

Then we can see from the above example that by decreasing the value of either the capacitance, C or the inductance, L will have the effect of increasing the frequency of oscillation of the LC tank circuit.

LC Oscillators Summary:

The basic conditions required for an **LC oscillator** resonant tank circuit are given as follows.

- For oscillations to exist an oscillator circuit **MUST** contain a reactive (frequency-dependant) component either an “Inductor”, (L) or a “Capacitor”, (C) as well as a DC power source.
- In a simple inductor-capacitor, LC circuit, oscillations become damped over time due to component and circuit losses.
- Voltage amplification is required to overcome these circuit losses and provide positive gain.
- The overall gain of the amplifier must be greater than one, unity.
- Oscillations can be maintained by feeding back some of the output voltage to the tuned circuit that is of the correct amplitude and in-phase, (0°).
- Oscillations can only occur when the feedback is “Positive” (self-regeneration).
- The overall phase shift of the circuit must be zero or 360° so that the output signal from the feedback network will be “in-phase” with the input signal.

UNIT-V

Power Amplifiers:

Classification of amplifiers, Class A power Amplifiers and their analysis, Harmonic Distortions, Class B Push-pull amplifiers and their analysis, Complementary symmetry push pull amplifier,

Class AB power amplifier, Class-C power amplifier, Thermal stability and Heat sinks, Distortion in amplifiers.

Introduction:

When the output to be delivered is large, much greater than mW range and is of the order of few watts or more watts, conventional transistor (BJT) amplifiers cannot be used. Such electronic amplifier circuits, delivering significant output power to the load (in watts range) are termed as *Power Amplifiers*. Since the input to this type of amplifier circuits is also *large*, they are termed as *Large Signal Amplifiers*.

In order to improve the circuit efficiency, which is the ratio of output power delivered to the load P_o to input power, the device is operated in varying conduction angles of 360° , 180° less than 180° etc. Based on the variation of conduction angle, the amplifier circuits are classified as Class A, Class B, Class C, Class AB, Class D, and Class S.

Power Amplifier:

Large input signals are used to obtain appreciable power output from amplifiers. But if the input signal is large in magnitude, the operating point is driven over a considerable portion of the output characteristic of the transistor (BJT).

The transfer characteristic of a transistor which is a plot between the output current I_e and input voltage V_{BE} is not linear. The transfer characteristic indicates the change in i_c when V_b or I_B is changed. For equal increments of V_{BE} , increase in I_e will not be uniform since output characteristics are not linear (for equal increments of V_{BE} , I_e will not increase by the same current). So the transfer characteristic is not linear. Hence because of this, when the magnitude of the input signal is very large, distortion is introduced in the output in large signal power amplifiers. To eliminate distortion in the output, push pull connection and negative feedback are employed.

Class A Operation:

If the *Q point* is placed near the centre of the linear region of the dynamic curve, class A operation results. Because the transistor will conduct for the complete 360° , distortion is low for small signals and conversion efficiency is low.

Class B Operation:

Class B operation the Q point is set near cutoff. So output power will be more and conversion efficiency (η) is more. Conduction is only for 180° , from $t - \pi$ to t . Since the transistor Q point is beyond cutoff, the output is zero or the transistor will not conduct.

Output power is more because the complete linear region is available for an operating signal excursion, resulting from one half of the input wave. The other half of input wave gives no output, because it drives the transistor below cutoff.

Class C Operation:

Here Q point is set well beyond cutoff and the device conducts for less than 180°. The conversion efficiency (η) can theoretically reach 100%. Distortion is very high. These are used in radio frequency circuits where resonant circuit may be used to filter the output waveform.

Class A and class B amplifiers are used in the audio frequency range. Class B and class C are used in Radio Frequency range where conversion efficiency is important.

Large Signal Amplifiers:

With respect to the input signal, the amplifier circuits are classified as

- (i) Small signal amplifiers
- (ii)** (ii) Large signal amplifiers

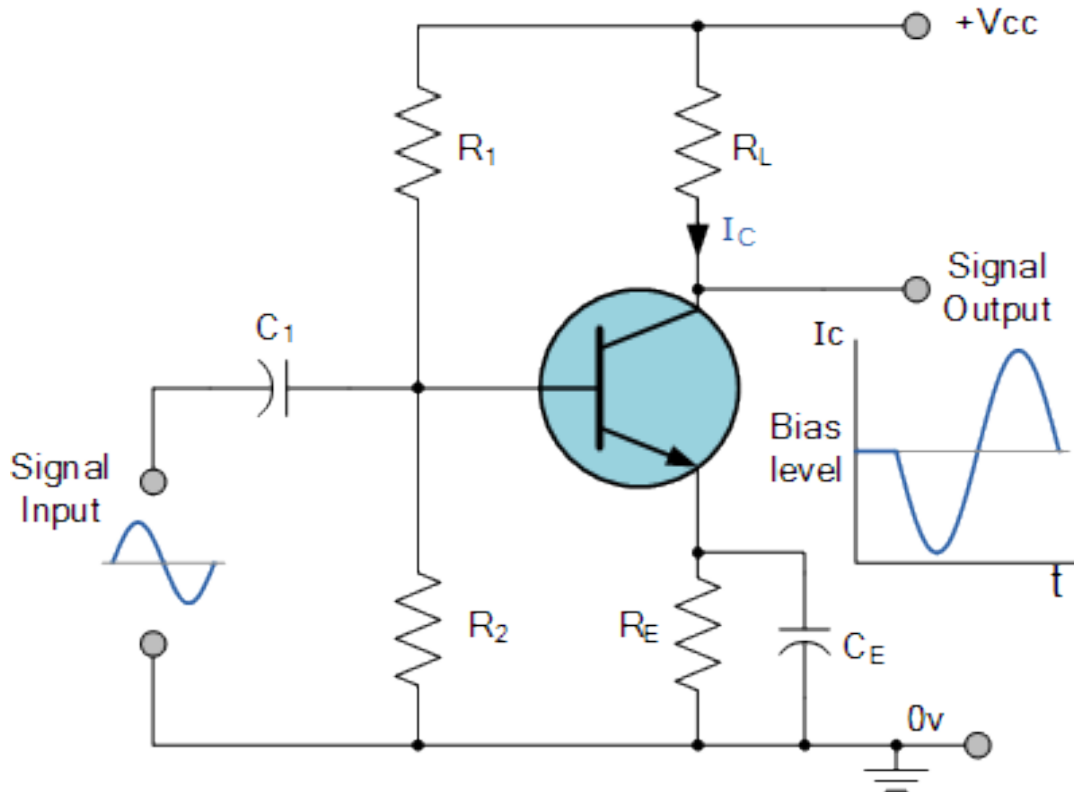
Class A Amplifier

The most commonly used type of power amplifier configuration is the **Class A Amplifier**. The Class A amplifier is the most common and simplest form of power amplifier that uses the switching transistor in the standard common emitter circuit configuration as seen previously.

The transistor is always biased “ON” so that it conducts during one complete cycle of the input signal waveform producing minimum distortion and maximum amplitude to the output. This means then that the **Class A Amplifier** configuration is the ideal operating mode, because there can be no crossover or switch-off distortion to the output waveform even during the negative half of the cycle.

