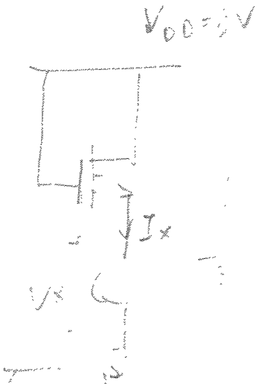
(a) $\lambda = 0.1$, $\gamma = 0.45$, $2\phi_F = 0.9$, $V_{TH0} = 0.7$




$V_{GS} = 3 - V_x$, $V_{DS} = 3 - V_x$, $V_{SB} = V_x$

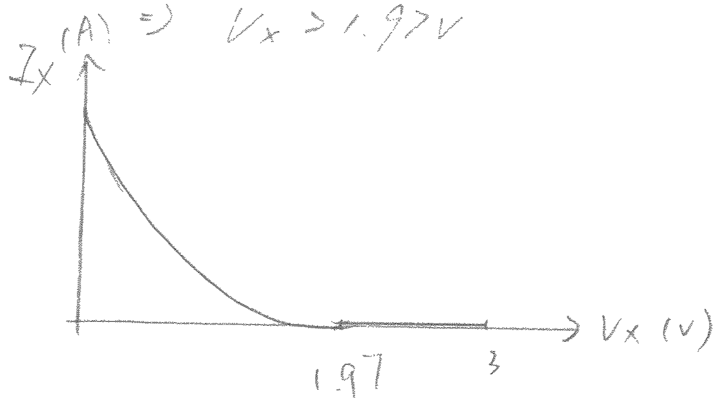
$V_{TH} = V_{TH0} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)$

So, $I_x = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(3 - V_x - 0.7 - 0.45\left(\sqrt{0.9 + V_x} - \sqrt{0.9}\right)\right)^2 \times \left(1 + \lambda(3 - V_x)\right)$

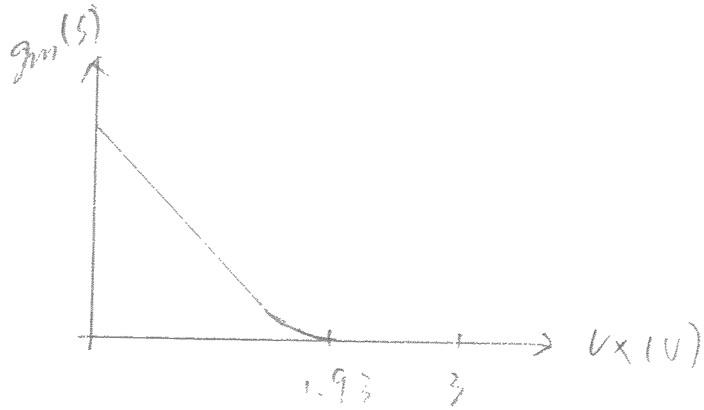
mos is off when

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

$\Rightarrow V_x > 1.97V$




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



(b) $\lambda = \gamma = 0$. $V_{TH} = 0.7$.

(1) $V_x < 1V \Rightarrow$ S. D Terminals exchange.

$V_{GS} = 1.9 - V_x$, $V_{DS} = 1 - V_x$, $V_{OD} = 1.2 - V_x$

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

$\Rightarrow I_x = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(1 - V_x)(1.4 - V_x)$

$g_m = \mu_n C_{ox}\frac{W}{L}V_{DS} = \mu_n C_{ox}\frac{W}{L}(1 - V_x)$

(2) $V_x > 1V$

$V_{GS} = 1.9 - 1 = 0.9$ $V_{DS} = V_x - 1$, $V_{OD} = 0.9 - 0.7 = 0.2$

if $V_x < 1.2V \Rightarrow$ Triode

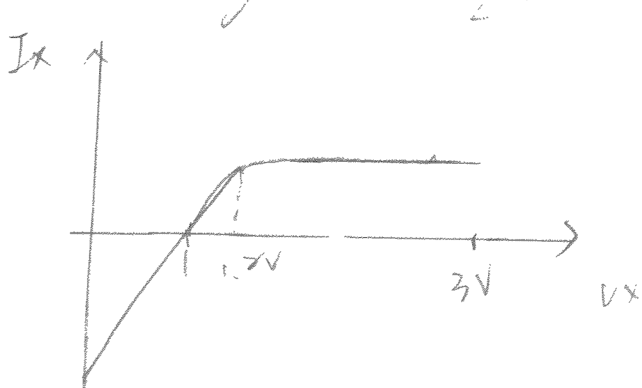
$I_x = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2 \times 0.2 \times (V_x - 1) - (V_x - 1)^2\right]$

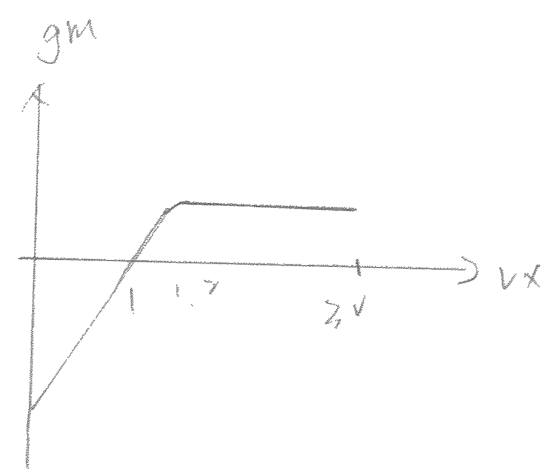
$g_m = \mu_n C_{ox}\frac{W}{L}(V_x - 1)$

if $V_x > 1.2V \Rightarrow$ Saturation

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

$g_m = \mu_n C_{ox}\frac{W}{L}(0.2)$



(c) $\lambda = \gamma = 0$. $V_{TH} = 0.7$, S, D terminals exchange

$V_{GS} = 1 - V_x$ $V_{DS} = 1.9 - V_x$, $V_{OD} = V_{GS} - V_{TH} = 0.3 - V_x$

$I_x$:

- $V_x < 0.3V \Rightarrow$ saturation

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

- $V_x > 0.3V \Rightarrow$ off

  $I_x = 0$

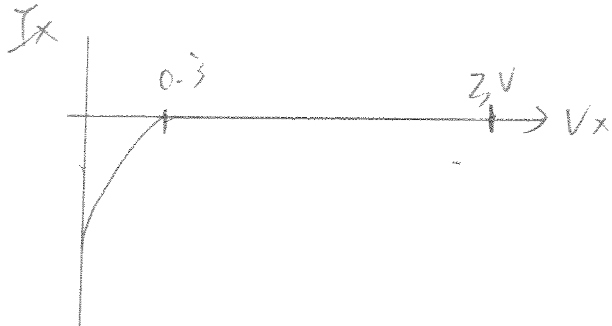
$g_m$:

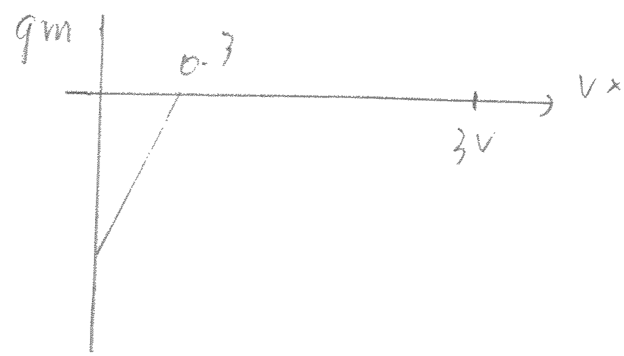
- $V_x < 0.3V \Rightarrow$ sat.

  $g_m = -\mu_n C_{ox} \frac{W}{L} (0.3 - V_x)$

- $V_x > 0.3$

  $g_m = 0$

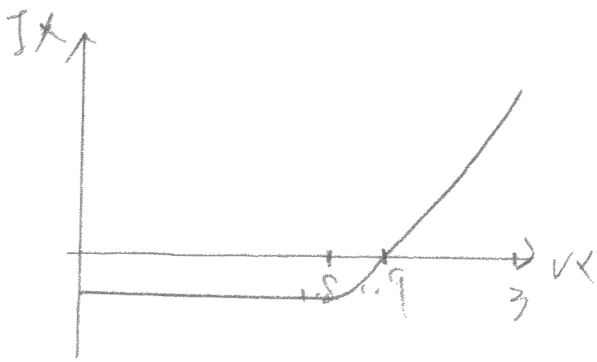


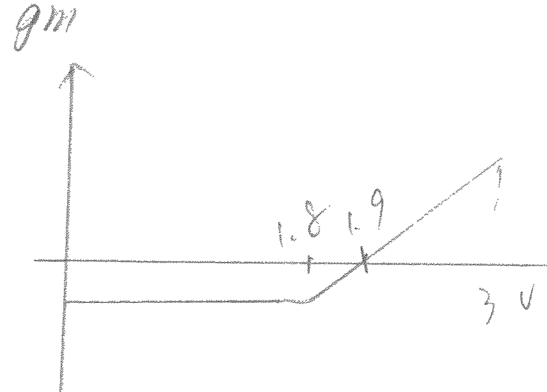



(d) $V_{TH} = -0.8 \quad \gamma = 0$

$0 < V_x < 1.8 \Rightarrow \begin{cases} I_x = -\frac{1}{2}\mu_p C_{ox}\frac{W}{L}(0.1)^2 \\ g_m = -\mu_p C_{ox}\frac{W}{L}(0.1)^2 \end{cases}$

$1.8 < V_x < 3 \Rightarrow \begin{cases} I_x = \mu_p C_{ox}\frac{W}{L} \times \frac{1}{2}(V_x - 1.9)(V_x - 1.7) \\ g_m = \mu_p C_{ox}\frac{W}{L}(V_x - 1.9) \end{cases}$



(e) $V_{TH0} = 0.7$, $\gamma = 0.45$, $2\phi_F = 0.9$, $\lambda = 0$

$V_{SB} = 1 - V_x$

$V_{TH} = 0.7 + 0.45(\sqrt{0.9 + 1 - V_x} - \sqrt{0.9})$

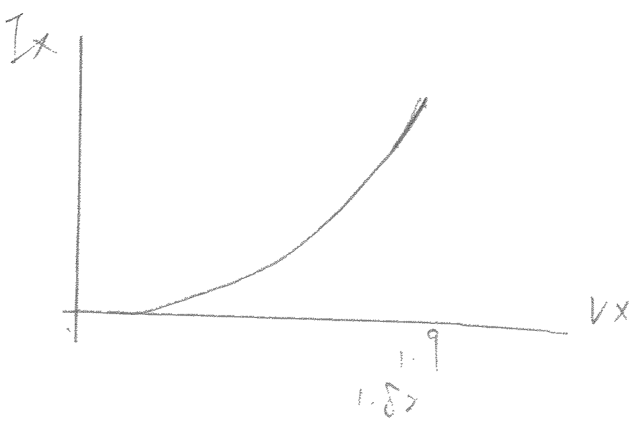
$V_{GS} = 0.7$ $V_{DS} = 0.5$, $V_{GS} - V_{TH} = 0 \Rightarrow V_x = 1.82V$

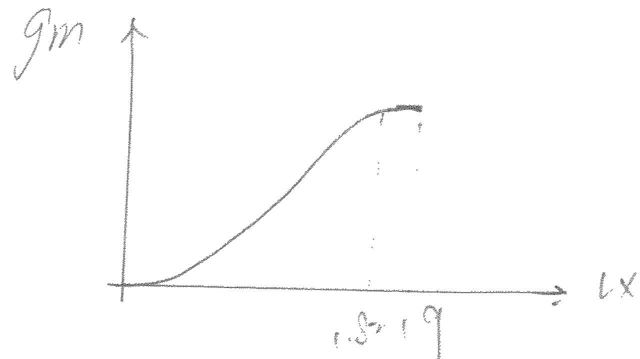
(1) $V_x < 1.82V \Rightarrow$ Sat.

