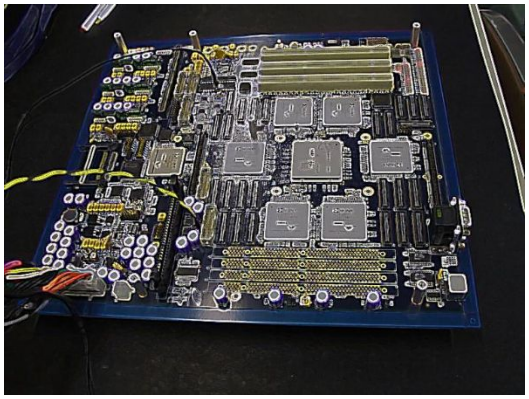
МЕЖДУНАРОДНЫЙ УНИВЕРСИТЕТ INTERNATIONAL UNIVERSITY
ХАЛЫҚАРАЛЫҚ УНИВЕРСИТЕТІ



Lecture # 10

The Field-Effect Transistor (FETs). Junction Field-effect transistor fundamentals

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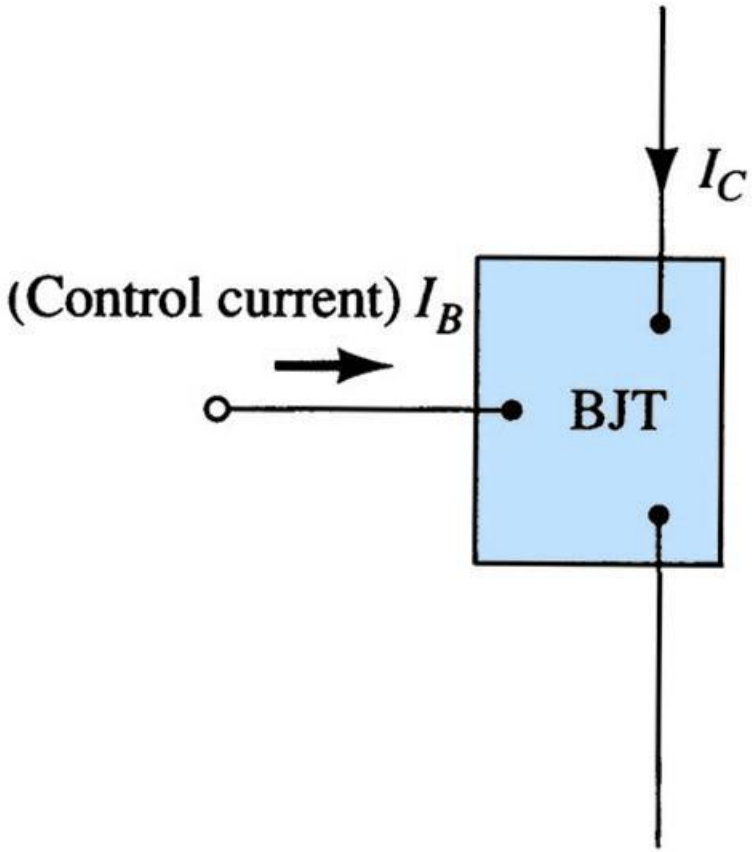
Introduction (FET)

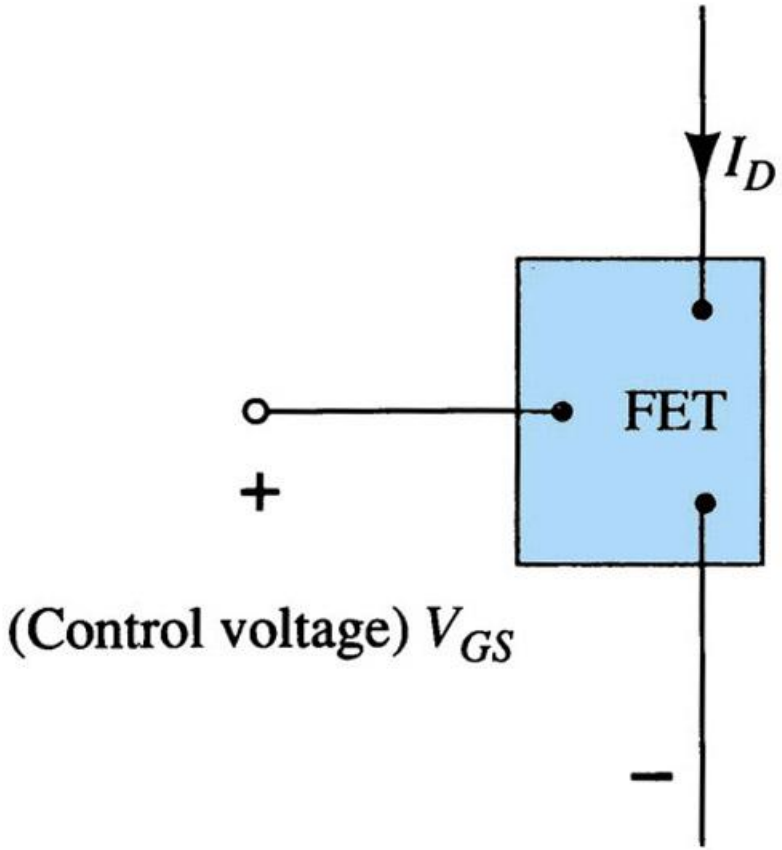
- Field-effect transistor (FET) are important devices such as BJTs
- Also used as amplifier and logic switches
- Types of FET:
  - JFET (junction field-effect transistor)
  - MOSFET (metal-oxide-semiconductor field-effect transistor)
- What is the difference between JFET and MOSFET?

Current-controlled amplifiers



(a)

Voltage-controlled amplifiers



(b)

Introduction.. (Advantages of FET)

- High input impedance (MΩ) (Linear AC amplifier system)
- Temperature stable than BJT
- Smaller than BJT
- Can be fabricated with fewer processing
- BJT is bipolar – conduction both hole and electron
- FET is unipolar – uses only one type of current carrier
- Less noise compare to BJT
- Usually use as logic switch

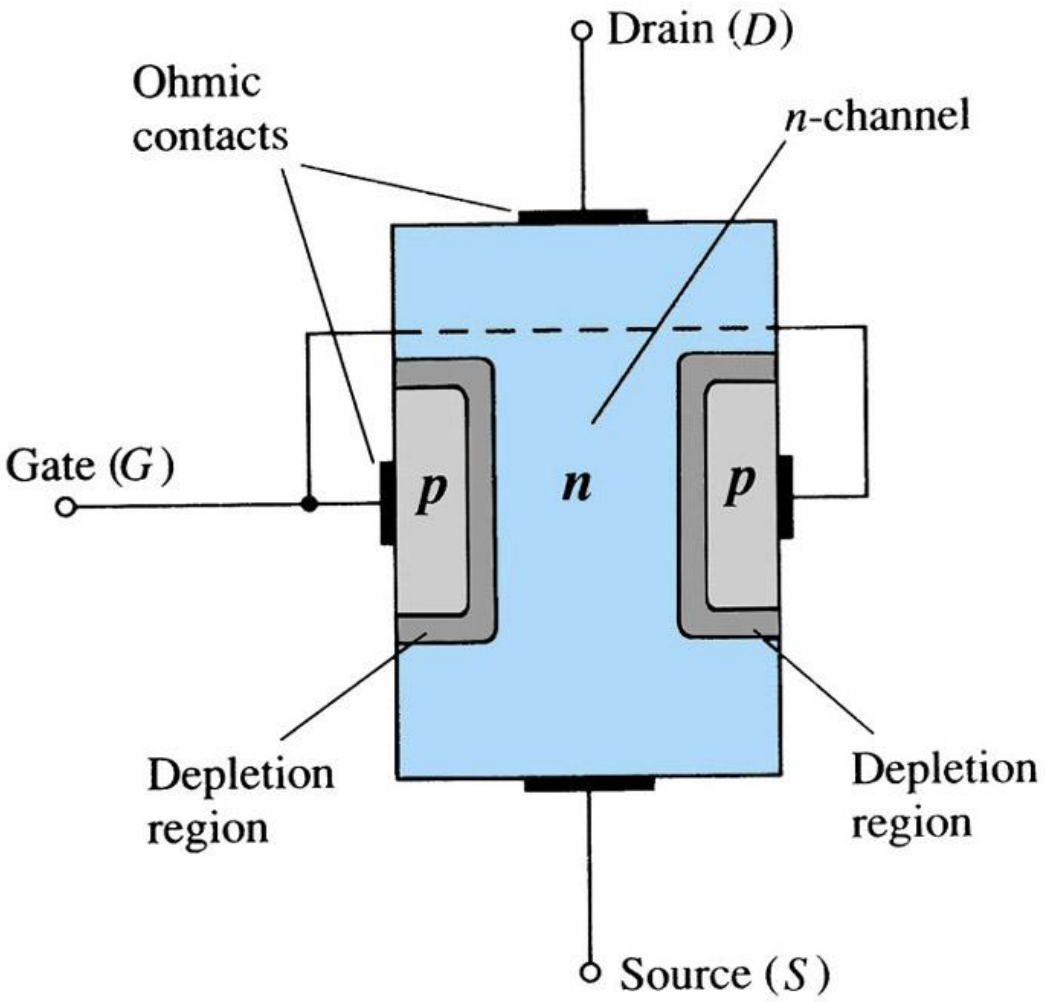
Disadvantages of FET

- Easy to damage compare to BJT
- ???

Junction field-effect transistor..

