Dr.D.Y. Patil Technical Campus

(Engineering and MCA)

First Year Engineering (2024 Pattern)

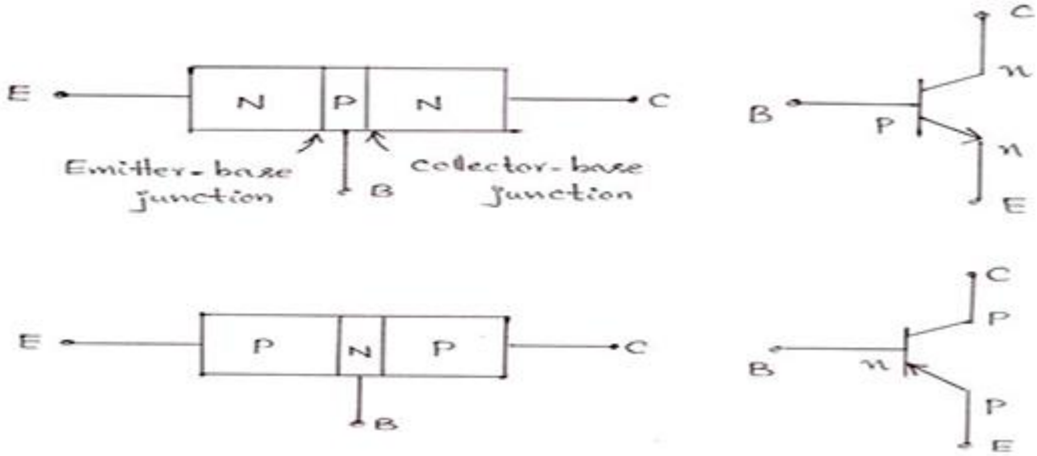
Name of Subject-Basic Electronics Engineering

Subject Code-(ESC-101-ETC)

UNITE NO-2. Transistors and Technology

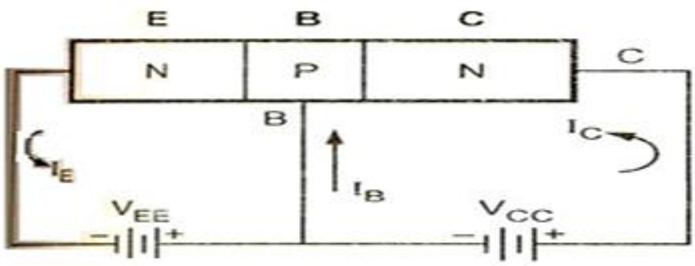
SYLLABUS- Bipolar Junction Transistor: Construction, type, Operation, V-I Characteristics in common emitter mode, BJT as switch and Common Emitter (CE) amplifier. Enhancement Metal Oxide Semiconductor Field Effect Transistors (EMOSFET): Construction, Types, Operation, V-I characteristics, MOSFET as switch & amplifier. Introduction to VLSI Technology, Feature size/Channel Length, N Well method of VLSI CMOS manufacturing.

Bipolar Junction Transistor: - Transistor means Transfer Resistor i.e., signals are transferred from low resistance circuit into high resistance circuit. It is a three terminal semiconductor device: Base, Emitter & Collector. It can be operated in three configurations: CB, CE & CC. According to configuration it can be used for voltage as well as current amplification. Basically, it is referred as Bipolar Junction Transistor (BJT), because the operation of transistor depends on the interaction of both majority and minority carriers. A BJT is formed by placing a P-type silicon layer in between two n-type semiconducting materials or by placing a n-type silicon layer in between two p-type semiconducting materials.



¬ The emitter terminal is heavily doped so that a large number of charge carriers are injected into the base.
¬ The base is very lightly doped and is very thin. It allows most of the charge carriers from emitter region to the collector region.
¬ The collector is moderately doped. Its main function is to collect the majority charge carriers coming from the emitter and passing through the base.

n-p-n Transistor-



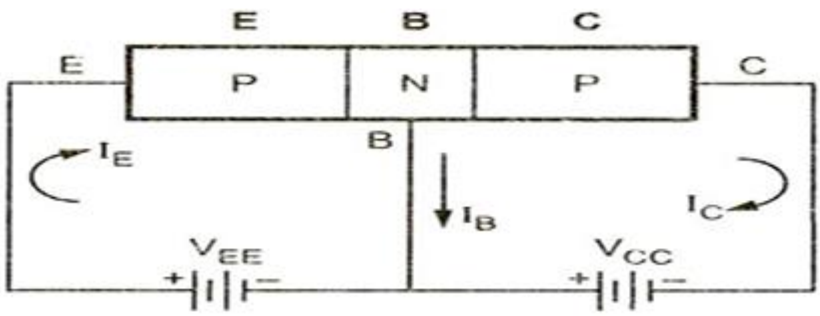
Working of n-p-n Transistor

¬ The n-p-n transistor with base to emitter junction forward biased and collector base junction reverse biased is as shown in figure.

¬ As the base to emitter junction is forward biased the majority carriers emitted by the n type emitter i.e., electrons have a tendency to flow towards the base which constitutes the emitter current IE.

¬ As the base is p-type there is chance of recombination of electrons emitted by the emitter with the holes in the p-type base. But as the base is very thin and lightly doped only few electrons emitted by the n-type emitter less than 5% combines with the holes in the p- type base, the remaining more than 95% electrons emitted by the n-type emitter cross over into the collector region constitute the collector current. The current distributions are as shown in fig. IE = IB + IC.

p-n-p Transistor



¬ The p-n-p transistor with base to emitter junction is forward biased and collector to base junction reverse biased is as show in figure.

¬ As the base to emitter junction is forward biased the majority carriers emitted by the p type emitter i.e., holes have a tendency to flow towards the base which constitutes the emitter current IE.

¬ As the base is n-type there is a chance of recombination of holes emitted by the emitter with the electrons in the n-type base. But as the base us very thin and lightly doped only few electrons less than 5% combine with the holes emitted by the p-type emitter, the remaining 95% charge carriers cross over into the collector region to constitute the collector current. The current distributions are shown in figure. IE = IB + IC.

Transistor circuit configurations:

Following are the three types of transistor circuit configurations:

1) Common-Base (CB)

2) Common-Emitter (CE)

3) Common-Collector (CC)

V-I input and output characteristics of CE configuration-

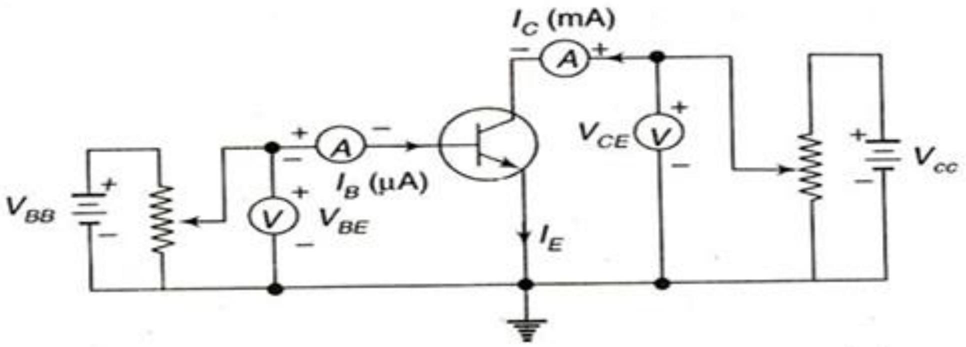


Fig. Circuit to determine CE Static characteristics.

Input Characteristics:

¬ To determine the input characteristics, the collector to emitter voltage is kept constant at zero volts and base current is increased from zero in equal steps by increasing VBE in the circuit.

¬ The value of VBE is noted for each setting of IB. This procedure is repeated for higher fixed values of VCE, and the curves of IB versus VBE are drawn.

¬ The input characteristics thus obtained are shown in figure below.

