# Field effect transistor

The field effect transistor or FET is a semiconductor device with the output current controlled by an electric field. Since the current is carried predominantly by one type of carriers, the FET is known as a unipolar transistor. Thus it is different from the bipolar transistor which involves two types of carriers i.e electron and holes. FET is a three terminal semiconductor device having a single p-n junction and is extensively in many digital & some analog circuit.

## Comparison between FET and BJT :-

i) The input impedence of the FET is very high (about 1 mega-ohm) compared to that of a BJT.

ii) The operation of FET depends only one type of carrier i.e majority carrier so it is unipolar device. On the other hand BJT is bipolar device because both majority and minority carrier are involved for its operation.

iii) The operation of FET depends on applied electric field so it is voltage control device. But the operation of BJT depends on emitter current so it is called current control device.

iv) FET is less noisy than BJT

v) FET has higher switching speed and can be operated at higher frequency because there is no minority carriers. BJT is lower switching speed the FET.

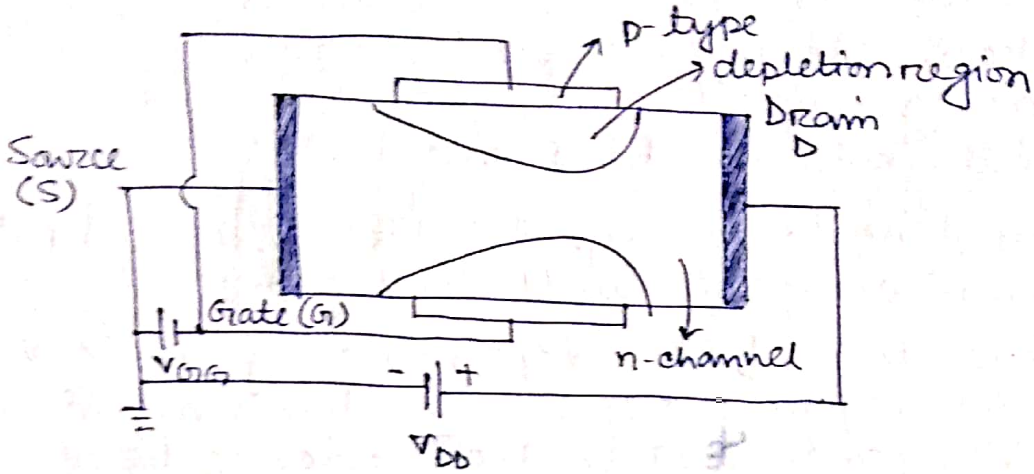
vi)

FET
Field effect transistor

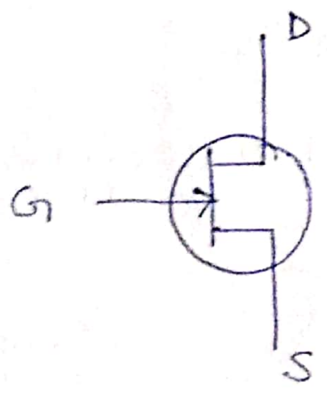
- Junction field effect transistor (JFET)
  - n-channel JFET
  - p-channel JFET
- Metal oxid semiconductor FET (MOSFET)
  - Depletion type MOSFET
    - n-channel depletion type
    - p-channel depletion type
  - Enhancement type MOSFET
    - n-channel enhancement type
    - p-channel enchancement type.

## Junction field effect transistor :-

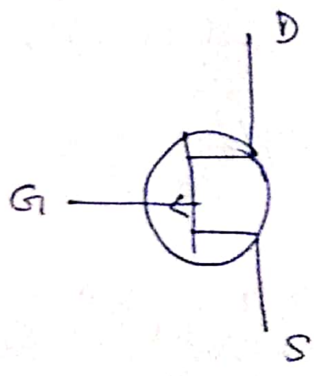
The JFET consists of a uniformly doped semiconductor bar usually of Si or GaAs. The bar has ohmic contacts at the two ends and semiconductor junctions on its two sides. If the semiconductor bar is n-type, the JFET is called an n-channel JFET. If the bar is p-type, the device is termed a p-channel




JFET. Two sides of the bar are heavily doped with impurities opposite to that of the bar i.e p-type impurities for an n-type bar and vice versa. Current is caused to flow through the bar by applying a voltage between the end terminal. The terminal through which the majority carriers enter the bar is called the ~~drain~~ source. and through which the majority carrier leave the bar is called the drain. The region of the bar between the two gate regions through which majority carriers move from source to drain is called the channel.




