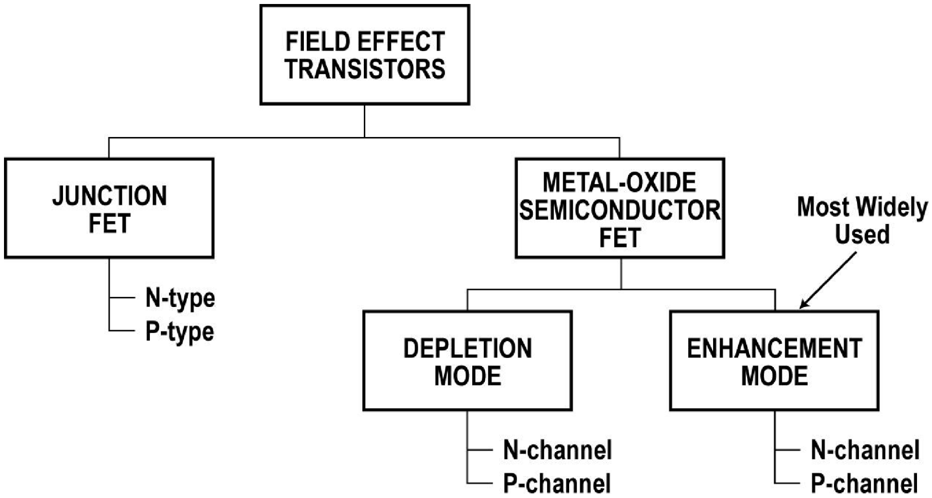
Review of MOSFETs

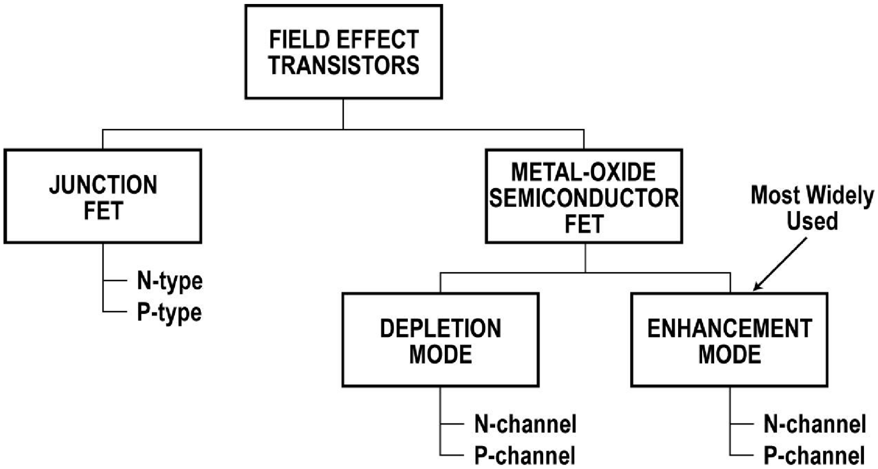
Field Effect Transistors



There are two main types of field effect transistors: junction FETs and MOSFETs.

Junction FETs are no longer widely used as they have been superceded by MOSFETs. Their primary usage is in high input impedance amplifiers both discrete and integrated and some types of microwave amplifiers.

