Electronic Devices

Final Term
Lecture - 04

Reference book:

Electronic Devices and Circuit Theory (Chapter-6)

Robert L. Boylestad and L. Nashelsky , (11th Edition)

P-CHANNEL JFET CHARACTERISTICS

- As V_{GS} increases more positively:
  - The depletion zone increases
  - I_D decreases ($I_D < I_{DSS}$)
  - Eventually I_D = 0A
- Also note that at high levels of V_{DS} the JFET reaches a breakdown situation. I_D increases uncontrollably if $V_{DS} > V_{DSmax}$.

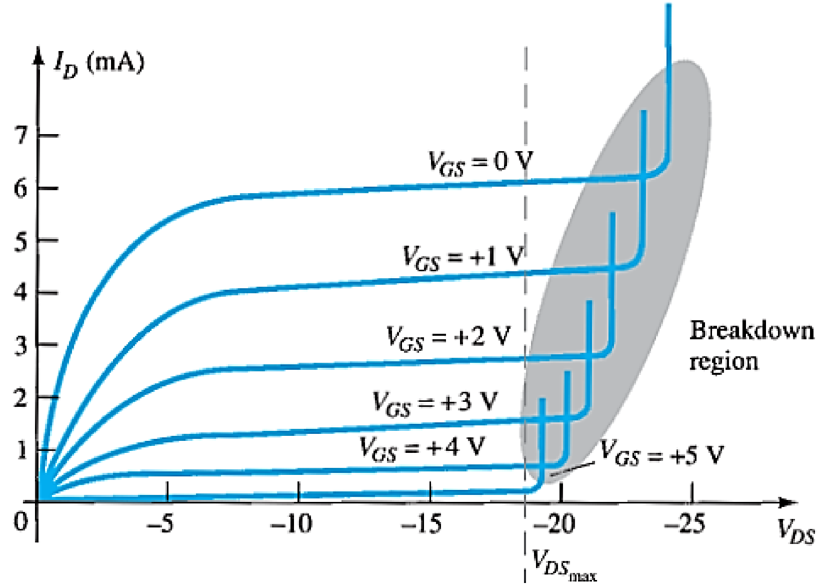


FIG. 6.13
p-Channel JFET characteristics with I_{DSS} = 6 mA and V_P = +6 V.

JFET SYMBOLS

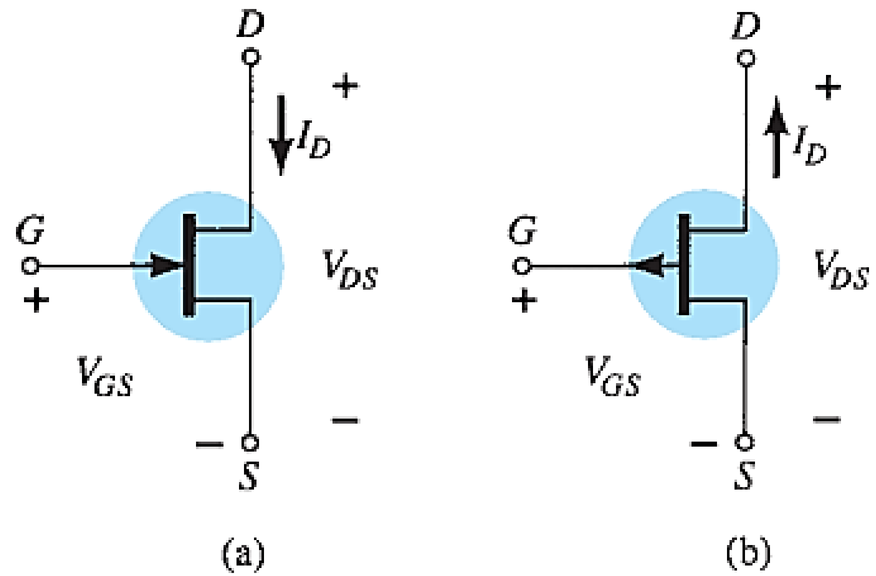


FIG. 6.14

JFET symbols: (a) n-channel; (b) p-channel.

SUMMARY TILL NOW

- The maximum current is defined as I_{DSS} and occurs when $V_{GS} = 0$ V and $V_{DS} \geq |V_p|$, as shown in Fig. 6.15a .

