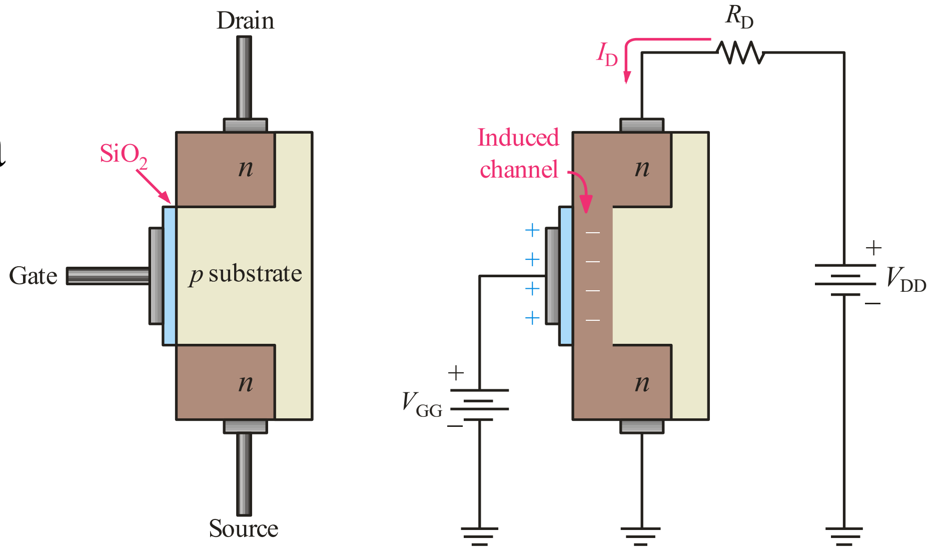
Lecture 11: Field Effect Transistors (FETs) (2)

MOSFET structure, Characteristics and parameters, Biasing of MOSFET, examples

MOSFET Transistor

The metal oxide semiconductor FET uses an insulated gate to isolate the gate from the channel. Two types are the enhancement mode (E-MOSFET) and the depletion mode (D-MOSFET).

E-MOSFET



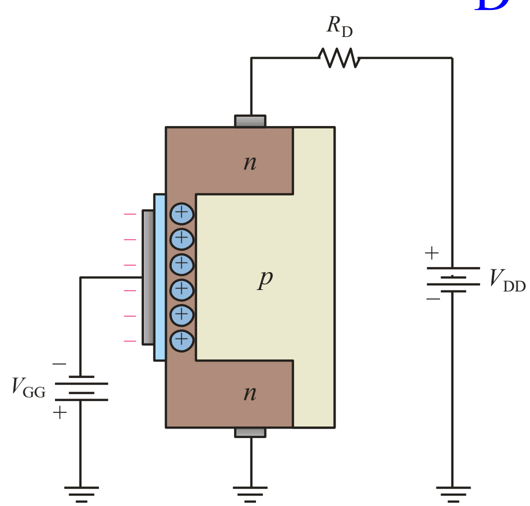
An E-MOSFET has no channel until it is induced by a voltage applied to the gate, so it operates only in enhancement mode. An n-channel type is illustrated here; a positive gate voltage induces the channel.

D-MOSFET

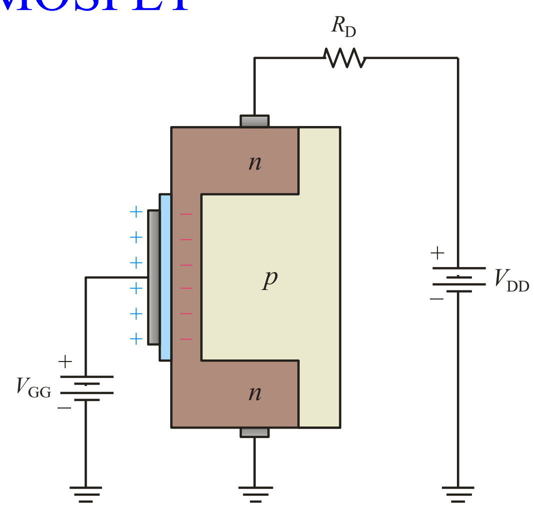
The D-MOSFET has a channel that can be controlled by the gate voltage. For an *n*-channel type, a negative voltage depletes the channel; and a positive voltage enhances the channel.

