



Lecture (05) MOSFET

By:

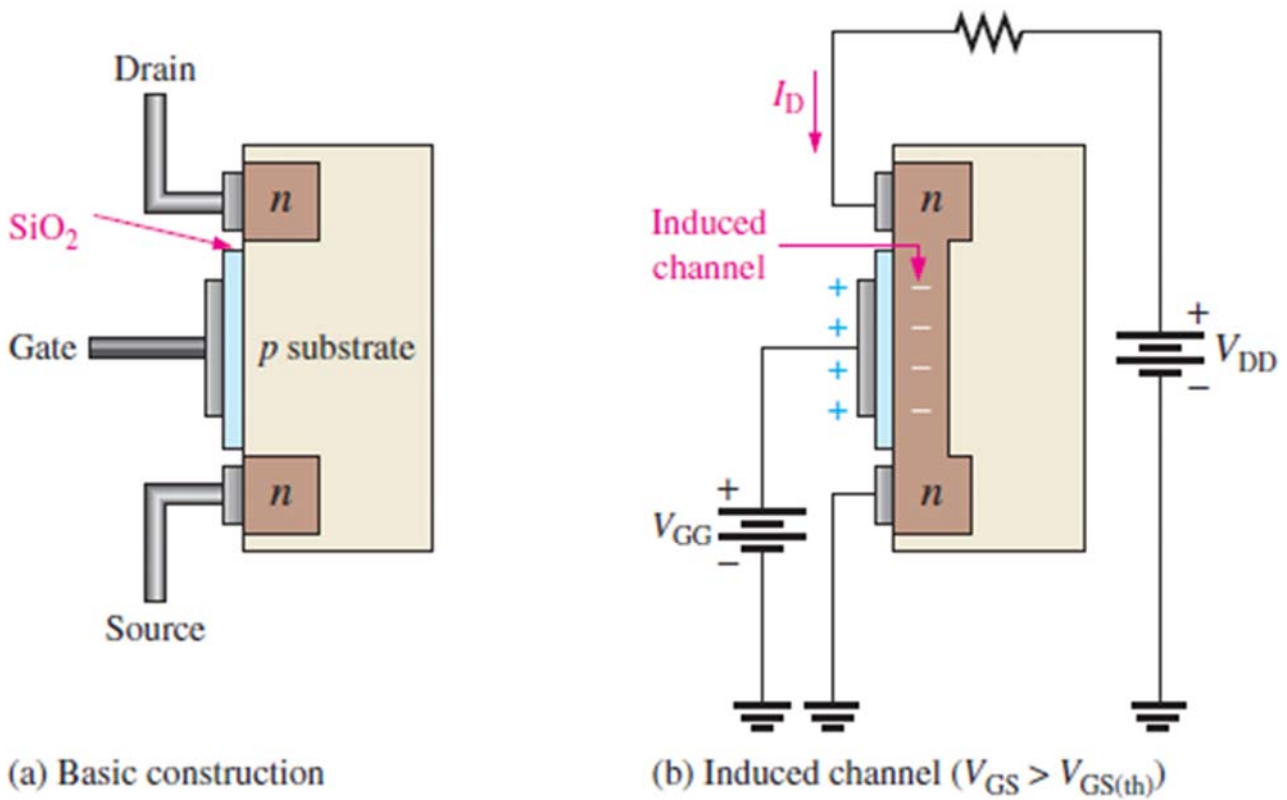
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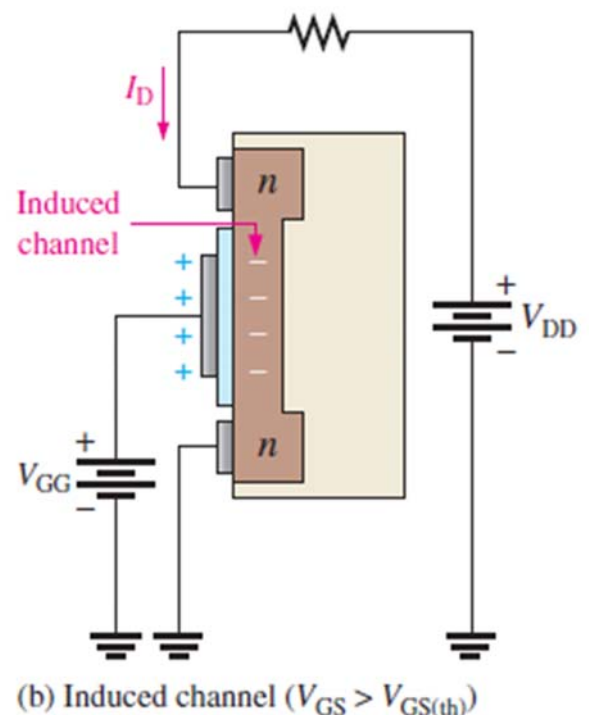
Introduction

- The **MOSFET** (metal oxide semiconductor field-effect transistor) is another category of field-effect transistor.
- The MOSFET, different from the JFET, has no *pn* junction structure;
- instead, the gate of the MOSFET is insulated from the channel by a silicon dioxide (SiO_2) layer.
- The two basic types of MOSFETs are enhancement (E) and depletion (D).
- Of the two types, the enhancement MOSFET is more widely used.
- Because polycrystalline silicon is now used for the gate material instead of metal, these devices are sometimes called IGFETs (insulated-gate FETs).

