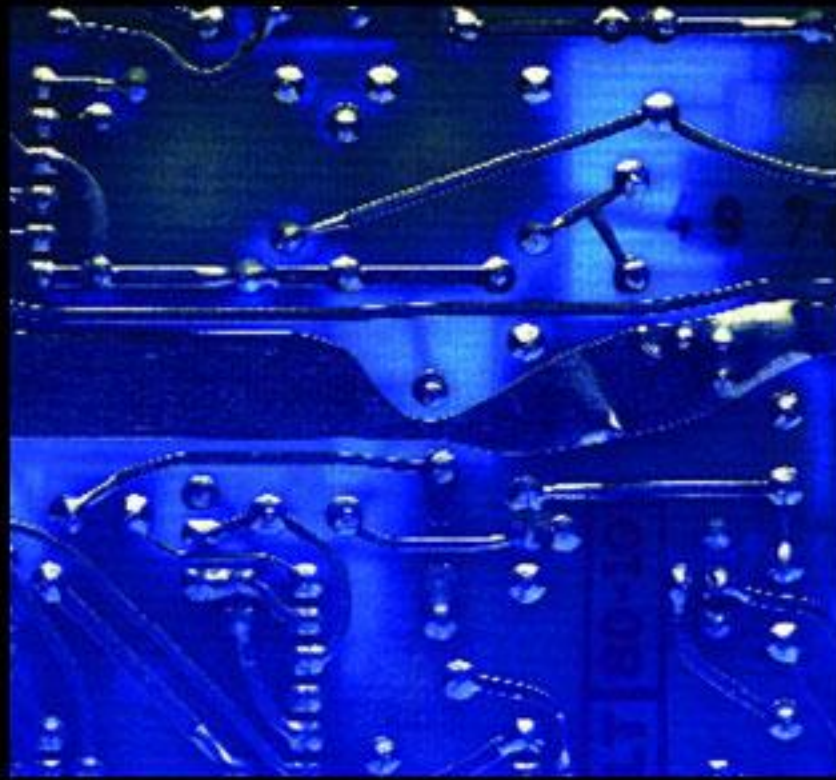
ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION

BOYLESTAD



PEARSON

Chapter 6:
Field-Effect Transistors

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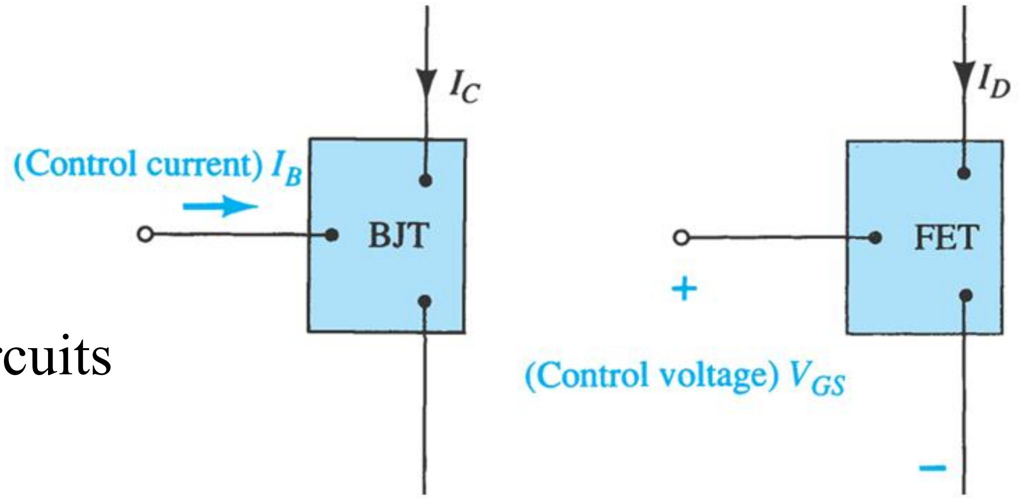
FETs vs. BJTs



Similarities:

- Amplifiers
- Switching devices
- Impedance matching circuits

Differences:

- FETs are voltage controlled devices. BJTs are current controlled devices.
- FETs have a higher input impedance. BJTs have higher gains.
- FETs are less sensitive to temperature variations and are more easily integrated on ICs.

FET Types

- **JFET:** Junction FET
- **MOSFET:** Metal–Oxide–Semiconductor FET
  - **D-MOSFET:** Depletion MOSFET
  - **E-MOSFET:** Enhancement MOSFET

