Different Configurations of Transistors

Introduction

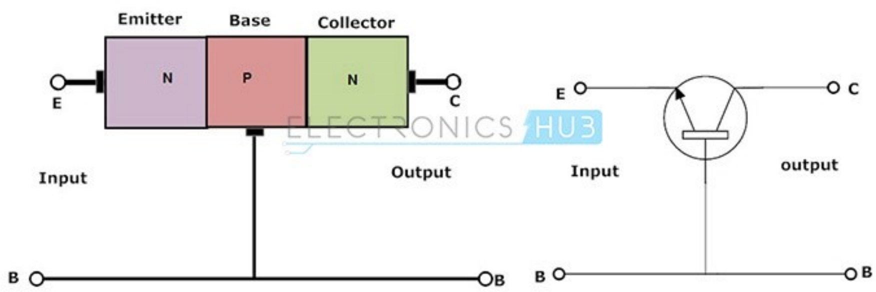
We know that generally the transistor has three terminals – emitter (E), base (B) and collector. But in the circuit connections we need four terminals, two terminals for input and another two terminals for output. To overcome these problems, we use one terminal as common for both input and output actions. 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.

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

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

Now we discuss about these three different configurations of transistors with their input and output characteristics in the below sections.

Common Base Configuration



In this configuration we use base as 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 to 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 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 are looks like characteristics of illuminated photo diode while the output characteristics represents 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. ratio of output resistance to input resistance is high. The voltage gain for this configuration of circuit is given below.

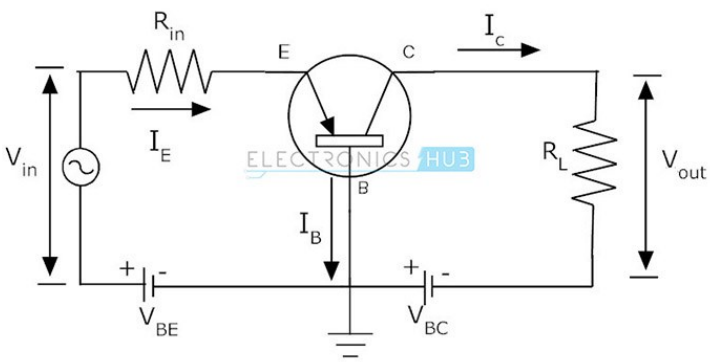
$A_V = V_{out}/V_{in} = (I_C*R_L) / (I_E*R_{in})$

Current gain in common base configuration is given as

α = Output current/Input current

$\alpha = I_C/I_E$

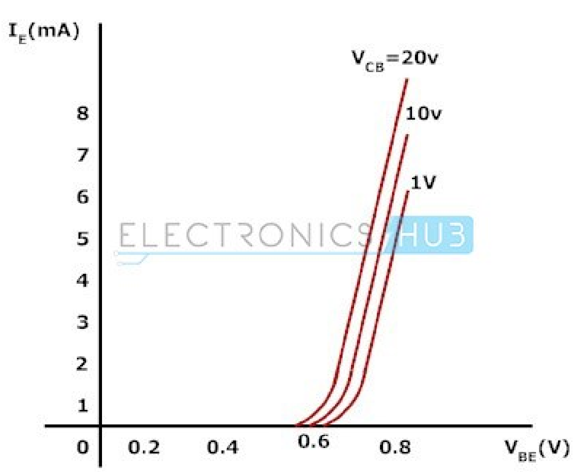
The common base circuit is mainly used in single stage amplifier circuits, such as microphone pre amplifier or radio frequency amplifiers because of their high frequency response. The common base transistor circuit is given below.



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 show the input characteristics of common base configuration. The equation to calculate the input resistance R_{in} value is given below.

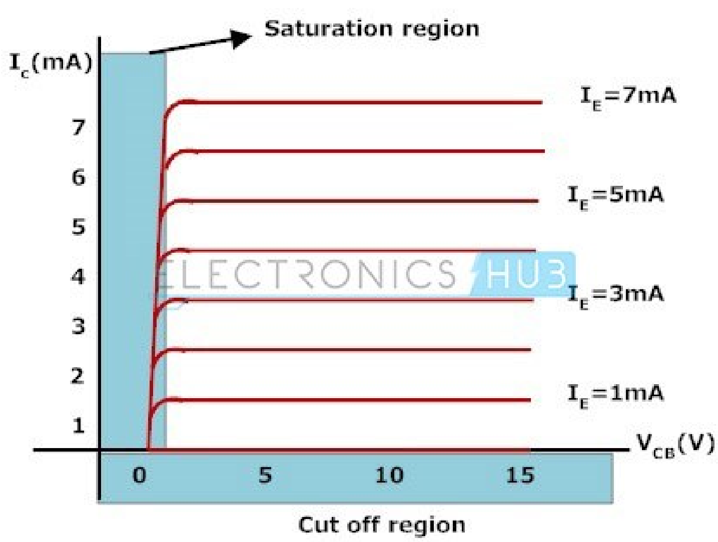
$R_{in} = V_{EB} / I_E$ (when V_{CB} is constant)



