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.**

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* 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 :

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

$G < G_1 \times G_2 \times G_3$

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.

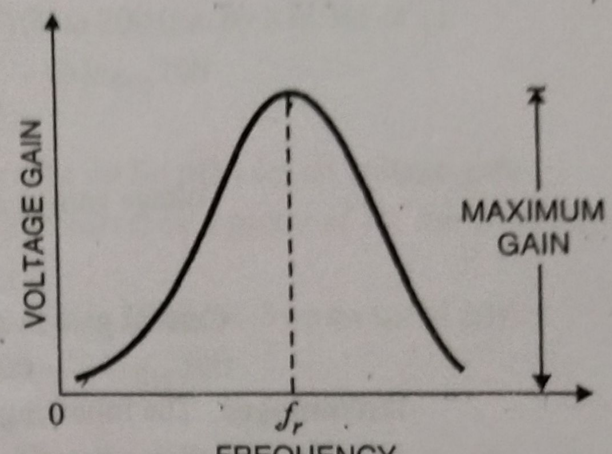

Fig. 11.4

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.*

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

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

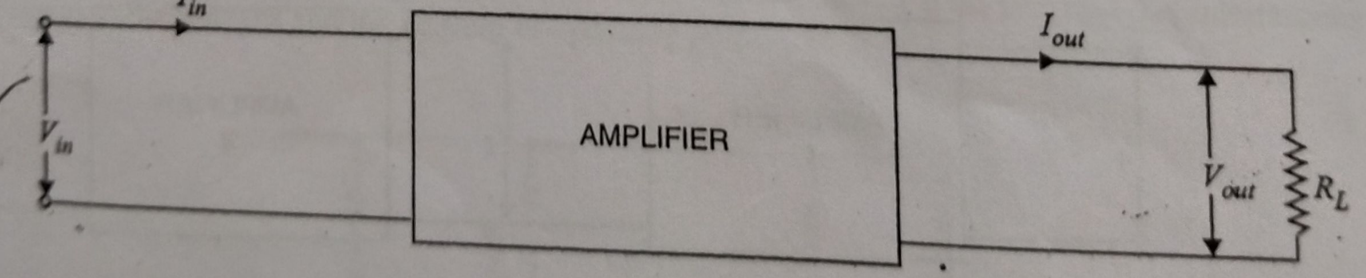

Fig. 11.5

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

$$\text{Output of first stage} = G_1 V$$

$$\text{Output of second stage} = (G_1 V)\, G_2 = G_1 G_2 V$$

$$\text{Output of third stage} = (G_1 G_2 V) G_3 = G_1 G_2 G_3 V$$

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

or

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

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

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,

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

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

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

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

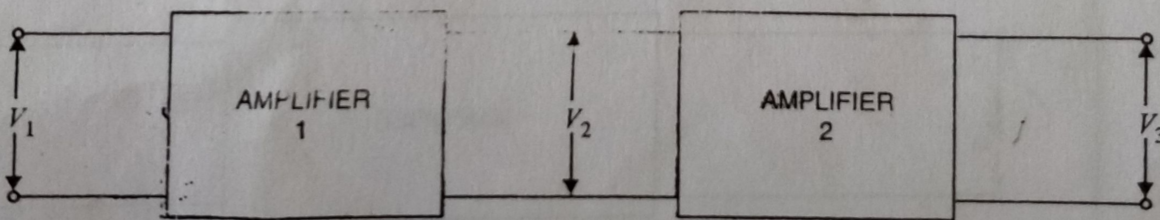


Fig. 11.6

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

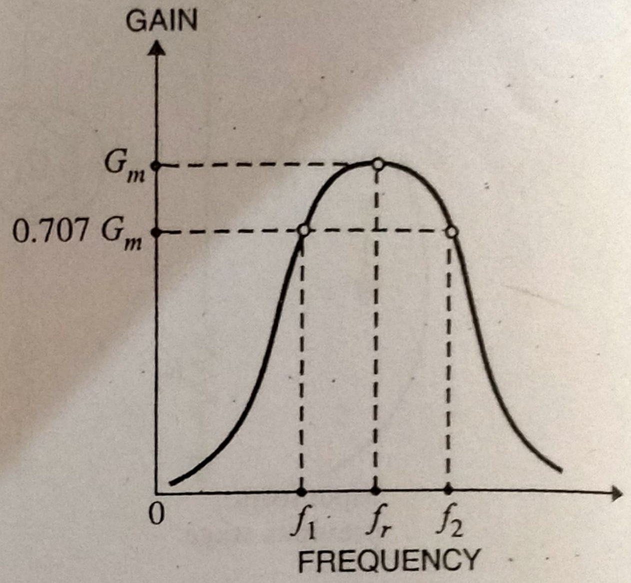


Fig. 11.7

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.

