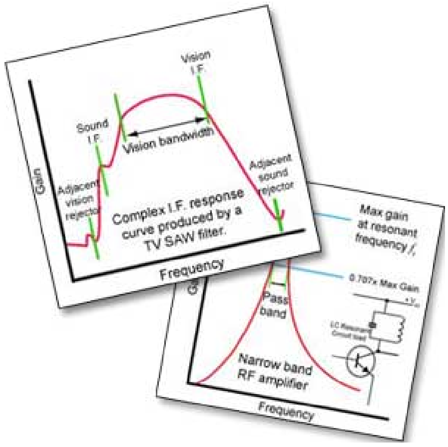
Amplifiers

1.0 Introduction to Amplifiers

What you'll learn in Module 1



An amplifier is used to increase the amplitude of a signal waveform, without changing other parameters of the waveform such as frequency or wave shape. They are one of the most commonly used circuits in electronics and perform a variety of functions in a great many electronic systems.

The general symbol for an amplifier is shown in Fig 1.0.1. The symbol gives no detail of the type of amplifier described, but the direction of signal flow can be assumed (as flowing from left to right of the diagram). Amplifiers of different types are also often described in system or block diagrams by name.

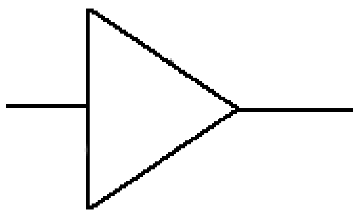


Fig 1.0.1 Amplifier general symbol, used in system diagrams

For example look at the block diagram of an analogue TV receiver in Fig 1.0.2 and see how many of the individual stages (shaded green) that make up the TV are amplifiers. Also notice that the names indicate the type of amplifier used. In some cases the blocks shown are true amplifiers and in others, the amplifier has extra components to modify the basic amplifier design for a special purpose. This method of using relatively simple, individual electronic circuits as "building blocks" to create large complex circuits is common to all electronic systems; even computers and microprocessors are made up of millions of logic gates, which are simply specialised types of amplifiers. Therefore to recognise and understand basic circuits such as amplifiers is an essential step in learning about electronics.

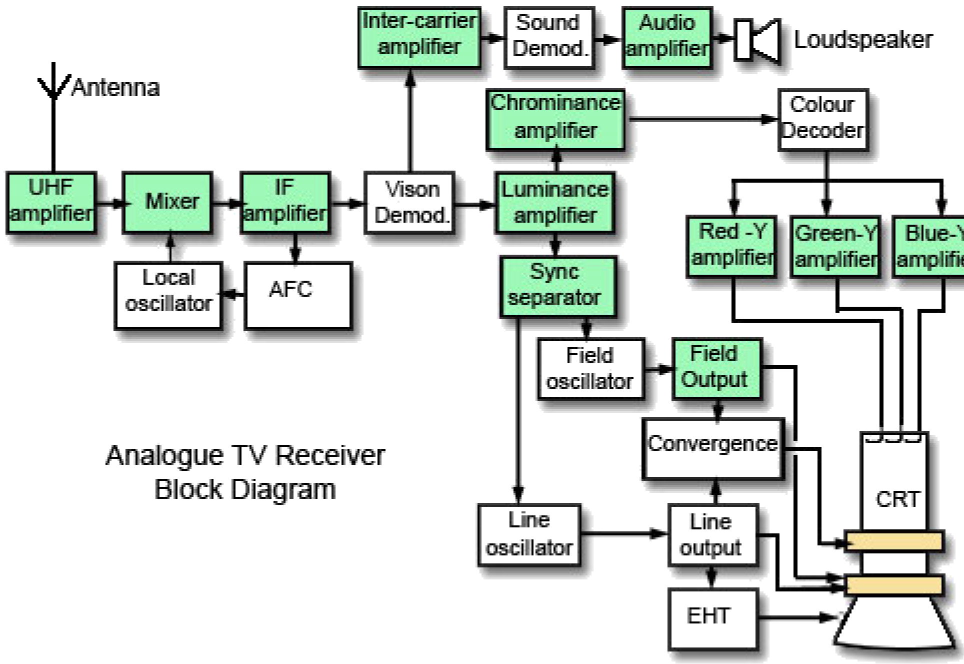


Fig 1.0.2 Analogue TV receiver block diagram, showing amplifiers used in many stages.

One way to describe an amplifier is by the type of signal it is designed to amplify. This usually refers to a band of frequencies that the amplifier will handle, or in some cases, the function that they perform within an electronic system.

A.F. Amplifiers

Audio frequency amplifiers are used to amplify signals in the range of human hearing, approximately 20Hz to 20kHz, although some Hi-Fi audio amplifiers extend this range up to around 100kHz, whilst other audio amplifiers may restrict the high frequency limit to 15kHz or less.

Voltage amplifiers are used to amplify the low level signals from microphones, tape and disk pickups etc. With extra circuitry they also perform functions such as tone correction equalisation of signal levels and mixing from different inputs, they generally have high voltage gain and medium to high output resistance.

Power amplifiers are used to receive the amplified input from a series of voltage amplifiers, and then provide sufficient power to drive loudspeakers.

I.F. Amplifiers

Intermediate Frequency amplifiers are tuned amplifiers used in radio, TV and radar. Their purpose is to provide the majority of the voltage amplification of a radio, TV or radar signal, before the audio or video information carried by the signal is separated (demodulated) from the radio signal.

They operate at a frequency lower than that of the received radio signal, but higher than the audio or video signals eventually produced by the system. The frequency at which I.F. amplifiers operate and the bandwidth of the amplifier depends on the type of equipment. For example, in AM radio receivers the I.F. amplifiers operate at around 470kHz and their bandwidth is normally 10kHz (465 kHz to 475kHz), while TV commonly uses 6Mhz bandwidth for the I.F. signal at around 30 to 40MHz, and in radar a band width of 10 MHz may be used.

R.F. Amplifiers

Radio Frequency amplifiers are tuned amplifiers in which the frequency of operation is governed by a tuned circuit. This circuit may or may not, be adjustable depending on the purpose of the amplifier. Bandwidth also depends on use and may be relatively wide, or narrow. Input resistance is generally low, as is gain. (Some RF amplifiers have little or no gain at all but are primarily a buffer between a receiving antenna and later circuitry to prevent any high level unwanted signals from the receiver circuits reaching the antenna, where it could be re-transmitted as interference). A special feature of RF amplifiers where they are used in the earliest stages of a receiver is low noise performance. It is important that background noise generally produced by any electronic device, is kept to a minimum because the amplifier will be handling very low amplitude signals from the antenna (µV or smaller). For this reason it is common to see low noise FET transistors used in these stages.

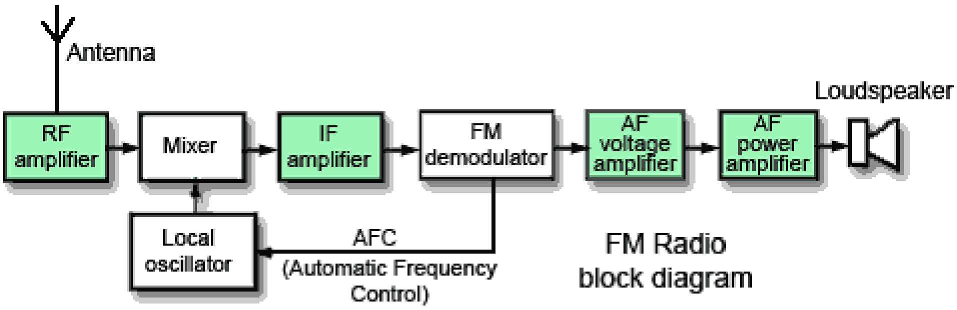


Fig. 1.0.3 FM Radio using AF, IF and RF amplifiers.

Ultrasonic Amplifiers

Ultrasonic amplifiers are a type of audio amplifier handling frequencies from around 20kHz up to about 100kHz; they are usually designed for specific purposes such as ultrasonic cleaning, metal fatigue detection, ultrasound scanning, remote control systems etc. Each type will operate over a fairly narrow band of frequencies within the ultrasonic range.

Wideband Amplifiers

Wideband amplifiers must have a constant gain from DC to several tens of MHz. They are used in measuring equipment such as oscilloscopes etc. where there is a need to accurately measure signals over a wide range of frequencies. Because of their extremely wide bandwidth, gain is low.

