Unit 2
Transistors and MOSFET’s

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Transistor:

A transistor consists of two pn junction formed by sandwiching either p-type or n-type between a pair of opposite types.

Transistor is a three terminal device. It can be used for voltage as well as current amplification.

There are two types of transistors.

1. Unipolar junction transistor(UJT)
2. Bipolar junction transistor(BJT)

1. UJT:

In this type of transistor, the current conduction is only due to one type of charge carriers that is majority charge carriers.

2. BJT:

In this type of transistor the current conduction is due to both the type of charge carriers that is both the electrons and holes.

Types of BJT:

There are two types of BJT.

1. npn type
2. pnp type

Transistor terminals:

There are three terminals in a transistor.

1. Emitter
2. Base
3. Collector.

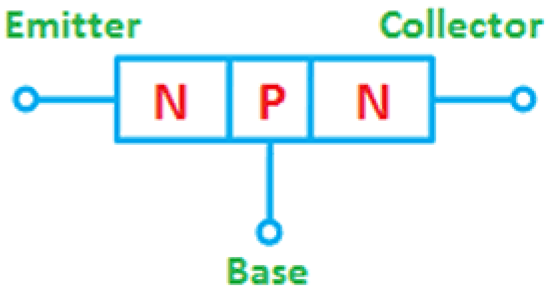
1. **Emitter:** The section on one side that supplies or emits the charge carriers. That is electrons or holes is called emitter.
   The emitter is always forward biased with respect to base.

2. **Base:** The middle section which forms the pn junction between the emitter and collector is called base.
   The base always acts as a path between emitter and collector.
   The base emitter junction is always forward biased and collector base junction is always reverse biased.

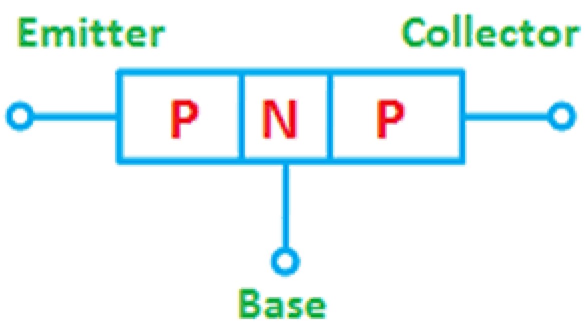
3. **Collector:** The section on either side of the transistor which collects the charge carriers is called collector.
   The collector is always reverse biased with the base.

Formation of pnp and npn transistor.

1. When a transistor is formed by sandwiching a single p region between two n regions as shown in the figure below is an npn transistor.



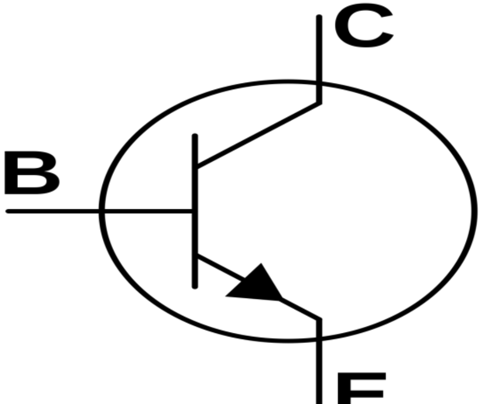
2. The pnp type transistor formed by sandwiching a single n region between two p regions as shown in the figure below is an pnp transistor.



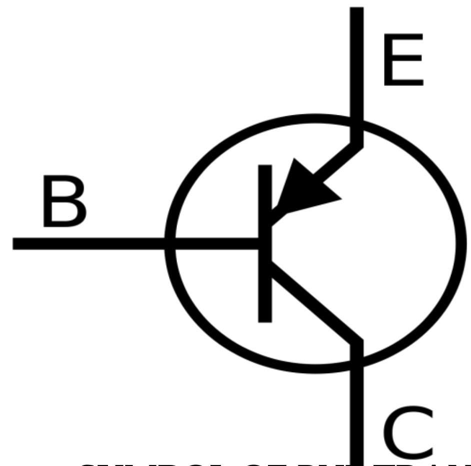
3. The middle section of each transistor type is called as base of the transistor. This region is very thin and lightly doped.

4. The emitter and collector are heavily doped but the doping level in emitter is slightly greater than that of collector.

Transistor symbols and terminals:



SYMBOL OF NPN TRANSISTOR



SYMBOL OF PNP TRANSISTOR

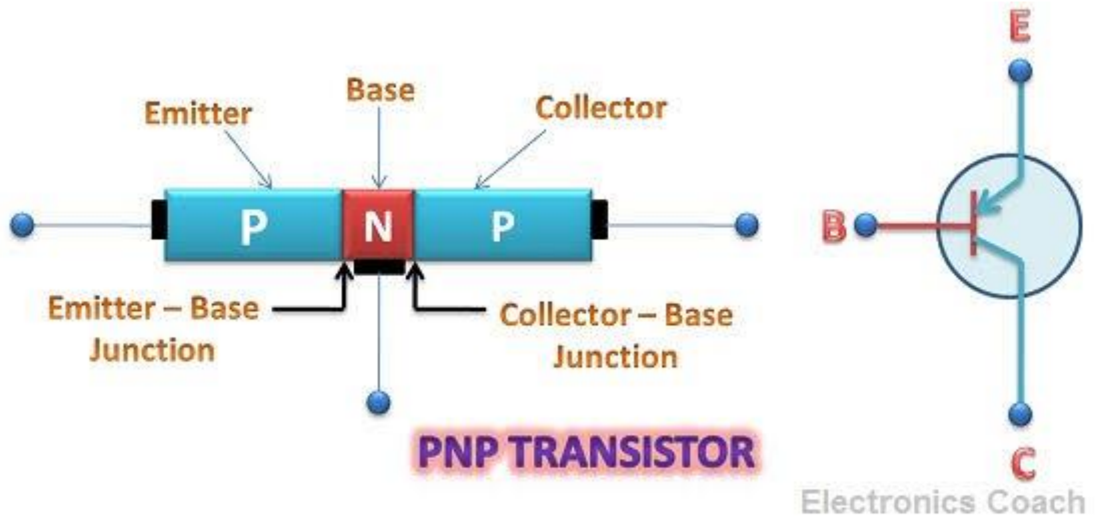
The figure a and b shows the symbol of npn and pnp transistor, arrow head on a transistor symbol indicates the direction of flow of conventional current which is opposite to the direction of current.

