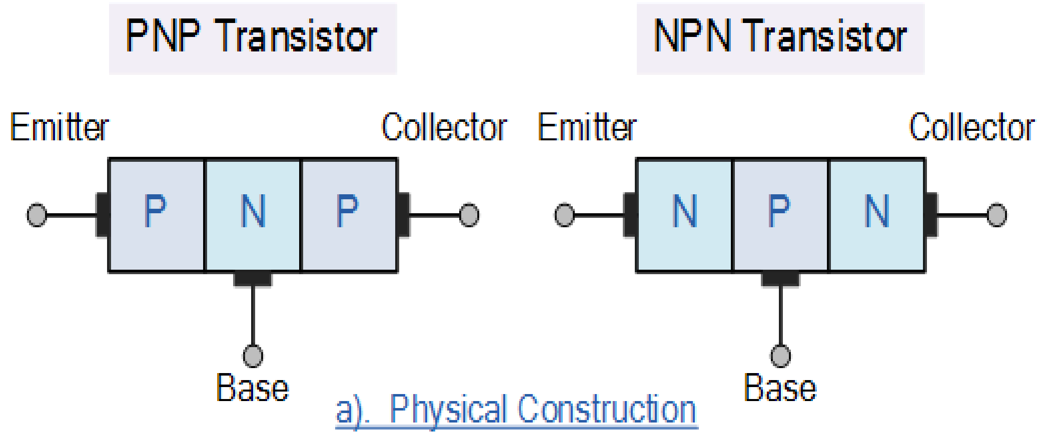
Bipolar Junction Transistor

A bipolar junction transistor is a three-terminal semiconductor device that consists of two p-n junctions which are able to amplify or magnify a signal. It is a current controlled device. The three terminals of the BJT are the base, the collector, and the emitter.

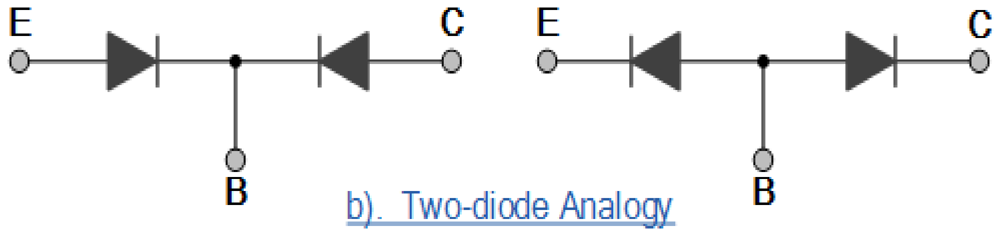
A BJT is a type of transistor that uses both electrons and holes as charge carriers. A signal of small amplitude if applied to the base is available in the amplified form at the collector of the transistor. This is the amplification provided by the BJT. But it does require an external source of DC power supply to carry out the amplification process.

Bipolar Junction Transistor Symbol

There are two types of bipolar junction transistors – NPN transistors and PNP transistors. A diagram of these two types of bipolar junction transistors is given below.



a). Physical Construction



b). Two-diode Analogy

Types of Bipolar Junction Transistor

There are two types of bipolar junction transistors:

- PNP bipolar junction transistor
- NPN bipolar junction transistor

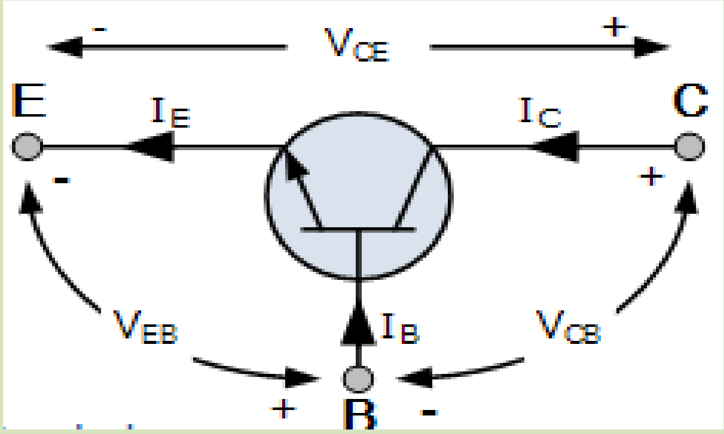
Operation of Bipolar Junction Transistor

