Example 13-1

A 2N5486 JFET has a gate current of 1 nA when the reverse gate voltage is 20 V. What is the input resistance of this JFET?

SOLUTION Use Ohm's law to calculate:

$$R_{in} = \frac{20\text{ V}}{1\text{ nA}} = 20{,}000\text{ M}\Omega$$

PRACTICE PROBLEM 13-1 In Example 13-1, calculate the input resistance if the JFET's gate current is 2 nA.

13-2 Drain Curves

Figure 13-4*a* shows a JFET with normal biasing voltages. In this circuit, the gate-source voltage V_{GS} equals the gate supply voltage V_{GG}, and the drain-source voltage V_{DS} equals the drain supply voltage V_{DD}:

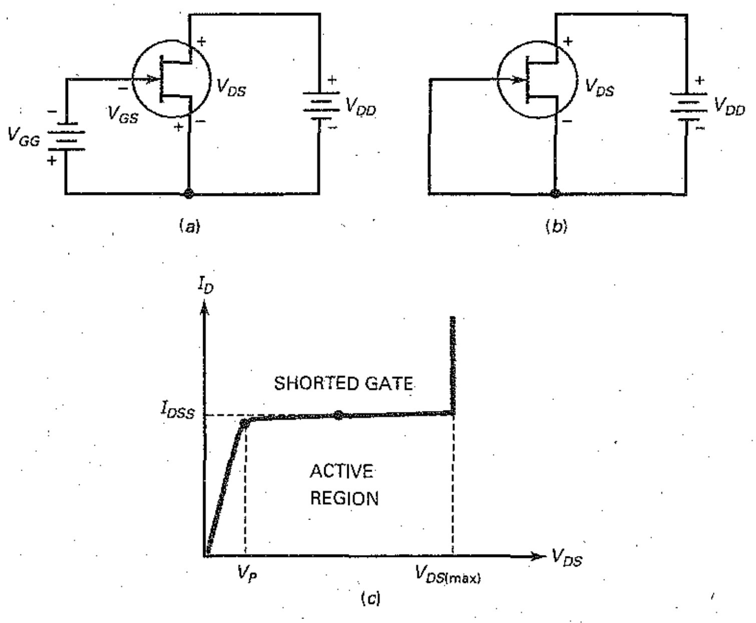
Maximum Drain Current

If we short the gate to the source, as shown in Fig. 13-4*b*, we will get maximum drain current because $V_{GS} = 0$. Figure 13-4*c* shows the graph of drain current I_D versus drain-source voltage V_{DS} for this shorted-gate condition. Notice how the drain current increases rapidly and then becomes almost horizontal when V_{DS} is greater than V_P.

GOOD TO KNOW

The pinchoff voltage V_P is the point at which further increases in V_{DS} are offset by a proportional increase in the channel's resistance. This means that if the channel resistance is increasing in direct proportion to V_{DS} above V_P, I_D must remain the same above V_P.

Figure 13-4 (*a*) Normal bias; (*b*) zero gate voltage; (*c*) shorted gate drain current.



Why does the drain current become almost constant? When V_{DS} increases, the depletion layers expand. When $V_{DS} = V_P$, the depletion layers are almost touching. The narrow conducting channel therefore pinches off or prevents a further increase in current. This is why the current has an upper limit of I_{DSS}.

The active region of a JFET is between V_P and $V_{DS(max)}$. The minimum voltage V_P is called the **pinchoff voltage,** and the maximum voltage $V_{DS(max)}$ is the *breakdown voltage.* Between pinchoff and breakdown, the JFET acts like a current source of approximately I_{DSS} when $V_{GS} = 0$.

I_{DSS} stands for the current drain to source with a shorted gate. This is the maximum drain current a JFET can produce. The data sheet of any JFET lists the value of I_{DSS}. This is one of the most important JFET quantities, and you should always look for it first because it is the upper limit on the JFET current.

