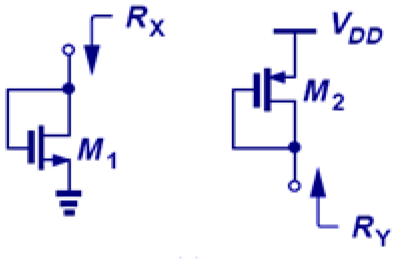
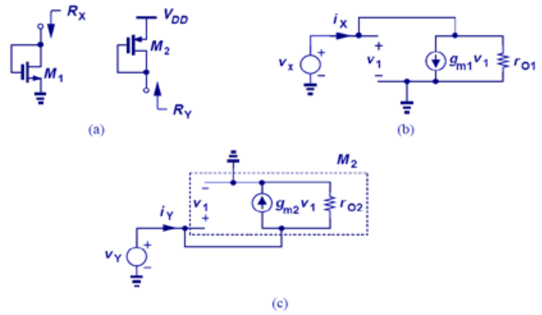
Digital Electronics Spring 2010 Final exam 06/28/2010

Name: ID#

1. In the following circuit, determine the small signal resistances of R_X and R_Y. (5%)



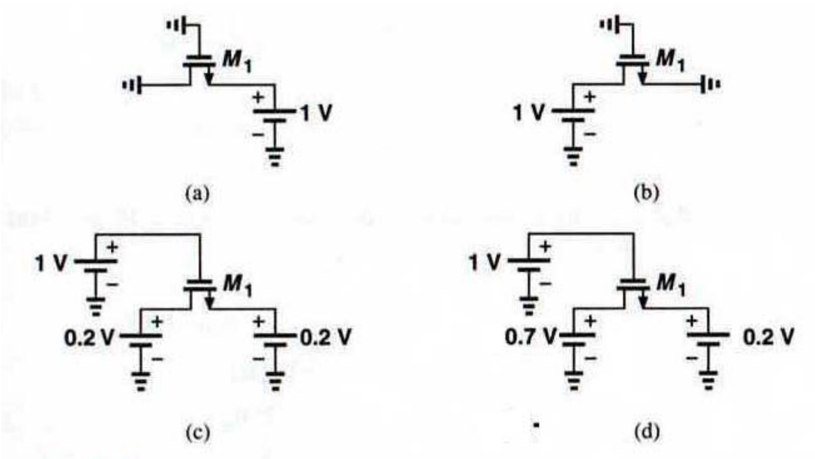
Ans:



$$R_X = \frac{v_X}{i_X} = (g_{m1} v_X + \frac{v_X}{r_{O1}}) \frac{1}{i_X} = \frac{1}{g_{m1}} \| r_{O1}$$

$$R_Y = \frac{v_Y}{i_Y} = (g_{m2} v_Y + \frac{v_Y}{r_{O2}}) \frac{1}{i_Y} = \frac{1}{g_{m2}} \| r_{O2}$$

2. Determine the region of operation of M_1 in each of circuits shown below. (10%) V_{THN}=0.6V



Ans:

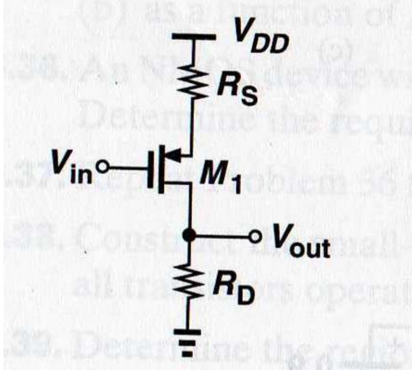
2a. (a) OFF ∵ $V_{GS} = 0$ $(V_{GS} < V_{TH})$

(b) OFF ∵ $V_{GS} = 0$ $(V_{GS} < V_{TH})$

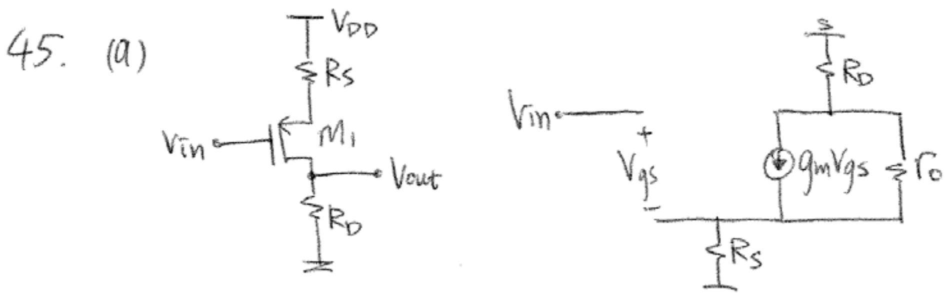
(c) TRIODE (LINEAR) ∵ $V_{GS} > V_{TH}$ & $V_{DS} \ll 2(V_{GS} - V_{TH})$

