4.3 Differential Amplifier

A device which accepts an input signal and produces an output signal proportional to the input, is called an amplifier. An amplifier which amplifies the difference between the two input signals is called differential amplifier. The differential amplifier configuration is used in variety of analog circuits. The. differential amplifier is an essential and basic building block in modern IC amplifier .The Integrated Circuit (IC) technology is well known now a days, due to which the design of complex circuits become very simple. The IC version of operational amplifier is inexpensive, takes upless space and consumes less power. The. Differential amplifier is the basic building block of such IC operational amplifier.

Basics of Differential Amplifier

The Differential Amplifier amplifies the difference between two input voltage signals. Hence it is also called as difference amplifier.

Consider an ideal differential amplifier shown in the Fig. A

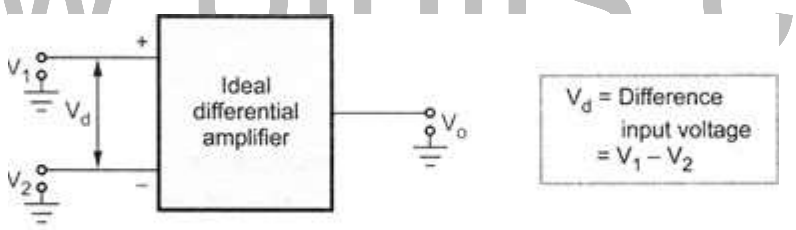

Figure: 4.3.1 Differential Amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 144]

V1 and V2 are the two input signals while Vo is the output. Each signal is measured with respect to the ground.

In an ideal differential amplifier, the output voltage VType equation here.o is proportional to the difference between the two input signals.

$$V_0 \propto V_1 - V_2$$

$$Differential\ gain\ A_d$$

4.4 Differential Mode Operation

In the differential mode, the two input signals are different from each other. Considerthe two input signals which are same in magnitude but 180" out of phase. These signals, with opposite phase can be obtained from the center tap transformer. The circuit used in differential mode operation is shown in the Fig.

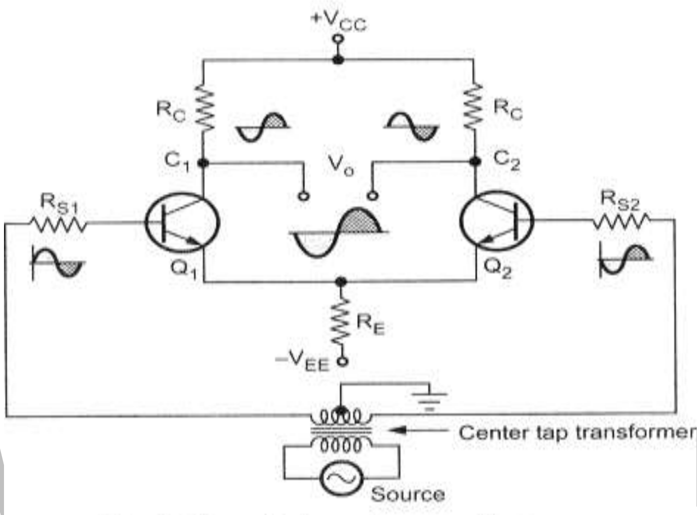

Fig Differential mode operation

Figure: 4.4.1 Differential mode operation

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 145]

Assume that the sine wave on the base of Q 1is positive going while on the base of Q 2 is negative going. With a positive going signal on the base of Q 1, m amplified negative going signal develops on the collector of Q1. Due to positive going signal, current through R E also increases and hence a positive going wave is developed across R E. Due to negative going signal on the base of Q2, an amplified positive going signal develops on the collector of Q 2. And a negative going signal develops across R E, because of emitter follower action of Q 2. So signal voltages across R E, due to the effect of Q1 and Q2 are equal in magnitude and 180o out of phase, due to matched pair of transistors. Hence these two signals cancel each other and there is no signal across the emitter resistance. Hence there is no a.c. signal current flowing through the emitter resistance. Hence R E in this case does not introduce negative feedback. While Vo is the output taken across collector of Q1 and collector of Q 2. The two outputs on collector L and 2 are equal in magnitude but opposite in polarity. And Vo is the difference between these two signals, e.g. +10 - (-10) = + 20.

Hence the difference output Vo is twice as large as the signal voltage from either collector to ground

Common Mode operation

In this mode, the signals applied to the base of Q1 and Q2 are derived from the same source. So the two signals are equal in magnitude as well as in phase. The circuit diagram is shown in the Fig.