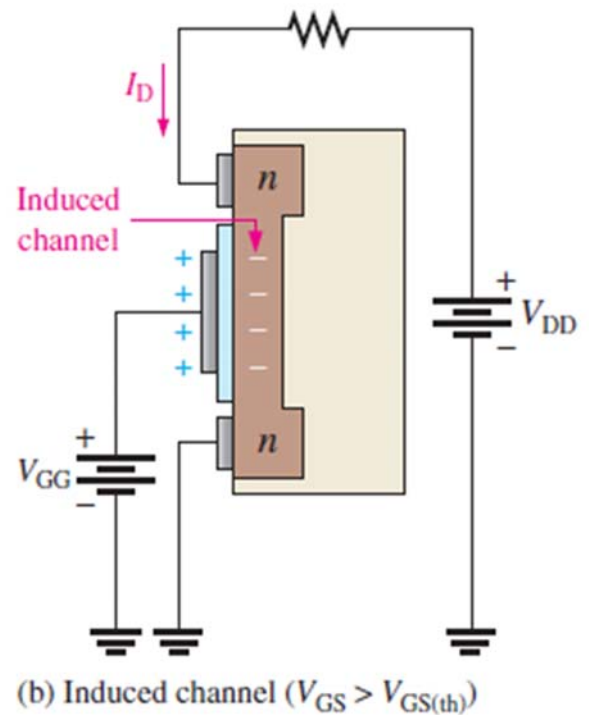
Enhancement MOSFET (E-MOSFET)



- The E-MOSFET operates *only* in the enhancement mode and has no depletion mode.
- it has no structural channel.
- For an n -channel device, a positive gate voltage above a threshold value *induces* a channel by creating a thin layer of negative charges in the substrate region adjacent to the SiO₂ layer,



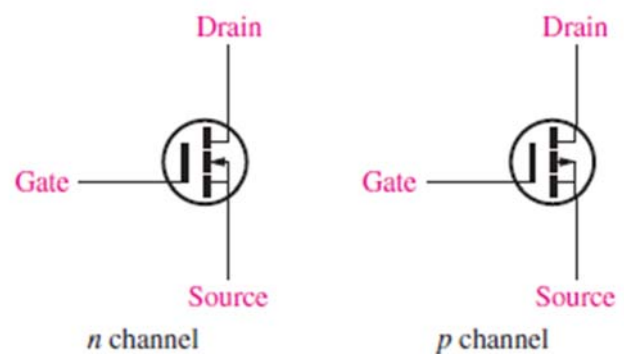
- The conductivity of the channel is enhanced by increasing the gate-to-source voltage and thus pulling more electrons into the channel area.
- For any gate voltage below the threshold value, there is no channel



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- The broken lines symbolize the absence of a physical channel.
- An inward pointing substrate arrow is for n channel, and an outward-pointing arrow is for p channel.
- Some E-MOSFET devices have a separate substrate connection.

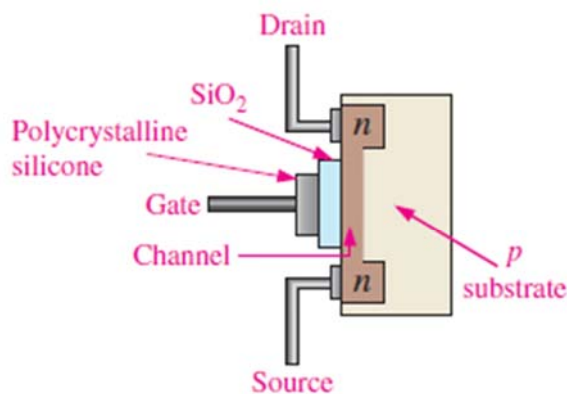


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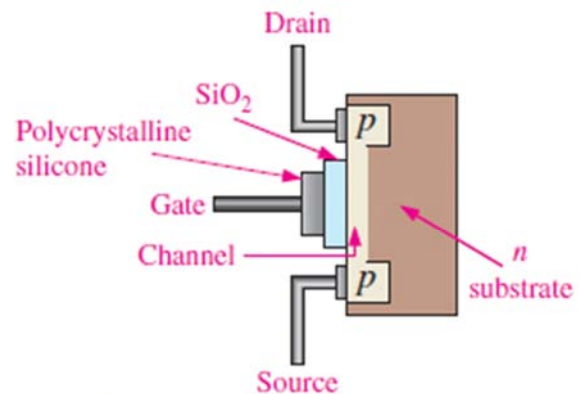
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Depletion MOSFET (D-MOSFET)

- Another type of MOSFET is the depletion MOSFET (D-MOSFET),
- The drain and source are diffused into the substrate material and then connected by a narrow channel adjacent to the insulated gate