$= 46 - 40 = 6$ 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.

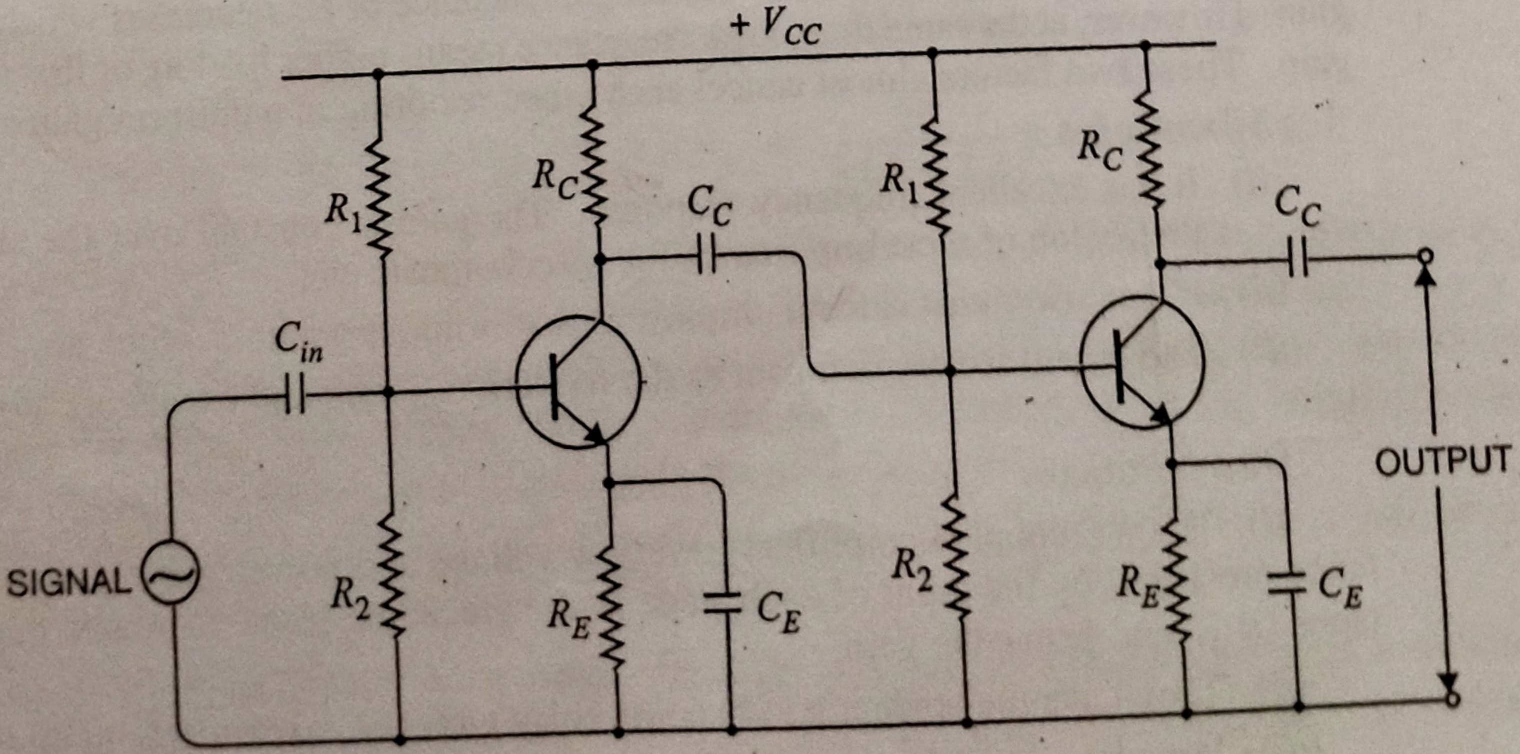


Fig. 11.9

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.

(*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.