DC Amplifiers

DC amplifiers are used to amplify DC (0Hz) voltages or very low frequency signals where the DC level of the signal is important. They are common in many electrical control systems and measuring instruments.

Video Amplifiers

Video amplifiers are a special type of wide band amplifier that also preserve the DC level of the signal and are used specifically for signals that are to be applied to CRTs or other video equipment. The video signal carries all the picture information in TV, video and radar systems. The bandwidth of video amplifiers depends on use. In TV receivers it extends from 0Hz (DC) to 6MHz and is wider still in radar.

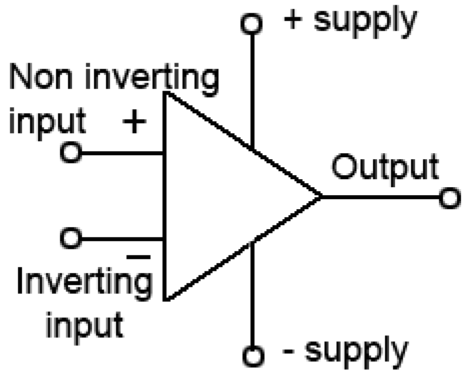
Buffer Amplifiers

Buffer amplifiers are a commonly encountered, specialised amplifier type that can be found within any of the above categories, they are placed between two other circuits to prevent the operation of one circuit affecting the operation of the other. (They ISOLATE the circuits from each other). Often buffer amplifiers have a gain of one, i.e. they do not actually amplify, so that their output is the same amplitude as their input, but buffer amplifiers have a very high input impedance and a low output impedance and can therefore be used as an impedance matching device. This ensures that signals are not attenuated between circuits, as happens when a circuit with a high output impedance feeds a signal directly to another circuit having a low input impedance.

Operational Amplifiers

Operational amplifiers (Op-amps) have developed from circuits designed for the early analogue computers where they were used for mathematical operations such as adding and subtracting. Today they are widely used in integrated circuit form where they are available in single or multiple amplifier packages and often incorporated into complex integrated circuits for specific applications.

The design is based on a differential amplifier, which has two inputs instead of one, and produces an output that is proportional to the difference between the two inputs. Without negative feedback, op amps have an extremely high gain, typically in the hundreds of thousands. Applying negative feedback increases the op amp's bandwidth so they can operate as wideband amplifiers with a bandwidth in the MHz range, but reduces their gain. A simple resistor network can apply such feedback externally and other external networks can vary the function of op-amps.



LM324N Low power Quad Operational Amplifier IC by ST Microelectronics.

The Output Properties of Amplifiers

Amplifiers are used to increase the amplitude of a voltage or current, or to increase the amount of power available usually from an AC signal. Whatever the task, there are three categories of amplifier that relate to the properties of their output;

1. Voltage amplifiers.

2. Current amplifiers.

3. Power amplifiers.

The purpose of a voltage amplifier is to make the amplitude of the output voltage waveform greater than that of the input voltage waveform (although the amplitude of the output current may be greater or smaller than that of the input current, this change is less important for the amplifier's designed purpose).

The purpose of a current amplifier is to make the amplitude of the output current waveform greater than that of the input current waveform (although the amplitude of the output voltage may be greater or smaller than that of the input voltage, this change is less important for the amplifier's designed purpose).

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. Note that either voltage or current may be less at the output than at the input. It is the product of the two that is significantly increased.

Module 1.1

Amplifier Parameters

What you'll learn in Module 1.1.

After studying this section, you should be able to:

Describe typical amplifier parameters.

- Gain.
- Frequency response.
- Bandwidth.
- Input impedance.
- Output impedance.
- Phase shift.
- Feedback.

Amplifier Parameters

Any amplifier is said to have certain parameters. These are the particular properties that make the amplifier perform in a certain way, and so make it suitable for a given task. Typical amplifier parameters are described below.

Gain

The gain of an amplifier is a measure of the "Amplification" of an amplifier, i.e. how much it increases the amplitude of a signal. More precisely it is the ratio of the output signal amplitude to the input signal amplitude, and is given the symbol "A". It can be calculated for voltage (A_v), current (A_i) or power (A_p), When the subscript letter after the A is in lower case this refers to small signal conditions, and when the subscript is in capitals it refers to DC conditions. The gain or amplification for the three differnt types of amplifiers can be described using the appropriate formula:

Voltage gain Av = Amplitude of output voltage ÷ Amplitude of input voltage.

$$A_v = \frac{V_{out}}{V_{in}}$$

Current gain A_i = Amplitude of output current ÷ Amplitude of input current.

$$A_i = \frac{I_{out}}{I_{in}}$$

Power gain Ap = Signal power out ÷ Signal power in.

$$A_p = \frac{P_{out}}{P_{in}}$$

The gain of an amplifier is governed, not only by the components (transistors etc.) used, but also by the way they are interconnected within the amplifier circuit.

Frequency Response

Amplifiers do not have the same gain at all frequencies. For example, an amplifier designed for audio frequency amplification will amplify signals with a frequency of less than about 20kHz but will not amplify signals having higher frequencies. An amplifier designed for radio frequencies will amplify a band of frequencies above about 100kHz but will not amplify the lower frequency audio signals. In each case the amplifier has a particular frequency response, being a band of frequencies where it provides adequate amplification, and excluding frequencies above and below this band, where the amplification is less than adequate.

To show how the gain of an amplifier varies with frequency, a graph, showing the frequency response of the amplifier is used. Fig. 1.1.1a shows the typical frequency response curve of an audio amplifier, and Fig. 1.1.1b, that of a RF amplifier. In such graphs, it is common that very large values may be encountered for both gain and frequency. For this reason it is usual for both the frequency and gain axes of the graph to use logarithmic scales. It can be seen from Fig. 1.1.1a that scales on the (horizontal) x-axis do not increase in a linear manner; each equal division represents a tenfold increase in the frequency plotted. This ensures that a very wide range of frequency can be plotted on a single graph. The (vertical) y-axis uses linear divisions but logarithmic units (deciBels dB). The curve of the graph shows how gain, measured in deciBels, varies with frequency.

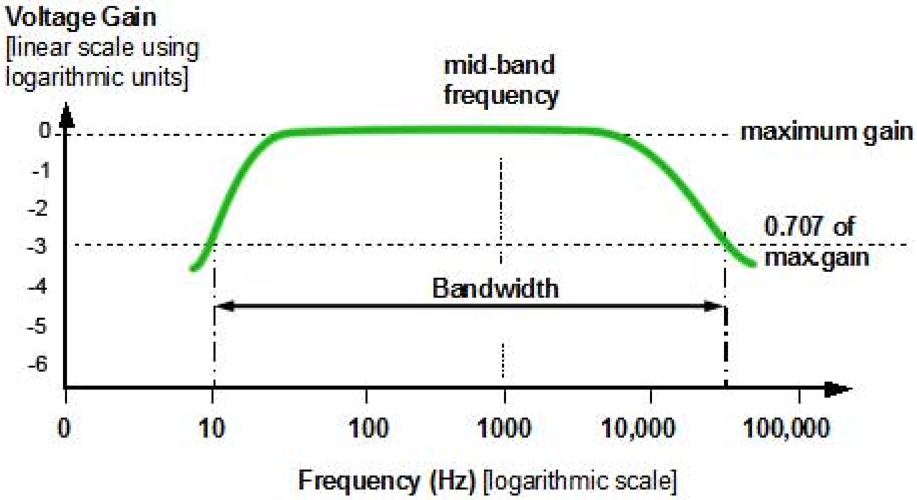


Fig. 1.1.1a Response curve for an audio amplifier

Comparing Figs. 1.1.1a and b drawn in this manner, shows how each type of amplifier (audio, RF etc) has its own characteristic shape of frequency response curve. An amplifier which has a very narrow, sharply peaked response curve is said to be very "selective". This is typical of an RF amplifier and is precisely what is needed in an amplifier designed for the tuning stages of a radio where only one radio carrier wave among many hundred others, crowded along the medium wave band for example, must be selected.

