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

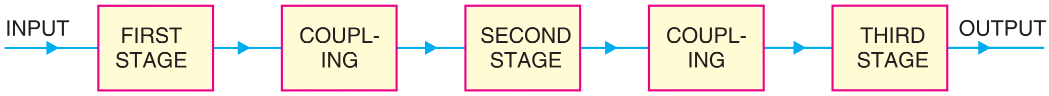

Fig. 11.1

(*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.

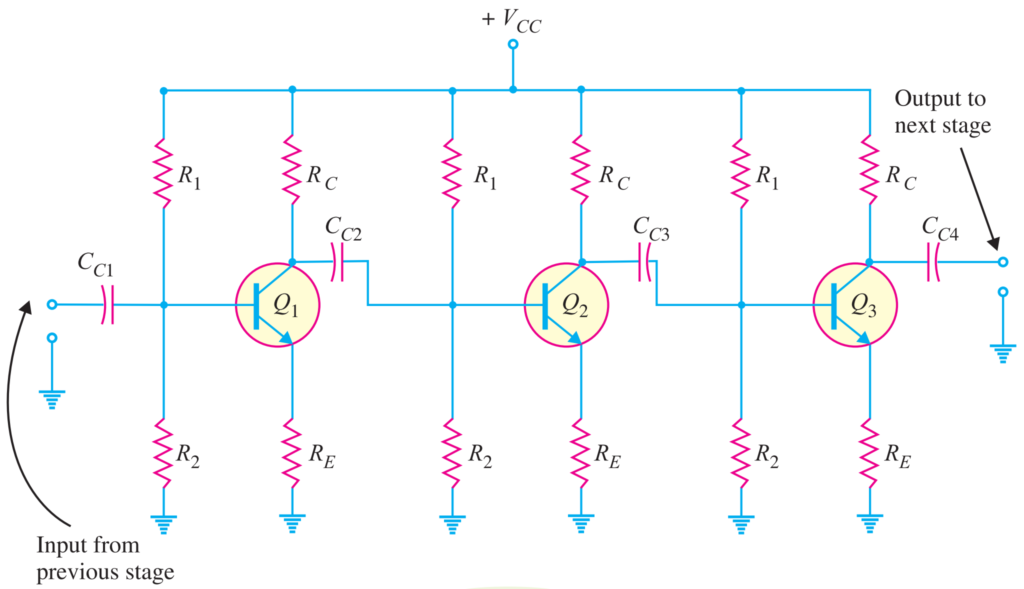

Fig. 11.2

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.

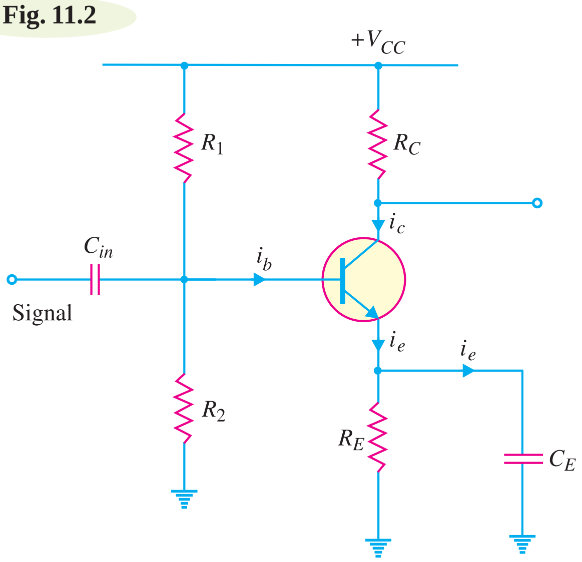

Fig. 11.3

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.

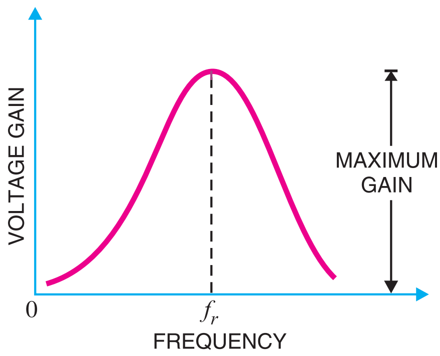

Fig. 11.4

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.*

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

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

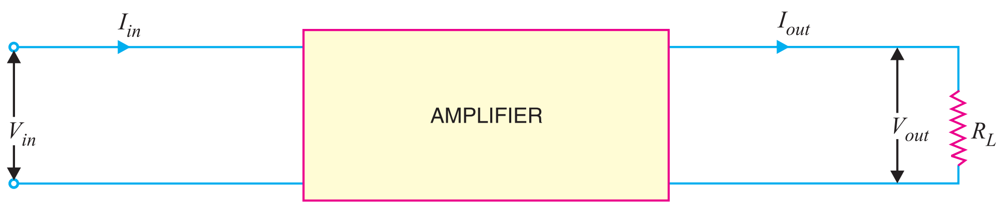

Fig. 11.5

* This can be easily proved. Suppose 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
$$G = \frac{G_1 G_2 G_3 V}{V} = G_1 \times G_2 \times G_3$$

