Field-Effect Transistors

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FET vs. BJT

Similarities:

- Amplifiers
- Switching devices

Differences:

- FET's are voltage controlled devices. BJT's are current controlled devices.
- FET's have a higher input impedance. BJT's have higher gains.
- BJT's are bipolar devices whereas FET's are unipolar.
- FET's are less sensitive to temperature variations that means they provide better thermal stability as compared to BJT.

FET Types

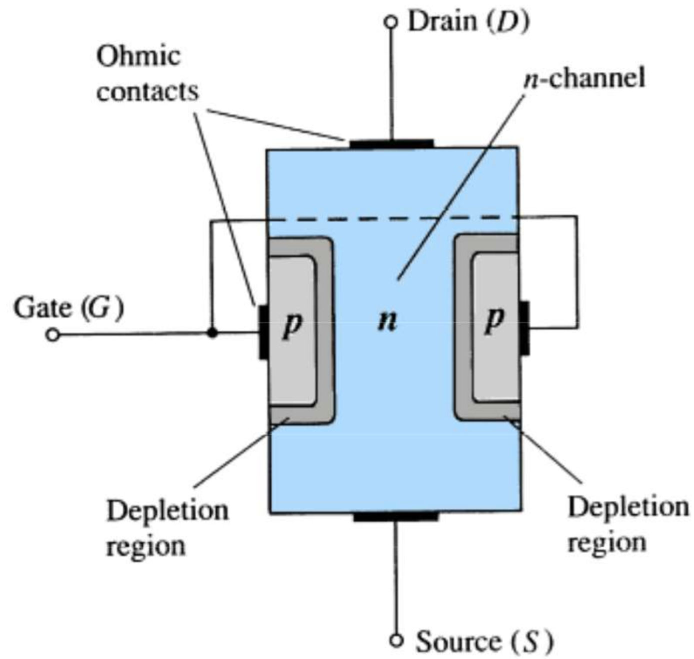
- **JFET:** **Junction FET**
- **MOSFET:** **Metal–Oxide–Semiconductor FET**
  - **D-MOSFET:** **Depletion MOSFET**
  - **E-MOSFET:** **Enhancement MOSFET**

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**

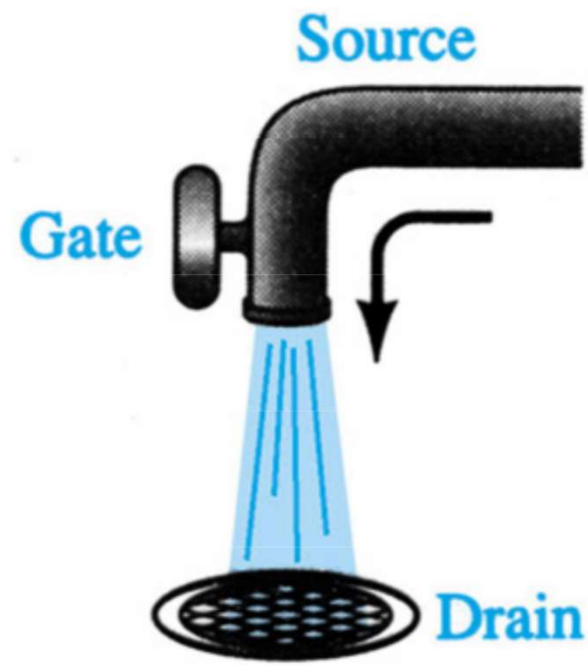
JFET Operation: The Basic Idea

JFET operation can be compared to a water spigot.

The source of water pressure is the accumulation of electrons at the negative pole of the drain-source voltage.

The drain of water is the electron deficiency (or holes) at the positive pole of the applied voltage.

The control of flow of water is the gate voltage that controls the width of the n-channel and, therefore, the flow of charges from source to drain.



