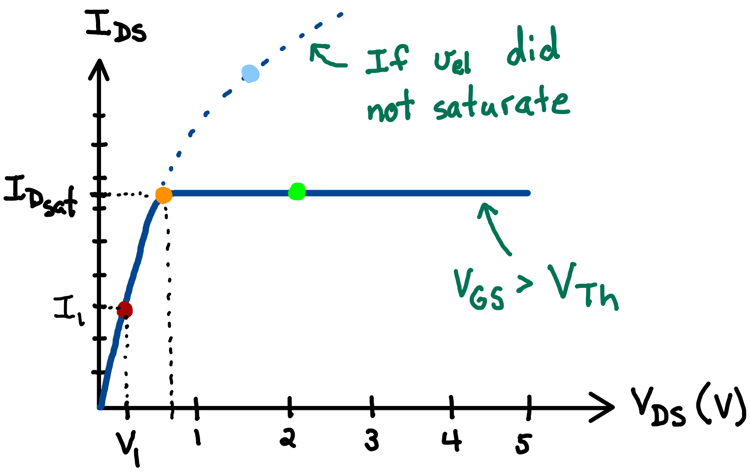
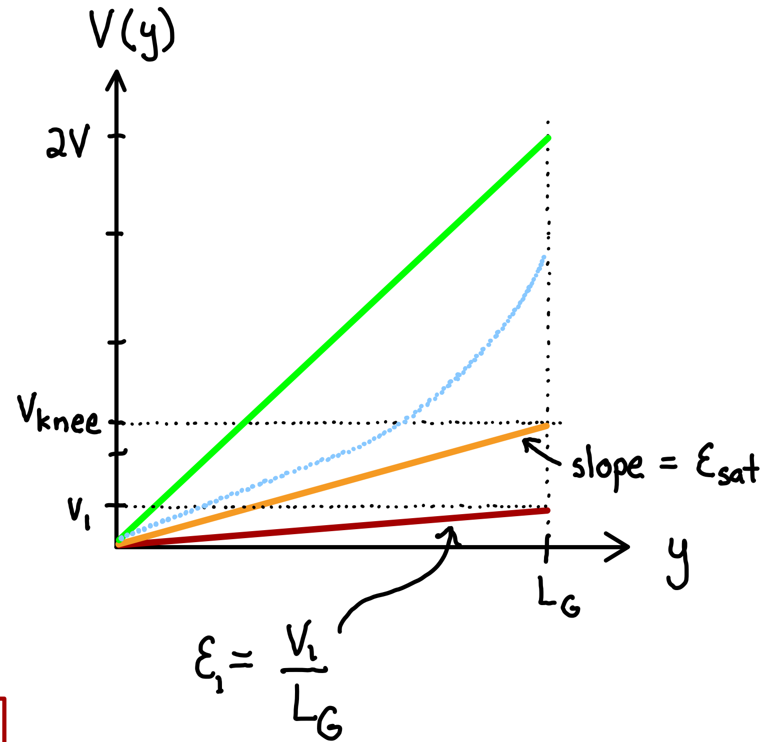
# Short Channel MOSFET: $(L_G \lesssim 0.2\ \mu m)$




$$\boxed{V_{knee} = \mathcal{E}_{sat} \cdot L_G = \frac{\upsilon_{sat}}{\mu_n} L_G}$$

$$I_1 = q n_s W_G \cdot \upsilon_{el}$$

$$= C_{ox}(V_{GS} - V_{Th}) \cdot W_G \cdot \mu_n \mathcal{E}_1$$

$$= \frac{W_G}{L_G} \mu_n C_{ox} (V_{GS} - V_{Th}) V_1$$

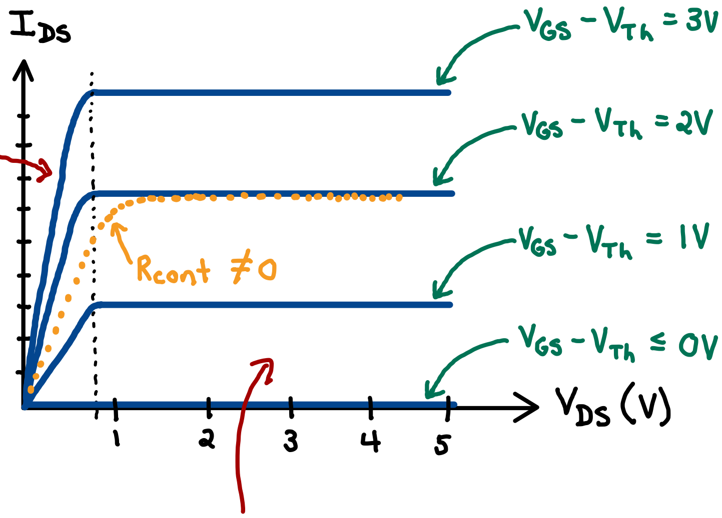
$V_{DS} < V_{knee}$:

$$I_{DS} = \frac{W_G}{L_G} \mu_n C_{ox} (V_{GS} - V_{Th}) V_{DS}$$

$V_{DS} > V_{knee}$:

$$I_{DS} = I_{Dsat} = W_G C_{ox} (V_{GS} - V_{Th}) \upsilon_{sat}$$

$$\text{slope} = g_D = \frac{1}{R_{ON}}$$




Curves evenly spaced in saturation regime ($g_m = \text{const}$)

$$g_m = \left.\frac{\partial I_{DS}}{\partial V_{GS}}\right|_{V_{DS} > V_{knee}} = W_G C_{ox} \upsilon_{sat}$$

$$R_{ON} = \frac{1}{g_D} = \left[\left.\frac{\partial I_{DS}}{\partial V_{DS}}\right|_{V_{DS} < V_{knee}}\right]^{-1} = \frac{L_G}{W_G \mu_n C_{ox} (V_{GS} - V_{Th})}$$

If we account for contact resistances ($R_S = R_D = R_{cont}$):

$$R_{ON} = \frac{L_G}{W_G \mu_n C_{ox} (V_{GS} - V_{Th})} + 2R_{cont}$$

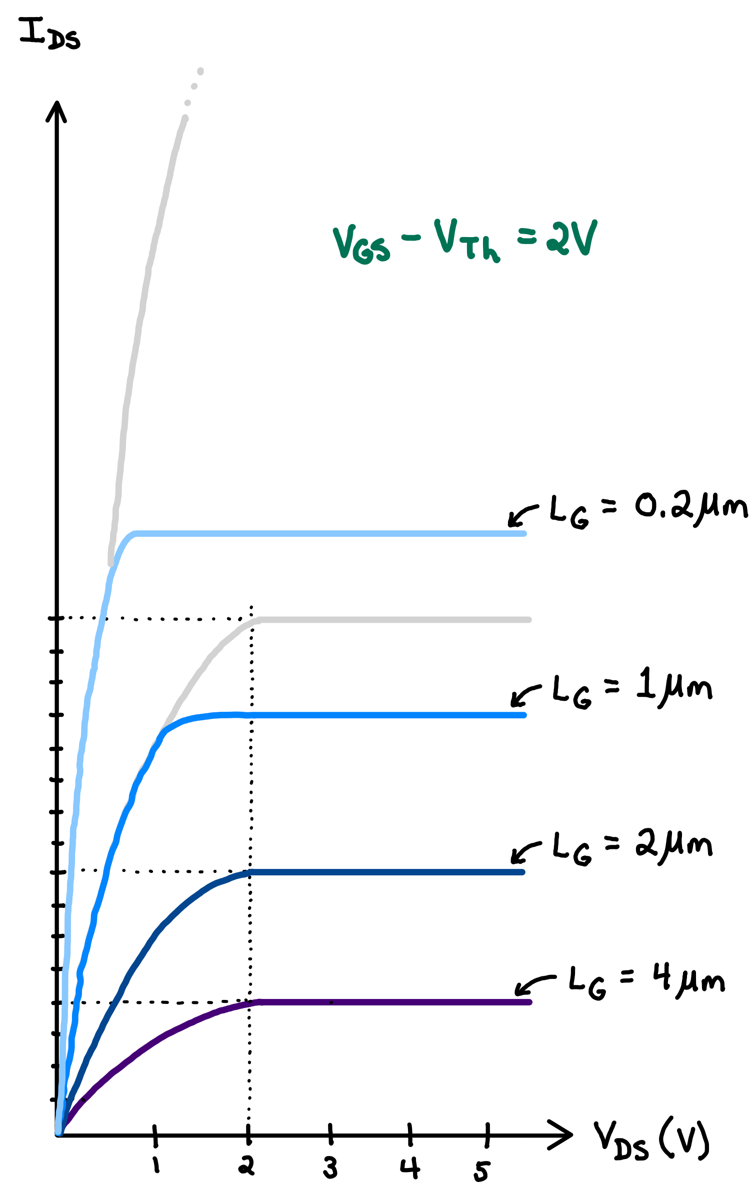
$$\frac{V_{knee}}{I_{Dsat}} = R_{ON} \longrightarrow V_{knee} = \frac{\upsilon_{sat}}{\mu_n} \cdot L_G + 2 W_G C_{ox} (V_{GS} - V_{Th}) \upsilon_{sat} R_{cont}$$