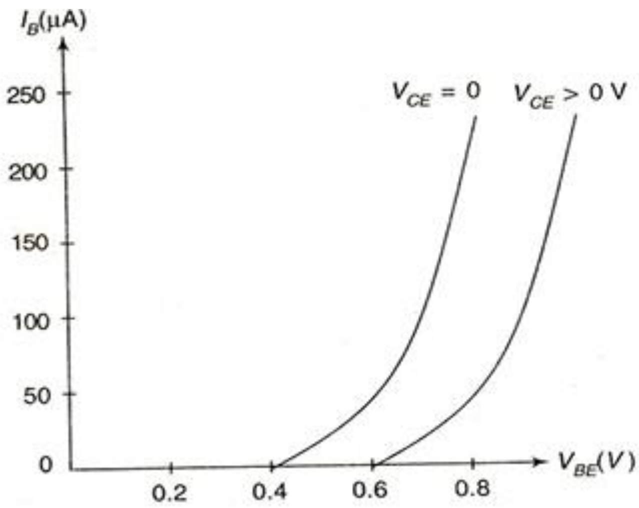


Fig. CE Input Characteristics.

¬ When VCE=0 , the emitter-base junction is forward biased and the junction behaves as a forward biased diode.

¬ When VCE is increased, the width of the depletion region at the reverse biased collector-base junction will increase. Hence he effective width of the base will decrease. This effect causes a decrease in the base current IB. Hence, to get the same value of IB as that for VCE=0, VBE should be increased. Therefore, the curve shifts to the right as VCE increases.

Output Characteristics: To determine the output characteristics, the base current IB is kept constant at a suitable value by adjusting base-emitter voltage, VBE. The magnitude of collector-emitter voltage VCE is increased in suitable equal steps from zero and the collector current IC is noted for each setting of VCE. Now the curves of IC versus VCE are plotted for different constant values of IB. The output characteristics thus obtained are shown in figure below.

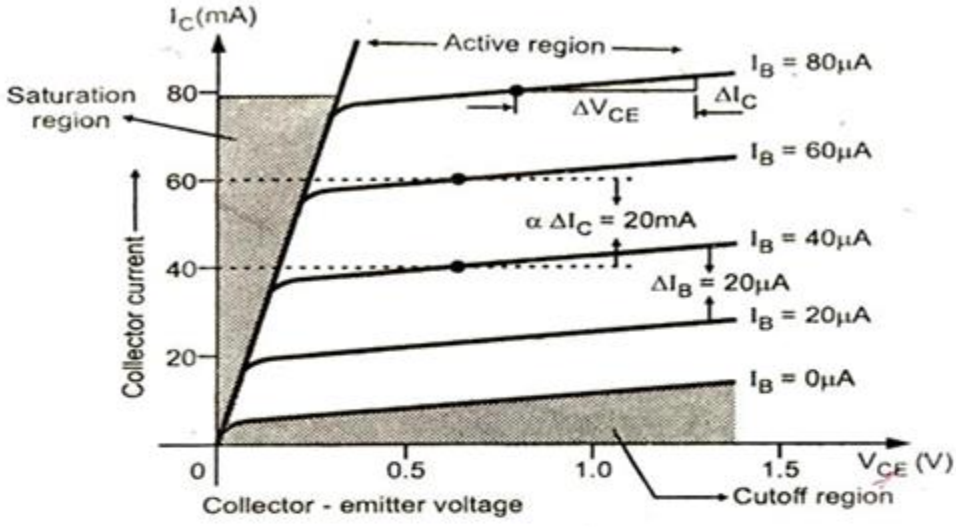


Fig. CE Output characteristics

The output characteristics of common emitter configuration consist of three regions: Active, Saturation and Cut-off regions.

Active Region: The region where the curves are approximately horizontal is the "Active" region of the CE configuration. In the active region, the collector junction is reverse biased. As VCE is increased, reverse bias increase. This causes depletion region to spread more in base than in collector, reducing the changes of recombination in the base. This increase the value of αdc . This Early effect causes collector current to rise more sharply with increasing VCE in the active region of output characteristics of CE transistor.

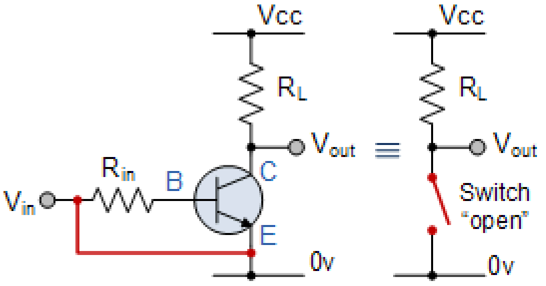
Saturation Region: If VCE is reduced to a small value such as 0.2V, then collector-base junction becomes forward biased, since the emitter-base junction is already forward biased by 0.7V. The input junction in CE configuration is base to emitter junction, which is always forward biased to operate transistor in active region. Thus, input characteristics of CE configuration are similar to forward characteristics of p-n junction diode. When both the junctions are forwards biased, the transistor operates in the saturation region, which is indicated on the output characteristics. The saturation value of VCE, designated VCE(Sat), usually ranges between 0.1V to 0.3V.

Cut-Off Region: When the input base current is made equal to zero, the collector current is the reverse leakage current ICEO. Accordingly, in order to cut off the transistor, it is not enough to reduce IB=0. Instead, it is necessary to reverse bias the emitter junction slightly. We shall define cut off as the condition where the collector current is equal to the reverse saturation current ICO and the emitter current is zero.

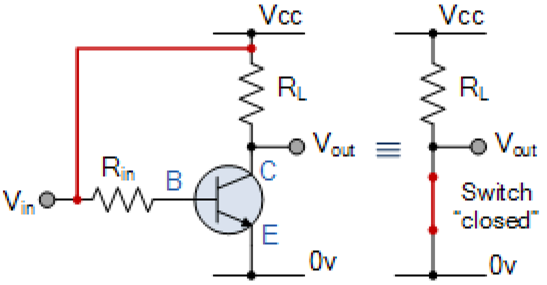
Application of Transistor

1) As a switch
2) As an amplifier

Transistor as a switch-



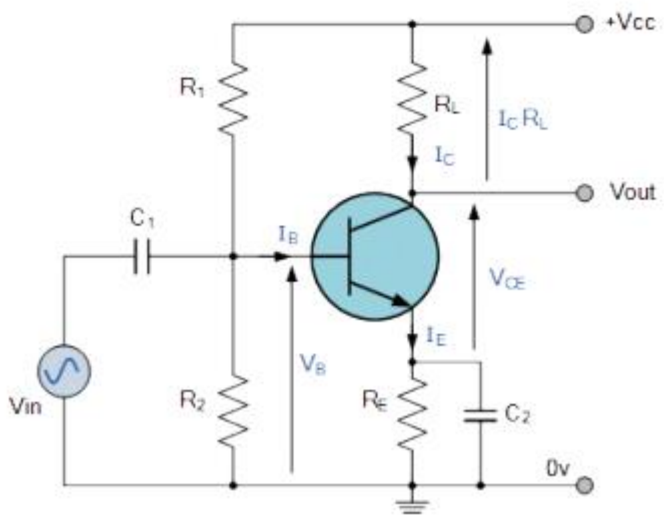
- The input and Base are grounded (0v)
- Base-Emitter voltage V_{BE} < 0.7v
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows ($I_C = 0$)
- $V_{OUT} = V_{CE} = V_{CC}$ = "1"
- Transistor operates as an "open switch"



- The input and Base are connected to V_{CC}
- Base-Emitter voltage V_{BE} > 0.7v
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows ($I_C = Vcc/R_L$)
- $V_{CE} = 0$ (ideal saturation)
- $V_{OUT} = V_{CE}$ = "0"
- Transistor operates as a "closed switch"

<u>Transistor acts as an amplifier: -</u>

¬ A load resistor RL is connected in series with the collector supply voltage VCC of CB transistor configuration as shown in figure.



1. Biasing Circuit: Resistors R1, R2 and RE forms the voltage divider biasing circuit for CE amplifier and it sets the proper operating point for CE amplifier.