(d) SATURATION ∵ $V_{GS} > V_{TH}$ & $V_{DS} > V_{GS} - V_{TH}$

3. Construct the small-signal model of the following circuit if the transistor operates in saturation and assume λ=0 (5%).



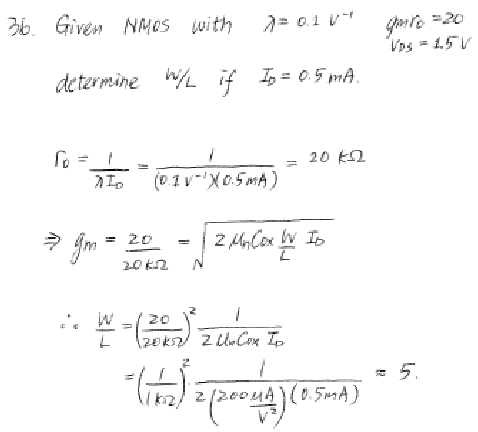
Ans:



5. An NMOS device with λ=0.1V^{-1} must provide a $g_m r_o$ of 20 with V_{DS}=1.5V, Determine the required value of W/L if I_D=0.5mA. (5%)

$\mu_n C_{ox}$ =200 $\mu A/V^2$ $\mu_p C_{ox}$ =100 $\mu A/V^2$ V_{THN}=0.4V V_{THP}=−0.4V

Ans:



36. Given NMOS with $\lambda = 0.1\,V^{-1}$ $g_m r_o = 20$, $V_{DS} = 1.5\,V$

determine W/L if $I_D = 0.5\,mA$.

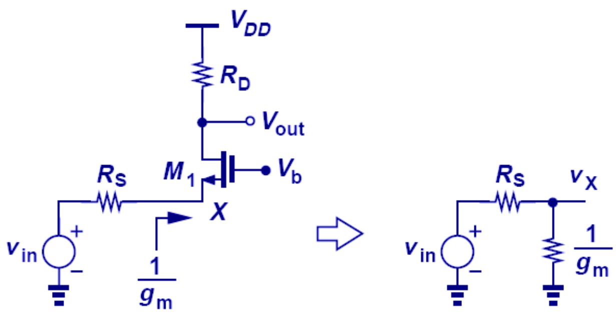
$$r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.1V^{-1})(0.5mA)} = 20\,k\Omega$$

$$\Rightarrow g_m = \frac{20}{20\,k\Omega} = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}$$

$$\therefore \frac{W}{L} = \left(\frac{20}{20k\Omega}\right)^2 \frac{1}{2\mu_n C_{ox} I_D}$$

$$= \left(\frac{1}{1k\Omega}\right)^2 \frac{1}{2\left(200\frac{\mu A}{V^2}\right)(0.5mA)} \approx 5.$$

6. Please find the gain of following common gate stage with signal source resistance. (5%)



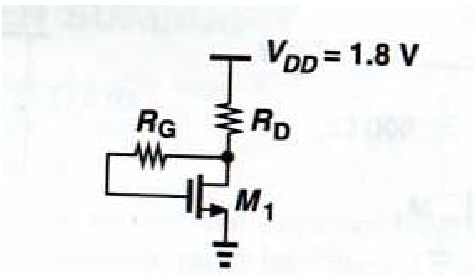
Ans:

$$v_X = \frac{\frac{1}{g_m}}{\frac{1}{g_m} + R_S} v_{in} = \frac{1}{1 + g_m R_S} v_{in}$$

$$\frac{v_{out}}{v_{in}} = \frac{v_{out}}{v_X}\frac{v_X}{v_{in}} = \frac{g_m R_D}{1 + g_m R_S} = \frac{R_D}{\frac{1}{g_m} + R_S}$$