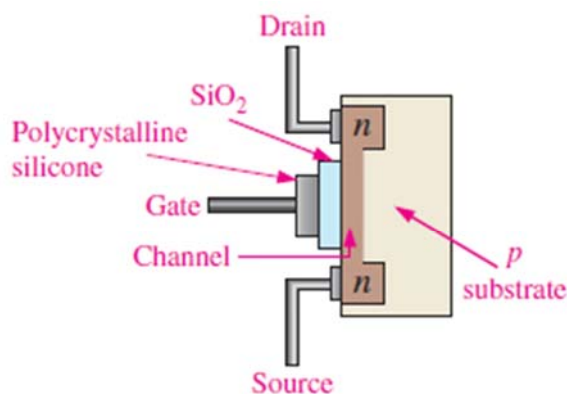


(a) *n* channel

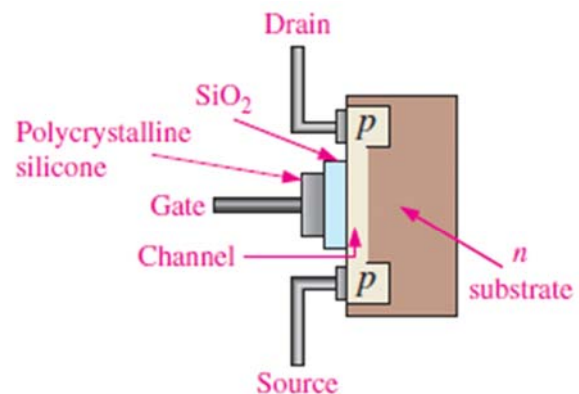


(b) *p* channel

- We will use the *n*-channel device to describe the basic operation.
- The *p*-channel operation is the same, except the voltage polarities are opposite those of the *n*-channel.

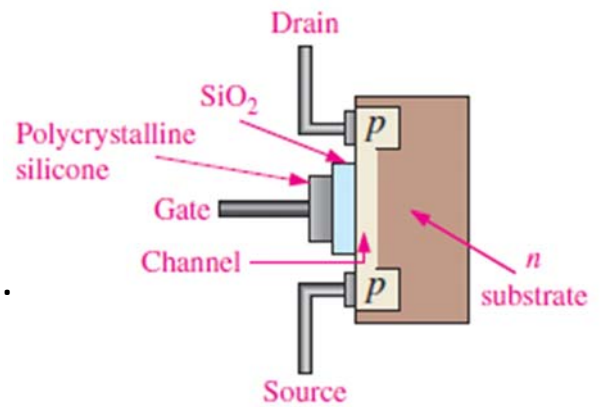


(a) *n* channel

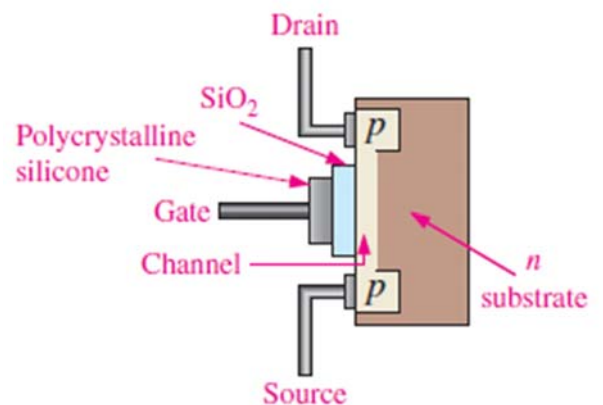


(b) *p* channel

- The D-MOSFET can be operated in either of two modes—the depletion mode or the enhancement mode—and is sometimes called a *depletion/enhancement MOSFET*.
- Since the gate is insulated from the channel, either a positive or a negative gate voltage can be applied.

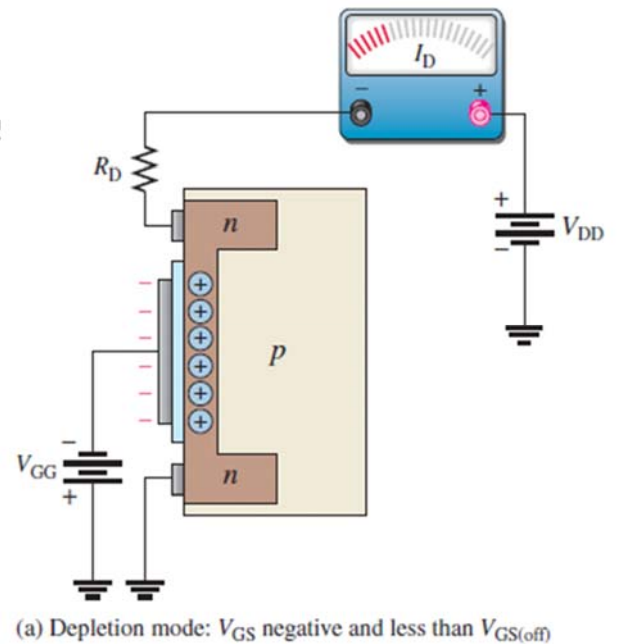


- The *n*-channel MOSFET operates in the **depletion** mode when a negative gate-to-source voltage is applied and in the **enhancement** mode when a positive gate-to-source voltage is applied.
- These devices are generally operated in the depletion mode



p-channel MOSFET *Depletion Mode*

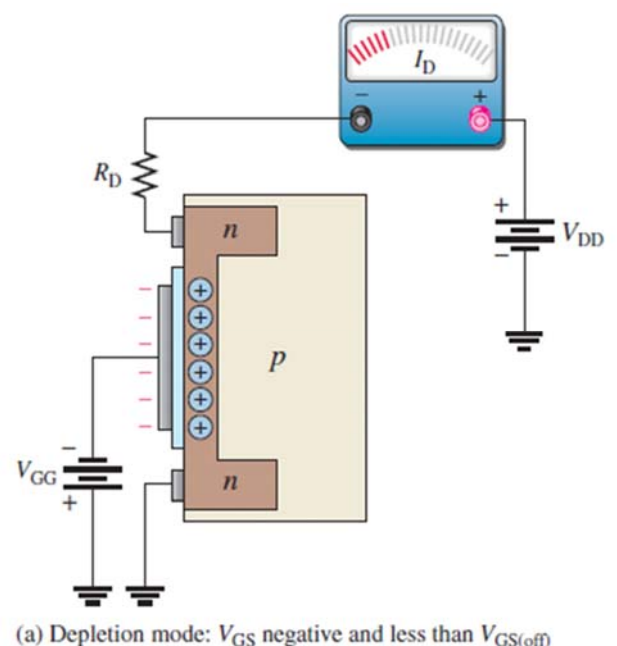
- gate as one plate of a parallel-plate capacitor and the channel as the other plate.
- silicon dioxide insulating layer is the dielectric.
- With a negative gate voltage, the negative charges on the gate repel conduction electrons from the channel, leaving positive ions in their place, the *n* channel is depleted of some of its electrons, thus decreasing the channel conductivity



