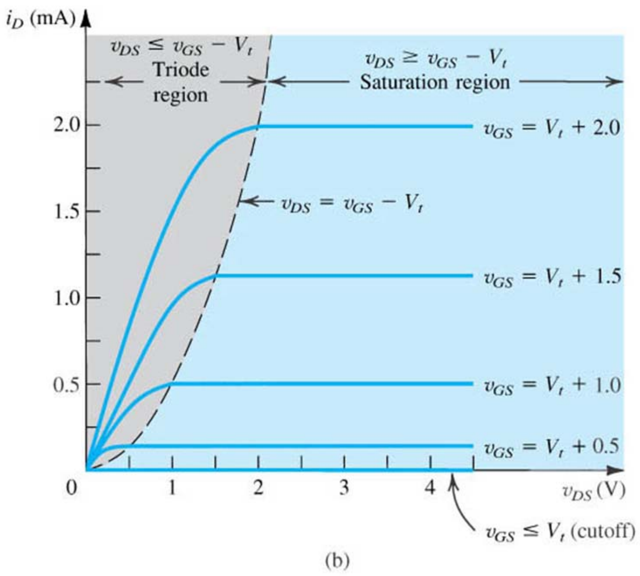
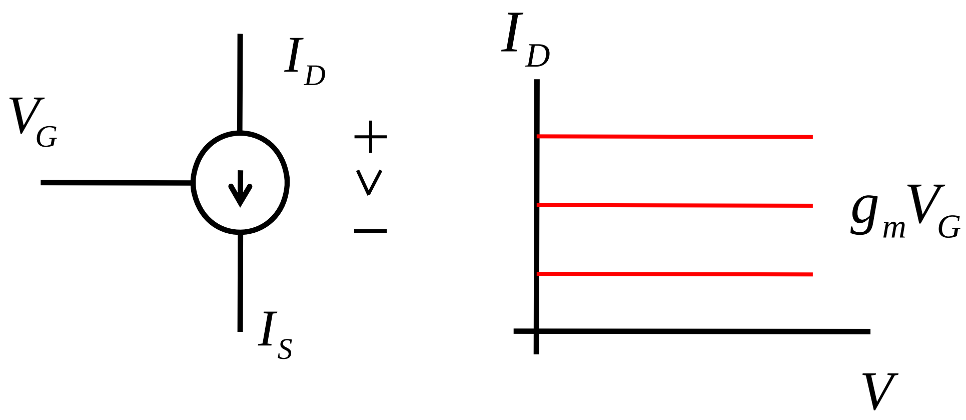
Lect. 4: MOS Transistors (3)



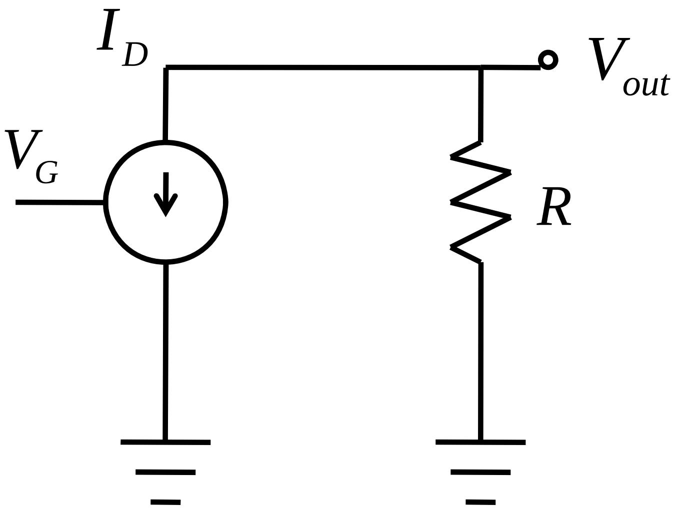
➔ Voltage-controlled current source (In saturation)



$$I_D = g_m V_G$$

What's special about this?

