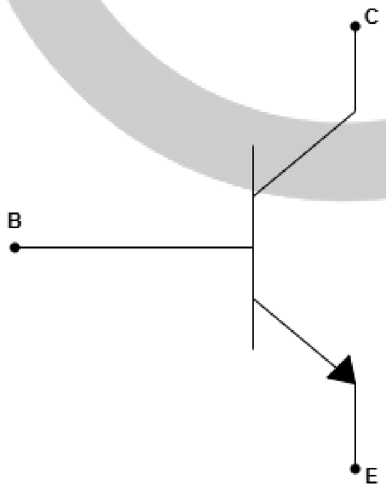
Transistor

A transistor is a tiny but incredibly important electronic component that acts as both a switch and an amplifier. It is a semiconductor device that controls the flow of current between the terminals based on the voltage applied to it. Transistors are mostly made up of silicon, these materials have properties that allow them to control the flow of electricity. Other materials like Germanium can also be used. In simple words, transistors acts like a tiny electronic switch or an amplifier. Some of the applications of transistors are: Computers, Smartphones, Televisions, Radios and other electronic systems.

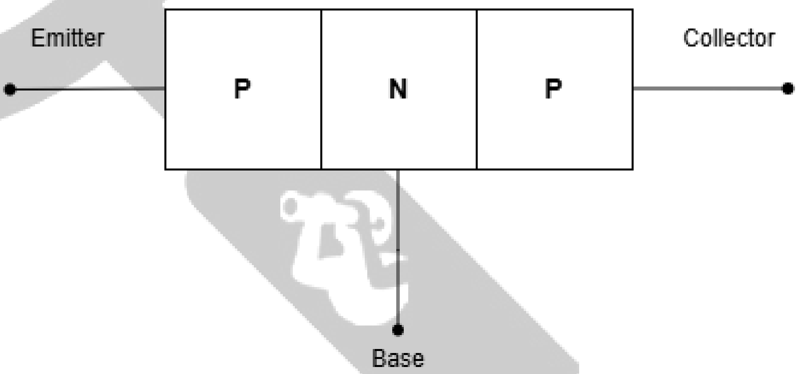
The three main components of a transistor

A transistor consists of three main components: the emitter, the base and the collector.

1) **Emitter**: The emitter supplies the charge carriers to the base. The charge carriers can be either electrons or holes. The emitter is heavily doped, it means they have high concentration of impurities to provide large number of carriers. Emitter is always forward biased with respect to base so it can supply carrier.
2) **Base**: The primary role of base is to control the flow of charge carriers from the emitter to the collector. It is highly doped compared to the emitter and collector.
3) **Collector**: The collector as the name suggests collects the carriers that have been supplied by the emitter and passed through the base. The collector is moderately doped. The collector is always reverse biased with respect to base.



a) Transistor



b) PNP transistor

Types

There are two types of transistors-

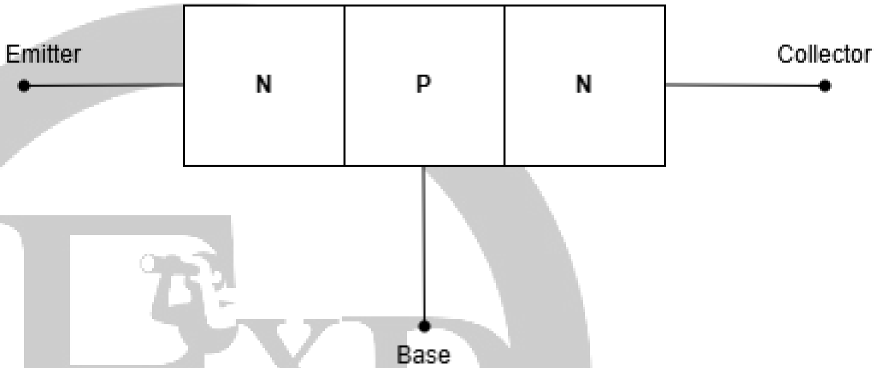
1) Bipolar Junction Transistors (BJTs)
2) Field Effect Transistors (FETs)

1) Bipolar Junction Transistors (BJTs):

BJTs use both electrons and holes for current conduction (hence bipolar). They are current-controlled devices, meaning that a small current flowing into the base terminal controls a much larger current flowing between the collector and emitter terminals. BJTs are widely used in Amplifiers (audio, radio frequency, etc.), switching circuits, and Voltage regulators.

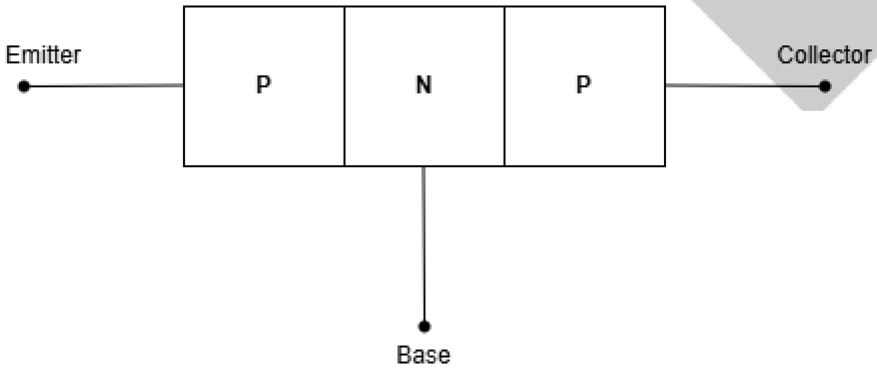
There are mainly 2 types of BJTs: NPN and PNP.

a) **NPN**: It consists of a thin layer of P-type semiconductor sandwiched between two N-type semiconductors.



Working: - By adjusting the base current, the NPN transistor regulates the movement of electrons from the emitter to the collector. When a small positive voltage is applied to the n base terminal comparable to the emitter, the base-emitter junction becomes forward biased. This will allow the electrons from the emitter to flow to the base region. Since the base region is very thin and lightly doped, most of the electrons supplied from the emitter don't recombine with the holes in the base. Instead, they are carried to the base-collector junction (which is reversed-biased) and into the collector region. A small change in the base current results in a much larger change in the collector current. This is the amplification property of the transistor. A small current supplied into the base, controls a much larger current flow from the collector to the emitter. They have three terminals: Emitter, Base and Collector.

b) **PNP**: Consists of a thin layer of N-type semiconductor sandwiched between two P-type semiconductors.



Working: - A PNP transistor works by essentially regulating how many holes move from the emitter to the collector, and this flow is controlled by the small current flowing through the base terminal. The emitter-base junction must be forward-biased, for a PNP transistor to conduct. This is obtained by applying a negative voltage to the base comparative to the emitter. This forward bias causes holes from the emitter to be injected into the base region. The base region is thin and lightly doped, so most of the injected holes don't recombine with electrons in the base. Instead, they are supplies across the base-collector (which is reverse-biased) and into the collector region. A small change in the base current (which is actually a flow of electrons leaving the base) results in a much larger change in the collector current (flow of holes). This is the transistor's amplification property. The conventional current flows from the emitter to the collector, opposite to the direction of electron flow but in the same direction as the holes flow. The current flows from the emitter to the collector.