Junctions in transistor:

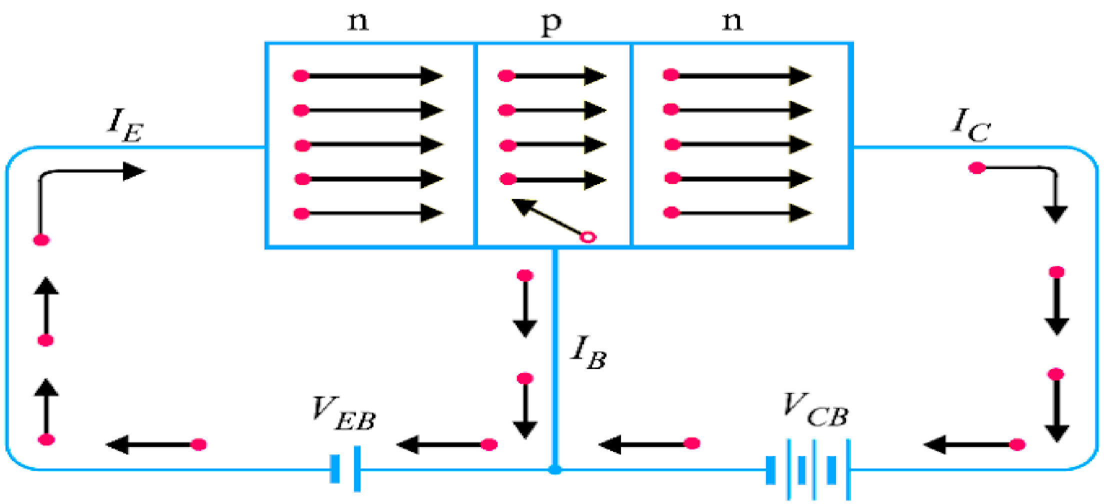
A transistor has two pn junction.

1. The junction between the emitter and base is called emitter base junction or emitter junction(Je).

2. The other junction is between the base and the collector is called collector base junction or collector junction(Jc).



Formation and working of npn transistor:



Basic connection of *npn* transistor

1. An npn transistor consists of two n type semiconductor separated by a thin section of p type semiconductor.

2. Figure shows the npn transistor with base emitter junction forward biased and collector base junction reverse biased.

3. The forward biased causes the electrons in the n type emitter to flow towards the base to constitute the emitter current IE.

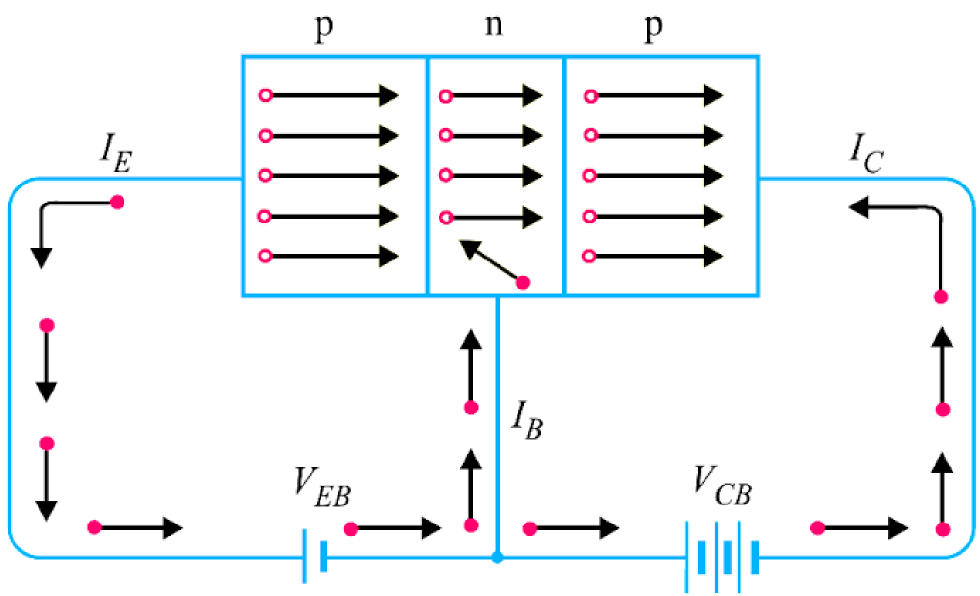
4. As these electrons flow towards the p type base, they tend to combine with holes, as the base is lightly doped and very thin. Therefore only a few electrons(less than 5%) combined with holes to constitute a current called base current IB.

5. The remaining electrons(more than 95%) cross over into the collector region to constitute a collector current IC.

6. In this way almost the entire emitter current flows in the collector circuit . That is the emitter current is sum of the base current and collector current.

7. Therefore IE=IB+IC.

Formation and working of pnp transistor:



Basic connection of *pnp* transistor

1. A pnp transistor is formed by two p type semiconductor separated by a thin section on n type semiconductor.
2. Figure shows the basic pnp transistor, forward biasing the base emitter junction and reverse biasing the collector base junction.
3. The forward bias causes the holes in the p type emitter to flow towards the base. This causes an emitter current IE.

4. As these holes cross into the n type base tends to combine with the free electrons. As the base is lightly doped and very thin, only a few holes(less than 5%) combines with the free electrons to constitute a base current IB.

5. The remaining holes(more than 95%) cross into the collector region to constitute a collector current called IC.

6. In this way, almost the entire emitter current flows in the collector circuit. The current conduction in the pnp transistor is by holes.

7. Therefore IE=IB+IC.

Transistor biasing:

The proper flow of collector current and maintaining the collector emitter voltage during passing of a signal is known as transistor biasing.

Necessity or Importance of transistor biasing:

Transistor biasing is required for faithful amplification. The basic purpose transistor biasing is to keep base emitter junction properly forward biased and collector base junction reverse biased during the amplification of the signal.

