Assignment -1 : MOSFET DC Circuits

AV 211: Analog Electronics Circuits

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SC22B146

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

Soln: For n-channel MOSFET,

$$I_D = K_n\left[(V_{GS} - V_{th})V_{DS} - \frac{1}{2}V_{DS}^2\right]$$

From given values,

$$0.4\times10^{-3} = K_n\left[(1-V_{th}).1 - \frac{1}{2}\right] \quad - ①$$

and,

$$0.1\times10^{-3} = K_n\left[(0.8-V_{th})\times0.8 - \frac{1}{2}(0.8)^2\right] \quad - ⓘⓘ$$

Dividing ①/ⓘⓘ,

$$\Rightarrow 4 = \frac{(1-V_{th}) - \frac{1}{2}}{(0.8-V_{th})0.8 - 0.32} = \frac{0.5 - V_{th}}{0.32 - 0.8V_{th}}$$

$$\Rightarrow 1.28 - 3.2V_{th} = 0.5 - V_{th}$$

$$\Rightarrow 0.78 = 2.2V_{th}$$

$$\Rightarrow V_{th} = \frac{0.78}{2.2} \approx 0.35 \text{ V}$$

$$① \Rightarrow 0.4\times10^{-3} = K_n[0.5 - 0.35]$$

$$\Rightarrow K_n = 2.67 \text{ mA/V}^2$$

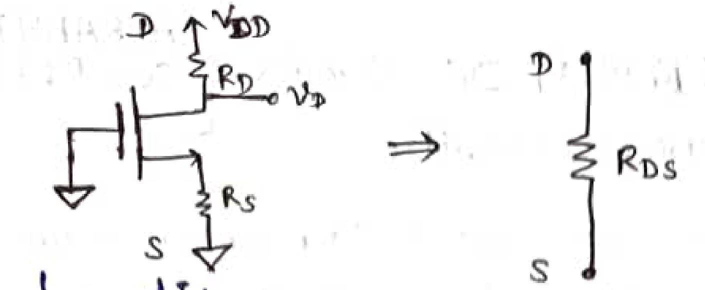
$\therefore K_n = 2.67 \text{ mA/V}^2,\ V_{th} \approx 0.35$ V.

② An NMOS transistor, fabricated with $W = 20\ \mu m$ and $L = 1\ \mu m$ in a technology for which $K_n = 100\ \mu A/V^2$ and $V_{th} = 0.8$ V, is to be operated at very low values of V_{DS} as a linear resistor. For V_{GS} varying from 1.0 V to 4.8 V, what range of ~~transistor~~ resistor values can be obtained? What is the available range if ⓐ the device width is halved?

ⓑ the device length is halved?

ⓒ both the width and length are halved?

Soln:



$$\frac{1}{R_{DS}} = \frac{dI_d}{dV_{DS}}$$

$$= \frac{\mu_n C_{ox}(W/L)\left[(V_{GS}-V_{TH})\cancel{V_{DS}} - \frac{1}{2}\cancel{V_{DS}^2}\right]}{\cancel{V_{DS}}} \quad \text{(As } V_{DS} \text{ is very small)}$$

$$= \mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_{TH})$$

For $V_{GS} = 1\,V$, $\frac{1}{R_{DS}} = 100\times10^{-6}(1-0.8) = 2\times10^{-5}\,\mho \Rightarrow R_{DS} = 50\,k\Omega$

For $V_{GS} = 4.8\,V$, $\frac{1}{R_{DS}} = 100\times10^{-6}(4.8-0.8) = 4\times10^{-4}\,\mho$

$\Rightarrow R_{DS} = 2.5\,k\Omega$

$\therefore$ Range of resistor $R_{DS} \rightarrow 2.5\,k\Omega$ to $50\,k\Omega$.

(a) $R_{DS} = \frac{L}{\mu_n C_{ox} \cdot W} \cdot \frac{1}{(V_{GS}-V_{TH})}$

$\Rightarrow R_{DS} \propto \frac{1}{W}$

If the device width is ~~half~~ halved, R_{DS} will be doubled.

$\therefore$ Range of $R_{DS} \rightarrow 5\,k\Omega$ to $100\,k\Omega$.

(b) $R_{DS} \propto L$

If the length is halved, R_{DS} will become half.

$\therefore$ Range of $R_{DS} \rightarrow 1.25\,k\Omega$ to $25\,k\Omega$.