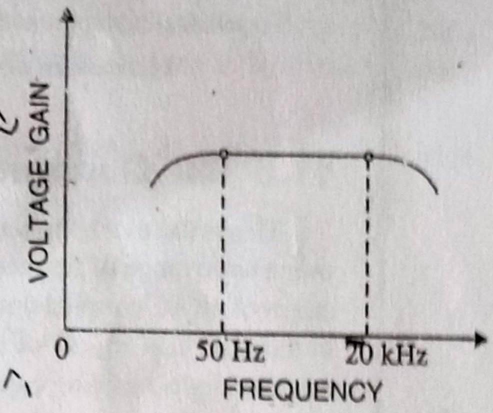


Fig. 11.10

(*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

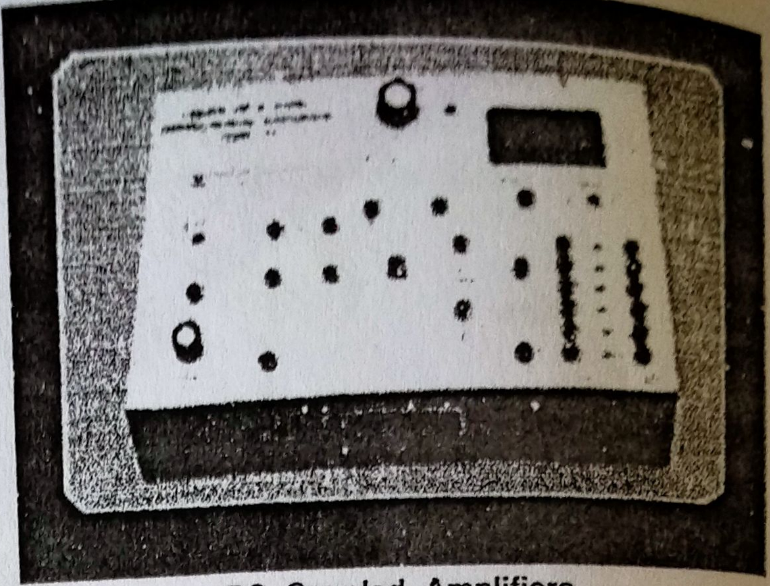
(*i*) The *RC* coupled amplifiers have low voltage and power gain. It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (R_{AC}) and hence the gain.

(*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 everal hundred ohms whereas the input impedance of a speaker is only a few ohms. Hence, little power will be transferred to the speaker.

Applications.

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



RC Coupled Amplifiers

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 $R_C = 500\ \Omega$ and the input impedance is $1k\Omega$. 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.

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

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

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

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

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.

$$= 53 \times 191.4 = 10144$$

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.

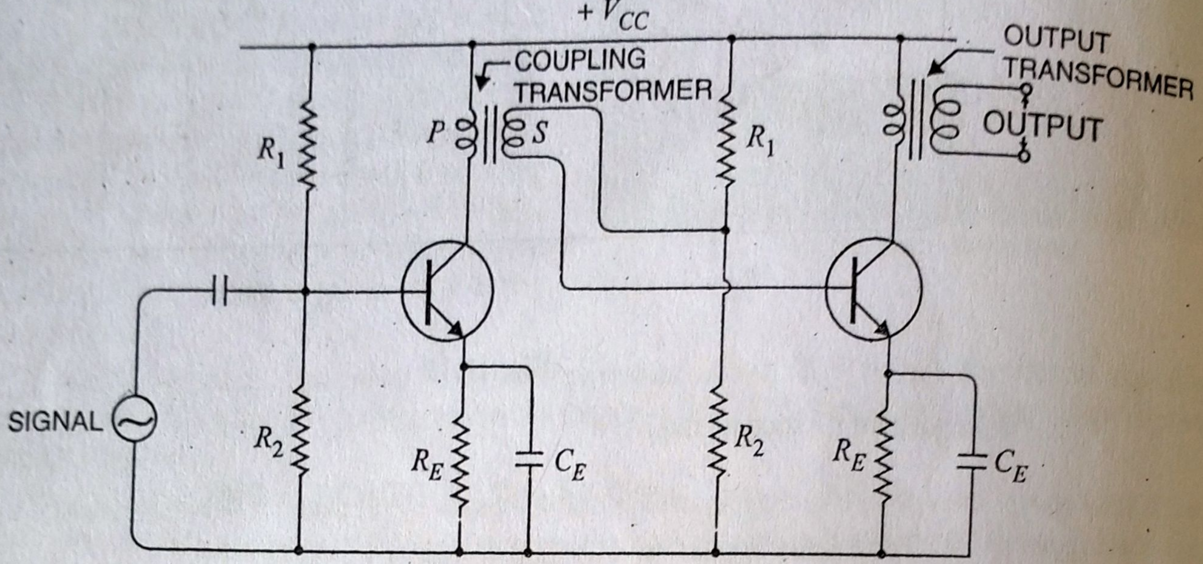


Fig. 11.15

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.*

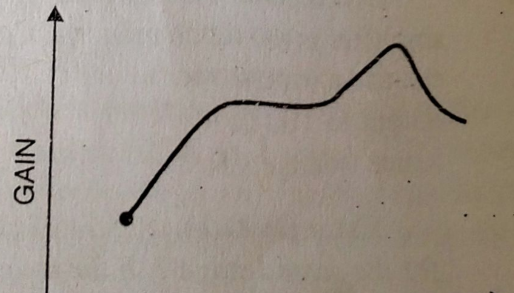


Fig. 11.16

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 t 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 t 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 :

