Lecture (10) MOSFET

By:

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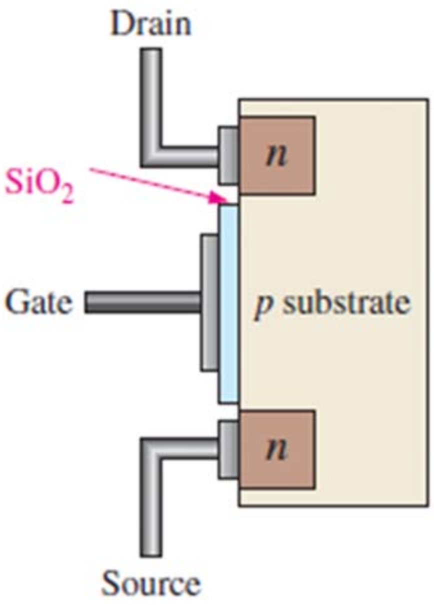
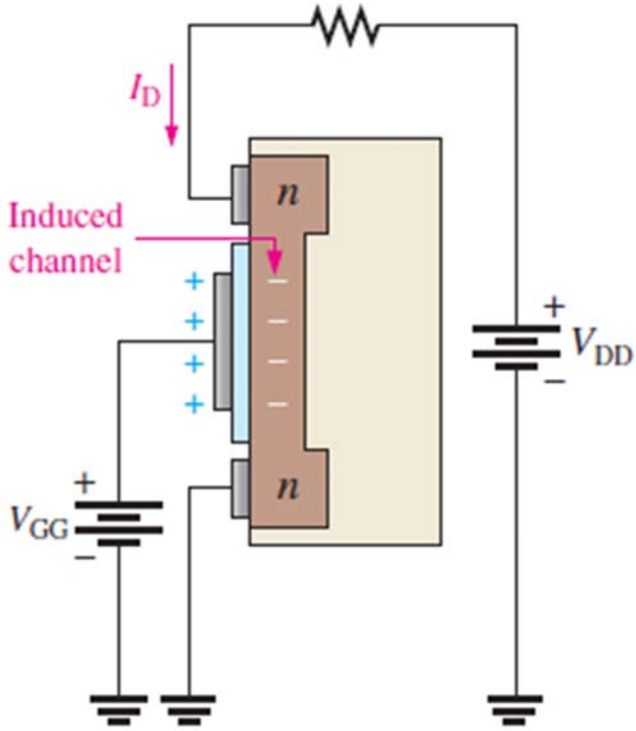
Introduction

- 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 (SiO2) 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)