Note:

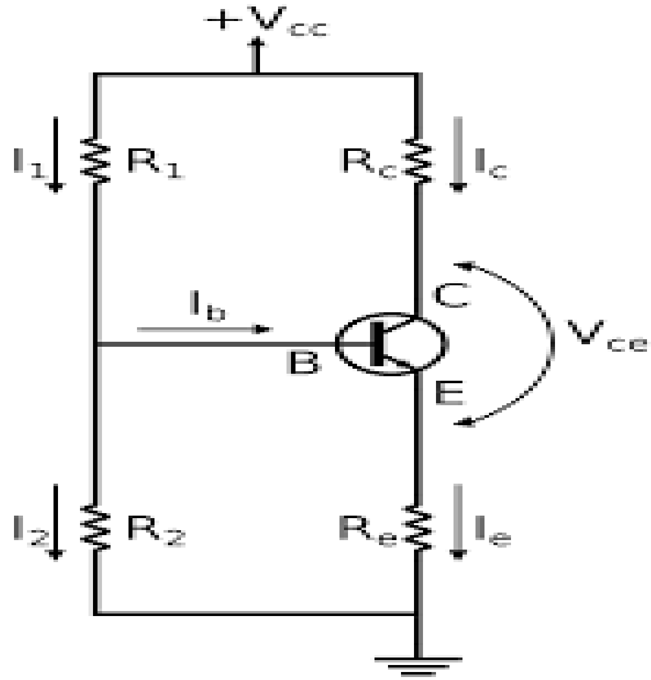
Faithful amplification: The process of raising the strength of weak signal without any change in its general shape is known as faithful amplification.

Types of biasing:

1. Fixed bias circuit
2. Collector to base bias circuit
3. Emitter bias circuit.
4. Voltage divider bias circuit.

Voltage divider bias circuit:

This is the most widely used method of providing biasing and stabilization to a transistor. In this method resistance R1 and R2 are connected across supplied voltage Vcc and provides biasing. The emitter resistance RE provides stabilization.



If collector current increases due to change in temperature or change in the ratio of Ic to the IB, the emitter current IE also increases and voltage drop across RE also increases, reducing the voltage difference between the base and emitter. Due to reduction in VBE, base current IB and collector current flow in the zero signal condition.

Stabilization:

The process of making the operating point independent of temperature change or variation in transistor parameters is known as stabilization.

Thermal runaway:

The excess heat produced at the collector base junction may even burn or destroy the transistor. This situation is called as thermal runaway of the transistor.

Or

The self destruction of unstabilized transistor is known as thermal runaway.

Heat sink:

A heat sink is a mechanical device which is connected or press fit to the case of the transistor, that provides the large surface area to dissipate the developed heat.

Or

The metal sheet that serves to dissipate the additional heat from the power transistor is known as heat sink.

Alpha (α):

It is defined as the ratio of collector current to the emitter current.

That is.,

$$\alpha = \frac{Ic}{IE}$$

Beta:

It is defined as the ratio of collector current to the base current.

That is.,

$$\beta = \frac{Ic}{IB}$$

Relation between alpha (α) and Beta (β)

In both the types of a transistor, the emitter current I_E is always equal to the sum of base current and collector current.

Therefore, $I_E = I_B + I_C \longrightarrow$ (i)

we know that $\beta = \dfrac{I_C}{I_B} \longrightarrow$ (ii)

From equation (i) we can write $I_B = I_E - I_C$

Substituting the value of I_B in equation (ii) we get,

$$\beta = \frac{I_C}{I_E - I_C} \longrightarrow \text{(iii)}$$

Dividing both the numerator and denominator of the RHS by I_E to the equation (iii) we get

$$\beta = \frac{I_C/I_E}{\frac{I_E - I_C}{I_E}}$$

$$\beta = \frac{I_C/I_E}{\cancel{\frac{I_E}{I_E}} - \frac{I_C}{I_E}}$$

$$\beta = \frac{I_C/I_E}{1 - \frac{I_C}{I_E}} \longrightarrow \text{(iv)}$$

we know that, $\alpha = \dfrac{I_C}{I_E}$

$$\therefore \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

Similarly we know that

$$\alpha = \frac{I_C}{I_E} \longrightarrow (v)$$

we know that $I_E = I_B + I_C$

$\therefore$ Substituting the value of I_E in equation (v) we get

$$\alpha = \frac{I_C}{I_B + I_C} \longrightarrow (vi)$$

Dividing both numerator and denominator by I_B in the equation (vi) we get

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

$$\alpha = \frac{I_C/I_B}{\frac{\cancel{I_B}}{\cancel{I_B}} + \frac{I_C}{I_B}}$$

$$\alpha = \frac{I_C/I_B}{1 + \frac{I_C}{I_B}}$$

But $\beta = \frac{I_C}{I_B}$

$$\therefore \boxed{\alpha = \frac{\beta}{1+\beta}}$$

Transistor configuration:

Transistors can be connected in the circuit in the following three configuration.

1. Common base configuration: For high frequency application.
2. Common emitter configuration: For audio frequency application
3. Common collector configuration: For amplification and impedance matching application.

