Junction Field Effect Transistors

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The JFET

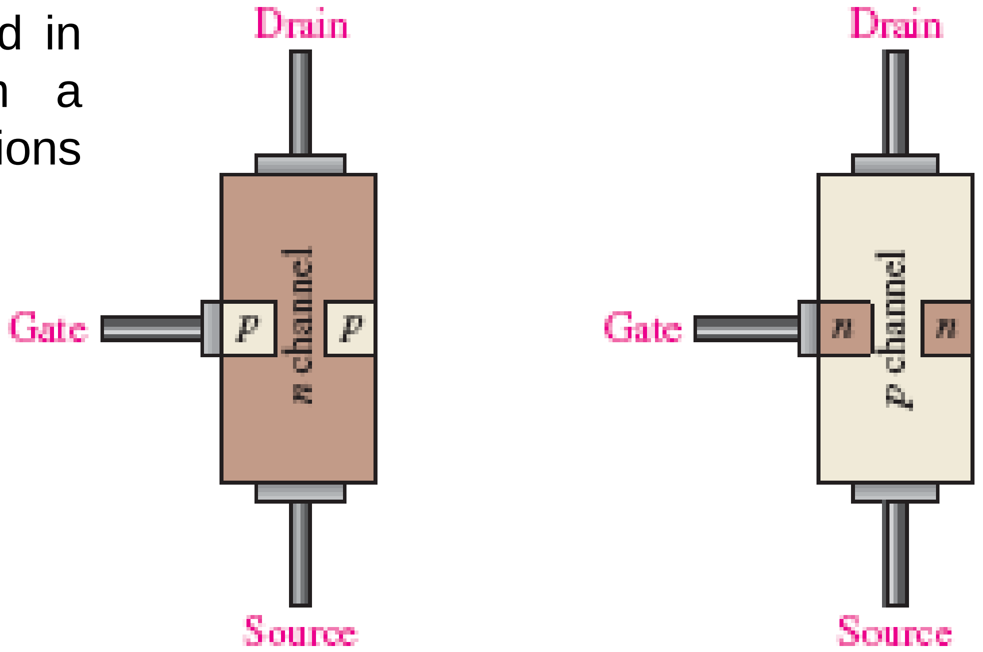
The **JFET (junction field-effect transistor) is a type of FET that operates with a** reverse-biased pn junction to control current in a channel.

Depending on their structure, JFETs fall into either of two categories, n channel or p channel.

Basic Structure

Wire leads are connected to each end of the n-channel; the drain is at the upper end, source is at the lower end.

Two p-type regions are diffused in the n-type material to form a channel, and both p-type regions are connected to the gate lead.

