

Review of JFET

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Abstract: The technology behind the Buffers used in measuring instrument and receivers has been done in large amount in last decade by JFET which is a three terminal semiconductor device in which current conduction is by one type of carriers i.e. electrons or holes. Here, we will discuss the construction details, working principles, difference between the JFET and BJT. We will also study JFET as an amplifier. Besides discussing the output characteristic of JFET, parameters will also be discussed. Finally advantage of JFET will be discussed

JFET

1. INTRODUCTION

A JFET is a long channel of semiconductor material with a three terminal semiconductor device in which current conduction is by one type of carrier i.e. electrons or holes. The JFET was developed at the same time as the transistor but it came into general use only in the late 1960s. In a JFET, the current conduction is controlled by means of an electric field between the gate electrode and the conducting channel of the device.⁴ Because a Junction Field Effect Transistor is a voltage controlled device, "NO current flows into the gate!" then the Source current (I_d) flowing out of the device equals the Drain current flowing into it and therefore ($I_d = I_s$).

2. CONSTRUCTION DETAILS

A JFET consists of a p-type or n-type silicon bar containing two p-n junctions at the sides. The bar forms the conducting channel for the charge carriers. If the bar is of the n-type, it is called n-channel JFET. JFET operation is like that of a garden hose. The flow of water through a hose can be controlled by squeezing it to reduce the cross section; the flow of electric charge through a JFET is controlled by constricting the current-carrying channel. The two p-n junctions forming diodes are connected internally and a common terminal called gate is taken out. Other terminals are source and drain taken out from the bar. Thus a JFET has essentially three terminals via, gate (G), source (S) and drain (D). In each case the voltage between the gate and the source is such that the gate is reverse biased. This is the normal way of JFET connections. The drain and source terminals are interchangeable i.e., either end can be used as source and the other end as drain.

3. WORKING PRINCIPLE OF JFET

The working principle of n-channel JFET with normal polarities is

- When a voltage V_{DS} is applied between drain and source terminals and voltage on the gate is zero, the two p-n junctions at the sides of the bar establish layers. The electrons flow from source to drain through a channel between the depletion layers. The size of these layers determines the width of the channel and hence the current conduction through the bar.
- When a reverse voltage V_{GS} is applied between the gate and source, the width of the depletion layers is increased. This reduces the width of conducting channel, thereby increasing the resistance of n-type bar. Consequently, the current from source to drain is decreased. If the reverse voltage is decreased on the gate, the width of the depletion layers also decreases. This increases the width of conducting channel and hence source to drain current.

This is generally valid for low frequency applications. However, it is true at high frequencies.

It is clear that current from source to drain can be controlled by the application of potential (i.e., electric field) on the gate. For this reason, the device is called field effect transistor. It may be noted that a p-channel JFET operates in the same manner as an n-channel JFET except that channel current carriers will be the holes instead of electrons and the polarities of V_{GS} and V_{DS} are reversed. This voltage becomes less positive as we go from the Drain terminal to the Source terminal.

The result is that the PN-junction therefore has a high reverse bias at the Drain terminal and a lower reverse bias at the Source terminal. The magnitude of the current flowing through the channel between the Drain and the Source terminals is controlled by a voltage applied to the Gate terminal, which is a reverse-biased. In an N-channel JFET this Gate voltage is negative while for a P-channel JFET the Gate voltage is positive.

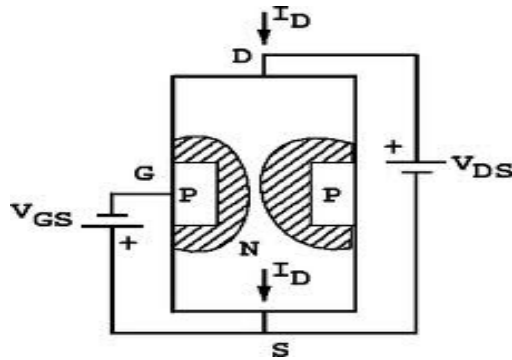


Fig. 1: n-channel JFET

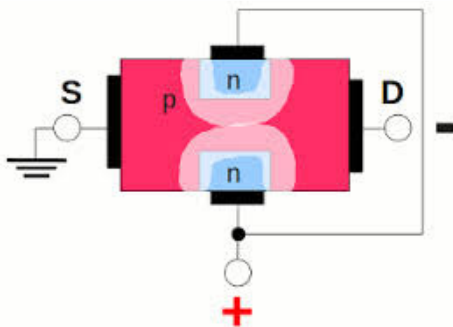


Fig. 2: p-channel JFET

Difference between JFET and Bipolar Transistor

The JFET differs from an ordinary or bipolar transistor in the following ways:

- In a JFET, there is only one type of carriers, holes in p-type channel and electrons in n-type channel. For this reason, it is also called a unipolar transistor. However, in an ordinary transistor, both holes and electrons and holes play part in conduction. Therefore, an ordinary transistor is sometimes called a bipolar transistor.
- As the input circuit (i.e., gate to source) of a JFET is reverse biased, therefore the device has high input impedance. However, the input circuit of an ordinary transistor is forward biased and hence has low input impedance.
- As the gate is reverse biased, therefore, it carries very small current. JFET is essentially a voltage driven device. However, ordinary transistor is a current operated device i.e., input current controls the output current.