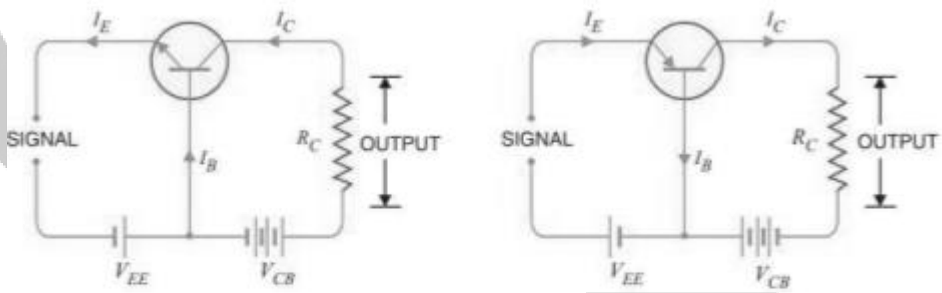
Transistor connection:

Transistor can be connected in circuit in following three ways –

i) Common Base
ii) Common Emitter
iii) Common collector

i) Common Base Connection:

The common-base terminology is derived from the fact that the base is common to both the input and output of the configuration.



First Figure shows common base npn configuration and second figure shows common base pnp configuration

Current Amplification factor (α):

The ratio of change in collector current to the change in emitter current at constant VCB is known as current amplification factor.

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

Practical value of is less than unity, but in the range of 0.9 to 0.99.

Expression for Collector Current

Total emitter current does not reach the collector terminal, because a small portion of it constitute base current. So, $I_E = I_B + I_C$

Also, collector diode is reverse biased, so very few minority carrier passes the collector-base junction which actually constitute leakage current. So, collector current constitute of portion of emitter current αI_E and leakage current I_{CBO}.

$$I_C = \alpha I_E + I_{CBO}$$

$$I_C = \alpha(I_C + I_{CBO}) + I_{CBO}$$

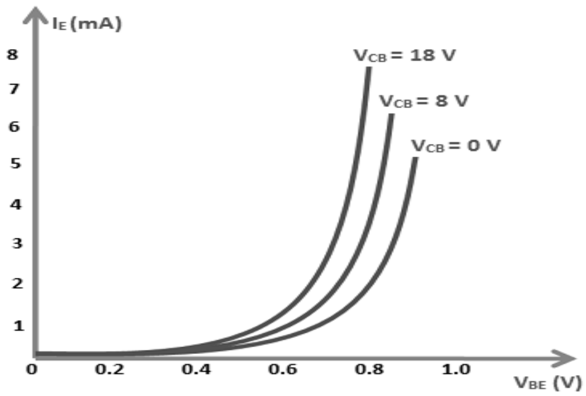
$$I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

Characteristics of Common base configuration

Input characteristics:

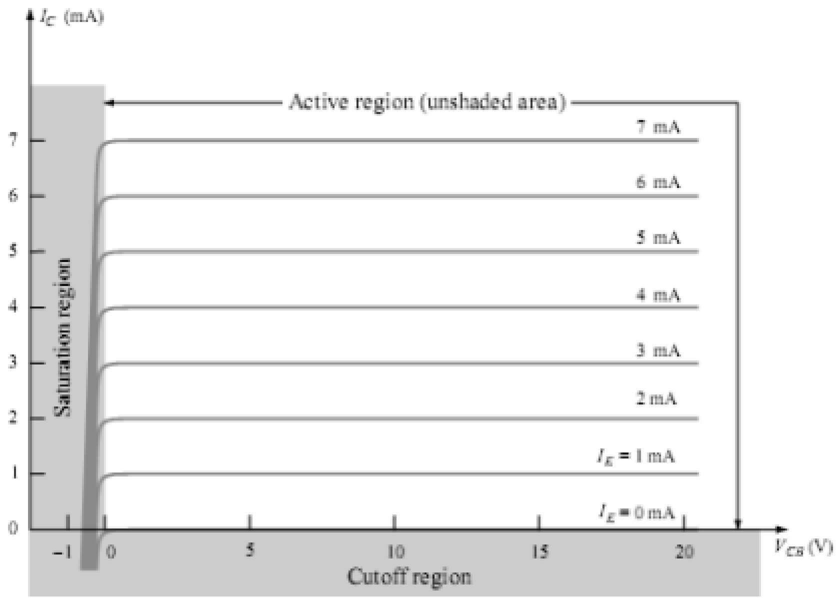
- V_{BE} vs I_E characteristics is called input characteristics.
- I_E increases rapidly with V_{BE}. It means input resistance is very small.
- I_E almost independent of V_{CB}.



I/p characteristics CB configuration

Output characteristics:

- V_{Bc} vs I_c characteristics is called output characteristics.
- I_C varies linearly with V_{Bc}, only when V_{Bc} is very small.
- As, V_{Bc} increases, I_c becomes constant.



Input and output resistance of a common base configuration

Input Resistance: The ratio of change in emitter-base voltage to the change in emitter current is called Input Resistance.

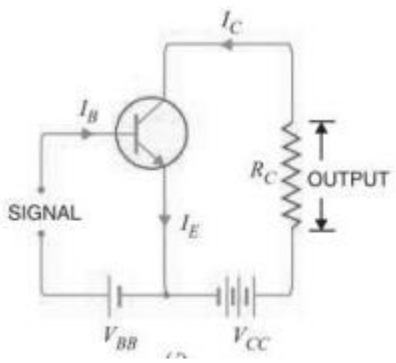
$$r_i = \frac{\Delta VBE}{\Delta IE}$$

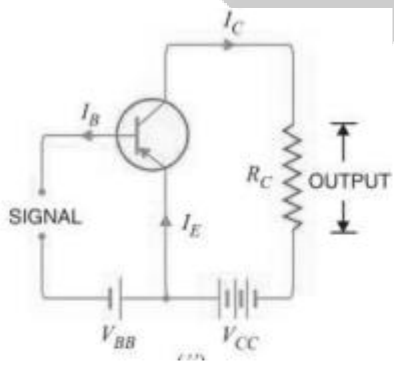
Output Resistance: The ratio of change in collector-base voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta VBC}{\Delta IC}$$

ii) Common Emitter Connection:

The common-emitter terminology is derived from the fact that the emitter is common to both the input and output sides of the configuration.





First Figure shows common emitter npn configuration and second figure shows common emitter pnp configuration.

Base Current amplification factor (β):

• In common emitter connection input current is base current and output current is collector current.
• The ratio of change in collector current to the β change in base current is known as base current amplification factor,

$$\beta = \frac{\Delta IC}{\Delta IB}$$

Normally only 5% of emitter current flows to base, so amplification factor is greater than 20. Usually this range varies from 20 to 500.