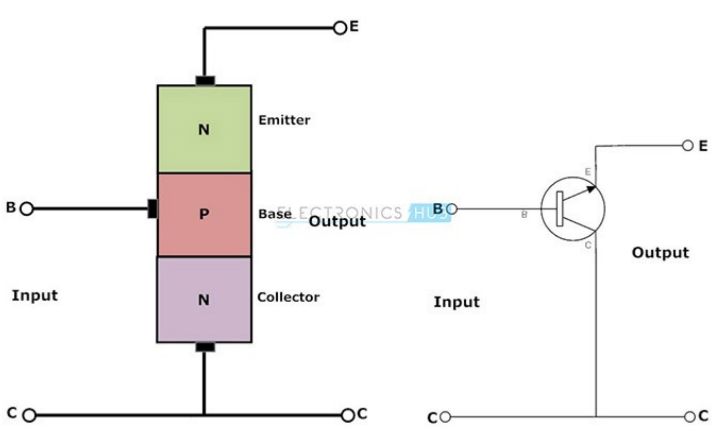
Output Characteristics

The output characteristics of common base configuration are obtained between output current and output voltage with 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 show the output characteristics of common base configuration. The equation to calculate the output resistance value is given below.

$R_{out} = V_{CB} / I_C$ (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 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 collector current and the base current. Now let us calculate the current gain for this configuration.

Current gain,

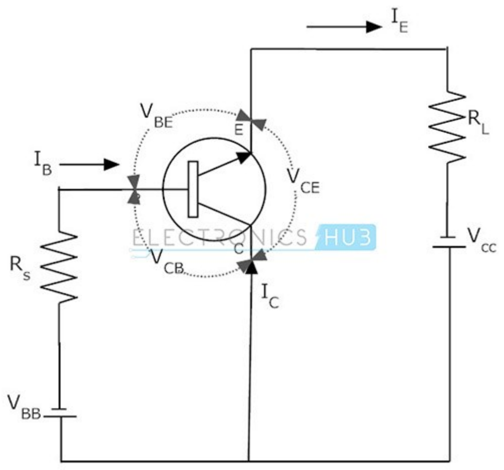
A_i = output current/Input current

$$A_i = I_E/I_B$$

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

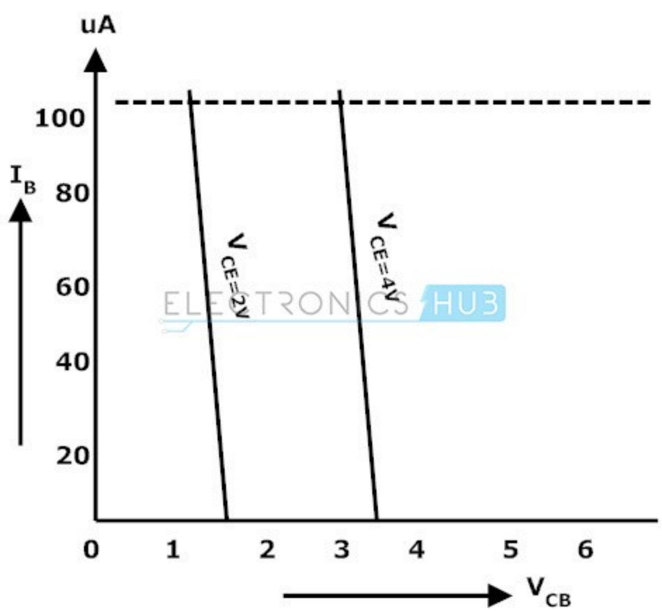
$$A_i = (I_C/I_B) + 1$$

$$A_i = \beta + 1$$



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 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,

