Homework #9

Problems 5.9, 5.10, 5.11, 5.18, and 5.19

Problem 5.9

An NMOS transistor with k_n = 4 mA/V^2 and V_t = 0.5 V is operated with V_{GS} = 1.0 V. At what value of V_{DS} does the transistor enter the saturation region? What value of I_D is obtained in saturation?

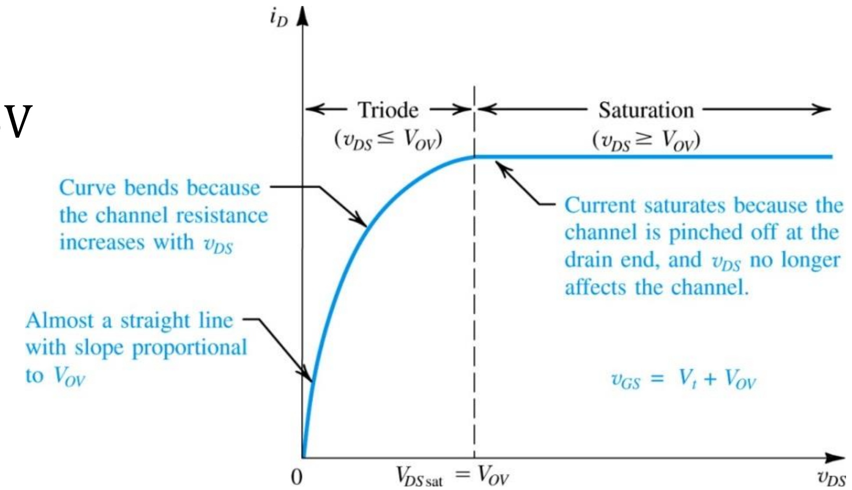
The NMOS FET enters saturation when $V_{DS} = V_{OV}$

$$V_{DSsat} = V_{OV} = V_{GS} - V_t = 1.0 - 0.5 = 0.5\text{V}$$

In saturation when $V_{DS} \geq V_{OV}$

$$i_D = \frac{1}{2} k_n v_{OV}^2 = \frac{1}{2}\left(\frac{4\text{mA}}{\text{V}^2}\right)(0.5\text{V})^2$$

$$= 0.5\text{mA}$$



Problem 5.10

Consider a CMOS process for which L_{min} = 0.25 μm, t_{ox} = 6 nm ,μ_n = 460 cm²/V·s, and V_t = 0.5V.

(a) Find C_{ox}, and k'_n.

(b) For an NMOS transistor with W/L = 20 μm/0.25 μm, calculate the values of V_{OV}, V_{GS}, and V_{DSmin} needed to operate the transistor in the saturation region with a dc current I_D = 0.5 mA.

(c) For the device in (b). find the value of V_{OV} and V_{GS} required to cause the device to operate as a 100-Ω resistor for very small v_{DS}.

(a) Find C_{ox}, and k'_n

$$c_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

$$\varepsilon_{ox} = 3.9\varepsilon_0 = 3.45 \times 10^{-11}\ \mathrm{F/m}$$

$$k'_n = \mu_n c_{ox}\ \left[\mathrm{A/V^2}\right]$$

$$C_{ox} := \frac{3.9\varepsilon_0}{t_{ox}} = 5.755\times 10^{-3}\ \frac{\mathrm{pF}}{\mu\mathrm{m}^2}$$

$$k_{nprime} := C_{ox}\cdot 460\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}} = 0.265\frac{\mathrm{mA}}{\mathrm{V}^2}$$

Problem 5.10 cont…

Consider a CMOS process for which L_{min} = 0.25 μm, t_{ox} = 6 nm ,μ_n = 460 cm²/V·s, and V_t = 0.5V.

(b) For an NMOS transistor with W/L = 20 μm/0.25 μm, calculate the values of V_{OV}, V_{GS}, and V_{DSmin} needed to operate the transistor in the saturation region with a dc current I_D = 0.5 mA.