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- At a sufficiently negative gate-to-source voltage, $V_{GS(off)}$, the channel is totally depleted and the drain current is zero.

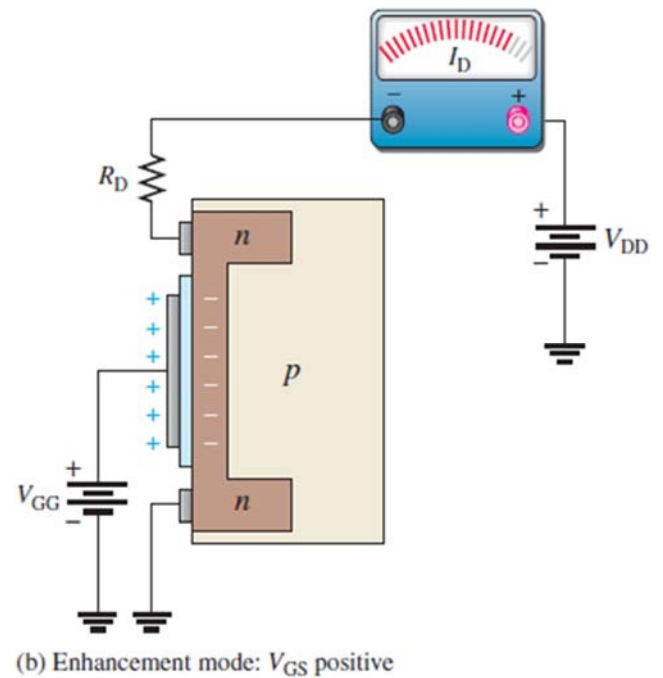


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Enhancement Mode

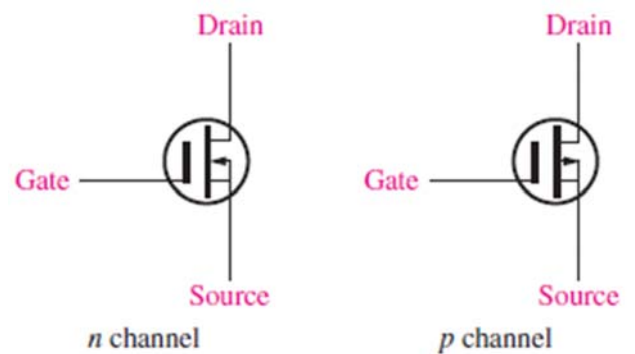
- With a positive gate voltage, more conduction electrons are attracted into the channel, thus increasing (enhancing) the channel conductivity,



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- The schematic symbols for both the n -channel and the p -channel depletion MOSFETs
- The substrate, indicated by the arrow, is normally (but not always) connected internally to the source.



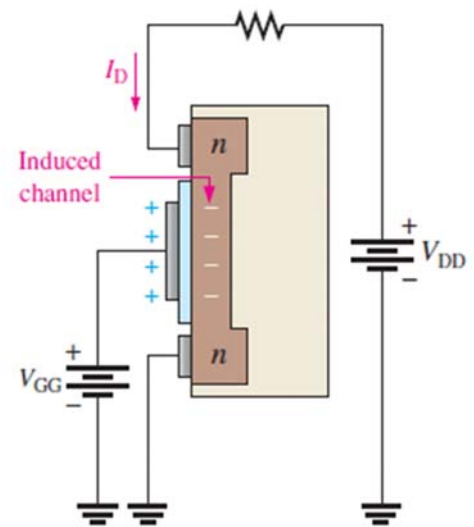
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MOSFET CHARACTERISTICS AND PARAMETERS

