The Metal Oxide FET – MOSFET

As well as the Junction Field Effect Transistor (JFET), there is another type of Field Effect Transistor available whose Gate input is electrically insulated from the main current carrying channel and is therefore called an Insulated Gate Field Effect Transistor or IGFET. The most common type of insulated gate FET which is used in many different types of electronic circuits is called the Metal Oxide Semiconductor Field Effect Transistor or MOSFET for short.

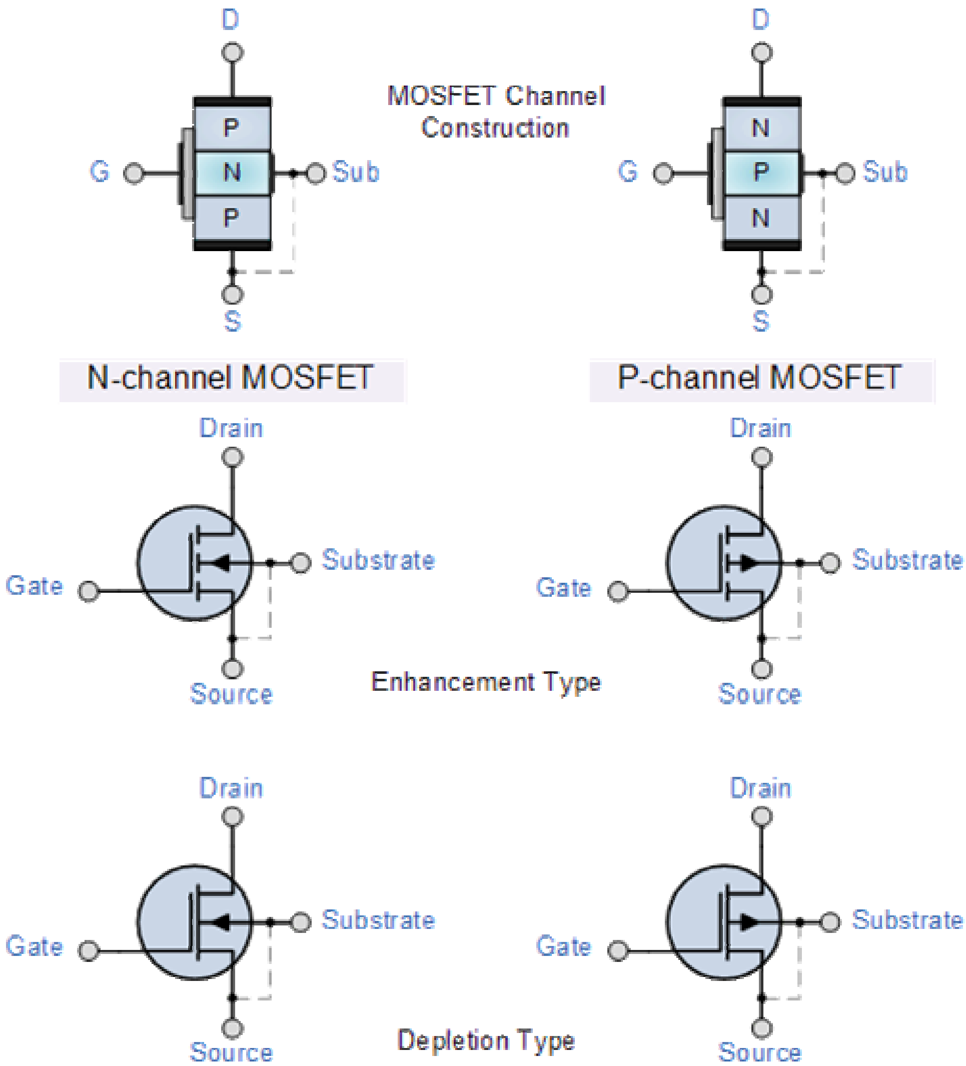
The IGFET or MOSFET is a voltage controlled field effect transistor that differs from a JFET in that it has a "Metal Oxide" Gate electrode which is electrically insulated from the main semiconductor N-channel or P-channel by a thin layer of insulating material usually silicon dioxide (commonly known as glass). This insulated metal gate electrode can be thought of as one plate of a capacitor. The isolation of the controlling Gate makes the input resistance of the MOSFET extremely high in the Mega-ohms (MΩ) region thereby making it almost infinite.

As the Gate terminal is isolated from the main current carrying channel "NO current flows into the gate" and just like the JFET, the MOSFET also acts like a voltage controlled resistor were the current flowing through the main channel between the Drain and Source is proportional to the input voltage. Also like the JFET, this very high input resistance can easily accumulate large amounts of static charge resulting in the MOSFET becoming easily damaged unless carefully handled or protected.

Like the previous JFET tutorial, MOSFETs are three terminal devices with a Gate, Drain and Source and both P-channel (PMOS) and N-channel (NMOS) MOSFETs are available. The main difference this time is that MOSFETs are available in two basic forms:

1. Depletion Type - the transistor requires the Gate-Source voltage, (VGS) to switch the device "OFF". The depletion mode MOSFET is equivalent to a "Normally Closed" switch.

2. Enhancement Type - the transistor requires a Gate-Source voltage, (VGS) to switch the device "ON". The enhancement mode MOSFET is equivalent to a "Normally Open" switch.