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

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

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

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

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

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

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,

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

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

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

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

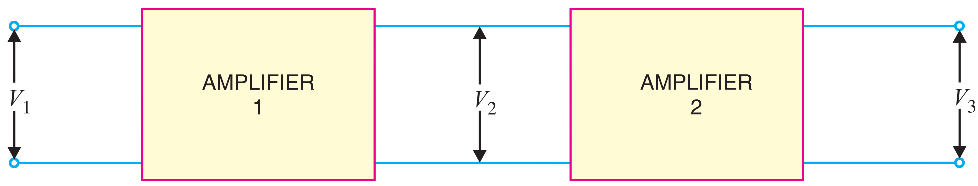

Fig. 11.6

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

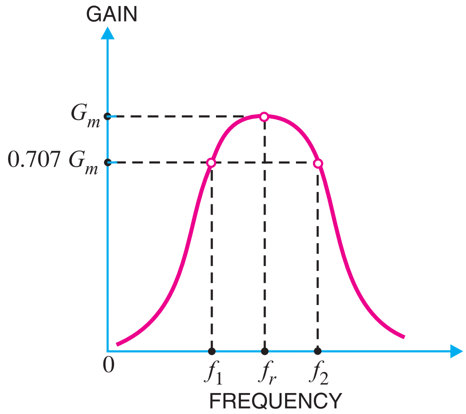

Fig. 11.7

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.

$\therefore$ Gain $=$ Antilog 4 $= 10^4 =$ **10,000**

(ii) Power gain $= 43\ db = 4.3\ bel$

$\therefore$ Power gain $=$ Antilog 4.3 $= 2 \times 10^4 =$ **20,000**

Alternatively.
$$10 \log_{10} \frac{P_2}{P_1} = 43\ db$$

or
$$\log_{10} \frac{P_2}{P_1} = 43/10 = 4.3$$

$$\therefore \quad \frac{P_2}{P_1} = (10)^{4.3} = \textbf{20,000}$$

In general, we have,
$$\frac{V_2}{V_1} = (10)^{gain\ in\ db/20}$$
$$\frac{P_2}{P_1} = (10)^{gain\ in\ db/10}$$

Example 11.3. *A three-stage amplifier has a first stage voltage gain of 100, second stage voltage gain of 200 and third stage voltage gain of 400. Find the total voltage gain in db .*

Solution.

First-stage voltage gain in $db = 20 \log_{10} 100 = 20 \times 2 = 40$

Second-stage voltage gain in $db = 20 \log_{10} 200 = 20 \times 2.3 = 46$

Third-stage voltage gain in $db = 20 \log_{10} 400 = 20 \times 2.6 = 52$

$\therefore$ Total voltage gain $= 40 + 46 + 52 =$ **138 db**

Example 11.4. (*i*) *A multistage amplifier employs five stages each of which has a power gain of 30. What is the total gain of the amplifier in db ?*

(*ii*) *If a negative feedback of 10 db is employed, find the resultant gain.*

Solution. Absolute gain of each stage $= 30$

No. of stages $= 5$

(i) Power gain of one stage in $db = 10 \log_{10} 30 = 14.77$

$\therefore$ Total power gain $= 5 \times 14.77 =$ **73.85 db**

(ii) Resultant power gain with negative feedback

$= 73.85 - 10 =$ **63.85 db**

It is clear from the above example that by expressing the gain in *db*, calculations have become very simple.

Example 11.5. *In an amplifier, the output power is 1.5 watts at 2 kHz and 0.3 watt at 20 Hz, while the input power is constant at 10 mW. Calculate by how many decibels gain at 20 Hz is below that at 2 kHz ?*

Solution.

db power gain at 2 kHz. At 2 kHz, the output power is 1.5 W and input power is 10 mW.

$$\therefore \quad \text{Power gain in } db = 10 \log_{10} \frac{1.5\ \text{W}}{10\ \text{mW}} = 21.76$$

db power gain at 20 Hz. At 20Hz, the output power is 0.3 W and input power is 10 mW.

$$\therefore \quad \text{Power gain in } db = 10 \log_{10} \frac{0.3\ \text{W}}{10\ \text{mW}} = 14.77$$

