MOSFET

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1. MOSFET Characteristics

Let's take **enhancement type N channel MOSFET** as an example. 3 important parameters are the **drain current (IDS)** (current passing through drain to source), the **drain – source voltage (VDS)** (potential difference between the drain and source), and **the gate – source voltage (VGS)** (potential difference between the gate and source). FETs are voltage-controlled transistors that will not conduct current unless the VGS is above a certain threshold, called **gate threshold voltage (VT)**. This region in the drain characteristics is called the **cut-off region**.

When the VGS is above VT, the MOSFET will be able to conduct current through drain to source depending on VDS. Initially, as VDS increases, IDS will increase linearly in proportion to VDS. This region is called the **ohmic/linear region** and is where the MOSFET can be used as an amplifier.

However, the IDS will not increase infinitely with VDS. When VDS reaches the **pinch off voltage**, the current passing through drain to source will saturate and will no longer increase with VDS. This area is called the **saturation region**.

The transfer characteristics show how the maximum / saturation IDS changes with VGS. As seen in figure 1(a), as VGS increases, the maximum current allowed by the MOSFET to conduct also increases. This means that it is possible to control not just the ability to flow current, but also how much current can flow through a MOSFET by controlling the voltage at the gate.

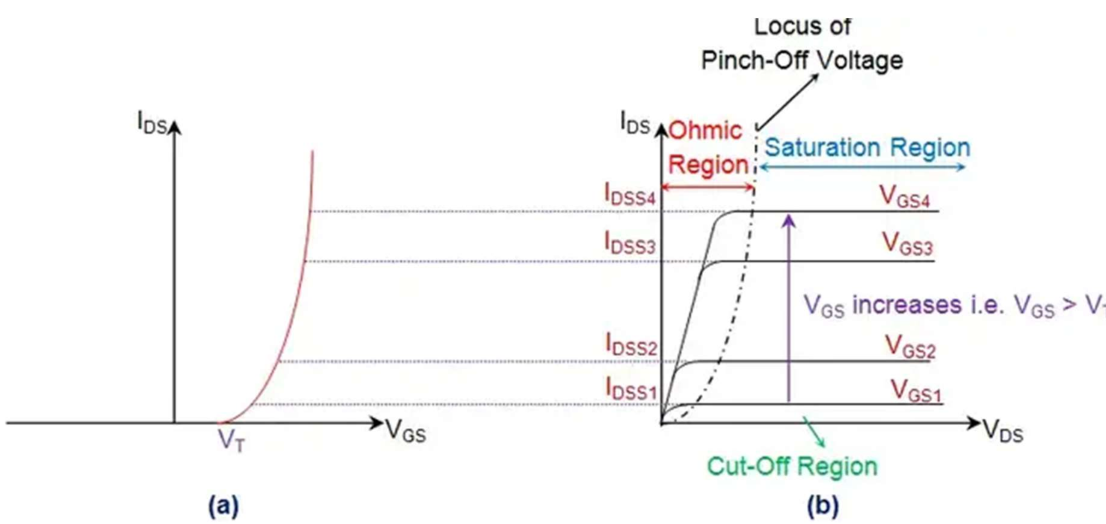

Figure 1: N Channel Enhancement MOSFET (a) Transfer Characteristics (b) Drain characteristics

For an **enhancement type P channel MOSFET**, the characteristics are mirrored across the origin. A P channel MOSFET conducts current from source to drain. The channel across source and drain is also created only VGS is negative. Since the current flows from source to drain, that also means that the potential difference between drain and source must be negative (in direction of current). The same rules for each region apply but following the P channel directions.

