HW3SOLUTION

2019年2月17日 15:31

1、a) NMOS Saturation

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right)(V_{GS} - V_{tn})^2 (1 + \lambda V_{DS})$$

$$= \frac{1}{2} \cdot 20.54u \cdot \left(\frac{144u}{8u}\right)(7-1.3)^2 (1 + 15\times10^{-3} \times 7) \ (A)$$

$$= \frac{1}{2} \cdot 20.54u \cdot 18 \cdot 5.7^2 \cdot 1.105$$

$$= 6.637 \times 10^3 \, uA = 6.637 \, mA$$

b) triode region

$$I_D = k_n' \left(\frac{W}{L}\right)\left[(V_{GS} - V_{tn}) V_{DS} - \frac{1}{2} V_{DS}^2\right]$$

$$= 20.54u \left(\frac{144u}{8u}\right)\left[(5-1.3) \times 2 - \frac{1}{2} \cdot 2^2\right]$$

$$= 20.54u \cdot 18 \,(3.7 \times 2 - 2)$$

$$= 1.996 \times 10^3 \, uA = 1.996 \, mA$$

c) $V_{DS} = V_{GS} = -7V$, $V_{tp} = -1.5V$

$V_{SD} = 7V > 5.5V = V_{SG} - |V_{tp}|$

pMOS works in Saturation region,

$$I_D = \frac{1}{2} k_p' \left(\frac{W}{L}\right)(V_{SG} - |V_{tp}|)^2 (1 + \lambda V_{SD})$$

$$= \frac{1}{2} \cdot 10.32u \left(\frac{328u}{8u}\right)(7-1.5)^2 (1 + 15\times10^{-3} \cdot 7)$$

$$= \frac{1}{2} \cdot 10.32u \cdot 41 \cdot 5.5^2 \cdot 1.105$$

$$= 7.0717 \, mA$$

larger than I_D of NMOS

The difference comes from different K, W, V_t

2、a) Saturation:

$$g_m = \frac{\partial i_D}{\partial v_{GS}}\Big| = k_n' \left(\frac{W}{L}\right)(V_{GS} - V_{tn})(1 + \lambda V_{DS})$$

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}} = k_n'\left(\frac{W}{L}\right)(V_{GS}-V_{tn})(1+\lambda V_{DS})$$

$$= 20.54u\left(\frac{144u}{8u}\right)(7-1.3)\cdot 1.105 \approx 2.3287\times10^{-3}\,S$$

$$g_o = \left.\frac{\partial i_D}{\partial v_{DS}}\right|_{v_{DS}=V_{DS}} = \lambda\cdot\frac{1}{2}k_n'(V_{GS}-V_{tn})^2\left(\frac{W}{L}\right)$$

$$= 15\times10^{-3}\times\frac{1}{2}\times 20.54u\left(\frac{144u}{8u}\right)\cdot(7-1.3)^2$$

$$\approx 9.009\times10^{-5}\,S$$

$$\begin{bmatrix} i_g \\ i_d \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ g_m & g_o \end{bmatrix}\begin{bmatrix} v_{gs} \\ v_{ds} \end{bmatrix}$$

$$\text{so } Y = \begin{bmatrix} 0 & 0 \\ 2.3287\times10^{-3}\,S & 9.009\times10^{-5}\,S \end{bmatrix}$$

triode:

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}} = k_n'\left(\frac{W}{L}\right)V_{DS}$$

$$= 20.54u\left(\frac{144u}{8u}\right)\cdot 2 = 7.3944\times10^{-4}\,S$$

$$g_o = \left.\frac{\partial i_D}{\partial v_{DS}}\right|_{v_{DS}=V_{DS}} = k_n'\left(\frac{W}{L}\right)\left[(V_{GS}-V_{tn})-V_{DS}\right]$$

$$= 20.54u\cdot 18\,(5-1.3-2) = 6.2852\times10^{-4}\,S$$

$$\text{so } Y = \begin{bmatrix} 0 & 0 \\ 7.3944\times10^{-4}\,S & 6.2852\times10^{-4}\,S \end{bmatrix}$$

