ordinary LC tank circuit, the values of L and C have large tolerances.

resonant circuit. For this condition, the impedance of the crystal is very low; being equal to R. The frequency at which the vibrating crystal behaves as a series-resonant circuit is called *series-resonant frequency* f_s. Its value is given by:

$$f_s = \frac{1}{2\pi\sqrt{LC}} \text{ Hz}$$

where L is in henry and C is in farad.

(iii) At a slightly higher frequency, the net reactance of branch $R - L - C$ becomes inductive and equal to X_{C_m}. The crystal now acts as a parallel-resonant circuit. For this condition, the crystal offers a very high impedance. The frequency at which the vibrating crystal behaves as a parallel-resonant circuit is called *parallel-resonant frequency* f_p.

$$f_p = \frac{1}{2\pi\sqrt{LC_T}}$$

where $$C_T = \frac{C \times C_m}{C + C_m}$$

Since C_T is less than C, f_p is always greater than f_s. Note that frequencies f_s and f_p are very close to each other.

(iv) At frequencies greater than f_p, the value of X_{C_m} drops and eventually the crystal acts as a short circuit.

Conclusion. The above discussion leads to the following conclusions :

(i) At f_s, the crystal will act as a series-resonant circuit.

(ii) At f_p, the crystal will act as a parallel-resonant circuit.

Therefore, we can use a crystal in place of a series LC circuit or in place of parallel LC circuit. If we use it in place of series LC circuit, the oscillator will operate at f_s. However if we use the crystal in place of parallel LC circuit, the oscillator will operate at f_p. In order to use the crystal properly, it must be connected in a cricuit so that its low impedance in the series resonant operating mode or high impedance in the parallel resonant operating mode is selected.

14.20 Transistor Crystal Oscillator

Fig. 14.23 shows the transistor crystal oscillator. Note that it is a Collpit's oscillator modified to act as a crystal oscillator. The only change is the addition of the crystal (Y) in the feedback network. The crystal will act as a parallel-tuned circuit. As you can see in this circuit that instead of

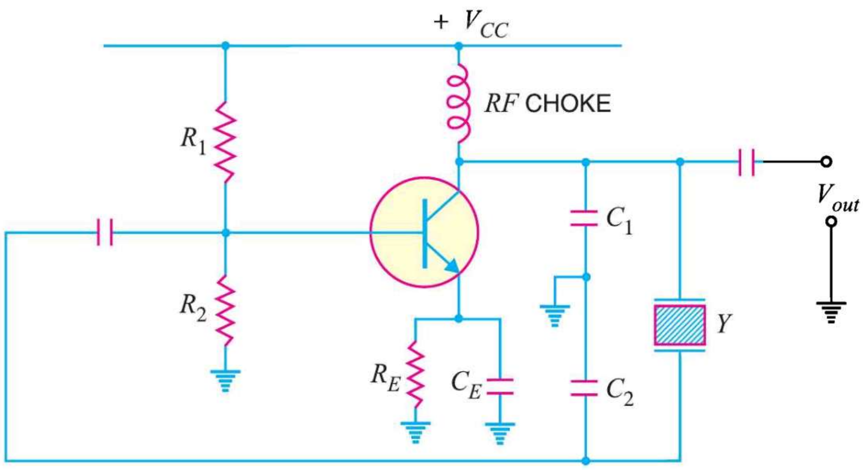


Fig. 14.23

resonance caused by L and $(C_1 + C_2)$, we have the parallel resonance of the crystal. At parallel resonance, the impedance of the crystal is maximum. This means that there is a maximum voltage drop across C_1. This in turn will allow the maximum energy transfer through the feedback network at f_p.

Note that feedback is positive. A phase shift of 180° is produced by the transistor. A further phase shift of 180° is produced by the capacitor voltage divider. This oscillator will oscillate only at f_p. Even the smallest deviation from f_p will cause the oscillator to act as an effective short. Consequently, we have an extremely stable oscillator.

Advantages

(*i*) They have a high order of frequency stability.