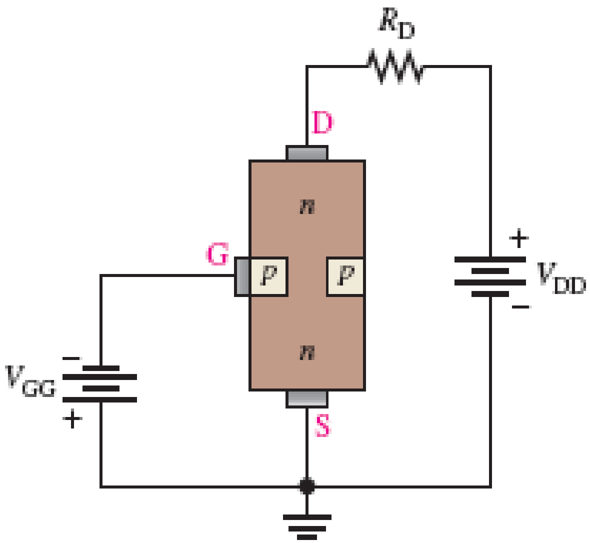


(a) n channel (b) p channel

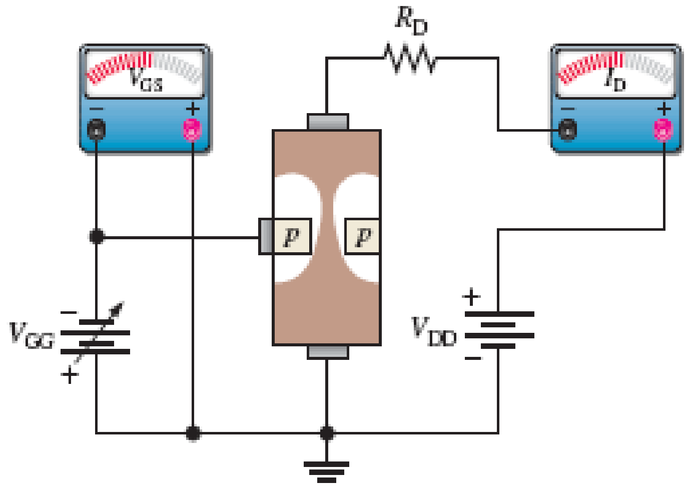
Basic Operation

V_{DD} provides a drain-to-source voltage and supplies current from drain to source.

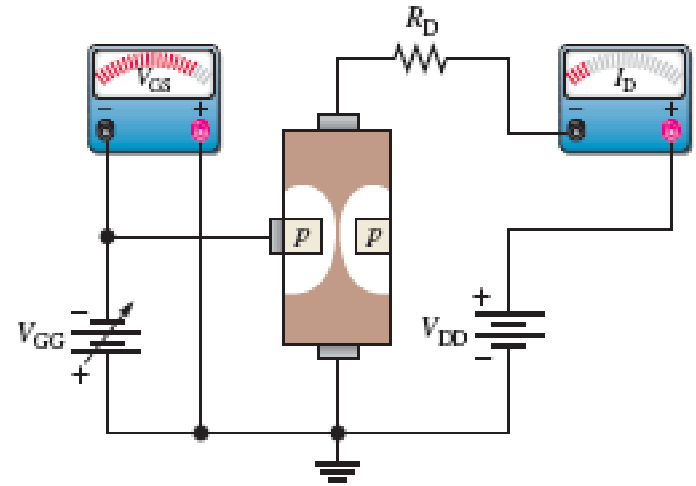
V_{GG} sets the reverse-bias voltage between the gate and the source,



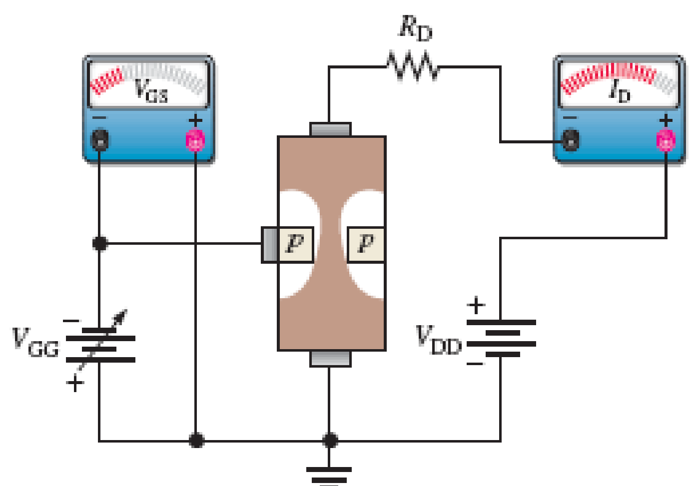
The JFET is always operated with the gate-source pn junction reverse-biased. Reverse biasing of the gate-source junction with a negative gate voltage produces a depletion region along the pn junction, which extends into the n channel and thus increases its resistance by restricting the channel width.



(a) JFET biased for conduction

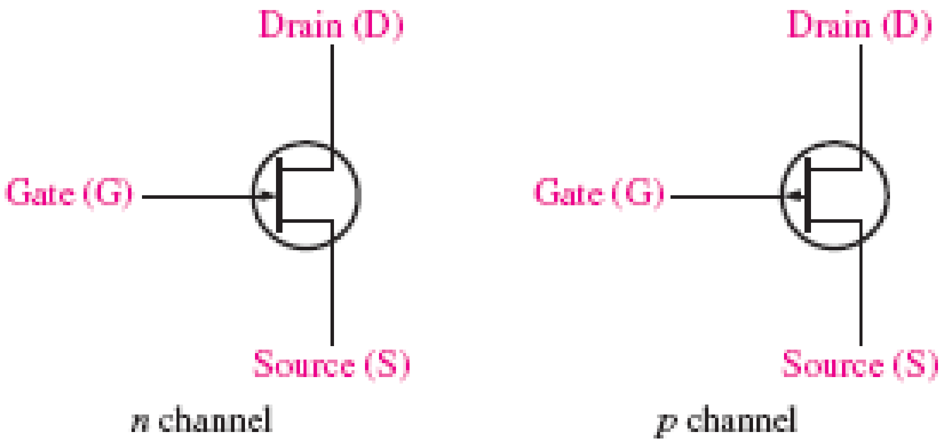


(b) Greater V_{GG} narrows the channel (between the white areas) which increases the resistance of the channel and decreases I_D.



