COURSE UNIT 3 AMPLIFIERS

Introduction to the Amplifier

An amplifier is an electronic device or circuit which is used to increase the magnitude of the signal applied to its input

Amplifier is the generic term used to describe a circuit which produces and increased version of its input signal. However, not all amplifier circuits are the same as they are classified according to their circuit configurations and modes of operation.

In “Electronics”, small signal amplifiers are commonly used devices as they have the ability to amplify a relatively small input signal, for example from a *Sensor* such as a photo-device, into a much larger output signal to drive a relay, lamp or loudspeaker for example.

There are many forms of electronic circuits classed as amplifiers, from Operational Amplifiers and Small Signal Amplifiers up to Large Signal and Power Amplifiers. The classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal, that is the relationship between input signal and current flowing in the load.

The type or classification of an Amplifier is given in the following table.

Classification of Signal Amplifier

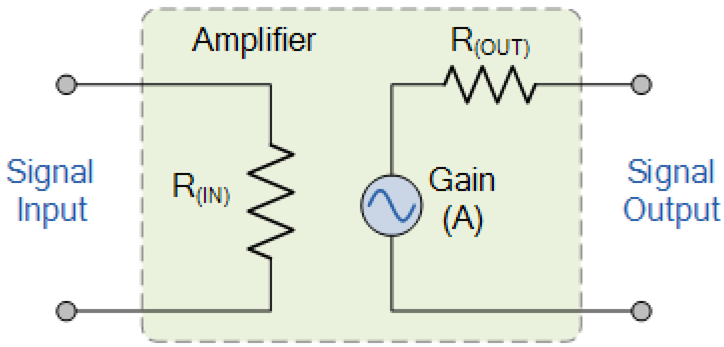
Type of	Type of	Classification	Frequency of

Signal	Configuration		Operation
Small Signal	Common Emitter	Class A Amplifier	Direct Current (DC)
Large Signal	Common Base	Class B Amplifier	Audio Frequencies (AF)
	Common Collector	Class AB Amplifier	Radio Frequencies (RF)
		Class C Amplifier	VHF, UHF and SHF Frequencies

Amplifiers can be thought of as a simple box or block containing the amplifying device, such as a Bipolar Transistor, Field Effect Transistor or Operational Amplifier, which has two input terminals and two output terminals (ground being common) with the output signal being much greater than that of the input signal as it has been "Amplified".

An ideal signal amplifier will have three main properties: Input Resistance or (R_{IN}), Output Resistance or (R_{OUT}) and of course amplification known commonly as Gain or (A). No matter how complicated an amplifier circuit is, a general amplifier model can still be used to show the relationship of these three properties.

Ideal Amplifier Model



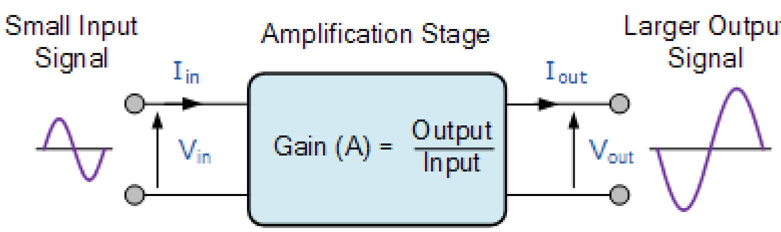
The amplified difference between the input and output signals is known as the Gain of the amplifier. Gain is basically a measure of how much an amplifier "amplifies" the input signal. For example, if we have an input signal of 1 volt and an output of 50 volts, then the gain of the amplifier would be "50". In other words, the input signal has been increased by a factor of 50. This increase is called **Gain**.

Amplifier gain is simply the ratio of the output divided-by the input. Gain has no units as its a ratio, but in Electronics it is commonly given the symbol "A", for Amplification. Then the gain of an amplifier is simply calculated as the "output signal divided by the input signal".

Amplifier Gain

The introduction to the amplifier gain can be said to be the relationship that exists between the signal measured at the output with the signal measured at the input. There are three different kinds of amplifier gain which can be measured and these are: *Voltage Gain* (Av), *Current Gain* (Ai) and *Power Gain* (Ap) depending upon the quantity being measured with examples of these different types of gains are given below.

Amplifier Gain of the Input Signal



Voltage Amplifier Gain

$$Voltage\,Gain\,(A_v) = \frac{Output\ Voltage}{Input\ Voltage} = \frac{Vout}{Vin}$$

Current Amplifier Gain

$$Current\,Gain\,(A_i) = \frac{Output\ Current}{Input\ Current} = \frac{Iout}{Iin}$$

Power Amplifier Gain

$$Power\,Gain\,(A_p) = A_v \ x \ A_i$$

Note that for the Power Gain you can also divide the power obtained at the output with the power obtained at the input. Also when calculating the gain of an amplifier, the subscripts v, i and p are used to denote the type of signal gain being used.

The power gain (Ap) or power level of the amplifier can also be expressed in **Decibels**, (**dB**). The Bel (B) is a logarithmic unit (base 10) of measurement that has no units. Since the Bel is too large a unit of measure, it is prefixed with *deci* making it **Decibels** instead with one decibel being one tenth (1/10th) of a Bel. To calculate the gain of the amplifier in Decibels or dB, we can use the following expressions.

- Voltage Gain in dB: a_v = 20*log(Av)
- Current Gain in dB: a_i = 20*log(Ai)
- Power Gain in dB: a_p = 10*log(Ap)

Note that the DC power gain of an amplifier is equal to ten times the common log of the output to input ratio, where as voltage and current gains are 20 times the common log of the ratio. Note however, that 20dB is not twice as much power as 10dB because of the log scale.

Also, a positive value of dB represents a **Gain** and a negative value of dB represents a **Loss** within the amplifier. For example, an amplifier gain of +3dB indicates that the amplifiers output signal has "doubled", (x2) while an amplifier gain of -3dB indicates that the signal has "halved", (x0.5) or in other words a loss.

The -3dB point of an amplifier is called the **half-power point** which is -3dB down from maximum, taking 0dB as the maximum output value.

Amplifier Example No1

Determine the Voltage, Current and Power Gain of an amplifier that has an input signal of 1mA at 10mV and a corresponding output signal of 10mA at 1V. Also, express all three gains in decibels, (dB).