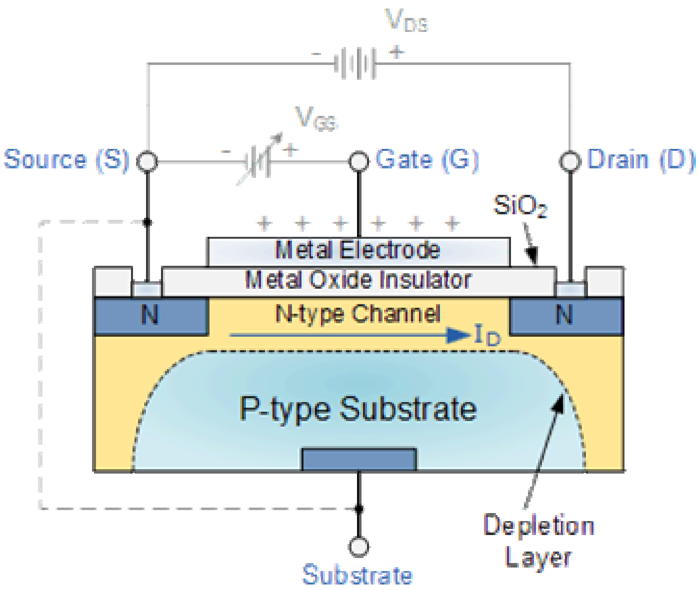


The symbols and basic construction for both configurations of MOSFETs are shown here.

The four MOSFET symbols show an additional terminal called the Substrate and is not normally used as either an input or an output connection but instead it is used for grounding the substrate. It connects to the main semiconductive channel through a diode junction to the body or metal tab of the MOSFET.

In discrete type MOSFETs, this substrate lead is connected internally to the source terminal. When this is the case, as in enhancement type, it is omitted from the symbol. The line between the drain and source connections represents the semiconductive channel. If this is a solid unbroken line then this represents a "Depletion" (normally closed) type MOSFET and if the channel line is shown dotted or broken it is an "Enhancement" (normally open) type MOSFET. The direction of the arrow indicates either a P-channel or an N-channel device.

Basic MOSFET Structure and Symbol



The construction of the Metal Oxide Semiconductor FET is very different to that of the Junction FET. Both the Depletion and Enhancement type MOSFETs use an electrical field produced by a gate voltage to alter the flow of charge carriers, electrons for N-channel or holes for P-channel, through the semiconductive drain-source channel. The gate electrode is placed on top of a very thin insulating layer and there are a pair of small N-type regions just under the drain and source electrodes.

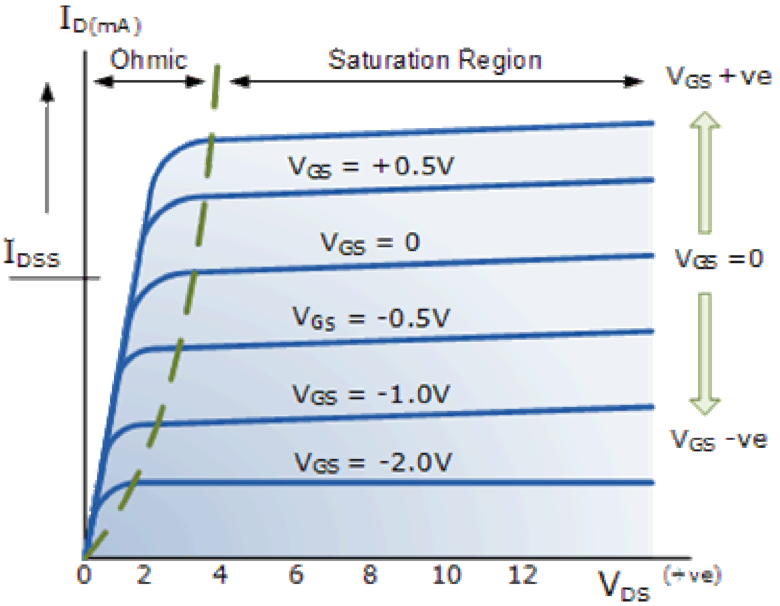
We saw in the previous tutorial, that the gate of a JFET must be biased in such a way as to forward-bias the PN-junction but with a insulated gate MOSFET device no such limitations apply so it is possible to bias the gate of a MOSFET in either polarity, +ve or -ve. This makes MOSFETs especially valuable as electronic switches or to make logic gates because with no bias they are normally non-conducting and this high gate input resistance means that very little or no control current is needed as MOSFETs are voltage controlled devices. Both the P-channel and the N-channel MOSFETs are available in two basic forms, the Enhancement type and the Depletion type.

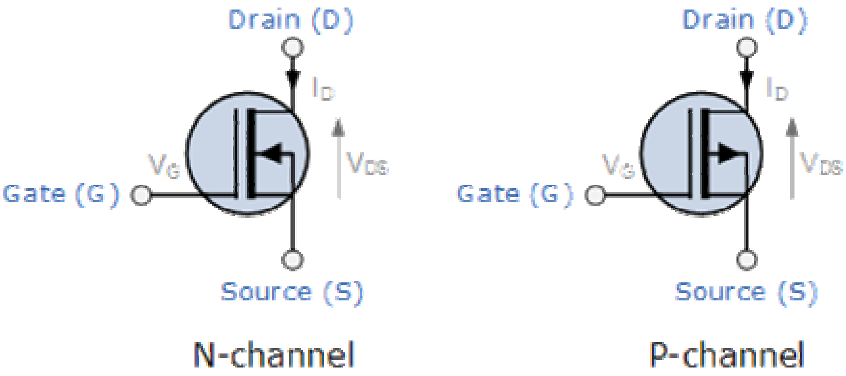
Depletion-mode MOSFET

The Depletion-mode MOSFET, which is less common than the enhancement types is normally switched "ON" without the application of a gate bias voltage making it a "normally-closed" device. However, a gate to source voltage (VGS) will switch the device "OFF". Similar to the JFET types, for an N-channel MOSFET, a "positive" gate voltage widens the channel, increasing the flow of the drain current and decreasing the drain current as the gate voltage goes more negative. In other words, for an N-channel depletion mode MOSFET: +VGS means more electrons and more current. While a -VGS means less electrons and less current. The opposite is also true for the P-channel types. Then the depletion mode MOSFET is equivalent to a "normally-closed" switch.

Depletion-mode N-Channel MOSFET and circuit Symbols

The depletion-mode MOSFET is constructed in a similar way to their JFET transistor counterparts were the drain-source channel is inherently conductive with the electrons and holes already present within the N-type or P-type channel. This doping of the channel produces a conducting path of low resistance between the Drain and Source with zero Gate bias.