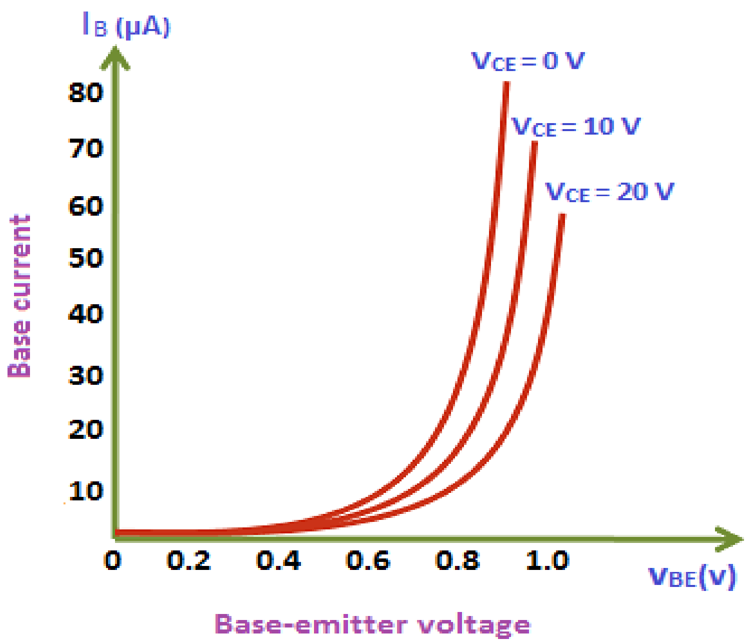
Characteristics of a common emitter configuration:

The important characteristics of the circuit arrangement are:

1. Input characteristics
2. Output characteristics.

1.Input characteristics:

It is the curve between the base current IB and base emitter voltage VBE at a constant collector emitter voltage VCE



I/P characteristics CE configuration

Keeping VCE as constant, note the base current IB for various values of VBE. Then plot the readings obtained on the graph by taking IB along y axis and VBE along x axis this gives the input characteristics as shown in the figure above.

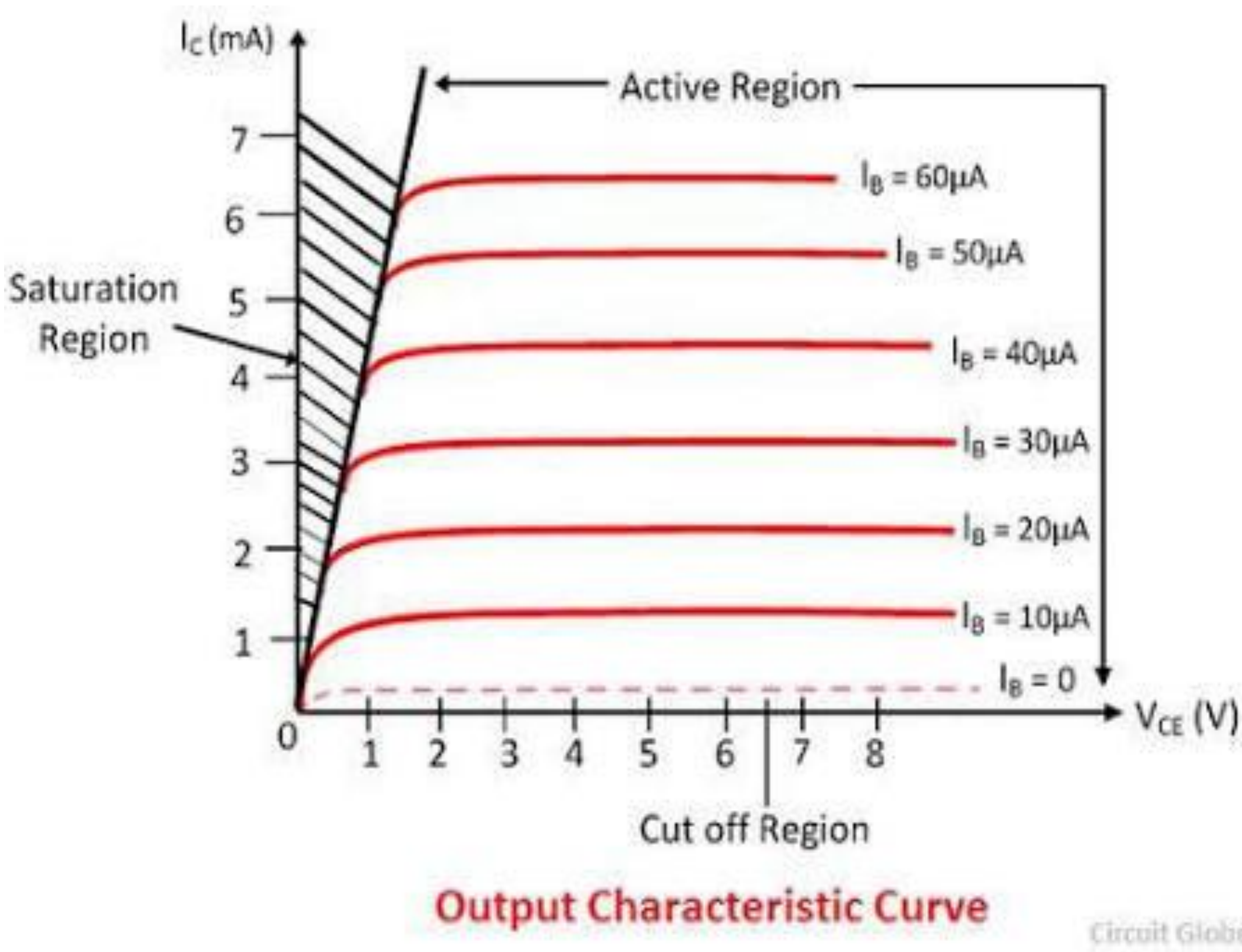
From the characteristics we observe the following points.

1. For a fixed value of VCE, IB increases as VBE is increased.
2. The common emitter input characteristics resembles that of forward characteristics of diode.
3. The input resistance is the ratio of change in base emitter voltage to the change in base current at constant VCE.

$$Ri = \Delta VBE / \Delta IB \text{ at constant } VCE$$

Output Characteristics:

It is the curve between the collector current IC and collector emitter voltage VCE at constant base current IB.



Keeping the base current IB constant, note the collector current IC for various values of VCE. Then plot the readings on a graph by taking IC along Y axis and VCE along X axis, this gives the output Characteristics as shown in the figure below.

