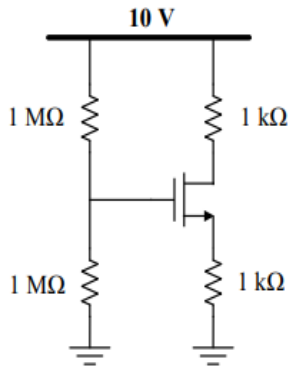
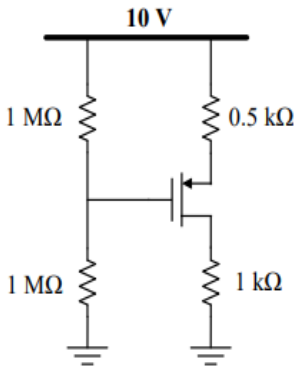
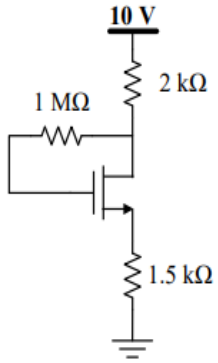
1- In the following circuits, determine the bias points of the transistors.



$$\begin{cases} V_{TH} = 2V \\ \mu_n C_{OX} \dfrac{W}{L} = 0.5 \dfrac{mA}{V^2} \end{cases}$$

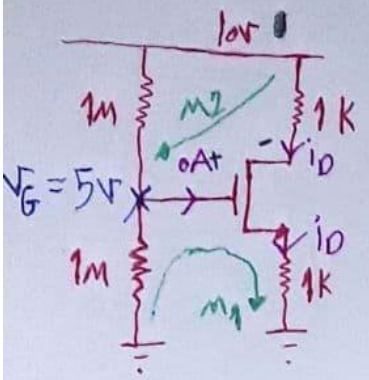


$$\begin{cases} V_{TH} = -1V \\ \mu_p C_{OX} \dfrac{W}{L} = 2 \dfrac{mA}{V^2} \end{cases}$$



$$\begin{cases} V_{TH} = 1V \\ \mu_n C_{OX} \dfrac{W}{L} = 1 \dfrac{mA}{V^2} \end{cases}$$

۱- نقطه کار ترانزیستورها



$V_{TH} = 2V$

$$\mu_n C_{ox} \frac{W}{L} = \frac{1}{2} \frac{mA}{V^2}$$

$$K = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} = \frac{1}{4} \frac{mA}{V^2}$$

شرط روشن بودن: $V_{GS} > V_{TH}$ ، شرط اشباع: $V_{GD} < V_P$ ، فرض: V_P در ناحیه اشباع

$$i_D = K (V_{GS} - V_{TH})^2$$

KVL @ M_1: $-5 + V_{GS} + i_D = 0$

$V_{GS} = 5 - i_D \longrightarrow$ با سعی $i_{D_{min}}$ قابل قبول

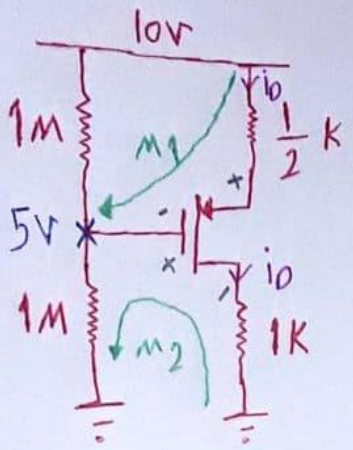
$$i_D = \frac{1}{4}(5 - i_D - 2)^2 \rightarrow 4i_D = (-i_D + 3)^2 \rightarrow$$

$$i_D^2 - 10 i_D + 9 = 0 \rightarrow (i_D - 1)(i_D - 9) = 0 \rightarrow i_D = 1mA$$

به ازای $i_D = 9 \leftarrow V_{GS} = -4$ ✗

KVL @ M_2: $V_{GD} = -10 + i_D + 5 = -4V < V_{TH} = 2$ اشباع ✓

نقطه کار: $1mA \rightarrow i_D$ ، $-4V \rightarrow V_{GD}$ ، V_P در ناحیه اشباع



$V_{TH} = -1V$

$\mu_p C_{ox} \frac{W}{L} = 2 \frac{mA}{V^2}$

$K = 1 \frac{mA}{V^2}$

$|V_{TH}|$ منفی نیست!