Class A power amplifier output stages may use a single power transistor or pairs of transistors connected together to share the high load current. Consider the **Class A amplifier** circuit below.

Single Stage Amplifier Circuit

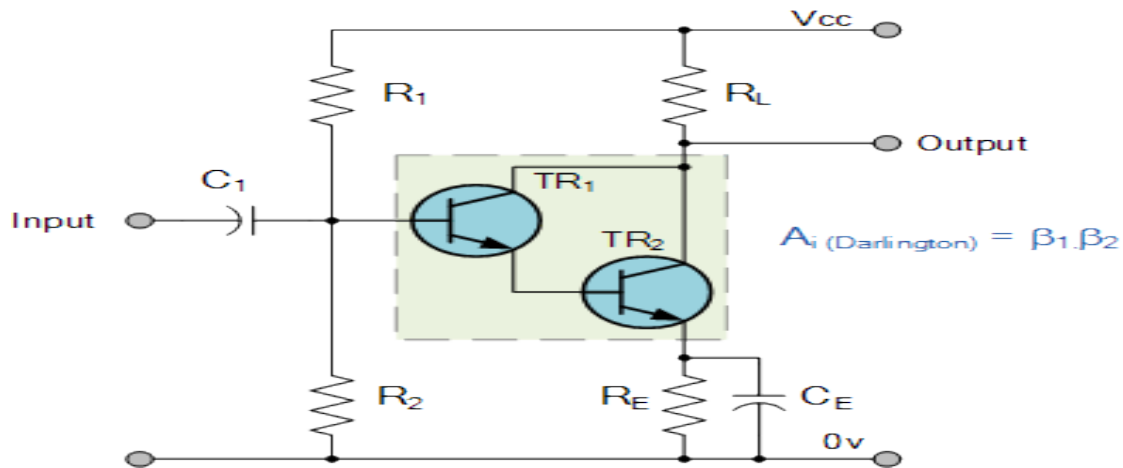


This is the simplest type of Class A power amplifier circuit. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches “ON” it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability.

The efficiency of this type of circuit is very low (less than 30%) and delivers small power outputs for a large drain on the DC power supply. A Class A amplifier stage passes the same load current even when no input signal is applied so large heatsinks are needed for the output transistors.

However, another simple way to increase the current handling capacity of the circuit while at the same time obtain a greater power gain is to replace the single output transistor with a **Darlington Transistor**. These types of devices are basically two transistors within a single package, one small “pilot” transistor and another larger “switching” transistor. The big advantage of these devices are that the input impedance is suitably large while the output impedance is relatively low, thereby reducing the power loss and therefore the heat within the switching device.

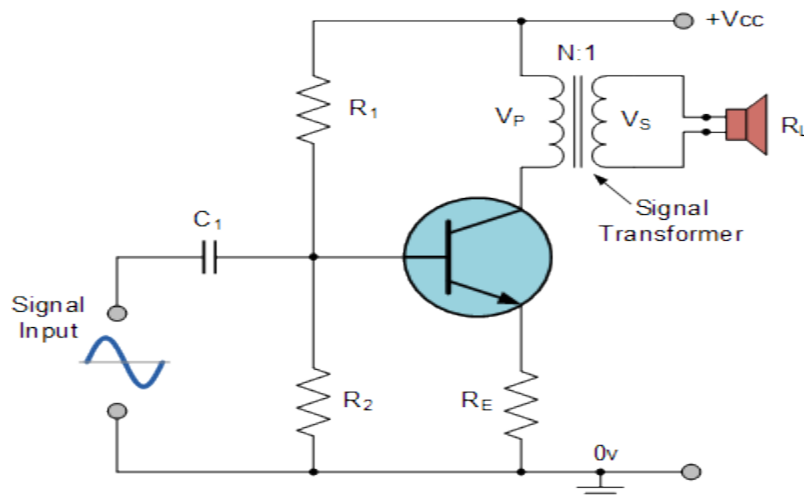
Darlington Transistor Configurations



The overall current gain Beta (β) or h_{fe} value of a Darlington device is the product of the two individual gains of the transistors multiplied together and very high β values along with high Collector currents are possible compared to a single transistor circuit.

To improve the full power efficiency of the **Class A amplifier** it is possible to design the circuit with a transformer connected directly in the Collector circuit to form a circuit called a **Transformer Coupled Amplifier**. The transformer improves the efficiency of the amplifier by matching the impedance of the load with that of the amplifiers output using the turns ratio (n) of the transformer and an example of this is given below.

Transformer-coupled Amplifier Circuit



As the Collector current, I_c is reduced to below the quiescent Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings. This causes an instantaneous

collector voltage to rise to a value of twice the supply voltage $2V_{CC}$ giving a maximum collector current of twice I_C when the Collector voltage is at its minimum. Then the efficiency of this type of Class A amplifier configuration can be calculated as follows.

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(\max)} - V_{C(\min)}}{2\sqrt{2}} = \frac{2V_{CC} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(\max)} - I_{C(\min)}}{2\sqrt{2}} = \frac{2I_C - 0}{2\sqrt{2}}$$

The r.m.s. Power delivered to the load (P_{ac}) is therefore given as:

$$P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{CC}}{2\sqrt{2}} \times \frac{2I_C}{2\sqrt{2}} = \frac{2V_{CC} 2I_C}{8}$$

The average power drawn from the supply (P_{dc}) is given by:

$$P_{dc} = V_{CC} \times I_C$$

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:

$$\eta_{(\max)} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC} 2I_C}{8V_{CC} I_C} \times 100\%$$

An output transformer improves the efficiency of the amplifier by matching the impedance of the load with that of the amplifiers output impedance. By using an output or signal transformer with a suitable turns ratio, class-A amplifier efficiencies reaching 40% are possible with most commercially available Class-A type power amplifiers being of this type of configuration.

However, the transformer is an inductive device due to its windings and core so the use of inductive components in amplifier switching circuits is best avoided as any back emf's generated may damage the transistor without adequate protection. Also another big disadvantage of this

type of transformer coupled class A amplifier circuit is the additional cost and size of the audio transformer required.

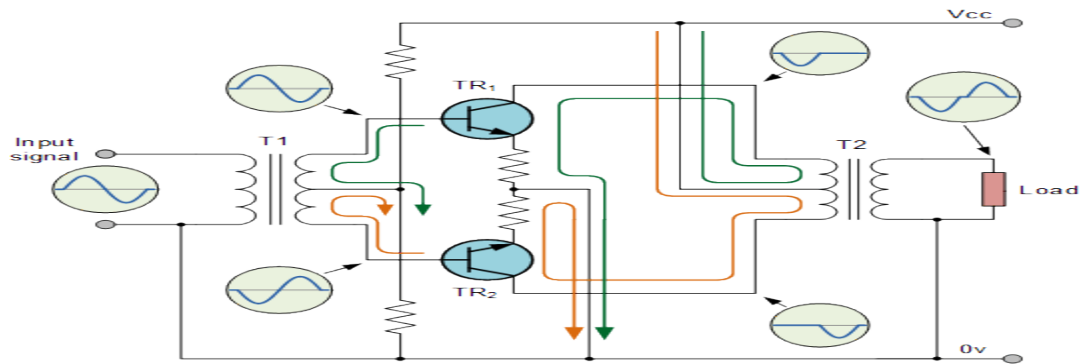
The type of “Class” or classification that an amplifier is given really depends upon the conduction angle, the portion of the 360° of the input waveform cycle, in which the transistor is conducting. In the Class A amplifier the conduction angle is a full 360° or 100% of the input signal while in other amplifier classes the transistor conducts during a lesser conduction angle.

