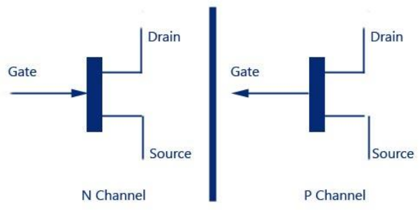
Unit-4: Field Effect Transistors

Unit-IV Field Effect Transistors	4a. Explain with sketches the construction and working principle of the given type of FET. 4b. Determine the FET parameters from the given FET charasteristic curve. 4c. Describe the specified JFET paramenter. 4d. Describe the specified MOSFET paramenter.	4.1 FET-Types: JFET and MOSFET 4.2 Classification of JFET 4.3 Symbol, construction and working principle of N-channel and P-channel JFET, Drain and transfer characteristics of JFET 4.4 JFET parameters: DC and AC drain resistance, Transconductance, amplification factor 4.5 Symbol, construction and working principle of MOSFET.

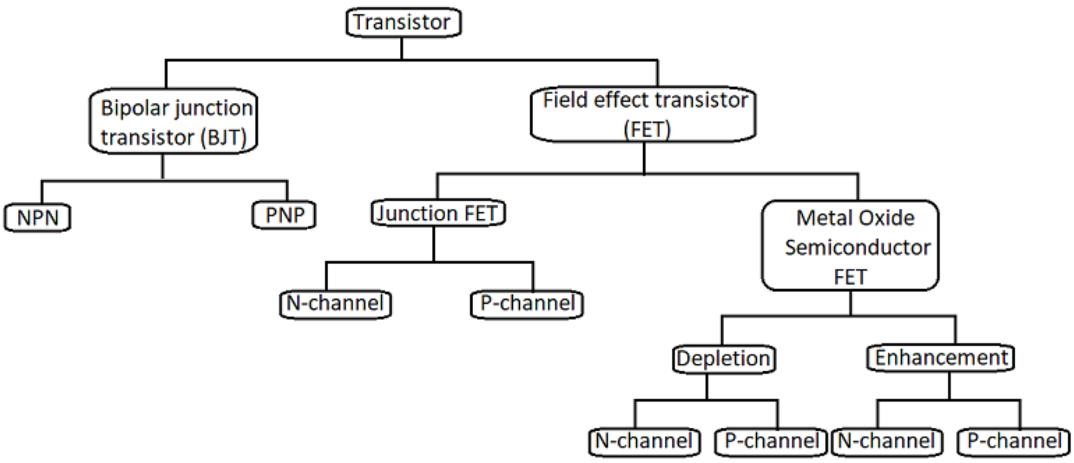
FET:

- **A Field Effect Transistor (FET) is a three-terminal Active semiconductor device, where the output current is controlled by an electric field generated by the input voltage.**
- **The field-effect transistor (FET) is a type of transistor that uses an electric field to control the flow of current in a semiconductor.**
- **FETs are also known as unipolar transistors since they involve single-carrier-type operation. That is, FETs use either electrons or holes as charge carriers in their operation, but not both.**
- **FET is unipolar device i.e. operation depends on only one type of charge carriers (*h* or *e*) .**
- **It is a Voltage controlled Device (gate voltage controls drain current)**



FET
Field Effect Transistor FET

Classification of FET:



Types of FET:

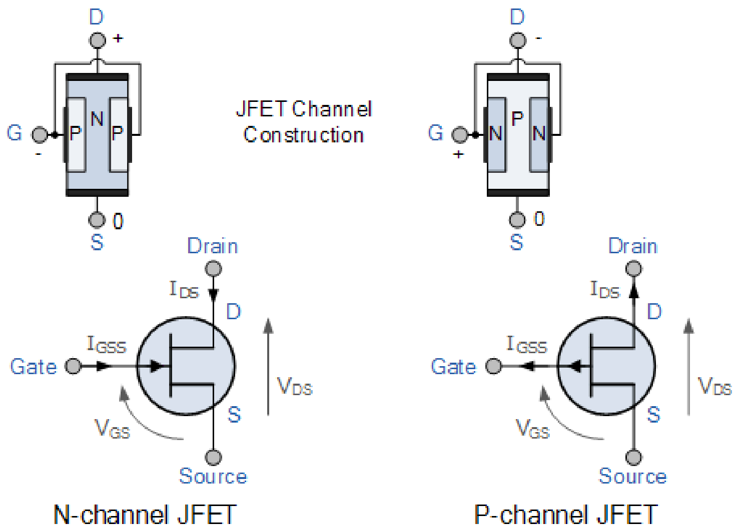
- **JFET : Junction Field Effect Transistor**
- **MOSFET : Metal Oxide Field Effect Transistor**

JFET:

- A JFET is a three terminal semiconductor device in which current conduction is by one type of carrier i.e. electrons or holes.
- The current conduction is controlled by means of an electric field between the gate and the conducting channel of the device.
- The JFET has high input impedance and low noise level.

