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Study on Frequency Response Curve of an RC Coupled Amplifier

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Abstract

A practical amplifier circuit is meant to raise the voltage level of the input signal. This signal may be obtained from the piezoelectric crystal of a record player, the sound head of a tape recorder, the microphone in case of a PA system, or from a detector circuit of a radio or TV receiver. Such a signal is not of a single frequency. But it consists of a band of frequencies. For example, the electrical signal produced by the voice of human being or by a musical orchestra may contain frequencies as low as 30 Hz and as high as 15 kHz. Such a signal is called audio signal. If the loudspeakers are to reproduce the original sound faithfully, the amplifier used must amplify all the frequency components of the signal equally well. If it does not do so, the output of the loudspeaker will not be an exact replica of the original sound. When this happens, we say that distortion has been introduced by the amplifier.

1. Introduction

The performance of an amplifier is judged by observing whether all frequency components of the signal are amplified equally well. This information is provided by its frequency response curve. This curve illustrates how the magnitude of the voltage gain (of amplifier) varies with the frequency of the input signal (sinusoidal). It can be plotted by measuring the voltage gain of the amplifier for different frequencies of the sinusoidal voltage fed to its input (see Figure 1.1).

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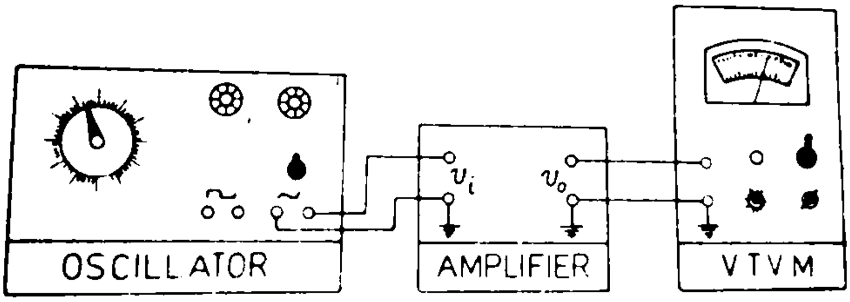

Figure 1.1 Measurement of Voltage Gain for Plotting Frequency – Response Curve

Figure 1.2 shows a frequency response curve of a typical RC-coupled amplifier. This curve is usually plotted on a semi log graph paper with frequency on logarithmic scale so as to accommodate large frequency range. Note that the gain is constant only for a limited band of frequencies. This range of frequencies is called the mid-frequency range and the gain is called mid-band gain, A_{vm}.

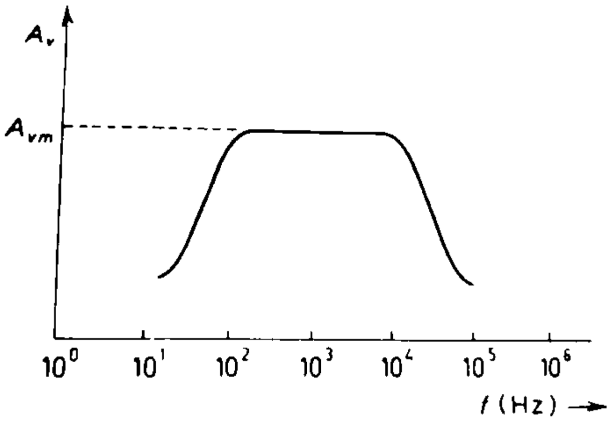

Figure 1.2 Frequency Response Curve of an RC Coupled Amplifier

On both sides of the mid-frequency range, the gain decreases. For very low and for very high frequencies, the gain of the amplifier reduces to almost zero.

1.1 Fall of Gain in Low-frequency Range

In the last section, we analyzed an amplifier circuit to determine its voltage gain. This was the mid-frequency gain. In mid-frequency range, the coupling and bypass capacitors are as good as short-circuits. But, when the frequency is low, these capacitors can no longer be replaced by the short-circuit approximation. The lower the frequency, the greater is the value of reactance of these capacitors, since

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Equation: 1

$$X_C = \frac{1}{2\pi f C}$$

Let us first examine how the coupling capacitor C_c affects the voltage gain of the amplifier at low frequencies. The output section of the first stage of the two-stage RC-coupled amplifier of Figure 1.3 is redrawn in Figure. 1.4.a.

