Lecture13:
MOSFET, small-signal model

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

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

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Review on MOSFET IV

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

$$I_D = 0$$

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

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

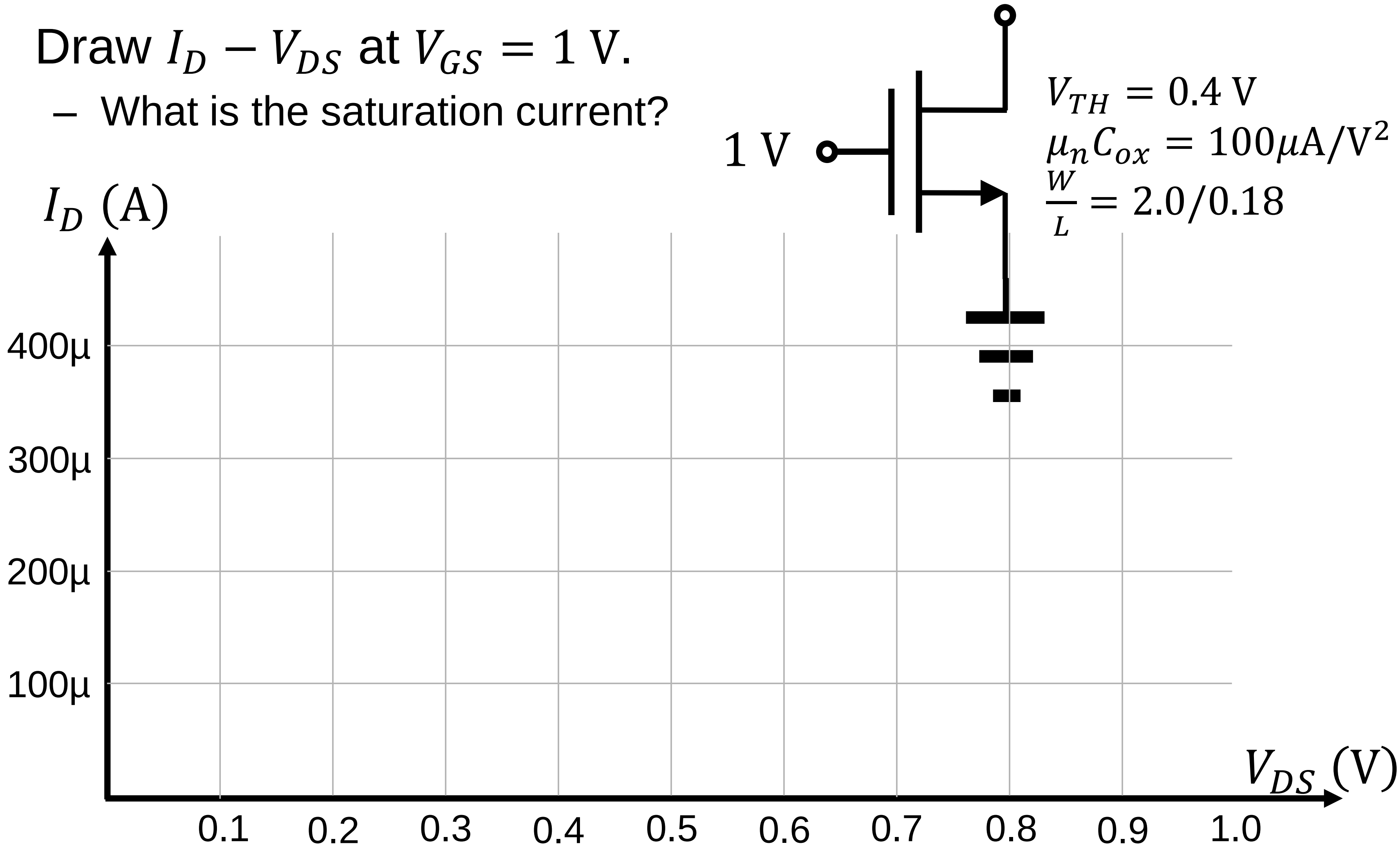
  - Saturation mode ($V_{DS} > V_G - V_{TH}$)

