Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

C10T (Analog Systems and Apllications)

Topic – Amplifiers (Part – 2)

Sub Topic – Amplifiers

We have already discussed part 1 of this e-report.

Now let us continue part 2 of it.

Important Terms of a Linear Circuit in *h* Parameters:

We have already seen that any linear circuit with input and output has a set of h parameters. Now, it is important to develop formulae for various important terms e.g. input impedance, current gain, voltage gain etc. of a linear circuit in terms of h parameters.

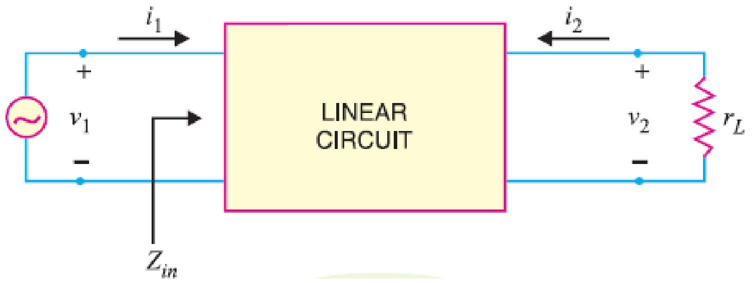

Fig. 1

1. Input Impedance. Let us consider a linear circuit with a load resistance r_L across its terminals as shown in Fig. 1. The input impedance Z_{in} of this circuit is the ratio of input voltage to input current $Z_{in} = \frac{v_1}{i_1}$. Since we already know that $v_1 = h_{11}i_1 + h_{12}v_2$ from h parameters, we can write $Z_{in} = \frac{h_{11}i_1+h_{12}v_2}{i_1} = h_{11} + \frac{h_{12}v_2}{i_1}$. Now from Fig. 1, we can write $i_2 = -\frac{v_2}{r_L}$. The minus sign is used here because the actual load current is opposite to the direction of i_2. But we

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

also know that $i_2 = h_{21}i_1 + h_{22}v_2$. Therefore we can write $-\frac{v_2}{r_L} = h_{21}i_1 + h_{22}v_2$ or $\frac{v_2}{i_1} = -\frac{h_{21}}{h_{22}+\frac{1}{r_L}}$. Using this value of $\frac{v_2}{i_1}$ in the expression of Z_{in}, we write

$$Z_{in} = h_{11} - \frac{h_{12}h_{21}}{h_{22}+\frac{1}{r_L}}$$

This is the expression for input impedance of a linear circuit in terms of h parameters and load connected to the output terminals. This expression can sometime be approximated as $Z_{in} \approx h_{11}$. This is valid when either h_{12} or r_L is very small.

2. Current Gain. Referring to Fig. 1, the current gain A_i of the circuit can be written as $A_i = \frac{i_2}{i_1}$. We already have $i_2 = h_{21}i_1 + h_{22}v_2$ and $i_2 = -\frac{v_2}{r_L}$. Using these two we can write $i_2 = h_{21}i_1 - h_{22}i_2r_L$ or $\frac{i_2}{i_1} = \frac{h_{21}}{1+h_{22}r_L}$. So, we get

$$A_i = \frac{h_{21}}{1+h_{22}r_L}$$

This is the expression for current gain. This expression can also be approximated as $A_i \approx h_{21}$, when $h_{22}r_L \ll 1$.

3. Voltage Gain. The voltage gain (A_v) of the circuit is given by $A_v = \frac{v_2}{v_1}$. We already have $v_1 = h_{11}i_1 + h_{12}v_2$ and $Z_{in} = \frac{v_1}{i_1}$. Therefore we write $v_1 = \frac{h_{11}v_1}{Z_{in}} + h_{12}v_2$ or $\frac{v_2}{v_1} = \frac{1-\frac{h_{11}}{Z_{in}}}{h_{12}}$. But $Z_{in} = h_{11} - \frac{h_{12}h_{21}}{h_{22}+\frac{1}{r_L}}$, so we get $\frac{v_2}{v_1} = \frac{1-\frac{h_{11}}{Z_{in}}}{h_{12}} = -\frac{h_{21}}{h_{11}h_{22}+\frac{h_{11}}{r_L}-h_{12}h_{21}}$. Therefore,

$$A_v = -\frac{h_{21}}{h_{11}h_{22}+\frac{h_{11}}{r_L}-h_{12}h_{21}}$$

This is the expression for voltage gain.

