CLASS 23

JFET

JUNCTION FIELD EFFECT TRANSISTOR (JFET)

<u>2 Types:</u>

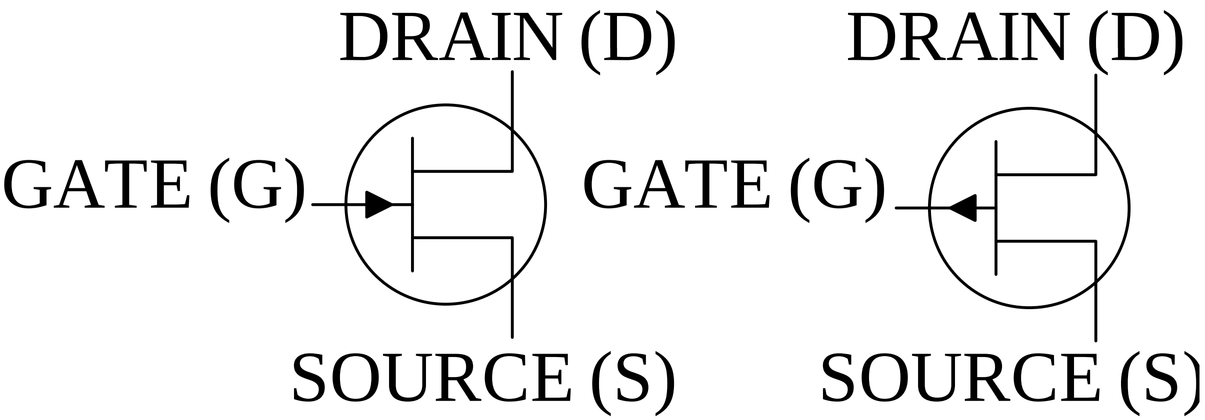
1. **n-channel JFET**

   The current carriers in an n-channel JFET are the electrons.

2. **p-channel JFET**

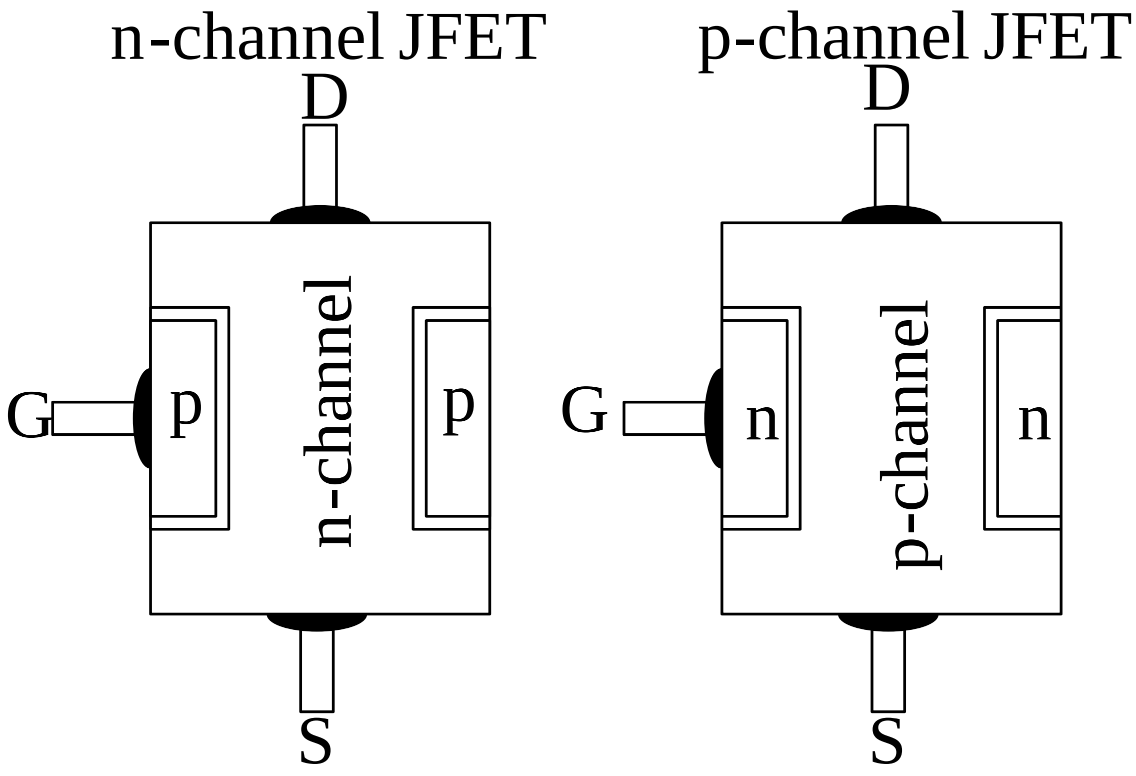
   The current carriers in a p-channel JFET are the holes.

<u>Symbols:</u>



n-channel JFET p-channel JFET

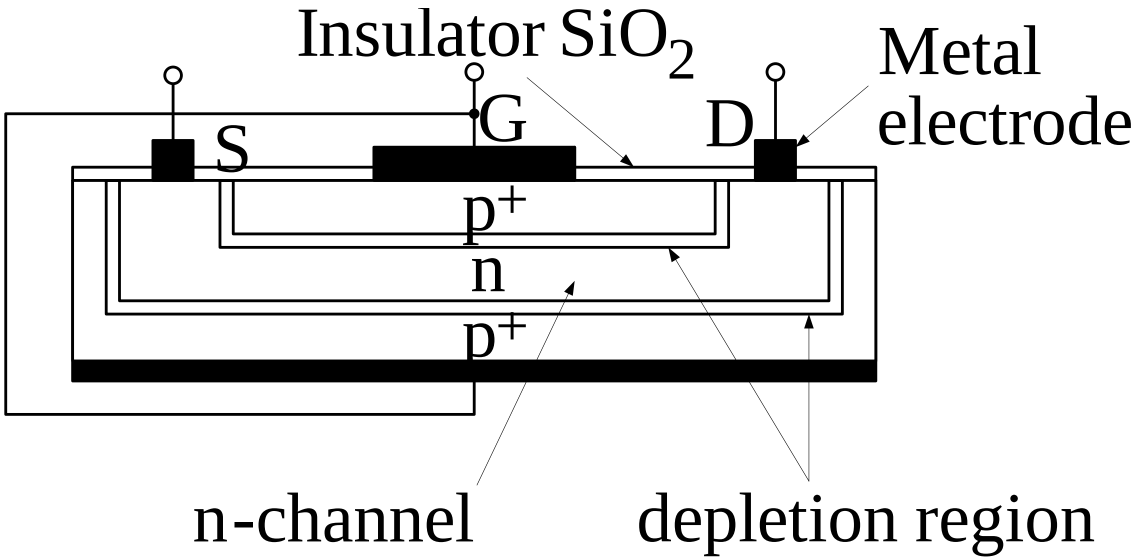
Simplified cross-section of a JFET



Both the p regions in the n-channel JFET and the n regions in the p-channel JFET are electrically connected.