In phase signal voltages at the bases of Q1 and Q2 causes in phase signal voltages to appear across R_E, which add together. Hence R_E carries a signal current and providesa negative feedback. This feedback reduces the common mode gain of differential amplifier.

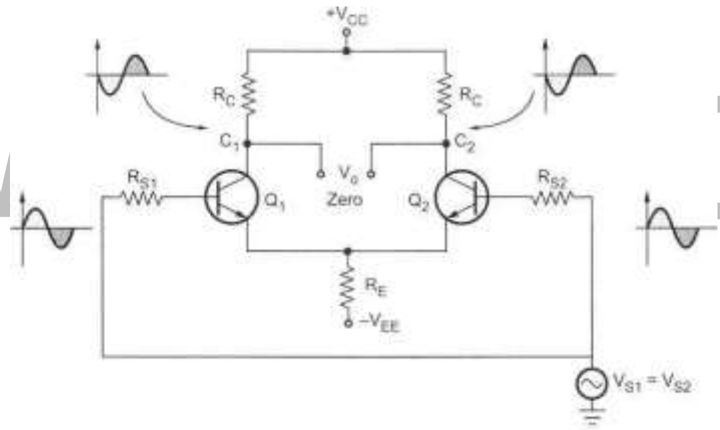

Fig. Common mode operation

Figure: 4.4.2 Common mode operation

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 146]

While the two signals causes in phase signal voltages of equal magnitude to appear across the two collectors of Q 1 and Q2. Now the output voltage is the difference between the two collector voltages, which are equal and also same in phase,

Eg. (20) - (20) = 0. Thus the difference output Vo is almost zero, negligibly small. Ideally it should be zero.

Configurations of Differential Amplifier

The differential amplifier, in the difference amplifier stage in the op-amp, can be used in four configurations:

i) Dual input balanced output differential amplifier.

ii) Dual input, unbalanced output differential amplifier.

iii) Single input, balanced output differential amplifier.

iv) Single input, unbalanced output differential amplifier.

The differential amplifier uses two transistors in common emitter configuration. If output is taken between the two collectors it is called balanced output or double ended output. While if the output is taken between one collectors with respect to ground it is called unbalanced output or single ended output. If the signal is given to both the input terminals it is called dual input, while if the signal is given to only one input terminal and other terminal is grounded it is called single input or single ended input Out of these four configurations the dual input, balanced output is the basic differential amplifier configuration. This is shown in the Fig. (a). The dual input, unbalanced output differential amplifier is shown in the Fig.(b). The single input, balanced output differential amplifier is shown in the Fig (c) and the single input, unbalanced output differential amplifier is shown in the Fig. (d).

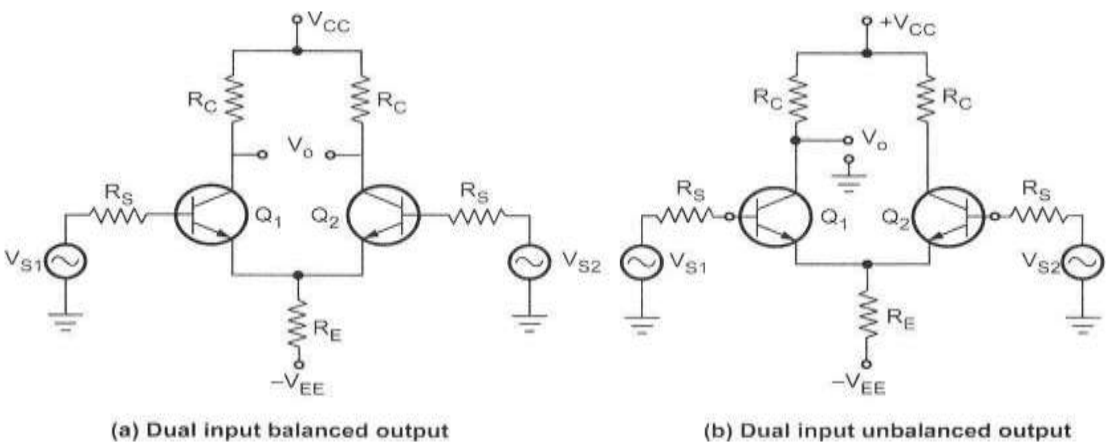

Figure: 4.4.3 Dual input balanced and Dual input unbalanced output

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 146]

