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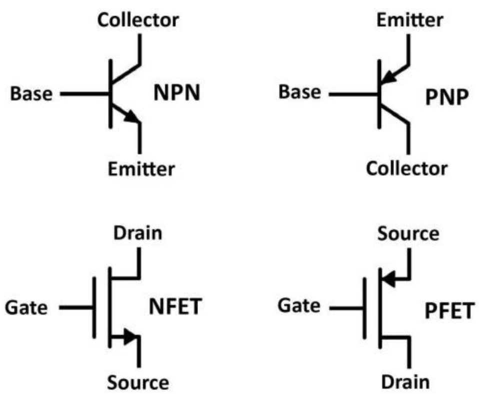
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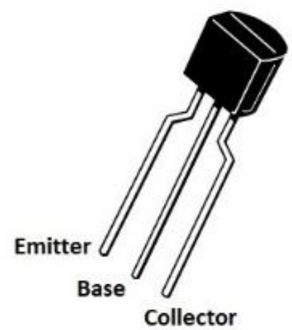
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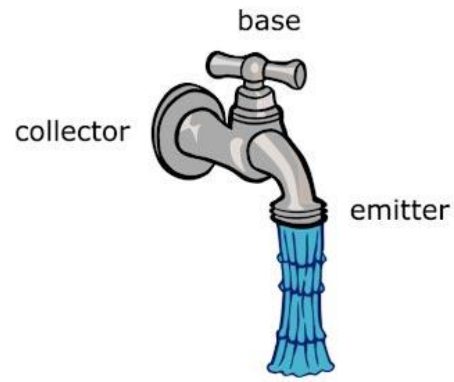
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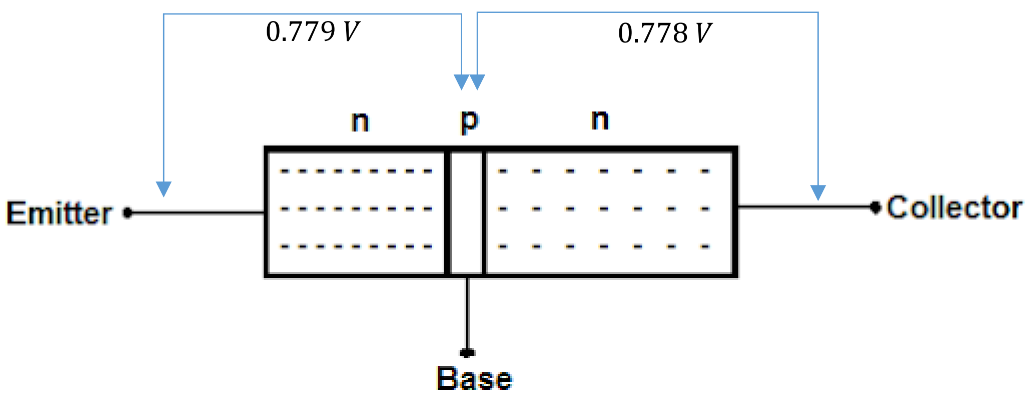
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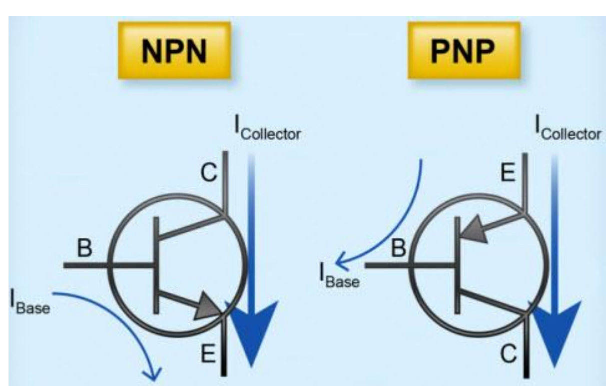
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Transistor CE, CB, CC Amplifiers

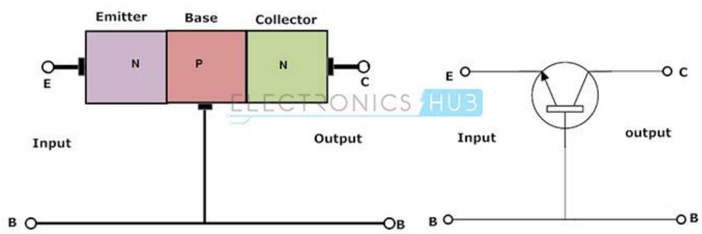
Since a Bipolar Junction Transistor is a 3-terminal device, there are three different configurations of Transistors possible with BJTs. Understanding these different configurations of transistors will help you in the better implementation of your application.

Using this property, we construct the circuits and these structures are called transistor configurations. Generally, there are three different configurations of transistors and they are common base (CB) configuration, common collector (CC) configuration, and common emitter (CE) configuration.

- **Common Base (CB) Configuration**: no current gain but a voltage gain
- **Common Collector (CC) Configuration**: current gain but no voltage gain
- **Common Emitter (CE) Configuration**: current gain and voltage gain

The behavior of these three different configurations of transistors with respect to gain is given below.

Common Base Configuration



In this configuration, we use the base as a common terminal for both input and output signals. The configuration name itself indicates the common terminal. Here the input is applied between the base and emitter terminals and the corresponding output signal is taken between the base and collector terminals with the base terminal grounded. Here the input parameters are V_{EB} and I_E and the output parameters are V_{CB} and I_C. The input current flowing into the emitter terminal must be higher than the base current and collector current to operate the transistor, therefore the output collector current is less than the input emitter current.

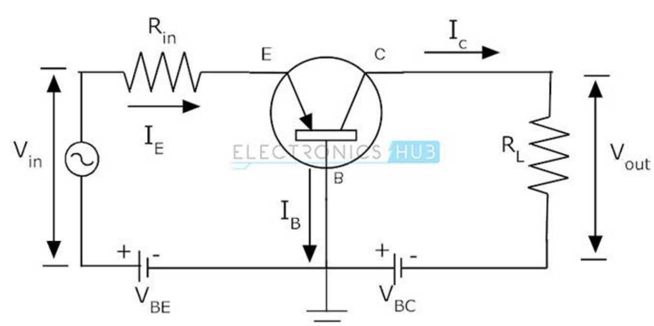
The current gain is generally equal or less than unity for this type of configuration. The input and output signals are in-phase in this configuration. The amplifier circuit configuration of this type is called as a non-inverting amplifier circuit. The construction of this configuration circuit is difficult because this type has high voltage gain values.

The input characteristics of this configuration look like characteristics of an illuminated photodiode while the output characteristics represent a forward-biased diode. This transistor configuration has high output impedance and low input impedance. This type of configuration has high resistance gain i.e., the ratio of output resistance to input resistance is high. The voltage gain for this configuration of the circuit is given below.

$$A_V = \frac{V_{out}}{V_{in}} = \frac{I_C \times R_C}{I_E \times R_{in}}$$

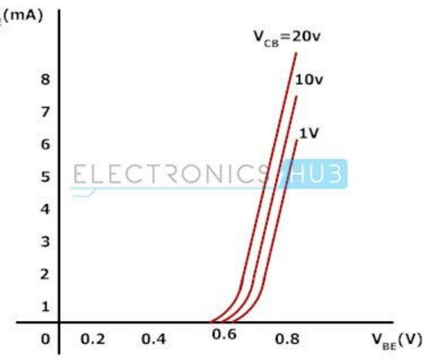
The current gain in common base configuration is given as

$$\alpha = \frac{Output\ current}{Input\ current} = \frac{I_C}{I_E}$$



The common base circuit is mainly used in single-stage amplifier circuits, such as microphone pre-amplifier or radiofrequency amplifiers because of their high-frequency response. The common base transistor circuit is given below.

