HW4

1. $V_{ov} = V_{GS} - V_t$

$\Rightarrow 0.2 = V_{GS} - 0.5$

$\Rightarrow V_{GS} = 0.7V$

$V_{DS} = 1V$

$V_{DS} > V_{GS} - V_{th}$

$I_D = \frac{1}{2} \cdot k_n (V_{GS} - V_{ov})^2$

$= \frac{10 \times 10^{-3} \times (0.2)^2}{2}$

$= 0.2mA$

$I_D = \frac{V_{DD} - V_{DS}}{R_D}$

$\Rightarrow 0.2 \times 10^{-3} = \frac{5-1}{R_D}$

$\Rightarrow R_D = 20k\Omega$ #

$g_m = \frac{2I_D}{V_{ov}}$

$= \frac{2(0.2 \times 10^{-3})}{0.2}$

$= 2 \times 10^{-3}$ #

$A_v = -g_m \cdot R_D$

$= -(2 \times 10^{-3}) 20 \times 10^3$

$= -40\ V/V$ #

$V_O > V_{GS} - V_t$

$V_O + v_o > V_{GS} - V_t$

$1 + v_o > 0.2$

$v_o > 0.2 - 1$

$v_o > 0.8V$

$\Rightarrow$ the negative swing of the output should be less than 0.8V, so the maximum allowable negative swing is about $-0.79V$ #

$A_v = \frac{v_o}{v_s}$

$\Rightarrow -40 = \frac{v_o}{-0.79V}$

$\Rightarrow v_o \doteqdot 19.5mV$ #

(b) $\frac{1}{2} k_n \cdot (V_{GS} - V_t)^2 = \frac{V_{DD} - (V_{GS} - V_t)}{R_D}$

$\Rightarrow \frac{1}{2} \times 10^{-2} \times V_{ov}^2 = \frac{5 - V_{ov}}{20 \times 10^3}$

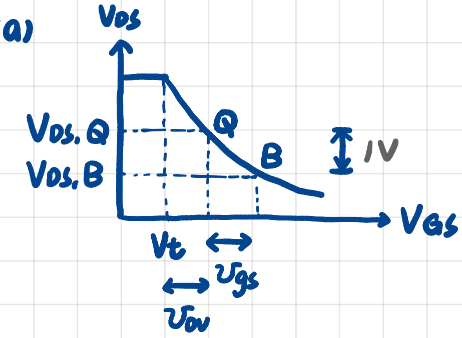
$\Rightarrow V_{ov} = 0.219 = V_{DS}$

$\Rightarrow V_{GS} = 0.219 + V_t$

$= 0.719$

$B(0.719, 0.219)$ #

2. (a)



① $V_{DS} + 0.5 \le V_{DD}$

$\Rightarrow V_{DS} \le 4.5$

② $V_{DS} - 0.5 \ge V_{ov}$

$\Rightarrow V_{DS} \ge 0.7$ #

$V_{DS,Q} = V_{DS,B} + 0.5V$

$V_{ov,B} = \frac{\sqrt{2k_nR_DV_{DD}+1} - 1}{k_nR_D} = V_{DS,B}$ —— ①

$V_{DS,B} = V_{ov} + \hat{V}_{gs} = 0.2 + \frac{2.5}{k_n \cdot R_D}$ —— ②

$\hat{V}_{gs} = \frac{0.5}{|A_v|} = \frac{0.5}{k_nR_DV_{ov}} = \frac{0.5}{k_nR_D(0.2)} = \frac{2.5}{k_nR_D}$

①,② $\Rightarrow \frac{\sqrt{2k_nR_DV_{DD}+1} - 1}{k_nR_D} = 0.2 + \frac{2.5}{k_nR_D}$

$\Rightarrow \sqrt{2k_nR_D(5)+1} = 0.2k_nR_D + 3.5$

$\Rightarrow k_nR_D = 213.684$

① $\Rightarrow V_{DS,B} = \frac{\sqrt{2(213.684)(5)+1} - 1}{213.684} = 0.212V$

$\therefore V_{DS,Q} = 0.212 + 0.5 = 0.712V$ #

(b) $A_v = -k_nR_DV_{ov}$

$= -213.684 \times 0.2$

$= -42.7368$ #

$|A_v| = \frac{\hat{V}_{ds}}{\hat{V}_{gs}} \Rightarrow 42.7368 = \frac{0.5V}{\hat{V}_{gs}}$ $\therefore \hat{V}_{gs} = 0.0117V$ #

$A_v = -g_mR_D = -\frac{2I_DR_D}{V_{ov}} = \frac{-2(V_{DD} - V_{DS})}{V_{ov}} = -43V/V = \frac{0.5}{V_{gs}}$