The following points may be noted from the characteristics

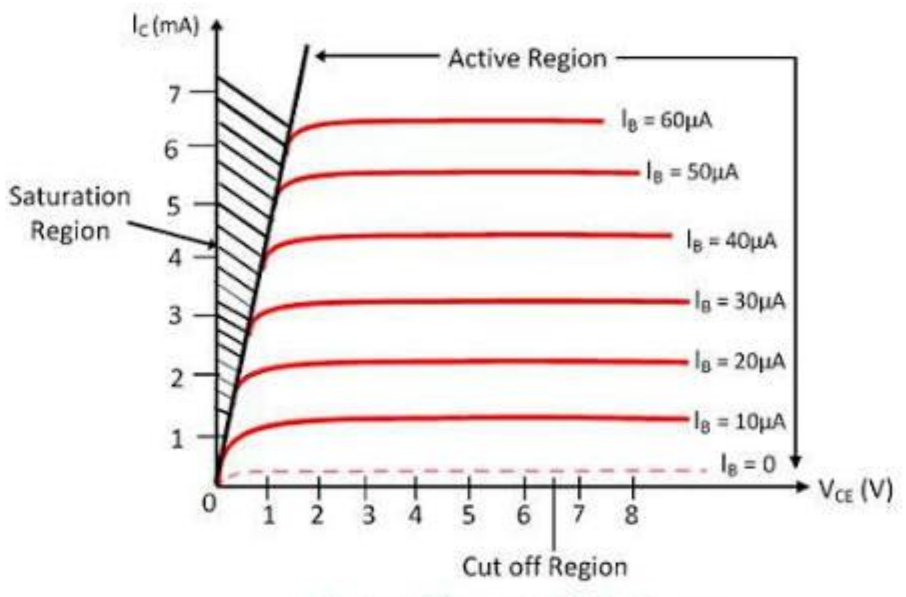
1. The collector current IC varies with VCE between 0 to 1 volt only after this the collector current becomes almost constant and independent of VCE. This value of VCE up to which the collector current changes is called knee voltage.
2. The transistor always operated in a region above the knee voltage.
3. The output resistance is the ratio of change in collector emitter voltage to the change in collector current at constant base current.

That is $Ro = \Delta VCE / \Delta IC$ at constant IB

Cutoff, Saturation and Active region of a transistor:

The output characteristics of a common emitter configuration consists of three regions namely.

1. Active region
2. Saturation region
3. Cutoff region.



Output Characteristic Curve

1. **Active region:**

The region between the cut off and saturation is known as active region. In this active region emitter base junction is forward biased and collector base junction is reverse biased. The transistor will function normally in this region.

2. **Saturation region:**

The region of the output characteristics where both the emitter base junction and collector base junctions are forward biased is known as saturation region. At saturation region collector base junction is no longer reverse biased and normal transistor action is lost.

3. **Cutoff region:**

The region of the output characteristics where both the emitter base junction and collector base junctions are reverse biased is known as cutoff region. The region below that is IB=0 is the cutoff region and the transistor is said to be off.

Application of transistor:

1. Switch and digital circuit application.
2. Used in amplification.
3. Used in inverters
4. Used in voltage regulators
5. Used in switch mode power supply.

Transistor as a switch:

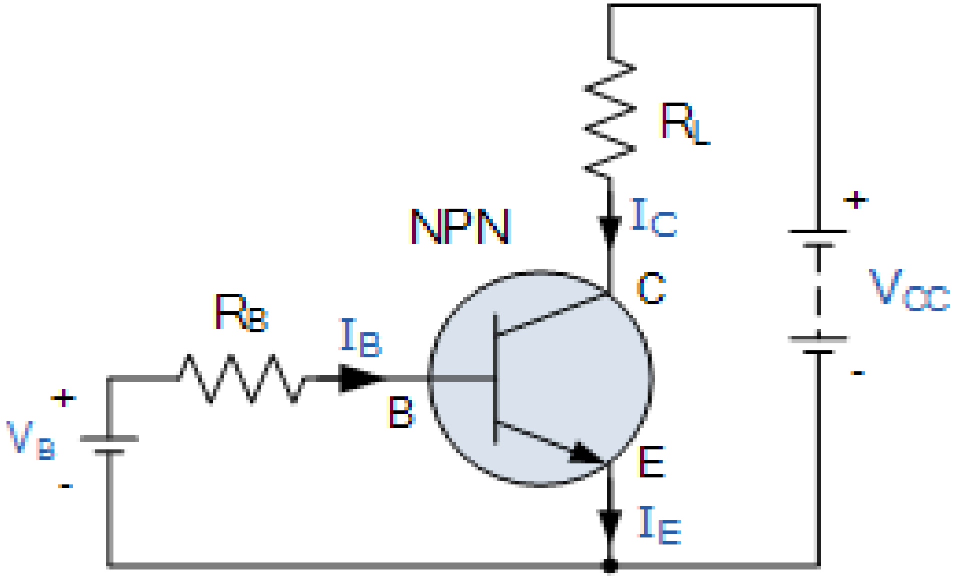


Figure shows the circuit arrangement of a transistor as a switch. If the base current IB is zero, the collector current IC is negligibly small and transistor is in cutoff region which is the off state of a transistor. In this region both the collector base junction and emitter base junction are reverse biased and transistor behaves as a open switch.

On the other hand if the base current IB is sufficient to drive the transistor into saturation region that is the collector current is very high then the transistor behaves as a closed switch. In this case the transistor is in saturation region and both the junctions are forward biased.