JFET as an Amplifier

JFET act as an amplifier circuit, when the weak signal is applied between the gate and the source, amplified output is obtained in the drain-source circuit. For proper JFET, the gate must be negative with respect to source i.e., input circuit should always be reverse biased (achieved either by inserting a battery V_{GG} in the gate circuit or by a circuit known as biasing circuit).

A small change in the reverse bias on the gate produces a large change in drain current which makes JFET capable of raising the strength of a weak signal. During the positive half of signal, the reverse bias on the gate decreases. This increases the channel width and hence the drain current. During the negative half cycle of the signal, the reverse bias on the gate increases. Accordingly, the drain current decreases. The result is that a small change in voltage at the gate produces a large change in drain current. The large variations in the drain current produce large output across the load R_L . In this way JFET acts as an amplifier.

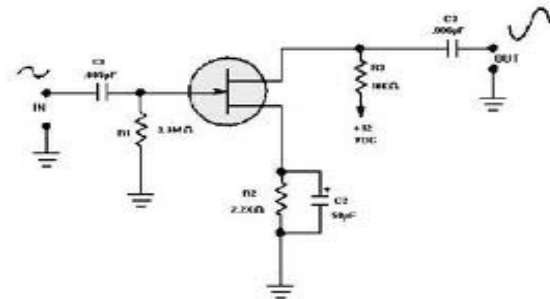


Fig. 3: JFET as an amplifier

Output Characteristics of JFET

The current between drain current (I_D) and drain-source voltage (V_{DS}) of a JFET at constant gate-source voltage (V_{GS}) is known as output characteristic of JFET. Keeping V_{GS} fixed at some value the drain voltage is changed in steps. Corresponding to each value of V_{DS} , the drain source voltage is changed in steps. A plot of this value gives the output characteristics of JFET at V_{GS} . Repeating similar procedure, output characteristics at other gate-source voltages can be drawn.

The important terms used are:

- Shorted-gate drain current (I_{DSS})
- Pinch off voltage (V_P)
- Gate-source cut off voltage ($V_{GS(OFF)}$)

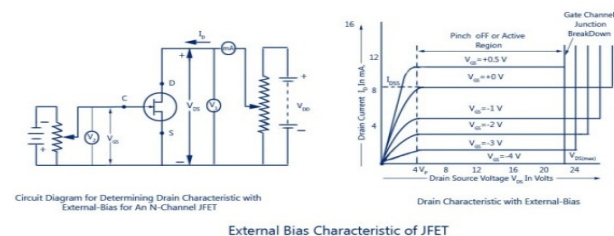


Fig. 4: basic characteristic of JFET

1. Shorted-gate drain current (I_{DSS})

It is the drain current with source short-circuited to gate (i.e. $V_{GS}=0$) and drain voltage (V_{DS}) equal to pinch off voltage. It is sometimes called zero-bias current. The JFET circuit with $V_{GS}=0$ i.e. source short circuited to gate and is normally called shorted-gate condition. The drain current rises rapidly at first and then level off at pinch off voltage V_p . The drain current has now reached a maximum value I_{DSS} .

When V_{DS} is increased beyond V_p , the depletion layer expands at the top of the channel. The channel now acts as a current limiter and holds drain current constantly at I_{DSS} .

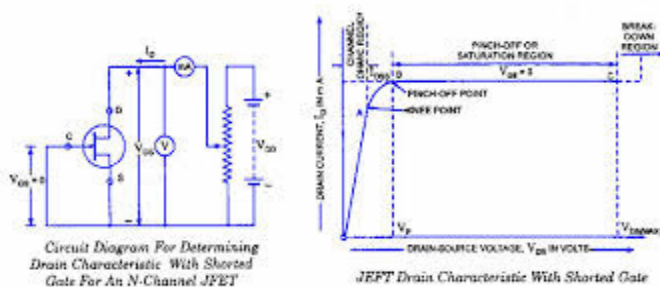


Fig. 5: Drain characteristic with shorted gate

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

2. Pinch off voltage (V_p)

It is the minimum drain source voltage at which the drain current essentially becomes constant. For value of V_{DS} greater than V_p the drain current is almost constant because when $V_{DS}=V_p$ the channel is effectively closed and does not allow further increase in drain current. It may be noted that for proper function of JFET, it is always operated for $V_{DS} > V_p$. However, V_{DS} should not exceed $V_{DS(max)}$ otherwise JFET may break down. When drain voltage equals V_p , the channel becomes narrow and the depletion layers almost touch each other. The channel now acts as a current limiter and holds drain current at constant value of I_{DSS} . The Gate voltage, V_{GS} controls the channel current and V_{DS} has little or no effect.