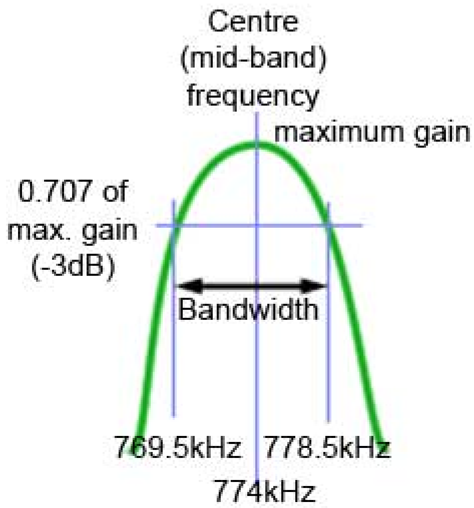


Fig. 1.1.1b Response curve for a RF amplifier tuned to 774kHz

Bandwidth

An important piece of information that can be obtained from a frequency response curve is the Bandwidth of the amplifier. This refers to the ‘band’ of frequencies for which the amplifier has a useful gain. Outside this useful band the gain of the amplifier is considered to be insufficient compared with the gain at the centre of the bandwidth. Bandwidth specified for voltage amplifiers is the range of frequencies for which the amplifier’s gain is greater than 0.707 of the maximum gain (see Fig. 1.1.1.b). Alternatively, decibels are used to indicate the gain, the ratio of output to input voltage, (see Fig. 1.1.1.a). The useful bandwidth in Fig. 1.1.1a would be described as extending to those frequencies at which the voltage gain is −3dB down compared to the gain at the mid band frequency. Several ways of describing the bandwidth can be used, firstly it could be said (of Fig 1.1.1a), that "The bandwidth is from 10Hz to 20kHz." Alternatively it could be said (of Fig. 1.1.1b) "The bandwidth is 9kHz, centred on 774kHz." or even that it is "774kHz plus or minus 4.5kHz."

Input Impedance

The word impedance means opposition to AC current flow. At 0 Hz, (that is, DC) impedance (symbol Z) is the same as resistance (R), but at frequencies other than 0Hz impedance and resistance are not the same. The input impedance of an amplifier is the effective impedance between the input terminals. "Effective" means that the impedance is not necessarily just that of the amplifier components (resistors, capacitors etc.) actually connected across the input terminals, but is the impedance experienced as the amount of current able to flow into the input terminals for a given signal voltage applied at a particular frequency. Input Impedance is influenced by a number of factors including the frequency of the applied signal, the gain of the amplifier, any signal feedback used and even what is connected to the output of the amplifier.

Output Impedance

The output impedance of an amplifier is not solely dependent on the actual components connected within the output of an amplifier. It is an ‘apparent’ impedance and can best be demonstrated as being responsible for a fall in signal voltage at the output terminals of an amplifier, when a current is drawn from the output terminals. The more current drawn from the output terminals, the greater the reduction in output signal voltage. The effect is that of an impedance or resistance in series with the output terminals.

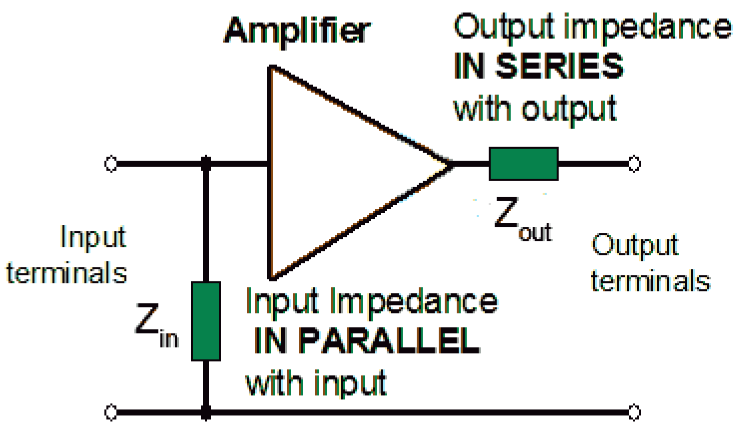


Fig. 1.1.2 Amplifier Input and Output Impedances

Calculation of gain in multi stage amplifiers.

Matching of inputs and outputs is necessary to ensure that the maximum amount of signal can be transferred between the amplifier, and any other circuit or device preceding or following it. This is usually the case when the gain of a single amplifier is insufficient for a given purpose. Then several stages of amplification are used which involves feeding the output of one amplifier into the input of another. (This is called connecting the amplifiers in 'Cascade'). In such designs the output

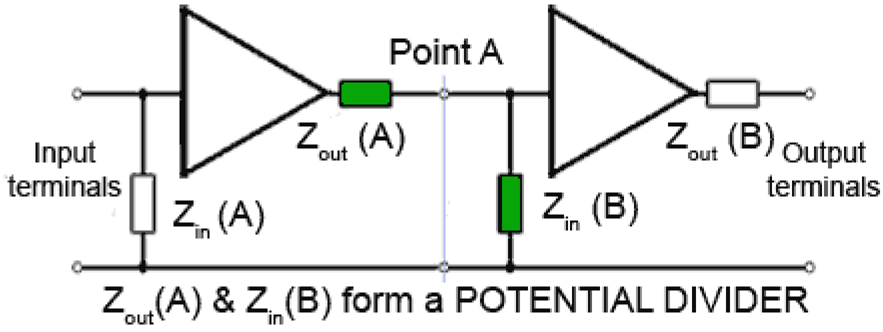


Fig. 1.1.3 Potential divider effect of amplifiers in Cascade

impedance of the first amplifier and the input impedance of the second amplifier form a potential divider, as shown in Fig. 1.1.3

When connecting voltage amplifiers in cascade, the input signal to the second stage should ideally be 100% of the output voltage of stage 1, i.e. have as high a voltage amplitude as possible. This will occur if the output impedance of the first amplifier is a much lower value than the input impedance of the second amplifier. This allows most of the voltage available at the output terminal (point A) to be developed across the input impedance of the second amplifier (and therefore across its input terminals) rather than across the first amplifier's output impedance.

If the second amplifier is a current amplifier however, it will be necessary that as much current as possible flows into its input terminals. In this case therefore, the input impedance of the second amplifier must be low.

In the case of power amplifiers, the maximum power is transferred from output to input if both impedances are equal.

The values of input and output impedance have a considerable effect on the gain of multi stage amplifiers, and there is always some loss of signal amplitude which occurs due to the coupling of successive amplifier stages. In calculating the overall gain of a multi stage amplifier, the overall gain should be equal to the product of the individual gains of each amplifier. i.e. if each stage of a two stage amplifier has a gain of 10, then the overall gain should be 10 x 10 = 100. In practice however, this is not achievable due to the coupling losses incurred in matching the amplifiers, and a slightly lower overall gain results.

Phase Shift

Phase shift in an amplifier is the amount (if any) by which the output signal is delayed or advanced in phase with respect to the input signal expressed in degrees. If a phase shift of 90 degrees occurs then the peak of the output wave occurs one quarter of a cycle after the peak of input wave. Such a shift can be caused by the effect of components such as resistors inductors and capacitors in the amplifier circuit. The action of the transistor in a single stage amplifier can cause 180 degrees of phase shift, and therefore the input and output will be in "anti-phase." Whether a phase shift in an amplifier is important depends on the purpose of the amplifier.

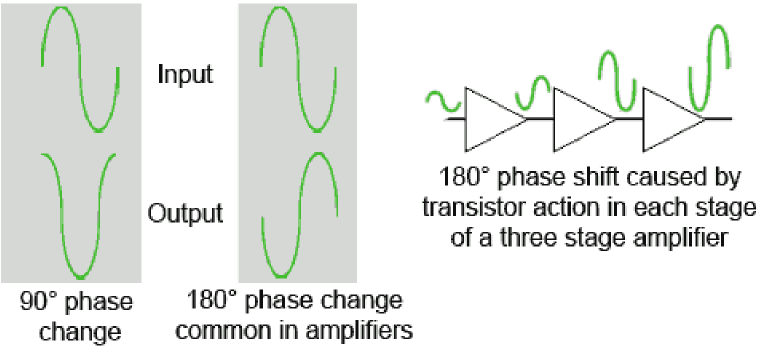


Fig. 1.1.4 Phase Shift

The design of multi stage amplifiers must take phase shift into consideration, as the amount of phase shift will vary with frequency it is possible that at some frequencies the total phase shift may add up to 360 degrees. If the output signal of such a system is allowed to re-enter the input then positive feedback occurs and the amplifier will become unstable and is likely to oscillate.