A D-MOSFET can operate in either mode, depending on the gate voltage.

D-MOSFET



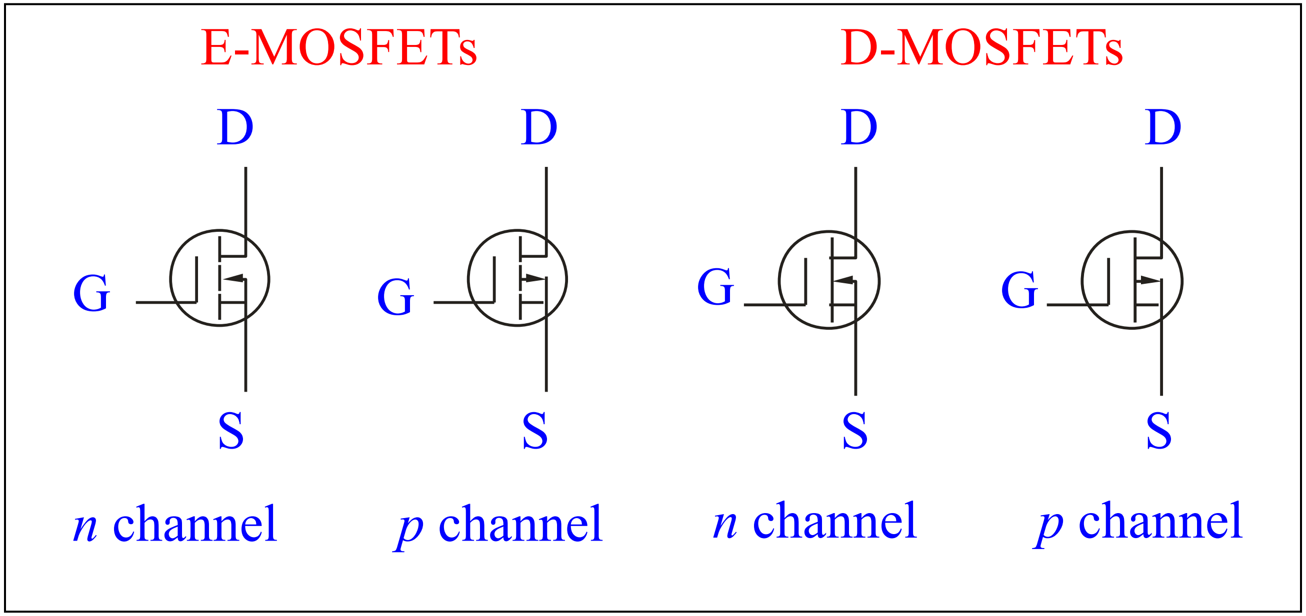
operating in D-mode



operating in E-mode

Circuit Symbols of MOSFETs

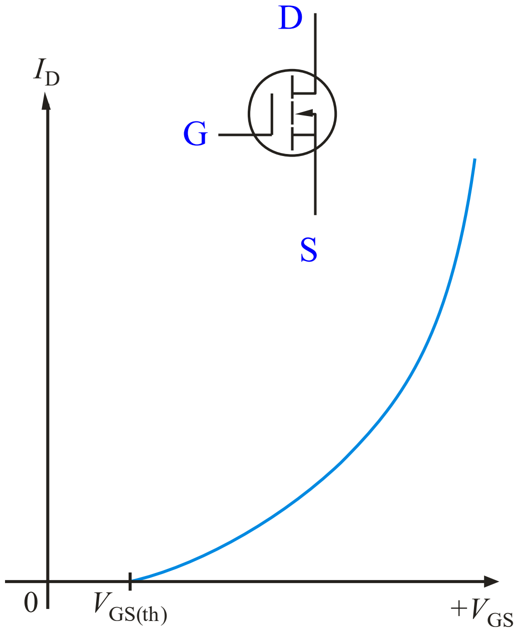
MOSFET symbols are shown. Notice the broken line representing the E-MOSFET that has an induced channel. The *n* channel has an i**n**ward pointing arrow.