Relation Between α and β

$$\beta = \frac{\Delta IC}{\Delta IB} \qquad \beta = \frac{(\Delta IC / \Delta IE)}{(\frac{\Delta IE}{\Delta IE} - \frac{\Delta IC}{\Delta IE})} \qquad \beta = \frac{\Delta IC}{(\Delta IE - \Delta IC)}$$

$$\alpha = \frac{\Delta IC}{\Delta IE} \qquad \beta = \frac{\alpha}{(1-\alpha)}$$

$I_E = I_B + I_C$

$\Delta I_E = \Delta I_B + \Delta I_C$

$\Delta I_B = \Delta I_E - \Delta I_C$

Expression for collector current

$$I_C = \alpha\, I_E + I_{CBO}$$

$$I_E = I_B + I_C = I_B + (\alpha\, I_E + I_{CBO})$$

$$I_E\,(1 - \alpha) = I_B + I_{CBO}$$

$$I_E = \frac{I_B}{(1-\alpha)} + \frac{I_{CBO}}{(1-\alpha)}$$

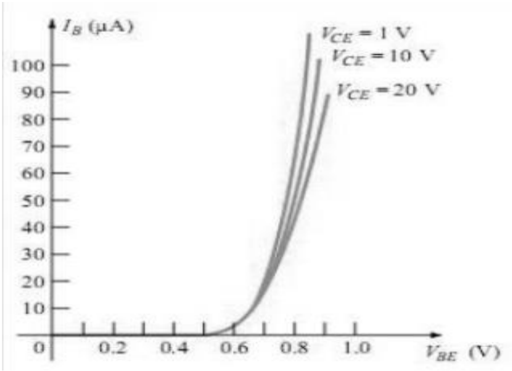
$$I_E = (\beta + 1)\, I_B + (\beta + 1)\, I_{CBO}$$

Characteristics of common emitter configuration

Input characteristics

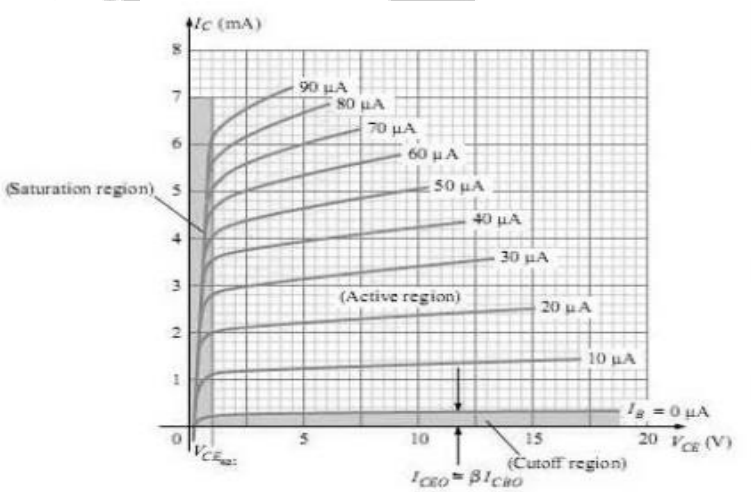
- V_{BE} vs I_B characteristics is called input characteristics.
- I_B increases rapidly with V_{BE}. It means input resistance is very small.

- IE almost independent of VCE.
- IB is of the range of micro amps.



Output characteristics

- VCE vs Ic characteristics is called output characteristics.
- IC varies linearly with VCE, only when VCE is very small.
- As, VCE increases, IC becomes constant.



Input and Output Resistance of common emitter configuration

Input Resistance: The ratio of change in emitter-base voltage to the change in base current is called Input Resistance.

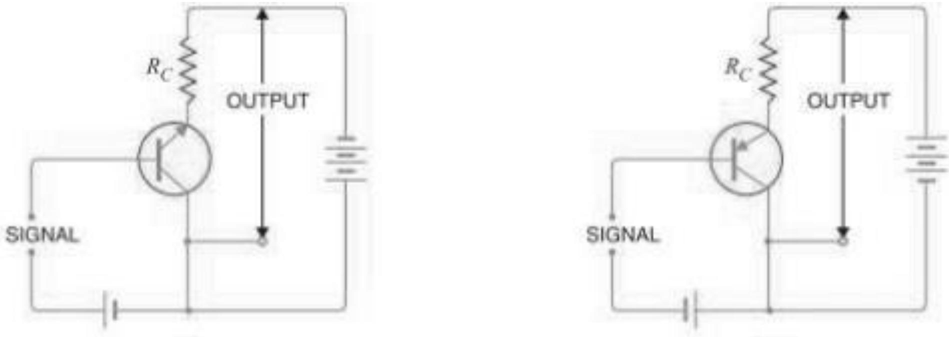
$$ri = \frac{\Delta VBE}{\Delta IB}$$

Output Resistance: The ratio of change in collector-emitter voltage to the change in collector current is called Output Resistance.

$$r0 = \frac{\Delta VCE}{\Delta IC}$$

iii) Common Collector configuration

The common-collector terminology is derived from the fact that the collector is common to both the input and output sides of the configuration.



(i) (ii)

First Figure shows common collector npn configuration and second figure shows common collector pnp configuration.

Current amplification factor (γ):

• In common emitter connection input current is base current and output current is emitter current.
• The ratio of change in emitter current to the change in base current is known as current amplification factor in common collector configuration.

$$\gamma = \frac{\Delta IE}{\Delta \mathrm{IB}}$$

Relation between γ and α:

$$\gamma = \frac{\Delta IE}{\Delta \mathrm{IB}} \qquad \gamma = \frac{\Delta \mathrm{IE}}{(\Delta \mathrm{IE} - \Delta \mathrm{IC})} \qquad I_E = I_B + I_C$$

$$\alpha = \frac{\Delta IC}{\Delta IE} \qquad \gamma = \frac{(\Delta \mathrm{IE} \,/\, \Delta \mathrm{IE})}{\left(\frac{\Delta \mathrm{IE}}{\Delta \mathrm{IE}} - \frac{\Delta \mathrm{IC}}{\Delta \mathrm{IE}}\right)} = \frac{1}{(1-\alpha)} \qquad \Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

Expression for collector current:

$$\beta = \frac{\alpha}{(1-\alpha)} \qquad \therefore \beta + 1 = \frac{\alpha}{(1-\alpha)} + 1 = \frac{1}{(1-\alpha)}$$

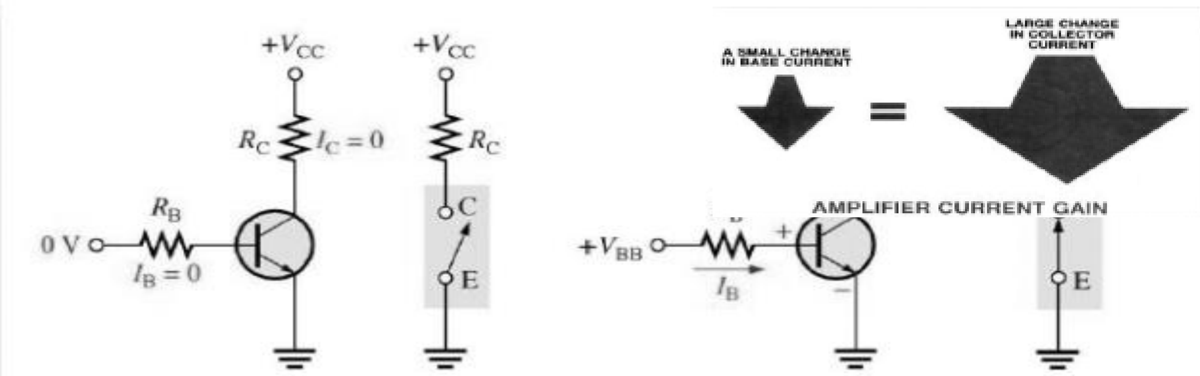
Comparison of Transistor Connection:

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Transistor applications

Transistor as a switch:

When used as an electronic switch, the transistor is normally operated alternately in cut-off and saturation regions.



(a) Cutoff — open switch (b) Saturation — closed switch

Transistor as Amplifier:

Due to the small changes in base current the collector current will mimic the input with greater amplitude.