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

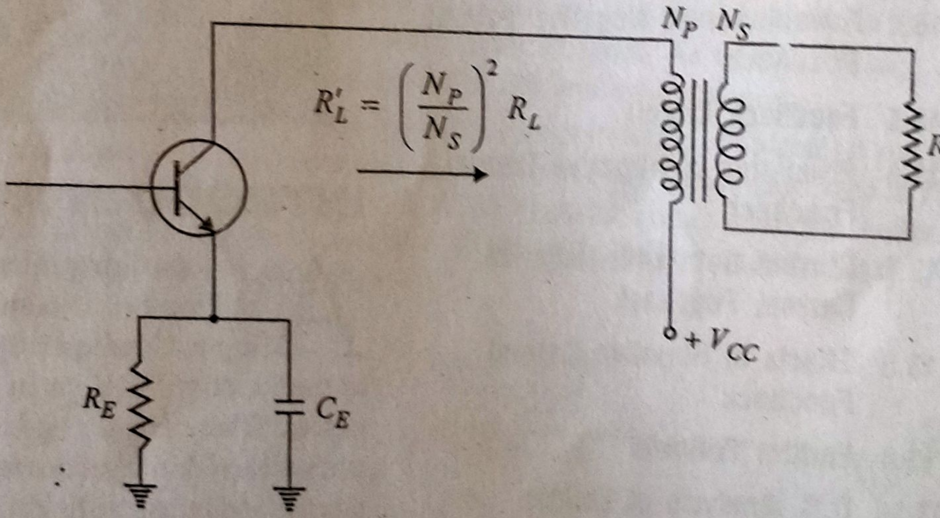


Fig. 11.17

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* 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.*,

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

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

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 $n\ (= N_P/N_S)$.

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

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

or

$$n^2 = 1000/10 = 100$$

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

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

Example 11.17. *Determine the necessary transf*

Principle of feedback amplifeers :-

An Ordinary amplifier is an amplifier which does not employ any feedback. we know that the voltage gain of such an amplifier is given by the ratio of the output voltage (V_o) to the input voltage (V_{in}), Mathematically, the voltage gain,

$$A_V = \frac{V_o}{V_{in}}$$

The voltage gain (A_v) is also known as open loop gain. Now let us add a feedback circuit to the amplifier gain, its input as well as the output voltages

Let,

V_o' = output voltage of feedback amplifier

β = Fraction of the output voltage fed to the input. It is called feedback ratio and is different from common emitter transister current gain,

A_v' = voltage gain of feedback amplifier.

feedback circuit injects a fraction (β) of the output voltage V_o' and returns it to the input voltage, whose value changes to $V_{in} \pm \beta . V_o'$. It will be intresting to know that the value of input voltage. And it is equal to $V_{in} - \beta . V_o'$, if the feedback voltage is out of phase with input voltage. This input voltage is amplified by the circuit and its value at the output.

$$A_v (V_{in} + \beta . V_o') = AV'$$

Rearranging the above equation,

$$V_o' (1 - \beta . A_v) = A_v . V_{in}$$

$$\frac{V_o'}{V_{in}} = \frac{A_v}{1 - \beta . A_v} = A_v'$$

When A_v' is equal to V_o' / V_{in} and is the voltage gain of the feedback amplifier.

a) Negative feedback :-

It may be noted from the voltage gain expression of negative feedback that as the term $(1 + \beta . V_v) > 1$, the value of A_v' is smaller than A_v.

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 so 50 years ago that feedback has come into use in connection with electronic circuits. It has been fo very useful in reducing noise in amplifiers and making amplifier operation stable. Depending up whether the feedback energy aids or opposes the input signal, there are two basic types of feedback amplifiers *viz positive feedback* and *negative feedback.*

(*i*) **Positive feedback.** When the feedback energy (voltage or current) is in phase with the inp signal and thus aids it, it is called *positive feedback.* This is illustrated in Fig. 13.1. Both amplifi and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around t loop, causing the *feedback voltage* V_f to be in phase with the input signal V_{in}.