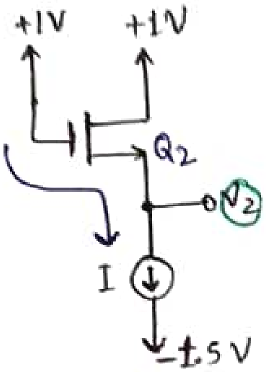
(c) $R_{DS} \propto \frac{L}{W} \Rightarrow R_{DS_0} = \frac{L_0}{W_0} \cdot K_0$

$R_{DS}' = \frac{L'}{W'} \cdot K_0 \Rightarrow R_{DS}' = \frac{L_0/2}{W_0/2} \cdot K_0 = \frac{L_0}{W_0} \cdot K_0 = R_{DS_0}$

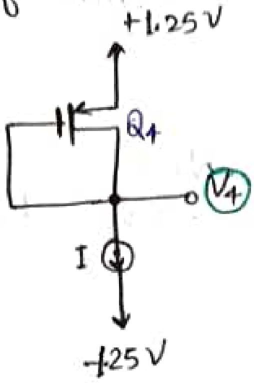
If both length and R_{DS} are halved, there will be no change in R_{DS}.

$\therefore$ Range of $R_{DS} \rightarrow 2.5\,k\Omega$ to $50\,k\Omega$.

3. Find the indicated voltages of the circuits if $|V_t| = 0.5\,V$ and $I = 0.1\,mA$. How large a resistor can be inserted in series with each drain while maintaining saturation? If the current source I requires at least 0.5V between its terminal to operate properly, what is the largest resistor that can be placed in series with each MOSFET source while ensuring saturated-mode of operation of each transistor at $I_D = I$?



Ckt. 1



Ckt. 2

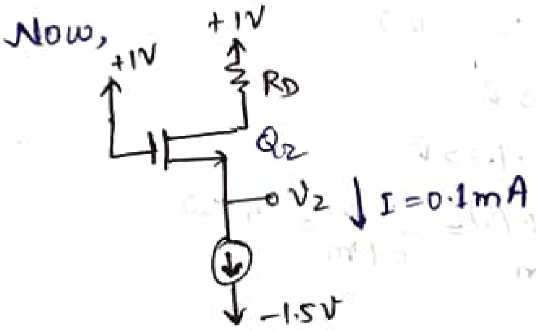
Soln: For ckt. 1, for no resistor inserted

~~false~~ $V_2 = -1.5V$

Similarly for ckt. 2,

$V_4 = -1.25V$

Now,



As $V_t = 0.5V$

$V_2 = -1.5 - 0.5 = -2V$

and,

$1 - I_D R_D - V_{DS} = V_2$

$\Rightarrow V_{DS} = 3 - I_D R_D$

For saturation,

$V_{DS} = V_{GS} - V_{TH}$

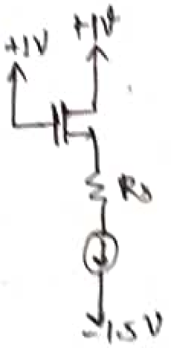
$= 1 - (-2) - 0.5$

$= 2.5V$

$\therefore\ 3 - I_D R_D = 2.5$

$\Rightarrow I_D R_D = 3 - 2.5 = 0.5V \Rightarrow R_D = \dfrac{0.5V}{0.1mA} = 5K\Omega.$

Now,



$$V_{GS} \geq V_{tH}$$

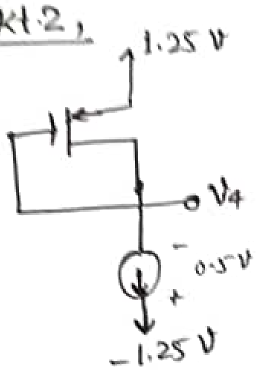
$$\Rightarrow 1 - V_{GS} - I_D R_S + 0.5 = -1.5$$

$$\Rightarrow 1 - \cancel{0.5} - I_D R_S + \cancel{0.5} = -1.5$$

$$\Rightarrow I_D R_S = 2.5\,V$$

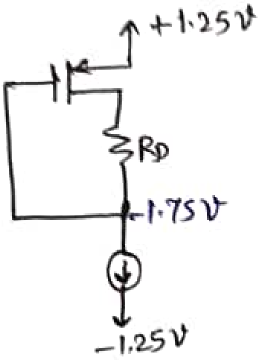
$$\Rightarrow R_S = \frac{2.5\,V}{0.1\,mA} = 25\,k\Omega$$