The Ohmic Region

In Fig. 13-5, the pinchoff voltage separates two major operating regions of the JFET. The almost-horizontal region is the active region. The almost-vertical part of the drain curve below pinchoff is called the **ohmic region.**

When operated in the ohmic region, a JFET is equivalent to a resistor with a value of approximately:

$$R_{DS} = \frac{V_P}{I_{DSS}} \tag{13-1}$$

R_{DS} is called the *ohmic resistance of the JFET.* In Fig. 13-5, $V_P = 4$ V and $I_{DSS} = 10$ mA. Therefore, the ohmic resistance is:

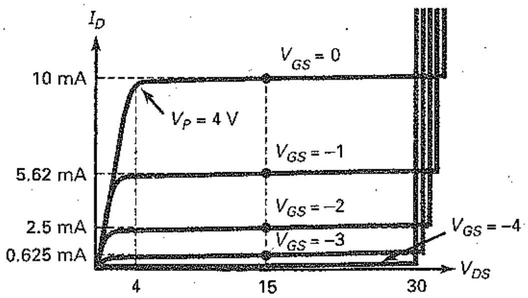
$$R_{DS} = \frac{4\ \text{V}}{10\ \text{mA}} = 400\ \Omega$$

If the JFET is operating anywhere in the ohmic region, it has an ohmic resistance of 400 Ω.

Gate Cutoff Voltage

Figure 13-5 shows the drain curves for a JFET with an I_{DSS} of 10 mA. The top curve is always for $V_{GS} = 0$, the shorted-gate condition. In this example, the pinchoff voltage is 4 V and the breakdown voltage is 30 V. The next curve down is for $V_{GS} = -1$ V, the next for $V_{GS} = -2$ V, and so on. As you can see, the more negative the gate-source voltage, the smaller the drain current.

Figure 13-5 Drain curves.



GOOD TO KNOW

There is often a lot of confusion in textbooks and in manufacturers' data sheets regarding the terms *cutoff* and *pinchoff*. $V_{GS(off)}$ is the value of V_{GS} that completely pinches off the channel, thus reducing the drain current to zero. On the other hand, the pinchoff voltage is the value of V_{DS} at which I_D levels off with $V_{GS} = 0$ V.

The bottom curve is important. Notice that a V_{GS} of -4 V reduces the drain current to almost zero. This voltage is called the **gate-source cutoff voltage** and is symbolized by $V_{GS(off)}$ on data sheets. At this cutoff voltage the depletion layers touch. In effect, the conducting channel disappears. This is why the drain current is approximately zero.

In Fig. 13-5, notice that

$$V_{GS(off)} = -4\text{ V} \qquad \text{and} \qquad V_P = 4\text{ V}$$

This is not a coincidence. The two voltages always have the same magnitude because they are the values where the depletion layers touch or almost touch. Data sheets may list either quantity, and you are expected to know that the other has the same magnitude. As an equation:

$$V_{GS(off)} = -V_P \tag{13-2}$$

Example 13-2

An MPF4857 has $V_P = 6$ V and $I_{DSS} = 100$ mA. What is the ohmic resistance? The gate-source cutoff voltage?

SOLUTION The ohmic resistance is:

$$R_{DS} = \frac{6\text{ V}}{100\text{ mA}} = 60\ \Omega$$

Since the pinchoff voltage is 6 V, the gate-source cutoff voltage is:

$$V_{GS(off)} = -6\text{ V}$$

PRACTICE PROBLEM 13-2 A 2N5484 has a $V_{GS(off)} = -3.0$ V and $I_{DSS} = 5$ mA. Find its ohmic resistance and V_p values.

13-3 The Transconductance Curve

GOOD TO KNOW

The transconductance curve of a JFET is unaffected by the circuit or configuration in which the JFET is used.

The **transconductance curve** of a JFET is a graph of I_D versus V_{GS}. By reading the values of I_D and V_{GS} of each drain curve in Fig. 13-5, we can plot the curve of Fig. 13-6*a*. Notice that the curve is nonlinear because the current increases faster when V_{GS} approaches zero.

Any JFET has a transconductance curve like Fig. 13-6*b*. The end points on the curve are $V_{GS(off)}$ and I_{DSS}. The equation for this graph is:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 \tag{13-3}$$

Because of the squared quantity in this equation, JFETs are often called *square-law devices*. The squaring of the quantity produces the nonlinear curve of Fig. 13-6*b*.

Figure 13-6*c* shows a *normalized transconductance curve*. *Normalized* means that we are graphing ratios like I_D/I_{DSS} and $V_{GS}/V_{GS(off)}$.