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

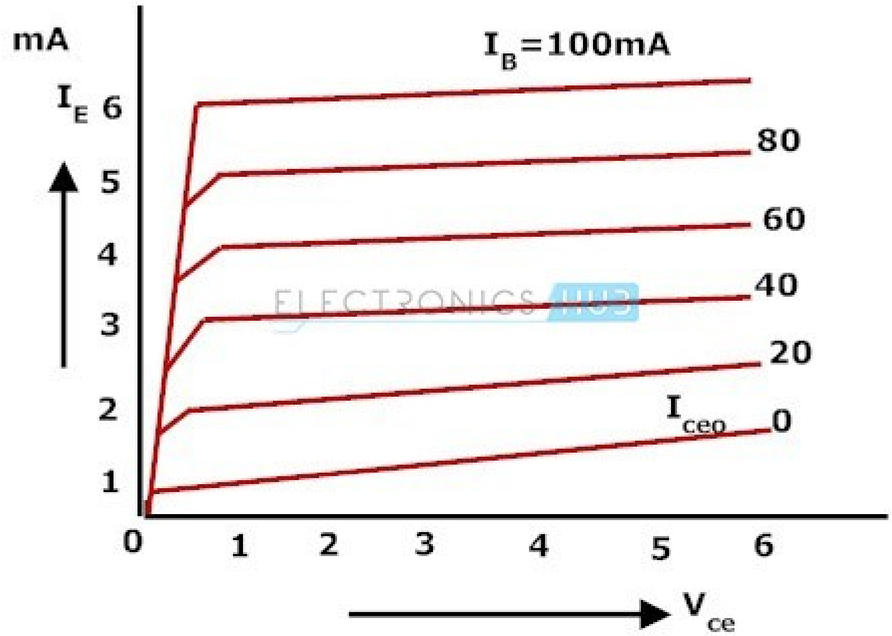
$V_{EB} = V_{EC} - V_{BC}$

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 same as that of 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 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

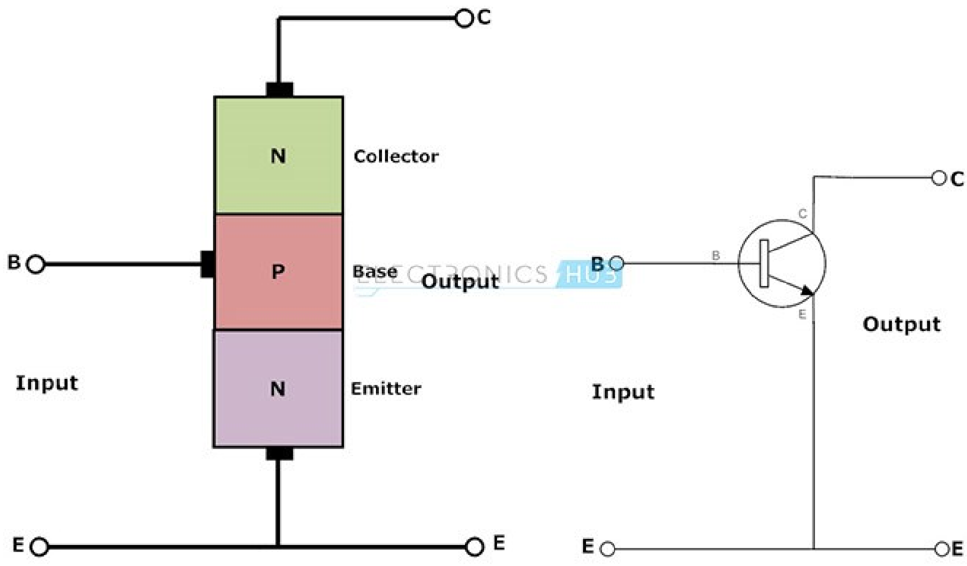
If the base current increases then the transistor operates in active region and finally reaches to saturation region. To plot the graph first we keep the I_B at constant value and we will vary the V_{EC} value for various points, now we need to record the value of I_E for each point. Repeat the same 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 show the output characteristics of common collector.



Common Emitter Configuration

In this configuration we use emitter as common terminal for both input and output. This common emitter configuration is an inverting amplifier circuit. Here the input is applied between 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 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.