Voltage-controlled current source: **What can you do with it?**



$$V_{out} = -I_D \cdot R$$

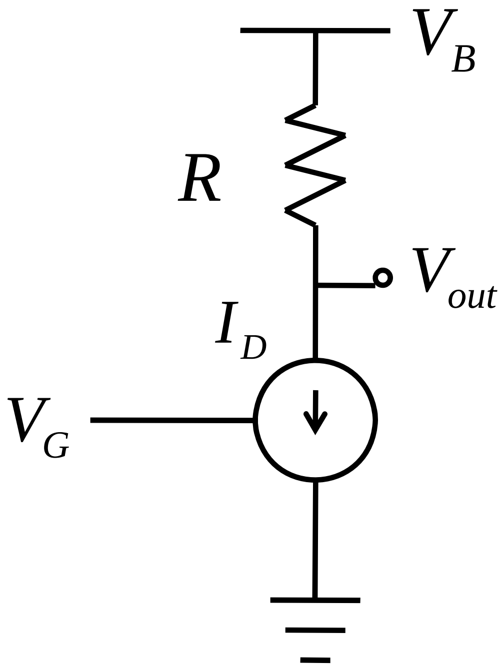
$$= -g_m V_G R$$

$$\frac{V_{out}}{V_G} = -g_m \cdot R$$

Voltage amplifier

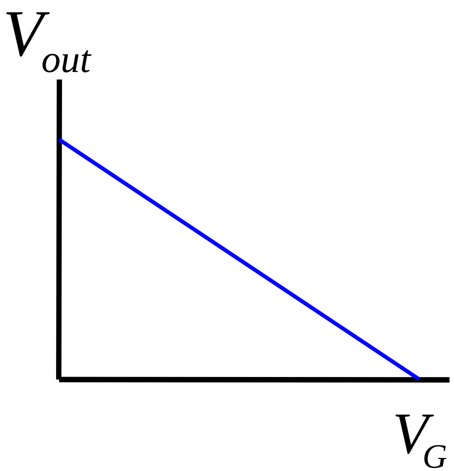
Lect. 4: MOS Transistors (3)

Voltage-controlled current source: **What can you do with it?**



$$V_{out} = V_B - I_D \cdot R$$

$$= V_B - g_m V_G \cdot R$$



Inverter

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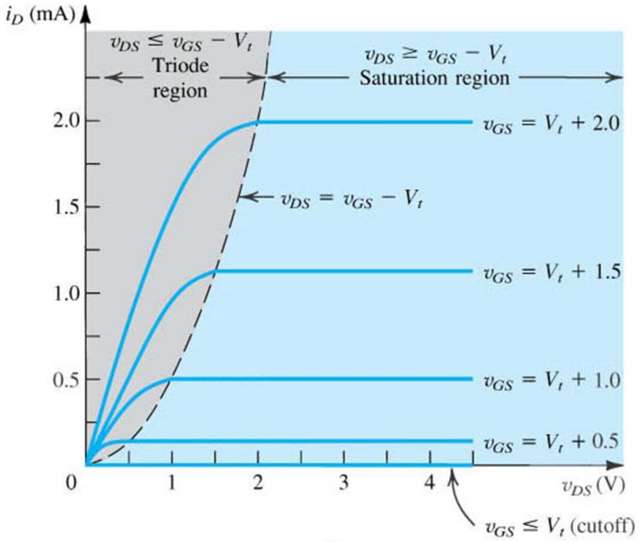
Lect. 4: MOS Transistors (3)

- Small-signal model for NMOS in saturation

- What happens when v_{GS} changes slightly?



(b)

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

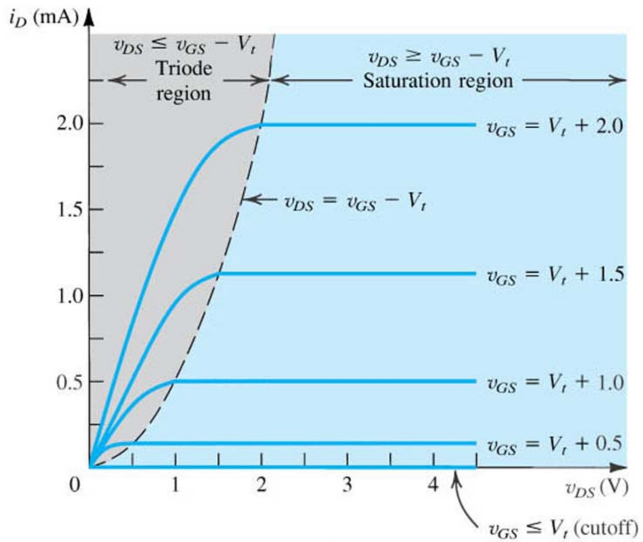
$$\Delta i_D \sim \frac{\partial i_D}{\partial v_{GS}} \cdot \Delta v_{GS} \qquad \frac{\partial i_D}{\partial v_{GS}} = g_m$$ Transconductance

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

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

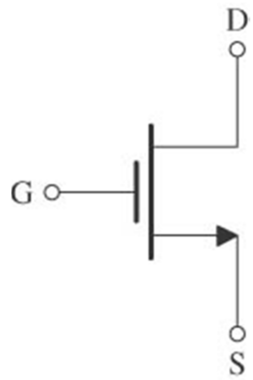
$$= \sqrt{2\mu_n C_{ox} \cdot \frac{W}{L} \cdot I_D}$$

