Bipolar Junction Transistor

Introduction

Bipolar junction transistor definition:A bipolar junction transistor or BJT is a three terminal electronic device that amplifies the flow of current. It is a current controlled device. In bipolar junction transistor, electric current is conducted by both free electrons and holes.

Unlike a normal pn junction diode, the transistor has two p-n junctions.

Types of Bipolar Junction Transistors (BJTs)

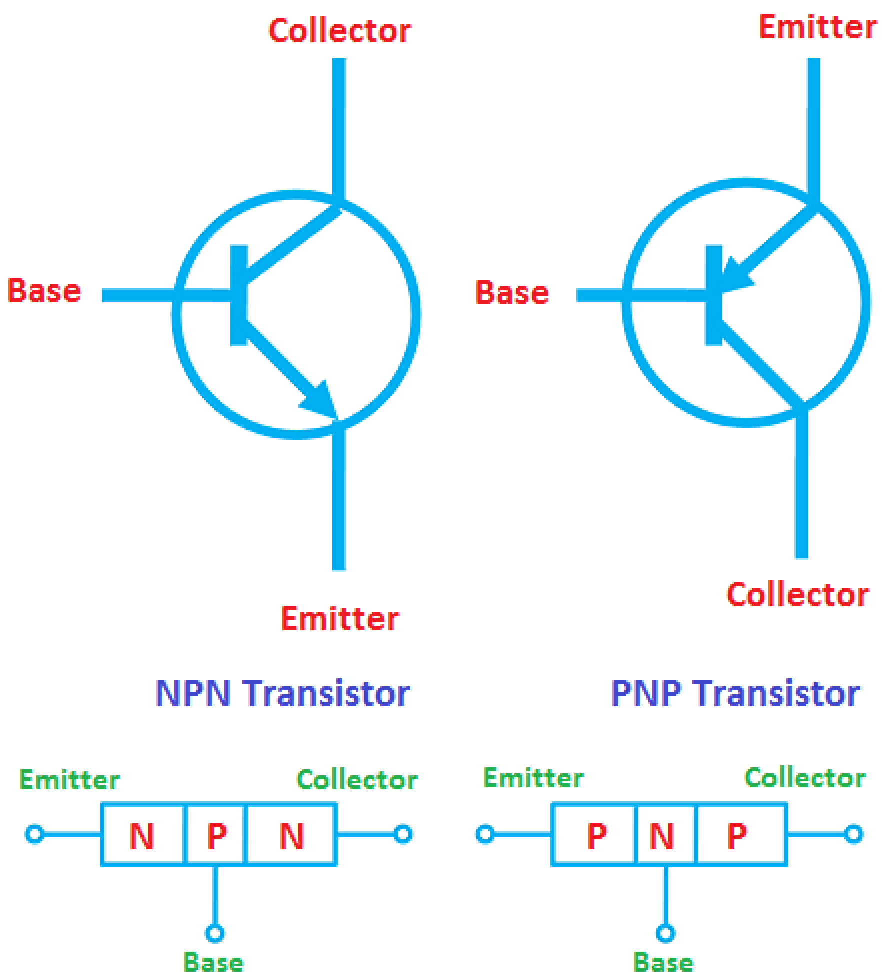
The bipolar junction transistors are formed by sandwiching either n-type or p-type semiconductor layer between pairs of opposite polarity semiconductor layers.

Bipolar junction transistors are classified into two types based on their construction: They are

- NPN transistor
- PNP transistor

NPN transistor

When a single p-type semiconductor layer is sandwiched between two n-type semiconductor layers, the transistor is said to be an npn transistor



PNP transistor

When a single n-type semiconductor layer is sandwiched between two p-type semiconductor layers, the transistor is said to be a pnp transistor.

Both PNP and NPN transistors consist of three terminals: they are emitter, base, and collector.

Terminals of BJT

Emitter:

As the name suggests, the emitter section supplies the charge carriers. The emitter section is heavily doped so that it can inject a large number of charge carriers into the base. The size of the emitter is always greater than the base.

Base:

The middle layer is called base. The base of the transistor is very thin as compared to emitter and collector. It is very lightly doped.

Collector:

The function of the collector is to collect charge carriers. It is moderately doped. That is the doping level of the collector section is in between emitter and base. The size of the collector is always greater than emitter and base. The collector area in the transistor is considerably larger than the emitter area. This is because the collector region has to handle more power than the emitter does and more surface area is required for heat dissipation.

In transistor, the amplification is achieved by passing input current from a region of low resistance to a region of high resistance.

Applications of bipolar junction transistor

The various applications of bipolar junction transistors include:

- Televisions
- Mobile phones

- Computers
- Radio transmitters
- Audio amplifiers

BJT operation modes

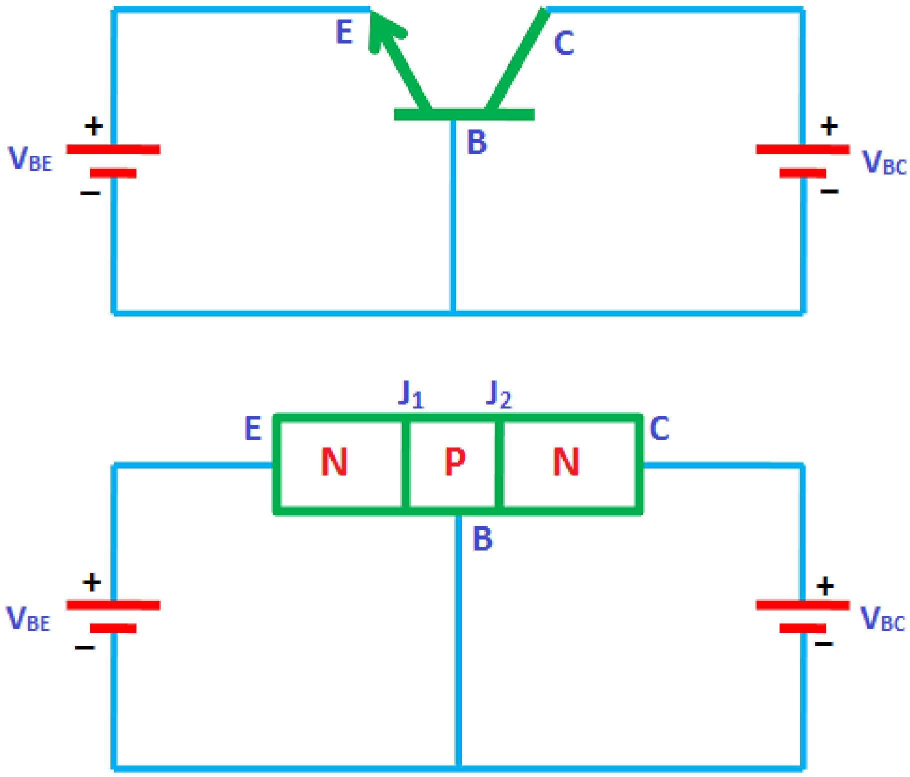
The transistor can be operated in three modes:

- Cut-off mode
- Saturation mode
- Active mode

In order to operate transistor in one of these regions, we have to supply dc voltage to the npn or pnp transistor. Based on the polarity of the applied dc voltage, the transistor operates in any one of these regions.

Applying dc voltage to the transistor is nothing but the biasing of transistor.

