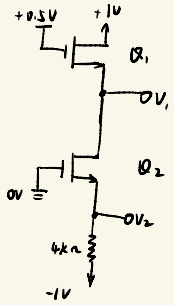
1. (a)



$V_{TH} = 0.4V$

$\mu_n C_{ox} \frac{W}{L} = 5\,mA/V^2$

$V_{GS2} = -V_2$

$V_{GS2} - V_{TH} = -V_2 - 0.4V$

$V_{GS1} = 0.5 - V_1$

$V_{GS1} - V_{TH} = 0.1 - V_1$

$V_{DS1} = 1 - V_1$

$V_{DS2} = V_1 - V_2$

$\because$ $V_{GS1} - V_{TH} < V_{DS1}$ 则 Q_1 为截止区或饱和区

假设：Q_1 为截止状态，则此时无电流

则 $V_2 = -1V$，$V_{GS2} - V_{TH} = 0.6V$

Q_2 如果是没有电流的就必须是线性区

(饱和区或为 VCCS)

$V_{DS2} < V_{GS2} - V_{TH}$

$V_1 - V_2 < -V_2 - 0.4V$

$V_1 < -0.4V$

此时 $V_{GS1} - V_{TH} = 0.1 + 0.4V = 0.5V$

则 Q_1 不处于截止状态，发生矛盾

即 Q_1 处于非饱和状态

$$I_D = \frac{V_2+1}{4k\Omega} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS1}-V_{TH})^2$$

$$= \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(0.1-V_1)^2 \cdots\cdots ①$$

$$= \frac{5}{2}(0.1-V_1)^2\ mA$$

则 Q_2 不截止，$V_{GS2} - V_{TH} > 0$，$V_2 < -0.4V$

由 Q_1 不截止条件得出 $-1 < V_1 < 0.1$

$V_2 = 10(0.1-V_1)^2 - 1 < -0.4V$

$-0.145 < V_1 < 0.345V$

得 $-0.145 < V_1 < 0.1$

无法判断 Q_2 的工作状态.

如果 Q_2 工作在饱和区

$$I_D = \frac{V_2+1}{4k\Omega} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(-V_2-0.4)^2 \cdots\cdots ②$$

如果 Q_2 工作在线性区

$$I_D = \frac{V_2+1}{4k\Omega} = \mu_n C_{ox}\frac{W}{L}\left((-V_2-0.4)(V_1-V_2) - \frac{1}{2}(V_1-V_2)^2\right) \cdots ②'$$

根据 ①.②

$$V_2 = 10(0.1-V_1)^2-1 \quad \cdots ①$$

$$V_2 = 10(-V_2-0.4)^2-1 \quad \cdots ②$$

$$V_2 = 10(V_2^2+0.8V_2+0.16)-1$$

$$0 = 10V_2^2+7V_2+0.6$$

$$V_2 = \frac{-7\pm\sqrt{49-4\times10\times0.6}}{2\times10} = \frac{-7\pm5}{20} = -0.1V(\text{舍去})\text{或}-0.6V$$

舍去

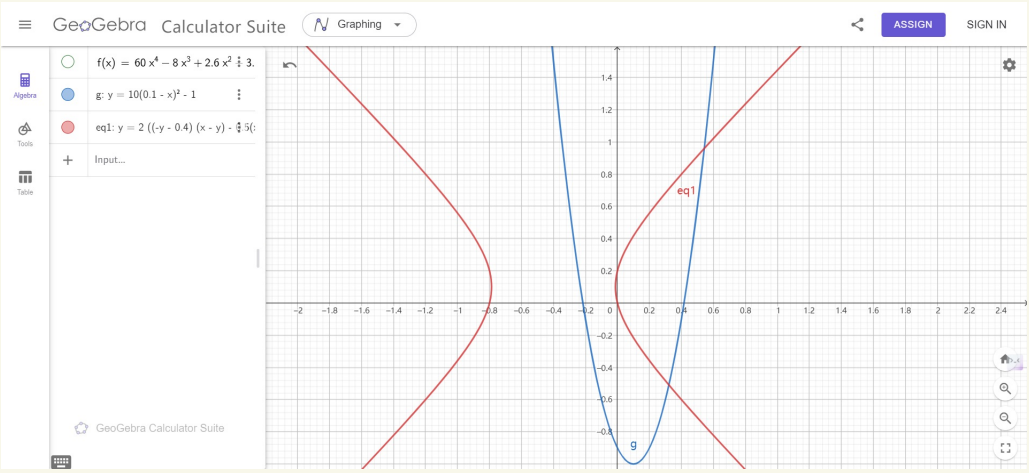
$$V_1 = 0.1\pm0.2 = -0.1V$$

(已知 $-0.1V < V_1 < 0.1V$)

根据 ①②'

$$V_2 = 10(0.1-V_1)^2-1 \quad \cdots ①$$

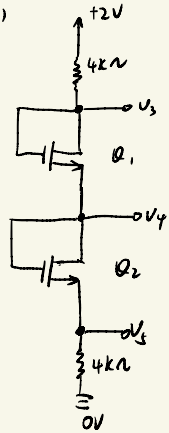
$$V_2 = 2\left((-V_2-0.4)(V_1-V_2)-\tfrac{1}{2}(V_1-V_2)^2\right) \quad \cdots ②'$$