- There are 2 types of JFET
  - n-channel JFET
  - p-channel JFET
- Three Terminal
  - **gate:** as in the "gate" keeper of the current
  - **source:** the source of the current
  - **drain:** the destination of the current

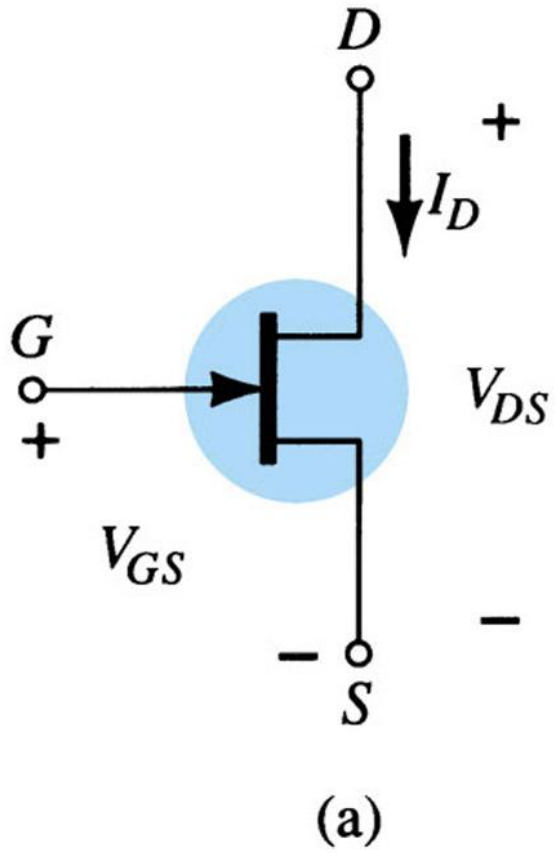
Junction field-effect transistor (JFET)

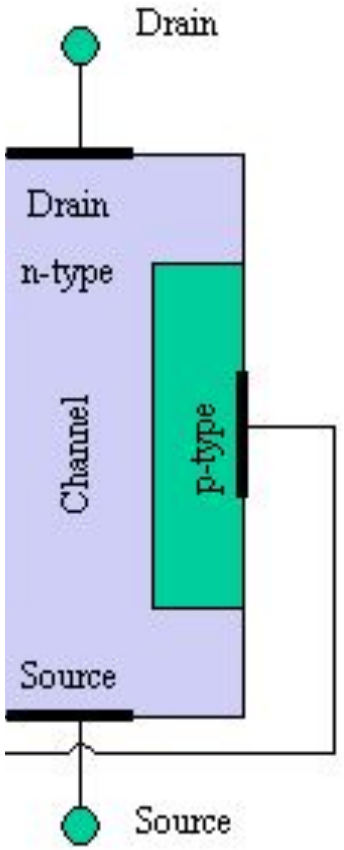


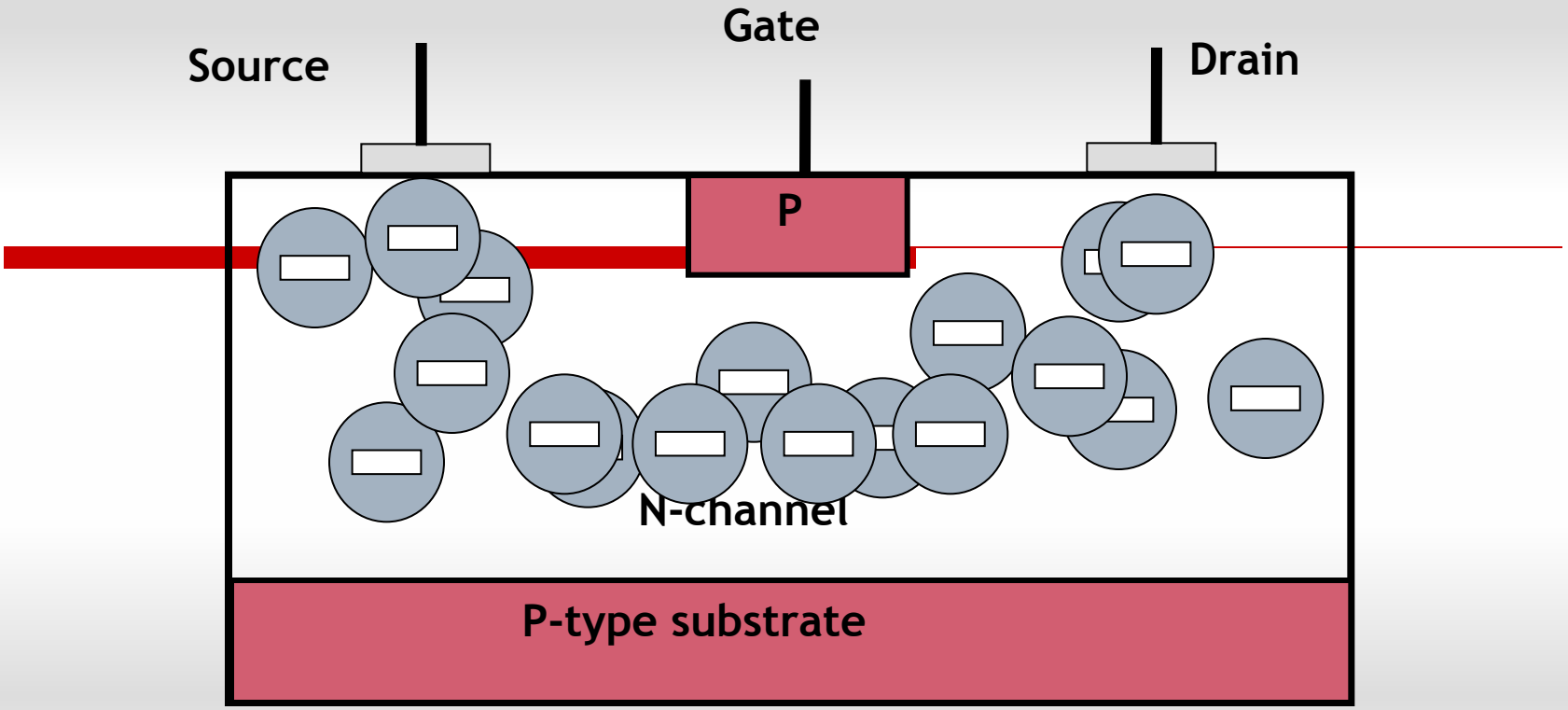
N-channel JFET

- N channel JFET:
  - Major structure is n-type material (channel) between embedded p-type material to form 2 p-n junction.
  - In the normal operation of an n-channel device, the Drain (D) is positive with respect to the Source (S). Current flows into the Drain (D), through the channel, and out of the Source (S)
  - Because the resistance of the channel depends on the gate-to-source voltage (V_{GS}), the drain current (I_D) is controlled by that voltage

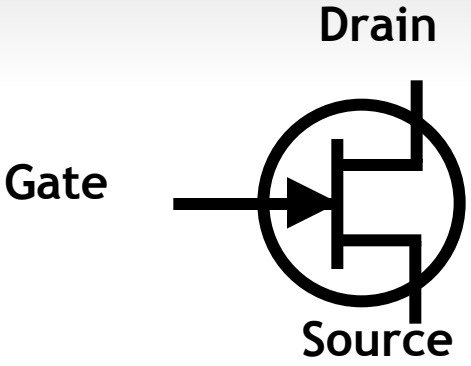
N-channel JFET..