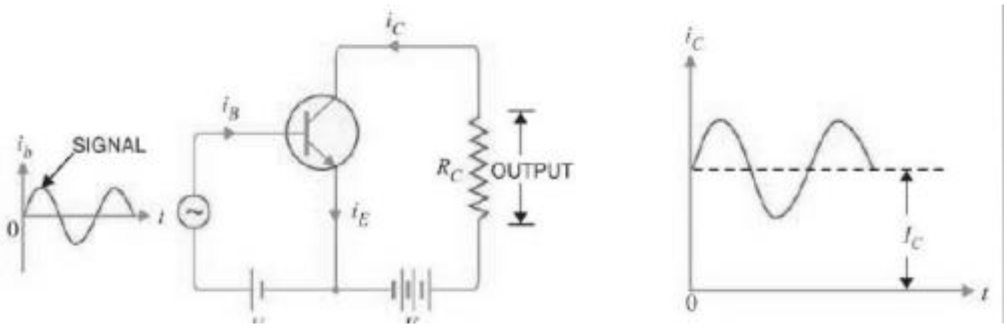


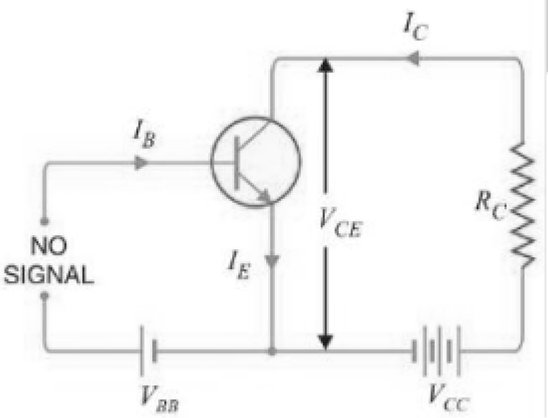
Figure shows CE amplifier for npn transistor

- Battery VBB is connected with base in-order to make base forward biased, regardless of input ac polarity.
- Output is taken across Load R.
  During positive half cycle input ac will keep the emitter base junction more forward biased. So, more carrier will be emitted by emitter, this huge current will flow through load and we will find output amplified signal.
- During negative half cycle input ac will keep the emitter-base junction less forward biased. So, less carrier will be emitted by emitter. Hence collector current decreases.
- This results in decreased output voltage (In opposite direction).

Transistor Load line analysis

Consider common emitter npn transistor circuit shown in figure.

- There is no input signal.
- Apply KVL in the output circuit.



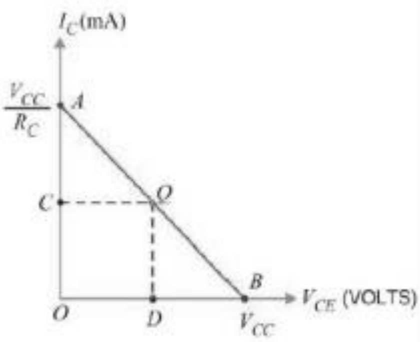
$V_{CE} = V_{CC} - I_C R_C$

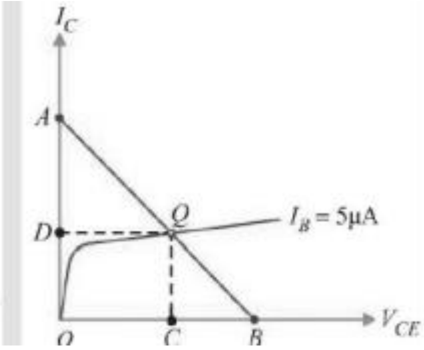
(*i*) When the collector current $I_C = 0$, then collector-emitter voltage is maximum and is equal to V_{CC} *i.e.*

$$\text{Max. } V_{CE} = V_{CC} - I_C R_C = V_{CC} \qquad (\because I_C = 0)$$

When the collector-emitter voltage $V_{CE} = 0$,

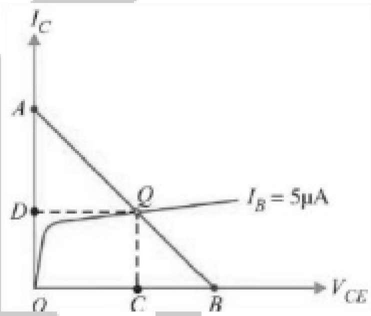
$$V_{CE} = V_{CC} - I_C R_C$$
$$0 = V_{CC} - I_C R_C$$
$$\text{Max. } I_C = V_{CC}/R_C$$





Operating point

The zero signal values of IC and VCE is known as operating point.



•It is called operating point because variation of IC takes place about this point.

•It is also called quiescent point or Q-point.

2) Field Effect Transistors (FETs)

FETs use an electric field to control current flow. They are unipolar, meaning they use either electrons or holes as charge carriers, but not both. A very common type of FET is MOSFET. FETs are voltage-controlled devices. This means that the voltage applied to the gate terminal controls the current flow between the source and the drain terminal. They have three terminals: Source, Drain and Gate.

1) **Source**: The terminal from which charge carriers enter the channel.
2) **Drain**: The terminal through which charge carriers leave the channel.
3) **Gate**: The terminal that controls the current flow.

There are two types of FETs:

a) Junction Field-Effect Transistor (JFETs).
b) Metal-oxide-Semiconductor Field Effect Transistors (MOSFETs).

Working:

N Channel FET	P Channel FET
Source connected to -VE	Source connected to +VE
Drain Connected to +ve	Drain Connected to -ve
Gate connected to –ve (Reverse Biased)	Gate connected to +ve (Reverse Biased)

Difference between N-channel FET and P-channel FET

N Channel FET	P Channel FET
1. Current carriers are Electrons 2. Mobility of electrons is almost twice that of Holes in P channel FET 3. Low input Noise 4. Large Transconductance	1.Current carriers are holes 2.Mobility of holes is poor 3.More noise 4.Low Transconductance

a) Junction Field Effect Transistor (JFETs):

The Junction Field-Effect Transistor (JFET) is a type of field-effect transistor that uses a reverse-biased p-n junction to control the flow of current in a channel. Unlike bipolar junction transistors (BJTs) which are current-controlled, JFETs are voltage-controlled. This means the voltage applied to the gate terminal controls the current flow between the source and drain terminals. JFETs are commonly used in amplifiers. They can be used as voltage-controlled switches. They are used in sensors and transducers to convert physical quantities into electrical signals. Some advantages are High impedance, low noise and gives linear output.

Working: - The JFET has a channel (either n-type or p-type semiconductor) through which current flows. Surrounding this channel are regions of the opposite semiconductor type, forming p-n junctions. When a reverse bias is applied to these p-n junctions (between the gate and the channel), a depletion region forms. This depletion region is devoid of mobile charge carriers. By varying the voltage applied to the gate, the width of the depletion region is altered. An increased reverse bias widens the depletion region, effectively narrowing the conductive channel. A decreased reverse bias allows the depletion region to shrink, widening the channel. The current flowing between the source and drain is determined by the width of the conductive channel. A narrower channel restricts current flow, while a wider channel allows more current to pass.

JFETs come in two main types:

i) **N-channel JFETs**: The channel is made of n-type semiconductor material, and current flow is primarily due to electrons.

Working: -

• Zero Gate Voltage (VGS = 0V):

- With no voltage applied to the gate, the depletion regions are relatively small, and the channel is wide.
- Maximum current (IDSS) flows between the source and drain when a voltage (VDS) is applied.