شرط اشباع: $V_{GD} > |V_{TH}|$

شرط روشن بودن FET: $V_{SG} > |V_{TH}|$

$i_{D,min}$ یا مثبت قابل قبول

$KVL@M_1: -10 + \frac{i_D}{2} + V_{SG} + 5 = 0 \rightarrow V_{SG} = 5 - \frac{i_D}{2}$

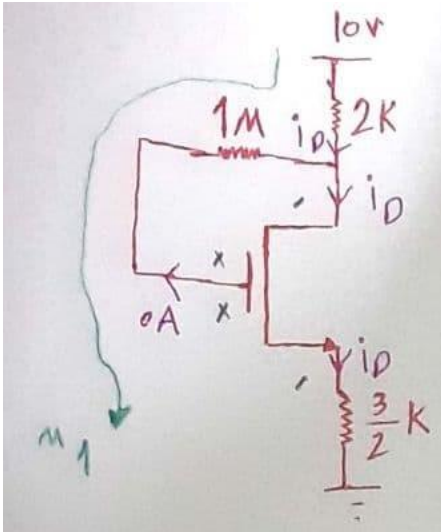
$i_D = K(V_{SG} - |V_{TH}|)^2 \rightarrow i_D = (5 - \frac{i_D}{2} - 1)^2 \rightarrow$

$i_D = (\frac{8 - i_D}{2})^2 \rightarrow 4i_D = (8 - i_D)^2 \rightarrow i_D^2 - 20i_D + 64 = 0$

$(i_D - 4)(i_D - 16) = 0 \rightarrow \boxed{i_D = 4mA}$ $V_{SG} = 5 - \frac{i_D}{2} = 3V > 1V$ ✓

$KVL@M_2: V_{GD} = -i_D + 5 = 1V > -1V = V_{TH}$ ✓ اشباع

تقاطع با $\begin{cases} 4mA \rightarrow i_D \\ +1V \rightarrow V_{GD} \end{cases}$ در ناحیه اشباع FET



$v_{TH} = 1v$

$\mu_n C_{ox} \frac{W}{L} = 1 \frac{mA}{v^2}$

KVL@M_1 : $-10 + 2i_D + v_{GS} + \frac{3}{2} i_D = 0 \rightarrow$

$v_{GS} = 10 - \frac{7}{2} i_D \rightarrow$ تابل قبول $i_{D_{min}}$ یا

$i_D = \frac{1}{2}\left(10 - \frac{7}{2} i_D - 1\right)^2 \rightarrow i_D = \frac{1}{2}\left(\frac{18 - 7i_D}{2}\right)^2 \rightarrow$

$8i_D = (18 - 7i_D)^2 \rightarrow 49 i_D^2 - 260 i_D + 324 = 0$

$\Delta = \sqrt{260^2 - (2 \times 7 \times 18)^2} = \sqrt{(260-252)(260+252)}$

252 ; $8 = 2 \times 4$; 512

$\sqrt{4 \times 1024} = 64 = \sqrt{\Delta}$; $4 = 2^2$; $1024 = 2^{10}$

$i_D = \frac{260 \pm 64}{2 \times 49} = 2\,mA$

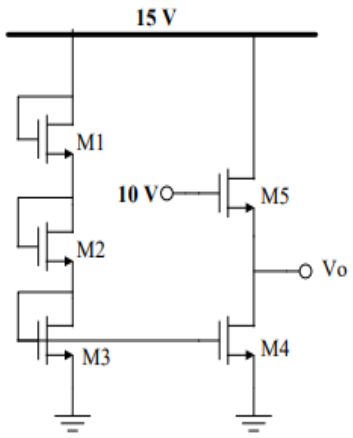
$v_{GS} = 3v > 1v \rightarrow$ روشن ، $+v$