Cutoff mode



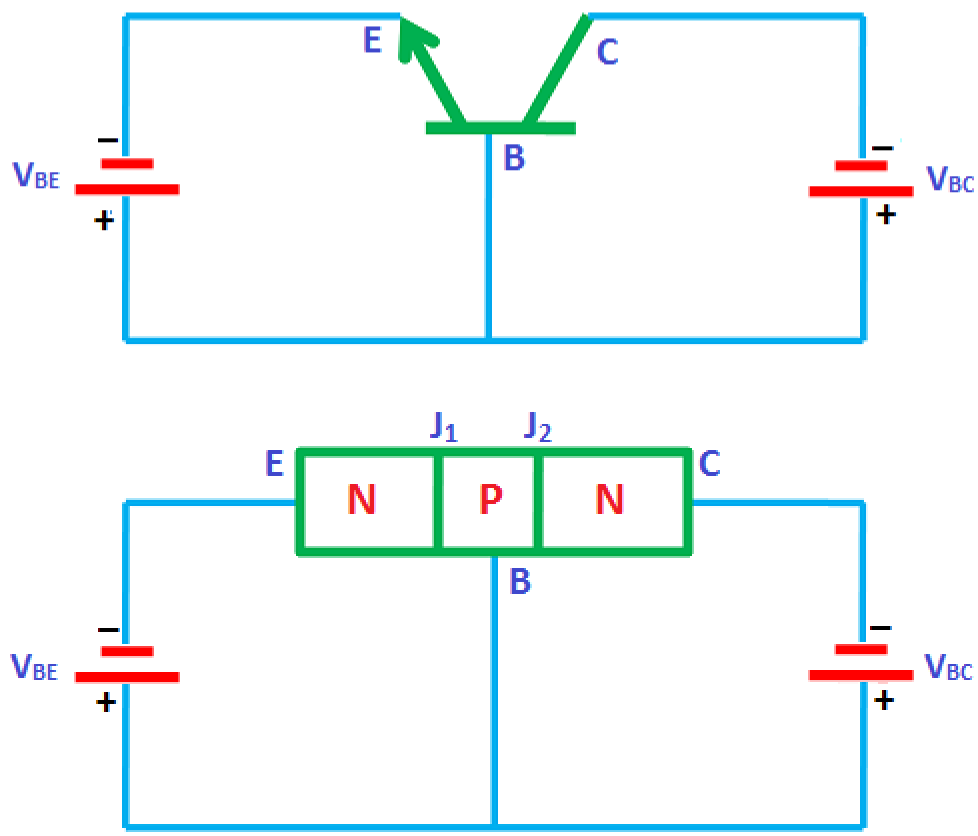
Cutoff mode

In the cutoff mode, both the junctions of the transistor (emitter to base and collector to base) are reverse biased. In other words, if we assume two p-n junctions as two p-n junction diodes, both the diodes are reverse biased in cutoff mode. We know that in reverse bias condition, no current flows through the device. Hence, no current flows through the transistor. Therefore, the transistor is in off state and acts like an open switch.

The cutoff mode of the transistor is used in switching operation for switch OFF application.

Saturation mode

In the saturation mode, both the junctions of the transistor (emitter to base and collector to base) are forward biased. In other words, if we assume two p-n junctions as two p-n junction diodes, both the diodes are forward biased in saturation mode. We know that in forward bias condition, current flows through the device. Hence, electric current flows through the transistor.



Saturation mode

In saturation mode, free electrons (charge carriers) flows from emitter to base as well as from collector to base. As a result, a huge current will flow to the base of transistor.

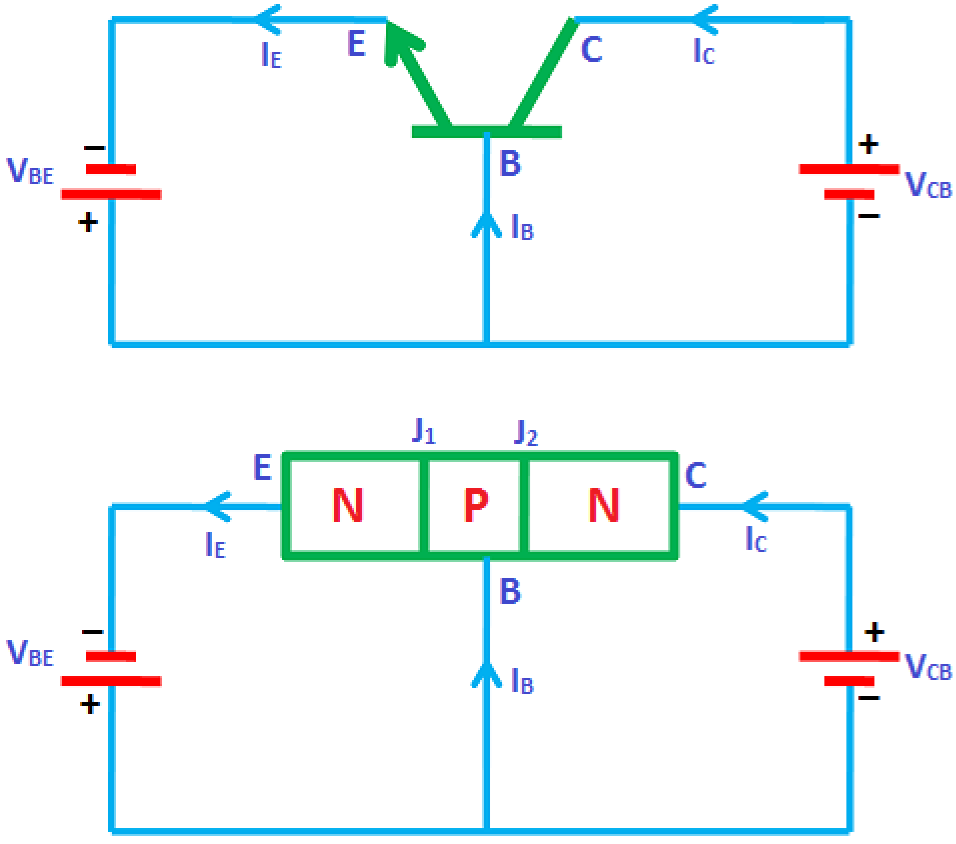
Therefore, the transistor in saturation mode will be in on state and acts like a closed switch.

The saturation mode of the transistor is used in switching operation for switch ON application.

From the above discussion, we can say that by operating the transistor in saturation and cutoff region, we can use the transistor as an ON/OFF switch.

Active mode

In the active mode, one junction (emitter to base) is forward biased and another junction (collector to base) is reverse biased. In other words, if we assume two p-n junctions as two p-n junction diodes, one diode will be forward biased and another diode will be reverse biased.



Active mode

The active mode of operation is used for the amplification of current.

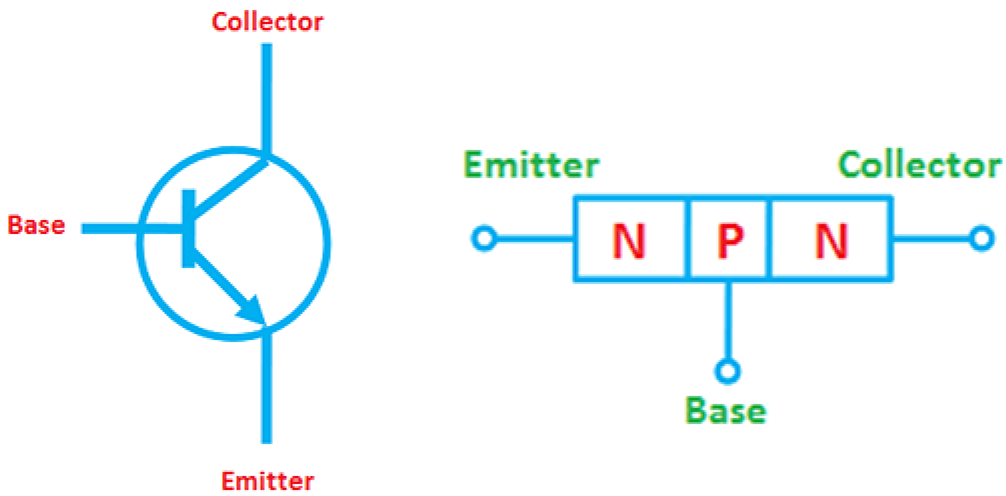
From the above discussion, we can say that the transistor works as an ON/OFF switch in saturation and cutoff modes whereas it works as an amplifier of current in active mode.

NPN transistor

When a single p-type semiconductor layer is sandwiched between two n-type semiconductor layers, an npn transistor is formed.

NPN transistor symbol

The circuit symbol and diode analogy of npn transistor is shown in the below figure.



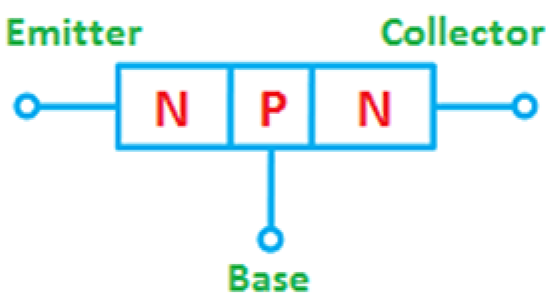
NPN transistor symbol

In the above figure, it is shown that the electric current always flows from p-region to n-region.

NPN transistor construction

The npn transistor is made up of three semiconductor layers: one p-type semiconductor layer and two n-type semiconductor layers.

The p-type semiconductor layer is sandwiched between two n-type semiconductor layers.