Feedback

Feedback is the process of taking a proportion of an amplifier's output signal and feeding it back into the input. Feedback can be arranged to either increase or decrease the input signal. When feedback is used to increase the input signal it is called POSITIVE FEEDBACK, and when the effect of the feedback reduces the input signal it is called NEGATIVE FEEDBACK.

POSITIVE FEEDBACK occurs when the feedback signal is in phase with the input signal, this increases the amplitude of the input and hence the output signal, effectively increasing the gain of the amplifier.

NEGATIVE FEEDBACK occurs when the feedback signal is in anti-phase with the input signal, effectively reducing the amplitude of the input and hence also the output signal. This causes a reduction in gain. See Fig. 1.1.5.

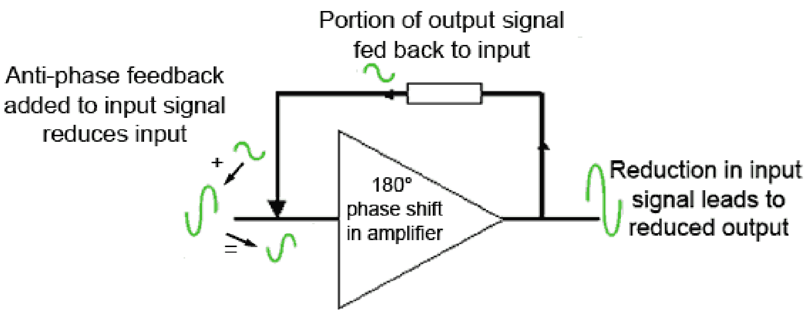


Fig. 1.1.5 Negative feedback reduces gain, distortion and noise, it also increases bandwidth.

In high quality amplifiers negative feedback is often used to reduce the gain of the amplifier. A particular benefit of this, is that any distortion of the signal or background noise produced by the amplifier is also reduced. A further beneficial effect is that applying negative feedback increases the bandwidth of the amplifier. The reason for this can be seen in Fig. 1.1.6 where reducing the height

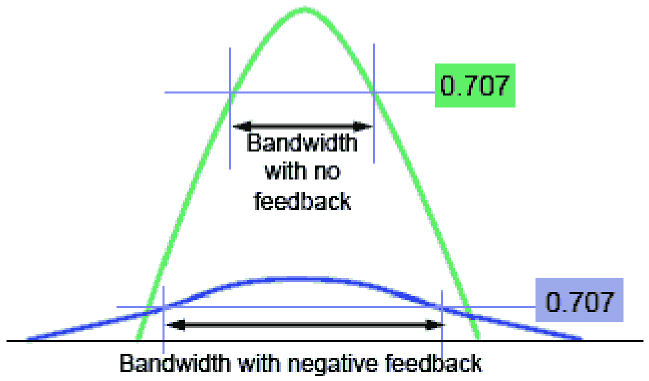


Fig. 1.1.6 The effect of negative feedback on amplifier bandwidth.

of the gain curve produces wider spacing of the 0.707 points, therefore widening the bandwidth.

Module 1.2

Class A Biasing

What you'll learn in Module 1.2.

After studying this section, you should be able to describe:

The Reasons for DC Bias in Amplifiers.

Advantages and Disadvantages Class A Bias.

Simple Common Emitter Fixed DC Bias.

- The Use of Input Characteristics.
- Quiescent Conditions.
- Preventing Distortion with Correct Bias.
- Output Characteristics.
- Load Line.
- Basic Fixed Bias Calculations.

Bias Stabilisation.

- Collector Derived Bias.
- Base Bias networks.
  - Emitter Stabilisation.
  - Use of Emitter Bypass Capacitors.

FET Biasing.

An Amplifier's Common Connection

Transistors in amplifiers commonly use one of three basic modes of connection. A transistor has three connections (collector, base and emitter), whilst the input and output of an amplifier circuit each require two connections, making four in total, therefore one of the transistor's three connections must be common to both input and output. Whether collector, base or emitter is chosen as being common to both input and output has a marked effect on how a transistor amplifier operates. This section describes how the transistor is biased in common emitter mode, the most commonly used of the three connection modes for voltage amplifiers.

Class A Bias

Class A amplifiers are biased with a DC voltage applied across the transistor base-emitter junction so that their quiescent (or no signal) operating point is on a linear part of the transistor's characteristics. Also, the signal waveform applied to the base should not drive the transistor either into saturation or into cut-off. If this were allowed to happen it would cause the waveform peaks to be flattened, causing distortion. In class A biasing, the collector voltage is kept at approximately half the supply voltage, however this means that the transistor is permanently passing collector current, even when no signal is applied, so power is being wasted, and although class A provides for very low distortion, it is also relatively inefficient in its use of power.

The theoretical maximum efficiency of a class A amplifier is 50% but in practice the figure would be nearer 25%. The main use for class A bias is in low power audio and radio frequency voltage amplifiers, where the amount of power wasted is less significant than the amplifier's main advantage of low distortion. However class A may also be used for low distortion power amplifiers in mains (line) powered hi-fi audio systems where efficiency is less vital.

Common Emitter Fixed Biasing

Amplifiers are needed in most pieces of electronic equipment, not only for sound and picture reproduction but also in control systems and communications. The design of amplifiers is aimed at producing a circuit that has a predicted gain over a particular band of frequencies with minimum distortion. The amplifier must also be stable and not prone to oscillation. Bipolar PNP or NPN transistors or FETs may be used in a wide variety of designs depending on their intended purpose.

Consider the simple bipolar NPN common emitter amplifier shown in Fig. 1.2.1 consisting of a transistor and two resistors. To function correctly the amplifier should produce at its output, an amplified version of the signal at its input without distortion. In order to do this, its quiescent or no signal (DC) conditions, must first be correct. Its output can only be undistorted if its input is undistorted.

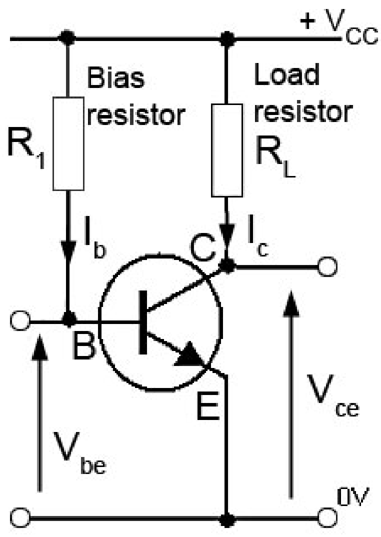


Fig 1.2.1 Simple bias for a common emitter amplifier.

Using the Input Characteristics.

Fig. 1.2.2 shows a typical input characteristic curve for a small signal amplifier transistor where changes in base voltage V_b are plotted against the resulting changes in base current I_b.

If changes in the AC signal voltage (changes in V_b) applied to the base, are to produce proportional changes in AC base current I_b then some DC value of V_B must be used so that positive and negative excursions of the signal voltage occur only on the linear part of the input curve (waveform b in Fig. 1.2.2). This DC voltage (0.7V in Fig. 1.2.2) applied to the base is called the base bias voltage. It can be seen from Fig. 1.2.2 that if the bias voltage is insufficient, then only the positive tips of the input voltage waveform would produce base current, and consequently severe distortion will occur in the base current waveform a.

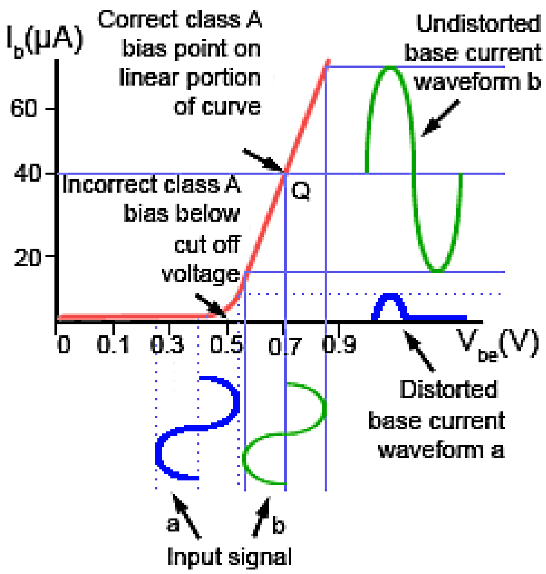


Fig. 1.2.2 Input Characteristics.

It can also be seen that for this transistor, a DC base bias voltage (R_B) of 0.7V produces a quiescent (DC) base current of 40µA. These values are set by the correct choice of resistance value for R_B (Fig. 1.2.1).