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

(2) $V_x > 1.82V$

$$\begin{cases} I_x = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}[2 \times 0.5 \times (0.2 - 0.45(\sqrt{1.9 - V_x} - \sqrt{0.9})) - 0.5^2] \\ g_m = \mu_n C_{ox}\frac{W}{L}(0.5) \end{cases}$$



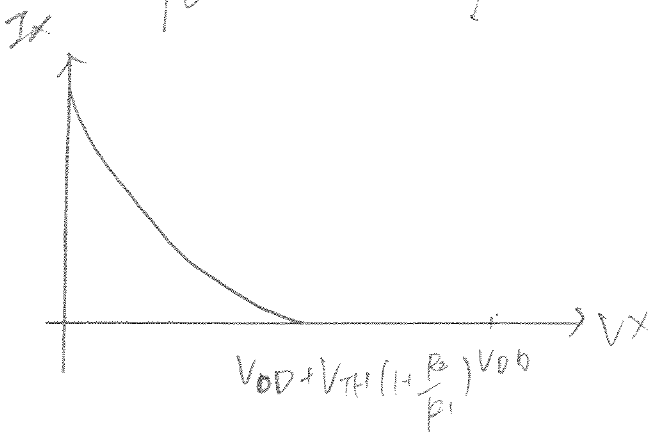



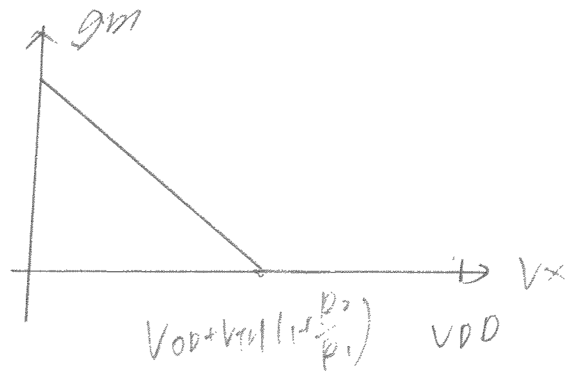
2.6 (a) $V_{SG} > |V_{TH}|$

$$\Rightarrow (V_{DD} - V_X)\frac{R_1}{R_1+R_2} > -V_{TH}$$

$$\Rightarrow V_X < V_{DD} + V_{TH}\left(1+\frac{R_2}{R_1}\right)$$

$$\Rightarrow \begin{cases} I_X = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}\left[(V_{DD}-V_X)\frac{R_1}{R_1+R_2} + V_{TH}\right]^2 \\ g_m = \mu_p C_{ox}\frac{W}{L}\left[(V_{DD}-V_X)\frac{R_1}{R_1+R_2} + V_{TH}\right] \end{cases}$$



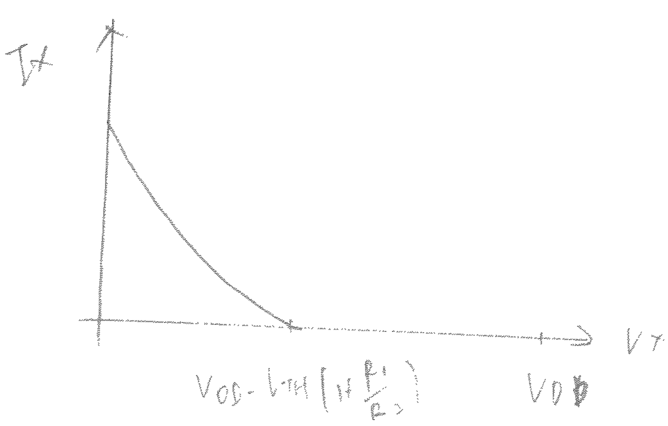



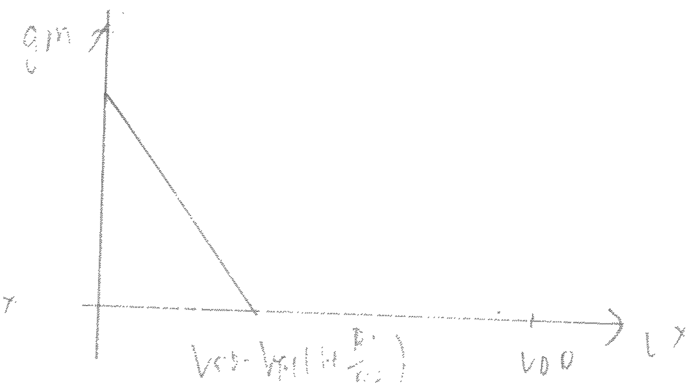

if $V_{DD} + V_{TH}\left(1+\frac{R_2}{R_1}\right) < 0 \Rightarrow$ off.

(b) $V_{GS} > V_{TH0} \Rightarrow V_X < V_{DD} - V_{TH0}\left(1+\frac{R_1}{R_1}\right)$

$$\Rightarrow \begin{cases} I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[(V_{DD}-V_X)\frac{R_2}{R_1+R_2} - V_{TH}\right]^2 \\ g_m = \mu_n C_{ox}\frac{W}{L}\left[(V_{DD}-V_X)\frac{R_2}{R_1+R_2} - V_{TH}\right] \end{cases}$$

if $V_{DD} - V_{TH}\left(1+\frac{R_2}{R_1}\right) < 0 \Rightarrow$ OFF



1C) ① $0 < V_X < 2 - V_{TH} \Rightarrow$ triode

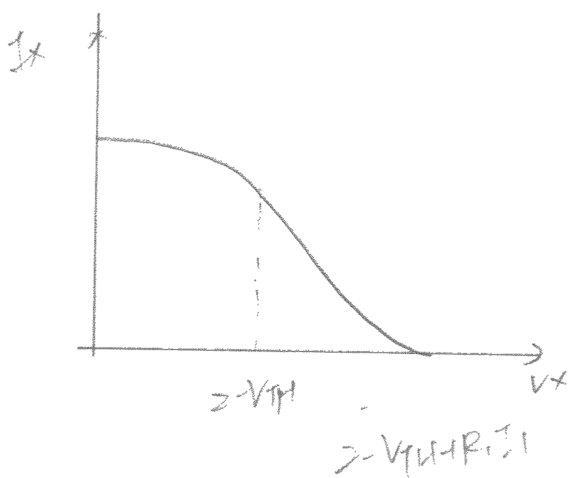
$V_{GS} = 2 - V_X + R_1(I_1 - I_X)$ , $V_{DS} = R_1(I_1 - I_X)$

