FIELD EFFECT TRANSISTORS

Introduction

In the previous chapters, we have discussed the circuit applications of an ordinary transistor. In this type of transistor, both holes and electrons play part in the conduction process. For this reason, it is sometimes called a bipolar transistor. The ordinary or bipolar transistor has two principal disadvantages. First, it has a low input impedance because of forward biased emitter junction. Secondly, it has considerable noise level. Although low input impedance problem may be improved by careful design and use of more than one transistor, yet it is difficult to achieve input impedance more than a few megaohms. The field effect transistor (*FET*) has, by virtue of its construction and biasing, large input impedance which may be more than 100 megaohms. The *FET* is generally much less noisy than the ordinary or bipolar transistor. The rapidly expanding *FET* market has led many semiconductor marketing managers to believe that this device will soon become the most important electronic device, primarily because of its integrated-circuit applications. In this chapter, we shall focus our attention on the construction, working and circuit applications of field effect transistors.

21.1. Types of Field Effect Transistors

A bipolar junction transistor (*BJT*) is a current controlled device *i.e.*, output characteristics of the device are controlled by base current and not by base voltage. However, in a field effect transistor (FET), the output characteristics are controlled by input voltage (*i.e.*, electric field) and not by input current. This is probably the biggest difference between BJT and FET. There are two basic types of field effect transistors:

(*i*) Junction field effect transistor (*JFET*)

(*ii*) Metal oxide semiconductor field effect transistor (*MOSFET*)

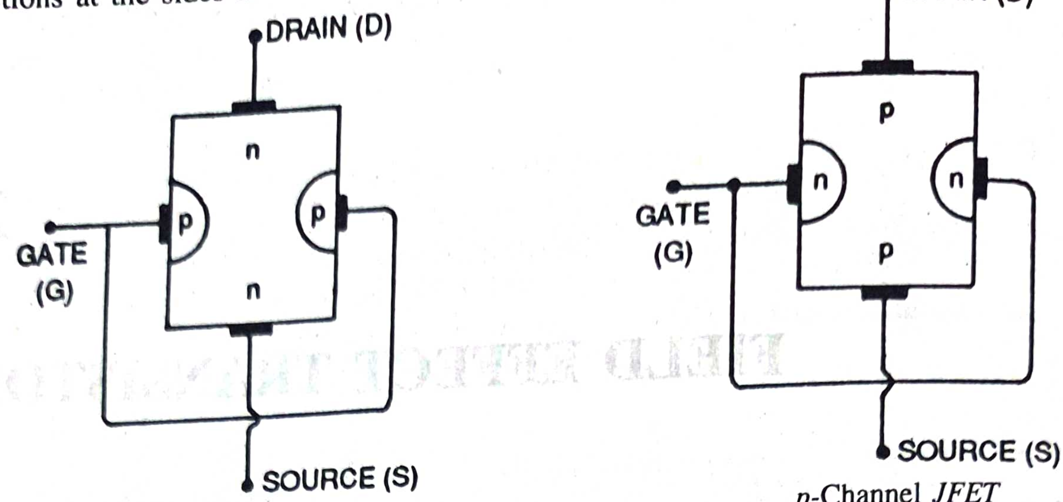
To begin with, we shall study about *JFET* and then improved form of *JFET*, namely; *MOSFET*

21.2. Junction Field Effect Transistor (JFET)

A **junction field effect transistor** *is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes.*

The *JFET* was developed about the same time as the transistor but it came into general use only in the late 1960*s*. In a *JFET*, the current conduction is either by electrons or holes and is controlled by means of an electric field between the gate electrode and the conducting channel of the device. The *JFET* has high input impedance and low noise level.

Constructional details. A *JFET* consists of a *p*-type or *n*-type silicon bar containing two *pn* junctions at the sides as shown in Fig. 21.1 The bar forms the conducting channel for the charge carriers. If the bar is of *n*-type, it is called *n-channel JFET* as shown in Fig. 21.1 *(i)* and if the bar is of *p*-type, it is called a *p-channel JFET* as shown in Fig. 21.1 *(ii)*. The two *pn* junctions forming diodes are connected internally and a common terminal called *gate* is taken out. Other terminals are *source* and *drain* taken out from the bar as shown. Thus a *JFET* has essentially three terminals *viz., gate (G)*, source *(S)* and drain *(D)*.