- For gate-to-source voltages V_{GS} is less than (more negative than) the pinch-off level, the drain current is 0 A ($I_D = 0$ A), as in Fig. 6.15b .

- For all levels of V_{GS} between 0 V and the pinch-off level, the current I_D will range between I_{DSS} and 0 A, respectively, as in Fig. 6.15c.

- A similar list can be developed for p-channel JFETs.

SUMMARY TILL NOW

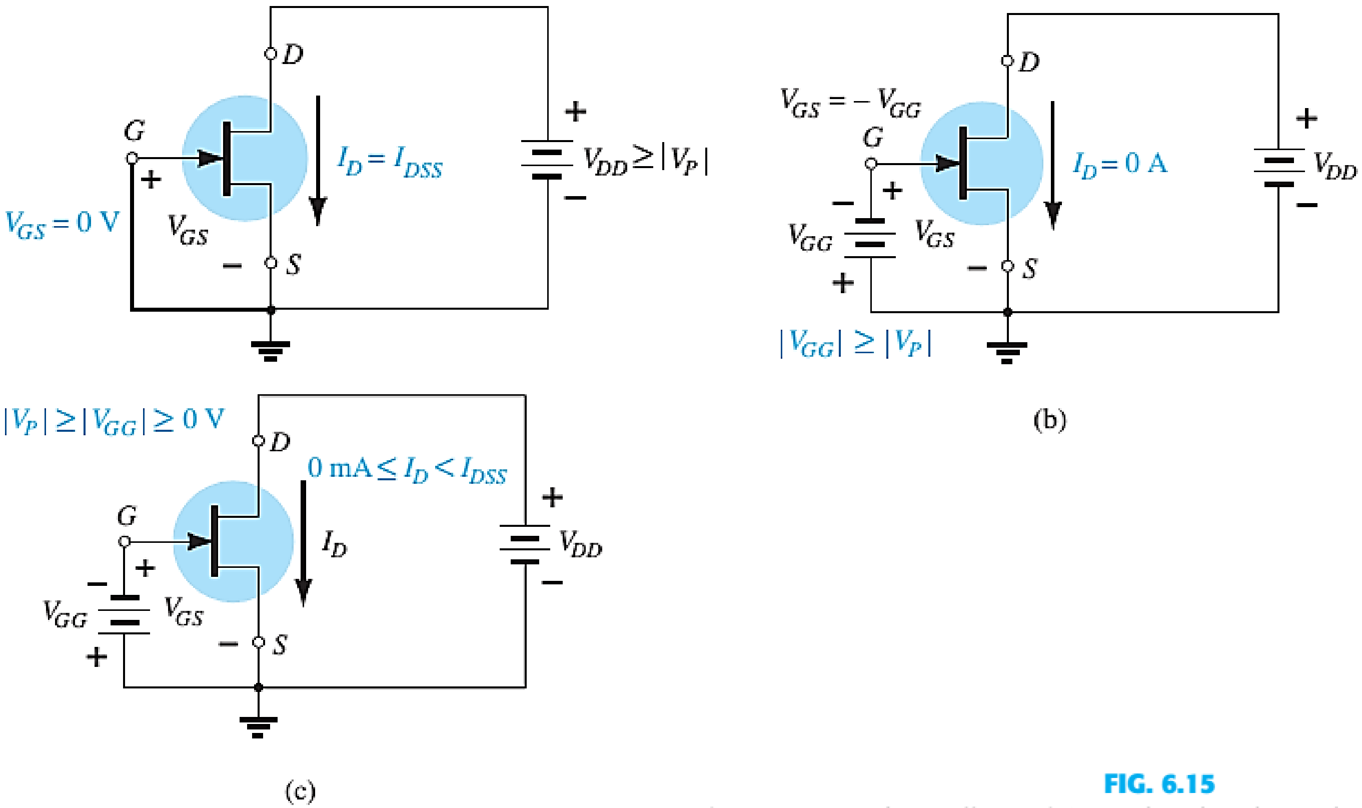


FIG. 6.15

(a) $V_{GS} = 0$ V, $I_D = I_{DSS}$; (b) cutoff ($I_D = 0$ A) V_{GS} less than the pinch-off level; (c) I_D is between 0 A and I_{DSS} for $V_{GS} \leq 0$ V and greater than the pinch-off level.