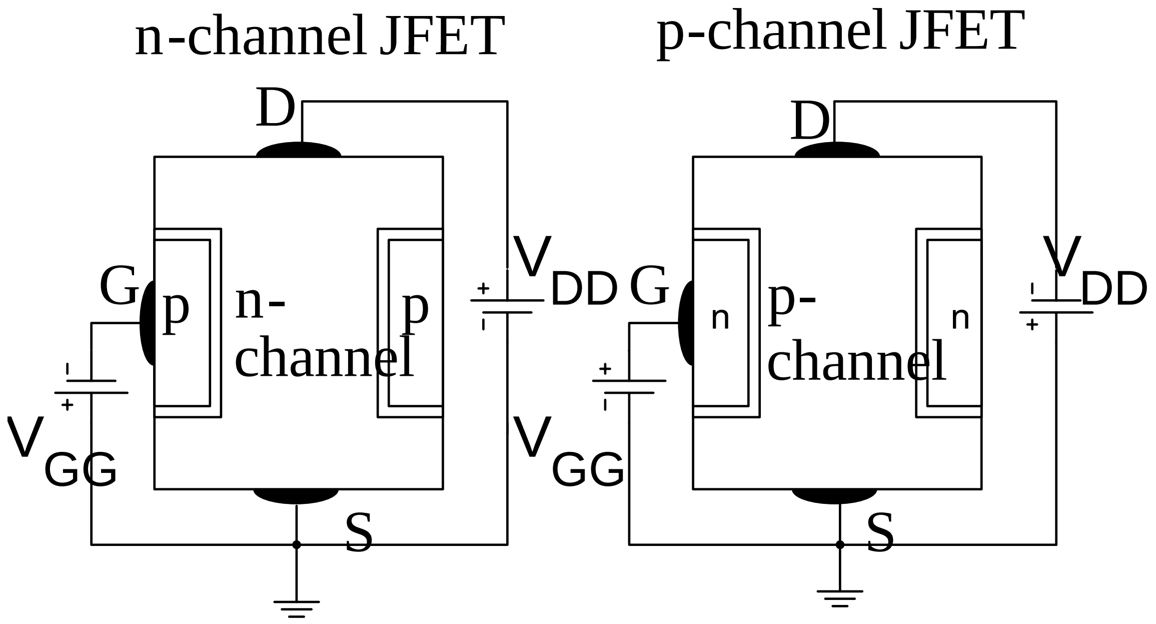
A more practical cross-section of an n-channel JFET

Both the p^+ regions in the n-channel JFET are electrically connected.



Basic operation of a JFET

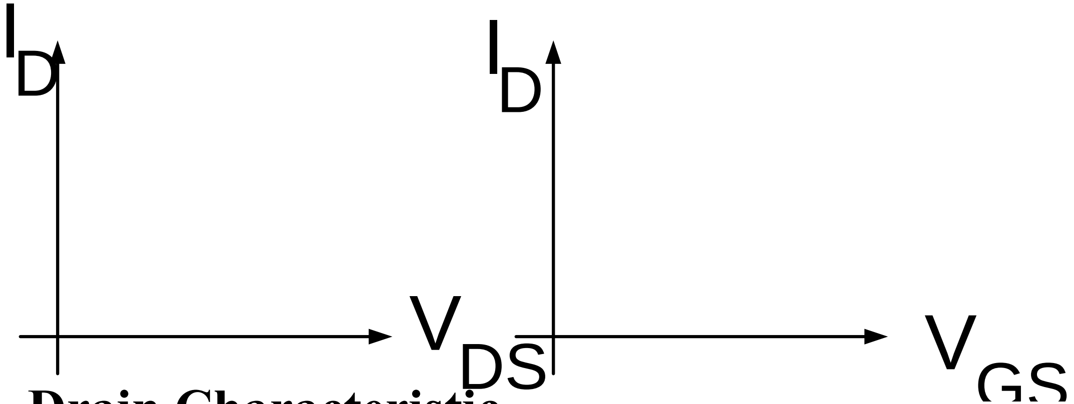
- **As an amplifier. The condition that enables the JFET to operate as an amplifier is the G-S that has to be reverse biased.**
- **V_{DD} is to provide the difference in potential between D-S to enable the majority current carrier to move from S to D.**
- **V_{GG} is to reverse bias the G-S.**



JFET Characteristics

1. **Drain characteristic**
2. **Transfer characteristic**

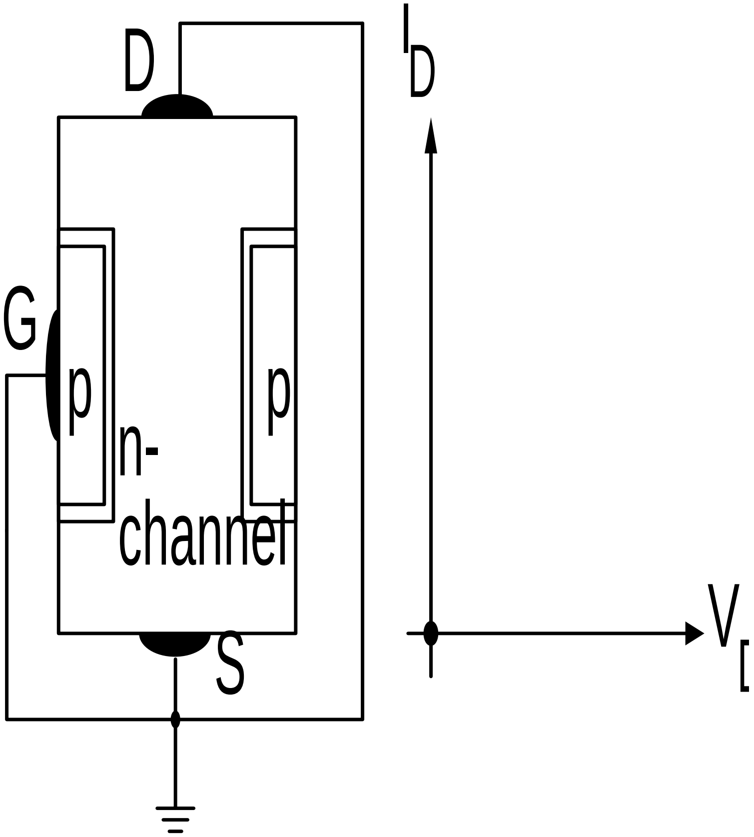
Drain characteristic **Transfer characteristic**



Drain Characteristic

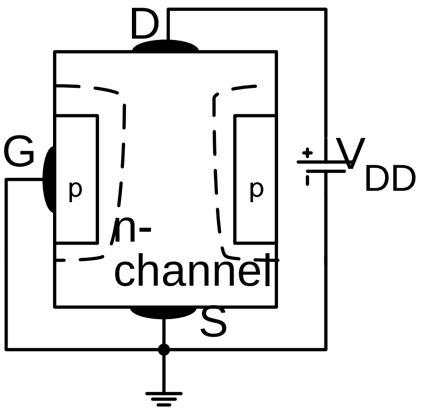
1. **$V_{GS} = 0$ and $V_{DS} = 0$**

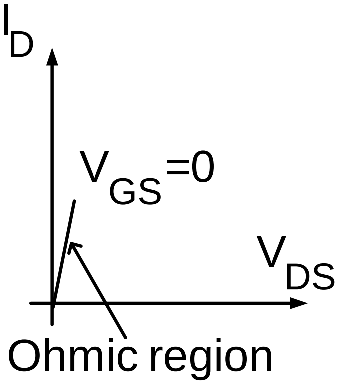
   No difference in potential between D and S. No majority carriers flowing from S to D. Hence, $I_D = 0$.