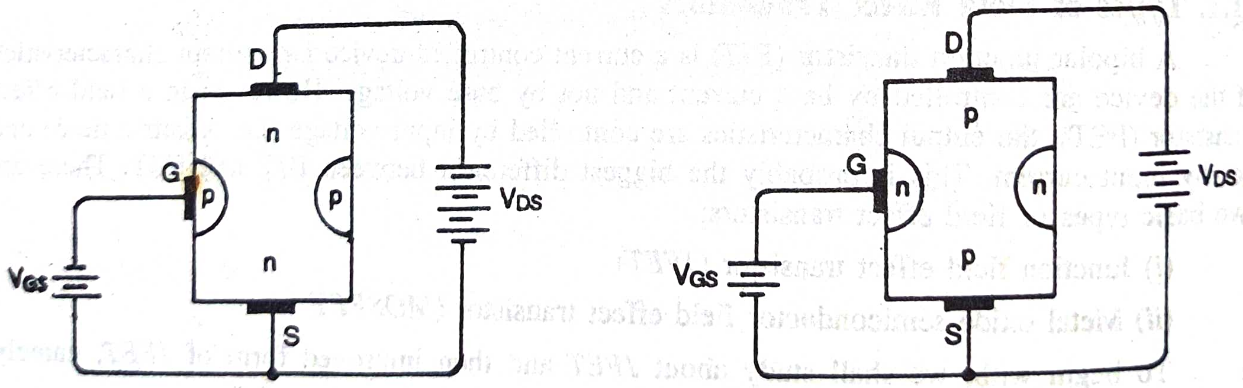


n-Channel *JFET*
(i)

p-Channel *JFET*
(ii)

Fig. 21.1

JFET polarities. Fig. 21.2 *(i)* shows *n*-channel *JFET* polarities whereas Fig. 21.2 *(ii)* shows the *p*-channel *JFET* polarities. Note that in each case, the voltage between the gate and source is such that the gate is reverse biased. This is the normal way of *JFET* connection. The drain and source terminals are *interchangeable *i.e.,* either end can be used as source and the other end as drain.



(i) *(ii)*

Fig. 21.2

21.3. Working Principle of JFET

Fig. 21.3 shows the circuit of *n*-channel *JFET* with normal polarities. The circuit action is as follows :

* This is generally valid for low frequency applications. However, it is not true at high frequencies.

(i) When a voltage V_{DS} is applied between drain and source terminals and voltage on the gate is zero [See Fig. 21.3 (i)], the two *pn* junctions at the sides of the bar establish depletion layers. The electrons will flow from source to drain through a channel between the depletion layers. The size of these layers determines the width of the channel and hence the current conduction through the bar.

(ii) When a reverse voltage V_{GS} is applied between the gate and source [See Fig. 21.3 (ii)], the width of the depletion layers is increased. This reduces the width of conducting channel, thereby increasing the resistance of *n*-type bar. Consequently, the current from source to drain is decreased. On the other hand, if the reverse voltage on the gate is decreased, the width of the depletion layers also decreases. This increases the width of the conducting channel and hence source to drain current.

