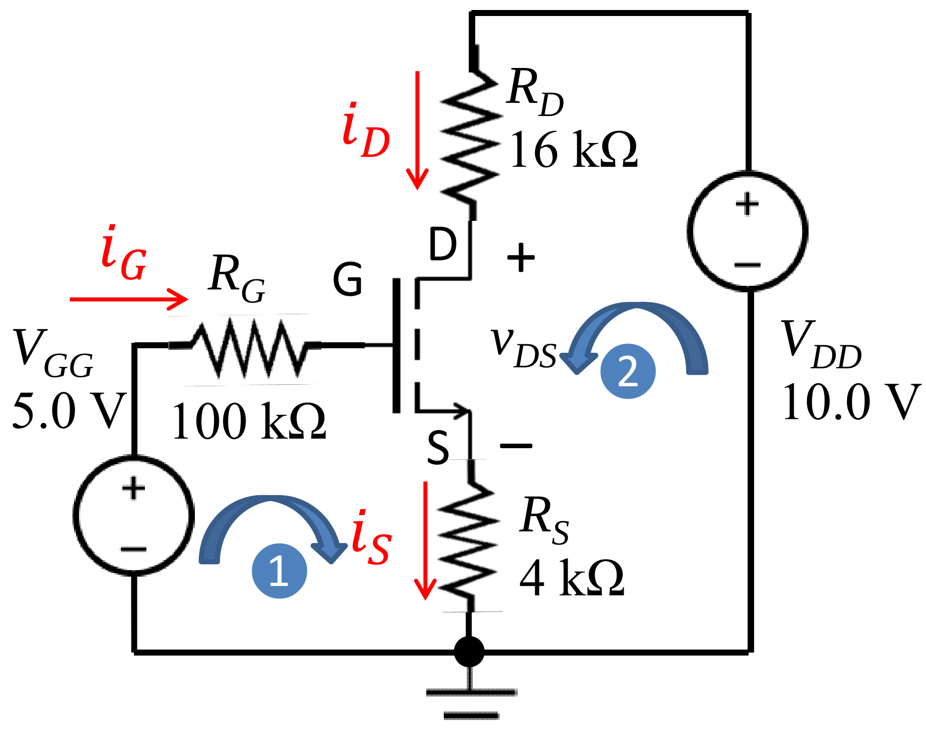
Announcements

- HW 5 due Friday.
- Emily Allstot will give Friday's lecture.
- Exam 1 regrade requests to me by 2pm today (grades may go up or down upon regrade).

MOSFET Circuit Analysis (e.g. 2')

Now R_D changes to $16\ \text{k}\Omega$



<u>Known:</u> NMOS, $V_{TO} = 1.0\ \text{V}, \lambda = 0, K_n' = 25\mu\text{A/V}^2, \frac{W}{L} = 10$

<u>Solve:</u> Q-point (i_D, v_{DS})

- Everything would be the same until the last check for saturation:

$$v_{DS} = V_{DD} - i_D(R_D + R_S)$$
$$= 10\text{V} - 500\mu\text{A} \cdot 20\text{k}\Omega = 0\text{V}$$