JFET Operating Characteristics

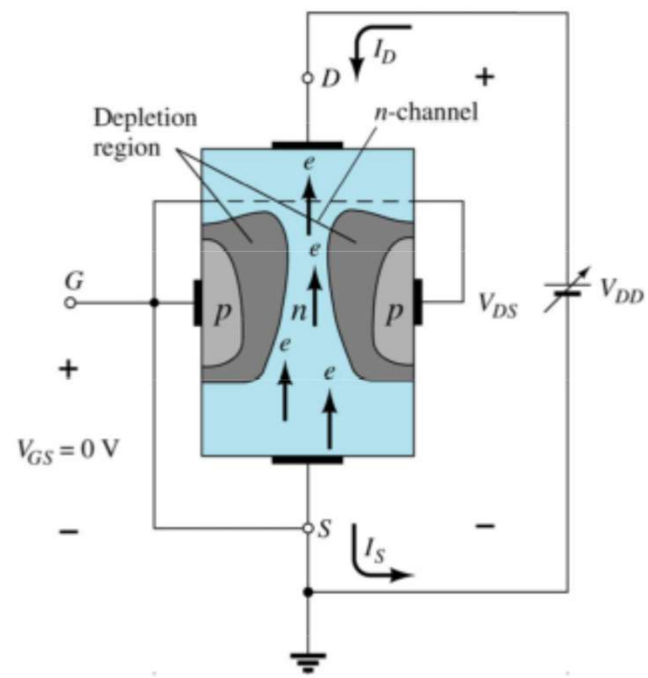
There are three basic operating conditions for a JFET:

- **$V_{GS} = 0$, V_{DS} increasing to some positive value**
- **$V_{GS} < 0$, V_{DS} at some positive value**
- **Voltage-controlled resistor**

JFET Operating Characteristics: $V_{GS} = 0$ V

Three things happen when $V_{GS} = 0$ and V_{DS} is increased from 0 to a more positive voltage

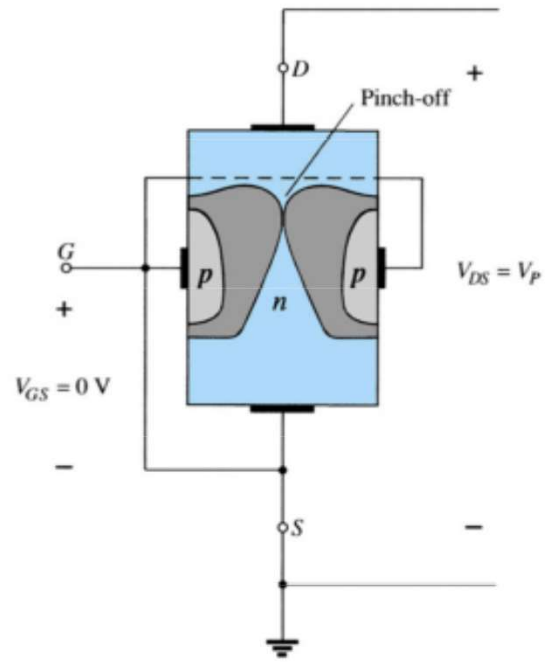
- The depletion region between p-gate and n-channel increases as electrons from n-channel combine with holes from p-gate.
- Increasing the depletion region, decreases the size of the n-channel which increases the resistance of the n-channel.
- Even though the n-channel resistance is increasing, the current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



JFET Operating Characteristics: 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.

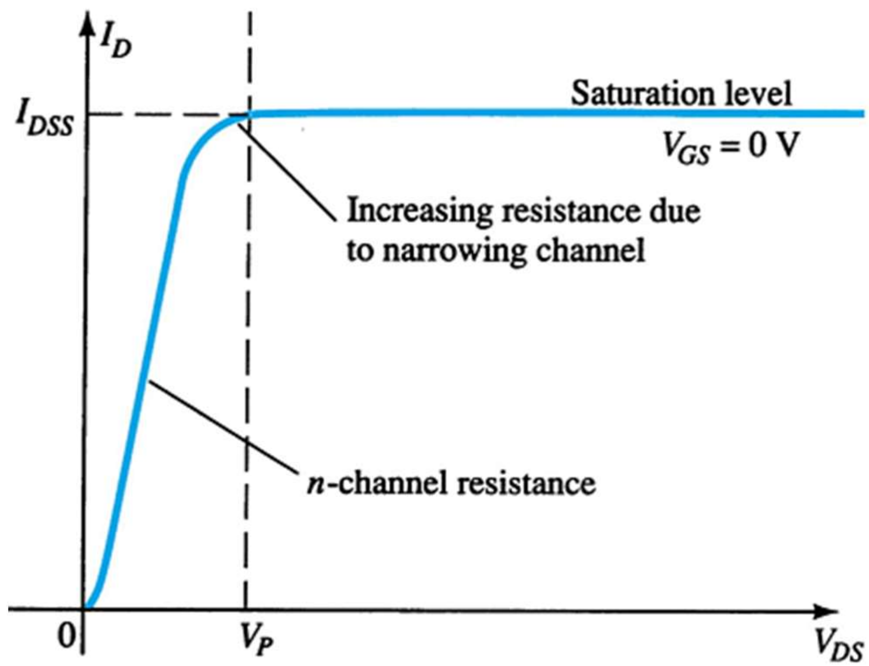
This suggests that the current in the n-channel (I_D) would drop to 0A, but it does just the opposite–as V_{DS} increases, so does I_D.