7. The self-biased stage of the following figure must be designed for a drain current of 1 mA. If M_1 is to provide a transconductance of $1/(100\Omega)$, calculate the required value of R_D. (5%)

$\mu_n C_{ox}$ =200 $\mu A/V^2$ $\mu_p C_{ox}$ =100 $\mu A/V^2$ V_{THN}=0.4V V_{THP}=−0.4V



Ans:

7.6

$$I_D = 1 \text{ mA}$$

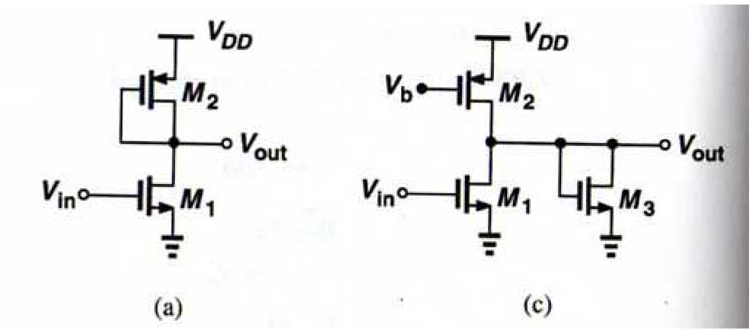
$$g_m = \frac{2I_D}{V_{GS} - V_{TH}} = \frac{1}{100}$$

$$V_{GS} = 0.6 \text{ V}$$

$$V_{GS} = V_{DD} - I_D R_D$$

$$R_D = \boxed{1.2 \text{ k}\Omega}$$

8. If $\lambda \neq 0$, determine the voltage gain of the stages shown in the following Figure (5%)



Ans:

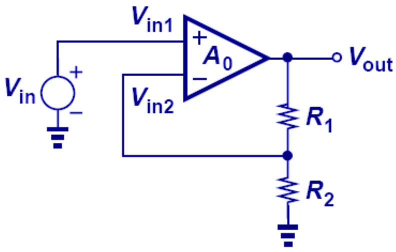
(a)

$$A_v = \boxed{-g_{m1}\left(r_{o1} \parallel \frac{1}{g_{m2}} \parallel r_{o2}\right)}$$

(c)

$$A_v = \boxed{-g_{m1}\left(r_{o1} \parallel r_{o2} \parallel \frac{1}{g_{m3}} \parallel r_{o3}\right)}$$

9. Please find the gain of the following non-inverting amplifier (Infinite A_0) (5%)



Ans:

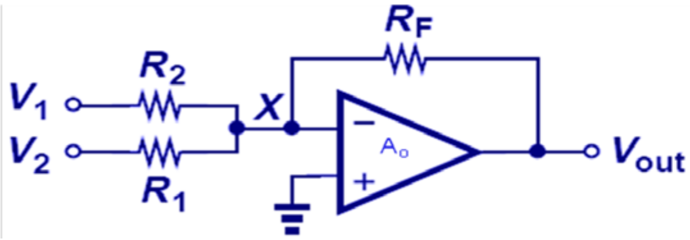
$$V_{in2} = \frac{R_2}{R_1 + R_2} V_{out}$$

$$V_{in2} \approx V_{in1} \approx \frac{R_2}{R_1 + R_2} V_{out}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_2}$$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_2}$$

9. The OP in the following figure suffers from a finite gain. Calculate V_{out} in terms of V_1 and V_2. (Be aware V_1 connect to R_2, Be aware V_2 connect to R_1) (10%)



Ans:

8.31

$$v_{out} = -A_0 v_X$$

$$\frac{v_1 - v_X}{R_2} + \frac{v_2 - v_X}{R_1} = \frac{v_X - v_{out}}{R_F}$$

$$\frac{v_{out}}{R_F} + \frac{v_1}{R_2} + \frac{v_2}{R_1} = \frac{v_X}{R_1 \parallel R_2 \parallel R_F}$$

$$v_{out} = -A_0 (R_1 \parallel R_2 \parallel R_F) \left(\frac{v_{out}}{R_F} + \frac{v_1}{R_2} + \frac{v_2}{R_1} \right)$$