JFET TRANSFER CHARACTERISTICS

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

- In a BJT, β indicated 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 (Shockley's equation):

control variable

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

constants

TRANSFER CURVE

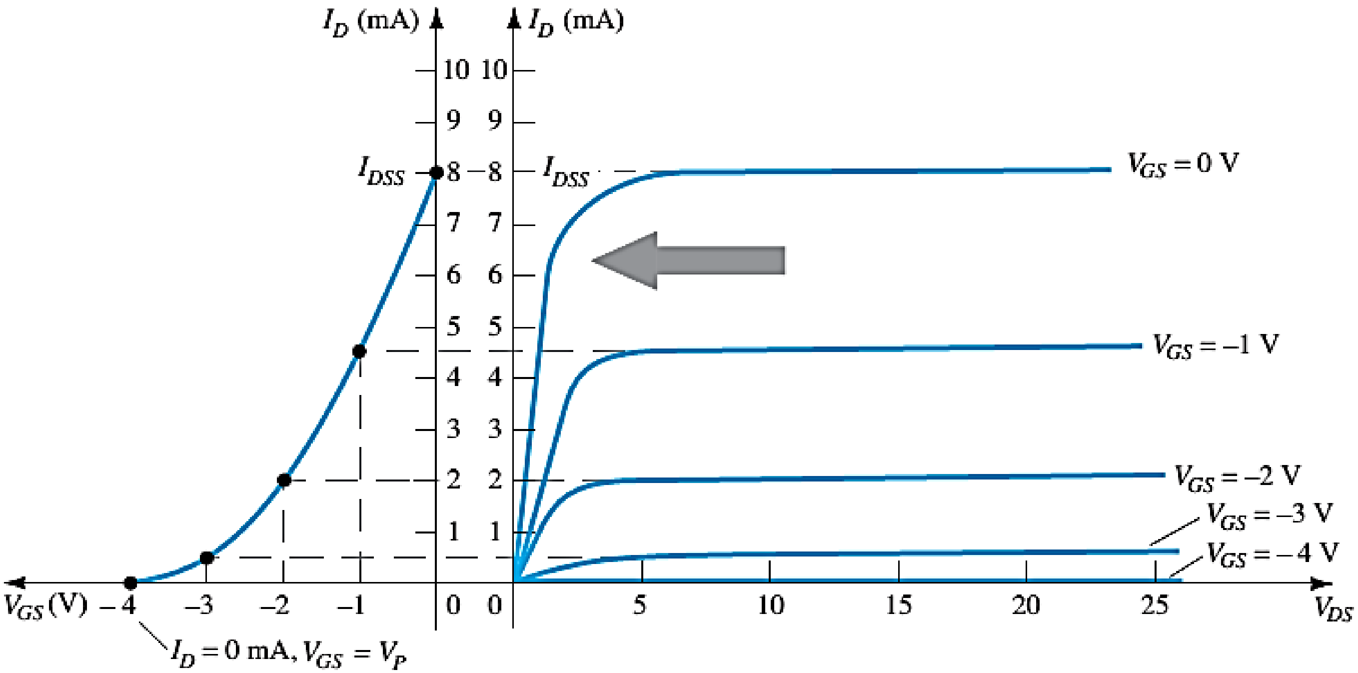


FIG. 6.17
Obtaining the transfer curve from the drain characteristics.

PLOTTING THE TRANSFER CURVE

- Using I_{DSS} and V_p ($V_{GS(off)}$) values found in a specification sheet, the Transfer Curve can be plotted using these 3 steps:

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

Solving for V_{GS} = 0V: $I_D = I_{DSS} \,/\, V_{GS} = 0V$

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

Solving for V_{GS} = V_p ($V_{GS(off)}$): $I_D = 0A \,/\, V_{GS} = V_P$

- Step 3:

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

SHORTHAND METHOD

V_{GS}	I_D
0	I_{DSS}
$0.3V_P$	$I_{DSS}/2$
$0.5V_P$	$I_{DSS}/4$
V_P	0mA

When VGS = 0 V, ID = $IDSS$

When VGS = VP, ID = 0 mA

EXAMPLE

EXAMPLE 6.1 Sketch the transfer curve defined by $I_{DSS} = 12$ mA and $V_P = -6$ V.