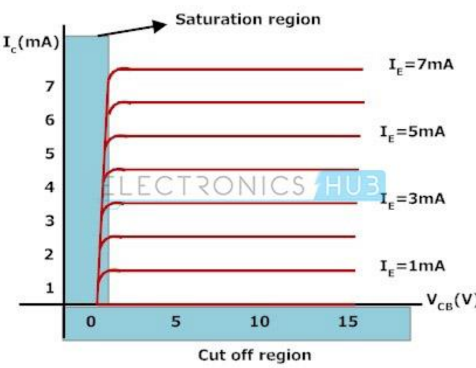
Input Characteristics



Input characteristics are obtained between input current and input voltage with constant output voltage. First, keep the output voltage V_{CB} constant and vary the input voltage V_{EB} for different points then at each point record the input current I_E value. Repeat the same process at different output voltage levels. Now with these values, we need to plot the graph between I_E and V_{EB} parameters. The below figure shows the input characteristics of the common base configuration. The equation to calculate the input resistance R_{in} value is given below.

$$R_{in} = \frac{V_{EB}}{I_E} \quad (when\ V_{CB}\ is\ constant)$$

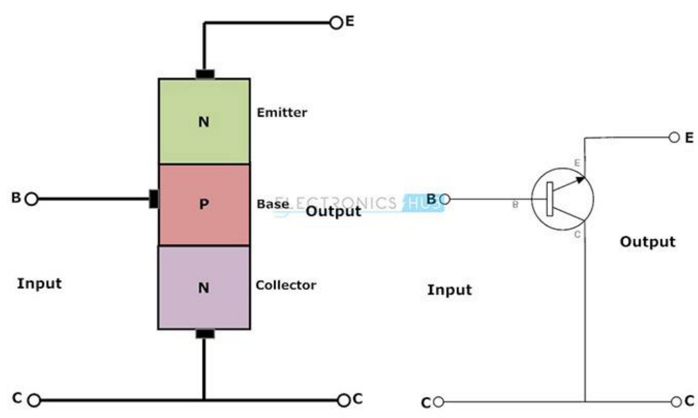
Output Characteristics



The output characteristics of the common base configuration are obtained between the output current and output voltage with the constant input current. First, keep the emitter current constant and vary the V_{CB} value for different points, now record the I_C values at each point. Repeat the same process at different I_E values. Finally, we need to draw the plot between V_{CB} and I_C at constant I_E. The below figure shows the output characteristics of the common base configuration. The equation to calculate the output resistance value is given below.

$$R_{out} = \frac{V_{CB}}{I_C} \quad (when\ I_E\ is\ constant)$$

Common Collector Configuration



In this configuration, we use collector terminal as common for both input and output signals. This configuration is also known as the emitter follower configuration because the emitter voltage follows the base voltage. This configuration is mostly used as a buffer. These configurations are widely used in impedance matching applications because of their high input impedance.

In this configuration the input signal is applied between the base-collector region and the output is taken from the emitter-collector region. Here the input parameters are VBC and IB and the output parameters are VEC and IE. The common collector configuration has high input impedance and low output impedance. The input and output signals are in phase. Here also the emitter current is equal to the sum of the collector current and the base current. Now let us calculate the current gain for this configuration.

Current gain,

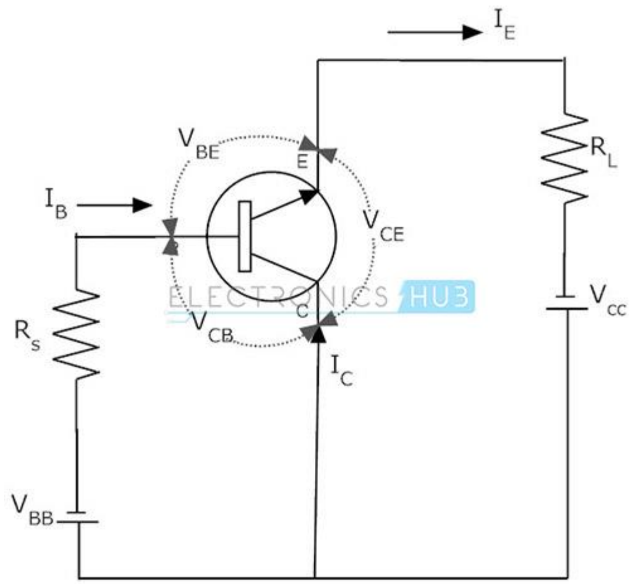
$$A_i = \text{output current/Input current}$$

$$A_i = I_E/I_B$$

$$A_i = (I_C + I_B)/I_B$$

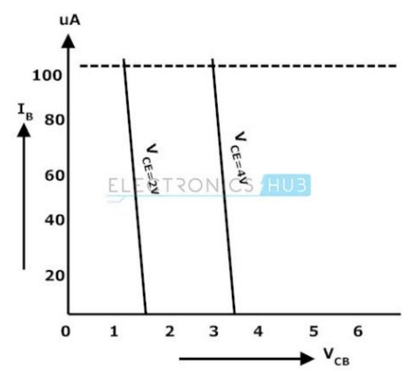
$$A_i = (I_C/I_B) + 1$$

$$A_i = \beta + 1$$



The common collector transistor circuit is shown above. This common collector configuration is a non-inverting amplifier circuit. The voltage gain for this circuit is less than unity but it has a large current gain because the load resistor in this circuit receives both the collector and base currents.

Input Characteristics



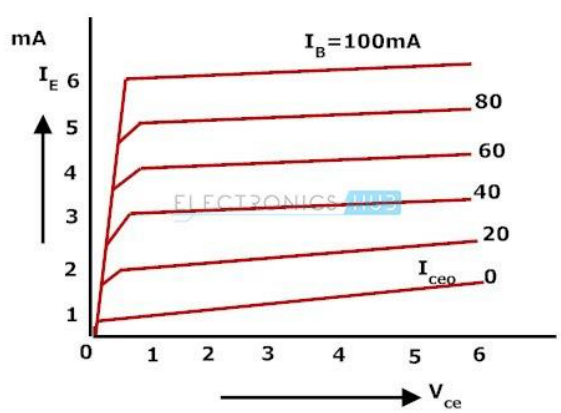
The input characteristics of a common collector configuration are quite different from the common base and common emitter configurations because the input voltage V_{BC} is largely determined by V_{EC} level. Here,

$V_{EC} = V_{EB} + V_{BC}$

$V_{EB} = V_{EC} – V_{BC}$

The input characteristics of a common-collector configuration are obtained between inputs current I_B and the input voltage V_{CB} at constant output voltage V_{EC}. Keep the output voltage V_{EC} constant at different levels and vary the input voltage V_{BC} for different points and record the I_B values for each point. Now using these values, we need to draw a graph between the parameters of V_{BC} and I_B at constant V_{EC}.

Output Characteristics

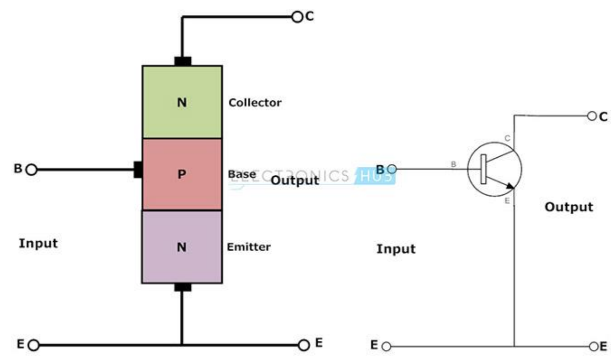


The operation of the common collector circuit is the same as that of the common-emitter circuit. The output characteristics of a common collector circuit are obtained between the output voltage V_{EC} and output current I_E at constant input current I_B. In the operation of a common collector circuit if the base current is zero then the emitter current also becomes zero. As a result, no current flows through the transistor

If the base current increases, then the transistor operates in the active region and finally reaches to saturation region. To plot the graph first we keep the I_B at a constant value and we will vary the V_{EC} value for various points, now we need to record the value of I_E for each point. Repeat the same process for different I_B values. Now using these values, we need to plot the graph between the parameters of I_E and V_{CE} at constant values of I_B. The below figure shows the output characteristics of the common collector.