没有符合条件的解

所以 $V_2 = -0.6V$, $V_1 = -0.1V$

(b)



$V_{GS1} = V_3 - V_4$

$V_{GS2} = V_4 - V_5$

$V_{TH} = 0.4V$

$V_{GS1} - V_{TH} = V_3 - V_4 - 0.4V$

$V_{GS2} - V_{TH} = V_4 - V_5 - 0.4V$

$V_{DS1} = V_3 - V_4$

$V_{DS2} = V_4 - V_5$

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

则 Q_1, Q_2 工作在 截止区 或 饱和区

而本题只允许一个截止 一个饱和

假设 Q_1, Q_2 都截止, 无电流.

$V_3 = 2V$, $V_5 = 0V$

$V_3 - V_4 - 0.4 = 1.6 - V_4 < 0$

$V_4 > 1.6V$

且 $V_4 < 0.4V$

发生矛盾,

所以不能两个均饱和

$$\frac{V_5}{4k\Omega} = \frac{2-V_3}{4k\Omega} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_4 - V_5 - 0.4)^2 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_3 - V_4 - 0.4)^2$$

$$V_5 + V_3 = 2$$

$$V_5 = 10(V_4 - V_5 - 0.4)^2 = 10(V_3 - V_4 - 0.4)^2$$

$$V_3 - V_4 > 0.4$$

$$V_4 - V_5 > 0.4 \qquad 1 - V_5 > 0.4, \rightarrow \quad V_5 < 0.6V$$

$$V_5 = 10(1 - V_5 - 0.4)^2$$

$$= 0.9(\text{舍去}) \text{ 或 } 0.4V$$

$$V_3 = 2 - V_5 = 1.6V$$

2、 $V_{TH} = V_{TH0} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{|2\phi_F|}\right)$

$= 1 + \frac{1}{2}\left(\sqrt{0.6 + V_{SB}} - \sqrt{0.6}\right)$

$V_{TH\,min} = 1\,V$

$V_{TH\,max} = 1 + \frac{1}{2}\left(\sqrt{0.6 + 4} - \sqrt{0.6}\right) = 1.685V$

如果 t_{ox} 变为 4倍.

C_{ox} 变为 $\frac{1}{4}$, γ 变为原来4倍

$V_{TH\,min} = 1V$

$V_{TH\,max} = 1 + \frac{1}{2} \times 4\left(\sqrt{0.6+4} - \sqrt{0.6}\right) = 3.74V$

2.2 $\frac{W}{L} = \frac{50}{0.5} = 100$

$|I_D| = 0.5\,mA$

对于 NMOS: $C_{ox} = \frac{\varepsilon_0 \varepsilon_{SiO_2}}{t_{ox}} = \frac{4 \times 8.85 \times 10^{-12}}{9 \times 10^{-9}} = 3.93 \times 10^{-3}\ F/m^2$

$\mu_n = 350 \times 10^{-4}$

$g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D} = \sqrt{2 \times 350 \times 10^{-4} \times 3.93 \times 10^{-3} \times 100 \times 0.5 \times 10^{-3}}$

$= 10^{-3} \times 3.7\ S$

$r_o = \frac{1}{\lambda_n I_D} = \frac{1}{0.1 \times 0.5\,mA} = \frac{1}{5 \times 10^{-5}} = 2 \times 10^4\ \Omega$

$g_m r_o = 10^{-3} \times 3.7 \times 2 \times 10^4 = 74$

对于 PMOS:

$\mu_p = 100\ cm^2/V/s = 100 \times 10^{-4}\ m^2/V/s = 10^{-2}\ m^2/V/s$

$\mu_p C_{ox} = 3.93 \times 10^{-5}$

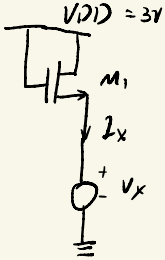
$g_m = \sqrt{2 \mu_p C_{ox} \frac{W}{L} I_D} = \sqrt{2 \times 3.93 \times 10^{-5} \times 100 \times 0.5 \times 10^{-3}} = 1.982 \times 10^{-3}\ S$

$r_o = \frac{1}{\lambda_p I_D} = \frac{1}{0.2 \times 0.5\,mA} = 10^4\ \Omega$

$g_m r_o = 10^4 \times 1.982 \times 10^{-3} = 19.82$

2-5

(a)



由于 $V_{SB} \neq 0$.

