Module 1 Part B : AMPLIFIERS

Types of amplifiers

Amplifier is an electronic circuit which increases the amplitude of its input signal without changing other parameters.

AC coupled amplifiers

In AC coupled amplifiers, stages are coupled together in such a way that DC levels are blocked and only the AC components of a signal are transferred from stage to stage.

DC coupled amplifiers

In DC (or direct) coupled amplifiers, stages are coupled together in such a way that stages are not isolated to DC potentials. Both AC and DC signal components are transferred from stage to stage.

Large-signal amplifiers

Large-signal amplifiers are designed to cater for appreciable voltage and/or current levels (typically from 1 V to 100 V or more).

Small-signal amplifiers

Small-signal amplifiers are designed to cater for low-level signals (normally less than 1 V and often much smaller). Small-signal amplifiers have to be specially designed to combat the effects of noise.

Audio frequency amplifiers

Audio frequency amplifiers operate in the band of frequencies that is normally associated with audio signals (e.g. the range of human hearing 20 Hz to 20 kHz).

Wideband amplifiers

Wideband amplifiers are capable of amplifying a very wide range of frequencies, typically from a few tens of hertz to several megahertz.

Radio frequency amplifiers

Radio frequency amplifiers operate in the band of frequencies that is normally associated with radio signals (e.g. from 100 kHz to over 1 GHz). Note that it is desirable for amplifiers of this type to be frequency selective and thus their frequency response may be restricted to a relatively narrow band of frequencies (see fig.15).

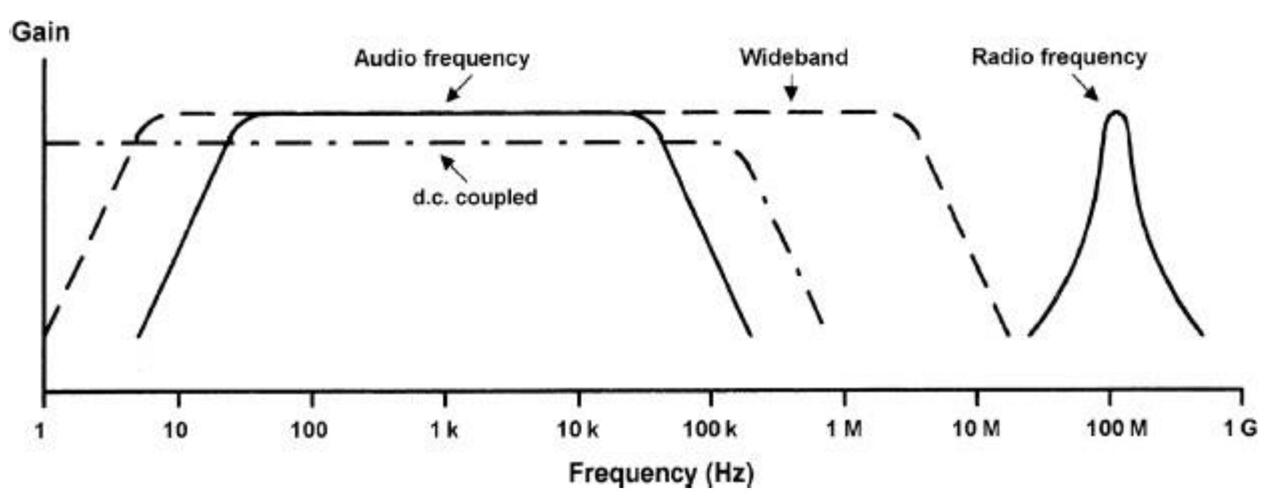


Fig.15. Frequency response and bandwidth (output power plotted against frequency)

Low-noise amplifiers

Low-noise amplifiers are designed so that they contribute negligible noise (signal disturbance) to the signal being amplified. These amplifiers are usually designed for use with very small signal levels (usually less than 10 mV or so).

Voltage Amplifier

The purpose of a voltage amplifier is to make the amplitude of the output voltage waveform greater than that of the input voltage waveform.

Current amplifier

The purpose of a current amplifier is to make the amplitude of the output current waveform greater than that of the input current waveform.

Power amplifier

In a power amplifier, the product of voltage and current (i.e. power = voltage x current) at the output is greater than the product of voltage x current at the input.