• Negative Gate Voltage (VGS < 0V):

- Applying a negative voltage to the gate increases the reverse bias on the p-n junctions, widening the depletion regions.
- This narrows the channel, reducing the current flow between the source and drain.
- As the negative gate voltage increases, the channel becomes progressively narrower, and the current decreases.

• Pinch-Off:

- At a specific negative gate voltage (the pinch-off voltage, VP), the depletion regions meet, completely closing the channel.
- At this point, the current flow between the source and drain is nearly zero.

• Saturation Region:

- After the pinch off voltage is reached, the drain current becomes relatively constant, and is then said to be in the saturation region.

ii) **P-channel JFETs**: The channel is made of p-type semiconductor material, and current flow is primarily due to holes.

Working: -

•The operation of a p-channel JFET is similar to that of an n-channel JFET, but the polarities of the voltages are reversed.

•A positive gate voltage controls the width of the depletion region.

JFET Parameters:

Electrical behaviour is described in terms of the parameters of the Device. They are obtained from the characteristics. Important Parameters for FET are

1. DC Drain resistance
2. AC drain Resistance
3. Transconductance

- **DC Drain resistance**: Defined as ratio of Drain to source Voltage V_{DS} to Drain current I_D. Also called static or Ohmic Resistance.

$$R_{DS} = V_{DS} / I_D$$

- **AC Drain resistance:** Defined as the resistance between Drain to source when JFET is operating in Pinch off Region or saturation Region.

$$r_D = V_{DS} / I_D \quad \text{When is } V_{GS} \text{ constant}$$

- **Transconductance (gm):** It is given by the ratio of small change in drain current to the Corresponding change in the Gate to source Voltage VGS. Also known as Forward Transmittance.

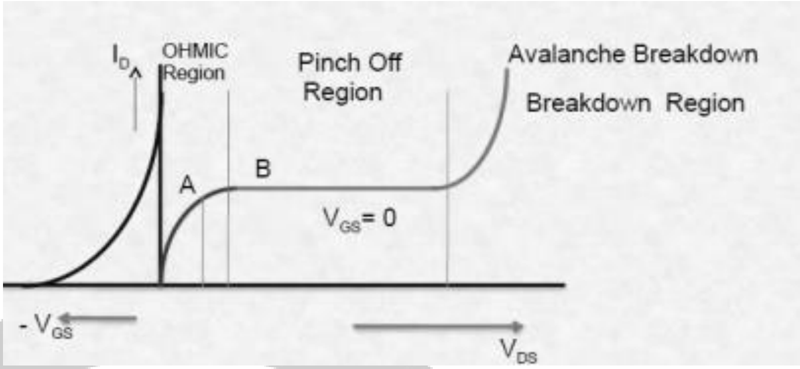
$$g_m = \Delta I_D / \Delta V_{DS}$$

Difference between FET and BJT

FET	BJT
1. Uni polar device	1. Bipolar device
2. Voltage controlled Device	2.Current controlled device
3. High input impedance (in Mega ohms)	3.Low input impedance
4. Better thermal stability	4.Low thermal stabilty
5. High switching speeds	5.Lower switching speeds
6. Less Noisy	6.More noisy
7. Easy to fabricate	7.Diffuicult to fabricate on IC

Drain Characteristics

Drain characteristics show the relation between the drain to source voltage and V_{DS} and drain current I_D.



•At the Drain to source Voltage corresponding to point B Channel width reduces to a minimum value and is known as pinch off

Drain current I_D is given by,

$$I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2$$

•The device gets damaged due to avalanche Breakdown mechanism.

FET Applications:

- Phase shift oscillators: The high input impedance of FET is especially valuable in phase shift oscillator to minimize the loading effect.
- **In voltmeters:** The high input impedance of FET is useful in voltmeters to act as an input stage.
- As a buffer amplifier which isolates the preceding stage from the following stage.
- FET has low noise operation. So it is used in RF amplifiers in FM tuners and communication equipment.
- FET has low input capacitance, so it is used in cascade amplifiers in measuring and test equipment.
- Since FET is a voltage controlled device, it is used as a voltage variable resistor in operational amplifiers and tone controls.
- FET has low inner modulation distortion. So it is used in mixer circuits in FM and TV receivers, and communication equipment.
- Since it is low-frequency drifts, it is used in oscillator circuits.

DISADVANTAGES OF FET OVER BJT

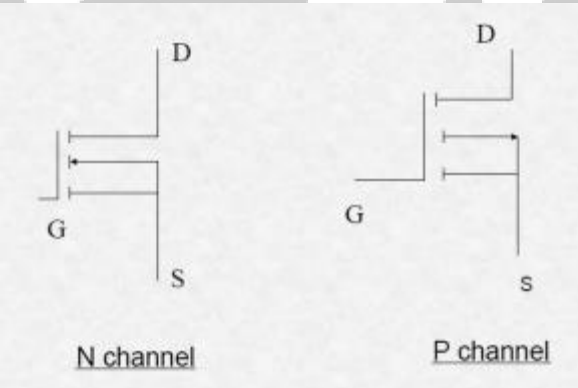
- **Lower Gain-Bandwidth:** BJTs often amplify better at high frequencies.
- **Slower Switching:** BJTs can switch faster.
- **Lower Transconductance:** FETs may have less gain in some amplifiers.
- **Static Sensitivity:** MOSFETs are easily damaged by static.
- **Power Limitations:** Some BJTs handle very high power better.

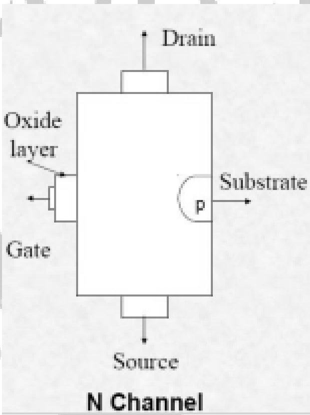
b) Metal-oxide-Semiconductor Field Effect Transistors (MOSFETs):

Like other FETs, the MOSFET's operation is based on controlling the conductivity of a channel by applying an electric field. A key characteristic is the insulated gate, typically separated from the channel by a thin layer of silicon dioxide (or another insulating material). This insulation gives the MOSFET a very high input impedance. The voltage applied to the gate terminal controls the flow of current between the source and drain terminals. MOSFETs are the building blocks of digital integrated circuits, including microprocessors and memory chips. They are used in power electronics for switching applications due to their ability to handle high currents and voltages. MOSFETs can also be used as amplifiers. Some advantages are High input impedance, low power consumption and Scalable.

- MOSFET is an important semiconductor device and is widely used in many circuit application.
- The input impedance of a MOSFET is much more than that if a FET because of very small leakage current.
- MOSFETs has much greater commercial Importance than JFET.
- The MOSFET can be used in any of the circuits covered for the FET.
- Therefore all the equations apply equally well to the MOSFET and FET in amplifier connections.
- MOSFETs uses a metal gate electrode (instead of p-n junction in JFET), separated from the semi-conductor by an Insulating thin layer SiO2 to modulate the resistance of the conduction channel.
- It is also called as insulated gate FET (IGFET).
- MOSFETs operates both in the depletion mode as well as the enhancement mode.

Circuit symbols of MOSFET





Differences between FET and MOSFET

- There is only a single *p-region. This is called substrate.*
- A thin layer of metal oxide is deposited over the left side of the channel. A metallic gate is deposited over the oxide layer. As silicon dioxide is an insulator, therefore a gate is insulated from the channel. For this reason MOSFET is sometimes called insulated gate FET.