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{DS})$$

$$V_{GS} = V_{DD} - V_X = 3 - V_X \quad , \quad V_{DS} = V_{DD} - V_X = 3 - V_X$$

$$V_{TH} = V_{TH0} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$$

其中 $\lambda = 0.1\ V^{-1}$ $\quad \gamma = 0.45\ V^{\frac{1}{2}}$ $\quad 2\phi_f = 0.9\ V$ $\quad V_{TH0} = 0.7$

$V_{SB} = V_X$ ，由于 $V_{GS} - V_{TH} < V_{DS}$，

$$I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(3 - V_X - 0.7 - 0.45\left(\sqrt{0.9+V_X} - \sqrt{0.9}\right)\right)^2(1+0.1(3-V_X))$$

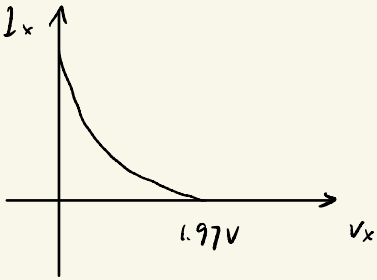
有电流的条件是：$V_{GS} - V_{TH} > 0$，即上式平方项括号内大于0

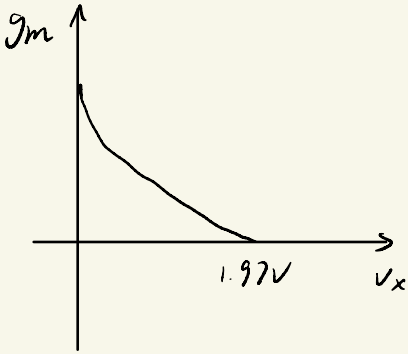
$$3 - V_X - 0.7 - 0.45\left(\sqrt{0.9+V_X} - \sqrt{0.9}\right) > 0$$

解得 $V_X < 1.97V$

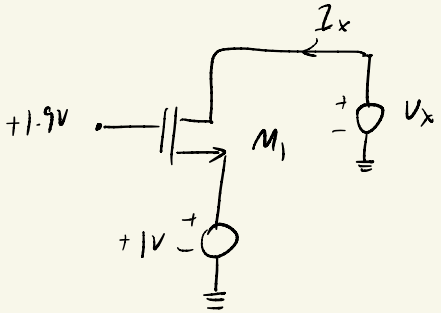
$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}$$

画出两者图像如下：





(b)



$0 < V_x < 1V$ 时. $V_{DS} = 1 - V_x$

$V_{GS} = 1.9 - V_x$

$V_{GS} - V_{TH} = 1.9 - V_x - 0.7 = 1.2 - V_x > V_{DS}$ 成立

2作时 线性区

$$I_x = -\mu_n C_{ox} \frac{W}{L} \left((1.2 - V_x)(1 - V_x) - \frac{1}{2}(1 - V_x)^2 \right)$$

$$= -\mu_n C_{ox} \frac{W}{L} (1 - V_x)(0.7 - 0.5V_x)$$

$1 < V_x < 3V$ 时 $V_{DS} = V_x - 1$, $V_{GS} = 1.9 - 1 = 0.9V$

$V_{GS} - V_{TH} = 0.2V$

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

$V_x - 1 < 0.2$

$V_x < 1.2$

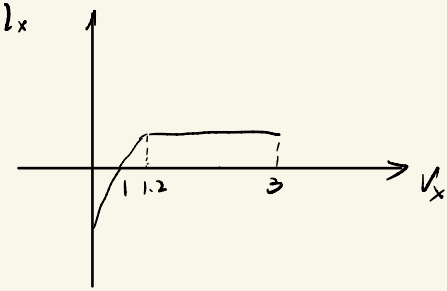
即 $1 < V_x < 1.2V$ 时, 2作在线性区

$$I_x = \mu_n C_{ox} \frac{W}{L} \left(0.2(V_x - 1) - \frac{1}{2}(V_x - 1)^2 \right)$$

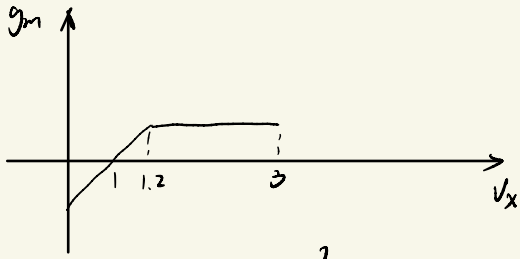
$1.2 < V_x < 3V$. 2作在饱和区

$$I_x = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \cdot 0.04 = 0.02 \cdot \mu_n C_{ox} \frac{W}{L}$$

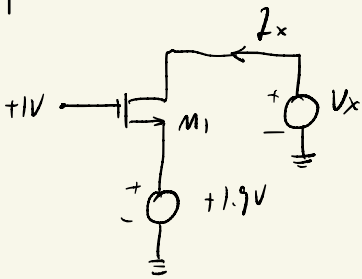
可画出 I_x 图象如下



$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_x}$ ，画出图象如下：



(c)



当 $V_x < 1.9V$ 时， $V_{DS} = 1.9 - V_x$

$V_{GS} = 1 - V_x$

$V_{TH} = 0.7V$

$V_{GS} - V_{TH} = 0.3 - V_x$.