b) Similarly

$$g_m = k_p'\left(\frac{W}{L}\right)(V_{SG} - |V_{tp}|)(1 + \lambda V_{SD})$$

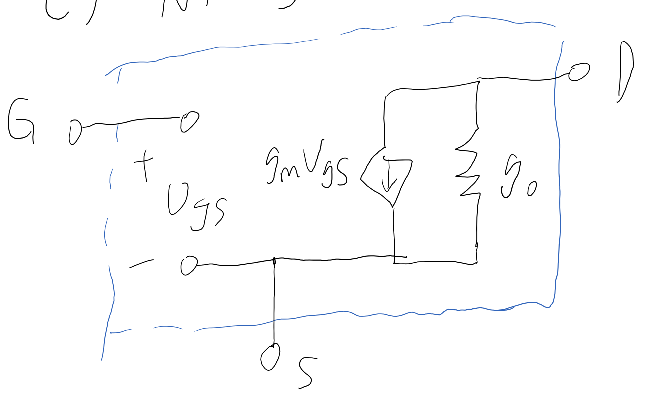
$$= 10.32u \cdot 41 \cdot (7 - 1.5) \cdot 1.105 \approx 2.5715 \times 10^{-3} S$$

$$g_o = \lambda \cdot \frac{1}{2} k_p'\left(\frac{W}{L}\right)(V_{SG} - |V_{tp}|)^2$$

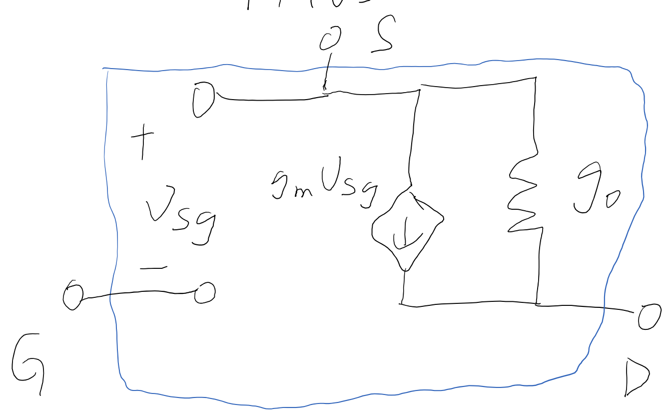
$$= 15 \times 10^{-3} \cdot \frac{1}{2} \cdot 10.32u \cdot 41 \cdot 5.5^2 \approx 9.60 \times 10^{-5} S$$

$$\begin{bmatrix} i_g \\ i_g \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 2.57 \times 10^{-3} S & 9.60 \times 10^{-5} S \end{bmatrix} \begin{bmatrix} v_{sg} \\ v_{sd} \end{bmatrix}$$

c) NMOS



PMOS



Difference: source and drain are reversed

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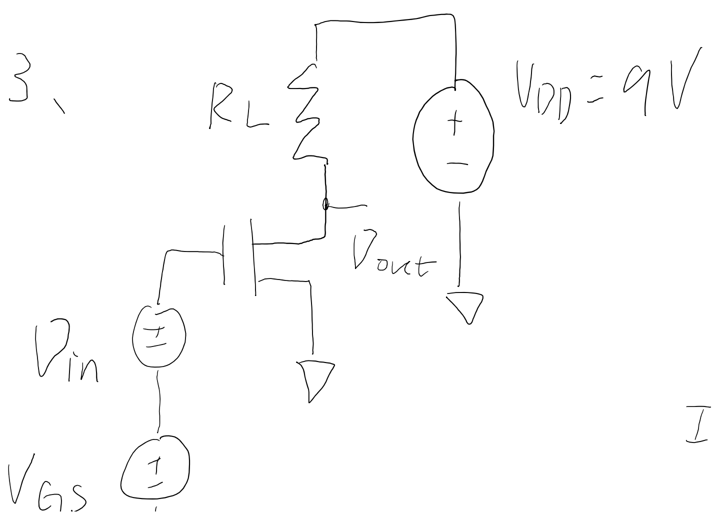


a)