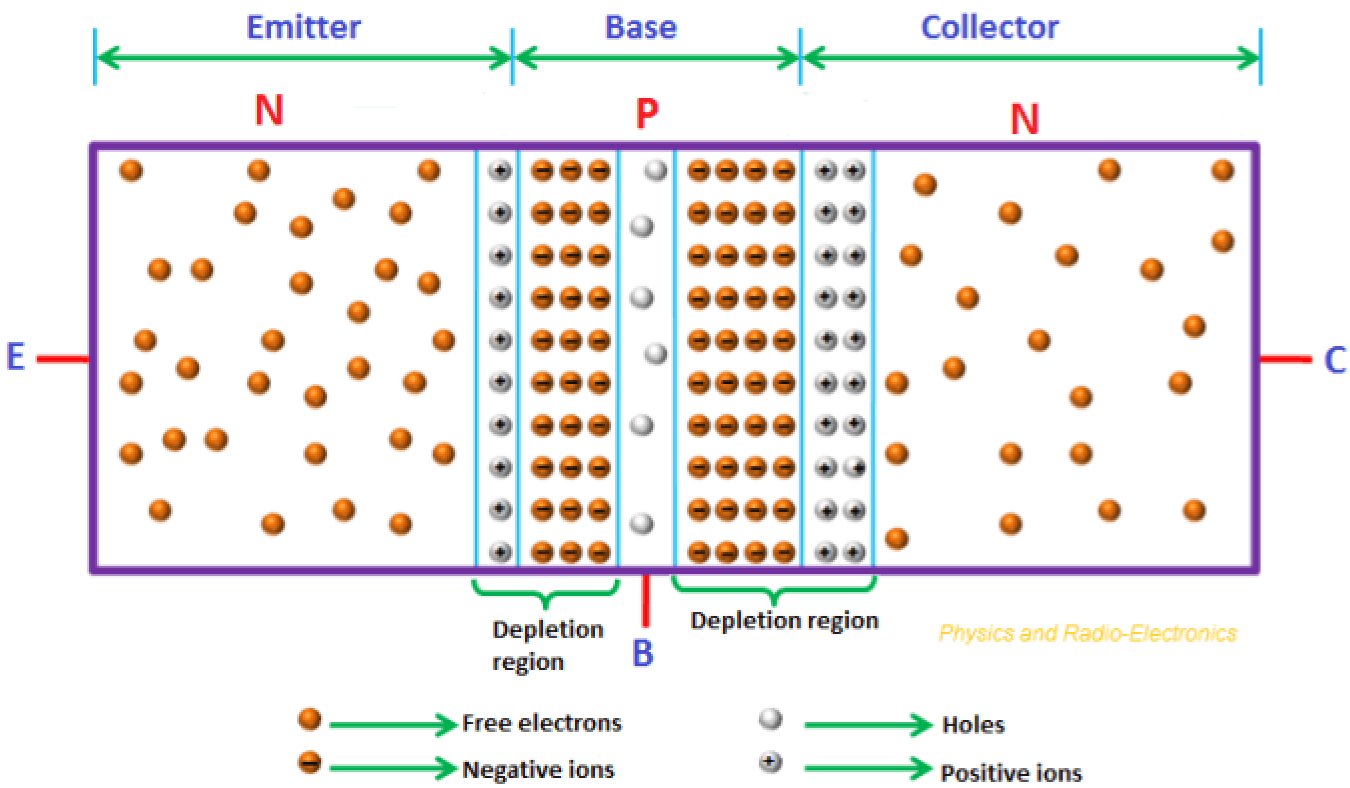
The npn transistor has three terminals: emitter, base and collector. The emitter terminal is connected to the left side n-type layer. The collector terminal is connected to the right side n-type layer. The base terminal is connected to the p-type layer.

The npn transistor has two p-n junctions. One junction is formed between the emitter and the base. This junction is called emitter-base junction or emitter junction. The other junction is formed between the base and the collector. This junction is called collector-base junction or collector junction.

Working of a npn transistor

Unbiased npn transistor

When no voltage is applied to a transistor, it is said to be an unbiased transistor. At the left side n-region (emitter) and right side n-region (collector), free electrons are the majority carriers and holes are the minority carriers whereas in p-region (base), holes are the majority carriers and free electrons are the minority carriers.

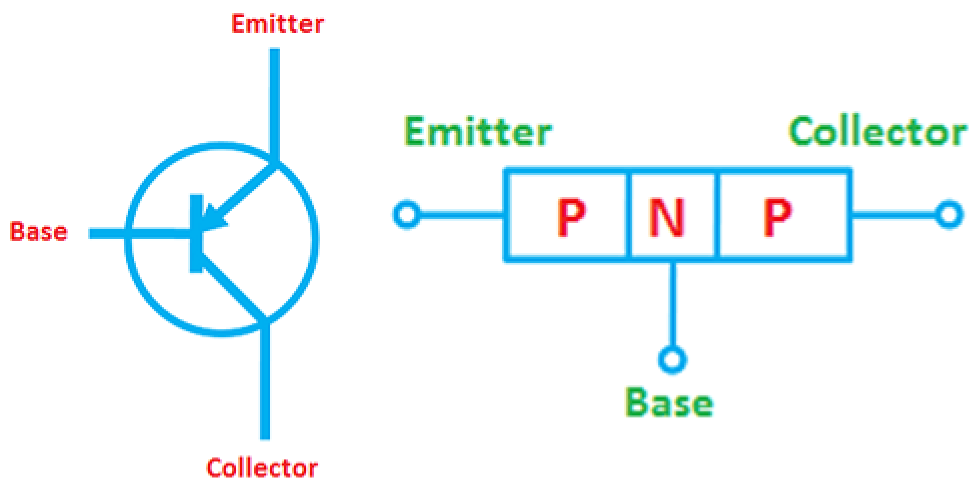


PNP transistor

When a single n-type semiconductor layer is sandwiched between two p-type semiconductor layers, a pnp transistor is formed.

PNP transistor symbol

The circuit symbol and diode analogy of pnp transistor is shown in the below figure.

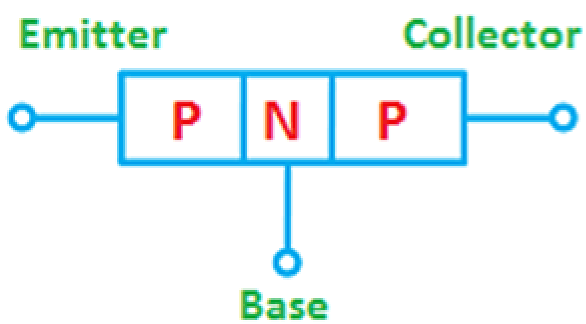


PNP transistor symbol

PNP transistor construction

The pnp transistor is made up of three semiconductor layers: one n-type semiconductor layer and two p-type semiconductor layers.

The n-type semiconductor layer is sandwiched between two p-type semiconductor layers.