Common Emitter Configuration

In this configuration, we use emitter as the common terminal for both input and output. This common emitter configuration is an inverting amplifier circuit. Here the input is applied between the base-emitter region and the output is taken between collector and emitter terminals. In this configuration, the input parameters are V_{BE} and I_B and the output parameters are V_{CE} and I_C.



This type of configuration is mostly used in the applications of transistor-based amplifiers. In this configuration, the emitter current is equal to the sum of the small base current and the large collector current. i.e., $I_E = I_C + I_B$. We know that the ratio between collector current and emitter current gives current gain alpha in Common Base configuration similarly, the ratio between collector current and base current gives the current gain beta in common emitter configuration.

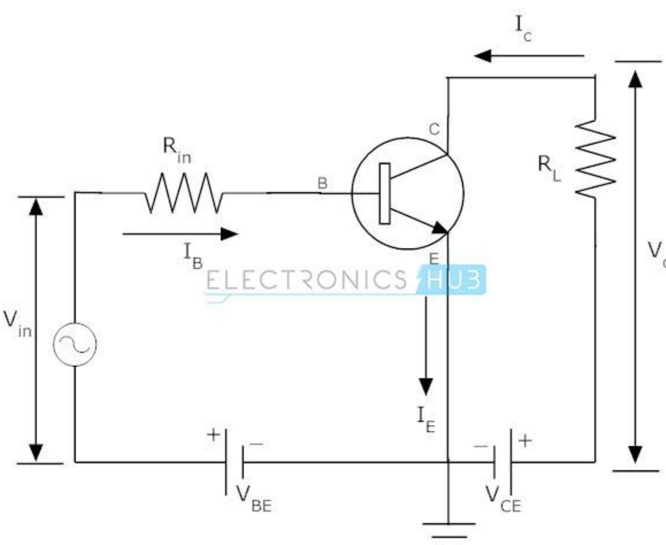
Now let us see the relationship between these two current gains.

Current gain (α) = I_C/I_E

Current gain (β) = I_C/I_B

Collector current $I_C = \alpha\ I_E = \beta I_B$

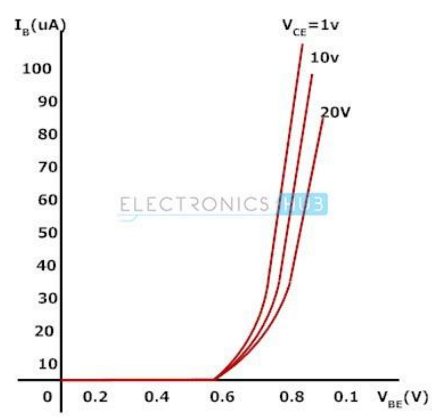
This configuration is mostly used one among all the three configurations. It has medium input and output impedance values. It also has medium current and voltage gains. But the output signal has a phase shift of 180 i.e. both the input and output are inverse to each other.



Input Characteristics

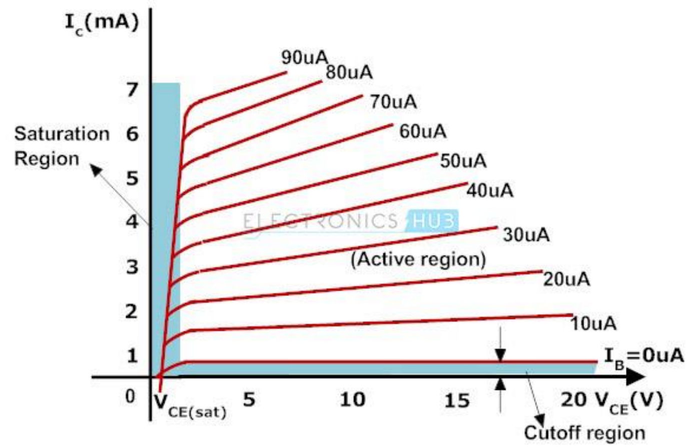
The input characteristics of common emitter configuration are obtained between input current I_B and input voltage V_{BE} with constant output voltage V_{CE}. Keep the output voltage V_{CE} constant and vary the input voltage V_{BE} for different points, now record the values of input current at each point. Now using these values, we need to draw a graph between the values of I_B and V_{BE} at constant V_{CE}. The equation to calculate the input resistance R_{in} is given below.

$$R_{in} = V_{BE}/I_B \text{ (when } V_{CE} \text{ is at constant)}$$



Output Characteristics

The output characteristics of the common-emitter configuration are obtained between the output current I_C and output voltage V_{CE} with constant input current I_B. Keep the base current I_B constant and vary the value of output voltage V_{CE} for different points, now note down the value of collector I_C for each point. Plot the graph between the parameters I_C and V_{CE} in order to get the output characteristics of the common-emitter configuration. The equation to calculate the output resistance from this graph is given below.



$$R_{out} = V_{CE}/I_C \text{ (when } I_B \text{ is at constant)}$$

Configurations of Transistors Summary

Transistor Configuration Summary Table			
Transistor Configuration	Common Base	Common Collector (Emitter Follower)	Common Emitter
Voltage Gain	High	Low	Medium
Current Gain	Low	High	Medium
Power Gain	Low	Medium	High
Input / Output Phase Relationship	0°	0°	180°
Input Resistance	Low	High	Medium
Output Resistance	High	Low	Medium

The table which gives the main characteristics of a transistor in the three configurations is given above. The BJT transistors have mainly three types of configurations. They are common-emitter, common-base, and common-collector configurations. Among all these three configurations common-emitter configuration is mostly used type. These three have different characteristics corresponding to both input and output signals. And also these three configurations have few similarities.

Cascading

In practical applications, the output of a single state amplifier is usually insufficient, though it is a voltage or power amplifier. Hence, they are replaced by **multi-stage transistor amplifiers**.

In Multi-stage amplifiers, the output of the first stage is coupled to the input of the next stage using a coupling device. These coupling devices can usually be a capacitor or a transformer. This process of joining two amplifier stages using a coupling device can be called **cascading**.

The following figure shows a two-stage amplifier connected in cascade.

The overall gain is the product of the voltage gain of individual stages.

$$A_V = A_{V_1} \times A_{V_2} = \frac{V_2}{V_i} \times \frac{V_o}{V_2} = \frac{V_o}{V_i}$$

Where A_V = Overall gain, A_{V_1} = Voltage gain of 1st stage, and A_{V_2}= Voltage gain of 2nd stage.

If there are **n** number of stages, the product of voltage gains of those **n** stages will be the overall gain of that multistage amplifier circuit.

Coupling

Coupling in Amplifier means the method of connecting multiple stages of amplifier in a cascade. If the gain of a single amplifier is low or insufficient to drive the load then we need to use multiple stages in a cascade. But we cannot directly connect the output of one stage to the input of the next stage. If we connect two stages directly, the DC biasing of the amplifier will be affected and noise will occur.