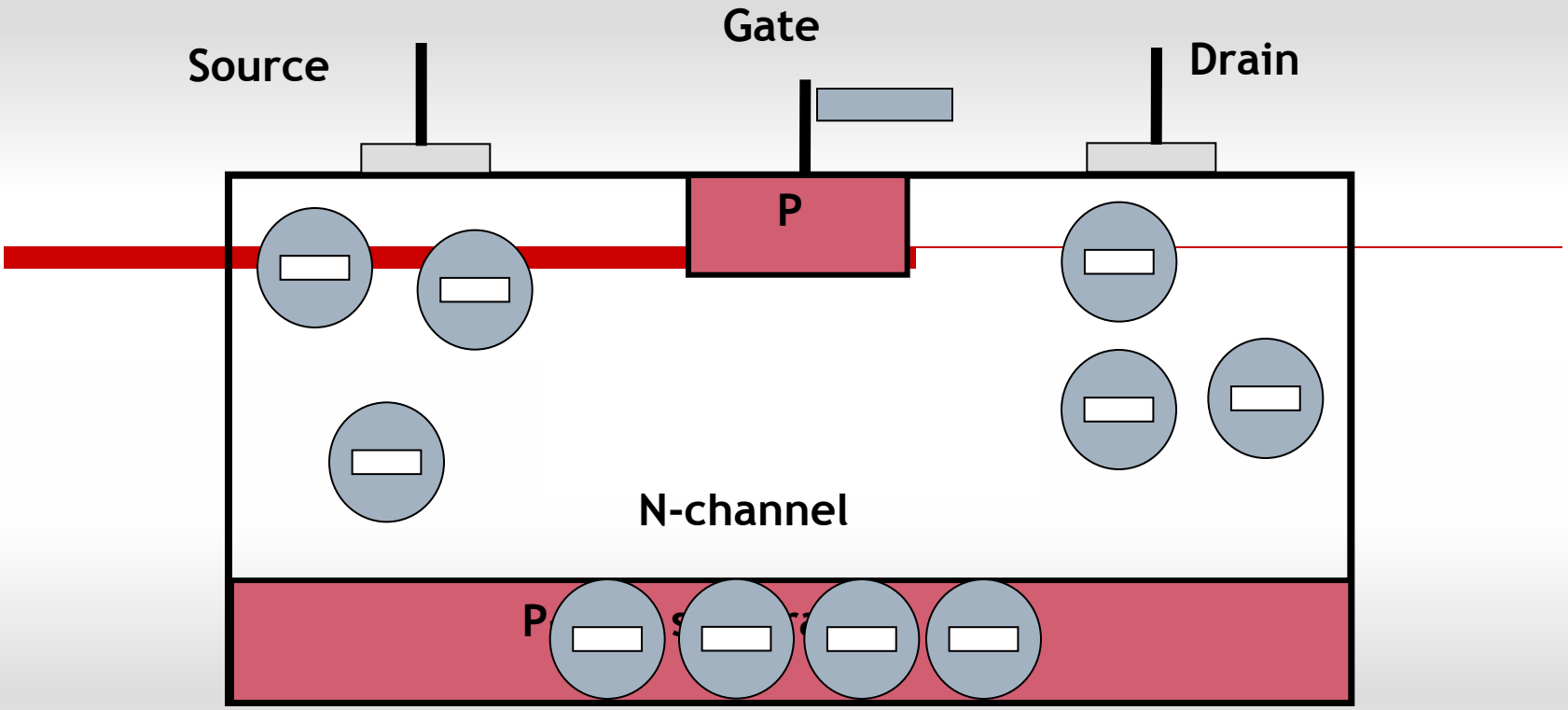


Structure of an
N-channel JFET

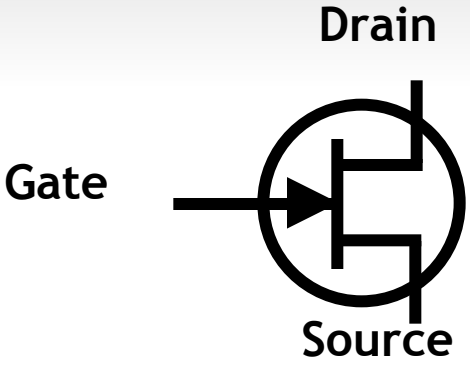


The channel has carriers so it

conducts from source to



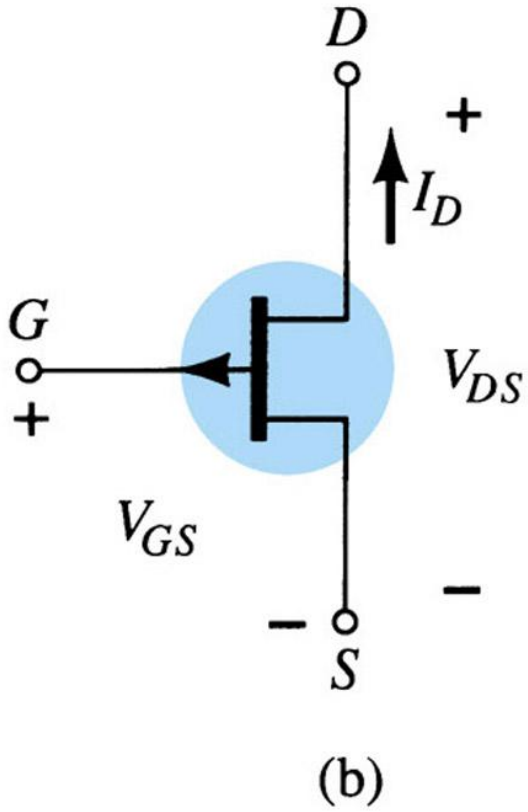
A negative gate voltage can push the carriers from the channel and turn the JFET off

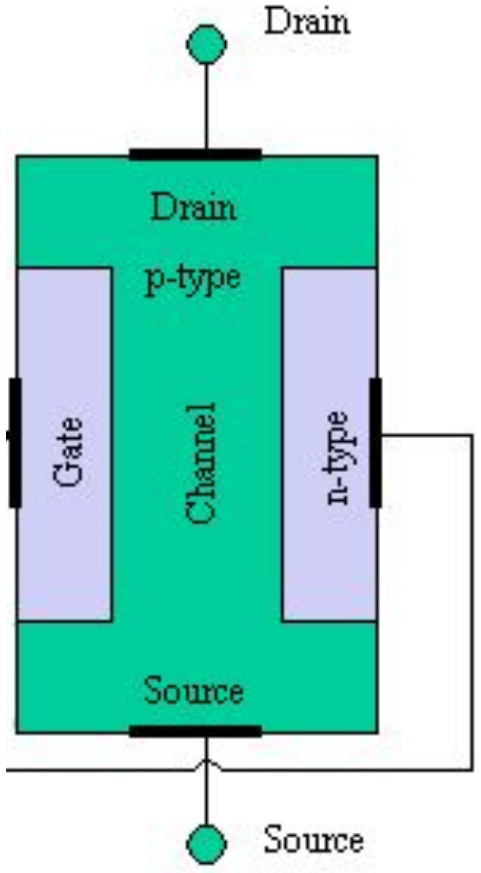


P-channel JFET

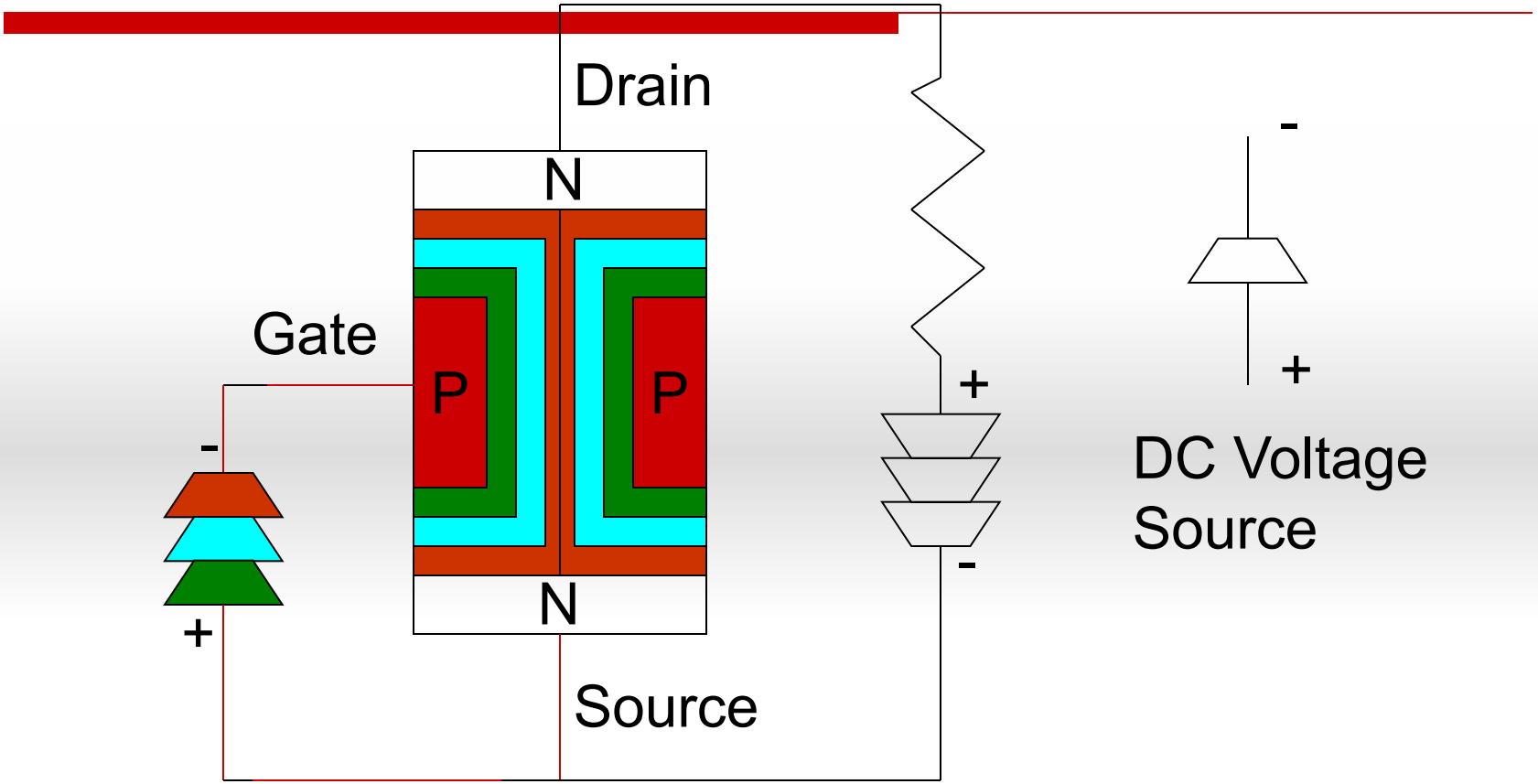
- P channel JFET:
  - Major structure is p-type material (channel) between embedded n-type material to form 2 p-n junction.
  - Current flow : from Source (S) to Drain (D)
  - Holes injected to Source (S) through p-type channel and flowed to Drain (D)

P-channel JFET..

