Lecture10: MOSFET, transconductance

Sung-Min Hong (smhong@gist.ac.kr)

Semiconductor Device Simulation Lab.
School of Electrical Engineering and Coumputer Science
Gwangju Institute of Science and Technology

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Summary

- When $V_G < V_{TH}$,
  - No drain current!

$$I_D = 0$$

- When $V_G > V_{TH}$,
  - Triode mode ($V_{DS} < V_G - V_{TH}$)

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

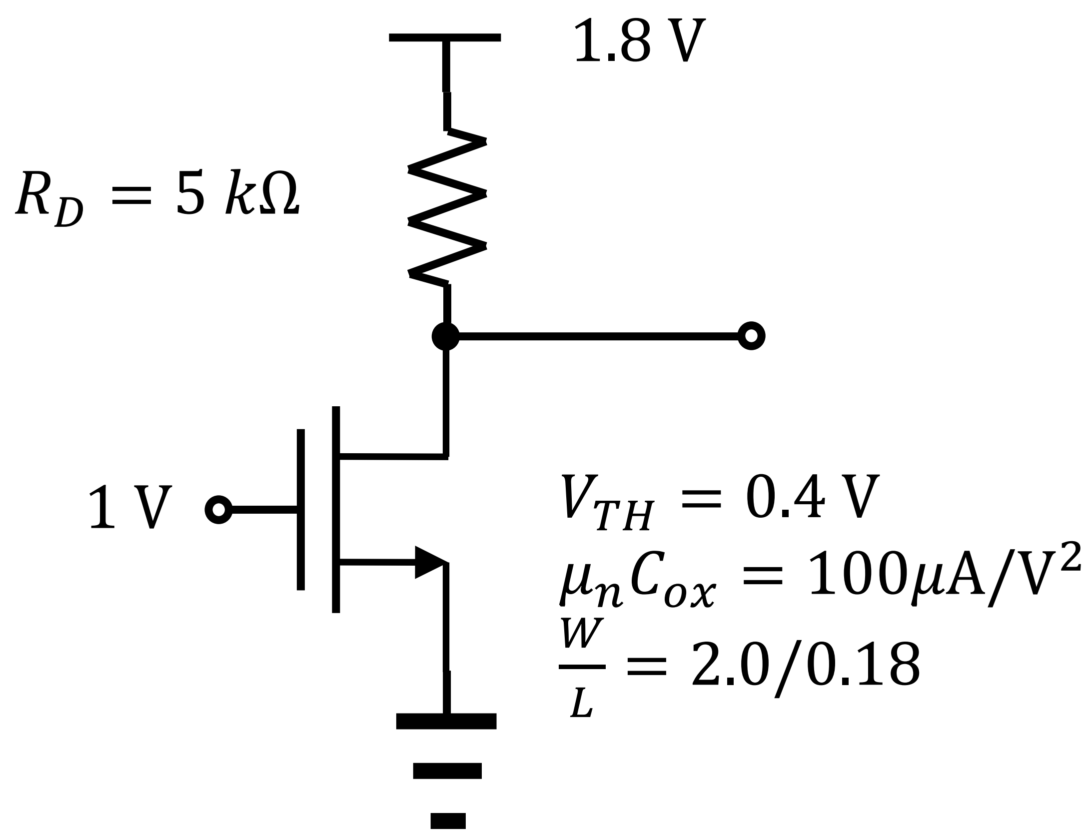
  - Saturation mode ($V_{DS} > V_G - V_{TH}$)

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

  - For a short channel device, I_D increases slightly as V_{DS} increases.