Fall in gain from 2 kHz to 20 Hz $= 21.76 - 14.77 =$ **6.99 db**

Example 11.6. *A certain amplifier has voltage gain of 15 db. If the input signal voltage is 0.8V, what is the output voltage ?*

Solution.

$$db \text{ voltage gain} = 20 \log_{10} V_2/V_1$$

or $$15 = 20 \log_{10} V_2/V_1$$

or $$15/20 = \log_{10} V_2/V_1$$

or $$0.75 = \log_{10} V_2/0.8$$

Taking antilogs, we get,

$$\text{Antilog } 0.75 = \text{Antilog } (\log_{10} V_2/0.8)$$

or $$10^{0.75} = V_2/0.8$$

$\therefore$ $$V_2 = 10^{0.75} \times 0.8 = \textbf{4.5 V}$$

Example 11.7. *An amplifier has an open-circuit voltage gain of 70 db and an output resistance of 1.5 kΩ. Determine the minimum value of load resistance so that voltage gain is not more than 67db.*

Solution.

$$A_0 = 70\ db \quad ; \quad A_v = 67\ db$$

$$A_0 \text{ in } db - A_v \text{ in } db = 70 - 67 = 3\ db$$

or $$20 \log_{10} A_0 - 20 \log_{10} A_v = 3$$

or $$20 \log_{10} \frac{A_0}{A_v} = 3$$

or $$\frac{A_0}{A_v} = (10)^{3/20} = 1.41$$

But $$\frac{A_v}{A_0} = \frac{R_L}{R_{out} + R_L} \qquad \text{[See Art. 10.20]}$$

$\therefore$ $$\frac{1}{1.41} = \frac{R_L}{1.5 + R_L}$$

or $$R_L = \textbf{3.65 k}\boldsymbol{\Omega}$$

Example 11.8. *An amplifier feeding a resistive load of 1kΩ has a voltage gain of 40 db. If the input signal is 10 mV, find (i) output voltage (ii) load power.*

Solution.

(i) $$\frac{V_{out}}{V_{in}} = (10)^{db\ gain/20} = (10)^{40/20} = 100$$

$\therefore$ $$V_{out} = 100 \times V_{in} = 100 \times 10 \text{ mV} = 1000 \text{ mV} = \textbf{1 V}$$

(ii) $$\text{Load power} = \frac{V_{out}^2}{R_L} = \frac{(1)^2}{1000} = 10^{-3} \text{ W} = \textbf{1 mW}$$

Example 11.9. *An amplifier rated at 40W output is connected to a 10Ω speaker.*

(i) *Calculate the input power required for full power output if the power gain is 25 db.*

(ii) *Calculate the input voltage for rated output if the amplifier voltage gain is 40 db.*

Solution.

(i) Power gain in $db = 10 \log_{10} \dfrac{P_2}{P_1}$ or $25 = 10 \log_{10} \dfrac{40\text{W}}{P_1}$

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

(*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**

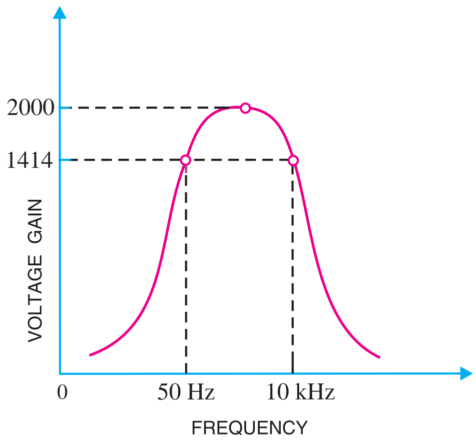

Fig. 11.8

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.

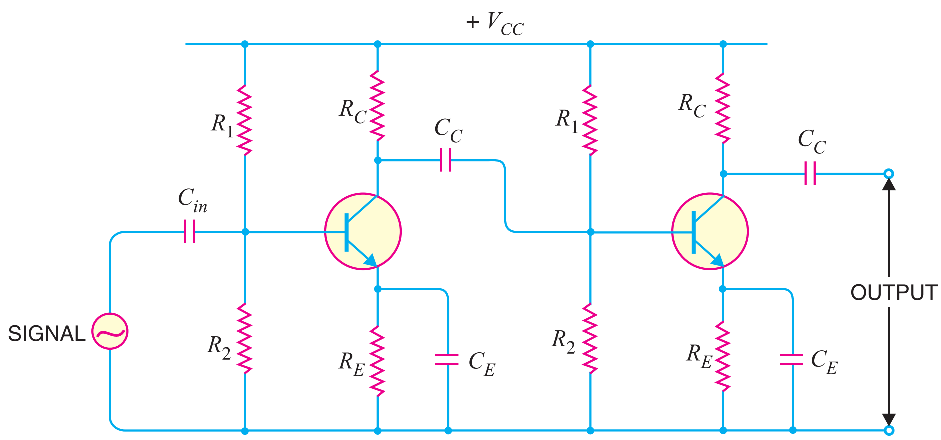

Fig. 11.9

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.