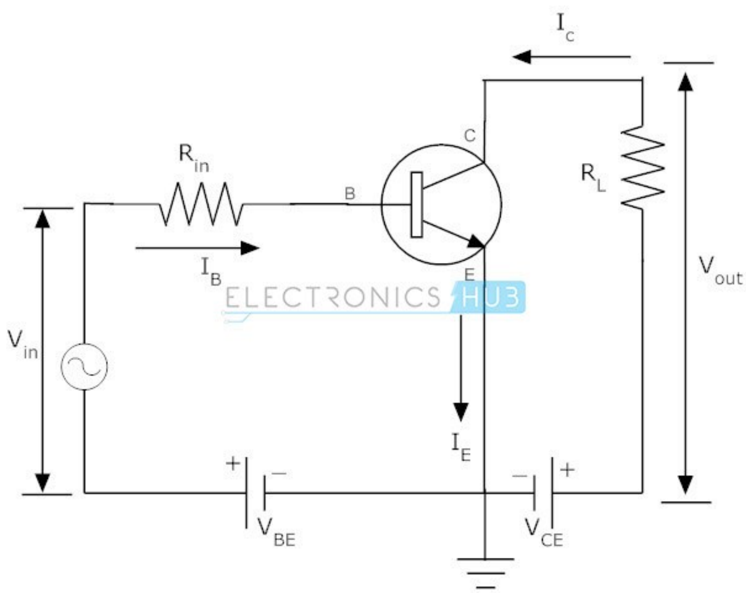
Now let us see the relationship between these two current gains.

Current gain (α) = I_C/I_E

Current gain (β) = I_C/I_B

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

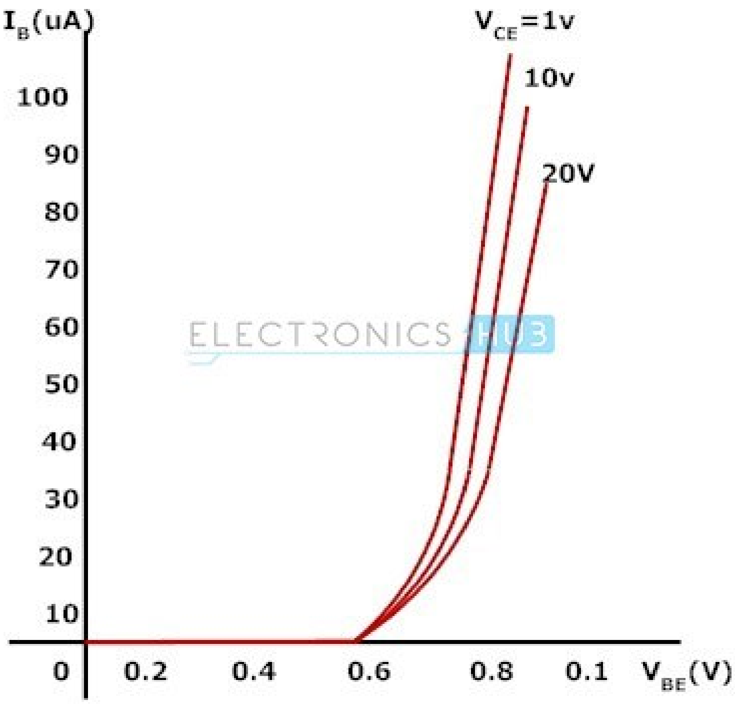
This configuration is mostly used one among all the three configurations. It has medium input and output impedance values. It also has the medium current and voltage gains. But the output signal has a phase shift of 1800 i.e. both the input and output are inverse to each other.



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.