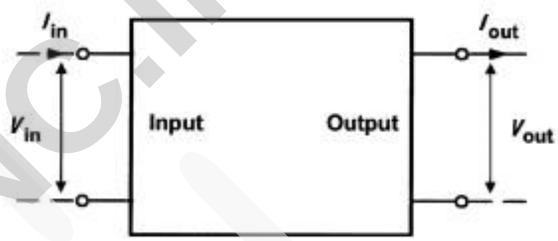
Amplifier Parameters

Gain: The amount of amplification (or gain) is simply the ratio of output voltage to input voltage, output current to input current, or output power to input power (see Fig. 7.2). These three ratios give, respectively, the voltage gain, current gain and power gain.

$$\text{Voltage gain}, A = \frac{V_{out}}{V_{IN}}$$

$$\text{Current gain}, A = \frac{I_{out}}{I_{IN}}$$

$$\text{Power gain}, A = \frac{P_{out}}{P_{IN}}$$



Power is the product of current and voltage ($P = I\,V$),

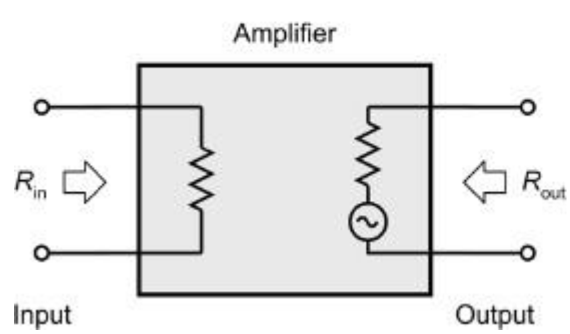
$$A_p = \frac{P_{out}}{P_{in}} = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{I_{out}}{I_{in}} \times \frac{V_{out}}{V_{in}} = A_i \times A_v$$

Input resistance (R_{in}): Input resistance is the ratio of input voltage to input current and it is expressed in Ω. The input of an amplifier is normally purely resistive (i.e. any reactive component is negligible) in the middle of its working frequency range (i.e. the **mid-band**). In some cases, the reactance of the input may become appreciable (e.g. if a large value of stray capacitance appears in parallel with the input resistance). In such cases we would refer to **input impedance** rather than input resistance.

Output resistance (R_{out}): Output resistance is the ratio of open-circuit output voltage to short-circuit outputcurrent, measured in Ω.

As with input resistance, the output of an amplifier is normally purely resistive and we can safely ignore any reactive component. If this is not the case, we would once again need to refer to **output impedance** rather than output resistance.

[Note: This resistance is internal to the amplifier and should not be confused with the resistance of a load connected externally]



Frequency response: It is the graph plotted for gain verses input frequency of an amplifier. The frequency response of an amplifier is usually specified in terms of the upper (f_2) and lower (f_1) cut-off frequencies of the amplifier. These frequencies are those at which the output power has dropped to 50% (otherwise known as the **−3 dB points**) or where the voltage gain has dropped to 70.7% of its mid-band value. Fig. 16 show how the bandwidth can be expressed in terms of either power or voltage.

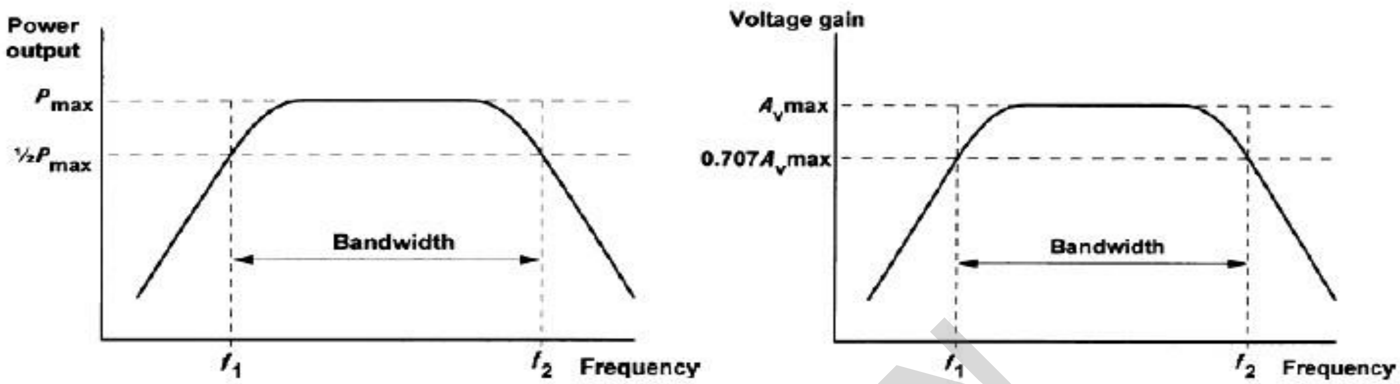


Fig.16. Frequency response and bandwidth a) output power Vs frequency b) output voltage Vs frequency