There are three operating regions of a bipolar junction transistor:

- Active region: The region in which the transistors operate as an amplifier.
- Saturation region: The region in which the transistor is fully on and operates as a switch such that collector current is equal to the saturation current.
- Cut-off region: The region in which the transistor is fully off and collector current is equal to zero.

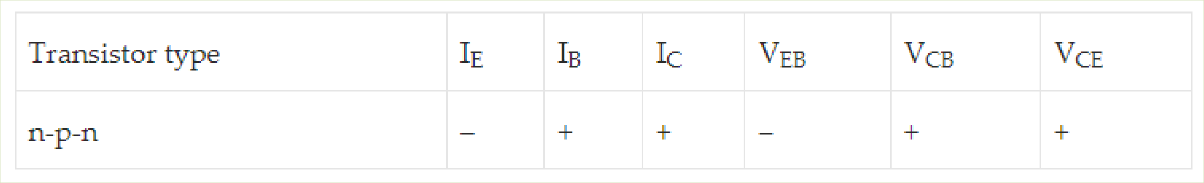
NPN Bipolar Junction Transistor

In an **n-p-n bipolar transistor** one p-type semiconductor resides between two n-type semiconductors the diagram below an n-p-n transistor is shown



Now IE, IC is emitter current and collect current respectively and VEB and VCB are emitter-base voltage and collector-base voltage respectively.

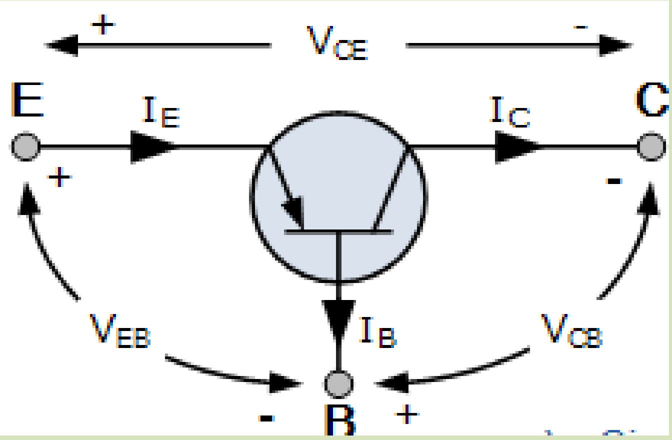
According to the convention if for the emitter, base and collector current IE, IB and IC current goes into the transistor the sign of the current is taken as positive and if current goes out from the transistor then the sign is taken as negative. We can tabulate the different currents and voltages inside the n-p-n transistor.



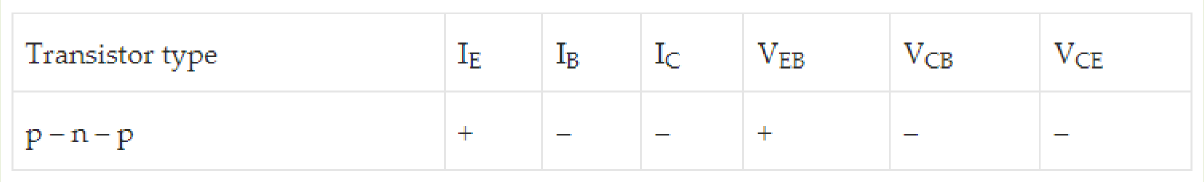
Transistor type	I_E	I_B	I_C	V_{EB}	V_{CB}	V_{CE}
n-p-n	–	+	+	–	+	+

PNP Bipolar Junction Transistor

Similarly for **p-n-p bipolar junction** transistor, an n-type semiconductor is sandwiched between two p-type semiconductors. The diagram of a p-n-p transistor is shown below.