It is possible to obtain greater power output and efficiency than that of the **Class A amplifier** by using two complementary transistors in the output stage with one transistor being an NPN or N-channel type while the other transistor is a PNP or P-channel (the complement) type connected in what is called a “push-pull” configuration. This type of configuration is generally called a **Class B Amplifier** and is another type of audio amplifier circuit that we will look at in the next tutorial.

Push-pull amplifiers use two “complementary” or matching transistors, one being an NPN-type and the other being a PNP-type with both power transistors receiving the same input signal together that is equal in magnitude, but in opposite phase to each other. This results in one transistor only amplifying one half or 180° of the input waveform cycle while the other transistor amplifies the other half or remaining 180° of the input waveform cycle with the resulting “two-halves” being put back together again at the output terminal.

Then the conduction angle for this type of amplifier circuit is only 180° or 50% of the input signal. This pushing and pulling effect of the alternating half cycles by the transistors gives this type of circuit its amusing “push-pull” name, but are more generally known as the **Class B Amplifier** as shown below.

Class B Push-pull Transformer Amplifier Circuit



The circuit above shows a standard **Class B Amplifier** circuit that uses a balanced center-tapped input transformer, which splits the incoming waveform signal into two equal halves and which are 180° out of phase with each other.

Another center-tapped transformer on the output is used to recombined the two signals providing the increased power to the load. The transistors used for this type of transformer push-pull amplifier circuit are both NPN transistors with their emitter terminals connected together.

Here, the load current is shared between the two power transistor devices as it decreases in one device and increases in the other throughout the signal cycle reducing the output voltage and current to zero.

The result is that both halves of the output waveform now swings from zero to twice the quiescent current thereby reducing dissipation. This has the effect of almost doubling the efficiency of the amplifier to around 70%.

Assuming that no input signal is present, then each transistor carries the normal quiescent collector current, the value of which is determined by the base bias which is at the cut-off point.

If the transformer is accurately center tapped, then the two collector currents will flow in opposite directions (ideal condition) and there will be no magnetization of the transformer core, thus minimizing the possibility of distortion.

When an input signal is present across the secondary of the driver transformer T1, the transistor base inputs are in “anti-phase” to each other as shown, thus if TR1 base goes positive driving the transistor into heavy conduction, its collector current will increase but at the same time the base current of TR2 will go negative further into cut-off and the collector current of this transistor decreases by an equal amount and vice versa.

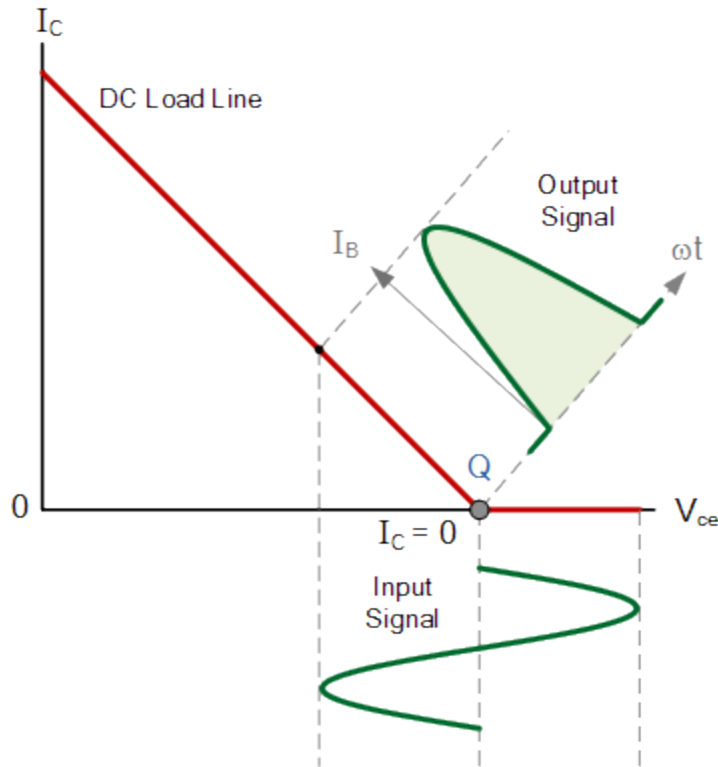
Hence negative halves are amplified by one transistor and positive halves by the other transistor giving this push-pull effect.

Unlike the DC condition, these alternating currents are **ADDITIVE** resulting in the two output half-cycles being combined to reform the sine-wave in the output transformers primary winding which then appears across the load.

Class B Amplifier operation has zero DC bias as the transistors are biased at the cut-off, so each transistor only conducts when the input signal is greater than the base-emitter voltage.

Therefore, at zero input there is zero output and no power is being consumed. This then means that the actual Q-point of a Class B amplifier is on the Vce part of the load line as shown below.

Class B Output Characteristics Curves



The **Class B Amplifier** has the big advantage over their Class A amplifier cousins in that no current flows through the transistors when they are in their quiescent state (ie, with no input signal), therefore no power is dissipated in the output transistors or transformer when there is no signal present unlike Class A amplifier stages that require significant base bias thereby dissipating lots of heat – even with no input signal present.

So the overall conversion efficiency (η) of the amplifier is greater than that of the equivalent Class A with efficiencies reaching as high as 70% possible resulting in nearly all modern types of push-pull amplifiers operated in this Class B mode.

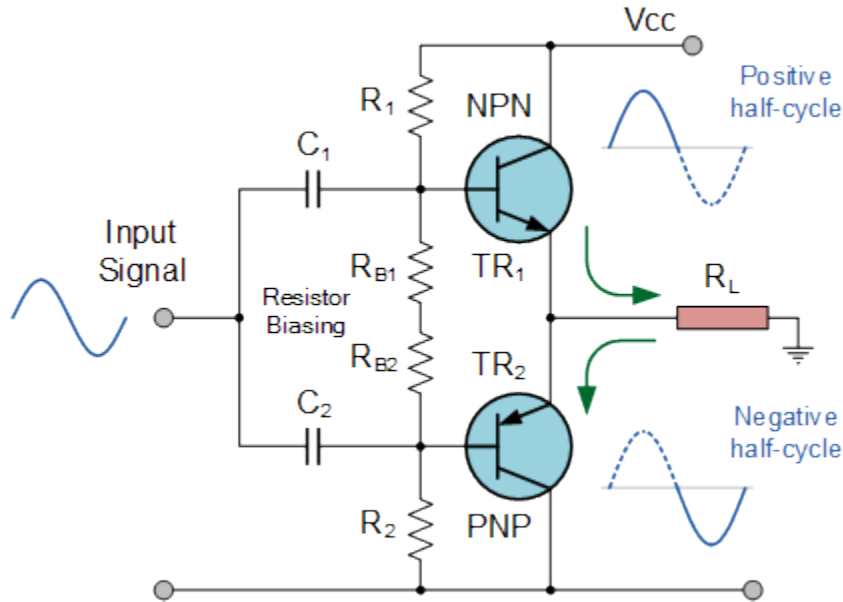
Complementary symmetry push pull amplifier

One of the main disadvantages of the Class B amplifier circuit above is that it uses balanced center-tapped transformers in its design, making it expensive to construct. However, there is another type of Class B amplifier called a **Complementary-Symmetry Class B Amplifier** that does not use transformers in its design therefore, it is transformer less using instead complementary or matching pairs of power transistors.

