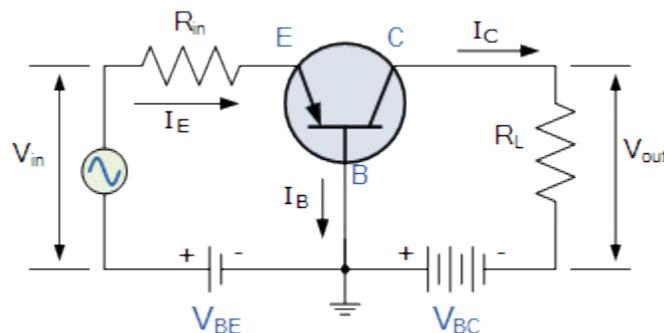# UNIT-3 MPHYCC-7

Bipolar Junction Transistor

Bipolar Transistor

The Bipolar Junction Transistor is a semiconductor device which can be used for switching or amplification. We know, that simple diodes are made up from two pieces of semiconductor material to form a simple pn-junction and we also know about their properties and characteristics.

If we now join together two individual signal diodes back-to-back, this will give us two PN-junctions connected together in series that share a common P or N terminal. The fusion of these two diodes produces a three layer, two junction, three terminal device forming the basis of a **Bipolar Junction Transistor**, or **BJT** for short. Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then bipolar transistors have the ability to operate within three different regions:

- Active Region – the transistor operates as an amplifier and $Ic = \beta * Ib$
- Saturation – the transistor is "Fully-ON" operating as a switch and $Ic = I(saturation)$
- Cut-off – the transistor is "Fully-OFF" operating as a switch and $Ic = 0$

The word Transistor is a combination of the two words Transfer + Varistor which describes their mode of operation way back in their early days of electronics

development. There are two basic types of bipolar transistor construction, PNP and NPN, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.
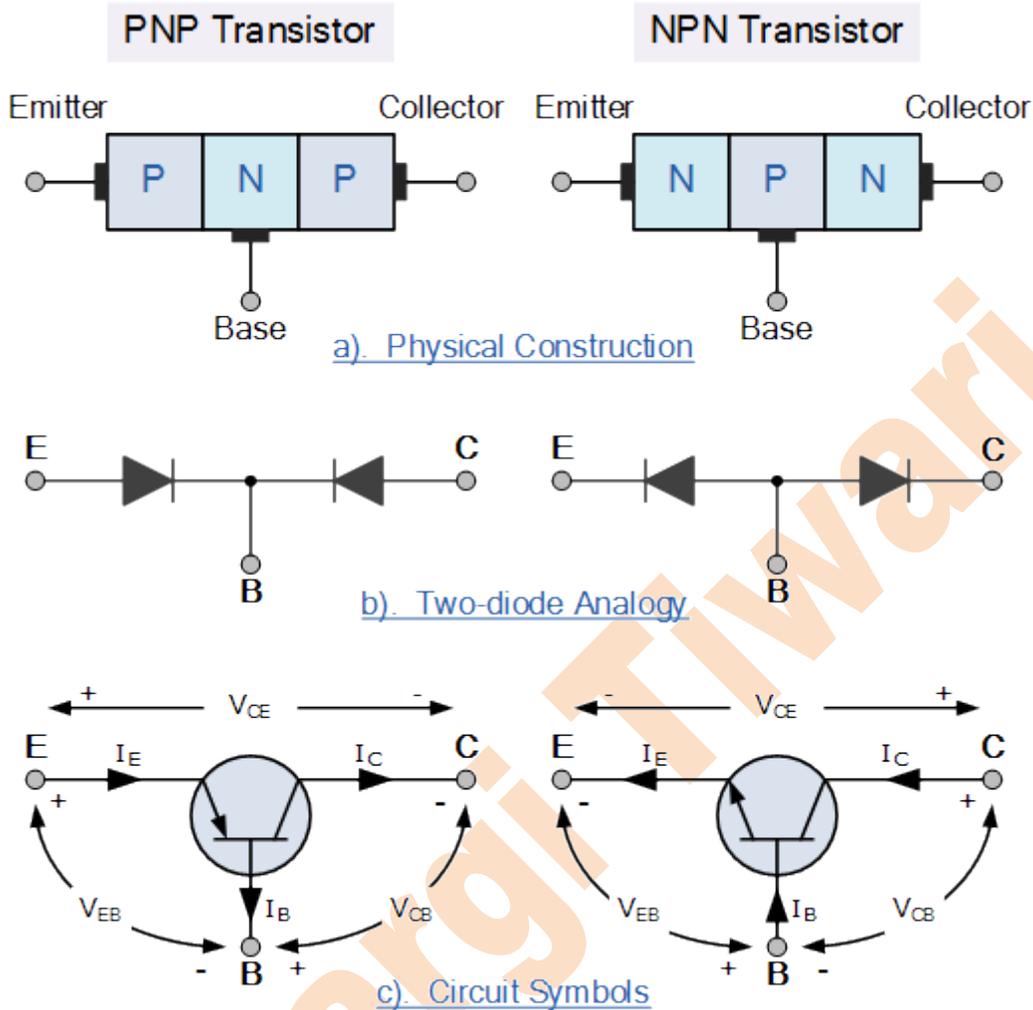
The Bipolar Transistor basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labeled as the Emitter (E), the Base (B) and the Collector (C) respectively.