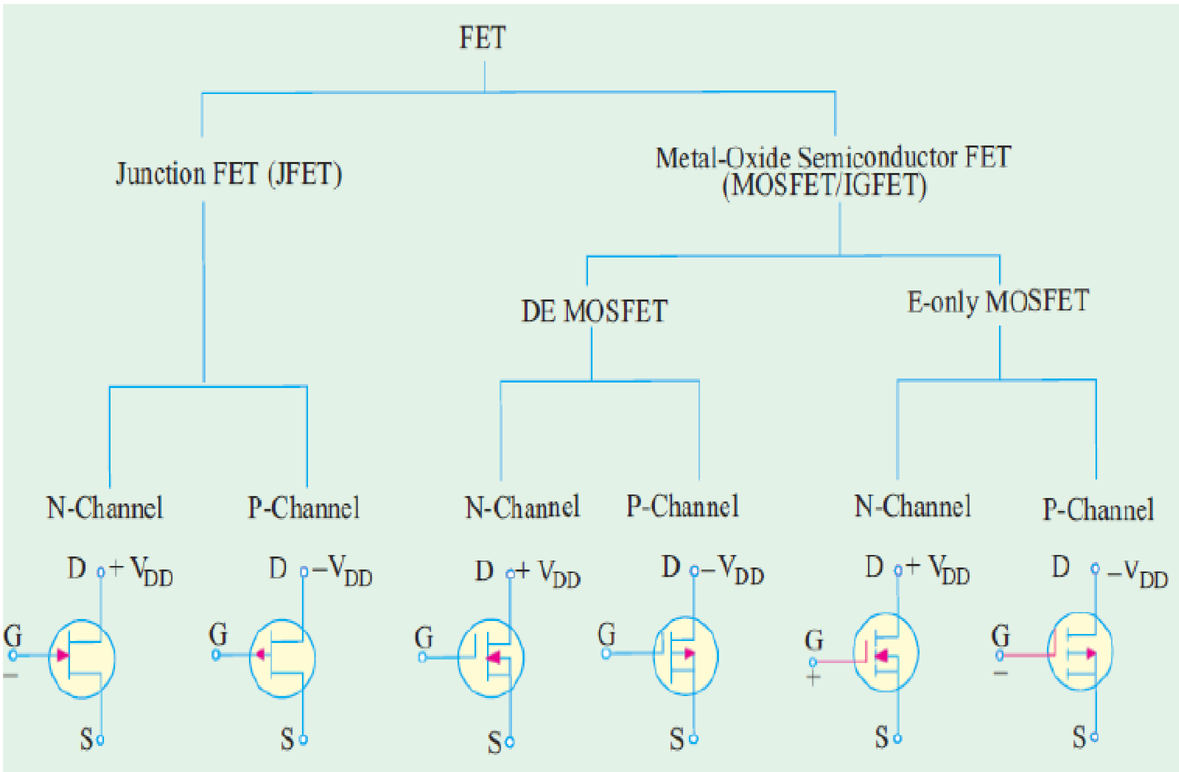
2. Input Capacitor C1: C1 couples the signal to base of the transistor. It blocks any D.C. component present in the signal and passes only A.C. signal for amplification.

3. Emitter Bypass Capacitor CE: CE is connected in parallel with emitter resistance RE to provide a low reactance path to the amplified A.C. This will reduce the output voltage and reducing the gain value.

4. Output Coupling Capacitor C2: C2 couples the output of the amplifier to the load or to the next stage of the amplifier. It blocks D.C. and passes only A.C. part of the amplified signal. Need for C1, C2, and CE: The impedance of the capacitor is given by, XC = 1/ (2∏fc).

FET-

Classification of FET as below-



Enhancement MOSFET which is commonly called as E-MOSFET is a type of field effect transistor which is used mainly in voltage-controlled devices. It is a unipolar device, i.e. device in which conduction of current takes place either by electrons or holes. It is a three-terminal device which is mainly used as amplifier or in switching devices.

This type of transistor can be used both in analog and digital devices. These transistors are more popular than Bipolar junction transistors due to less power dissipation and negligible leakage current. These are smaller in size and hence find its application in integrated circuits (ICs).

Enhancement Type MOSFET

The full form of E-MOSFET is Enhancement- Metal Oxide Semiconductor Field Effect Transistor. It is called as enhancement MOSFET because for a creating a conduction channel between drain and source terminal, a positive voltage is required at the gate terminal. Metal is for the metallic contacts that are used to connect drain(D), gate(G) and source(S) terminals.

Oxide is for the silicon dioxide (SiO2) layer which is used as an insulating layer between substrate and gate terminal. Semiconductor is for the structure which is used in the construction of this transistor. To sum up, the name E-MOSFET is given to this type of device.

Types of E-MOSFET

Based on the type of charge carriers (electrons or holes), E-MOSFET can be classified into two types:

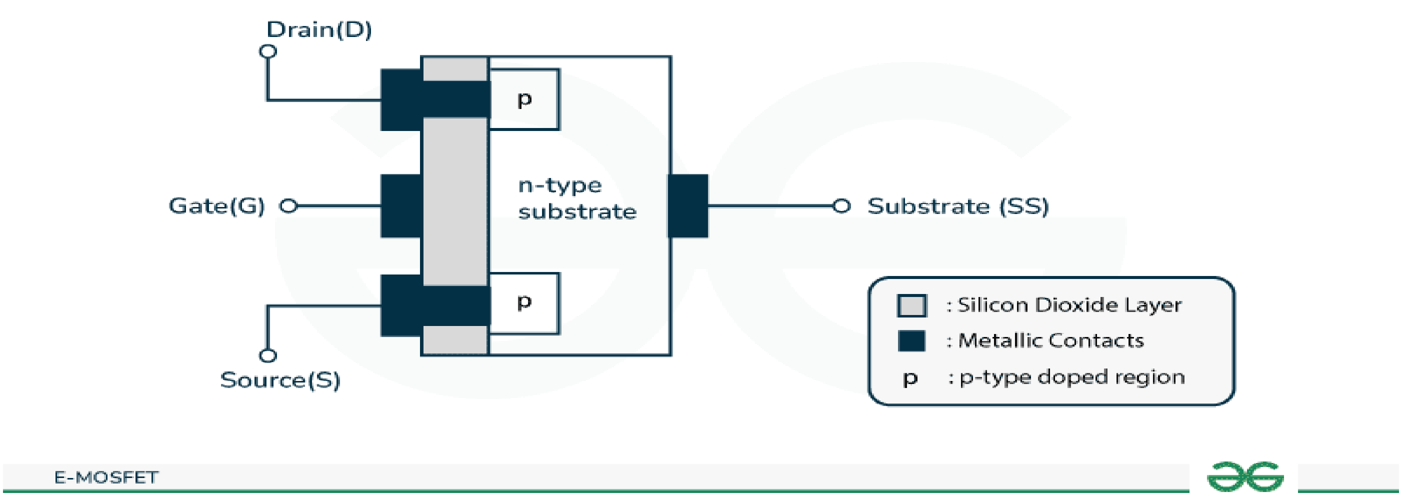
- N-Channel E-MOSFET
- P-Channel E-MOSFET

N-Channel E-MOSFET

This type of MOSFET is called as n-channel MOSFET because the flow of current takes place by conduction of negative charge carriers, i.e., electrons.