Transfer Curves of E-MOSFET

The transfer curve for a MOSFET has the same parabolic shape as the JFET but the position is shifted along the *x*-axis. The transfer curve for an *n*-channel E-MOSFET is entirely in the first quadrant as shown

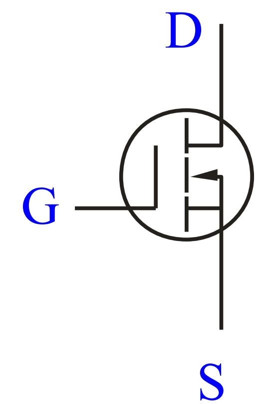
The curve starts at $V_{GS(th)}$, which is a nonzero voltage that is required to have channel conduction. The equation for the drain current is $I_D = K\left(V_{GS} - V_{GS(th)}\right)^2$



Example for E-MOSFET Drain Current

Problem 1: The datasheet for an E-MOSFET gives $I_{D(ON)}$= 500 mA (minimum) at V_{GS}=10 V and $V_{GS(\mathrm{th})}$=1 V. Determine the drain current for V_{GS} = 5 V.

Solution 1:



$$K = \frac{I_{D(ON)}}{\left(V_{GS} - V_{GS(th)}\right)^2}$$

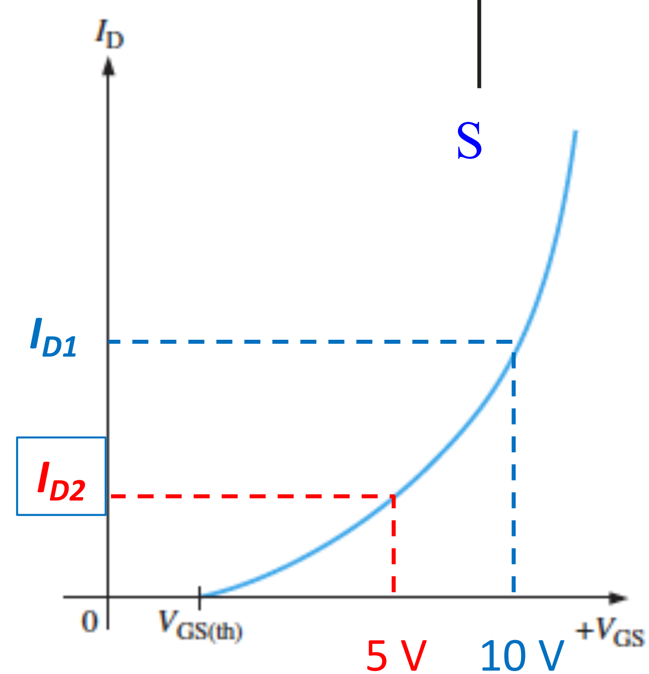
$I_{D(ON)}=I_{D1}$

$$K = \frac{500\ mA}{(10V - 1V)^2} = 6.17\ mA/V^2$$

Using V_{GS}=5 V,

$$I_{D2} = K\left(V_{GS} - V_{GS(th)}\right)^2 = (6.17\ mA/V^2)(5V - 1V)^2$$