As transformers are not needed this makes the amplifier circuit much smaller for the same amount of output, also there are no stray magnetic effects or transformer distortion to effect the

quality of the output signal. An example of a “transformer less” Class B amplifier circuit is given below.

Class B Transformer less Output Stage



The Class B amplifier circuit above uses complimentary transistors for each half of the waveform and while Class B amplifiers have a much high gain than the Class A types, one of the main disadvantages of class B type push-pull amplifiers is that they suffer from an effect known commonly as Crossover Distortion.

Hopefully we remember from our tutorials about Transistors that it takes approximately 0.7 volts (measured from base to emitter) to get a bipolar transistor to start conducting. In a pure class B amplifier, the output transistors are not “pre-biased” to an “ON” state of operation.

This means that the part of the output waveform which falls below this 0.7 volt window will not be reproduced accurately as the transition between the two transistors (when they are switching over from one transistor to the other), the transistors do not stop or start conducting exactly at the zero crossover point even if they are specially matched pairs.

The output transistors for each half of the waveform (positive and negative) will each have a 0.7 volt area in which they are not conducting. The result is that both transistors are turned “OFF” at exactly the same time.

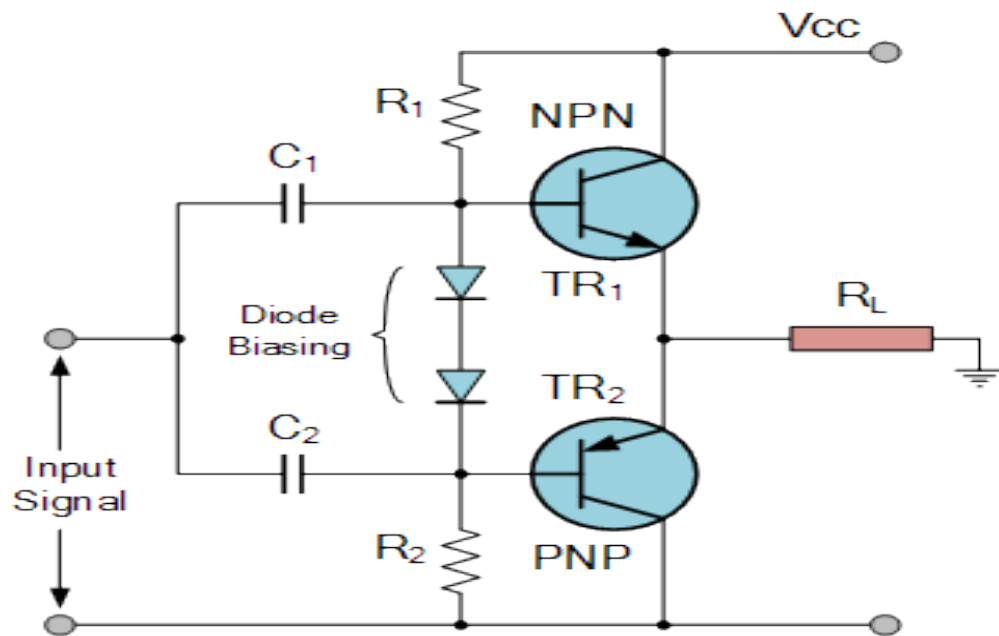
A simple way to eliminate crossover distortion in a Class B amplifier is to add two small voltage sources to the circuit to bias both the transistors at a point slightly above their cut-off point. This

then would give us what is commonly called an **Class AB Amplifier** circuit. However, it is impractical to add additional voltage sources to the amplifier circuit so PN-junctions are used to provide the additional bias in the form of silicon diodes.

The Class AB Amplifier

We know that we need the base-emitter voltage to be greater than 0.7V for a silicon bipolar transistor to start conducting, so if we were to replace the two voltage divider biasing resistors connected to the base terminals of the transistors with two silicon Diodes, the biasing voltage applied to the transistors would now be equal to the forward voltage drop of the diode. These two diodes are generally called **Biassing Diodes** or **Compensating Diodes** and are chosen to match the characteristics of the matching transistors. The circuit below shows diode biasing.

Class AB Amplifier



The **Class AB Amplifier** circuit is a compromise between the Class A and the Class B configurations. This very small diode biasing voltage causes both transistors to slightly conduct even when no input signal is present. An input signal waveform will cause the transistors to operate as normal in their active region thereby eliminating any crossover distortion present in pure Class B amplifier designs.

A small collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration. This means then that the transistor will be “ON” for more than half a cycle of the waveform but much less than a full cycle giving a conduction angle of

between 180° to 360° or 50 to 100% of the input signal depending upon the amount of additional biasing used. The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series.

Class B amplifiers are greatly preferred over Class A designs for high-power applications such as audio power amplifiers and PA systems. Like the class-A amplifier circuit, one way to greatly boost the current gain (A_i) of a Class B push-pull amplifier is to use Darlington transistors pairs instead of single transistors in its output circuitry.

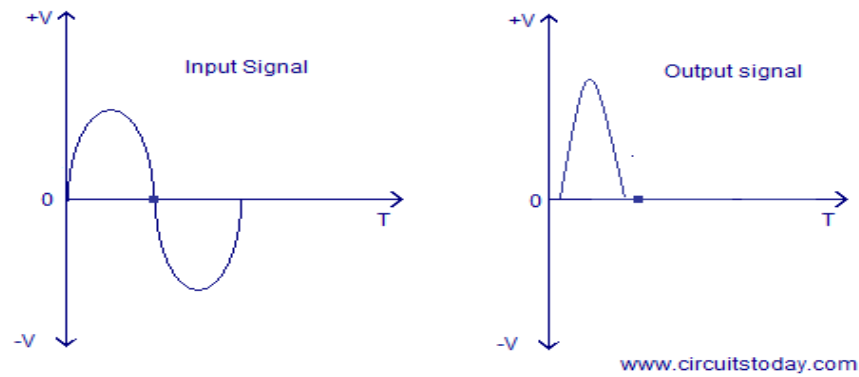
In the next tutorial about Amplifiers we will look more closely at the effects of Crossover Distortion in Class B amplifier circuits and ways to reduce its effect.

But we also know that we can improve the amplifier and almost double its efficiency simply by changing the output stage of the amplifier to a Class B push-pull type configuration. However, this is great from an efficiency point of view, but most modern Class B amplifiers are transformerless or complementary types with two transistors in their output stage.

Class C power amplifier.