JFET Operating Characteristics: Saturation

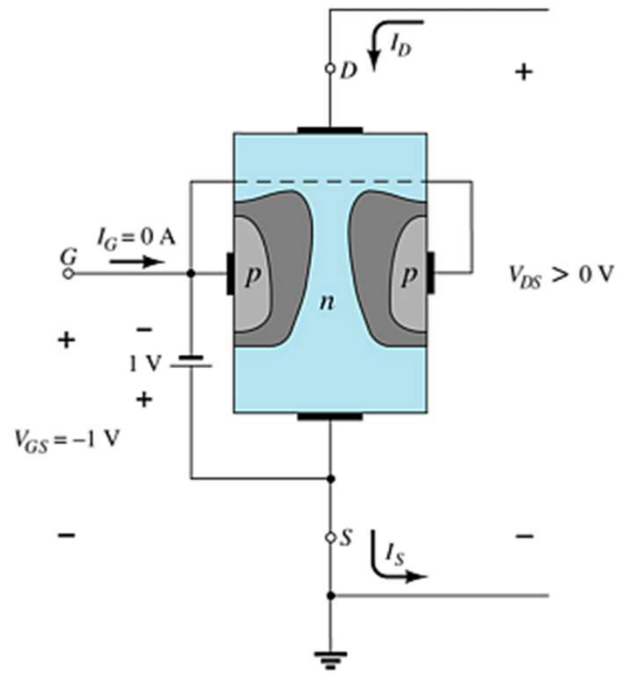
At the pinch-off point:

- Any further increase in V_{DS} does not produce any increase in I_D. V_{GS} at pinch-off is denoted as V_p.
- I_D is at saturation or maximum. It is referred to as I_{DSS}.
- The ohmic value of the channel is maximum.



JFET Operating Characteristics: $V_{GS} < 0$ V

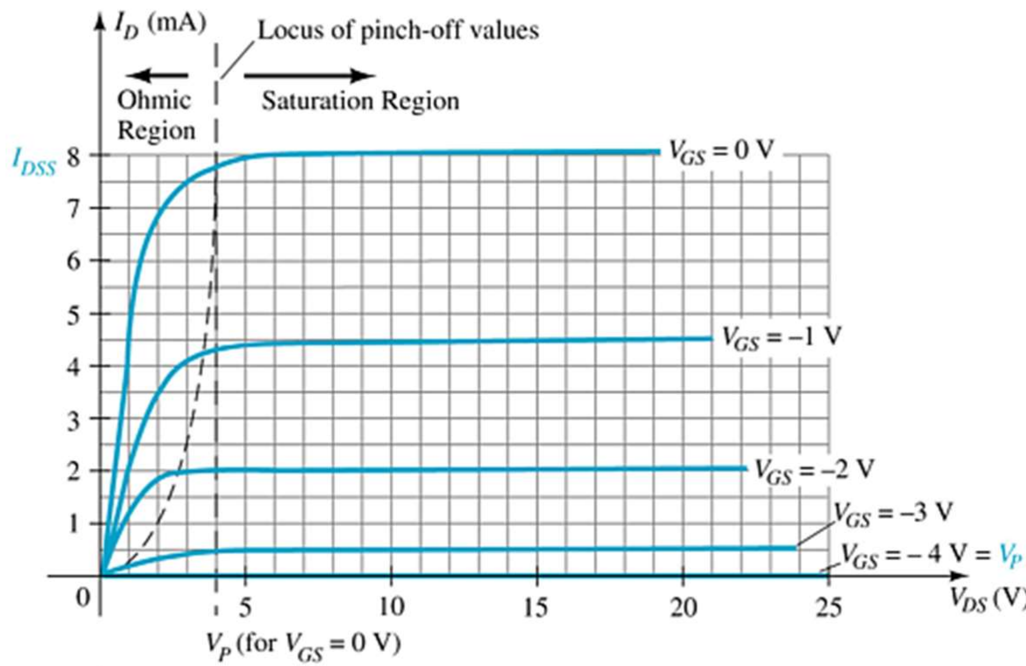
As V_{GS} becomes more negative, the depletion region increases.