JFET Construction

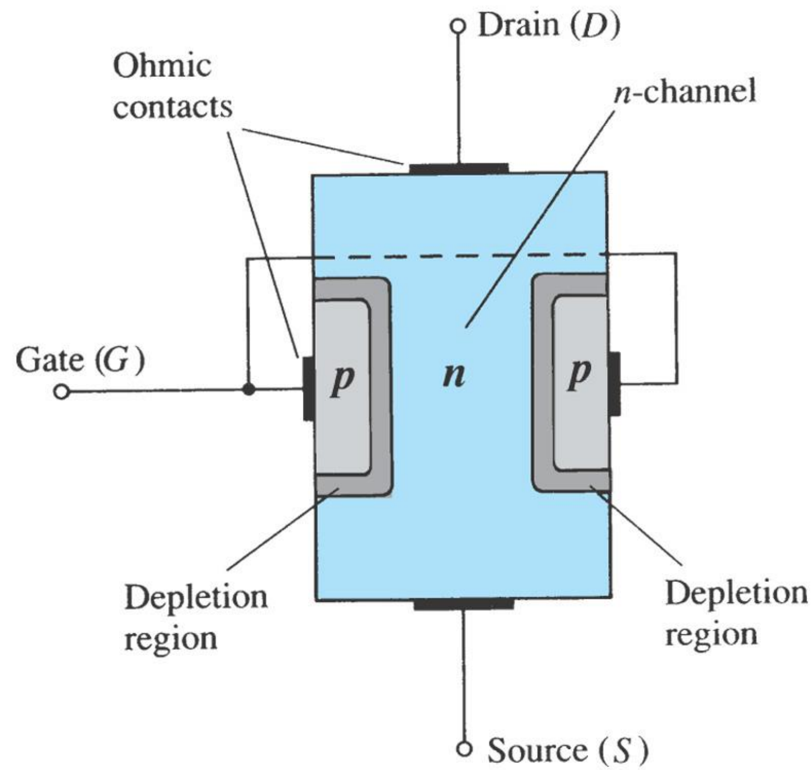
There are two types of JFETs

- ***n*-channel**
- ***p*-channel**

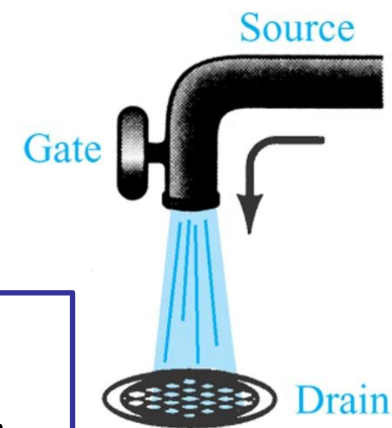
The n-channel is more widely used.

There are three terminals:

- **Drain (D) and Source (S) are connected to the *n*-channel**
- **Gate (G) is connected to the *p*-type material**



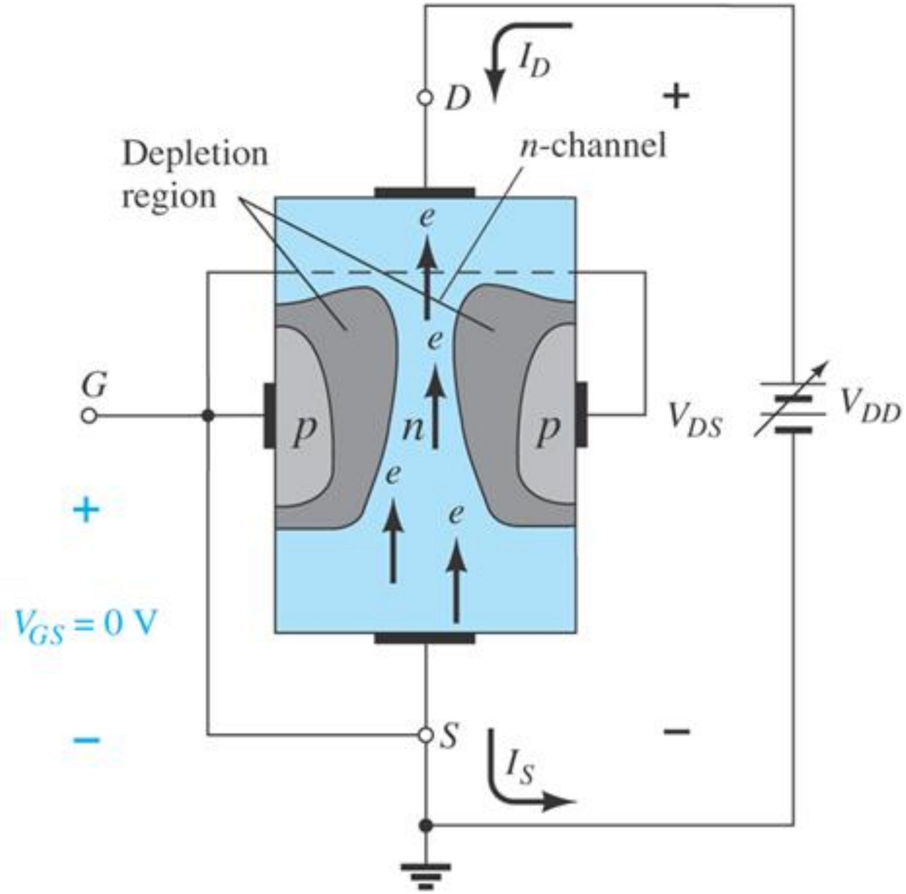
Water analogy for the JFET control mechanism.



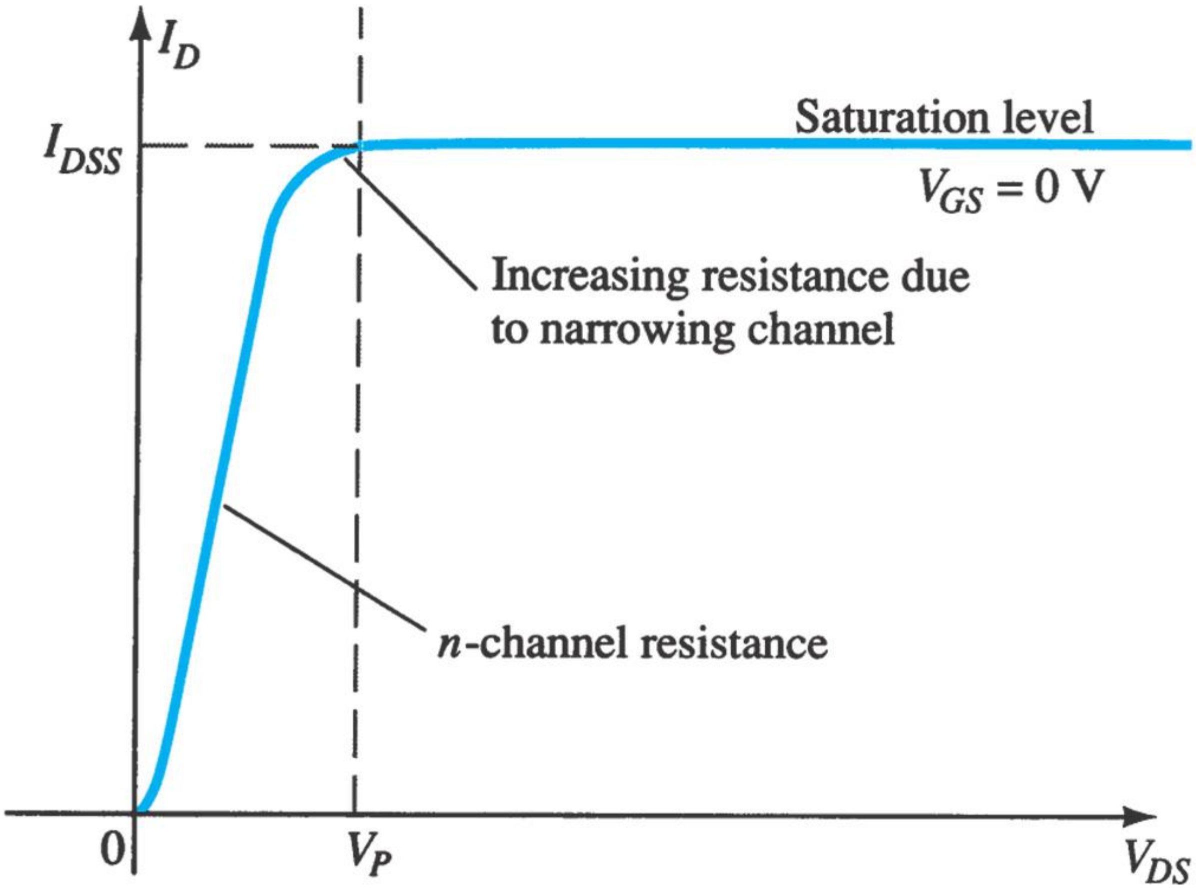
JFET Operating Characteristics: $V_{GS} = 0$ V , V_{DS} some positive value

