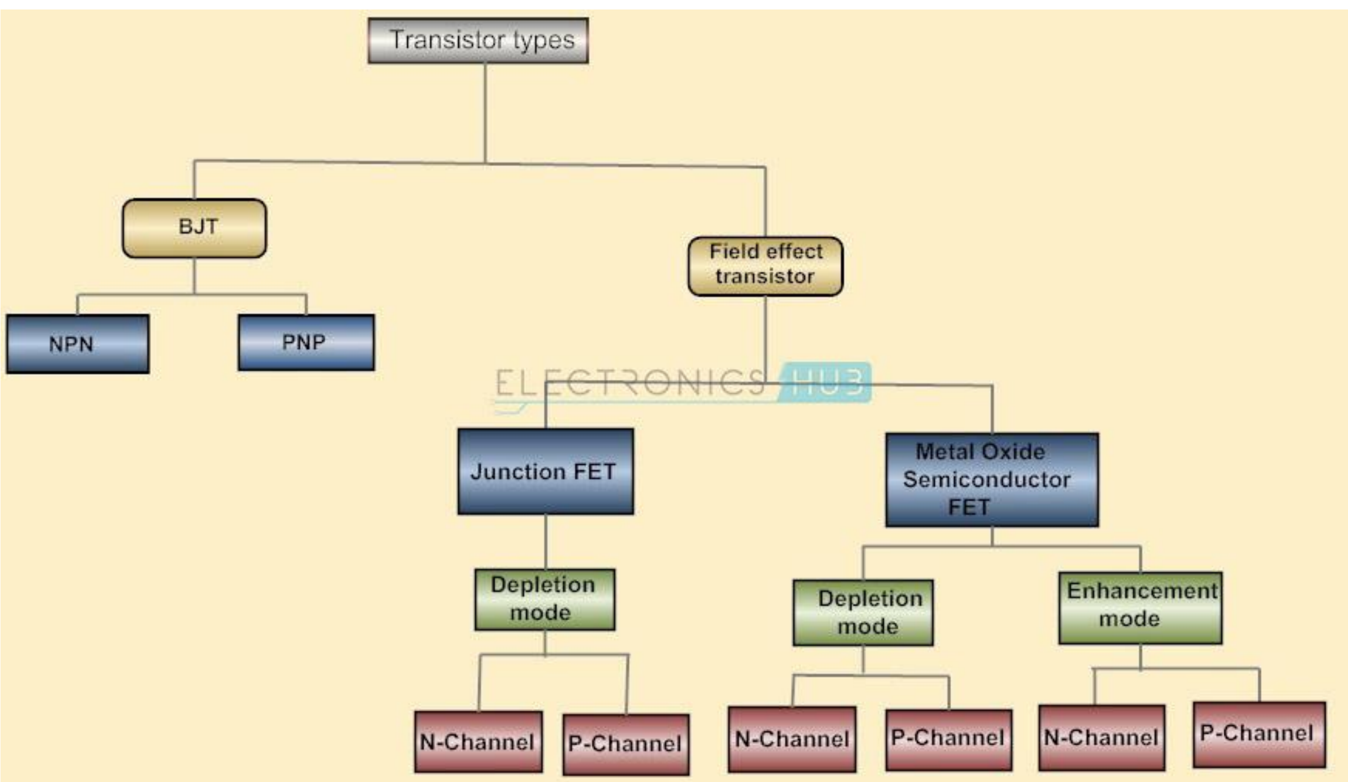
4 – 1 Introduction

Transistor is a semiconductor device which is used to amplify the signals as well as in switching circuits. Generally transistor is made of solid material which contains three terminals such as emitter (E), Base (B) and Collector (C) for connections with other components in the circuit. Some transistors contains fourth terminal also i.e. substrate (S). Transistor is one of the active components.

From the time of first transistor invention to present days the transistors are classified into different types depending on either construction or operation, they are explained using tree diagram as below.

4 -2 Transistor Tree Diagram



The transistors classification can be understood by observing the above tree diagram. Transistors are basically classified into two types; they are Bipolar Junction Transistors (BJT) and Field Effect Transistors (FET). The BJTs are again classified into NPN and PNP transistors. The FET transistors are classified into JFET and MOSFET.