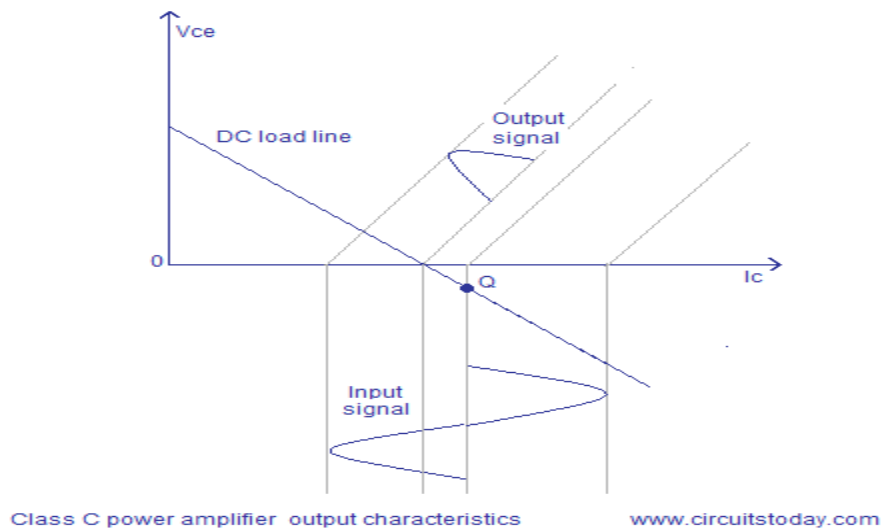
Class C power amplifier is a type of amplifier where the active element (transistor) conduct for less than one half cycle of the input signal. Less than one half cycle means the conduction angle is less than 180° and its typical value is 80° to 120° . The reduced conduction angle improves the efficiency to a great extent but causes a lot of distortion. Theoretical maximum efficiency of a Class C amplifier is around 90%.

Due to the huge amounts of distortion, the Class C configurations are not used in audio applications. The most common application of the Class C amplifier is the RF (radio frequency) circuits like RF oscillator, RF amplifier etc where there are additional tuned circuits for retrieving the original input signal from the pulsed output of the Class C amplifier and so the distortion caused by the amplifier has little effect on the final output. Input and output waveforms of a typical Class C power amplifier are shown in the figure below.



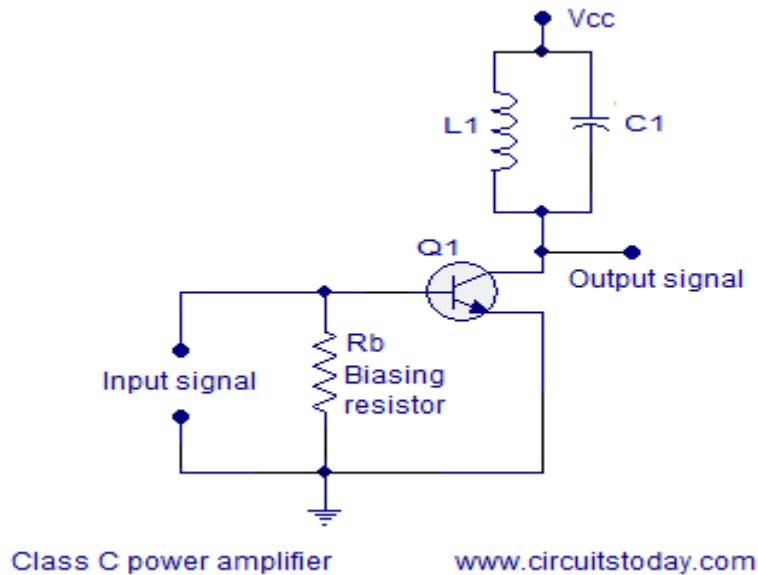
From the above figure it is clear that more than half of the input signal is missing in the output and the output is in the form of some sort of a pulse.

Output characteristics of Class C power amplifier



In the above figure you can see that the operating point is placed some way below the cut-off point in the DC load-line and so only a fraction of the input waveform is available at the output.

Class C power amplifier circuit diagram.



Biasing resistor R_b pulls the base of Q1 further downwards and the Q-point will be set some way below the cut-off point in the DC load line. As a result the transistor will start conducting only after the input signal amplitude has risen above the base emitter voltage ($V_{be} \sim 0.7V$) plus the downward bias voltage caused by R_b . That is the reason why the major portion of the input signal is absent in the output signal.

Inductor L1 and capacitor C1 forms a tank circuit which aids in the extraction of the required signal from the pulsed output of the transistor. Actual job of the active element (transistor) here is to produce a series of current pulses according to the input and make it flow through the resonant circuit. Values of L1 and C1 are so selected that the resonant circuit oscillates in the frequency of the input signal. Since the resonant circuit oscillates in one frequency (generally the carrier frequency) all other frequencies are attenuated and the required frequency can be squeezed out using a suitably tuned load. Harmonics or noise present in the output signal can be eliminated using additional filters. A coupling transformer can be used for transferring the power to the load.

Advantages of Class C power amplifier.

- High efficiency.
- Excellent in RF applications.
- Lowest physical size for a given power output.

Disadvantages of Class C power amplifier.

- Lowest linearity.
- Not suitable in audio applications.
- Creates a lot of RF interference.
- It is difficult to obtain ideal inductors and coupling transformers.
- Reduced dynamic range.

Applications of Class C power amplifier.

- RF oscillators.
- RF amplifier.
- FM transmitters.
- Booster amplifiers.
- High frequency repeaters.
- Tuned amplifiers etc.

There is not a clear cut difference between ‘ordinary’ transistors used in voltage amplifiers and power transistors, but generally Power transistors can be categorized as those that can handle more than 1 Ampere of collector (or Drain in the case of FETs) current. Because power transistors, such as those voltages, they have a different construction to small signal devices. They must have low output resistances so that they can deliver large currents to the load, and good junction insulation to withstand high voltages. They must also be able to dissipate heat very quickly so they do not overheat. As most heat is generated at the collector/base junction, the area of this junction is made as large as possible.

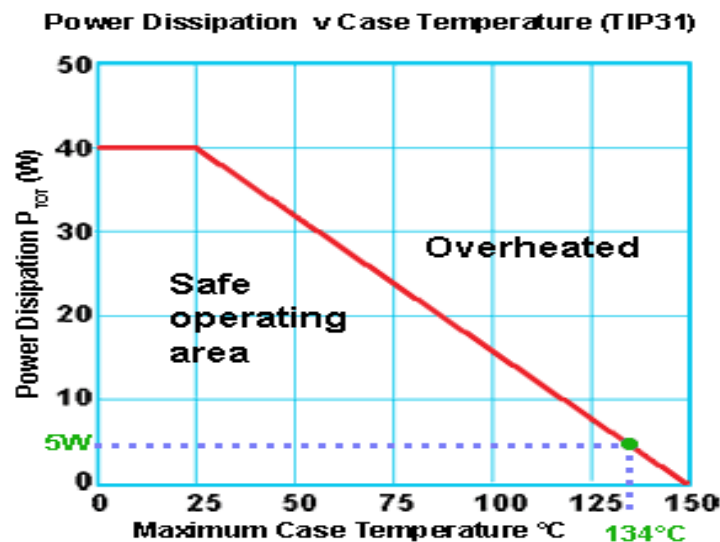
Power and Temperature

The maximum power rating of a transistor is largely governed by the temperature of the collector/base junction as can be seen from the power de-rating graph in power is dissipated, this junction gets too hot and the transistor will be destroyed, a typical maximum temperature is between 100°C and 150°C, although some devices can withstand higher maximum junction temperatures. The maximum power output available from a power transistor is closely linked to temperature, and above 25°C falls in a linear manner to zero power output as the maximum permissible temperature is reached.