For p-n-p transistors, current enters into the transistor through the emitter terminal. Like any bipolar junction transistor, the emitter-base junction is forward biased and the collector-base junction is reverse biased. We can tabulate the emitter, base and collector current, as well as the emitter-base, collector base and collector-emitter voltage for p-n-p transistors also.



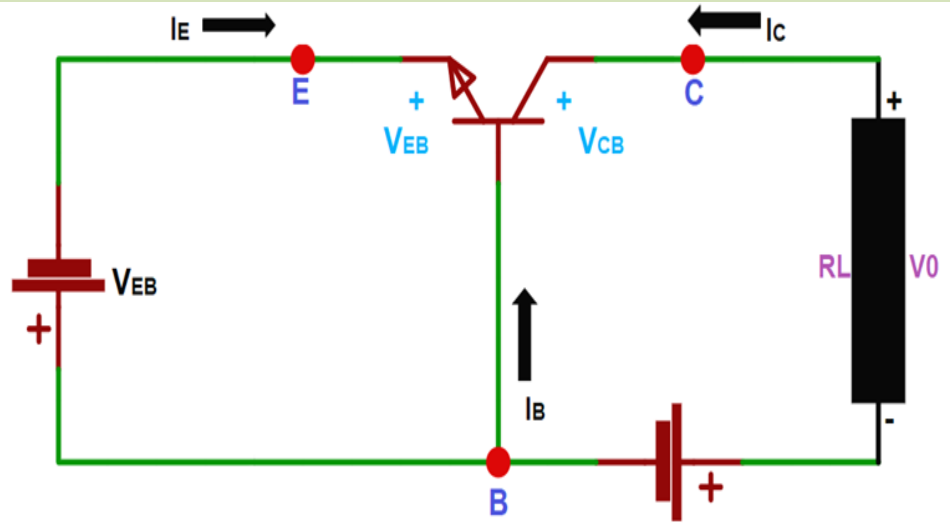
Transistor type	I_E	I_B	I_C	V_{EB}	V_{CB}	V_{CE}
p – n – p	+	–	–	+	–	–

Working of Transistor (BJT)

Practically the working of a transistor is very simple, it can be used as a switch or as an amplifier. But for basic understanding lets start with how **transistor as a switch** works in a circuit.

When a control voltage is provided to the base pin, the required **base current (**I_B**)** flows into the base pin which is controlled by a **base resistor**. This current turns on the transistor (switch is closed) and allows the current to flow from collector to emitter. This current is called the **collector current (**I_C**)** and the voltage across the collector and emitter is called V_{BE}. As you can see in the image, we are using a low-level voltage like 5V to drive a higher voltage load of 12V using this transistor.

Now for the theory, consider an NPN transistor, the BE junction is **forward biased** and the CB junction is **reverse biased**. The width of the depletion region at the Junction CB is higher when compared with the depletion region of the Junction BE. When the BE junction is forward biased it decreases the barrier potential, hence the electrons start flowing from the emitter to the base. The base region is very thin and it is lightly doped when compared with other regions, hence it consists of a very small number of holes, the electrons that are flowing from the emitter will recombine with the holes present in the base region and start to flow out of the base region in the form of the base current. A large number of electrons that are left will move across the reverse bias collector junction in the form of the collector current.



Based on the Kirchoff's Current Law, we can frame the current equation as

$\mathbf{I_E = I_B + I_C}$

The base current is very small as compared to emitter and collector current

Therefore $\mathbf{I_E \sim I_C}$

Where, I_E, I_B, and I_C are the emitter, base, and collector current respectively.

Similarly, when you consider the PNP Transistor, they operate in the same way as the NPN transistor, but in NPN transistors the majority charge carriers are holes (Positively charged particle) but in the NPN transistor the charge carriers are the electrons (negatively charged particle).

