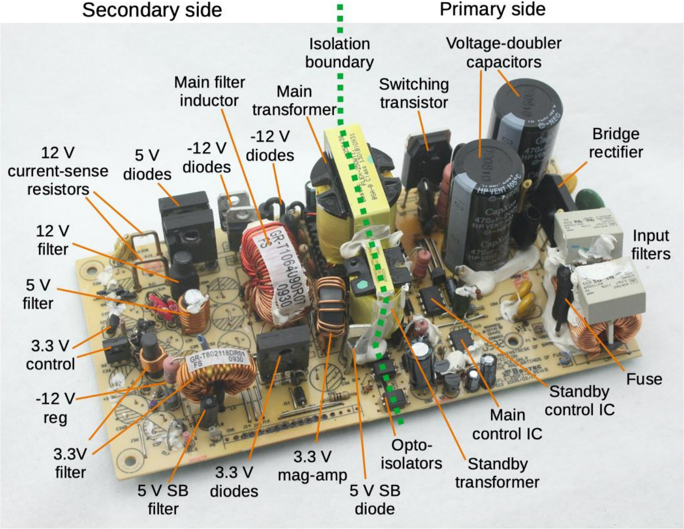

MOSFET circuits at DC

Kizito NKURIKIYEYEZU, Ph.D.

Introduction

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- We will neglect the effects of channel length modulation (assuming $\lambda = 0$).
- We will work in terms of overdrive voltage v_{OV}, which reduces need to distinguish between PMOS and NMOS.

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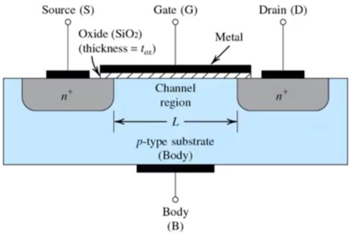
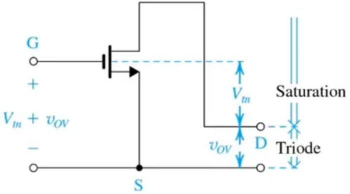
Review: Regions of Operation of a MOSFET Transistor

Cutoff

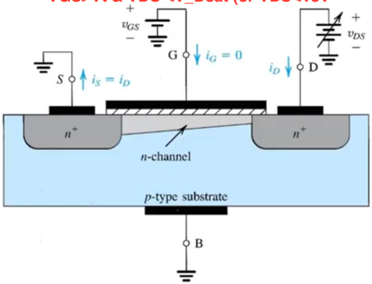
VGS < Vt





Triode

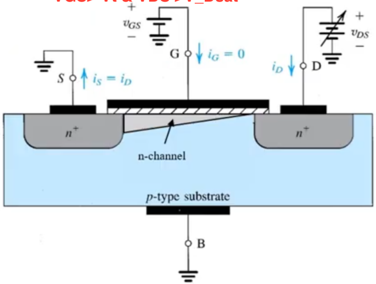
VGS>Vt & VDS <V_Dsat (or VDS<Vov



$$i_D = k_n'\left(\frac{W}{L}\right)\left(V_{OV} - \frac{1}{2}v_{DS}\right)v_{DS}$$

Saturation

VGS> Vt & VDS >V_Dsat

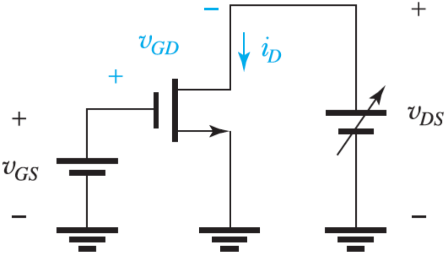


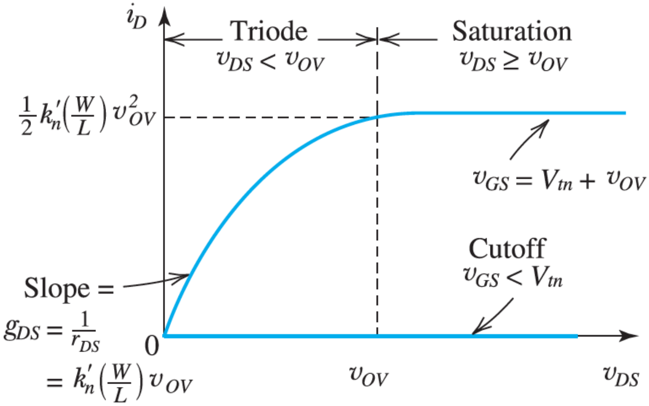
$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)v_{OV}^2$$

FIG 1

Review: Regions of Operation of an NMOS Transistor

- $v_{GS} < V_t$—no channel. The transistor is in the cut-off mode. $i_D = 0$





[0] In the triode, i_D is controlled by three terminals (hence the name triode), unlike in the saturation mode, where the transistor's operation is controlled by two terminals

Analysis at DC

A MOSFET is non-linear, and has different operating modes:

1. Cut-off, when $v_{GS} < V_t$
   - $i_D = 0$
   - no channel is formed
2. Triode, when $v_{GS} = V_t + v_{OV}$
   - Existence of a resistance $r_{DS} = k_n v_{OV}$ between the drain and the source
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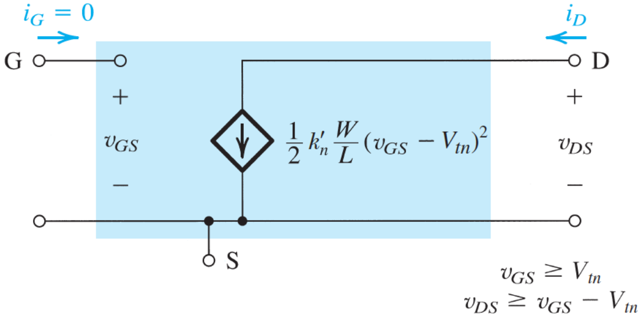

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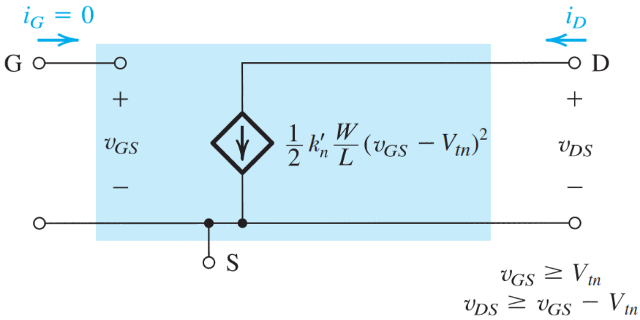

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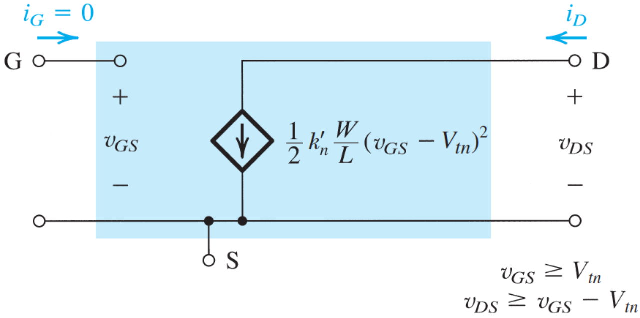

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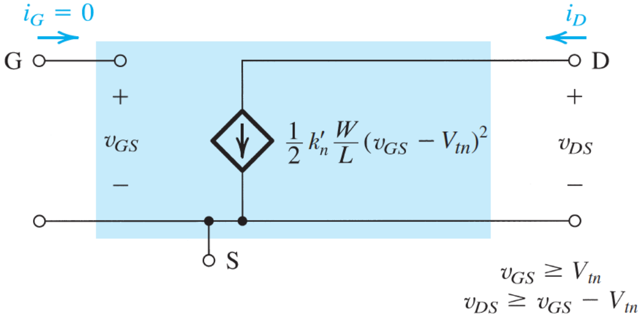

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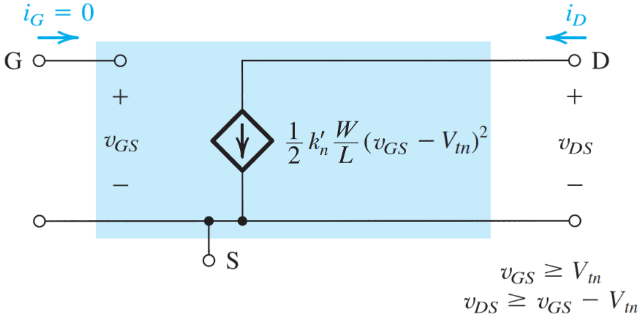

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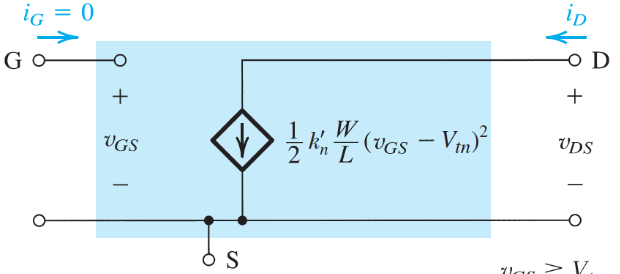