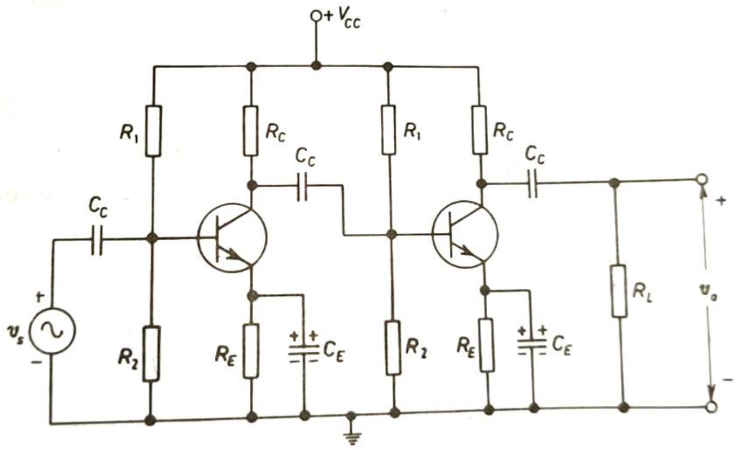

Figure 1.3 Two –Stage RC Coupled Amplifier using Transistors

The output voltage v_o of this stage is the input to the second stage. The resistors R_1 and R_2 are the biasing resistors for the second stage. From the ac point of view, this circuit is equivalent to the one drawn in Figure 1.4.b. Assume for the time being, that the capacitor C_E is replaced by a short circuit. The resistors R_1,R_2 and input impedance h_{ie} of the next stage are in parallel and are equivalent to a resistor RRR. This resistance forms a part of the load resistance of the previous (first) stage. It really does not matter whether the output voltage $v_o$is taken at the left side or at the right side of the resistor R.

The capacitor C_c is in series with the resistor R, and this series combination is in parallel with the collector resistor R_c. The whole of this impedance forms the ac load for the preceding stage. But the effective output of the stage is the ac voltage developed across the resistor RRR (see Figure 1.4.c). At mid-frequencies (and also at high frequencies), the reactance of the capacitor Cc is sufficiently small compared to R. We can treat it as a short-circuit so that the resistor R comes in parallel with the resistor Rc. In such a case, the voltage v_1 across resistor R_c will be the same as the voltage v_o across R.

However, at low frequencies, the reactance of C_c becomes sufficiently large. This causes a significant voltage drop across C_c. The result is that the effective output voltage v_o decreases. The lower the frequency of this signal, higher will be the reactance of the capacitor C_c, and more will be the reduction in output voltage v_o.

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At zero frequency (dc signals), the reactance of capacitor C_c is infinitely large (an open circuit). The effective output voltage v_o then reduces to zero. Thus we see that the output voltage v_o (and hence the voltage gain) decreases as the frequency of the signal decreases below the mid-frequency range.