Bipolar Transistors are current regulating devices that control the amount of current flowing through them from the Emitter to the Collector terminals in proportion to the amount of biasing voltage applied to their base terminal, thus acting like a current-controlled switch. As a small current flowing into the base terminal controls a much larger collector current forming the basis of transistor action.

The principle of operation of the two transistor types PNP and NPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.

Bipolar Transistor Construction

a). Physical Construction

b). Two-diode Analogy

c). Circuit Symbols

The construction and circuit symbols for both the PNP and NPN bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal. The direction of the arrow always points from the positive P-type region to the negative N-type region for both transistor types, exactly the same as for the standard diode symbol.

Bipolar Transistor Configurations

As the Bipolar Transistor is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor vary with each circuit arrangement.

Common Base Configuration   –   has Voltage Gain but no Current Gain.

Common Emitter Configuration   –   has both Current and Voltage Gain.

Common Collector Configuration   –   has Current Gain but no Voltage Gain.

The Common Base (CB) Configuration

As its name suggests, in the Common Base or grounded base configuration, the BASE connection is common to both the input signal AND the output signal. The input signal is applied between the transistors base and the emitter terminals, while the corresponding output signal is taken from between the base and the collector terminals as shown. The base terminal is grounded or can be connected to some fixed reference voltage point. The input current flowing into the emitter is quite large as its the sum of both the base current and collector current respectively therefore, the collector current output is less than the emitter current input resulting in a current gain for this type of circuit of "1" (unity) or less, in other words the common base configuration "attenuates" the input signal.

The Common Base Transistor Circuit
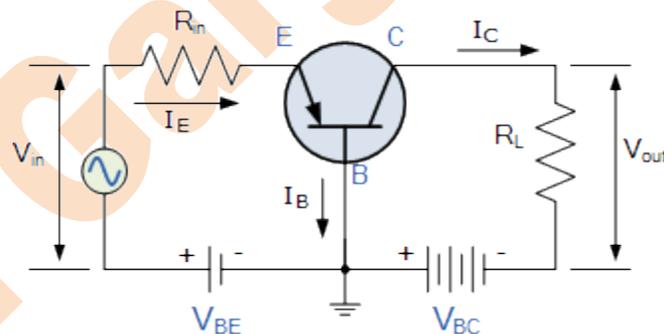
This type of amplifier configuration is a non-inverting voltage amplifier circuit, in that the signal voltages V_{in} and V_{out} are "in-phase". This type of transistor arrangement is not very common due to its unusually high voltage gain characteristics. Its input characteristics represent that of a forward biased diode while the output characteristics represent that of an illuminated photo-diode.

Also this type of bipolar transistor configuration has a high ratio of output to input resistance or more importantly "load" resistance (R_L) to "input" resistance (R_{in})

giving it a value of "Resistance Gain". Then the voltage gain (Av) for a common base configuration is therefore given as:

Common Base Voltage Gain

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

Where: Ic/Ie is the current gain, alpha (α) and R_L/R_{in} is the resistance gain.