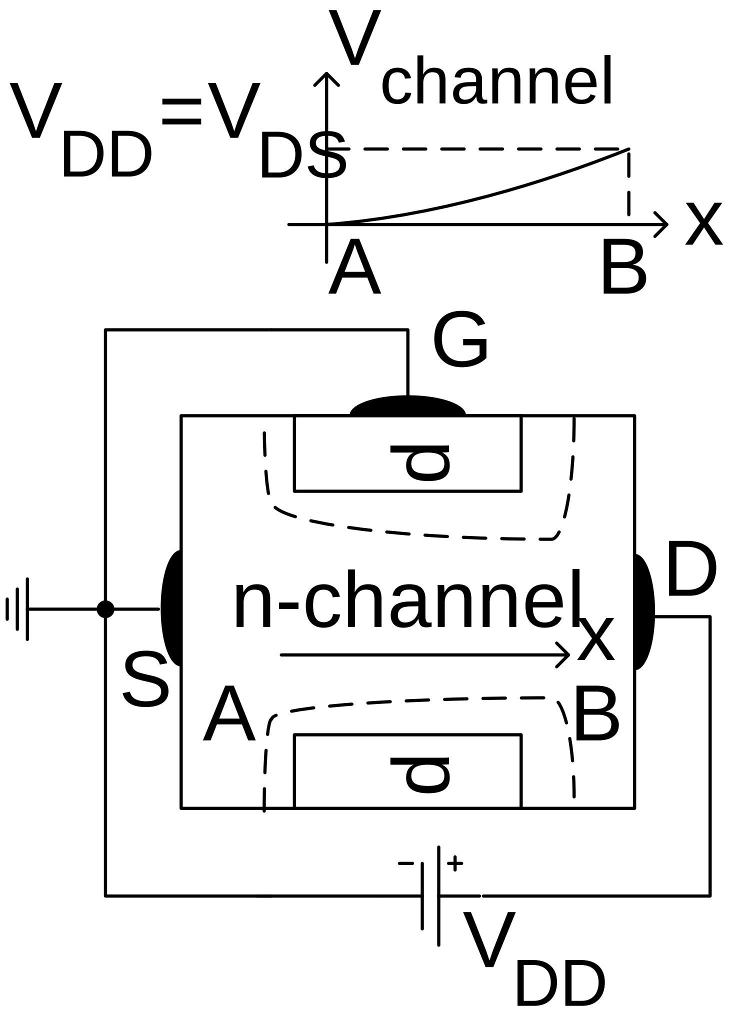
2. **$V_{GS} = 0$ and V_{DS} is small.**

- **$V_{DS} = V_D - V_S = V_{DD} - 0 = V_{DD}$**
- **$V_{GS} = V_G - V_S = 0$**
- **G–S is reverse biased.**
- **Depletion regions exist.**
- **V_D is positive. Therefore, G-D is reverse biased. Again, depletion region exists.**
- **Comparing G-D and G-S, G-D is more reverse biased. Hence, the depletion region grows wider towards D.**
- **For a small V_{DS}, the size of the G-D depletion region does not affect the width of the channel significantly. Under this condition, the depletion region does not influence the current. When V_{DS} increases, I_D will also increase. The I_D versus V_{DS} characteristic is linear. Under this condition, $V_{DS} = I_D R$ and the n-channel is a basically a resistance. Hence, this region of the drain characteristic is known as the ohmic region.**



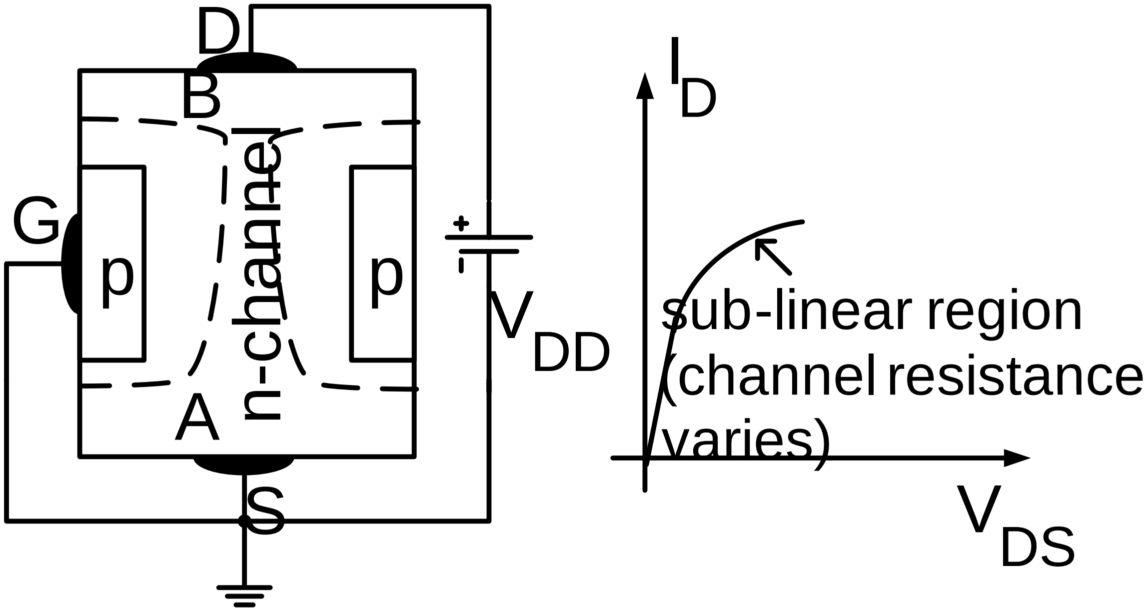


There is a voltage drop along the channel from A to B. $V_A = V_S = 0$ and $V_B = V_D = V_{DD}$. The voltage becomes more positive towards B. Hence, the p-n junction from G to channel becomes more reverse biased from A to B.



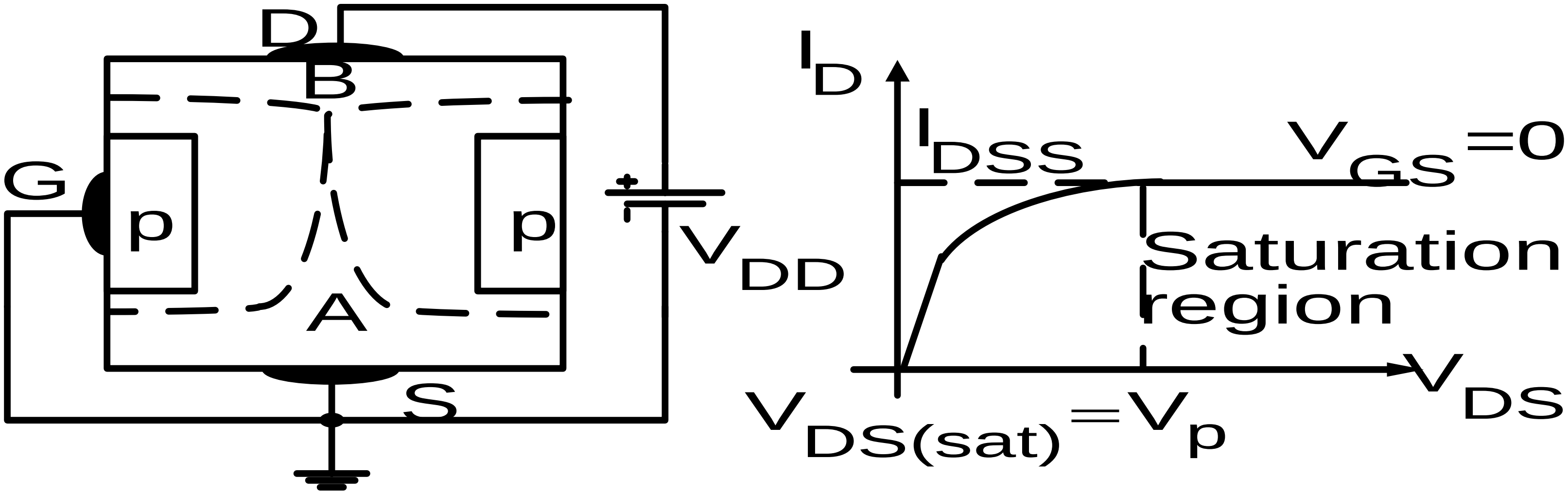
3. $V_{GS} = 0$ and V_{DS} is increased.