Bandwidth: The bandwidth of an amplifier is usually taken as the difference between the upper and lower cut- off frequencies (i.e. $f2 - f1$ in Fig.16). The range of frequencies within a band is known as bandwidth.

Example: Audio amplifiers have a flat frequency response (as shown in fig.17) over the audio range of frequencies from 20 Hz to 20 kHz. This range of frequencies, for an audio amplifier is called its Bandwidth, (BW).
The bandwidth of an amplifier must be sufficient to accommodate the range of frequencies present within the signals that it is to be presented with.

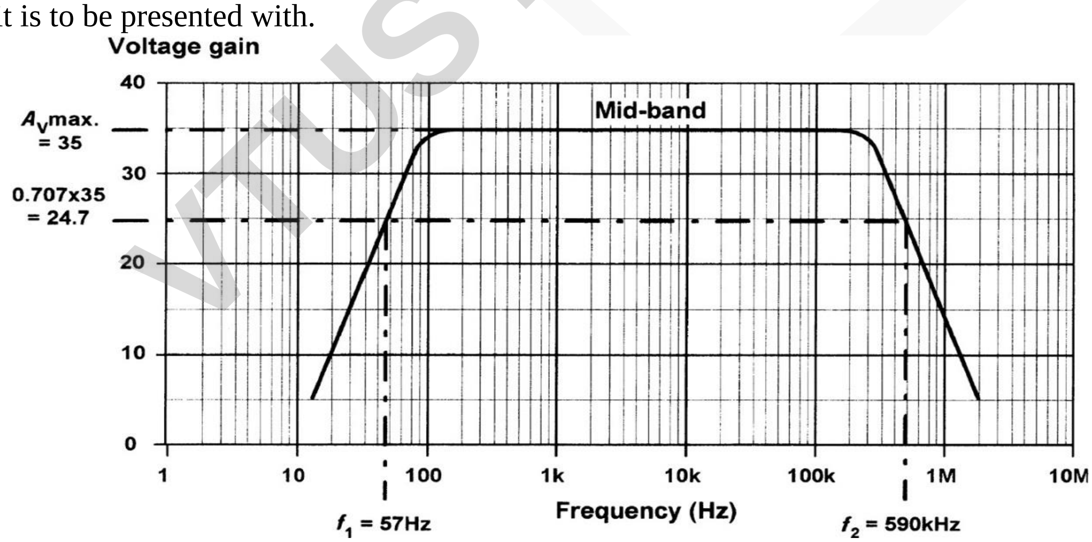


Fig.17. Mid-band voltage gain, upper and lower cut-off frequencies of amplifier with frequency response

Phase shift: Phase shift is the phase angle between the input and output signal voltages measured in degrees. The measurement is usually carried out in the mid-band where, for most amplifiers, the phase shift remains relatively constant. Note also that conventional single-stage transistor amplifiers provide phase shifts of either 180° or 360°.

Negative feedback

Many practical amplifiers use negative feedback in order to precisely control the gain, reduce distortion and improve bandwidth. The gain can be reduced to a manageable value by feeding back a small proportion of the output. The amount of feedback determines the overall (or **closed-loop**) gain. The form of feedback has the effect of reducing the overall gain of the circuit, is known as **negative feedback**.

An alternative form of feedback, where the output is fed back in such a way as to reinforce the input (rather than to subtract from it) is known as **positive feedback**.

