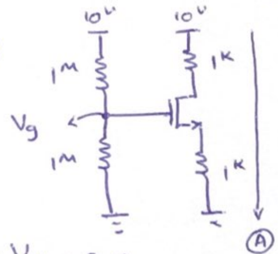
In the name of God

Assignment 2 :

1. In the following circuits, determine the bias points of the transistors.

a)



$$V_g = \frac{1^M \times 10}{1+1} = 5^V \Rightarrow I_D = \frac{K'}{2}\frac{W}{L}(V_{gs}-V_{th})^2$$ با فرض اینکه ترانزیستور در اشباع قرار دارد.

$$I_D = \frac{0.5}{2}(V_g - V_s - 2)^2 = \frac{1}{4}(3 - 1^K I_D)^2 \Rightarrow \begin{cases} I_D = 1^{mA} \checkmark \\ I_D = 9^{mA} \end{cases}$$

$$\begin{cases} V_{th} = 2^V \\ \mu_n C_{ox}\frac{W}{L} = 0.5\ \frac{mA}{V^2} \end{cases}$$

if $I_D = 1^{mA}$: $V_s = 1^V \Rightarrow V_{gs} = 5-1 = 4^V$ ✓ $\longrightarrow$ $\cancel{V_{gs}-V_{th} > V_{DS}}$ $V_{DS} > V_{gs} - V_{th}$

if $I_D = 9^{mA}$: $V_s = 9^V \Rightarrow V_{gs} = 5-9 = -4^V$ ✗

KVL @ A: $-10 + 1^K I_D + V_{DS} + 1^K I_D = 0 \Rightarrow \boxed{V_{DS} = 8^V}$

hint: * nmos:

- Sat: $\frac{K'}{2}\frac{W}{L}(V_{gs}-V_{th})^2 = I_D$
- Triode: $\frac{K'}{2}\frac{W}{L}\left[2(V_{gs}-V_{th})V_{DS} - V_{DS}^2\right] = I_D$

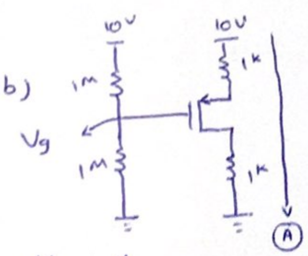
* Pmos:

- $I_D = \frac{K'}{2}\frac{W}{L}(V_{gs}-|V_{th}|)^2$: sat
- $I_D = \frac{K'}{2}\frac{W}{L}\left[2(|V_{gs}-V_{th}|)|V_{DS}| - V_{DS}^2\right]$: Triode

* $\beta = \underbrace{\mu C_{ox}\frac{W}{L}}_{=K'}$

* In Triode regin: $|V_{gs}-V_{th}| > |V_{DS}|$
* In Saturation regin: $|V_{DS}| \geq |V_{gs}-V_{th}|$ OR $V_{SD} \geq V_{SG} - |V_{th}|$

b)



$$V_g = \frac{1^M \times 10}{2} = 5^V \Rightarrow I_D = \frac{K'}{2}\frac{W}{L}(V_{gs}-|V_{th}|)^2 = \frac{2}{2}(5 - V_s - 1)^2$$

$$= (4 - 0.5^K I_D)^2 \rightarrow \begin{cases} I_D = 16^{mA} \\ I_D = 4^{mA} \checkmark \end{cases}$$

$$\begin{cases} V_{th} = -1^V \\ \mu_p C_{ox}\frac{W}{L} = 2\ \frac{mA}{V^2} \end{cases}$$

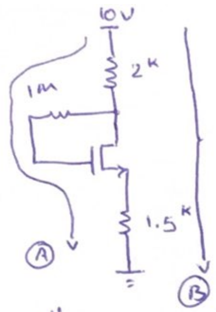
$V_{sg} = -3$

if $I_D = 16^{mA}$: $V_s = 28^V \Rightarrow$ ~~[illegible]~~ $\not> |V_{th}|$

if $I_D = 4^{mA}$: $V_s = 8^V \Rightarrow V_{sg} = 3^V > |V_{th}|$

KVL @ A: $-10 + 0.5^K I_D + V_{SD} + 1^K I_D = 0 \Rightarrow V_{SD} = 4^V$ ~~[illegible]~~ $\geq V_{SG} - |V_{th}|$

c)