(c) Less V_{GG} widens the channel (between the white areas) which decreases the resistance of the channel and increases I_D.

Circuit Symbols

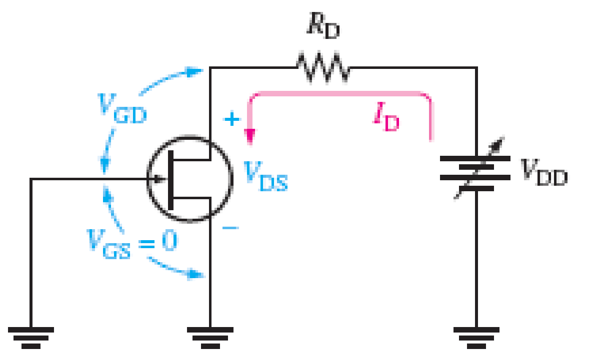


JFET CHARACTERISTICS AND PARAMETERS

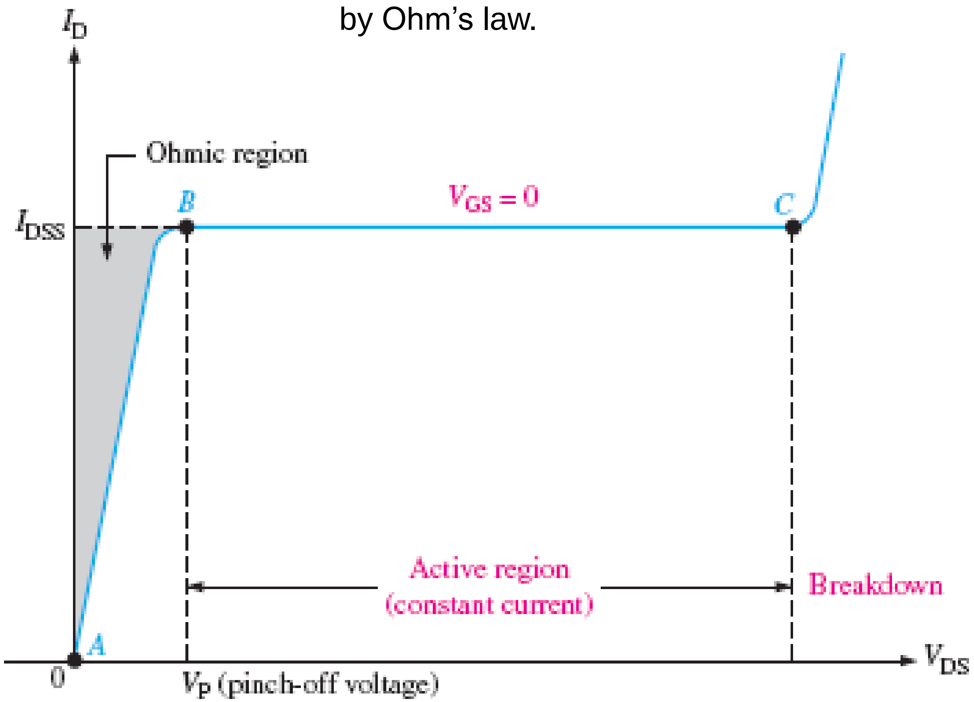
The JFET operates as a voltage-controlled, constant-current device

Drain Characteristic Curve

Between points A and B, the channel resistance is essentially constant because the depletion region is not large enough to have significant effect. This is called the ohmic region because V_{DS} and I_D are related by Ohm's law.



(a) JFET with $V_{GS} = 0$ V and a variable V_{DS} (V_{DD})



(b) Drain characteristic

At point B, the curve levels off and enters the active region where I_D becomes essentially constant.