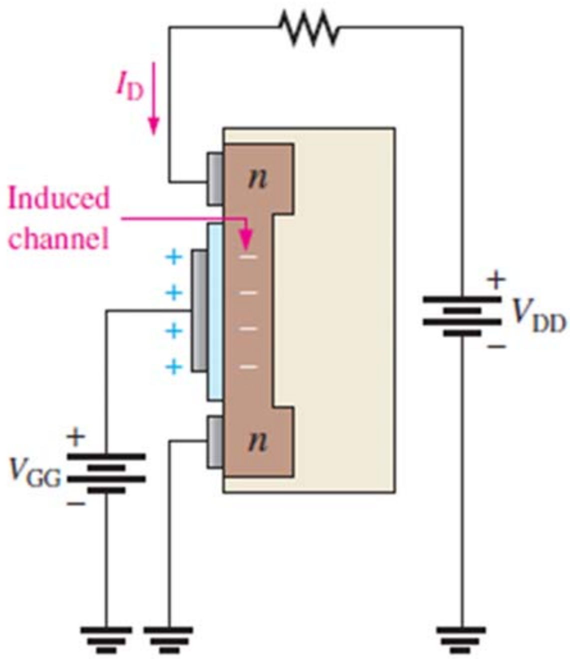


(a) Basic construction



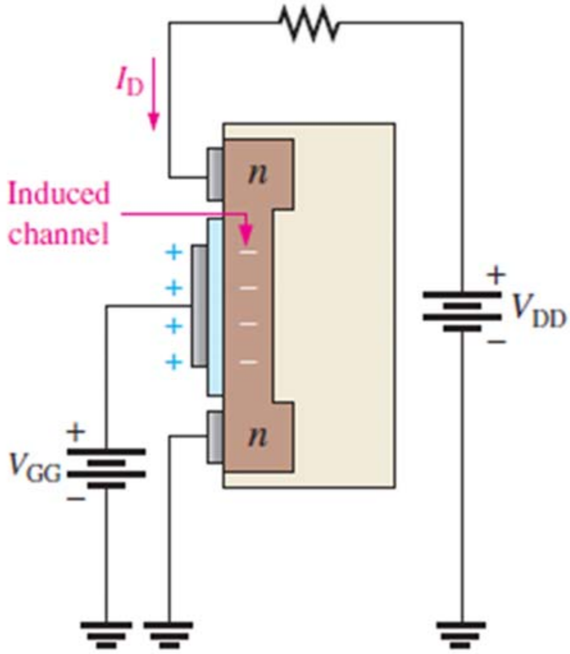
(b) Induced channel ($V_{GS} > V_{GS(th)}$)

- 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,



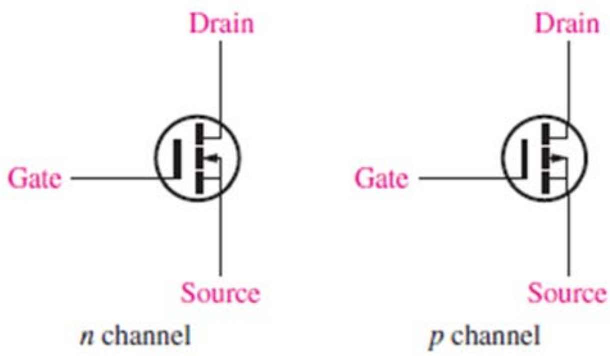
(b) Induced channel ($V_{GS} > V_{GS(th)}$)

- 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



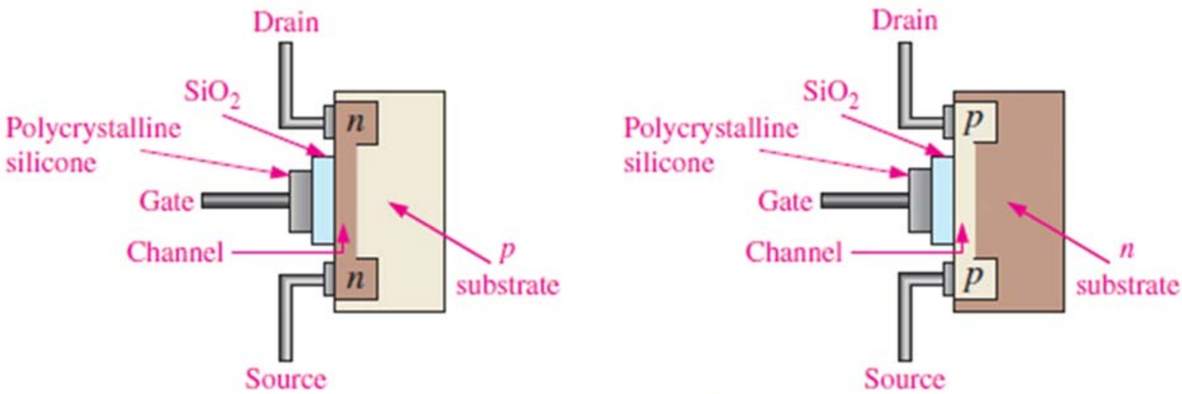
(b) Induced channel ($V_{GS} > V_{GS(th)}$)

- 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.



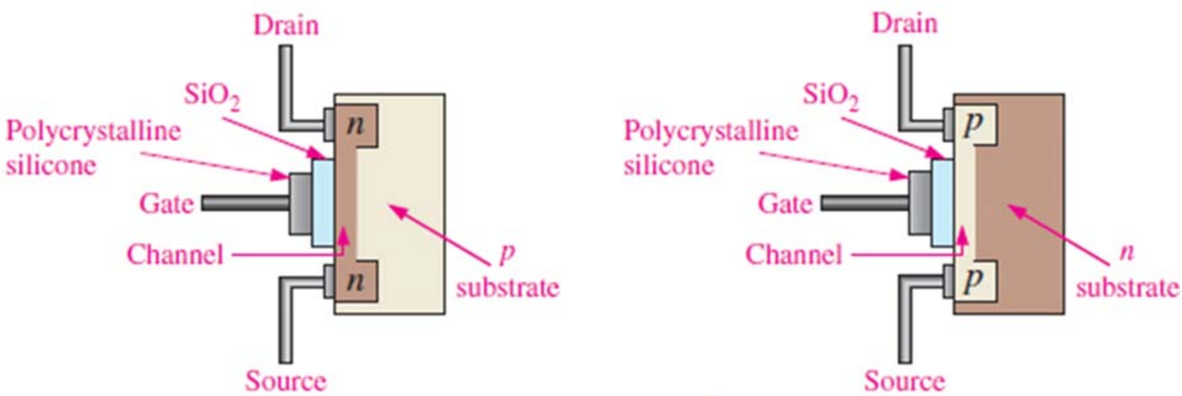
Depletion MOSFET (D-MOSFET)