Junction FET transistors are classified into N-channel JFET and P-channel JFET depending on their function. MOSFET transistors are classified into Depletion mode and Enhancement mode. Again depletion and enhancement mode transistors are classified into N-channel JFET and P-channel.

Nowadays, the vacuum tubes are replaced with transistors because the transistors have more benefits over vacuum tubes. Transistors are small in size and it requires low voltage for operation and also it has low power dissipation. Due to these reasons the transistor is used in many applications such as amplifiers, switching circuits, oscillators and also in almost all electronic circuit

Types of Transistors

Transistor is the proper arrangement of different semiconductor materials. General semiconductor materials used for transistor are silicon, germanium, and gallium-arsenide. Basically the transistors are classified depending on their structure. Each type of transistors has their own characteristics, advantages and disadvantages.

Some transistors are designed primarily for switching purpose, other side some are designed for amplification purpose and some transistors are designed for both amplification and switching purposes. Depending on the structure the transistors are classified into BJT and FET.

4 – 3 Junction Transistors

Junction transistor is generally called as Bipolar Junction Transistor (BJT). The BJT transistors have three terminals named emitter (E), Base (B), Collector (C). The name itself indicates that it has two junctions between p-type and n-type semiconductors. The BJT transistors are classified in to NPN and PNP transistors depending on the construction.

Unlike FET transistors, the BJT transistors are current-controlled devices. If small amount of current flows through the base of a BJT transistor then it causes to flow large current from emitter to collector. The BJT transistors have low input impedance and it causes to flow large current through the transistor.

The BJT transistors are only the transistors which are turned ON by the input current which is given to the base. Bipolar junction transistors can operate in three regions, they are

- **Cut-off Region:** Here the transistor is in ‘OFF’ state i.e the current flowing through the transistor is zero.
- **Active Region:** Here the transistor acts as an amplifier.
- **Saturation Region:** Here the transistor is in fully ‘ON’ state and also works as a closed switch.

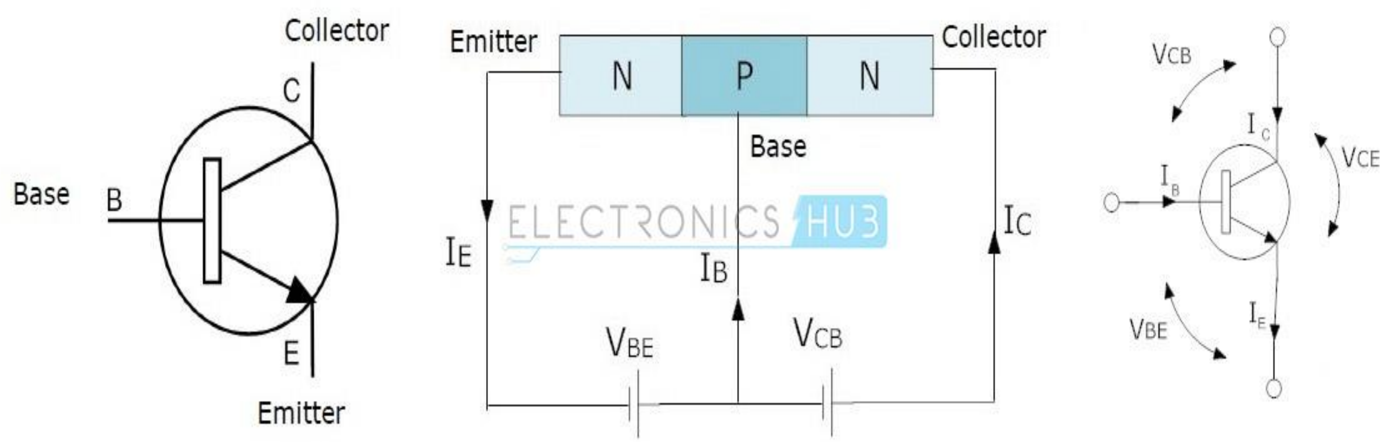
4 – 4 NPN Transistor

NPN is one of the two types of Bipolar Junction Transistors (BJT). The NPN transistor consists of two n-type semiconductor materials and they are separated by a thin layer of p-type semiconductor. Here the majority charge carriers are electrons and holes are the minority charge carriers. The flowing of electrons from emitter to collector forms the current flow in the transistor through the base terminal.