The necessity of Coupling in Amplifier

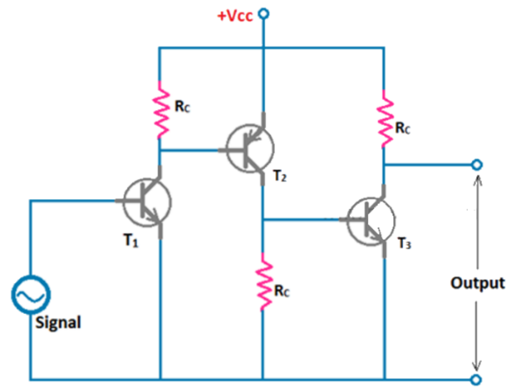
a. Coupling in an amplifier is needed to connect multiple successive stages in a cascade.
b. Proper amplifier coupling is needed to avoid effect in DC biasing when multiple amplifier stages are connected.
c. Coupling is needed to increase the overall gain of the amplifier.
d. Coupling is needed to reduce noise when multiple amplifier stages are connected.
e. Proper coupling is needed to reduce the wastage of power.

Different Types of Amplifier Coupling

Different types of coupling can be used to connect multiple amplifier stages according to gain, frequency level, distortion, application requirements. Here different types of amplifier coupling are explained with application and advantages.

Direct Coupling in Amplifier

When the output of an amplifier stage is directly connected to the input of the next stage then it is called Direct Coupling. In the Direct Coupling technique, no coupling device (such as a resistor, capacitor, inductor) is used.



Direct Coupled Amplifier Circuit

Here, you can see in the below figure a three-stage direct-coupled amplifier is shown. Here, the output of the Transistor 1 is directly connected to the input of transistor 2, and the output of transistor 2 is directly connected to the input of transistor 3.
Here, you can also see the first transistor is NPN and the second transistor is PNP, again the third transistor is NPN. This is because the variations in one transistor will cancel the variations in others. If the same transistor is used then gain will decrease, distortion came.

Direct Coupled Amplifier Applications

- Direct Coupled Amplifiers are used for low-frequency applications, such as sensors, transducers, etc.
- Direct Coupled Amplifiers are used to amplify DC signals also.
- They are used for low current applications such as Buzzer, Tonner, etc.

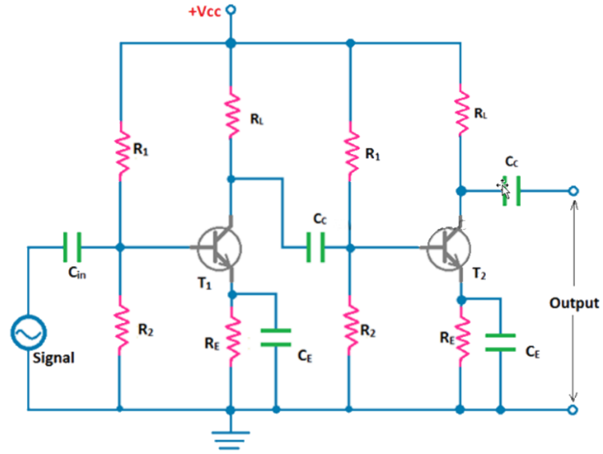
Advantages of Direct Coupled Amplifier

- It does not use any coupling elements that's why the circuit is very simple and easy to make.
- This circuit is very low-cost.
- This circuit can amplify both the AC and DC signals.

Disadvantages of Direct Coupled Amplifier

- It is suitable for low-frequency applications only.
- It is suitable for low-current applications only.
- It has very low bandwidth.
- The Q-point is not stable due to temperature variations.

RC Coupling in Amplifier



RC Coupled Amplifier Circuit

In the below figure, you can see a Two-stage RC Coupled amplifier is shown. Here you can see, there are two transistors are connected. The output of the first transistor is connected to the input of the second transistor through a capacitor Cc which is called a coupling capacitor.

Here, you can also see a capacitor Ce is connected in parallel with resistor Re, this is the bypass capacitor used to provide the low reactance path for unwanted noise signals. The resistance RL is used as a load Impedance. So as the stages of the amplifier are connected with coupling devices resistor and capacitor that's why it is called RC Coupled Amplifier.

RC Coupled Amplifier Applications

- RC coupled amplifiers are used for RF signal, Audio signal amplifying purposes.
- RC coupled amplifiers are used for the preamplification of signals generated from microphones, audio devices, and signal transmission and distribution systems.
- These amplifiers are used in Radio and TV communication systems as small-signal amplifiers.
- RC coupled amplifier is used as voltage amplifiers.

Advantages of RC Coupled Amplifier

- It is suitable for high-frequency applications.
- Its Q-factor is stable and has a smooth bandwidth.
- It provides constant gain over a wide frequency range.
- As it uses cheaper coupling devices such as resistors, capacitors, it is low-cost and economical.

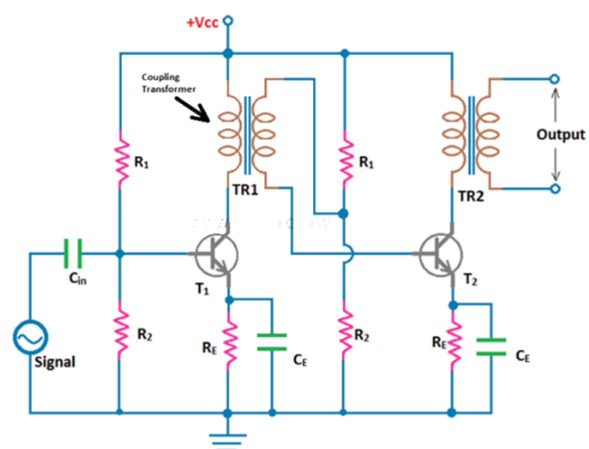
Disadvantages of RC Coupled Amplifier

- The main disadvantage is it has very poor impedance matching characteristics.
- Due to the effective load resistance, it provides low voltage and power gain.
- It is not suitable for Low-frequency applications.
- These amplifiers become noisy with increasing their age.

Transformer Coupling in Amplifier

When the output of the amplifier stage is connected to the input of the next stage through a transformer, then it is called a transformer-coupled amplifier. The transformer used to couple two stages is called a coupling transformer. Here, you can see in the below figure, a two-stage transformer-coupled amplifier is shown.

Here, you can see the collector load of the first transformer is replaced by the primary winding of the transformer. The secondary of the transformer is connected between the potential divider and the base of the next transistor.



Transformer-Coupled Amplifier Circuit

Transformer Coupled Amplifier Applications

- Transformer Coupling in amplifier is mainly used for impedance matching.
- Transformer coupled amplifiers are used as power amplifiers to drive high power speaker load.
- Transformer coupling is used in high-power audio amplifiers.

Advantages of Transformer Coupled Amplifier

- It provides a very high gain.
- It provides a very good impedance matching property.
- These amplifiers have high efficiency and low losses.

Disadvantages of Transformer Coupling Amplifier

- These amplifiers have poor frequency response, the gain decreases with an increase in frequency.
- These amplifiers are costly because of using the transformer as a coupling device.
- Humming noise occurs in the transformer.

Role of Capacitors in Amplifiers

Other than the coupling purpose, there are other purposes for which few capacitors are especially employed in amplifiers. To understand this, let us know about the role of capacitors in Amplifiers.

The Input Capacitor C_{in}

The input capacitor C_{in} present at the initial stage of the amplifier, couples AC signal to the base of the transistor. This capacitor C_{in} if not present, the signal source will be in parallel to resistor R_2 and the bias voltage of the transistor base will be changed.

Hence C_{in} allows the AC signal from the source to flow into the input circuit, without affecting the bias conditions.

The Emitter By-pass Capacitor C_e

The emitter by-pass capacitor C_e is connected in parallel to the emitter resistor. It offers a low reactance path to the amplified AC signal.