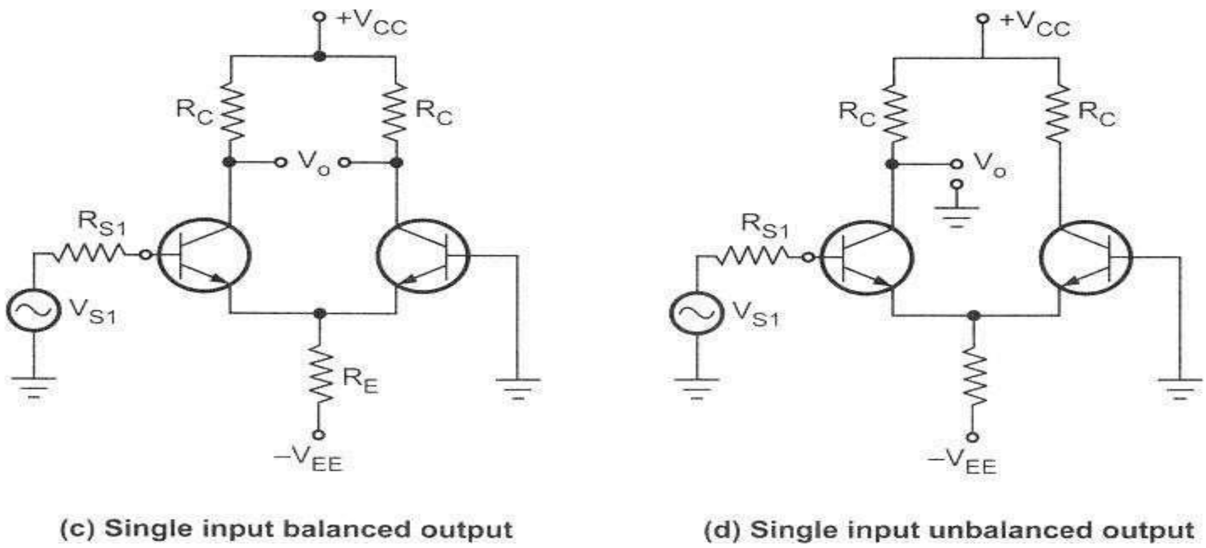

Figure: 4.4.3 Single input balanced and single input unbalanced output

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 147]

4.1 Multistage Amplifiers

In practice, we need amplifier which can amplify a signal from a very weak source such as a microphone, to a level which is suitable for the operation of another transducer such as loudspeaker. This is achieved by cascading number of amplifier stages, known as multistage amplifier

Need for Cascading

For faithful amplification amplifier should have desired voltage gain, current gain and it should match its input impedance with the source and output impedance with the load. Many times these primary requirements of the amplifier cannot be achieved with single stage amplifier, because of the limitation of the transistor/FET parameters. In such situations more than one amplifier stages are cascaded such that input and output stages provide impedance matching requirements with some amplification and remaining middle stages provide most of the amplification.

We can say that,

- When the amplification of a single stage amplifier is not sufficient,

Or

- When the input or output impedance is not of the correct magnitude, for a particular application two or more amplifier stages are connected, in cascade. Such amplifier, with two or more stages is also known as multistage amplifier.

- Two Stage Cascaded Amplifier

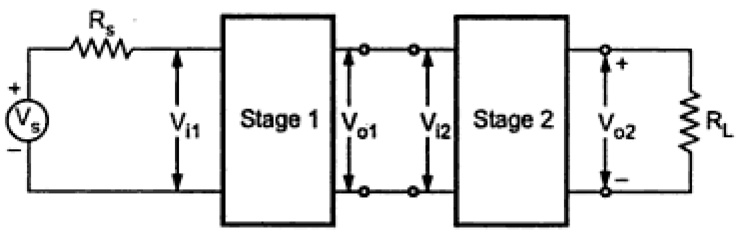

Figure: 4.1.1 Two Stage Cascaded Amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 140]

- Vi1 is the input of the first stage and Vo2 is the output of second stage.So,
- Vo2/Vi1 is the overall voltage gain of two stage amplifier.

N-Stage Cascaded Amplifier

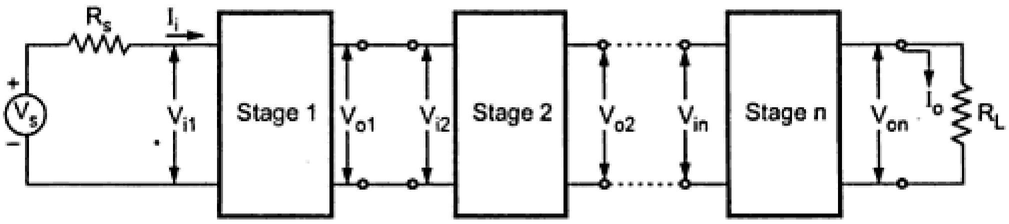

Figure: 4.1.2 N-Stage Cascaded Amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 140]

Voltage gain:

The resultant voltage gain of the multistage amplifier is the product of voltage gains of the various stages.