A small amount of current at base terminal causes to flow large amount current from emitter to collector. Nowadays the generally used bipolar transistor is NPN transistor, because the mobility of electrons is greater than mobility of holes. The standard equation for the currents flowing in the transistor is

$$I_E = I_B + I_C$$

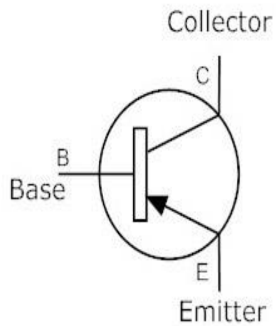
The symbols and structure for NPN transistors are given below.

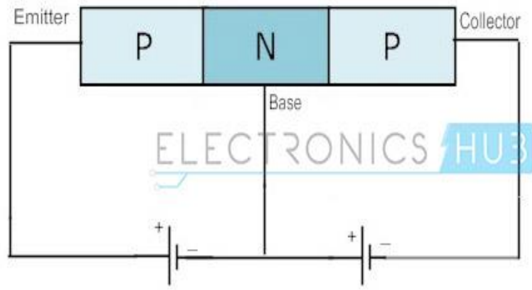


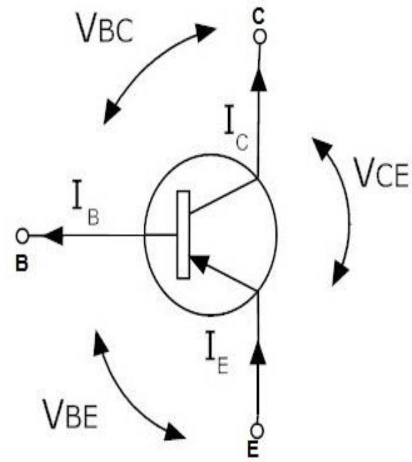
PNP Transistor

The PNP is another type of Bipolar Junction Transistors (BJT). The PNP transistors contain two p-type semiconductor materials and are separated by a thin layer of n-type semiconductor. The majority charge carriers in the PNP transistors are holes and electrons are minority charge carriers. The arrow in the emitter terminal of transistor indicates the flow of conventional current. In PNP transistor the current flows from Emitter to Collector.

The PNP transistor is ON when the base terminal is pulled to LOW with respect to emitter. The symbol and structure for PNP transistor is shown below.







4 – 5 FET (Field Effect Transistor)

The Field-Effect-Transistor (FET) is another transistors type. Basically the FET transistors have three terminals they are gate (G), Drain (D) and Source (S). FET transistors are classified into Junction Field Effect transistors (JFET) and Insulated Gate FET (IG-FET) or MOSFET transistors. For the connections in the circuit we also consider fourth terminal called base or substrate. The FET transistors have control on the size and shape of a channel between source and drain which is created by applied voltage. The FET transistors are uni-polar transistors because they perform single channel operation where as BJT transistors are bipolar junction transistors. The FET transistors have high current gain than BJT transistors.

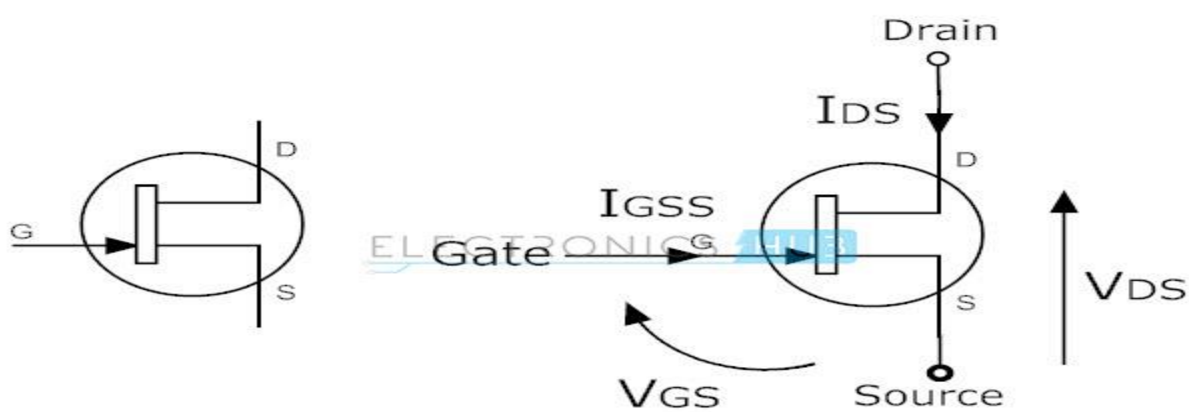
JFET (Junction-Field Effect Transistor)

The Junction-Field-Effect transistor (JFET) is an earliest and simple type of FET transistors. These JFETs are used as switches, amplifiers and resistors.

