Lecture7: MOSFET, IV

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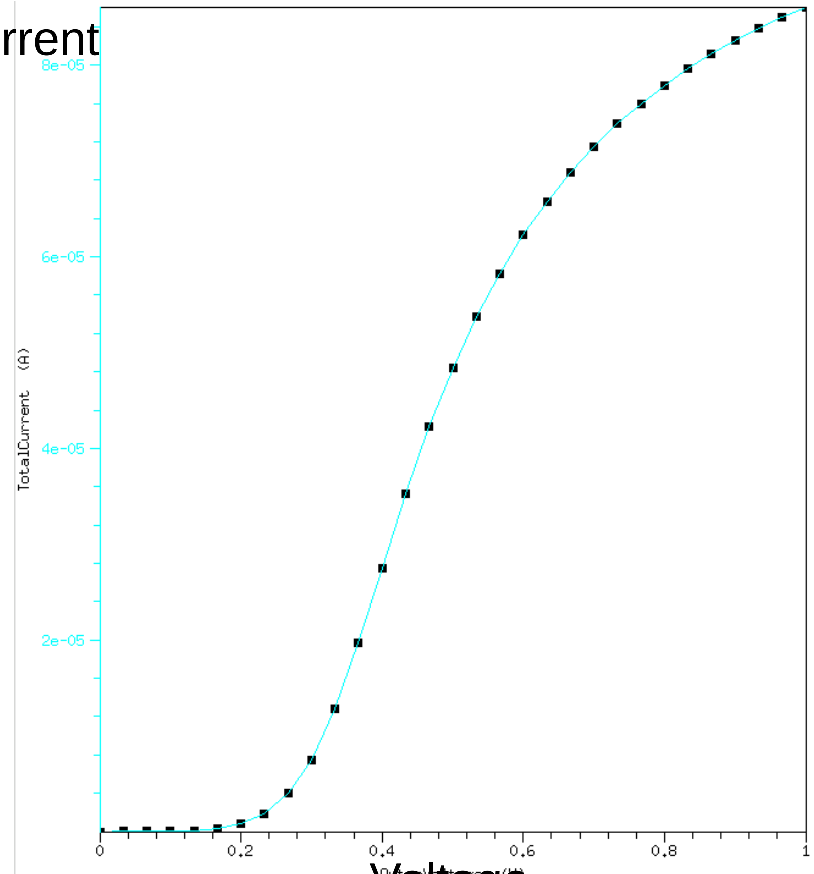
Review

- The MOSFET has three terminals.
  - (Low-frequency) gate current is zero. (Isolated by the dielectric material)
  - Source current + drain current = 0
  - Source is connected to the GND.
  - Gate voltage and drain voltage are variables.

Threshold voltage

- Threshold behavior
  - Physical reason? (*See p. 248*)

Current



Voltage

← A typical Id-Vg curve

A door threshold and a dog (Google images)

Derivation of IV (1/2)

- Drain current
  - First of all, the current is given by

$$I = Q\ v \tag{6.4}$$

  - Here, Q is the charge density *per unit length*.
  - It follows

$$Q = WC_{ox}[V_G - V(x) - V_{TH}] \tag{6.3}$$

  - Also v is the electron velocity.

$$v = -\mu_n E = +\mu_n \frac{dV}{dx} \qquad \text{(6.5 and 6.6)}$$

  - The drain current is

$$I_D = WC_{ox}[V_G - V(x) - V_{TH}]\mu_n \frac{dV}{dx} \tag{6.7}$$

Derivation of IV (2/2)