当 $0.3 < V_x < 1.9V$ 时 截止，无电流

当 $V_x < 0.3V$ 时， $0 < V_{GS} - V_{TH} < V_{DS}$ ，饱和区

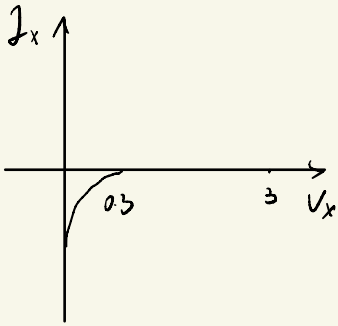
$I_x = -\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(0.3 - V_x)^2$

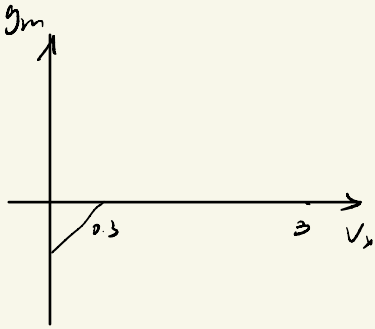
当 $V_x > 1.9V$ 时，$V_{DS} = V_x - 1.9$ $V_{GS} = 1 - 1.9 = -0.9V$

截止

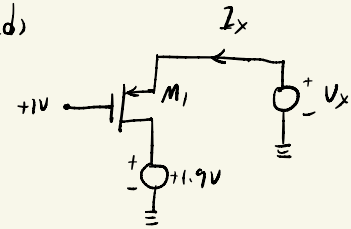
$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L} I_x}$$

可作出图象：





(d)



$V_x < 1.9V$ 时，$V_{DS} = V_x - 1.9V$ $V_{GS} = 1 - 1.9 = -0.9V$

$V_{GS} - V_{TH} = -0.9 + 0.8 = -0.1V < 0$，不截止

$V_{GS} - V_{TH} < V_{DS} < 0$，$-0.1 < V_x - 1.9$

$1.9V > V_x > 1.8V$ 时，工作于线性区

$$I_x = -\mu_p C_{ox}\frac{W}{L}\left(-0.1(V_x - 1.9) - \frac{1}{2}(V_x - 1.9)^2\right)$$

$$= -\mu_p C_{ox}\frac{W}{L}\left(0.1(1.9 - V_x) - \frac{1}{2}(1.9 - V_x)^2\right)$$

$0 < V_x < 1.8V$ 时，工作于饱和区

$$I_x = -\frac{1}{2}\mu_p C_{ox}\frac{W}{L}(0.1)^2.$$

当 $V_x > 1.9V$ 时. $V_{DS} = 1.9 - V_x$ $V_{GS} = 1 - V_x$

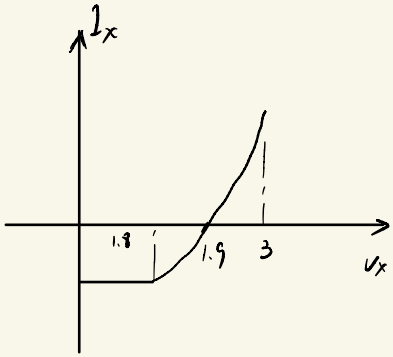
$V_{GS} - V_{TH} = 1 - V_x + 0.8 = 1.8 - V_x < 0$ 不截止

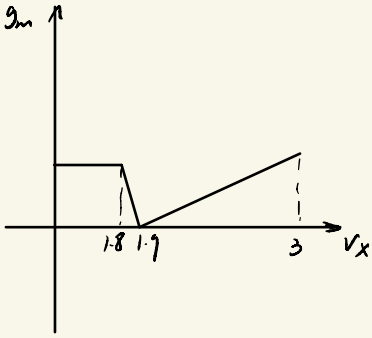
$V_{GS} - V_{TH} < V_{DS} < 0$. $1.8 - V_x < 1.9 - V_x$ 成立

工作于线性区

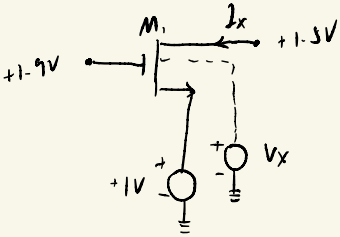
$$I_x = \mu_p C_{ox} \frac{W}{L} \left((1.8 - V_x)(1.9 - V_x) - \frac{1}{2}(1.9 - V_x)^2 \right)$$

又由 $g_m = \sqrt{2 \mu_p C_{ox} \frac{W}{L} I_x}$ 可推出图象:





(e)



$V_{DS} = 1.5 - 1 = 0.5V$

$V_{GS} - V_{TH} = 1.9 - 1 - V_{TH} = 0.9 - V_{TH}$

$V_{SB} = 1 - V_x$

$$V_{TH} = V_{TH0} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)$$

$$= 0.7 + 0.45\left(\sqrt{0.9+1-V_x} - \sqrt{0.9}\right)$$

$$= 0.7 + 0.45\left(\sqrt{1.9-V_x} - \sqrt{0.9}\right)$$

$$V_{GS} - V_{TH} < 0$$

$$0.2 < 0.45\left(\sqrt{1.9-V_x} - \sqrt{0.9}\right)$$

$$V_x < -0.04\,V$$

则 NMOS 处于截止

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

$$-0.3 < 0.45\left(\sqrt{1.9-V_x} - \sqrt{0.9}\right)$$

$$(0 <)\ V_x < 1.82V$$

此时 NMOS 工作于饱和区

$$I_x = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(0.2 - 0.45\left(\sqrt{1.9-V_x} - \sqrt{0.9}\right)\right)^2$$