This transistor is a voltage controlled device. It doesn't need any biasing current. The voltage applied between gate and source controls the flow of electric current between source and drain of a transistor. The JFET transistors are available in both N-channel and P-channel types.

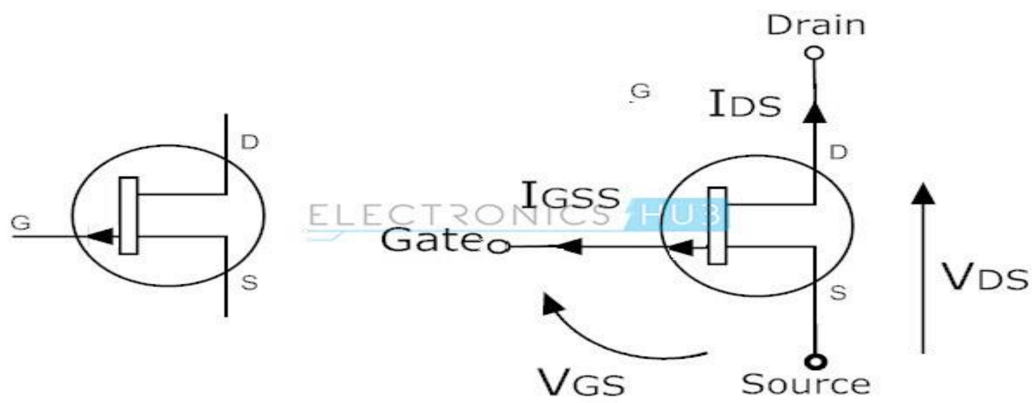
N-Channel JFET

In N-channel JFET the current flow is due to the electrons. When voltage is applied between gate and source, a channel is formed between source and drain for current flow. This channel is called N-channel. Nowadays N-channel JFET transistor is most preferable type than P-channel JFET. The symbols for N-channel JFET transistor are given below.



P-Channel JFET

In this JFET transistor the current flow is because of holes. The channel between source and drain is called P-channel. The symbols for P-channel JFET transistors are given below. Here arrow marks indicates the direction of current flow.