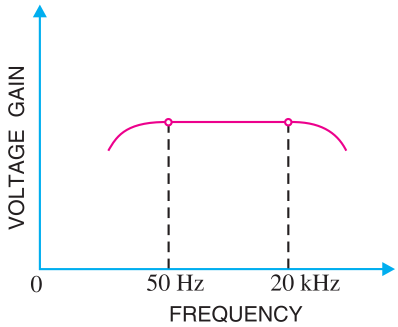

Fig. 11.10

(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.

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 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.

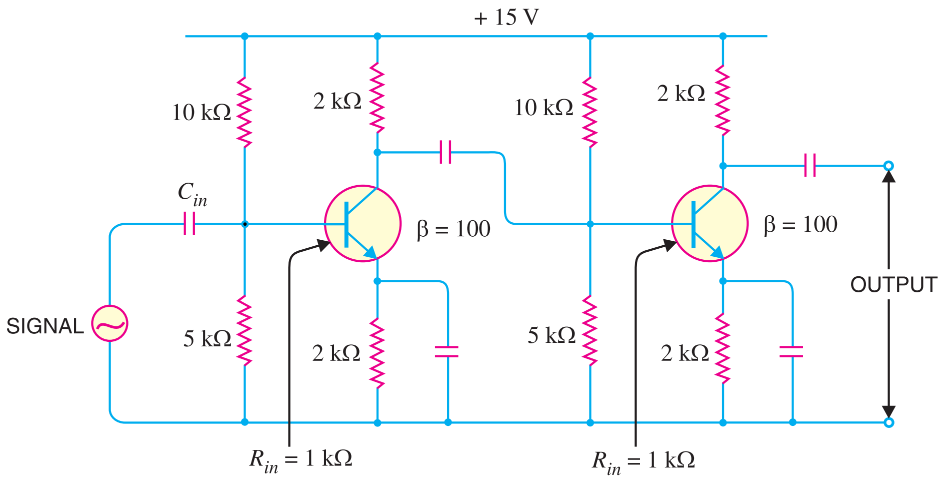

Fig. 11.11

∴ Voltage gain of second stage

$$= \beta \times R_C / R_{in} = 100 \times 2/1 = \mathbf{200}$$

(*iii*) Total voltage gain $= 66 \times 200 = \mathbf{13200}$

Example 11.13. *A single stage amplifier has collector load R_C = 10 kΩ; input resistance R_{in} = 1kΩ and β = 100. If load R_L = 100Ω, find the voltage gain. Comment on the result.*

Solution. Effective collector load, $R_{AC} = R_C \,||\, R_L = 10 \text{ k}\Omega \,||\, 100\ \Omega = {}^*100\ \Omega$

∴ Voltage gain $= \beta \times \dfrac{R_{AC}}{R_{in}} = 100 \times \dfrac{100}{1000} = \mathbf{10}$

Comments. As the load (*e.g.* speaker) is only of 100 ohms, therefore, effective load of the amplifier is too much reduced. Consequently, voltage gain is quite small. Under such situations, we can use a *transformer* to improve the voltage gain and signal handling capability. For example, if the output to 100 Ω load is delivered through a step-down transformer, the effective collector load and hence voltage gain can be increased.

Example 11.14. *Fig. 11.12 shows a 2-stage RC coupled amplifier. What is the biasing potential for the second stage ? If the coupling capacitor C_C is replaced by a wire, what would happen to the circuit ?*

Solution. Referring to Fig. 11.12, we have,

$$\text{Voltage across } R_4, V_B = \frac{V_{CC}}{R_3 + R_4} \times R_4 = \frac{20}{10 + 2.2} \times 2.2 = \mathbf{3.6\ V}$$

Thus biasing potential for the second stage is 3.6 V.