When $V_{GS} = 0$ and V_{DS} is increased from 0 to a more positive voltage:

- The depletion region between p-gate and n-channel increases.
- Increasing the depletion region, decreases the size of the n-channel which increases the resistance of the n-channel.
- Even though the n-channel resistance is increasing, the current (I_D) from source to drain through the n-channel is increasing. This is because V_{DS} is increasing.



JFET Operating Characteristics:
V_{GS} = 0 V , V_{DS} some positive value

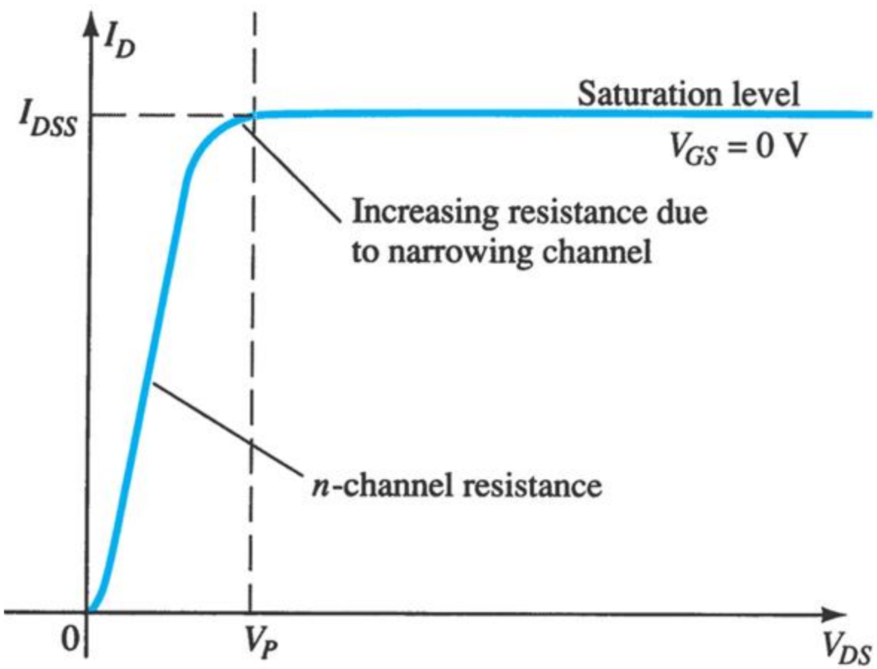


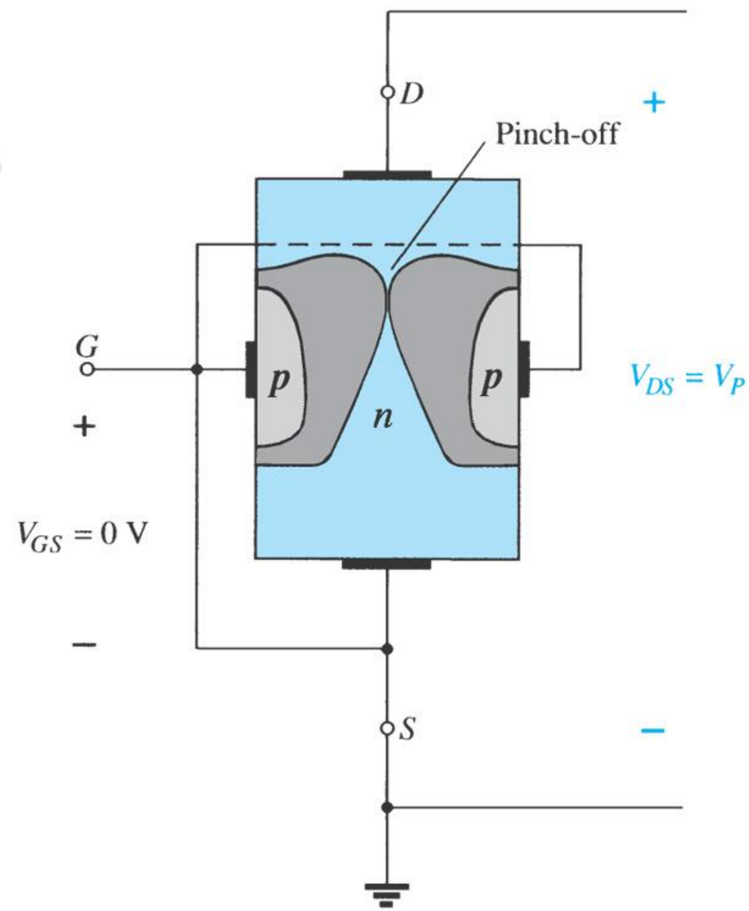
I_D versus V_{DS} for V_{GS} = 0 V.

JFET Operating Characteristics: Pinch Off

If $V_{GS} = 0$ and V_{DS} is further increased to a more positive voltage, then the depletion zone gets so large that it pinches off the n-channel.