Types:

i) **N-channel MOSFET (NMOS):** Uses electrons as charge carriers.
ii) **P-channel MOSFET (PMOS):** Uses holes as charge carriers.

iii) **Enhancement-mode MOSFET:** Normally off; requires a gate voltage to create a channel.

iv) **Depletion-mode MOSFET:** Normally on; a gate voltage is needed to deplete the channel.

v) **CMOS (Complementary MOS):** A common configuration that uses both NMOS and PMOS transistors to create logic gates with very low power consumption.

1) N-channel MOSFET (NMOS):

An N-channel MOSFET (NMOS) is a fundamental type of Metal-Oxide-Semiconductor Field-Effect Transistor that utilizes electrons as the primary charge carriers. The "N-channel" designation indicates that the conductive channel formed between the source and drain is composed of n-type semiconductor material. This channel is created within a p-type substrate. NMOS transistors can be either enhancement-mode or depletion-mode -

- **Enhancement-mode NMOS:** These are the most common. They are normally "off" (no current flow) when the gate voltage is zero. A positive voltage applied to the gate creates the n-channel, allowing current to flow.
- **Depletion-mode NMOS:** These are normally "on" when the gate voltage is zero. A negative voltage applied to the gate depletes the channel, reducing or stopping current.

Working: -

- When a positive voltage is applied to the gate, an electric field is created.
- This field attracts free electrons from the p-type substrate to the region beneath the gate, forming an n-type channel.
- With the channel established, current can flow between the source and drain when a voltage is applied between them.

2) P-channel MOSFET (PMOS):

A P-channel MOSFET (PMOS) is a type of MOSFET where the channel is formed by holes, which are positive charge carriers. The "P-channel" designation signifies that the conductive channel created between the source and drain is composed of p-type semiconductor material. This channel is formed within an n-type substrate. A crucial difference from NMOS is that PMOS transistors are activated by a negative voltage applied to the gate. Specifically, to turn a PMOS on, the gate voltage must be lower than the source voltage. The primary charge carriers in a PMOS transistor are holes. Holes have lower mobility than electrons, meaning PMOS transistors generally have slower switching speeds compared to NMOS transistors.

Working: -

- When a sufficiently negative voltage is applied to the gate of a PMOS transistor, it creates an electric field that repels electrons and attracts holes from the n-type substrate to the region beneath the gate.
- This accumulation of holes forms a p-type channel, allowing current to flow between the source and drain.

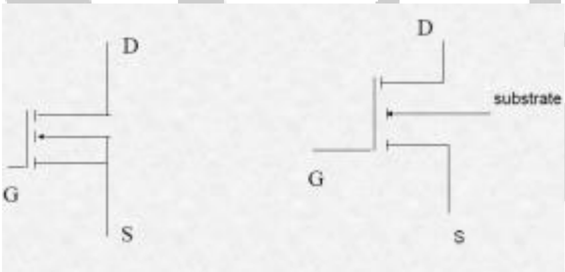
- The amount of current flow is controlled by the magnitude of the negative gate voltage.

3) Enhancement-mode MOSFET:

An enhancement-mode MOSFET is a type of MOSFET that is normally "off" when the gate-source voltage (Vgs) is zero. Unlike depletion-mode MOSFETs, enhancement-mode MOSFETs do not have a built-in channel. This means that when there is no voltage applied to the gate, there is no conductive path between the source and drain. Applying a voltage to the gate creates an electric field that induces a conductive channel in the semiconductor material. In an N-channel enhancement-mode MOSFET, a positive gate voltage attracts electrons to form an N-type channel. In a P-channel enhancement-mode MOSFET, a negative gate voltage attracts holes to form a P-type channel. A certain minimum gate voltage, called the threshold voltage, is required to create a conductive channel. Once the gate voltage exceeds the threshold voltage, the MOSFET begins to conduct. Enhancement-mode MOSFETs are the most common type of MOSFET and are widely used in digital logic circuits, including microprocessors, memory chips, and other integrated circuits. They are also used in various switching applications.

a) N-Channel Enhancement MOSFET:

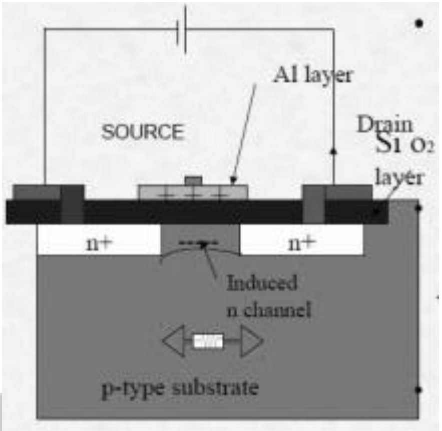
An N-channel MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) is a type of transistor that uses an electric field to control the flow of current.



Working:

•It consists of a lightly doped p type substrate in to which two heavily doped n type material are diffused.
• The surface is coated with a layer of silicon dioxide (SiO2).
• Holes are cut through the SiO2 to make contact with n-type blocks.
•Metal (Al) is deposited through the Holes to form drain and source terminals.

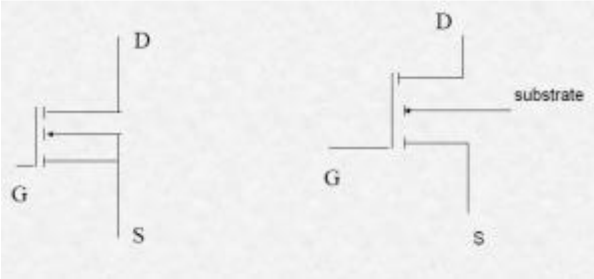
•The surface area between drain and source a metal plate is deposited from which gate terminal is taken out.



Gate is insulated from the body of FET so it is called insulated gate FET (IGFET).
•Structurally there exists no channel between source and drain so MOSFET sometimes called as N-channel enhancement type
•Because a thin layer of P-type substrate touching the metal oxide film provides channel for electrons and hence acts like N-type material.
Drain is made positive with respect to the source and no potential is applied to the gate as shown in figure.
• The two n-blocks and p-type substrate form back to back pn junctions connected by the Resistance of the p-type material.
• Both the junctions cannot be forwarded at the same time so small drain current order of few nano amperes flows.
•So MOSFET is cut off when gate source voltage is zero.
• That is why it is called normally- OFF MOSFET.
• The gate is made positive with respect to source substrate as shown in figure.
• A channel of electrons (n channel) is formed in between the source and drain regions.
•Behaves as a capacitor with gate metal acting as one electrode, upper surface of the substrate as other electrode and sio2 layer as dielectric medium.
•When positive voltage is applied to gate the capacitor begin to charge. •Consequently positive charges appears on the gate and negative charges appears in the substrate between the drain and source.
•The n-channel thus formed is called induced n-channel or n-type inversion layer. •As V GS increases, no. electrons in the channel increases, ID increases.
•The minimum gate source voltage which produces then induced n-channel is called threshold voltage VGS (th).when VGS < VGS (th), ID=0.
•Drain current starts only VGS >VGS (th).
•For a given value of VDS as VGS is increased, more and more electrons accumulate under the gate and ID increases.
•So the conductivity of the channel is enhanced by the positive bias on the gate, the device is known as enhancement mode MOSFET.
•The n-channel MOSFET can never operate with a negative gate voltage.