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

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

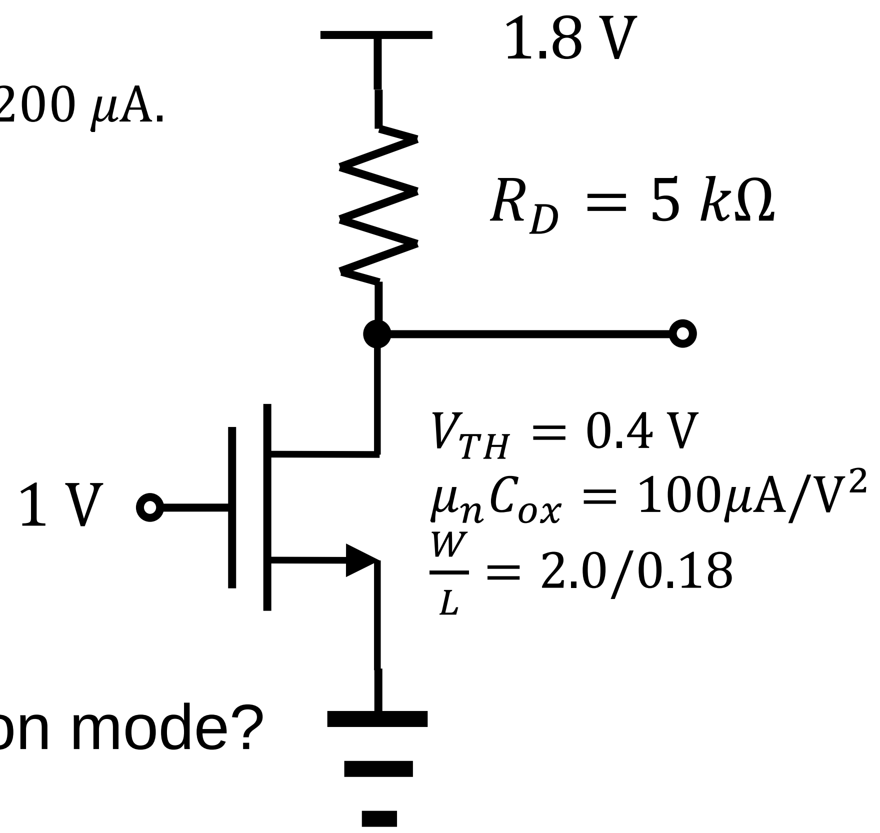
An example

- Draw $I_D - V_{DS}$ at $V_{GS} = 1\ \mathrm{V}$.
  - What is the saturation current?



Example 6.6 (Razavi)

- Assume the saturation region.
  - The saturation current becomes $200\ \mu\text{A}$.
  - Then, the drain voltage is
- Is the MOSFET in the saturation mode?
- Graphical visualization



V_{out} versus V_{in}

- A table

V_{in} (V)	V_{out} (V)
0.0	1.8
<0.4	1.8
0.7	1.55
1.0	0.8
X	$X - 0.4$
1.8	Y

  – What are the values of X and Y?

MOS transconductance

- "conductance" of a simple resistor: $\partial I/\partial V = I/V$
- "trans" + "conductance" between different terminals