In the absence of this capacitor, the voltage developed across R_E will feedback to the input side thereby reducing the output voltage. Thus, in the presence of C_e, the amplified AC will pass through this.

Coupling Capacitor C_C

The capacitor C_C is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the operating point from shifting. This is also called as **blocking capacitor** because it does not allow the DC voltage to pass through it.

In the absence of this capacitor, R_C will come in parallel with the resistance R_1 of the biasing network of the next stage and thereby changing the biasing conditions of the next stage.

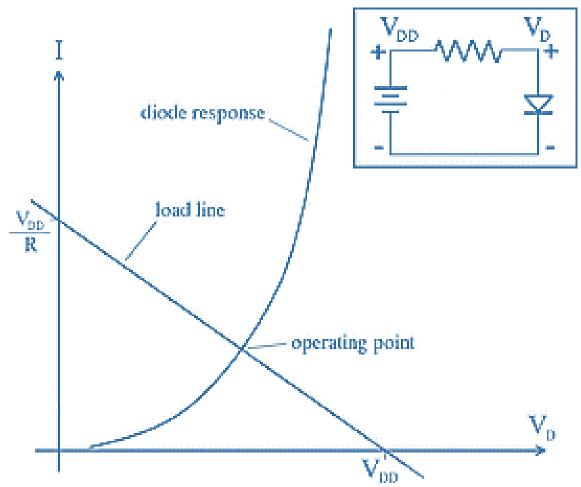
Load Line

A load line is a line drawn on the characteristic curve, a graph of the current vs. the voltage in a nonlinear device like a diode or transistor. It represents the constraint put on the voltage and current in the nonlinear device by the external circuit. The load line, usually a straight line, represents the response of the linear part of the circuit, connected to the nonlinear device in question. The points where the characteristic curve and the load line intersect are the possible operating point(s) (Q points) of the circuit; at these points the current and voltage parameters of both parts of the circuit match.

The example at right shows how a load line is used to determine the current and voltage in a simple diode circuit. The diode, a nonlinear device, is in series with a linear circuit consisting of a resistor, R and a voltage source, V_{DD} The characteristic curve *(curved line)*, representing the current I through the diode for any given voltage across the diode V_D, is an exponential curve. The load line *(diagonal line)*, representing the relationship between current and voltage due to Kirchhoff's voltage law applied to the resistor and voltage source, is

$$V_D = V_{DD} - IR$$

Since the same current flows through each of the three elements in series, and the voltage produced by the voltage source and resistor is the voltage across the terminals of the diode, the operating point of the circuit will be at the intersection of the curve with the load line.



In a circuit with a three-terminal device, such as a transistor, the current-voltage curve of the collector-emitter current depends on the base current. This is depicted on graphs by a series of (I_C–V_{CE}) curves at different base currents. A load line drawn on this graph shows how the base current will affect the operating point of the circuit.

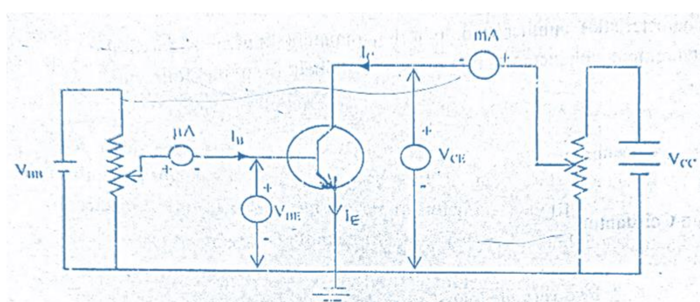
Q-point

The operating point of a device, also known as bias point, quiescent point, or Q-point, is the DC voltage or current at a specified terminal of an active device (a transistor or vacuum tube) with no input signal applied. A bias circuit is a portion of the device's circuit which supplies this steady current or voltage.

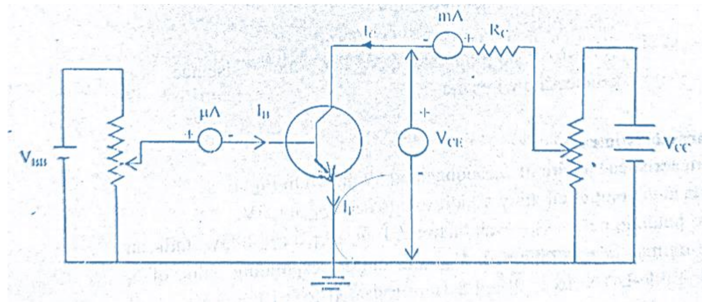
Transistor Characteristics:

Static characteristics of a transistor are curves that represent the relationship between different d.c. currents and voltages of a transistor. These help study the operation of a transistor when connected to a circuit. The characteristic curves are:

Input Characteristics: The input characteristics are the curves that indicate the variation of the base current I_B with the change in the base emitter-voltage V_{BE} at constant collector-emitter voltages V_{CE}.



Output characteristics: The output characteristics a common emitter transistor are the curves between collector current I_C and collector-emitter voltage V_{CE} at constant base currents I_B:



DC Load Line: It is the line on the output characteristics of a common-emitter configuration between the points $((I_C)_{max}, 0)$ and $(0, V_{CC})$. From KVL, the value of the collector-emitter voltage V_{CE} at any time is given by

$$V_{CE} = V_{CC} - I_C R_C \tag{1}$$

When, $I_C = 0, V_{CE} = V_{CC}$

When, $V_{CE} = 0$, I_C will be $(I_C)_{max}$ and then $V_{CC} = (I_C)_{max} R_C$

So, $(I_C)_{max} = \frac{V_{CC}}{R_C}$

Hybrid Parameters: From the input characteristics two-hybrid parameters — the input impedance h_{ie} and reverse voltage ratio h_{re} can be determined by the following expressions:

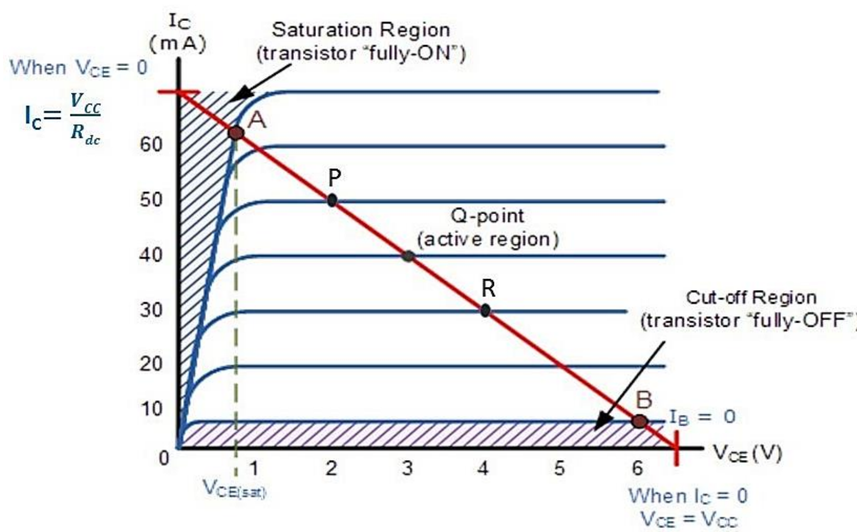
$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B}\bigg|_{V_{CE}=Constant}$$

$$h_{re} = \frac{\Delta V_{BE}}{\Delta V_{CE}}\bigg|_{I_B=Constant}$$

From the output characteristics another two-hybrid parameter known as forward current gain h_{fe} and output conductance h_{oe} can be obtained from the following relations:

$$h_{fe} = \frac{\Delta I_C}{\Delta I_B}\bigg|_{V_{CE}=Constant}$$

$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}}\bigg|_{I_B=Constant}$$



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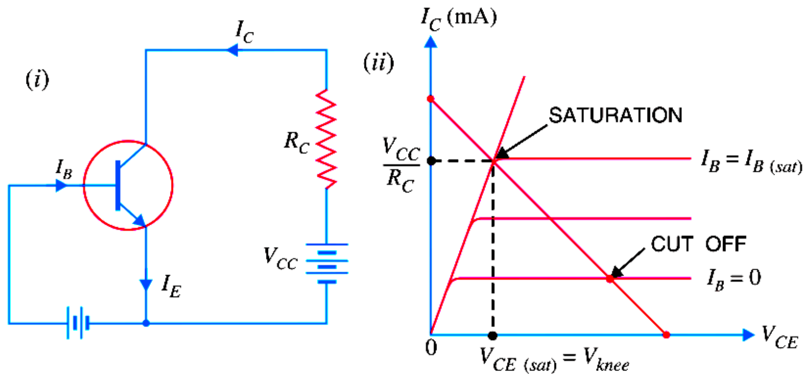
Different Regions in Transistor Characteristics