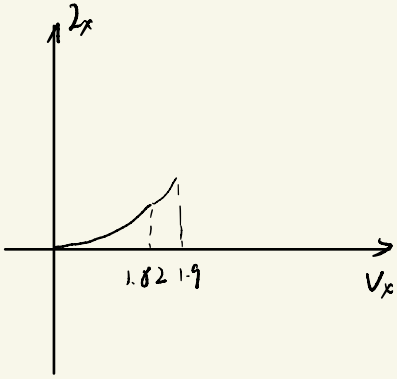
$$g_m = \mu_n C_{ox}\frac{W}{L}\left(0.2 - 0.45\left(\sqrt{1.9-V_x} - \sqrt{0.9}\right)\right)$$

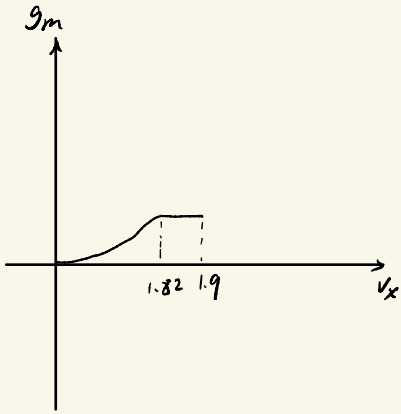
当 $1.82 < V_x < 1.9V$ 时，此时 NMOS 工作于线性区

$$I_x = \mu_n C_{ox}\frac{W}{L}\left(\left(0.2 - 0.45\sqrt{1.9-V_x} - \sqrt{0.9}\right)0.5 - \frac{1}{2}\times 0.5^2\right)$$

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

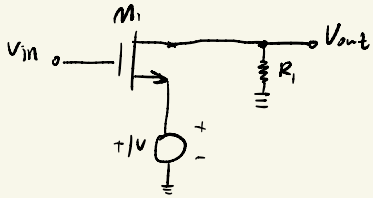
可作出 I_x，g_m 图象：





2.7

(a)



$V_{GS} = V_{in} - V_{out}$

$V_{DS} = 1 - V_{out}$

(1)

NMOS截止时. $V_{out} = 0$

$V_{GS} - V_{TH} = V_{in} - 0.7 < 0$. $V_{in} < 0.7V$

(2)

在线性区,有 $V_{GS} - V_{TH} = V_{in} - V_{out} - 0.7 > V_{DS} = 1 - V_{out}$

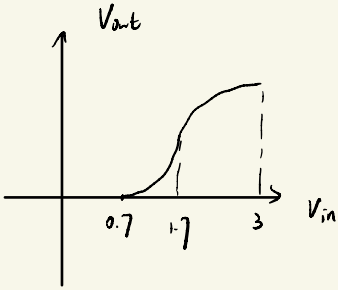
$V_{in} > 1.7V$

$1.7V < V_{in} < 3V$, 工作于线性区

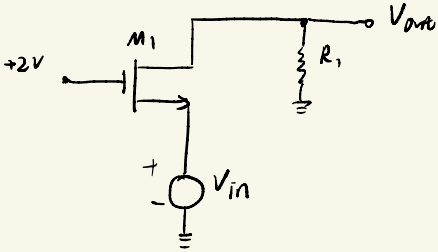
$$I_D = \frac{V_{out}}{R_1} = \mu_n C_{ox} \frac{W}{L} \left((V_{in} - V_{out} - 0.7)(1 - V_{out}) - \frac{1}{2}(1 - V_{out})^2 \right)$$

$0.7 < V_{in} < 1.7V$. 工作于饱和区

$$I_D = \frac{V_{out}}{R_1} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{out} - 0.7)^2$$



(b)



$V_{GS} = 2 - V_{out}$ $\quad V_{DS} = V_{in} - V_{out}$.

$V_{GS} - V_{TH} = 1.3 - V_{out}$

当 $V_{out} > 1.3V$ 时，器件截断

$V_{GS} - V_{TH} = 1.3 - V_{out} > V_{DS} = V_{in} - V_{out}$

$1.3 > V_{in}$

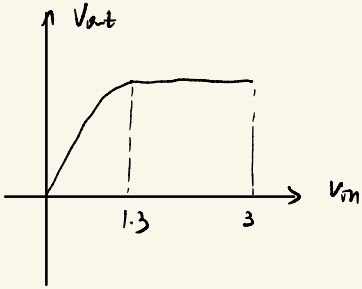
当 $0 < V_{in} < 1.3V$，工作线性区

$$\frac{V_{out}}{R_1} = I_D = \mu_n C_{ox} \frac{W}{L} \left((1.3 - V_{out})(V_{in} - V_{out}) - \frac{1}{2}(V_{in} - V_{out})^2 \right)$$

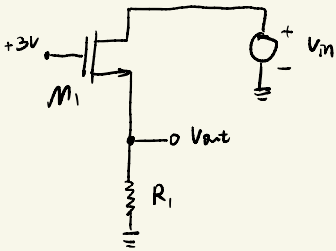
当 $1.3 < V_{in} < 3V$ 时，工作在饱和区

$$\frac{V_{out}}{R_1} = I_n = \frac{1}{2} \mu C_{ox} \frac{W}{L} (1.3 - V_{out})^2$$