The common base circuit is generally only used in single stage amplifier circuits such as microphone pre-amplifier or radio frequency (Rf) amplifiers due to its very good high frequency response.
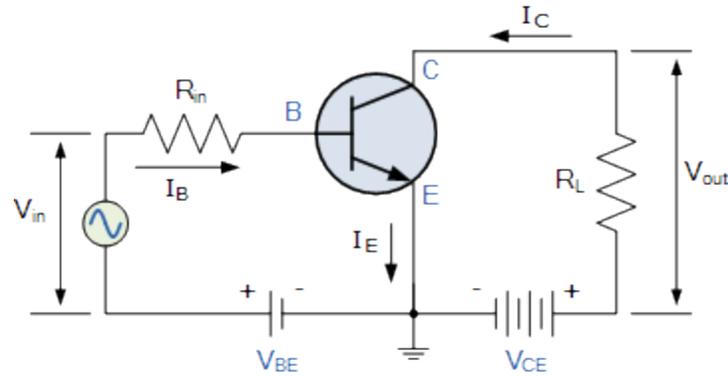
The Common Emitter (CE) Configuration

In the Common Emitter or grounded emitter configuration, the input signal is applied between the base and the emitter, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers and which represents the "normal" method of bipolar transistor connection.

The common emitter amplifier configuration produces the highest current and power gain of all the three bipolar transistor configurations. This is mainly because the input impedance is LOW as it is connected to a forward biased PN-junction, while the output impedance is HIGH as it is taken from a reverse biased PN-junction.

The Common Emitter Amplifier Circuit

Also this type of bipolar transistor configuration has a high ratio of output to input resistance or more importantly "load" resistance (RL) to "input" resistance (Rin) giving it a value of "Resistance Gain". Then the voltage gain (Av) for a common base configuration is therefore given as:

In this type of configuration, the current flowing out of the transistor must be equal to the currents flowing into the transistor as the emitter current is given as

$$Ie = Ic + Ib.$$

As the load resistance (R_L) is connected in series with the collector, the current gain of the common emitter transistor configuration is quite large as it is the ratio of Ic/Ib. A transistors current gain is given the Greek symbol of Beta, (β).

As the emitter current for a common emitter configuration is defined as Ie = Ic + Ib, the ratio of Ic/Ie is called α (Greek symbol). Note: that the value of α will always be less than unity. Since the electrical relationship between these three currents, Ib, Ic and Ie is determined by the physical construction of the transistor itself, any small change in the base current (Ib), will result in a much larger change in the collector current (Ic).

By combining the expressions for both Alpha, α and Beta, β the mathematical relationship between these parameters and therefore the current gain of the transistor can be given as:

$$\text{Alpha,}(\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta,}(\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha.I_E = \beta.I_B$$

$$\text{as:} \quad \alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

$$I_E = I_C + I_B$$

Where: "Ic" is the current flowing into the collector terminal, "Ib" is the current flowing into the base terminal and "Ie" is the current flowing out of the emitter terminal.

This type of bipolar transistor configuration has a greater input impedance, current and power gain than that of the common base configuration but its voltage gain is much lower. The common emitter configuration is an inverting amplifier circuit. This means that the resulting output signal has a 180° phase-shift with regards to the input voltage signal.

The Common Collector (CC) Configuration

In the Common Collector or grounded collector configuration, the collector is connected to ground through the supply, thus the collector terminal is common to both the input and the output. The input signal is connected directly to the base terminal, while the output signal is taken from across the emitter load resistor as shown. This type of configuration is commonly known as a Voltage Follower or Emitter Follower circuit. The common collector, or emitter follower configuration is very useful for impedance matching applications because of its very high input impedance, in the region of hundreds of thousands of Ohms while having a relatively low output impedance.

