University of California
College of Engineering
Department of Electrical Engineering
and Computer sciences

EE140 **Midterm Exam** **Mar. 13, 2003**

Name: Solution SID#: ____________________

grad ☐ undergrad ☐

- Closed book except for 1 - 8.5" x 11" sheet of your notes.
- There are two problems. Be sure to show all your work to receive full or partial credit.

1	
2	
Total	

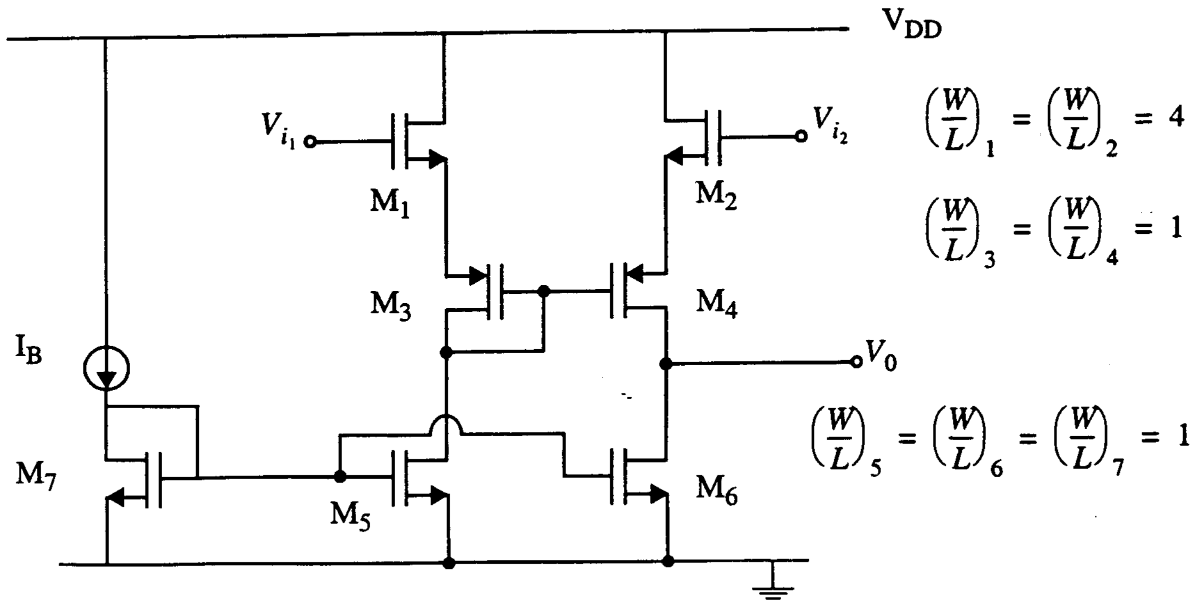


Fig. 1.

1) In the amplifier of Fig. 1, assume all NMOS devices have $V_T = V_{T_n}$, and all PMOS devices have $V_T = V_{T_p}$. You may neglect body effect. Further, assume all devices are minimum length, and are characterized by k'_n, λ_n and k'_p, λ_p for NMOS and PMOS devices respectively.

a) (10 pts.)
For the nominal input $V_{i_1} = V_{i_2} = V_{DD}$, determine the circuit operating point. Fill in the data below in terms of symbolic parameters. V_{T_n}, V_{T_p}, k'_n, k'_p, λ_n, λ_p, I_B, $\left(\frac{W}{L}\right)$'s, etc.

I_{D_1}	I_B
I_{D_2}	I_B
V_{S_1}	$V_{DD} - V_{T_n} - \Delta V_{1,2}$
V_{S_2}	$V_{DD} - V_{T_n} - \Delta V_{1,2}$
V_{D_3}	$V_{DD} - V_{T_n} - \Delta V_{1,2} - \lvert V_{T_p}\rvert - \lvert\Delta V_{3,4}\rvert$
V_O	$= V_{D_3}$ (symmetry!)

$$\Delta V_{1,2} = \sqrt{\frac{2 I_B}{k'_n \left(\frac{W}{L}\right)_{1,2}}}$$

$$\lvert\Delta V_{3,4}\rvert = \sqrt{\frac{2 I_B}{k'_p \left(\frac{W}{L}\right)_{3,4}}}$$

b) (10 pts.)
Determine the common mode input range, consistent with keeping all devices active.

$$\Delta V_{5,6} + |V_{T_p}| + |\Delta V_{3,4}| + V_{T_n} + \Delta V_{1,2} \le V_{in_{cm}} \le V_{DD} + V_{T_n}$$

c) (10 pts.)
If $V_{i_2} = V_{DD}$, determine the output range, consistent with keeping all devices active.

$$\Delta V_6 \le V_o \le V_{DD} - V_{T_n} - \Delta V_2 - |\Delta V_4|$$

d) (10 pts.)
For the operating point with $V_{I_1} = V_{I_2} = V_{DD}$, determine the differential mode circuit G_m, i.e. $G_{m_{diff}} = \dfrac{i_{out}}{(v_{i_1} - v_{i_2})}$.

$$\frac{g_{m2}}{1 + g_{m2}\frac{1}{g_{m4}}} = \frac{g_{m2}\, g_{m4}}{g_{m2} + g_{m4}}$$

e) (10 pts.)

For the operating point with $V_{i_1} = V_{i_2} = V_{DD}$, determine R_{out}.

$$r_{o6} \,//\, r_{o4}\left(1 + \frac{g_{m4}}{g_{m2}}\right)$$

f) (10 pts.)