When V_{DS} increases, the G to channel p-n junction becomes more reverse-biased near D. Depletion region becomes wider and channel becomes narrower near D. The channel is basically a resistor and the effective channel resistance increases when depletion region widens. R_{AB} increases with the increment of V_{DS}. $R_{AB} = \Delta V_{DS} / \Delta I_D$. I_D does not increase linearly with V_{DS} anymore. In the sub-linear region, slope decreases and resistance increases.



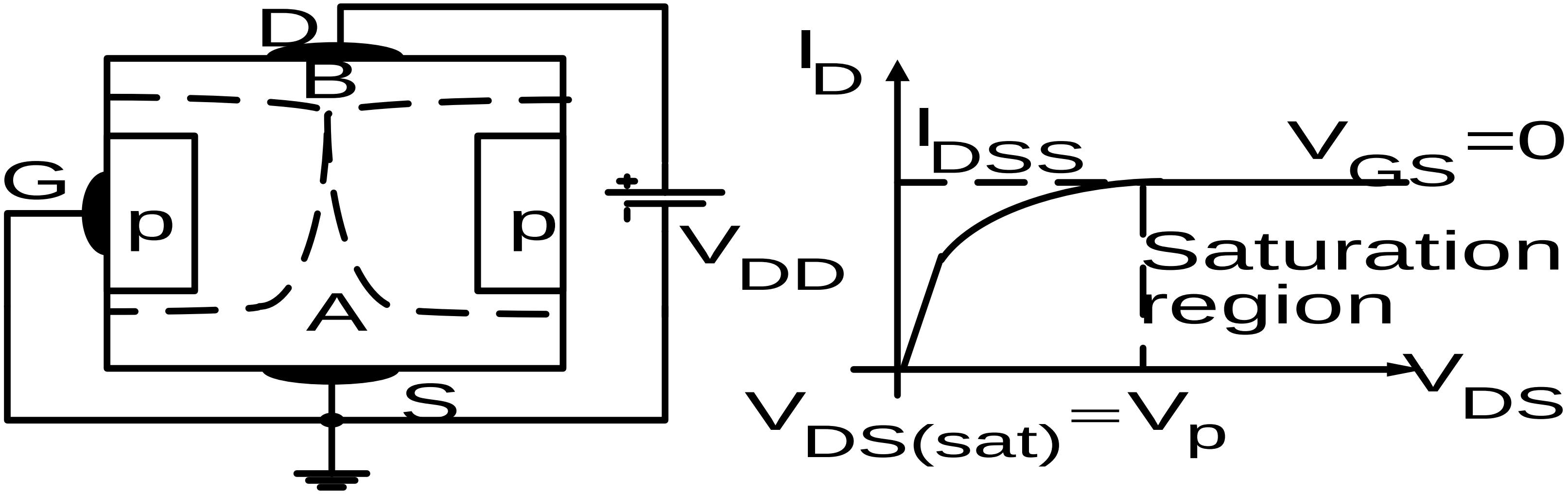
4. $V_{GS} = 0$ and V_{DS} is further increased.

- **The reverse biasing of the G to D p-n junction is enough to make the depletion regions meet near D. The channel is said to be pinched-off. Any further increment to the V_{DS} will no longer increase the I_D.**
- **At pinched-off, $V_{DS} = V_{DS(sat)}$.**
- **$V_{DS(sat)}$ = the voltage across D-S when pinched-off occurs.**
- **For $V_{DS} > V_{DS(sat)}$, I_D is fixed. Transistor is in the saturation region and I_D is independent of V_{DS}.**
- **When $V_{GS} = 0$, $V_{DS(sat)} = V_p$ and $I_D = I_{DSS}$ for $V_{DS} \geq V_{DS(sat)}$.**



- **I = Js = neU$_D$s where J is the current density, s is the cross section area of the channel, U$_D$ is the carrier drift velocity, e is the electronic charge and n is the carrier concentration. For an n-channel JFET, I = N$_D$eU$_D$s where N$_D$ is the electron concentration ≈ donor dopant concentration.**

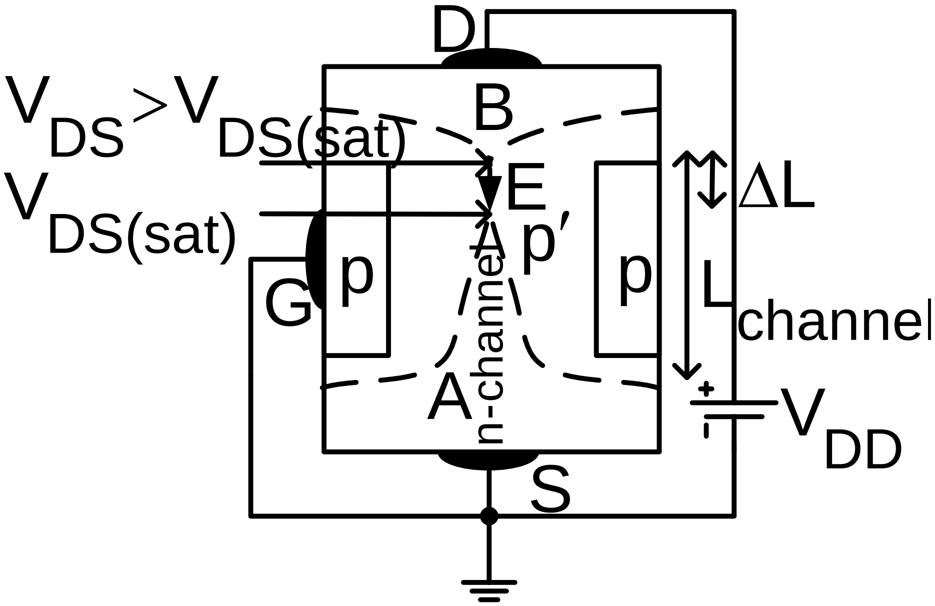
- **When approaching pinched-off, s becomes very small and U$_D$ has to become very large to maintain the current flow. The current density J = N$_D$eU$_D$ becomes very high and under this condition, the drift velocity U$_D$ is at its maximum.**