Enhancement-mode MOSFET

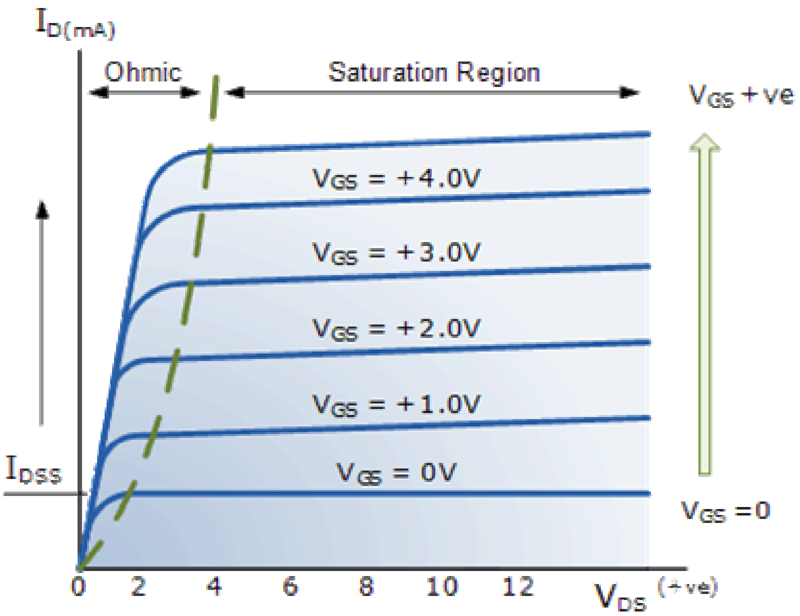
The more common Enhancement-mode MOSFET is the reverse of the depletion-mode type. Here the conducting channel is lightly doped or even undoped making it non-conductive. This results in the device being normally "OFF" when the gate bias voltage is equal to zero.

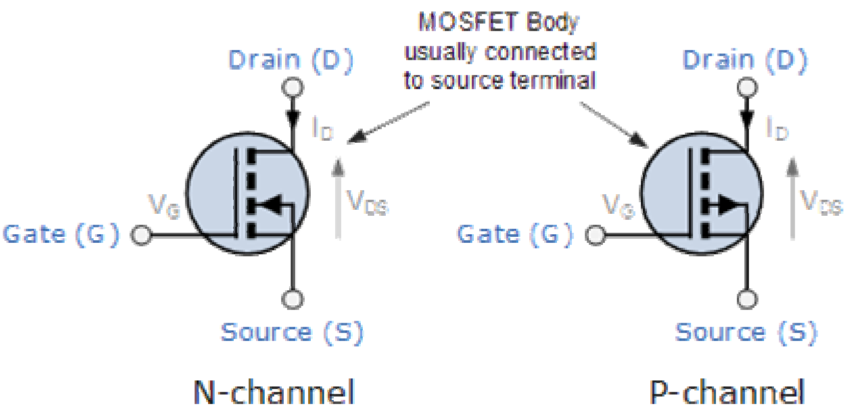
A drain current will only flow when a gate voltage (VGS) is applied to the gate terminal greater than the threshold voltage (VTH) level in which conductance takes place making it a transconductance device. This positive +ve gate voltage pushes away the holes within the channel attracting electrons towards the oxide layer and thereby increasing the thickness of the channel allowing current to flow. This is why this kind of transistor is called an enhancement mode device as the gate voltage enhances the channel.

Increasing this positive gate voltage will cause the channel resistance to decrease further causing an increase in the drain current, ID through the channel. In other words, for an N-channel enhancement mode MOSFET: +VGS turns the transistor "ON", while a zero or -VGS turns the transistor "OFF". Then, the enhancement-mode MOSFET is equivalent to a "normally-open" switch.

Enhancement-mode N-Channel MOSFET and circuit Symbols

Enhancement-mode MOSFETs make excellent electronics switches due to their low "ON" resistance and extremely high "OFF" resistance as well as their infinitely high gate resistance. Enhancement-mode MOSFETs are used in integrated circuits to produce CMOS type Logic Gates and power switching circuits in the form of as PMOS (P-channel) and NMOS (N-channel) gates. CMOS actually stands for Complementary MOS meaning that the logic device has both PMOS and NMOS within its design.





The MOSFET Amplifier

Just like the previous Junction Field Effect transistor, MOSFETs can be used to make single stage class A amplifier circuits with the Enhancement mode N-channel MOSFET common source amplifier being the most popular circuit. The depletion mode MOSFET amplifiers are very similar to the JFET amplifiers, except that the MOSFET has a much higher input impedance. This high input impedance is controlled by the gate biasing resistive network formed by R1 and R2. Also, the output signal for the enhancement mode common source MOSFET amplifier is inverted because when VG is low the transistor is switched "OFF" and VD (Vout) is high. When VG is high the transistor is switched "ON" and VD (Vout) is low as shown.