KVL @ A : $-10 + 2^k I_D + 1^M \cancel{I_G}^{\,0} + V_{gs} + 1.5^k I_D = 0$

$$\boxed{3.5^k I_D + V_{gs} = 10} \quad (I)$$

$$I_D = \frac{k'}{2}\frac{W}{L}(V_{gs} - V_{th})^2 \xrightarrow{(I)} I_D = \frac{1}{2}\left(10 - 3.5^k I_D - 1\right)^2$$

$$\begin{cases} V_{th} = 1^V \\ \mu_n C_{ox}\frac{W}{L} = 1 \frac{mA}{V^2} \end{cases} \qquad \begin{cases} I_D = 2^{mA} \checkmark \\ I_D = 3.3^{mA} \end{cases}$$

if $I_D = 2^{mA} \longrightarrow V_{gs} = 10 - 3.5(2) = 3^V > V_{th}$ ✓

if $I_D = 3.3^{mA} \longrightarrow V_{gs} = 10 - 3.5(3.3) = -1.55 < V_{th}$

KVL @ B : $-10 + 2^k I_D + V_{DS} + 1.5^k I_D = 0 \xrightarrow{I_D = 2^{mA}} V_{DS} = 3^V > \overset{3}{V_{gs}} - \overset{1}{V_{th}}$

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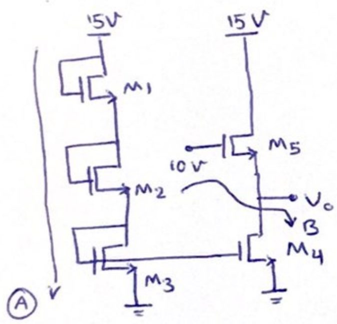
2. In the circuits shown below, all of the transistors are the same and operate in the saturation regin. Calculate the output voltage.

a)



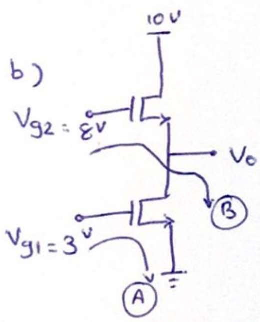
KVL @ A : $-15 + V_{gs_1} + V_{gs_2} + V_{gs_3} = 0 \xrightarrow{V_{gs_1} = V_{gs_2} = V_{gs_3}}$

$3V_{gs} = 15 \Rightarrow \boxed{V_{gs} = 5^V}$

KVL @ B : $-10 + V_{gs} + V_o = 0 \Rightarrow V_o = 10 - V_{gs}$

$$\boxed{V_o = 5^V}$$

b)



KVL @ A : $V_{gs_1} = 3^V \longrightarrow I_{D_1} = I_{D_2}, \; V_{th_1} = V_{th_1}$

$\Rightarrow V_{gs_1} = V_{gs_2} = 3^V$

KVL @ B : $-8 + V_{gs} + V_o = 0 \Rightarrow \boxed{V_o = 8 - 3 = 5^V}$

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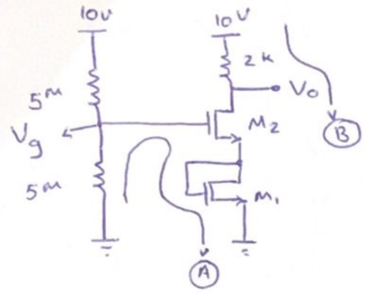
3. In the following circuit, the transistors are the same and oprate in the saturation. Calculate the output voltage. Assume $\beta = 0.5 \frac{mA}{V^2}$, $V_{th} = 0.5^V$



$V_g = \frac{5 \times 10}{10} = 5^v$

KVL @ A : $-5^v + V_{gs_1} + V_{gs_2} = 0 \xrightarrow[I_{D_1} = I_{D_2}]{V_{gs_1} = V_{gs_2},\ V_{th_1} = V_{th_2}}$

$2V_{gs} = 5 \Rightarrow V_{gs} = \frac{5}{2} = \boxed{2.5^v}$

$I_D = \frac{k'}{2}\frac{W}{L}(V_{gs} - V_{th})^2 = \frac{0.5}{2}(2.5 - 0.5)^2 = \boxed{1^{mA}}$

KVL @ B : $-10 + 2^k I_D + V_o = 0 \Rightarrow V_o = 10 - 2 = \boxed{8V}$

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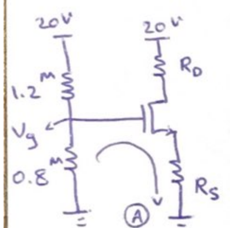
4. specify R_D and R_S so that the transistor operates in saturation and $I_D = 1^{mA}$



$\begin{cases} V_{th} = 2^v \\ \mu_n C_{ox}\frac{W}{L} = 0.5 \frac{mA}{v^2} \end{cases}$

$I_D = \frac{k'}{2}\frac{W}{L}(V_{gs} - V_{th})^2 \Rightarrow V_{gs} = \sqrt{\frac{I_D}{\frac{k'}{2}\frac{W}{L}}} + V_{th}$

$V_{gs} = \sqrt{\frac{1^{mA}}{\frac{0.5}{2}}} + 2^v = \boxed{4^v}$

$V_g = \frac{0.8 \times 20}{0.8 + 1.2} = \frac{16}{2} = 8^v$

KVL @ A : $-8 + V_{gs} + R_S I_D = 0 \xrightarrow{I_D = 1^{mA},\ V_{gs} = 4} \boxed{R_S = 4^k}$