JFET Operating Characteristics: $V_{GS} < 0$ V

As V_{GS} becomes more negative:

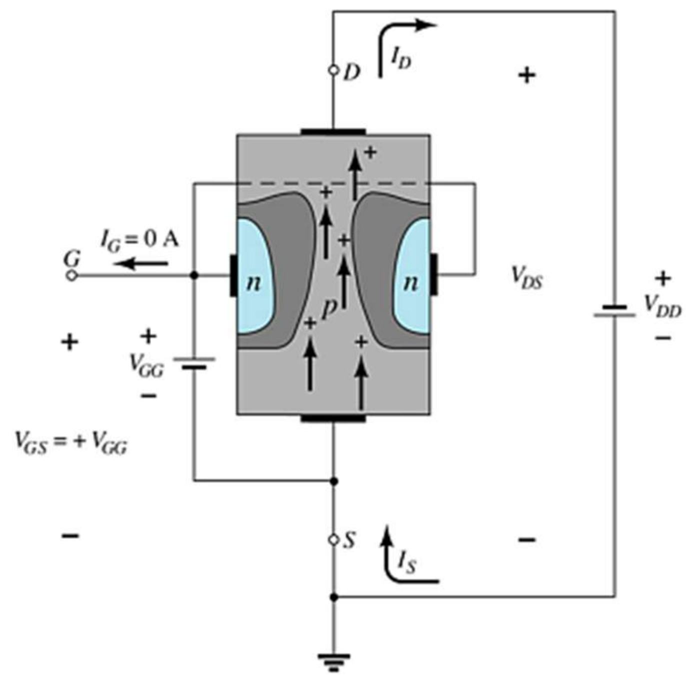
- The JFET experiences pinch-off at a lower voltage (V_P).
- I_D decreases ($I_D < I_{DSS}$) even though V_{DS} is increased.
- Eventually I_D reaches 0 A. V_{GS} at this point is called V_p or $V_{GS(off)}$..



Drain Characteristics

p-Channel JFETS

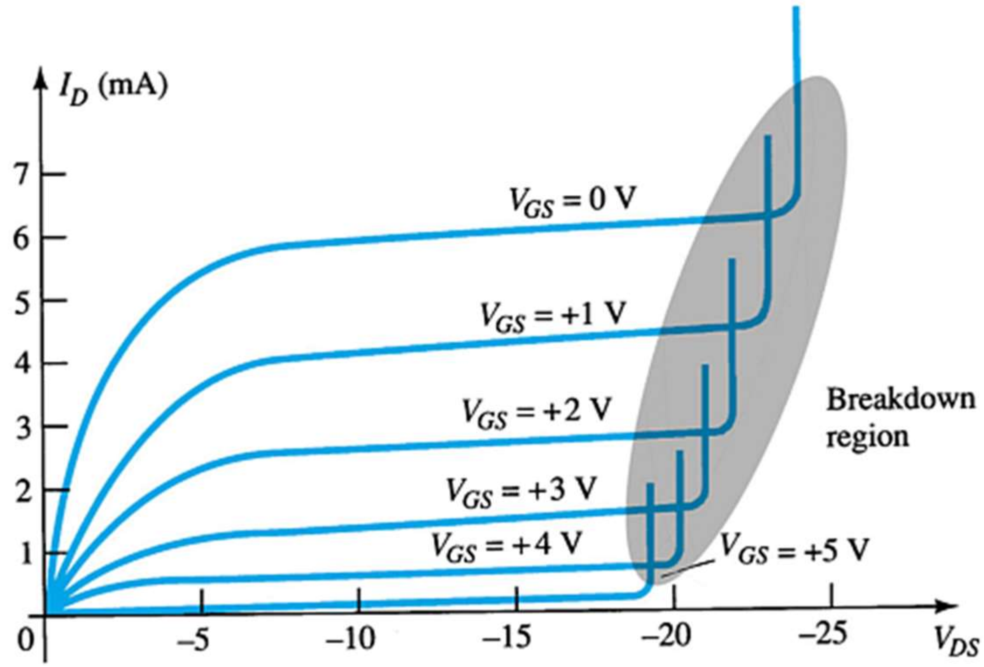
The *p*-channel JFET behaves the same as the *n*-channel JFET, except the voltage polarities and current directions are reversed.