$$g_m = \frac{\partial I_D}{\partial V_{GS}} \qquad \text{(Razavi 6.44)}$$

  - For the saturation region,

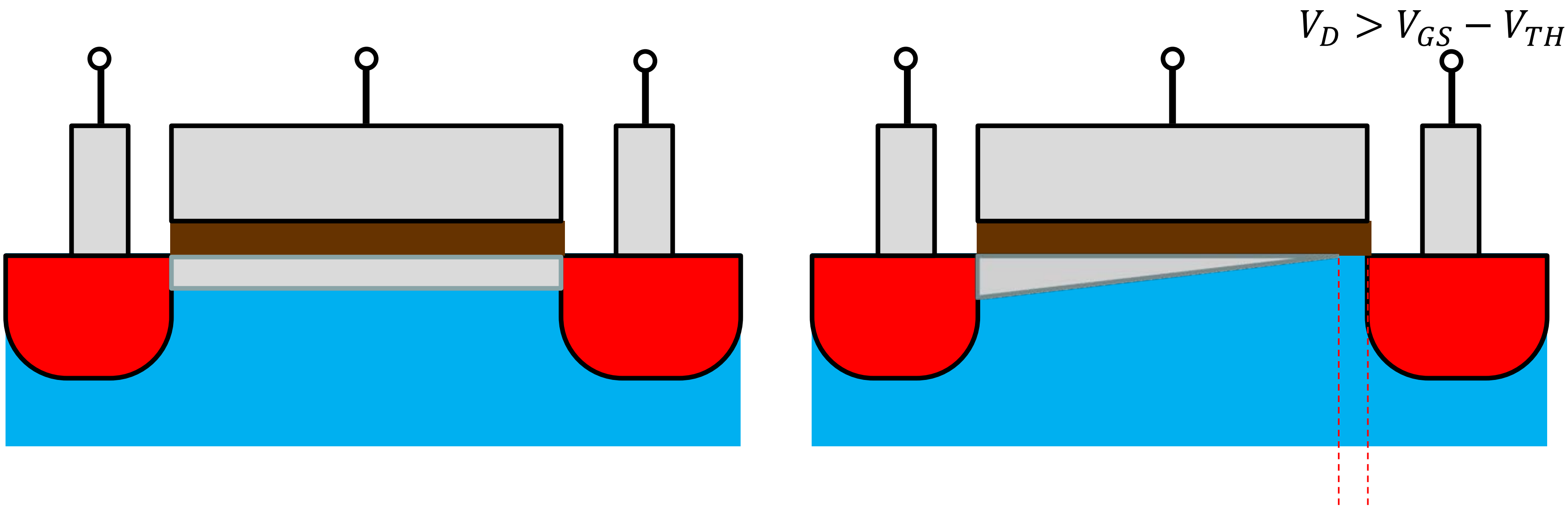
$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$$

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

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

Channel length modulation

- Channel length modulation

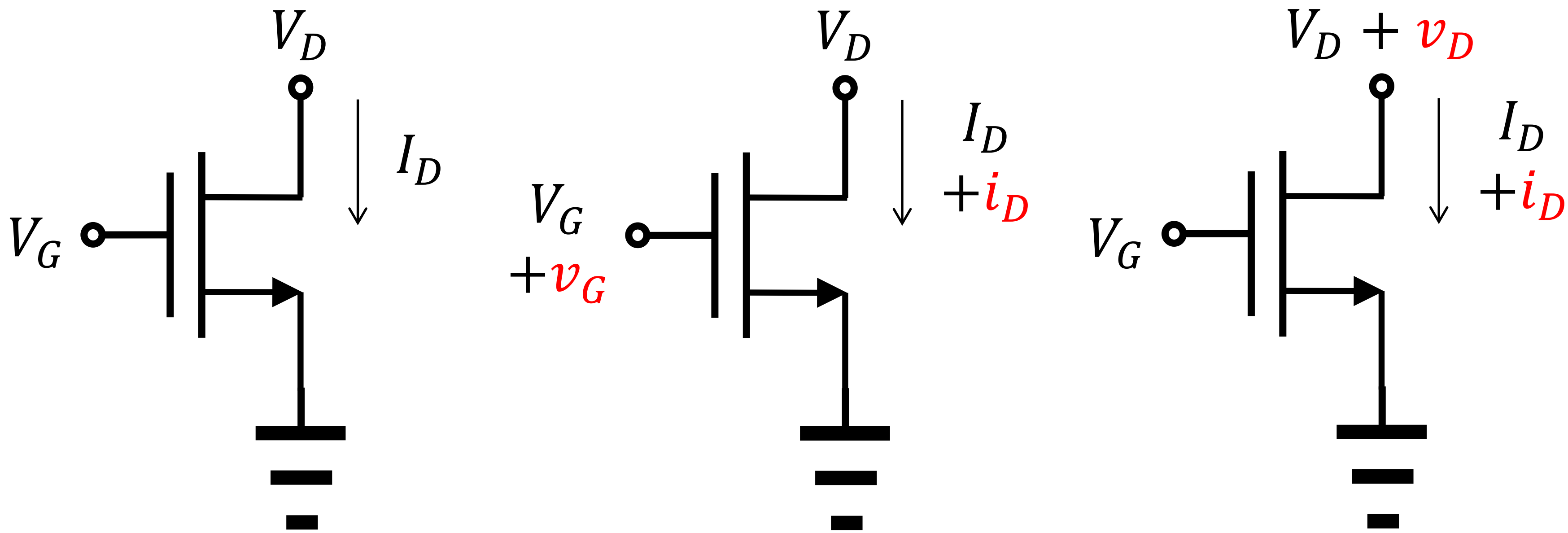


- Output resistance?