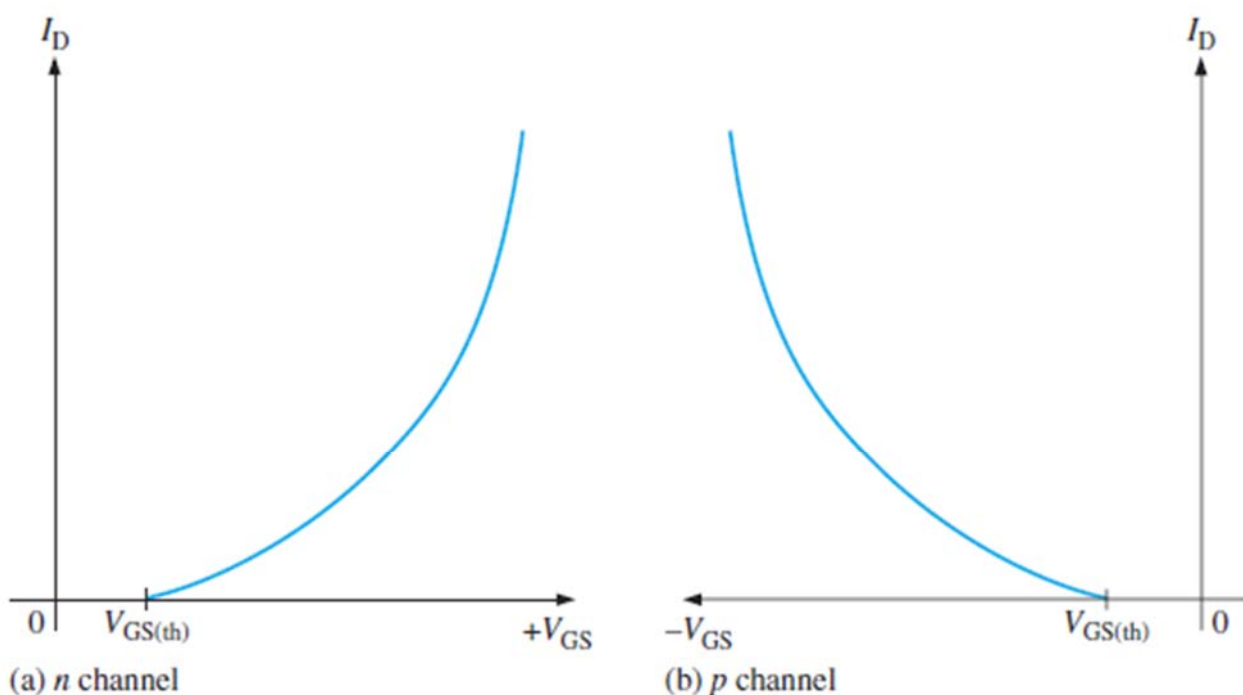
E-MOSFET Transfer Characteristic

- E-MOSFET uses only channel enhancement.
- an n -channel device requires a positive gate-to-source voltage, and a p -channel device requires a negative gate-to-source voltage.



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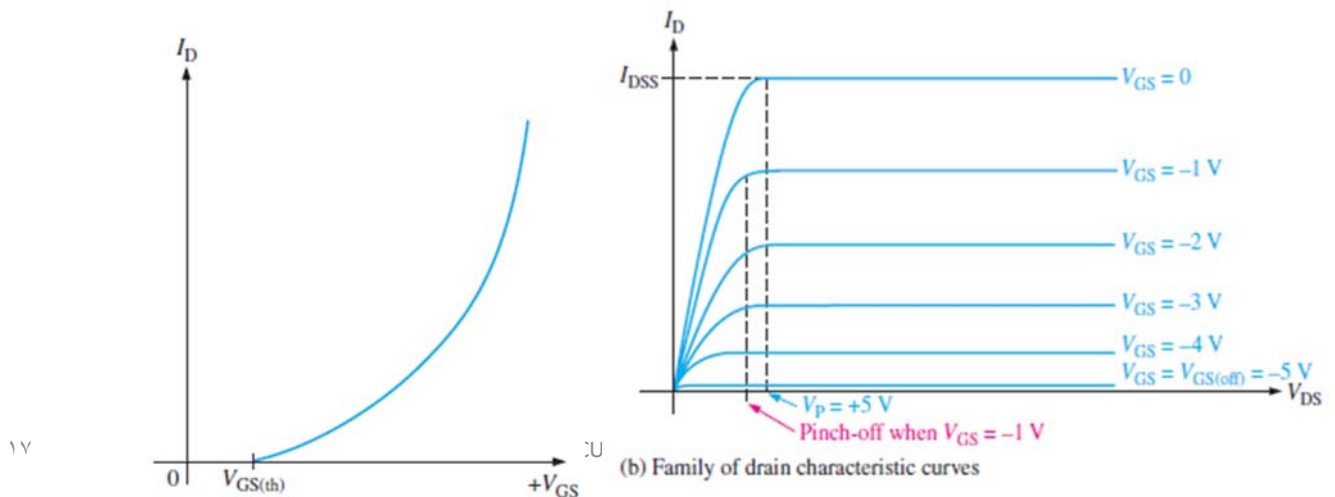
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- there is no drain current when $V_{GS} = 0$.
- The E-MOSFET does not have a significant I_{DSS} parameter, as do the JFET
- there is ideally no drain current until V_{GS} reaches a certain nonzero value called the *threshold voltage*, $V_{GS(th)}$.



- The equation for the parabolic transfer characteristic curve

$$I_D = K(V_{GS} - V_{GS(th)})^2$$

- The constant K depends on the particular MOSFET and can be determined from the datasheet by taking the specified value of I_D , called $I_D(on)$, at the given value of V_{GS} and substituting the values into Equation

Example 01

The datasheet (see www.fairchild.com) for a 2N7002 E-MOSFET gives $I_{D(on)} = 500 \text{ mA}$ (minimum) at $V_{GS} = 10 \text{ V}$ and $V_{GS(th)} = 1 \text{ V}$. Determine the drain current for $V_{GS} = 5 \text{ V}$.

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$$I_D = K(V_{GS} - V_{GS(th)})^2$$

$$I_{D(on)} = 500 \text{ mA}$$

$$V_{GS} = 10 \text{ V}$$

$$V_{GS(th)} = 1 \text{ V.}$$

Determine the drain current

$$V_{GS} = 5 \text{ V.}$$

First, solve for K using Equation

$$K = \frac{I_{D(on)}}{(V_{GS} - V_{GS(th)})^2} = \frac{500 \text{ mA}}{(10 \text{ V} - 1 \text{ V})^2} = \frac{500 \text{ mA}}{81 \text{ V}^2} = 6.17 \text{ mA/V}^2$$

Next, using the value of K , calculate I_D for $V_{GS} = 5 \text{ V}$.