MOSFET Types

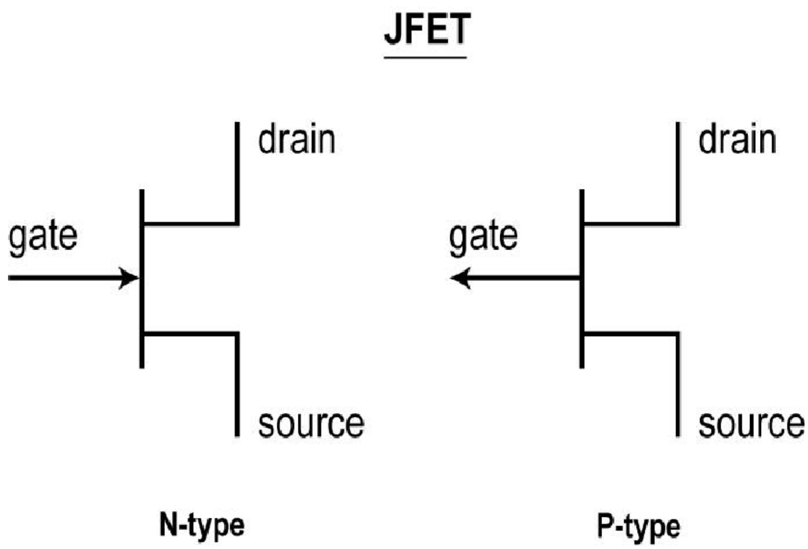


The two types of MOSFETs are the depletion mode and enhancement mode. The enhancement mode type is the most dominant.

All FETs are made as either P-channel or N-channel types where the dominant current carriers are either holes or electrons.

While both P and N channel types are used, N-channel devices are perhaps more common especially in discrete component circuits.

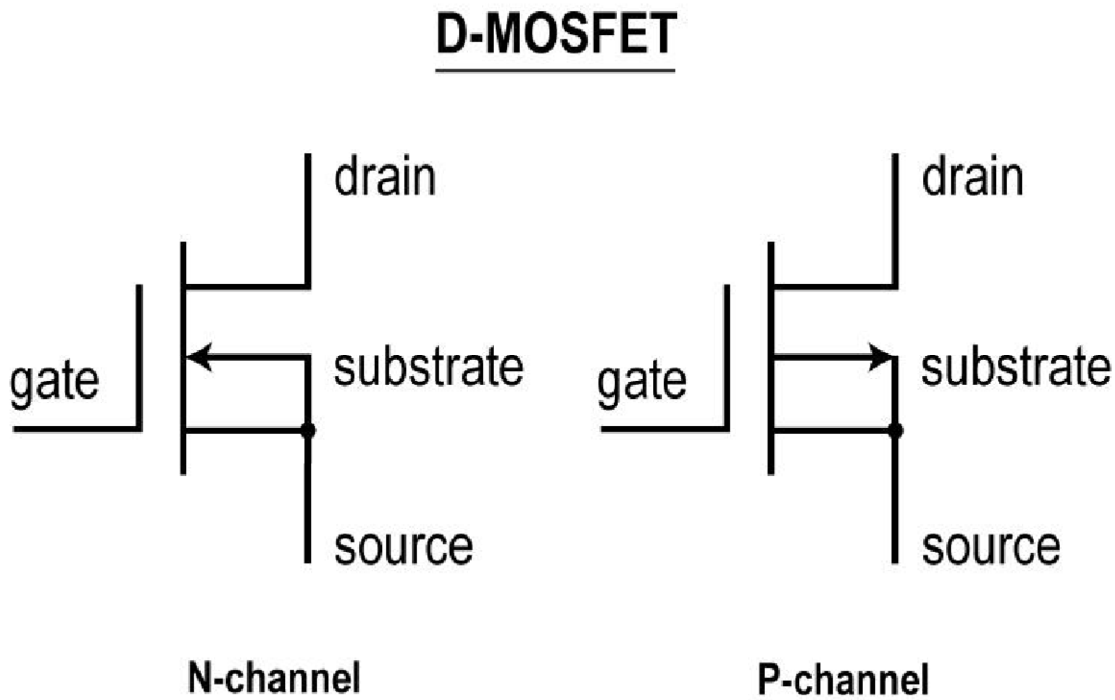
MOSFET Symbols: JFET



The most commonly used schematic symbols for FETs are shown over the next few pages.