Solution: Two plot points are defined by

$$I_{DSS} = \mathbf{12\ mA} \quad \text{and} \quad V_{GS} = \mathbf{0\ V}$$

and

$$I_D = \mathbf{0\ mA} \quad \text{and} \quad V_{GS} = \boldsymbol{V_P}$$

At $V_{GS} = V_P/2 = -6\text{ V}/2 = \mathbf{-3\ V}$ the drain current is determined by $I_D = I_{DSS}/4 = 12\text{ mA}/4 = \mathbf{3\ mA}$. At $I_D = I_{DSS}/2 = 12\text{ mA}/2 = \mathbf{6\ mA}$ the gate-to-source voltage is determined by $V_{GS} \cong 0.3V_P = 0.3(-6\text{ V}) = \mathbf{-1.8\ V}$. All four plot points are well defined on Fig. 6.18 with the complete transfer curve.

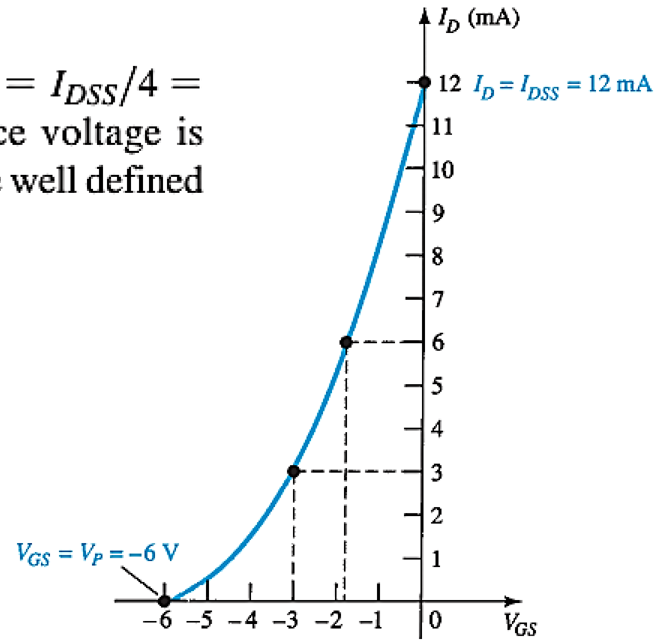


FIG. 6.18
Transfer curve for Example 6.1.

EXAMPLE

EXAMPLE 6.2 Sketch the transfer curve for a p-channel device with $I_{DSS} = 4$ mA and $V_P = 3$ V.

Solution: At $V_{GS} = V_P/2 = 3\text{ V}/2 = \mathbf{1.5\ V}$, $I_D = I_{DSS}/4 = 4\text{ mA}/4 = \mathbf{1\ mA}$. At $I_D = I_{DSS}/2 = 4\text{ mA}/2 = \mathbf{2\ mA}$, $V_{GS} = 0.3V_P = 0.3(3\text{ V}) = \mathbf{0.9\ V}$. Both plot points appear in Fig. 6.19 along with the points defined by I_{DSS} and V_P.