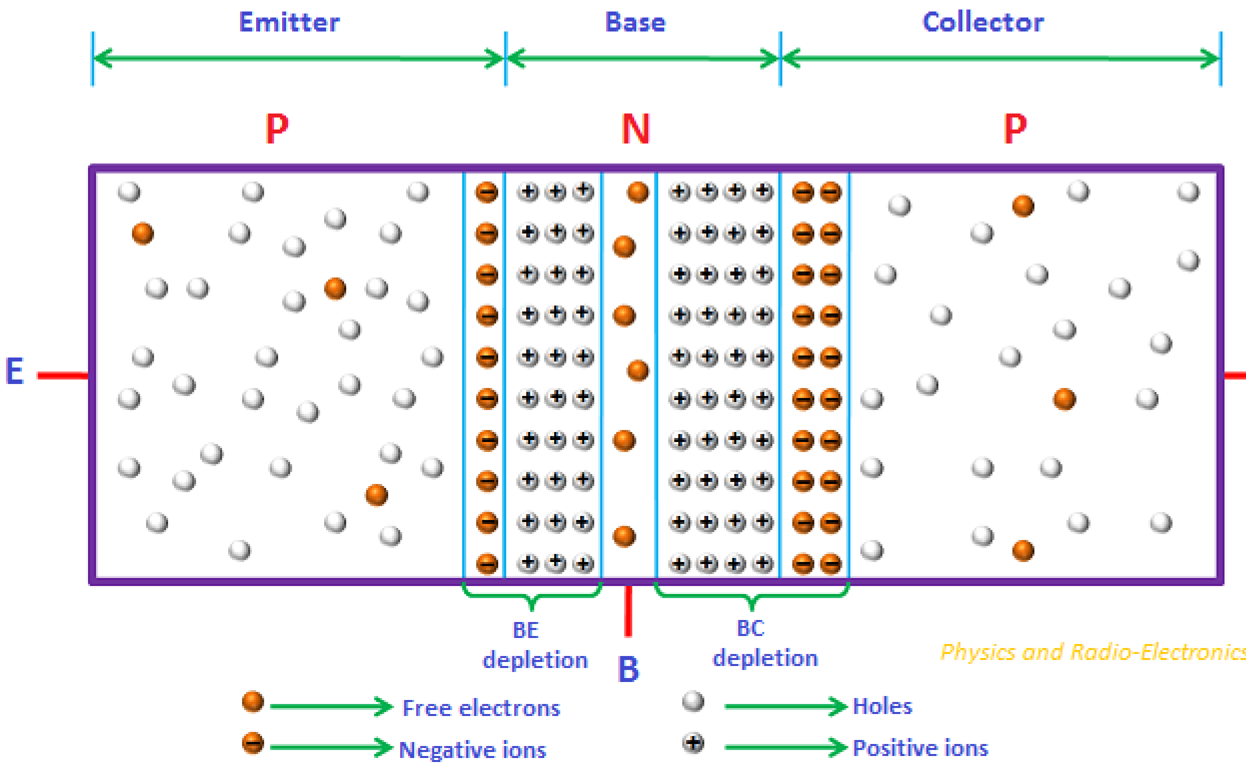
The pnp transistor has three terminals: emitter, base and collector. The emitter terminal is connected to the left side p-type layer. The collector terminal is connected to the right side p-type layer. The base terminal is connected to the n-type layer.

The pnp transistor has two p-n junctions. One junction is formed between the emitter and the base. This junction is called emitter-base junction or emitter junction. The other junction is formed between the base and the collector. This junction is called collector-base junction or collector junction.

Working of a pnp transistor

Unbiased pnp transistor

When no voltage is applied to a pnp transistor, it is said to be an unbiased pnp transistor. At the left side p-region (emitter) and right side p-region (collector), holes are the majority carriers and free electrons are the minority carriers whereas in n-region (base), free electrons are the majority carriers and holes are the minority carriers.



We know that the charge carriers (free electrons and holes) always try to move from higher concentration region to lower concentration region.

Types of Transistor Configuration

Transistor is an electronic device which is primarily used to amplify the electric current.

We know that transistor has three terminals namely emitter (E), base (B), and collector (C). But to connect a transistor in the circuit, we need four terminals: two terminals for input and other two terminals for output.

But the transistor does not have four terminals, then how do we connect transistor in a circuit. It is not as difficult as you think. One of the three terminals is used as common to both input and output.

When a transistor is to be connected in a circuit, one terminal is used as the input terminal, the other terminal is used as the output terminal and the third terminal is common to the input and output.

That means here input is applied between the input terminal and common terminal, and the corresponding output is taken between the output terminal and common terminal.

Depending upon the terminal which is used as a common terminal to the input and output terminals, the transistor can be connected in the following three configurations. They are:

- Common base (CB) configuration
- Common emitter (CE) configuration
- Common collector (CC) configuration

In every configuration, the base-emitter junction J_E is always forward biased and the collector-base junction J_C is always reverse biased to operate the transistor as a current amplifier.

Common base (CB) configuration

In common base configuration, emitter is the input terminal, collector is the output terminal, and base is the common terminal. The base terminal is grounded in the common base configuration. So the common base configuration is also known as grounded base configuration.

Common emitter (CE) configuration

In common emitter configuration, base is the input terminal, collector is the output terminal, and emitter is the common terminal. The emitter terminal is grounded in the common emitter configuration. So the common emitter configuration is also known as grounded emitter configuration.

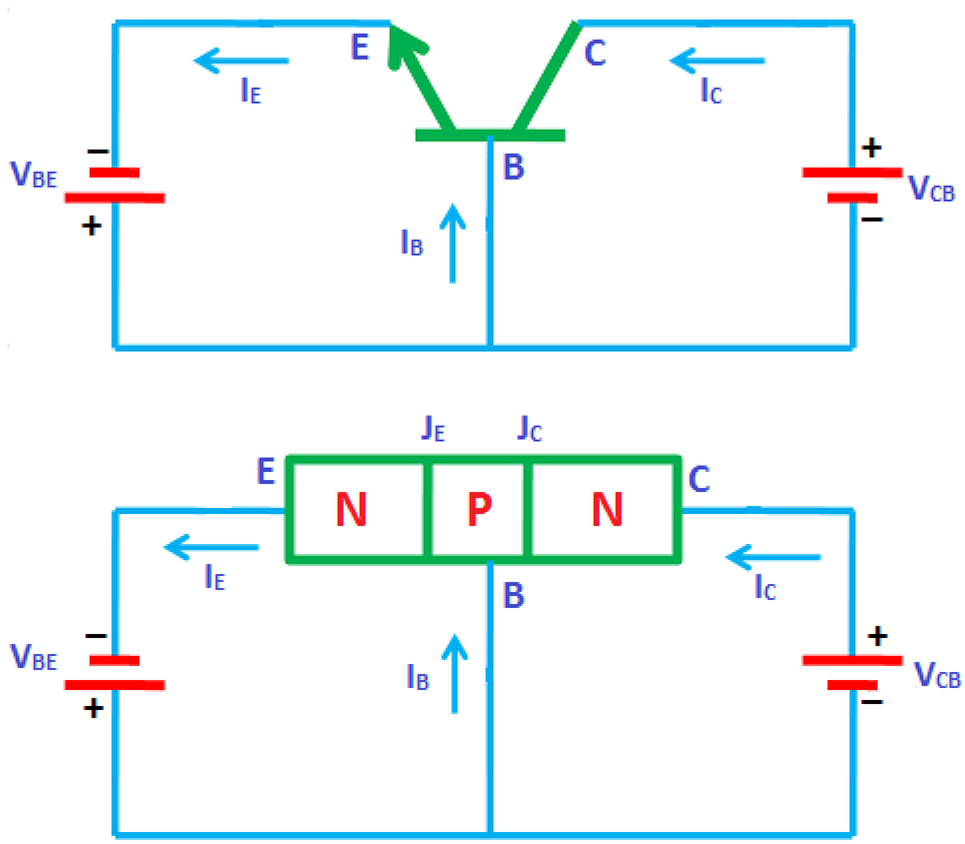
Common collector (CC) configuration

In common collector configuration, base is the input terminal, emitter is the output terminal, and collector is the common terminal. The collector terminal is grounded in the common collector configuration. So the common collector configuration is also known as grounded collector configuration.

Common Base Configuration

In common base configuration, emitter is the input terminal, collector is the output terminal and base terminal is connected as a common terminal for both input and output. That means the emitter terminal and common base terminal are known as input terminals whereas the collector terminal and common base terminal are known as output terminals.

In common base configuration, the base terminal is grounded so the common base configuration is also known as grounded base configuration. Sometimes common base configuration is referred to as common base amplifier, CB amplifier, or CB configuration.



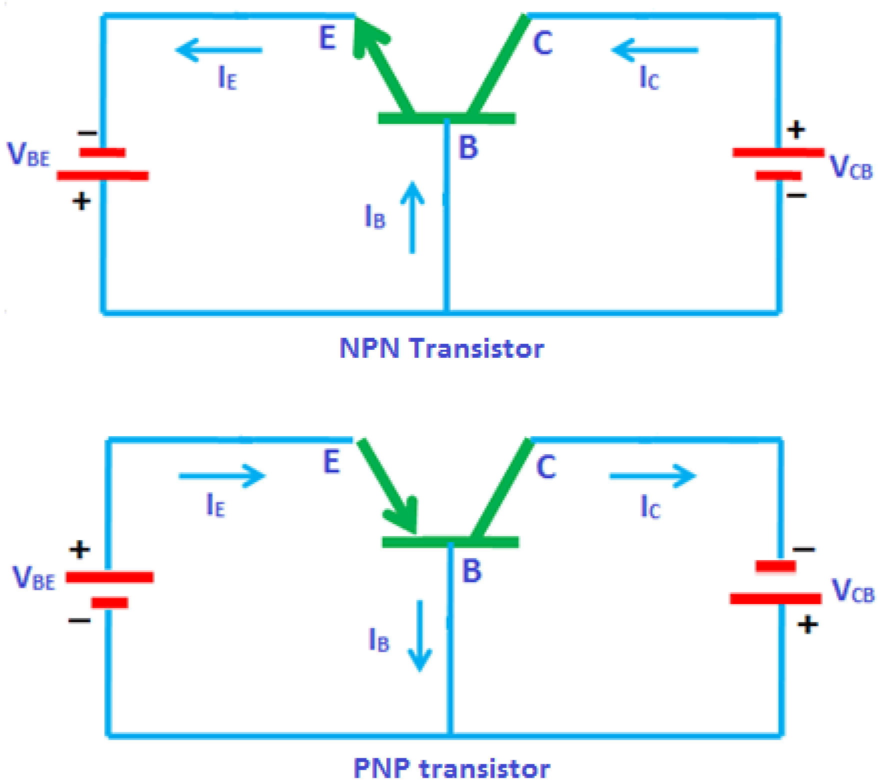
Common base configuration

The input signal is applied between the emitter and base terminals while the corresponding output signal is taken across the collector and base terminals. Thus the base terminal of a transistor is common for both input and output terminals and hence it is named as common base configuration.