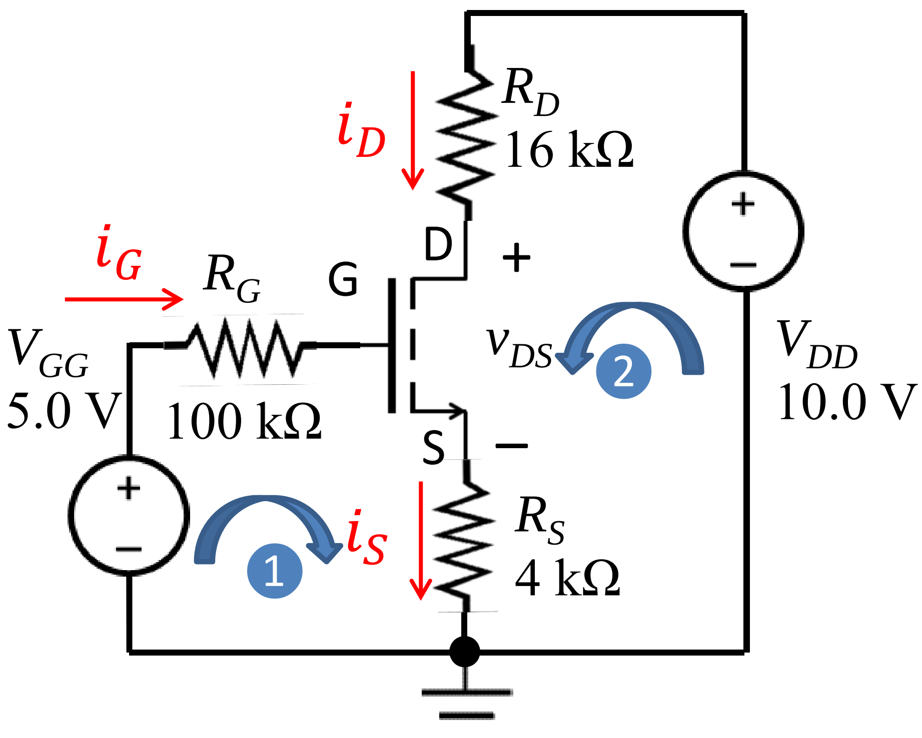
$v_{DS} = 0\ \text{V} < V_{GS} - V_{TN} = 2\ \text{V}$. Not in saturation.

- Guess in triode:

$$i_D = K_n' \frac{W}{L}\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right) v_{DS} \quad ①$$

MOSFET Circuit Analysis (e.g. 2')

Now R_D changes to $16\ \text{k}\Omega$



Q-point: (447 μA, 1.06 V)

- KVL:

$v_{DS} = V_{DD} - i_D(R_D + R_S)$ ②

$v_{GS} = V_{GG} - i_D R_S$ ③

- Substituting ② ③ into ①, we get a quadratic equation of i_D. Solution is:

$$i_D = 186\ \mu\text{A or } 447\ \mu\text{A}$$

- Check:
  - First root:

$v_{GS} = V_{GG} - i_D R_S = 4.25\ \text{V} > V_T$ √

$v_{DS} = V_{DD} - i_D(R_D + R_S)$
$= 6.27\ \text{V} > v_{GS} - V_{TN}$ ×

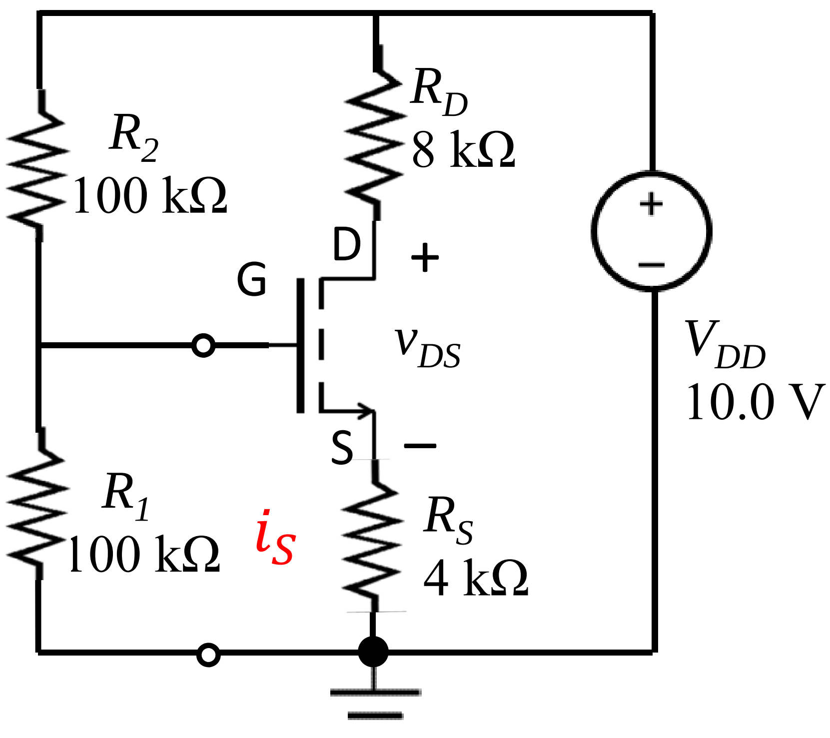
  - Second root:

$v_{GS} = V_{GG} - i_D R_S = 3.21\ \text{V} > V_T$ √

$v_{DS} = 1.06\ \text{V} < v_{GS} - V_{TN}$ √

MOSFET Circuit Analysis (e.g. 3)

Four-resistor circuit

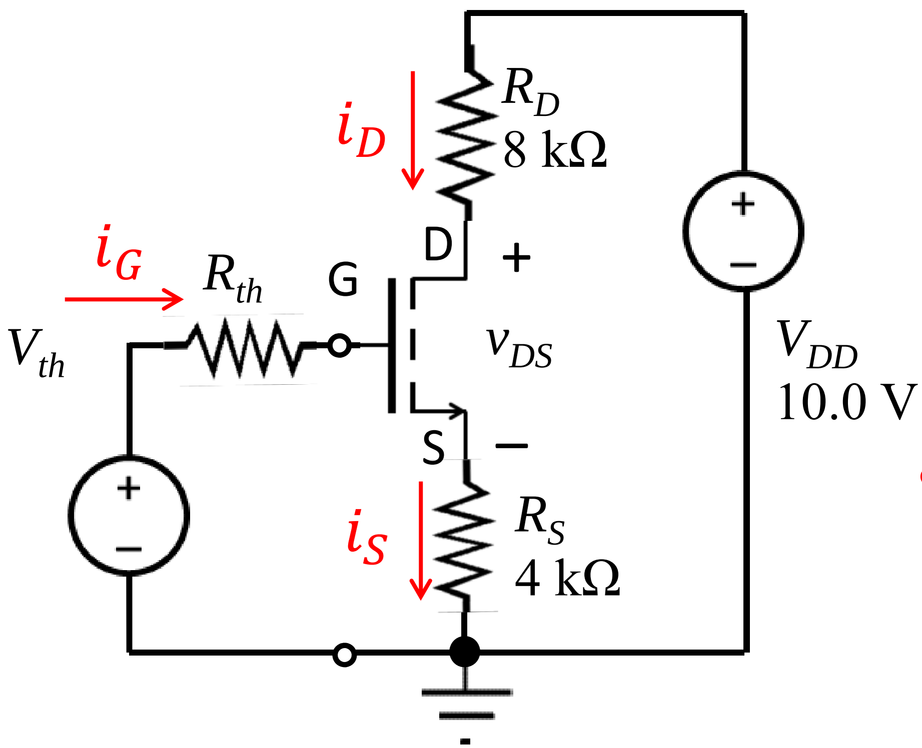


Known: NMOS, $V_{TO} = 1.0\text{ V}, \lambda = 0, K_n = 25\mu\text{A/V}^2, \frac{W}{L} = 10$

Solve: Q-point (i_D, v_{DS})

- Simplification: Find the Thevenin equivalent circuit of the left side.

MOSFET Circuit Analysis (e.g. 3)