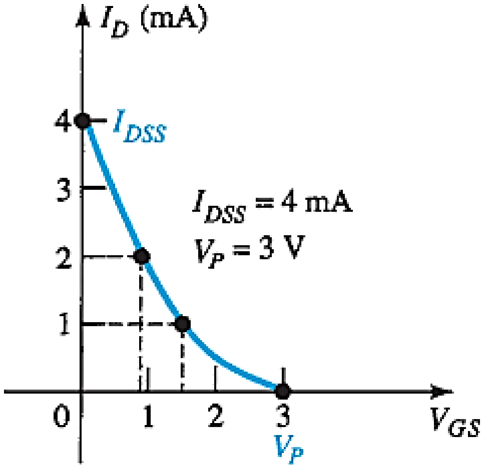
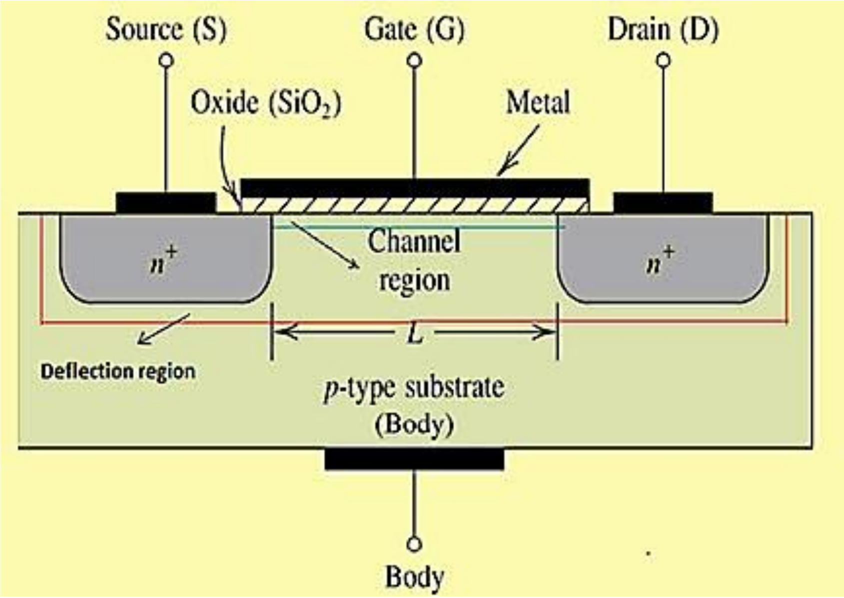


FIG. 6.19
Transfer curve for the p-channel device of Example 6.2.

MOSFETs

- MOSFETs have characteristics similar to JFETs and additional characteristics that make them very useful.

- There are 2 types:
  - Depletion-Type MOSFET
  - Enhancement-Type MOSFET



ENHANCEMENT-TYPE MOSFET CONSTRUCTION

- The Drain (D) and Source (S) connect to the to n-doped regions.
- The Gate (G) connects to the p-doped substrate via a thin insulating layer of SiO2.
- There is no channel. The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS.
- In summary, therefore, the construction of an enhancement-type MOSFET is quite similar to that of the depletion-type MOSFET, except for the absence of a channel between the drain and source terminals.

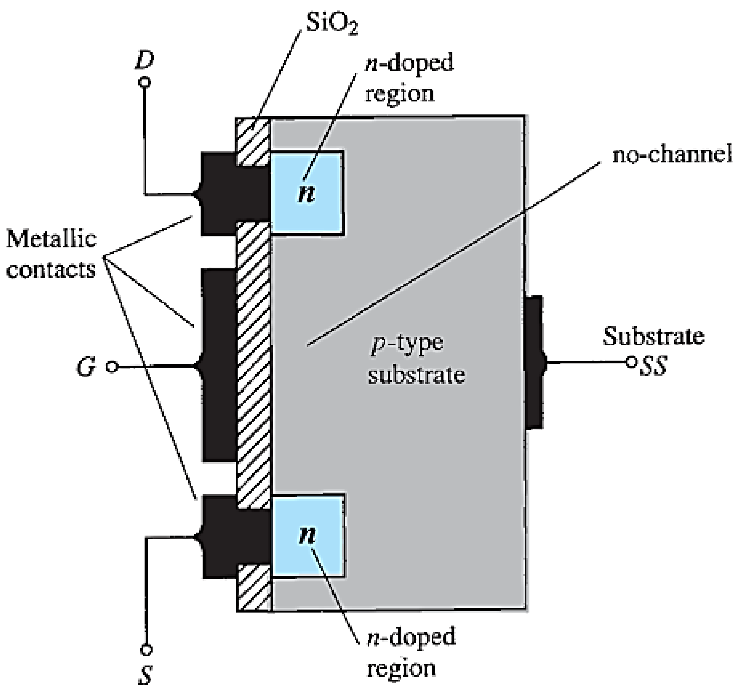


FIG. 6.32
n-Channel enhancement-type MOSFET.

CONTINUED…

- ***As V_{GS} increases*** in magnitude, the ***concentration of electrons near the SiO2 surface increases*** until eventually the induced n-type region can support a measurable flow between drain and source.