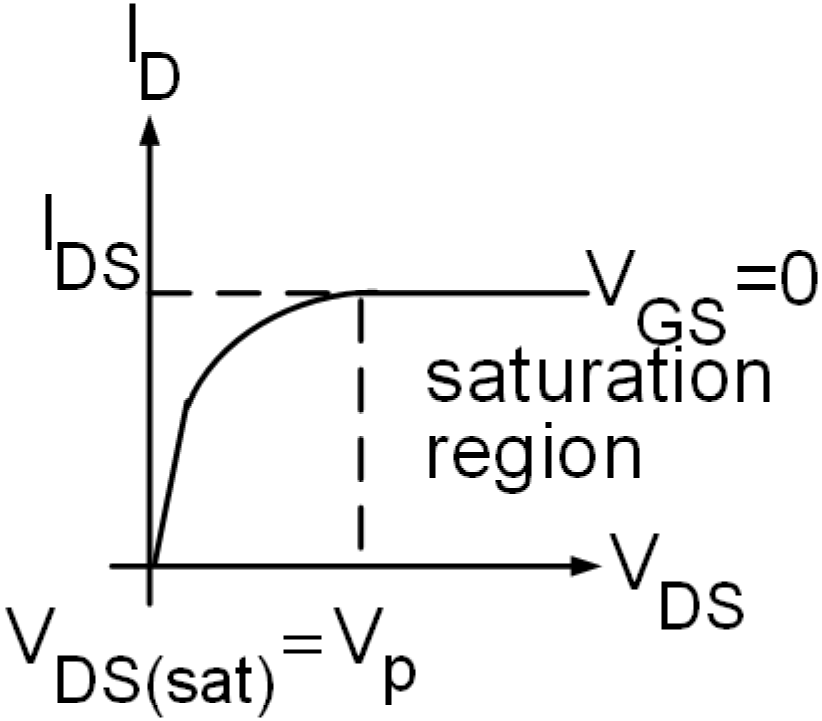


5. $V_{GS} = 0$ and $V_{DS} > V_{DS(sat)}$.

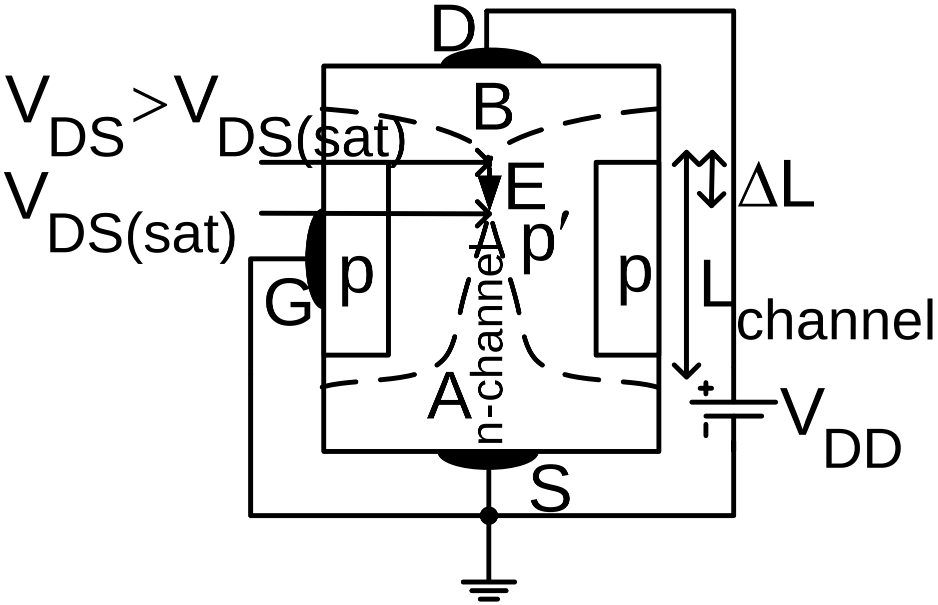
E is the electric field. The n-channel is separated from D by a space charge region that has a length of ΔL. From S, the electrons move along the channel, got injected into the space charge region, and subsequently being swept by E to move to D.

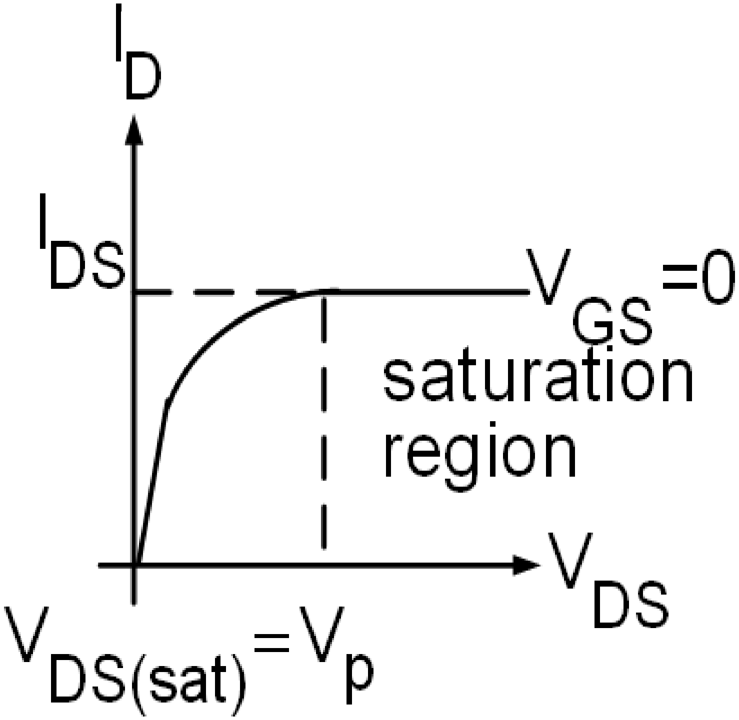
If $\Delta L << L_{channel}$, the electric field in the n-channel does not change from the one when $V_{DS} = V_{DS(sat)}$. I_D is fixed and independent of V_{DS}.