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

4. Output Impedance. In order to find the output impedance, we need to remove the load r_L first. Then the signal voltage v_1 is set to zero and a generator of voltage v_2 is connected at the output terminals. Then h parameter equivalent circuit becomes as shown in Fig. 2. By definition, the output impedance Z_{out} is

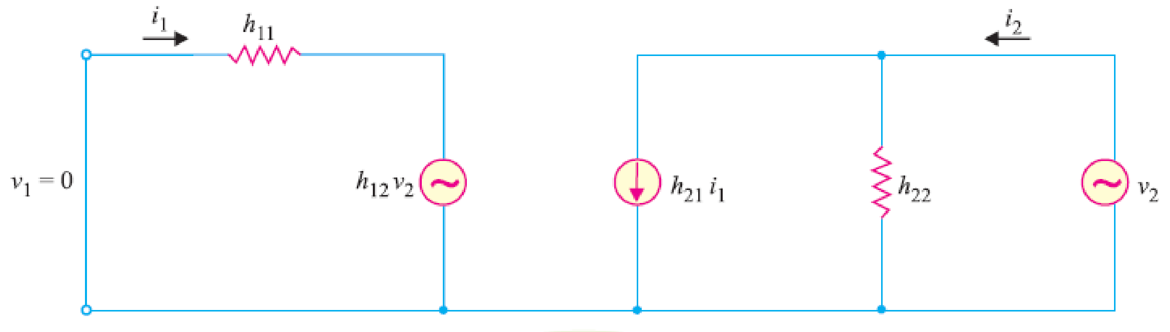

Fig. 2

given by $Z_{out} = \frac{v_2}{i_2}$. Applying Kirchhoff's voltage law to the input circuit, we have $v_1 = 0 = h_{11}i_1 + h_{12}v_2$ or $i_1 = -\frac{h_{12}v_2}{h_{11}}$. We also have in the output circuit $i_2 = h_{21}i_1 + h_{22}v_2 = -\frac{h_{21}h_{12}v_2}{h_{11}} + h_{22}v_2$. Therefore we get

$$Z_{out} = \frac{1}{h_{22} - \frac{h_{12}h_{21}}{h_{11}}}$$

This is the expression for output impedance of a linear circuit in terms of h parameters.

Analysis of Single Stage Transistor Circuit using *h* Parameters:

The expressions for input impedance, voltage gain etc. in terms of h parameters derived for general circuit analysis apply equally for transistor analysis also. However, it is profitable to rewrite them in standard transistor h parameter nomenclature.

Here in this e-report we will only analyze a single stage CE amplifier circuit.

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

Single Stage Transistor Amplifier: When only one transistor with associated circuitry is used for amplifying a weak signal, the circuit is known as *single stage transistor amplifier*. A single stage transistor amplifier has one transistor, bias circuit and other auxiliary components. Although a practical amplifier consists of a number of stages, yet such a complex circuit can be conveniently split up into separate single stages. By analysing carefully only a single stage and using this single stage analysis repeatedly, we can effectively analyze the complex circuit. It follows, therefore, that single stage amplifier analysis is of great value in understanding the practical amplifier circuits.

1. Input Impedance. The general expression for input impedance Z_{in} is given as

$$Z_{in} = h_{11} - \frac{h_{12}h_{21}}{h_{22}+\frac{1}{r_L}}$$

Using standard h parameter nomenclature for transistor, its value for CE amplifier arrangement will be $Z_{in} = h_{ie} - \frac{h_{re}h_{fe}}{h_{oe}+\frac{1}{r_L}}$. Here r_L is the AC load as seen by the transistor.

2. Current Gain. The general expression for current gain A_i is provided as

$$A_i = \frac{h_{21}}{1+h_{22}r_L}$$

Using standard h parameter nomenclature for transistor, its value for CE amplifier arrangement will be $A_i = \frac{h_{fe}}{1+h_{oe}r_L}$.

3. Voltage Gain. The general expression for current gain A_v is provided as

$$A_v = -\frac{h_{21}}{h_{11}h_{22}+\frac{h_{11}}{r_L}-h_{12}h_{21}}$$

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

Using standard h parameter nomenclature for transistor, its value for CE amplifier arrangement will be $A_v = -\frac{h_{fe}}{h_{ie}h_{oe}+\frac{h_{ie}}{r_L}-h_{re}h_{fe}}$.