As V_{DS} is increased beyond $|V_P|$, the level of I_D remains the same ($I_D = I_{DSS}$).

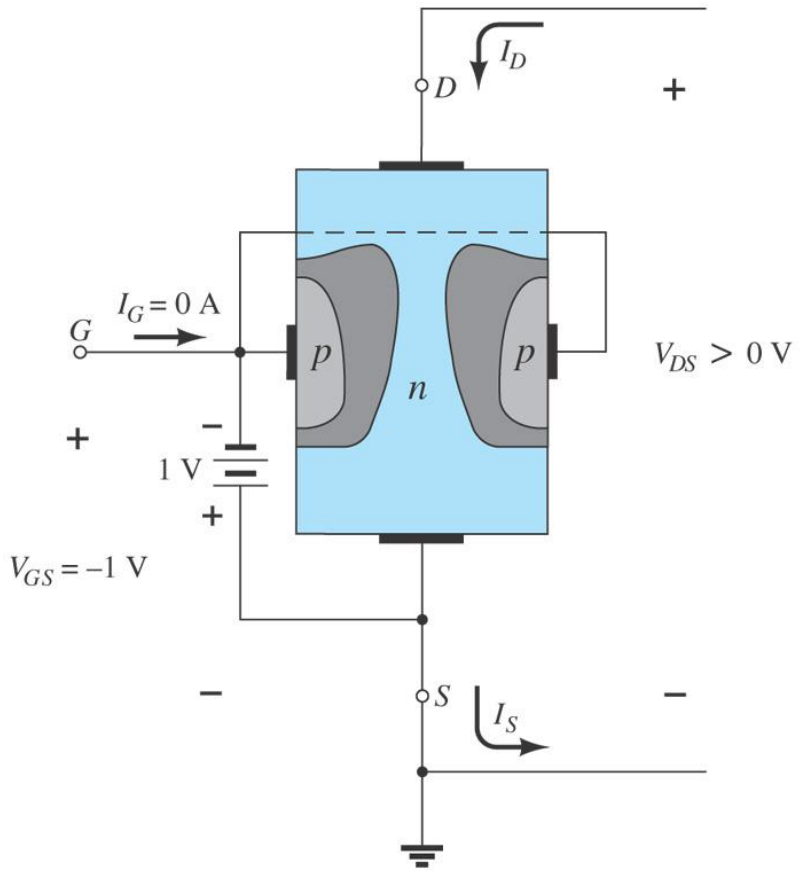




I_{DSS} is the maximum drain current for a JFET and is defined by the conditions V_{GS}=0 and $V_{DS} > |V_P|$.

JFET Operating Characteristics , $V_{GS}<0$

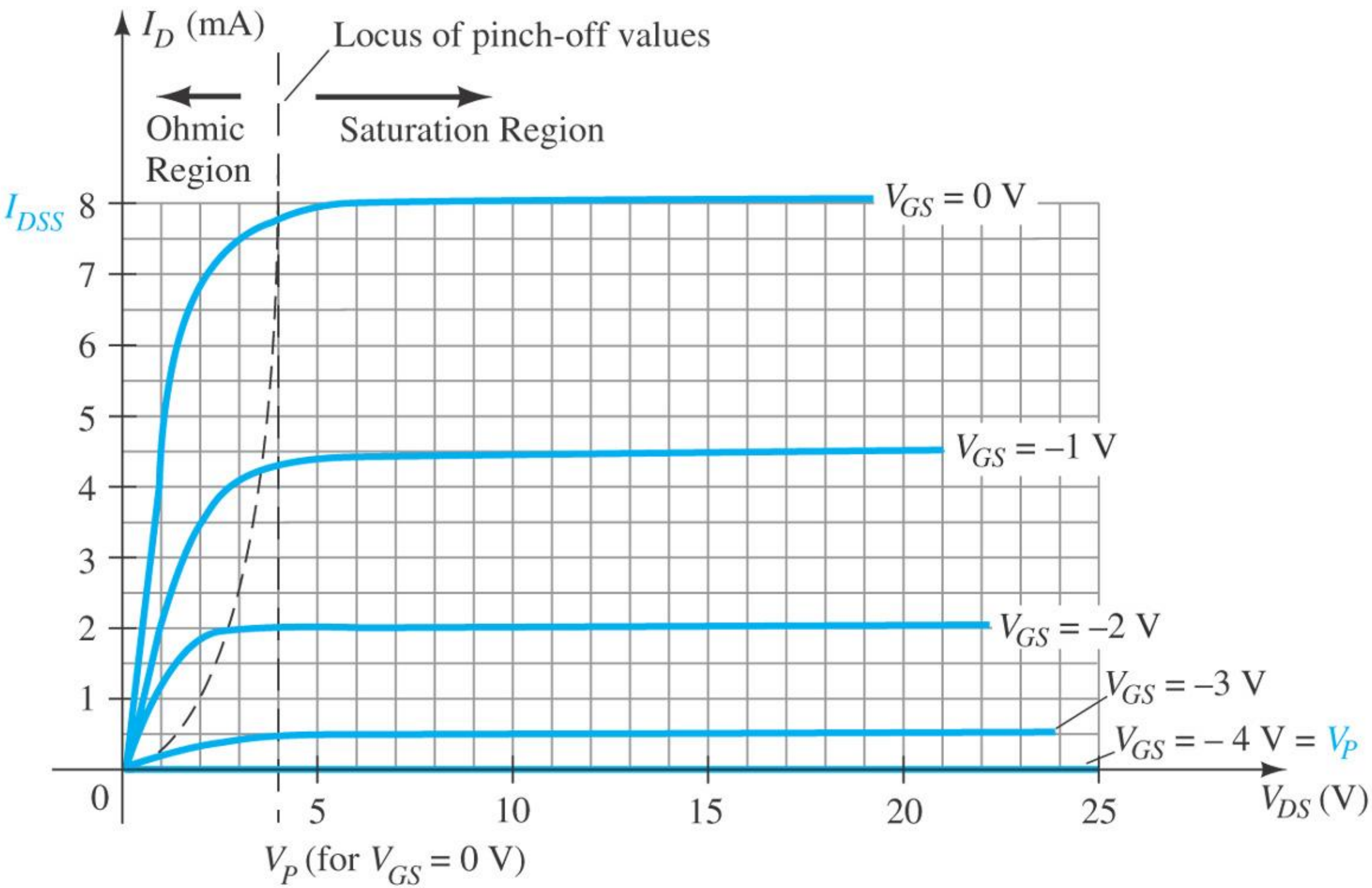
- As V_{GS} becomes more negative, the depletion region increases.
- The more negative V_{GS}, the resulting level for I_D is reduced.
- Eventually, when $V_{GS}=V_P$ (-ve) [$V_P=\mathbf{V_{GS(off)}}$], I_D is 0 mA. (the device is "***turned off***".