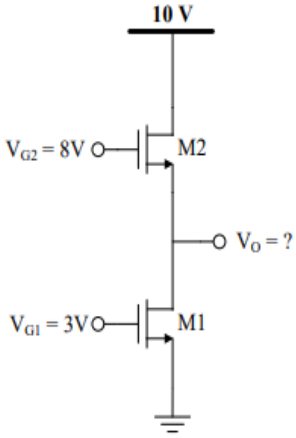
$v_{GD} < v_{TH} \rightarrow v_{GD} = 0v < 1v \rightarrow +v$

↳ شرط اشباع

در ناحیه اشباع

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



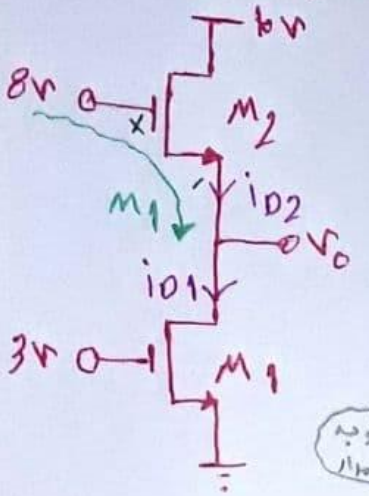


2- ۴۲ ها مشابه بود در ناحیه اشباع جایابی شده اند. $v_o = ?$

۴۲ ها مشابه ← $K_1 = K_2$, $V_{TH2} = V_{TH1}$

$$K = \frac{1}{2} \mu_n C_{ox} \frac{W}{L}$$

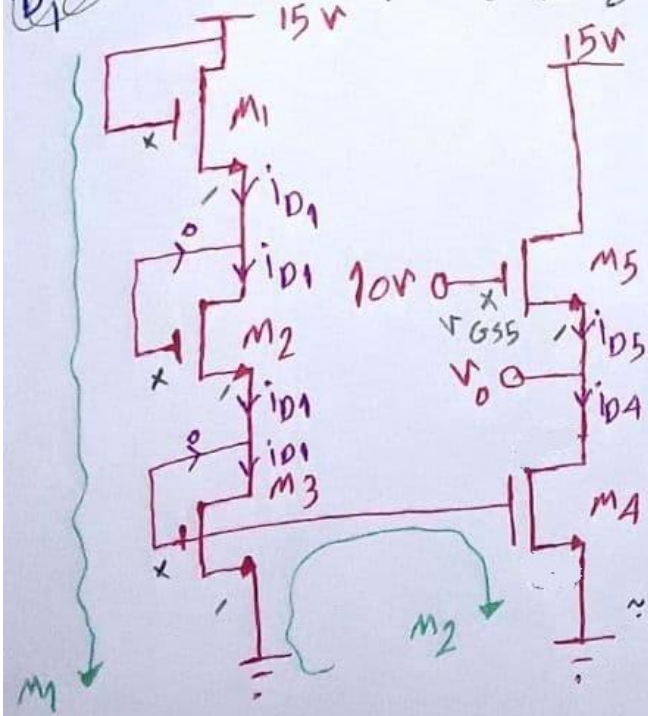
$$i_D = K \left(v_{GS} - V_{TH} \right)^2 \quad (I)$$



باتوجه به شباهت

$$\left.\begin{array}{l} i_{D1} = i_{D2} \\ K_1 = K_2 \\ V_{TH1} = V_{TH2} \end{array}\right\} \xrightarrow{(II)} v_{GS1} = v_{GS2} = 3v$$