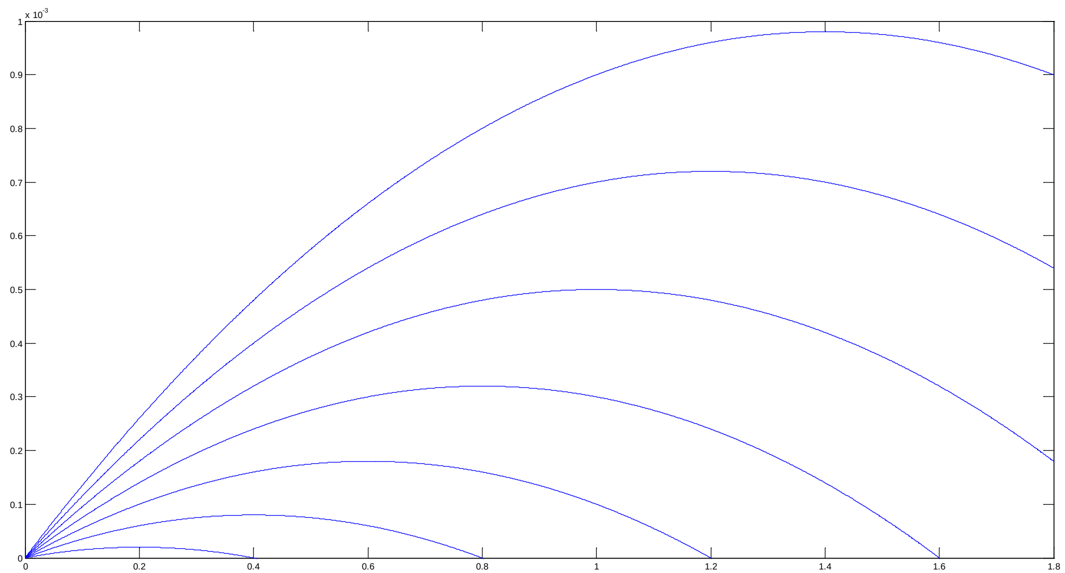
- Integration over the channel
  - Simply re-arranging,

$$I_D dx = \mu_n C_{ox} W [V_G - V(x) - V_{TH}] dV$$

  - When integrated,

$$I_D = \mu_n C_{ox} \frac{W}{L} \left[(V_G - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

Current



Voltage

🡰 Is it acceptable?

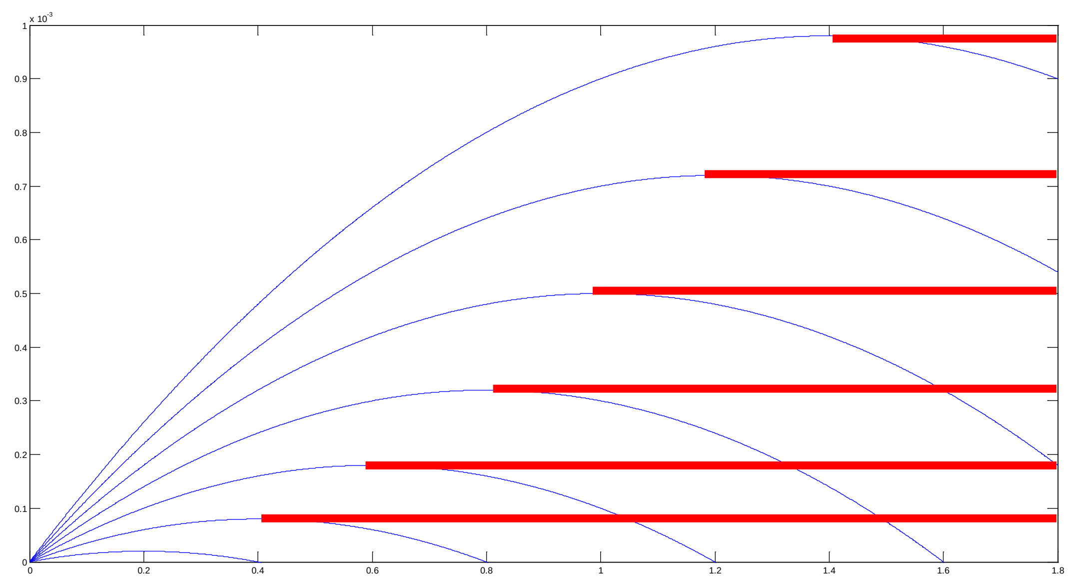
Of course, not!