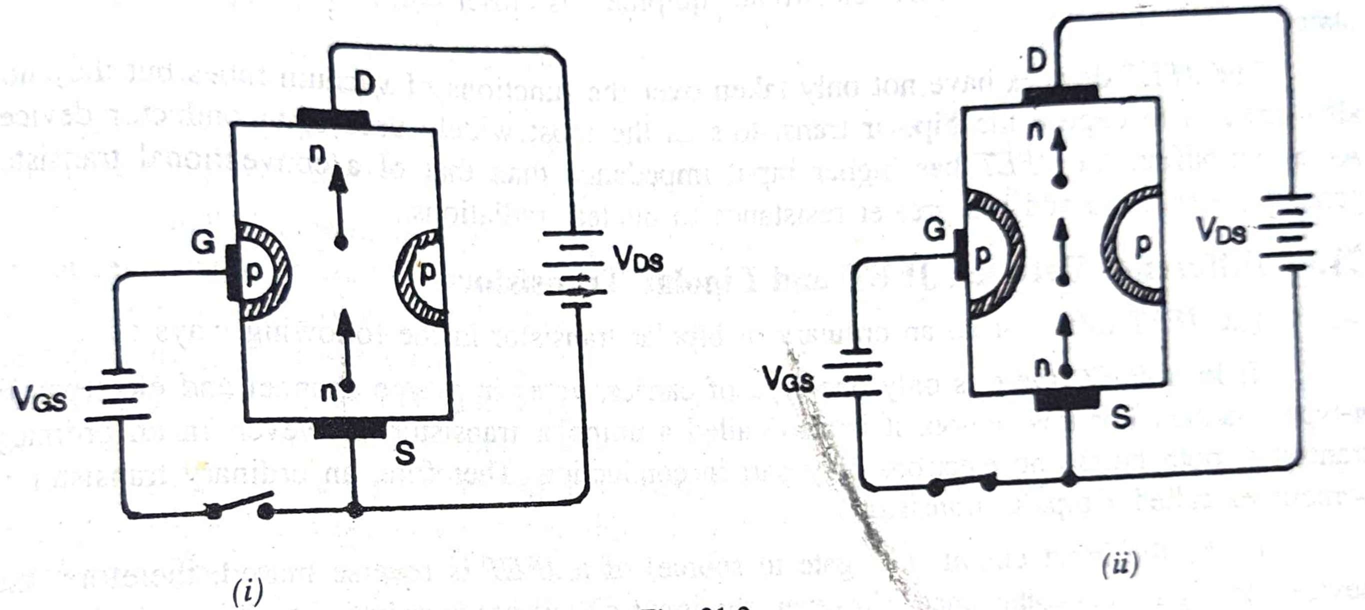
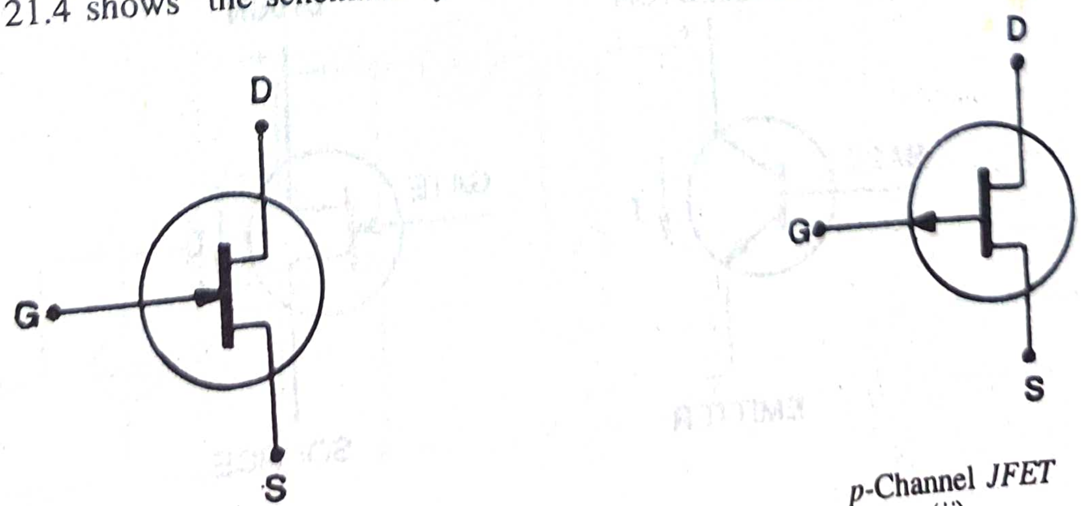


Fig. 21.3

It is clear from the above discussion that current from source to drain can be controlled by the application of potential (*i.e.* electric field) on the gate. For this reason, the device is called *field effect transistor*. It may be noted that a *p*-channel *JFET* operates in the same manner as an *n* -channel *JFET* except that channel current carriers will be the holes instead of electrons and the polarities of V_{GS} and V_{DS} are reversed.

21.4. Schematic Symbol of JFET

Fig. 21.4 shows the schematic symbol of *JFET*. The vertical line in the symbol may be



n-Channel *JFET*
(i)

p-Channel *JFET*
(ii)

Fig. 21.4

thought as channel and source(S) and drain (D) connected to this line. If the channel is *n*-type, the arrow on the gate points towards the channel as shown in Fig. 21.4 (*i*). However, for *p*-type channel, the arrow on the gate points from channel to gate. [See Fig 21.4 (*ii*)].