Av = Avl Av2 ... Avn Gain in Decibels

In many situations it is found very convenient to compare two powers on logarithmic scale rather than on a linear scale. The unit of this logarithmic scale is called decibel (abbreviated dB). The number N decibels by which a power P2 exceeds the power P1 is defined by

Decibel, dB denotes power ratio. Negative values of number of dB means that the power P2 is less than the reference power P1 and positive value of number of dB means the power P2 is greater than the reference power P1.

For an amplifier, P1 may represent input power, and P2 may represent output power. Both can be given as. Where Ri and Ro are the input and output impedances of the amplifier respectively. Then,

If the input and output impedances of the amplifier are equal i.e. Ri = Ro= R, then

Gain of Multistage Amplifier in dB

The gain of a multistage amplifier can be easily calculated if the gain of the individual stages are known in dB, as shown below

20 log10 Av = 20 log10 Avl + 20 log10Av2 +… + 20 log10 Avn

Thus, the overall voltage gain in dB of a multistage amplifier is the decibel voltage gains of the individual stages. It can be given as

$$Av\ dB = Av\ l\ dB + Av2dB + ... + Av\ n\ dB$$

Advantages of Representation of Gain in Decibels

- Logarithmic scale is preferred over linear scale to represent voltage and power gainsbecause of the following reasons:
- In multistage amplifiers, it permits to add individual gains of the stages to calculateoverall gain.
- It allows us to denote, both very small as well as very large quantities of linear, scaleby considerably small figures.
- For example, voltage gain of 0.0000001 can be represented as -140 dB and voltage gainof 1, 00,000 can be represented as 100 db.
- Many times output of the amplifier is fed to loudspeakers to produce sound which is received by the human ear. It is important to note that the ear responds to the sound intensities on a proportional or logarithmic scale rather than linear scale. Thus use of dB unit is more appropriate for representation of amplifier gains.

Methods of coupling Multistage Amplifiers

In multistage amplifier, the output signal of preceding stage is to be coupled to the input circuit of succeeding stage. For this inter stage coupling, different types of coupling elements can be employed. These are:

4.6 Power Amplifiers

The ideal amplifier would deliver 100 percent of the power it draws from the dc powersupply to its load. In practice, 100 percent efficiency cannot be achieved (at this time) because every amplifier uses some percentage of the power it draws from the dc powersupply.

The efficiency of an amplifier is the ratio of ac output power to dc input power, written as a percentage. By formula:

$$\eta = \frac{\text{ac output power}}{\text{dc input power}} \times 100$$

The lower the position of the Q-point on the dc load line, the higher the maximum theoretical efficiency of a given amplifier. Typical Q-point locations for class A, B, AB, and C amplifiers are shown in Figure 11.1 of the text.

The ac load line is a graph of all possible combinations of i_c and v_{ce} for a given amplifier. Under normal circumstances, the ac and dc load lines for a given amplifier are not identical (see Figure 11.3 of the text).

Amplifier Compliance

The compliance (PP) of an amplifier is the limit that the output circuit places on its peak-to-peak output voltage. The compliance for a given amplifier is found using thefollowing equations: PP = $2I_{CQ}r_C$ and PP = $2V_{CEQ}$

These equations are developed as illustrated in Figure:

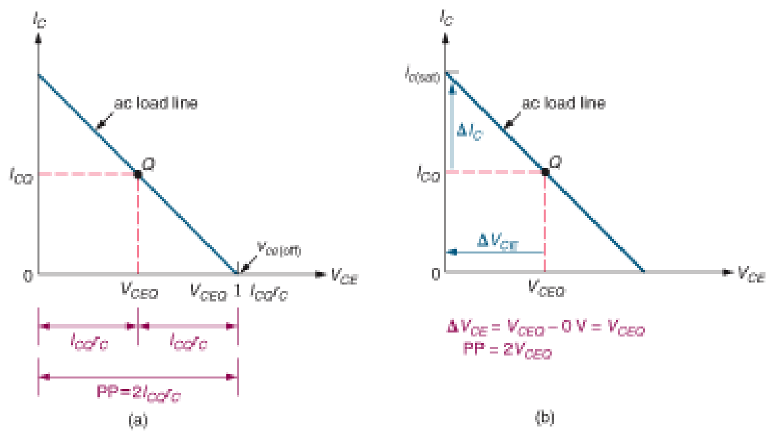

Figure: 4.4.3 Amplifier Compliance

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 151]