4. Output Impedance. The general expression for output impedance Z_{out} is given as

$$Z_{out} = \frac{1}{h_{22}-\frac{h_{12}h_{21}}{h_{11}}}$$

Using standard h parameter nomenclature for transistor, its value for CE amplifier arrangement will be $Z_{out} = \frac{1}{h_{oe}-\frac{h_{re}h_{fe}}{h_{ie}}}$.

The above expression for Z_{out} is for the transistor. If the transistor is connected in a circuit to form a single stage amplifier, then output impedance of the stage $= Z_{out} \parallel r_L$ where $r_L = R_C \parallel R_L$.

Limitations of the *h* Parameters:

The h parameter approach provides accurate information regarding the current gain, voltage gain, input impedance and output impedance of a transistor amplifier. However, there are two major limitations on the use of these parameters.

(i) It is very difficult to get the exact values of h parameters for a particular transistor. It is because these parameters are subject to considerable variation—unit to unit variation, variation due to change in temperature and variation due to change in operating point. In predicting an amplifier performance, care must be taken to use h parameter values that are correct for the operating point being considered.

(ii) The h parameter approach gives correct answers for small AC signals. It is because a transistor behaves as a linear device for small signals only.

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

Classifications of Class A, Class B & Class C Amplifiers:

Transistor power amplifiers handle large signals. Many of them are driven so hard by the input large signal that collector current is either cut-off or is in the saturation region during a large portion of the input cycle. Therefore, such amplifiers are generally classified according to their mode of operation i.e. the portion of the input cycle during which the collector current is expected to flow. On this basis, they are classified as (i) class A power amplifier, (ii) class B power amplifier and (iii) class C power amplifier.

Class A Power Amplifier. If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as class A power amplifier. Obviously, for this to happen, the power amplifier must be biased in such a way that no part of the signal is cut off.

The operating point is so selected that collector current flows at all times throughout the full cycle of the applied signal. As the output wave shape is exactly similar to the input wave shape, therefore, such amplifiers have least distortion. However, they have the disadvantage of low power output and low collector efficiency.

Class B Power Amplifier. If the collector current flows only during the positive half-cycle of the input signal, it is called a class B power amplifier. In class B operation, the transistor bias is so adjusted that zero signal collector current is zero i.e. no biasing circuit is needed at all. During the positive half-cycle of the signal, the input circuit is forward biased and hence collector current flows. However, during the negative half-cycle of the signal, the input circuit is reverse biased and no collector current flows. Hence a severe distortion occurs in the signal. However, class B amplifiers provide higher power output and collector efficiency. Such amplifiers are mostly used for power amplification in push-pull arrangement. In such an arrangement, two transistors are used in class B operation. One transistor amplifies the positive half-cycle of the signal while the other amplifies the negative half-cycle.

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

Class C Power Amplifier. If the collector current flows for less than half-cycle of the input signal, it is called class C power amplifier. In class C amplifier, the base is given some negative bias so that collector current does not flow just when the positive half-cycle of the signal starts. Such amplifiers are never used for power amplification. However, they are used as tuned amplifiers i.e. to amplify a narrow band of frequencies near the resonant frequency.

Frequency Response of an Amplifier:

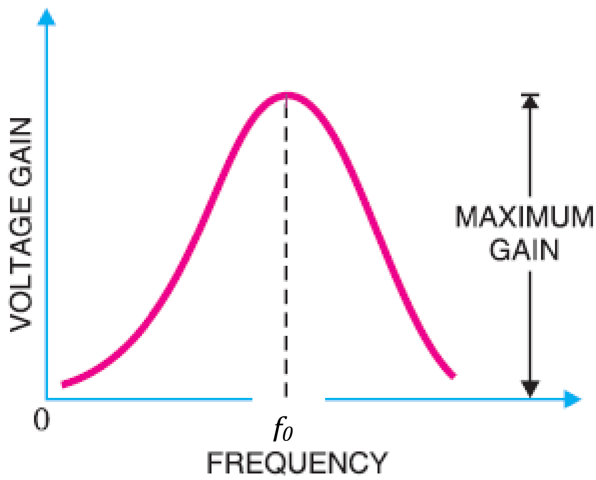

Fig. 3

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 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. 3 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_0, called *resonant frequency*. If the frequency of signal increases beyond f_0, the gain decreases.

