Application Note: Introduction to JFETs

Introduction

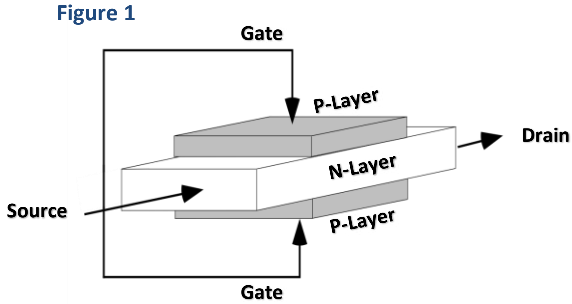
The field effect transistor was conceived before the more familiar bipolar transistor. Due to limited technology and later the rapid rise of the bipolar device it was not pursued until the early 1940's as a viable semiconductor alternative. At this time further investigation of the field effect transistor and advances in semiconductor process technology led to the types in use today.

Field effect transistors include the Junction FET (JFET) and the MOSFET. The MOSFET is a metal-oxide semiconductor technology and is sometimes referred to as the IGFET or Insulated Gate FET. All field effect transistors are majority carrier devices. This means that current is conducted by the majority carrier species present in the channel of the FET. This majority carrier consists of hole for P-Channel devices and electrons for N-Channel devices. The JFET operates with current flow through a controlled channel in the semiconductor material. The MOSFET creates a channel under the insulated gate region which is produced by an electric field induced in the semiconductor by applying a voltage to the gate. The JFET is a depletion mode device whereas the MOSFET can operate as a depletion mode or an enhancement mode device. Depletion mode devices are controlled by depleting the current channel of charge carriers. Enhancement mode devices are controlled by enhancing the channel with additional charge carriers.

The JFET

The junction field effect transistor in its simplest form is essentially a voltage-controlled resistor. The resistive element is usually a bar of silicon. For an N-Channel JFET this bar is an N-type material sandwiched between two layers of P-type material. The two layers of P-type material are electrically connected and are called the gate. One end of the N-type bar is called the source and the other is called the drain. Current is injected into the channel from the source terminal and collected at the drain terminal. The interface region of the P- and the N-type materials forms a P-N junction as shown in Figure 1.

Figure 1



As in any material, the resistance of the conducting channel is defined by:

(1) $R = \rho l / A$

R = total channel resistance
ρ = resistivity of the silicon
l = length of the conducting path
A = cross sectional area

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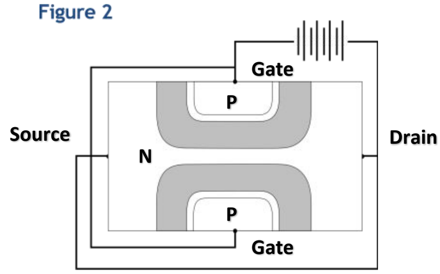
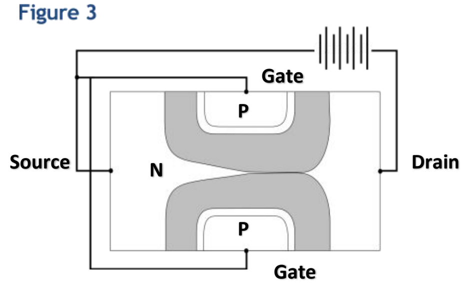
Figure 2 illustrates a JFET with the two gate areas electrically connected, as are the source and the drain. Application of a reverse bias voltage on the drain/gate terminals results in the formation of depletion regions at the PN junction. Increasing the voltage causes the depletion regions to reach further into the channel and effectively reduces its cross-sectional area. It can be seen from Equation 1 that this increases the channel resistance. Continuing to increase the voltage will result in the depletion regions touching in the middle of the channel. The channel is then said to be pinched off and the voltage required to cause this is called the pinch-off voltage.

Figure 2



Connecting the gate to the source and applying a voltage between the drain and source also produces the formation of a depletion region at the PN junction. The depletion region is then concentrated at the drain end of the channel, as shown in Figure 3. Once again, increasing the voltage causes the depletion region to spread farther into the channel. This results in a corresponding increase in channel resistance due to the reduction in the cross sectional area of the channel. The voltage at which the two depletion regions just touch in the middle of the channel is called the drain saturation voltage. Operation of the JFET at voltages below and above the drain saturation voltage are referred to the linear (or resistive) and saturation regions, respectively. When operated in the saturated region, changes in voltage cause little change in channel net current. The amount of current which will flow in the channel of a JFET operating in this manner is called the drain saturation current. The JFET is normally operated in the saturated region when used as an amplifier.

Figure 3

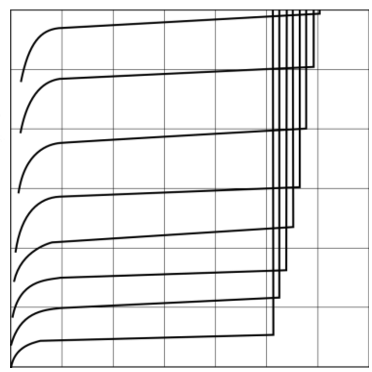


The application of an additional voltage between the gate and the source in reverse bias condition causes the depletion region to become more evenly distributed throughout the channel. This further increases the channel resistance and reduces the amount of channel current with a given drain voltage. Continuing to increase the gate voltage to the pinch off point will reduce the drain current to a very low value, effectively zero. This illustrates the operation of the JFET by showing that a voltage modulation of the gate results in a corresponding drain current modulation.

A typical set of JFET characteristic curves is shown in Figure 4. The three primary regions shown on the graph are the linear region, the saturated region, and the breakdown region. The linear region is that region where the drain to source voltage is less than the drain saturation voltage. It can be seen that the voltage current relationship is a linear function. At the point where the drain to source voltage reaches the drain saturation voltage, the saturated region begins. The curves illustrate that increasing the gate reverse voltage reduces the drain current as well as the drain saturation voltage. This also shows the manner in which the drain current is modulated when modulating the gate voltage. The final region of interest is the breakdown region. This is the point at which the gate to drain reverse biased depletion region breaks down due to the voltage applied and the current is no longer blocked. When operated in this manner the current flow is essentially uncontrolled and the device could be damaged and destroyed.

Figure 4

Drain Current (Id)



Drain to Source Voltage (Vds)

Conclusions

The previous discussion of the JFET illustrates that:

1. The JFET is basically a voltage controlled resistor,
2. The JFET operates as a depletion mode device, and,
3. The JFET performs as a voltage controlled current amplifier.

The JFET is preferred in many circuit applications due to its high input impedance because it is a reverse biased PN junction. Its operation is that of the flow of majority carriers only and therefore acts as a resistive switch. It also is inherently less noisy than bipolar devices and can be used in low signal level applications.

References

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