$$I_{D2} = (6.17\ mA/V^2)(5V - 1V)^2 = 98.7\ mA$$

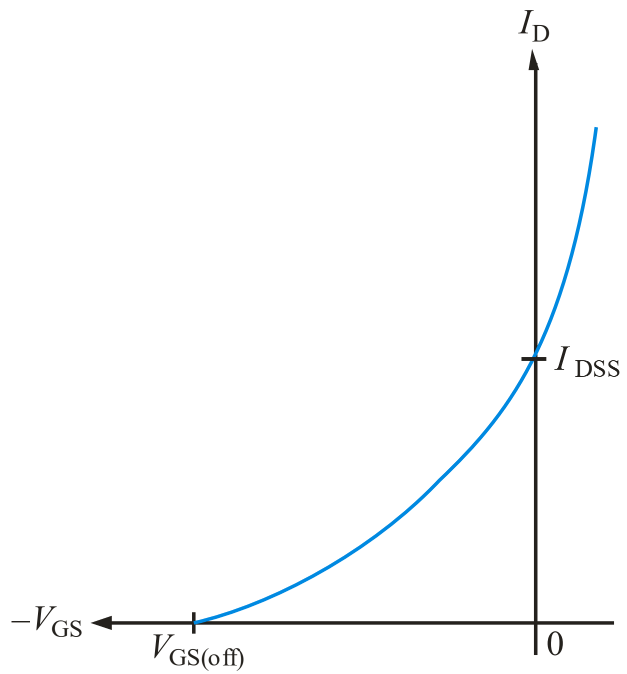


Transfer Curves of D-MOSFET

Recall that the D-MOSFET can be operated in either mode. For the *n*-channel device illustrated, operation to the left of the *y*-axis means it is in depletion mode; operation to the right means is in enhancement mode.

As with the JFET, I_D is zero at $V_{GS(off)}$. When V_{GS} is 0, the drain current is I_{DSS}, which for this device is *not* the maximum current. The equation for drain current is

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



Example for D-MOSFET Drain Current

Problem 2: For a certain D-MOSFET, I_{DSS} =10 mA and $V_{GS(off)}$= − 8V
Is this an n-channel or a p-channel? Calculate I_D at V_{GS}=±3 V.

Solution 2:

This is an n-channel MOSFET because it has negative V_{GS}.

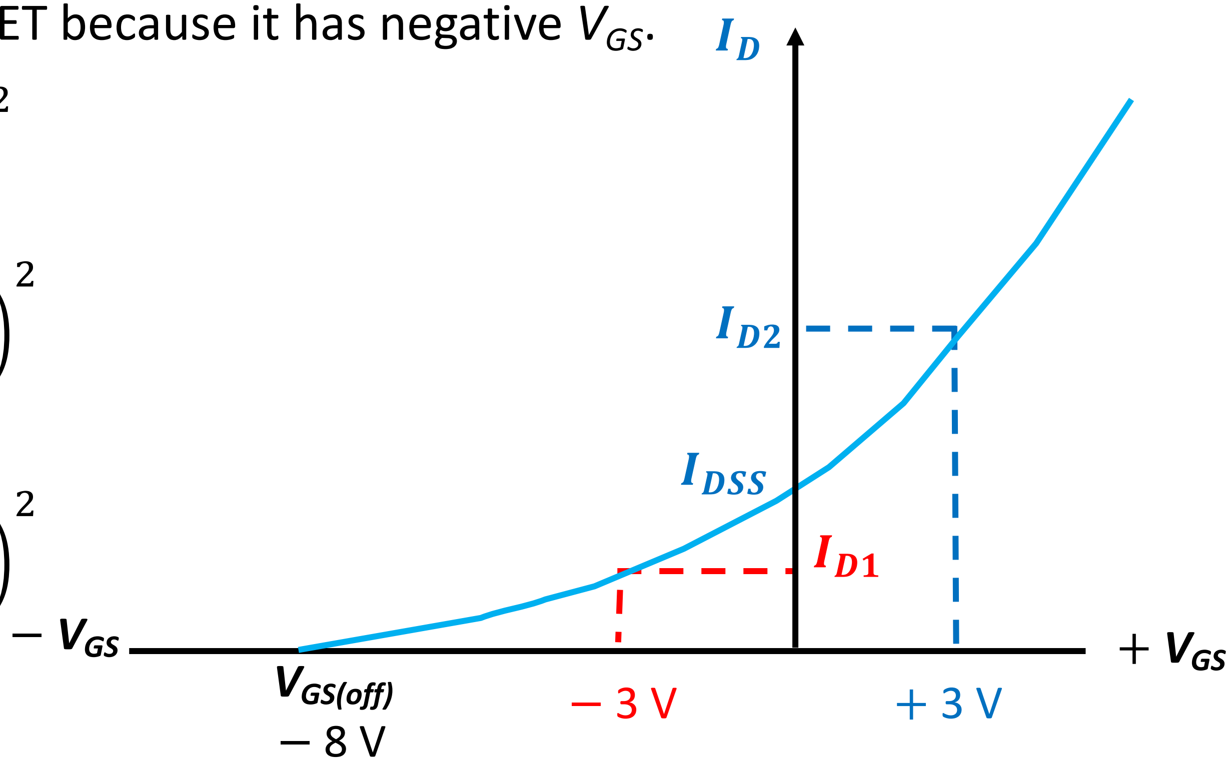
$$I_{D1} = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$$