- 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



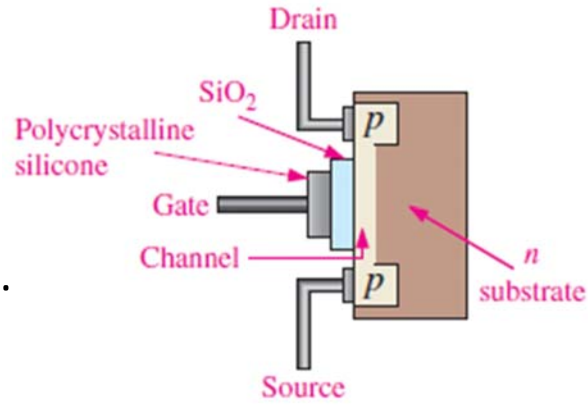
(a) *n* channel (b) *p* channel

- 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.

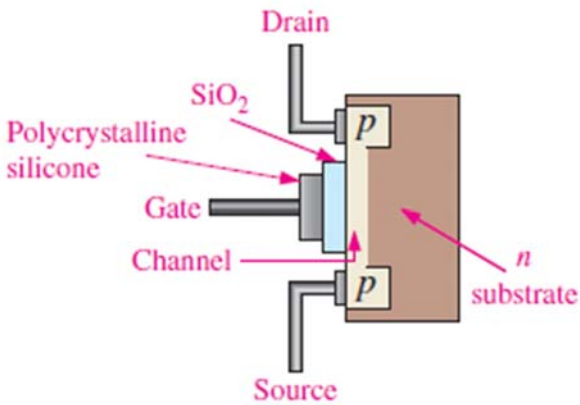


(a) *n* channel (b) *p* channel

- 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.

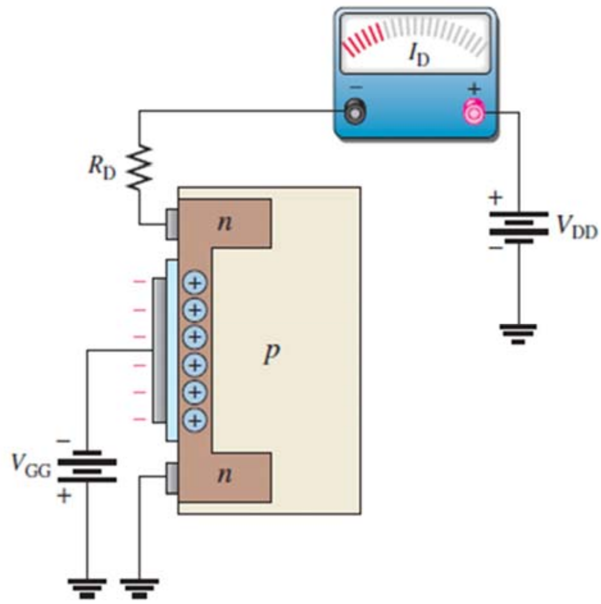


- The *n*-channel MOSFET operates in the **depletion** mode when a negative gate-to-source voltage is applied and in the **enhancement** mode when a positive gate-to-source voltage is applied.
- These devices are generally operated in the depletion mode