$i_{D1} = K_{VL}$ @ M_1 : $v_o = 8 - v_{GS2} = 5v$ ✓



$$i_D = K \left(v_{GS} - V_{TH} \right)^2 \quad (I)$$

$$i_{D1} = i_{D2} = i_{D3} \xrightarrow{(I)} v_{GS1} = v_{GS2} = v_{GS3}$$

KVL @ M_1 : $-15 + v_{GS1} + v_{GS1} + v_{GS1} = 0$

$v_{GS1} = 5v = v_{GS3}$

KVL @ M_2 : $v_{GS3} = v_{GS4}$

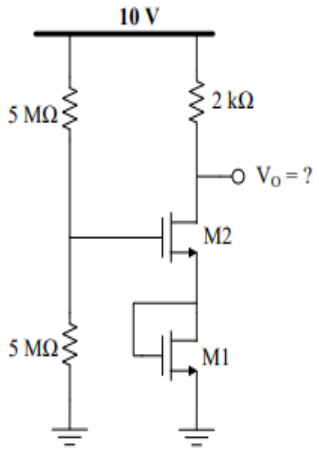
M_4, M_3 مشابه ← $K_3 = K_4$, $V_{TH3} = V_{TH4}$

$$\xrightarrow{(I)} i_{D3} = i_{D4}$$

$v_{GS4} = v_{GS3} = 5v$ * $i_{D4} = i_{D5} \longrightarrow v_{GS4} = v_{GS5} = 5v$

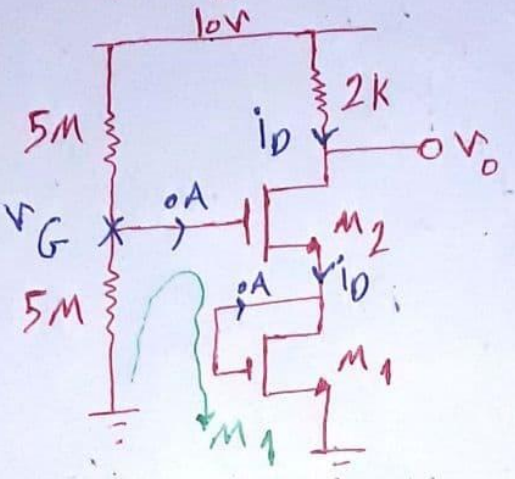
$v_{GS5} = 10 - v_o \longrightarrow v_o = 10 - v_{GS5} = 5v = v_o$

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



۶- ترانزیستورها مشابه و در ناحیه اشباع بایاس شده اند.

$v_o = ?$



$5v = \frac{5 \times 10}{10} = v_G$

$i_{D1} = i_{D2}$ (ترانزیستورها مشابه) $\rightarrow v_{GS1} = v_{GS2} = v_{GS}$

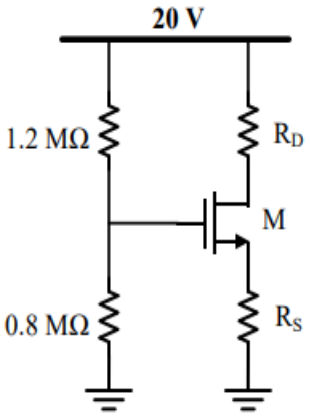
$v_{GS} > v_{TH} \rightarrow$ ON :M1

KVL @ M_1 : $-5 + v_{GS} + v_{GS} = 0 \rightarrow v_{GS} = 2.5v$

$i_D = \frac{\beta}{2}(v_{GS} - v_{TH})^2 = \frac{1}{4}(2.5 - 0.5)^2 = 1mA$

$v_o = 10 - 2i_D = 8v$ ✓

4- Specify R_D and R_S so that the transistor operates in saturation and I_D=1 mA.