- The level of V_{GS} that results in I_D=0 mA is defined by $V_{GS}=V_P$, with V_P being a negative voltage for n-channel devices and a positive voltage for p-channel JFETs.

Application of a negative voltage to the gate of a JFET.

JFET Operating Characteristics

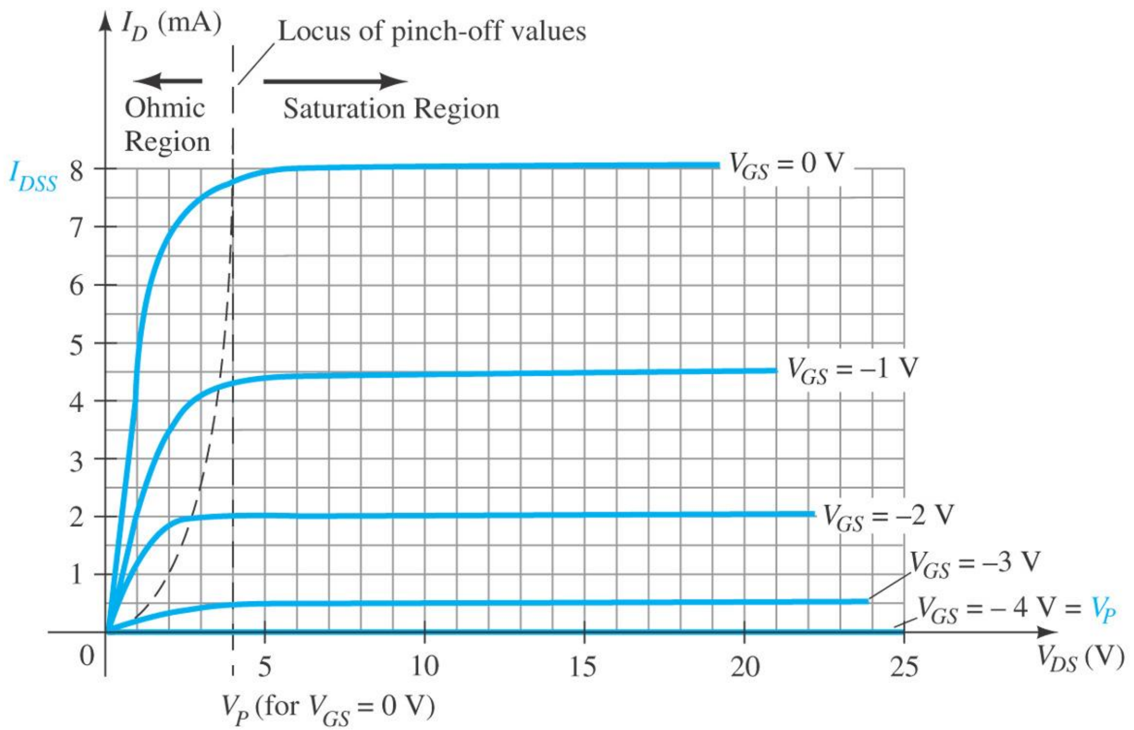


n-Channel JFET characteristics with I_{DSS} = 8 mA and V_P = -4 V.

JFET Operating Characteristics: Voltage-Controlled Resistor

•The region to the left of the pinch-off point is called the ohmic region.

•The JFET can be used as a variable resistor, where V_{GS} controls the drain-source resistance (r_d). As V_{GS} becomes more negative, the resistance (r_d) increases.