circuit symbol for n-channel JFET

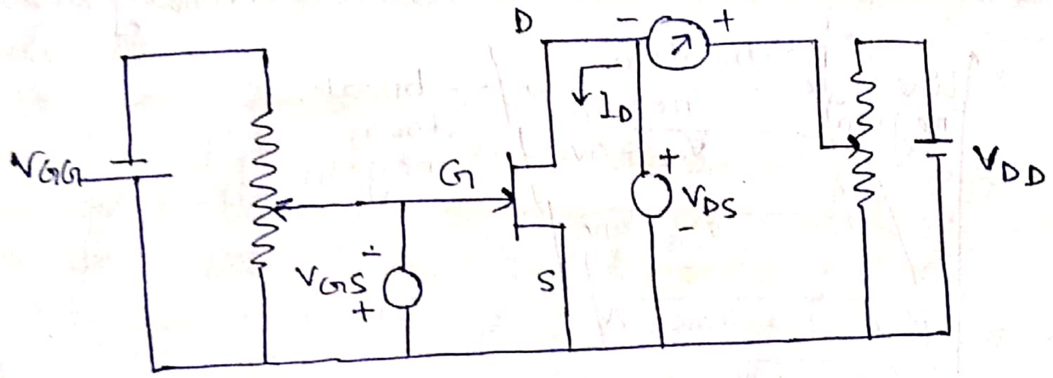



circuit symbol for p-channel JFET.

## Operation :-

The junction between the bar and the gate is reverse biased by applying a voltage $V_{GG}$ as shown in fig (1). The resulting depletion regions extend into the bar. The widths of the depletion regions can be controlled by changing the gate to source voltage. The depletion regions are devoid of current carriers, so that conductivity of these regions is nominally zero. Therefore, the effective cross sectional area through which the current flows in the bar decreases with increasing reverse bias. It follows that for a given drain to source voltage, the drain current is a function of the gate to source voltage. The name field effect is used for the device because the transverse field produced by the gate gives the effect of controlling the drain current.

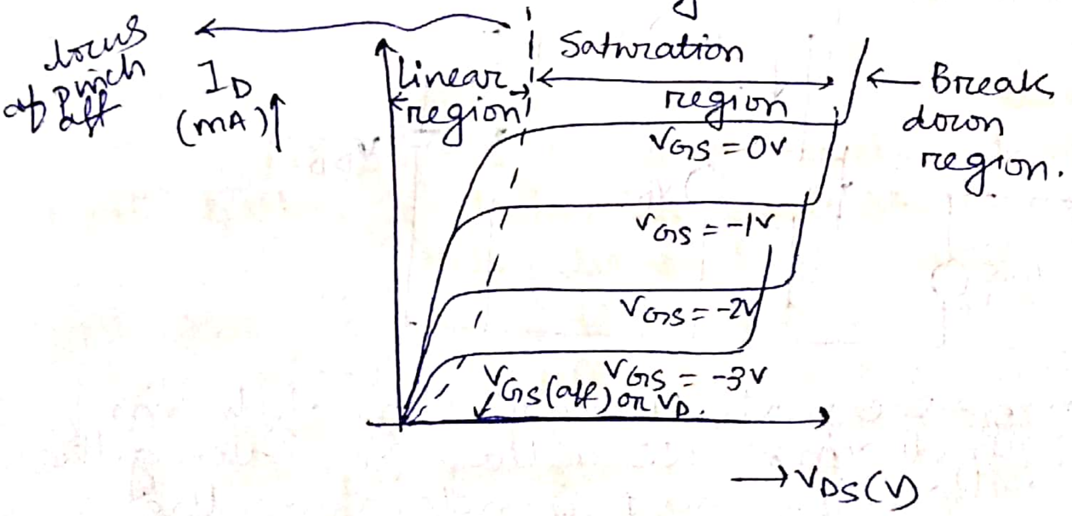
## Static characteristics of a JFET :-



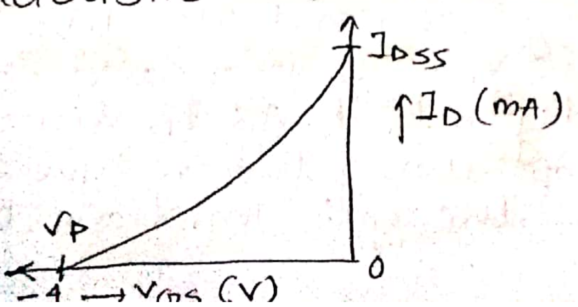

In common source mode the variation of drain current $I_D$ with drain source voltage $V_{DS}$ taking the gate source voltage $V_{GS}$ as parameter gives the common source drain characteristics.

Each of characteristic curves can be divided into three region (i) linear region (ii) saturation region (iii) breakdown region.

