Lecture7: MOSFET, IV

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Review

- The MOSFET has three terminals.
  - The gate current, I_G, is zero. (Isolated by the dielectric material)
  - Source current (I_S) + drain current (I_D) = 0
  - Source is connected to the GND.
  - The gate-to-source voltage (V_{GS}) and drain-to-source voltage (V_{DS}) are variables.

- Therefore, we want to know

$$I_D(V_{GS}, V_{DS})$$

Oxide capacitance

- A problem from “General Physics” cource
  - Consider a dielectric layer (whose thickness is d) sandwiched by two parallel metal plates.
  - A voltage difference, V, is applied.
  - The area of the plates is A.
  - The charges are $+Q$ and $-Q$, respectively.
  - By applying the Gauss law,

$$Q = \epsilon|\mathbf{E}|A = \epsilon\frac{V}{d}A$$

  - Therefore, the capacitance *per unit area* becomes

$$C = \frac{\epsilon}{d}$$

- The same problem in this course!

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

Threshold voltage

- Threshold behavior

Derivation of IV (1/2)

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

$$I = Q\,v \qquad (6.4)$$

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

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

  - Also v is the electron velocity.

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

  - The drain current is

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

Derivation of IV (2/2)

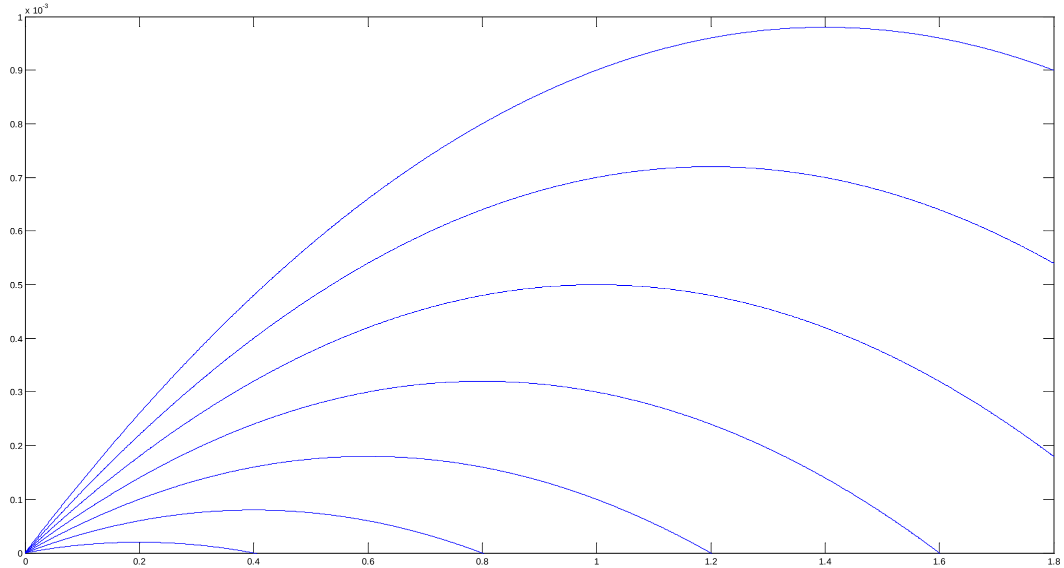
- Integration over the channel
  - Simply re-arranging,

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

  - 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?