Classification of JFET:

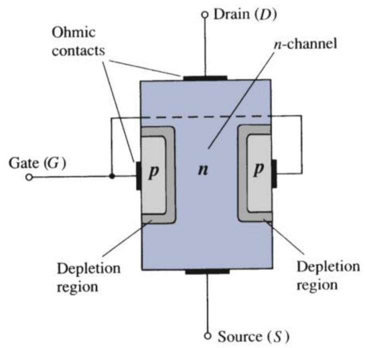
- N-channel
- P-channel



Working principle of JFET:

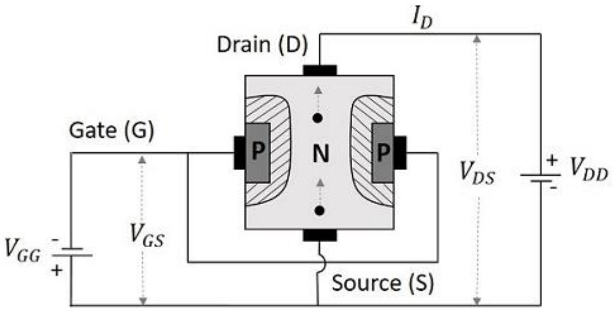
- When voltage VDS is applied between the drain and source terminals and gate terminal voltage is zero, the two pn-junctions at the sides establishes depletion layers.
- The electrons flow from source to drain through the channel between the depletion layers. The width of these depletion layers determine the width of the channel and hence the current conduction through the bar.
- Now, when a reverse voltage V_{GS} is applied between the gate and the source terminals, the width of depletion layers is increased and this decreases the width of the conduction channel, thereby increasing the resistance of conduction channel.
- Consequently, the current from source to drain is decreased. On the other hand, when the reverse voltage V_{GS} is decreased the width of depletion layer also decreases. Hence, the widths of conduction channel increases and the resulting source to drain current.
- Therefore, the current from source to drain can be controlled by the application voltage (electric field) on the gate terminal. For this reason it is known as Field Effect Transistor.
- Hence, the JFET operates on the principle that the width and resistance of conduction channel can be varied by changing the reverse voltage V_{GS}.

N-channel JFET:



- **It consists of an n – type silicon bar forming the conduction channel for the charge carriers. The pn – junction forming diodes are connected internally and a common terminal called GATE is taken out from the p - Region. The other two terminals viz. Source and Drain are taken out from the bar.**

Working of N-channel JFET:

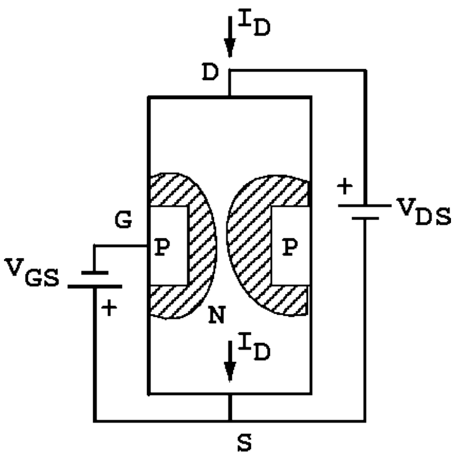


Case: 1 When V_{GS} = 0v

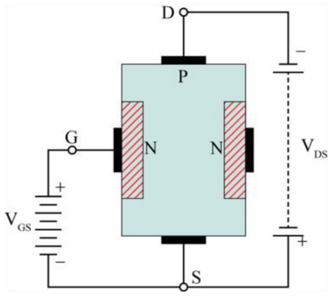
- **When VGS=0v and external voltage V_{DS} is applied between drain and source, the electrons flows from source to drain through the narrow channel.**

Case: 2 When V_{GS} is increased

- **VGS is applied to make junction between gate to source reverse.**
- **When this reverse bias voltage VGS is increased the depletion region becomes more wide. This reduces the effective width of the channel and therefore controls the flow of current through channel.**
- **When gate to source voltage increased further a stage is reached at which two depletion region touch each other as shown in fig above.**
- **At this stage the channel is completely blocked or pinch off and drain current reduced to zero**
- **The gate to source voltage at which the drain current is zero is called as pinch off voltage (VP).**



P-channel JFET:

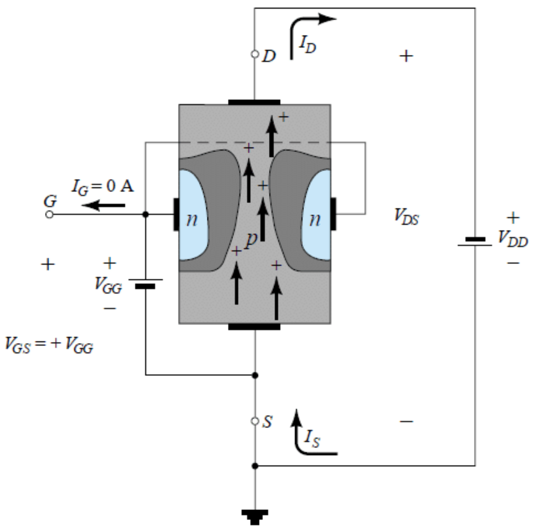


- **It consists of a p – type silicon bar forming the conduction channel for the charge carriers. The pn – junction forming diodes are connected internally and a common terminal called GATE is taken out from the n - Region. The other two terminals viz. Source and Drain are taken out from the bar.**

Working of P-channel JFET:

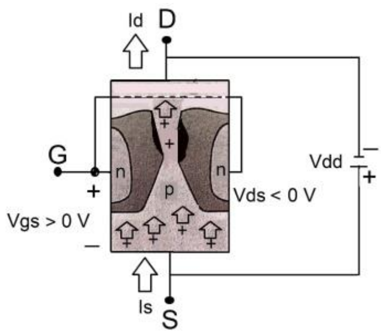
Case: 1 When V_{GS} = 0v

- **When there is no applied voltage the drain (D) and source (S), the depletion layer is symmetrical around the P-N junction.**
- **The conductivity depletion layer is zero because there are no mobile charge carriers in this region.**



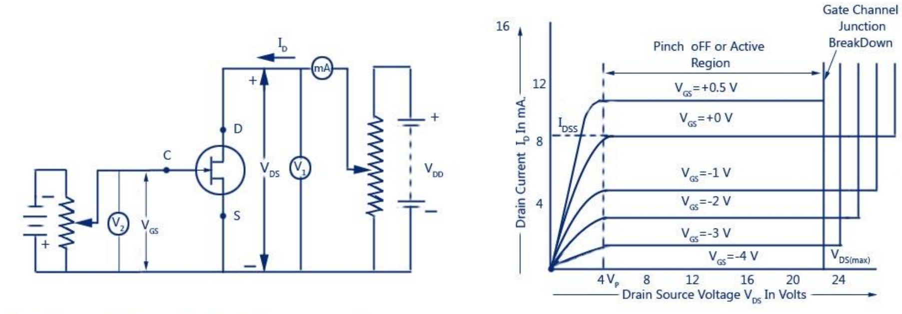
Case: 2 When V_{GS} is increased

- **When the voltage is applied between the drain and the source, with a battery V_{DD}, the holes flow from the source to the drain through the narrow channel existing between the depletion regions. This constitutes the drain current I_D, the value of drain current is now maximum I_{DSS}.**
- **When the gate to source voltage V_{GS} is applied and is increased above zero, the reverse bias voltage across the gate-source junction is now increased. As a result of this, the depletion layers are widened.**
- **This reduces the effective width of the conducting channel, thereby increasing the resistance of type bar Consequently, the flow of holes from source-to-drain decreases, thereby decreasing the drain current.**



- **On the other hand, if the reverse voltage on the gate is decreased, the width of the depletion region also decreases. This increases the width of the conducting channel and hence the drain current increases**
- **When the reverse voltage on the gate is increased further, a stage is reached at which two depletion regions touch each other. At this gate voltage V_{GS} the conducting channel is completely blocked (or pinched off) and the drain current is reduced to zero.**

Drain or Output Characteristics of JFET:



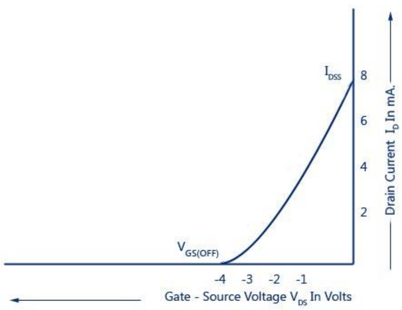
Circuit Diagram for Determining Drain Characteristic with External-Bias for An N-Channel JFET