The supply voltage between base and emitter is denoted by V_{BE} while the supply voltage between collector and base is denoted by V_{CB}.

As mentioned earlier, in every configuration, the base-emitter junction J_E is always forward biased and collector-base junction J_C is always reverse biased. Therefore, in common base configuration, the base-emitter junction J_E is forward biased and collector-base junction J_C is reverse biased.

The common base configuration for both NPN and PNP transistors is shown in the below figure.



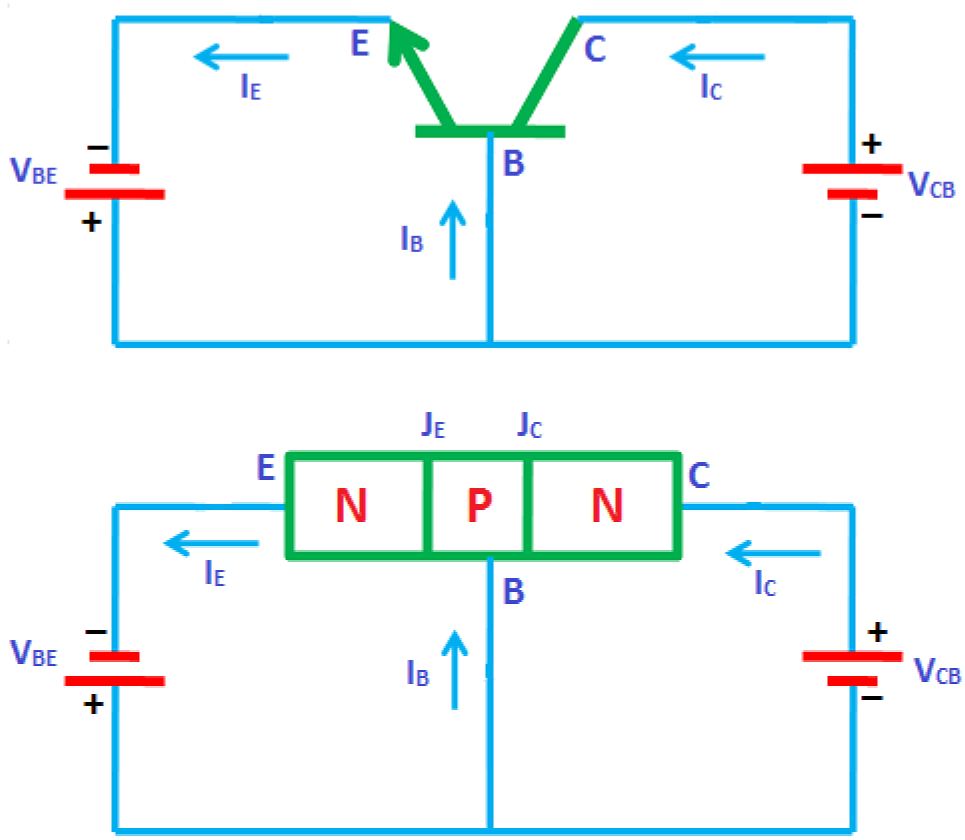
Common base configuration

From the above circuit diagrams of npn and pnp transistors, it can be seen that for both npn and pnp transistors, the input is applied to the emitter and the output is taken from the collector. The common terminal for both the circuits is the base.

Current flow in common base amplifier

For the sake of understanding, let us consider NPN transistor in common base configuration.

The npn transistor is formed when a single p-type semiconductor layer is sandwiched between two n-type semiconductor layers.



Common base configuration

The base-emitter junction J_E is forward biased by the supply voltage V_{BE} while the collector-base junction J_C is reverse biased by the supply voltage V_{CB}.

Due to the forward bias voltage V_{BE}, the free electrons (majority carriers) in the emitter region experience a repulsive force from the negative terminal of the battery similarly holes (majority carriers) in the base region experience a repulsive force from the positive terminal of the battery.

As a result, free electrons start flowing from emitter to base similarly holes start flowing from base to emitter. Thus free electrons which are flowing from emitter to base and holes which are flowing from base to emitter conducts electric current. The actual current is carried by free electrons which are flowing from emitter to base.

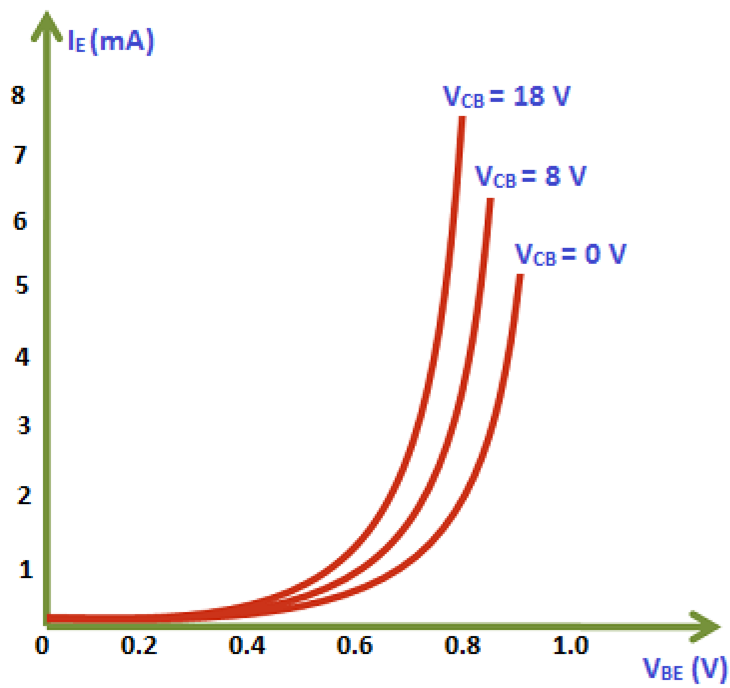
Input characteristics

The input characteristics describe the relationship between input current (I_E) and the input voltage (V_{BE}).

First, draw a vertical line and horizontal line. The vertical line represents y-axis and horizontal line represents x-axis. The input current or emitter current (I_E) is taken along the y-axis (vertical line) and the input voltage (V_{BE}) is taken along the x-axis (horizontal line).

To determine the input characteristics, the output voltage V_{CB} (collector-base voltage) is kept constant at zero volts and the input voltage V_{BE} is increased from zero volts to different voltage levels. For each voltage level of the input voltage (V_{BE}), the input current (I_E) is recorded on a paper or in any other form.

A curve is then drawn between input current I_E and input voltage V_{BE} at constant output voltage V_{CB} (0 volts).