The compliance of an amplifier is determined by solving both PP equations and usingthe lower of the two results, as demonstrated in Example 11.1 of the text. Note the following:

- When an amplifier has a value of PP = $2V_{CEQ}$, exceeding the value of PP results in saturation clipping.
- When an amplifier has a value of PP = $2I_{CQ}r_C$, exceeding the value of PP results in cutoff clipping. However, the circuit will experience nonlinear distortion before the amplifier peak-to-peak output reaches the value of PP.

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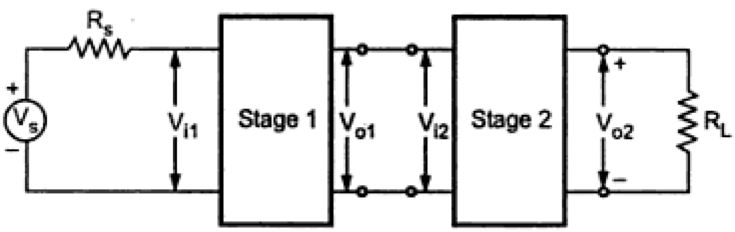
- Two Stage Cascaded Amplifier



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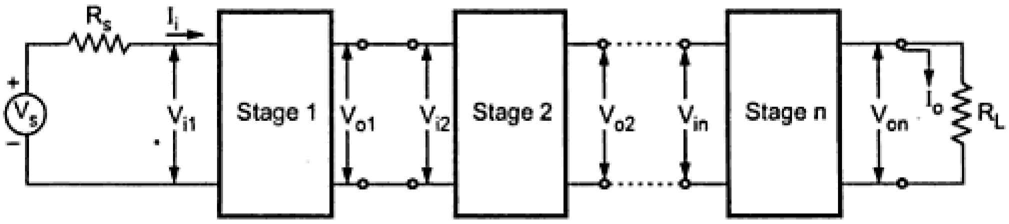

Figure: 4.1.2 N-Stage Cascaded Amplifier

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4.5 Tuned amplifier

- Communication circuit widely uses tuned amplifier and they are used in MW & SW radio frequency 550 KHz – 16 MHz, 54 – 88 MHz, FM 88 – 108 MHz, cell phones 470 - 990 MHz
- Band width is 3 dB frequency interval of pass band and –30 dB frequency interval
- Tune amplifiers are also classified as A, B, C similar to power amplifiers based on conduction angle of devices.

Series resonant circuit

Series resonant features minimum impedance (RS) at resonant.

$$f\,r = ½\sqrt{LC};\ q = L/Rs \text{ at resonance } L=1/c,\ BW=fr/Q$$

It behaves as purely resistance at resonance, capacitive below and inductive above resonance

Parallel resonant circuit

Parallel resonance features maximum impedance at resonance = L/ Rs C

$$\text{At resonance } Fr=1/2\sqrt{1/(LC-Rs2/L2)};\ \text{if } Rs=0,\ fr=1/2\sqrt{(LC)}$$

At resonance it exhibits pure resistance and below fr parallel circuit exhibits inductive and above capacitive impedance

Single tuned amplifier

Single Tuned Amplifiers consist of only one Tank Circuit and the amplifying frequency range is determined by it. By giving signal to its input terminal of various Frequency Ranges. The Tank Circuit on its collector delivers High Impedance on resonant Frequency, Thus the amplified signal is Completely Available on the output Terminal. And for input signals other than Resonant Frequency, the tank circuit provides lower impedance, hence most of the signals get attenuated at collector Terminal.