21.5. Importance of JFET

A *JFET* acts like a voltage controlled device *i.e.* input voltage (V_{GS}) controls the output current. This is different from ordinary transistor (or bipolar transistor) where input current controls the output current. Thus *JFET* is a semiconductor device acting *like a vacuum tube. The need for *JFET* arose because as modern electronic equipment became increasingly transistorised, it became apparent that there were many functions, in which bipolar transistors were unable to replace vacuum tubes. Owing to their extremely high input impedance, *JFET* devices are more like vacuum tubes than are the bipolar transistors and hence are able to take over many vacuum-tube functions. Thus, because of *JFET*, electronic equipment is closer today to being completely solid state.

The *JFET* devices have not only taken over the functions of vacuum tubes but they now also threaten to depose the bipolar transistors as the most widely used semiconductor devices. As an amplifier, the *JFET* has higher input impedance than that of a conventional transistor, generates less noise and has greater resistance to nuclear radiations.

21.6. Difference Between JFET and Bipolar Transistor

The *JFET* differs from an ordinary or bipolar transistor in the following ways :

(i) In a *JFET*, there is only one type of carrier, holes in *p*-type channel and electrons in *n*-type channel. For this reason, it is also called a unipolar transistor. However, in an ordinary transistor, both holes and electrons play part in conduction. Therefore, an ordinary transistor is sometimes called a bipolar transistor.

(ii) As the input circuit (*i.e.*, gate to source) of a *JFET* is reverse biased, therefore, the device has high input impedance. However, the input circuit of an ordinary transistor is forward biased and hence has low input impedance.

(iii) As the gate is reverse biased, therefore, it carries very small current. Obviously, *JFET* is just like a vacuum tube where control grid (corresponding to gate in *JFET*) carries extremely small current and input voltage controls the output current. For this reason, *JFET* is essentially a *voltage-driven device.* However, ordinary transistor is a current operated device *i.e.*, input current controls the output current.

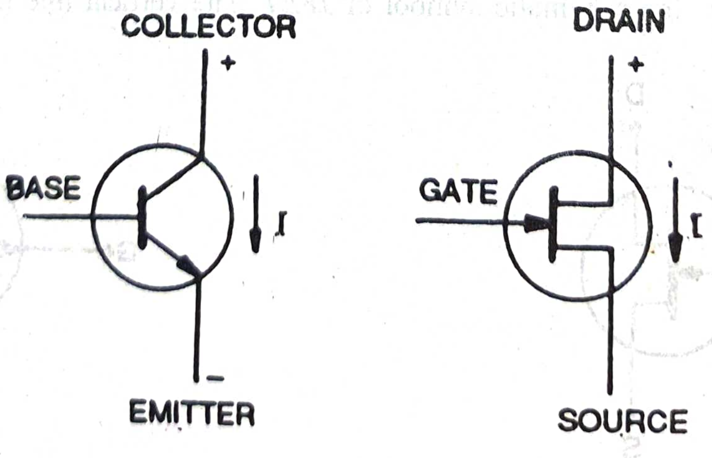


Fig. 21.5

* The gate, source and drain of a *JFET* correspond to grid, cathode and anode of a vacuum tube.

(iv) A bipolar transistor uses a current into its base to control a large current between collector and emitter whereas a *JFET* uses *voltage* on the 'gate' (= base) terminal to control the current between drain (= collector) and source (= emitter). Thus a bipolar transistor gain is characterised by current gain whereas the *JFET* gain is characterised as a transconductance *i.e.*, the ratio of change in output current (drain current) to the input (gate) voltage.

(v) In *JFET*, there are no junctions as in an ordinary transistor. The conduction is through an *n*- type or *p*-type semi-conductor material. For this reason, noise level in *JFET* is very small.

21.7. JFET as an Amplifier

Fig. 21.6 shows *JFET* amplifier circuit. The weak signal is applied between gate and source and amplified output is obtained in the drain-source circuit. For the proper operation of *JFET*, the gate must be negative *w.r.t.* source *i.e.*, input circuit should always be reverse biased. This is achieved either by inserting a battery V_{GG} in the gate circuit or by a circuit known as biasing circuit. In the present case, we are providing biasing by the battery V_{GG}.