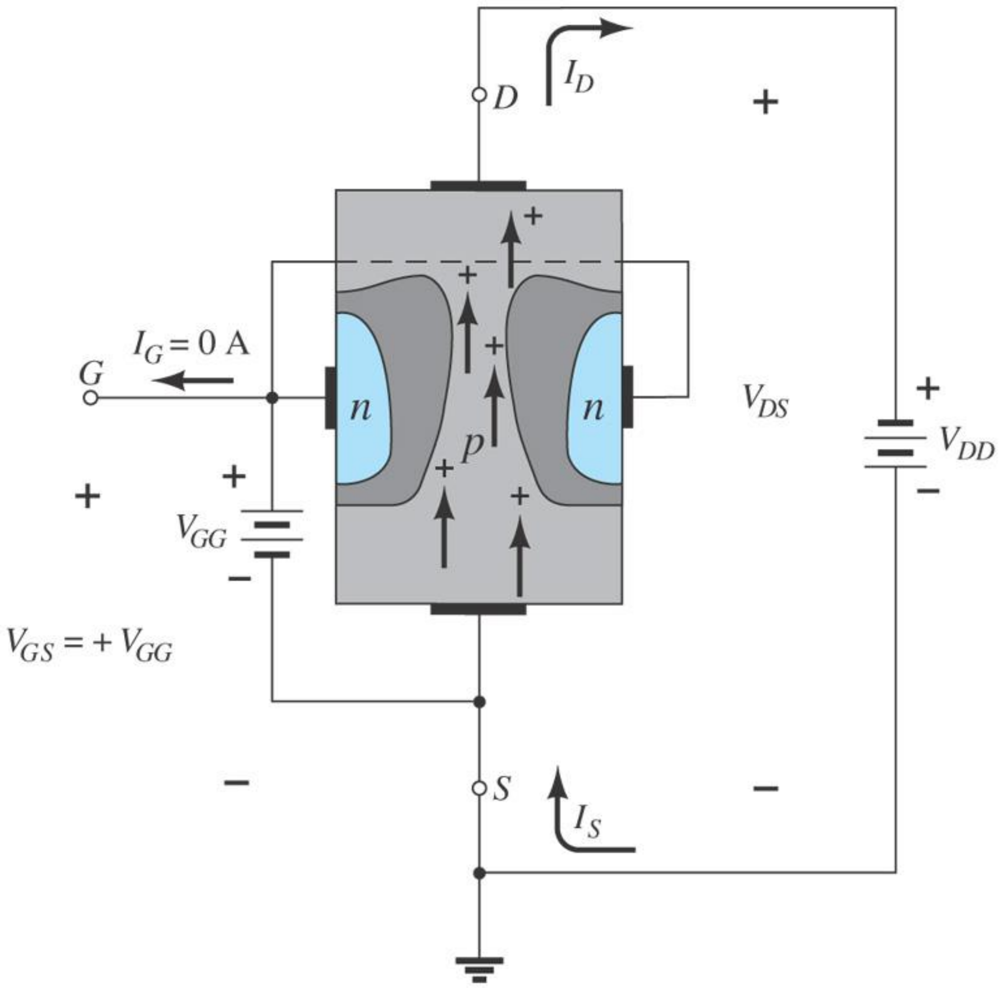


$$r_d = \frac{r_o}{\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

where r_o is the resistance with $V_{GS}=0$ and r_d is the resistance at a particular level of V_{GS}.

p-Channel JFETS

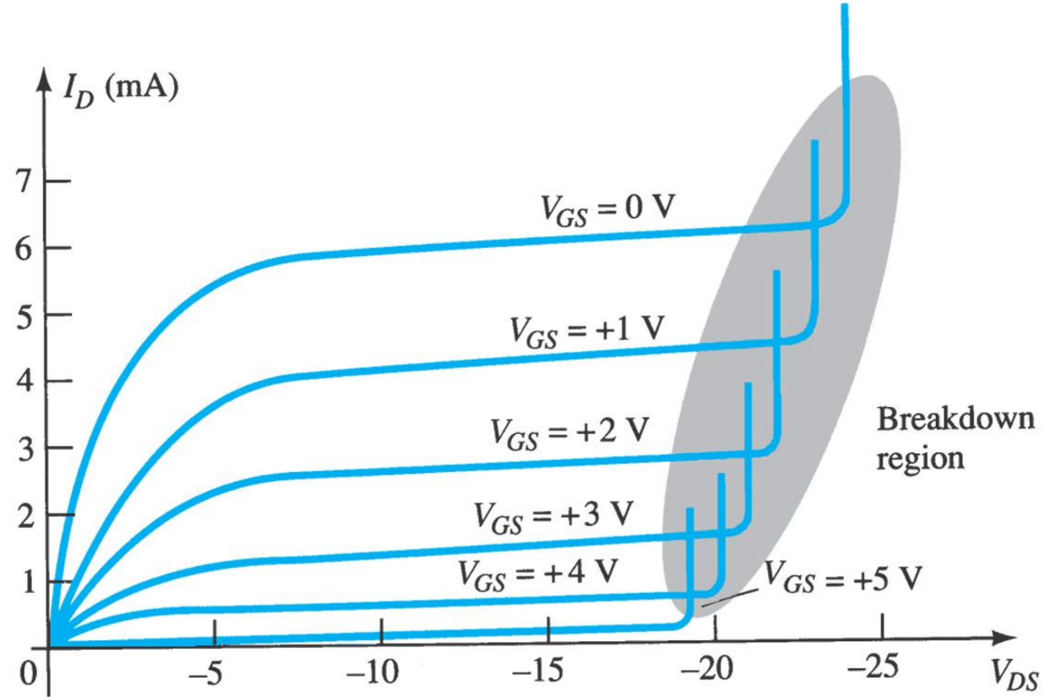
The *p*-channel JFET behaves the same as the *n*-channel JFET, except the voltage polarities and current directions are reversed.