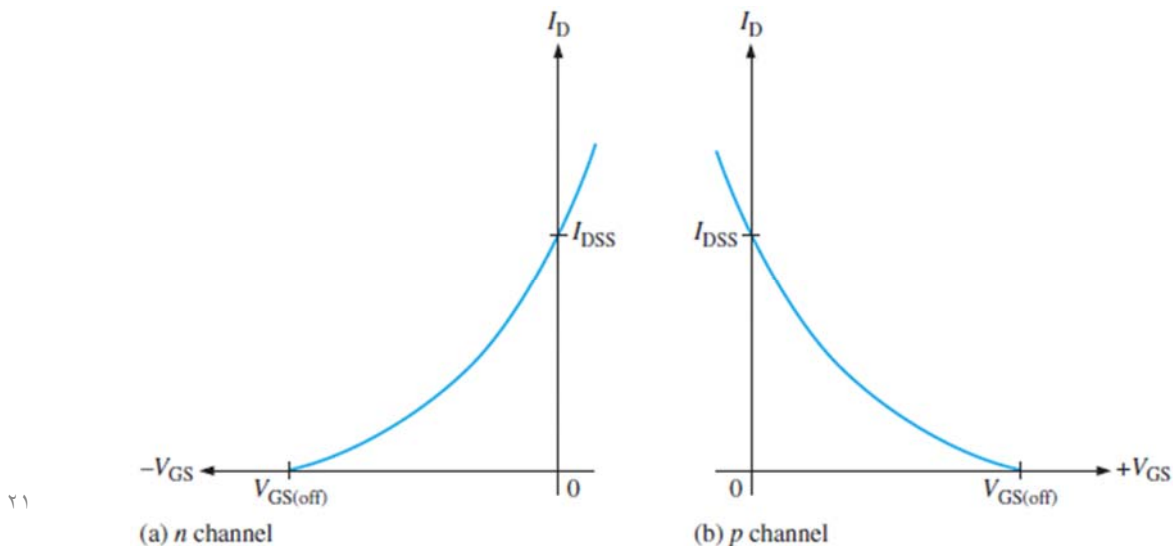
$$I_D = K(V_{GS} - V_{GS(th)})^2 = (6.17 \text{ mA/V}^2)(5 \text{ V} - 1 \text{ V})^2 = 98.7 \text{ mA}$$

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D-MOSFET Transfer Characteristic

- the D-MOSFET can operate with either positive or negative gate voltages.
- The point on the curves where $V_{GS} = 0$ corresponds to I_{DSS} .
- The point where $I_D = 0$ corresponds to $V_{GS(off)}$.



Example 02

For a certain D-MOSFET, $I_{DSS} = 10 \text{ mA}$ and $V_{GS(off)} = -8 \text{ V}$.

- Is this an *n*-channel or a *p*-channel?
- Calculate I_D at $V_{GS} = -3 \text{ V}$.
- Calculate I_D at $V_{GS} = +3 \text{ V}$.

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

$$I_{DSS} = 10 \text{ mA and } V_{GS(off)} = -8 \text{ V.}$$

Is this an n -channel or a p -channel?

Calculate I_D at $V_{GS} = -3 \text{ V}$.

Calculate I_D at $V_{GS} = +3 \text{ V}$.

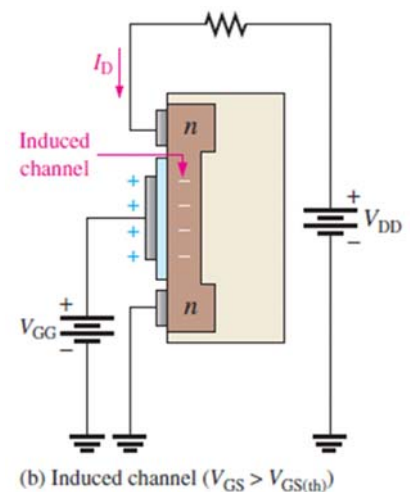
(a) The device has a negative $V_{GS(off)}$; therefore, it is an n -channel MOSFET.

$$(b) I_D \cong I_{DSS} \left(1 - \frac{V_{GS}}{V_{GS(off)}} \right)^2 = (10 \text{ mA}) \left(1 - \frac{-3 \text{ V}}{-8 \text{ V}} \right)^2 = 3.91 \text{ mA}$$

$$(c) I_D \cong (10 \text{ mA}) \left(1 - \frac{+3 \text{ V}}{-8 \text{ V}} \right)^2 = 18.9 \text{ mA}$$

MOSFET BIASING/E-MOSFET Bias

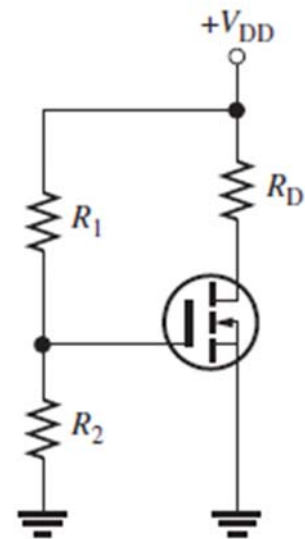
- E-MOSFETs must have a V_{GS} greater than the threshold value, $V_{GS(th)}$, zero bias cannot be used.
- An n -channel device is used
- two ways to bias
 - voltage-divider or
 - drain-feedback bias
- the purpose is to make the gate voltage more positive than the source by an amount exceeding $V_{GS(th)}$.