$$I_{D1} = 10\ mA \times \left(1 - \frac{-3\ V}{-8\ V}\right)^2$$

$$I_{D1} = 3.91\ mA$$

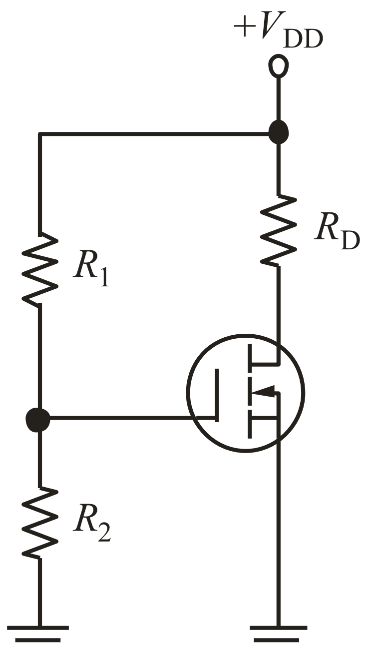
$$I_{D2} = 10\ mA \times \left(1 - \frac{+3\ V}{-8\ V}\right)^2$$

$$I_{D2} = 18.9\ mA$$

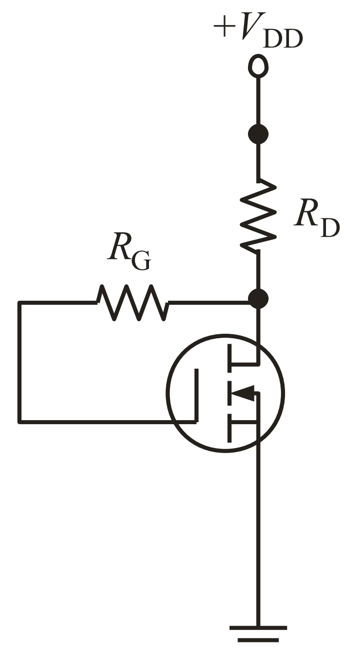


Biasing of E-MOSFET

E-MOSFETs can be biased using bias methods like the JFETS and BJTs. Voltage-divider bias and drain-feedback bias are illustrated for *n*-channel devices.