Setting the Quiescent Output Conditions

The quiescent **output** conditions must also be considered, as the quiescent base current I_b will produce a quiescent collector current I_c that will depend on the value of I_b and the current gain h_{fe} of the transistor. Also, because I_c flows through the load resistor (R_L) it will produce a potential difference across R_L that when subtracted from the supply voltage (V_{cc}) gives the value of the transistor collector/emitter voltage (V_{ce}).

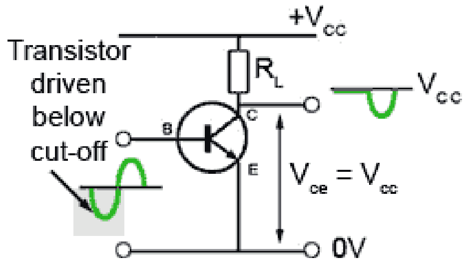


Fig. 1.2.3a Cut off condition Fig 1.2.3b Saturation condition

Fig. 1.2.3 Incorrect Bias Conditions

Fig. 1.2.3 shows the two extreme conditions for the values of Ic and Vce. It can be seen in the first case (Fig. 1.2.3a), that if the collector current IC is zero, owing to the base voltage being low enough to cut off base current, the voltage developed across RL will be zero and the whole of Vcc will be developed across the transistor so Vce will rise to the supply voltage Vcc.

If a signal is applied under these conditions (Fig. 1.2.3a), positive going half cycles of the output signal (which is in anti phase to the voltage waveform at the base) cannot make V_{ce} rise any further than V_{cc} and so the positive going half cycles of collector voltage will not be reproduced, causing severe distortion.

Alternatively if I_c is very high (Fig 1.2.3b) due to excessive base bias, the transistor will be in a saturated condition and V_{ce} will fall to almost zero. As the collector voltage cannot fall below 0V the negative going half cycles of the output signal will be lost. It follows therefore, that to reproduce the full waveform at the collector, the ideal quiescent value for V_{ce} will be around midway between V_{cc} and zero volts. This will allow the maximum amplitudes of both positive and negative going half cycles of the output wave to be reproduced without distortion.

Using the Output Characteristics

In the output characteristics shown in Fig. 1.2.4 changes in I_c are plotted against changes in V_{ce} for various constant base currents I_b .

A ´load line´ is drawn on Fig. 1.2.4 between the two extreme points described in Fig. 1.2.3.

Point P is where $V_{CE} = V_{cc}$ (which in this case equals 10V) and I_c= zero, and because no current collector is flowing, the transistor is said to be "Cut off".

Point R is the maximum value of I_c (where $I_c = V_{cc} \div R_L$) and V_{ce} is zero (because practically the whole of V_{cc} is developed across R_L). This is called "Saturation" as no further increase in collector current will occur.

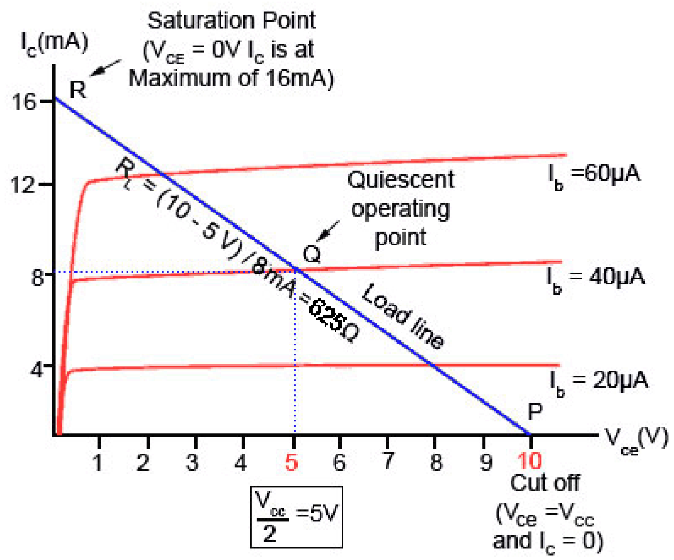


Fig. 1.2.4 Output Characteristics and Load Line

With the load line drawn from P to R, it can be seen that a value of V_{ce} can be chosen mid-way along the load line at point Q, which in this case coincides with the curve for I_B.

A vertical line projected downwards from Q then intersects the V_{CE} axis midway between V_{cc} and zero, and a horizontal line projected from Q intersects the I_C axis to give a quiescent value of 8mA.

From the values of V_{Cce} and IC indicated, it is now possible to calculate a value for R_L using:

$$R_L = (V_{cc} - V_{ce}) \div I_c$$

So using the load line at point Q (or any other point with different pairs of values):

$$R_L = (10 - 5) \div 8 \text{ x}10^{-3} = 625\Omega$$

Biasing an amplifier so that the operating point is at the centre of the linear part of the transistor's characteristic curves is called ´Class A bias´.

Example:

Design the DC fixed bias conditions for the simple class A common emitter amplifier shown in Fig. 1.2.1, assuming a supply voltage (V_{cc}) of 10V using a transistor with a common emitter current gain (h_{fe}) of 200.

From the input characteristics (Fig. 1.2.3) I_b needs to be 40µA, which indicates a value for V_{be} of 0.7V.

Therefore:

$$R_b = (V_{cc} - V_{be}) \div I_b$$

$$= (10 - 0.7) \div 40\mu A = 232.5K\Omega$$

Because, in a practical circuit, the nearest preferred value for the base resistor R_b would be chosen to make $R_b = 220K\Omega$.

Since the base current chosen is 40µA and the transistor h_{fe} is 200:

$$I_C = I_b \text{ x } h_{fe} = 40\mu A \text{ x } 200 = 8mA$$

If a collector current (I_c) of 8mA is sufficient to drop V_{ce} to 5V (half of V_{cc}) then 16mA will cause V_{ce} to fall to practically zero and saturate the transistor. 16mA will therefore be point R on the load line.

As the quiescent collector voltage is to be 5V (half of V_{cc}), and the voltage across R_L is also 5V, it is possible to calculate the value of R_L to give the correct conditions at point Q:

$$R_L = V_{RL} \div I_c = 5V \div 8mA = 625\Omega$$

or approximately 680Ω (the next higher resistor preferred value).

Problems with the fixed bias design.

While the design described in Fig. 1.2.1 is simple and requires a minimum of components, there are some problems that need to be overcome for practical use.

If, the supply voltage or transistor temperature changes for any reason, the bias voltage will also change. If the bias voltage increases then more base current will flow, which will cause an increase collector current. This will in turn cause a rise in junction temperature within the transistor, and so, a further increase in current. The transistor will then pass even more current, creating a further rise in temperature and so on.

The ultimate result of this process called "Thermal Runaway", is that the transistor will get hotter and hotter until it is destroyed. Although Thermal Runaway is much less of a problem in modern power transistors, in small signal types it is still a possible hazard that should be avoided by building some form of bias stabilisation into the amplifier design.

DC Stabilisation

Fig. 1.2.5 shows a simple method of improving the temperature stabilisation of a common emitter amplifier. Instead of feeding the bias current from V_{cc} it is fed from the collector end of R_L.

With this arrangement, any increase in collector current will cause an increase in the potential difference across R_L and, as the top of R_L is held steady by V_{cc}, the collector voltage V_{ce} at the bottom of R_L must fall. This in turn will cause V_{be} to fall, and so reduce collector current. The bias conditions are to a large extent self adjusting and said to be stabilised by a form of DC feedback.

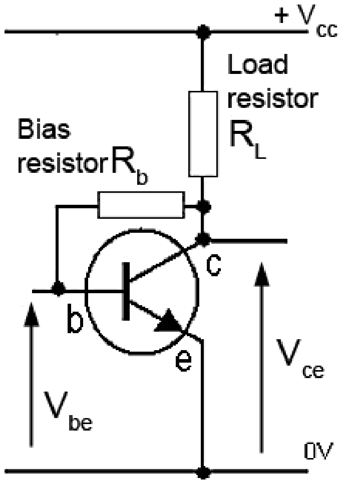


Fig. 1.2.5 Collector Derived Bias.

Emitter Stabilised Bias

An alternative, and much more common bias arrangement used in most commercial circuits, uses a potential divider comprising two resistors (R_1 and R_2 in Fig. 1.2.6) to provide a steady value of V_{be} and an emitter resistor R_e to provide stabilisation by DC feedback.