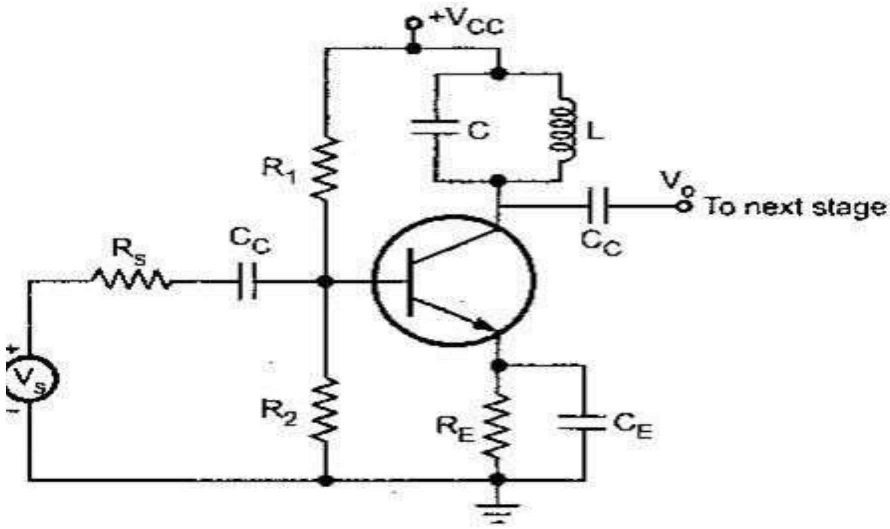

Figure: 4.5.1 Single tuned amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 148]

Ri- input resistance of the next stage

R**0**-output resistance of the generator

gm Vb'eCc & CE are negligible small

The equivalent circuit is simplified by

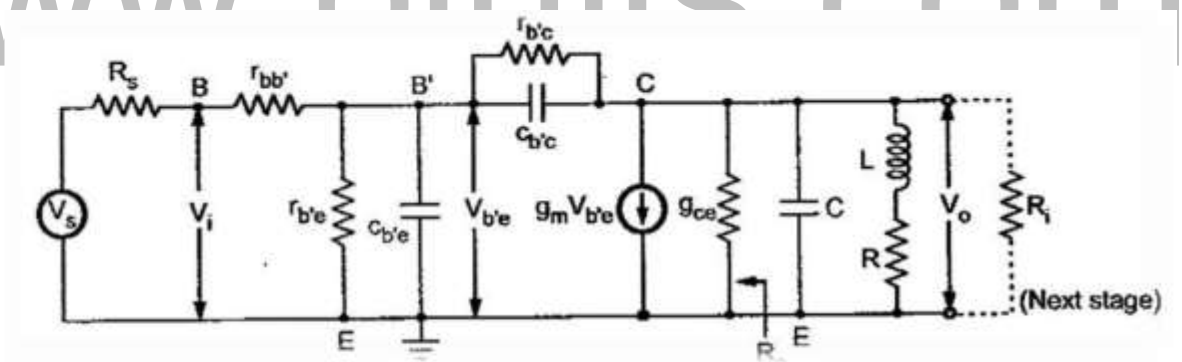

Figure: 4.5.2 Single tuned amplifier equivalent circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 148]

General shape of frequency response of amplifiers:

An audio frequency amplifier which operates over audio frequency range extending from 20 Hz to 20 kHz. Audio frequency amplifiers are used in radio receivers, large public meeting and various announcements to be made for the passengers on railway platforms. Over the range of frequencies at which it is to be used an amplifier should ideally provide the same amplification for all frequencies. The degree to which this is done is usually indicated by the curve known as frequency response curve of the amplifier.

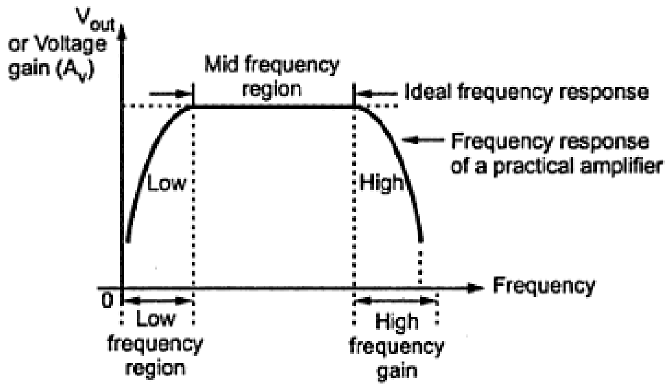

Fig. A typical frequency response of an amplifier

Figure: 4.5.3 Frequency response of an amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 148]

To plot this curve, input voltage to the amplifier is kept constant and frequency of input signal is continuously varied. The output voltage at each frequency of input signal is noted and the gain of the amplifier is calculated. For an audio frequency amplifier, the frequency range is quite large from 20 Hz to 20 kHz. In this frequency response, the gain of the amplifier remains constant in mid-frequency while the gain varies with frequency in low and high frequency regions of the curve. Only at low and high frequency ends, gain deviates from ideal characteristics. The decrease in voltage gain with frequency is called roll-off.