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

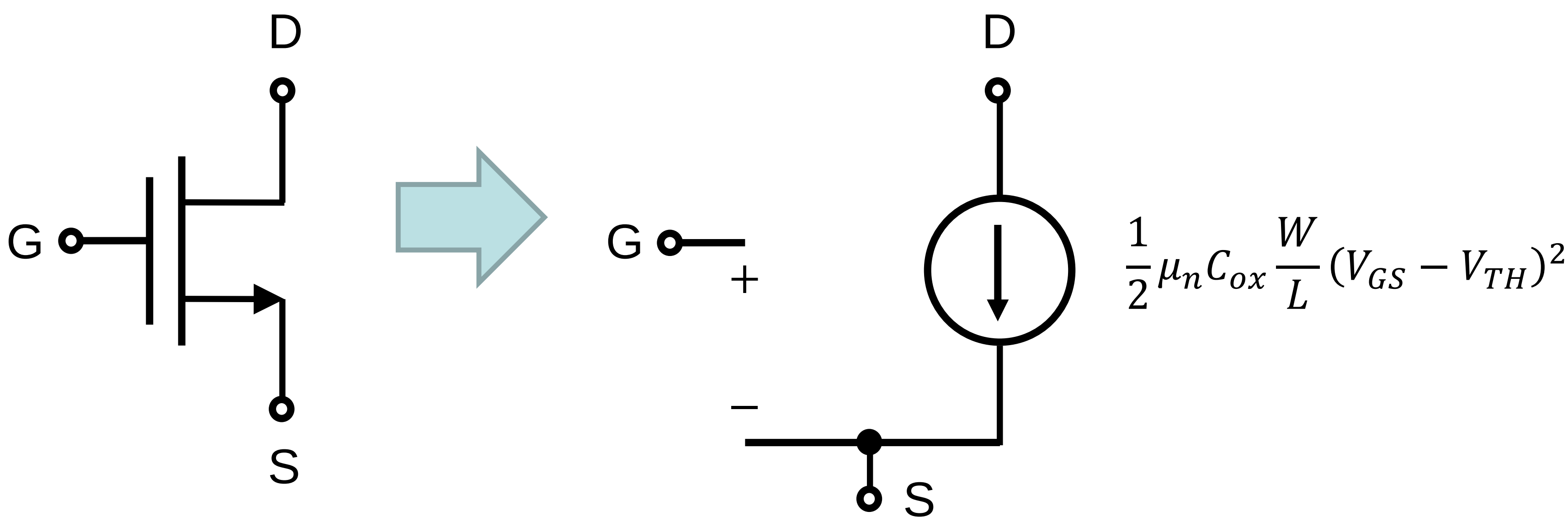
Derivatives

- We can define two derivatives.
  - Transconductance, g_m. Output resistance, r_O.