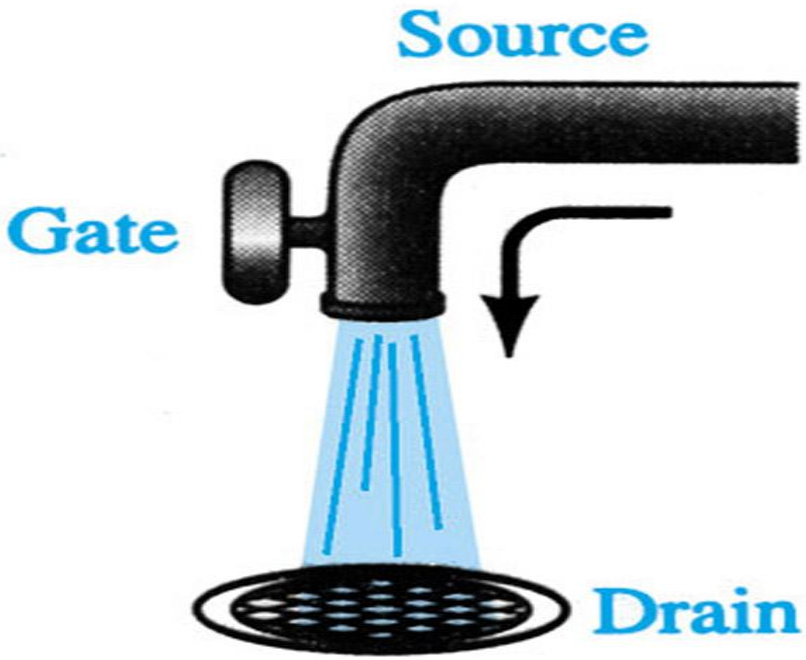




Operation of a JFET



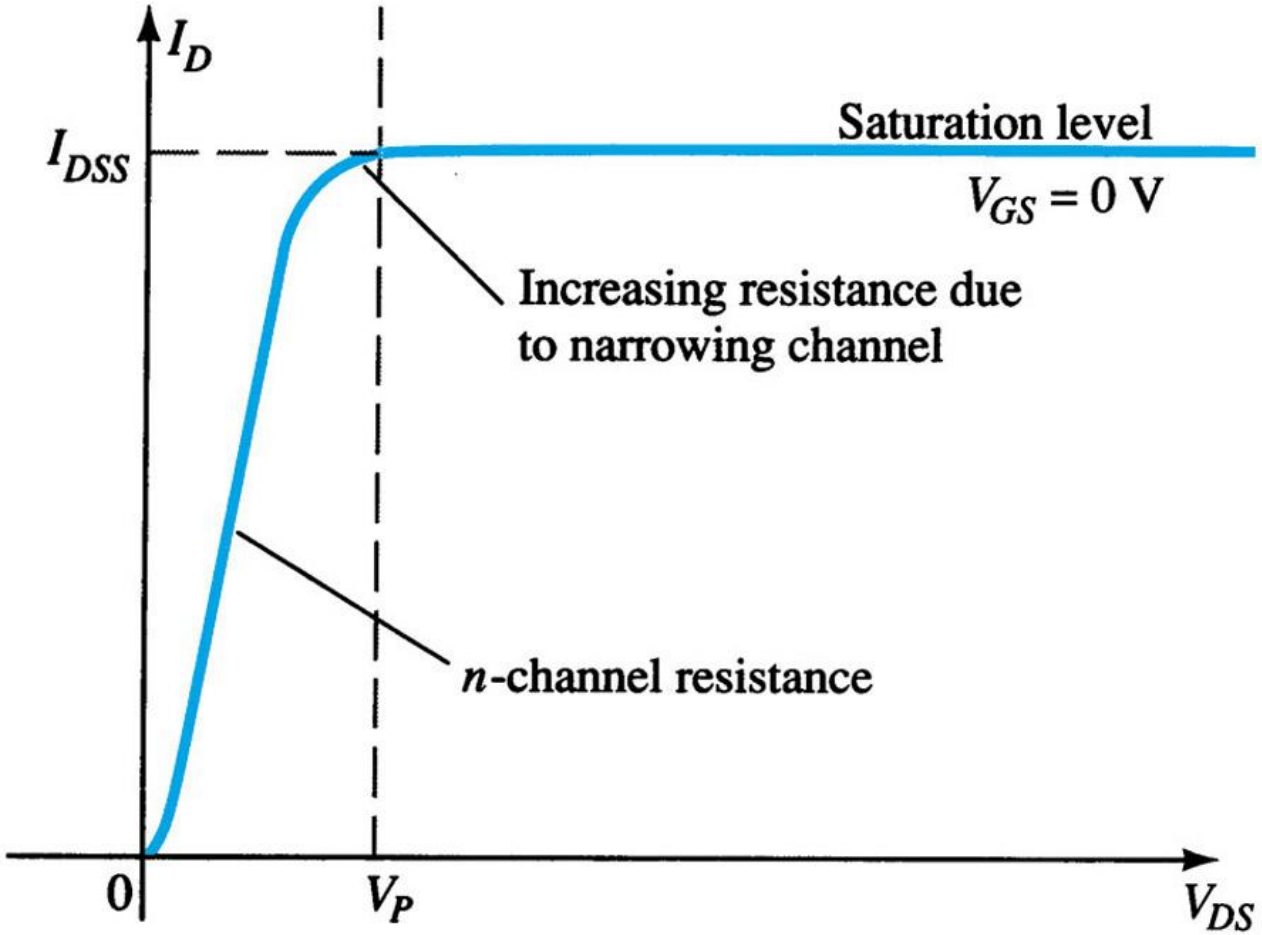
Water analogy for the JFET control mechanism



JFET Characteristic Curve

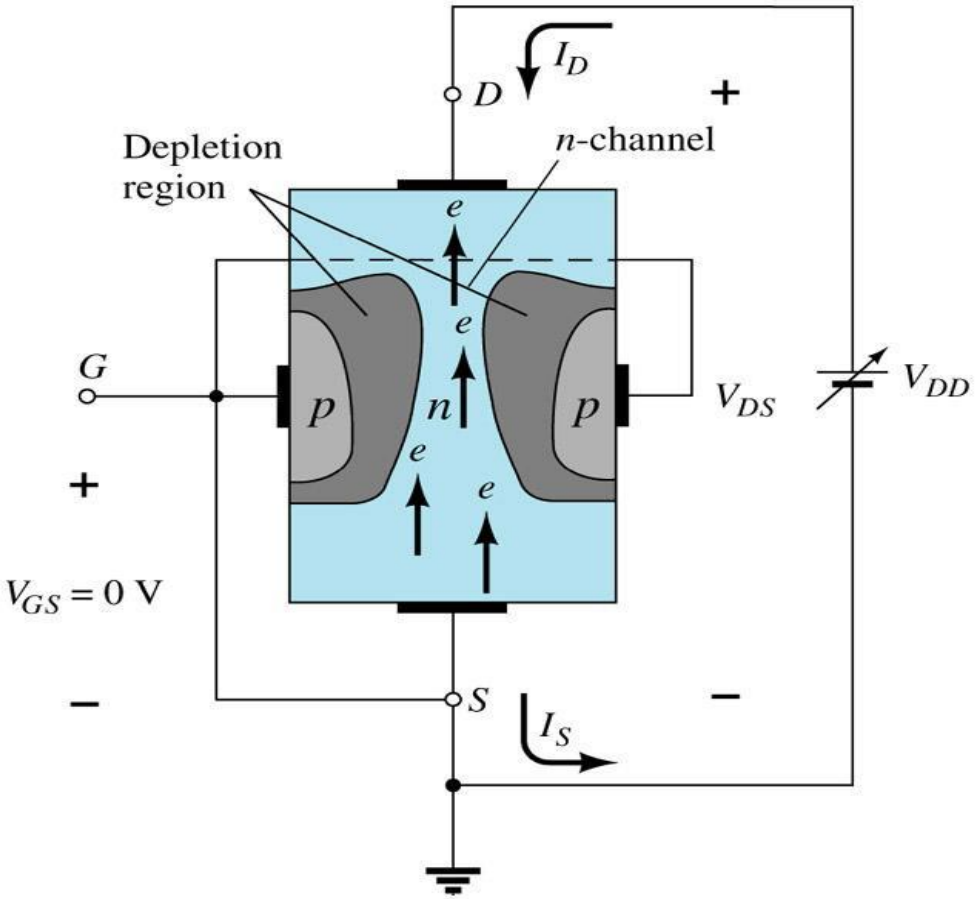
- To start, suppose $V_{GS}=0$
- Then, when V_{DS} is increased, I_D increases. Therefore, I_D is proportional to V_{DS} for small values of V_{DS}
- For larger value of V_{DS}, as V_{DS} increases, the depletion layer become wider, causing the resistance of channel increases.
- After the pinch-off voltage (V_p) is reached, the I_D becomes nearly constant (called as I_D maximum, I_{DSS}-Drain to Source current with Gate Shorted)

I_D versus V_{DS} for V_{GS} = 0 V.