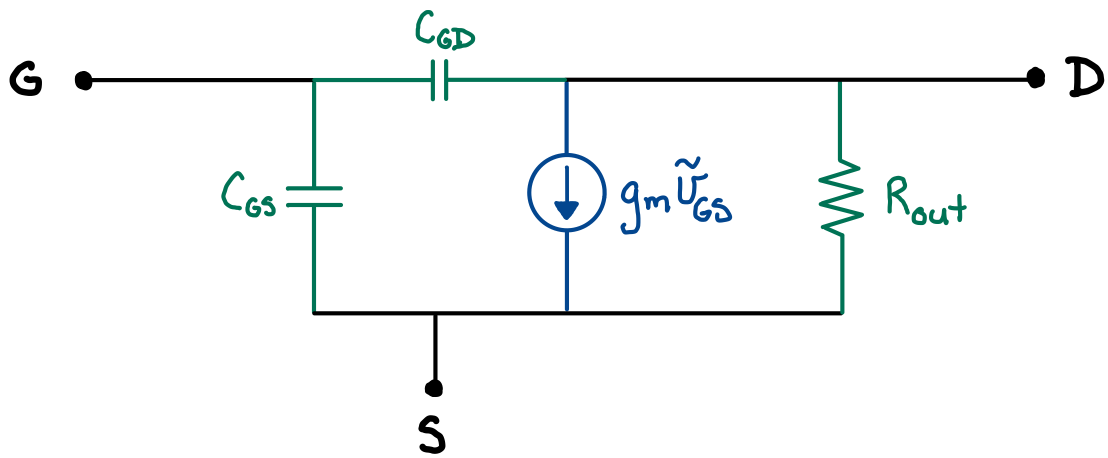
Questions:

1. Referring to the I-V curves on the previous page, how would they differ if $L_G$ was reduced by a factor of 2 (assuming zero contact resistance)?

2. If $L_G$ was reduced by a factor of 2 and $t_{ox}$ was also reduced by a factor of 2 (constant field scaling), how would the I-V characteristics change (assuming no change in $V_{th}$)?

## Scaling of MOSFETs






$$f_T = \frac{g_m}{2\pi(C_{GS} + C_{GD})}$$

Short channel:

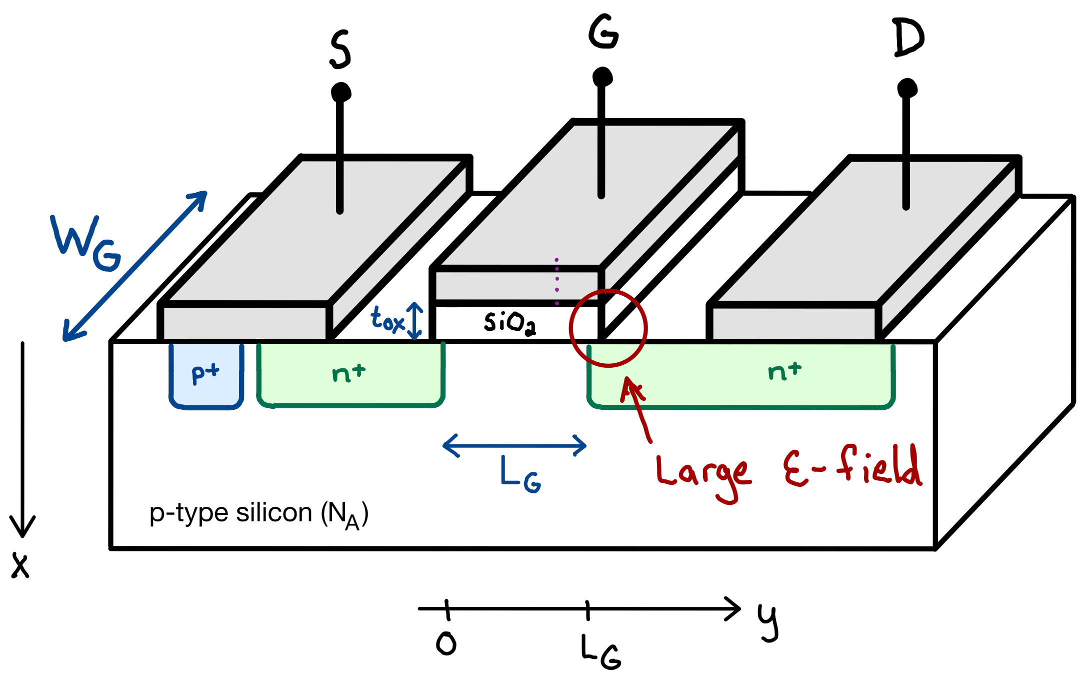
- $g_m$ does not depend on $L_G$
- $C_{GS} \sim L_G$ and $C_{GD} \sim L_G$
- If only $L_G$ is varied, $f_T \propto \frac{1}{L_G}$
- Constant field scaling:
  - $g_m \propto \frac{1}{L_G}$
  - $f_T \propto \frac{1}{L_G^2}$

## Challenges in scaling of MOSFETs:

1. Small gate lengths

   - EUV lithography technology

2. Thin gate oxides: electron tunneling through gate oxide




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

High-dielectric oxides (High-K dielectrics):

| | |
|---|---|
| $Al_2O_3$ | $\epsilon_r = 9.5$ |
| $ZrO_2$ | $\epsilon_r = 20-40$ |
| $HfO_2$ | $\epsilon_r = 20-30$ |
| $TiO_2$ | $\epsilon_r = 80$ |
| $Ta_2O_5$ | $\epsilon_r = 250$ |