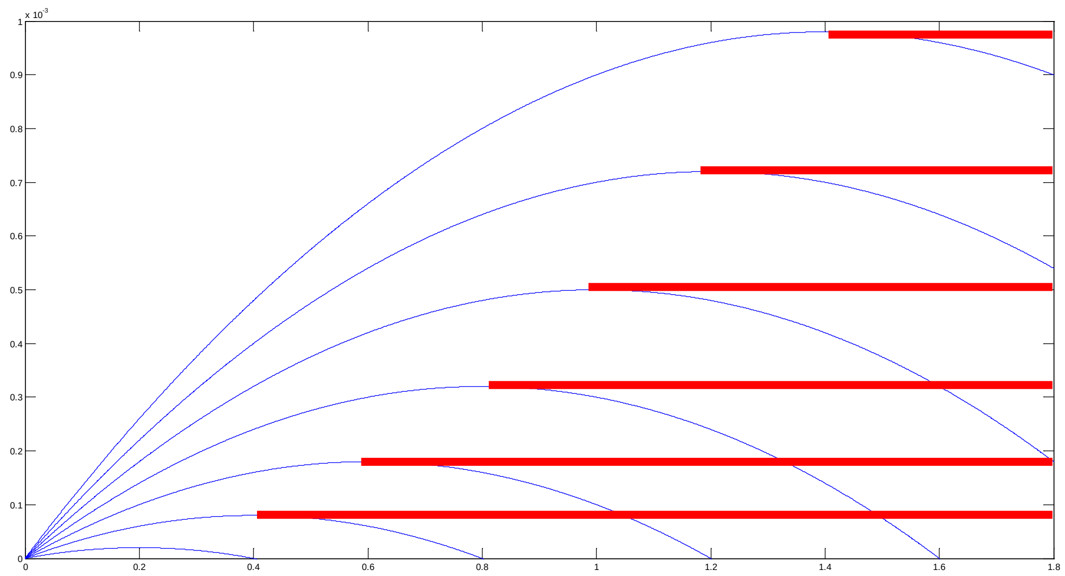
Of course, not!

- 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

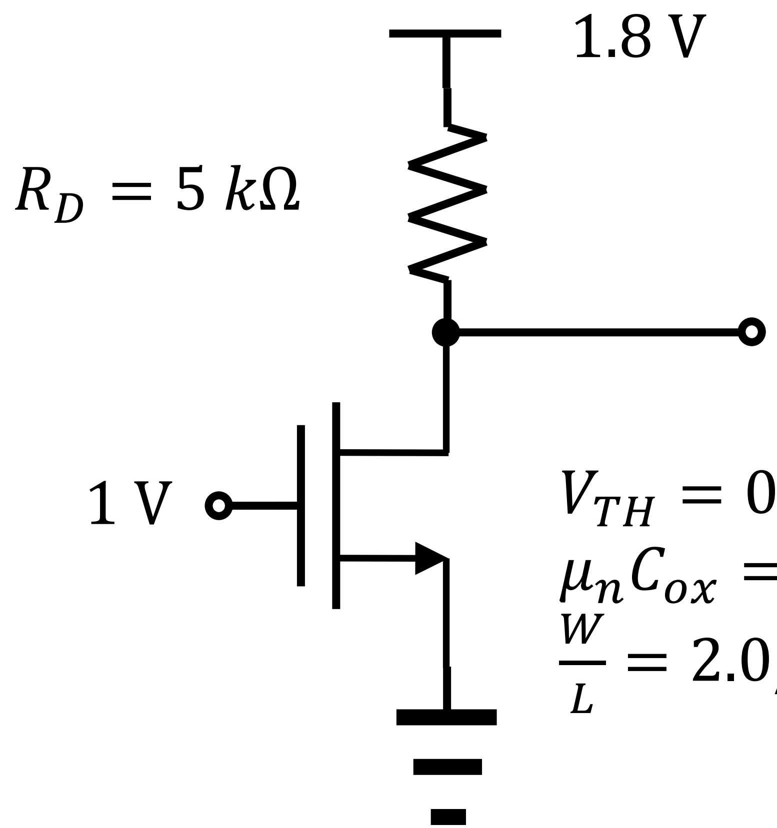


← Instead, the current is saturated. (Red lines)

Voltage

Example 6.6

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



$V_{TH} = 0.4\ \text{V}$
$\mu_n C_{ox} = 100 \mu\text{A/V}^2$
$\frac{W}{L} = 2.0/0.18$

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 $x = [I_1^V \;\; I_2^V \;\; V_1^V \;\; V_2^V \;\; I_1^R \;\; I_2^R \;\; V_1^R \;\; V_2^R \;\; V_0 \;\; V_{in}]^T$.
  - 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, $x = [1 \;\; 1 \;\; 2 \;\; 2 \;\; 1 \;\; 1 \;\; 2 \;\; 2 \;\; 3 \;\; 3]^T$.
  - 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