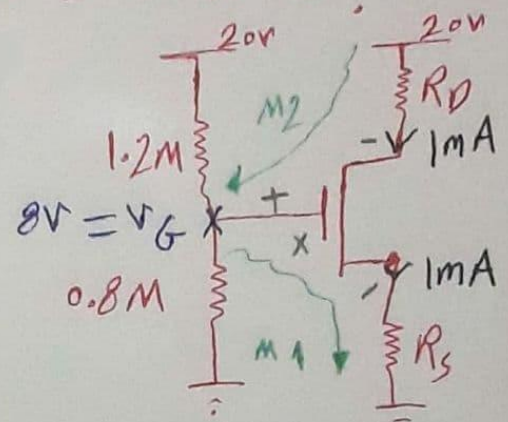


$$\begin{cases} V_{TH} = 2V \\ \mu_n C_{OX} \dfrac{W}{L} = 0.5 \dfrac{mA}{V^2} \end{cases}$$

$i_D = 1mA$. تا $4V$ در ناحیه اشباع باشد $R_S = ?$ ، $R_D - 4$

$V_{TH} = 2V$

$\beta = \frac{1}{2}$



$$i_D = \frac{\beta}{2}(V_{GS} - V_{TH})^2 \rightarrow V_{GS} = V_{TH} + \sqrt{\frac{2i_D}{\beta}}$$

$$V_{GS} = 2 + \sqrt{\frac{2}{\frac{1}{2}}} = 4V$$

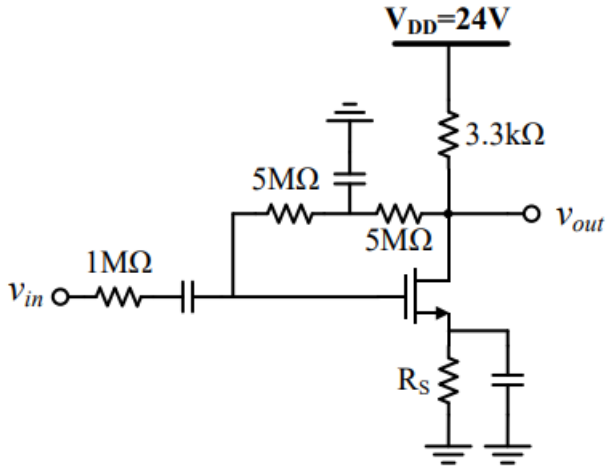
KVL@M_1 : $-8 + V_{GS} + R_S = 0 \rightarrow R_S = 4k\Omega$ ✓

ترانزیستور در ناحیه اشباع $\leftarrow V_{GD} < V_{TH}$

KVL@M_2 : $V_{GD} = -20 + R_D + 8 \rightarrow V_{GD} = R_D - 12$

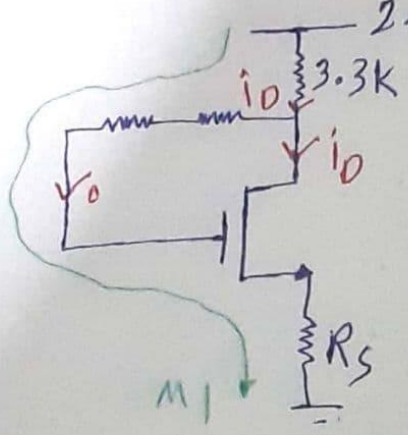
$R_D - 12 < 2 \rightarrow R_D < 14k\Omega$ ✓

5- Specify the source resistance such that the bias point current will be equal to 2.5 mA.



$$\begin{cases} \beta = 0.25\dfrac{mA}{V^2} \\ |V_{TH}| = 3V \end{cases}$$

DC:



? $= R_S \leftarrow i_D = 2.5mA\_5$

$\beta = \frac{1}{4}$ $V_{TH} = 3V$

KVL@M_1: $-24 + 3.3i_D + V_{GS} + R_S i_D =$

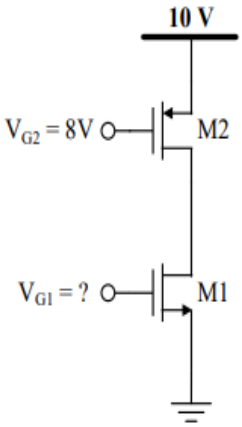
$V_{GS} = 24 - (3.3 + R_S) i_D$

$$i_D = \frac{1}{8}\left(24 - (3.3 + R_S) i_D - 3\right)^2 \rightarrow$$

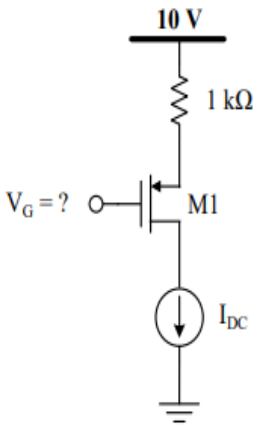
$$20 = (12.75 - 2.5R_S)^2 \xrightarrow{\sqrt{\ }} 4.47 = 12.75 - 2.5R_S$$