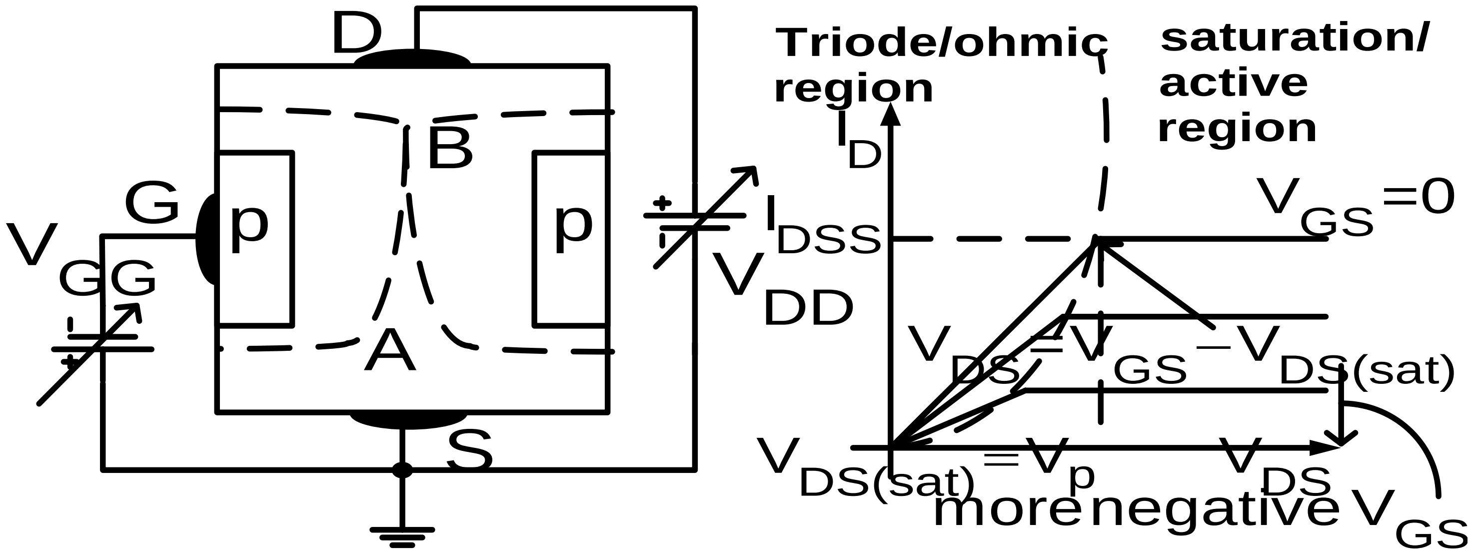


- **I_D is determined by the channel resistance from A to p', and not by the pinched-off part of the channel. When $V_{DS} > V_{DS(sat)}$, the excess voltage i.e. $V_{DS} - V_{DS(sat)}$, is across ΔL as this part is depleted of carriers and consequently has high resistivity.**
- **p' has a voltage $V_{DS(sat)} = V_p$ as this is the potential that causes the depletion regions to meet. $I_D = V_{DS(sat)} / R_{Ap'}$. If $\Delta L << L_{channel}$, then $I_D = V_{DS(sat)} / R_{Ap'}$ is equivalent to $V_{DS(sat)} / R_{AB}$ when $V_{DS} = V_{DS(sat)}$. Hence, although $V_{DS} > V_{DS(sat)}$, I_D remains unchanged.**

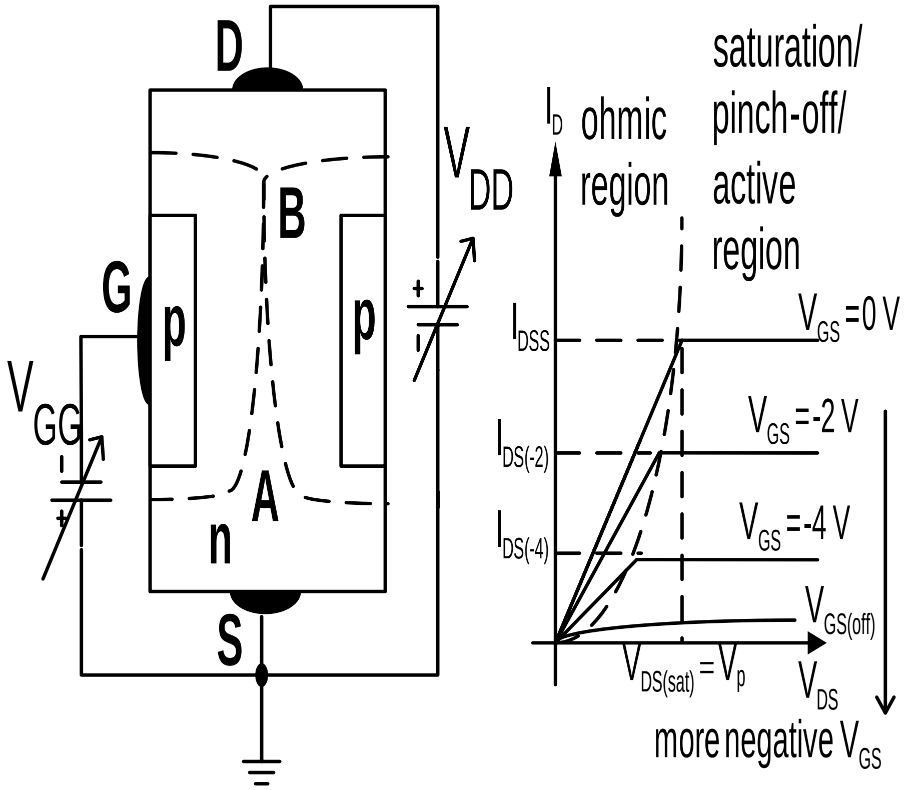


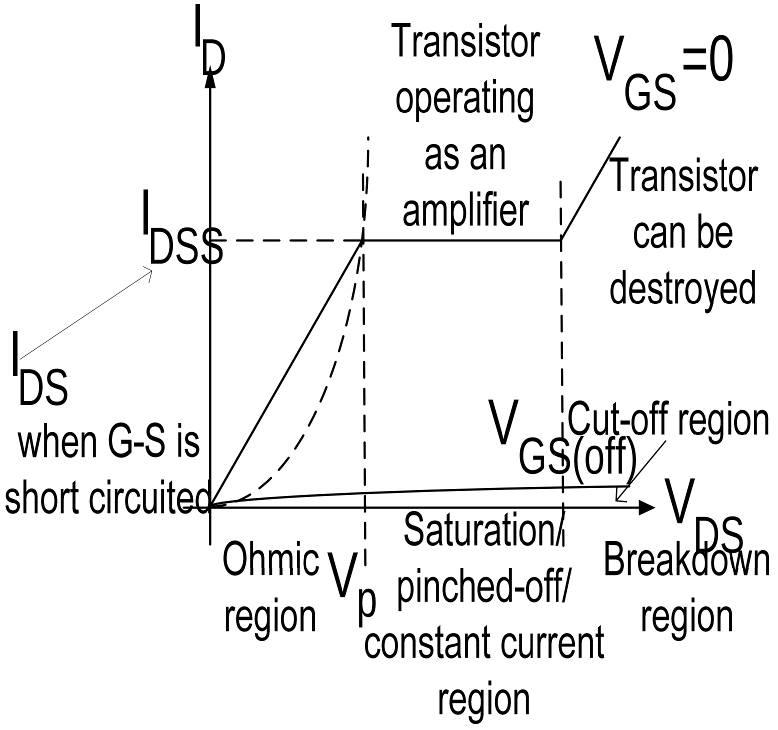


- If the magnitude of V_{GG} (V_{GS}) increases, V_G becomes more negative and the G-S becomes more reverse biased. Hence, a smaller V_{DS} is required to achieve pinched-off and the I_D at saturation will be smaller than I_{DSS}.
- To operate a JFET as an amplifier, the JFET has to be biased in the saturation region. This means that $V_{DS} \geq V_{GS} - V_{DS(sat)}$. The triode region is for $V_{DS} \leq V_{GS} - V_{DS(sat)}$.
- V_p and I_{DSS} are the JFET parameters and specified in the data sheet.