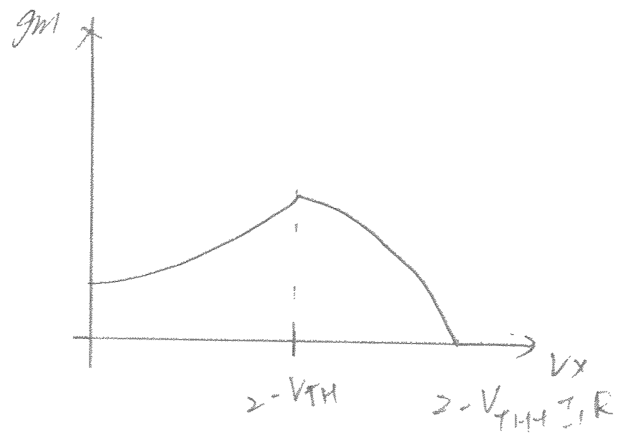
$\Rightarrow \begin{cases} I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[R_1(I_1 - I_X) + 2(2 - V_{TH} - V_X)\right](R_1(I_1 - I_X)) \\ g_m = \mu_n C_{ox} V_{DS} = \mu_n C_{ox} R_1 (I_1 - I_X) \end{cases}$

② $V_{GS} = 2 - V_X + R_1(I_1 - I_X) \Rightarrow$ Sat

$\Rightarrow \begin{cases} I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2 - V_X - R_1(I_1 - I_X) - V_{TH}\right]^2 \\ g_m = \mu_n C_{ox}\frac{W}{L}\left[2 - V_X + R_1(I_1 - I_X) - V_{TH}\right] \end{cases}$

③ $V_X = 2 - V_{TH} + R_1 I_1 \Rightarrow$ OFF



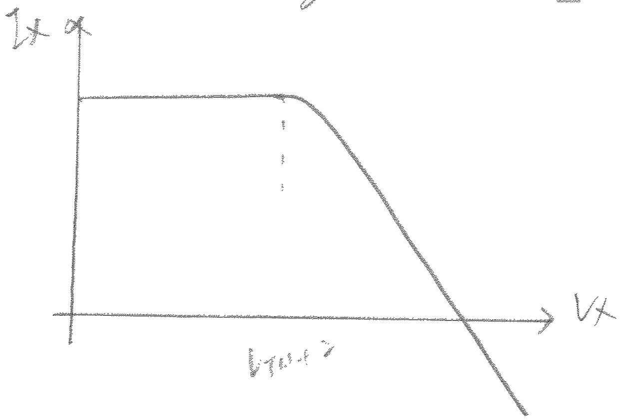



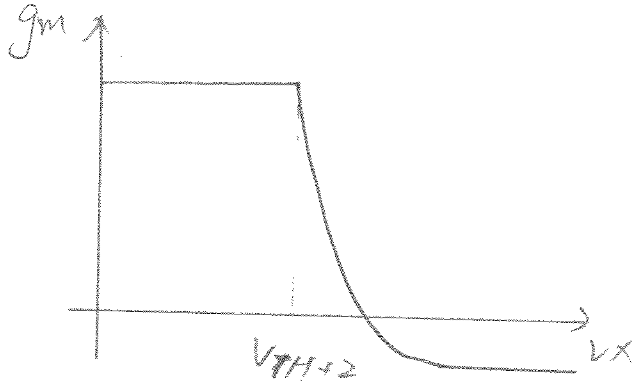
(d) $0 < V_X < 2 + V_{TH} \Rightarrow$ Sat

$$\begin{cases} I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[R_1(I_1 - I_X) - V_{TH}\right]^2 \\ g_m = \mu_n C_{ox}\frac{W}{L}\left[R_1(I_1 - I_X) - V_{TH}\right] \end{cases}$$

$V_X > 2 + V_{TH} \Rightarrow$ Triode

$$\begin{cases} I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[(R_1(I_1 - I_X) - V_{TH})^2 - (V_X - 2 - V_{TH})^2\right] \\ g_m = \mu_n C_{ox}\frac{W}{L}\left[R_1(I_1 - I_X) + 2 - V_X\right] \end{cases}$$



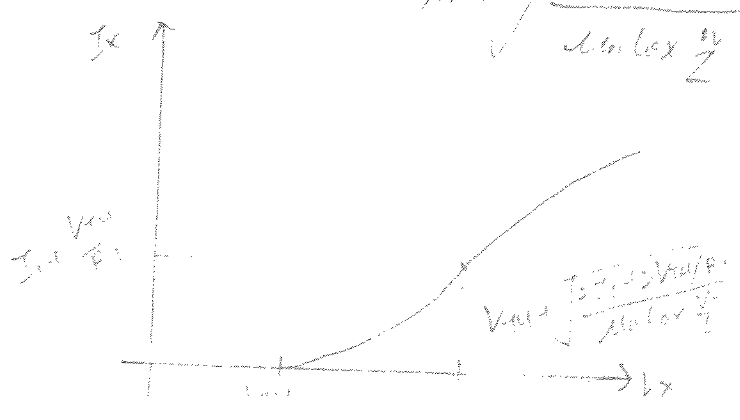

(e) (1) $0 < V_X < V_{TH} \Rightarrow$ OFF

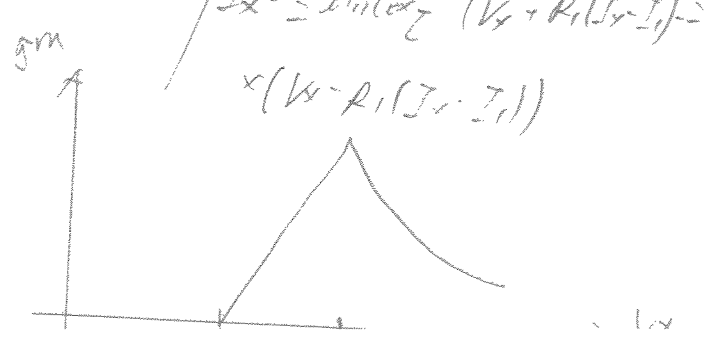
(2) $V_{TH} < V_X < V_{TH} + \sqrt{\dfrac{2I_1 + 2V_{TH}/R_1}{\mu_n C_{ox}\frac{W}{L}}}$

$$\Rightarrow \begin{cases} I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_X - V_{TH})^2 \\ g_m = \mu_n C_{ox}\frac{W}{L}(V_X - V_{TH}) \end{cases}$$

(3) $V_X > V_{TH} + \sqrt{\dfrac{2I_1 + 2V_{TH}/R_1}{\mu_n C_{ox}\frac{W}{L}}} \Rightarrow$ Triode

$$\begin{cases} g_m = \mu_n C_{ox}\frac{W}{L}(V_X - R_1(I_X - I_1)) \\ I_X = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_X + R_1(I_X - I_1) - 2V_{TH}) \times (V_X - R_1(I_X - I_1)) \end{cases}$$