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{OV}^2 \qquad V_{OV} = \sqrt{\frac{I_D}{\frac{1}{2} k_n' \left(\frac{W}{L}\right)}} \qquad V_{OV} := \sqrt{\frac{0.5\text{mA}}{\frac{1}{2}\left(.265\frac{\text{mA}}{\text{V}^2}\right)\left(\frac{20\mu\text{m}}{0.25\mu\text{m}}\right)}} = 0.217\text{V}$$

$$V_{GS} = V_t + V_{OV} = 0.5 + 0.217 = 0.717\text{V}$$

$$V_{DSsatmin} = V_{OV} = 0.217\text{V}$$

Problem 5.10 cont…

Consider a CMOS process for which $L_{\min}$ = 0.25 mm, t_{ox} = 6 nm ,μ_n = 460 cm^2/V·s, and V_t = 0.5V.

(c) For the device in (b), find the value of V_{OV} and V_{GS} required to cause the device to operate as a 100-Ω resistor for very small v_{DS}.

The NMOS FET would be operating in the triode region to act as a resistor so $V_{DS} < V_{OV}$

$$r_{DS} = 100\Omega = \frac{1}{g_{DS}} = \frac{1}{(\mu_n c_{ox})(W/L)V_{OV}}$$

$$V_{OV} := \frac{1}{\left[\left(.265\frac{\text{mA}}{\text{V}^2}\right)\left(\frac{20\mu\text{m}}{0.25\mu\text{m}}\right)\cdot 100\Omega\right]} = 0.472\text{V}$$

$$V_{GS} = V_t + V_{OV} = 0.5 + 0.472 = 0.972\text{V}$$

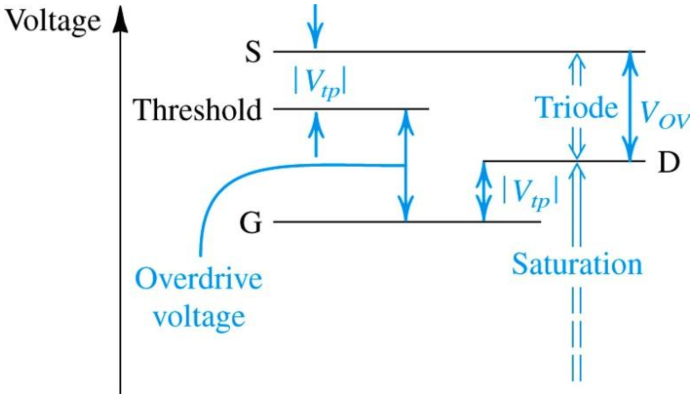
Problem 5.11a

A *p*-channel MOSFET with a threshold voltage V_{tp} = -0.7 V has its source connected to ground.

(a) What should the gate voltage be for the device to operate with an overdrive voltage of $|V_{OV}|$ = 0.4 V?

(b) With the gate voltage as in (a), what is the highest voltage allowed at the drain while the device operates in the saturation region?

(c) If the drain current obtained in (b) is 0.5 mA, what would the current be for V_D = -20 mV and for V_D = -2 V?



a) $V_{SG} = |V_{tp}| + |V_{OV}| = |-0.7| + 0.4 = 1.1\text{V}$

$$\Rightarrow V_G = V_S - V_{SG} = -1.1\text{V}$$

b) $V_{GD} = V_{tp} = -0.7\text{V}$

$$\Rightarrow V_D = V_{SG} - V_{GD} = -1.1\text{V} - -0.7\text{V} = -0.4\text{V}$$

Problem 5.11b

A p-channel MOSFET with a threshold voltage V_{tp} = -0.7 V has its source connected to ground.