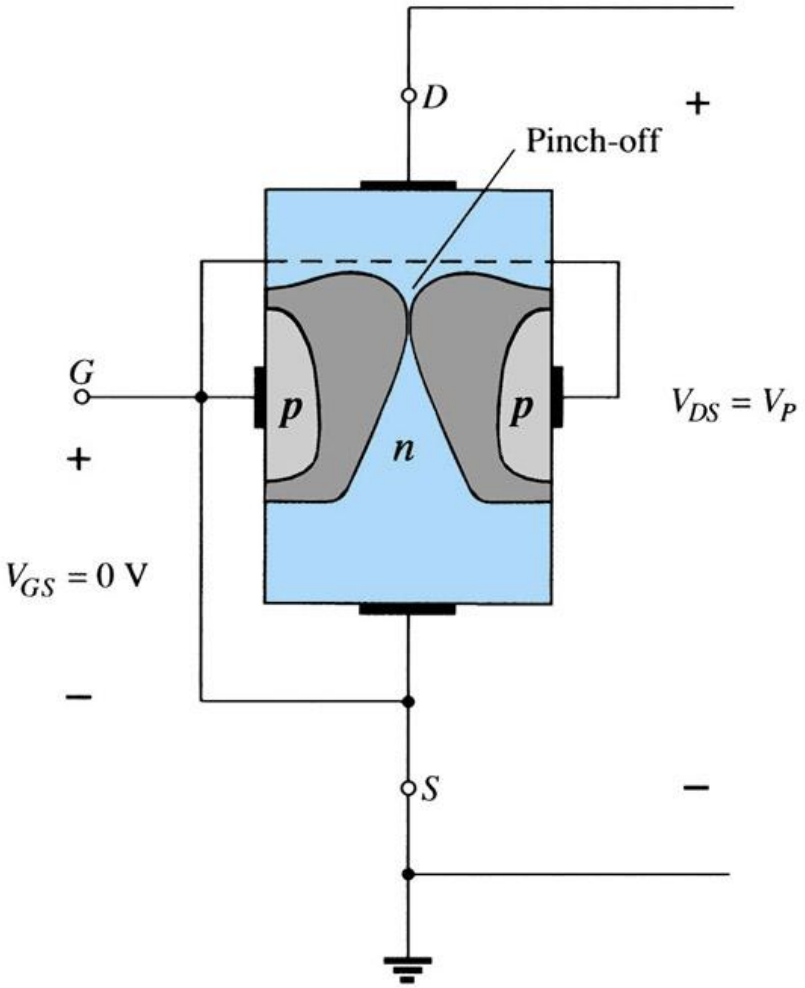
JFET Characteristic Curve

JFET for $V_{GS} = 0$ V and $0 < V_{DS} < |V_p|$

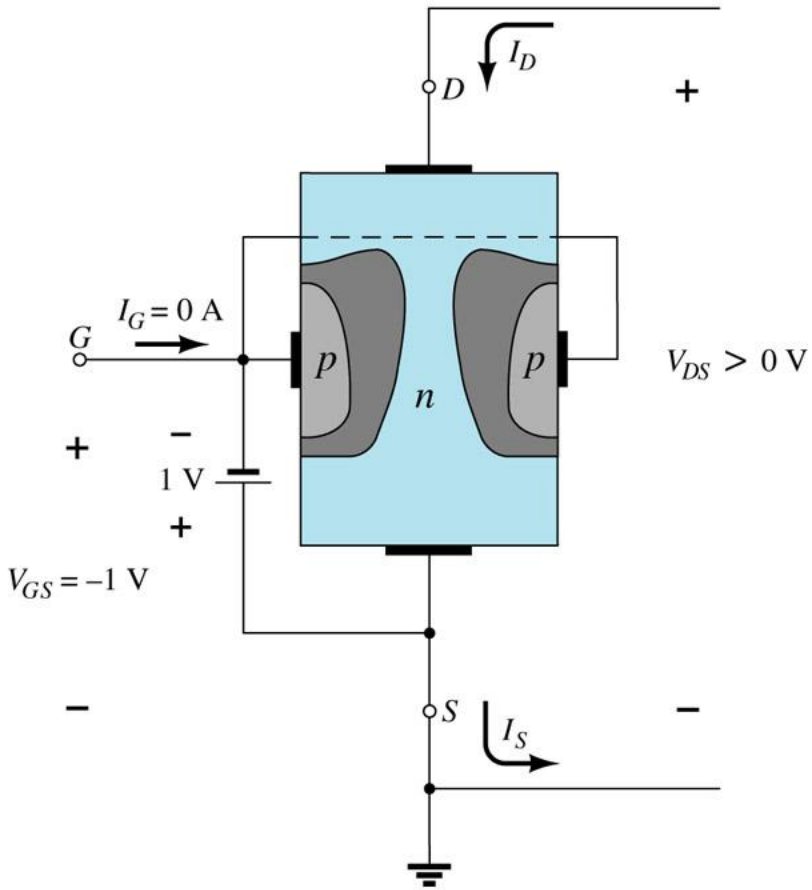


Channel becomes narrower as V_{DS} is increased

Pinch-off (V_{GS} = 0 V, $V_{DS} = V_P$).

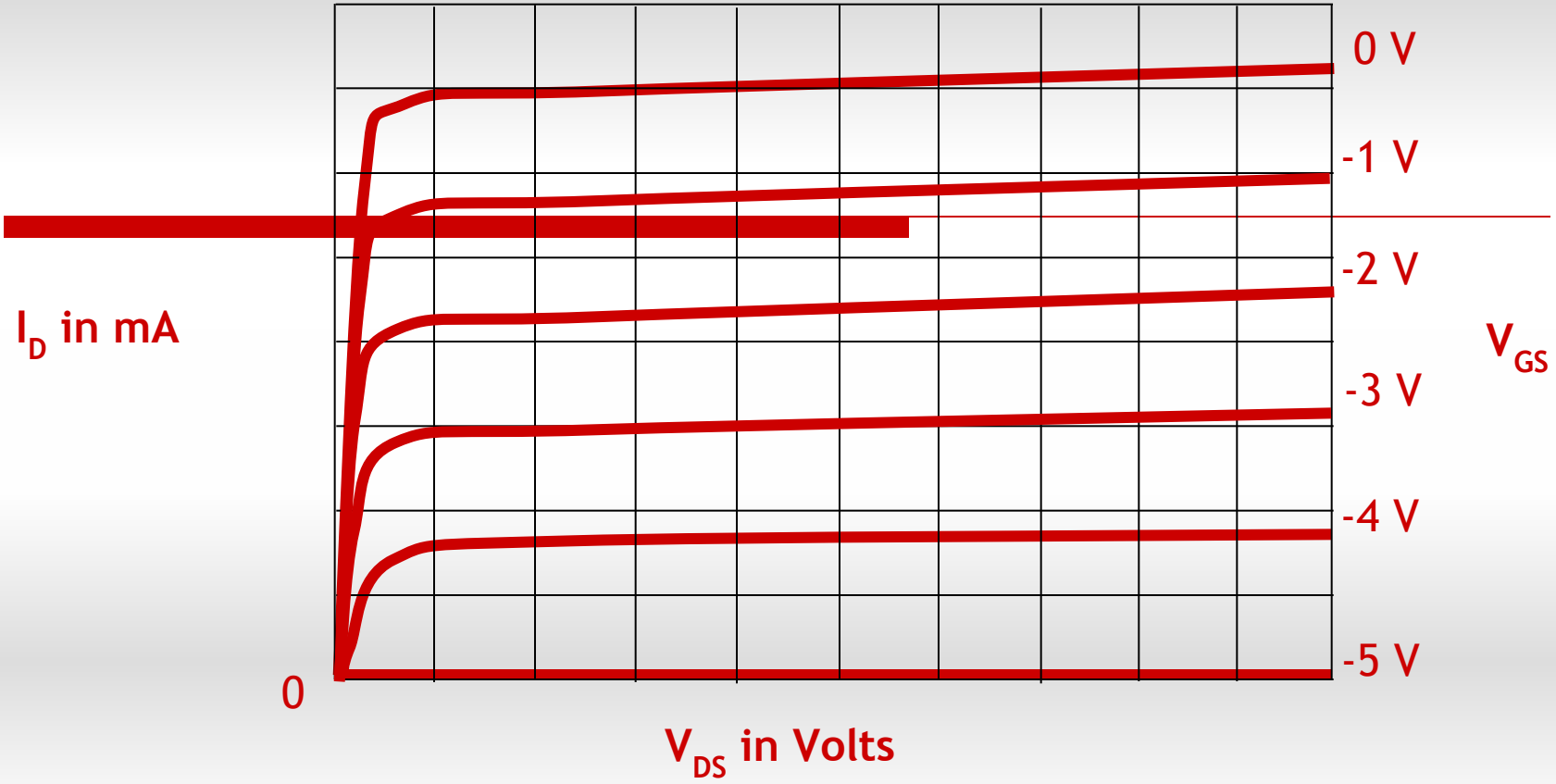


Application of a negative voltage to the gate of a JFET.



JFET Characteristic Curve..

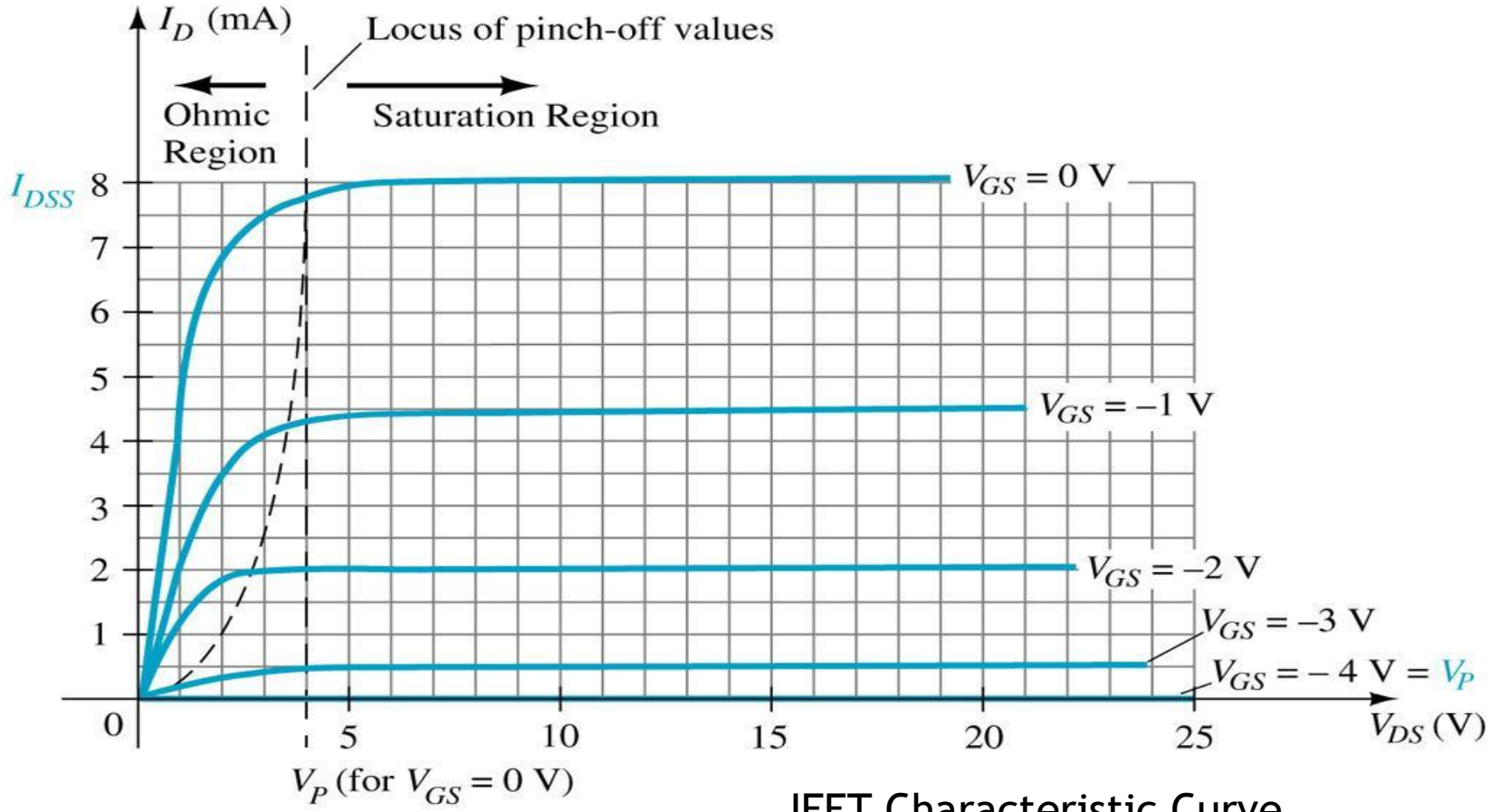
- For negative values of V_{GS}, the gate-to-channel junction is reverse biased even with $V_{DS}=0$
- Thus, the initial channel resistance is higher (in which the initial slope of the curves is smaller for values of V_{GS} closer to the pinch-off voltage (V_P)
- The resistance value is under the control of V_{GS}
- If V_{GS} is less than pinch-off voltage, the resistance becomes an open-circuit ;therefore the device is in cutoff ($V_{GS}=V_{GS(off)}$)
- The region where I_D constant – The saturation/pinch-off region
- The region where I_D depends on V_{DS} is called the linear/triode/ohmic region



This is known as a depletion-mode device.