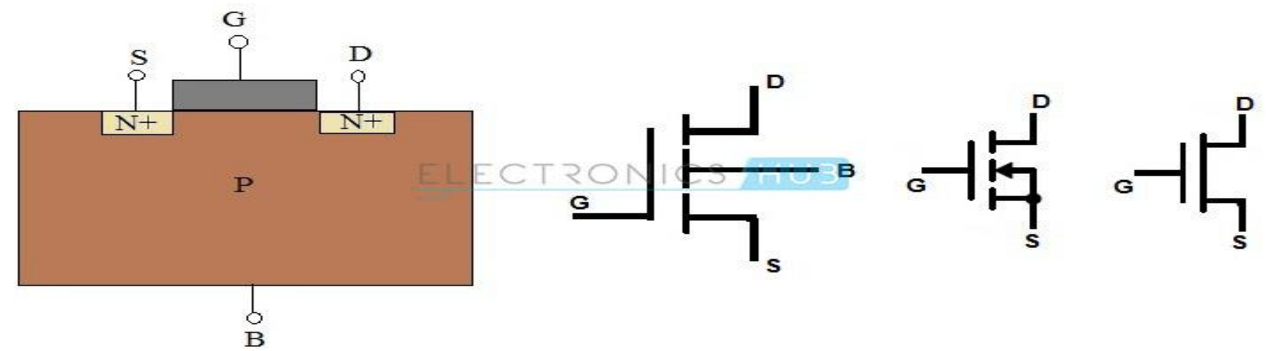
MOSFET

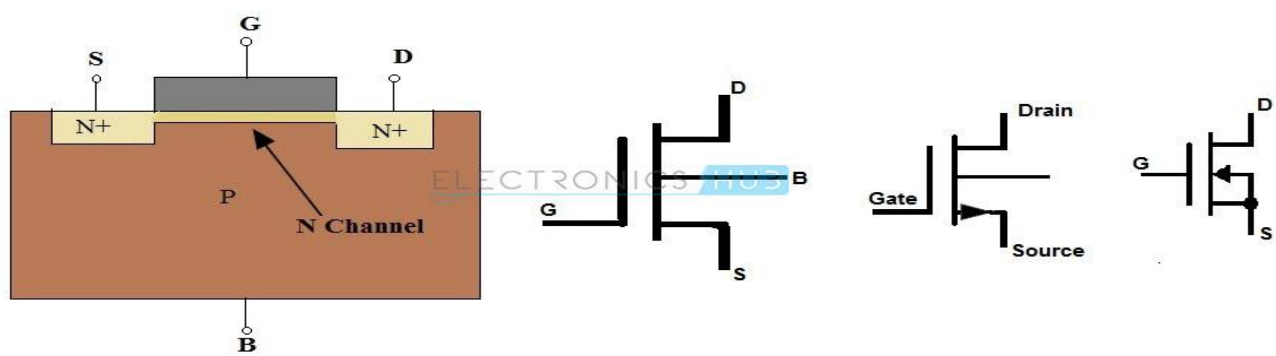
Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) is most useful type of among all transistors. The name itself indicates that it contains metal gate terminal. The MOSFET has four terminals drain, source, gate and body or substrate (B). MOSFET has many advantages over BJT and JFET, mainly it offer high input impedance and low output impedance. It is used in low power circuits mainly in chip designing technologies.

The MOSFET transistors are available in depletion and enhancement types. Further the depletion and enhancement types are classified into N-channel and P-channel types.

N-Channel MOSFET

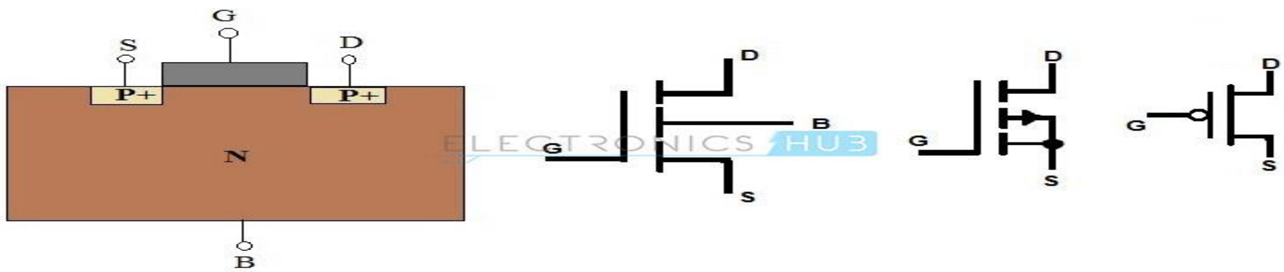
The MOSFET having N-channel region between source and drain is called N-channel MOSFET. Here the source and gate terminals are heavily doped with n-type materials and substrate is doped with p-type semiconductor material. Here the current flow between source and drain is because of electrons. The gate voltage controls the current flow in the circuit. N-channel MOSFET is most preferable than P-channel MOSFET because the mobility of electrons is high than mobility of holes. The symbols for N-channel MOSFET transistors are given below.