The Common Collector Transistor Circuit
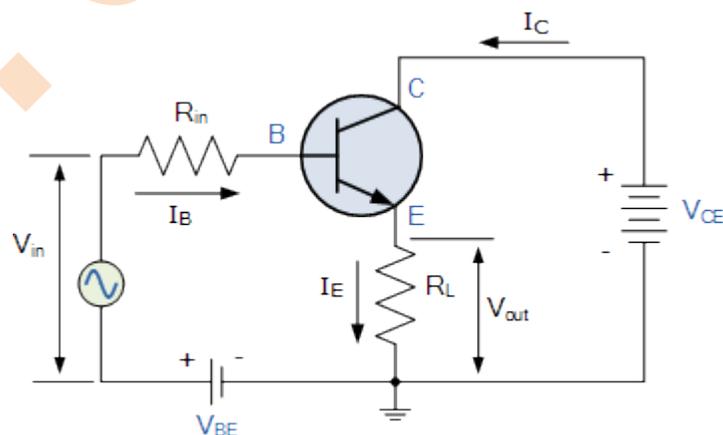
The common emitter configuration has a current gain approximately equal to the β value of the transistor itself. However in the common collector configuration, the load resistance is connected in series with the emitter terminal so its current is equal to that of the emitter current. As the emitter current is the combination of the collector and the base current combined, the load resistance in this type of transistor configuration also has both the collector current and the input current of the base flowing through it. Then the current gain of the circuit is given as:

The Common Collector Current Gain

$$I_E = I_C + I_B$$

$$A_i = \frac{I_E}{I_B} = \frac{I_C + I_B}{I_B}$$

$$A_i = \frac{I_C}{I_B} + 1$$

$$A_i = \beta + 1$$

This type of bipolar transistor configuration is a non-inverting circuit in that the signal voltages of Vin and Vout are "in-phase". The common collector configuration has a voltage gain of about "1" (unity gain). Thus it can considered as a voltage-buffer since the voltage gain is unity. The load resistance of the common collector transistor receives both the base and collector currents giving a large current gain (as with the common emitter configuration) therefore, providing good current amplification with very little voltage gain.

Having looked at the three different types of bipolar transistor configurations, we can now summarize the various relationships between the transistors individual DC currents flowing through each leg and its DC current gains given above in the following table.

Relationship between DC Currents and Gains

$I_E = I_B + I_C$ $I_C = I_E - I_B$ $I_B = I_E - I_C$	$\alpha = \dfrac{I_C}{I_E} = \dfrac{\beta}{1+\beta}$ $\beta = \dfrac{I_C}{I_B} = \dfrac{\alpha}{1-\alpha}$
$I_B = \dfrac{I_C}{\beta} = \dfrac{I_E}{1+\beta} = I_E(1-\alpha)$	
$I_C = \beta.I_B = \alpha.I_E$	$I_E = \dfrac{I_C}{\alpha} = I_B(1+\beta)$

Bipolar Transistor Summary

To summarize, the behavior of the bipolar transistor in each one of the above circuit configurations is very different and produces different circuit characteristics with regards to input impedance, output impedance and gain whether this is voltage gain, current gain or power gain and this can be given as below.

Bipolar Transistor Configurations

| Two-Port Model | Common Base | Common Emitter | Common Collector |
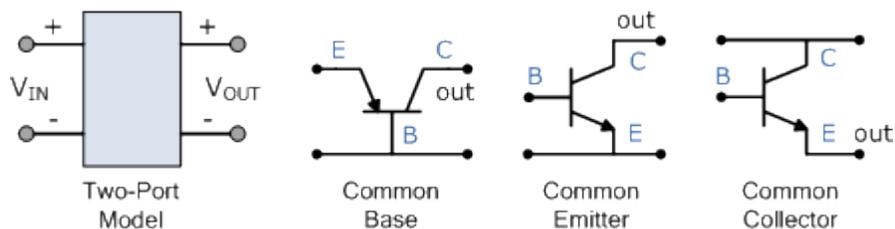
Characteristics of the different transistor configurations are given in the following table:

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Shift	0°	180°	0°
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

References: 1. Handbook of Electronics

By S. L. Gupta, V. Kumar

2. Electronic Principles

By Albert Malvino , David J Bates