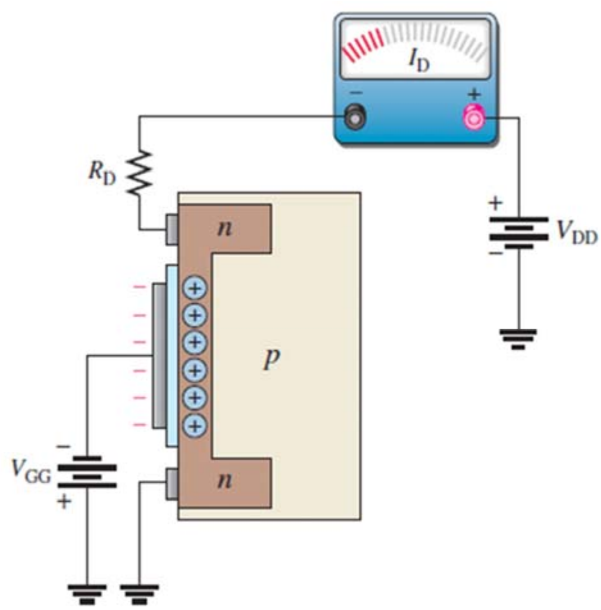
n-channel MOSFET ***Depletion Mode***

- 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



(a) Depletion mode: V_{GS} negative and less than $V_{GS(off)}$

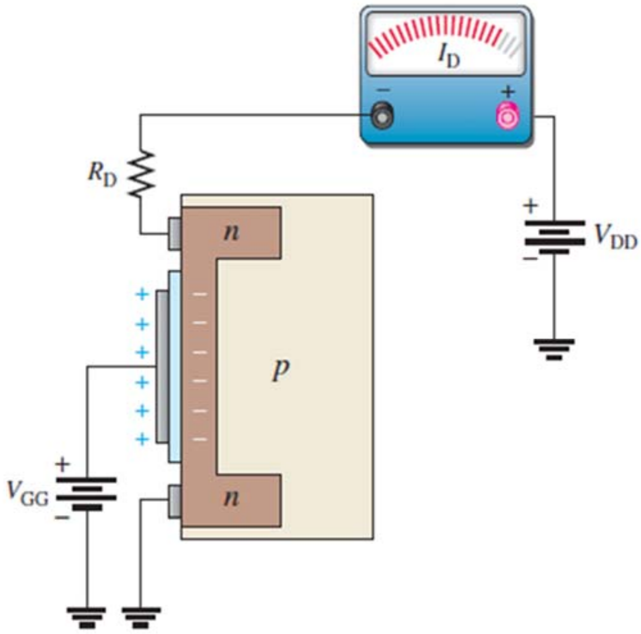
- At a sufficiently negative gate-to-source voltage, *V*GS(off), the channel is totally depleted and the drain current is zero.



(a) Depletion mode: V_{GS} negative and less than $V_{GS(off)}$

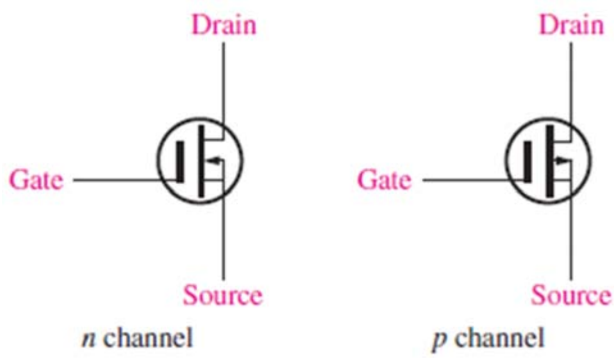
Enhancement Mode

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



(b) Enhancement mode: V_{GS} positive

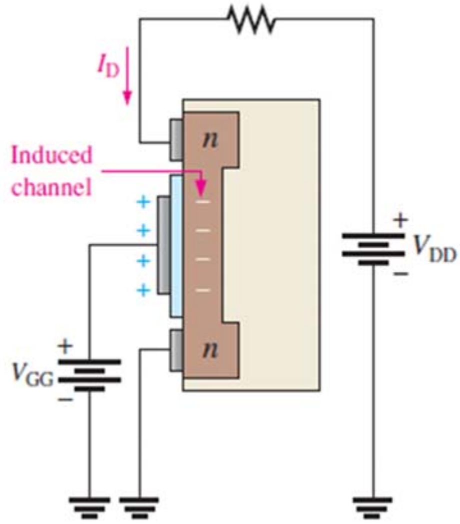
- The schematic symbols for both the *n*-channel and the *p*-channel depletion MOSFETs
- The substrate, indicated by the arrow, is normally (but not always) connected internally to the source.