$$\rightarrow R_S = \frac{12.75 - 4.47}{2.5} = 3.3k\Omega \checkmark$$

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

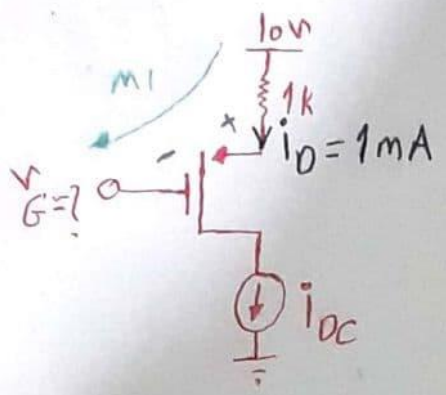


$$\begin{cases} \mu_n C_{ox} = 400\,\mu A/V^2 \\ \mu_p C_{ox} = 100\,\mu A/V^2 \\ \left(\frac{W}{L}\right)_{n,p} = \frac{1\,\mu m}{0.1\,\mu m} \\ |V_{TH}| = 1V \end{cases}$$



$$\begin{cases} I_{DC} = 1mA \\ \mu_p C_{ox} = 400\,\mu A/V^2 \\ \frac{W}{L} = \frac{2\,\mu m}{0.1\,\mu m} \\ V_{TH} = 0.5V \end{cases}$$

6- ترانزیستور هارر نامید اشباع. $? = v_G$



$i_{DC} = 1mA$

$\mu_p C_{ox} = 0.4 \frac{mA}{V^2}$

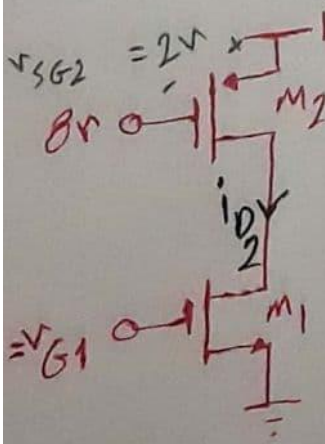
$\frac{W}{L} = \frac{2\mu m}{0.1\mu m}$

$v_{TH} = 0.5V$

$\beta = \frac{4}{10} \times \frac{2}{\frac{1}{10}} = 8 \frac{mA}{V^2}$ $\quad K = 4$

$v_{SG} = |v_{TH}| + \sqrt{\frac{i_D}{K}} = \frac{1}{2} + \sqrt{\frac{1}{4}} = 1V$

KVL @ M_1: $v_G = -v_{SG} - i_D + 10 = 8V$ ✓



$\mu_n C_{ox} = 400 \frac{\mu A}{V^2} \rightarrow \beta_1 = 4 \frac{mA}{V^2} \rightarrow K_1 = 2$

$\mu_p C_{ox} = 100 \frac{\mu A}{V^2} \rightarrow \beta_2 = 1 \frac{mA}{V^2} \rightarrow K_2 = \frac{1}{2}$

$\left(\frac{W}{L}\right) = \frac{1}{\frac{1}{10}} \frac{\mu m}{\mu m}$

$|v_{TH}| = 1V$

$i_{D_2} = K_2 (v_{SG2} - |v_{TH}|)^2 = \frac{1}{2}(2-1)^2 = \frac{1}{2} mA = i_{D_1}$

$v_{GS1} = v_{TH1} + \sqrt{\frac{i_D}{K_1}} = 1 + \sqrt{\frac{\frac{1}{2}}{2}} = \frac{3}{2}V = v_{G1}$ ✓