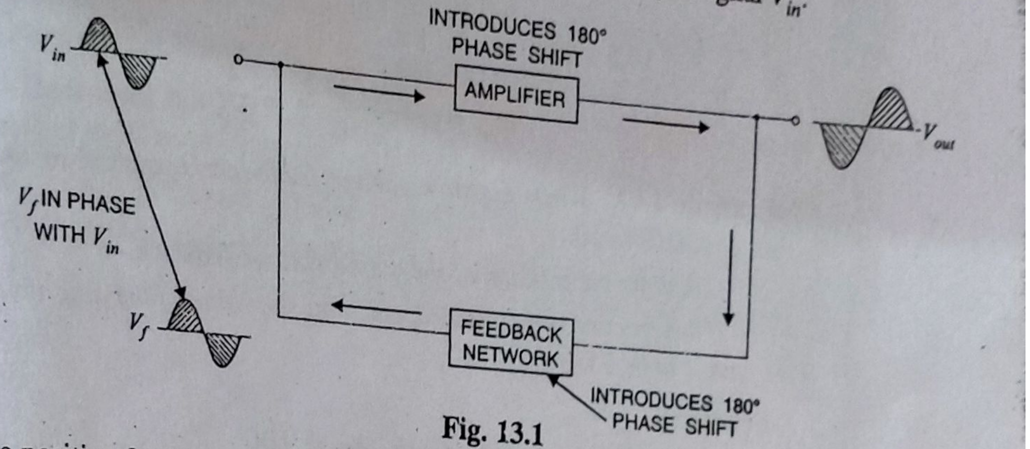


Fig. 13.1

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}.

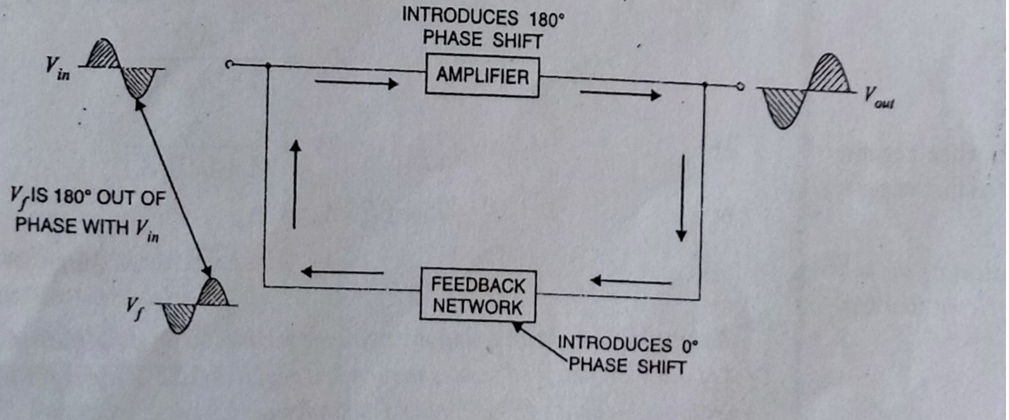


Fig. 13.2

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.

13.8 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 inpu 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

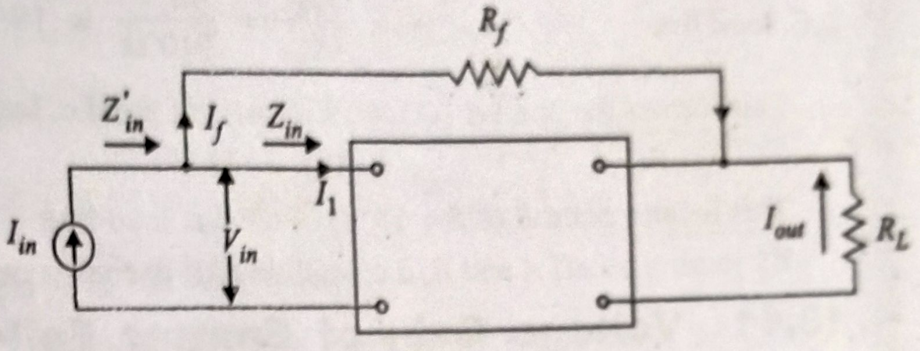


Fig. 13.11

Referring to Fig. 13.11, we have,

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

and

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

But

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

$\therefore$

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

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

$\therefore \quad BW' = 400[1 + (0.01)\, 250] = 1400$ 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 :