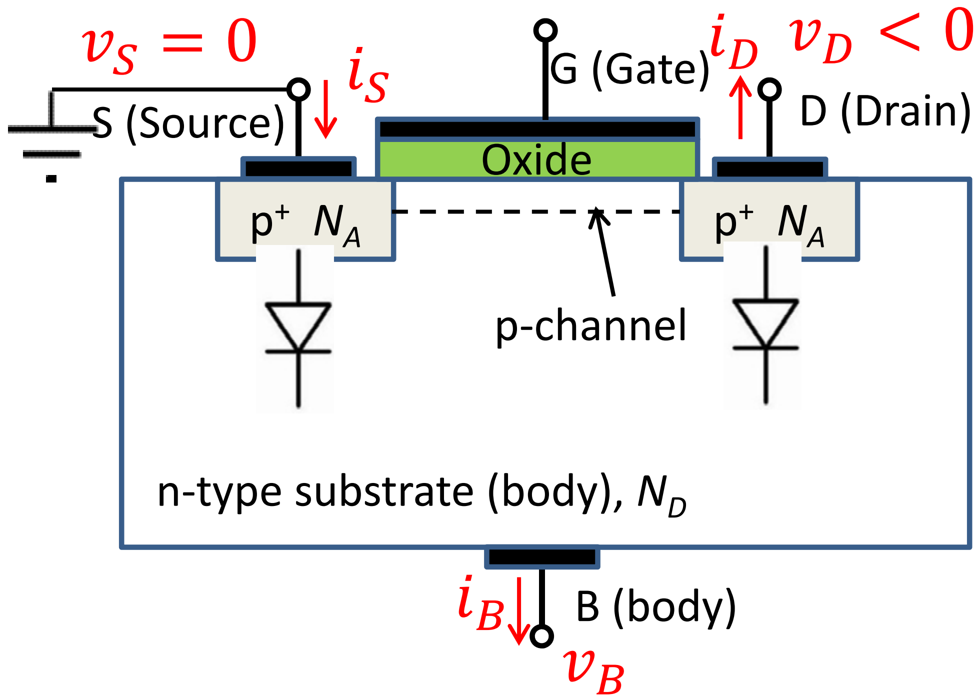
- Same circuit as in e.g. 2, with

$$V_{th} = V_{DD}\frac{R_1}{R_1+R_2} = 5\ \text{V}$$

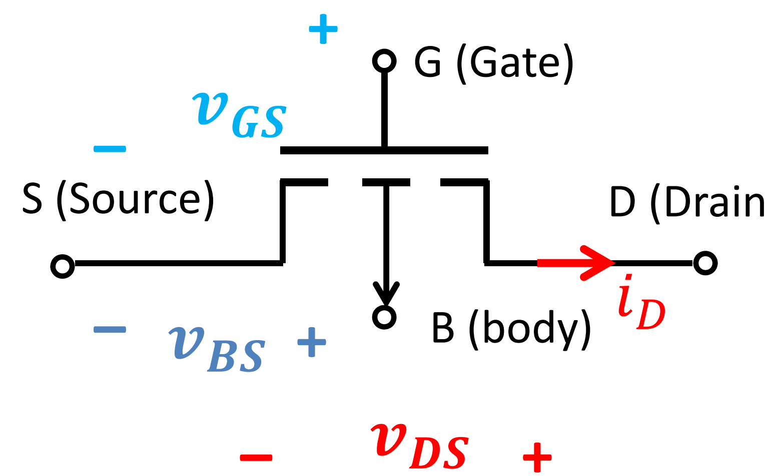
$$R_{th} = R_1 || R_2 = 50\ \text{k}\Omega$$

- Read Example 4.3 in the textbook
  - Circuit analysis
  - Advantage of 4-resistor circuits

PMOS Transistors

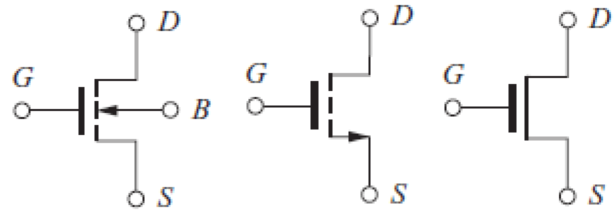
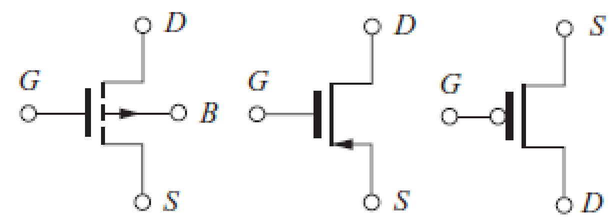
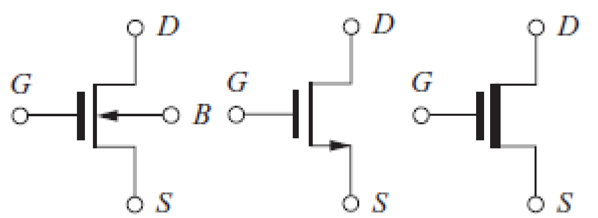
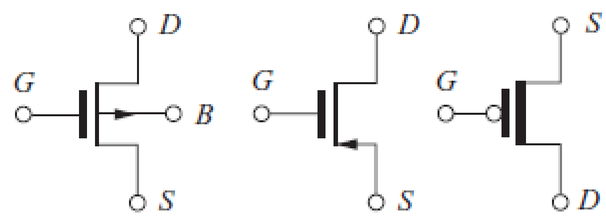