I/p characteristics CB configuration

Output characteristics

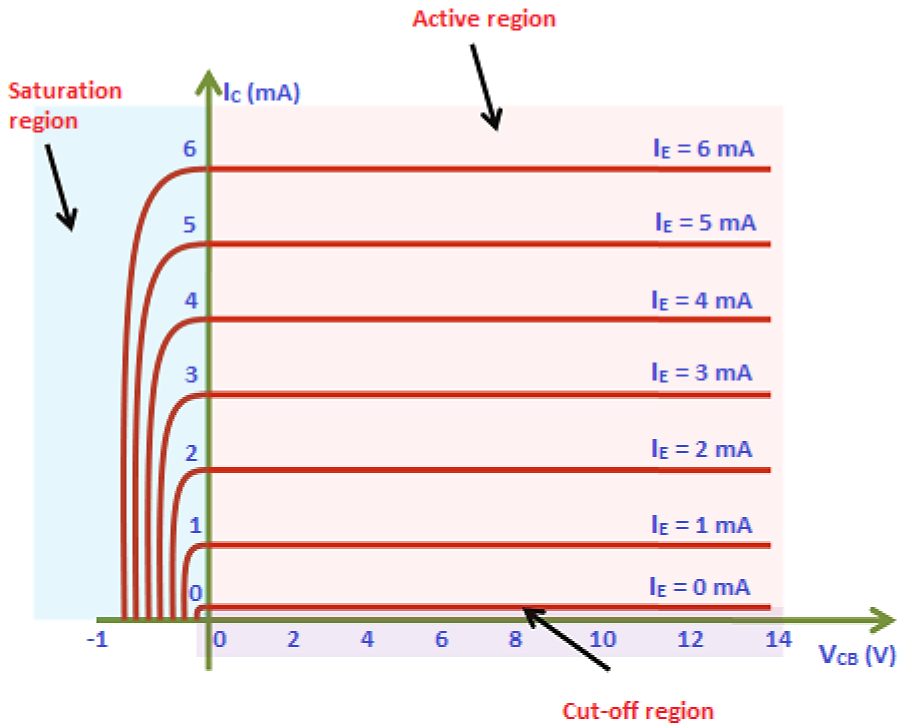
The output characteristics describe the relationship between output current (I_C) and the output voltage (V_{CB}).

First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-axis. The output current or collector current (I_C) is taken along the y-axis (vertical line) and the output voltage (V_{CB}) is taken along the x-axis (horizontal line).

To determine the output characteristics, the input current or emitter current I_E is kept constant at zero mA and the output voltage V_{CB} is increased from zero volts to different voltage levels. For each voltage level of the output voltage V_{CB}, the output current (I_C) is recorded.

A curve is then drawn between output current I_C and output voltage V_{CB} at constant input current I_E (0 mA).

When the emitter current or input current I_E is equal to 0 mA, the transistor operates in the cut-off region.



O/P characteristics CB configuration

Current gain (α)

The current gain of a transistor in CB configuration is defined as the ratio of output current or collector current (I_C) to the input current or emitter current (I_E).

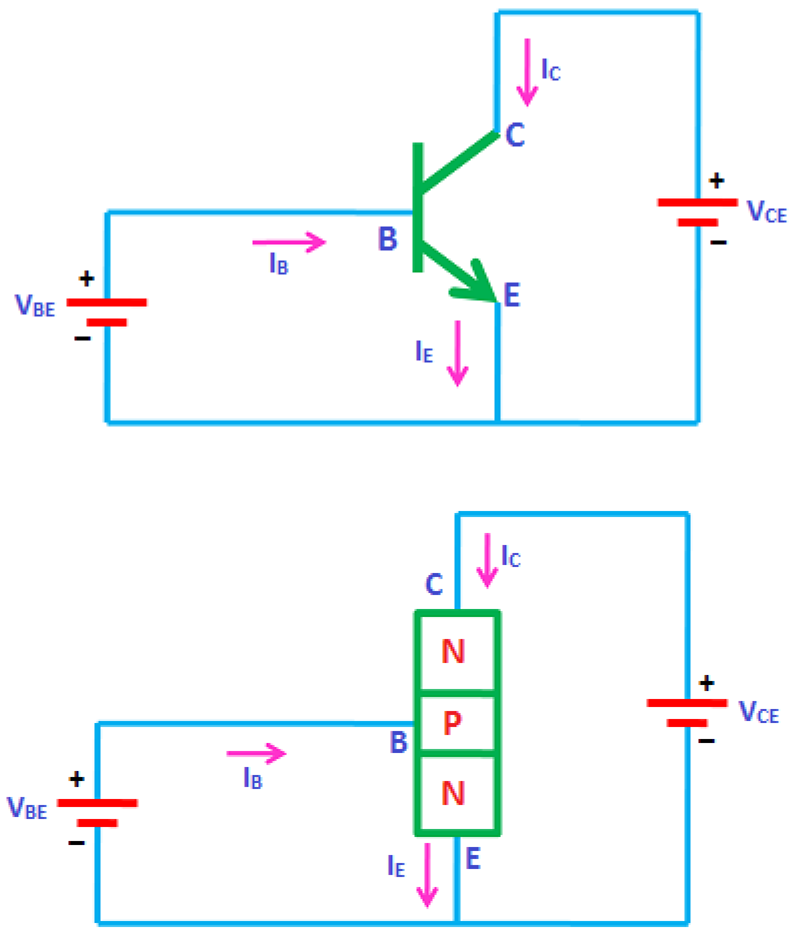
$$\alpha = \frac{I_C}{I_E}$$

The current gain of a transistor in CB configuration is less than unity. The typical current gain of a common base amplifier is 0.98

Common Emitter Configuration

In common emitter configuration, base is the input terminal, collector is the output terminal and emitter is the common terminal for both input and output.

In common emitter configuration, the emitter terminal is grounded so the common emitter configuration is also known as grounded emitter configuration. Sometimes common emitter configuration is also referred to as CE configuration, common emitter amplifier, or CE amplifier. The common emitter (CE) configuration is the most widely used transistor configuration.



Common emitter configuration

The common emitter (CE) amplifiers are used when large current gain is needed.

Input characteristics

The input characteristics describe the relationship between input current or base current (I_B) and input voltage or base-emitter voltage (V_{BE}).

First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-axis. The input current or base current (I_B) is taken along y-axis (vertical line) and the input voltage (V_{BE}) is taken along x-axis (horizontal line).

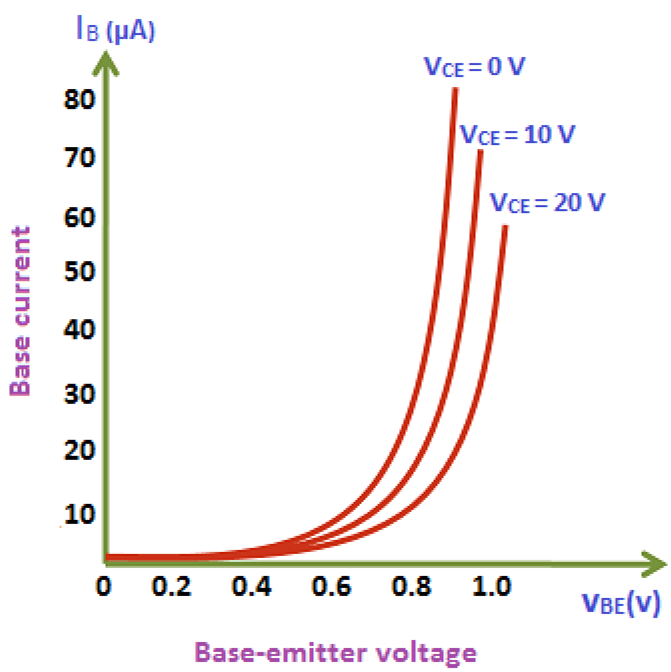
To determine the input characteristics, the output voltage V_{CE} is kept constant at zero volts and the input voltage V_{BE} is increased from zero volts to different voltage levels. For each voltage level of input voltage (V_{BE}), the corresponding input current (I_B) is recorded.

Input characteristics

The input characteristics describe the relationship between input current or base current (I_B) and input voltage or base-emitter voltage (V_{BE}).

First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-axis. The input current or base current (I_B) is taken along y-axis (vertical line) and the input voltage (V_{BE}) is taken along x-axis (horizontal line).

To determine the input characteristics, the output voltage V_{CE} is kept constant at zero volts and the input voltage V_{BE} is increased from zero volts to different voltage levels. For each voltage level of input voltage (V_{BE}), the corresponding input current (I_B) is recorded.