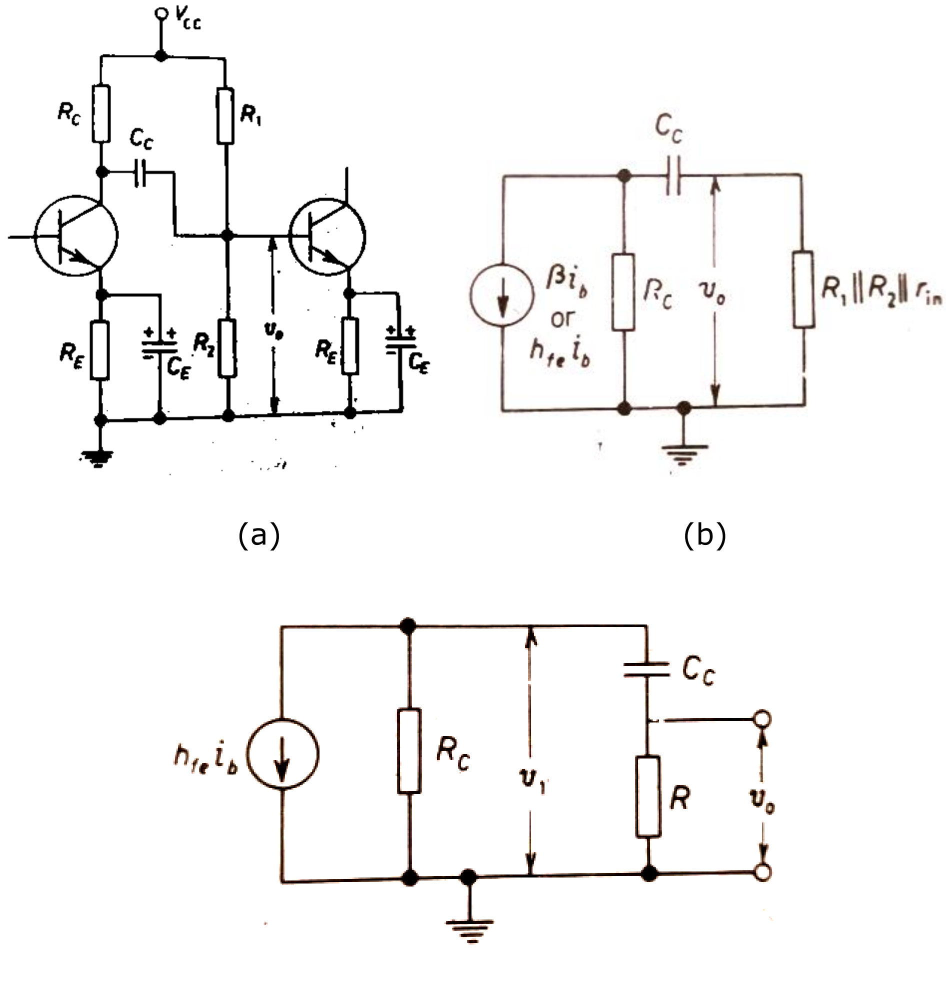

Figure 1.4 (a) Output Section of RC Couple Amplifier (b) its ac equivalent (c) The same equivalent circuit redrawn in another way

The other component, due to which the gain decreases at low frequencies, is the bypass capacitor C_E. Figure 2.1 shows the input section of the amplifier. The capacitor C_E is connected across the emitter resistor R_E. This capacitor is meant to bypass the ac current to ground. The impedance of this capacitor is quite low (as good as a short-circuit) in the mid-frequency range as well as in high-frequency range. Therefore, at these frequencies, the emitter is effectively grounded for ac current. However, as the frequency decreases, the reactance of the capacitor C_E becomes comparable to resistance R_E. The bypassing action of the capacitor is no longer as good as at mid- and high-frequencies. The emitter is not at ground potential for ac. The emitter current i_e divides into two parts, i_1 and i_2. A part of

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current i_1 passes through the resistor R_E. The rest of the current i2(==i_e−i_1) passes through the capacitor C_E. Due to current i_1 in R_E, an ac voltage $i_1 \times R_E$ is developed.

When the polarity of the input signal voltage is as shown in figure, the current i_1 flows from the emitter to ground. The polarity of the voltage i_1R_E is also marked in the figure. Then, the effective input voltage to the amplifier (that is the voltage between the base and emitter of the transistor) becomes

Equation: 2

$$v_{be} = v_s + i_1 R_E$$

The effective input voltage is thus reduced. The output voltage vo of the amplifier will now naturally be reduced. In other words, the gain of the amplifier (=v_o/v_i) reduces. This reduction in gain occurs due to the inability of the capacitor C_E to bypass ac current. The lower the frequency, the higher is the impedance of the capacitor C_E, and greater is the reduction in gain.