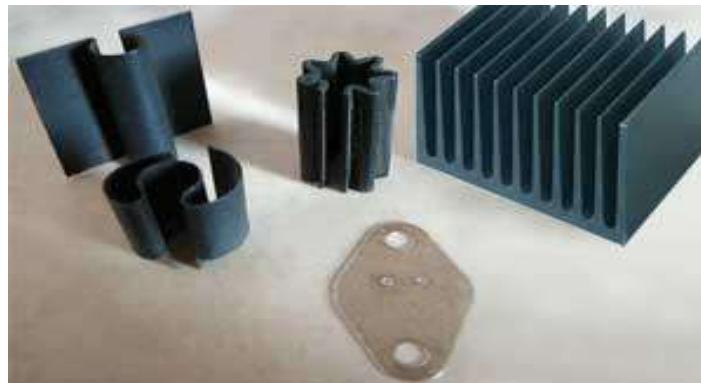
Power De-rating

For example, a transistor such as the TIP31 having a quoted maximum power output PTOT of 40W can only handle 40W of power IF the case temperature (slightly less than the junction temperature) is kept below 25°C. The performance of a power transistor is closely

dependent on its ability to dissipate the heat generated at the collector base junction. Minimizing the problem of heat is approached in two main ways:



1. By operating the transistor in the most efficient way possible, that is by choosing a class of biasing that gives high efficiency and is least wasteful of power.



2. By ensuring that the heat produced by the transistor can be removed and effectively transferred to the surrounding air as quickly as possible. Method 2 above highlights the importance of the relationship between a power transistor and its heat sink, a device attached to the transistor for the purpose of removing heat. The physical construction of power transistors is therefore designed to maximize the transfer of heat to the heat sink. In addition to the usual collector lead-out wire, the collector of a power transistor, which has a much larger area than that of a small signal transistor, is normally in direct contact with the metal case of the transistor, or a metal mounting pad, which may then be bolted or clipped directly on to a heat-sink. Typical metal cased and metal body power transistors are Because power amplifiers generate substantial

amounts of heat, which is wasted power, they are made to be as efficient as possible. With voltage amplifiers, low distortion is of greater importance than efficiency, but with power amplifiers, although distortion cannot be ignored, efficiency is vital.

Calculating the Required Thermal Resistance R_{th} for a Heat-sink

The heat-sink chosen must be able to dissipate heat from the transistor to the surrounding air, quickly enough to prevent the junction temperature of the transistor exceeding its maximum permitted value (usually quoted on the transistor's data sheet), typically 100 to 150°C.

Each heat-sink has a parameter called its Thermal Resistance (R_{th}) measured in °C/Watt and the lower the value of R_{th} the faster heat is dissipated. Other factors affecting heat dissipation include the power (in Watts) being dissipated by the transistor, the efficiency of heat transfer between the internal transistor junction and the transistor case, and the case to the heat-sink.

The difference between the temperature of the heat-sink and the air temperature surrounding the heat-sink (the ambient temperature) must also be taken into account. The main criteria is that the heat-sink should be efficient enough, too efficient is not a problem.

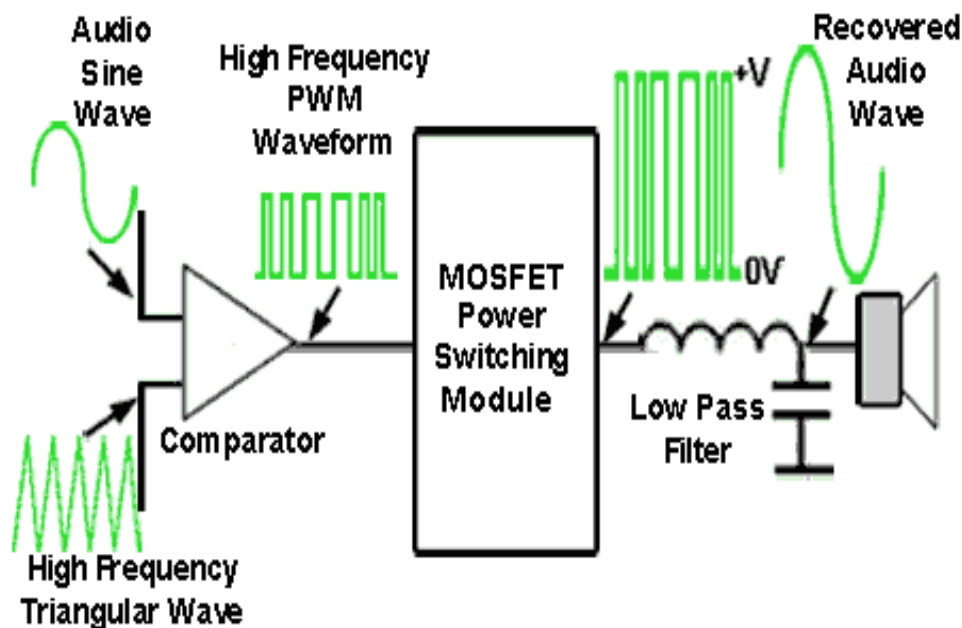
Therefore, any heat-sink with a thermal resistance lower or equal to the calculated value should be OK, but to avoid continually running the transistor at, or close to the maximum permitted temperature, which is almost guaranteed to shorten the life of the transistor, it is advisable to use a heat-sink with a lower thermal resistance where possible.

The power de-rating graph for a [TIP31](#) transistor shown in Fig illustrates the relationship between the power dissipated by the transistor and the case temperature. When the transistor is dissipating 5W, it can be estimated from the graph that the maximum safe case temperature, for a junction temperature of 150°C would be about 134 to 135°C, confirming the above calculation of max. case temperature.

The TIP31 transistor has maximum power dissipation P_{TOT} of 40W but it can be seen from the graph in Fig that this is only attainable if the case temperature of the transistor can be held at 25°C. The case temperature can only be allowed to rise to 150°C (the same as the maximum junction temperature) if the power dissipation is zero.

The class A Common Emitter Voltage Amplifier described in Amplifier Module 1, Module 2 and Module 3 has some excellent properties that make it useful for many amplification tasks; however it is not suitable for every purpose. Class A biasing is good at preserving the original wave shape as the transistor is biased using the most linear part of the transistor's characteristics. However the big problem with class A is its poor efficiency. Amplifiers Module explains how push-pull class B power amplifiers improve efficiency at the expense of added crossover distortion.

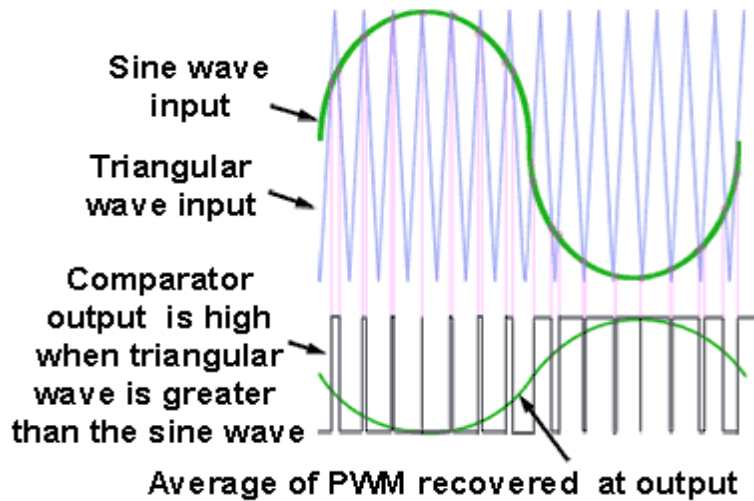
Class D operation makes the output circuit extremely efficient (around 90%) allowing high power output without the need for such high power transistors and elaborate heat-sinks. However this big increase in efficiency is only achieved at the expense of some increase in distortion and especially of noise, in the form of electromagnetic interference (EMI).



