ECE 523/421 - Analog Electronics:
University of New Mexico
Solutions Homework 1

Problem 5.4
An NMOS transistor that is operated with a small v_{DS} is found to exhibit a resistance r_{DS}. By what factor will r_{DS} change in each of the following situations?

Using the formula for the drain current for a small v_{DS}.

$$i_D = \left[(\mu_n C_{ox})\left(\frac{W}{L}\right)(v_{OV})\right] v_{DS}$$

We can obtain $r_{DS} = \frac{v_{DS}}{i_D}$

$$r_{DS} = \frac{1}{(\mu_n C_{ox})\left(\frac{W}{L}\right)(v_{OV})}$$

a) v_{OV} is doubled.

$$r_{DS}' = \frac{1}{(\mu_n C_{ox})\left(\frac{W}{L}\right)(2v_{OV})}$$

$$r_{DS}' = \frac{r_{DS}}{2}$$

The resistance is reduced by half when v_{OV} is doubled.

b) The device is replaced with another fabricated in the same technology but with double the width.

$$r_{DS}' = \frac{1}{(\mu_n C_{ox})\left(\frac{2W}{L}\right)(v_{OV})}$$

$$r_{DS}' = \frac{r_{DS}}{2}$$

The resistance is reduced by half when the width W is doubled.

c) **The device is replaced with another fabricated in the same technology but with both the width and length doubled.**

$$r_{DS}' = \frac{1}{(\mu_n C_{ox})\left(\frac{2W}{2L}\right)(v_{OV})}$$

$$r_{DS}' = r_{DS}$$

The resistance remains the same when the width W the length L are doubled.

d) **The device is replaced with another fabricated in a more advanced technology for which the oxide thickness is halved and similarly for W and L (assume $\boldsymbol{\mu_n}$ remains unchanged).**

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

$$r_{DS}' = \frac{1}{\left(\mu_n \frac{\varepsilon_{ox}}{\frac{t_{ox}}{2}}\right)\left(\frac{\frac{W}{2}}{\frac{L}{2}}\right)(v_{OV})}$$

$$r_{DS}' = \frac{r_{DS}}{2}$$

The resistance is reduced by half when the oxide thickness t_{ox}, width W and length L are halved.

Problem 5.7

An n-channel MOS device in a technology for which oxide thickness is 4 nm, minimum channel length is 0.18 µm, $K_n' = 400\ \mu A/V^2$, and V_t =0.5 V operates in the triode region, with small v_{DS} and with the gate–source voltage in the range 0V to +1.8V. What device width is needed to ensure that the minimum available resistance is 1 kΩ?

Using the formula for the drain current for a small v_{DS}.

$$i_D = \left[(\mu_n C_{ox})\left(\frac{W}{L}\right)(v_{OV})\right] v_{DS}$$

We can obtain $r_{DS} = \frac{v_{DS}}{i_D}$

$$r_{DS} = \frac{1}{(k_n{}')\left(\frac{W}{L}\right)(v_{GS} - V_t)}$$

Substituting the values into the equation (check the units).

$$1000\Omega = \frac{1}{(400x10^{-6})\left(\frac{W}{0.18x10^{-6}}\right)(1.8 - 0.5)}$$

Solving for W

$$W = \frac{1}{(400x10^{-6})\left(\frac{1000}{0.18x10^{-6}}\right)(1.8 - 0.5)}$$

$$W = 0.346\ \mu m$$

Problem 5.25

For the circuit in Fig. P5.25, sketch i_D versus v_S for v_S varying from 0 to VDD. Clearly label your sketch.

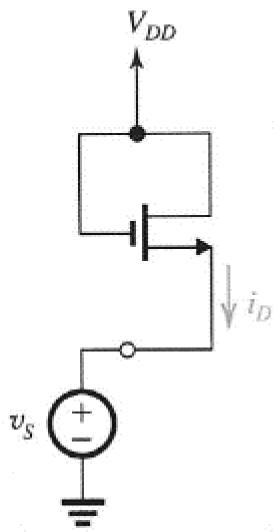


Figure P5.25

$V_{GD} = 0\ V$

$V_{GS} = V_{DD} - v_S$

For $V_{GD} < V_{th}$ the transistor is in saturation

The drain current i_D is:

$$i_D = \frac{1}{2} k_n (v_{GS} - V_t)^2$$

Substituting $V_{GS} = V_{DD} - v_S$

$$i_D = \frac{1}{2} k_n (V_{DD} - v_S - V_t)^2$$

$$i_D = \frac{1}{2} k_n [(V_{DD} - V_t)^2 - 2v_S(V_{DD} - V_t) + \ {v_S}^2]$$

For $V_{GS} < V_{th}$ the transistor is in cut-off region

Substituting $V_{GS} = V_{DD} - v_S$

$$V_{DD} - v_S < V_t$$

$$v_S > V_{DD} - V_t$$

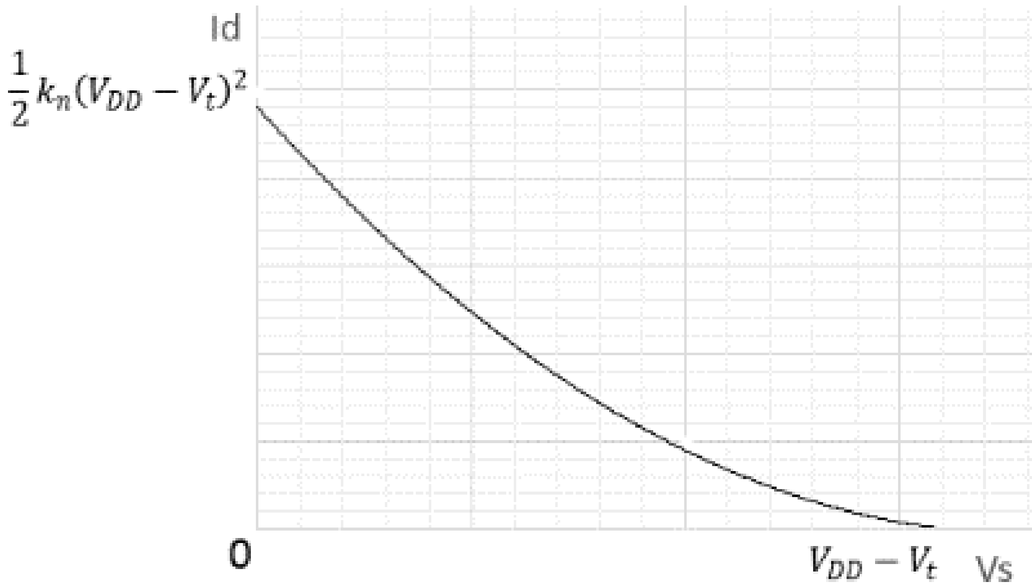
For $v_S > V_{DD} - V_t$ the drain current is zero, so we only need to plot in the region:

$$0\ \leq v_S \leq V_{DD} - V_t$$

When $v_S = 0$, i_D is:

$$i_D = \frac{1}{2} k_n [(V_{DD} - V_t)^2 - 2(0)(V_{DD} - V_t) + \ 0^2]$$

$$i_D = \frac{1}{2} k_n (V_{DD} - V_t)^2$$



Plot I_D vs. Vs

Problem 5.32

In a particular IC design in which the standard channel length is 1 μm, an NMOS device with W/L of 10 operating at 200 μA is found to have an output resistance of 100 kΩ, about $^{1}/_{5}$ of that needed. What dimensional change can be made to solve the problem? What is the new device length? The new device width? The new W/L ratio? What is V_A for the standard device in this IC? The new device?

Using the device parameter V_A

$$V_A = V_A{}'L$$

And r_o

$$r_o = \frac{V_A}{I_D{}'} = \frac{V_A{}'L}{I_D{}'}$$

To obtain the output resistance needed that is 500 kΩ (100x5) we need to increase the channel length L 5 times, so the new channel length will be 5 μm.

Also to keep the operating current unchanged, the ratio $\left(\frac{W}{L}\right)$ has to be constant and therefore the with W will be 50 μm. With this value of W, we assure that the ratio is the same.