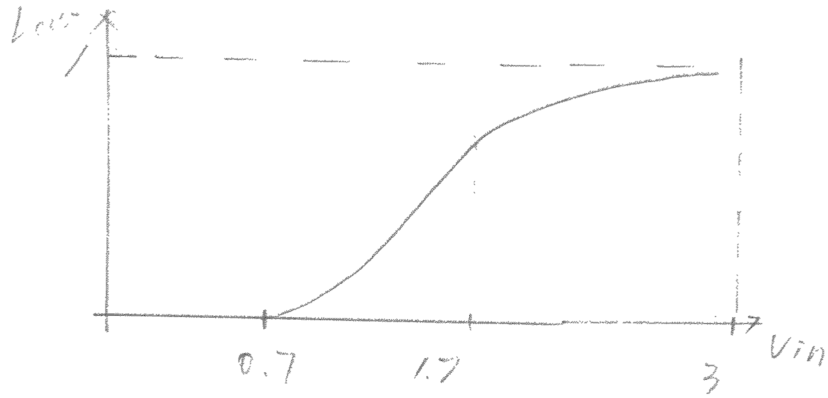


2.1 (a) $0 < V_{in} < 0.7 \Rightarrow$ OFF $\Rightarrow V_{out} = 0$

$0.7 < V_{in} < 1.7 \Rightarrow$ Sat

$1.7 < V_{in} < 3 \Rightarrow$ Triode. $\Rightarrow V_{DS} = 1 - V_{out}$

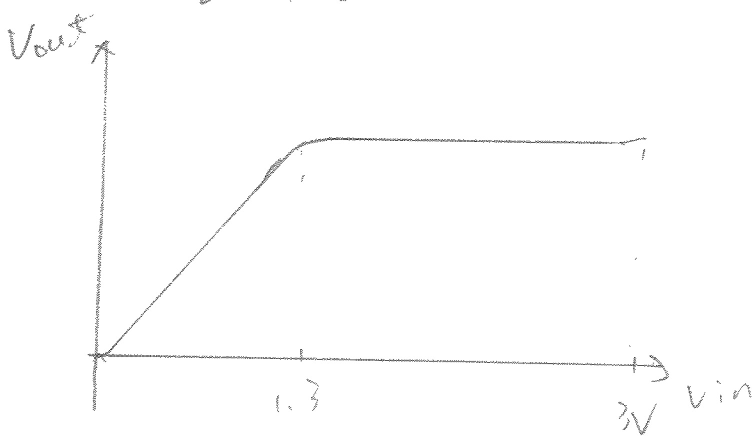



(b) $0 < V_{in} < 1.3 \Rightarrow$ Triode

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

$1.3 < V_{in} < 3 \Rightarrow$ Sat.

$V_{out}$ constant

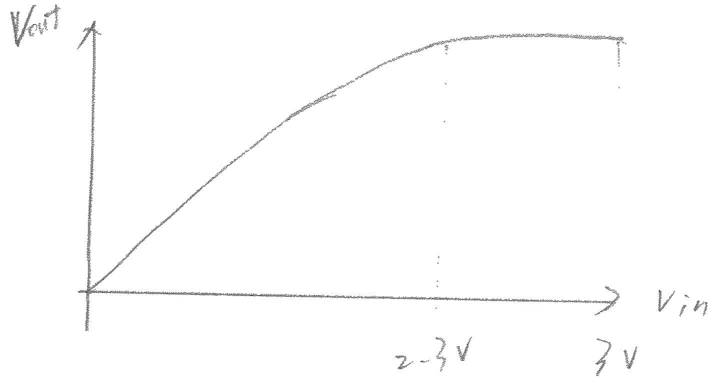


(c) $0 < V_{in} < 2.3 \Rightarrow$ Triode

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

$2.3 < V_{in} < 3 \Rightarrow$ Sat

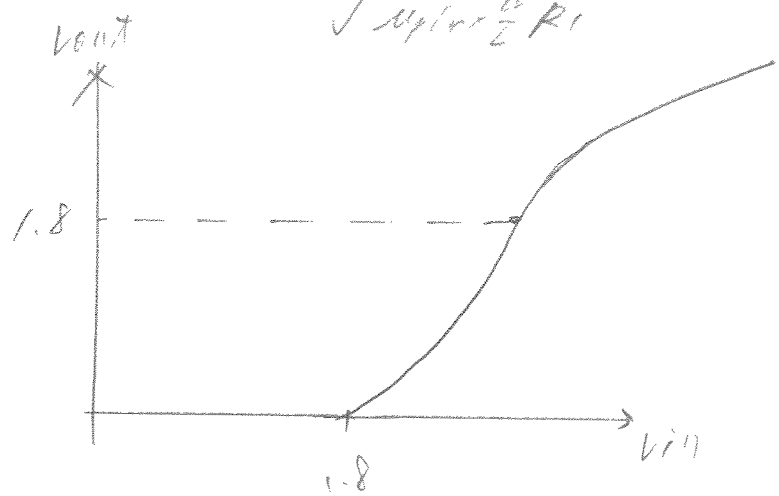
$V_{out}$ = constant



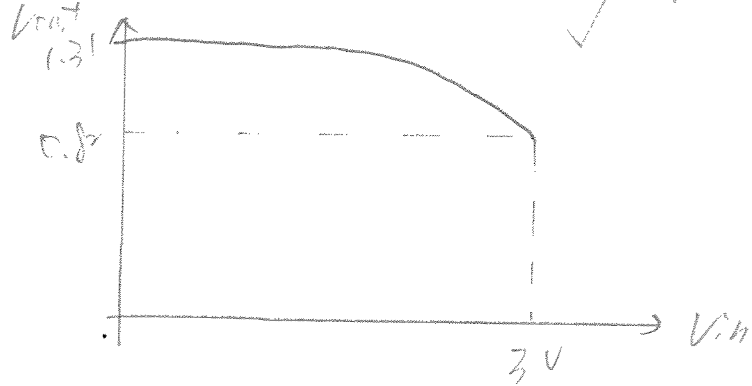

(d) $0 < V_{in} < 1.8 \Rightarrow$ OFF, $V_{out} = 0$

$1.8 < V_{in} < 1.8 + \sqrt{\frac{2 \times 1.8}{\mu_p C_{ox} \frac{W}{L} R_1}} \Rightarrow$ Sat