- Current usually increases as the voltage increases…
- Recall (6.3).

$$Q = WC_{ox}[V_G - V(x) - V_{TH}] \tag{6.3}$$

  - What happens when $V(x) = V_G - V_{TH}$?
  - “Saturation region”

Current

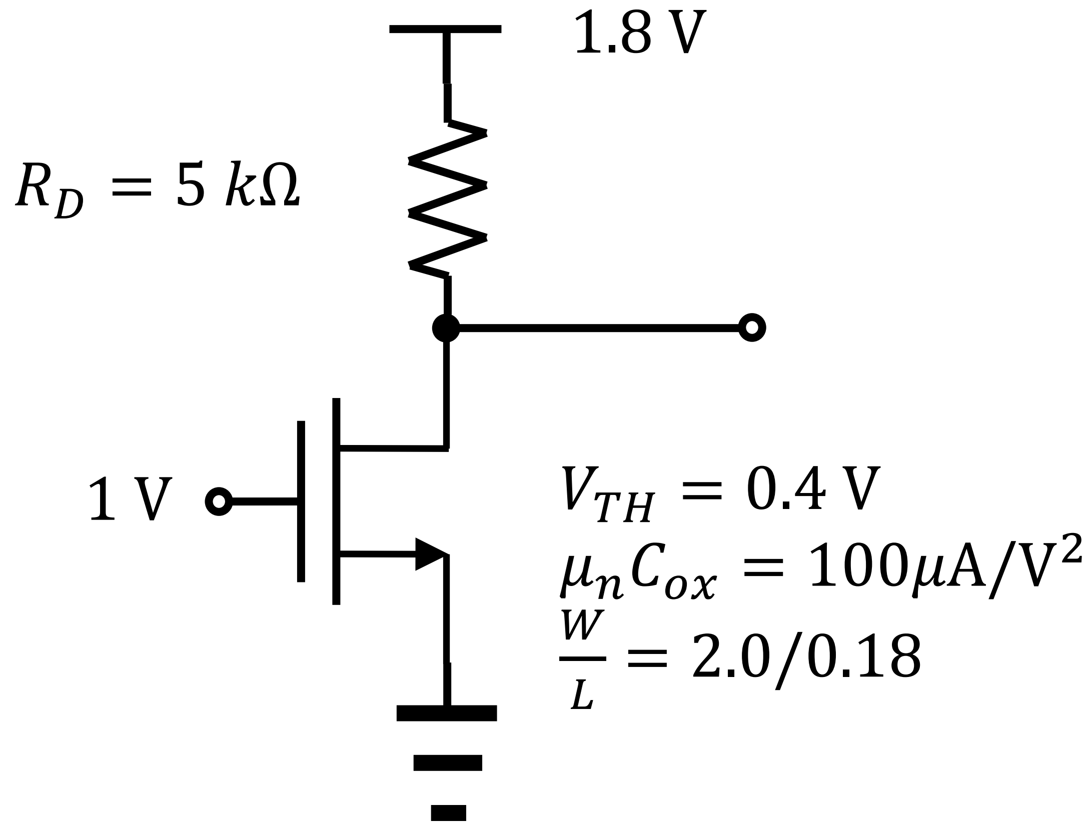


Voltage

← Instead, the current is saturated. (Red lines)

Example 6.6

- Assume the saturation region.
  - Then, the saturation current becomes $200\ \mu\text{A}$.