(*ii*) The quality factor (Q) of the crystal is very high. The Q factor of the crystal may be as high as 10,000 compared to about 100 of *L-C* tank.

Disadvantages

(*i*) They are fragile and consequently can only be used in low power circuits.

(*ii*) The frequency of oscillations cannot be changed appreciably.

Example 14.10. *A crystal has a thickness of t mm. If the thickness is reduced by 1%, what happens to frequency of oscillations ?*

Solution. Frequency, $f = \dfrac{K}{t}$

or $f \propto \dfrac{1}{t}$

If the thickness of the crystal is reduced by 1%, the frequency of oscillations will increase by 1%.

Example 14.11. *The ac equivalent circuit of a crystal has these values: L = 1H, C = 0.01 pF, R = 1000 Ω and C_m = 20 pF. Calculate f_s and f_p of the crystal.*

Solution.

$$L = 1\text{ H}$$

$$C = 0.01\text{ pF} = 0.01 \times 10^{-12}\text{ F}$$

$$C_m = 20\text{ pF} = 20 \times 10^{-12}\text{ F}$$

$$\therefore \quad f_s = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\pi\sqrt{1 \times 0.01 \times 10^{-12}}}\text{ Hz}$$

$$= 1589 \times 10^3\text{ Hz} = \mathbf{1589\ kHz}$$

Now

$$C_T = \frac{C \times C_m}{C + C_m} = \frac{0.01 \times 20}{0.01 + 20} = 9.99 \times 10^{-3}\text{ pF}$$

$$= 9.99 \times 10^{-15}\text{ F}$$

$$\therefore \quad f_p = \frac{1}{2\pi\sqrt{LC_T}}$$

$$= \frac{1}{2\pi\sqrt{1 \times 9.99 \times 10^{-15}}}\text{ Hz}$$

$$= 1590 \times 10^3\text{ Hz} = \mathbf{1590\ kHz}$$

If this crystal is used in an oscillator, the frequency of oscillations will lie between 1589 kHz and 1590 kHz.

MULTIPLE-CHOICE QUESTIONS

1. An oscillator converts ....
   (*i*) a.c. power into d.c. power
   (*ii*) d.c. power into a.c. power
   (*iii*) mechanical power into a.c. power
   (*iv*) none of the above
2. In an LC transistor oscillator, the active device is ....
   (*i*) LC tank circuit (*ii*) biasing circuit
   (*iii*) transistor (*iv*) none of the above
3. In an LC circuit, when the capacitor energy is maximum, the inductor energy is ....
   (*i*) minimum (*ii*) maximum
   (*iii*) half-way between maximum and minimum
   (*iv*) none of the above
4. In an *LC* oscillator, the frequency of oscillator is .... *L* or *C*.
   (*i*) proportional to square of
   (*ii*) directly proportional to
   (*iii*) independent of the values of
   (*iv*) inversely proportional to square root of
5. An oscillator produces .... oscillations.
   (*i*) damped (*ii*) undamped
   (*iii*) modulated (*iv*) none of the above
6. An oscillator employs .... feedback.
   (*i*) positive (*ii*) negative
   (*iii*) neither positive nor negative
   (*iv*) data insufficient
7. An LC oscillator cannot be used to produce .... frequencies.
   (*i*) high (*ii*) audio
   (*iii*) very low (*iv*) very high
8. Hartley oscillator is commonly used in ....
   (*i*) radio receivers (*ii*) radio transmitters
   (*iii*) TV receivers (*iv*) none of the above
9. In a phase shift oscillator,we use .... *RC* sections.
   (*i*) two (*ii*) three
   (*iii*) four (*iv*) none of the above
10. In a phase shift oscillator, the frequency determining elements are ....
    (*i*) L and C (*ii*) R, L and C
    (*iii*) R and C (*iv*) none of the above
11. A Wien bridge oscillator uses .... feedback.
    (*i*) only positive (*ii*) only negative
    (*iii*) both positive and negative
    (*iv*) none of the above
12. The piezoelectric effect in a crystal is ....
    (*i*) a voltage developed because of mechanical stress
    (*ii*) a change in resistance because of temperature
    (*iii*) a change of frequency because of temperature
    (*iv*) none of the above
13. If the crystal frequency changes with temperature, we say that crystal has .... temperature coefficient.
    (*i*) positive (*ii*) zero
    (*iii*) negative (*iv*) none of the above
14. The crystal oscillator frequency is very stable due to .... of the crystal.
    (*i*) rigidity (*ii*) vibrations
    (*iii*) low *Q* (*iv*) high *Q*
15. The application where one would most likely find a crystal oscillator is ....
    (*i*) radio receiver (*ii*) radio transmitter
    (*iii*) AF sweep generator
    (*iv*) none of the above
16. An oscillator differs from an amplifer because it ....
    (*i*) has more gain
    (*ii*) requires no input signal
    (*iii*) requires no d.c. supply
    (*iv*) always has the same input
17. One condition for oscillation is ....
    (*i*) a phase shift around the feedback loop of 180°
    (*ii*) a gain around the feedback loop of one-third