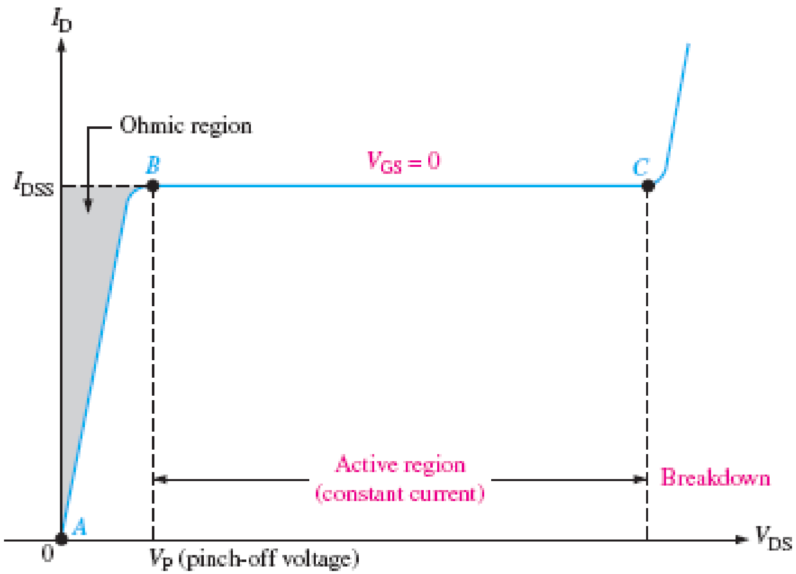
As V_{DS} increases from point B to point C, the reverse-bias voltage from gate to drain (V_{GD}) produces a depletion region large enough to offset the increase in V_{DS}, thus keeping I_D relatively constant.

Pinch-Off Voltage

For V_{GS} 0 V, the value of V_{DS} at which I_D becomes essentially constant (point B on the curve) is the pinch-off voltage, V_P.

For a given JFET, V_P has a fixed value. As you can see, a continued increase in V_{DS} above the pinch-off voltage produces an almost constant drain current. This value of drain current is I_{DSS} (Drain to Source current with gate Shorted) and is always specified on JFET datasheets.

I_{DSS} is the maximum drain current that a specific JFET can produce regardless of the external circuit, and it is always specified for the condition, V_{GS} 0 V.



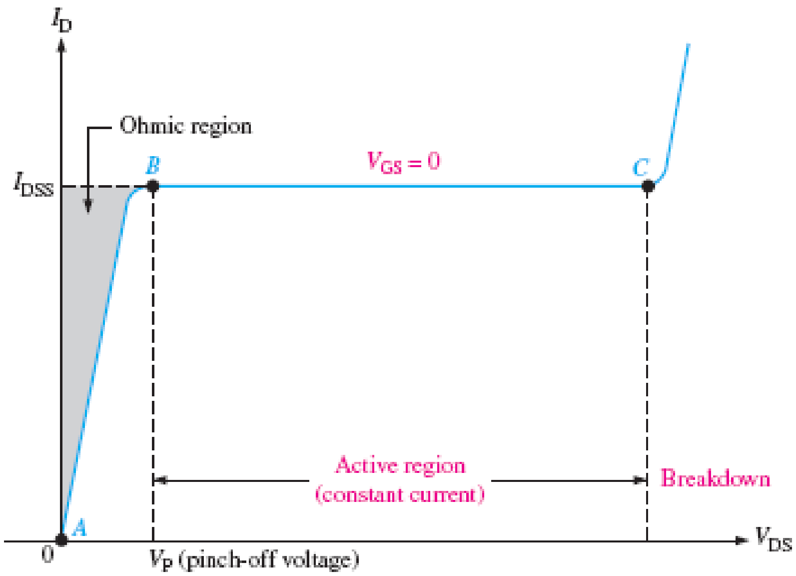
(b) Drain characteristic

Breakdown

As shown in the graph breakdown occurs at point C when I_D begins to increase very rapidly with any further increase in V_{DS}.

Breakdown can result in irreversible damage to the device, so JFETs are always operated below breakdown and within the active region (constant current) (between points B and C on the graph).

The JFET action that produces the drain characteristic curve to the point of breakdown forV_{GS} 0 V is illustrated in Figure.