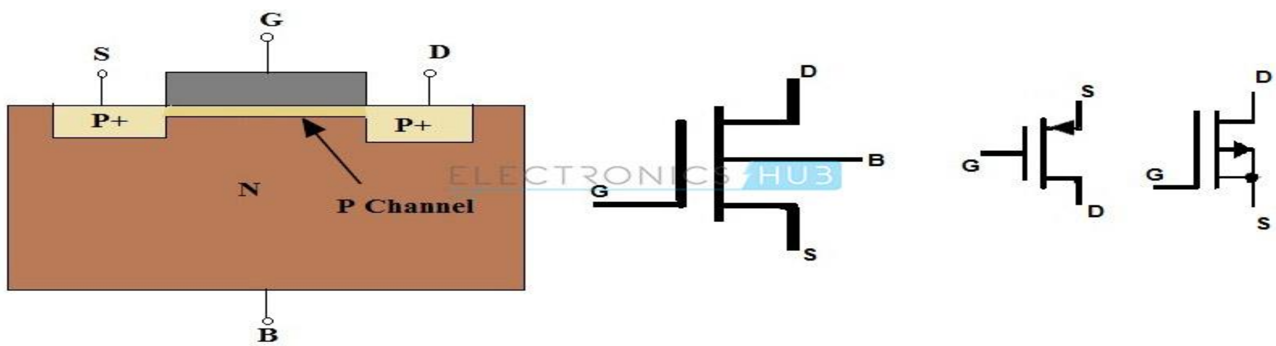




P- Channel MOSFET

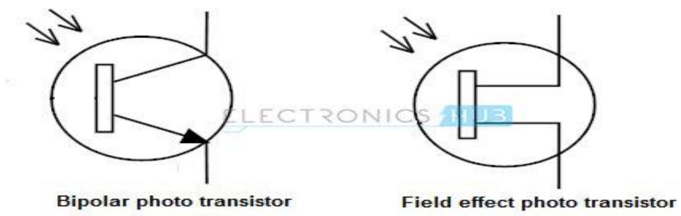
The MOSFET having P-channel region between source and drain is called as P-channel MOSFET. Here the source and drain terminals are heavily doped with P-type material and the substrate is doped with N-type material. The current flow between source and drain is because of holes concentration. The applied voltage at gate will controls the flow of current through channel region. The symbols for P-channel MOSFET transistors in depletion and enhancement types are given below.





4 – 6 Photo Transistor

Photo transistors are the transistors which operate depending on the light that means these transistors are light sensitive. The general photo transistor is nothing but a bipolar transistor which contains light sensitive area instead of base terminal. The photo transistors have only 2 terminals instead of general 3 terminals. The transistor operates depending on the light. When the light sensitive area is dark then no current flows in transistor i.e. transistor is in OFF state.



When light sensitive area is exposed to light then a small amount of current generates at base terminal and it causes to flow large current from collector to emitter. The photo transistors are available in both BJT and FET transistor types. These are named as photo-BJTs and photo-FETs.

Unlike photo-BJTs, the photo-FETs are generating gate current by using light which controls the current flow between drain and source terminals. Photo-FETs are more sensitive to light than photo-BJTs. The symbols for photo-BJT and photo-FETs are shown above.

Advantages of BJT

- High driving capability
- High-frequency operation
- The digital logic family has an emitter-coupled logic used in BJTs as a digital switch

4 – 7 Applications of BJT

Following are the two different types of applications in BJT they are

- Switching
- Amplification

This article gives information about what is a bipolar junction transistor, Types of BJT, advantages, applications, and characteristics of the bipolar junction transistors. I hope the given information in the article is helpful to give some good information and understanding the project. For furthermore, if you have any queries regarding this article or on the electrical and electronic projects you can comment in the below section. Here is a question for you, if transistors are used in digital circuits they generally operate in which region?

What are Transistor Configurations?

Generally, there are three types of configurations and their descriptions with respect to gain is as follows:

Common Base (CB) Configuration: It has no current gain but has voltage gain.

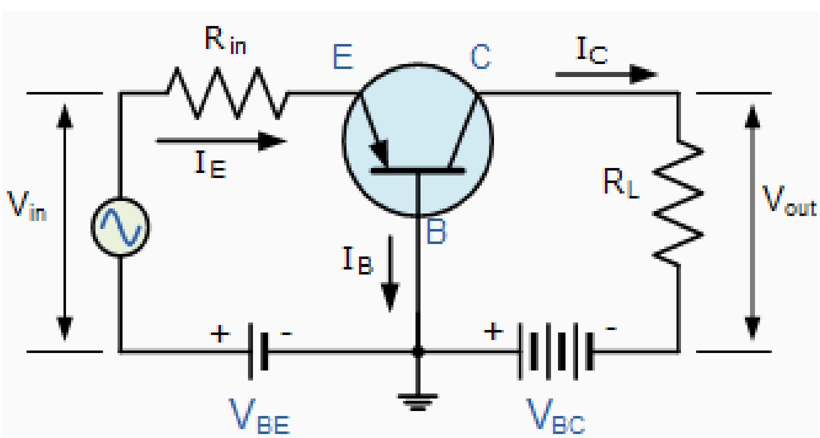
Common Collector (CC) Configuration: It has current gain but no voltage gain.