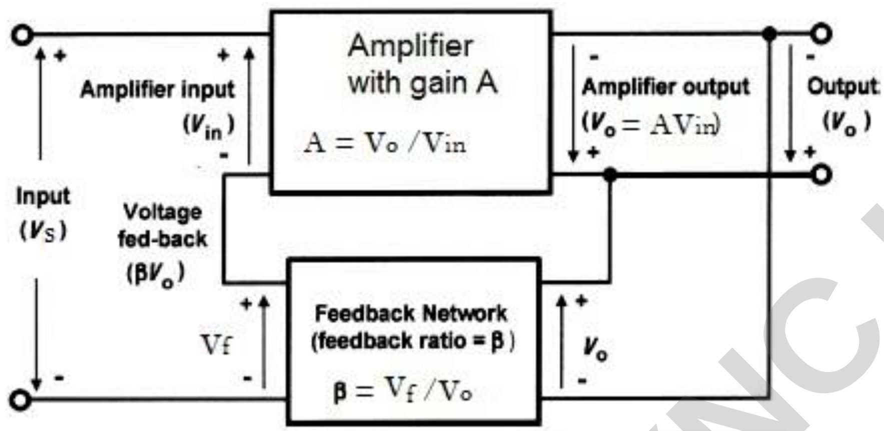


Fig.18. Amplifier with negative feedback applied

$A = Vo/V_{in}$

$Vo = A\,V_{in}$, where $V_{in} = V_S - V_f$

and $V_f = \beta Vo$

$Vo = A(Vs - \beta Vo)$

$Vo = AVs - A\,\beta Vo$

$Vo + A\,\beta Vo = AVs$

$AVs = Vo\,(1+A\beta)$

So, the equation of overall gain with negative feedback is given by

$$\frac{V_o}{V_s} = A_f = \frac{A}{1 + A\beta}$$

Fig.18 shows the block diagram of an amplifier stage with negative feedback applied. In this circuit, the proportion of the output voltage fed back to the input is given by β and the overall voltage gain will be given by:

$$Overall\ gain, G = \frac{V_o}{V_s}$$

Multi-stage amplifiers

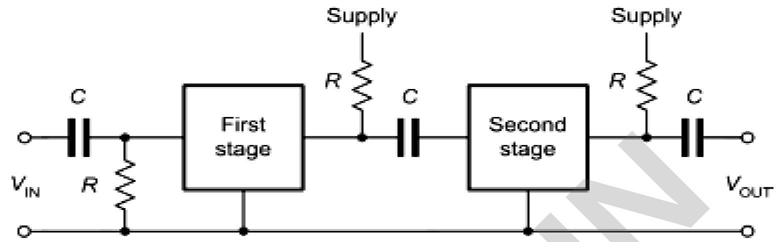
Output of first stage is connected to the input of the second stage through a suitable coupling device and so on. In order to provide sufficiently large values of gain, it is frequently necessary to use a number of interconnected stages within an amplifier.

The overall gain of an amplifier with several stages (i.e. a multi-stage amplifier) is simply the product of the individual voltage gains. Hence:

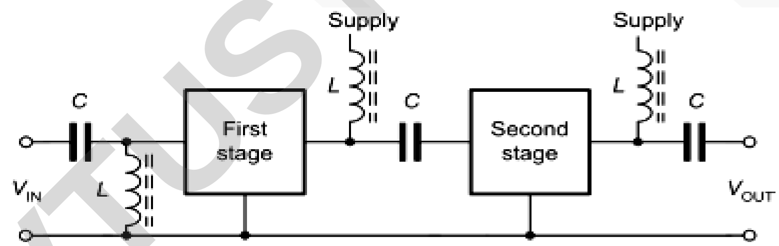
$$AV = AV1 \times AV2 \times AV3, \text{ etc.}$$

Note, however, that the bandwidth of a multistage amplifier will be less than the bandwidth of each individual stage. In other words, an increase in gain can only be achieved at the expense of a reduction in bandwidth.

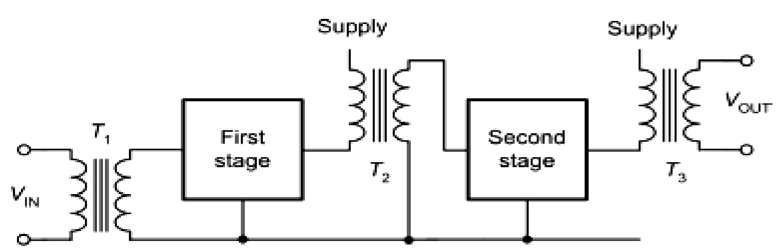
Types of coupling
Coupling devices transfer energy from one stage to the other.
a)In RC coupling: Resistor (R) used as load impedance and capacitor (C) is used as the coupling element. The capacitor (C) connects the output of one stage to the input of the next stage which allows the AC signal while blocking the DC voltages. Since the DC resistance of R is high, the efficiency of the amplifier is decreased.
Disadvantage: i) Causes loss for the low frequency signals.
ii)Difficult to match the impedance from stage to stage