Construction of N-Channel E-MOSFET

A n-channel E-MOSFET consists mainly of three terminals: Source(S), Gate(G) and Drain(D). A substrate (SS) is made up of a p-type semiconductor and is internally connected with source terminal or sometimes brought out in a form fourth terminal. The other three terminals, i.e., drain, gate and source as connected to each other by n-doped region through metallic contacts. The figure given below shows the construction of N-Channel E-MOSFET:



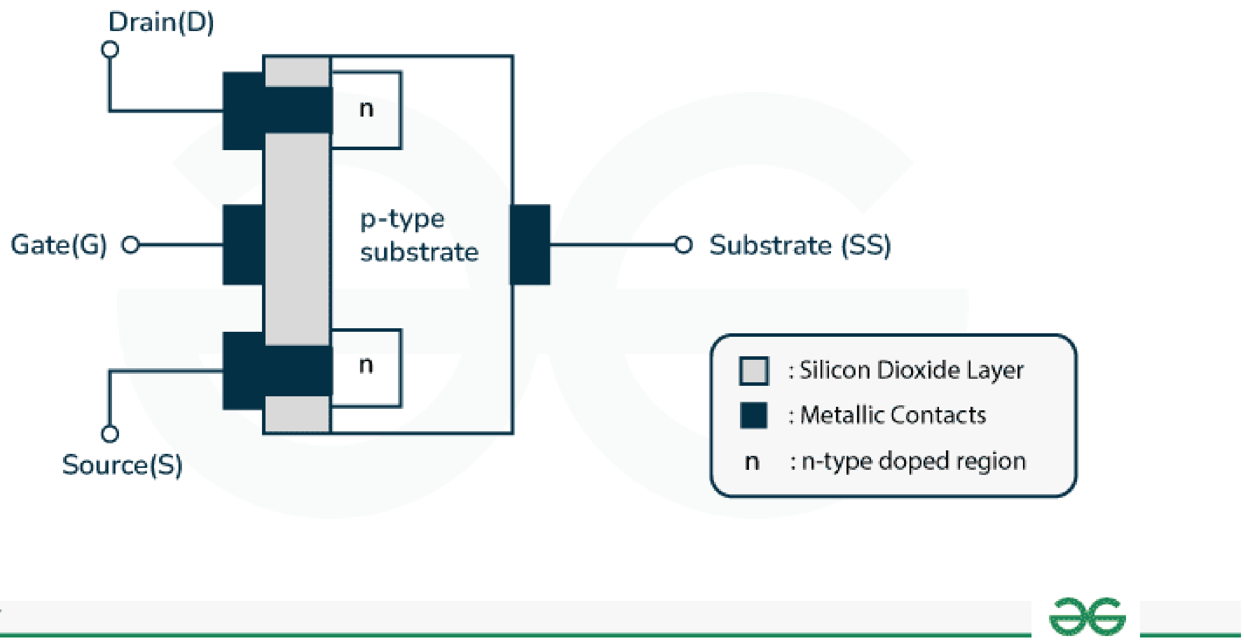
Construction-of-N-Channel-E-MOSFET

P-Channel E-MOSFET

This type of MOSFET is called as p-channel MOSFET because the flow of current takes place by conduction of positive charge carriers, i.e., holes.

Construction of P-Channel E-MOSFET

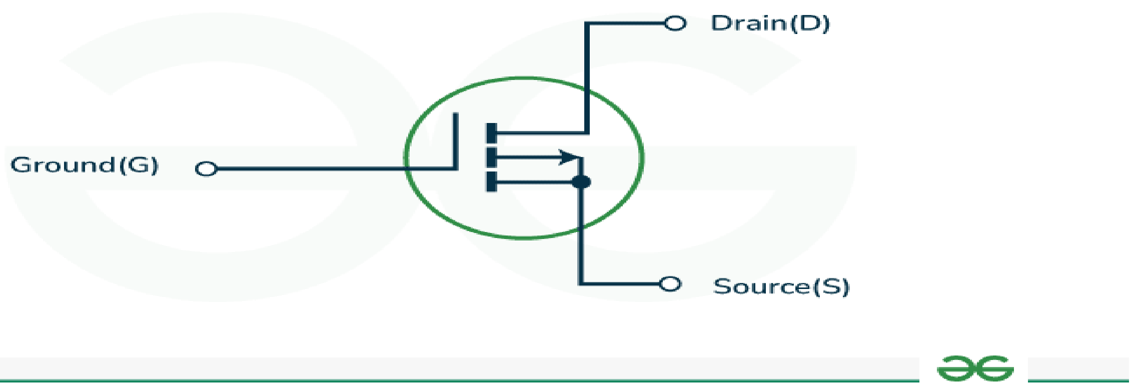
A p-channel E-MOSFET consists mainly of three terminals: Source(S), Gate(G) and Drain(D). A substrate (SS) is made up of a n-type semiconductor and is internally connected with source terminal or sometimes brought out in a form fourth terminal. The other three terminals, i.e., drain, gate and source as connected to each other by p-doped region through metallic contacts. The figure given below shows the construction of p-channel E-MOSFET:



Construction-of-p-channel-E-MOSFET

Circuit symbol of P-Channel E-MOSFET

Circuit symbol of p-channel E-MOSFET is shown below:



Circuit-symbol of P-channel E-MOSFET

Working of E-MOSFET

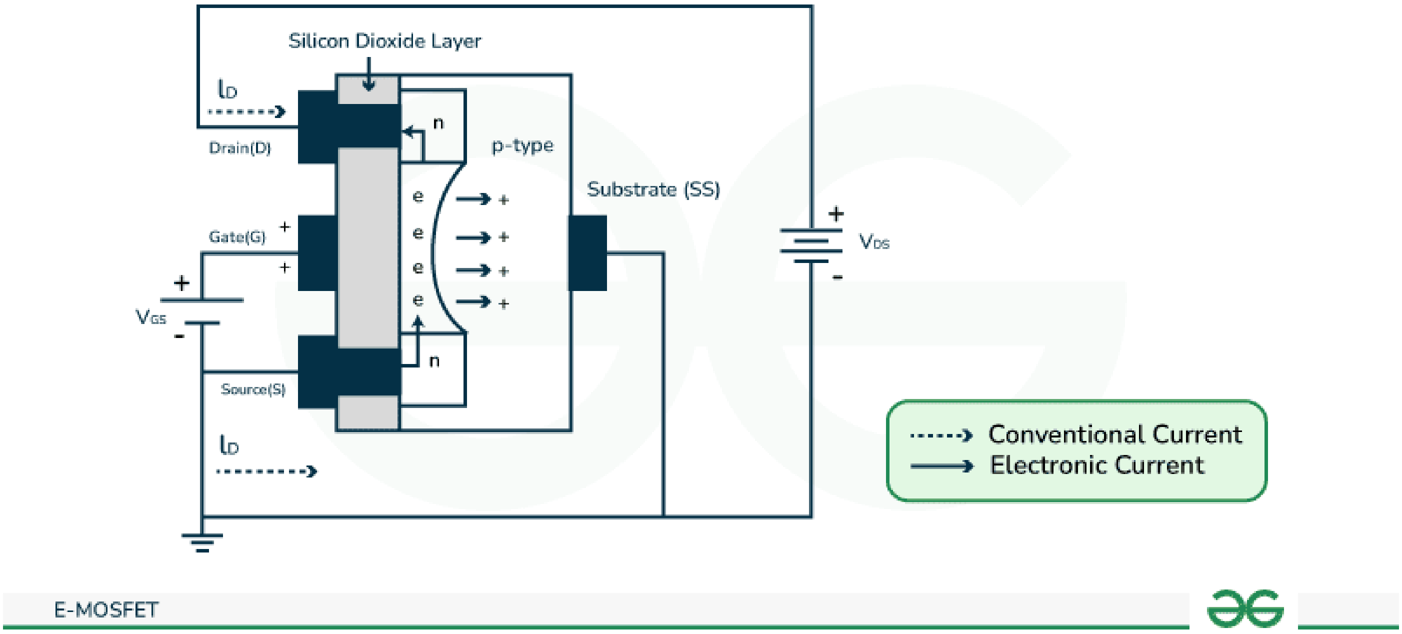
The working principle of E-MOSFET is that when a positive voltage is applied on the gate terminal, then a conduction channel appears between source and drain terminal.

In n-channel E-MOSFET when the value of gate-to-source voltage is zero, then no drain current flows in a transistor. When the value of gate-to-source voltage is positive then the holes in p-doped region would be repelled by the positive terminal voltage which is applied at gate terminal.