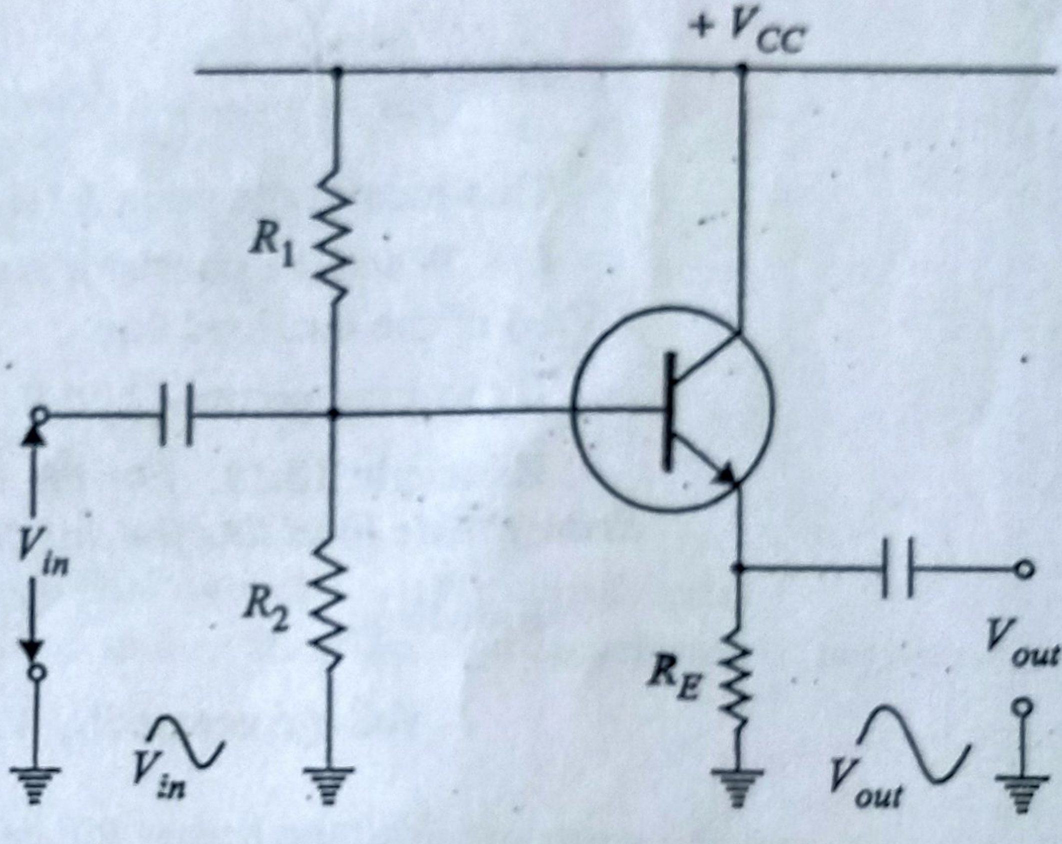


Fig. 13.12

(*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

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

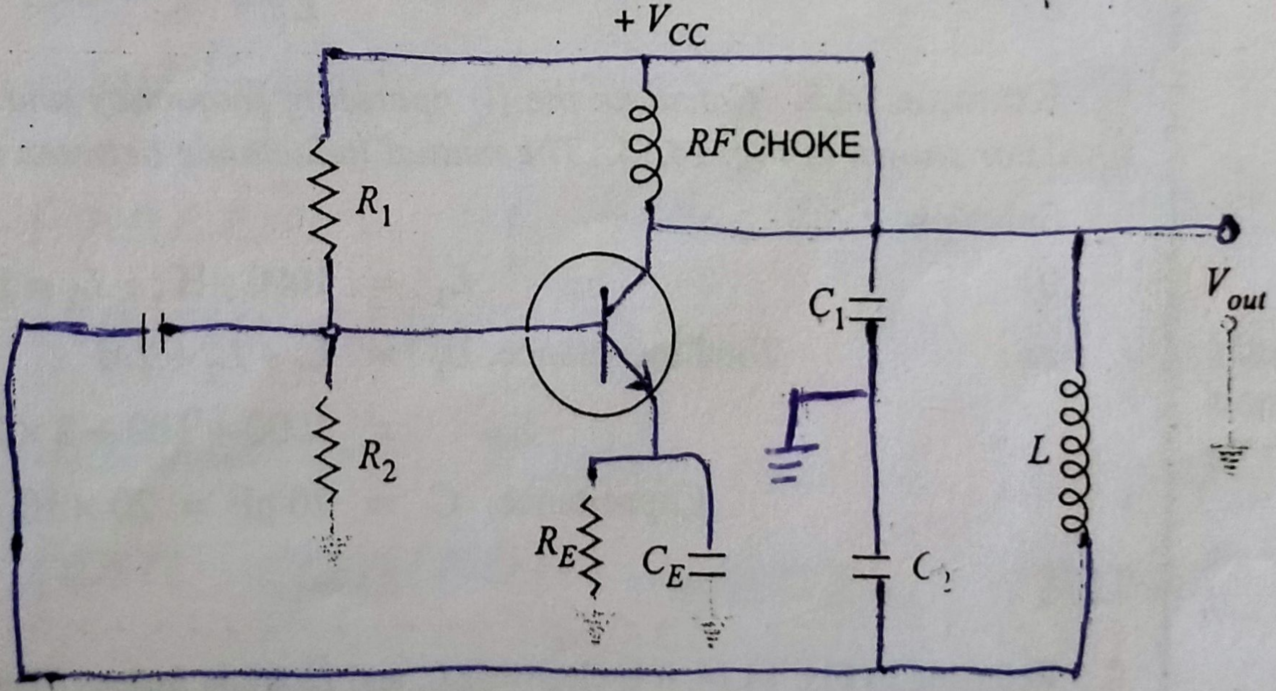
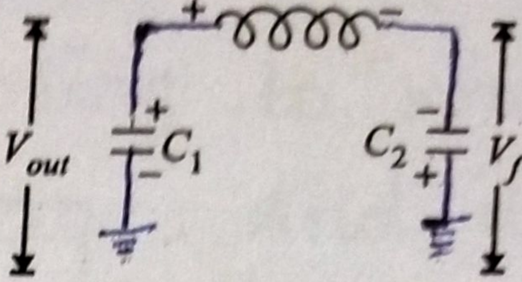