The Various Amplifier Gains:

$$A_V = \frac{\text{Output Voltage}}{\text{Input Voltage}} = \frac{1}{0.01} = 100$$

$$A_i = \frac{\text{Output Current}}{\text{Input Current}} = \frac{10}{1} = 10$$

$$A_p = A_V \times A_i = 100 \times 10 = 1{,}000$$

Amplifier Gains given in Decibels (dB):

$$a_v = 20\log A_v = 20\log 100 = 40\,\text{dB}$$

$$a_i = 20\log A_i = 20\log 10 = 20\,\text{dB}$$

$$a_p = 10\log A_p = 10\log 1000 = 30\,\text{dB}$$

Then the amplifier has a Voltage Gain, (Av) of 100, a Current Gain, (Ai) of 10 and a Power Gain, (Ap) of 1,000

Generally, amplifiers can be sub-divided into two distinct types depending upon their power or voltage gain. One type is called the **Small Signal Amplifier** which include pre-amplifiers, instrumentation amplifiers etc. Small signal amplifies are designed to amplify very small signal voltage levels of only a few micro-volts (μV) from sensors or audio signals.

The other type are called **Large Signal Amplifiers** such as audio power amplifiers or power switching amplifiers. Large signal amplifiers are designed to amplify large input voltage signals or switch heavy load currents as you would find driving loudspeakers.

Power Amplifiers

The **Small Signal Amplifier** is generally referred to as a "Voltage" amplifier because they usually convert a small input voltage into a much larger output voltage. Sometimes an amplifier circuit is required to drive a motor or feed a loudspeaker and for these types of applications where high switching currents are needed **Power Amplifiers** are required.

As their name suggests, the main job of a "Power Amplifier" (also known as a large signal amplifier), is to deliver power to the load, and as we know from above, is the product of the voltage and current applied to the load with the output signal power being greater than the input signal power. In other words, a power amplifier amplifies the power of the input signal which is why these types of amplifier circuits are used in audio amplifier output stages to drive loudspeakers.

The power amplifier works on the basic principle of converting the DC power drawn from the power supply into an AC voltage signal delivered to the load. Although the amplification is high the efficiency of the conversion from the DC power supply input to the AC voltage signal output is usually poor.

The perfect or ideal amplifier would give us an efficiency rating of 100% or at least the power "IN" would be equal to the power "OUT". However, in reality this can never happen as some of the power is lost in the form of heat and also, the amplifier itself consumes power during the amplification process. Then the efficiency of an amplifier is given as:

Amplifier Efficiency

$$Efficiency\ (\eta) = \frac{Power\ delivered\ to\ the\ Load}{Power\ taken\ from\ the\ Supply} = \frac{P_{OUT}}{P_{IN}}$$

Ideal Amplifier

We can know specify the characteristics for an ideal amplifier from our discussion above with regards to its **Gain**, meaning voltage gain:

- The amplifiers gain, (A) should remain constant for varying values of input signal.
- Gain is not be affected by frequency. Signals of all frequencies must be amplified by exactly the same amount.
- The amplifiers gain must not add noise to the output signal. It should remove any noise that is already exists in the input signal.
- The amplifiers gain should not be affected by changes in temperature giving good temperature stability.

- The gain of the amplifier must remain stable over long periods of time.

Electronic Amplifier Classes

The classification of an amplifier as either a voltage or a power amplifier is made by comparing the characteristics of the input and output signals by measuring the amount of time in relation to the input signal that the current flows in the output circuit.

Amplifiers are classified into classes according to their construction and operating characteristics. Not all amplifiers are the same and there is a clear distinction made between the way their output stages are configured and operate. The main operating characteristics of an ideal amplifier are linearity, signal gain, efficiency and power output but in real world amplifiers there is always a trade off between these different characteristics.

Generally, large signal or power amplifiers are used in the output stages of audio amplifier systems to drive a loudspeaker load. A typical loudspeaker has an impedance of between 4Ω and 8Ω, thus a power amplifier must be able to supply the high peak currents required to drive the low impedance speaker.

One method used to distinguish the electrical characteristics of different types of amplifiers is by “class”, and as such amplifiers are classified according to their circuit configuration and method of operation. Then **Amplifier Classes** is the term used to differentiate between the different amplifier types.

Amplifier Classes represent the amount of the output signal which varies within the amplifier circuit over one cycle of operation when excited by a sinusoidal input signal. The classification of amplifiers range from entirely linear operation (for use in high-fidelity signal amplification) with very low efficiency, to entirely non-linear (where a faithful signal reproduction is not so important) operation but with a much higher efficiency, while others are a compromise between the two.

Amplifier classes are mainly lumped into two basic groups. The first are the classically controlled conduction angle amplifiers forming the more common amplifier classes of A, B, AB and C, which are defined by the length of their conduction state over some portion of the output waveform, such that the output stage transistor operation lies somewhere between being "fully-ON" and "fully-OFF".

The second set of amplifiers are the newer so-called "switching" amplifier classes of D, E, F, G, S, T etc, which use digital circuits and pulse width modulation (PWM) to constantly switch the signal between "fully-ON" and "fully-OFF" driving the output hard into the transistors saturation and cut-off regions.

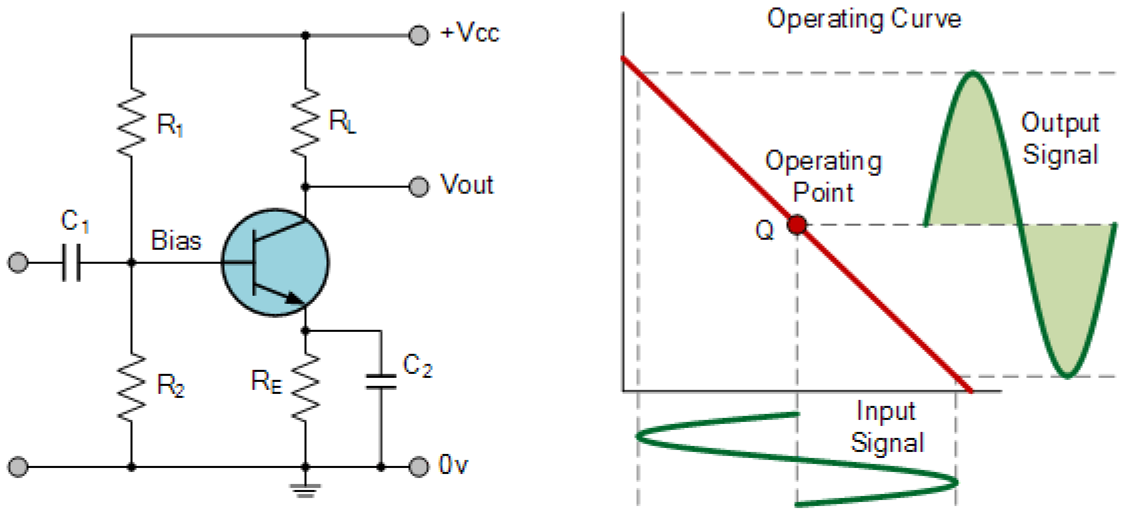
The most commonly constructed amplifier classes are those that are used as audio amplifiers, mainly class A, B, AB and C and to keep things simple, it is these types of **amplifier classes** we will look at here in more detail.