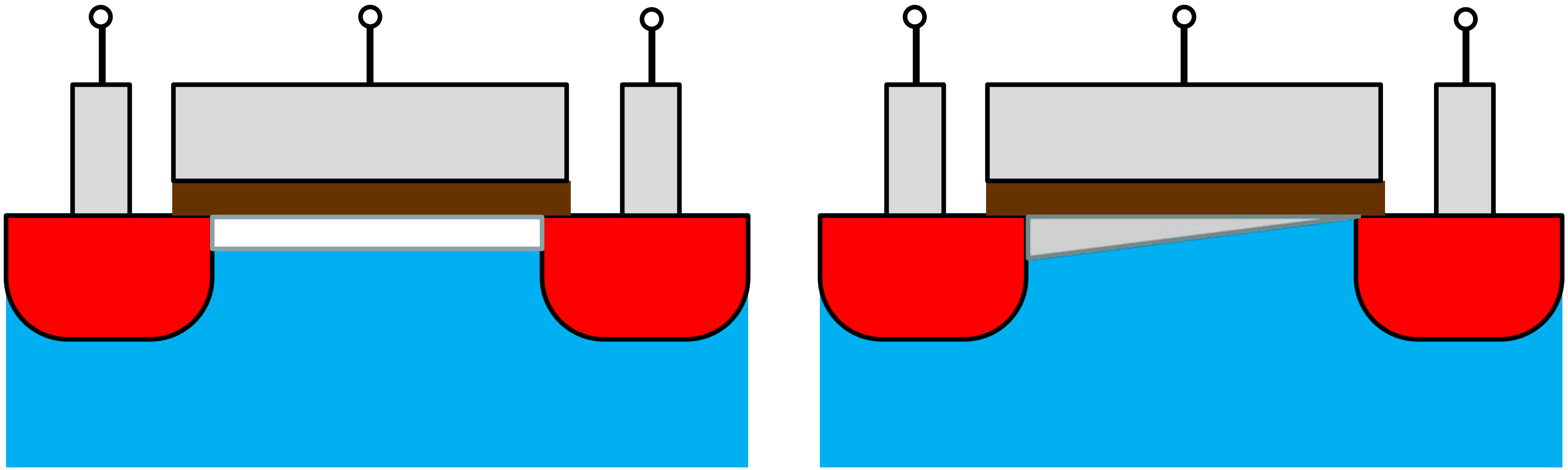


Long vs. short

- Long channel device
  - "Long"?
  - It depends on the situation.
- Short channel device
  - "Short"?
  - Again, it depends on the situation.
- Channel-length modulation
- Velocity saturation
- Body effect

Channel length modulation

- Channel length modulation



- Output resistance?

$$r_O = \frac{\Delta V_{DS}}{\Delta I_D}$$

MOS transconductance

- "conductance" of a simple resistor
  - It means $\frac{I}{V}$.
- "trans" + "conductance"
  - Between different terminals