When the coupling capacitor C_C is replaced by a wire, this changes the entire picture. It is because now R_C of the first stage is in parallel with R_3 of the second stage as shown in Fig. 11.13(*i*). The total resistance of R_C (= 3.6 kΩ) and R_3 (= 10 kΩ) is given by:

* 10 kΩ || 100 Ω is essentially 100 Ω.

$$R_{eq} = \frac{R_3\ R_C}{R_3 + R_C} = \frac{10 \times 3.6}{10 + 3.6} = 2.65\ \text{k}\Omega$$

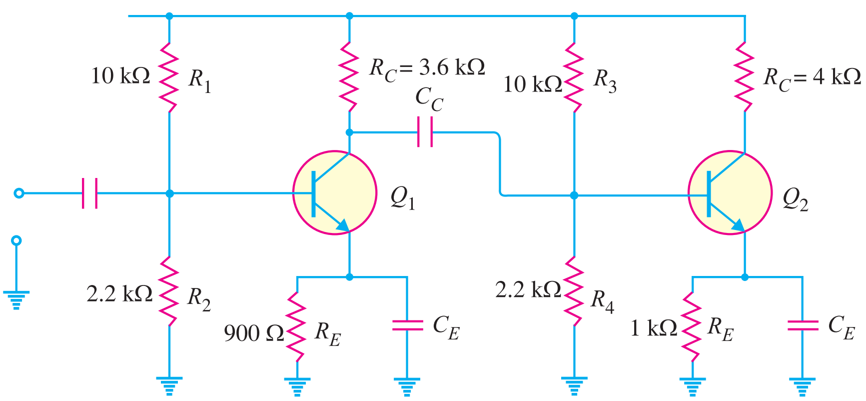

Fig. 11.12

The circuit shown in Fig. 11.13 (*i*) then reduces to the one shown in Fig. 11.13 (*ii*). Referring to Fig. 11.13 (*ii*), we have,

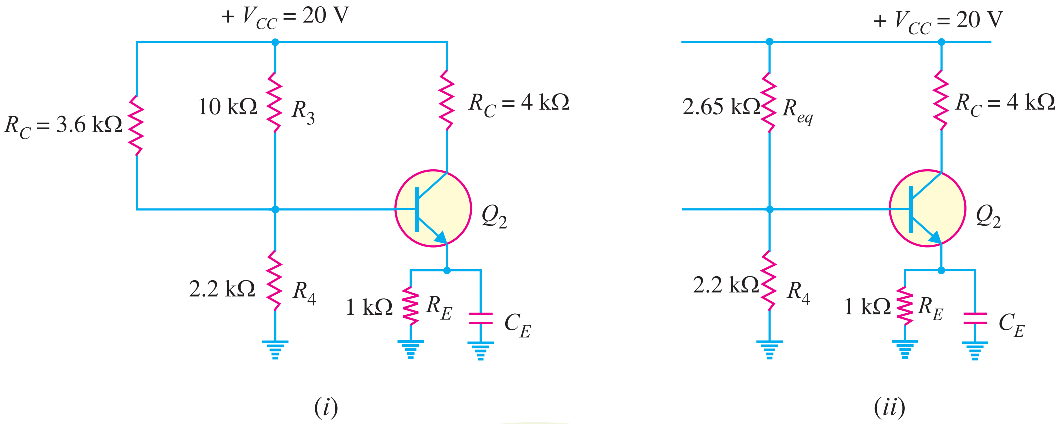

Fig. 11.13

$$\text{Voltage across } R_4,\ V_B = \frac{V_{CC}}{R_{eq} + R_4} \times R_4 = \frac{20}{2.65 + 2.2} \times 2.2 = 9.07\ \text{V}$$

Thus the biasing potential of second stage is drastically changed. The 9.07 V at the base of Q_2 would undoubtedly cause the transistor to saturate and the device would be rendered useless as an amplifier. This example explains the importance of dc isolation in a multistage amplifier. The use of coupling capacitor allows each stage to maintain its independent biasing potential while allowing the ac output from one stage to pass on to the next stage.

Example 11.15. *Fig. 11.14 shows a 2-stage RC coupled amplifier. Find the voltage gain of (i) first stage (ii) second stage and (iii) overall voltage gain.*

Solution. (*i*) Voltage gain of First stage. The input impedance of the second stage is the load for the first stage. In order to find input impedance of second stage, we shall first find r'_e (*ac* emitter resistance) for the second stage.