(*i*) Cut off. This is the region in which the transistor tends to behave as an open switch. The transistor has the effect of its collector and base being opened. The collector, emitter, and base currents are all zero in this mode of operation.

The point where the load line intersects the $I_B = 0$ curve is known as *cut off*. At this point, $I_B = 0$ and only small collector current (*i.e.*, collector leakage current I_{ceo}) exists. At cut-off, the base-emitter junction no longer remains forward biased, and normal transistor action is lost. The collector-emitter voltage is nearly equal to V_{CC} *i.e.* $V_{CE\ (cut\ off)} = V_{CC}$

(*ii*) Saturation. The BJT operates in the saturation region when its collector current is not dependent on the base current and has reached a maximum. The condition for this to happen is that both the base-emitter and the base-collector junctions should be forward-biased.

The point where the load line intersects the $I_B = I_{B\ (sat)}$ the curve is called *saturation*. At this point, the base current is maximum and so is the collector current. At saturation, collector-base junction no longer remains to reverse biased, and normal transistor action is lost.

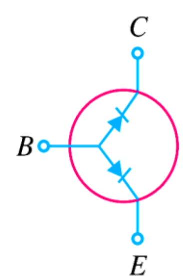
$$I_{C\ (sat)} \simeq \frac{V_{CC}}{R_C}\ ; \quad V_{CE} = V_{CE(sat)} = V_{knee}$$

If the base current is greater than $I_{B\ (sat)}$, then collector current cannot increase because the collector-base junction is no longer reverse-biased.

(*iii*) Active region. The region between cut-off and saturation is known as the *active region*. In the active region, collector-base junction remains reverse biased while base-emitter junction remains forward biased. Consequently, the transistor will function normally in this region.

Note. We provide biasing to the transistor to ensure that it operates in the active region.

Summary: A transistor has two *pn* junctions *i.e.*, it is like two diodes. The junction between base and emitter may be called *emitter diode*. The junction between base and collector may be called *collector diode*. We have seen above that transistors can act in one of the three states: **cut-off, saturated** and **active**. The state of a transistor is entirely determined by the states of the emitter diode and collector diode. The relations between the diode states and the transistor states are:

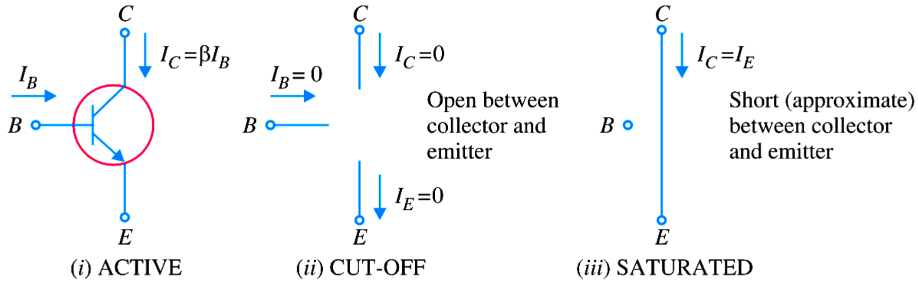


Cut-off:	Emitter diode and collector diode are **off**
Active:	Emitter diode is **on** and collector diode is **off** (reverse biased)
Saturated:	Emitter diode and collector diode are **on**

In the **active state**, collector current [See Below Fig (i)] is β times the base current (i.e. $I_C = \beta I_B$). If the transistor is **cut-off,** there is no base current, so there is no collector or emitter current. That is collector-emitter pathway is open [See Below Fig.(*ii*)].

In **saturation**, the collector and emitter are, in effect, shorted together. That is the transistor behaves as though a switch has been closed between the collector and emitter [See Below Fig. (*iii*)].

Note. When the transistor is in the active state, $I_C = \beta I_B$. Therefore, a transistor acts as an amplifier when operating in the active state. Amplification means *linear amplification.* In fact, small signal amplifiers are the most common *linear devices*.



Amplifier Classes

In electronics, power amplifier classes are letter symbols applied to different power amplifier types. The class gives a broad indication of an amplifier's characteristics and performance. The classes are related to the time period that the active amplifier device is passing current, expressed as a fraction of the period of a signal waveform applied to the input. A class A amplifier is conducting through all the period of the signal; Class B only for one-half the input period, class C for much less than half the input period. A Class D amplifier operates its output device in a switching manner; the fraction of the time that the device is conducting is adjusted so a pulse width modulation output is obtained from the stage.

Amplifier classes are mainly lumped into two basic groups. The first is 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”.

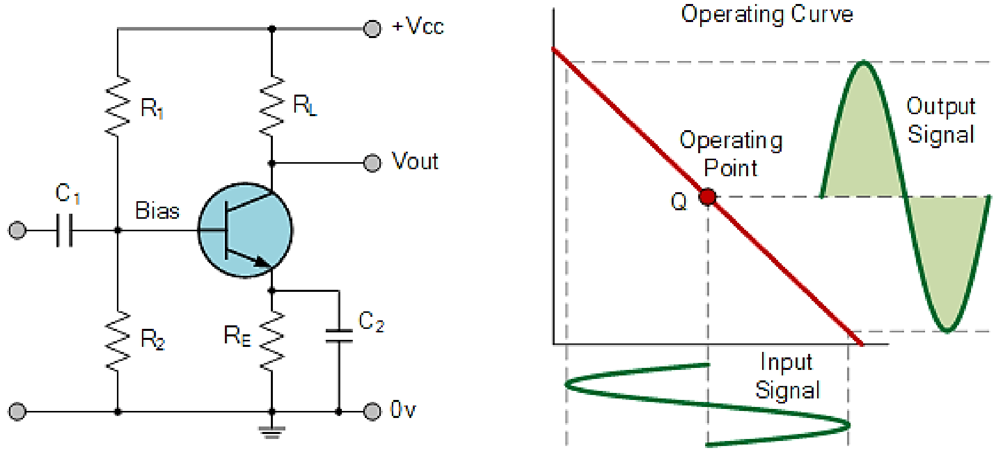
The second set of amplifiers are the newer so-called “switching” amplifier classes of D, E, F, G, S, T etc, which use digital circuits and pulse width modulation (PWM) to constantly switch the signal between “fully-ON” and “fully-OFF” driving the output hard into the transistor’s saturation and cut-off 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 (*Linearity refers to the ability of the amplifier to produce signals that are accurate copies of the input*), 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.



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.