Class A Amplifier

Class A Amplifiers are the most common type of amplifier topology as they use just one output switching transistor (Bipolar, FET, IGBT, etc) within their amplifier design. This single output transistor is biased around the Q-point within the middle of its load line and so is never driven into its cut-off or saturation regions thus allowing it to conduct current over the full 360 degrees of the input cycle. Then the output transistor of a class-A topology never turns "OFF" which is one of its main disadvantages.

Class "A" amplifiers are considered the best class of amplifier design due mainly to their excellent linearity, high gain and low signal distortion levels when designed correctly. Although seldom used in high power amplifier applications due to thermal power supply considerations, class-A amplifiers are probably the best sounding of all the amplifier classes mentioned here and as such are used in high-fidelity audio amplifier designs.

Class A Amplifier



To achieve high linearity and gain, the output stage of a class A amplifier is biased "ON" (conducting) all the time. Then for an amplifier to be classified as "Class A" the zero signal idle current in the output stage must be equal to or greater than the maximum load current (usually a loudspeaker) required to produce the largest output signal.

As a class A amplifier operates in the linear portion of its characteristic curves, the single output device conducts through a full 360 degrees of the output waveform. Then the class A amplifier is equivalent to a current source.

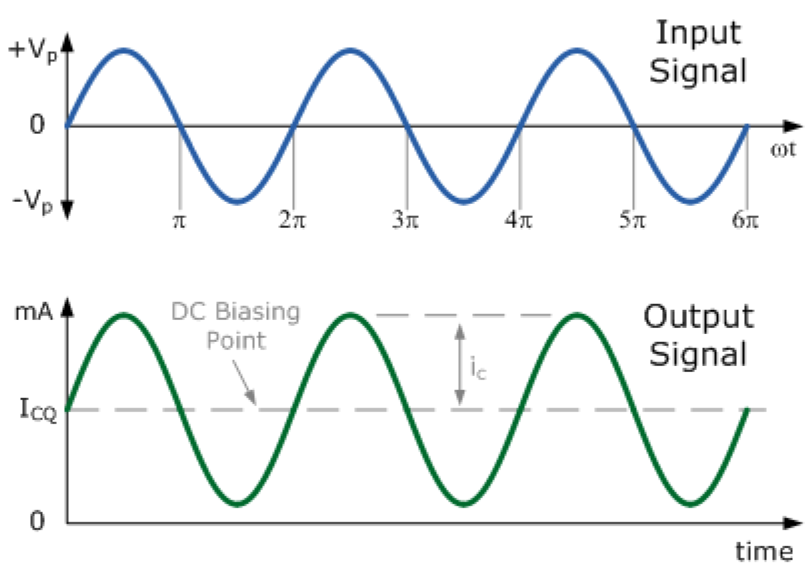
Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion. However, as the output device is "ON" at all times, it is constantly carrying current, which represents a continuous loss of power in the amplifier.

Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

Class A Amplifier operation

Class A Amplifier operation is where the entire input signal waveform is faithfully reproduced at the amplifiers output terminal as the transistor is perfectly biased within its active region. This means that the switching transistor is never driven into its cut-off or saturation regions. The result is that the AC input signal is perfectly "centred" between the amplifiers upper and lower signal limits as shown below.

Class A Amplifier Output Waveform



A Class-A amplifier configuration uses the same switching transistor for both halves of the output waveform and due to its central biasing arrangement, the output transistor always has a constant DC biasing current, (I_{CQ}) flowing through it, even if there is no input signal present. In other words the output transistors never turns "OFF" and is in a permenant state of idle.

This results in the Class-A type of operation being somewhat inefficient as its conversion of the DC supply power to the AC signal power delivered to the load is usually very low.

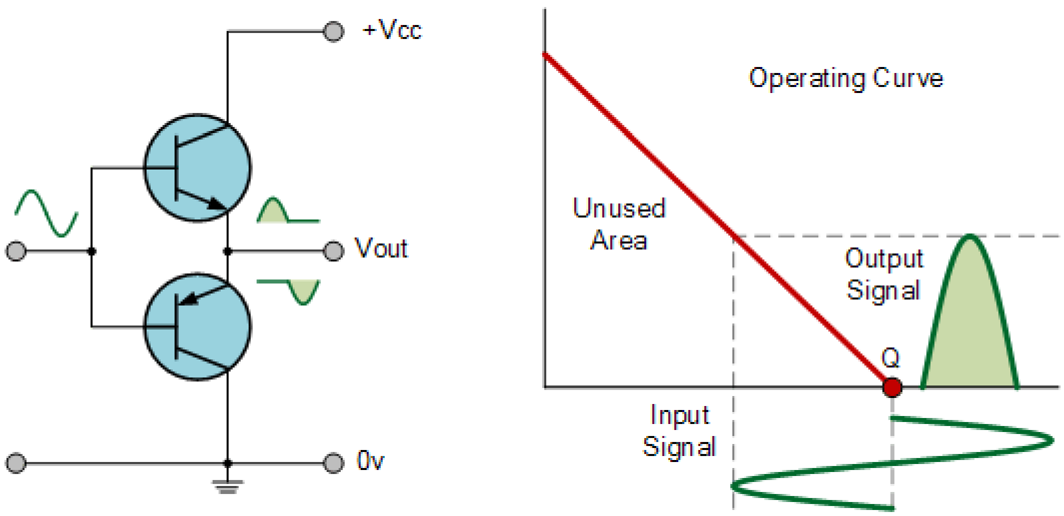
Due to this centered biasing point, the output transistor of a Class-A amplifier can get very hot, even when there is no input signal present, so some form of heat sinking is required. The DC biasing current flowing through the collector of the transistor (I_{CQ}) is equal to the current flowing through the collector load. Thus a Class-A amplifier is very inefficient as most of this DC power is converted to heat.