If collector current increases in this circuit, so does the emitter current, which causes a rise in the emitter voltage V_e. This rise compared with the steady base voltage, causes a reduction in the base-emitter voltage V_{be} and subsequent drop in collector current. DC feedback using an emitter stabilising resistor keeps circuit conditions stable when other conditions (e.g. temperature or transistor h_{fe}) may change.

However the emitter resistor will also cause unwanted AC feedback because under signal conditions the AC waveform appearing on the emitter will be in phase with the base waveform, and the two waveforms changing together will tend to reduce the variations in base-emitter voltage, causing a substantial reduction in gain. To avoid this problem it is usual for the emitter stabilising resistor R_e to be bypassed by a (usually) large value capacitor connected across R_E that will form a very low impedance path to any AC signal present, preventing any AC appearing on the emitter, but without changing any of the DC conditions.

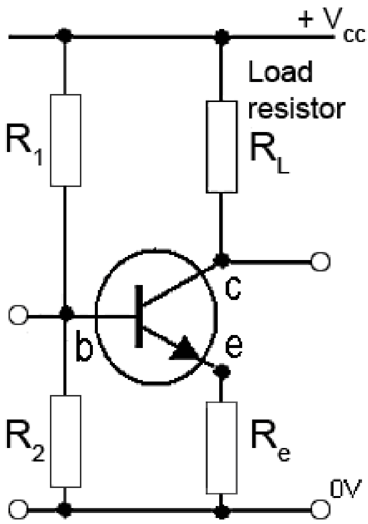


Fig. 1.2.6 Emitter Stabilisation

FET Biasing

The biasing of FETs is simpler than in bipolar designs as no gate (input) current is flowing. Fig. 1.2.7 shows a typical JFET bias arrangement. (MOSFETs also use a similar bias circuit).

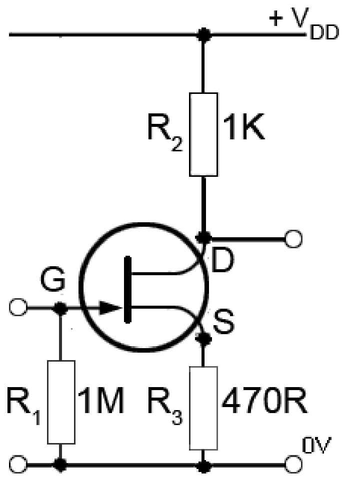


Fig. 1.2.7 FET Bias

When used in depletion mode, the gate of the FET must be more negative than the source. This is achieved by holding the gate at zero volts, whilst the drain/source current through R_3 makes the source terminal positive. As no gate current flows in FETs there can be no voltage developed across R_1 and the gate remains at zero volts. The use of a very high value for R_1 maintains the very high input impedance, which is a useful property of FET amplifiers.

An AC signal applied to the gate will cause small variations of gate voltage above and below zero, which will cause AC changes in drain-source current and, as in a bipolar amplifier, these are converted to voltage changes by R_2. The source resistor R_3 performs DC stabilisation in the same way as the emitter resistor in a bipolar amplifier, and is also normally bypassed to prevent AC negative feedback.

Module 1.3

Amplifier Gain & Decibels

What you'll learn in Module 1.3.

After studying this section, you should be able to:

Describe voltage amplification as a ratio.

Compare linear and logarithmic scales.

Describe ratios using the decibel.

- Positive and negative decibel values.
- Convert power gain to decibels.
- Convert voltage gain to decibels.
- Recognise commonly used dB values.

Amplification

The Voltage Amplification (Av) or Gain of a voltage amplifier is given by:

$$A_v = \frac{V_{out}}{V_{in}}$$

With both voltages measured in the same way (i.e. both RMS, both Peak, or both Peak to Peak), Av is a ratio of how much bigger is the output than the input, and so has no units. It is a basic measure of the Gain or effectiveness of the amplifier.

Because the output of an amplifier varies at different signal frequencies, measurements of output power, or often voltage, which is easier to measure than power, are plotted against frequency on a graph (response curve) to show comparative output across the working frequency band of the amplifier.

Logarithmic Scales

Response curves normally use a logarithmic scale of frequency, plotted along the horizontal x-axis. This allows for a wider range of frequency to be accommodated than if a linear scale were used.

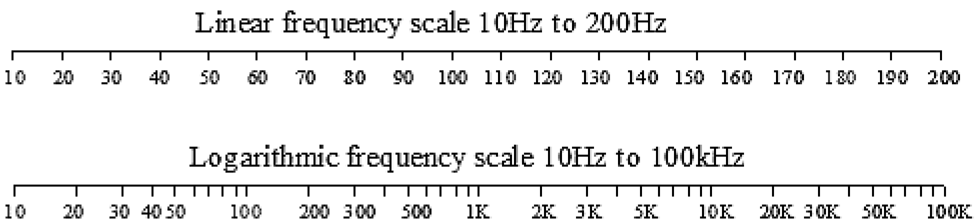


Fig. 1.3.1 Logarithmic and Linear Scales Compared

The vertical y-axis is marked in linear divisions but using the logarithmic units of decibels allowing for a much greater range within the same distance. The logarithmic unit used is the decibel, which is one tenth of a Bel, a unit originally designed for measuring losses of telephone cables, but as the Bel is generally too large for most electronic uses, the decibel (dB) is the unit of choice. Apart from providing a more convenient scale the decibel has another advantage in displaying audio information, the human ear also responds to the loudness of sounds in a manner similar to a logarithmic scale, so using a decibel scale gives a more meaningful representation of audio levels.

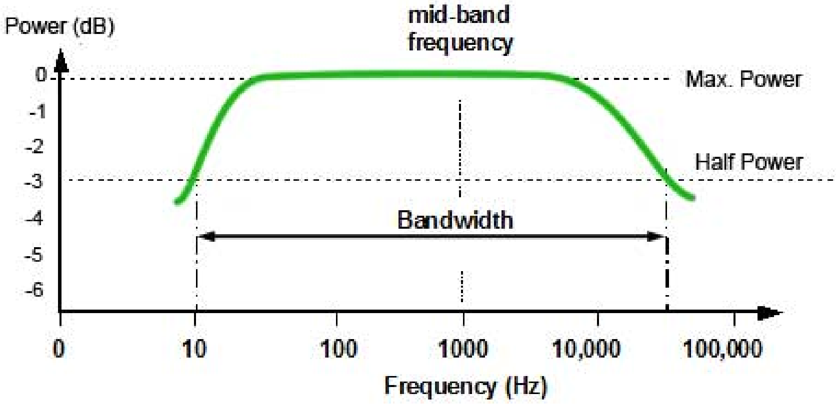


Fig 1.3.2 Audio Power Response Curve

To describe a change in output power over the whole frequency range of the amplifier, a response curve, plotted in decibels is used to show variations in output. The powers at various frequencies throughout the range are compared to a particular reference frequency, (the mid band frequency). The difference in power at the mid band frequency and the power at any other frequency being measured, is given as so many decibels greater (+dB) or less (-dB) than the mid band frequency, which is given a value of 0dB. Notice that, on the logarithmic frequency scale in Fig 1.3.1 the middle of the 10Hz to 100kHz band is 1kHz and frequencies around this figure (where the output is usually at its maximum) are normally chosen as the reference frequency.

Converting a power gain ratio to dBs is calculated by multiplying the log of the ratio by 10:

$$\text{Power (dB)} = 10\log\left(\frac{P_1}{P_2}\right)$$

Where P_1 is the power at mid band and P_2 is the power being measured.

Note:

When using this formula in a calculator the use of brackets is important, so that 10 x the log of (P_1/P_2) is used, rather than 10 x the log of P_1, divided by P_2.

e.g. if $P_1 = 6$ and $P_2 = 3$

10 x log(6/3) =3dB (right answer), but 10 x log 6/3 = 2.6dB (wrong answer).

Although it is common to describe the voltage gain of an amplifier as so many decibels, this is not really an accurate use for the unit. It is OK to use decibels to compare the output of an amplifier at different frequencies, since all the measurements of output power or voltage are taken across the same impedance (the amplifier load), but when describing the voltage gain (between input and output) of an amplifier, the input and output voltages are being developed across quite different impedances. However it is quite widely accepted to also describe voltage gain in decibels.