$$g_m = \frac{\partial I_D}{\partial V_{GS}} \tag{6.44}$$

  - For the saturation region,

$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$$

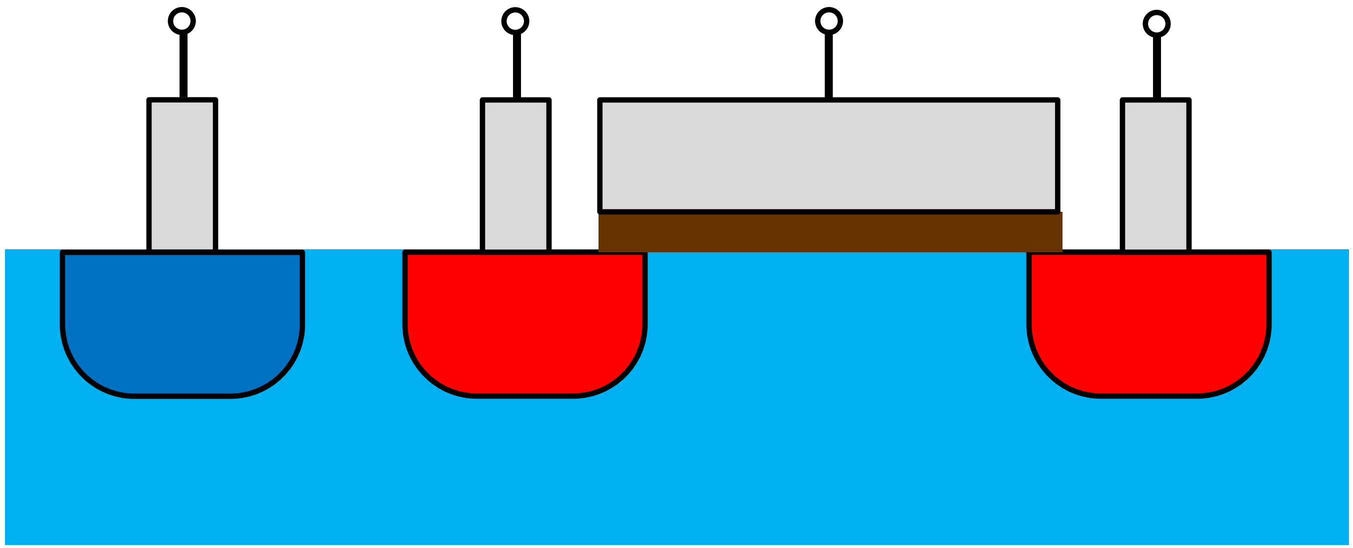
← Why?

$$g_m = \sqrt{2\mu_n C_{ox} \frac{W}{L} I_D}$$

$$g_m = \frac{2I_D}{V_{GS} - V_{TH}}$$

Body effect

- Actually, a MOSFET is a four-terminal device.
  - Substrate (or bulk)
  - Threshold voltage, V_{TH}, varies. (In which direction?)



Two more issues

- Velocity saturation
  – Once again, the current is given by

$$I = Q\ v \tag{6.4}$$

  – How did we have the saturation?

- Subthreshold conduction
  – Although not covered, it’s the critical issue!

Summary

- MOS structure
  - Two different mechanisms to provide negative charges
  - Threshold voltage
  - Once the MOS is inverted, it is a capacitor.
- MOS IV
  - Current as a product of density and velocity
  - Triode region and saturation region
  - Concept of transconductance
  - Channel length modulation
  - Body effect
  - Velocity saturation
  - Subthreshold swing

Homework#4 (1)

- Due: 09:00, April 2
- Write a program, which reads a netlist file.
  - From the netlist file, determine the total number of unknown variables, N.
  - For each circuit element with two terminals, assign 4 variables. The first one is I_1. The second one is I_2. The third one is V_1. The fourth one is V_2.
  - For each circuit node (including the ground), assign 1 variable. It is the node voltage.
  - Build a $N \times 1$ vector, x. Each entry has its own meaning.
  - The first four entries are $[I_1\ I_2\ V_1\ V_2]^T$ of the first element.
  - The next four entries are $[I_1\ I_2\ V_1\ V_2]^T$ of the second element.
  - It is repeated until all elements are considered.
  - The last entries are for the node voltages.

Homework#4 (2)

- (Continued)
  - For example, consider a simple circuit with two circuit elements (a voltage source and a resistor) and two circuit nodes (`0` and `in`).
  - Then, $N = 10$. Also the vector is given as $x = [I_1^V \quad I_2^V \quad V_1^V \quad V_2^V \quad I_1^R \quad I_2^R \; V_1^R \; V_2^R \; V_0 \quad V_{in}]^T$.
  - Entries for the terminal currents are 1.
  - Entries for the terminal voltages are 2.
  - Entries for ther circuit nodes are 3.
  - In the above example, $x = [1 \quad 1 \quad 2 \quad 2 \quad 1 \quad 1 \quad 2 \quad 2 \quad 3 \quad 3]^T$.
  - The program prints out the vector, x.

Homework#4 (3)

- Solve the following problems of the mid-term exam in 2017.
  - P17
  - P18
  - P19
  - P20
  - P21
  - P22
  - P23
  - P24