Q Point

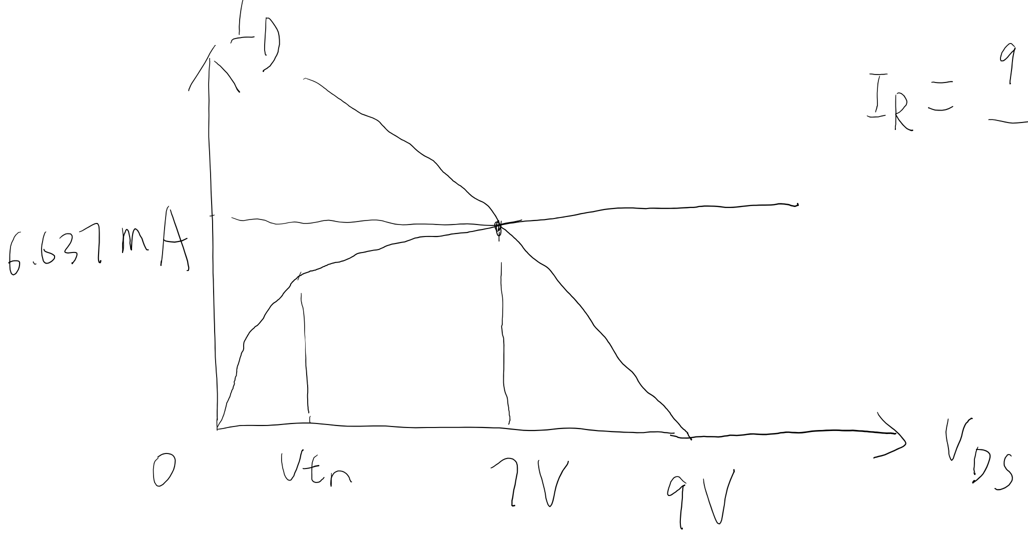
$V_{GS} = V_{DS} = 7V$

$I_D = 6.637 mA$

$I_D = 6.637\,mA$

$V_{DD} - V_{DS} = I_D \cdot R_L$

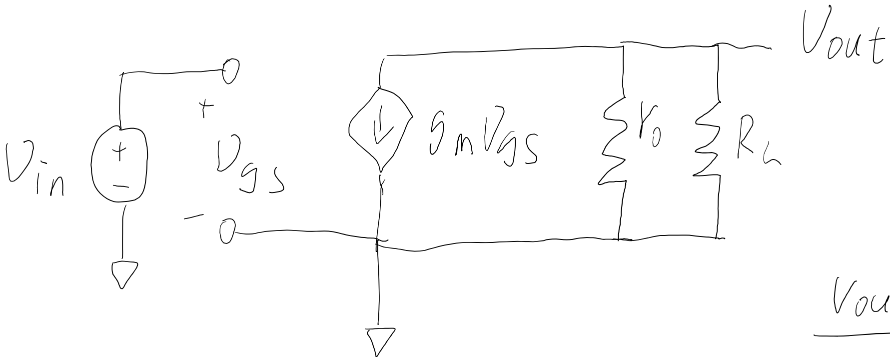
$$R_L = \frac{9V - 7V}{6.637m} = 0.301\,k\Omega$$



$$I_R = \frac{9V - V_{DS}}{R_L}$$

b) $A_{v\,ideal} = -g_m R_L = -2.3287 \times 10^{-3} \times 0.301 \times 10^{3}$

$= -0.7009$



KCL at V_{out}:

$$g_m V_{in} = \frac{0 - V_{out}}{r_o} + \frac{0 - V_{out}}{R_L}$$

$$\frac{V_{out}}{V_{in}} = -\frac{1}{\frac{1}{R_L} + \frac{1}{r_o}} g_m$$

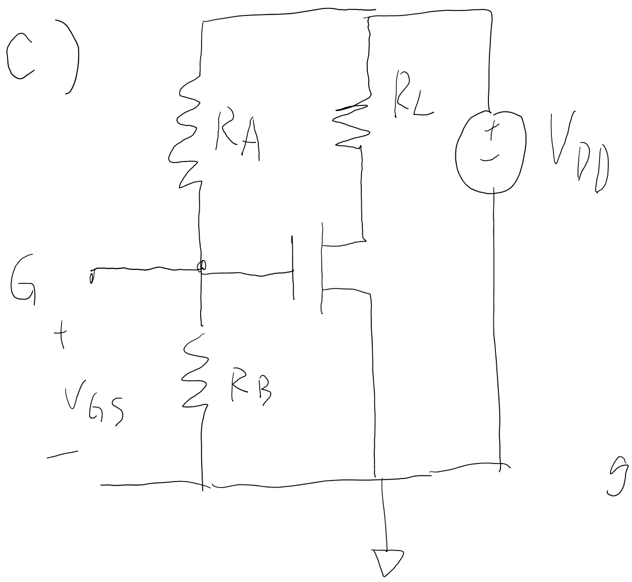
$$= -g_m (R_L // r_o)$$

$$A_{v\text{-}r_o} = -g_m \cdot \frac{1}{\frac{1}{R_L} + g_o} = -\frac{2.3287 \times 10^{-3}}{\frac{1}{0.301 \times 10^3} + 9.009 \times 10^{-5}}$$

$= -0.6824$

with r_o parallel to R_L, $|A_v|$ becomes smaller

c)



$V_{DD} = 9V$

$V_{GS} = 7V$

$$\frac{R_A}{R_B} = -1 + \frac{V_{DD}}{V_{GS}} = \frac{2}{7}$$

give $R_A = 2\,M\Omega$

$R_B = 7\,M\Omega$