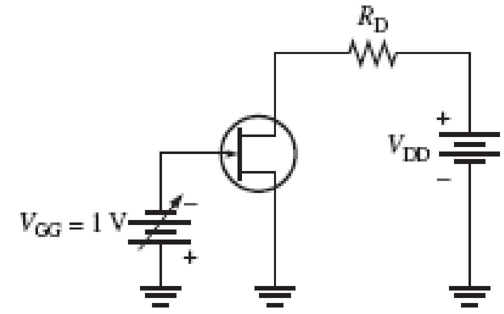
(b) Drain characteristic

V_{GS} Controls I_D

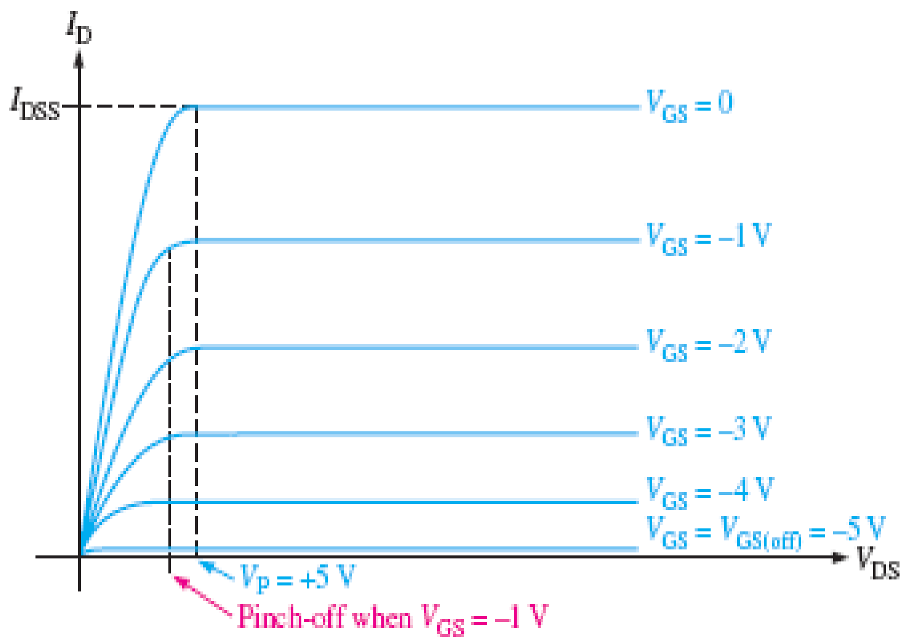
Let's connect a bias voltage, V_{GG}, from gate to source as shown in Figure (a). As V_{GS} is set to increasingly more negative values by adjusting V_{GG}, a family of drain characteristic curves is produced, as shown in Figure (b).

Notice that I_D decreases as the magnitude of V_{GS} is increased to larger negative values because of the narrowing of the channel.

Also notice that, for each increase in V_{GS}, the JFET reaches pinch-off (where constant current begins) at values of V_{DS} less than V_P. The term pinch-off is not the same as pinchoff voltage, V_p. Therefore, the amount of drain current is controlled by V_{GS}.



(a) JFET biased at $V_{GS} = -1$ V

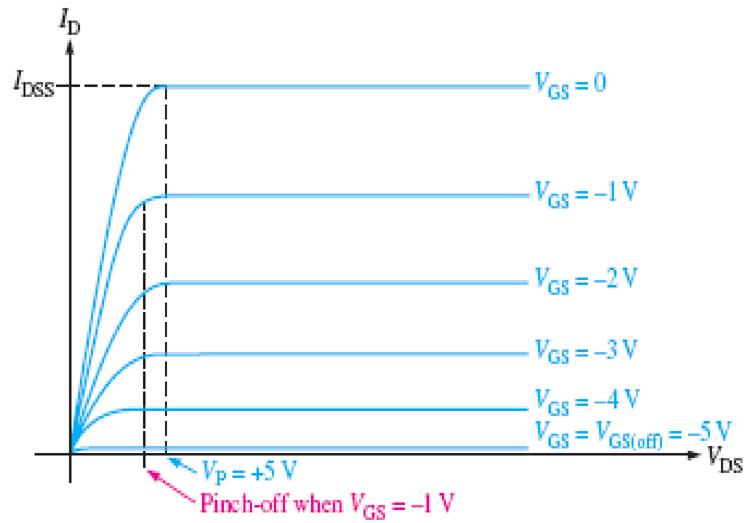


(b) Family of drain characteristic curves

Cutoff Voltage

The value of VGS that makes I_D approximately zero is the **cutoff voltage, VGS(off).**

The JFET must be operated between V_{GS} 0 V and $V_{GS(off)}$. For this range of gate-to-source voltages, I_D will vary from a maximum of I_{DSS} to a minimum of almost zero.