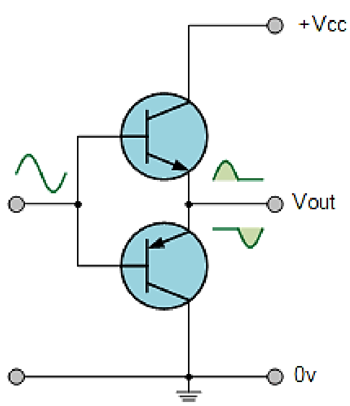
Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion. However, as the output device is "ON" at all times, it is constantly carrying current, which represents a continuous loss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

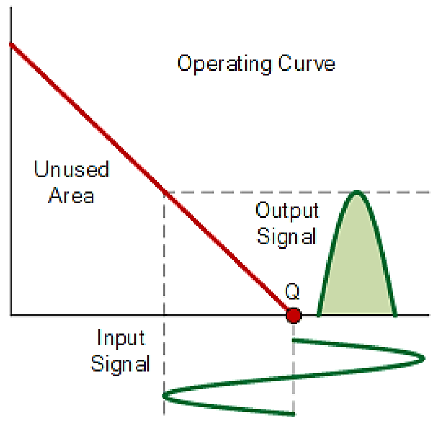
Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplification. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well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

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 complementary transistors either bipolar or 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 (*the current drawn by a system in standby mode with no load*) 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.





When the input signal goes positive, the positive biased transistor conducts while the negative biased transistor is switched "OFF". Likewise, when the input signal goes negative, the positive biased 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 the 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 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 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.

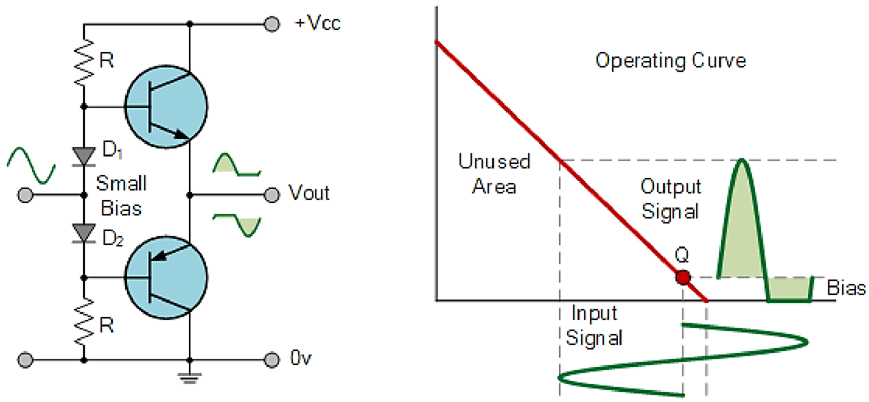
To overcome this zero-crossing distortion (also known as Crossover Distortion) class AB amplifiers were developed.

Class 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 the amplifier is currently one of the most commonly 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 or 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° and 360° depending upon the chosen bias point as shown.



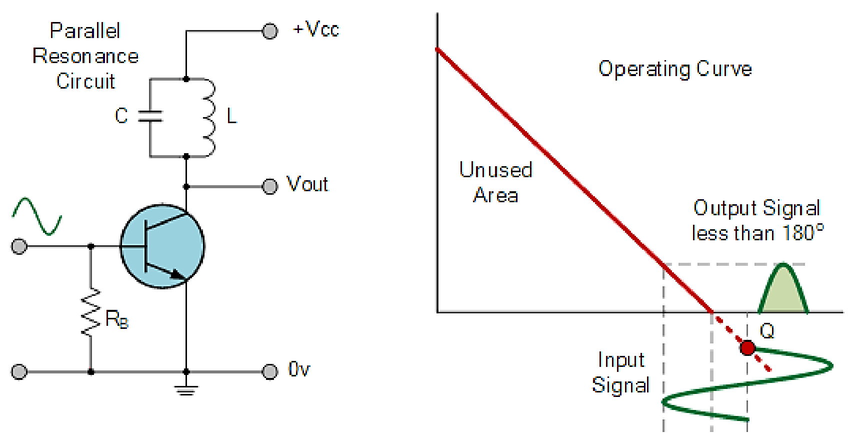
The advantage of this small bias voltage, provided by series diodes or resistors, is that the crossover distortion created by the class B amplifier characteristics is overcome, without the inefficiencies of the class A amplifier design. So, the class AB amplifier is a good compromise between class A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

Class 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.



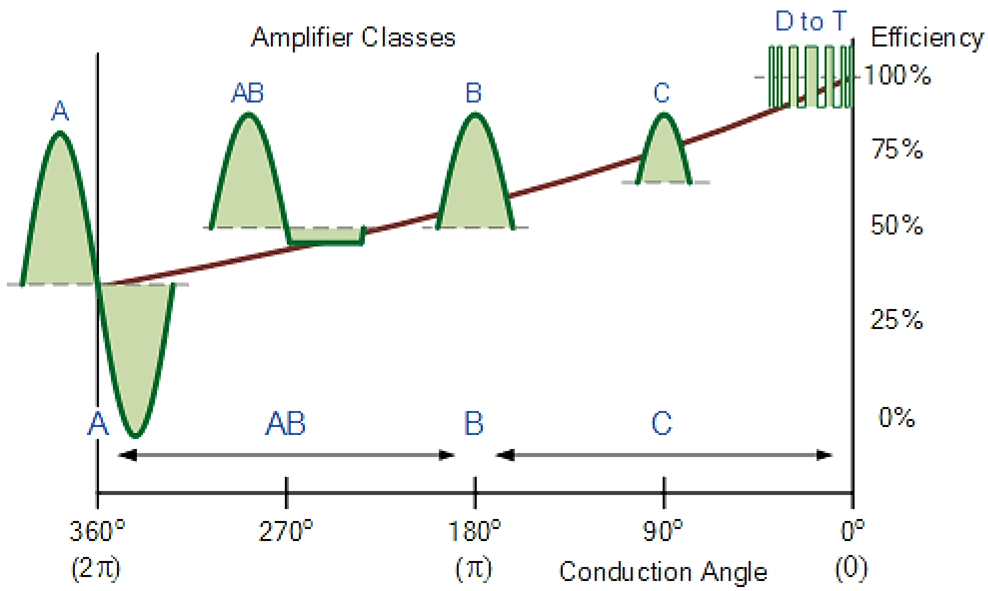
Due to its heavy audio distortion, class C amplifiers are commonly used in high-frequency sine wave oscillators and certain types of radiofrequency amplifiers, where the pulses of current produced at the output of the amplifier can be converted to complete sine waves of a particular frequency by the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

Amplifier Classes Summary

Then we have seen that the quiescent DC operating point (Q-point) of an amplifier determines the amplifier classification. By setting the position of the Q-point at halfway on the load line of the amplifier's characteristics curve, the amplifier will operate as a class A amplifier. By moving the Q-point lower down the load line changes the amplifier into a class AB, B, or C amplifier.

Then the class of operation of the amplifier with regards to its DC operating point can be given as:

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

a. 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 where the voltage and current waveforms overlap as current is drawn only through the transistor that is on.
b. 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.
c. 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.
d. Class I Amplifier – The class I amplifier has two sets of the 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 canceling out any high-frequency signals.