V_A for the standard device is:

$$V_A = r_o I_D{}' = (100k\Omega)(200\mu A) = 20\,V$$

V_A for the new device is:

$$V_A = 5r_o I_D{}' = (500k\Omega)(200\mu A) = 100\,V$$

Problem 5.45

The NMOS transistor in the circuit of Fig. P5.44 has V_t = 0.4 V and k_n = 4 mA/V2. The voltages at the source and the drain are measured and found to be −0.6 V and +0.2 V, respectively. What current I_D is flowing, and what must the values of R_D and R_S be? What is the largest value for R_D for which I_D remains unchanged from the value found?

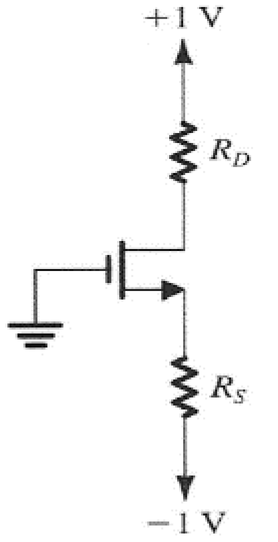


Figure P5.44

V_G = 0 V

V_t = 0.4 V

V_S = -0.6 V

V_d = 0.2 V

Reading the values from the circuit.

$$v_{DS} = 0.8\,V$$

$$v_{GS} = 0.6\,V$$

Checking that the transistor is operating in saturation mode.

$$v_{DS} > (v_{GS} - V_t)$$

$$0.8 > (0.6 - 0.4)$$

The NMOS is indeed in saturation mode.

The drain current for the NMOS in saturation mode is:

$$i_D = \frac{1}{2}k_n(v_{GS} - V_t)^2$$

$$i_D = \frac{1}{2}4\,{}^{mA}/_{V^2}\,(0.6 - 0.4)^2$$

$$i_D = 0.08\,mA$$

Determining R_D

$$R_D = \frac{V_{DD} - V_D}{I_D}$$

$$R_D = \frac{1 - 0.2}{0.08mA}$$

$$R_D = 10k\Omega$$

Determining R_S

$$R_S = \frac{V_S - V_{SS}}{I_D}$$

$$R_S = \frac{-0.6 - (-1)}{0.08mA}$$

$$R_S = 5k\Omega$$

Problem 5.47

The transistor in the circuit of Fig. P5.47 has $k_n{}' = 0.4\ mA/V^2$, $V_t = 0.4\ V$, and $\lambda=0$. Show that operation at the edge of saturation is obtained when the following condition is satisfied:

$$\left(\frac{W}{L}\right) R_D \cong 2.5k\Omega$$

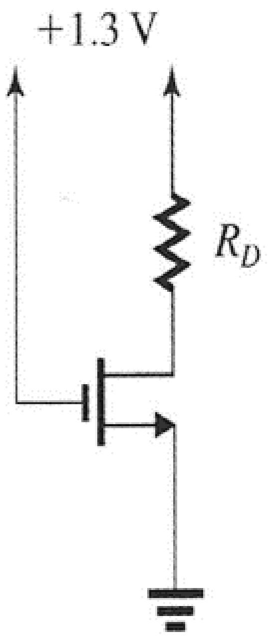


Figure P5.47

$$V_t = 0.4\ V$$

$$k_n{}' = 0.4\ mA/V^2$$

$$V_S = 0\ V$$

$$V_G = 1.3\ V$$

When $\lambda=0$, the drain current i_D is:

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

$$i_D = \frac{1}{2}(0.4\,mA/V^2)\left(\frac{W}{L}\right)(1.3 - 0 - 0.4)^2$$

$$i_D = \frac{1}{2}(0.4\,mA/V^2)\left(\frac{W}{L}\right)(1.3 - 0 - 0.4)^2$$

$$i_D = 1.62x10^{-4}\left(\frac{W}{L}\right)A$$

At the edge of saturation

$$v_{DS} = (v_{GS} - V_t)$$

Since $v_S = 0$

$$v_D - 0 = (1.3 - 0 - 0.4)$$

$$v_D = 0.9\ V$$

$$R_D = \frac{V_{DD} - V_D}{I_D}$$

$$R_D = \frac{1.3 - 0.9}{1.62x10^{-4}\left(\frac{W}{L}\right)}$$

$$R_D\left(\frac{W}{L}\right) = \frac{1.3 - 0.9}{1.62x10^{-4}}$$

$$R_D\left(\frac{W}{L}\right) = 2469\ \Omega\ \cong 2.5k\Omega$$