$V_{in} > 1.8 + \sqrt{\frac{2 \times 1.8}{\mu_p C_{ox} \frac{W}{L} R_1}} \Rightarrow$ Triode

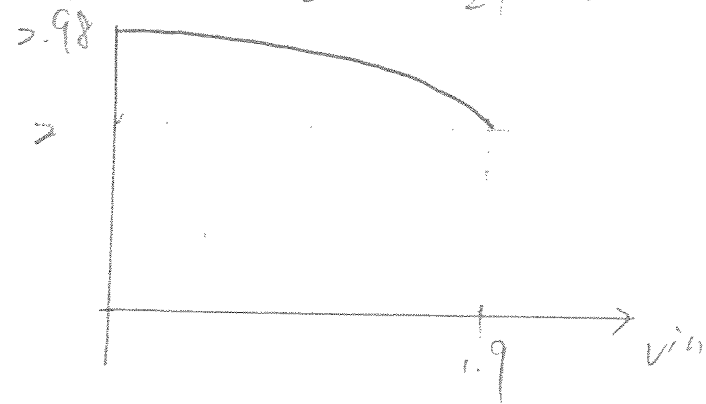


(a) $I_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{out} - V_{TH0} - \gamma\left(\sqrt{2\Phi_F + V_{DD} - V_{out} - V_{in}} - \sqrt{2\Phi_F}\right)\right)^2$




$\frac{W}{L} = \frac{50}{0.5}$ $I = 1mA$

(b) $V_{out} = 3 - R_1 \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(0.3 - 0.45\left(\sqrt{1.9 - V_{in}} - \sqrt{0.9}\right)\right)^2$

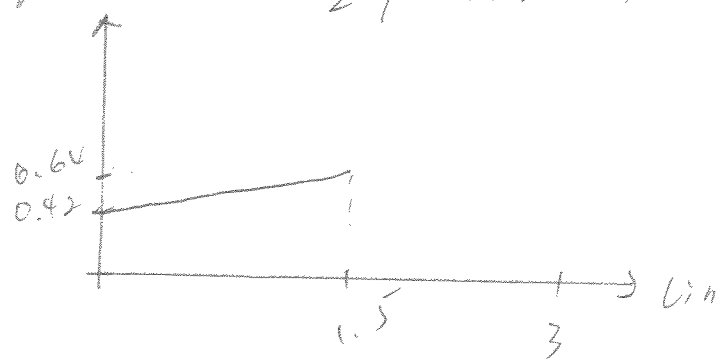



$\frac{W}{L} = \frac{50}{0.5}$

$R = 0.2K$

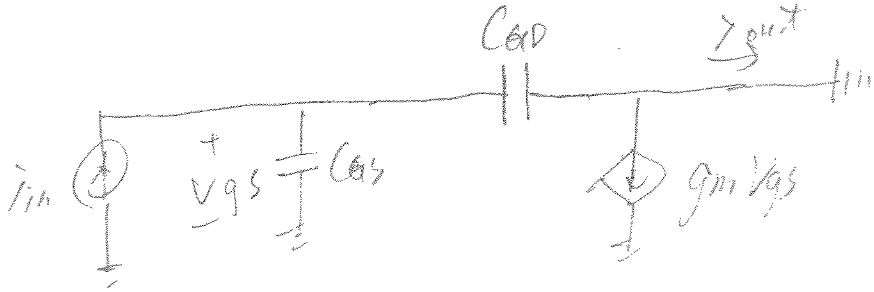
(c) $\frac{V_{out}}{R_1} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(2 - V_{out} - 0.7 - 0.45\left(\sqrt{0.9 + V_{out} - V_{in}} - \sqrt{0.9}\right)\right)^2$

$\frac{W}{L} = \frac{50}{0.5}$ $R = 1000\Omega$



(13)

(a)




$i_{in} = ((C_{GS}+C_{GD}) s V_{gs}$

$i_{out} = g_m V_{gs}$

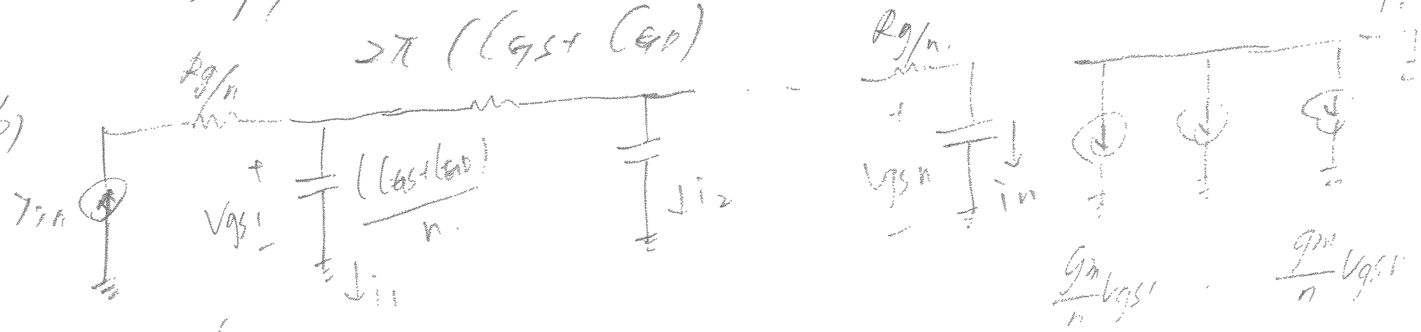
$$\Rightarrow \beta = \frac{i_{out}}{i_{in}} = \frac{g_m}{((C_{GS}+C_{GD})s}$$

By definition $|\beta| = 1 \Rightarrow \frac{g_m}{\omega_T((C_{GS}+C_{GD})} = 1$

$$\Rightarrow \omega_T = \frac{g_m}{C_{GS}+C_{GD}}$$

$$\Rightarrow f_T = \frac{g_m}{2\pi((C_{GS}+C_{GD})}$$

(b)




$i_k = \frac{1}{n}((C_{GS}+C_{GD}) s V_{gsk}, \quad k = 1 \ldots n$

$i_{in} = i_1+i_2+\ldots+i_n = \frac{1}{n}((C_{GS}+C_{GD}) s (V_{gs1}+V_{gs2}+\ldots V_{gsn})$