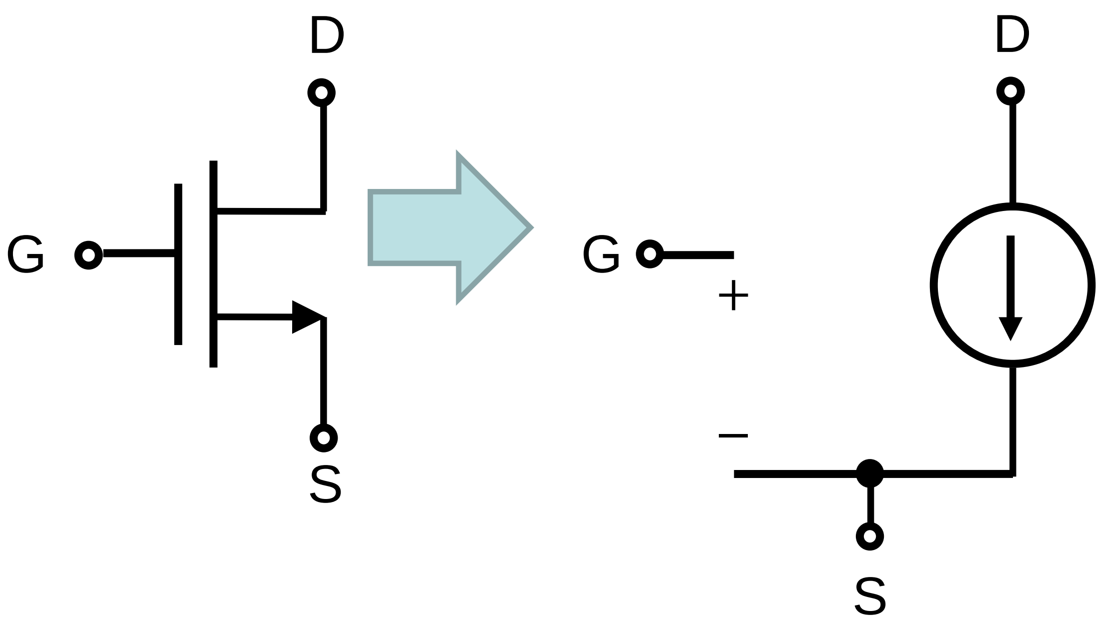
Large-signal model (1/2)

- Saturation region
  - Drain current is determined by gate voltage. (*voltage-controlled current source*)



Large-signal model (2/2)

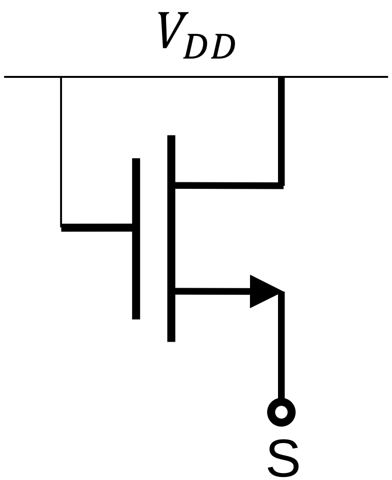
- Triode region
  - Still, it can be described by a *voltage-controlled current source*.

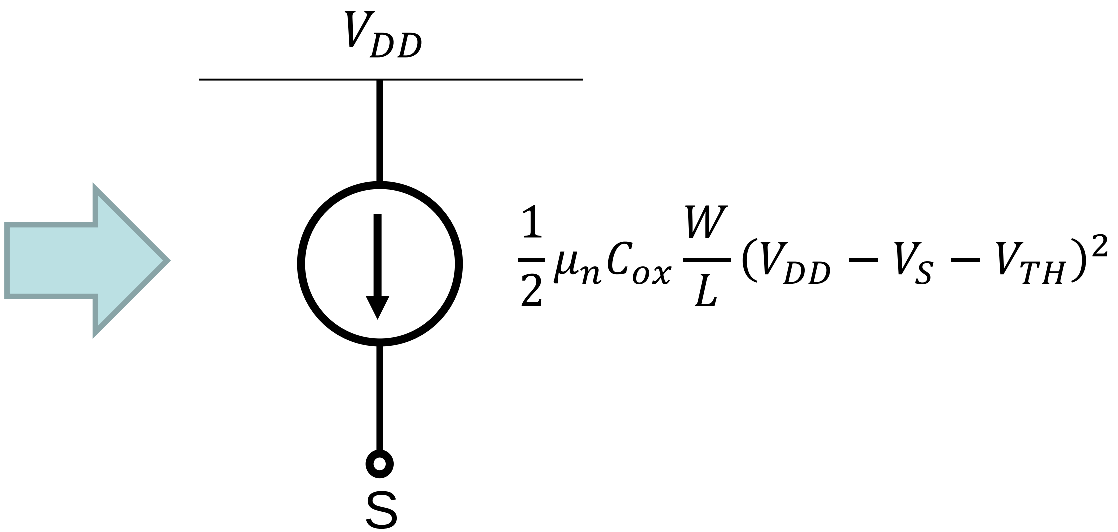


$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}[2(V_{GS}-V_{TH})V_{DS}-V_{DS}^2]$$