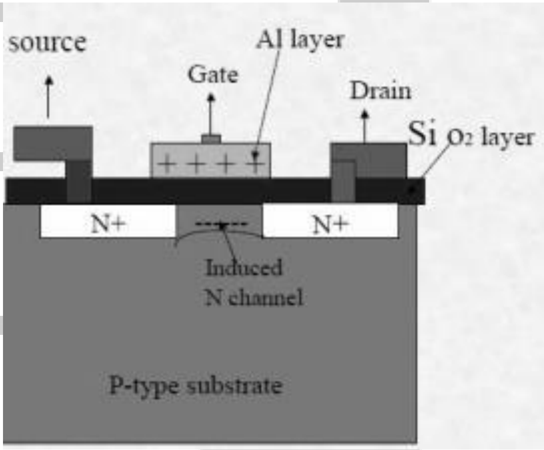
b) P-Channel Enhancement MOSFET:

A P-channel MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) is a type of MOSFET where the channel between the source and drain terminals is made of P-type semiconductor material.



- A p-channel MOSFET consists of lightly doped n-substrate into which two heavily doped p+ regions act as the source and the drain.
- A thin layer of SiO2 is grown over the surface of the entire assembly.

Construction:



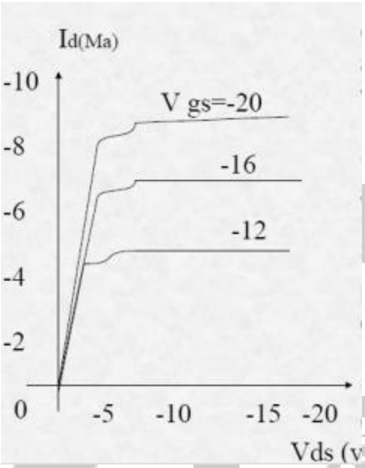
- Holes are cut into this SiO_2 layer for making contact with p+ source and drain regions.
- On the SiO_2 layer, a metal (aluminium) layer is overlaid covering the entire channel region from source to drain.
- This aluminium layer constitutes the gate.
- The area of MOSFET is typically 5 square mills or less.
- This area is extremely small being only about 5% of the area required for a bipolar junction transistor.
- A parallel plate capacitor is formed with the metal areas of the gate and the semiconductor channel acting as the electrodes of the capacitor.
- The oxide layer acts as the dielectric between the electrodes.
-

Working:

- The substrate will be connected to the common terminal i.e., to the ground terminal.
- A negative potential will be applied to the gate.
- This results in the formation of an electric field normal the SiO_2.

- This electric field originates from the induced positive charges on the semiconductor side on the lower surface of the SiO_2 layer.
- The induced positive charge become minority carriers in the n-type of substrate.

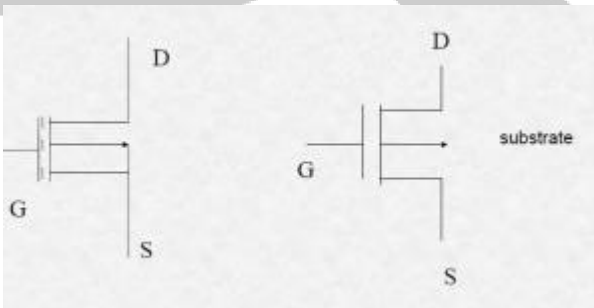
Drain characteristics



It is observed that the drain current has been enhanced on application of negative gate voltage.
•This is the reason for calling it as enhancement MOSFET.
•By increasing the gate potential, pinch off voltage and drain currents are increased.
•The curves are similar to drain characteristics of JFET.

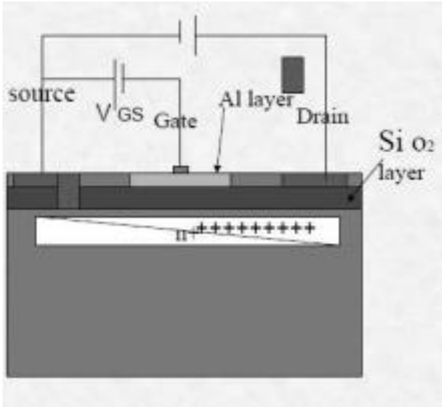
4) Depletion-mode MOSFET:

A depletion-mode MOSFET is a type of MOSFET that is normally "on" when the gate-source voltage (Vgs) is zero. A depletion-mode MOSFET has a physically implanted channel during manufacturing. This means that even with no voltage applied to the gate, there is a conductive path between the source and drain. To reduce or stop the current flow, a voltage is applied to the gate that "depletes" the channel of charge carriers. In an N-channel depletion-mode MOSFET, a negative gate voltage repels electrons from the channel, reducing its conductivity. In a P-channel depletion-mode MOSFET, a positive gate voltage repels holes from the channel.



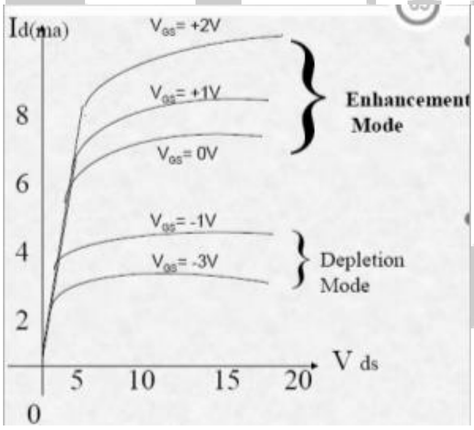
Working: -

•Negative gate operation of a depletion MOSFET is called Its depletion mode Operation

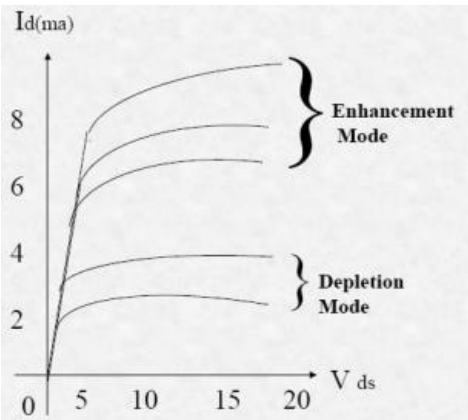


•When V_{gs} =0 electrons can flow freely from source to drain through the conducting channel. Since a channel exists between drain & source, Id flows even when V_{gs}=0.
• It is also known as normally –ON MOSFET.
•When negative voltage is applied to the gate as shown.
In Fig positive charges are induced in the channel by capacitor action.
• The induced positive charges make the channel less conductive and drain current decreases as V GS is made more negative.
•With negative voltage a depletion MOSFET behave like JFET.
•When positive voltage is applied to the gate free electrons are Induced channel.
•This enhances the conductivity of the channel so increasing amount of current between terminals.
• Since the action of negative voltage on gate is to deplete the channel of free n-type charge carriers so named as depletion MOSFET.

Drain characteristics



•When the gate source voltage is zero considerable drain current flows.
•When the gate is applied with negative voltage, positive charge are induced in the n channel through the SiO2 layer of the gate capacitor.