Drain Characteristic with External-Bias

External Bias Characteristic of JFET

- **The curve showing the relation between the drain current (I_D) and the drain-source voltage (V_{DS}) at constant gate-source voltage (V_{GS}) is known as the Output or Drain Characteristics of JFET.**
- **At the start, the drain current (ID) increases rapidly with increase in drain-source voltage (VDS) but then becomes constant. The value of VDS above which the drain current becomes constant is called as Pinch off Voltage (V_P).**
- **After pinch off voltage, the channel width becomes so narrow that the depletion layers touch each other. Therefore, after pinch off voltage the change in the drain current is small with change in the VDS. Hence, the drain current remains constant.**

Transfer Characteristics of JFET:



Transfer Characteristics of JFET

- **The characteristic curve which gives the relationship between the drain current I_D and gate-to-source voltage V_{GS} for a constant drain-to-source voltage V_{DS} is known as transfer characteristics.**
- **These curves may be obtained by using the unapt arrangement as shown in fig. above**
- **First of all, we adjust the drain-to-source voltage V, to some suitable value**
- **Then increase the gate-to-source V_{GS}, in small suitable steps and record the corresponding values of drain current I_D each step**
- **If we plot a graph with the voltage V_{GS}, along the horizontal (X) axis and the current Io along the vertical (Y) axis, we shall get a curve as shown in Fig above**
- **A similar procedure may be used to obtain curves at different values of voltage V_{GS}**
- **When V_{GS} = 0 V. then drain current is maximum It is known as I_{DSS} i.e saturation state drain current**
- **When V_{GS} is more negative (reverse bias) then drain current becomes zero This V_{GS}, value is known as pinch-of voltage**

Parameters of JFET

The JFET has parameters which determine the performance of it −

- **AC drain resistance (r_d) − It is defined as the ratio of the change in the drain-source voltage (ΔV_{DS}) to the corresponding change in the drain current (ΔI_D) at constant gate-source voltage (V_{GS}).**

AC Drain Resistance (r_d)

$$r_d = \frac{\Delta V_{DS}}{\Delta I_D} \text{ at constant } V_{GS}$$

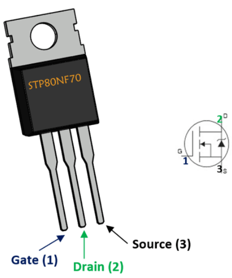
- **Trans-conductance (g_m) − It is defined as the ratio of change in drain current (ΔI_{DS}) to the change in gate – source voltage (ΔV_{GS}) at constant drain-source voltage.**
  The trans-conductance of JFET is expressed either in mA/V or micro Siemens.

$$g_M = \frac{I_D}{V_{GS}}$$

- **Amplification Factor (μ) − It is defined as the ratio of change in drain-source voltage (ΔV_{DS}) to the change in gate-source voltage (Δ_{GS}) at constant drain current.**
  The amplification factor of JFET shows how much control the gate voltage has over the drain current.

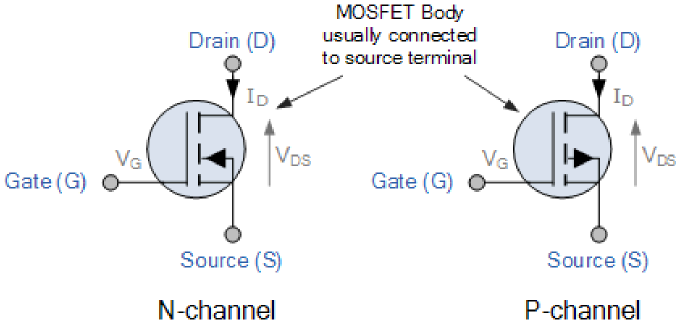
$$\text{Amplification Factor}(\mu) = \frac{(\Delta V_{DS})}{(\Delta V_{GS})}$$

MOSFET:

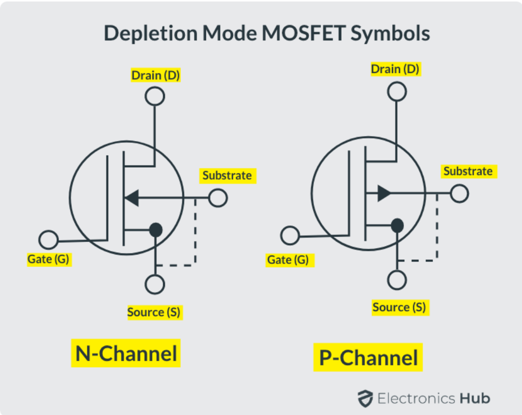


- **FETs have a few disadvantages like high drain resistance, moderate input impedance and slower operation. To overcome these disadvantages, the MOSFET which is an advanced FET is invented.**
- **MOSFET stands for Metal Oxide Silicon Field Effect Transistor or Metal Oxide Semiconductor Field Effect Transistor.**
- **This is also called as IGFET meaning Insulated Gate Field Effect Transistor. The FET is operated in both depletion and enhancement modes of operation.**