I/P characteristics CE configuration

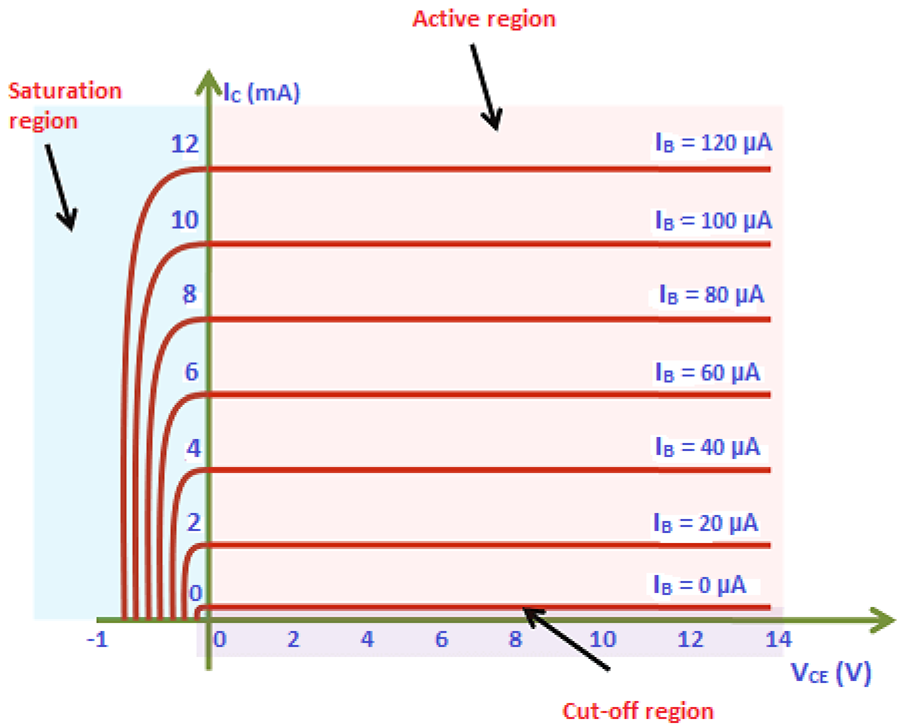
A curve is then drawn between input current I_B and input voltage V_{BE} at constant output voltage V_{CE}

Output characteristics

The output characteristics describe the relationship between output current (I_C) and output voltage (V_{CE}).

First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-axis. The output current or collector current (I_C) is taken along y-axis (vertical line) and the output voltage (V_{CE}) is taken along x-axis (horizontal line).

To determine the output characteristics, the input current or base current I_B is kept constant at 0 μA and the output voltage V_{CE} is increased from zero volts to different voltage levels. For each level of output voltage, the corresponding output current (I_C) is recorded.



O/P Characteristics CE Configuration

A curve is then drawn between output current I_C and output voltage V_{CE} at constant input current I_B (0 μA).

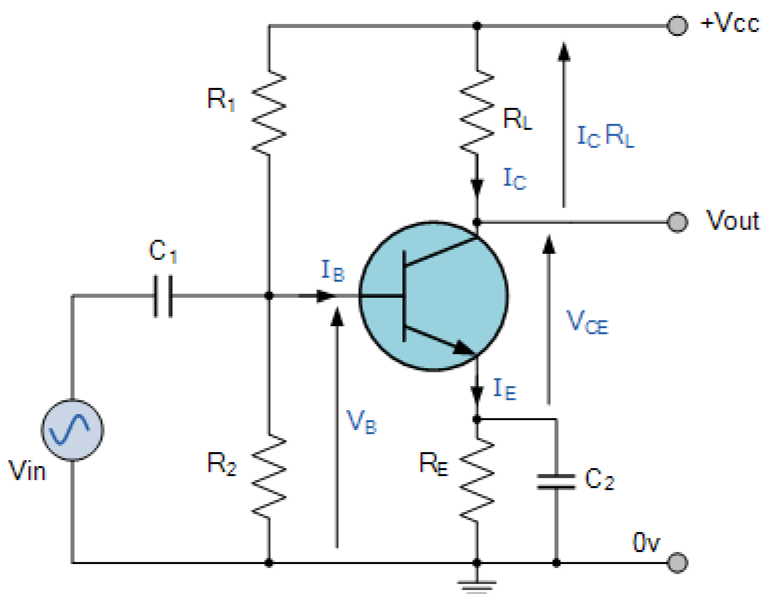
Current gain (α)

The current gain of a transistor in CE configuration is defined as the ratio of output current or collector current (I_C) to the input current or base current (I_B).

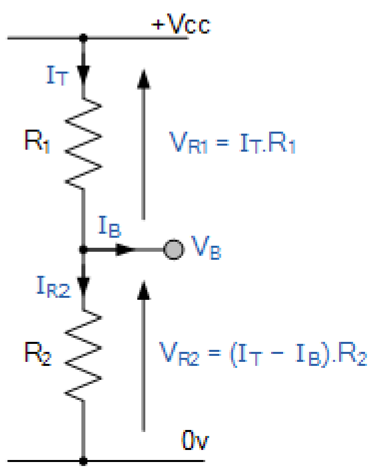
$$\alpha = \frac{I_C}{I_B}$$

The current gain of a transistor in CE configuration is high. Therefore, the transistor in CE configuration is used for amplifying the current.

The Common Emitter Amplifier Circuit

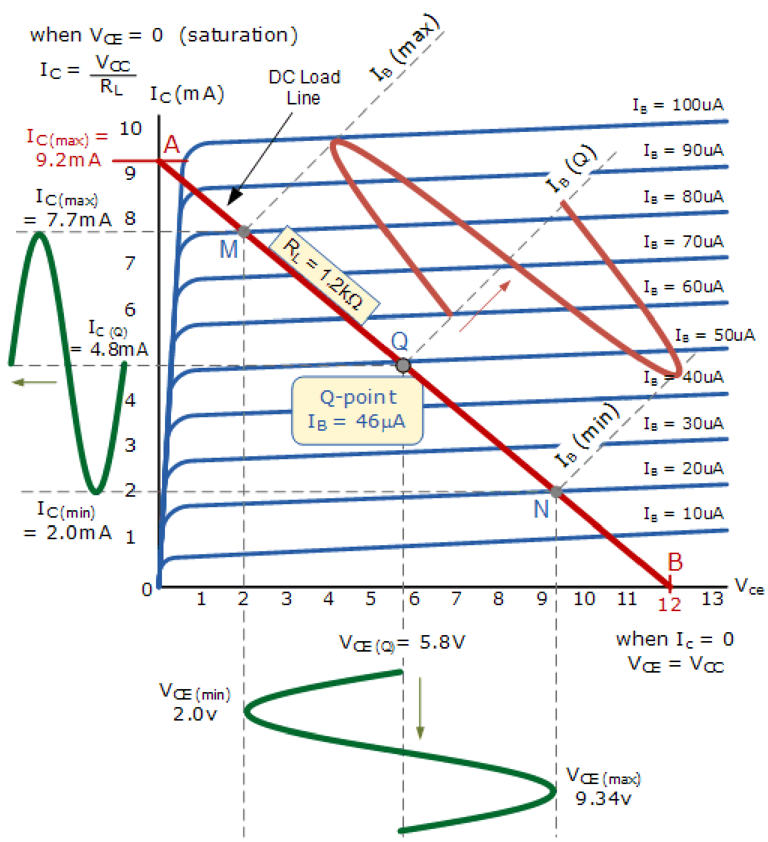


The single stage common emitter amplifier circuit shown above uses what is commonly called "Voltage Divider Biasing". This type of biasing arrangement uses two resistors as a potential divider network across the supply with their center point supplying the required Base bias voltage to the transistor. Voltage divider biasing is commonly used in the design of bipolar transistor amplifier circuits.



This method of biasing the transistor greatly reduces the effects of varying Beta, (β) by holding the Base bias at a constant steady voltage level allowing for best stability. The quiescent Base voltage (Vb) is determined by the potential divider network formed by the two resistors, R1, R2 and the power supply voltage Vcc as shown with the current flowing through both resistors. The best possible position for this Q-point is as close to the center position of the load line as reasonably possible, thereby producing a Class A type amplifier operation, ie. Vce = 1/2Vcc. Consider the **Common Emitter Amplifier** circuit shown below.