Lect. 4: MOS Transistors (3)

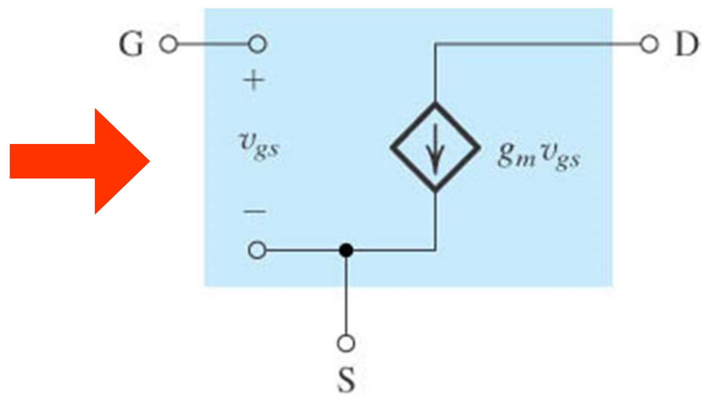


(b)

- Small-signal circuit model for NMOS in saturation



(c)



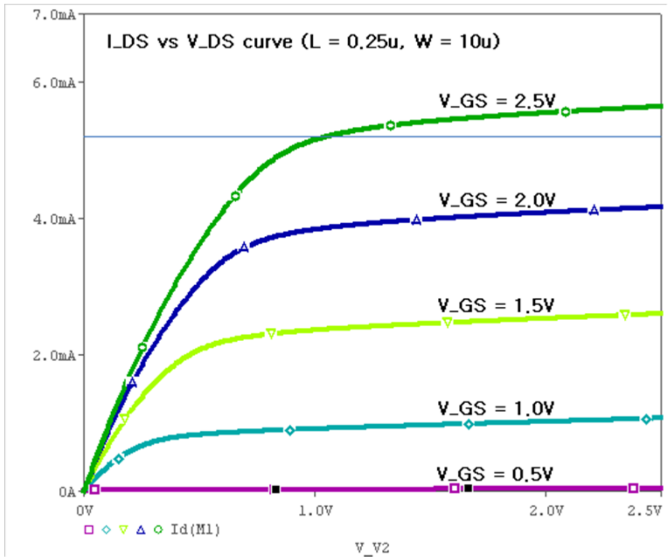
(a)

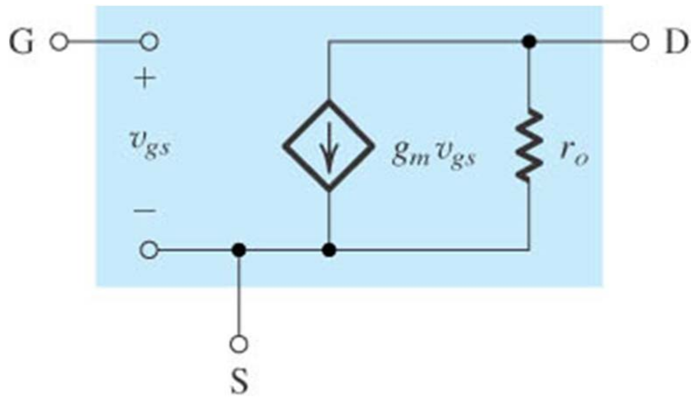
- Linearization of non-linear characteristics of transistors

- Depends on bias

Lect. 4: MOS Transistors (3)

- Small-signal model with channel length modulation





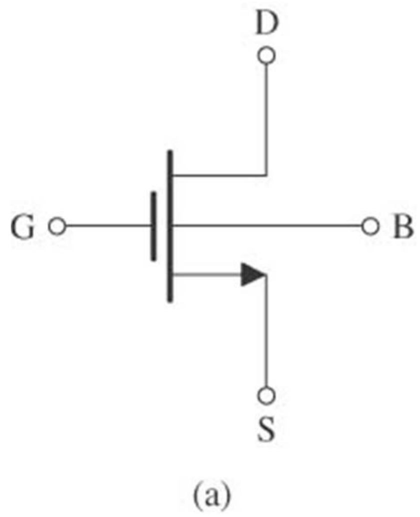
$$\frac{1}{r_0} = \frac{\partial i_D}{\partial v_{DS}} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS} - V_{TH})^2 \lambda$$