Enhancement-mode N-Channel MOSFET Amplifier

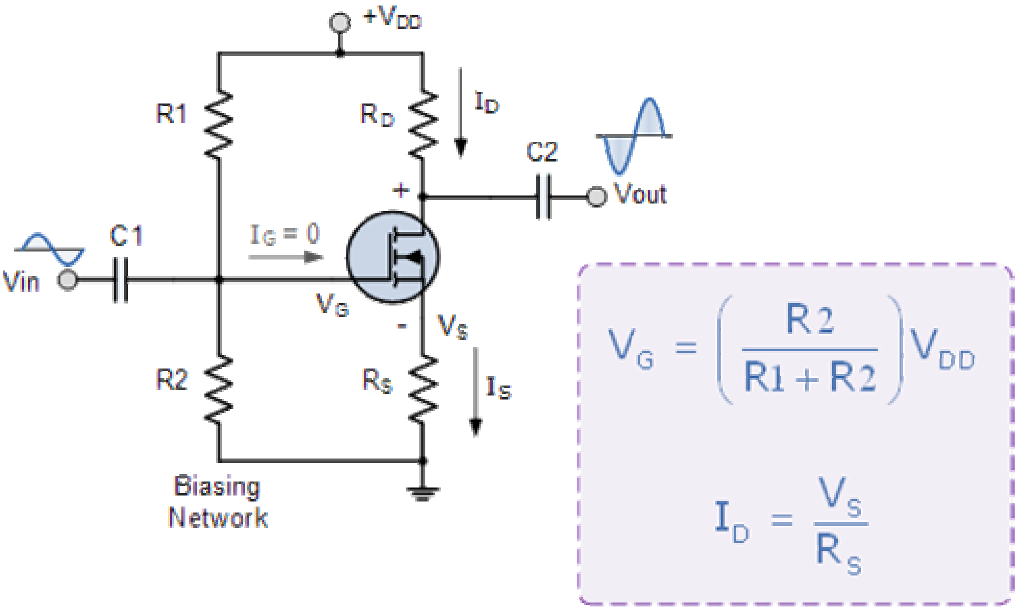
The DC biasing of this common source (CS) MOSFET amplifier circuit is virtually identical to the JFET amplifier. The MOSFET circuit is biased in class A mode by the voltage divider network formed by resistors R1 and R2. The AC input resistance is given as RIN = RG = 1MΩ.

Metal Oxide Semiconductor Field Effect Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The MOSFETs ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then MOSFETs have the ability to operate within three different regions:

1. Cut-off Region - with VGS < Vthreshold the gate-source voltage is lower than the threshold voltage so the transistor is switched "fully-OFF" and IDS = 0, the transistor acts as an open circuit

2. Linear (Ohmic) Region - with VGS > Vthreshold and VDS > VGS the transistor is in its constant resistance region and acts like a variable resistor whose value is determined by the gate voltage, VGS

3. Saturation Region - with VGS > Vthreshold the transistor is in its constant current region and is switched "fully-ON". The current IDS = maximum as the transistor acts as a closed circuit.



MOSFET Summary

The Metal Oxide Semiconductor FET, MOSFET has an extremely high input gate resistance with the current flowing through the channel between the source and drain being controlled by the gate voltage. Because of this high input impedance and gain, MOSFETs can be easily damaged by static electricity if not carefully protected or handled. MOSFETs are ideal for use as electronic switches or as common-source amplifiers as their power consumption is very small. Typical applications for MOSFETs are in Microprocessors, Memories, Calculators and Logic CMOS Gates etc.

Also, notice that a dotted or broken line within the symbol indicates a normally "OFF" enhancement type showing that "NO" current can flow through the channel when zero gate-source voltage VGS is applied. A continuous unbroken line within the symbol indicates a normally "ON" Depletion type showing that current "CAN" flow through the channel with zero gate voltage. For P-channel types the symbols are exactly the same for both types except that the arrow points outwards. This can be summarised in the following switching table.

MOSFET type	V_{GS} = +ve	V_{GS} = 0	V_{GS} = -ve
N-Channel Depletion	ON	ON	OFF
N-Channel Enhancement	ON	OFF	OFF
P-Channel Depletion	OFF	ON	ON
P-Channel Enhancement	OFF	OFF	ON

So for N-channel enhancement type MOSFETs, a positive gate voltage turns "ON" the transistor and with zero gate voltage, the transistor will be "OFF". For a P-channel enhancement type MOSFET, a negative gate voltage will turn "ON" the transistor and with zero gate voltage, the transistor will be "OFF". The voltage point at which the MOSFET starts to pass current through the channel is determined by the threshold voltage VTH of the device and is typical around 0.5V to 0.7V for an N-channel device and -0.5V to -0.8V for a P-channel device.

In the next tutorial about Field Effect Transistors instead of using the transistor as an amplifying device, we will look at the operation of the transistor in its saturation and cut-off regions when used as a solid-state switch. Field effect transistor switches are used in many applications to switch a DC current "ON" or "OFF" such as LED's which require only a few milliamps at low DC voltages, or motors which require higher currents at higher voltages.

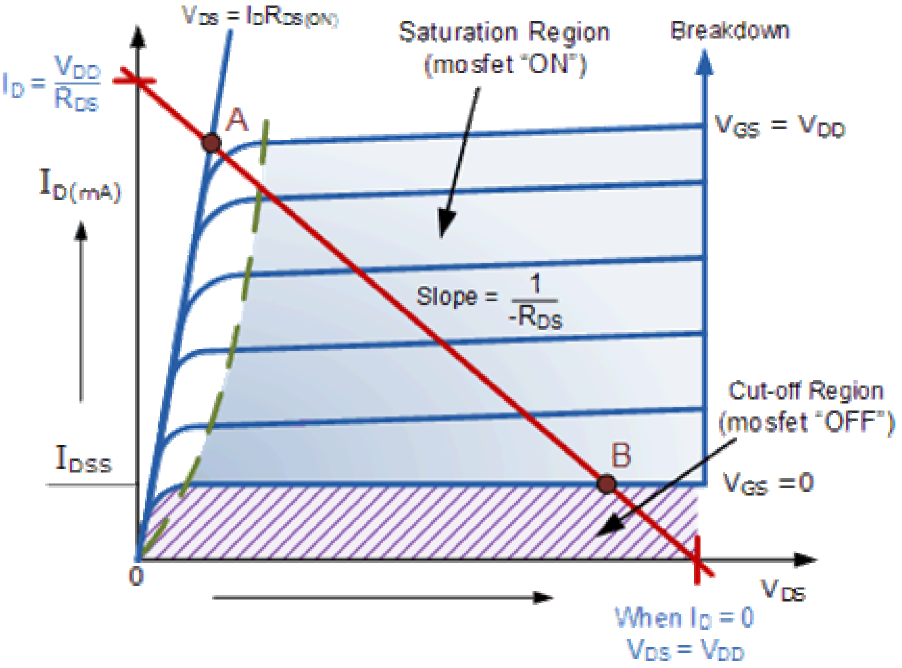
The MOSFET as a Switch

We saw previously, that the N-channel, Enhancement-mode MOSFET operates using a positive input voltage and has an extremely high input resistance (almost infinite) making it possible to interface with nearly any logic gate or driver capable of producing a positive output. Also, due to this very high input (Gate) resistance we can parallel together many different MOSFETs until we achieve the current handling limit required. While connecting together various MOSFETs may enable us to switch high currents or high voltage loads, doing so becomes expensive and impractical in both components and circuit board space. To overcome this problem Power Field Effect Transistors or Power FET's were developed.