(c) If the drain current obtained in (b) is 0.5 mA, what would the current be for V_D = -20 mV and for V_D = -2 V?

$$i_D = \frac{1}{2} k_p V_{OV}^2 \qquad \Rightarrow k_p = \frac{2i_D}{V_{OV}^2} = \frac{2 \times 0.5\text{mA}}{(0.4\text{V})^2} = 6.25\frac{\text{mA}}{\text{V}^2}$$

c) V_D = -20 mV – ohmic region

$$i_D = k_p\left(\left(V_{SG} - \left|V_{tp}\right|\right)v_{SD} - \frac{1}{2}v_{SD}^2\right) = \frac{6.25\text{mA}}{\text{V}^2}\left(\left(-1.1\text{V} - 0.7\text{V}\right)\times 0.02\text{V} - 0.5\times\left(0.02\text{V}\right)^2\right)$$

$$= 48.75\mu\text{A}$$

c) V_D = -2 V – saturation region

$$\Rightarrow i_D = 0.5\text{mA}$$

Problem 5.18

A particular MOSFET for which $V_{tn} = 0.5$ V and $k_n'(W/L) = 1.6$ mA/V^2 is to be operated in the saturation region. If i_D is to be 50 μA, find the required v_{GS} and the minimum required v_{DS}. Repeat for $i_D = 200$ μA.

$i_D = 50$ μA

$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)v_{OV}^2 \qquad v_{OV} = \sqrt{\frac{i_D}{\frac{1}{2}k_n'\left(\frac{W}{L}\right)}} \qquad V_{OV} := \sqrt{\frac{50\mu A}{\frac{1}{2}\left(1.6\frac{mA}{V^2}\right)}} = 0.25V$$

$$v_{GS} = V_t + v_{OV} = 0.5 + 0.25 = 0.75\text{V} \qquad v_{DS} \ge V_{OV} = 0.25\text{V}$$

$i_D = 200$ μA

$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)v_{OV}^2 \qquad v_{OV} = \sqrt{\frac{i_D}{\frac{1}{2}k_n'\left(\frac{W}{L}\right)}} \qquad V_{OV} := \sqrt{\frac{200\mu A}{\frac{1}{2}\left(1.6\frac{mA}{V^2}\right)}} = 0.5V$$

$$v_{GS} = V_t + v_{OV} = 0.5 + 0.5 = 1.0\text{V} \qquad v_{DS} \ge V_{OV} = 0.5\text{V}$$

Problem 5.19

A particular *n*-channel MOSFET is measured to have a drain current of 0.4 mA at $V_{GS} = V_{DS} = 1$ V and of 0.1 mA at $V_{GS} = V_{DS} = 0.8$ V. What are the values of k_n and V_t for this device?

$$i_D = \frac{1}{2}k_n V_{OV}^2 = \frac{1}{2}k_n\left(V_{GS} - V_t\right)^2$$

$$\Rightarrow i_{D1} = \frac{1}{2}k_n\left(1 - V_t\right)^2 = 0.4\text{mA}, i_{D2} = \frac{1}{2}k_n\left(0.8 - V_t\right)^2 = 0.1\text{mA}$$

$$\frac{i_{D1}}{i_{D2}} = \frac{0.4\text{mA}}{0.1\text{mA}} = 4 = \frac{\frac{1}{2}k_n\left(1 - V_t\right)^2}{\frac{1}{2}k_n\left(0.8 - V_t\right)^2} = \frac{\left(1 - V_t\right)^2}{\left(0.8 - V_t\right)^2}$$

$$\text{roots} = 0.6\text{V}, 0.867\text{V}$$

$$\Rightarrow V_t = 0.6\text{V}$$

$$k_n = \frac{2i_D}{V_{OV}^2} = \frac{2i_D}{\left(V_{GS} - V_t\right)^2} = \frac{2 \times 0.4\text{mA}}{\left(1\text{V} - 0.6\text{V}\right)^2} = 5\frac{\text{mA}}{\text{V}^2}$$