Example 6.6 (Razavi)

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



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,

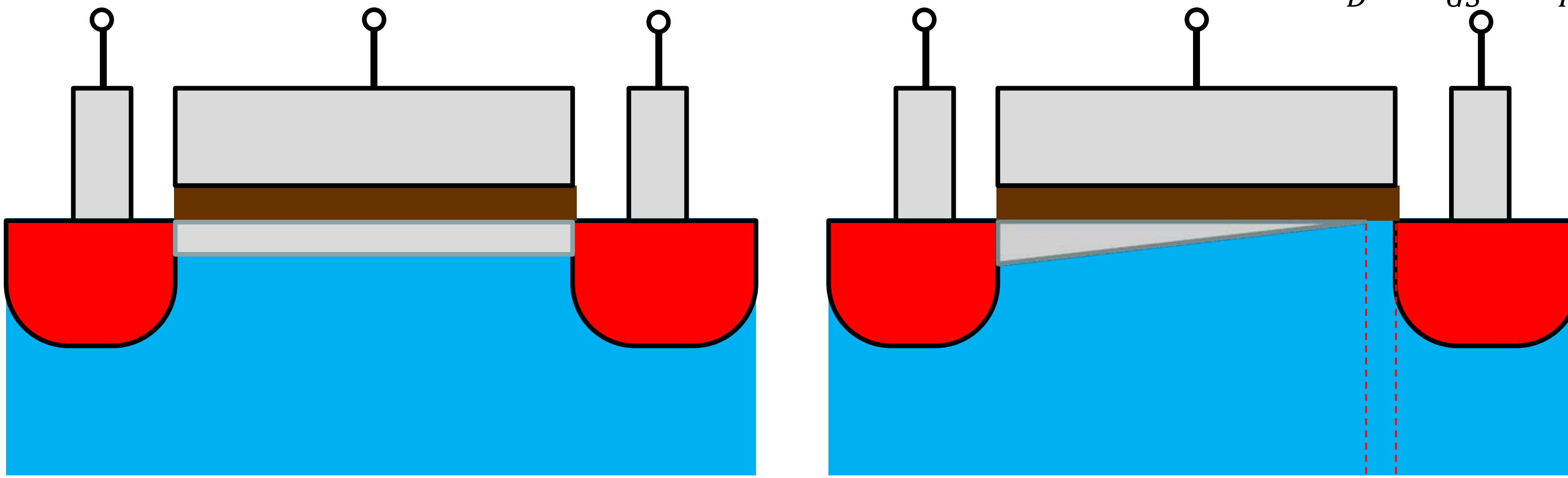
$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$$

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

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

Channel length modulation

- Channel length modulation



- Output resistance?

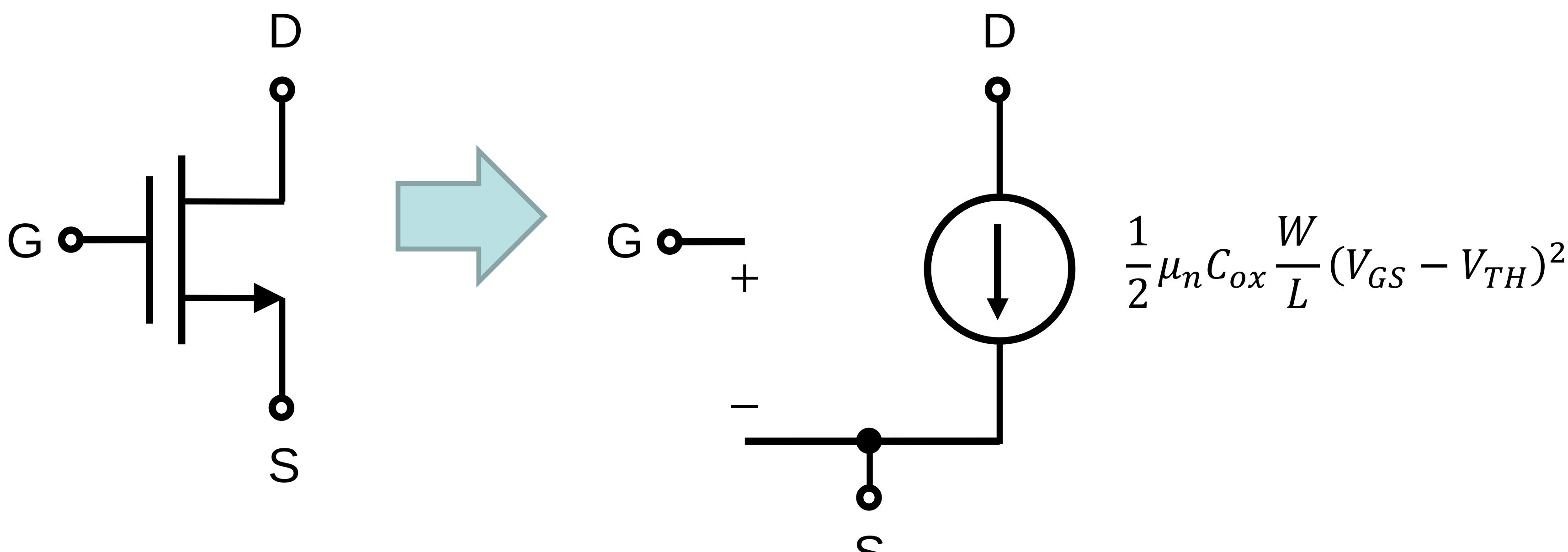
$$r_O = \frac{\Delta V_{DS}}{\Delta I_D}$$