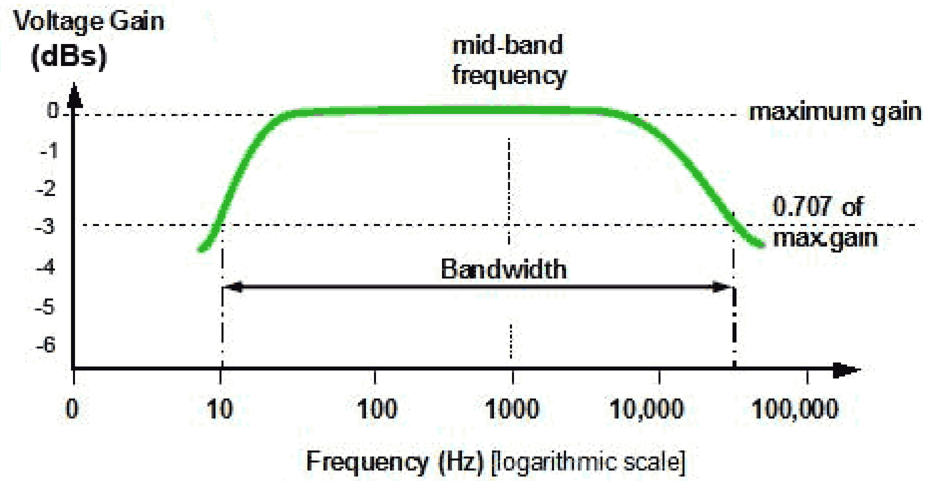


Fig 1.3.3 Audio Voltage Response Curve

When voltage gain(A_v) or current gain (A_i) is plotted against frequency the −3dB points are where the gain falls to 0.707 of the maximum (mid band) gain.

$$\text{Voltage (dB)} = 20 \log\left(\frac{V_{out}}{V_{in}}\right) \qquad \text{Current (dB)} = 20 \log\left(\frac{I_{out}}{I_{in}}\right)$$

Notice that converting voltage ratios to dBs uses 20 log(V_{out}/V_{in})

Describing the voltage gain of an amplifier that produces an output voltage of 3.5V for an input of 35mV as being 40dB, is equivalent to saying that the output voltage is 100 times greater than the input voltage.

$$\text{Voltage Ratio } A_v = \text{antilog}\left(\frac{dB}{20}\right)$$

To reverse the process, and convert dBs to a voltage ratios for example, use:

Note that the brackets are important and antilog may be shown on calculator keypads as 10^x or 10^ and is also usually Shift +log. Use the same formula for dBs to Current gain ratio, and to convert dBs to a power ratio, simply replace the 20 in the formula with 10.

An advantage of using dBs to indicate the gain of amplifiers is that in multi stage amplifiers, the total gain of a series of amplifiers expressed in simple ratios, would be the product of the individual gains, Av1 x Av2 x Av3 x Av4 ...etc.

This can produce some very large numbers, but the total of individual gains expressed in dBs would

$$20 \log\left(\frac{3.5V}{35 \times 10^{-3}}\right) = 20 \log 100 = 40dB$$

be the sum of the individual gains:

Av1 + Av2 + Av3 + Av4 ...etc.

Likewise losses due to circuits such as filters, attenuators etc. are subtracted to give the total loss.

Table 1.3.1 dB/Power dB/Voltage Ratio Conversion			
Power Ratio P_{out}/P_{in}	dB 10 log(P_{out}/P_{in})	Voltage or Current Ratio V_{out}/V_{in} or I_{out}/I_{in}	dB 20 log(V_{out}/V_{in}) 20 log(I_{out}/I_{in})
10 000 000 000	100	100 000	100
1 000 000 000	90	31 623	90
100 000 000	80	10 000	80
10 000 000	70	3 162	70
1 000 000	60	1 000	60
100 000	50	316.23	50
10 000	40	100	40
1 000	30	31.623	30
100	20	10	20
10	10	3.162	10
4	6	2	6
2	3	1.414	3
1.26	1	1.122	1
1	0	1	0
0.79	−1	0.891	−1
0.5	−3	0.707	−3
0.25	−6	0.5	−6
0.1	−10	0.316 2	−10
0.01	−20	0.1	−20
0.001	−30	0.031 62	−30
0.000 1	−40	0.01	−40
0.000 01	−50	0.003 162	−50
0.000 001	−60	0.001	−60
0.000 000 1	−70	0.000 316 2	−70
0.000 000 01	−80	0.000 1	−80
0.000 000 001	−90	0.000 0316 2	−90
0.000 000 000 1	−100	0.000 01	−100

Commonly Encountered dB Values

0dB The reference level to which all +dB and −dB figures refer.

±1dB The least noticeable change in audio levels, also used for the limits of bandwidth on high quality audio amplifiers.

−3dB Commonly used for limits of bandwidth in amplifiers, indicating the points where the output voltage has fallen to 0.707 of the maximum (mid band) output or half the maximum mid band power, (Half the VOLTAGE amplitude is **−6dB**).

−20 dB Reduces amplitude of signal voltage by 10 times (often quoted on signal generator attenuators.)

−40dB Reduces amplitude of signal voltage by 100 times

Module 1.4

Amplifier Bandwidth

What you'll learn in Module 1.4.

After studying this section, you should be able to:

Describe factors affecting bandwidth in single stage common emitter amplifiers.

- Stray capacitance and inductance in circuits and components.
- Gain bandwidth product, cut off frequency f_T.

Describe basic methods for controlling bandwidth

- in AF amplifiers.
- in RF amplifiers

Controlling Bandwidth

Any amplifier should ideally have a bandwidth suited to the range of frequencies it is intended to amplify, too narrow a bandwidth will result in the loss of some signal frequencies, too wide a bandwidth will allow the introduction of unwanted signals, in the case of an audio amplifier for example these would include low frequency hum and perhaps mechanical noise, and at high frequencies, audible hiss.

AC Components in a Common Emitter Amplifier

The class A common emitter amplifier circuit shown in Fig 1.4.1 has the DC bias components discussed in Module 1.3 with the AC components (capacitors C1 to C4) added that are necessary for use with an AC signal and also to achieve control over both gain and bandwidth.

The signal must pass through the input and output coupling capacitors C1 and C2 as it passes from input to output. The primary function of these capacitors is to provide DC isolation from voltages in preceding and following circuits. Also however, because the action of capacitors is frequency dependent they also can have an effect on the bandwidth of the amplifier.

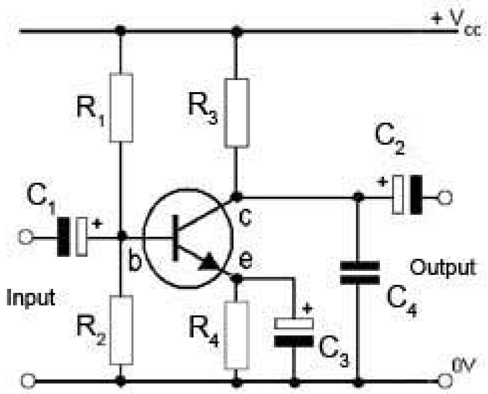


Fig. 1.4.1 Class A common emitter amplifier

C1, together with R1, R2 and the input resistance of the transistor forms a high pass filter, and C1 will normally have a quite large value of capacitance, making the corner frequency of the filter very low. At frequencies below this point however, amplifier gain will be reduced.

C2 will act in a similar manner with the input impedance of any following circuit, also contributing a fall off in gain at low frequencies.

Emitter Decoupling

The emitter decoupling capacitor C3, connected across the emitter stabilising resistor R_4 is intended to prevent any AC signal appearing on the emitter, which would otherwise act as negative feedback, severely reducing the gain of the amplifier. The relatively large value of C3 almost entirely removes any AC from the emitter, but it will have some reactance at the lowest frequencies and so allow some very low frequency signals to appear on the emitter, (assuming that these frequencies have not been removed by the action of C1 and C2 as described above) and whilst C3 contributes to higher gain over most of the bandwidth, gain at very low frequencies may not be improved.

The values of C_1, C_2 and C_3 are therefore chosen to give the required fall off in gain at the low frequency end of the bandwidth.

High Frequency Effects

At high frequencies the amplifier gain tends to be reduced to some extent by the presence of small amounts of inductive reactance (which increases with frequency) within the circuit wiring and components, but mainly by stray capacitances. These are not necessarily recognisable capacitor components but may be unavoidable capacitance effects within the circuit wiring and the components themselves.