By this a depletion region is created near silicon dioxide layer. But, minority charge carriers of substrate, i.e., electrons would be attracted to the gate terminal near the insulating layer of silicon dioxide. When there is increase in positive voltage from gate-to-source terminal, the gathering of electrons near insulating layer of silicon dioxide increases.

This results in formation of induced n-channel between n-doped region of drain to source terminal. This induced channel connects drain and source terminals internally and current starts flowing through it. The minimum voltage at which current starts flowing through it is called as threshold voltage (VT).

The working of p-channel E-MOSFET is exactly opposite to that of p-channel E-MOSFET, i.e., all voltage polarities are reversed and thus the flow of current is also reversed.



Working-of-E-MOSFET

Characteristics of E-MOSFET

There are two types of characteristics of E-MOSFET- drain characteristics and transfer characteristics. Both type of E-MOSFET, i.e., n-channel E-MOSFET and p-channel E-MOSFET have these characteristics, and are discussed below:

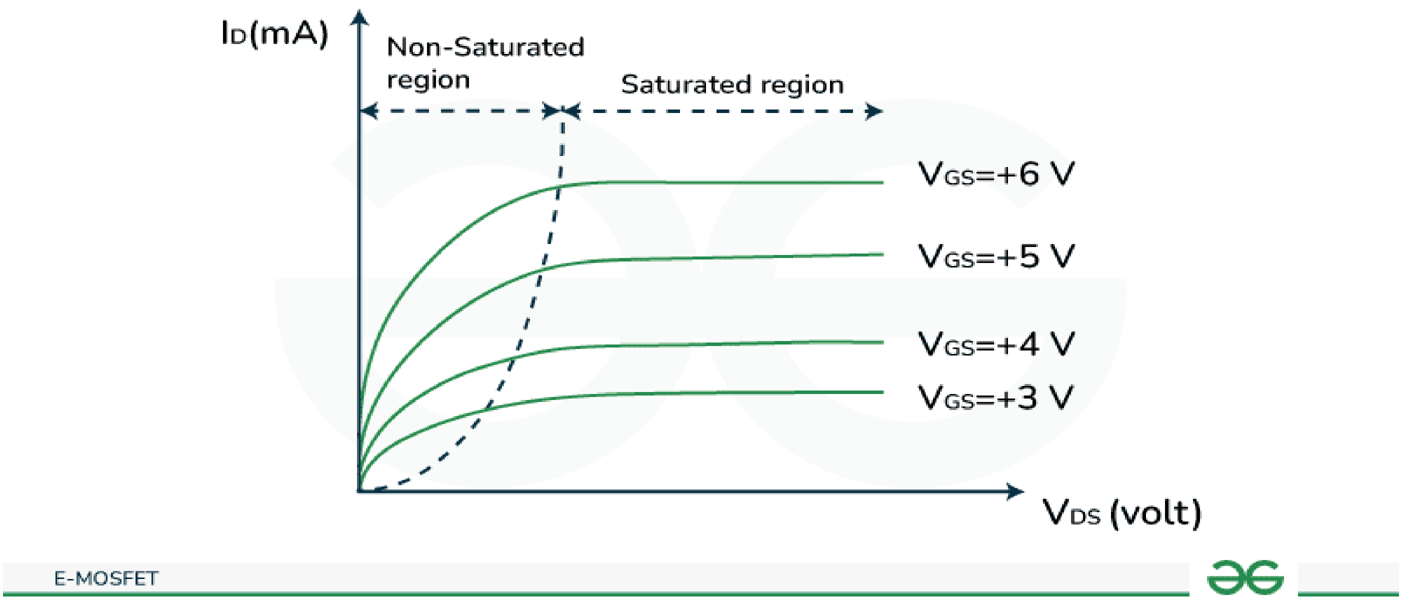
Characteristics of N-Channel E-MOSFET

Characteristics of n-channel E-MOSFET refers to the curves which relate the current and voltage of device with each other. There are mainly two types of characteristics in n-channel E-MOSFET:

- **Drain Characteristics:** These curves provide the relationship between drain current (ID) and drain-to-source voltage (VDS). When different values of drain current and drain-to-source voltage are plotted on graph, it gives respective values of gate-to-source voltage (VGS). These characteristics are also called as V-I characteristics of a curve.

From the graph shown below, it is observed that when the positive value of VGS is increased, the current ID will also increase. This graph consists of two regions: non-saturated region and saturated region. The non-saturated region of the curve is also called as ohmic region, in this region when drain current is increased then subsequently the value of drain-to-source voltage also increases.

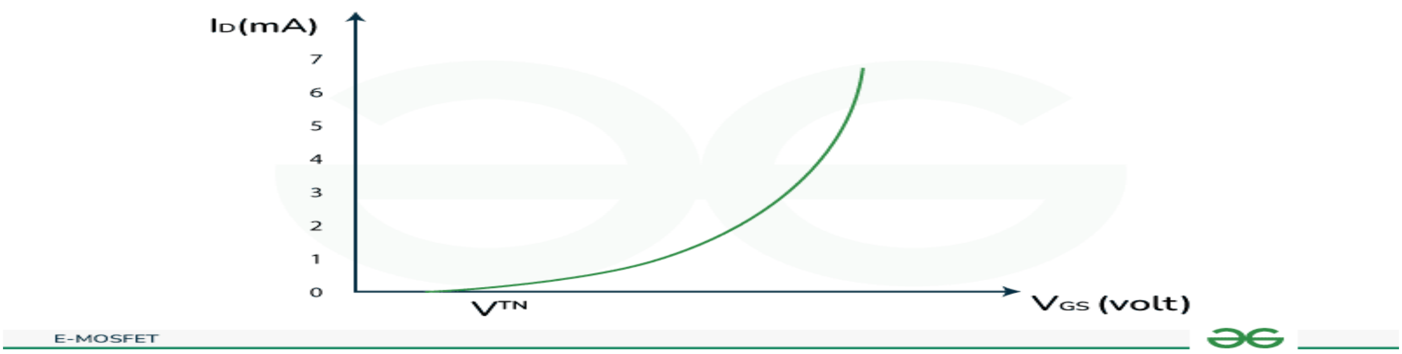
Ohmic region lasts till when the value of drain-to-source voltage reaches a threshold value called as threshold voltage (VTN). After this voltage saturation of n-channel E-MOSFET takes place. Hence, the region of curve after threshold voltage is achieved is called as saturated region.



Drain-Characteristics-of-n-channel-E-MOSFET

- **Transfer characteristics:** These curves provide the relationship between drain current (ID) and gate-to-source voltage (VGS). When different values of drain current and gate-to-source voltage are plotted on X- axis and Y-axis respectively, it provides different values of drain-to-source voltage (VDS). These curves are also called as transconductance curves.

From the transfer characteristics of n-channel E-MOSFET shown below it is observed that when the value of gate-to-source voltage is below the threshold voltage (VTN) then no drain current flows. When gate-to-source voltage is increased, and it reaches to threshold voltage then drain current (ID) starts flowing.