$$V_{GS} = \left(\frac{R_2}{R_1 + R_2} \right) V_{DD}$$

$$V_{DS} = V_{DD} - I_D R_D$$

$$\text{where } I_D = K(V_{GS} - V_{GS(th)})^2$$

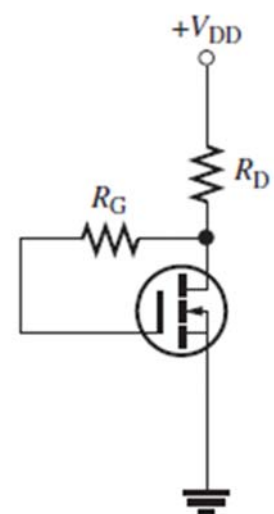


(a) Voltage-divider bias

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- there is negligible gate current and, therefore, no voltage drop across R_G .
- This makes $V_{GS} = V_{DS}$.



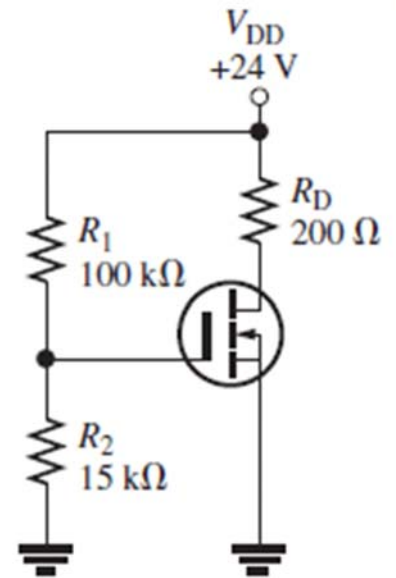
(b) Drain-feedback bias

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Example 03

Determine V_{GS} and V_{DS} for the E-MOSFET circuit in Figure 1. Assume this particular MOSFET has minimum values of $I_{D(on)} = 200 \text{ mA}$ at $V_{GS} = 4 \text{ V}$ and $V_{GS(th)} = 2 \text{ V}$.



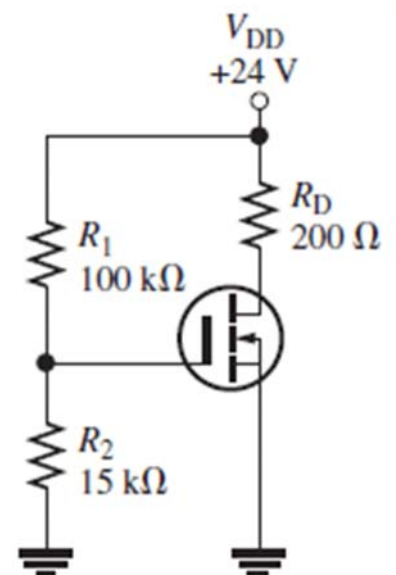
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$I_{D(on)} = 200 \text{ mA}$ at $V_{GS} = 4 \text{ V}$ and $V_{GS(th)} = 2 \text{ V}$.

For the E-MOSFET in Figure 1, the gate-to-source voltage is

$$V_{GS} = \left(\frac{R_2}{R_1 + R_2} \right) V_{DD} = \left(\frac{15 \text{ k}\Omega}{115 \text{ k}\Omega} \right) 24 \text{ V} = 3.13 \text{ V}$$



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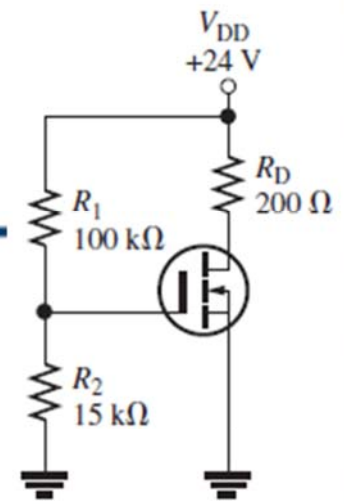
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$$I_D = K(V_{GS} - V_{GS(th)})^2$$

$$I_{D(on)} = 200 \text{ mA at } V_{GS} = 4 \text{ V and } V_{GS(th)} = 2 \text{ V.}$$

Determine V_{GS} and V_{DS}

$$V_{GS} = 3.13 \text{ V}$$



To determine V_{DS} , first find K using the minimum value of $I_{D(on)}$ and the specified voltage values.

$$K = \frac{I_{D(on)}}{(V_{GS} - V_{GS(th)})^2} = \frac{200 \text{ mA}}{(4 \text{ V} - 2 \text{ V})^2} = \frac{200 \text{ mA}}{4 \text{ V}^2} = 50 \text{ mA/V}^2$$

Now calculate I_D for $V_{GS} = 3.13 \text{ V}$.

$$\begin{aligned} I_D &= K(V_{GS} - V_{GS(th)})^2 = (50 \text{ mA/V}^2)(3.13 \text{ V} - 2 \text{ V})^2 \\ &= (50 \text{ mA/V}^2)(1.13 \text{ V})^2 = 63.8 \text{ mA} \end{aligned}$$

