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Multistage Transistor Amplifiers

Introduction

The output from a single stage amplifier is usually insufficient to drive an output device. Anther words, the gain of a single amplifier is inadequate for practical purposes. Consequently, additional amplification over two or three stages is necessary. To achieve this, the output of each amplifier stage is *coupled* in some way to the input of the next stage. The resulting system is referred to as multistage amplifier. It may be emphasized 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 a multistage amplifier, a number of single amplifiers are connected in *cascade arrangement (*means *connected in series*) *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.

(ii) To isolate the d.c. conditions of one stage from the next stage.

Fig. 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*

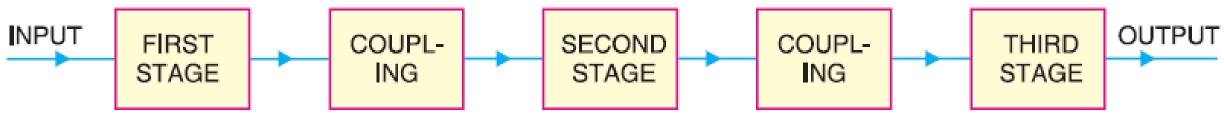

Fig.1: the block diagram of a 3-stage amplifier

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

(*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 ac signal on while blocking the dc 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 dc) but permits in addition impedance matching.

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

The capacitors serve the following two roles in transistor amplifiers:

1. As coupling capacitors

2. As bypass capacitors

1. As coupling capacitor

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.2 shows the coupling capacitors (C_{C1}; C_{C2}; C_{C3} and C_{C4}) in a multistage amplifier.

*$X_C = 1/2\pi fC$. For dc $f = 0$ so that $X_C \rightarrow \infty$. Therefore, a capacitor behaves as an open to dc

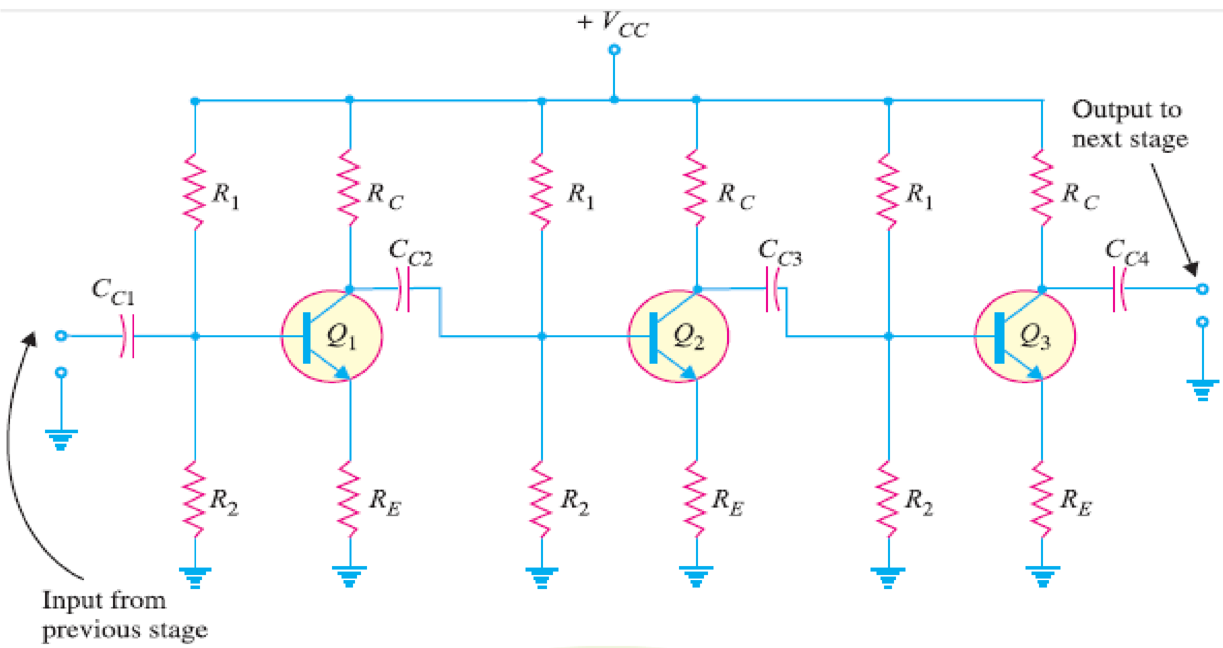

Fig.2: the coupling Capacitors in a multistage amplifier

2. As bypass capacitors

Like a coupling capacitor, a bypass capacitor also blocks dc and behaves as a short or wire to an ac 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 ac signal. Fig.3 shows a bypass capacitor *CE* connected across the emitter resistance *RE*. Since *CE* behaves as a short to the ac signal, the whole of ac signal (*ie*) passes through it. Note that *CE* keeps the emitter at ac ground. Thus for ac purposes, *RE* does not exist. *CE* plays an important role in determining the voltage gain of the amplifier circuit. If *CE* is removed, the voltage gain of the amplifier is greatly reduced. Note that *Cin* is the coupling capacitor in this circuit.