- ***The level of V_{GS}*** that results in the ***significant increase in drain current*** is called the ***threshold voltage*** and is given the symbol V_T.

- Since the channel is nonexistent with V_{GS}=0 V and "enhanced" by the application of a positive gate-to-source voltage, this type of MOSFET is called an enhancement-type MOSFET.

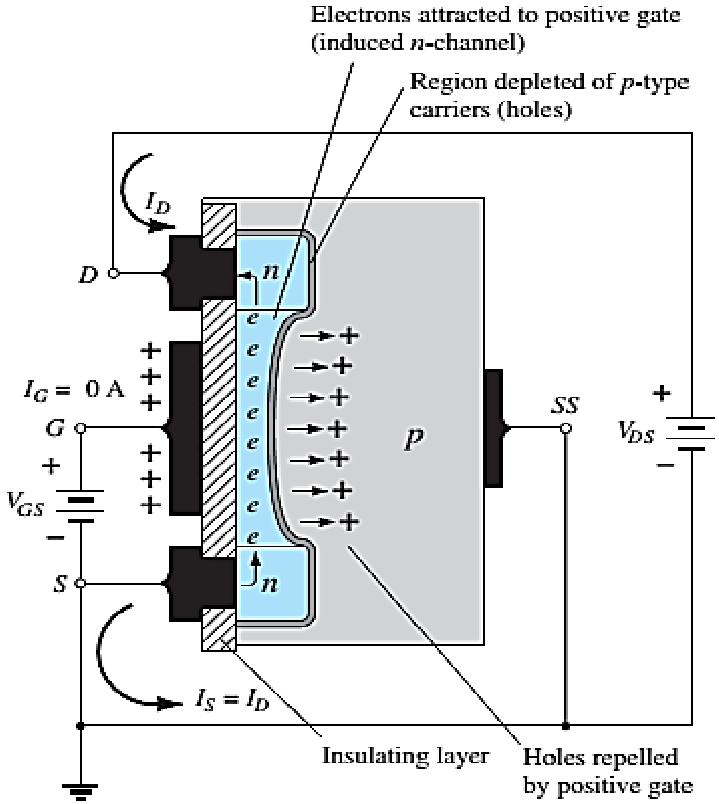


FIG. 6.33
Channel formation in the n-channel enhancement-type MOSFET.

CONTINUED…

- ***As V_{GS} is increased beyond the threshold level***, the ***density of free carriers*** in the induced channel ***will increase***, resulting in ***an increased level of drain current.***

- However, if we hold V_{GS} constant and increase the level of V_{DS}, the drain current will eventually reach a saturation level The levelling off of I_D is due to a pinching-off process depicted by the narrower channel at the drain end of the induced channel.

- By applying KVL we get – $\boxed{V_{DG} = V_{DS} - V_{GS}}$
- If ***V_{GS} is held fixed*** at some value such as 8 V and ***V_{DS} is increased*** from 2 to 5V, the voltage will drop from -6 to -3 V. This ***reduction in gate-to-drain voltage*** will in turn ***reduce the attractive forces for free carriers*** (electrons) in this region of the induced channel***, causing a reduction in the effective channel width.***

- Eventually, the channel will be reduced to the point of pinch-off and a saturation condition will be established.