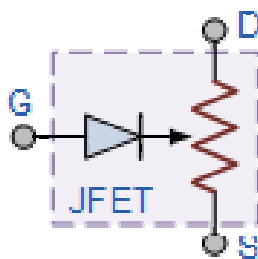


Fig. 6: JFET

The result is that the FET acts more like a voltage controlled resistor which has zero resistance when $V_{GS} = 0$ and maximum “ON” resistance (R_{DS}) when the Gate voltage is very negative. Under normal operating conditions, the JFET gate is always negatively biased relative to the source.

It is essential that the Gate voltage is never positive since if it is all the channel current will flow to the Gate and not to the Source, the result is damage to the JFET. Then to close the channel:

- No Gate voltage (V_{GS}) and V_{DS} is increased from zero.
- No V_{DS} and Gate control is decreased negatively from zero.

3. Gate-source cut off voltage ($V_{GS(OFF)}$)

It is the gate-source voltage where the channel is completely cut off and the drain current becomes zero. The idea of gate-source cut off voltage can be easily understood if we refer to the characteristic of JFET. As the reverse gate source voltage is increased, the cross-sectional area of the channel decreases. This in turn decreases the drain current. At some reverse gate source voltage, the depletion layers extend completely across the channel. In this condition, the channel is cut off and the drain current reduces to zero. The gate voltage at which the channel is cut off (i.e. channel becomes conducting) is called gate source cut off voltage $V_{GS(OFF)}$ which will always have the same magnitude value of V_p there is a distinct difference between $V_{GS(OFF)}$ and V_p .

The characteristics curves example shown above shows the four different regions of operation for a JFET and these are given as:

• Ohmic Region –

When $V_{GS} = 0$ the depletion layer of the channel is very small and the JFET acts like a voltage controlled resistor.

• Cut-off Region –

This is also known as the pinch-off region where the Gate voltage, V_{GS} is sufficient to cause the JFET to act as an open circuit as the channel resistance is at maximum.

• Saturation or Active Region –

The JFET becomes a good conductor and is controlled by the Gate-Source voltage, (V_{GS}) while the Drain-Source voltage, (V_{DS}) has little or no effect.

• Breakdown Region –

The voltage between the Drain and the Source, (V_{DS}) is high enough to causes the JFET's resistive channel to break down and pass uncontrolled maximum current.

4. ADVANTAGE OF JFET

JFET is a voltage controlled, constant current device (similar to a vacuum pentad) in which variations in input voltage control the output current. It contains many advantages of both BPT and vacuum pentad. Some of the advantages are:

1. It has very high input impedance (of the order of 100 Mohm). This permits high degree of isolation between the input and output circuit.
2. The operation of a JFET depends upon the bulk material current carriers that do not cross junctions; therefore, the inherent noises of tubes (due to high temperature operation) and those of transistor due to junction transition are not present in a JFET.
3. A JFET has a negative temperature co-efficient of resistance. This avoids the risk of thermal runaway.
4. A JFET has a very high power gain. This eliminates the necessity of using driver stages.
5. A JFET has a smaller size, longer life and high efficiency.

Bipolar Transistor	Field Effect Transistor
Emitter – (E) >> Source – (S)	
Base – (B) >> Gate – (G)	
Collector – (C) >> Drain – (D)	

Parameters of JFET

Like vacuum tubes, a JFET has certain parameters which determine its performance in a circuit. The main parameters of a JFET are

- a. A.c. drain resistance
- b. Transconductance
- c. Amplification factor

A. A.c. drain resistance

Corresponding to the a.c. plate resistance, we have a.c. drain resistance in a JFET. It may be defined as the ratio of change in drain-source voltage (ΔV_{DS}) to the change in drain current (ΔI_D) at constant gate-source voltage i.e.

$$R_{DS} = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{1}{g_m}$$

b. Transconductance

The control that the gate voltage has over the drain voltage is measured by Transconductance and is similar to the Transconductance of the tube. It is the ratio of change in drain current to the change in gate-source voltage at constant drain source voltage

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Where,

g_m = Transconductance in Siemens

ΔI_D = Change in drain current

ΔV_{GS} = Change in gate-source voltage

c. Amplification factor

It is the ratio of change in drain source voltage to the change in gate source voltage at constant drain current. It indicates how much more control the gate voltage has over drain voltage. For instance, if the amplification factor of a JFET is 50, it means that gate voltage is 50 times as effective as three drain voltage in controlling the drain current.

$$\mu = \frac{V_{DS}}{V_{GS}} \bigg|_{I_D = 0} \quad \therefore \mu = g_m r_d$$

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