Nevertheless, class D is a very efficient class of amplifier suited to both high power audio and RF amplifiers and low power portable amplifiers, where battery life can be considerably extended because of the amplifier's high efficiency. The increased interest in class D amplifiers has led to a number of class D integrated circuits becoming available.

Class E and F Power Amplifiers:

Amplifier classes such as E and F are basically enhancements of class D, offering more complex and improved output filtering, including some additional wave shaping of the PWM signal to prevent audio distortion.



Class G and H Power Amplifiers:

Classes G and H offer enhancements to the basic class AB design.

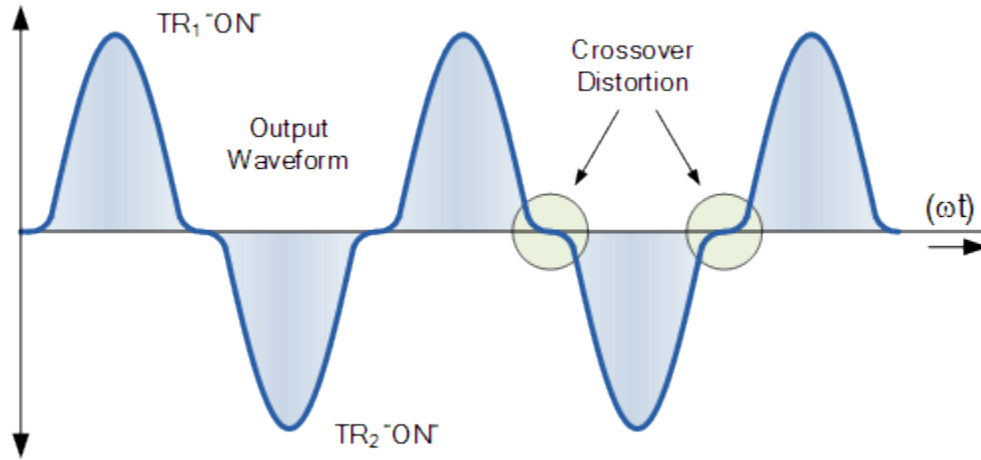
Class G uses multiple power supply rails of various voltages, rapidly switching to a higher voltage when the audio signal wave has a peak value that is a higher voltage than the level of supply voltage, and switching back to a lower supply voltage when the peak value of the audio signal reduces. By switching the supply voltage to a higher level only when the largest output signals are present and then switching back to a lower level, average power consumption, and therefore heat caused by wasted power is reduced.

Class H improves on class G by continually varying the supply voltage at any time where the audio signal exceeds a particular threshold level. The power supply voltage tracks the peak level of the signal to be only slightly higher than the instantaneous value of the audio wave, returning to its lower level once the signal peak value falls below the threshold level again. Both classes G and H therefore require considerably more complex power supplies, which add to the cost of implementing these features.

Crossover Distortion

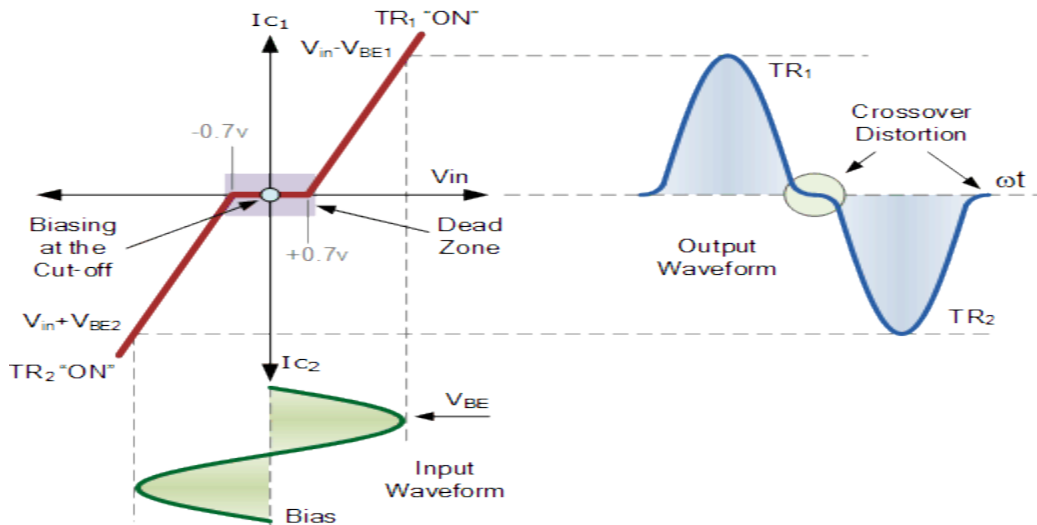
It produces a zero voltage “flat spot” or “deadband” on the output wave shape as it crosses over from one half of the waveform to the other. The reason for this is that the transition period when the transistors are switching over from one to the other, does not stop or start exactly at the zero crossover point thus causing a small delay between the first transistor turning “OFF” and the second transistor turning “ON”. This delay results in both transistors being switched “OFF” at the same instant in time producing an output wave shape as shown below.

Crossover Distortion Waveform:



In order that there should be no distortion of the output waveform we must assume that each transistor starts conducting when its base to emitter voltage rises just above zero, but we know that this is not true because for silicon bipolar transistors the base voltage must reach at least 0.7v before the transistor starts to conduct thereby producing this flat spot. This crossover distortion effect also reduces the overall peak to peak value of the output waveform causing the maximum power output to be reduced as shown below.