(c) $V_D = I_DR_D = V_{DD} - V_{DS}$

$\Rightarrow R_D = \frac{5 - 0.712}{100 \times 10^{-6}} = 42.88k\Omega$ #

(d) $A_v = -k_n'\left(\frac{W}{L}\right)V_{ov}\cdot R_D$

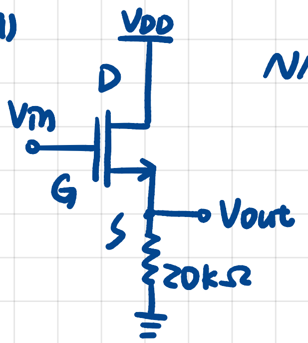
$\Rightarrow -42.7368 = -200\times10^{-6}A/V^2\cdot\left(\frac{W}{L}\right)\times0.2V\times42.88k\Omega$

$\Rightarrow \frac{W}{L}=24.9$ #

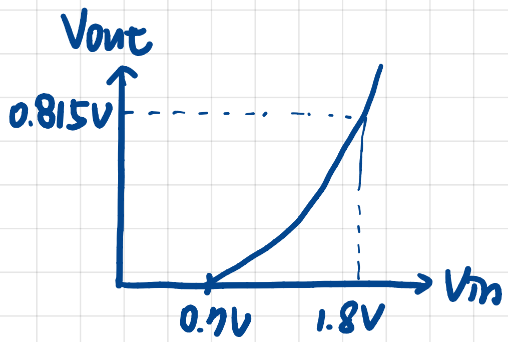
3. 脫離 cut-off：$V_{GS}-V_{th}>0$

脫離 sat.：$V_{DS}<V_{ov}$

(a)



NMOS



① $V_{in}=0$

$V_{GS}=\underset{0}{V_{in}}-V_{out}$

$V_{GS}-\underset{0.7V}{V_{th}}>0$

$V_{in}-V_{out}-\underset{0.7}{V_{th}}>0$

② sat.
$$\begin{cases} I_D=\frac{1}{2}\times200\times10^{-6}\times5\times(V_{GS}-V_{th})^2 \\ \quad =5\times10^{-4}\times(V_{in}-V_{out}-0.7)^2 \\ \frac{V_{out}-0}{20k}=I_D \end{cases}$$

$\Rightarrow \frac{V_{out}}{20k}=5\times10^{-4}(1.1-V_{out})^2$

$\Rightarrow V_{out}=0.815$ or 1.485

檢查有沒有符合 $V_{GS}-V_{th}>0$

$V_{in}-V_{out}>0.7$

∴1.485不合

③要跑到 linear $\Rightarrow V_{DS}<V_{ov}$

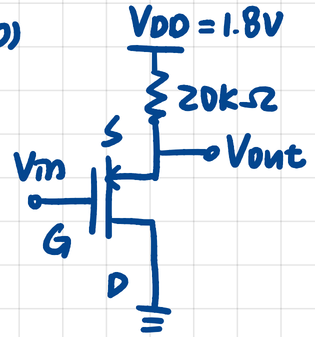
$\underset{1.8}{V_{DD}}-\cancel{V_{out}} > V_{GS}-V_{th}$

$\qquad\qquad\qquad \underset{1.8}{V_{in}}-\cancel{V_{out}}-\underset{0.7}{V_{th}}$

$\Rightarrow$ ∵V_{in}就算最大了 $V_{DS}>V_{ov}$

∴不會進到 linear

(b)



PMOS

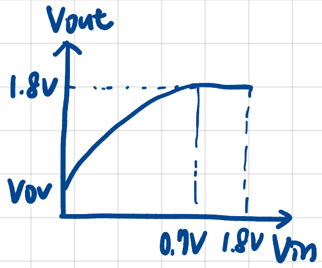
② sat. $\begin{cases} I_D = \frac{1}{2} \times 200 \times 10^{-6} \times 5 \times (V_{out} - V_{in} - 0.7)^2 \\ \frac{1.8 - V_{out}}{20k} = I_D \end{cases}$

$\Rightarrow \frac{1.8 - V_{out}}{20k} = 5 \times 10^{-4} (V_{out} - 2.5)^2$

$\Rightarrow 1.8 - V_{out} = 10 (V_{out} - 2.5)^2$

① $V_{SG} > |V_{th}|$

$V_{out} - V_{in} > 0.7$



③ linear $\Rightarrow V_{SD} < |V_{ov}|$

$V_{out} - 0 \qquad V_{SG} - V_{th}$

$\cancel{V_{out}} > \cancel{V_{out}} - V_{in} - \underset{0.7}{V_{th}}$

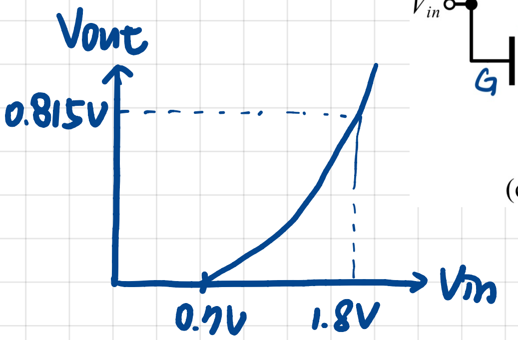
$\because V_{in} > 0 \ \therefore V_{SD} > |V_{ov}|$ (always)