$v_{GS} \geq V_{tn}$
$v_{DS} \geq v_{GS} - V_{tn}$

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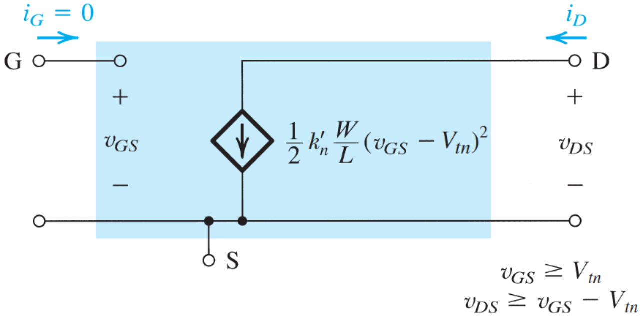
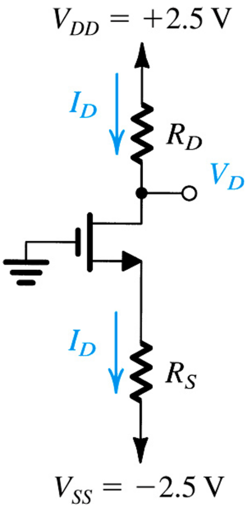


EXAMPLES

Example 1

Determine the values of R_D and R_S so that the transistor operates at $i_D = 0.4mA$ and $V_D = +0.5V$. The NMOS transistor has $V_t = 0.7V$, $\mu_n C_{ox} = 100\mu A/V^2$, $L = 1\,\mu m$, and $W = 32\,\mu m$. Neglect the channel-length modulation effect (i.e., assume that $\lambda = 0$).



Example 1—Solution

- For a V_D voltage, we have

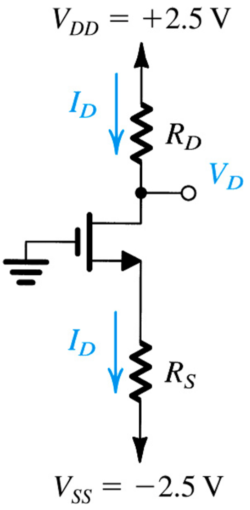
$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{2.5 - 0.5}{0.4} = 5\,\mathrm{k}\Omega \qquad (1)$$

- Calculating R_S is a bit more complex because we need to know the voltage at the source terminal.
  - Since $V_D = 0.5 > V_G$, the transistor is in the saturation mode. Thus,

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{OV}^2 \qquad (2)$$

The overdrive voltage is thus given by

$$V_{OV} = \sqrt{\frac{I_D}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}}} = 0.5\,V \qquad (3)$$



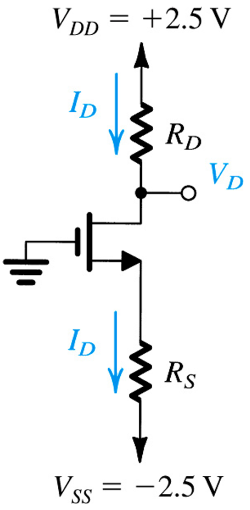
Example 1—Solution

- It is now possible to calculate V_{GS}

$$V_{GS} = V_t + V_{OV} = 0.7V + 0.5V = 1.2V \quad (4)$$

- The source resistor is thus given by

$$R_S = \frac{V_G - V_S - V_{SS}}{I_D} = \frac{0 - 1.2 - (-2.5)}{0.4} = 3.25\,\text{k}\Omega \quad (5)$$



Example 2

Find the value of R that results in $V_D = 0.7V$. The MOSFET has $V_{tn} = 0.5V$, $\mu_n Cox = 0.4\,\text{mA}\,\text{V}^{-2}$, $W = 0.72\,\mu\text{m}$, $L = 0.18\,\mu\text{m}$ and $\lambda = 0$

- Saturation mode since $v_{GD} = 0 < V_{tn}$
- Thus, the drain current is given by

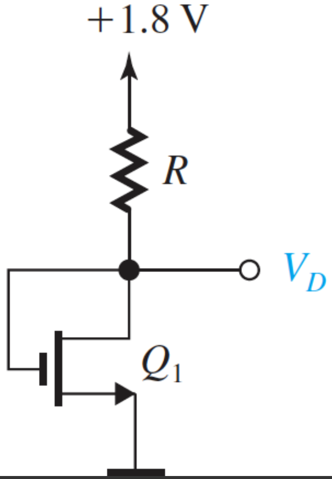
$$i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_D - V_{tn})^2 = 0.032mA \tag{6}$$

- The resistor R is given by

$$R = (1.8V - V_D)/I_D \tag{7}$$

- Since $V_D = 1.8V - I_D R = 0.7V$,

$$R = (1.8V - 0.7V)/0.032mA = 34.4\,\text{k}\Omega \tag{8}$$



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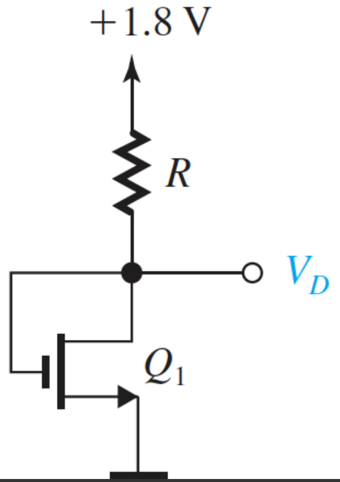

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