Bipolar Junction Transistors Characteristics

Transistor Characteristics are the plots which represent the relationships between the current and the voltages of a transistor in a particular configuration. By considering the transistor configuration circuits to be analogous to two-port networks, they can be analysed using the characteristic-curves which can be of the following types

- **Input Characteristics**: These describe the changes in input current with the variation in the values of input voltage keeping the output voltage constant.

- **Output Characteristics**: This is a plot of output current versus output voltage with constant input current.

- **Current Transfer Characteristics**: This characteristic curve shows the variation of output current in accordance with the input current, keeping output voltage constant.

BJT can be connected in three different configurations by keeping one terminal common and using the other two terminals for the input and output. These three types of configurations respond differently to the input signal applied to the circuit because of the **static characteristics** of the BJT.

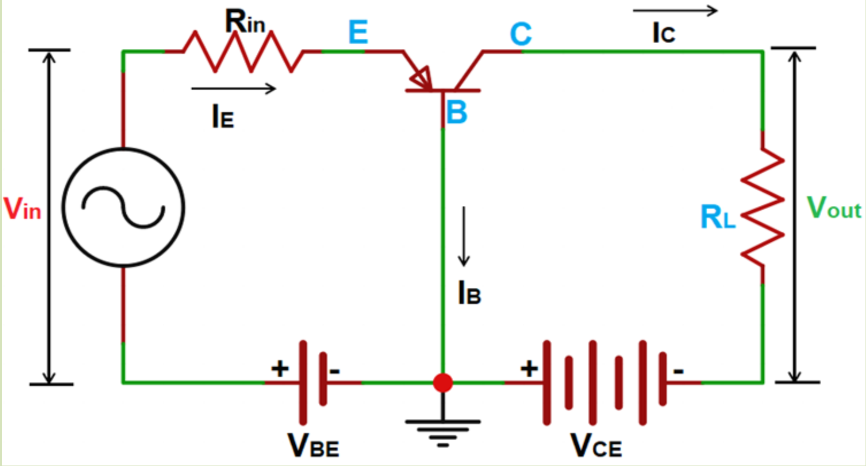
The three **different configurations of BJT** are listed below.

- Common Base (CB) configuration
- Common Emitter (CE) configuration
- Common Collector (CC) Configuration

Among these, the Common Base configurations will have voltage gain, but no current gain, whereas the Common Collector Configuration has current gain, but no voltage gain and the Common Emitter Configuration will have both current and voltage gain.