Large-signal model (1/2)

- Saturation region

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

  – Drain current is determined by gate voltage. (*voltage-controlled current source*)
  – *Channel-length modulation?*

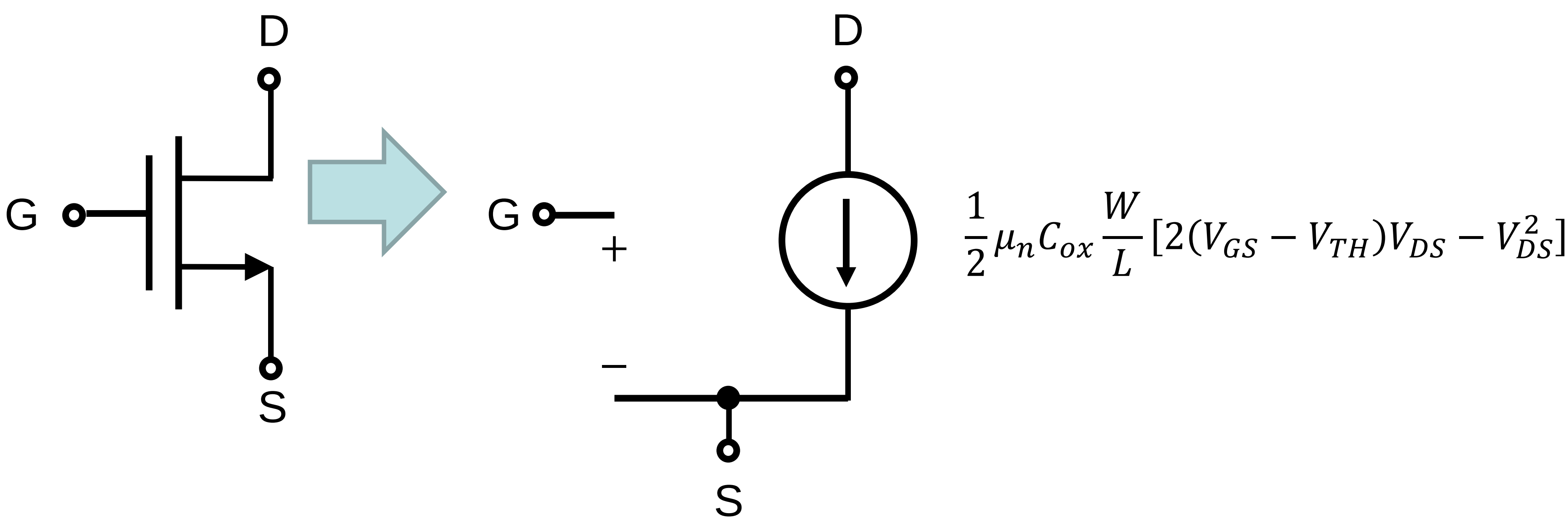


Large-signal model (2/2)