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

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 audible sound spectrum (i.e. from 20 Hz to 20 kHz) should be uniformly amplified otherwise speaker will give a distorted sound output.

Sub Topic – Coupled Amplifier

Introduction:

The output from a single stage amplifier is usually insufficient to drive an output device. In other 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 (or a *coupled 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.

Here in this e-report we will discuss about RC −coupled transistor amplifier.

RC −coupled Transistor Amplifier:

RC coupling 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. 4 shows two stages of an RC − coupled amplifier. A coupling capacitor C_C is used to connect the collector (i.e. 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 or* $RC -$ *coupled amplifiers*.

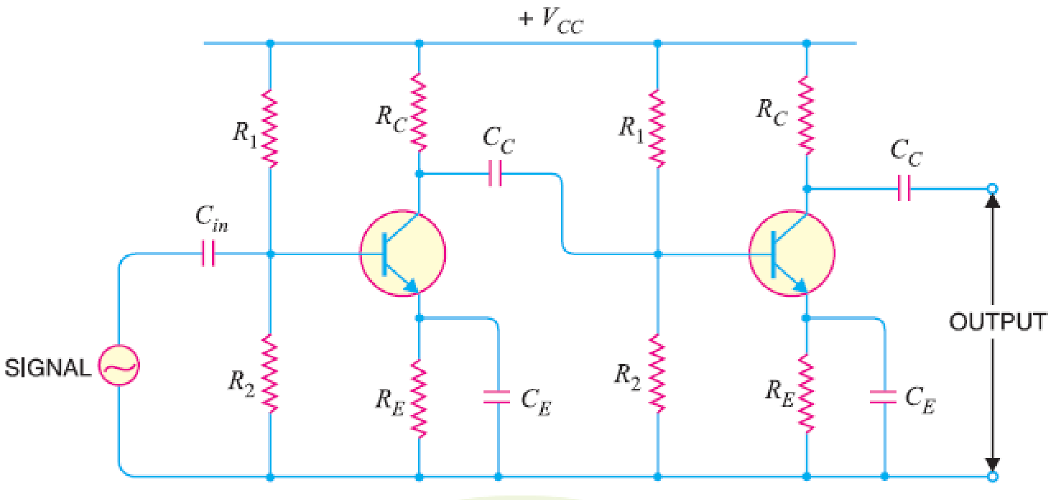

Fig. 4

The resistances R_1, R_2 and R_E form the biasing and stabilization network. The emitter bypass capacitor (C_E) offers low reactance path to the signal. Without it, the voltage gain of each stage would be lost. The coupling capacitor C_C transmits AC signal but blocks DC. This prevents DC interference between various stages and the shifting of operating point.

Operation. When AC 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* (or one after another) stages amplify the signal and the overall gain is considerably increased.

Frequency response. Fig. 5 shows the frequency response of a typical $RC -$ coupled amplifier. It is clear that voltage gain drops off at low frequencies ($<$ 50 Hz) and high frequencies ($>$ 20 kHz) whereas it is uniform over mid-

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

frequency range (~50 Hz to 20 kHz). This behaviour of the amplifier is briefly explained below:

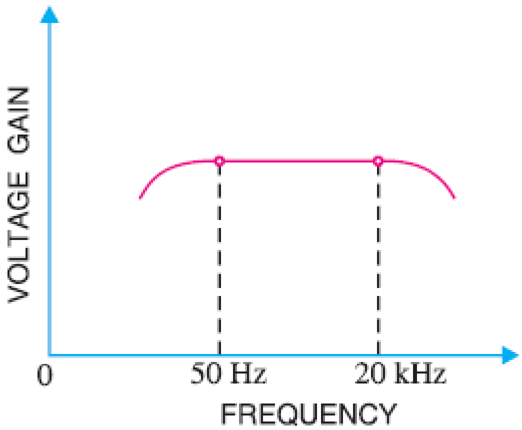

Fig. 5

(i) At low frequencies, 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, 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, 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.

Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

Advantages of $RC-$ coupled Amplifier:

An $RC-$ coupled amplifier has several advantages, viz.

(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.

This concludes part 2 of this e-report.

The discussion will be continuing in the part 3 of this e-report.

Reference:

Principles of Electronics, V.K. Mehta & Rohit Mehta, S. Chand & Company

(All the figures have been collected from the above mentioned reference)