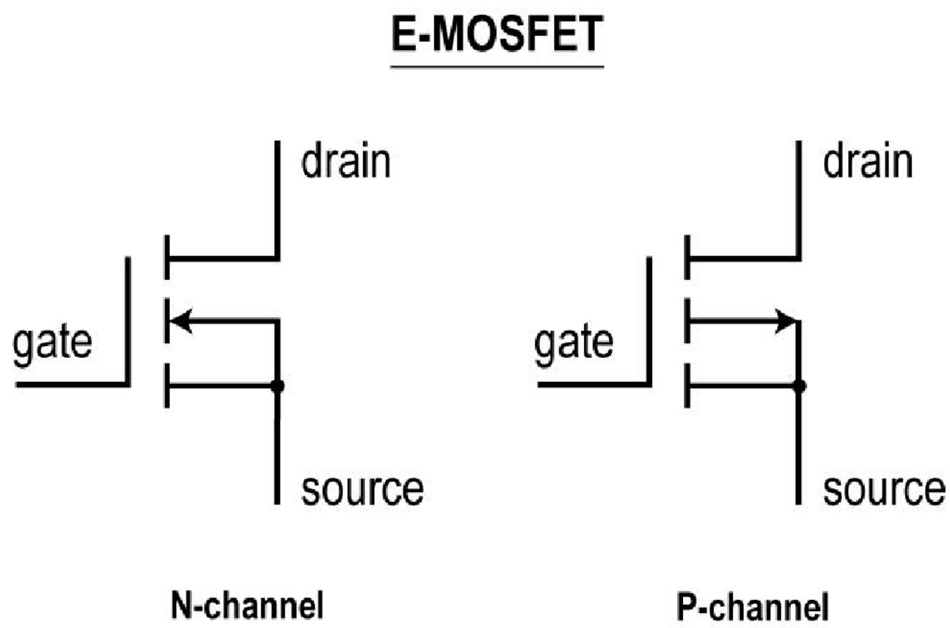
This figure shows the JFET symbol for both N and P channels types.

MOSFET Symbols: Depletion Mode



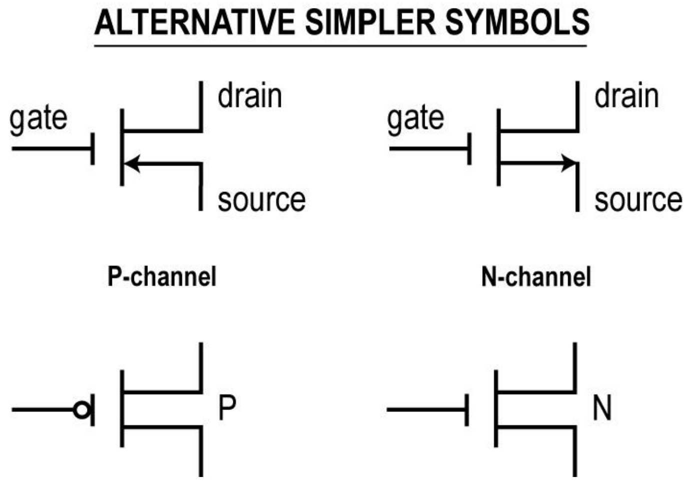
The figure on the left shows the N channel depletion-mode or D-MOSFET symbol. The one on the right shows the P channel versions.