For ckt.2,



$$V_4 + 0.5 = -1.25\,V$$

$$\Rightarrow V_4 = -1.75\,V$$



$$V_G = -1.75\,V$$

$$\therefore V_{SG} = 1.25 + 1.75$$

$$= 3\,V$$

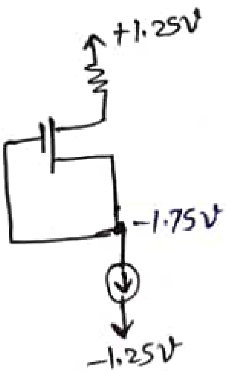
For saturation,

$$V_{SD} \geq V_{SG} - |V_{tH}|$$

$$\Rightarrow 1.25 - V_D \geq 3 - 0.5$$

$$\Rightarrow V_D \leq -1.25\,V$$

$$\therefore V_{D\,max} = -1.25\,V$$



$$\Rightarrow R_{D\,max} = \frac{-1.25 - (-1.75)}{0.1\,m} = \frac{0.5}{0.1\,m} = 5\,k\Omega.$$

$$V_G = -1.75\,V$$

For $V_{SG} \geq |V_{tH}|$

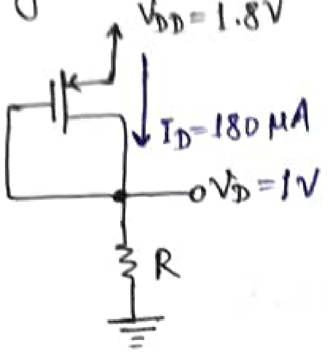
$$\Rightarrow V_S + 1.75 \geq 0.5$$

$$\Rightarrow V_S \geq -1.25\,V$$

$$\Rightarrow V_S = -1.25\,V$$

$$\therefore R_S = \frac{1.25 + 1.25\,V}{0.1\,mA} = 25\,k\Omega.$$

4) The PMOS transistor in the circuit shown below has $V_t = -0.5V$, $\mu_p C_{ox} = 100\ \mu A/V^2$, $L = 0.18\ \mu m$ and $\lambda = 0$. Find the values required for W and R in order to established a drain current of $180\ \mu A$ and a voltage V_D of 1V.



Soln: $R = \dfrac{V_D - 0}{I_D}$

$= \dfrac{1-0}{180\ \mu A} = 5.55 \times 10^{3}\ \Omega$

$= \underline{5.55\ k\Omega}$

As $V_{SD} (= 0.8V) \geq V_{SG} - |V_{tp}|$
$(= 0.8 - 0.5 = 0.3V)$,
the device is in saturation region.

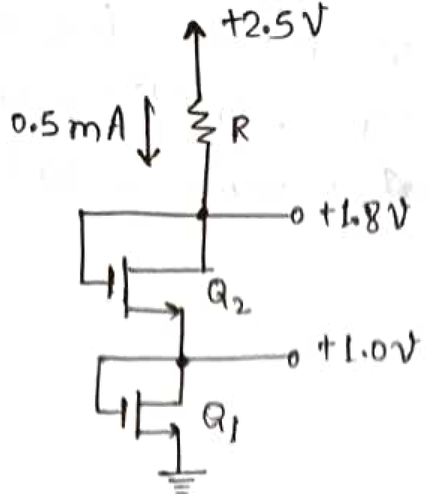
$\therefore I_D = \dfrac{k_p}{2} \left(\dfrac{W}{L}\right) (V_{SG} - |V_{tp}|)^2$

$\Rightarrow 180 \times 10^{-6} = \dfrac{100 \times 10^{-6}}{2} \times \left(\dfrac{W}{0.18 \times 10^{-6}}\right) (0.8 - 0.5)^2$

$\Rightarrow W = \dfrac{180 \times 0.36}{100 \times 0.09}\ \mu m$

$\Rightarrow W = \underline{7.2\ \mu m}$.

5) The NMOS transistors in the circuit shown below have $V_t = 0.5V$, $\mu_n C_{ox} = 250\ \mu A/V^2$, $\lambda = 0$ and $L_1 = L_2 = 0.25\ \mu m$. Find the required values of gate width for each Q_1 and Q_2, and the value of R, to obtain the voltage and current values indicated.



Soln: $R = \frac{2.5V - 1.8V}{0.5mA} = 1.4 k\Omega$

For Q_2: As $V_{DS} (= 0.8V) \geq V_{GS} - V_{TH} (= 0.8 - 0.5 = 0.3V)$,

$$I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W_2}{L_2}\right)(V_{GS} - V_{tH})^2$$

$$\Rightarrow 0.5 \times 10^{-3} = \frac{250 \times 10^{-6}}{2} \times \frac{W_2 \times 100000}{0.28 \times 10^{-6}}(0.8 - 0.5)^2$$

$$\Rightarrow W_2 = \frac{10}{0.09} \times 10^{-6} = 11.11 \mu m$$

For Q_1: $V_{DS} (= 1V) \geq V_{GS} - V_{TH}$
$(1V - 0.5V = 0.5V)$

$$I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W_1}{L_1}\right)(V_{GS} - V_{tH})^2$$

$$\Rightarrow \cancel{0.5} m = \frac{\cancel{250}\mu}{2}\left(\frac{W_1}{0.25\mu}\right)(\cancel{1 - 0.5})^2 \; 0.5$$