(*iii*) a phase shift around the feedback loop of 0°

(*iv*) a gain around the feedback loop of less than 1

18. A second condition for oscillations is ....

(*i*) a gain of 1 around the feedback loop

(*ii*) no gain around the feedback loop

(*iii*) the attenuation of the feedback circuit must be one-third

(*iv*) the feedback circuit must be capacitive

19. In a certain oscillator, $A_v = 50$. The attenuation of the feedback circuit must be ....

(*i*) 1 (*ii*) 0.01

(*iii*) 10 (*iv*) 0.02

20. For an oscillator to properly start, the gain around the feedback loop must initially be ....

(*i*) 1 (*ii*) greater than 1

(*iii*) less than 1

(*iv*) equal to attenuation of feedback circuit

21. In a Wien-bridge oscillator, if the resistances in the positive feedback circuit are decreased, the frequency ....

(*i*) remains the same

(*ii*) decreases

(*iii*) increases

(*iv*) insufficient data

22. In a Colpitt's oscillator, feedback is obtained ....

(*i*) by magnetic induction

(*ii*) by a tickler coil

(*iii*) from the centre of split capacitors

(*iv*) none of the above

23. The *Q* of a crystal is of the order of ....

(*i*) 100 (*ii*) 1000

(*iii*) 50 (*iv*) more than 10,000

24. Quartz crystal is most commonly used in crystal oscillators because ....

(*i*) it has superior electrical properties

(*ii*) it is easily available

(*iii*) it is quite inexpensive

(*iv*) none of the above

25. In *LC* oscillators, the frequency of oscillations is given by ....

(*i*) $\dfrac{2\pi}{\sqrt{LC}}$ (*ii*) $\dfrac{1}{2\pi\sqrt{LC}}$

(*iii*) $\dfrac{\sqrt{LC}}{2\pi}$ (*iv*) $\dfrac{2\pi L}{\sqrt{LC}}$

26. The operating frequency of a Wien-bridge oscillator is given by ....

(*i*) $\dfrac{1}{2\pi\sqrt{LC}}$ (*ii*) $\dfrac{1}{4\pi\sqrt{LC}}$

(*iii*) $\dfrac{1}{2\pi RC}$ (*iv*) $\dfrac{1}{29\,RC}$

27. .... is a fixed frequency oscillator.