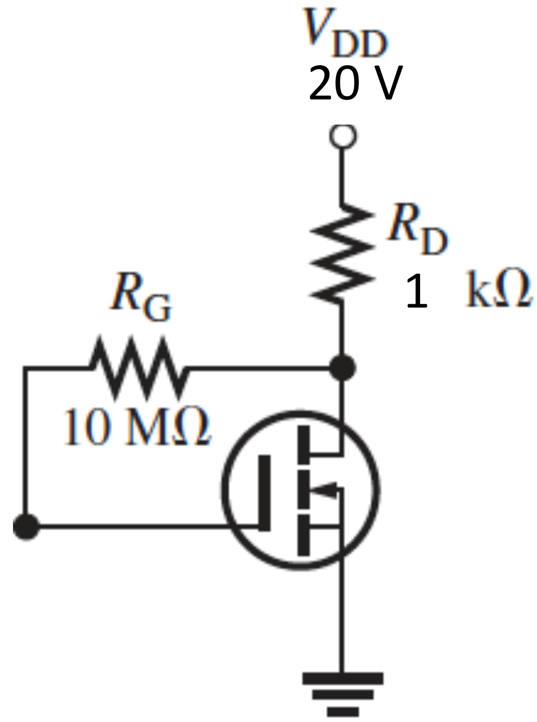
Voltage-divider bias



Drain-feedback bias

Example for Drain Current and V_{DS}

Problem 3: The datasheet for this E-MOSFET shows that I_D= 10 mA when V_{GS}=V_{DS}. Find I_D and V_{DS}.



Solution 3:

Since no current flows in R_G

$$V_{GS} = V_{DS} \quad I_D = 10\ mA$$

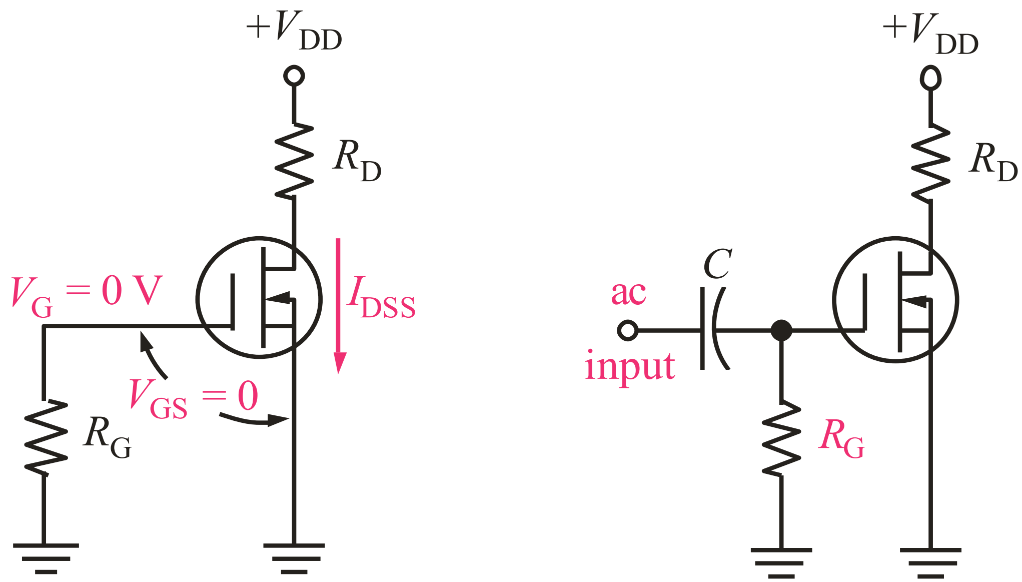
$$V_{DS} = V_{DD} - I_D R_D$$

$$V_{DS} = 20V - 10mA \times 1k\Omega = 10\ V$$

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

Biasing of a D-MOSFET

The simplest way to bias a D-MOSFET is with zero bias. This works because the device can operate in either depletion or enhancement mode, so the gate can go above or below 0 V.



Example for Drain to Source Voltage

Problem 4: Determine the drain-to-source voltage in the given circuit. The MOSFET datasheet gives $V_{GS(off)}$ = -8 V and I_{DSS} = 12 mA.

Solution 4:

No current flows in R_G

$$V_{GS} = 0 \qquad I_D = I_{DSS}$$

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

$$V_{DS} = 18V - 12mA \times 620\Omega = 10.56\,V$$

$$V_{DS} = 10.56\,V$$