(b) Family of drain characteristic curves

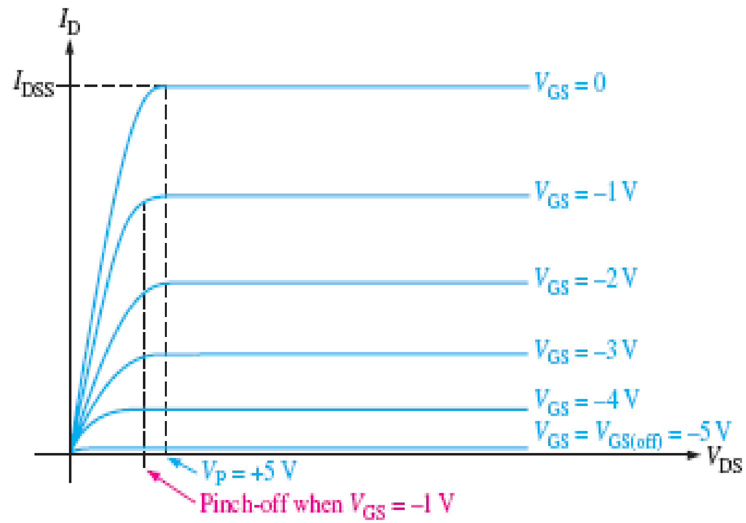
Comparison of Pinch-Off Voltage and Cutoff Voltage

There is a difference between pinch-off and cutoff voltages.

There is also a connection. The pinch-off voltage V_P is the value of V_{DS} at which the drain current becomes constant and equal to I_{DSS} and is always measured at $V_{GS} = 0$ V. However, pinch-off occurs for V_{DS} values less than V_P when V_{GS} is nonzero. So, although V_P is a constant, the minimum value of V_{DS} at which I_D becomes constant varies with V_{GS}.

$V_{GS(off)}$ and V_P are always equal in magnitude but opposite in sign.

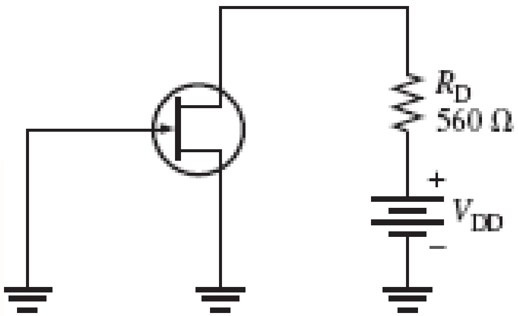
A datasheet usually will give either $V_{GS(off)}$ or V_P, but not both. However, when you know one, you have the other. For example, if $V_{GS(off)} = -5V$, then $V_P = +5$ V as shown in Figure.



(b) Family of drain characteristic curves

Example

For the JFET in Figure, $V_{GS(off)}$ = -4V and I_{DSS} = 12mA. Determine the minimum value of V_{DD} required to put the device in the constant-current region of operation when V_{GS} = 0 V.



Since $V_{GS(off)} = -4\text{ V}$, $V_P = 4\text{ V}$. The minimum value of V_{DS} for the JFET to be in its constant-current region is

$$V_{DS} = V_P = 4\text{ V}$$

In the constant-current region with $V_{GS} = 0\text{ V}$,

$$I_D = I_{DSS} = 12\text{ mA}$$

The drop across the drain resistor is

$$V_{R_D} = I_D R_D = (12\text{ mA})(560\ \Omega) = 6.72\text{ V}$$

Apply Kirchhoff's law around the drain circuit.

$$V_{DD} = V_{DS} + V_{R_D} = 4\text{ V} + 6.72\text{ V} = \mathbf{10.7\text{ V}}$$

This is the value of V_{DD} to make $V_{DS} = V_P$ and put the device in the constant-current region.