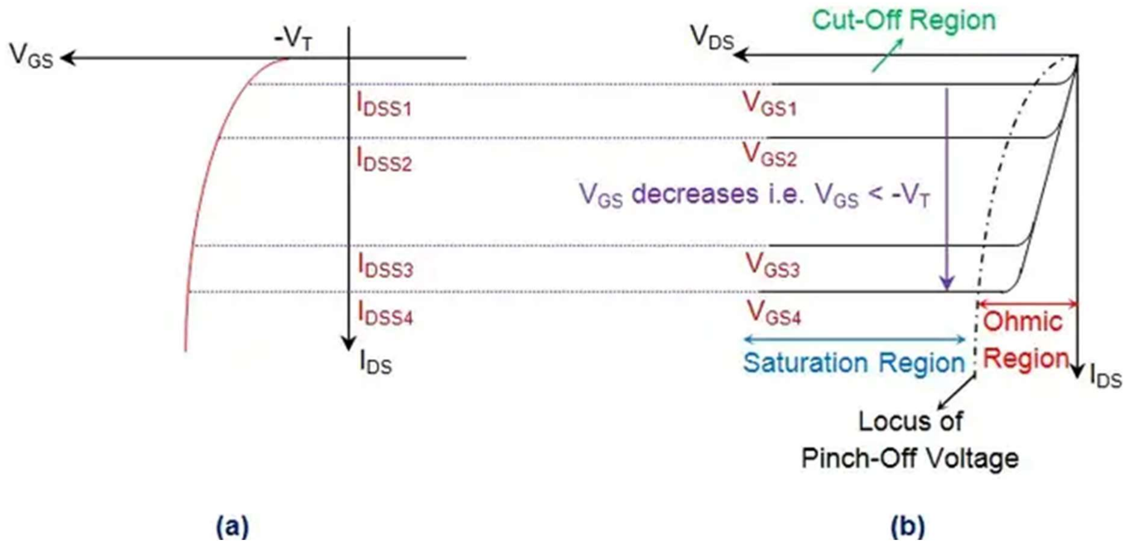

Figure 2: P Channel Enhancement MOSFET (a) Transfer Characteristics (b) Drain characteristics

For **depletion type MOSFETs** (which are known as Normally Closed), the MOSFET is conducting when VGS is zero. All the difference lies in the location of VT. For n channel, VT is negative. While for p channel, VT is positive. This means that a negative VGS is required to turn off an N channel MOSFET and vice versa for a P channel MOSFET. It is important to note that a depletion type MOSFET at zero VGS has quite low saturation current and therefore is use for low current circuits.

The drain characteristics are equivalent to their enhancement region counterparts.

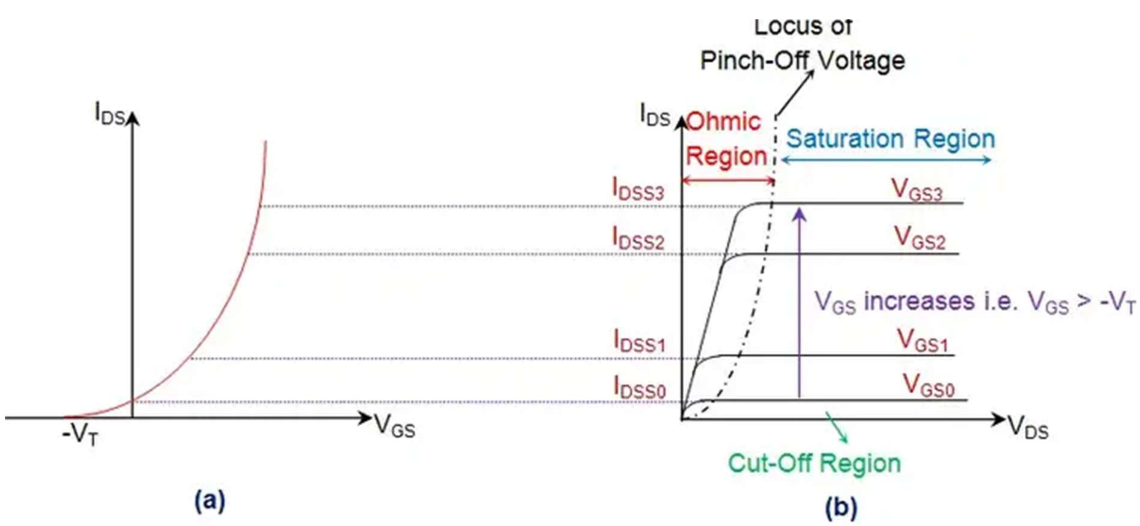

Figure 3:N Channel Depletion MOSFET (a) Transfer Characteristics (b) Drain characteristics