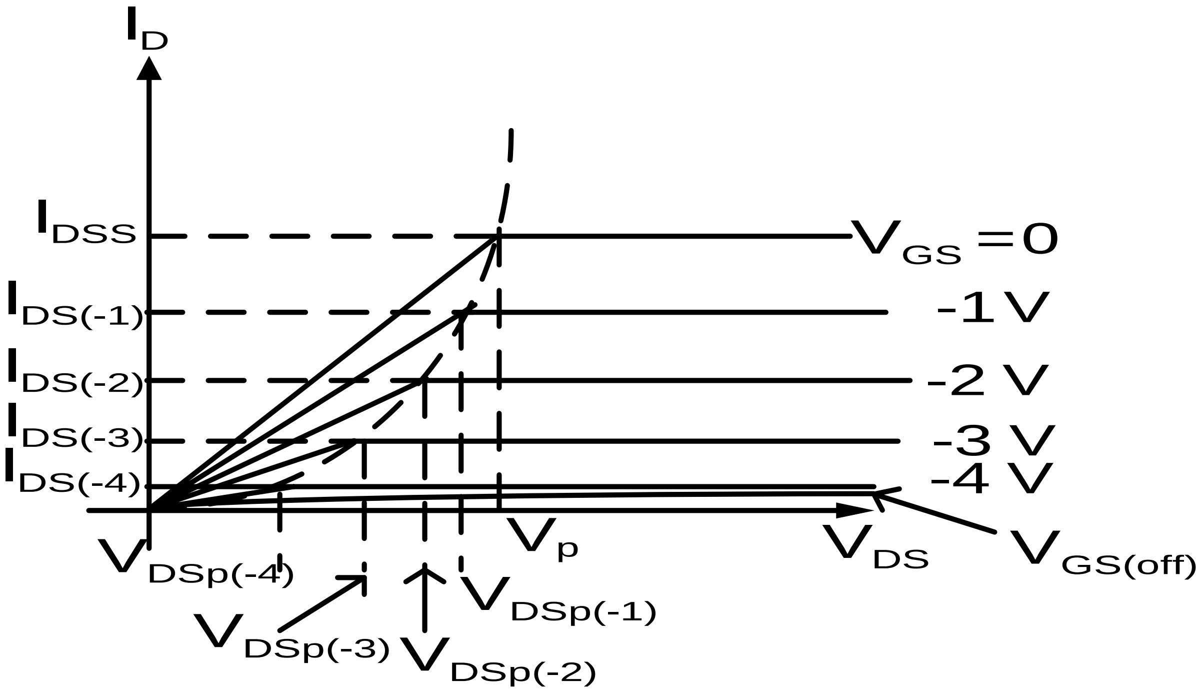


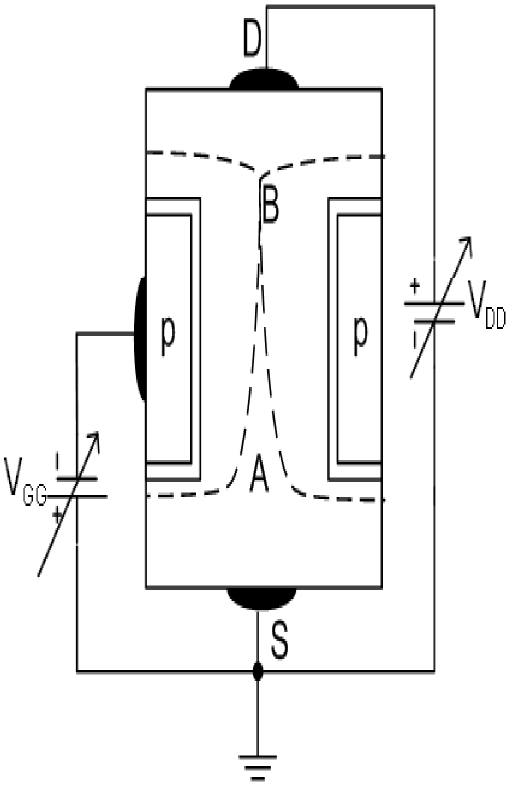
- **From the drain characteristic, as V_{GS} becomes more negative, the saturated current, I_{DS}, becomes smaller. When the V_{GS} is negative enough (i.e. when $V_{GS} = V_{GS(off)}$), $I_D \approx 0$. This condition occurs as when $V_{GS} = V_{GS(off)}$, the depletion region becomes large enough that it closes the channel. $V_{GS(off)} = - V_p$**





- The family of drain characteristic curves shows that when V_{GS} becomes more negative, V_{DSp} (or $V_{DS(sat)}$) and I_{DS} become smaller.
- I_D is dependent on the width of the channel. The width of the channel is dependent on the depletion region. The depletion region is dependent on the V_{GS}. Hence, V_{GS} is controlling the value of I_D. This is the reason why the JFET is known as a voltage controlled device.
- Pinched-off occurs when $V_{DS} = V_{DS(sat)}$.

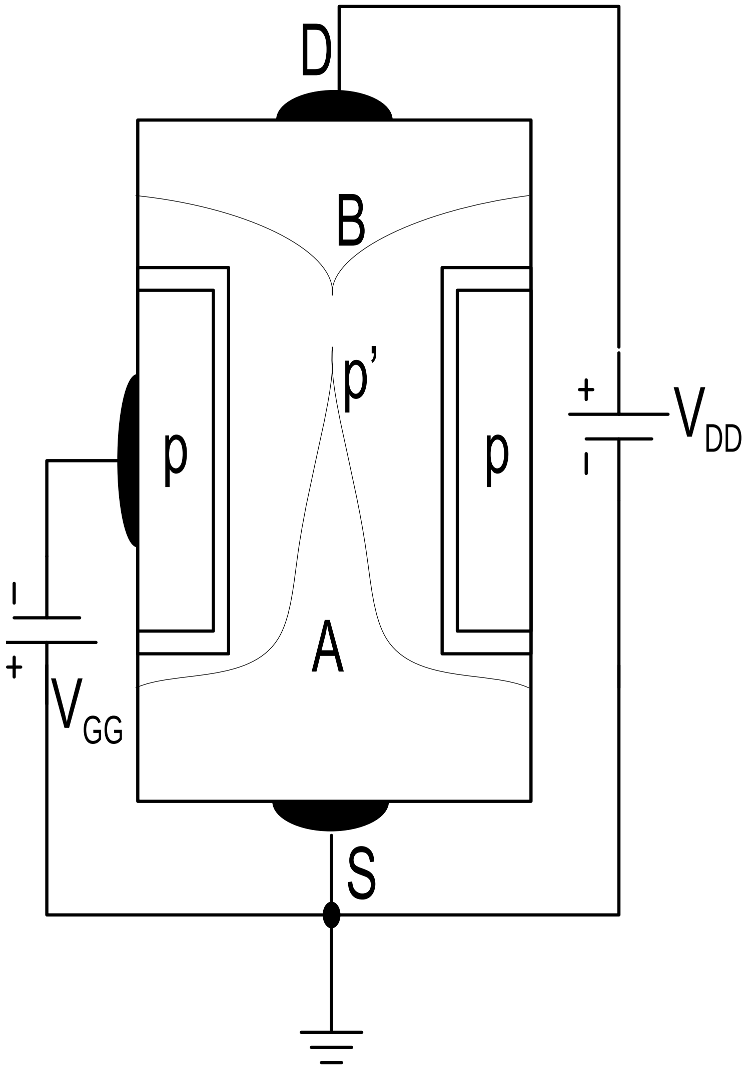




- **During pinch-off:**

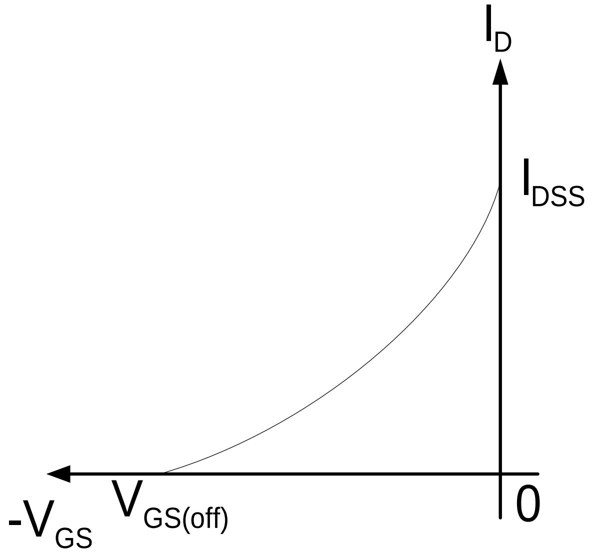
$$I_{DS} = \frac{V_{DS(sat)}}{R_{Ap'(V_{GS})}} = \frac{V_p + V_{GS}}{R_{Ap'(V_{GS})}}$$