- Triode region

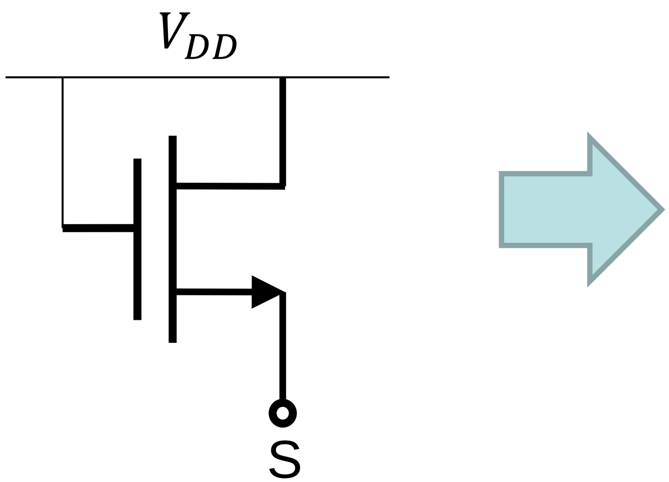
$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}[2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2]$$

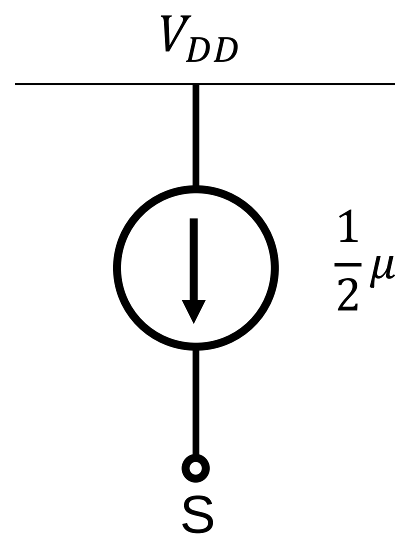
  - Still, it can be described by a *voltage-controlled current source*.



Example 6.13 (Razavi)

- Always in the saturation region!
  - Any necessary condition?