由此可画出 $V_{out} - V_{in}$ 图象：



(c)



$V_{GS} = 3 - V_{out}$ $\quad V_{DS} = V_{in} - V_{out}$

$V_{GS} - V_{TH} = 2.3 - V_{out} > V_{DS} = V_{in} - V_{out}$

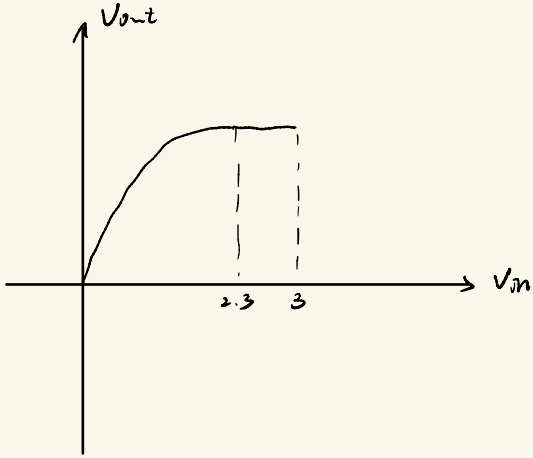
$0 < V_{in} < 2.3V$ 时，工作于线性区

$$I_D = \frac{V_{out}}{R_1} = \mu_n C_{ox} \frac{W}{L}\left((2.3 - V_{out})(V_{in} - V_{out}) - \frac{1}{2}(V_{in} - V_{out})^2\right)$$

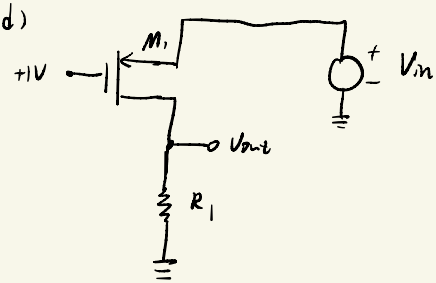
$2.3V < V_{in} < 3V$ 时，工作于饱和区

$$I_D = \frac{V_{out}}{R_1} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(2.3 - V_{out})^2$$

由此画出 V_{out} - V_{in} 图象.



(d)



$V_{GS} = 1 - V_{in}$ $\quad V_{DS} = V_{out} - V_{in}$

$V_{GS} - V_{TH} = 1.8 - V_{in} > 0$

$0 < V_{in} < 1.8\,V$，工作于截止区，$V_{out} = 0\,V$

$1.8 - V_{in} < V_{DS} < 0$

$< V_{out} - V_{in}$

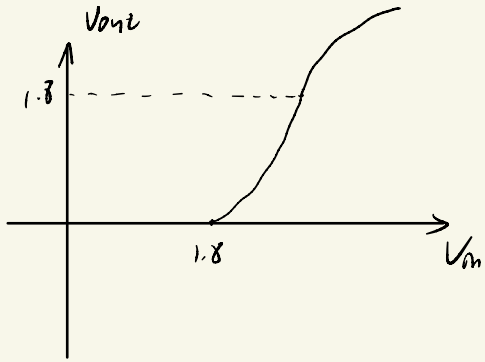
$V_{out} > 1.8\,V$，工作于线性区

$$I_D = \frac{V_{out}}{R_1} = \mu_p C_{ox} \frac{W}{L} \left((1.8 - V_{in})(V_{out} - V_{in}) - \frac{1}{2}(V_{out} - V_{in})^2 \right)$$

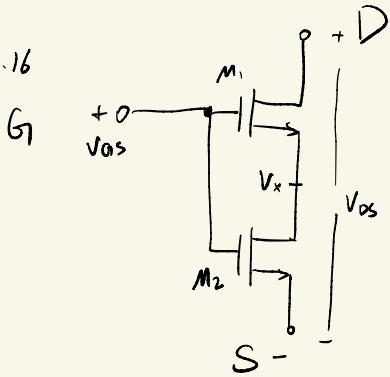
$V_{out} < 1.8\,V$时，工作于饱和区

$$I_D = \frac{V_{out}}{R_1} = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(1.8-V_{in})^2$$

由此画出 $V_{out}-V_{in}$ 图象



2.16



对两个 mos 而言，$V_{GS1} = V_{GS} - V_x$. $V_{DS1} = V_{DS} - V_x$

$V_{GS2} = V_{GS}$ $V_{DS2} = V_x$

$V_{GS} < V_{TH}$ 时，M_2 截止

$V_{GS} > V_{TH}$ 时，M_2 不截止.