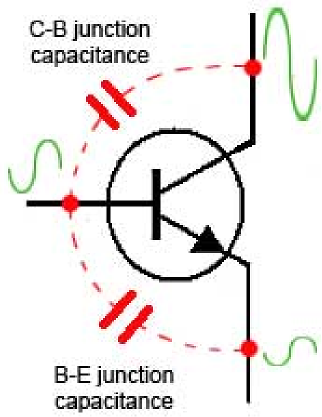


Fig. 1.4.2 Junction Capacitance.

Transistors possess capacitance in their junctions. As shown in Fig 1.4.2, the base-collector and base-emitter junctions of a bipolar transistor actually form very small capacitors due to the (insulating) depletion layers on either side of the base. At very high frequencies, normally in the hundreds of MHz, these tiny ´capacitors´ will form negative feedback paths by feeding anti phase signals between the collector and base, and in phase signals across the base-emitter junction.

Each transistor therefore has a limit to its high frequency current gain, and this is normally listed in transistor data sheets as the cut-off frequency f_T. This is the frequency at which the small signal current gain h_{fe} falls to 1. As gain begins to fall off at 6dB per octave (a doubling in frequency) well before f_T is reached, the transistor needs to be operated at frequencies considerably lower than f_T. Because of the relationship between frequency and gain in transistors, f_T is also commonly listed as "Gain Bandwidth Product".

Stray capacitance between closely packed wiring and components can also reduce gain at high frequencies, as well as causing other problems such as instability and oscillation, so the practical upper limit of operation for an amplifier is affected by a number of causes. In many practical amplifier circuits however, these extreme high frequency limits would not be approached; there is no point in designing an amplifier that has appreciable gain at frequencies higher than the highest signal frequency required. To do so would mean that in this region the amplifier would be amplifying mainly high frequency noise (e.g. hiss in the case of an audio amplifier.

Audio Harmonics

However restricting high frequency above about 20kHz assumes that the signals to be amplified are pure sine waves; In practice there is a trade off between a bandwidth wide enough to handle **all** the signals required, and a high frequency limit low enough to limit unwanted noise.

Most audio signals will be complex waves of many different and ever changing shapes. Audio signals are complex AC waves having fundamental frequencies in the range of 20Hz to 20kHz but also many higher frequency harmonics. To preserve the original shape of the signals (i.e. not introduce distortion) it is important that at least some of these harmonics are preserved. Therefore it is not advisable to sharply cut off the high frequencies at an arbitrary 20kHz, but rather allow some amplification of the apparently inaudible harmonic frequencies, which will contribute to the complex shape of the audible waves, especially where these signals contain sudden changes (fast transients) that require the presence of high frequency components to maintain their wave shape.

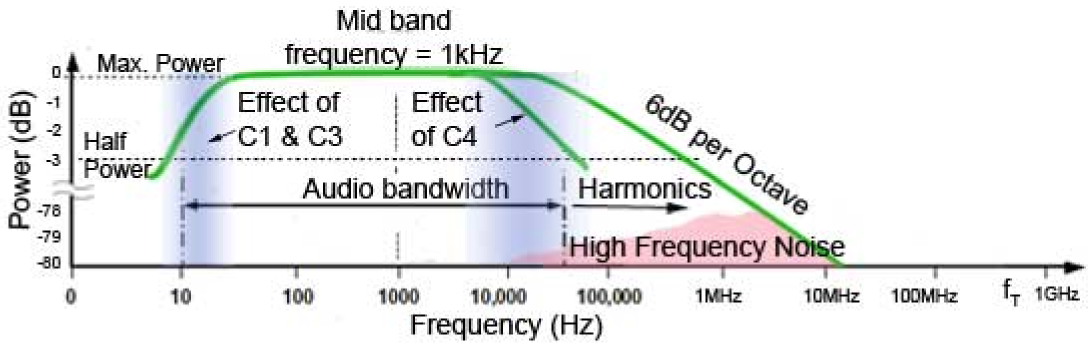


Fig. 1.4.3 Shaping the Audio Response Curve

There are several ways to ensure that the high frequency cut-off occurs at an appropriate frequency, reducing noise and instability but keeping the important harmonics in an audio amplifier. One such way is in a multi stage amplifier is to use a low pass filter in one of the amplifier stages. In Fig. 1.4.1 for example, C4 is effectively acting in conjunction with R3 as a low pass filter, (remember that as far as AC signals are concerned, the top end of R3, connected to the positive supply (+Vcc) is the same point as ground) preventing amplification of unwanted high frequencies. Its effect is to limit HF gain as shown in Fig. 1.4.3.

Tuned RF Amplifiers

In circuits designed to amplify radio frequency (RF) signals, the load resistor is replaced by either a LC parallel resonant circuit (Fig. 1.4.4a) or some form of ceramic or crystal filter. The design of these filters, or the values of L and C are such that the load circuit resonates and effectively becomes a high resistance at the centre of the amplified frequency band. This can give a frequency response curve that that is sharply peaked over a narrow band of frequencies, called the pass band, frequencies above and below this band being rejected.

In modern designs, the use of ceramic filters and surface acoustic wave (SAW) filters allows designs with quite complex frequency response curves (Fig. 1.4.4b) that do not (as with LC circuits) require manual adjustment. They are commonly used in systems such as cell phones, and also in analogue TV receivers where both sound and vision signals at different frequencies are amplified by different amounts in the same amplifier. The amplifier response is also designed to have low gain at specific frequencies to reject signals of other transmissions on adjacent channels.

Amplifiers Module 1.5

Amplifiers Quiz 1

Amplifiers Quiz

Try our quiz, based on the information you can find in Amplifiers Module 1. You can check your answers by going to:

http://www.learnabout-electronics.org/Amplifiers/amplifiers15.php

1.

If a power amplifier produces an output 10 times greater than its input, what will its power gain be, measured in deciBels?

a) 3dB

b) 6dB

c) 10dB

d) 20dB

2.

If the base current I_b of a common emitter amplifier is 40µA and the h_{fe} of the transistor is 200, what will the collector current?

a) 240µA b) 800µA c) 25µA d) 8mA

3.

In Fig 1.5.1 what is the purpose of block B?

a) A Tuned RF amplifier

b) An FM amplifier

c) An IF amplifier

d) An AF pre-amplifier

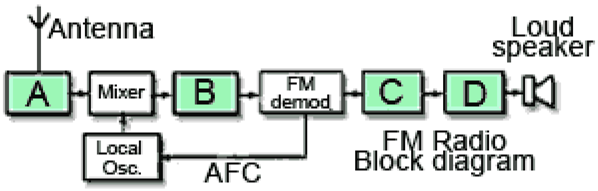


Fig. 1.5.1

4.

Which of these formulae gives the voltage gain of an amplifier ?

a) Vout/ Vin b) Vin/ Vout c) Vout/ Iin d) Vin x hfe

5.

Complete this sentence: "Class A bias...

a) ...gives high gain and low distortion."

b) ...gives low distortion and high efficiency."

c) ...gives low distortion and low efficiency."

d) ...gives low distortion and low gain."

6.

Complete this sentence: "Class A bias sets the quiescent current...

a) ...below cut off."

b) ...above cut off."

c) ...at $I_b = 0$."

d) ...at cut off."

7.

What is the voltage gain of an amplifier at the half power points on the amplifier response curve?

a) 0.5 b) 0.707 c) 1.414 d) 6.0

8.

What is the purpose of C3 in Fig 1.5.2?

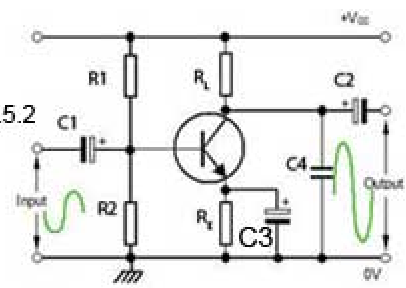
a) To prevent HF noise.

b) To prevent saturation.

c) To prevent thermal runaway.

d) To prevent negative feedback.

Fig. 1.5.2



9.

In Fig 1.5.2 which component will be mainly responsible for limiting high frequency gain?

a) Tr1 b) C2 c) C3 d) C4

10.

What is the advantage of extending the bandwidth of audio amplifiers to frequencies higher than the audible limit?

a) To reduce noise.

b) To increase efficiency.

c) To preserve wave shape.

d) To reduce transients.