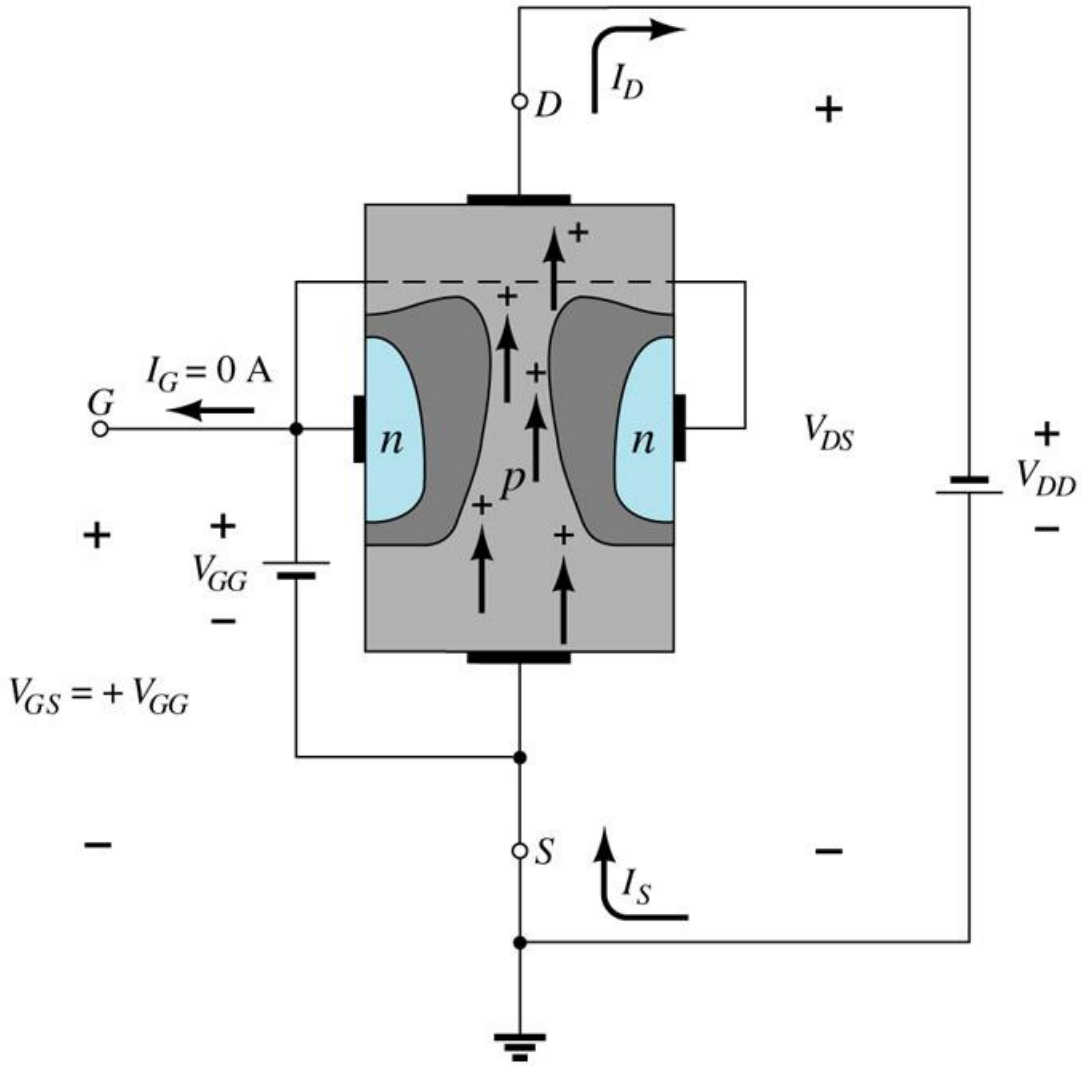
N-channel JFET drain family of characteristic curves

n-Channel JFET characteristics curve with I_{DSS} = 8 mA and V_P = -4 V.