如果 M_1 截止. $V_{GS} - V_x - V_{TH} < 0$

$V_x > V_{GS} - V_{TH}$

和会导致 M_2 处于饱和区，发生矛盾

所以 M_1 也不截止. 即:

$V_{GS} > V_{TH}$ 时, 相当于整体开启

且 $V_x < V_{GS} - V_{TH}$

和这会导致 M_2 处于线性区

$$I_D = \mu_n C_{ox} \frac{W}{L} \left((V_{GS} - V_{TH}) V_x - \frac{1}{2} V_x^2 \right)$$

$$V_{GS1} - V_{TH} - V_{DS1} = V_{GS} - V_{TH} - V_{DS}$$

① 当 $V_{DS} > V_{GS} - V_{TH}$ 时, $V_{GS1} - V_{TH} - V_{DS1} < 0$

M_1 工作于饱和区

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \left(V_{GS} - V_x - V_{TH} \right)^2$$

$$\begin{cases} I_D = \mu_n C_{ox} \frac{W}{2L} \left(2V_{GS} V_x - 2V_{TH} V_x - V_x^2 \right) \\ I_D = \mu_n C_{ox} \frac{W}{2L} \left(V_{GS} - V_x - V_{TH} \right)^2 = \mu_n C_{ox} \frac{W}{2L} \left(V_{GS}^2 + V_x^2 + V_{TH}^2 - 2V_{GS} V_x - 2V_{GS} V_{TH} - 2V_x V_{TH} \right) \end{cases}$$

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{2L} \left(V_{GS}^2 - 2V_{GS} V_{TH} + V_{TH}^2 \right)$$

$$= \frac{1}{2} \mu_n C_{ox} \frac{W}{2L} \left(V_{GS} - V_{TH} \right)^2$$

相当于是一个 $\frac{W}{2L}$ 的 MOS 饱和工作

② 当 $V_{DS} < V_{GS} - V_{TH}$ 时, $V_{GS1} - V_{TH} - V_{DS1} < 0$

M_1 工作于线性区, 有

$$\begin{cases} I_D = \mu_n C_{ox} \frac{W}{2L} \left(2V_{GS} V_x - 2V_{TH} V_x - V_x^2 \right) \\ I_D = \mu_n C_{ox} \frac{W}{2L} \left(2(V_{GS} - V_x - V_{TH})(V_{DS} - V_x) - (V_{DS} - V_x)^2 \right) \end{cases}$$

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{2L} \left(\underline{2V_{GS} V_x} \underline{- 2V_{TH} V_x} \underline{- V_x^2} + 2V_{GS} V_{DS} \underline{- 2V_{GS} V_x} \underline{- 2V_{DS} V_x} \underline{+ 2V_x^2} \right.$$

$$\left. - 2V_{TH} V_{DS} \underline{+ 2V_{TH} V_x} - V_{DS}^2 \underline{- V_x^2} \underline{+ 2V_{DS} V_x} \right)$$

$$I_D = \mu_n C_{ox} \frac{W}{2L} \left((V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right)$$

相当于 $\frac{W}{2L}$ 的 MOS 工作于线性区

所以可以认为上图等效为一个宽长比为 $\frac{W}{2L}$ 的晶体管

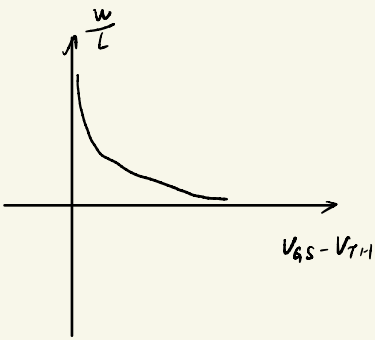
2.17

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

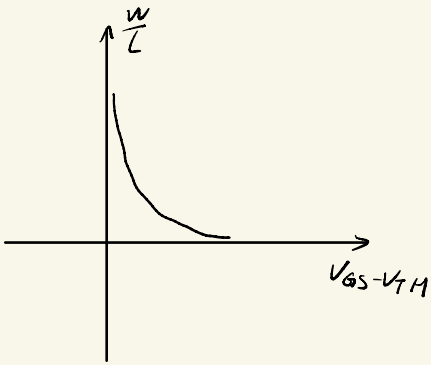
$$g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$$

$$\frac{W}{L} = \frac{2 I_D}{\mu_n C_{ox} (V_{GS} - V_{TH})^2}$$

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



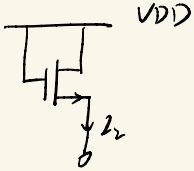
I_D 为定值



g_m 为定值

2.18 (a)

(b)



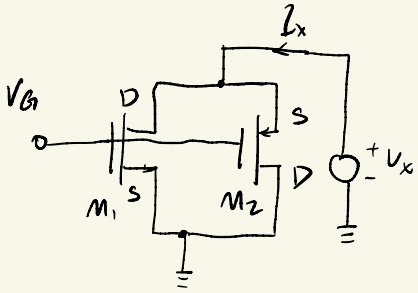
电流源是需要在无外界条件下，仅凭自己就可以产生稳定电流

由于与种效应（体效应等）的存在，会使得接不同电压时

源漏电压会发生变化，产生的电流并不恒稳不变，所以不适合作电流源。

2.24 $\lambda = \gamma = 0$

(a)