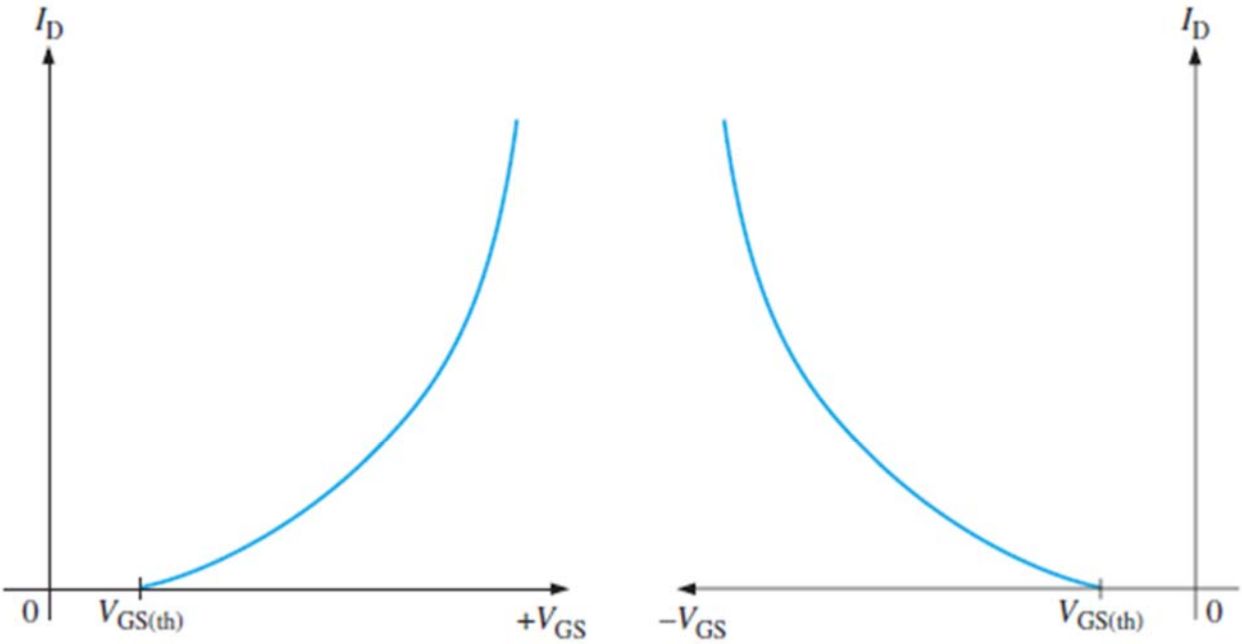


MOSFET CHARACTERISTICS AND PARAMETERS

E-MOSFET Transfer Characteristic

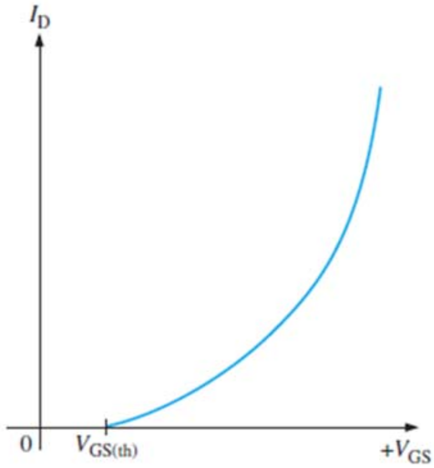
- E-MOSFET uses only channel enhancement.
- an *n*-channel device requires a positive gate-to-source voltage, and a *p*-channel device requires a negative gate-to-source voltage.

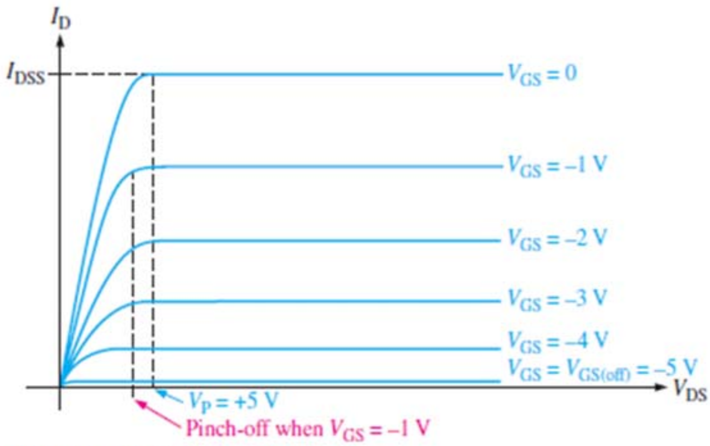




(a) *n* channel (b) *p* channel

- there is no drain current when $V_{DS} = 0$.
- 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,* $V_{GS(th)}$.