TRANSFER-Characteristics-of-n-channel-E-MOSFET

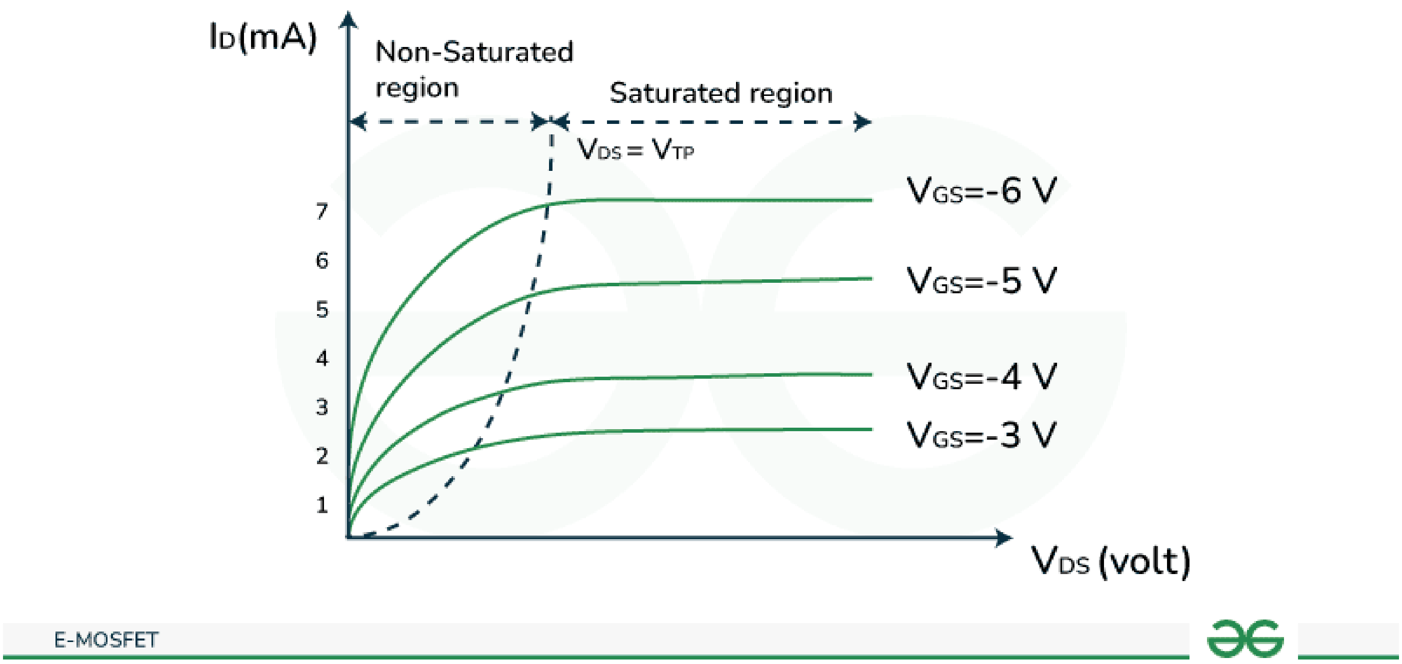
Characteristics of P-Channel E-MOSFET

Characteristics of p-channel E-MOSFET refers to the curves which relate the current and voltage of device with each other. There are mainly two types of characteristics in p-channel E-MOSFET:

- **Drain Characteristics:** These curves provide the relationship between drain current (ID) and drain-to-source voltage (VDS). When different values of drain current and drain-to-source voltage are plotted on graph, it gives respective values of gate-to-source voltage (VGS).

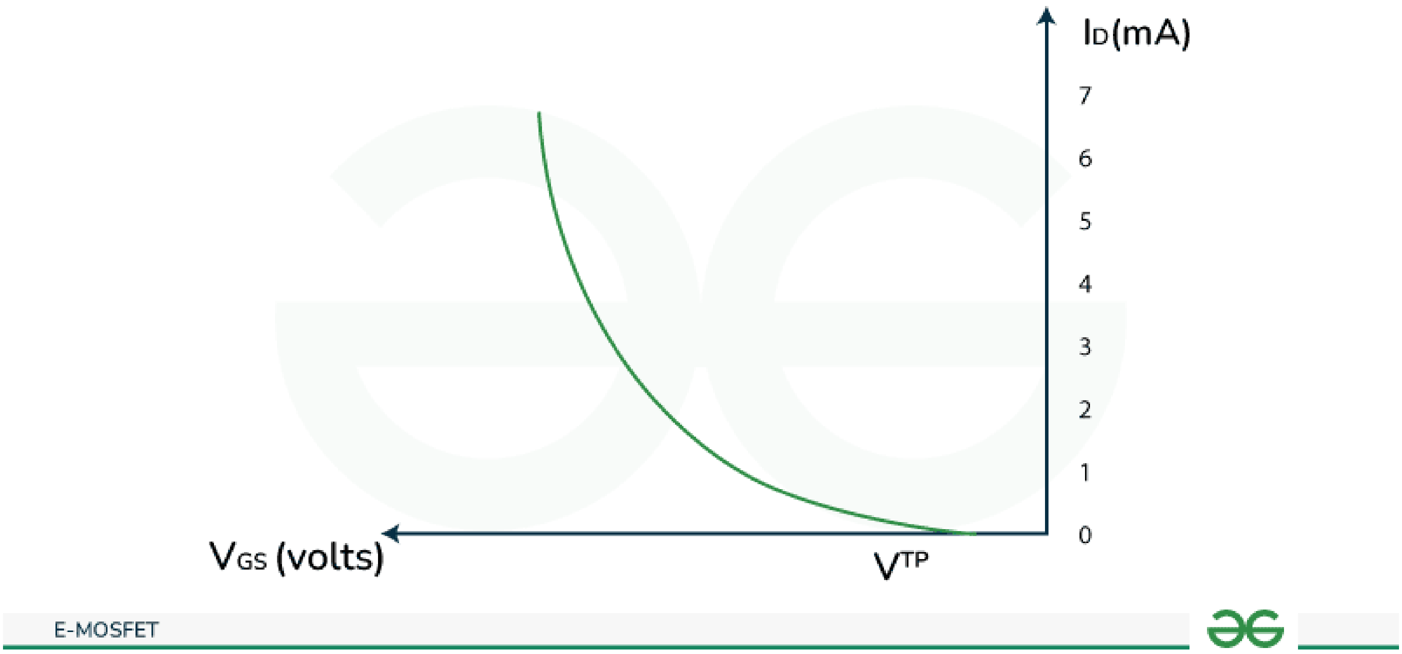
From the graph shown below, it is observed that when the negative value of VGS is increased, the current ID will also increase. The graph of p-channel E-MOSFET consists of two regions: non-saturated region and saturated region. The non-saturated region of the curve is also called as ohmic region, in this region when drain current is increased then subsequently the value of drain-to-source voltage also increases.

In non-saturated or ohmic region Enhancement MOSFET works as amplifiers. Ohmic region lasts till when the value of drain-to-source voltage reaches a threshold value called as threshold voltage (VTP). After this voltage p-channel E-MOSFET works under saturated region. Hence, the region of curve after threshold voltage is achieved is called as saturated region. In this region Enhancement-MOSFET works as a voltage-controlled resistor.



Drain-Characteristics-of-p-channel-E-MOSFET

- **Transfer characteristics:** These curves provide the relationship between drain current (ID) and gate-to-source voltage (VGS). When different values of drain current and gate-to-source voltage are plotted on X- axis and Y-axis respectively, it provides different values of drain-to-source voltage (VDS).



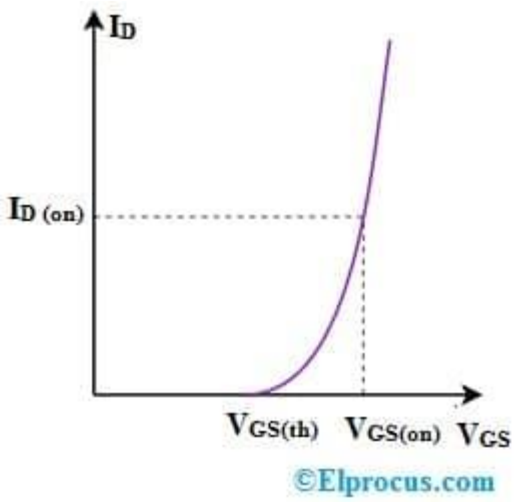
TRANSFER-Characteristics-of-p-channel-E-MOSFET

The transfer characteristics of p-channel of Enhancement type MOSFET is the mirror image of transfer characteristics of n-channel E-MOSFET. In this curve the value of drain current increases when the value of gate-to-source voltage decreases.

Voltage Divider Bias

The Voltage Divider bias for N-channel enhancement MOSFET is given below. This configuration is similar to the divider circuit utilized with BJT transistors. Specifically the N Channel MOSFET requires a gate voltage higher than its source just like NPN BJT uses base voltage higher than its emitter.