MOSFET Symbols: Enhancement Mode



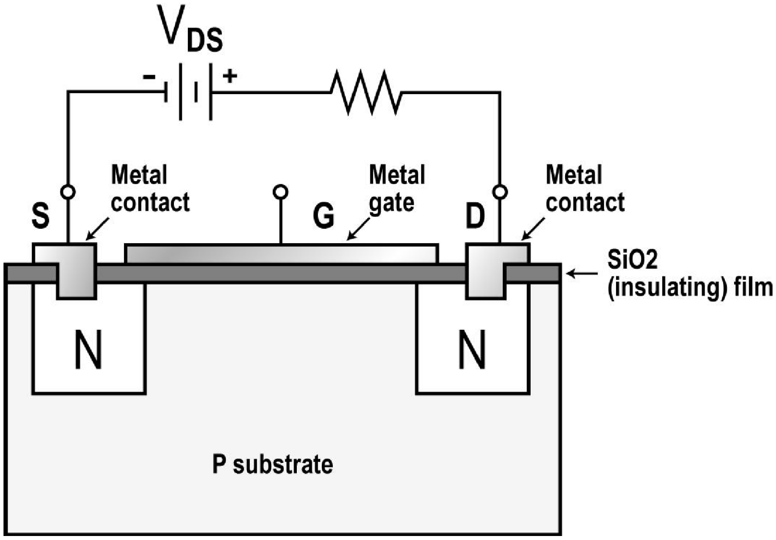
This figure shows the enhancement-mode or E-MOSFETs symbols in N and P channel form.

MOSFET Symbols: Simplified Symbols



The symbols of the depletion mode and enhancement mode are complex to draw and take up more space. The simplified symbols shown here are easier and faster to draw. These symbols are not standardized but are used by manufacturers to draw large complex circuits. The top figures are the D-MOSFET and the E-MOSFET is shown on the bottom.

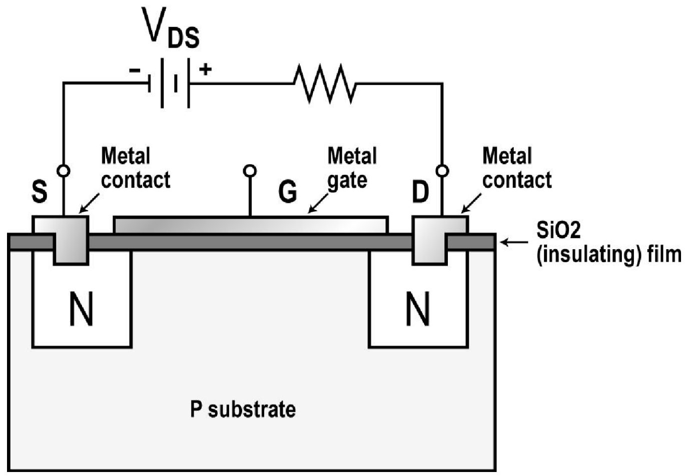
MOSFET Construction



This is a cross sectional view of the silicon chip showing construction of an N-channel enhancement mode MOSFET and the major elements involved.

This N-channel MOSFET is made on a base or substrate of P-type material into which has been diffused or implanted two N-type areas that make up the source (S) and drain (D) elements of the device.

MOSFET Construction: Layering

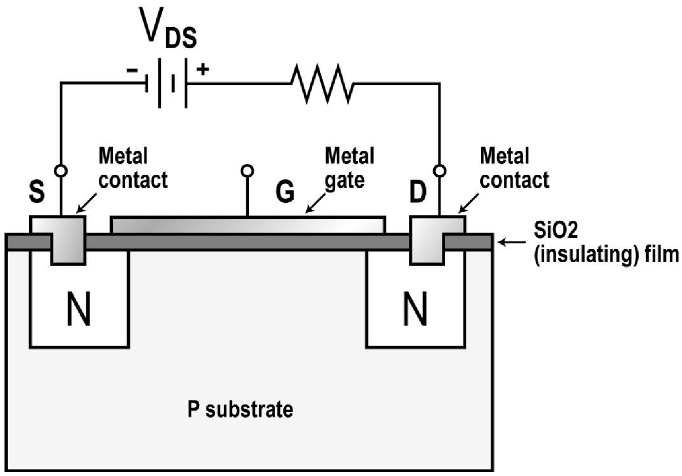


A very thin layer of silicon dioxide, a glass insulator, is deposited on top of the P-type substrate.

A gate (G) made of metal such as aluminum or highly conductive silicon is deposited on top of the silicon dioxide.

The name metal oxide semiconductor (MOS) is derived from this layering of materials. They are sometimes referred to as an insulated gate FET (IGFET).