We now know that there are two main differences between field effect transistors, depletion-mode only for JFET's and both enhancement-mode and depletion-mode for MOSFETs. In this tutorial we will look at using the Enhancement-mode MOSFET as a Switch as these transistors require a positive gate voltage to turn "ON" and a zero voltage to turn "OFF" making them easily understood as switches and also easy to interface with logic gates.

The operation of the enhancement-mode MOSFET can best be described using its I-V characteristics curves shown below. When the input voltage, (VIN) to the gate of the transistor is zero, the MOSFET conducts virtually no current and the output voltage, (VOUT) is equal to the supply voltage VDD. So the MOSFET is "fully-OFF" and in its "cut-off" region.

MOSFET Characteristics Curves



The minimum ON-state gate voltage required to ensure that the MOSFET remains fully-ON when carrying the selected drain current can be determined from the V-I transfer curves above. When VIN is HIGH or equal to VDD, the MOSFET Q-point moves to point A along the load line.

The drain current ID increases to its maximum value, due to a reduction in the channel resistance. ID becomes a constant value independent of VDD, and is dependent only on VGS. Therefore, the transistor behaves like a closed switch but the channel ON-resistance does not reduce fully to zero due to its RDS (on) value, but gets very small.

Likewise, when VIN is LOW or reduced to zero, the MOSFET Q-point moves from point A to point B along the load line. The channel resistance is very high so the transistor acts like an open circuit and no current flows through the channel.

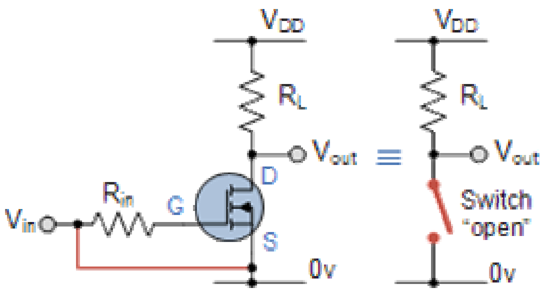
So if the gate voltage of the MOSFET toggles between two values, HIGH and LOW the MOSFET will behave as a "single-pole single-throw" (SPST) solid state switch and this action is defined as:

1. Cut-off Region:

Here the operating conditions of the transistor are zero input gate voltage (VIN), zero drain current ID and output voltage VDS = VDD Therefore the MOSFET is switched "Fully-OFF".

Cut-off Characteristics

- The input and Gate are grounded (0v)
- Gate-source voltage less than threshold voltage VGS < VTH
- MOSFET is "fully-OFF" (Cut-off region)
- No Drain current flows (ID = 0)
- VOUT = VDS = VDD = "1"
- MOSFET operates as an "open switch"



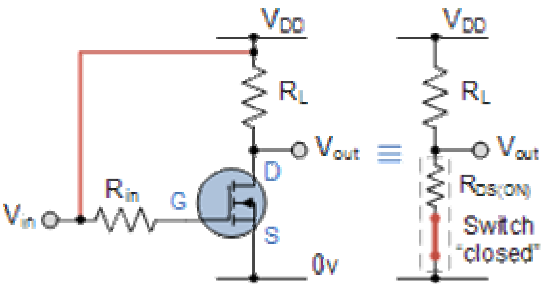
Then we can define the "cut-off region" or "OFF mode" of a MOSFET switch as being, gate voltage, VGS < VTH and ID = 0. For a P-channel MOSFET, the gate potential must be negative.

2. Saturation Region

In the saturation or linear region, the transistor will be biased so that the maximum amount of gate voltage is applied to the device which results in the channel resistance RDS(on) being as small as possible with maximum drain current flowing through the MOSFET switch. Therefore the MOSFET is switched "Fully-ON".

Saturation Characteristics

- The input and Gate are connected to VDD
- Gate-source voltage is much greater than threshold voltage VGS > VTH
- MOSFET is "fully-ON" (saturation region)
- Max Drain current flows (ID = VDD / RL)
- VDS = 0V (ideal saturation)
- Min channel resistance RDS(on) < 0.1Ω
- VOUT = VDS = 0.2V (RDS.ID)
- MOSFET operates as a "closed switch"



Then we can define the "saturation region" or "ON mode" of a MOSFET switch as gate-source voltage, VGS > VTH and ID = Maximum. For a P-channel MOSFET, the gate potential must be positive.

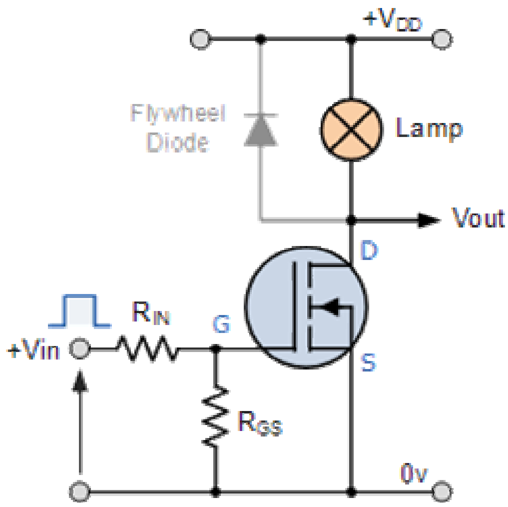
By applying a suitable drive voltage to the gate of an FET, the resistance of the drain-source channel, RDS(on) can be varied from an "OFF-resistance" of many hundreds of kΩ's, effectively an open circuit, to an "ON-resistance" of less than 1Ω, effectively a short circuit. We can also drive the MOSFET to turn "ON" faster or slower, or pass high or low currents. This ability to turn the power MOSFET "ON" and "OFF" allows the device to be used as a very efficient switch with switching speeds much faster than standard bipolar junction transistors.