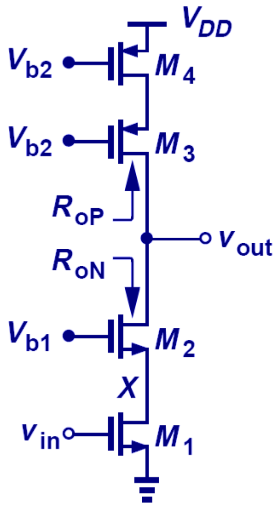
$$v_{out} \left[1 + A_0 \frac{(R_1 \parallel R_2 \parallel R_F)}{R_F} \right] = -A_0 (R_1 \parallel R_2 \parallel R_F) \left(\frac{v_1}{R_2} + \frac{v_2}{R_1} \right)$$

$$v_{out} = -A_0 (R_1 \parallel R_2 \parallel R_F) \frac{\frac{v_1}{R_2} + \frac{v_2}{R_1}}{1 + A_0 \frac{(R_1 \| R_2 \| R_F)}{R_F}}$$

$$= -A_0 R_F (R_1 \parallel R_2 \parallel R_F) \frac{\frac{v_1}{R_2} + \frac{v_2}{R_1}}{R_F + A_0 (R_1 \parallel R_2 \parallel R_F)}$$

$$= \boxed{-\left(\frac{v_1}{R_2} + \frac{v_2}{R_1} \right) [R_F \parallel A_0 (R_1 \parallel R_2 \parallel R_F)]}$$

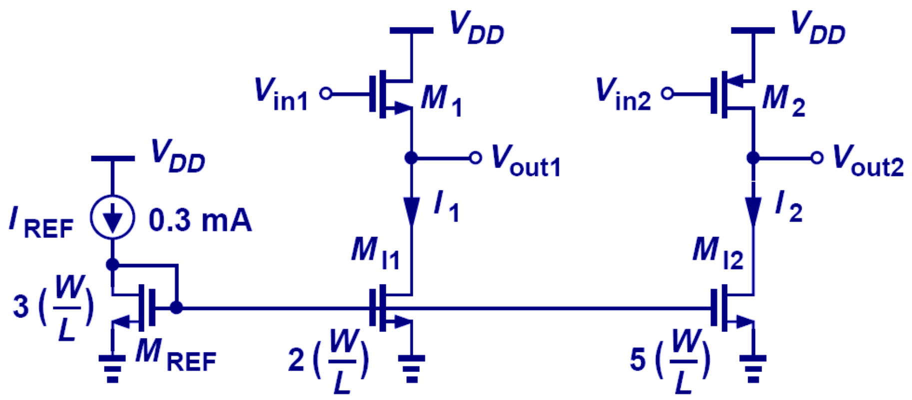
10. Please find the voltage gain of the following cascode stage. (5%)



Ans:

$$R_{on} \approx g_{m2} r_{O2} r_{O1}$$
$$R_{op} \approx g_{m3} r_{O3} r_{O4}$$
$$R_{out} = R_{on} \parallel R_{op}$$
$$A_v = -g_{m1}[(g_{m2} r_{O2} r_{O1}) \| (g_{m3} r_{O3} r_{O4})]$$

11. In the following figure, I_{REF} is 0.3mA, what are the value of I_1 and I_2 ? (5%)

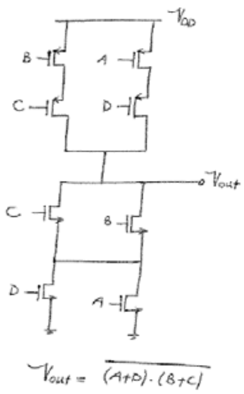


Ans: **I_1 = (2/3)*0.3=0.2mA,**

I_2 =(5/3)*0.3= 0.5mA

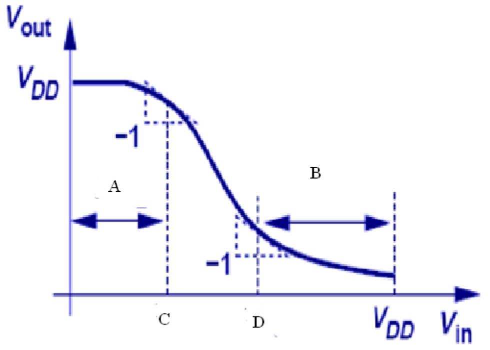
12. Please draw a CMOS logic gate which performs the following function: $\overline{(A+D)\bullet(B+C)}$. (5%)

Ans:



13. Please fill in A, B, C, or D by identify the correct definition in the following figure. (10%)

(1) V_{IL} (   ) (2) V_{IH} (   ) (3) NM_L (   ) (4) NM_H (   )



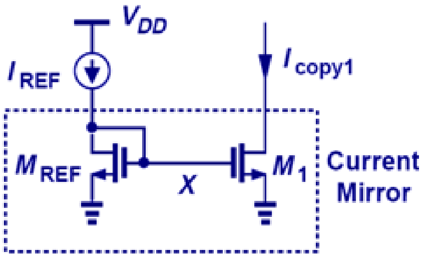
Ans:

(1) V_{IL} (C) (2) V_{IH} (D) (3) NM_L (A) (4) NM_H (B)

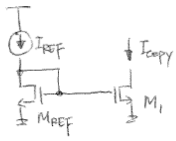
14. Consider the MOS current mirror shown below, and assume M_1 and M_{REF} are identical, but $\lambda \neq 0$. (10%)

(1) How should V_{DS1} be chosen so that I_{copy1} is exactly equal to I_{REF}?

(2) Determine the error be chosen in I_{copy1} with respect to I_{REF} if V_{DS1} is equal to $V_{GS} - V_{TH}$ (so that M1 resides at the edge of saturation).



53.



$V_{GS,REF} = V_{GS,1} = V_{GS}$

$\lambda \neq 0$

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

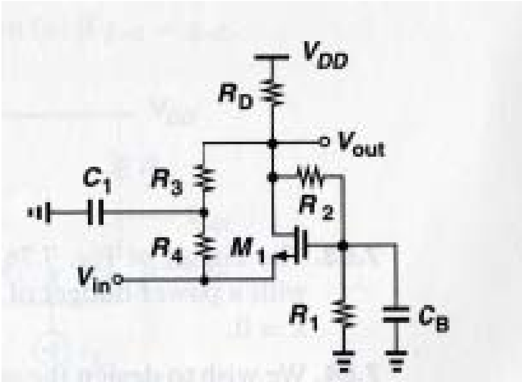
$I_{copy} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_{TH})^2(1+\lambda V_{DS1})$

For $I_{REF} = I_{copy} \Rightarrow V_{DS1} = V_{GS}$

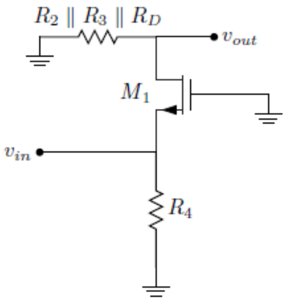
(b) $\frac{I_{REF}}{I_{copy}} = \frac{1+\lambda V_{GS}}{1+\lambda(V_{GS}-V_{TH})}$

$\Rightarrow I_{copy} = I_{REF}\left(1-\frac{\lambda V_{TH}}{1+\lambda V_{GS}}\right)$

15. Calculate the voltage gain of the following circuit. Assume $\lambda=0$ and the capacitors are very large. (5%)

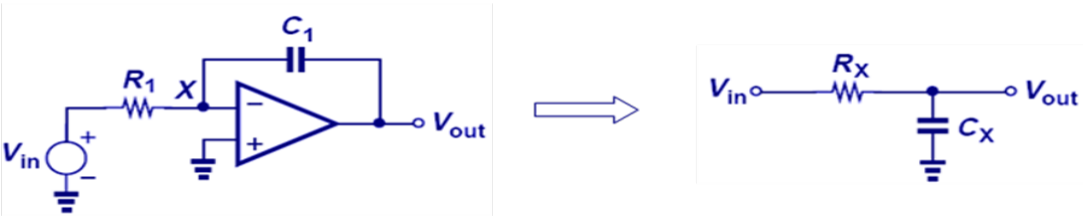


Ans:



$$A_v = \boxed{g_m (R_2 \parallel R_3 \parallel R_D)}$$

16. Determine the transfer function of the following circuit. (5%)



Ans:

$$\frac{V_{in} - V_X}{R_1} = \frac{V_X - V_{out}}{\dfrac{1}{C_1 s}} \qquad V_X = \frac{V_{out}}{-A_0}$$

$$\frac{V_{out}}{V_{in}} = \frac{-1}{\dfrac{1}{A_0} + \left(1 + \dfrac{1}{A_0}\right) R_1 C_1 s} \qquad s_p = \frac{-1}{(A_0 + 1) R_1 C_1}$$