CONTINUED…

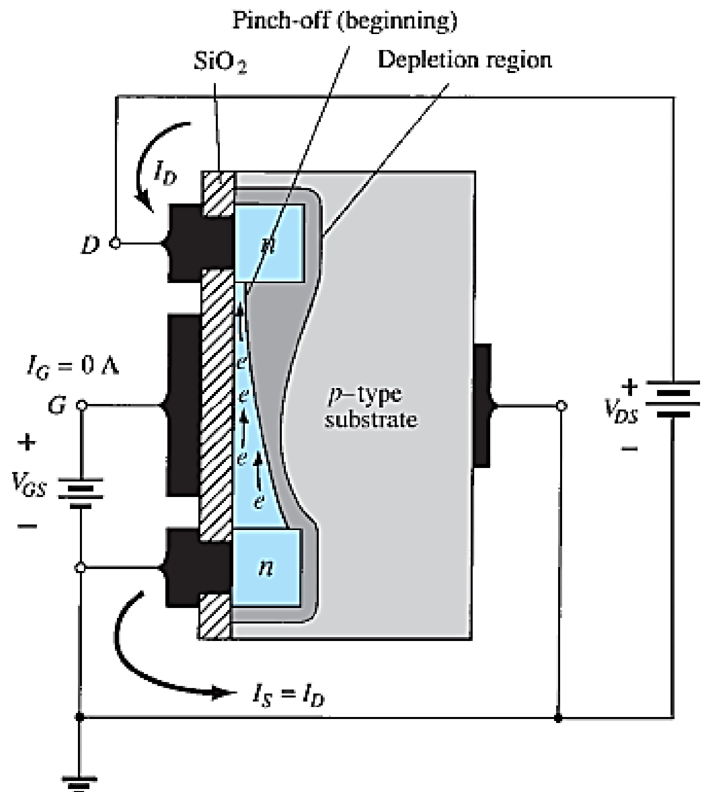


FIG. 6.34

Change in channel and depletion region with increasing level of V_{DS} for a fixed value of V_{GS}.

BASIC OPERATION

- The Enhancement-type MOSFET only operates in the enhancement mode.

- ***V_{GS} is always positive.***
- As ***V_{GS} increases***, ***I_D increases.***
- But if ***V_{GS} is kept constant*** and ***V_{DS} is increased***, then ***I_D saturates (I_{DSS}).***
- The saturation level, ***V_{DSsat} is reached.***

$$V_{Dsat} = V_{GS} - V_T$$

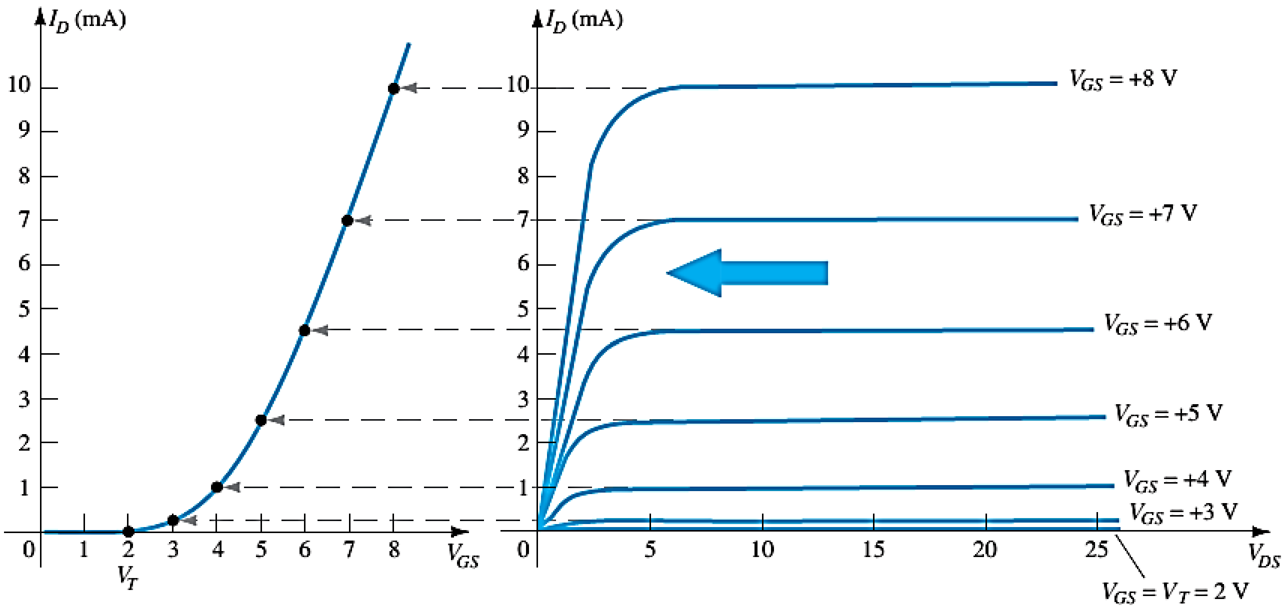


FIG. 6.36
Sketching the transfer characteristics for an n-channel enhancement-type MOSFET from the drain characteristics.

Check this: http://www-g.eng.cam.ac.uk/mmg/teaching/linearcircuits/jfet.html

End of Lecture-4