- The conduction in n channel FET is due to electrons i.e., the majority carriers.
- Therefore the induced positive charges make the n-channel less conductive.
- The drain current therefore gets reduced with increase in the gate bias voltage
- The distribution of charges in the channel results in depletion of majority carriers.
- That is why this type of FET is called depletion MOSFET.
- The voltage drop due to the drain current causes the channel region nearer to the drain to be more depleted than the region due to the source.
- The depletion MOSFET can also be operated in enhancement mode simply by applying a positive voltage to the gate

Comparison of MOSFET and JFET

Sno	JFET	MOSFET
1.	JFET Gate is not insulated from the channel	MOSFET or IGFET is insulated from the channel
2.	Channel and gate forms two pn junctions	Channel and gate forms parrallel plate capacitor.
3.	There are only 3 leads	There are 4 leads
4.	Can be operated in depletion mode only	Can be operated inboth depletion and enhancement mode
5.	Input impedance is high	Input impedance is very high
6.	Signal handling capacity is less	Signal handling capacity is more
7.	Gate current is more	Gate current is very less
8.	Fabrication is complex and costly	Easy to fabricate,cheap. Most

Advantages of MOSFET over JFET

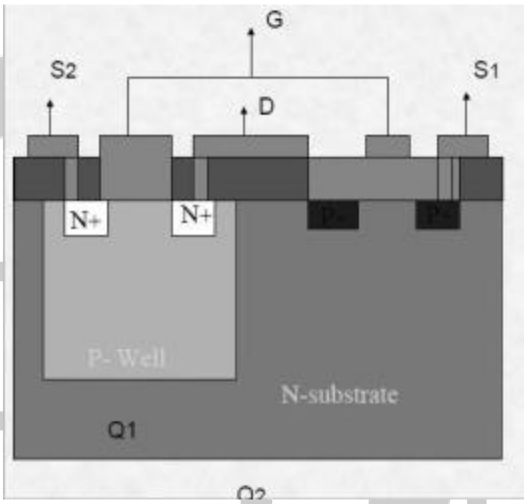
• The insulated gate in MOSFET s result in much greater input impedance than that of JFET
• Inter electrode capacitance are independent of bias voltage and these capacitances are smaller in case of MOSFETs than JEFT.
• It is easier to fabricate MOSFET than JFET.
• MOSFET has no gate diode. This makes it possible to operate with +ve or –ve gate voltages.

Applications of MOSFETs

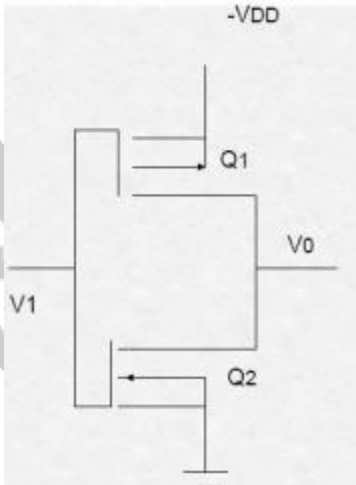
• Because of higher input resistance, the enhancement type MOS devices have been used as micro-resistor in integrated micro-circuits.
• For electrometer circuits where exceptionally low currents are to be measured MOSFETs are most nearly ideal.
• MOSFET s are very small in size .which make them suitable for highly complex digital arrays.
•MOSFET is used for switching and amplifying electronics signals in the electronic devices.
•It is used as an inverter.
•It can be used in digital circuit.
•MOSFET can be used as a high frequency amplifier.
•It can be used as a passive element e.g. resistor, capacitor and inductor.
•It can be used in brushless DC motor drive.
•It can be used in electronic DC relay.
•It is used in switch mode power supply (SMPS).

5) CMOS (Complementary MOS):

CMOS, or Complementary Metal-Oxide-Semiconductor, is a technology that's fundamental to modern digital electronics. CMOS technology uses both N-channel MOSFETs (NMOS) and P-channel MOSFETs (PMOS) in a complementary configuration. This means they work together in a way that minimizes power consumption. The key advantage of CMOS is its very low static power consumption. In a stable state (not switching), one of the MOSFETs is always off, which greatly reduces the flow of current. CMOS is the dominant technology for building digital logic circuits, including: Microprocessors, Memory chips (like RAM) and Microcontrollers.



Key Features and Operation:

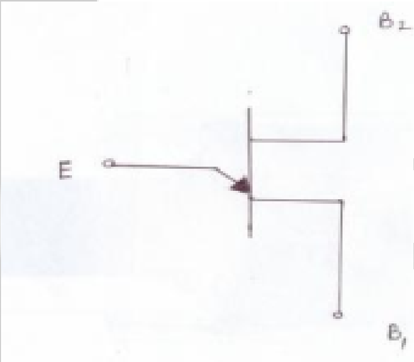


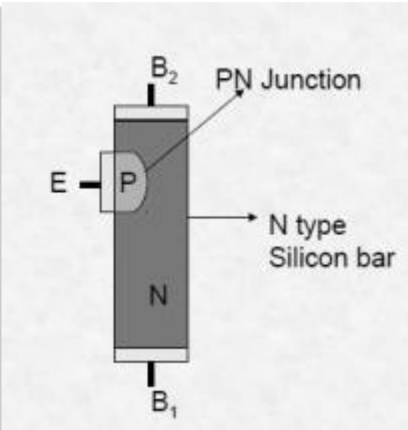
- **Complementary Transistors:**
  - NMOS transistors conduct well when their gate voltage is high (logic 1).
  - PMOS transistors conduct well when their gate voltage is low (logic 0).
- **Low Power Consumption:**
  - The complementary arrangement is the key to CMOS's low power consumption.
  - In a stable state (either logic 0 or logic 1), one of the transistors is always off. This minimizes the flow of current between the power supply and ground, resulting in very low static power dissipation.
  - Power is primarily consumed during switching, when both transistors momentarily conduct.
- **Basic Building Block: The CMOS Inverter:**
  - The simplest CMOS circuit is the inverter, which consists of one NMOS and one PMOS transistor.
  - When the input is high (logic 1), the NMOS is on and the PMOS is off, pulling the output low (logic 0).
  - When the input is low (logic 0), the PMOS is on and the NMOS is off, pulling the output high (logic 1).
- **Logic Gates:**

- More complex logic gates (like NAND and NOR gates) are created by combining multiple NMOS and PMOS transistors in specific configurations.
- The complementary nature of CMOS ensures that these gates also have low power consumption.

Unit Junction transistor

•The UJT as the name implies, is characterized by a single pn junction.
•It exhibits negative resistance characteristic that makes it useful in oscillator circuits.
•With only one p-n junction, the device is really a form of diode because two base terminal are taken from one section of the diode this device is also called double-based diode
•The emitter is heavily doped the n-region, is lightly doped for this reason the resistance between the base terminals is very high (5to10 k ohms) when emitter lead is open.





Equivalent circuit of UJT

- The PN junction behaves like a diode
- The lightly doped silicon bar has high resistance can be represented by two resistors connected in series RB1 and R B2.
- The Resistance offered by N-type bar between Base-1 and Emitter is referred as R B1.
- The Resistance offered by N-type bar between Base-2 and Emitter is referred as R B2.
- The Resistance of N-type bar is known as Base spreading resistance RBB.
- R BB = RB1 + RB2.

Intrinsic stand of ratio

- The intrinsic stand-off ratio is denoted by η.
- η = RB1 / (RB1 + RB2)
- The intrinsic stand-off ratio is the property of a UJT is always less than unity.
- Typical range of η is lies between 0.5 to 0.8.

Applications of UJT

- Phase control.
- Relaxation oscillator.
- Timing circuits.
- Switching.
- Pulse generation.
- Sine wave generator.
- Voltage or current regulator supplies.

Features of UJT

- A stable triggering voltage i.e., a fixed fraction of applied inter base voltage VBB.
- A very low value of triggering current.
- A high pulse current capability.
- A negative resistance characteristic.
- Low cost.