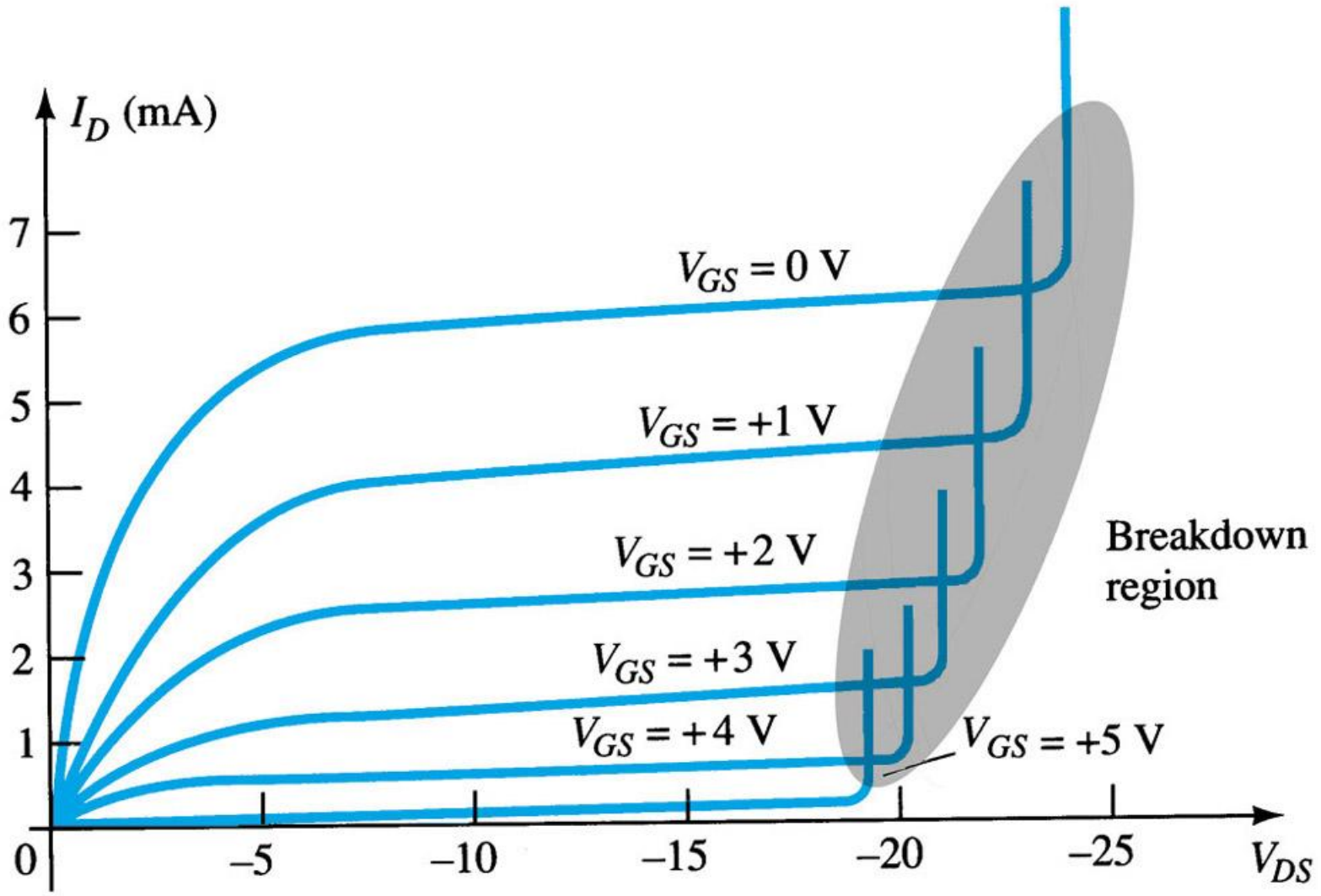


JFET Characteristic Curve

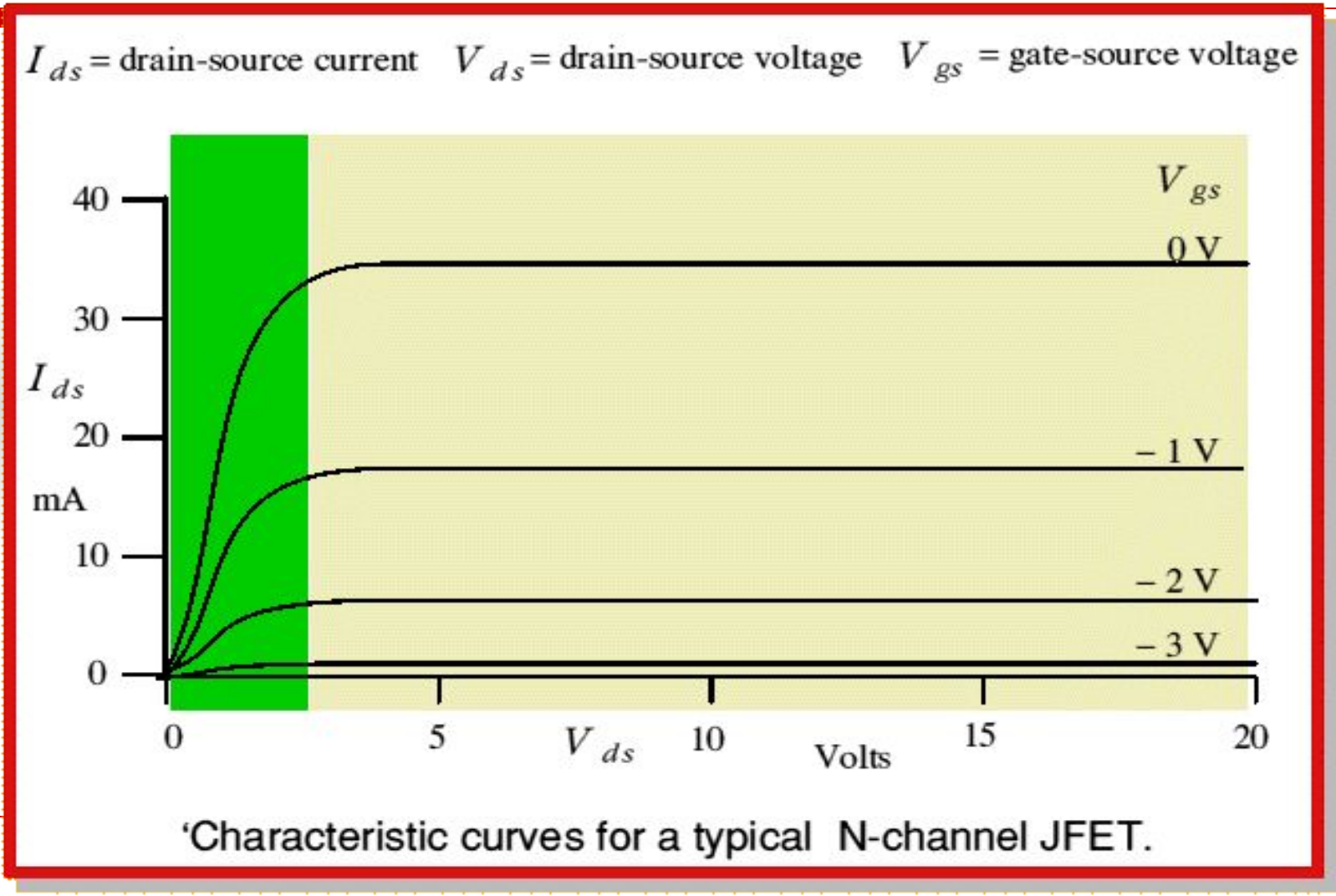
p-Channel JFET



p-Channel JFET characteristics with I_{DSS} = 6 m

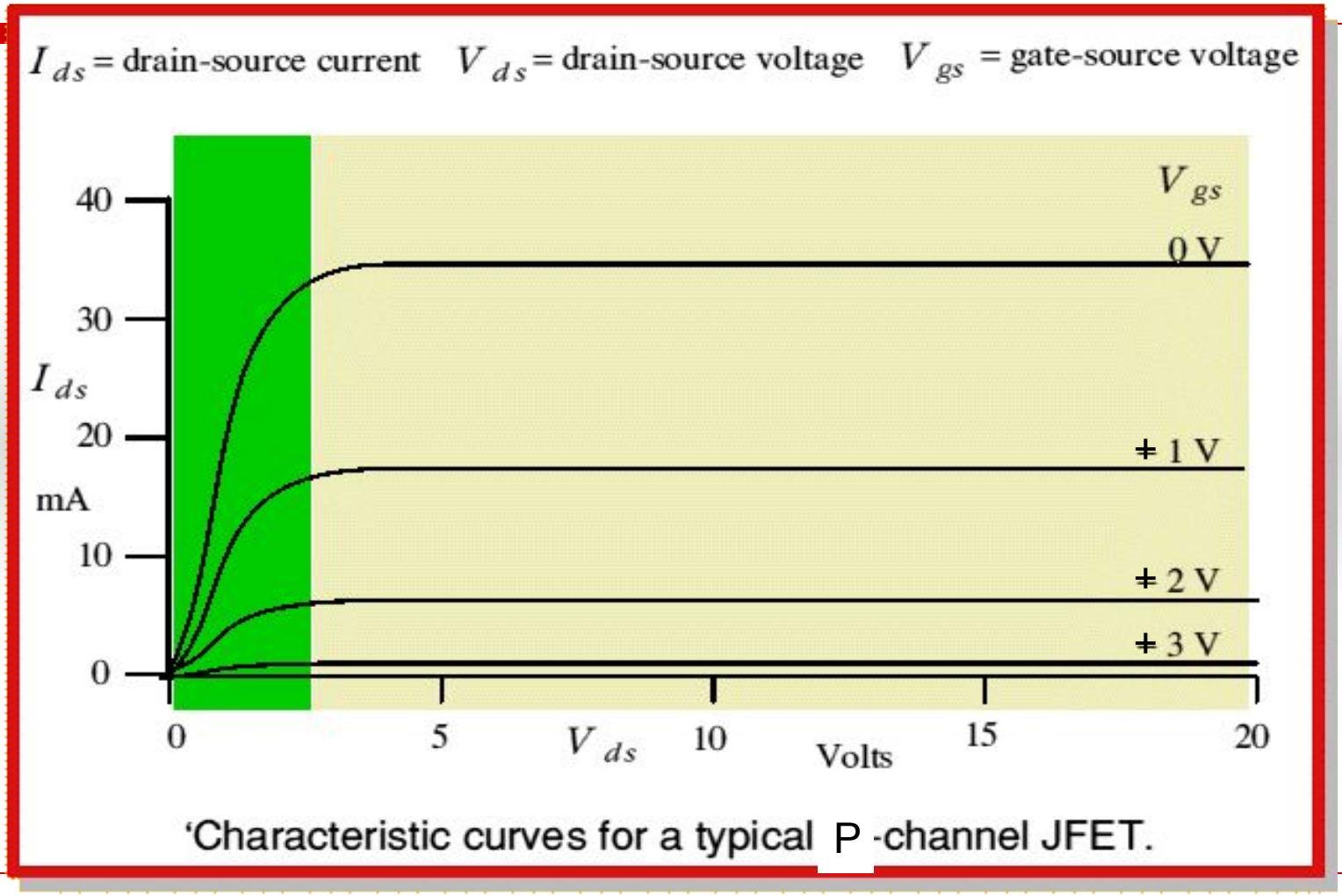


Characteristics for n-channel JFET



'Characteristic curves for a typical N-channel JFET.

Characteristics for p-channel JFET



'Characteristic curves for a typical P -channel JFET.

Operation of n-channel JFET

- JFET is biased with two voltage sources:
  - V_{DD}
  - V_{GG}
- ***V_{DD}*** generate voltage bias between Drain (D) and Source (S) – V_{DS}
- ***V_{DD}*** causes drain current, I_D flows from Drain (D) to Source (S)
- ***V_{GG}*** generate voltage bias between Gate (G) and Source (S) with negative polarity source is connected to the Gate Junction (G) – reverse-biases the gate; therefore gate current, $I_G = 0$.
- ***V_{GG}*** is to produce depletion region in N channel so that it can control the amount of drain current, I_D that flows through the channel

Transfer Characteristics

The input-output transfer characteristic of the JFET is not as straight forward as it is for the BJT. In BJT:

$$I_C = \beta I_B$$

which β is defined as the relationship between I_B (input current) and I_C (output current).

Transfer Characteristics..

In JFET, the relationship between V_{GS} (input voltage) and I_D (output current) is used to define the transfer characteristics. It is called as Shockley's Equation:

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

$V_P = V_{GS\ (OFF)}$

The relationship is more complicated (and not linear)

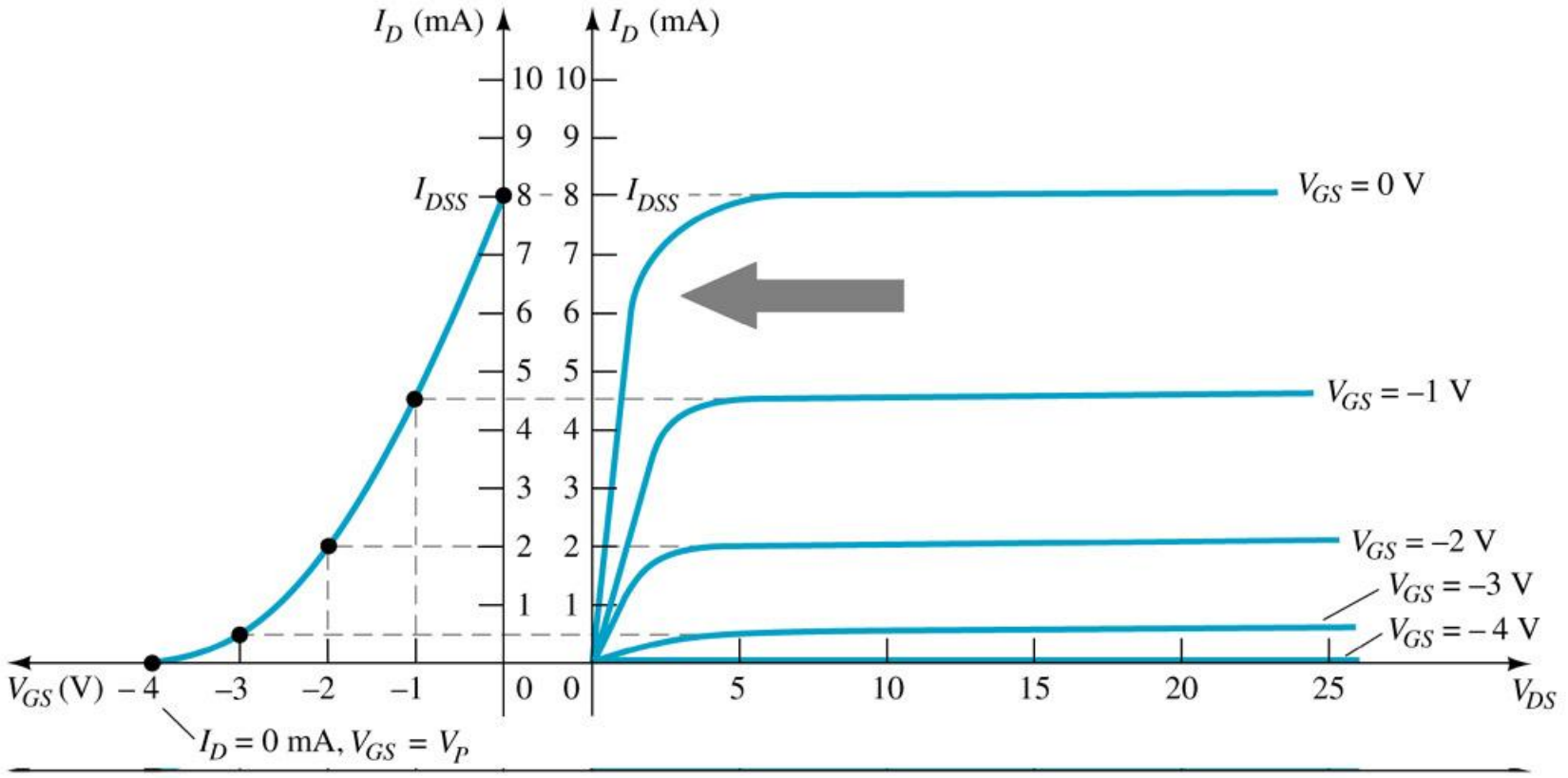
As a result, FET's are often referred to a square law devices