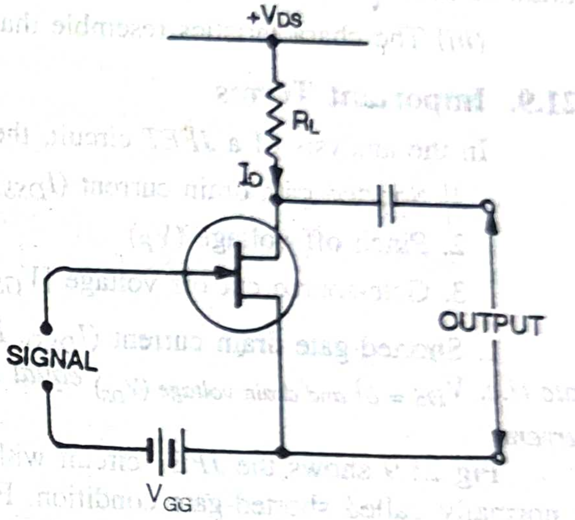


Fig. 21.6

A small change in the reverse bias on the gate produces a large change in drain current. This fact makes *JFET* capable of raising the strength of a weak signal. During the positive half of signal, the reverse bias on the gate decreases. This increases the channel width and hence the drain current. During the negative half-cycle of the signal, the reverse voltage on the gate increases. Consequently, the drain current decreases. The result is the small change in voltage at the gate produces a large change in drain current. These large variations in drain current produce large output across the load R_L. In this way, *JFET* acts as an amplifier.

21.8. Output Characteristics of JFET

The curve between drain current (I_D) and drain-source voltage (V_{DS}) of a *JFET* at constant gate-source voltage (V_{GS}) is known as *Output characteristics of JFET*. Fig. 21.7 shows the circuit

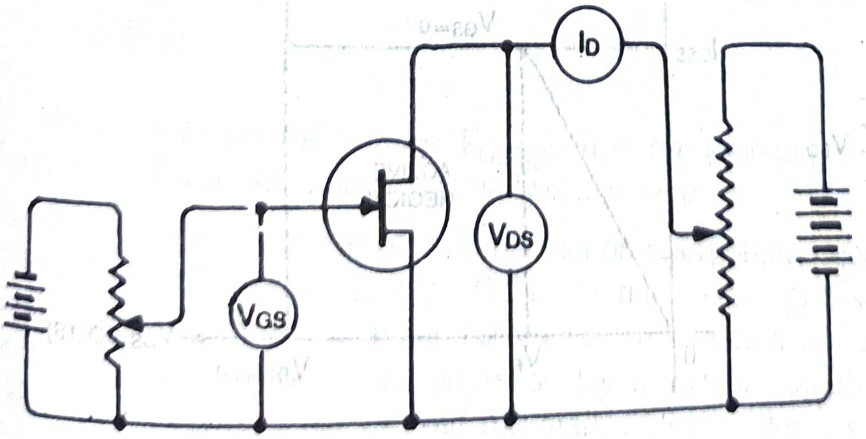


Fig. 21.7.

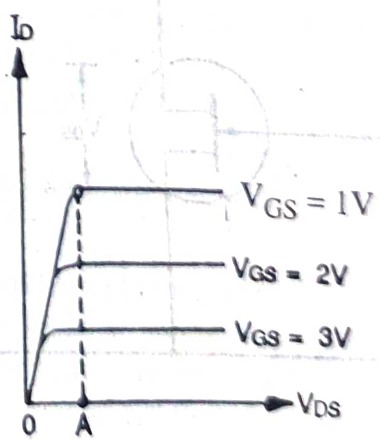


Fig. 21.8.

for determining the output characteristics of *JFET*. Keeping V_{GS} fixed at some value, say 1V, the drain-source voltage is changed in steps. Corresponding to each value of V_{DS}, the drain current

21.18. Metal Oxide Semiconductor FET (MOSFET)

Metal oxide semiconductor field effect transistor is an important semi-conductor device and is widely used in many circuit applications. The input impedance of a *MOSFET* is much more than that of a *JFET* because of very small gate leakage current. The *MOSFET* can be used in any of the circuits covered for the *JFET*. Therefore, all the equations apply equally well to the *MOSFET* and *JFET* in amplifier connections.