Example 6.13 (Razavi)

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

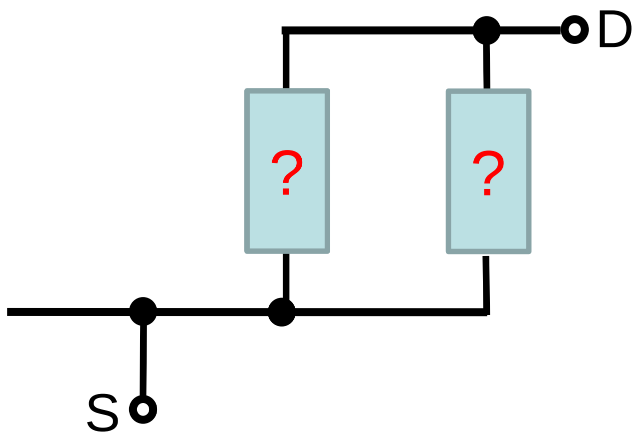




Gate and drain are tied.
They are connected to V_{DD}.

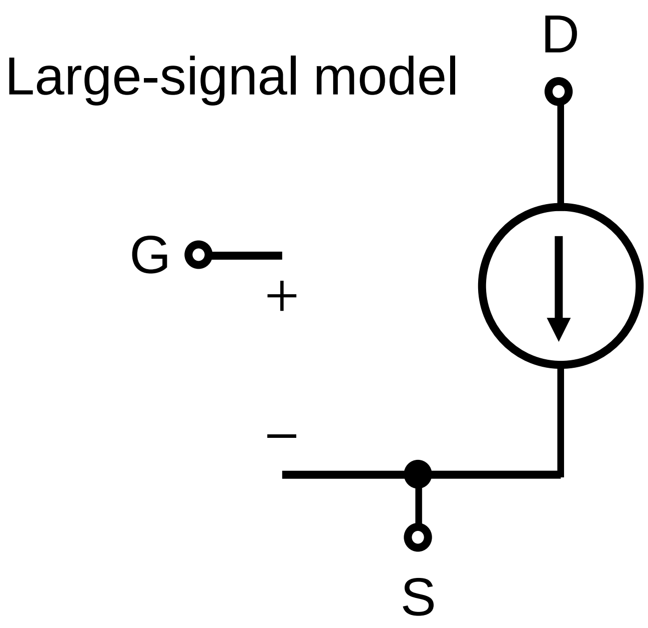
Small-signal current

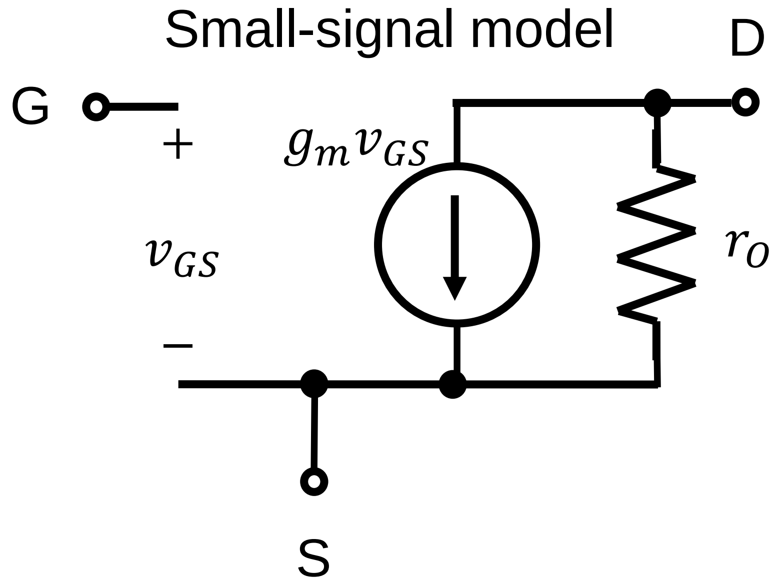
- Using the transconductance (g_m) and the output resistance (r_O),
  - The small-signal drain current is given as $i_D = g_m v_G + \frac{v_D}{r_O}$.
  - When we build a small-signal model, two contributions must be separately considered.