Fig. 14.10

*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 C2 is 180° is 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.



FEEDBACK CIRCUIT

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

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

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 :

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

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°.

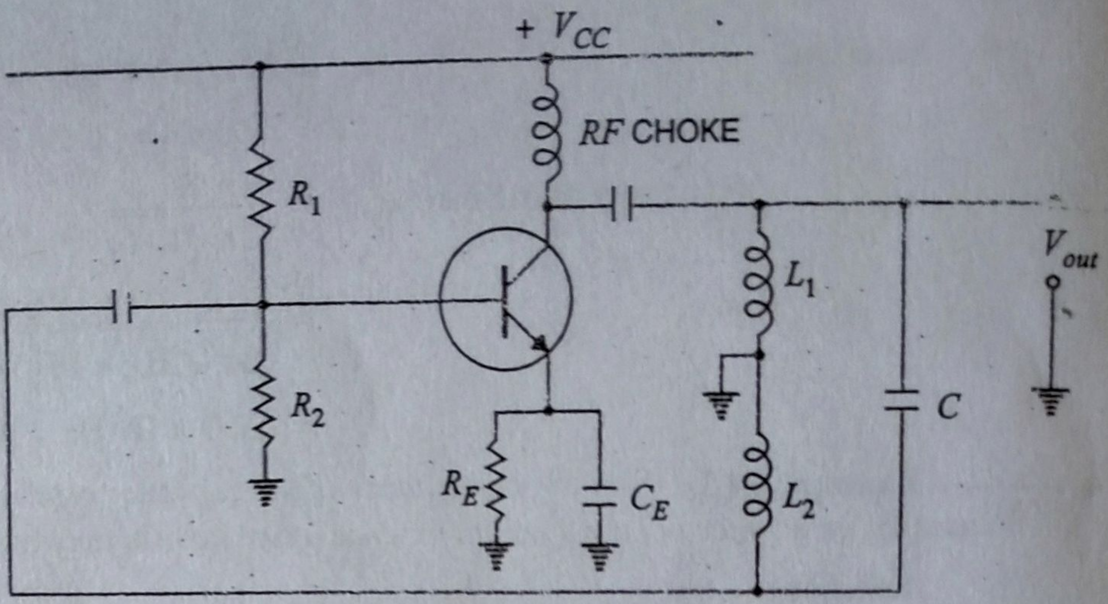


Fig. 14.13

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.

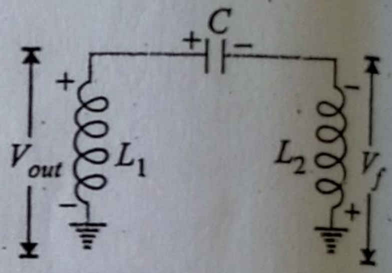


Fig. 14.14

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

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

or

$$m_v = \frac{L_2}{L_1}$$

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.