$i_B \approx 0 \Rightarrow i_D = i_S$

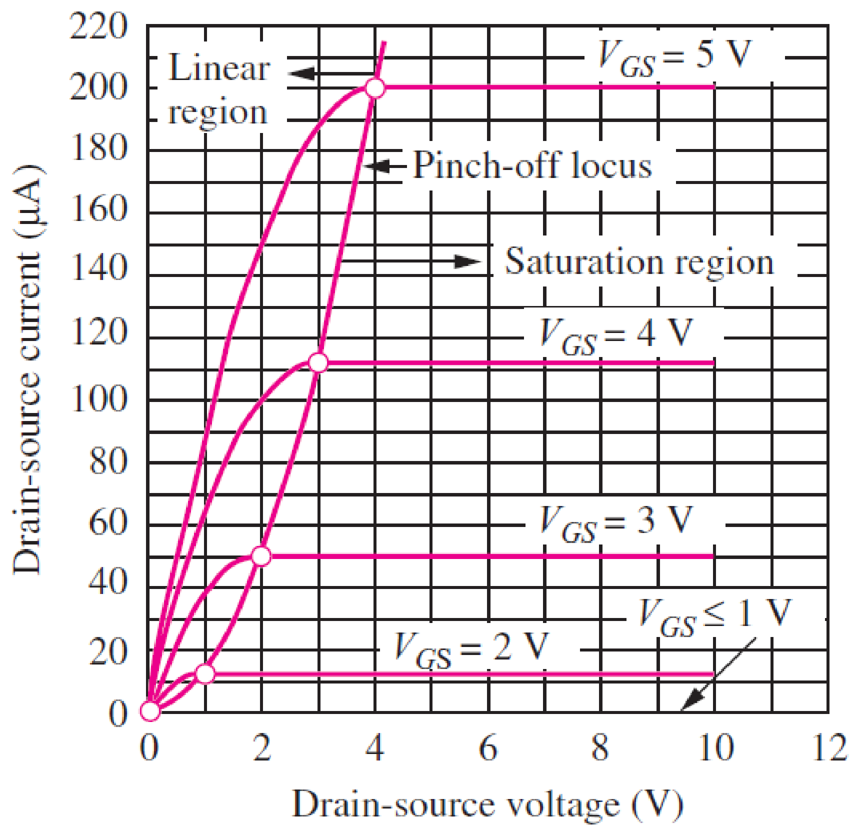


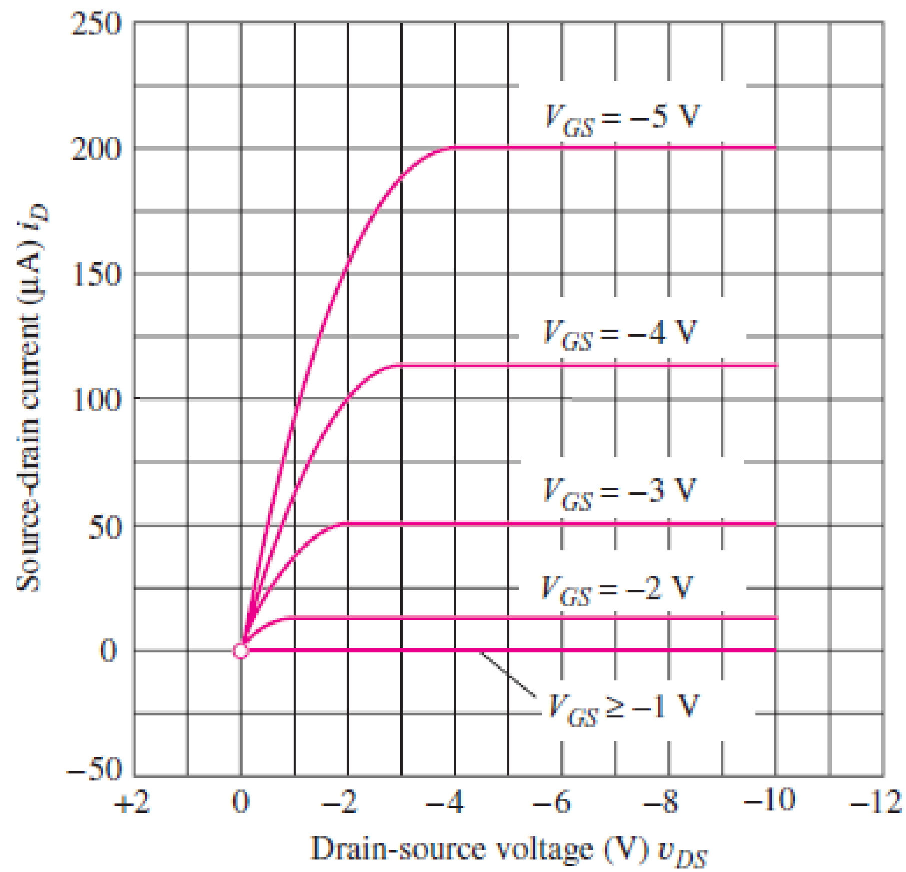
[PMOS Physics]

MOSFET Circuit Symbols

	NMOS	PMOS
E-Mode		
D-Mode		

N/P-MOS Output Characteristics





NMOS Operation Region

Operation Region	Current Equation	Condition
Cutoff	$i_D = 0$	$v_{GS} \le V_{TN}$
Triode	$i_D = K_n' \frac{W}{L}\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right) v_{DS}$	$v_{GS} > V_{TN}$ $v_{GS} - V_{TN} > v_{DS}$
Saturation	$i_D = \frac{K_n'}{2}\frac{W}{L}(v_{GS} - V_{TN})^2(1 + \lambda(v_{DS} - v_{DSat}))$	$v_{GS} > V_{TN}$ $v_{GS} - V_{TN} \le v_{DS}$

Channel Length Modulation

Body Effect:

$$V_{TN} = V_{TO} + \gamma(\sqrt{v_{SB} + 2\phi_F} - \sqrt{2\phi_F})$$

PMOS Operation Region

Operation Region	Current Equation	Condition
Cutoff	$i_D = 0$	$v_{GS} \geq V_{TP}$
Triode	$i_D = K_p' \frac{W}{L}\left(v_{GS} - V_{TP} - \frac{v_{DS}}{2}\right) v_{DS}$	$v_{GS} < V_{TP}$ $\lvert v_{GS} - V_{TP}\rvert \geq \lvert v_{DS}\rvert$
Saturation	$i_D = \frac{K_p'}{2}\frac{W}{L}(v_{GS} - V_{TP})^2(1 + \lambda\lvert v_{DS} - v_{DSat}\rvert)$	$v_{GS} < V_{TP}$ $\lvert v_{GS} - V_{TP}\rvert < \lvert v_{DS}\rvert$

Body Effect:

$$V_{TP} = V_{TO} - \gamma\left(\sqrt{v_{BS} + 2\phi_F} - \sqrt{2\phi_F}\right)$$

Enhancement mode PMOS: $V_{TP} < 0$

Depletion mode PMOS: $V_{TP} > 0$