(b) Family of drain characteristic curves

- 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 $I_{D(on)} = 500$ mA (minimum) at $V_{GS} = 10$ V and $V_{GS(th)} = 1$ V. Determine the drain current for $V_{GS} = 5$ V.

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

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

$V_{GS} = 10$ V

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

Determine the drain current $V_{GS} = 5$ V.

First, solve for K using Equation

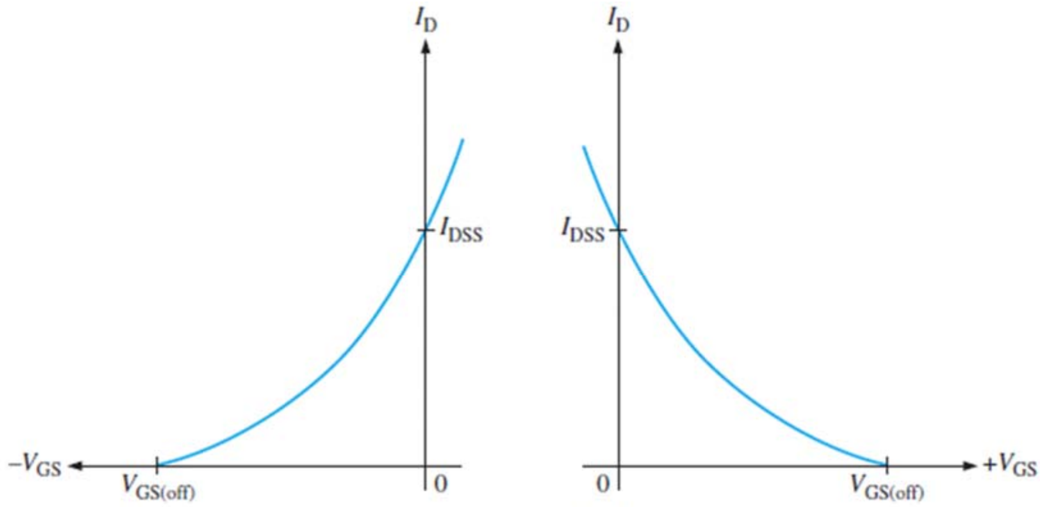
$$K = \frac{I_{D(on)}}{(V_{GS} - V_{GS(th)})^2} = \frac{500\text{ mA}}{(10\text{ V} - 1\text{ V})^2} = \frac{500\text{ mA}}{81\text{ V}^2} = 6.17\text{ mA/V}^2$$

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

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

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).



(a) *n* channel (b) *p* channel

Example 02

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

(a) Is this an *n*-channel or a *p*-channel?

(b) Calculate I_D at $V_{GS} = -3$ V.

(c) Calculate I_D at $V_{GS} = +3$ V.

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

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

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

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

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

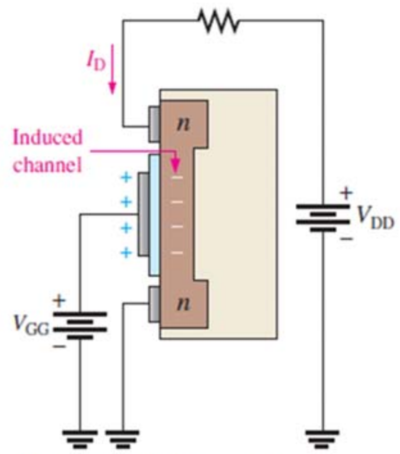
- (a) The device has a negative $V_{GS(off)}$; therefore, it is an ***n*-channel** MOSFET.

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

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

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).