In the given circuit the resistors R1 and R2 are used construct the divider circuit which sets the gate voltage. VGs is equal to when the source of the E-MOSFET is directly linked to ground. The Voltage Across the Resistor R2 must be greater than VGS(th) for proper operation.



Difference Between Depletion MOSFET and Enhancement MOSFET

Difference between D-MOSFET (Depletion MOSFET) and E-MOSFET (Enhancement MOSFET) is given below:

Parameter	**Depletion MOSFET**	**Enhancement MOSFET**
Presence of channel	Channel is present., either of n-type or p-type.	Channel is not present. It is induced during the time of operation.
Insulating layer	Insulating layer of silicon dioxide is presence between gate and channel.	Insulating layer of silicon dioxide is present between gate and substrate.
Working	It can work both in depletion and enhancement mode.	It works only in enhancement mode.
Type of transistor	It is normally called as ON transistor.	It is normally called as OFF transistor.
Effect of gate voltage	Flow of current takes place between source and drain terminal when no voltage is applied at gate terminal.	Flow of current does not take place between source and drain terminal when no voltage is applied at gate terminal.

Features of E-MOSFET

There are various features of E-MOSFET which makes it different from other types of transistors. Some of such features are discussed below:

- In enhancement MOSFET, channel is not present permanently, but it is induced during the time of working.
- A silicon dioxide layer which acts as an insulator is present between gate and substrate which isolates gate from the main structure.
- Due to the presence of metal-oxide (SiO2) layer input capacitance of enhancement MOSFET is high.
- It is a voltage-controlled device.
- E-MOSFET can be operated at very high frequencies (up to few mega-ohms).

Advantages of E-MOSFET

Enhancement – MOSFET offers many advantages, some of them are listed below:

- As E-MOSFET is a voltage-controlled transistor, so it offers a good control on the conductivity of current across source and drain terminal.

- It could be rapidly turned from off-state to on-state and vice-versa, hence could be used in high-speed switching devices.
- E-MOSFET are small in size, hence it helps in converting a gigantic and bulky device to compact and light-weighted devices.
- E-MOSFET have high reliability as these types of transistors have silicon dioxide layer as an insulating layer which ensure the flow of current through the intended channels.
- These transistors draw very less current from input source and also have a minimal signal loss due to the high input impedance of E-MOSFET.

Disadvantages of E-MOSFET

There are some limitations of using Enhancement – MOSFET, some of them are listed below:

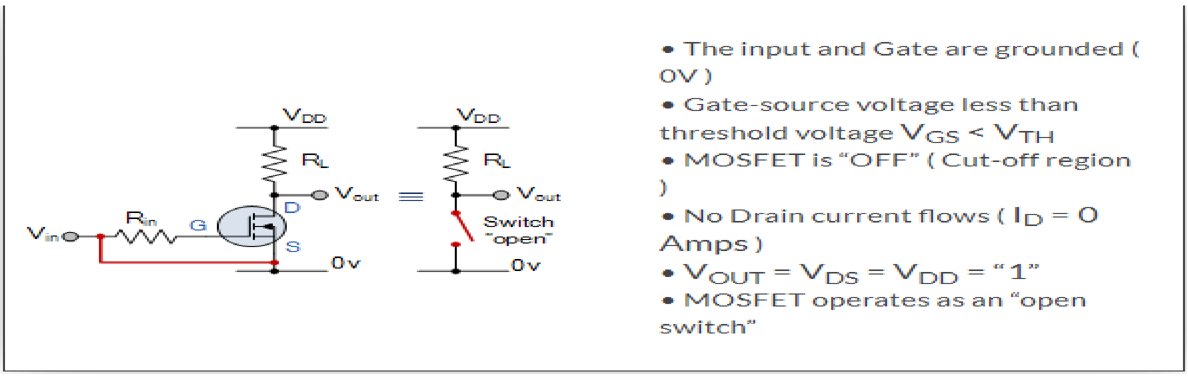
- E-MOSFET have a complex biasing in comparison to other types of transistors.
- E-MOSFET are temperature-sensitive, i.e., change in temperature will affect the working of the transistor.
- These types of transistors are generally costlier than other types of transistors, hence increase the cost of device in which it is used.
- E-MOSFET cannot perform efficiently at high frequencies.
- The properties of E-MOSFET gets altered if the type of semiconductor material is altered.

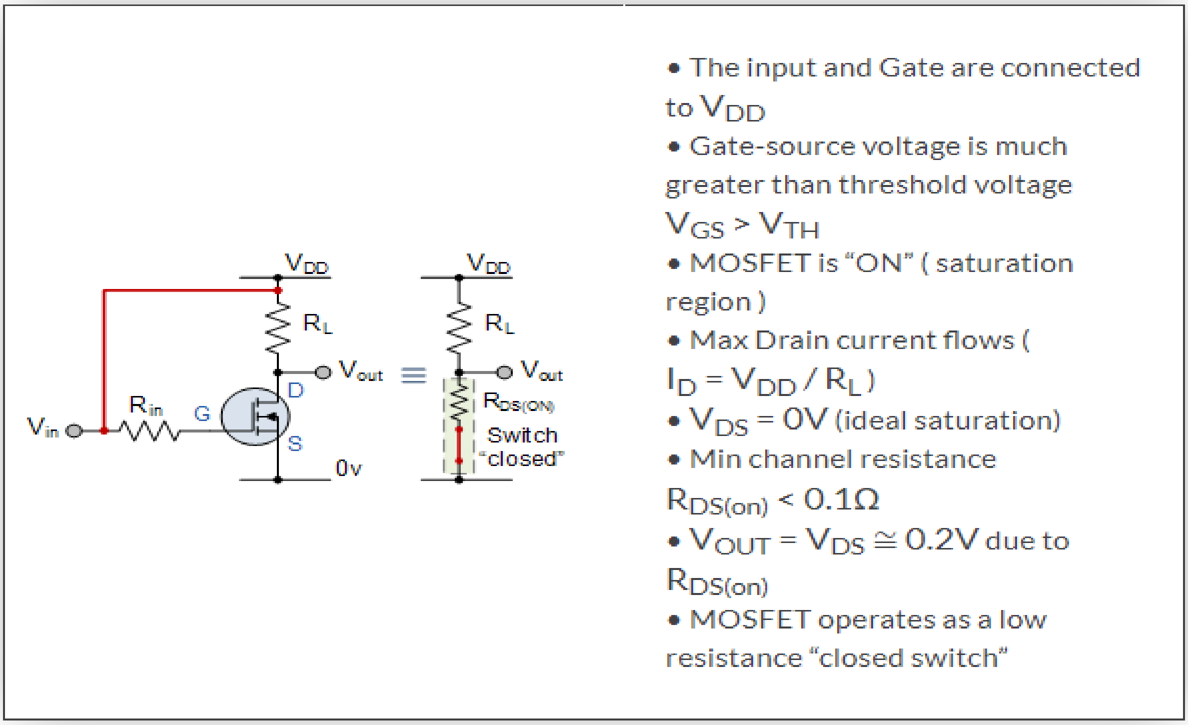
Applications of E-MOSFET

There are various applications of enhancement MOSFET, some of them are discussed below:

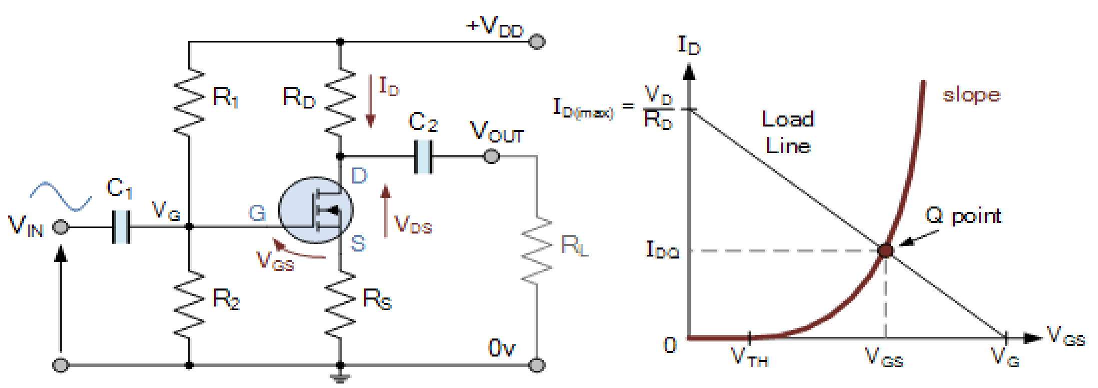
- It is used as an amplifier.
- These types of transistors also find its application in switching devices as it can rapidly be turned on or off when voltage is varied.
- It can also be used for storing memory and hence, finds its application in electronic memory or storage devices.
- E-MOSFETs are used in inverter circuits.
- It is also used in power electronic integrated circuits (IC's).