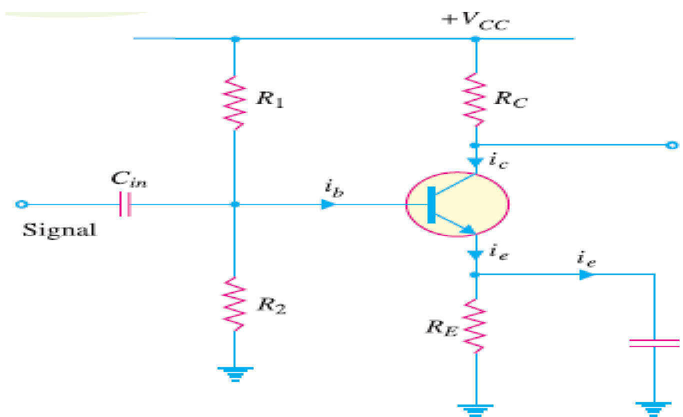

Fig.3: a bypass capacitor *CE* connected across the emitter resistance *RE*

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. Meaning *The ratio of the output electrical quantity to the input one of the amplifier* (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 = G1xG2xG3

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

Output of first stage = *G*1*V*

Output of second stage = (*G*1*V*) *G*2 = *G*1*G*2*V*

Output of third stage = $(G1G2V)\,G3 = G1G2G3V$

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

or $G = \dfrac{G1G2\,G3V}{V} = G1 \times G2 \times G3$

(*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.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 fr, called *resonant frequency*. If the frequency of signal increases beyond fr, the gain decreases.

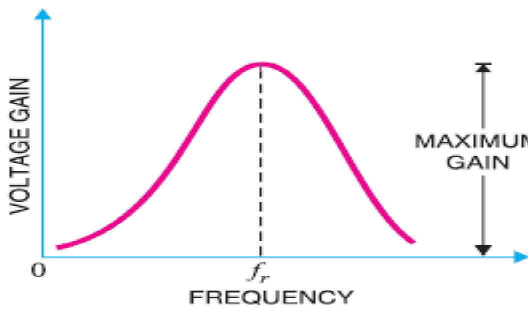

Fig.4: frequency response of a typical amplifier

(***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.

Power gain = $\log_{10}\dfrac{Pout}{Pin}$ bel 1 bel = 10 *db*

Power gain = $10\ \log_{10}\dfrac{Pout}{Pin}$ db

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

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

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

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

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

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

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

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

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

(*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 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 $f1$ and $f2$, the gain is equal to or greater than 70.7% of the maximum gain. Therefore, $f1 - f2$ is the bandwidth. It may be seen that $f1$ and $f2$ are the limiting frequencies. The former ($f1$) is called *lower cut-off frequency* and the latter ($f2$) 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.

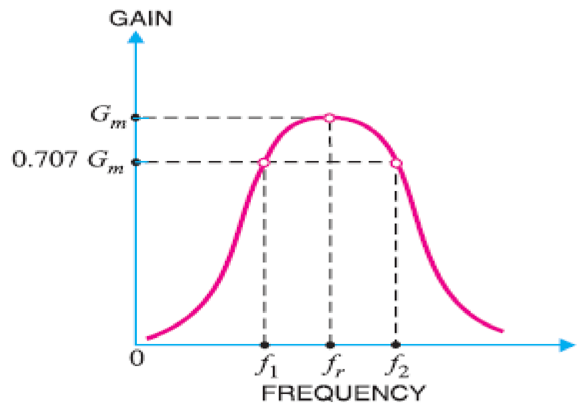

Fig.7: Bandwidth of frequency response

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.

$\therefore$ 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 $f1$ or $f2$ 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.

1. 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.
- Fig.8: shows two stages of an *RC* coupled amplifier. A coupling capacitor *CC* 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 emitter bypass capacitor offers low reactance path to the signal. Without it, the voltage gain of each stage would be lost.
- This prevents d.c. interference between various stages and the shifting of operating point.