Note that the resistor R_E is not only a part of the input section, but also is a part of the output section. The voltage i_1R_E developed across the resistor R_E depends upon the output ac current. In this way, the effective input to the amplifier depends on the output current. The reduction in gain due to such a process is technically described as *negative current feedback effect.*

In Figure 2.1, there is also a coupling capacitor C_c in the input section of the amplifier. Due to this capacitor, the effective input voltage is reduced at low frequencies in much the same way as the effective output voltage v_o is reduced due to the coupling capacitor in the output section. Thus, the coupling capacitor in the input side is also responsible for the decrease of gain at low frequencies.

In practical circuits, the value of the bypass capacitor C_E is very large (≈ 100 μF). Therefore, it is the coupling capacitor that has the more pronounced effect in reducing the gain at low frequencies.

2. Does Gain Fall at High Frequencies

As the frequency of the input signal increases, the gain of the amplifier reduces. Several factors are responsible for this reduction in gain. Firstly, the beta (β) of the transistor is frequency dependent. Its value decreases at high frequencies (see Figure. 2.2). Because of this, the voltage gain of the amplifier reduces as the frequency increases.

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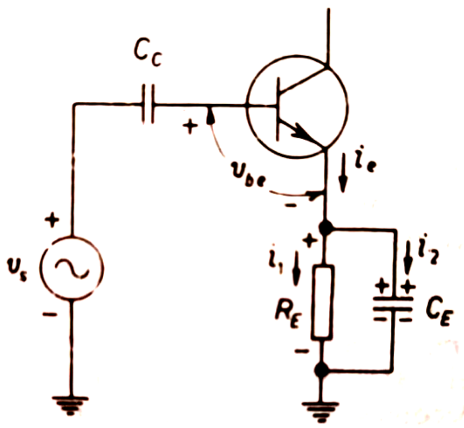

Figure 2.1 input section of RC Coupled amplifier

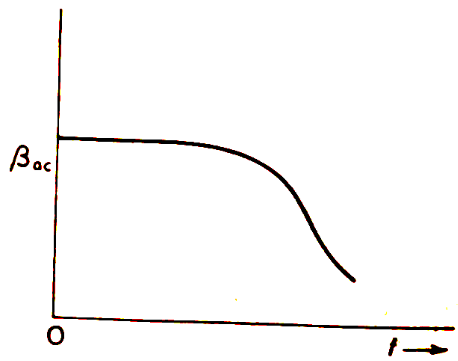

Figure 2.2 Variation of Short Circuit current gain with frequency

Another important factor responsible for the reduction in gain of the amplifier at high frequencies is the presence of the device. In case of a transistor, there exists some capacitance due to the formation of depletion layer at the junctions. These inter-electrode capacitances are shown in Fig. 9.17. Note that the connection for these capacitances is shown by dotted lines. This has been done to indicate that these are not physically present in the circuit, but are inherently present with the device (whether we like it or not).

The capacitance C_{bc} between the base and collector connects the output with the input. Because of this, negative feedback takes place in the circuit and the gain decreases. This feedback effect is more, when the capacitance C_{bc} provides a better conducting path for the ac current. Such is the case at high frequencies. As the frequency increases, the reactive impedance of the capacitor becomes smaller.

The capacitance C_{be} offers a low-impedance path at high frequencies in the input side. This reduces the input impedance of the device, and the effective input signal is reduced. So, the gain falls. Similarly, the capacitance C_{ce} produces a shunting effect at high frequencies in the output side.