Symbol: Enhancement mode

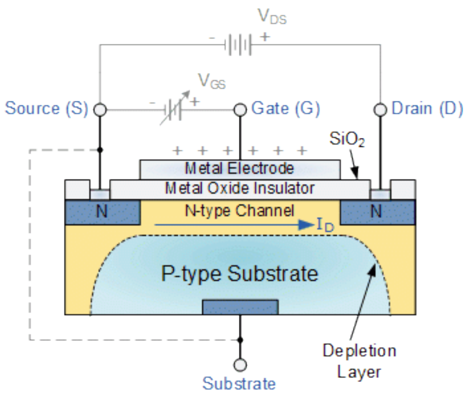


Symbol: Depletion mode



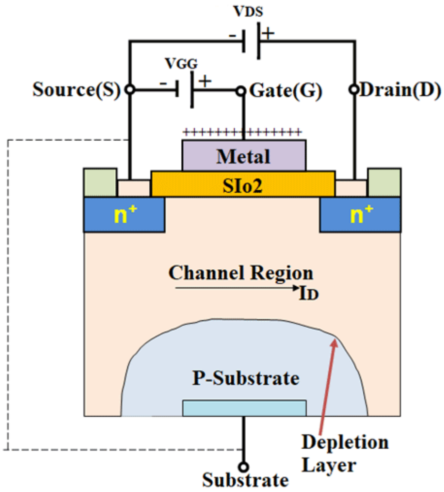
Construction of MOSFET:

- **The construction of a MOSFET is a bit similar to the FET.**
- **An oxide layer is deposited on the substrate to which the gate terminal is connected. This oxide layer acts as an insulator (sio_2 insulates from the substrate), and hence the MOSFET has another name as IGFET.**
- **In the construction of MOSFET, a lightly doped substrate, is diffused with a heavily doped region. Depending upon the substrate used, they are called as P-type and N-type MOSFETs.**
- **The following figure shows the construction of a MOSFET.**



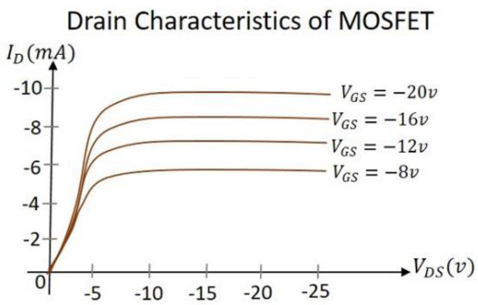
- **The voltage at gate controls the operation of the MOSFET. In this case, both positive and negative voltages can be applied on the gate as it is insulated from the channel. With negative gate bias voltage, it acts as depletion MOSFET while with positive gate bias voltage it acts as an Enhancement MOSFET.**

Working principle of MOSFET:



- In general, the MOSFET works as a switch, the MOSFET controls the voltage and current flow between the source and drain.
- The working of the MOSFET depends on the MOS capacitor, which is the semiconductor surface below the oxide layers between the source and drain terminal. It can be inverted from p-type to n-type, simply by applying positive or negative gate voltage respectively.
- When a drain-source voltage (V_{DS}) is connected between the drain and source, a positive voltage is applied to the Drain, and the negative voltage is applied to the Source. Here the PN junction at the drain is reverse biased and the PN junction at the Source is forward biased. At this stage, there will not be any current flow between the drain and the source.
- If we apply a positive voltage (V_{GG}) to the gate terminal, due to electrostatic attraction the minority charge carriers (electrons) in the P substrate will start to accumulate on the gate contact which forms a conductive bridge between the two n+ regions.
- The number of free electrons accumulated at the gate contact depends on the strength of positive voltage applied. The higher the applied voltage greater the width of the n-channel formed due to electron accumulation, this eventually increases the conductivity and the drain current (I_D) will start to flow between the Source and Drain.
- When there is no voltage applied to the gate terminal, there will not be any current flow apart from a small amount of current due to minority charge carriers. The minimum voltage at which the MOSFET starts conducting is called the threshold voltage.

Drain Characteristics



- The drain characteristics of a MOSFET are drawn between the drain current I_D and the drain source voltage V_{DS}. The characteristic curve is as shown below for different values of inputs.
- Actually when V_{DS} is increased, the drain current I_D should increase, but due to the applied V_{GS}, the drain current is controlled at certain level. Hence the gate current controls the output drain current.