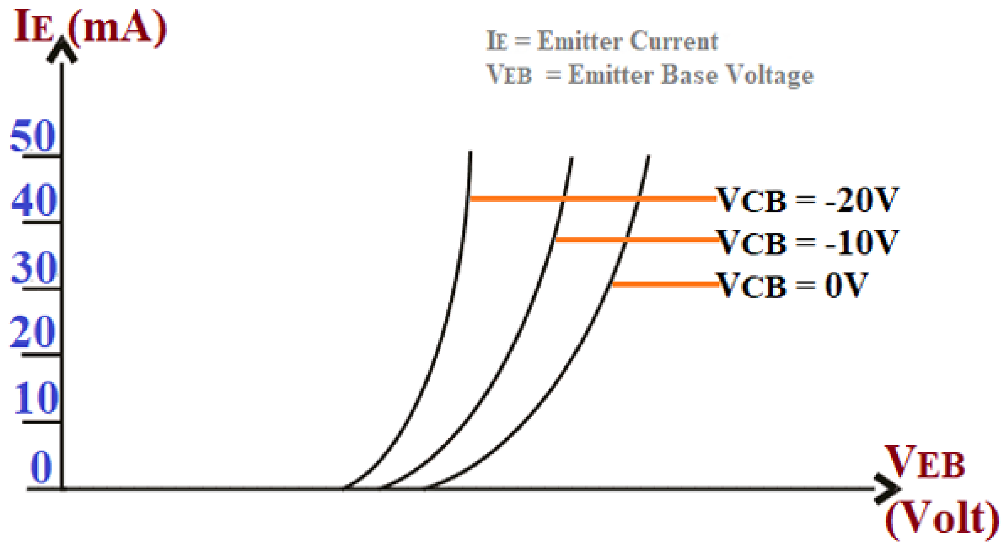
Common Base (CB) Configuration

The Common Base configuration is also called as the **grounded base configuration**, where the base of the BJT is connected as a common between both the input and output signal. The input to the BJT is applied across the Base and Emitter Terminals and the output from the BJT is obtained across the Base and Collector terminal. The input current (I_E) flowing through the emitter will be quite higher when compared with both the Base current (I_B) and the Collector Current (I_C) as the emitter current is the sum of both the Base current and Collector current. Since the collector current output is less than the Emitter current input the **current gain of this configuration will be unity (1) or less**.



Input characteristics

The input Characteristic curve for the Common Base configurations is drawn between the emitter current I_E and the voltage between the base and emitter V_{EB}. During the Common base configuration, the Transistor gets **forward biased** hence it will show characteristics similar to that of the forward characteristics of a p-n diode where the I_E increases for fixed V_{EB} when V_{CB} increases.



This leads to the expression for the input resistance as:

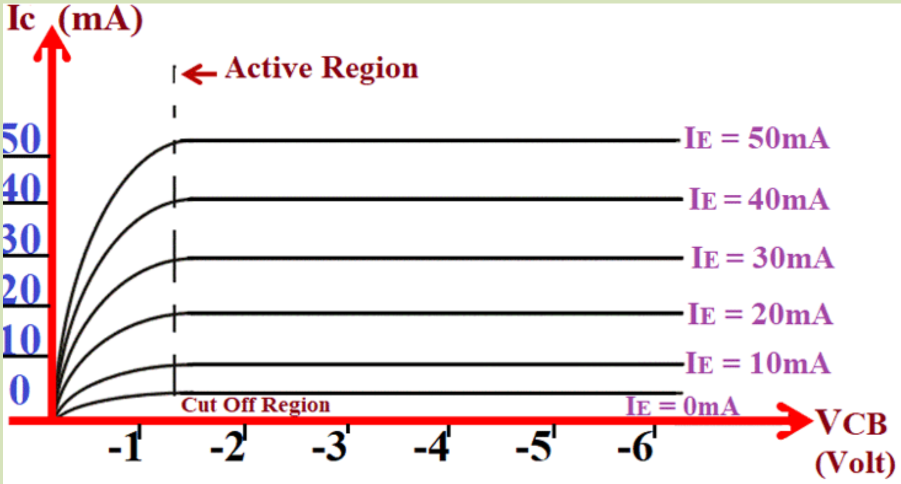
$$R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_E}\right|_{V_{CB}=constant}$$

Output Characteristics

The output characteristics of the Common Base configuration are given between the collector current IC and the voltage between the collector and base V_{CB}, here the emitter Current I_E is the measuring parameter.

Based on the operation, there are three different regions in the curve, at first, the active region, here the BJT will be operating normally and the emitter junction is reverse biased.

Next come the **saturation region** where both the emitter and collector junctions are **forward biased**. Finally, the **cut off region** where both emitter and the collector junctions are reverse biased.



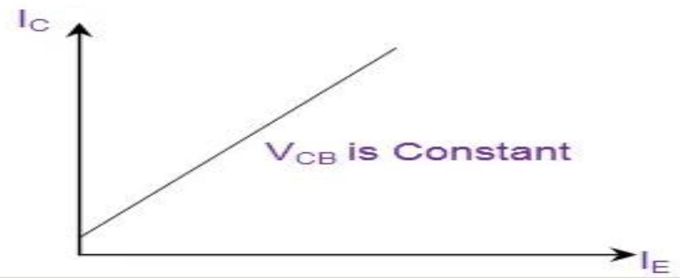
From the graph the output resistance can be obtained as:

$$R_{out} = \left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E = constant}$$

Current Transfer Characteristics for CB Configuration of Transistor

The current transfer characteristics for CB configuration which illustrates the variation of I_C with the IE keeping V_{CB} as a constant. The resulting current gain has a value less than 1 and can be mathematically expressed as:

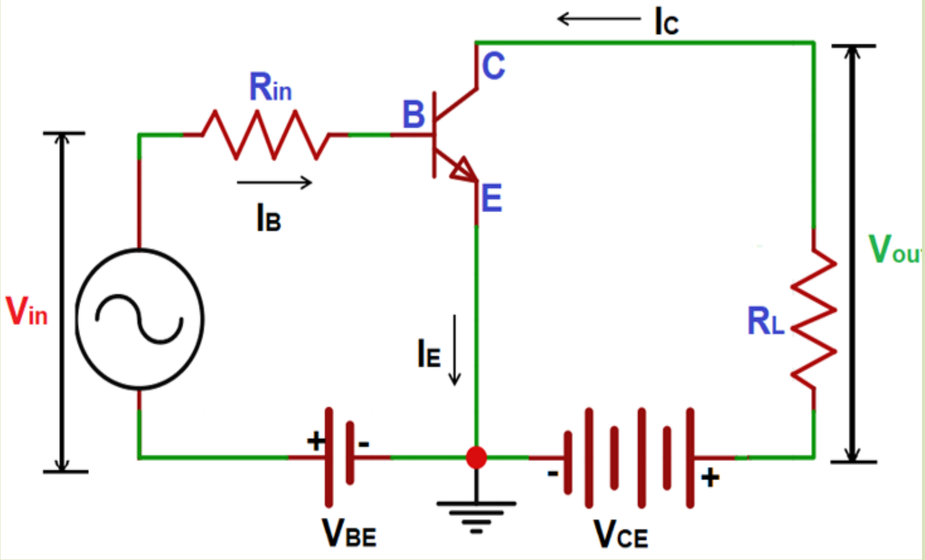
$$\alpha = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = constant}$$



Common Emitter (CE) Configuration

The Common Emitter Configuration is also called the grounded emitter configuration where the emitter acts as the common terminal between the input applied between the base and emitter and the output obtained between the collector and the emitter.

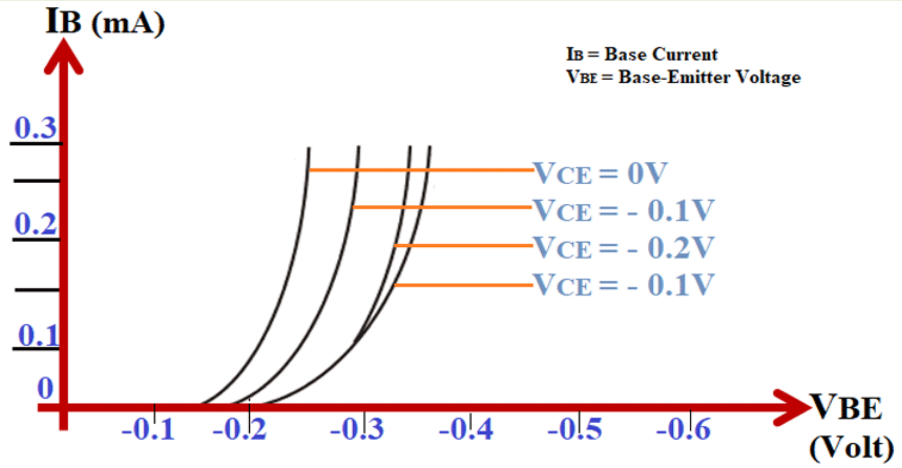
This configuration produces the **highest current and power gain** when compared with the other two types of configurations, this is because of the fact that the input impedance is low as it is connected to a forward-biased PN junction whereas the output impedance is high as it is obtained for the reverse-biased PN junction.



Input Characteristics

The input characteristics of the Common Emitter configuration are drawn between the base current I_B and the voltage between the base and emitter V_{BE}. Here the Voltage between the Collector and the emitter is the most common parameter.

If we observe see there will not be much difference between the characteristic curve of the previous configuration except for the change in parameters.