p-Channel JFET Characteristics

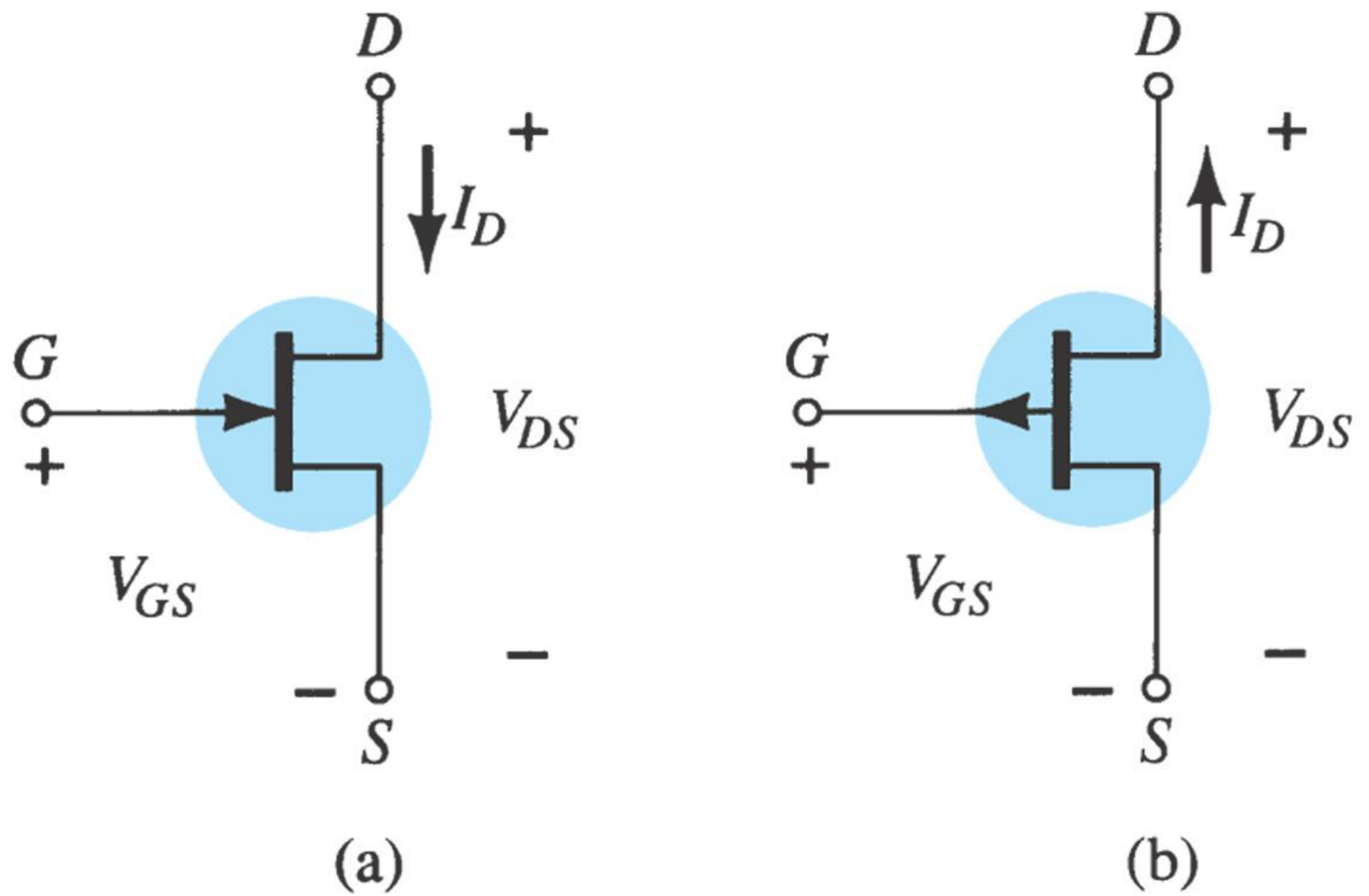
As V_{GS} increases more positively

- The depletion zone increases
- I_D decreases ($I_D < I_{DSS}$)
- Eventually $I_D = 0$ A

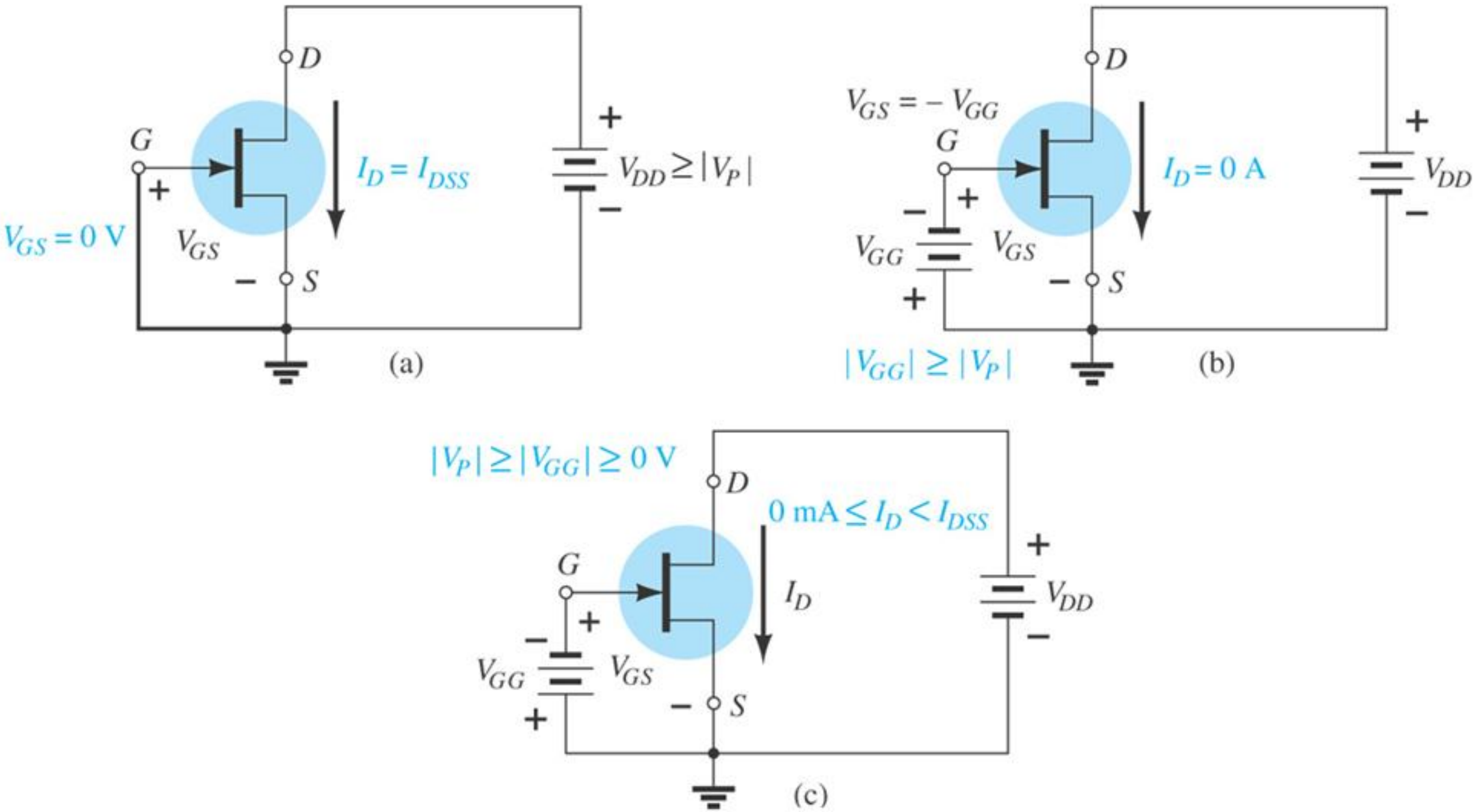


Also note that at high levels of V_{DS} the JFET reaches a breakdown situation: I_D increases uncontrollably if $V_{DS} > V_{DSmax}$.

JFET Symbols



JFET symbols: (a) n-channel; (b) p-channel.