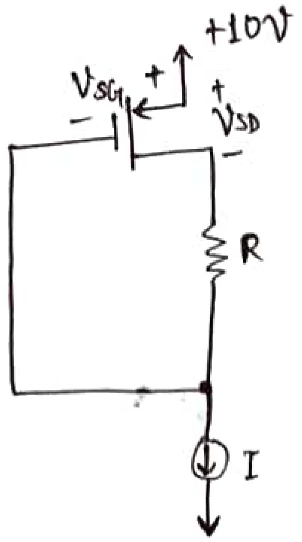
$$\Rightarrow W_1 = \frac{2}{0.5}\mu = 4 \mu m$$

$\therefore R = 1.4 k\Omega, \; W_1 = 4 \mu m, \; W_2 = 11.11 \mu m$

⑥ For the circuit shown below,

ⓐ Show that for the PMOS transistor to be in saturation, the following condition must be satisfied: $IR \leq |V_{tp}|$.

ⓑ If the transistor is specified to have $|V_{tp}| = 1V$ and $k_p = 0.2 mA/V^2$, and for $I = 0.1mA$, find the voltages V_{SD} and V_{SG} for $R = 10 k\Omega$ and $100 k\Omega$.



Soln: (a) For the PMOS transistor to be in the saturation region,

$$V_{SD} \geq V_{SG} - |V_{tp}|$$

$$\Rightarrow \cancel{V_S} - V_D \geq \cancel{V_S} - V_G - |V_{tp}|$$

$$\Rightarrow |V_{tp}| \geq V_D - V_G$$

$$\Rightarrow \boxed{|V_{tp}| \geq IR} \qquad (\because V_D - V_G = IR)$$

(b) As $|V_{tp}| = 1V \geq IR$ $(= 0.1\times10^{-3} \times 10\times10^{3} = 1V)$ for $R = 10K\Omega$.
the device is in saturation region.

$$\therefore I_D = \frac{K_P}{2}(V_{SG} - |V_{tp}|)^2$$

$$\Rightarrow 0.1\,\cancel{m} = \frac{0.\cancel{2}\,\cancel{m}}{\cancel{2}}(V_{SG} - 1)^2$$

$$\Rightarrow V_{SG} - 1 = \pm 1$$

$$\Rightarrow V_{SG} = 0 \text{ or } 2$$

$$\Rightarrow \boxed{V_{SG} = 2V} \qquad (\because V_S \neq V_G)$$

For $R = 10K\Omega$

$$V_{SD} = V_{SG} - V_{DG}$$
$$= V_{SG} - IR$$
$$= 2 - (0.1\times10^{-3} \times 10\times10^{3})$$
$$= 2 - 1$$
$$= \boxed{1V}$$

For $R = 100K\Omega$

$$V_{SD} = V_{SG} - IR$$
$$= 2 - (0.1\times10^{-3} \times 100\times10^{3})$$
$$= 2 - 10$$
$$= \boxed{-8V}$$

$$I_D = \frac{k_p}{2}(V_{SG} - V_{tp})^2$$
$$= \frac{0.2m}{2}(2-1)^2$$
$$= 0.1(1)\,m$$
$$= 0.1\,m$$
$$\therefore V_{SD} = V_{SG} - IR$$
$$= 2 - 0.1m \times 100k$$
$$= 2 - 10$$

$$I_D = k_p\left[(V_{SG} - |V_{tp}|)V_{SD} - \frac{1}{2}V_{SD}^2\right]$$
$$\Rightarrow 0.1m = 0.2m\left[(V_{SG}-1)(V_{SG} - IR) - \frac{1}{2}(V_{SG} - IR)^2\right]$$
$$\Rightarrow 1 = 2\left[(V_{SG}-1)(V_{SG}-10) - \frac{1}{2}(V_{SG}-10)^2\right]$$
$$\Rightarrow 2\ 4V_{SG}^2 + 40 - 44V_{SG} - V_{SG}^2 + 100 - 20V_{SG}$$
$$\Rightarrow 3V_{SG}^2 - 64V_{SG} + 138 = 0$$
$$\Rightarrow 1 = 2V_{SG}^2 + 20 - 22V_{SG} - V_{SG}^2 - 100 + 20V_{SG}$$
$$\Rightarrow V_{SG}^2 - 2V_{SG} - 81 = 0$$
$$\Rightarrow V_{SG} = \frac{2 + \sqrt{4 + 4\times 81}}{2}$$
$$= 10.055\ V.$$

$$\therefore V_{SD} = V_{SG} - IR$$
$$= 10.055 - (0.1m \times 100k)$$
$$= 0.055\ V.$$