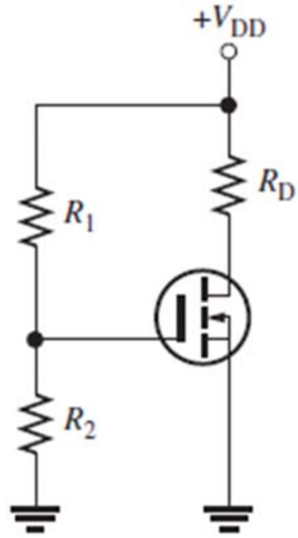


(b) Induced channel ($V_{GS} > V_{GS(th)}$)

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

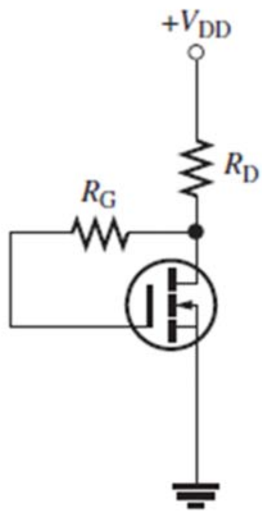
$$V_{DS} = V_{DD} - I_D R_D$$

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



(a) Voltage-divider bias

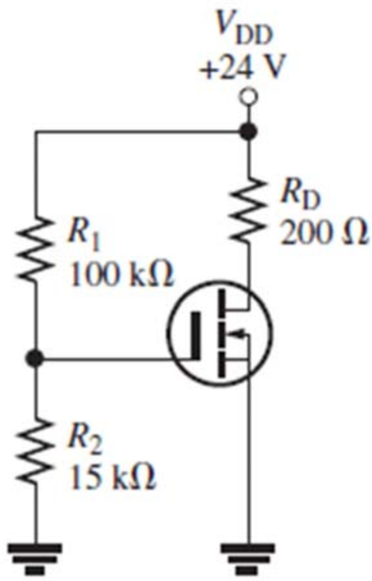
- there is negligible gate current and, therefore, no voltage drop across *R*G.
- This makes *V*GS = *V*DS.



(b) Drain-feedback bias

Example 03

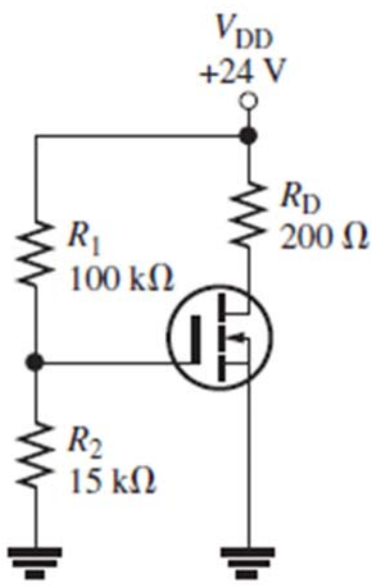
Determine V_{GS} and V_{DS} for the E-MOSFET circuit in Figure '. Assume this particular MOSFET has minimum values of $I_{D(on)} = 200$ mA at $V_{GS} = 4$ V and $V_{GS(th)} = 2$ V.



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

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

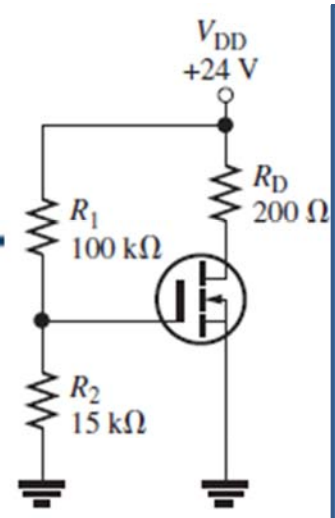
$$V_{GS} = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD} = \left(\frac{15\text{ k}\Omega}{115\text{ k}\Omega}\right)24\text{ V} = \mathbf{3.13\text{ V}}$$



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

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

Determine V_{GS} and V_{DS} $\quad V_{GS} = \mathbf{3.13\ V}$



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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 $V_{GS} = 3.13$ V.