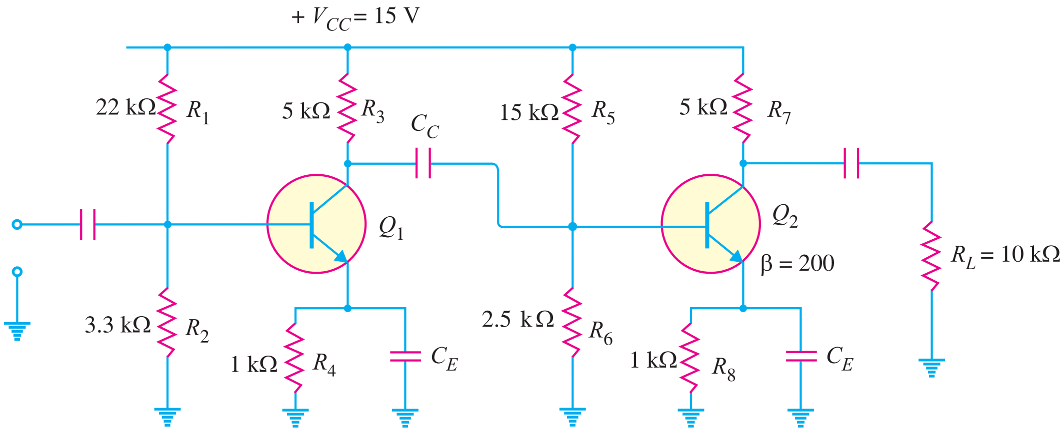

Fig. 11.14

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

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

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

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

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

$$= 53 \times 191.4 = \mathbf{10144}$$

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.

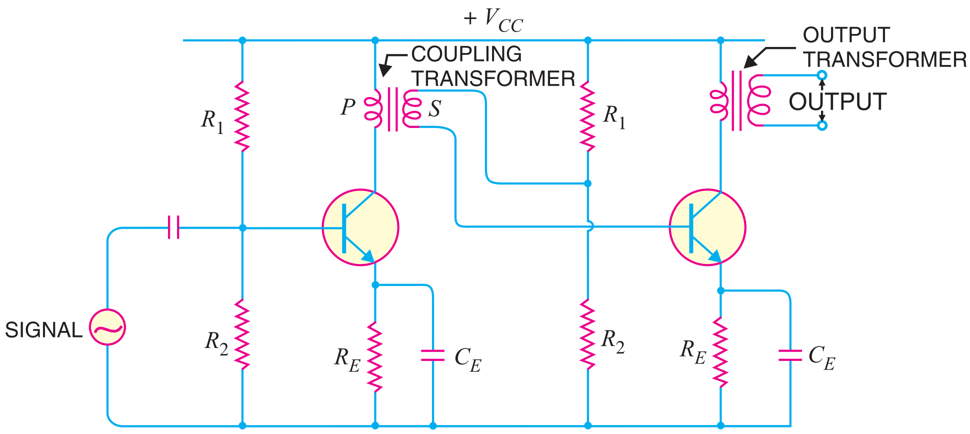

Fig. 11.15

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.*

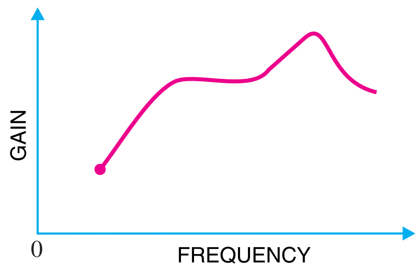

Fig. 11.16

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 :

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

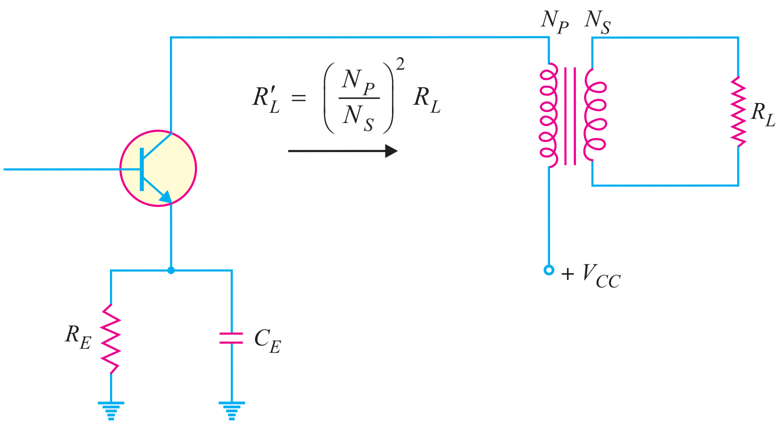

Fig. 11.17

* 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.