Common Emitter (CE) Configuration: It has current gain and voltage gain both.

4 – 8 Transistor 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 with the input signal being applied between the base and the emitter terminals. The corresponding output signal is taken from between the base and the collector terminals as shown with the base terminal grounded or connected to a 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 output characteristics represent that of a forward biased diode while the input 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 (A_v for a common base configuration is therefore given as:

Common Base Voltage Gain

$$A_V = \frac{Vout}{Vin} = \frac{I_C \times R_L}{I_E \times R_{IN}}$$

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.

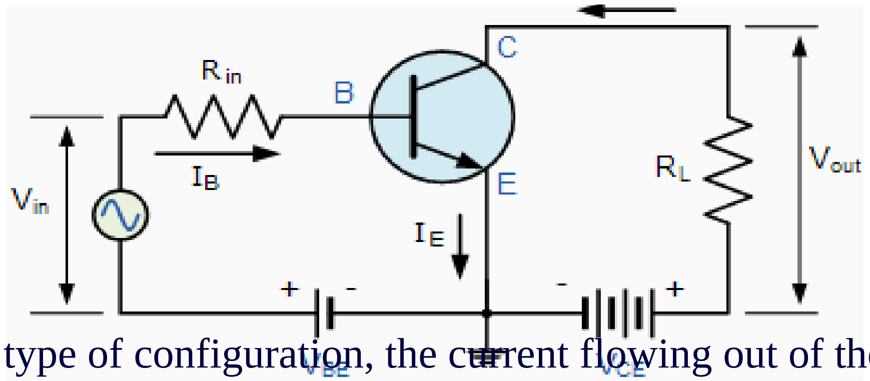
. It has low input impedance (50-500 ohms). It has high output impedance (1-10 mega ohms).Voltages measured with respect to base terminals. So, input voltage and current will be Vbe & Ie and output voltage and current will be Vcb & Ic.

- Current Gain will be less than unity i.e., **alpha(dc)= Ic/Ie**
- Voltage gain will be high.
- Power gain will be average.

4 – 9 Transistor Common Emitter (CE) Configuration:

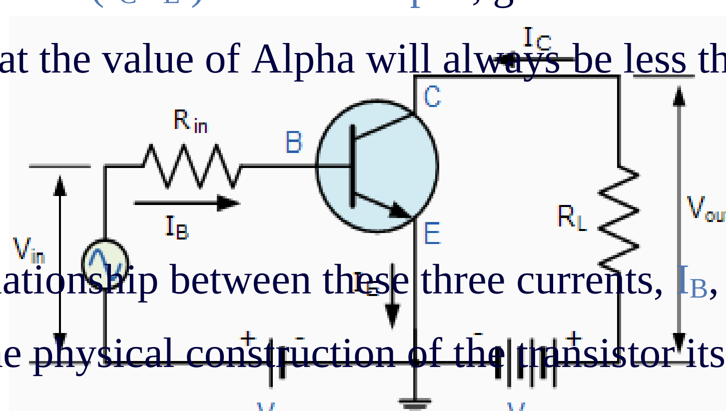
In the **Common Emitter** or grounded emitter configuration, the input signal is applied between the base and emitter, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers and which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



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($I_E = I_C + I_B$) . Also, 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 (I_C/I_B) and is given the Greek symbol of Beta, (β). As the emitter current for a common emitter configuration is defined as