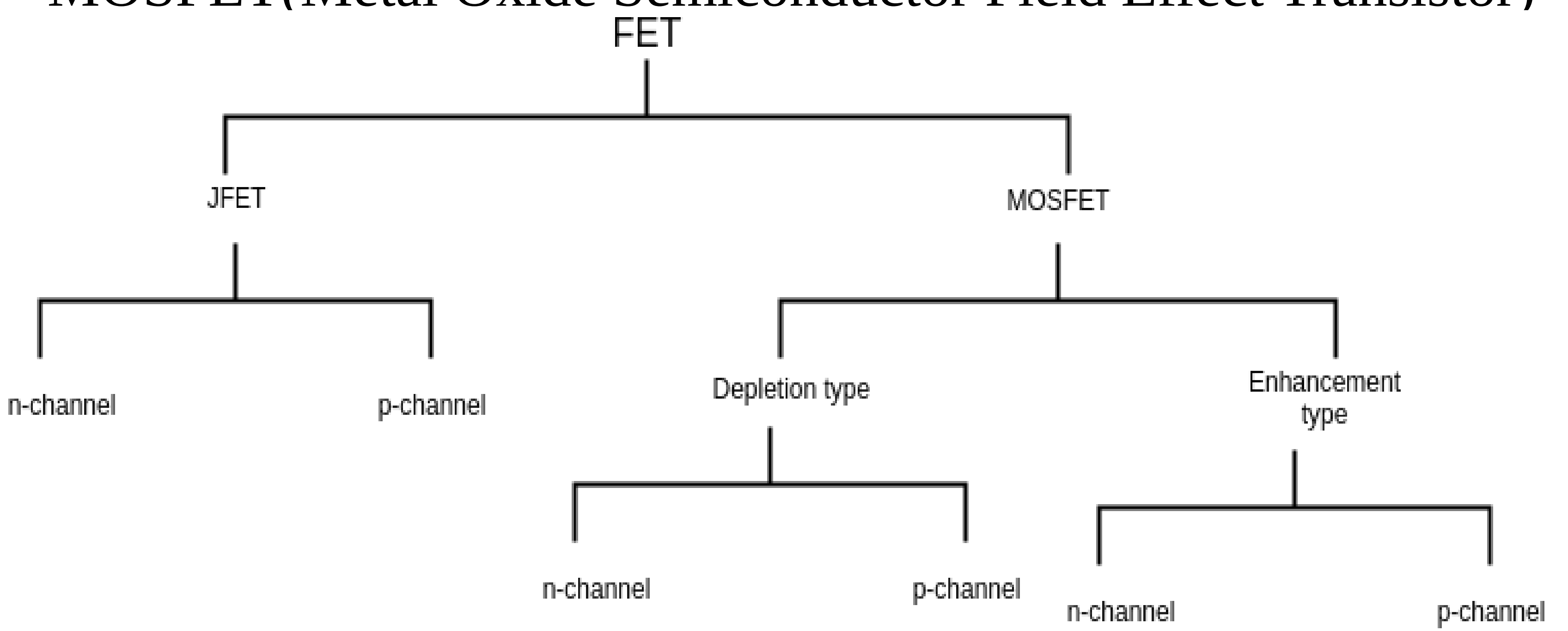
Field effect transistor(FET):

A field effect transistors are three terminal semiconductor device in which the current conduction is one type of charge carriers that is either holes or the electrons and is controlled by the effect of electric field.

Types of FET:

There are two kinds of FET they are

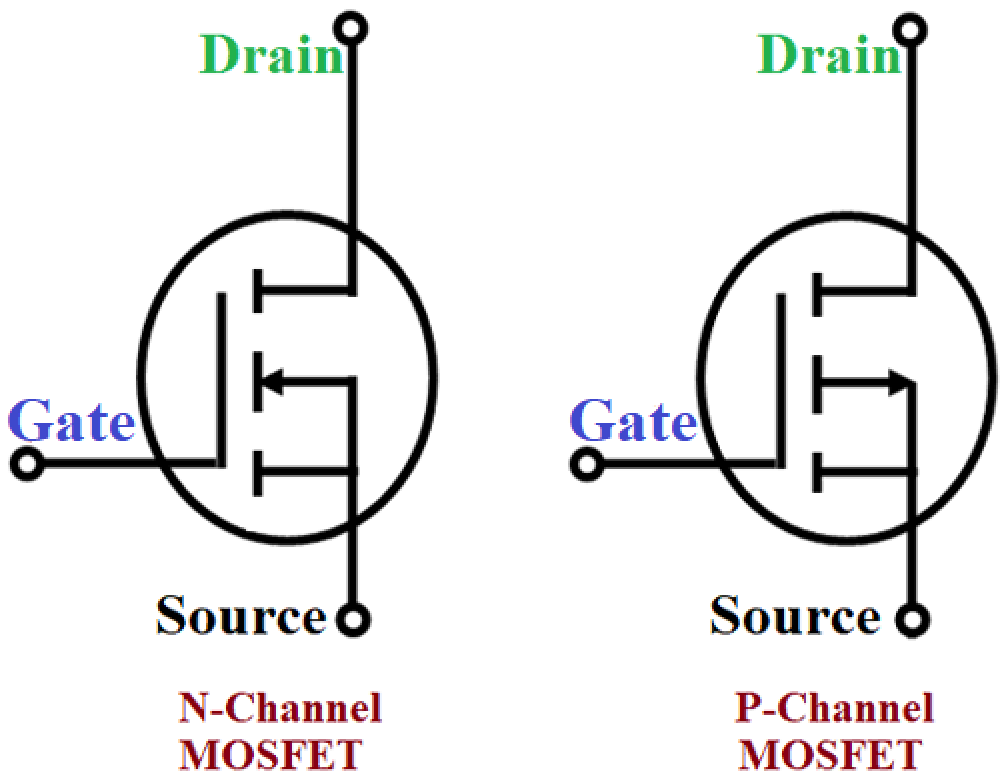
1. JFET(Junction Field Effect Transistor)
2. MOSFET(Metal Oxide Semiconductor Field Effect Transistor)



MOSFET(Metal Oxide Semiconductor Field Effect Transistor):

The MOSFET are the majority charge carrier device. It has three terminals that source(S), gate(G) and drain(D).