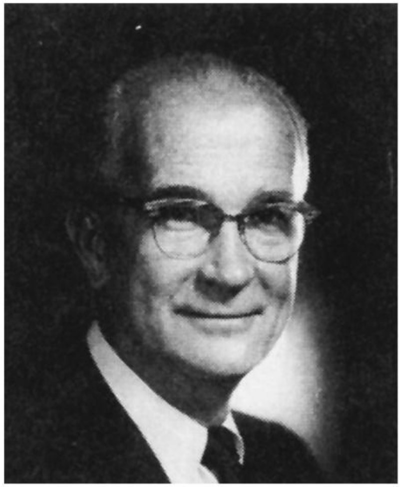
(a) $V_{GS} = 0$ V, $I_D = I_{DSS}$; (b) cutoff ($I_D = 0$ A) V_{GS} less than (more negative than) the pinch-off level; (c) I_D is between 0 A and I_{DSS} for $V_{GS} \leq 0$ V and greater than the pinch-off level.

JFET Transfer Characteristics

In a BJT, β indicates the relationship between I_B (input) and I_C (output).

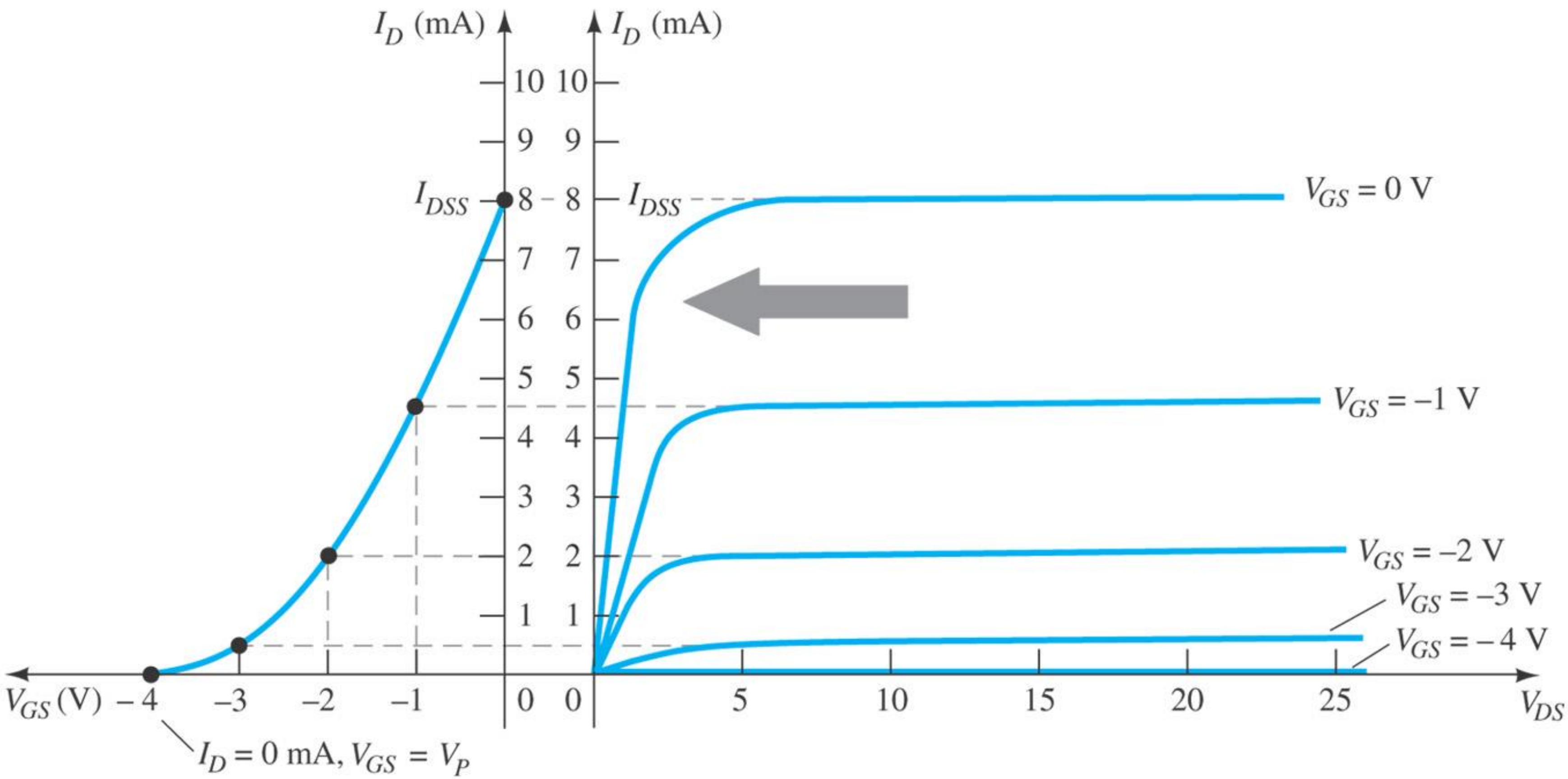
In a JFET, the relationship of V_{GS} (input) and I_D (output) is a little more complicated (*Shockley's equation*):

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



William Bradford Shockley
(1910–1989)

JFET Transfer Curve



This graph shows the value of I_D for a given value of V_{GS}.

Plotting the JFET Transfer Curve

Using I_{DSS} and Vp ($V_{GS(off)}$) values found in a specification sheet, the transfer curve can be plotted according to these three steps:

Step 1

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

Solving for $V_{GS} = 0V$ $\quad$ $I_D = I_{DSS}$

Step 2

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

Solving for $V_{GS} = V_p$ ($V_{GS(off)}$) $\quad$ $I_D = 0A$

Step 3

Solving for $V_{GS} = 0V$ to V_p $\quad$ $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

i.e. For $V_{GS} = -1$ V $\quad$ $I_D = 8mA\left(1 - \frac{-1}{-4}\right)^2 = 4.5\text{mA}$

Conversely , for a given I_D, V_{GS} can be obtained:

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$

Example 6.1

Sketch the transfer curve defined by I_{DSS}=12 mA and V_P=-6V.

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

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$