Non-Linear Transfer Characteristics

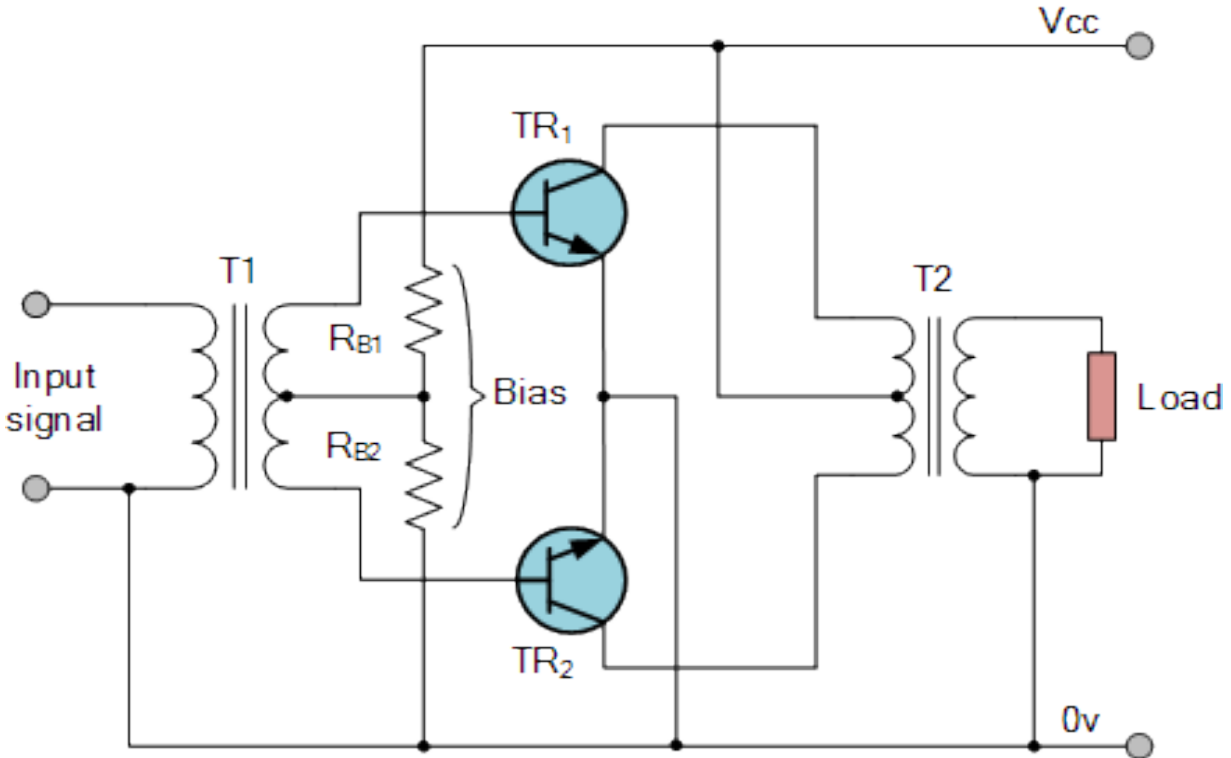


This effect is less pronounced for large input signals as the input voltage is usually quite large but for smaller input signals it can be more severe causing audio distortion to the amplifier.

Pre-biasing the Output

The problem of **Crossover Distortion** can be reduced considerably by applying a slight forward base bias voltage (same idea as seen in the [Transistor](#) tutorial) to the bases of the two transistors via the center-tap of the input transformer, thus the transistors are no longer biased at the zero cut-off point but instead are “Pre-biased” at a level determined by this new biasing voltage.

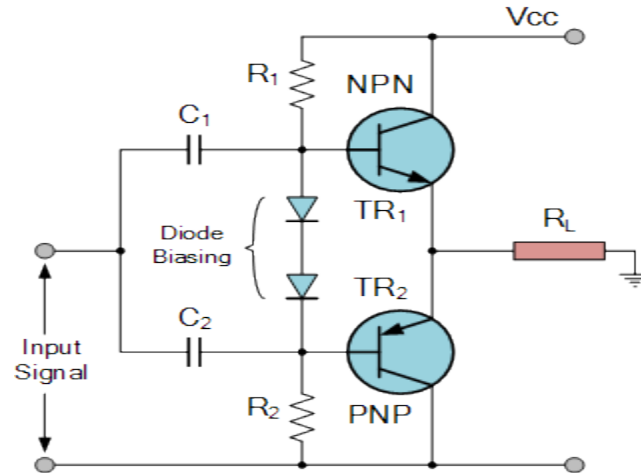
Push-pull Amplifier with Pre-biasing



This type of resistor pre-biasing causes one transistor to turn “ON” exactly at the same time as the other transistor turns “OFF” as both transistors are now biased slightly above their original cut-off point. However, to achieve this the bias voltage must be at least twice that of the normal base to emitter voltage to turn “ON” the transistors.

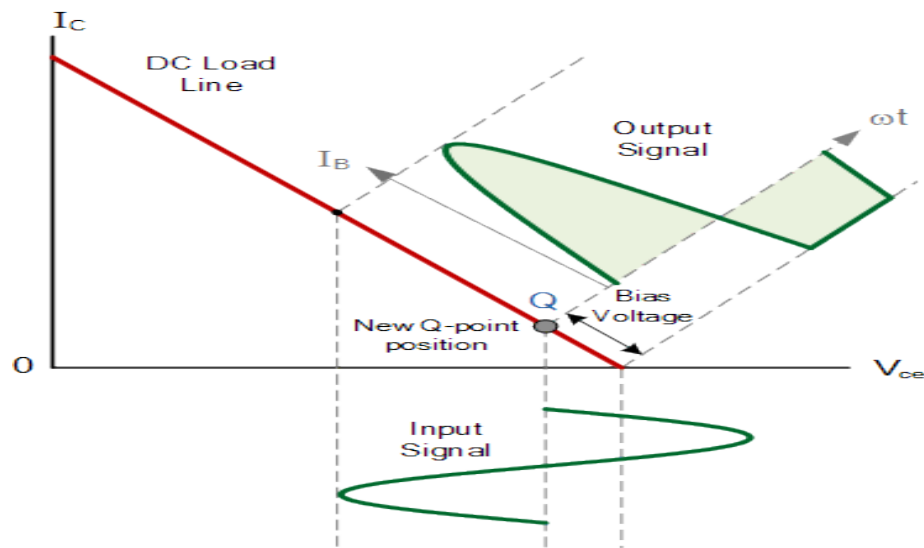
This pre-biasing can also be implemented in transformerless amplifiers that use complementary transistors by simply replacing the two potential divider resistors with **Biasing Diodes** as shown below.

Pre-biasing with Diodes



This pre-biasing voltage either for a transformer or transformer less amplifier circuit, has the effect of moving the amplifiers Q-point past the original cut-off point thus allowing each transistor to operate within its active region for slightly more than half or 180° of each half cycle. In other words $180^\circ + \text{Bias}$. The amount of diode biasing voltage present at the base terminal of the transistor can be increased in multiples by adding additional diodes in series. This then produces an amplifier circuit commonly called a **Class AB Amplifier** and its biasing arrangement is given below.

Class AB Output Characteristics



Crossover Distortion Summary

Then to summarize, **Crossover Distortion** occurs in Class B amplifiers because the amplifier is biased at its cut-off point. This then results in BOTH transistors being switched “OFF” at the same instant in time as the waveform crosses the zero axis. By applying a small base bias voltage either by using a resistive potential divider circuit or diode biasing this crossover distortion can be greatly reduced or even eliminated completely by bringing the transistors to the point of being just switched “ON”.

The application of a biasing voltage produces another type or class of amplifier circuit commonly called a **Class AB Amplifier**. Then the difference between a pure Class B amplifier and an improved Class AB amplifier is in the biasing level applied to the output transistors. One major advantage of using diodes over resistors is that the PN-junctions compensate for variations in the temperature of the transistors. Therefore, we can say the a Class AB amplifier is a Class B amplifier with “Bias” and we can therefore summaries as:

- Class A Amplifiers – No Crossover Distortion as they are biased in the center of the load line.
- Class B Amplifiers – Large amounts of Crossover Distortion due to biasing at the cut-off point.
- Class AB Amplifiers – Some Crossover Distortion if the biasing level is set too low.

As well as the three amplifier classes above, 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 of these amplifier designs use RLC resonators or multiple power-supply voltages to help reduce power loss and distortion.