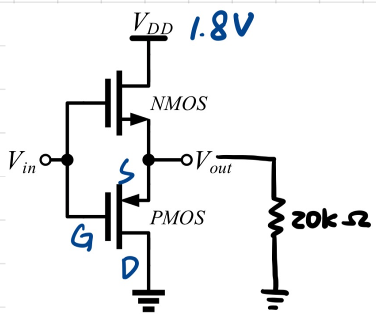
∴ 不會進到 linear

(c) ∵ PMOS 不會通

∴ 可忽略不計

⇒ 則 (c) 和 (a) 相同





(c)

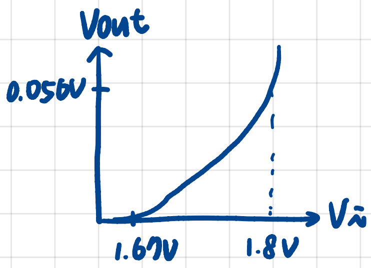
4. $V_{th} = 0.7 + 0.4(\sqrt{1.7} - \sqrt{0.7}) V^{\frac{1}{2}}$
≈ 1.67

(a) $I_D = \frac{1}{\cancel{2}} \times \overset{100}{\cancel{200}} \times 10^{-6} \times 5 \times (V_{GS} - V_{th})^2$

$= 10^{-4} \times 5 \times (1.8 - V_{out} - 1.67)^2$

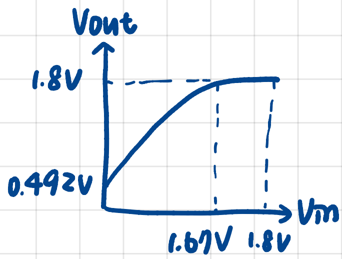
$= \dfrac{V_{out} - 0}{20 \times 10^3}$

$\Rightarrow V_{out} = 0.\cancel{8}04$ or 0.056



(b) $I_D(1.8 - V_{out} - 1.67)^2 = 1.8 - V_S$

$\Rightarrow V_S = 0.492$ or $-0.\cancel{8}32$



(c) 同(a) #

5. (a) $I_D = \frac{1}{2} \mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_{th})^2$

$= \frac{1}{2} \cdot 5 \times 10^{-3} \times (0.6 - 0.4)^2$

$= \cancel{\frac{1}{2}} \times 5 \times 10^{-3} \times \overset{0.02}{\cancel{0.04}}$

$= 10^{-4} A$ #

$1.8 - 10^{-4} \times 10 \times 10^3 = V_{DS}$

$\Rightarrow V_{DS} = 0.8V$ #

(b) $g_m = k_n(V_{GS} - V_{th})$ $\qquad g_m = \dfrac{2I_D}{V_{ov}}$

$= 5 \times 10^{-3}(0.6 - 0.4)$

$= 5 \times 10^{-3} \times 0.2$

$= 10^{-3}$ #

(c) $A_v = -g_m R_D$

$= -10^{-3} \cdot 10 \times 10^3$

$= -10 \, V/V$ #

(d) $r_o = \dfrac{1}{\lambda I_D}$

$= \dfrac{1}{0.1 \cdot 10^{-4}} = 10^5 \Omega$ #

$A_v = -g_m(r_o \| R_D)$

$= -10^{-3} \cdot \dfrac{10^5 \times 10^4}{10^5 + 10^4}$

$= -9.09 \, V/V$ #

6. NMOS

(a) $A_v = g_m R_o = 10\ V/V$

$\Rightarrow g_m \cdot 20\times 10^3 = 10$

$\Rightarrow g_m = 5\times 10^{-4}\ A/V$ #

(b) $V_D = 0.2V$

$V_{DD} = V_D + I_D \cdot R_D$

$\Rightarrow 1.8 = 0.2 + I_D \cdot 20\times 10^3$

$\Rightarrow I_D = 8\times 10^{-5} A$ #

$g_m = \frac{2I_D}{V_{ov}}$

$\Rightarrow V_{ov} = \frac{16\times 10^{-5}}{5\times 10^{-4}} = 3.2\times 10^{-1}\ V$ #

(c) $g_m = \mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot V_{ov}$

$\Rightarrow 5\times 10^{-4} = 200\times 10^{-6} \cdot \frac{W}{L} \cdot 3.2\times 10^{-1}$

$\Rightarrow \frac{W}{L} = 7.81$ #

(d) $V_{th} = 0.4V$

$I_{DS} = \frac{1}{2}\mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_{th})^2$

$\Rightarrow 8\times 10^{-5} = \frac{1}{2} \times \frac{5\times 10^{-4}}{3.2\times 10^{-1}} \times (V_{GS} - 0.4)^2$

$\Rightarrow 16\times \cancel{10^{-5}} = \frac{5\times \cancel{10^{-4}}}{32\times \cancel{10^{-2}}} \times \cancel{10^{-2}} \times (V_{GS} - 0.4)^2$

10^{-3}

$\Rightarrow \left[16 \times \frac{32}{5} \times 10^{-3}\right]^{\frac{1}{2}} + 0.4 = V_{GS}$

$\Rightarrow V_{GS} = 0.72V$ #