Class B Amplifier

Class B amplifiers were invented as a solution to the efficiency and heating problems associated with the previous class A amplifier. The basic class B amplifier uses two complimentary transistors either bipolar of FET for each half of the waveform with its output stage configured in a “push-pull” type arrangement, so that each transistor device amplifies only half of the output waveform.

In the class B amplifier, there is no DC base bias current as its quiescent current is zero, so that the dc power is small and therefore its efficiency is much higher than that of the class A amplifier. However, the price paid for the improvement in the efficiency is in the linearity of the switching device.

Class B Amplifier



When the input signal goes positive, the positive biased transistor conducts while the negative transistor is switched “OFF”. Likewise, when the input signal goes negative, the positive transistor switches “OFF” while the negative biased transistor turns “ON” and conducts the negative portion of the signal. Thus the transistor conducts only half of the time, either on positive or negative half cycle of the input signal.

Then we can see that each transistor device of the class B amplifier only conducts through one half or 180 degrees of the output waveform in strict time alternation, but as the output stage has devices for both halves of the signal waveform the two halves are combined together to produce the full linear output waveform.

This push-pull design of amplifier is obviously more efficient than Class A, at about 50%, but the problem with the class B amplifier design is that it can create distortion at the zero-crossing point of the waveform due to the transistors dead band of input base voltages from -0.7V to +0.7.

We remember from the **Transistor** tutorial that it takes a base-emitter voltage of about 0.7 volts to get a bipolar transistor to start conducting. Then in a class B amplifier, the output transistor is not “biased” to an “ON” state of operation until this voltage is exceeded.

This means that the the part of the waveform which falls within this 0.7 volt window will not be reproduced accurately making the class B amplifier unsuitable for precision audio amplifier applications.

To overcome this zero-crossing distortion (also known as Crossover Distortion) class AB amplifiers were developed.

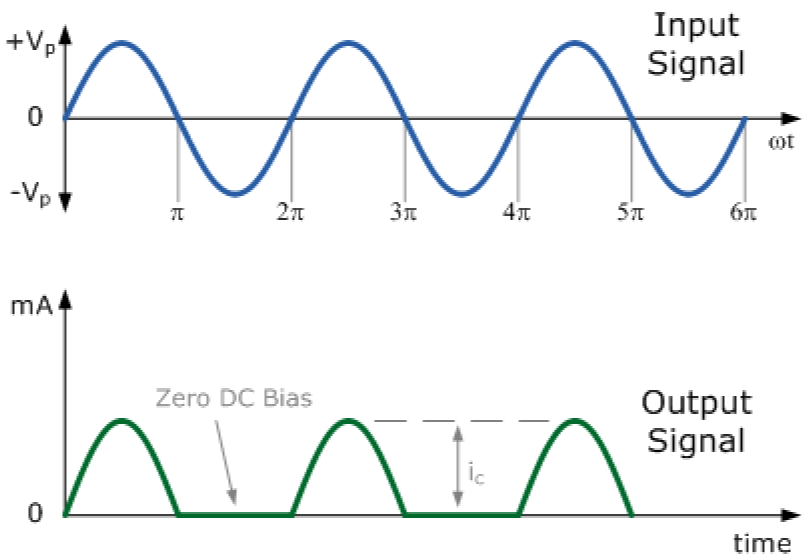
Class B Amplifier Operation

Unlike the Class-A amplifier mode of operation above that uses a single transistor for its output power stage, the **Class-B Amplifier** uses two complimentary transistors (either an NPN and a PNP or a NMOS and a PMOS) to amplify each half of the output waveform.

One transistor conducts for only one-half of the signal waveform while the other conducts for the other or opposite half of the signal waveform. This means that each transistor spends half of its time in the active region and half its time in the cut-off region thereby amplifying only 50% of the input signal.

Class-B operation has no direct DC bias voltage unlike the class-A amplifier, but instead the transistor only conducts when the input signal is greater than the base-emitter voltage (V_{BE}) and for silicon transistors, this is about 0.7v. Therefore with zero input signal there is zero output. As only half the input signal is presented at the amplifiers output this improves the amplifier efficiency over the previous Class-A configuration as shown below.

Class B Amplifier Output Waveform



In a Class-B amplifier, no DC voltage is used to bias the transistors, so for the output transistors to start to conduct each half of the waveform, both positive and negative, they need the base-emitter voltage V_{BE} to be greater than the 0.7v forward voltage drop required for a standard bipolar transistor to start conducting.

Thus the lower part of the output waveform which is below this 0.7v window will not be reproduced accurately. This results in a distorted area of the output waveform as one transistor turns "OFF" waiting for the other to turn back "ON" once $V_{BE} > 0.7V$. The result is that there is a small part of the output waveform at the zero voltage cross over point which will be distorted. This type of distortion is called **Crossover Distortion** and is looked at later on in this section.