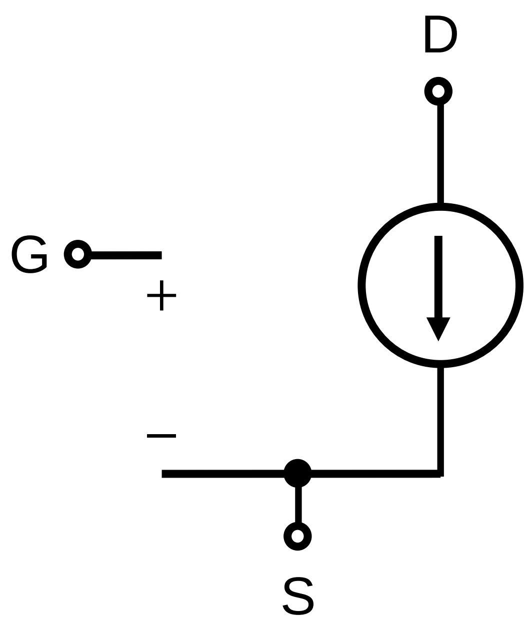


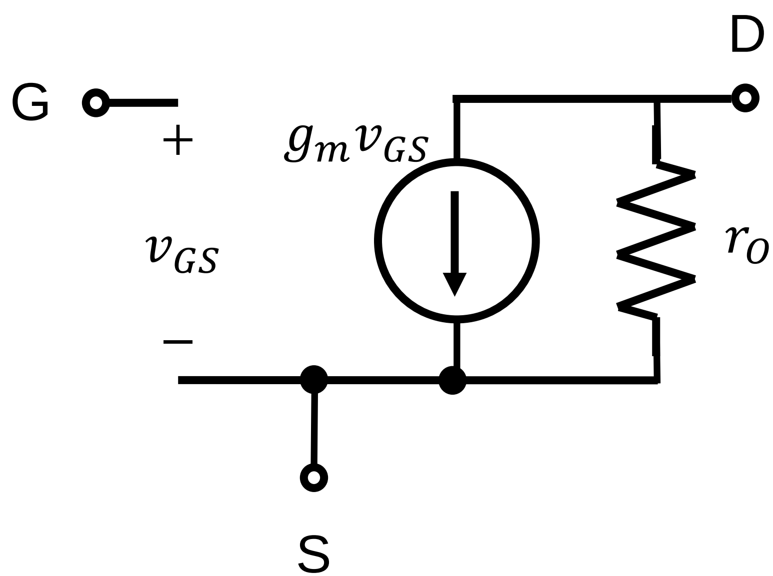
$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{DD}-V_S-V_{TH})^2$$

Gate and drain are tied.
They are connected to V_{DD}.

Small-signal model

- The large-signal model is complete (within its accuracy limitation).
  - But, for small-signal analysis, it is convenient to have the small-signal model.



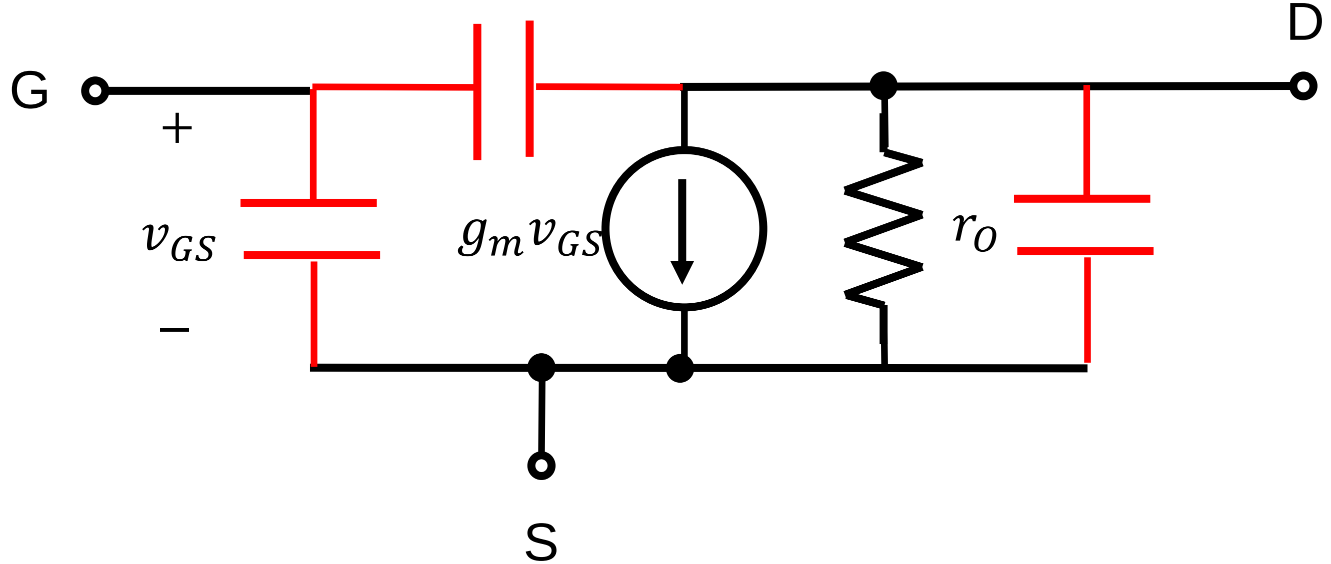


$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$

What is g_m and r_O?

Time-dependent one?

- Everything was in the dc steady-state…
  - How about the frequency-dependent case?
  - Capacitive components can be seen.
  - *Their physical origin?*



High-frequency, equivalent-circuit model for the case in which the source is connected to the substrate