An example of using the MOSFET as a switch

In this circuit arrangement an Enhancement-mode N-channel MOSFET is being used to switch a simple lamp "ON" and "OFF" (could also be an LED). The gate input voltage VGS is taken to an appropriate positive voltage level to turn the device and therefore the lamp either fully "ON", (VGS = +ve) or at a zero voltage level that turns the device fully "OFF", (VGS = 0).

If the resistive load of the lamp was to be replaced by an inductive load such as a coil, solenoid or relay a "flywheel diode" would be required in parallel with the load to protect the MOSFET from any self generated back-emf.

Above shows a very simple circuit for switching a resistive load such as a lamp or LED. But when using power MOSFETs to switch either inductive or capacitive loads some form of protection is required to prevent the MOSFET device from becoming damaged. Driving an inductive load has the opposite effect from driving a capacitive load. For example, a capacitor without an electrical charge is a short circuit, resulting in a high "inrush" of current and when we remove the voltage from an inductive load we have a large reverse voltage build up as the magnetic field collapses, resulting in an induced back-emf in the windings of the inductor.



For the power MOSFET to operate as an analogue switching device, it needs to be switched between its "Cut-off Region" where VGS = 0 and its "Saturation Region" were VGS(on) = +ve. The power dissipated in the MOSFET (PD) depends upon the current flowing through the channel ID at saturation and also the "ON-resistance" of the channel given as RDS(on). For example.

Example No1

Lets assume that the lamp is rated at 6v, 24W and is fully "ON", the standard MOSFET has a channel "ON-resistance" (RDS(on)) value of 0.1ohms. Calculate the power dissipated in the MOSFET switch.

The current flowing through the lamp is calculated as:

$$P = V \times I_D$$

$$\therefore I_D = \frac{P}{V} = \frac{24}{6} = 4.0\,\text{amps}$$

Then the power dissipated in the MOSFET will be given as:

$$P_D = I_D^2 \times R_{DS}$$

$$\therefore P_D = 4^2 \times 0.1 = 1.6\ \text{watts}$$

You may think, well so what!, but when using the MOSFET as a switch to control DC motors or high inrush current devices the "ON" channel resistance (RDS(on)) is very important. For example, MOSFETs that control DC motors, are subjected to a high in-rush current as the motor first begins to rotate as the starting current is only limited by the resistance of the motors windings. Then a high RDS(on) channel resistance value would simply result in large amounts of power being dissipated and wasted within the MOSFET itself resulting in an excessive temperature rise, and which in turn could result in the MOSFET becoming very hot and damaged due to a thermal overload.

A lower value RDS(on) on the other hand, is also a desirable parameter as it helps to reduce the channels effective saturation voltage (VDS(sat) = ID x RDS(on)) across the MOSFET. Power MOSFETs generally have a RDS(on) value of less than 0.01Ω.

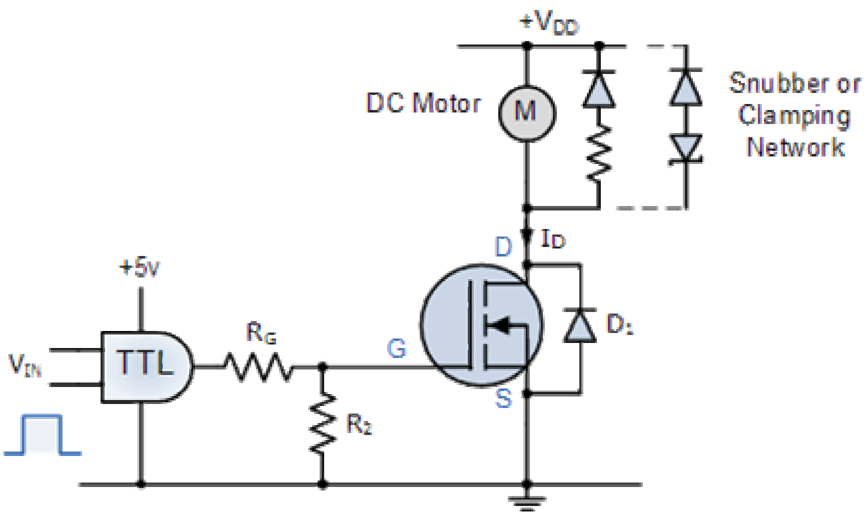
One of the main limitation of a MOSFET is the maximum current it can handle. So the RDS(on) parameter is an important guide to the switching efficiency of the MOSFET and is simply the ratio of VDS / ID when the transistor is turned "ON". When using a MOSFET or any type of field effect transistor for that matter as a solid-state switching device it is always advisable to select ones that have a very low RDS(on) value or at least mount them onto a suitable heatsink to help reduce any thermal runaway and damage. Power MOSFETs used as a switch generally have surge-current protection built into their design, but for high-current applications the bipolar junction transistor is a better choice.

Power MOSFET Motor Control

Because of the extremely high input or gate resistance that the MOSFET has, its very fast switching speeds and the ease at which they can be driven makes them ideal to interface with op-amps or standard logic gates. However, care must be taken to ensure that the gate-source input voltage is correctly chosen because when using the MOSFET as a switch the device must obtain a low RDS(on) channel resistance in proportion to this input gate voltage. Low threshold type MOSFETs may not switch "ON" until a least 3V or 4V has been applied to its gate and if the output from the logic gate is only +5V logic it may be insufficient to fully drive the MOSFET into saturation. Using lower threshold MOSFETs designed for interfacing with TTL and CMOS logic gates that have thresholds as low as 1.5V to 2.0V are available.