For $V_{GS} = 0V$, the channel between the gate regions is entirely open and the bar acts as a simple resistor. So, as $V_{DS}$ is increased from zero $I_D$ increases linearly with it. As $I_D$ increases the ohmic voltage drop along the n-type channel region reverse biases the gate junctions. Depletion layers are formed and the effective conducting channel crosssection decreases. Because of the gradual ohmic potential drop along the length of the channel the gate becomes more reverse biased near the drain end than at the source end. So, the depletion region increases as we go from source to drain end. As $V_{DS}$ is increased more the channel becomes narrower causing the resistance between the source and drain to increase. This makes $I_D$ vs $V_{DS}$ curve nonlinear. At some value of $V_{DS}$, the depletion region meet near the drain to pinchoff the channel. In pinch-off condition the current almost saturates. This value of $V_{DS}$ is the saturation voltage $V_{Dsat}$. Beyond pinch off, the current $I_D$ saturates at a value $I_{Dsat}$. At high values of $V_{DS}$, $I_D$ suddenly rise to large value. This is due to avalanche breakdown across the reverse biased gate junction, the region of the characteristics is called breakdown region as shown in fig below.




In saturation region $I_D$ depends on the reverse biasing gate voltage $V_{GS}$. The variation of $I_D$ with gate to source reverse bias voltage $V_{GS}$ at a constant value of $V_{DS}$ gives the transfer characteristic curve as shown in fig. The saturation drain current at $V_{GS} = 0$ is denoted by $I_{DSS}$. $I_{DSS}$ represents the upper limit on the



JFET current. The shape of the transfer curve is very nearly parabolic and can be approximately represented by Shockley's equation

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

where $V_P$ = pinch off voltage.

■ Explain "BJT is called current control device but FET is a voltage control device".

In a BJT, emitter base junction is forward biased. So, the impedence of the emitter circuit is low and a current flows between the emitter and the base. A change in the emitter current causes a change in the collector current in a BJT. Thus a BJT is a current controlled device.

In a FET, the application of a gate voltage causes a very small gate current since the input impedence at the gate is very high. A change in the gate voltage controls the drain current. Thus the FET is known as voltage controlled device.

■ FET parameter :-

The analytical method of analysis of JFET amplifiers involves three parameters, called JFET parameters. These are defined below:-

i) Drain resistance ($r_d$) :- It is the a.c resistance between drain and source terminals and is defined as the ratio of the small change in drain voltage to the corresponding change in drain current at a constant gate voltage. i.e

$$r_d = \left.\frac{\delta V_{DS}}{\delta I_D}\right|_{V_{GS} = \text{constant}}$$

ii) Mutual conductance ($g_m$) :- It is defined as ratio of small change in drain current to the corresponding change in the gate voltage at a constant drain voltage, i.e,

$$g_m = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS} = \text{constant}}$$

iii) Amplification factor ($\mu$) :- It is defined as the small change in drain voltage to the corresponding change in the gate voltage for a constant drain current, i.e,

$$\mu = -\left.\frac{\partial V_{DS}}{\partial V_{GS}}\right|_{I_D = \text{constant}}$$

where -ve sign indicates that any change in $I_D$ due to a positive increment of $V_{DS}$ is to be counterbalanced by a -ve increment of $V_{GS}$.

■ Relation between $\mu$, $r_d$ & $g_m$ :-

The drain current $I_D$ is a function of drain voltage $V_{DS}$ & gate voltage $V_{GS}$ i.e

$$I_D = f(V_{DS}, V_{GS})$$

$$\therefore dI_D = \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{GS}} dV_{DS} + \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}} dV_{GS}$$

If $V_{DS}$ and $V_{GS}$ are simultaneously so changed that $I_D$ remain constant, then $dI_D = 0$

$$\therefore \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{GS}} . dV_{DS} + \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}} dV_{GS} = 0$$

$$\Rightarrow \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{GS}} \cdot \left.\frac{\partial V_{DS}}{\partial V_{GS}}\right|_{I_D} + \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}} = 0$$

$$\Rightarrow \frac{1}{r_d}(-\mu) + g_m = 0$$

$$\Rightarrow \boxed{\mu = r_d \cdot g_m}$$

■

| n channel JFET | p-channel JFET |
|---|---|
| i) In n channel JFET, current carriers are electron & mobility of electron is large | i) In p-channel JFET, current carriers are holes and mobility of holes is poor. |
| ii) Input noise is less | ii) Input noise is more |
| iii) transconductance is large than p-channel JFET | iii) transconductance is smaller in p-channel JFET than n-channel JFET. |