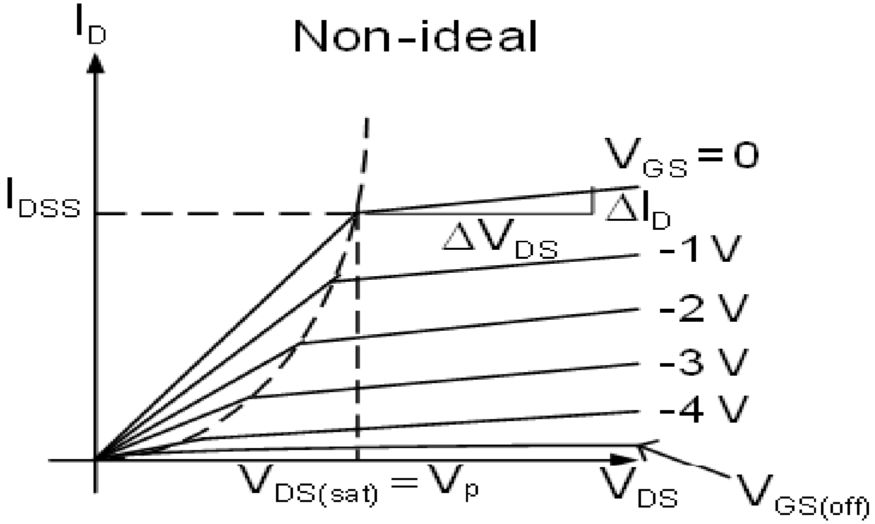
- **When V_{GS} becomes more negative, $V_{DS(sat)}$ reduces and $R_{Ap'(V_{GS})}$ increases. $R_{Ap'(V_{GS})}$ increases as the depletion region increases. Hence, I_{DS} decreases.**

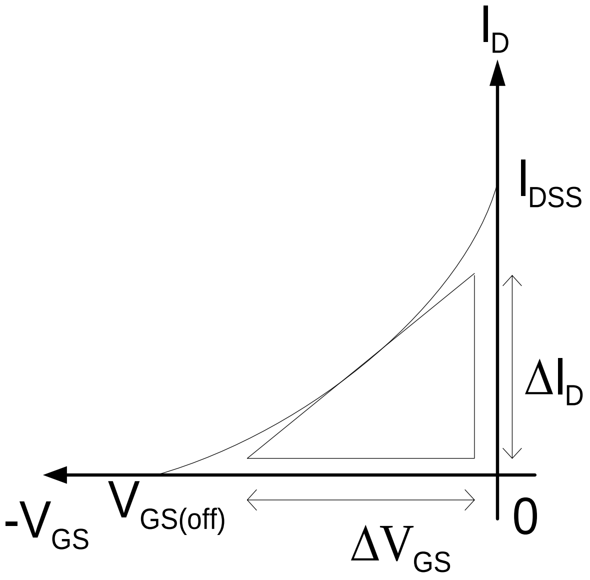


TRANSFER CHARACTERISTIC

- $I_D = I_{DSS}$ when V_{GS}=0 and I_D = 0 when $V_{GS}=V_{GS(off)}=-V_{p.}$
- I_{DSS} and $V_{GS(off)}$ are the JFET parameters which are available in the JFET data sheet.
- Another important JFET parameter is the forward transconductance, g_m.
- $g_m = \Delta I_D / \Delta V_{GS}$ at a fixed V_{DS} and the V_{DS} has to be in the saturation/fixed-current/pinch-off region.





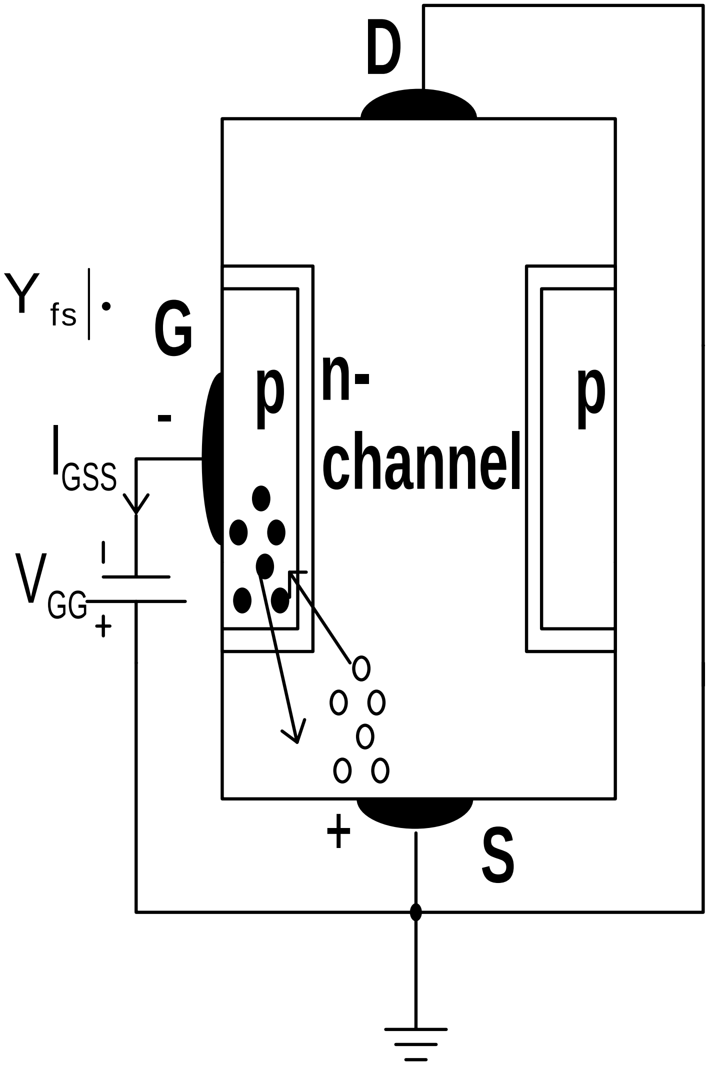


- **g_m at $V_{GS} = 0$ is known as g_{m0}.**
- $g_m = g_{m0}\left[1 - \dfrac{V_{GS}}{V_{GS(off)}}\right]$
- $g_{m0} = \dfrac{2I_{DSS}}{|V_{GS(off)}|}$
- **In the data sheet g_{m0} is represented by** $|Y_{fs}|$**.**

<u>Important parameters of the JFET</u>

Besides $V_{GS(off)}$, I_{DSS} and g_{m0}, another parameter of the JFET is R_{IN}.

$$R_{IN} = \left|\frac{V_{GS}}{I_{GSS}}\right|$$



- **I_{GSS} is the G-S current when the D-S is short circuited. I_{GSS} is given in the data sheet. Since I_{GSS} is from the flow of minority carriers, I_{GSS} increases with the increment of temperature, T, at a fixed V_{GS}. I_{GSS} is the G reverse current at a known V_{GS}. As I_{GSS} increases with T, R_{IN} will be reduced as** $R_{IN} = \left|\frac{V_{GS}}{I_{GSS}}\right|$.
- **The value of I_{GSS} is very small making the value of R_{IN} to be very large. Hence, the input impedance, *Z_i*, is very large.**