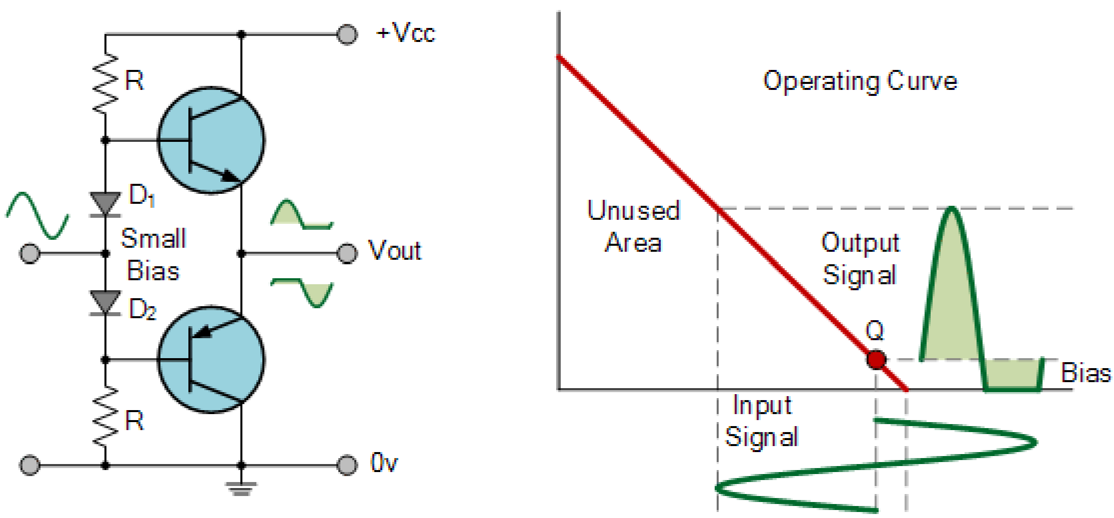
Class AB Amplifier

As its name suggests, the **Class AB Amplifier** is a combination of the "Class A" and the "Class B" type amplifiers we have looked at above. The AB classification of amplifier is currently one of the most common used types of audio power amplifier design. The class AB amplifier is a variation of a class B amplifier as described above, except that both devices are allowed to conduct at the same time around the waveforms crossover point eliminating the crossover distortion problems of the previous class B amplifier.

The two transistors have a very small bias voltage, typically at 5 to 10% of the quiescent current to bias the transistors just above its cut-off point. Then the conducting device, either bipolar of FET, will be "ON" for more than one half cycle, but much less than one full cycle of the input signal. Therefore, in a class AB amplifier design each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

In other words, the conduction angle of a class AB amplifier is somewhere between 180^o and 360^o depending upon the chosen bias point as shown.

Class AB Amplifier



The advantage of this small bias voltage, provided by series diodes or resistors, is that the crossover distortion created by the class B amplifier characteristics is overcome, without the inefficiencies of the class A amplifier design. So the class AB amplifier is a good compromise between class A and class B in terms of efficiency and linearity, with conversion efficiencies reaching about 50% to 60%.

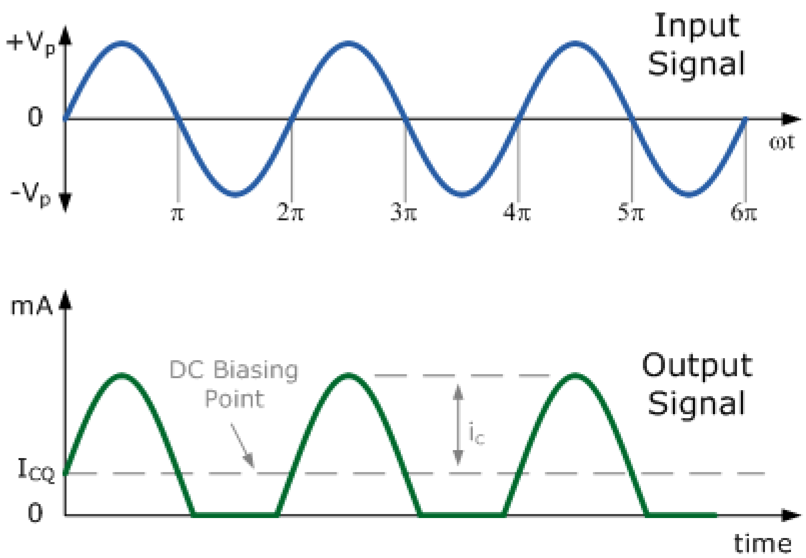
Class AB Amplifier Operation

The **Class-AB Amplifier** is a compromise between the Class-A and the Class-B configurations above. While Class-AB operation still uses two complementary transistors in its output stage a very small biasing voltage is applied to the Base of each transistor to bias them close to their cut-off region when no input signal is present.

An input signal will cause the transistor to operate as normal within its active region, eliminating any crossover distortion which is always present in the class-B configuration. A small biasing Collector current (I_{CQ}) will flow through the transistor when there is no input signal present, but generally it is much less than that for the Class-A amplifier configuration.

Thus each transistor is conducting, “ON” for a little more than half a cycle of the input waveform. The small biasing of the Class-AB amplifier configuration improves both the efficiency and linearity of the amplifier circuit compared to a pure Class-A configuration above.

Class AB Amplifier Output Waveform



When designing amplifier circuits, the class of operation of an amplifier is very important as it determines the amount of transistor biasing required for its operation as well as the maximum amplitude of the input signal.

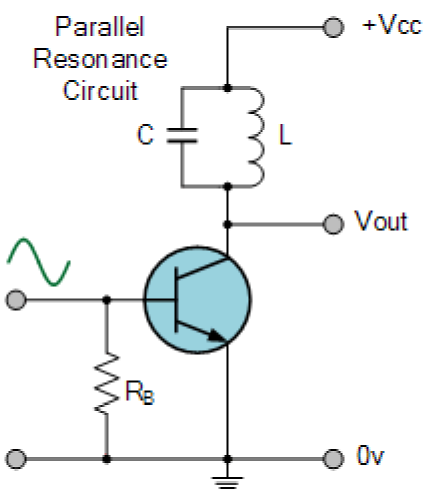
Class C Amplifier

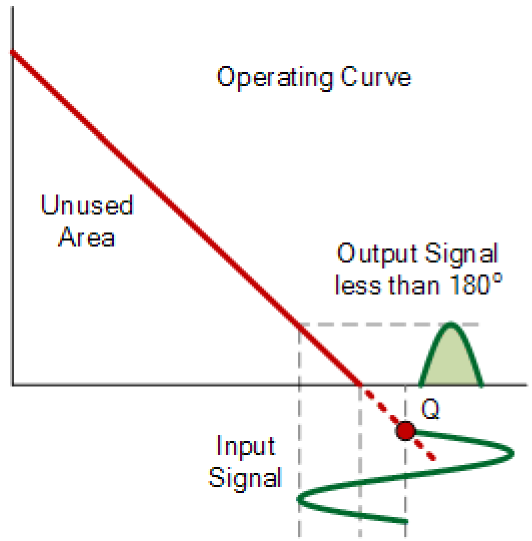
The **Class C Amplifier** design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned here. The previous classes, A, B and AB are considered linear amplifiers, as the output signals amplitude and phase are linearly related to the input signals amplitude and phase.