等效跨导: $\frac{\partial I_x}{\partial V_G}$

$V_{G1} = V_{G2} = V_G$. $V_{DS1} = V_x$ $V_{DS2} = -V_x$

$V_{GS1} = V_G$ $V_{GS2} = V_G - V_x$

$V_{GS1} - V_{THn} = V_G - V_{THn}$

小 当 $V_G < V_{THn}$. 此时 M_1 截止

① $V_{GS2} - V_{THp} > 0$

$V_G - V_x - V_{THp} > 0$

$V_G > V_x + V_{THp}$. M_2 也截止

$I_D = 0$, $g_m = 0$

② $V_{GS2} - V_{THp} < 0$

$V_G < V_x + V_{THp}$. M_2 导通

$V_{DS2} = -V_x$

$0 > V_{GS2} - V_{THp} = V_G - V_x - V_{THp} > V_{DS2}$

M_2 工作于饱和区

$$I_x = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_G - V_x - V_{THp})^2$$

$$g_m = \frac{\partial I_x}{\partial V_G} = \mu_p C_{ox}\frac{W}{L}(V_G - V_x - V_{THp})$$

(2) 当 $V_G > V_{THn}$ 时，此时 M_1 导通

① $V_{GS1} - V_{THn} > V_{DS1}$

$V_G - V_{THn} > V_X > 0$

此时有 M_1 工作于线性区

$V_x < V_G - V_{THn}$

即必有：$V_x < V_G - V_{THp}$，有 M_2 截止

$$I_x = \mu_n C_{ox} \frac{W}{L} \left((V_G - V_{THn}) V_x - \frac{1}{2} V_x^2 \right)$$

$$g_m = \frac{\partial I_x}{\partial V_G} = \mu_n C_{ox} \frac{W}{L} V_x$$

②. $V_x > V_G - V_{THn}$，M_1 工作于饱和区

此时不能判断 pmos 状态　　上面已经证明没有线性区

于是分 截止区（$V_x < V_G - V_{THp}$），饱和区（$V_x > V_G - V_{THp}$）

$V_x > V_G - V_{THn}$ 但 $V_x < V_G - V_{THp}$ 时

$$I_x = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_G - V_{THn})^2$$

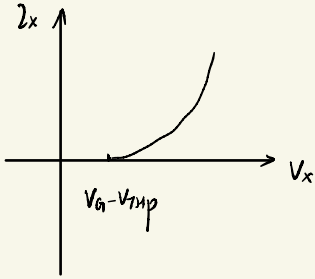
$$g_m = \frac{\partial I_x}{\partial V_G} = \mu_n C_{ox} \frac{W}{L} (V_G - V_{THn})$$

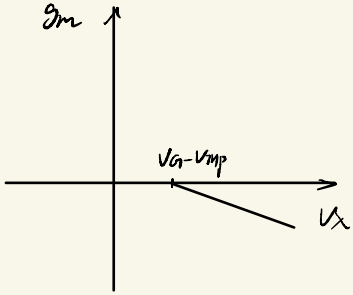
$V_x > V_G - V_{THn}$ 但 $V_x > V_G - V_{THp}$

$$I_x = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_G - V_{THn})^2 + \frac{1}{2} \mu_p C_{ox} \frac{W}{L} (V_G - V_x - V_{THp})^2$$

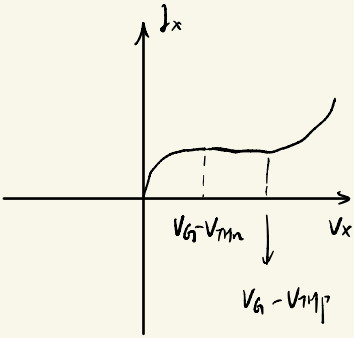
$$g_m = \frac{\partial I_x}{\partial V_G} = \mu_n C_{ox} \frac{W}{L} (V_G - V_{THn}) + \mu_p C_{ox} \frac{W}{L} (V_G - V_x - V_{THp})$$

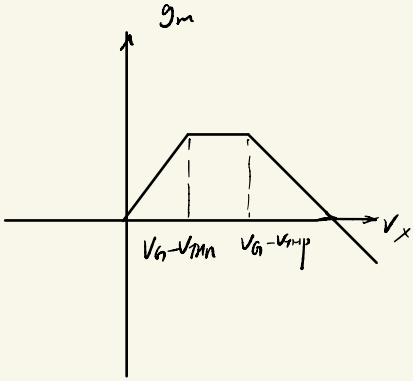
由此便可画出 $I_x - V_x$，$g_m - V_x$ 图象





$V_G < V_{TMn}$





$V_G > V_{TMn}$

2.28

(1) 降低 V_D

V_D 不断减小至0的过程中. (如 $V_{TH}=0.7V$, 则不会截止)

如果 $V_D > V_{GS}-V_{TH} = V_G - V_{TH}$, 工作在饱和区

如果 $V_{GS}-V_{TH} > V_D > 0$, 工作在线性区

如果 V_D 小于0, 则会源漏交换

$V_{GS} = V_G - V_D = 1.5 - V_D$

$V_{DS} = -V_D$

(如 $V_{TH}=0.7V$), 则会工作在线性区

(2) V_{SB} 上升 (大于0)

$$V_{TH} = V_{TH0} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)$$

V_B 增大, V_{SB} 减小, V_{TH} 减小, I_D 增大