Determine the common mode gain, i.e. $A_{v-cm} = \left.\frac{v_0}{v_{in}}\right|_{v_{i_1} = v_{i_2} = v_{in}}$.

$$\approx 1$$

$$\frac{r_{o5,6}}{\frac{1}{g_{m1}} + \frac{1}{g_{m3}} + r_{o5,6}}$$

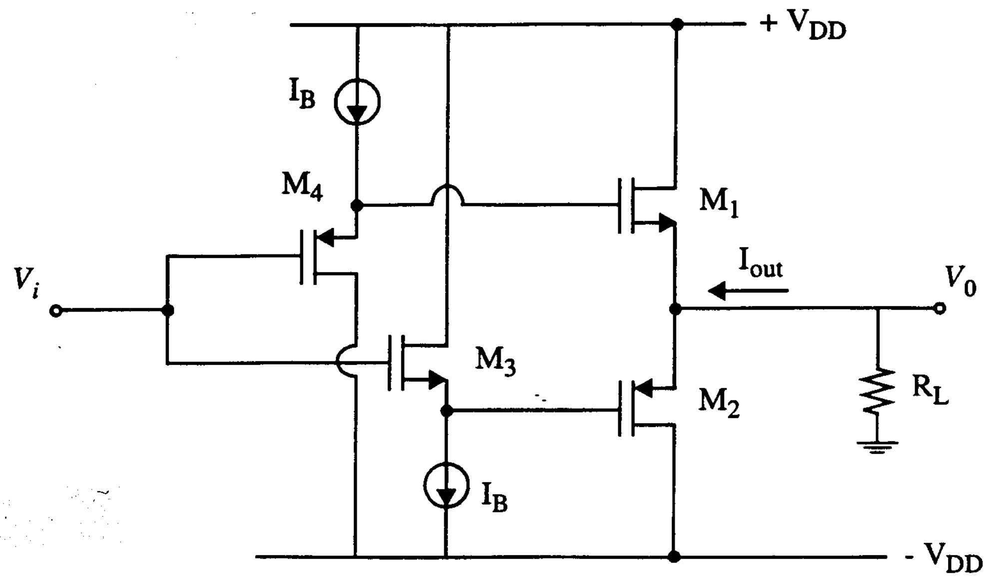


Fig. 2

2) For the circuit of Fig. 2, take the following: $\left(\frac{W}{L}\right)_1 = N\left(\frac{W}{L}\right)_3 ; \left(\frac{W}{L}\right)_2 = N\left(\frac{W}{L}\right)_4 ;$

$k'_n\left(\frac{W}{L}\right)_3 = k'_p\left(\frac{W}{L}\right)_4$. Neglect body effect and channel length modulation.

Assume $V_{T_n} = V_{T_p}$.

a) (10 pts.)

For $V_i = 0$ and $R_L = \infty$, determine V_0, I_{D_1} and I_{D_2}.

V_0	$V_o \approx 0$
I_{D_1}	$N\ I_B$
I_{D_2}	$N\ I_B$

b) (10 pts.)
For the bias condition determined in part (a), determine the circuit G_m.

$$g_{m_1} + g_{m_2}$$

$$g_{m_1} = \frac{2NI_B}{\Delta V_1} \qquad \Delta V_1 = \sqrt{\frac{2NI_B}{k_n'\left(\frac{W}{L}\right)_1}}$$

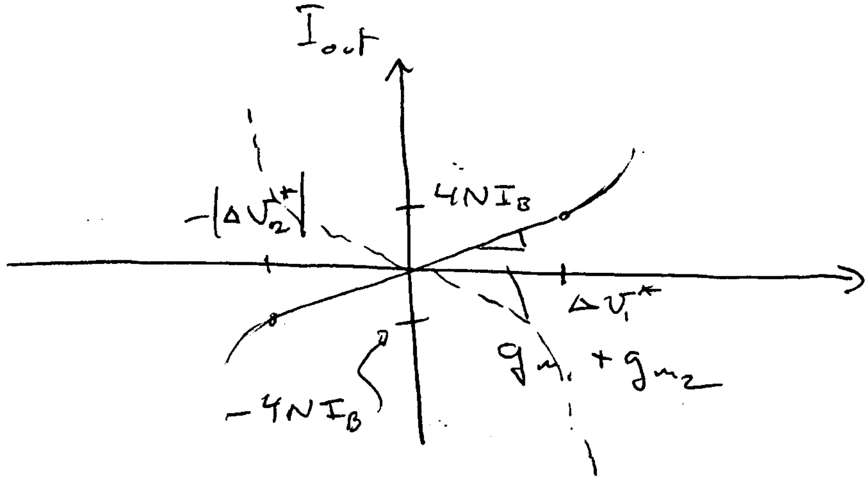
$$g_{m_2} = g_{m_1} \qquad \Delta V_2 = \Delta V_1$$

c) (10 pts.)
For the bias condition determined in part (a), determine R_{out}.

$$\frac{1}{g_{m_1}} \,//\, \frac{1}{g_{m_2}} = \frac{1}{g_{m_1} + g_{m_2}}$$

d) (10 pts.)

Take $V_i = 0$ and $R_L = \infty$. Determine the large signal I_{out} - V_O curve obtained by applying an appropriate test source at the circuit output.



$$g_{m_1}(v_o) = k_n'\left(\frac{W}{L}\right)_1 \Delta V_1(v_o) = k_n'\left(\frac{W}{L}\right)_1 (\Delta V_1^* - v_o)$$

$$v_o \leq \Delta V_1^*$$

$$g_{m_2}(v_o) = k_p'\left(\frac{W}{L}\right)_2 \Delta V_2(v_o) = k_p'\left(\frac{W}{L}\right)_2 (\Delta V_2^* + v_o)$$

$$-|\Delta V_2^*| \leq v_o$$

$$V_o > \Delta V_1^* \Rightarrow g_{m_1} = 0 \quad (\text{cut-off})$$

$$g_{m_2}$$