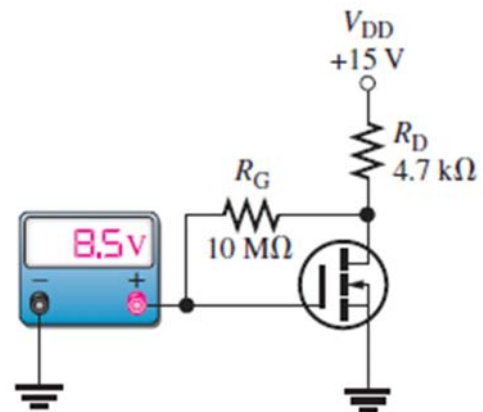
Finally, calculate V_{DS} .

$$V_{DS} = V_{DD} - I_D R_D = 24 \text{ V} - (63.8 \text{ mA})(200 \Omega) = 11.2 \text{ V}$$

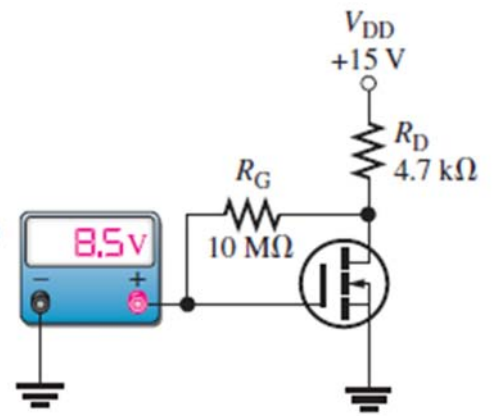
Example 04

Determine the amount of drain current in Figure :

The MOSFET has a $V_{GS(th)} = 3 \text{ V}$.



$$V_{GS(th)} = 3 \text{ V.}$$



The meter indicates $V_{GS} = 8.5 \text{ V}$. Since this is a drain-feedback configuration, $V_{DS} = V_{GS} = 8.5 \text{ V}$.

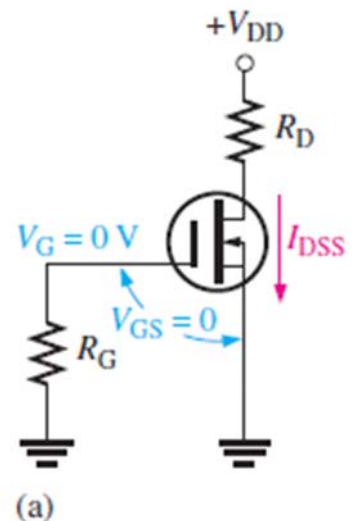
$$I_D = \frac{V_{DD} - V_{DS}}{R_D} = \frac{15 \text{ V} - 8.5 \text{ V}}{4.7 \text{ k}\Omega} = 1.38 \text{ mA}$$

D-MOSFET Bias

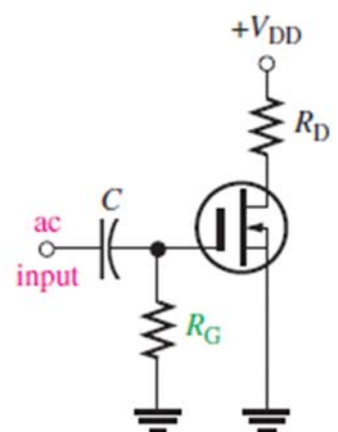
- D-MOSFETs can be operated with either positive or negative values of V_{GS}
- simple bias method is to set $V_{GS} = 0$
- then ac signal at the gate varies the gate-to-source voltage above and below this 0 V bias point
- Since $V_{GS} = 0$, $I_D = I_{DSS}$ as indicated

$$V_{DS} = V_{DD} - I_{DSS}R_D$$

- The purpose of R_G is to accommodate an ac signal input by isolating it from ground



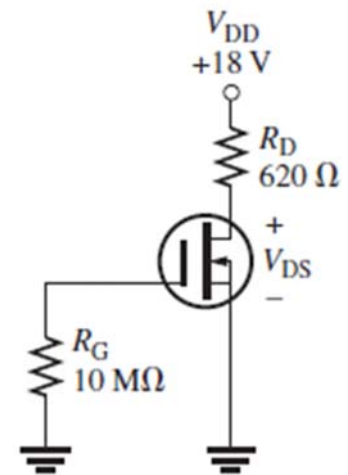
(a)



(b)

Example 05

Determine the drain-to-source voltage in the circuit of Figure . The MOSFET datasheet gives $V_{GS(off)} = -8\text{ V}$ and $I_{DSS} = 12\text{ mA}$.



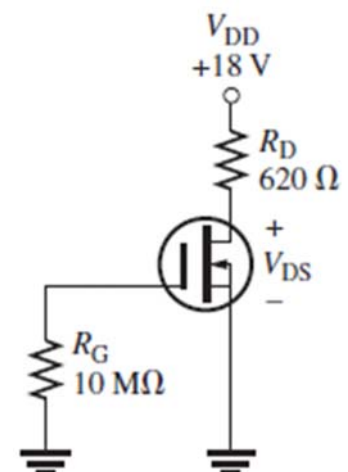
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$V_{GS(off)} = -8\text{ V}$ and $I_{DSS} = 12\text{ mA}$.

Since $I_D = I_{DSS} = 12\text{ mA}$, the drain-to-source voltage is

$$V_{DS} = V_{DD} - I_{DSS}R_D = 18\text{ V} - (12\text{ mA})(620\ \Omega) = 10.6\text{ V}$$



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Thanks,..
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