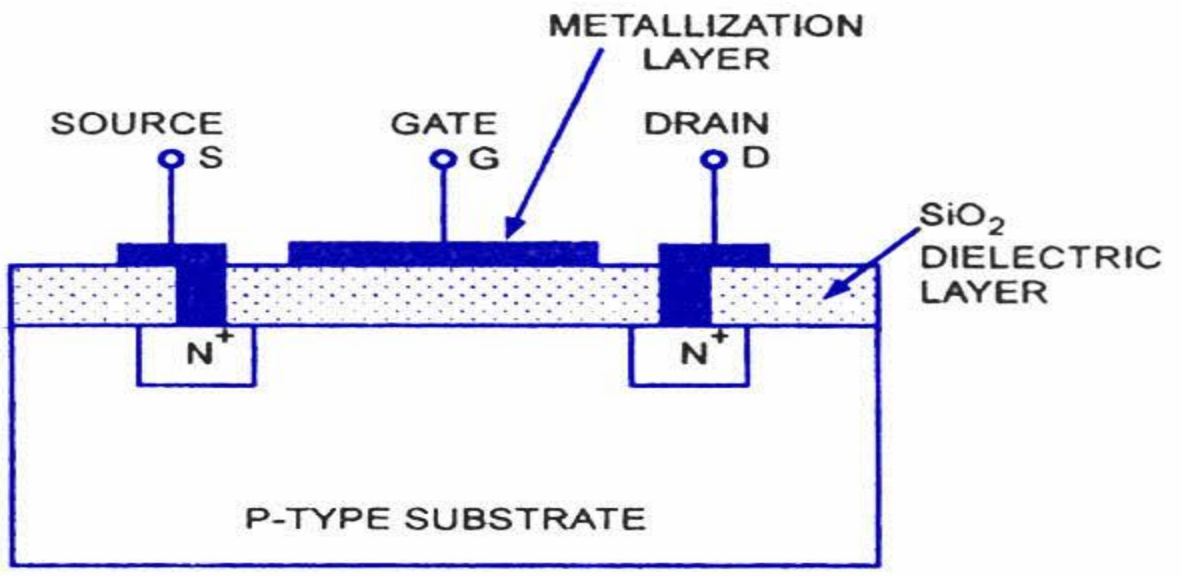
Symbol of MOSFET:



N type enhancement MOSFET:

Construction:

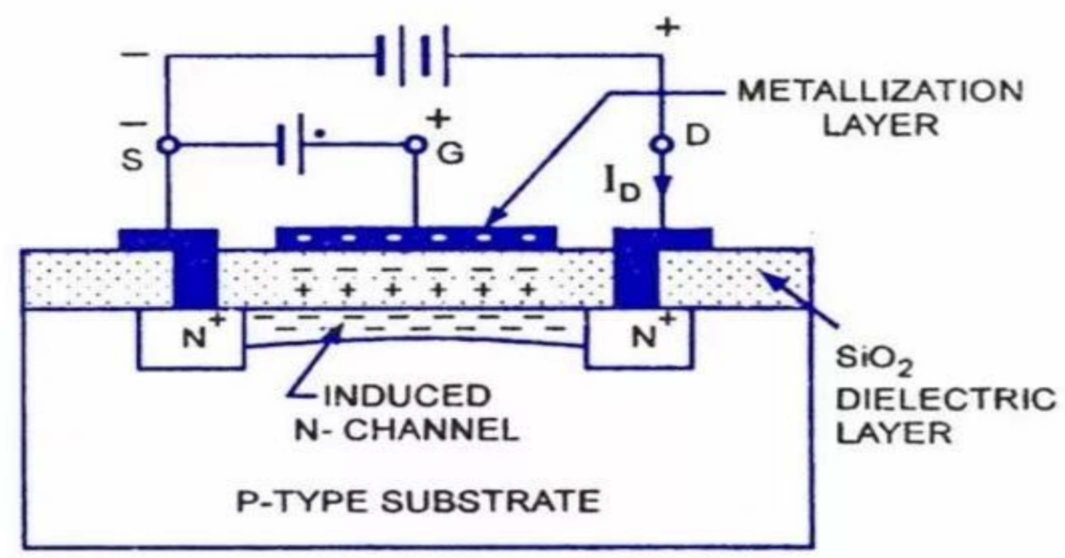
Figure shows the basic construction of n channel enhancement MOSFET .In n channel enhancement MOSFET two highly doped n regions are dipped into lightly doped p type substrate. The source and drain are taken out through metallic contacts to n doped regions as shown in the figure.



N-Channel E-MOSFET Structure

It does not have physical channel between the source and drain. A thin layer of SiO_2(Silicon di oxide) is present over the n type surface and holes are cut to make contact with source and drain. The gate is also connected to the metal surface and insulated from n channel by a thin layer of silicon di oxide. This layer results in extremely high impedance.

<u>**Working of n type enhancement MOSFET:**</u>



Operation of N-Channel E-MOSFET

1. On application of drain to source voltage VDS and keep the gate to source voltage VGS as zero by directly connecting the gate terminal to source terminal, practically zero current flows.
2. If we increase the magnitude VGS in positive direction, the concentration of the electrons near the SiO2 layer or surface increases.

3. At a particular value of VGS, there is a measurable current flows between the drain and source. This value of VGS is called threshold voltage and denoted by Vt.

4. Thus we can say that in an enhancement type n channel MOSFET, a positive gate voltage above a threshold voltage induces a channel and hence the drain current by creating a thin layer of negative charges in the substrate region.

5. The conductivity of the channel is enhanced by increasing the gate to source voltage and thus pulling more electrons into the channel.

6. Since the channel does not exits with the VGS=0 volt and enhances by the application of positive gate to source voltage. This type of MOSFET is called enhancement type MOSFET.

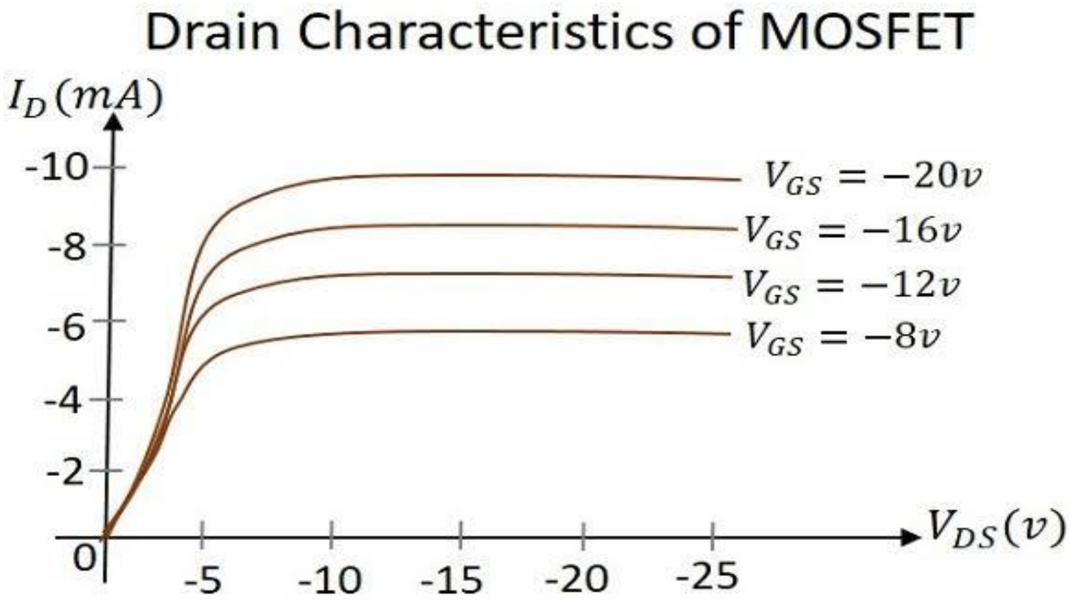
Characteristics of MOSFET:

MOSFET characteristics are of two types:

1. Drain Characteristics
2. Transfer Characteristics.

1. Drain Characteristics:

Figure shows the drain characteristics of a n channel enhancement MOSFET. As VGS increases beyond threshold value, the density of free electrons in the induced channel increases. However at some point of VDS for constant VGS, the drain current reaches a saturation level.



2. Transfer Characteristics:

Figure shows the transfer characteristics which is the plot of drain current versus gate to source voltage at a constant drain to source voltage. It shows that the drain current is zero until it reaches the threshold value, then the current increases linearly with the increase in voltage VGS.

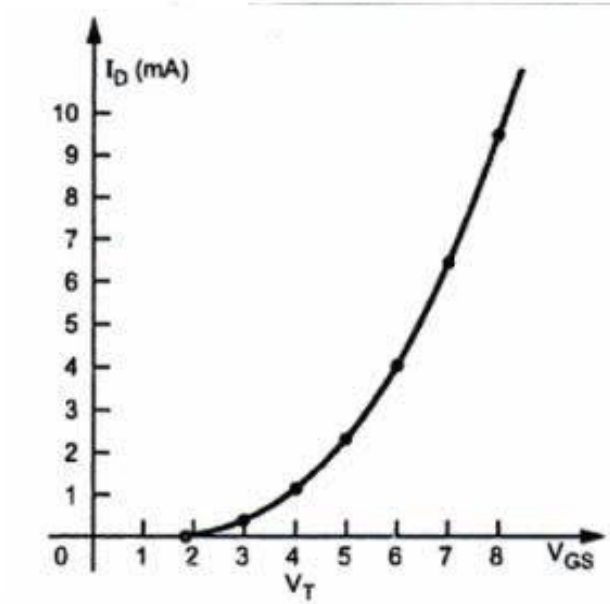
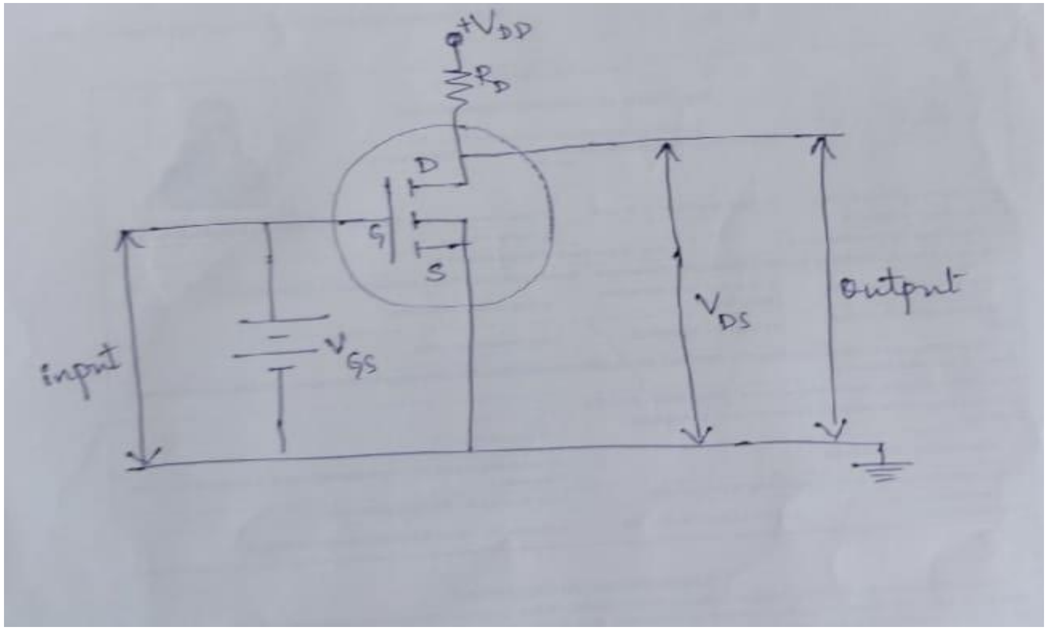


Fig 2.10: Transfer characteristic for n-channel enhancement type MOSFET

MOSFET as a switch:

MOSFET can be used in switching application. For enhancement type MOSFET no channel exists at VGS=0 volt when VGS =0 then drain current ID=0 ampere. Therefore MOSFET is said to be in OFF condition.

When VGS is made positive and greater the threshold voltage, drain current increases and MOSFET is said to be in ON condition.



Applications of MOSFET:

1.It is used as a switch.
2. High frequency and low power inverters, choppers in SMPS
3. Low power AC and DC drives.
4. In analog and digital circuits.
5. Used in amplifier circuit.

Comparison between BJT and MOSFET:

BJT	**MOSFET**
1. It is a bipolar device	1. It is a unipolar device
2. It is controlled by base terminal	2. It is controlled by gate terminal.
3. It is a current controlled device	3. It is a voltage controlled device.
4. Input impedance is low	4. Input impedance is high.
5.Thermal runaway exists	5. No thermal runaway
6. These are suitable for high power application	6. These are suitable for low power application.
7. Losses are less	7. Losses are more
8. Negative temperature co efficient	8. Positive temperature coefficient.