MOSFET as a Switch-





MOSFET as an Amplifier-



This simple enhancement-mode common source mosfet amplifier configuration uses a single supply at the drain and generates the required gate voltage, V_G using a resistor divider. We remember that for a MOSFET, no current flows into the gate terminal and from this we can make the following basic assumptions about the MOSFET amplifiers DC operating conditions.

ons about the MOSFET amplifiers DC operating conditions.

$$V_{DD} = I_D R_D + V_{DS} + I_D R_S$$
$$= I_D (R_D + R_S) + V_{DS}$$

$$\therefore R_D + R_S = \frac{V_{DD} - V_{DS}}{I_D}$$

Then from this we can say that:

$$R_D = \frac{V_{DD} - V_D}{I_D} \quad \text{and} \quad R_S = \frac{V_S}{I_D}$$

and the mosfets gate-to-source voltage, V_{GS} is given as:

$$V_{GS} = V_G - I_S R_S$$

As we have seen above, for proper operation of the mosfet, this gate-source voltage must be greater than the threshold voltage of the mosfet, that is $V_{GS} > V_{TH}$. Since $I_S = I_D$, the gate voltage, V_G is therefore equal too:

$$V_{GS} = V_G - I_D R_S$$

$$\therefore \; V_G = V_{GS} + I_D R_S$$

$$\text{or} \; V_G = V_{GS} + V_S$$

To set the mosfet amplifier gate voltage to this value we select the values of the resistors, R1 and R2 within the voltage divider network to the correct values. As we know from above, "no current" flows into the gate terminal of a mosfet device so the formula for voltage division is given as:

VLSI -Very-large-scale integration (VLSI) is the process of creating an integrated circuit (IC) by combining thousands of transistors into a single chip. VLSI began in the 1970s when complex semiconductor and communication technologies were being developed. The microprocessor is a VLSI device. Before the introduction of VLSI technology most ICs had a limited set of functions they could perform. An electronic circuit might consist of a CPU, ROM, RAM and other glue logic. VLSI lets IC designers add all of these into one chip.

Very large-scale integration (VLSI) is the process of integrating or embedding hundreds of thousands of transistors on a single silicon semiconductor microchip. VLSI technology was conceived in the late 1970s when advanced level computer processor microchips were under development. VLSI is a successor to large-scale integration (LSI), medium-scale integration (MSI) and small-scale integration (SSI) technologies.

VLSI Technology VLSI is one of the most widely used technologies for microchip processors, integrated circuits (IC) and component designing. It was initially designed to support hundreds of thousands of transistor gates on a microchip which, as of 2012, exceeded several billion. All of these transistors are remarkably integrated and embedded within a microchip that has shrunk over time but still has the capacity to hold enormous amounts of transistors. The first 1 mega byte RAM was built on top of VLSI design principles and included more than one million transistors on its microchip dye.

Why VLSI? ¬Integration improves the design

¬Lower parasitic = higher speed

¬Lower power consumption

¬Physically smaller

¬Integration reduces manufacturing cost-(almost) no manual assembly

Why Make ICs • Integration improves

– size

– speed

– power

VLSI advantages: VLSI has many advantages1. Reduces the Size of Circuits.

2. Reduces the effective cost of the devices.

3. Increases the Operating speed of circuits

4. Requires less power than Discrete components.

5. Higher Reliability

6. Occupies a relatively smaller area.

VLSI Applications: VLSI is an implementation technology for electronic circuitry

- analogue or digital It is concerned with forming a pattern of interconnected switches and gates on the surface of a crystal of semiconductor

• Microprocessors

• personal computers

• microcontrollers

• Memory - DRAM / SRAM

• Special Purpose Processors - ASICS (CD players, DSP applications)

• Optical Switches Has made highly sophisticated control systems mass-producable and therefore cheap

In today's world VLSI chips are widely used in various branches of Engineering like:

¬ Voice and Data Communication networks

¬ Digital Signal Processing

¬ Computers

¬ Commercial Electronics

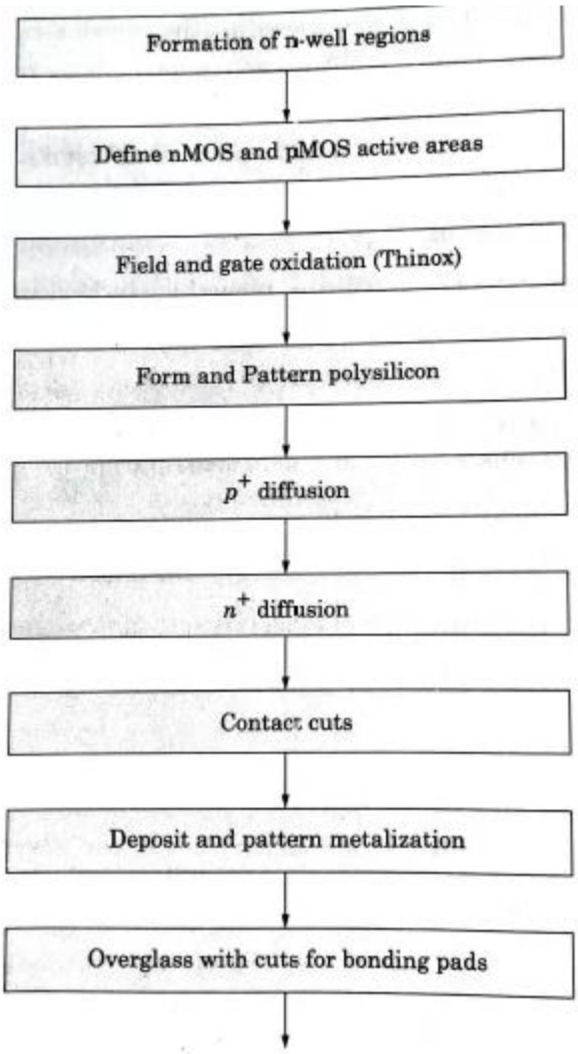
¬ Automobiles

¬ Medicine and many more.

The n-Well Process:

The n-well fabrication has gained wide acceptance.

N-well CMOS circuits are superior to *p-well* because of the lower substrate bias effect on transistor threshold voltage and inherently lower parasitic capacitances associated with the source and drain regions. The flow diagram of the fabrication for the *nMOS* process is illustrated in the figure below.



The *n-wells* are created in the p-type substrate. The typical processing steps for the fabrication of CMOS devices may be summarized as below:

1. It defines the areas in which the deep n-well diffusions have to take place.
2. It defines the thin oxide regions, i.e., those areas in which the thick oxide layer is to be stripped and thin oxide is to be grown for accommodating n- and p-type transistors and diffusion wires.
3. This mask is used to pattern the polysilicon layer, which is to be deposited after thin oxide.
4. In this, an n+ mask is used to define the areas for all types of diffusion of p-type impurity.
5. It is generally performed using a negative form of n+ mask and with step 2. It is used to define the areas for p-type diffusion.
6. Contact cuts are defined.
7. The metal layer pattern is defined.
8. At this stage, the overall passivation layer is applied and by this mask, openings for bonding pads are defined.