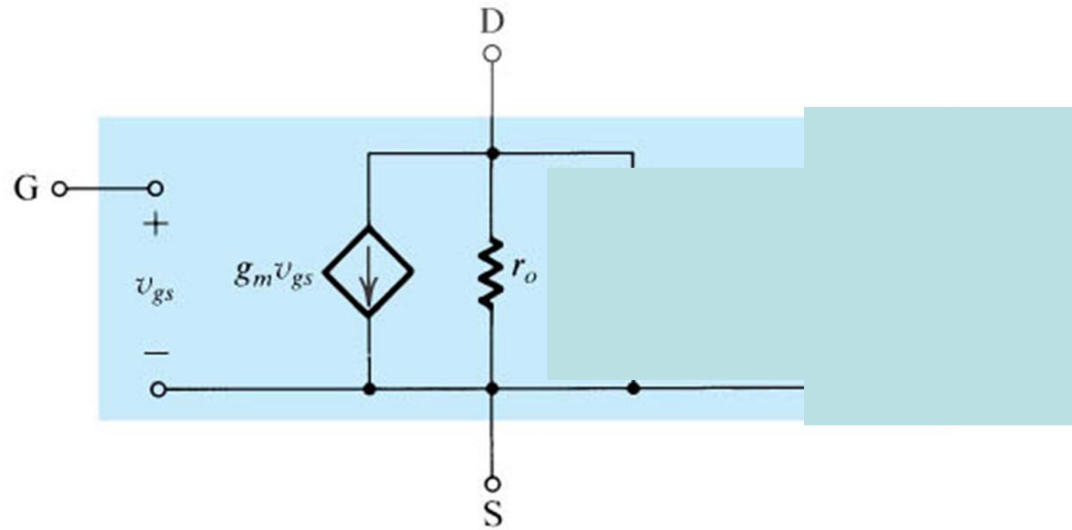
$$i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS} - V_{TH})^2(1 + \lambda \cdot v_{DS})$$

$$r_0 = \frac{1}{\lambda I_D}$$

Lect. 4: MOS Transistors (3)

Small-signal model including Body effect





Practically, Body Effect
Is not easy to model analytically.

➔ Simulation

$$g_{mb} \equiv \left. \frac{\partial i_D}{\partial v_{BS}} \right|_{\substack{v_{GS} = \text{constant} \\ v_{DS} = \text{constant}}}$$

$$g_{mb} \equiv \chi g_m \quad (\chi : 0.1 - 0.3)$$

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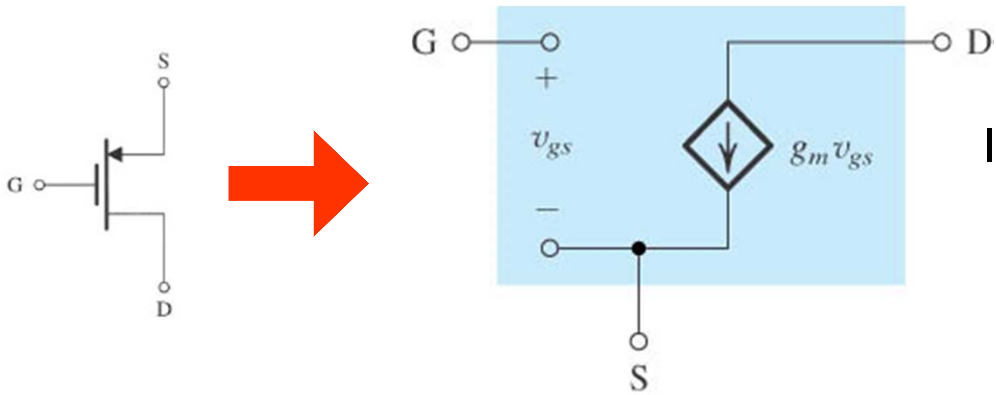
Lect. 4: MOS Transistors (3)

- Small-signal model for PMOS in saturation? $i_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(v_{SG} - |V_{TH}|)^2$

- What happens when v_{SG} changes slightly?

$$g_m = \frac{\partial i_D}{\partial v_{SG}} = \mu_p C_{ox}\frac{W}{L}(v_{SG} - |V_{TH}|) = \frac{2I_D}{V_{SG} - |V_{TH}|} = \sqrt{2\mu_p C_{ox}\cdot\frac{W}{L}\cdot I_D}$$



(a)

Identical to NMOS small-signal model

Lect. 4: MOS Transistors (3)

Homework

- Determine by simulation how g_m changes as a function of V_{GS} (for NMOS, from 1V to 2V) and V_{SG} (for PMOS, from 1V to 2V) for our MOS transistors.