Power MOSFETs can be used to control the movement of DC motors or brushless stepper motors directly from computer logic or by using pulse-width modulation (PWM) type controllers. As a DC motor offers high starting torque and which is also proportional to the armature current, MOSFET switches along with a PWM can be used as a very good speed controller that would provide smooth and quiet motor operation.

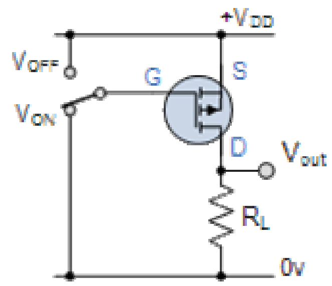
Simple Power MOSFET Motor Controller



As the motor load is inductive, a simple flywheel diode is connected across the inductive load to dissipate any back emf generated by the motor when the MOSFET turns it "OFF". A clamping network formed by a zener diode in series with the diode can also be used to allow for faster switching and better control of the peak reverse voltage and drop-out time. An additional silicon or zener diode D1 can also be placed across the channel of a MOSFET switch when using inductive loads, such as motors, solenoids, etc, for suppressing overvoltage switching transients and noise giving extra protection to the MOSFET switch if required. Resistor R2 is used as a pull-down resistor to help pull the TTL output voltage down to 0V when the MOSFET is switched "OFF".

P-channel MOSFET Switch

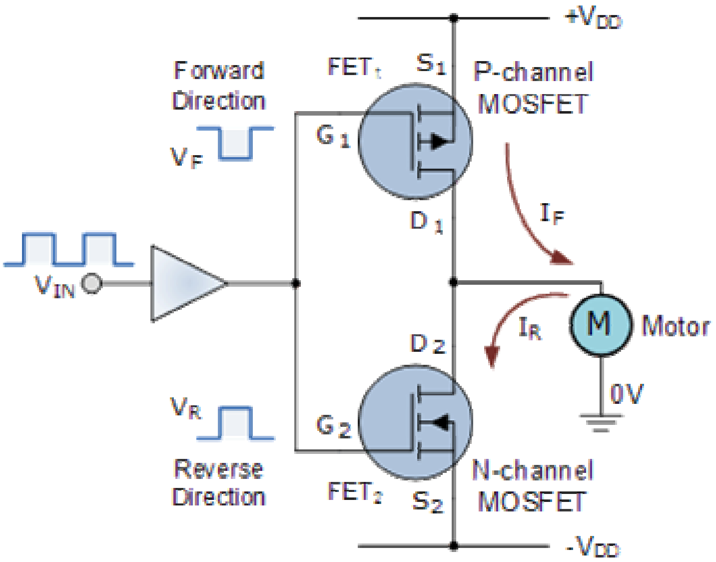
Thus far we have looked at the N-channel MOSFET as a switch were the MOSFET is placed between
P-channel MOSFET Switch the load and the ground. This also allows the gate drive or switching signal to be referenced to ground (low-side switching). But in some applications we require the use of P-channel enhancement-mode MOSFET were the load is connected directly to ground and the MOSFET switch is connected between the load and the positive supply rail (high-side switching) as we do with PNP transistors.



In a P-channel device the conventional flow of drain current is in the negative direction so a negative gate-source voltage is applied to switch the transistor "ON". This is achieved because the P-channel MOSFET is "upside down" with its source terminal tied to the positive supply +VDD. Then when the switch goes LOW, the MOSFET turns "ON" and when the switch goes HIGH the MOSFET turns "OFF".

This upside down connection of a P-channel enhancement mode MOSFET switch allows us to connect it in series with a N-channel enhancement mode MOSFET to produce a complementary or CMOS switching device as shown across a dual supply.

Complementary MOSFET Motor Controller



The two MOSFETs are configured to produce a bi-directional switch from a dual supply with the motor connected between the common drain connection and ground reference. When the input is LOW the P-channel MOSFET is switched-ON as its gate-source junction is negatively biased so the motor rotates in one direction. Only the positive +VDD supply rail is used to drive the motor.

When the input is HIGH, the P-channel device switches-OFF and the N-channel device switches-ON as its gate-source junction is positively biased. The motor now rotates in the opposite direction because the motors terminal voltage has been reversed as it is now supplied by the negative -VDD supply rail. Then the P-channel MOSFET is used to switch the positive supply to the motor for forward direction (high-side switching) while the N-channel MOSFET is used to switch the negative supply to the motor for reverse direction (low-side switching).

There are a variety of configurations for driving the two MOSFETs with many different applications. Both the P-channel and the N-channel devices can be driven by a single gate drive IC as shown. However, to avoid cross conduction with both MOSFETs conducting at the same time across the two polarities of the dual supply, fast switching devices are required to provide some time difference between them turning "OFF" and the other turning "ON". One way to overcome this problem is to drive both MOSFETs gates separately. This then produces a third option of "STOP" to the motor when both MOSFETs are "OFF".

MOSFET 1	MOSFET 2	Motor Function
OFF	OFF	Motor Stopped (OFF)
ON	OFF	Motor Rotates Forward
OFF	ON	Motor Rotates Reverse
ON	ON	NOT ALLOWED

It is important that no other combination of inputs are allowed as this may cause the power supply to be shorted out, ie both MOSFETs, FET1 and FET2 switched "ON" at the same time, (fuse = bang!).