$i_{out} = \frac{g_m}{n}V_{gs1}+\ldots \frac{g_m}{n}V_{gsn} = \frac{g_m}{n}(V_{gs1}+\ldots+V_{gsn})$

$$\Rightarrow \beta = \frac{i_{out}}{i_{in}} = \frac{g_m}{((C_{GS}+C_{GD})s} \Rightarrow \omega_T = \frac{g_m}{C_{GS}+C_{GD}}$$

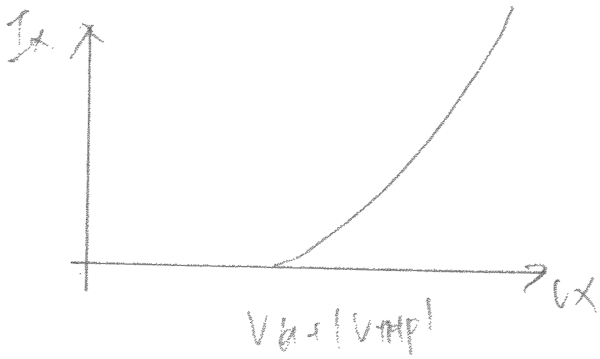
(c) $f_T = \frac{g_m}{2\pi (C_{GS} + C_{GD})}$

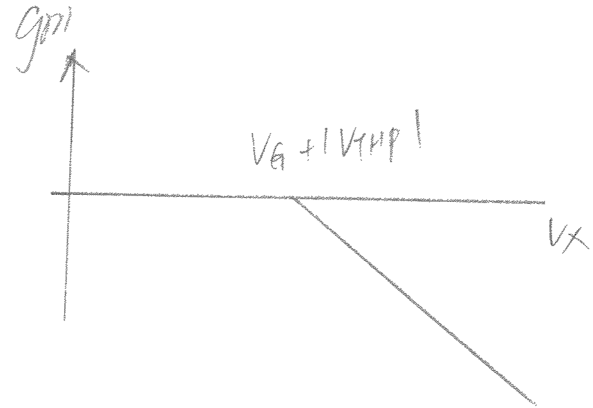
$g_m = \mu C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$

$C_{GS} + C_{GD} \approx C_{ox} \frac{W}{L}$

$\Rightarrow f_T = \frac{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)}{2\pi C_{ox} W \cdot L} \approx \frac{\mu}{2\pi} \frac{(V_{GS} - V_{TH})}{L^2}$

24 (a) Case I : $V_G < V_{THN}$



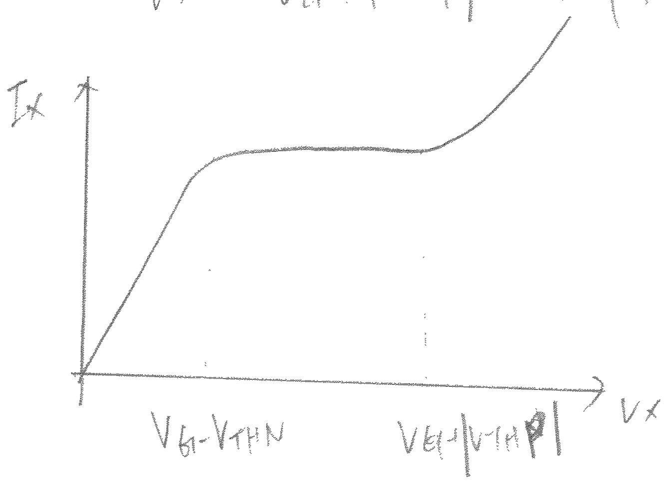



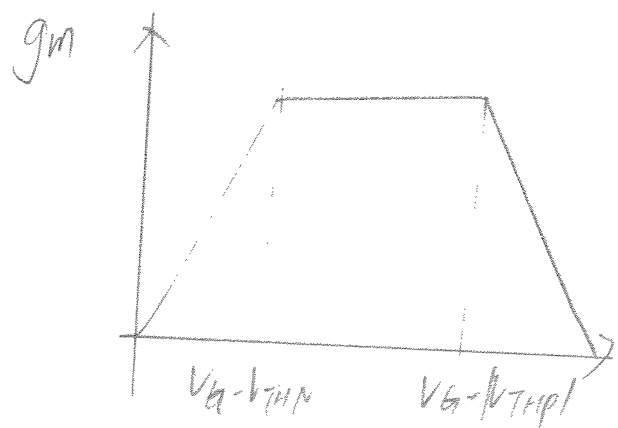

Case II : $V_G > V_{THN}$

$0 < V_X < V_G - V_{THN} \Rightarrow$ ($M_2$ off, $M_1$ triode)

$V_G - V_{THN} < V_X < V_G + |V_{THP}| \Rightarrow$ ($M_2$ off, $M_1$ sat)

$V_X > V_G + |V_{THP}| \Rightarrow$ ($M_1$, $M_2$ sat)



(b). Case I $V_G < V_{THN} \Rightarrow M_1$ off, $\begin{cases} I_x = 0 \\ g_m = 0 \end{cases}$