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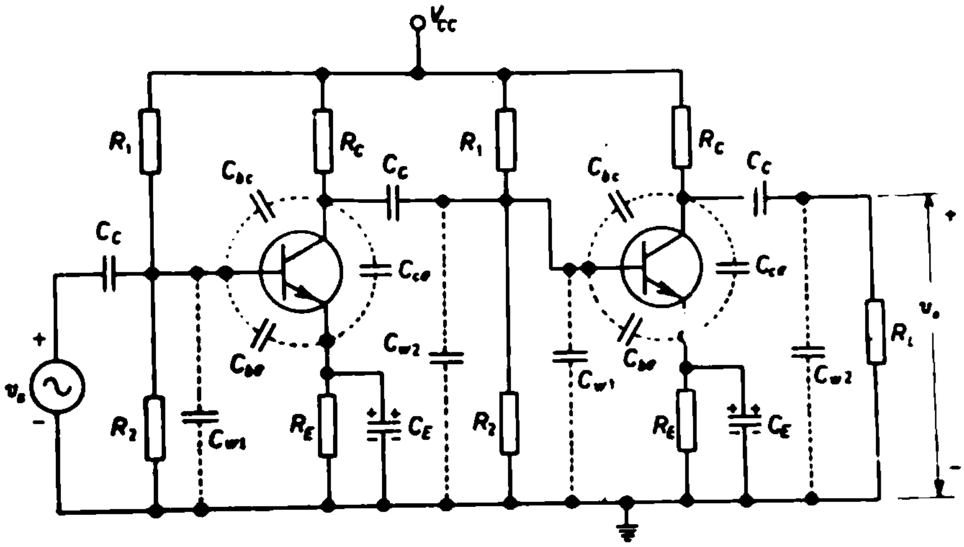

Figure 2.3 RC Coupled Amplifier, Capacitances that effect high frequency response are shown by dotted connection

Besides the junction capacitances, there are wiring capacitances $C_{w1}$and C_{w2}, as shown in Figure 2.3. The connecting wires of the circuit are separated by air which serves as a dielectric. This gives rise to some capacitance between the wires, though the capacitance value may be very small. But at high frequencies, even these small capacitances (5 to 20 pF) become important. For a multi-stage amplifier, the effect of the capacitance C_{ce} , Cw_2, and the input capacitance C_i of the next stage can be represented by a single shunt capacitance.

Equation: 3

$$C_s = C_{ce} + C_{w2} + C_i$$

The output section of the amplifier is shown in Fig. 9.18 from the ac point of view, for high-frequency considerations. The capacitance C_s is the equivalent shunt capacitance as given by Eq. 9.7. Note that the coupling and bypass capacitors do not appear in the figure, because they effectively represent short circuits at these frequencies.

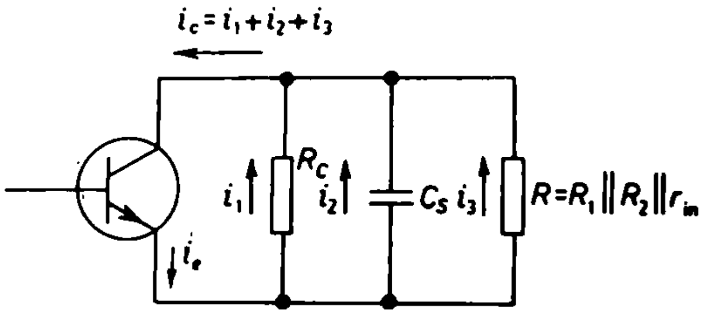

Figure 1.4 Output Section of RC Coupled Amplifier at high frequencies

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As can be seen from Figure 1.4, the collector current i_c is made up of three currents i_1, i_2 and i_3. As the frequency of the input signal increases, the impedance of the shunt capacitance Cs decreases, since

Equation: 4

$$XC_s = \frac{1}{2\pi f C_x}$$

As a result, the current i_2 through this capacitance increases. This reduces both the currents i_1 and i_3, since the total current $ic(=i_1+i_2+i_3)$ is almost constant. It means that the output voltage $v_o(=i_3R)$ decreases. The higher the frequency, the lower is the impedance offered by C_s and lower will be the output voltage v_o.

5. Conclusion

The purpose of an amplifier is to boost up the voltage or power level of a signal. During this process, the wave shape of the signal should not change. If the wave shape of the output is not an exact replica of the wave shape of the input, we say that distortion has been introduced by the amplifier. An ideal amplifier will amplify a signal without changing its wave shape at all. Such an amplifier faithfully amplifies the signal, and we say it has a good fidelity. Such an amplifier is called Hi-Fi (high fidelity) amplifier.

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