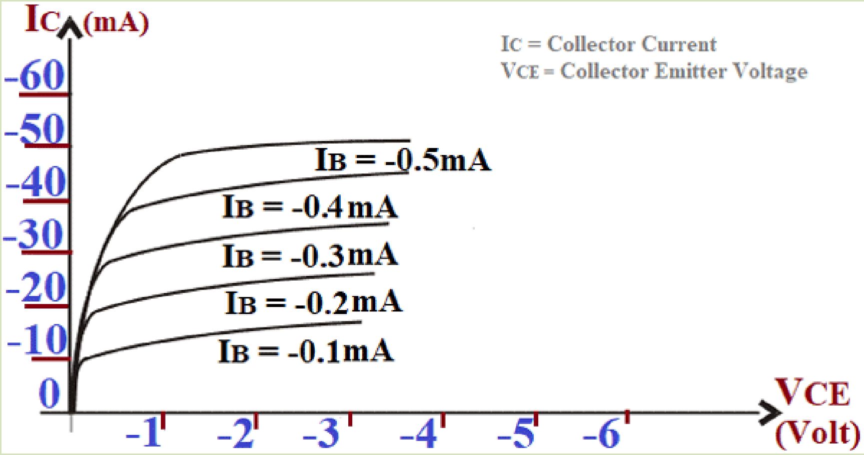


From the graph the input resistance of the transistor can be obtained as

$$R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}=constant}$$

Output Characteristics

The output characteristics are drawn between the Collector Current I_C and the voltage between the collector and the Emitter V_{CE}. The CE configuration also has the three different regions, in the **active** region the collector junction is reverse biased and the emitter junction is forward biased, in the **cut-off** region, the emitter junction is slightly **reverse** biased and the collector current is not completely **cut off**, and finally, in the **saturation** region, both the collector and the emitter junctions are forward biased.



From the graph shown, the output resistance can be obtained as:

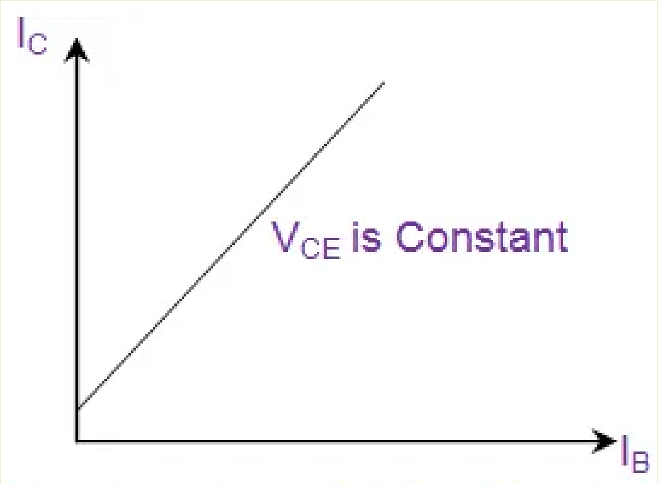
$$R_{out} = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B=constant}$$

Current Transfer Characteristics for CE Configuration of Transistor

This characteristic of CE configuration shows the variation of I_C with I_B keeping V_{CE} as a constant. This can be mathematically given by