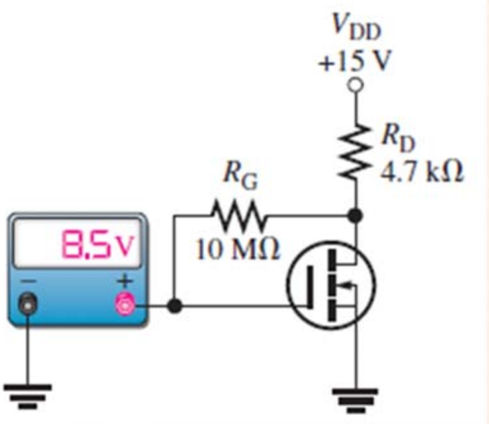
$$I_D = K(V_{GS} - V_{GS(th)})^2 = (50\text{ mA/V}^2)(3.13\text{ V} - 2\text{ V})^2$$
$$= (50\text{ mA/V}^2)(1.13\text{ V})^2 = 63.8\text{ mA}$$

Finally, calculate V_{DS}.

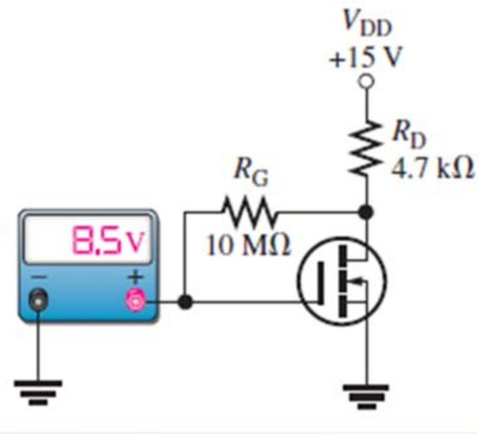
$$V_{DS} = V_{DD} - I_DR_D = 24\text{ V} - (63.8\text{ mA})(200\ \Omega) = \mathbf{11.2\ V}$$

Example 04

Determine the amount of drain current in Figure The MOSFET has a $V_{GS(th)} = 3$ V.



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



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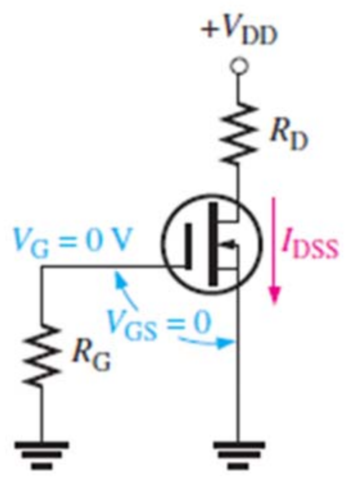
The meter indicates $V_{GS} = 8.5$ V. Since this is a drain-feedback configuration, $V_{DS} = V_{GS} = 8.5$ V.

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

D-MOSFET Bias

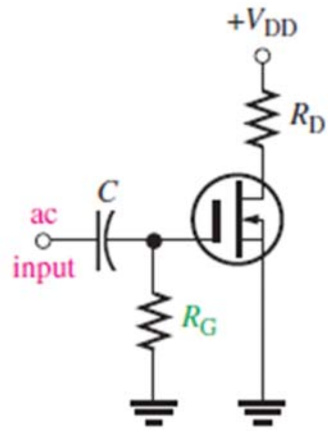


(a)

- 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

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

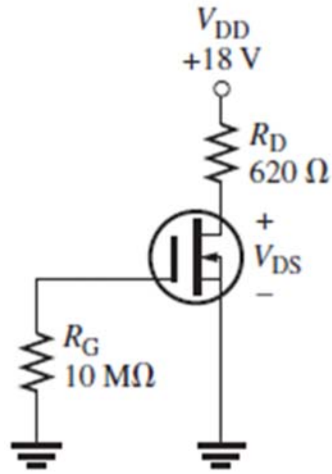
- The purpose of R_G is to accommodate an ac signal input by isolating it from ground



(b)

Example 05

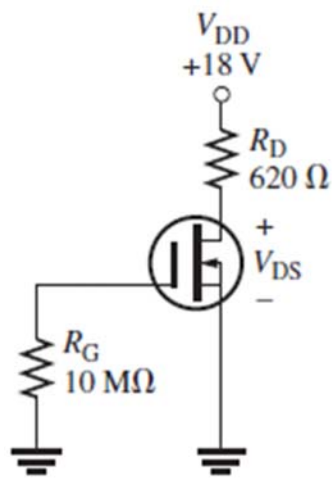
Determine the drain-to-source voltage in the circuit of Figure . The MOSFET datasheet gives $V_{GS(off)} = -8\text{ V}$ and $I_{DSS} = 12\text{ mA}$.



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

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

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



Thanks,..

See you next week (ISA),…