However, the class C amplifier is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cut-off point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.

While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers.

Class C Amplifier





Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

Amplifier Classes Summary

Amplifier classification takes into account the portion of the input signal in which the output transistor conducts as well as determining both the efficiency and the amount of power that the switching transistor both consumes and dissipates in the form of wasted heat. Here we can make a comparison between the most common types of amplifier classifications in the following table.

Power Amplifier Classes

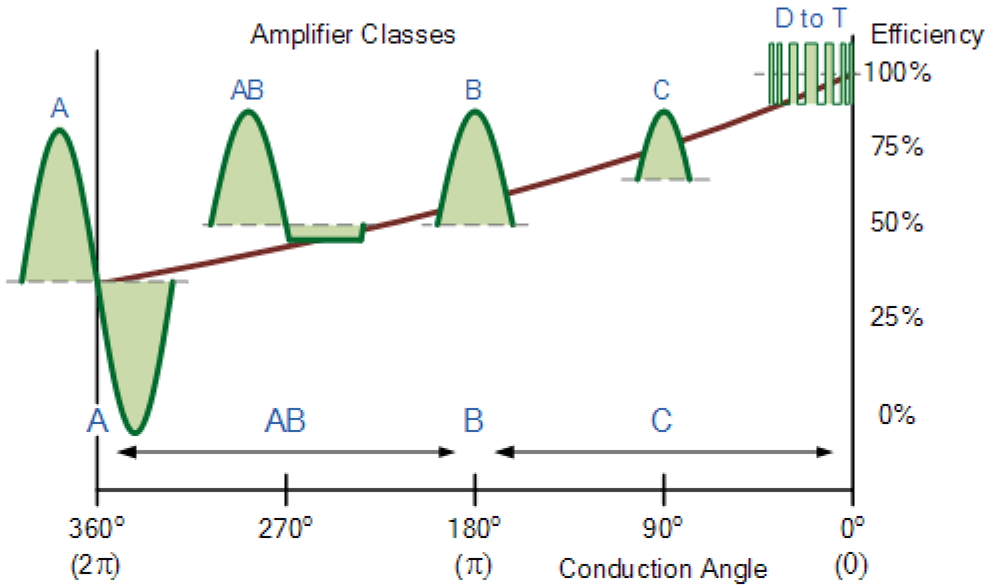
Class	A	B	C	AB

Conduction Angle	360^o	180^o	Less than 90^o	180 to 360^o
Position of the Q-point	Centre Point of the Load Line	Exactly on the X-axis	Below the X-axis	In between the X-axis and the Centre Load Line
Overall Efficiency	Poor 25 to 30%	Better 70 to 80%	Higher than 80%	Better than A but less than B 50 to 70%
Signal Distortion	None if Correctly Biased	At the X-axis Crossover Point	Large Amounts	Small Amounts

Badly designed amplifiers especially the Class "A" types may also require larger power transistors, more expensive heat sinks, cooling fans, or even an increase in the size of the power supply required to deliver the extra wasted power required by the amplifier. Power converted into heat from transistors, resistors or any other component for that matter, makes any electronic circuit inefficient and will result in the premature failure of the device.

So why use a Class A amplifier if its efficiency is less than 40% compared to a Class B amplifier that has a higher efficiency rating of over 70%. Basically, a Class A amplifier gives a much more linear output meaning that it has, **Linearity** over a larger frequency response even if it does consume large amounts of DC power.

Amplifier Classes and Efficiency



As well as audio amplifiers there are a number of high efficiency **Amplifier Classes** relating to switching amplifier designs that use different switching techniques to reduce power loss and increase efficiency. Some amplifier class designs listed below use RLC resonators or multiple power-supply voltages to reduce power loss, or are digital DSP (digital signal processing) type amplifiers which use pulse width modulation (PWM) switching techniques.

Other Common Amplifier Classes

- Class D Amplifier – A Class D audio amplifier is basically a non-linear switching amplifier or PWM amplifier. Class-D amplifiers theoretically can reach 100% efficiency, as there is no period during a cycle were the voltage and current waveforms overlap as current is drawn only through the transistor that is on.
- Class F Amplifier – Class-F amplifiers boost both efficiency and output by using harmonic resonators in the output network to shape the output waveform into a square wave. Class-F amplifiers are capable of high efficiencies of more than 90% if infinite harmonic tuning is used.

- Class G Amplifier – Class G offers enhancements to the basic class AB amplifier design. Class G uses multiple power supply rails of various voltages and automatically switches between these supply rails as the input signal changes. This constant switching reduces the average power consumption, and therefore power loss caused by wasted heat.
- Class I Amplifier – The class I amplifier has two sets of complementary output switching devices arranged in a parallel push-pull configuration with both sets of switching devices sampling the same input waveform. One device switches the positive half of the waveform, while the other switches the negative half similar to a class B amplifier. With no input signal applied, or when a signal reaches the zero crossing point, the switching devices are both turned ON and OFF simultaneously with a 50% PWM duty cycle cancelling out any high frequency signals.

  To produce the positive half of the output signal, the output of the positive switching device is increased in duty cycle while the negative switching device is decreased by the same and vice versa. The two switching signal currents are said to be interleaved at the output, giving the class I amplifier the named of: "interleaved PWM amplifier" operating at switching frequencies in excess of 250kHz.
- Class S Amplifier – A class S power amplifier is a non-linear switching mode amplifier similar in operation to the class D amplifier. The class S amplifier converts analogue input signals into digital square wave pulses by a delta-sigma modulator, and amplifies them to increases the output power before finally being demodulated by a band pass filter. As the digital signal of this switching amplifier is always either fully "ON" or "OFF" (theoretically zero power dissipation), efficiencies reaching 100% are possible.
- Class T Amplifier – The class T amplifier is another type of digital switching amplifier design. Class T amplifiers are starting to become more popular these days as an audio amplifier design due to the existence of digital signal processing (DSP) chips and multi-channel surround sound amplifiers as it converts analogue signals into digital pulse width modulated (PWM) signals for

amplification increasing the amplifiers efficiency. Class T amplifier designs combine both the low distortion signal levels of class AB amplifier and the power efficiency of a class D amplifier.