   To produce the positive half of the output signal, the output of the positive switching device is increased in the 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.

e. 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 analog input signals into digital square wave pulses by a delta-sigma modulator and amplifies them to increase the output power before finally being demodulated by a bandpass 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.

f. 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 analog signals into digital pulse width modulated (PWM) signals for amplification increasing the amplifier's 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 classifications 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

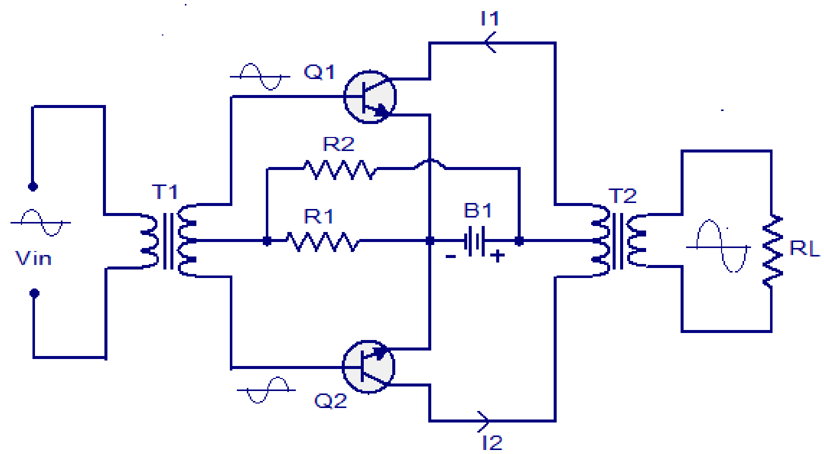
Amplifier Class	Description	Conduction Angle
Class-A	Full cycle 360° of Conduction	$\theta = 2\pi$
Class-B	Half cycle 180° of Conduction	$\theta = \pi$
Class-AB	Slightly more than 180° of conduction	$\pi < \theta < 2\pi$
Class-C	Slightly less than 180° of conduction	$\theta < \pi$
Class-D to T	ON-OFF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

Push-Pull Amplifier

A push-pull amplifier is an amplifier that has an output stage that can drive a current in either direction through the load. The output stage of a typical push-pull amplifier consists of two identical BJTs or MOSFETs one sourcing current through the load while the other one sinking the current from the load. Push-pull amplifiers are superior to single-ended amplifiers (using a single transistor at the output for driving the load) in terms of distortion and performance. A single-ended amplifier, how well it may be designed will surely introduce some distortion due to the non-linearity of its dynamic transfer characteristics.

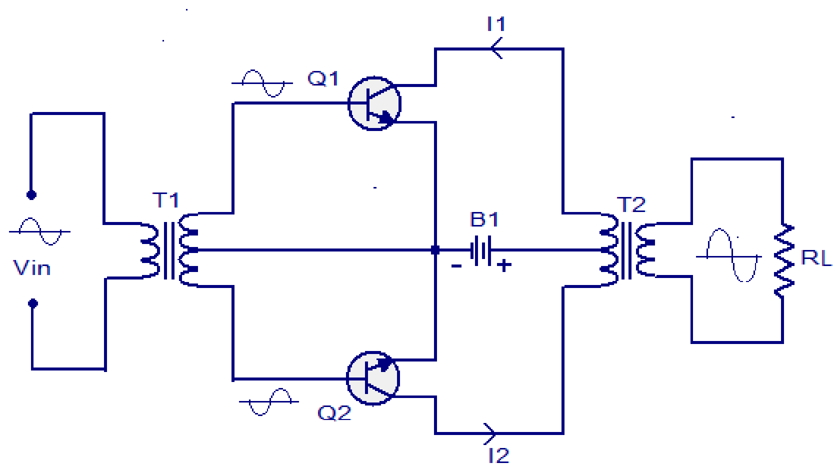
Push-pull amplifiers are commonly used in situations where low distortion, high efficiency, and high output power are required. The basic operation of a push-pull amplifier is as follows: The signal to be amplified is first split into two identical signals 180° out of phase. Generally, this splitting is done using an input coupling transformer. The input coupling transformer is so arranged that one signal is applied to the input of one transistor and the other signal is applied to the input of the other transistor. Advantages of the push-pull amplifier are low distortion, absence of magnetic saturation in the coupling transformer core, and cancellation of power supply ripples which results in the absence of hum while the disadvantages are the need of two identical transistors and the requirement of bulky and costly coupling transformers. A push-pull amplifier can be made in Class A, Class B, Class AB, or Class C configurations.

Class A push-pull amplifier.



The circuit diagram of a typical Class A push-pull amplifier is shown above. Q1 and Q2 are two identical transistor and their emitter terminals are connected together. R1 and R2 are meant for biasing the transistors. Collector terminals of the two transistors are connected to the respective ends of the primary of the output transformer T2. The power supply is connected between the center tap of the T2 primary and the emitter junction of the Q1 and Q2. The base terminal of each transistor is connected to the respective ends of the secondary of the input coupling transformer T1. The input signal is applied to the primary of T1 and output load RL is connected across the secondary of T2. The quiescent current of Q2 and Q1 flows in opposite directions through the corresponding halves of the primary of T2 and as a result, there will be no magnetic saturation. From the figure, you can see the phase splitted signals being applied to the base of each transistor. When Q1 is driven positive using the first half of its input signal, the collector current of Q1 increases. At the same time, Q2 is driven negative using the first half of its input signal and so the collector current of Q2 decreases. From the figure, you can understand that the collector currents of Q1 and Q2 ie; I1 and I2 flows in the same direction through the corresponding halves of the T2 primary. As a result, an amplified version of the original input signal is induced in the T2 secondary. The current through the T2 secondary is the difference between the two collector currents. Harmonics will be much less in the output due to cancellation and this is results in low distortion.

Class B push-pull amplifier



The Class B push-pull amplifier is almost similar to the Class A push-pull amplifier and the only difference is that there are no biasing resistors for a Class B push-pull amplifier. This means that the two transistors are biased at the cutoff point. The Class B configuration can provide better power output and has higher efficiency (up to 78.5%). Since the transistors are biased at the cutoff point, they consume no power during the idle condition and this adds to the efficiency. The advantages of Class B push-pull amplifiers are, ability to work in limited power supply conditions (due to the higher efficiency), the absence of even harmonics in the output, simple circuitry when compared to the Class A configuration, etc. The disadvantages are a higher percentage of harmonic distortion when compared to the Class A, cancellation of power supply ripples is not as efficient as in Class A push-pull amplifier and which results in the need of a well-regulated power supply. The circuit diagram of a classic Class B push-pull amplifier is shown in the diagram below.

The input signal is converted into two similar but phase opposite signals by the input transformer T1. One out of these two signals are applied to the base of the upper transistor while the other one is applied to the base of the other transistor. You can understand this from the circuit diagram. When transistor Q1 is driven to the positive side using the positive half of its input signal, the reverse happens in the transistor Q2. That means when the collector current of Q1 is going in the increasing direction, the collector current of Q2 goes in the decreasing direction. Anyway, the current flow through the respective halves of the primary of the T2 will be in the same direction. Have a look at the figure for a better understanding. This current flow through the T2 primary results in a waveform induced across its secondary. The waveform induced across the secondary is similar to the original input signal but amplified in terms of magnitude.

Cross over distortion.

Cross-over distortion is a type of distortion commonly seen in Class B amplifier configurations. As we said earlier, the transistor is biased at the cut-off point in the Class B amplifier. We all know a Silicon transistor requires 0.7V and a Germanium diode requires 0.2V of voltage across its base-emitter junction before entering into conducting mode and this base-emitter voltage is called cut-in voltage. Germanium diodes are out of scope in amplifiers and we can talk about a Class B push-pull amplifier based on Silicon transistors. Since the transistors are biased to cut off, the voltage across their base-emitter junction remains zero during the zero-input condition. The only source for the transistors to get the necessary cut-in voltage is the input signal itself and the required cut-in voltage will be looted from the input signal itself. As a result, portions of the input waveform that are below 0.7V (cut in voltage) will be canceled and so the corresponding portions will be absent in the output waveform too. Have a look at the figure below for a better understanding.

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