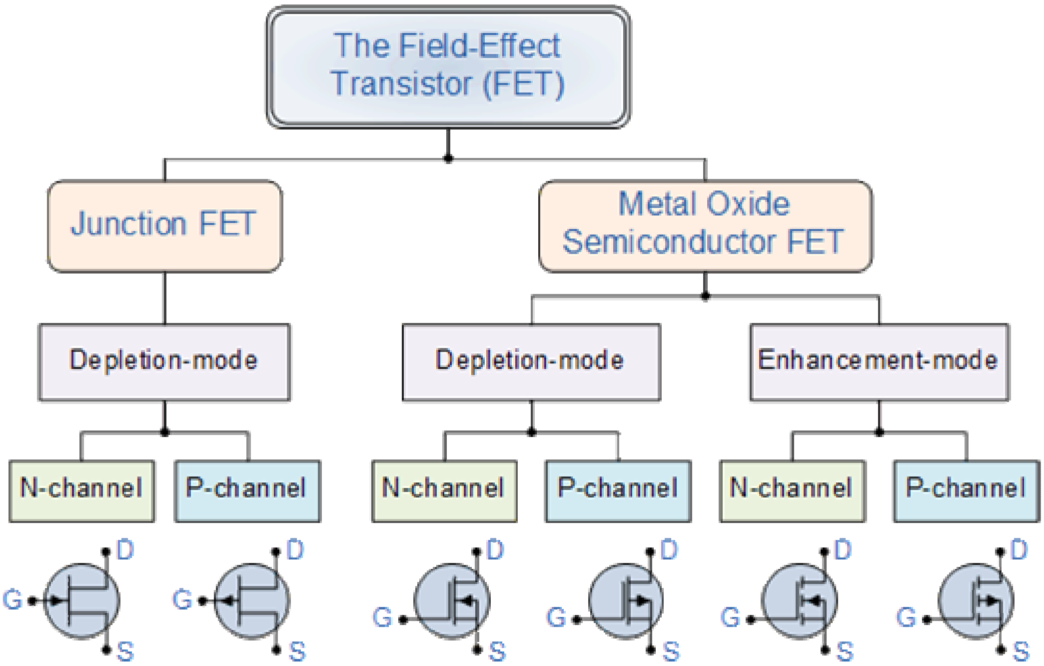
Summary of Bipolar Junction Transistors

- The Bipolar Junction Transistor (BJT) is a three layer device constructed form two semiconductor diode junctions joined together, one forward biased and one reverse biased.
- There are two main types of bipolar junction transistors, the NPN and the PNP transistor.
- Transistors are "Current Operated Devices" where a much smaller Base current causes a larger Emitter to Collector current, which themselves are nearly equal, to flow.
- The arrow in a transistor symbol represents conventional current flow.
- The most common transistor connection is the Common-emitter configuration.
- Requires a Biasing voltage for AC amplifier operation.
- The Base-Emitter junction is always forward biased whereas the Collector-Base junction is always reverse biased.
- The standard equation for currents flowing in a transistor is given as: $I_E = I_B + I_C$
- The Collector or output characteristics curves can be used to find either Ib, Ic or β to which a load line can be constructed to determine a suitable operating point, Q with variations in base current determining the operating range.
- A transistor can also be used as an electronic switch to control devices such as lamps, motors and solenoids etc.
- Inductive loads such as DC motors, relays and solenoids require a reverse biased "Flywheel" diode placed across the load. This helps prevent any induced back emf's generated when the load is switched "OFF" from damaging the transistor.
- The NPN transistor requires the Base to be more positive than the Emitter while the PNP type requires that the Emitter is more positive than the Base.

Summary of Field Effect Transistors

- Field Effect Transistors, or FET's are "Voltage Operated Devices" and can be divided into two main types: Junction-gate devices called JFET's and Insulated-gate devices calledIGFET´s or more commonly known as MOSFETs.
- Insulated-gate devices can also be sub-divided into Enhancement types and Depletiontypes. All forms are available in both N-channel and P-channel versions.
- FET's have very high input resistances so very little or no current (MOSFET types) flows into the input terminal making them ideal for use as electronic switches.
- The input impedance of the MOSFET is even higher than that of the JFET due to the insulating oxide layer and therefore static electricity can easily damage MOSFET devices so care needs to be taken when handling them.
- When no voltage is applied to the gate of an enhancement FET the transistor is in the "OFF" state similar to an "open switch".
- The depletion FET is inherently conductive and in the "ON" state when no voltage is applied to the gate similar to a "closed switch".
- FET's have very large current gain compared to junction transistors.
- They can be used as ideal switches due to their very high channel "OFF" resistance, low "ON" resistance.
- To turn the N-channel JFET transistor "OFF", a negative voltage must be applied to the gate.
- To turn the P-channel JFET transistor "OFF", a positive voltage must be applied to the gate.
- N-channel depletion MOSFETs are in the "OFF" state when a negative voltage is applied to the gate to create the depletion region.
- P-channel depletion MOSFETs, are in the "OFF" state when a positive voltage is applied to the gate to create the depletion region.
- N-channel enhancement MOSFETs are in the "ON" state when a "+ve" (positive) voltage is applied to the gate.
- P-channel enhancement MOSFETs are in the "ON" state when "-ve" (negative) voltage is applied to the gate.

The Field Effect Transistor Family-tree



Biasing of the Gate for both the junction field effect transistor, (JFET) and the metal oxide semiconductor field effect transistor, (MOSFET) configurations are given as:

	Junction FET		Metal Oxide Semiconductor FET			
Type	Depletion Mode		Depletion Mode		Enhancement Mode	
Bias	ON	OFF	ON	OFF	ON	OFF
N-channel	0v	-ve	0v	-ve	+ve	0v
P-channel	0v	+ve	0v	+ve	-ve	0v

Differences between a FET and a Bipolar Transistor

Field Effect Transistors can be used to replace normal Bipolar Junction Transistors in electronic circuits and a simple comparison between FET's and transistors stating both their advantages and their disadvantages is given below.

	Field Effect Transistor (FET)	Bipolar Junction Transistor (BJT)
1	Low voltage gain	High voltage gain
2	High current gain	Low current gain
3	Very input impedance	Low input impedance
4	High output impedance	Low output impedance
5	Low noise generation	Medium noise generation
6	Fast switching time	Medium switching time
7	Easily damaged by static	Robust
8	Some require an input to turn it "OFF"	Requires zero input to turn it "OFF"
9	Voltage controlled device	Current controlled device
10	Exhibits the properties of a Resistor	
11	More expensive than bipolar	Cheap
12	Difficult to bias	Easy to bias