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

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

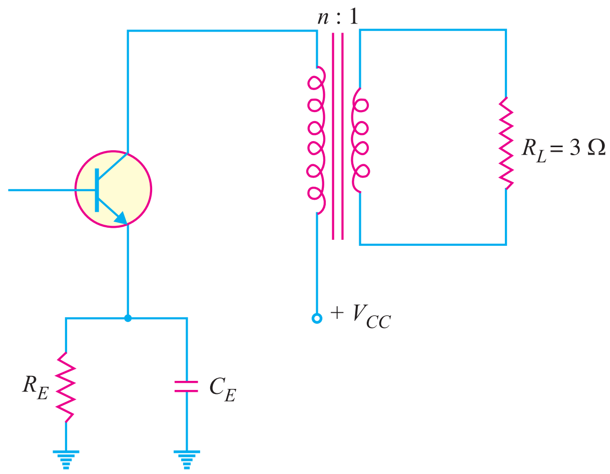

Fig. 11.18

Let n (= N_P/N_S) be the required turn ratio. When no signal is applied, the transistor 'sees' a load of R_P (= 300 Ω) only. However, when a.c. signal is applied, the load R_L in the secondary is reflected in the primary as n^2R_L. Consequently, the transistor now 'sees' a load of R_P in series with n^2R_L.

For transference of maximum power,

$$\text{Output resistance of transistor} = R_P + n^2 R_L$$

or $$3000 = 300 + n^2 \times 3$$

or $$n^2 = \frac{3000 - 300}{3} = 900$$

∴ $$n = \sqrt{900} = \mathbf{30}$$

Example 11.19. *A transistor uses transformer coupling for amplification. The output impedance of transistor is 10 kΩ while the input impedance of next stage is 2.5 kΩ. Determine the inductance of primary and secondary of the transformer for perfect impedance matching at a frequency of 200 Hz.*

Solution. Frequency, f = 200Hz

Output impedance of transistor = 10 kΩ = 10^4 Ω

Input impedance of next stage = 2.5 kΩ = 2.5×10^3 Ω

Primary inductance. Consider the primary side of the transformer. For perfect impedance matching,

Output impedance of transistor = Primary impedance

or $$10^4 = 2\pi f L_P$$

∴ $$\text{Primary inductance, } L_P = \frac{10^4}{2\pi \times 200} = \mathbf{8\ H}$$

Secondary inductance. Consider the secondary side of transformer. For impedance matching,

Input impedance of next stage = Impedance of secondary

or $$2.5 \times 10^3 = 2\pi f L_S$$

∴ $$\text{Secondary inductance, } L_S = \frac{2.5 \times 10^3}{2\pi \times 200} = \mathbf{2\ H}$$

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.

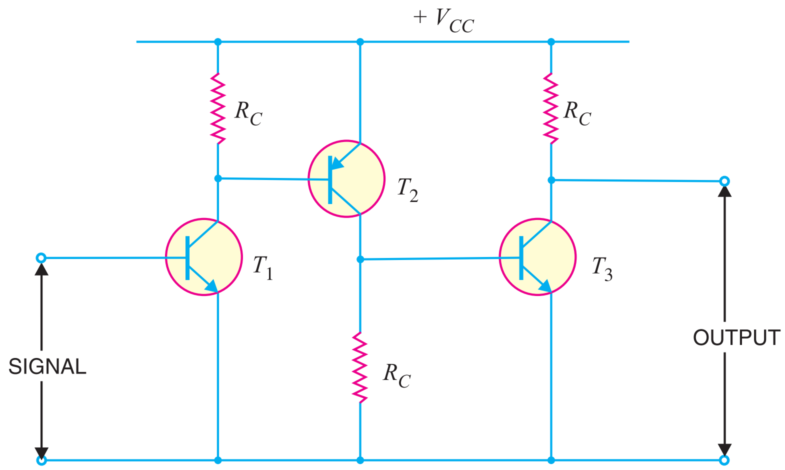

Fig. 11.19

* 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.*

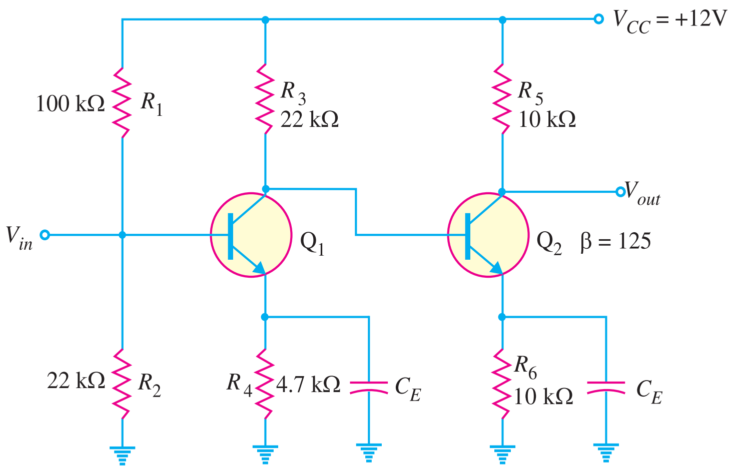

Fig. 11.20

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

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

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

$$\text{D.C. emitter current, } I_{E2} = \frac{V_{E2}}{R_6} = \frac{4.48\text{V}}{10\text{ k}\Omega} = 0.448\text{ mA}$$