(*i*) Phase-shift oscillator

(*ii*) Hartley oscillator

(*iii*) Colpitt's oscillator

(*iv*) Crystal oscillator

28. In an *LC* oscillator, if the value of *L* is increased four times, the frequency of oscillations is ....

(*i*) increased 2 times

(*ii*) decreased 4 times

(*iii*) increased 4 times

(*iv*) decreased 2 times

29. An important limitation of a crystal oscillator is ....

(*i*) its low output (*ii*) its high *Q*

(*iii*) less availability of quartz crystal

(*iv*) its high output

30. The signal generator generally used in the laboratories is .... oscillator.

(*i*) Wien-bridge (*ii*) Hartley

(*iii*) Crystal (*iv*) Phase shift

Answers to Multiple-Choice Questions

1. (*ii*)	**2.** (*iii*)	**3.** (*i*)	**4.** (*iv*)	**5.** (*ii*)
6. (*i*)	**7.** (*iii*)	**8.** (*i*)	**9.** (*ii*)	**10.** (*iii*)
11. (*iii*)	**12.** (*i*)	**13.** (*i*)	**14.** (*iv*)	**15.** (*ii*)
16. (*ii*)	**17.** (*iii*)	**18.** (*i*)	**19.** (*iv*)	**20.** (*ii*)
21. (*iii*)	**22.** (*iii*)	**23.** (*iv*)	**24.** (*i*)	**25.** (*ii*)
26. (*iii*)	**27.** (*iv*)	**28.** (*iv*)	**29.** (*i*)	**30.** (*i*)

Chapter Review Topics

1. What is an oscillator ? What is its need ? Discuss the advantages of oscillators.
2. What do you understand by damped and undamped electrical oscillations ? Illustrate your answer with examples.
3. Explain the operation of a tank circuit with neat diagrams.
4. What is the nature of oscillations produced by tank circuit ?
5. How will you get undamped oscillations from a tank circuit ?
6. Discuss the essentials of an oscillator.
7. Discuss the circuit operation of tuned collector oscillator.
8. With a neat diagram, explain the action of Hartley and Colpitt's oscillators.
9. What are the drawbacks of LC oscillators ?
10. Write short notes on the following :

    (*i*) *RC* oscillators (*ii*) Wien bridge oscillators (*iii*) Crystal oscillator

Problems

1. Figure 14.24 shows the Colpitt's oscillator. Determine the (*i*) operating frequency and (*ii*) feedback fraction. **[(*i*) 24.5 kHz (*ii*) 0.1]**

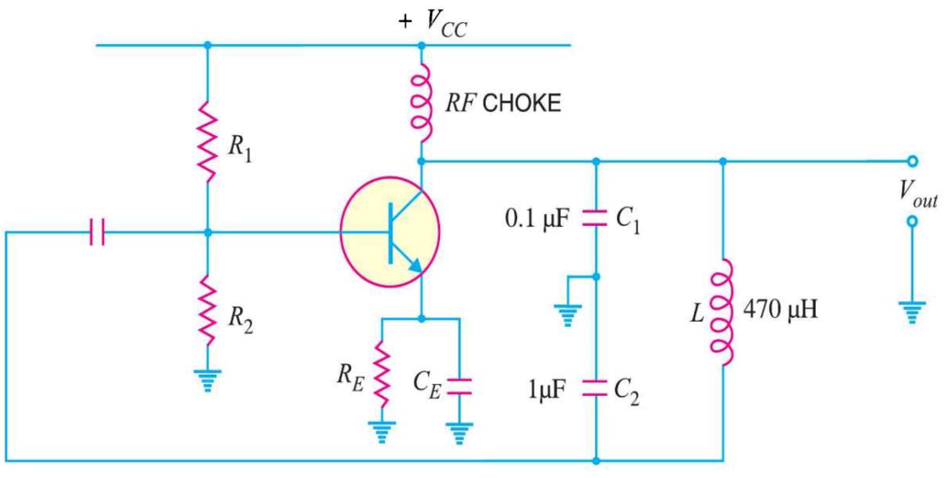


Fig. 14.24

2. Figure 14.25 shows the Hartley oscillator. If L_1 = 1000 μH, L_2 = 100 μH and C = 20 pF, find the (*i*) operating frequency and (*ii*) feedback fraction. **[(*i*) 1052 kHz (*ii*) 0.1]**
3. For the Colpitt's oscillator shown in Fig. 14.24, C_1 = 750 pF, C_2 = 2500 pF and L = 40 μH. Determine (*i*) the operating frequency and (*ii*) feedback fraction. **[(*i*) 1050 kHz (*ii*) 0.3]**