Output Characteristics Curves

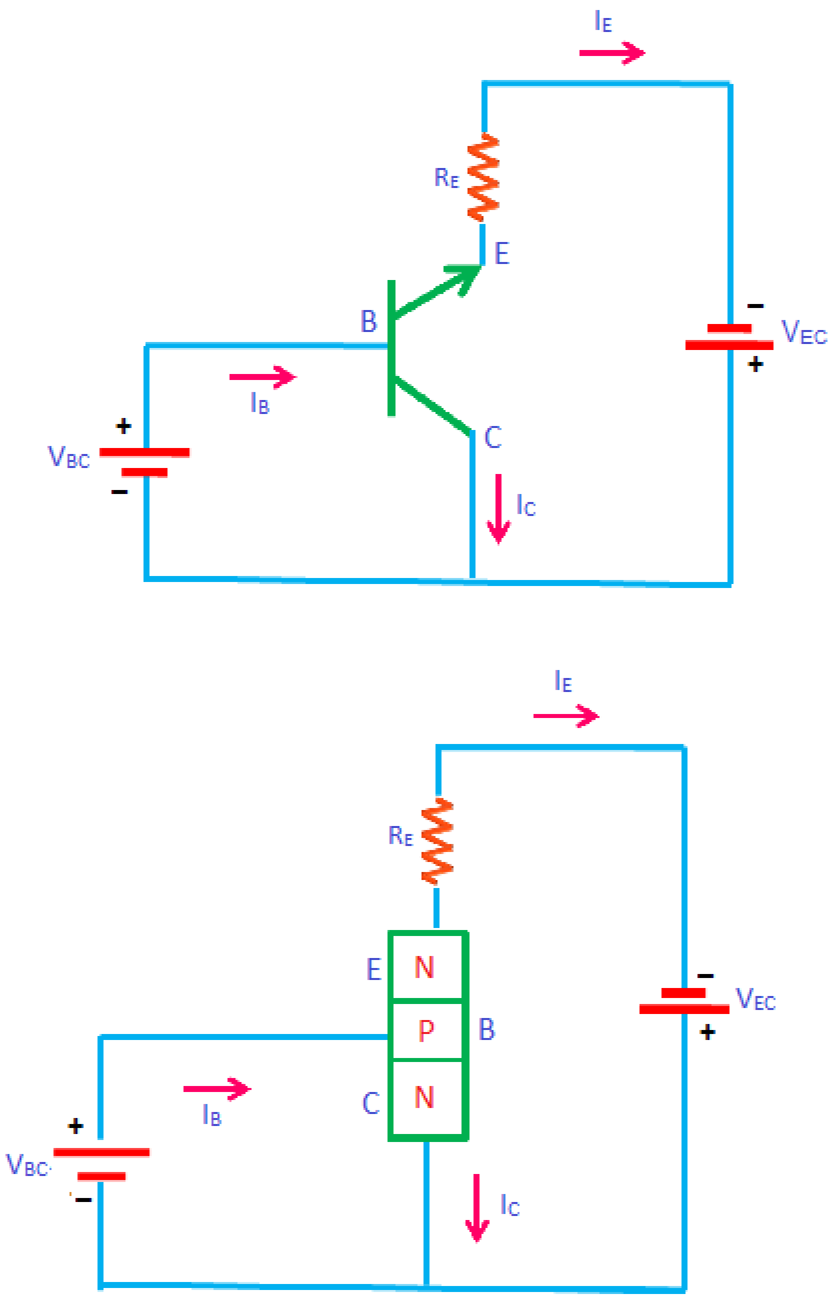


$$\text{Voltage Gain} = \frac{\text{Vout}}{\text{Vin}} = \frac{\Delta V_L}{\Delta V_B} = -\frac{R_L}{R_E}$$

Common Collector Configuration

In this configuration, the base terminal of the transistor serves as the input, the emitter terminal is the output and the collector terminal is common for both input and output. Hence, it is named as common collector configuration. The input is applied between the base and collector while the output is taken from the emitter and collector.

In common collector configuration, the collector terminal is grounded so the common collector configuration is also known as grounded collector configuration.



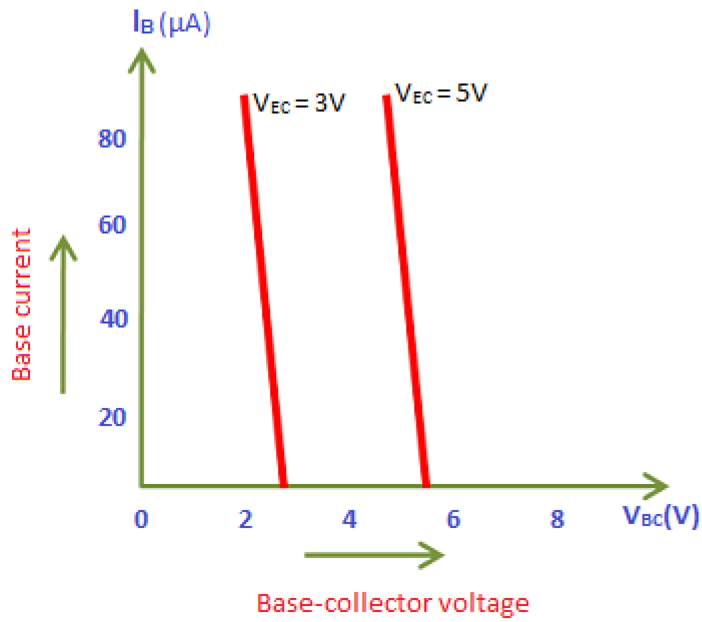
Common collector configuration

Input characteristics

The input characteristics describe the relationship between input current or base current

(I_B) and input voltage or base-collector voltage (V_{BC}).
First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-ax

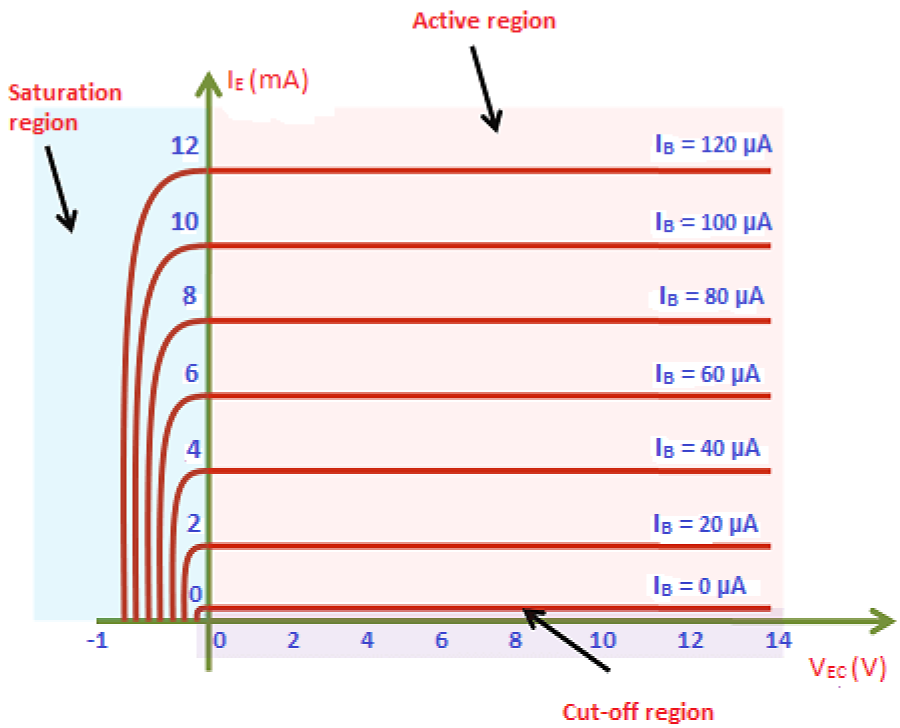
The input current or base current (I_B) is taken along y-axis (vertical line) and the input voltage or base-collector voltage (V_{BC}) is taken along x-axis (horizontal line).
To determine the input characteristics, the output voltage V_{EC} is kept constant at 3V and the input voltage V_{BC} is increased from zero volts to different voltage levels. For each level of input voltage $V_{BC,}$ the corresponding input current I_B is noted. A curve is then drawn between input current I_B and input voltage V_{BC} at constant output voltage V_{EC} (3V).



Input characteristics

Output characteristics

The output characteristics describe the relationship between output current or emitter current (I_E) and output voltage or emitter-collector voltage (V_{EC}).
First, draw a vertical line and a horizontal line. The vertical line represents y-axis and horizontal line represents x-axis.
The output current or emitter current (I_E) is taken along y-axis (vertical line) and the output voltage or emitter-collector voltage (V_{EC}) is taken along x-axis (horizontal line).
To determine the output characteristics, the input current I_B is kept constant at zero micro amperes and the output voltage V_{EC} is increased from zero volts to different voltage levels. For each level of output voltage V_{EC}, the corresponding output current I_E is noted. A curve is then drawn between output current I_E and output voltage V_{EC} at constant input current I_B (0 μA).



Output characteristics

Current amplification factor (γ)

The current amplification factor is defined as the ratio of change in output current or emitter current I_E to the change in input current or base current I_B. It is expressed by **γ.**

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

The current gain of a common collector amplifier is high.