MOSFET Operation: Source and Drain

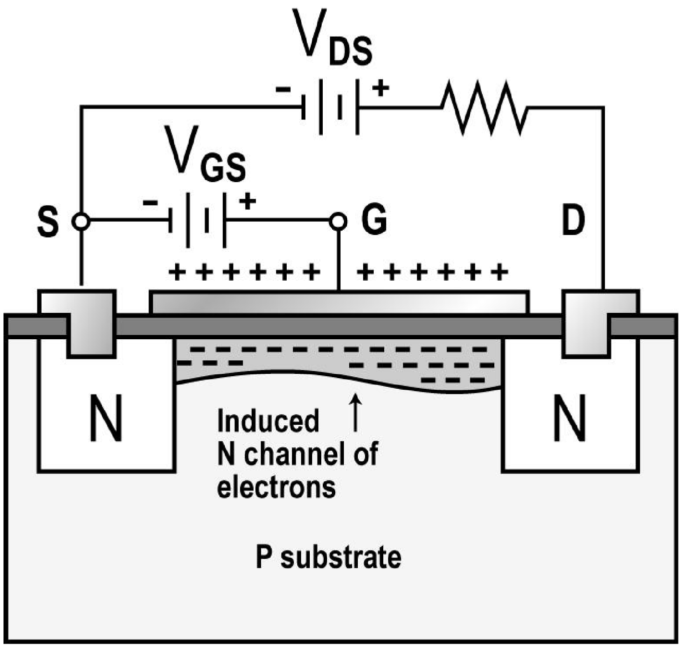


A voltage is applied between the source and drain (V_{DS}). The drain is positive for an N-channel device. A resistor or other current limiting element or load is typically connected in series with the DC voltage.

The substrate is normally connected to the source (S).

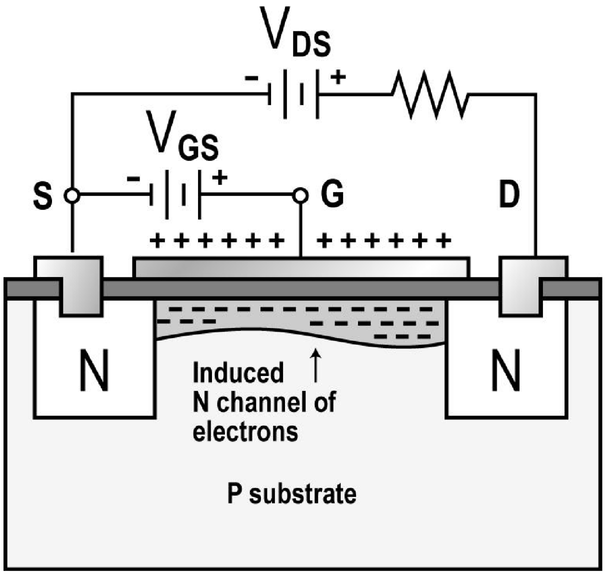
No current flows from the source to the drain because the source and drain form reverse biased PN junctions with the substrate.

MOSFET Operation: Gate-Source Voltage



To make the device conduct, a positive voltage is applied between the gate and the source. When this gate-source voltage V_{GS} is higher than the threshold voltage V_T, current flows between the source and the drain.