p-Channel JFET Characteristics

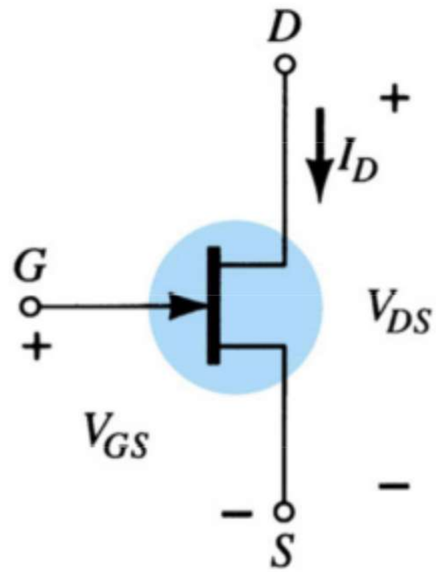
As V_{GS} increases more positively

- 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 $V_{DS} > V_{DSmax}$.

N-Channel JFET Symbol



JFET Transfer Characteristics

The transfer characteristic of input-to-output is not as straightforward in a JFET as it is in a BJT.

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:

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

Plotting the JFET Transfer Curve

Step 1

Pinch-off Condition

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

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

Step 2

Cut-off Condition

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

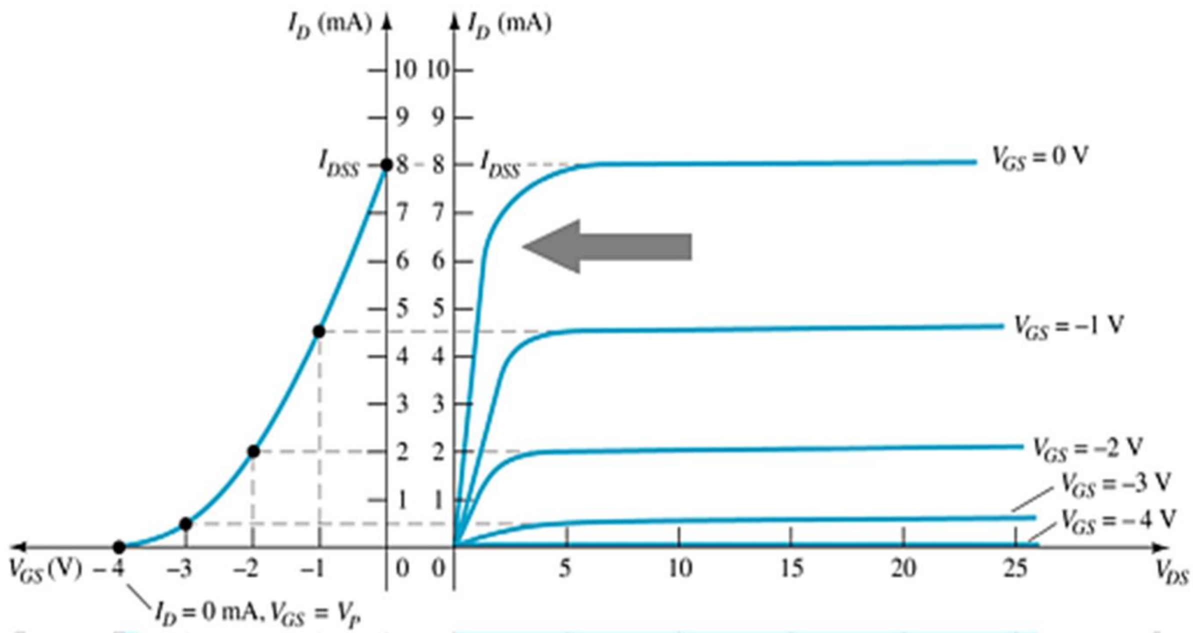
Solving for $V_{GS} = V_p$ ($V_{GS(off)}$) $\quad I_D = 0A$