b)**In L–C coupling**: Inductance (L) as load impedance and capacitance(C) used as coupling elements. The capacitor connects the output of one stage to the input of the next stage which allows the AC signal while blocking the DC voltages. The impedance of coupling coil (L) depends on its inductance and signal frequency. Since the DC resistance of the coil (L) is low, the efficiency of the amplifier is increased.
Disadvantage: only used in RF and high-frequency amplifiers.



c)In transformer coupling
Transformer is used as the coupling device. The transformer coupling provides two functions: i) to passAC signal and blocking DC and ii) permits impedance matching.



Disadvantage: i) Coupling transformer is expensive and bulky
ii) Transformers tend to produce hum noise
iii) It has a poor frequency response

Problem 1

An amplifier with negative feedback applied has an open-loop voltage gain of 50 and one-tenth of its output is fed back to the input (i.e. $\beta = 0.1$). Determine the overall voltage gain with negative feedback applied.

Solution

With negative feedback applied the overall voltage gain will be given by:

$$\frac{A_V}{1+\beta A_V} = \frac{50}{1+(0.1\times 50)} = \frac{50}{1+5} = \frac{50}{6} = 8.33$$

Problem 2

If, in Example 7.3, the amplifier's open-loop voltage gain increases by 20%, determine the percentage increase in overall voltage gain.

The new value of open-loop gain will be given by:

$$A_V = A_V + 0.2A_V = 1.2\times 50 = 60$$

The overall voltage gain with negative feedback will then be:

$$\frac{A_V}{1+\beta A_V} = \frac{60}{1+(0.1\times 60)} = \frac{60}{1+6} = \frac{50}{6} = 8.57$$

The increase in overall voltage gain, expressed as a percentage, will thus be:

$$\frac{8.57-8.33}{8.33}\times 100\% = 2.88\%$$

Problem 3

An amplifier produces an output voltage of 2 V for an input of 50 mV. If the input and output currents in this condition are, respectively, 4 mA and 200 mA, determine:

(a) the voltage gain;
(b) the current gain;
(c) the power gain.

Solution

(a) The voltage gain is calculated from:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{2\,V}{50\,mV} = 40$$

(b) The current gain is calculated from:

$$A_i = \frac{I_{out}}{I_{in}} = \frac{200\,mA}{4\,mA} = 50$$

(c) The power gain is calculated from:

$$A_p = \frac{P_{out}}{P_{in}} = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}}$$

$$= \frac{2\,V \times 200\,mA}{50\,mV \times 4\,mA} = \frac{0.4\,W}{200\,\mu W}$$

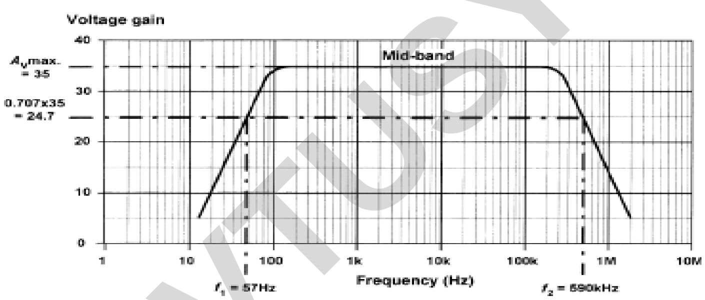
thus

$$A_p = 2000$$

(Note that $A_p = A_v \times A_i = 50 \times 40 = 2000$.)

Problem 4

Determine the mid-band voltage gain and upper and lower cut-off frequencies for the amplifier whose frequency response is shown in Fig. 7.11.



The voltage gain at the cut-off frequencies can be calculated from:

$$A_V \text{ cut-off} = 0.707 \times A_V \max$$
$$= 0.707 \times 35 = 24.7$$

This value of gain intercepts the frequency response at $f_1 = 57$ Hz and $f_2 = 590$ kHz (see Fig. 7.11).