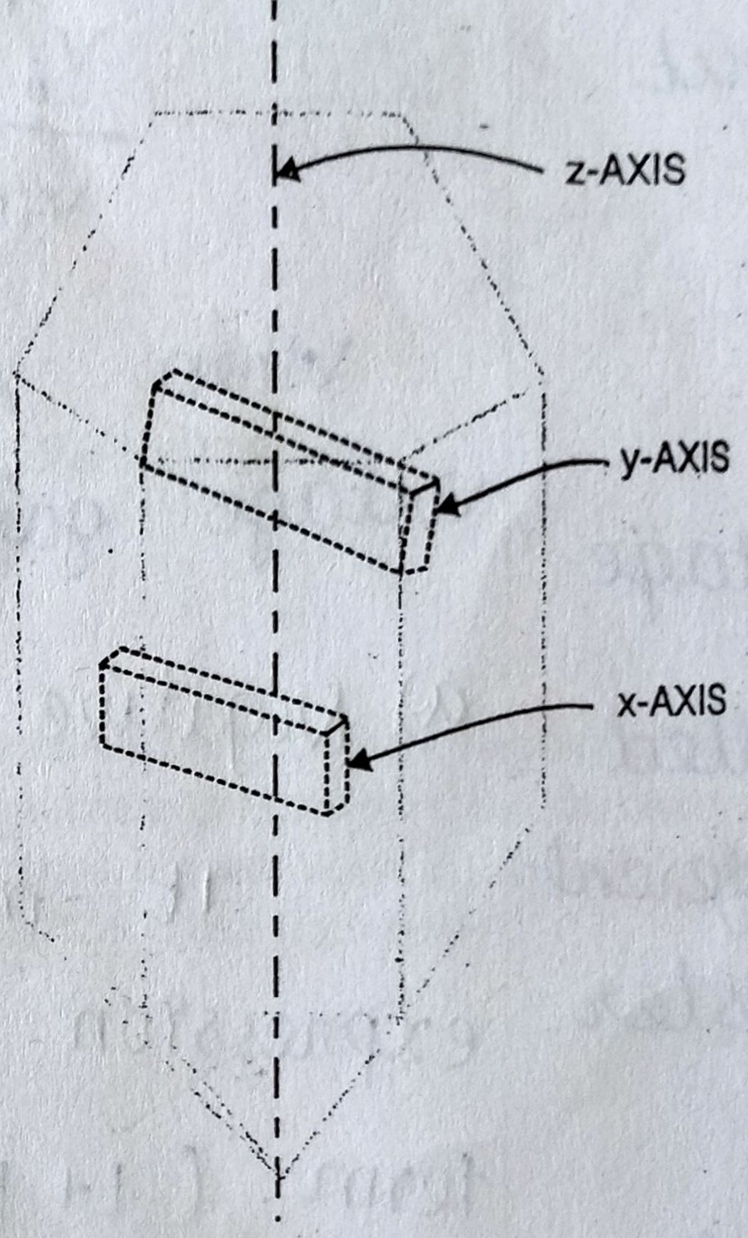
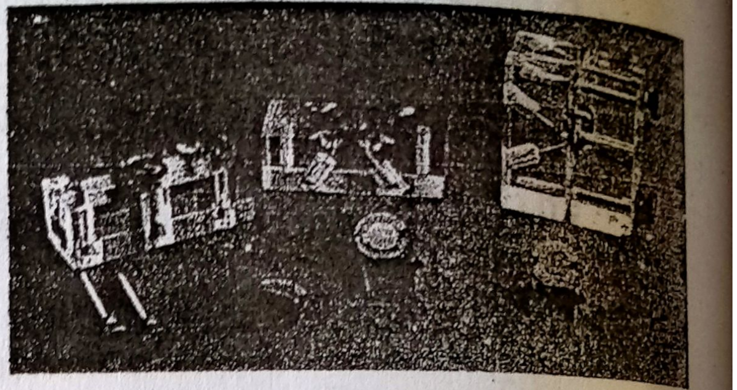


Fig. 14.19

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 :

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



Piezoelectric Crystals

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.

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.

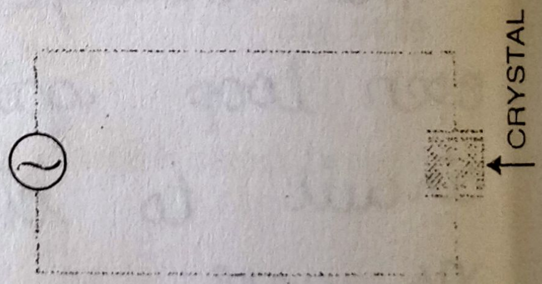


Fig. 14.20