Step 3

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

JFET Transfer Curve

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



JFET Parameters

1. Dynamic Drain Resistance

This is the ratio of change of drain to source voltage (δV_{DS}) to the change of drain current (δI_D) at a constant gate to source voltage (V_{GS} = Constant).

The ratio is denoted as r_d.

$$r_d = \frac{\delta V_{DS}}{\delta I_D} \quad at\ constant\ \ V_{GS}$$

JFET Parameters

2. Transconductance

Transconductance is the ratio of change in drain current (δI_D) to change in the gate to source voltage (δV_{GS}) at a constant drain to source voltage (V_{DS} = Constant).

The ratio is denoted as r_d.

$$g_m = \frac{\delta I_D}{\delta V_{GS}} \quad at\ constant\ \ V_{DS}$$

The expression of drain current (I_D) is $I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_{GS(off)}}\right]^2$

By partial differentiating the expression of drain current (ID) in respect of gate to source voltage (VGS)

$$g_m = \frac{\delta I_D}{\delta V_{GS}} = \frac{2I_{DSS}}{V_{GS(off)}}\left[1 - \frac{V_{GS}}{V_{GS(off)}}\right]$$

JFET Parameters

3. Amplification Factor

The amplification factor is defined as the ratio of change of drain voltage (δV_{DS}) to change of gate voltage (δV_{GS}) at a constant drain current (I_D = Constant).

$$\mu = \frac{\delta V_{DS}}{\delta V_{GS}} \quad at\ constant\ \ I_D$$

There is a relation between transconductance (g_m) and dynamic output resistance (r_d) and that can be established in the following way.

$$\mu = \frac{\delta V_{DS}}{\delta V_{GS}} = \frac{\delta V_{DS}}{\delta I_D} \times \frac{\delta I_D}{\delta V_{GS}}$$

$$\Rightarrow \mu = r_d \times g_m$$

Tutorial Sheet-I

1. When a Reverse Voltage of 10 V is applied between gate and source of JFET the gate current is 0.001uA. Determine resistance gate and Source.
   Ans: 10^4 MΩ.

2. When a drain- source voltage is changed by 1.5 V, the change in drain current is of 120 uA, the gate- source voltage is kept unchanged. Determine the ac drain resistance of the JFET.
   Ans: r_d=12.5KΩ.

3. In a JFET the drain current changes from 1.5 mA to 1.2 mA and gate to source voltage is varied from -4.25V to -4.10 V keeping the drain to source voltage constant. Determine the trans-conductance for the given JFET.
   Ans: g_m= 2mS.

4. An N-channel JFET has I_{DSS}=8mA and V_P=-4V.
   (a) If I_D= 3mA. Calculate the value of V_{GS}.
   (b) Calculate $V_{DS(Sat)}$ for I_D=3mA.
   Ans: V_{GS}= -1.55V and $V_{DS(Sat)}$ = 2.45V.

5. A JFET has a pinch off voltage of -4V and the saturation current of 9mA. Calculate the drain current if V_{GS}=-2V.
   Ans: I_D=2.25mA.

6. A certain JFET has I_{DSS}= 12mA and pinch off voltage V_P= -6V. Calculate the value of trans-conductance for V_{GS}=-1 V.
   Ans: g_m=3.33mS.

7. For a JFET the data is as follows: I_{DSS}= 10mA, V_P=-5V. Calculate the Trans-conductance and drain current of the JFET for V_{GS}= -2.5 V.