Transfer Characteristics…

- Defined by Shockley's equation:

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

- Relationship between I_D and V_{GS}.
- Obtaining transfer characteristic curve axis point from Shockley:
  - When V_{GS} = 0 V, $I_D = I_{DSS}$
  - When $V_{GS} = V_{GS(off)}$ or V_p, I_D = 0 mA



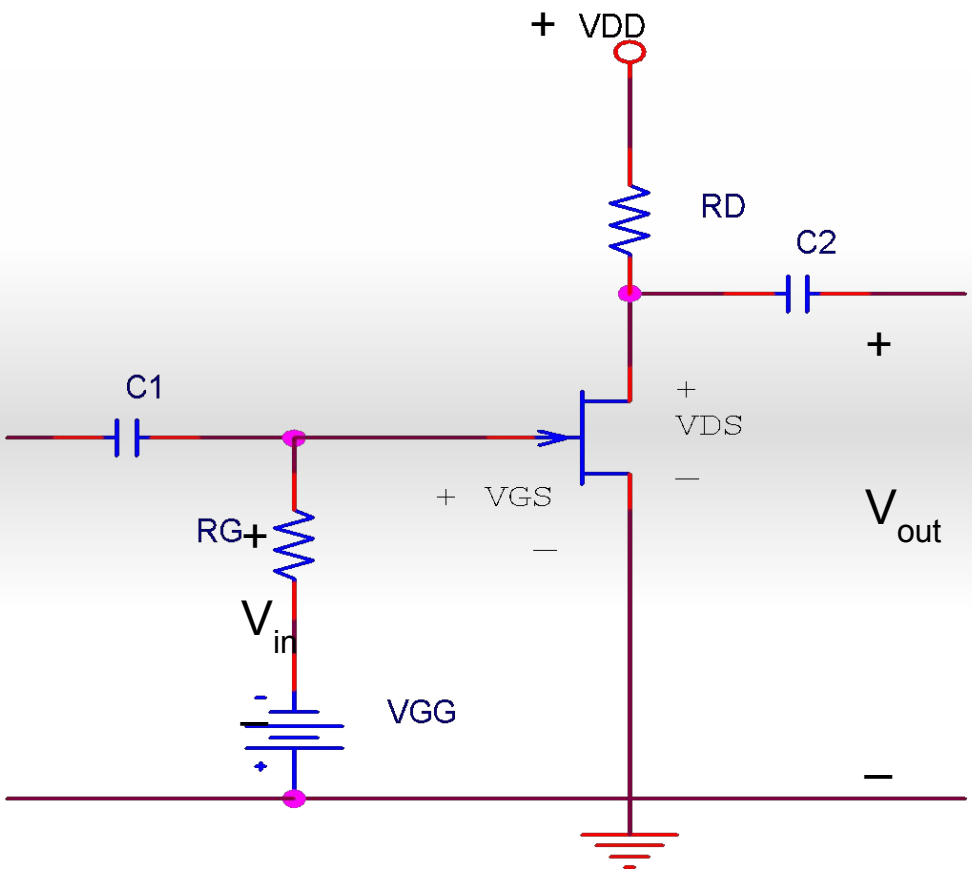
JFET Transfer Characteristic Curve

JFET Characteristic Curve

DC JFET Biasing

- Just as we learned that the BJT must be biased for proper operation, the JFET also must be biased for operation point (I_D, V_{GS}, V_{DS})
- In most cases the ideal Q-point will be at the middle of the transfer characteristic curve, which is about half of the I_{DSS}.
- 3 types of DC JFET biasing configurations :
  - Fixed-bias
  - Self-bias
  - Voltage-Divider Bias

Fixed-bias

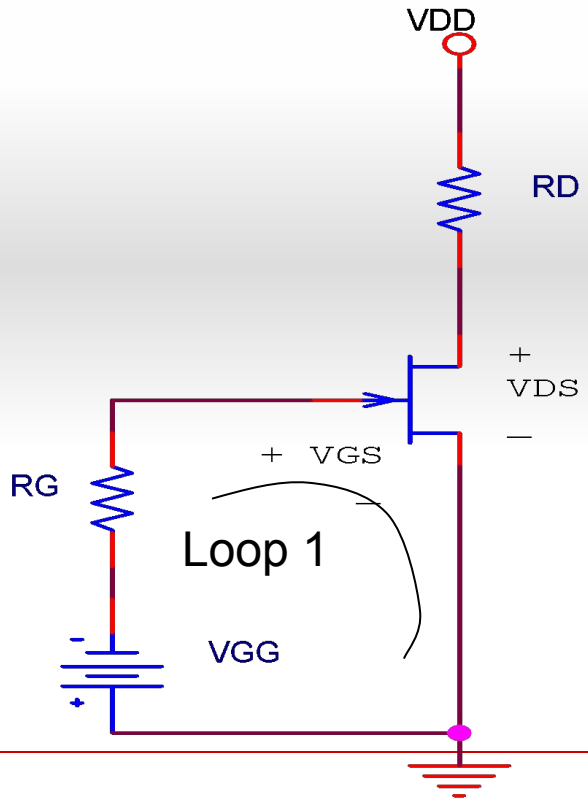


- Use two voltage sources: V_{GG}, V_{DD}
- V_{GG} is reverse-biased at the Gate – Source (G-S) terminal, thus no current flows through R_G (I_G = 0).

Fixed-bias

Fixed-bias..

- DC analysis
  - All capacitors replaced with open-circuit



Fixed-bias…

1. Input Loop

- By using KVL at loop 1:

$$V_{GG} + V_{GS} = 0$$
$$V_{GS} = - V_{GG}$$

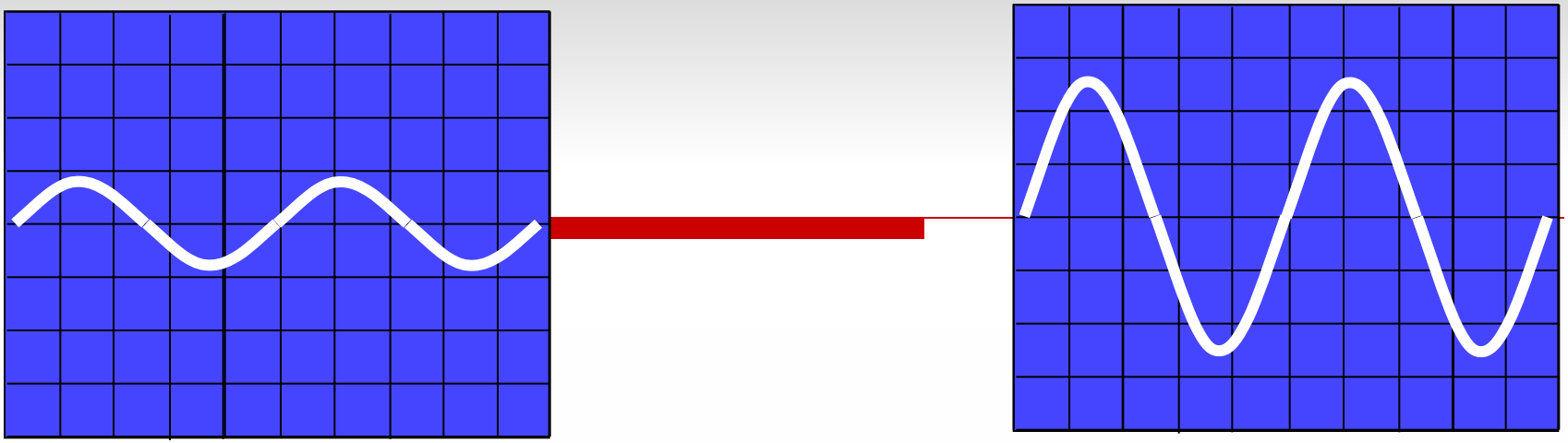
  - For graphical solution, use $\mathbf{V_{GS} = - V_{GG}}$ to draw the load line
  - For mathematical solution, replace $\mathbf{V_{GS} = -V_{GG}}$ in Shockley's Eq. ,therefore:

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

2. Output loop

$$- V_{DD} + I_D R_D + V_{DS} = 0$$
$$V_{DS} = V_{DD} - I_D R_D$$

3. Then, plot transfer characteristic curve by using Shockley's Equation



Voltage In

Voltage Amplifier

Current Out

The JFET is a voltage controlled amplifier.