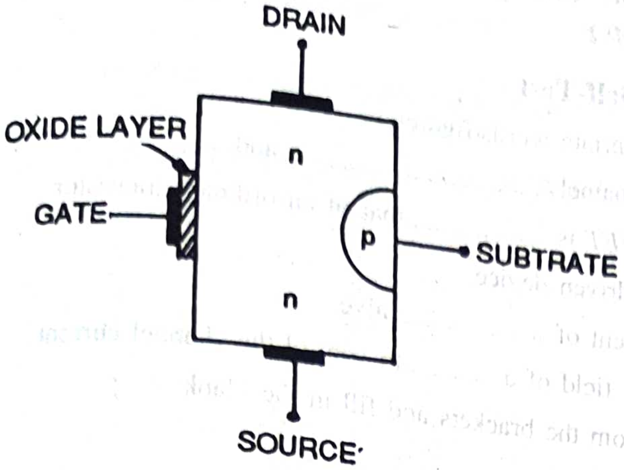
Constructional details Fig. 21.26 *(i)* shows the constructional details of *n*-channel *MOSFET*. It is similar to *JFET* except with the following modifications :

(i) There is only a single *p*-region. This region is called subtrate.

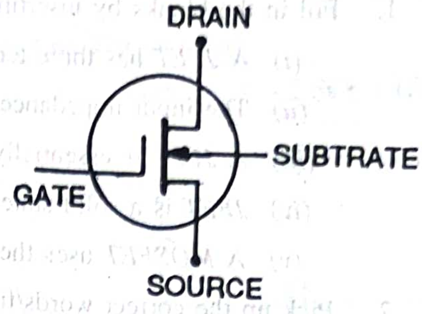
(ii) A thin layer of metal oxide (usually silicon dioxide) is deposited over the left side of the channel. A metallic *gate* is deposited over the oxide layer. As silicon dioxide is an insulator, therefore, gate is insulated from the channel. For this reason, *MOSFET* is sometimes called *insulated gate FET*.

(iii) Like *JFET*, a *MOSFET* has three terminals *viz.* source, gate and drain.

Fig. 21.26 *(ii)* shows the schematic symbol of *n*-channel *MOSFET*.



(i)



(ii)

Fig. 21.26

21.19. Working Principle of MOSFET

Fig. 21.27 shows the circuit of *MOSFET*. Instead of gate diode as in *JFET*, here gate is formed as a small capacitor. One plate of this capacitor is the gate and the other plate is the channel with metal oxide as the dielectric. When negative voltage is applied to the gate, electrons accumulate on it. These electrons *repel the conduction band electrons in the *n* -channel. Therefore, lesser number of conduction electrons are made available for current conduction through the channel. The greater the negative voltage on the gate, the lesser is the current conduction from source to drain. If the gate is given positive voltage, more electrons are made available in the *n*-channel. Consequently, current from source to drain increases. The following points may be noted:

(i) In a *MOSFET*, the source to drain current is controlled by the electric field of capacitor formed at the gate.

(ii) Unlike the *JFET*, a *MOSFET* has no gate diode. This makes it possible to operate the device with positive or negative gate voltage.

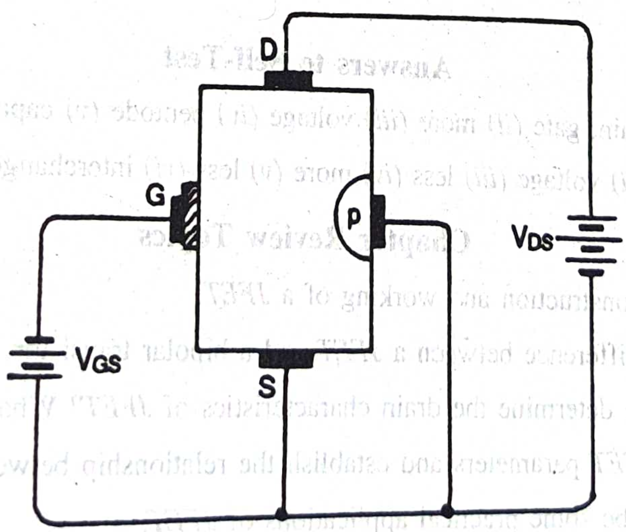


Fig. 21.27

* If one plate of capacitor is negatively charged, it induces positive charge on the other plate.

(iii) As the gate forms a capacitor, therefore, negligible gate current flows whether positive or negative voltage is applied to the gate. Consequently, the input impedance of *MOSFET* is very high, ranging from 10,000$M\Omega$ to 10,000,00$M\Omega$.