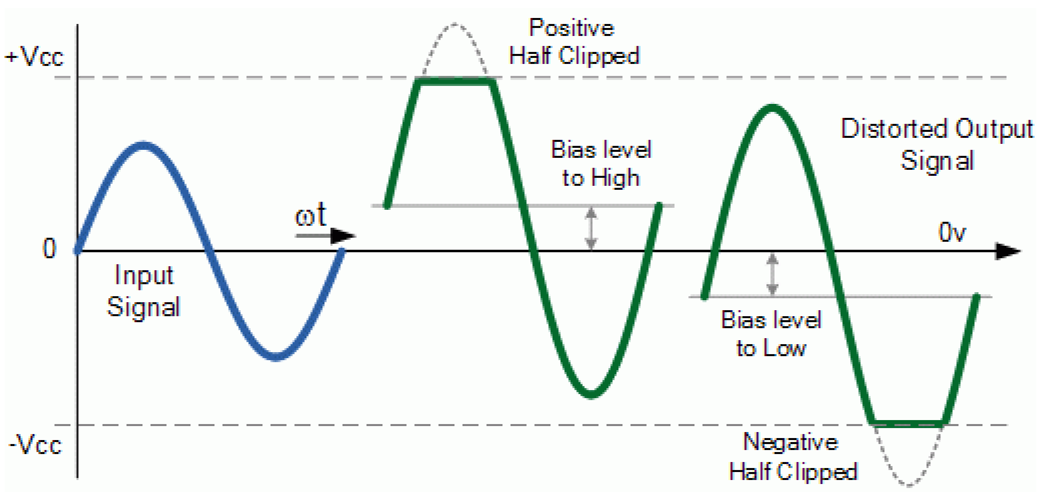
We have seen here a number of classification of amplifiers ranging from linear power amplifiers to non-linear switching amplifiers, and have seen how an amplifier class differs along the amplifiers load line. The class AB, B and C amplifiers can be defined in terms of the conduction angle, θ as follows:

Amplifier Class by Conduction Angle

Amplifier Class	Description	Conduction Angle
Class-A	Full cycle 360^o of Conduction	$\theta = 2\pi$
Class-B	Half cycle 180^o of Conduction	$\theta = \pi$
Class-AB	Slightly more than 180^o of conduction	$\pi < \theta < 2\pi$
Class-C	Slightly less than 180^o of conduction	$\theta < \pi$
Class-D to T	ON-OFF non-linear switching	$\theta = 0$

Amplifier Distortion

Amplifier Distortion can take on many forms such as Amplitude, Frequency and Phase Distortion due to Clipping



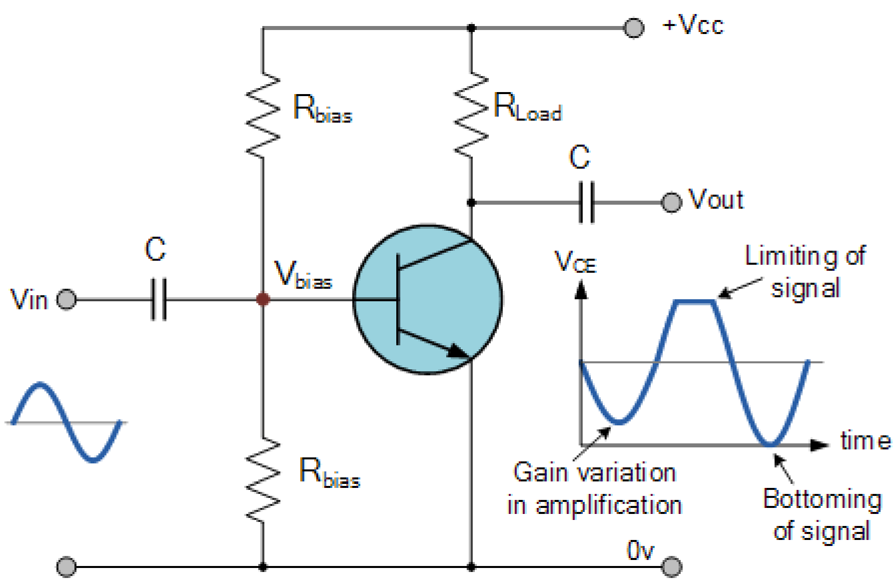
For a signal amplifier to operate correctly without any distortion to the output signal, it requires some form of DC Bias on its Base or Gate terminal. A DC bias is required so that the amplifier can amplify the input signal over its entire cycle with the bias “Q-point” set as near to the middle of the load line as possible.

The bias Q-point setting will give us a “Class-A” type amplification configuration with the most common arrangement being the “Common Emitter” for Bipolar transistors or the “Common Source” configuration for unipolar FET transistors.

The Power, Voltage or Current Gain, (amplification) provided by the amplifier is the ratio of the peak output value to its peak input value (Output ÷ Input).

However, if we incorrectly design our amplifier circuit and set the biasing Q-point at the wrong position on the load line or apply too large an input signal to the amplifier, the resultant output signal may not be an exact reproduction of the original input signal waveform. In other words the amplifier will suffer from what is commonly called **Amplifier Distortion**. Consider the common emitter amplifier circuit below.

Common Emitter Amplifier



Distortion of the output signal waveform may occur because:

- Amplification may not be taking place over the whole signal cycle due to incorrect biasing levels.
- The input signal may be too large, causing the amplifiers transistors to be limited by the supply voltage.
- The amplification may not be a linear signal over the entire frequency range of inputs.

This means then that during the amplification process of the signal waveform, some form of **Amplifier Distortion** has occurred.

Amplifiers are basically designed to amplify small voltage input signals into much larger output signals and this means that the output signal is constantly changing by some factor or value, called gain, multiplied by the input signal for all input frequencies. We saw previously that this multiplication factor is called the Beta, β value of the transistor.