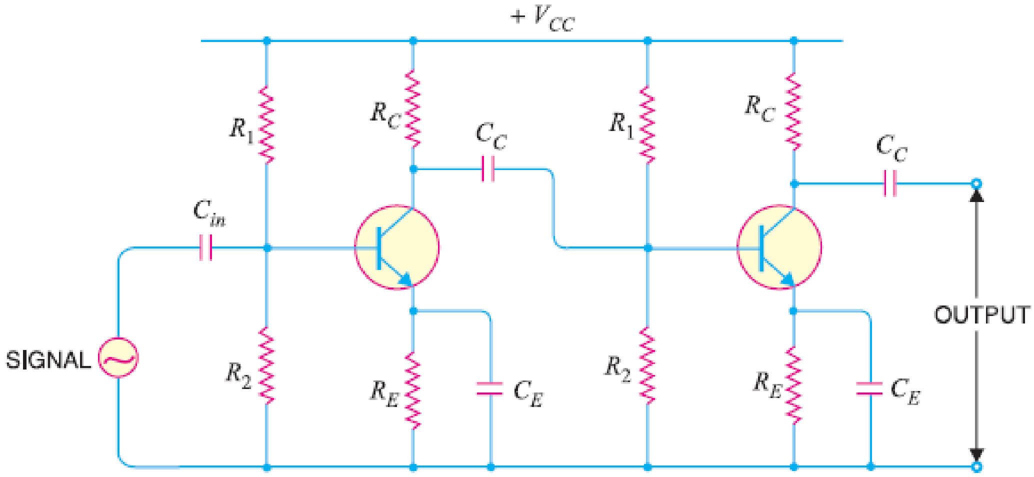

Fig.8: RC coupled transistor amplifier

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 of RC coupled. Fig.9 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 behavior of the amplifier is briefly explained below:

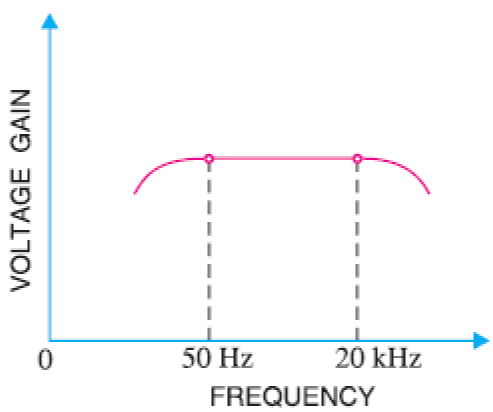

Fig.9: the frequency response of a typical RC coupled amplifier

(*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, *CE* cannot shunt the emitter resistance *RE* 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.

(*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 very 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.

2. Direct-Coupled Amplifier

There are many applications in which very 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 very low frequencies. Under such situations, one stage is *directly* connected to the next stage without any intervening coupling device.

Circuit details. Fig.11 shows the circuit of a three-stage direct-coupled amplifier. It uses complementary transistors (This makes the circuit stable w.r.t. temperature changes.). 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.

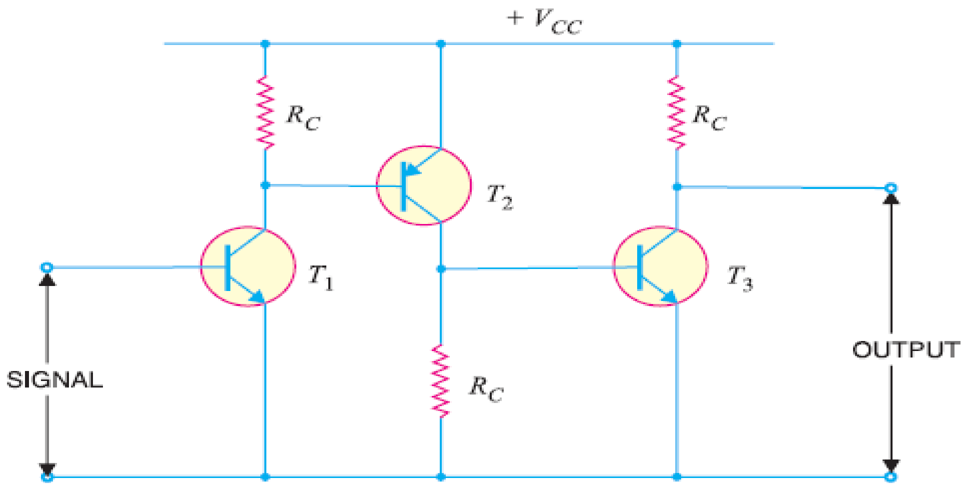

Fig.11: three stages direct coupled amplifier

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.