Small-signal model

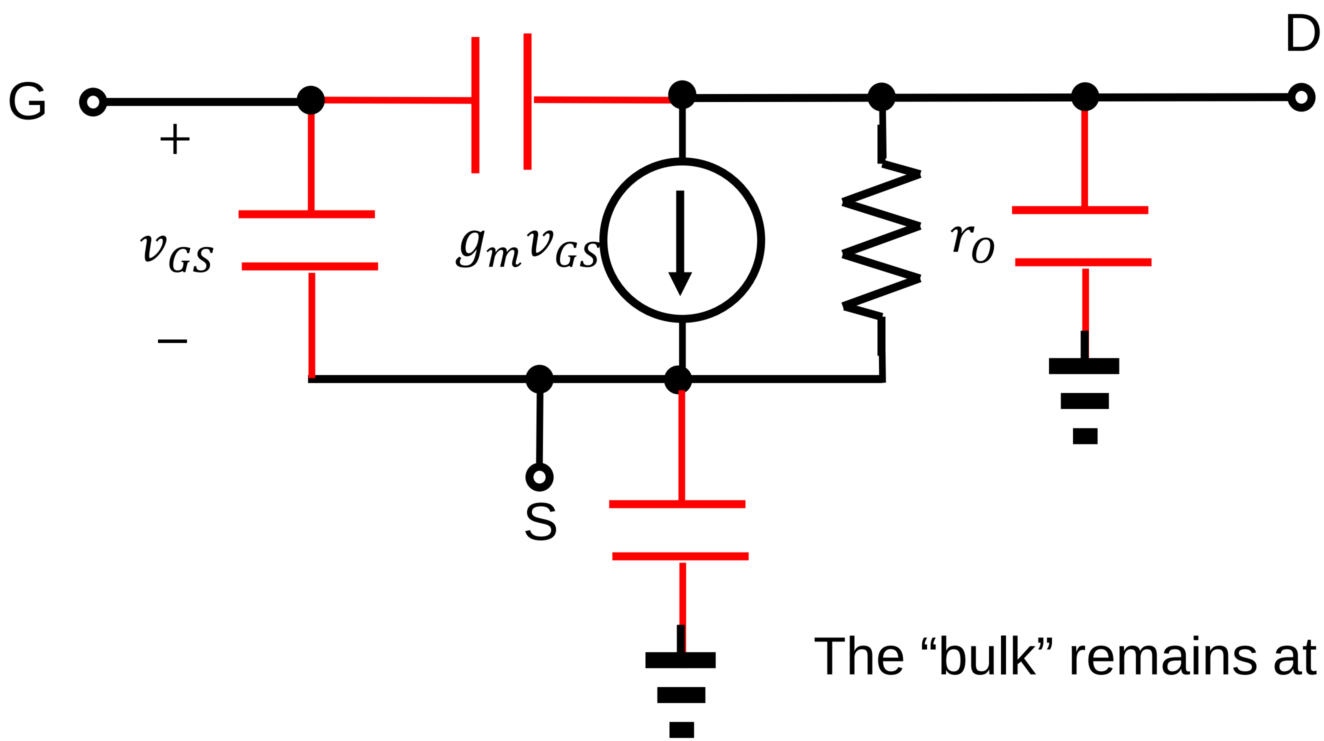
- For small-signal analysis, a small-signal model for the MOSFET is introduced.





Time-dependent one?

- In general, capacitive components can be seen.



The “bulk” remains at ac ground.

At low frequencies

- Capacitor current is $I = C\frac{dV}{dt}$.
  - When a sinusoidal dependence, for example $\sin \omega t$, is assumed, the capacitor current is proportional to ω.
  - At low frequencies, ω can be regarded as a small number.
  - In other words, the electric conduction between two nodes becomes rather weak.
  - Therefore, we often neglect the capacitive components in the small-signal model.
  - Of course, at higher frequencies, they become very important.