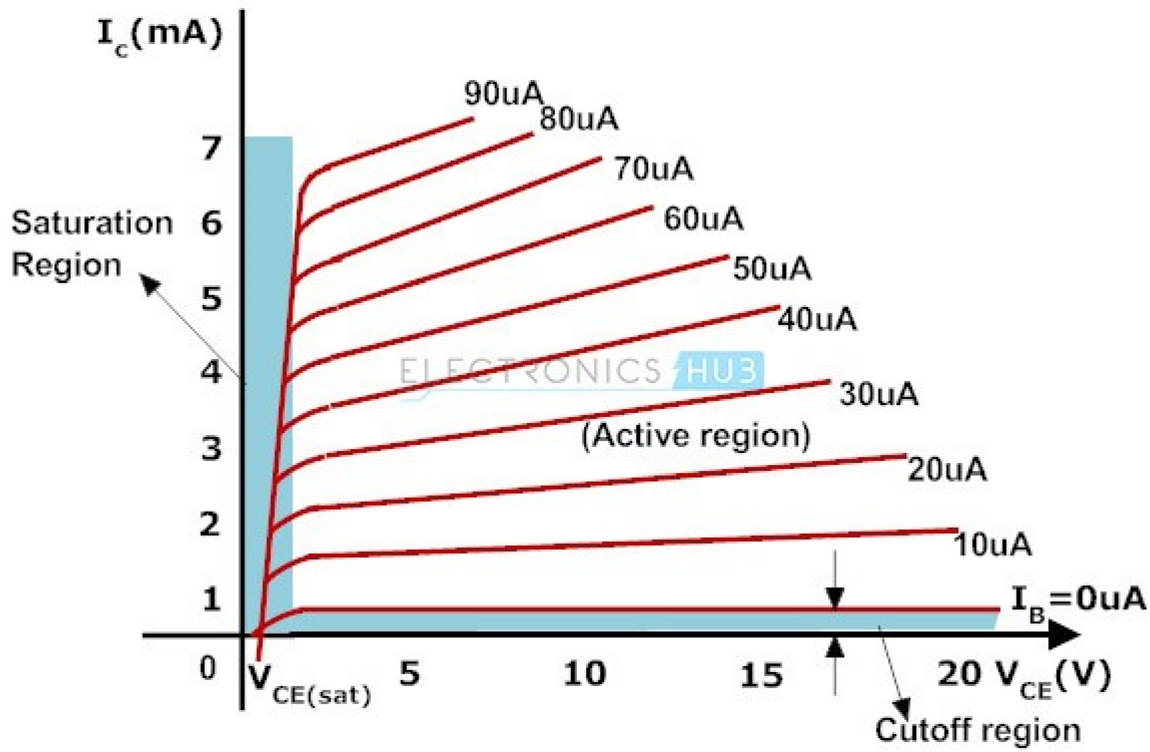
$R_{in} = V_{BE}/I_B$ (when V_{CE} is at constant)



Output Characteristics

The output characteristics of 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 common emitter configuration. The equation to calculate the output resistance from this graph is given below.

$R_{out} = V_{CE}/I_C$ (when I_B 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.

α and β Relationship in a NPN Transistor

$$\text{DC Current Gain} = \frac{\text{Output Current}}{\text{Input Current}} = \frac{I_C}{I_B}$$

$$I_E = I_B + I_C \text{ ..... (KCL)} \quad \text{and} \quad \frac{I_C}{I_E} = \alpha$$

$$\text{Thus:} \quad I_E = I_B + I_C = \frac{I_C}{\alpha}$$

$$\text{and} \quad I_B = I_C\left(1 - \frac{1}{\alpha}\right)$$

$$\therefore \quad \beta = \frac{I_C}{I_B} = \frac{1}{\left(1 - \frac{1}{\alpha}\right)} = \frac{\alpha}{1 - \alpha}$$

By combining the two parameters α and β we can produce two mathematical expressions that gives the relationship between the different currents flowing in the transistor.

$$\beta = \frac{\alpha}{1 - \alpha} \quad \text{and} \quad \alpha = \frac{\beta}{\beta + 1}$$

$$\text{If} \quad \alpha = 0.99 \quad \beta = \frac{0.99}{0.01} = 99$$

The values of Beta vary from about 20 for high current power transistors to well over 1000 for high frequency low power type bipolar transistors. The value of Beta for most standard NPN transistors can be found in the manufactures datasheets but generally range between 50 - 200.

The equation above for Beta can also be re-arranged to make Ic as the subject, and with a zero base current (Ib =0) the resultant collector current Ic will also be zero, (β x 0). Also when the base current is high the corresponding collector current will also be high resulting in the base current controlling the collector current. One of the most important properties of the **Bipolar Junction Transistor** is that a small base current can control a much larger collector current. Consider the following example.

Example No1

An NPN Transistor has a DC current gain, (Beta) value of 200. Calculate the base current Ib required to switch a resistive load of 4mA.

$$I_B = \frac{I_C}{\beta} = \frac{4\times10^{-3}}{200} = 20\mu A$$

Therefore, $\beta = 200$, $Ic = 4mA$ and $Ib = 20\mu A$.

One other point to remember about **NPN Transistors**. The collector voltage, (Vc) must be greater and positive with respect to the emitter voltage, (Ve) to allow current to flow through the transistor between the collector-emitter junctions. Also, there is a voltage drop between the Base and the Emitter terminal of about 0.7v (one diode volt drop) for silicon devices as the input characteristics of an NPN Transistor are of a forward biased diode. Then the base voltage, (Vbe) of a NPN transistor must be greater than this 0.7V otherwise the transistor will not conduct with the base current given as.

$$I_B = \frac{V_B - V_{BE}}{R_B}$$

Where: Ib is the base current, Vb is the base bias voltage, Vbe is the base-emitter volt drop (0.7v) and Rb is the base input resistor. Increasing Ib, Vbe slowly increases to 0.7V but Ic rises exponentially.