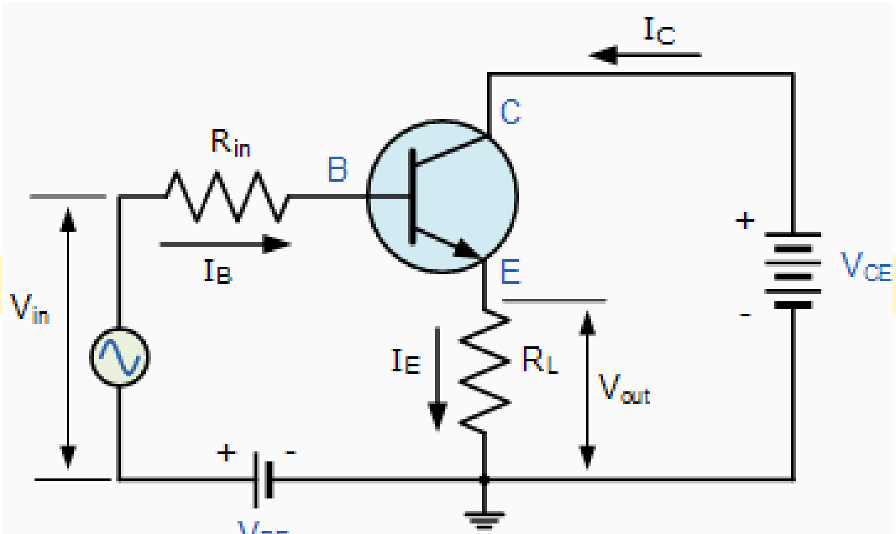
($I_E = I_C + I_B$), the ratio of (I_C/I_E) is called Alpha, given the Greek symbol of α . Note: that the value of Alpha will always be less than unity.



Since the electrical relationship between these three currents, I_B, I_C and I_E is determined by the physical construction of the transistor itself, any small change in the base current (I_B), will result in a much larger change in the collector current (I_C). Then, small changes in current flowing in the base will thus control the current in the emitter-collector circuit. Typically, Beta has a value between 20 and 200 for most general purpose transistors.

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

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



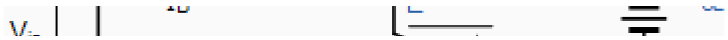
Where: "I_C" is the current flowing into the collector terminal, "I_B" is the current flowing into the base terminal and "I_E" is the current flowing out of the emitter terminal.

Then to summarise, 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 resulting in the output signal being 180^o out-of-phase with the input voltage signal.

- Current Gain will be high(98) i.e., **beta(dc) =Ic/Ie**
- Power gain is upto 37db.
- Output will be 180 degrees out of phase.

4 – 10 Transistor Common Collector Configuration:

In this circuit, collector is placed common to both input and output. This is also known as emitter follower. It has high input impedance (150-600 kilo ohms).It has low output impedance(100-1000 ohms).



- Current gain will be high(99).
- Voltage gain will be less than unity.
- Power gain will be average.

The common emitter configuration has a current gain approximately equal to the β value of the transistor itself. In the common collector configuration the load resistance is situated in series with the emitter 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. It has a voltage gain that is always less than "1" (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.

Bipolar Transistor Summary

Then to summarise, the behaviour 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 is summarised in the table below.

Bipolar Transistor Characteristics

The static characteristics for a **Bipolar Transistor** can be divided into the following three main groups.

Input Characteristics:-	Common Base	-	$\Delta V_{EB} / \Delta I_E$
	Common Emitter -		$\Delta V_{BE} / \Delta I_B$
Output Characteristics:-	Common Base	-	$\Delta V_C / \Delta I_C$
	Common Emitter -		$\Delta V_C / \Delta I_C$
Transfer Characteristics:-	Common Base	-	$\Delta I_C / \Delta I_E$

Common Emitter -	$\Delta I_C / \Delta I_B$

with the characteristics of the different transistor configurations given in the following table:

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Angle	0^o	180^o	0^o
Voltage Gain	High	Medium	Low

Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

In the next tutorial about **Bipolar Transistors**, we will look at the NPN Transistor in more detail when used in the common emitter configuration as an amplifier as this is the most widely used configuration due to its flexibility and high gain. We will also plot the output characteristics curves commonly associated with amplifier circuits as a function of the collector current to the base current

Example No1

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

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

Therefore, $\beta = 200$, $I_C = 4mA$ and $I_B = 20\mu A$.

One other point to remember about **NPN Transistors**. The collector voltage, (V_C) must be greater and positive with respect to the emitter voltage, (V_E) 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, (V_{BE}) 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: I_B is the base current, V_B is the base bias voltage, V_{BE} is the base-emitter volt drop (0.7v) and R_B is the base input resistor. Increasing I_B, V_{BE} slowly increases to 0.7V but I_C rises exponentially.

Example No2

An NPN Transistor has a DC base bias voltage, Vb of 10v and an input base resistor, Rb of 100kΩ. What will be the value of the base current into the transistor.

$$I_B = \frac{V_B - V_{BE}}{R_B} = \frac{10 - 0.7}{100k\Omega} = 93\mu A$$