MOSFET Operation

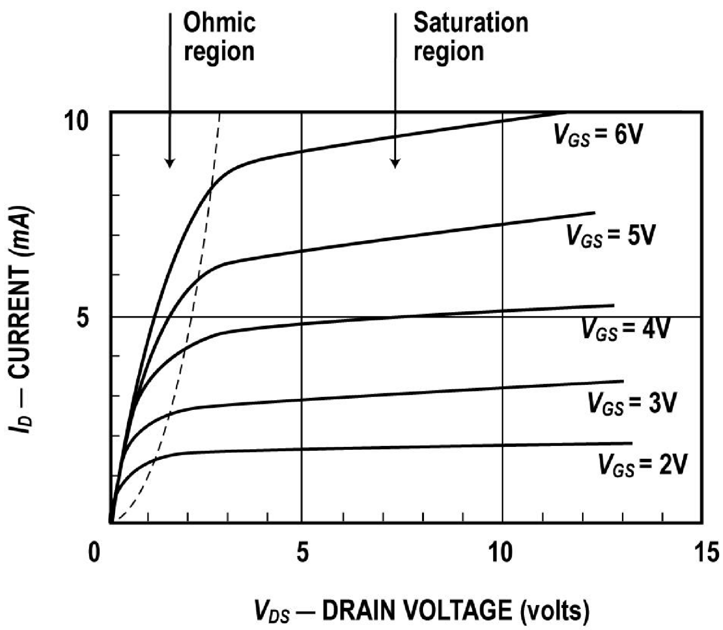


The positive voltage on the gate attracts electrons from the substrate and pulls them up under the gate. This forms a conductive region between the source and drain. In effect, the P-type substrate is inverted to N-type by the concentration of electrons under the gate. The induced channel carries electrons from source to drain and through the load.

MOSFET Characteristics: Drain Current

The source-to-drain current, called the drain current I_D, varies with different source-drain voltages (V_{DS}) for different gate-source voltages V_{GS}.

For a given V_{GS}, the drain current increases as the V_{DS} increases. This is called the ohmic region of the characteristics since the current follows standard ohms law theory. The ohmic region is to the left of the dashed curve.

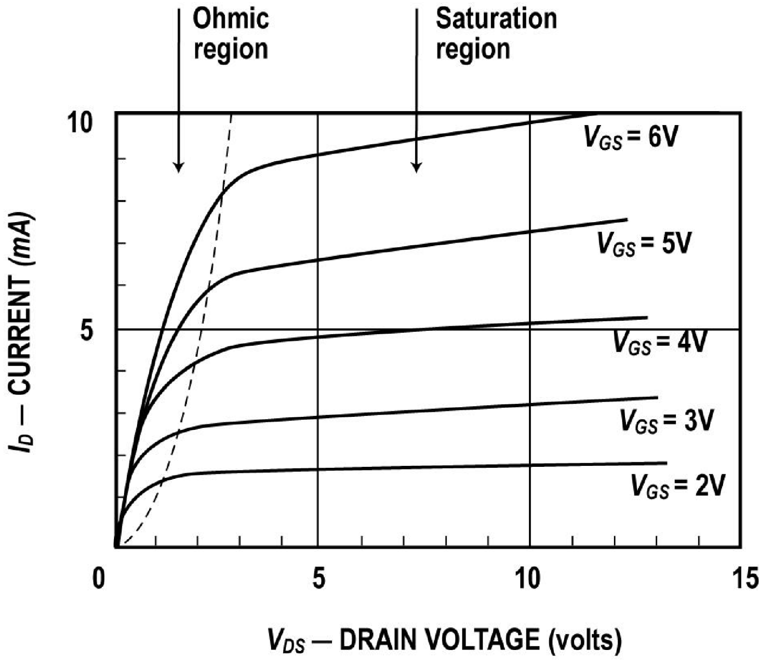


MOSFET Characteristics: Pinch Off Voltage

At some V_{DS} value, I_D stops increasing and flattens out. This point occurs where $V_{DS} = V_{GS} – V_T$. This is called the pinch off voltage. At values of V_{DS} beyond this point the MOSFET is said to be in saturation.

The dashed line in the figure is a plot of all the pinch off values with each value of V_{GS}.

The area to the right of the dashed line is called the saturation region.