Case II $V_G > V_{THN}$

$0 < V_X < V_G + |V_{THP}| \Rightarrow I_x = 0$. ($M_2$ off) $g_m = 0$

Case III

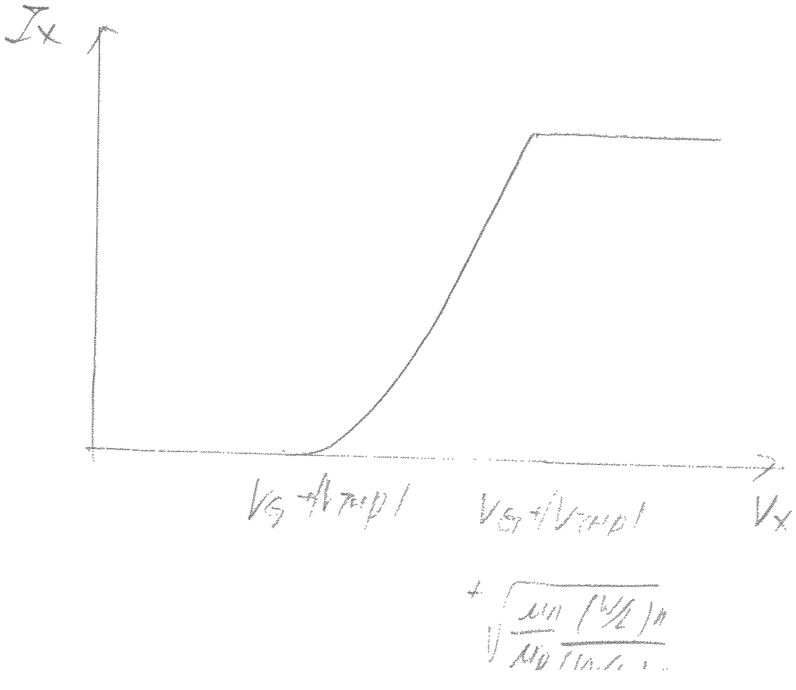
$V_G + |V_{THP}| < V_X < V_G + |V_{THP}| + \sqrt{\frac{\mu_n (W/L)_n}{\mu_p (W/L)_p}} (V_G - V_{THN})$

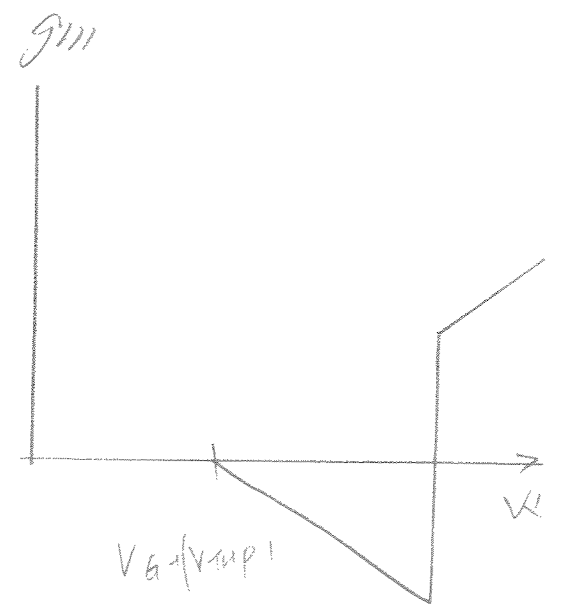
($M_2$ sat. $M_1$ triode)

Case IV

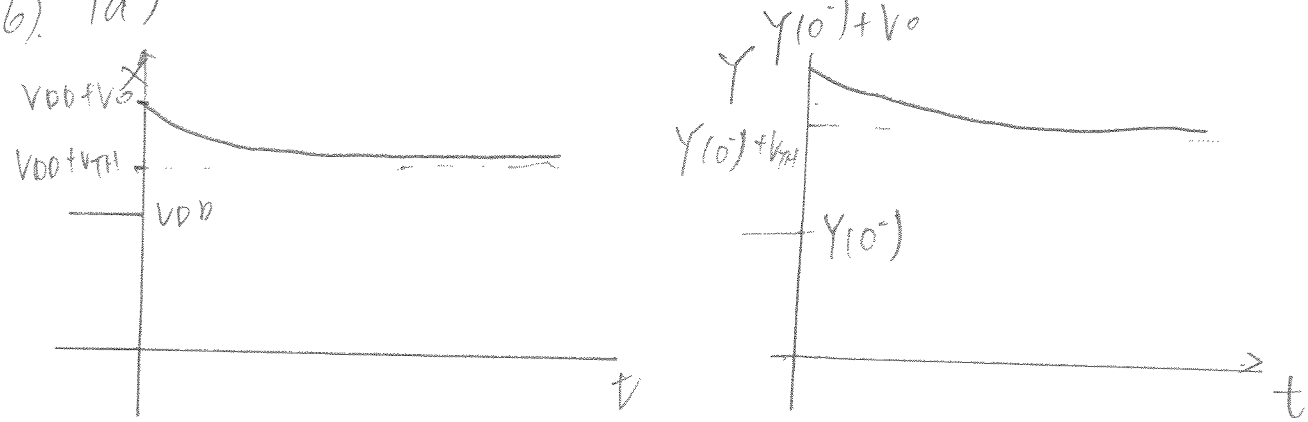
$V_X > V_G + |V_{THP}| + \sqrt{\frac{\mu_n (W/L)_n}{\mu_p (W/L)_p}} (V_G - V_{THN})$

($M_1$ sat. $M_2$ sat)

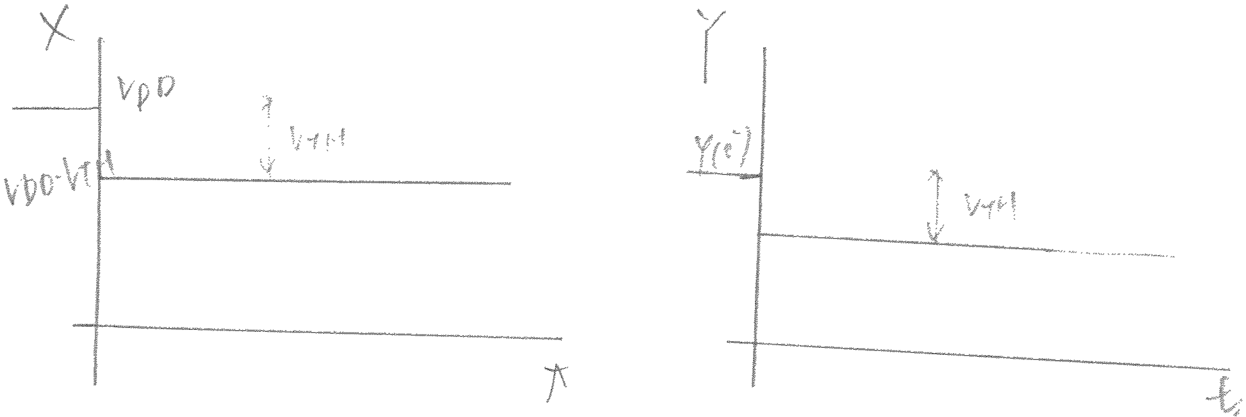


(26). (a)


X
VDD+V0
VDD+VTH
VDD
t
Y
Y(0⁻)+V0
Y(0⁻)+VTH
Y(0⁻)
t

(b)


X
VDD
VTH
VDD-VTH
t
Y
Y(0⁻)
VTH
t