$$\text{D.C. voltage at collector, } V_{C2} = V_{CC} - I_{C2}\,\text{R}_5 \quad (\because\ I_{E2} \simeq I_{C2})$$

$$= 12\text{V} - 0.448\text{ mA} \times 10\text{ k}\Omega = \mathbf{7.52V}$$

(ii) **Voltage gain** To find voltage gain, we shall use the standard formula : total a.c. collector load divided by total a.c. emitter resistance.

First stage

$$r'_{e1} = \frac{25\text{ mV}}{I_{E1}} = \frac{25\text{ mV}}{0.31\text{ mA}} = 80.6\Omega$$

Input impedance Z_{in} of the second stage is given by ;

$$Z_{in} = \beta r'_{e2}$$

$$\text{Here } r'_{e2} = \frac{25\text{ mV}}{I_{E2}} = \frac{25\text{ mV}}{0.448\text{ mA}} = 55.8\Omega$$

$$\therefore \quad Z_{in} = \beta r'_{e2} = 125 \times (55.8\Omega) \simeq 7000\Omega = 7\text{ k}\Omega$$

$$\text{Total a.c. collector load, } R_{AC} = R_3 \,||\, Z_{in} = 22\text{ k}\Omega \,||\, 7\text{ k}\Omega = 5.31\text{ k}\Omega$$

$$\therefore \quad \text{Voltage gain, } A_{v1} = \frac{R_{AC}}{r'_{e1}} = \frac{5.31\text{ k}\Omega}{80.6\,\Omega} = \mathbf{66}$$

Second stage. There is no loading effect of any subsequent stage. Therefore, total a.c. collector load, $R_{AC} = R_5 = 10\text{ k}\Omega$.

$$\text{Voltage gain, } A_{v2} = \frac{R_5}{r'_{e2}} = \frac{10\text{ k}\Omega}{55.8\,\Omega} = \mathbf{179}$$

$$\text{Overall voltage gain} = A_{v1} \times A_{v2} = 66 \times 179 = \mathbf{11{,}814}$$

11.8 Comparison of Different Types of Coupling

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

11.9 Difference Between Transistor and Tube Amplifiers

Although both transistors and grid-controlled tubes (*e.g.* triode, tetrode and pentode) can render the job of amplification, they differ in the following respects :

(i) The electron tube is a voltage driven device while transistor is a current operated device.

(ii) The input and output impedances of the electron tubes are generally quite large. On the other hand, input and output impedances of transistors are relatively small.

(iii) Voltages for transistor amplifiers are much smaller than those of tube amplifiers.

(iv) Resistances of the components of a transistor amplifier are generally smaller than the resistances of the corresponding components of the tube amplifier.

(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]**

6. A multistage amplifier consists of three stages ; the voltage gain of stages are 60, 100 and 160. Calculate the overall gain in *db*. **[119.64db]**
7. A multistage amplifier consists of three stages ; the voltage gains of the stages are 30, 50 and 60. Calculate the overall gain in *db*. **[99.1db]**
8. In an *RC* coupled amplifier, the mid-frequency gain is 2000. What will be its value at upper and lower cut-off frequencies? **[1414]**
9. A three-stage amplifier employs *RC* coupling. The voltage gain of each stage is 50 and $R_C = 5\ k\Omega$ for each stage. If input impedance of each stage is 2 kΩ, find the overall decibel voltage gain. **[80 db]**
10. We are to match a 16Ω speaker load to an amplifier so that the effective load resistance is 10 kΩ. What should be the transformer turn ratio ? **[25]**
11. Determine the necessary transformer turn ratio for transferring maximum power to a 50 ohm load from a source that has an output impedance of 5 kΩ. Also find the voltage across the external load if the terminal voltage of the source is 10V r.m.s. **[10, 1V]**
12. We are to match an 8Ω speaker load to an amplifier so that the effective load resistance is 8 kΩ. What should be the transformer turn ratio ? **[10]**

Discussion Questions

1. Why does *RC* coupling give constant gain over mid-frequency range ?
2. Why does transformer coupling give poor frequency response ?
3. How will you get frequency response comparable to *RC* coupling in a transformer coupling?
4. Why is transformer coupling used in the final stage of a multistage amplifier ?
5. Why do you avoid *RC* or transformer coupling for amplifying extremely low frequency signals ?
6. Why do you prefer to express the gain in *db* ?

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