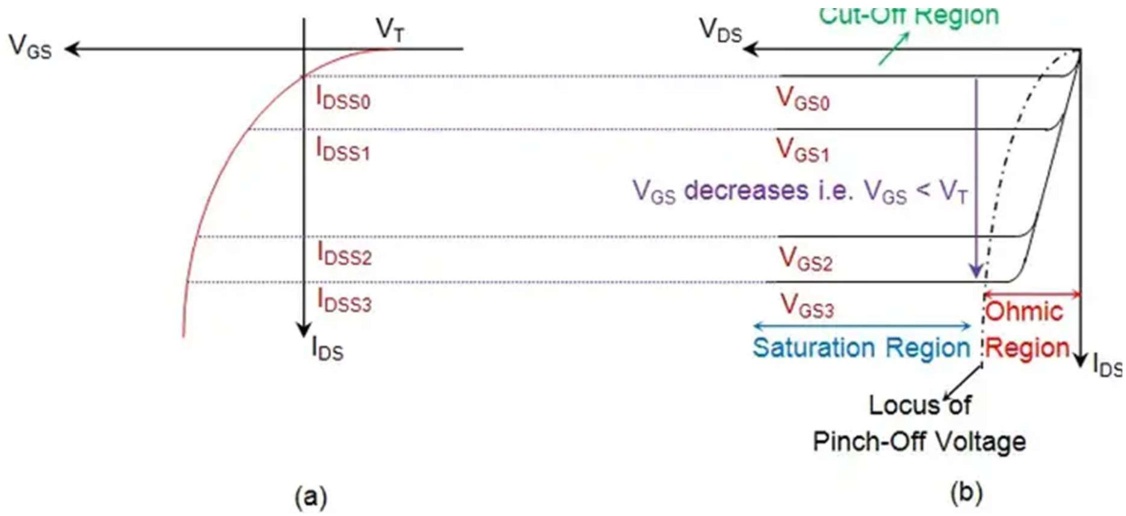

Figure 4: P Channel Depletion MOSFET (a) Transfer Characteristics (b) Drain characteristics

2. Key Parameters

When selecting a MOSFET for an application, some key parameters must be looked at and compared to choose the correct fit.

A very important parameter is Gate Threshold Voltage (VT) which was discussed above. The MOSFET will not conduct unless the VGS is increased beyond VT. This means that the controller used to switch the MOSFET must be capable of delivering voltages above VT. This comes up when choosing a microcontroller. Although most can produce 5 V, some are limited to a maximum of 3.3 V (like ESP chips).

3 important safety parameters are the absolute maximum values for the 3 variables discussed above: VDS, VGS and IDS.

It was discussed that as VGS increases the maximum saturation current increases. However, increasing VGS above the limit will cause a short circuit inside the MOSFET itself, ruining the device.

Maximum VDS (called Drain-Source Breakdown Voltage) occurs only when the MOSFET is turned off. If reached the MOSFET will enter the avalanche state. Some MOSFETs are built to withstand the avalanche state at specified conditions in the data sheet but most will be broken.

The drain to source current maximum is determined by how much heat can the MOSFET withstand (like any diode / transistor). There are two important types of maximum IDS however: continuous drain current and pulse drain current. Continuous drain current is the maximum when a MOSFET is in normal working condition and is compared with the current load of a circuit. Pulse drain current is the maximum current a MOSFET can withstand from a single pulse. The pulse drain current is much higher than the continuous drain current because the heat generated during a very small amount of time needs to be much higher than the heat generated during normal operation to break the MOSFET.

2 efficiency related parameters are the **on-state resistance (RDS(on))** and **total gate charge (QG)**. RDS(on) is the resistance between the drain and source when the MOSFET is conducting and is the cause of conduction losses. QG is electrical charge required by the gate driver to switch the MOSFET on or off and is the cause of switching losses. Both values need to be minimised to reduce the conduction and switching losses respectively and hence, increase the efficiency. (Important to note that the switching losses are only significant in high switching circuits!)

Total Power Dissipation is a parameter that depends on RDS(on) and the continuous drain current. It shows the maximum power that can be dissipated due to RDS(on) under different temperature conditions (for case temperature and ambient temperature).

The final key parameter is the **switching time** which is comprised of 4 times: turn-on delay time, rise time, turn-off delay time, fall time. These times are in the nano second range. They are important to look at for the required switching frequency and for conduction losses.

3. Selection Query

The following guidelines must be followed when selecting a MOSFET for a certain application:

1. Find the maximum power used when applying maximum load. The maximum power will contain the maximum power output of the application in addition to the losses when working at the power.
2. Using the maximum power find the peak circuit current. Divide the maximum power by minimum input voltage.
   Example of minimum input voltage: for a DC supply, a battery of 12 V has a range of 10 to 14 V output. Taking a margin of 40% of the minimum output will yield 6 V. Use this voltage to calculate the peak circuit current.
3. Select MOSFET rating based on the peak circuit current and the input voltage, with safety factors added. Minimum safety factors is to take double the maximum voltage input (14 x 2 in the previous example) and 1.5 times the peak circuit current.
4. Find the operating temperature of the system to select an appropriate MOSFET that can handle maximum power dissipation at the peak operating temperature.
5. Find the lowest possible RDS(on) and QG to get the highest efficiency and the same time abide by the maximum power dissipation and switching time requirements of the system respectively.

4. References

- How Does a MOSFET Work? By Explorer: https://www.youtube.com/watch?v=rkbjHNEKcRws
- https://www.electrical4u.com/mosfet-characteristics
- https://www.mouser.com/pdfDocs/an-1001_a1611.pdf
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