برای اینکه ترانزیستور در اشباع باشد : $V_{DS} \geq V_{gs} - V_{th}$: $V_D - V_S \geq 4^v - 2 \Rightarrow \boxed{V_D - V_S \geq 2^v}$ *

$V_S = R_S I_D = 4^k \times 1 = 4^v \overset{*}{\Rightarrow} V_D \geq 6^v \Rightarrow 20 - V_D = R_D I_D \xrightarrow{I_D = 1^{mA}}$

$20 - 1^{mA} R_D = V_D \geq 6^v \Rightarrow 20 - R_D \geq 6 \Rightarrow \boxed{R_D \leq 14^k}$

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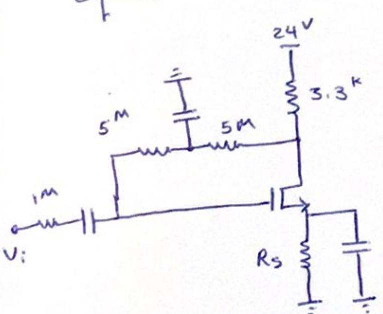
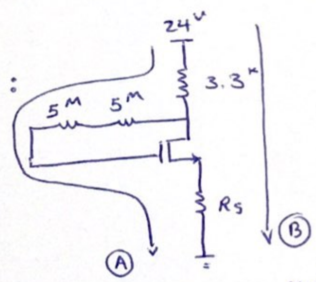
5. specify the source resistance such that the bias point current will be equal to 2.5^{mA}.



DC Analysis :



KVL @ A : $-24^v + 3.3^k I_D + \cancel{10^M I_G}^{\,0} + V_{gs} + R_S I_D = 0$

$\Rightarrow V_{gs} = 24 - 3.3^k I_D - R_S I_D = 24 - I_D(3.3^k + R_S)$

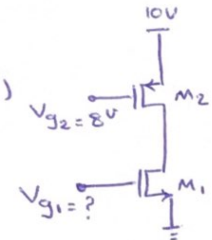
$I_D = \frac{k'}{2}\frac{W}{L}(V_{gs} - V_{th})^2 = \frac{0.25}{2}(24 - I_D(3.3^k + R_S) - 3)^2 = 2.5 \xrightarrow{I_D = 2.5} \boxed{R_S = 2.5^k},\ 7.7^k$

$V_{gs} = 24 - 2.5(3.3^k + 2.5^k) = 9.5^v$

KVL @ B : $-24^v + 3.3^k I_D + V_{DS} + R_S I_D = 0 \Rightarrow V_{DS} = 9.5 > \underset{9.5}{V_{gs}} - \underset{3^v}{V_{th}}$

6. Determine the requested parameters. Assume that the transistors are in saturation.

a)



$\mu_n C_{ox} = 400 \frac{\mu A}{V^2} = 0.4 \frac{mA}{V^2}$

$\mu_p C_{ox} = 100 \frac{\mu A}{V^2} = 0.1 \frac{mA}{V^2}$

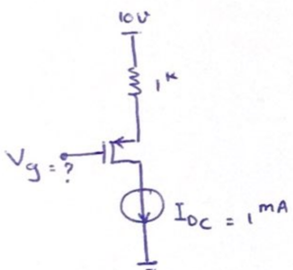
$\left(\frac{W}{L}\right)_{n,p} = \frac{1 \mu m}{0.1 \mu m}$

$|V_{th}| = 1^V$

$$I_D = \frac{K'}{2} \frac{W}{L} (V_{gs} - V_{th})^2 = \frac{1}{2} (2-1)^2 = \frac{1}{2}^{mA}$$

$$V_{gs_1} = \sqrt{\frac{I_D}{\frac{K'}{2}\frac{W}{L}}} + V_{th} = \sqrt{\frac{\frac{1}{2}}{\frac{4}{2}}} + 1 = \boxed{\frac{3}{2}^V}$$

b)



$\mu_p C_{ox} = 400 \frac{\mu A}{V^2}$

$\frac{W}{L} = \frac{2 \mu m}{0.1 \mu m}$

$V_{th} = 0.5^V$

$$I_D = \frac{K'}{2} \frac{W}{L} (V_{sg} - |V_{th}|)^2$$

$$1 = \frac{8}{2} (V_s - V_g - 0.5)^2$$

$$1 = 4(10 - 1^K(1) - V_g - 0.5)^2 \Rightarrow \begin{cases} \boxed{V_g = 8^V} \\ V_g = 9^V \end{cases}$$

$V_s = 10 - 1 = 9^V$

If $V_g = 8^V$: $V_{sg} = 9 - 8 = 1^V > V_{th}$ ✓

If $V_g = 9^V$: $V_{sg} = 9 - 9 = 0 \not> V_{th}$