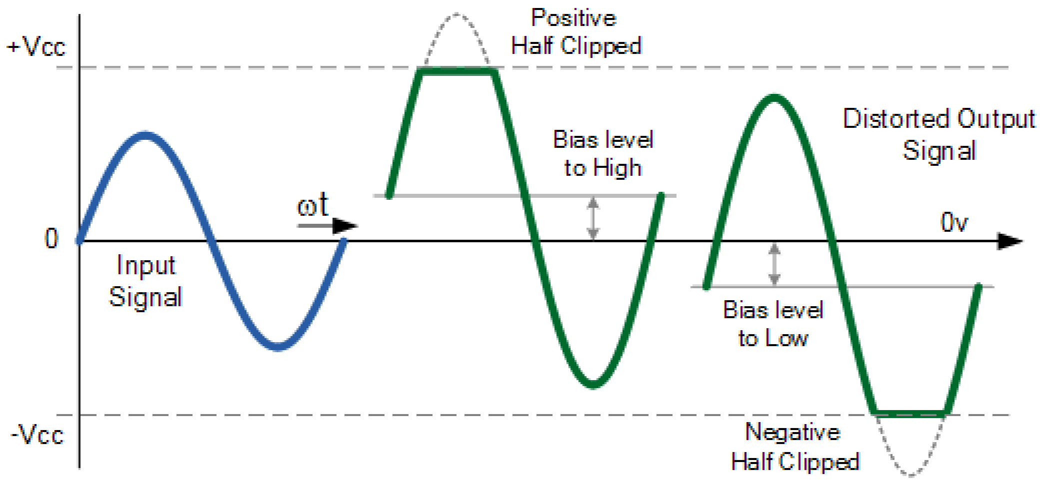
Common emitter or even common source type transistor circuits work fine for small AC input signals but suffer from one major disadvantage, the calculated position of the bias Q-point of a bipolar amplifier depends on the same Beta value for all transistors. However, this Beta value will vary from transistors of the same type, in other words, the Q-point for one transistor is not necessarily the same as the Q-point for another transistor of the same type due to the inherent manufacturing tolerances.

Then amplifier distortion occurs because the amplifier is not linear and a type of amplifier distortion called **Amplitude Distortion** will result. Careful choice of the transistor and biasing components can help minimise the effect of amplifier distortion.

Amplitude Distortion

Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

Amplitude Distortion due to Incorrect Biasing



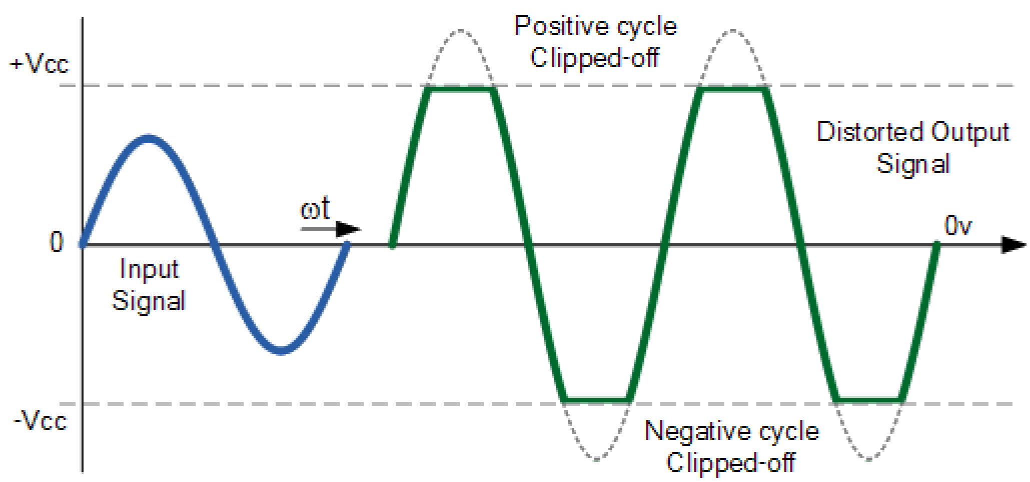
If the transistors biasing point is correct, the output waveform should have the same shape as that of the input waveform only bigger, (amplified). If there is insufficient bias and the Q-point lies in the lower half of the load line, then the output waveform will look like the one on the right with the negative half of the output waveform "cut-off" or clipped. Likewise, if there is too much bias and the Q-point lies in the upper half of the load line, then the output waveform will look like the one on the left with the positive half "cut-off" or clipped.

Also, when the bias voltage is set too small, during the negative half of the cycle the transistor does not fully conduct so the output is set by the supply voltage. When the bias is too great the positive half of the cycle saturates the transistor and the output drops almost to zero.

Even with the correct biasing voltage level set, it is still possible for the output waveform to become distorted due to a large input signal being amplified by the circuits gain. The output voltage signal becomes clipped in both the positive and negative parts of the waveform an no longer resembles a sine wave, even when the bias is correct. This type of amplitude distortion is called **Clipping** and is the result of "over-driving" the input of the amplifier.

When the input amplitude becomes too large, the clipping becomes substantial and forces the output waveform signal to exceed the power supply voltage rails with the peak (+ve half) and the trough (-ve half) parts of the waveform signal becoming flattened or "Clipped-off". To avoid this the maximum value of the input signal must be limited to a level that will prevent this clipping effect as shown above.

Amplitude Distortion due to Clipping



Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These "flat tops" of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency.

Having said all that, some well known guitarist and rock bands actually prefer that their distinctive sound is highly distorted or "overdriven" by heavily clipping the output waveform to both the +ve and -ve power supply rails. Also, increasing the amounts of clipping on a sinusoid will produce so much amplifier distortion that it will eventually produce an output waveform which resembles that of a “square wave” shape which can then be used in electronic or digital synthesizer circuits.

We have seen that with a DC signal the level of gain of the amplifier can vary with signal amplitude, but as well as Amplitude Distortion, other types of amplifier distortion can occur with AC signals in amplifier circuits, such as **Frequency Distortion** and **Phase Distortion**.

Frequency Distortion

Frequency Distortion is another type of amplifier distortion which occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the “Fundamental Frequency” plus a number of different frequencies called “Harmonics” superimposed onto it.

Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:

Phase Distortion

Phase Distortion or **Delay Distortion** is a type of amplifier distortion which occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output.

If we say that the phase change between the input and the output is zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier.

Other than high end audio amplifiers, most practical amplifiers will have some form of **Amplifier Distortion** being a combination of both "Frequency Distortion" and "Phase Distortion", together with amplitude distortion. In most applications such as in audio amplifiers or power amplifiers, unless the amplifiers distortion is excessive or severe it will not generally affect the operation or output sound of the amplifier.