$$\beta = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=constant}$$

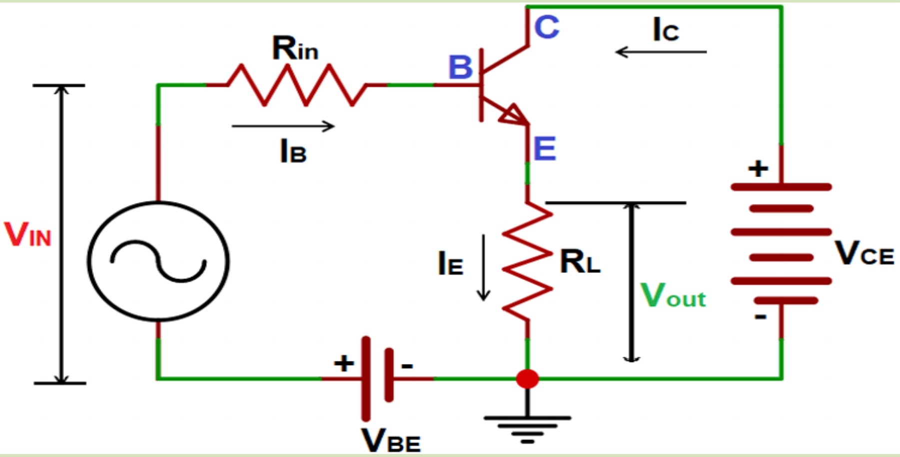
This ratio is referred to as common-emitter current gain and is always greater than 1.



Common Collector (CC) Configuration

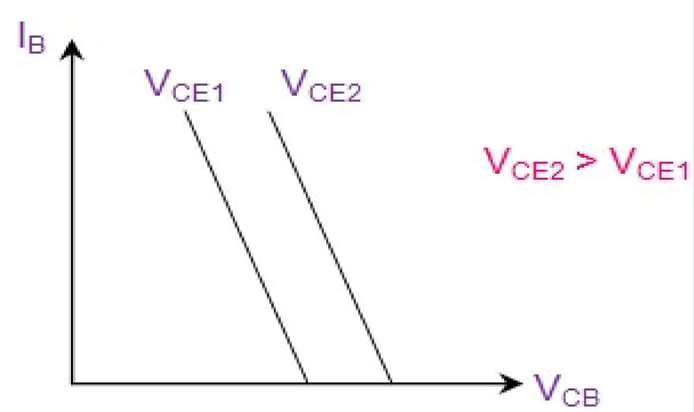
The Common Collector Configuration is also called the grounded Collector configuration where the collector terminal is kept as the common terminal between the input signal applied across the base and the emitter, and the output signal obtained across the collector and the emitter. This configuration is commonly called as the **Voltage follower or the emitter follower circuit**.

This configuration will be useful for **impedance matching applications** as it has very high input impedance, in the region of hundreds of thousands of ohms while having relatively low output impedance.



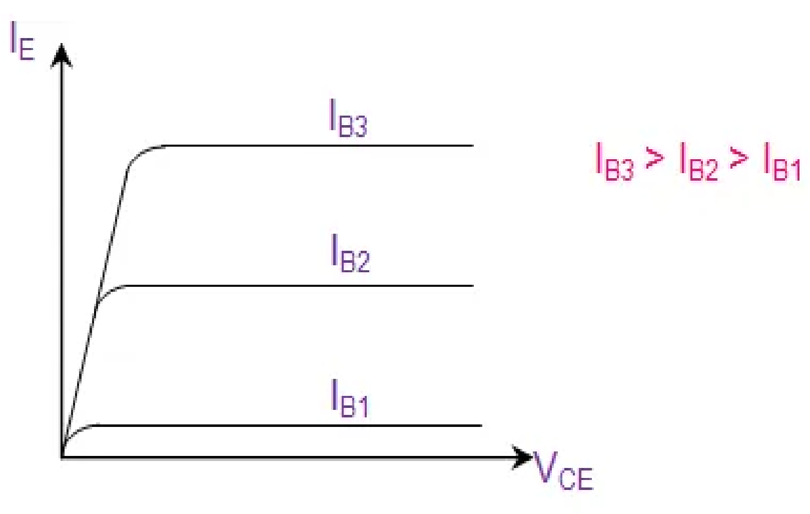
Input Characteristics

The input characteristics for CC configuration which describes the variation in I_B in accordance with V_{CB}, for a constant value of Collector-Emitter voltage, V_{CE}.



Output Characteristics

The output characteristics for the CC configuration which exhibit the variations in I_E against the changes in V_{CE} for constant values of I_B.



Current Transfer Characteristics for CC Configuration of Transistor

This characteristic of CC configuration shows the variation of IE with IB keeping VCE as a constant.