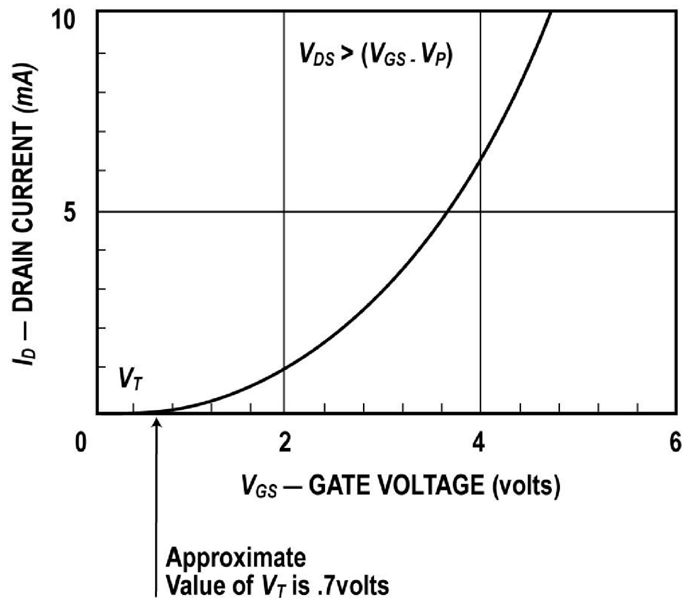
MOSFET Characteristics: I_D Calculation

I_D varies with V_{GS}. Below the threshold voltage V_T, no I_D flows. When the threshold has passed, I_D increases with V_{GS} in a parabolic or square law response.

I_D can be calculated with the expression

$$I_D = 0.5\beta(V_{GS} – V_T)^2$$

The value of β is a function of the geometry of the transistor and has a value in the range of 0.5×10^{-3}.



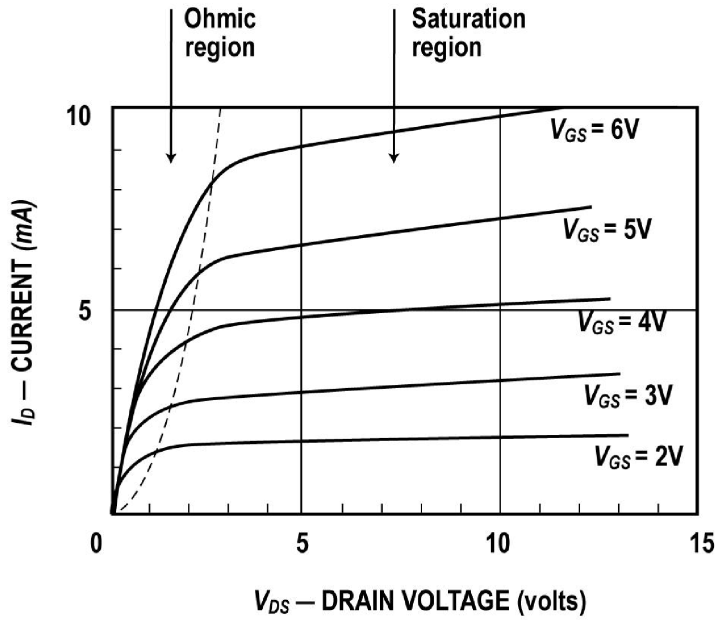
Regions of Operation

MOSFETs have three basic operating regions: cut-off, saturation, and ohmic.

When V_{GS} is less than V_T, the device is cut off and no I_D flows.

The ohmic range is to the left of the dashed curve. In this region, the device acts like a voltage controlled resistor as the source-to-drain resistance varies with V_{GS}.

In the saturation region to the right of the dashed curve, I_D is a function of V_{GS}. For linear operation, the device is biased into this region.



Two Types of MOSFET Operation

A transistor is used in one of two ways: amplification or switching.

When a MOSFET is operated alternately in the ohmic and cut-off regions, it is a switch.

When the MOSFET is biased into the saturation region, the device is used for linear amplification.

Test your knowledge

Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Common Electronic Circuits
Knowledge Probe 2
Review of MOSFETs

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