National Technological University

NEEI 6331 / IC 570-CA

Fall 2005

Midterm

Instructions

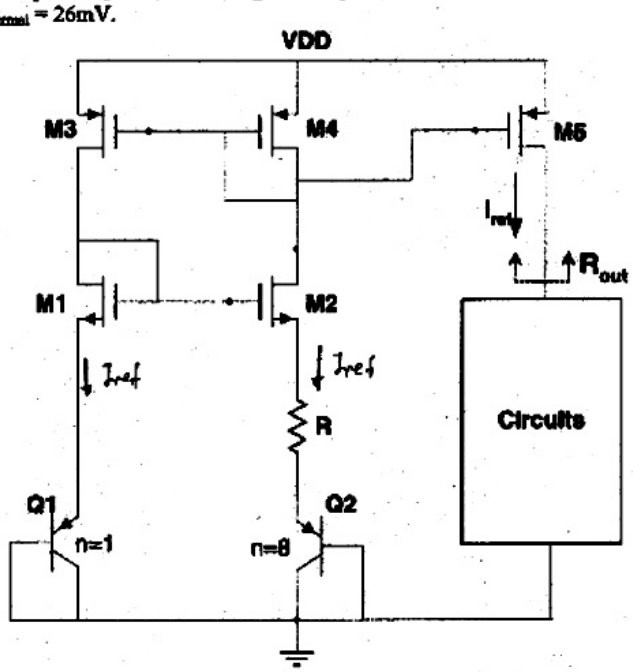
- **You may use one sheet (8.5" x 11") of you own notes. No other materials can be used. Calculator is allowed.**
- **There are two problems. Answer all of them.**
- **The total marks for this midterm is 100.**
- **The time allocated for this midterm is one and a half hours.**
- **There are a total of 6 pages, including this page.**

Name : Solutions

1	
2	
Total	

Question 1: (35 marks)

The figure below shows a current reference. You may assume all MOS transistors have the same (W/L) and are perfectly matched. Neglect body effect. Take $I_S = 10^{-16}$ for Q1 and thermal voltage, $V_{thermal} = 26mV$.



(a) Determine the value of R for I_{ref}=10μA. You may ignore r_o of the transistors. (15 marks)

$I_{ref} = I_{D3} = I_{D4}$ (current mirror)

$I_{ref} = I_{D3}$ (KCL) $\Rightarrow I_{D1} = I_{D2} \Rightarrow V_{GS1} = V_{GS2}$.

$I_{D2} = I_{D4}$ (KCL)

We have by KVL,

$V_{EB1} + V_{GS1} = V_{GS2} + I_{ref} R + V_{EB2}$.

$\Rightarrow V_T \ln\left(\frac{I_{D1}}{I_{S1}}\right) = I_{ref} R + V_T \ln\left(\frac{I_{D2}}{I_{S2}}\right)$

$\Rightarrow R = \frac{V_T}{I_{ref}} \ln\left(\frac{I_{S2}}{I_{S1}} \cdot \frac{I_{D1}}{I_{D2}}\right)^{=1}$ **ANS:** $R = 5.4\,k\Omega$

$= \frac{26mV}{10\mu A} \ln 8 = 5.4\,k\Omega$

(b). Determine R_{out}
(10 marks)

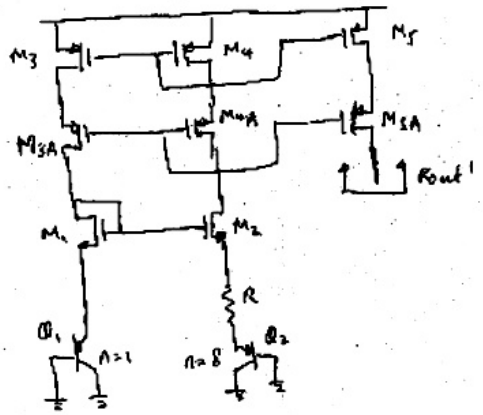
$R_{out} = r_{o5}$

V_{GS} is an a.c ground

ANS : $R_{out} = r_{o5}$

(c) Suggest a way to improve R_{out}.
(10 marks)

Use cascode transistors. (M_{3A}, M_{4A}, M_{5A})



Now $R_{out}' = r_{o5} + r_{o5A} + g_{m5A} r_{o5} r_{o5A}$

$\approx g_{m5A} r_{o5A} r_{o5}$

Improvement in Rout by a factor of $g_{m5A} r_{o5A}$

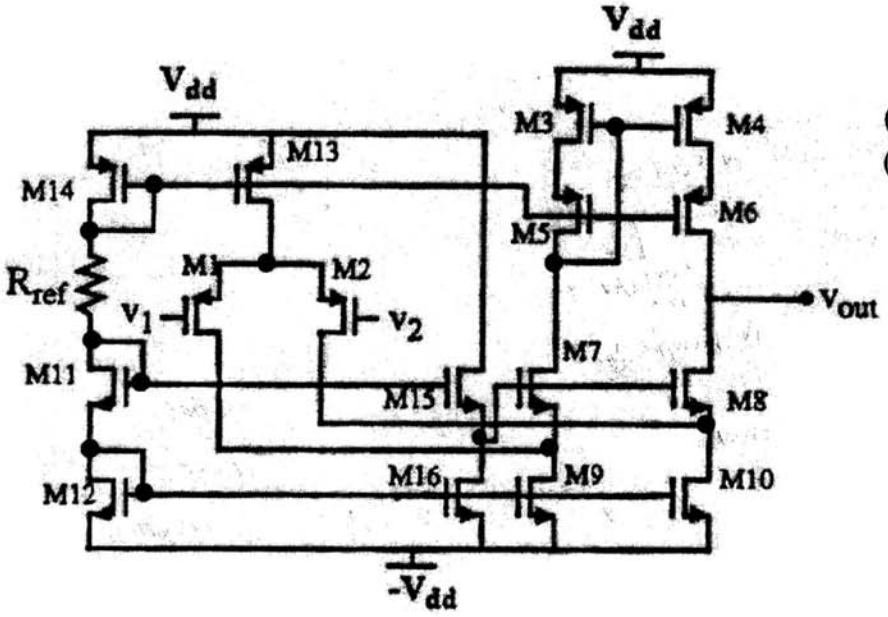
ANS : Add cascode transistors.

Note: You can also add source degeneration resistor for M_3, M_4, M_5 though it is not commonly use for MOS (more common in BJT circuits)

End of Paper

Question 2: (65 marks)

The figure below shows a folded cascode amplifier. Assume the bulk of all transistors are connected to their sources.



$(W/L)_{11} = 1$
$(W/L)_{14} = 1$

Choose the values of W/L's for all the transistors (except for M11 and M14 which are 1), so that the currents in all devices have the same value of I_o, except for M9, M10 and M13 which are twice that value or $2I_o$. Also choose those sizes so that M3, M4, M9 and M10 are biased at the edge of saturation and all other devices are in saturation. (Assume $\lambda=0$ for all devices).

$(W/L)_1$	Don't care
$(W/L)_2$	Don't care
$(W/L)_3$	4
$(W/L)_4$	4

pmos

① $(W/L)_1 = (W/L)_2$ = any value

② $I_{13} = 2I_{14} \Rightarrow \left(\frac{W}{L}\right)_{13} = 2$ #

③ V_{SG5} $V_{SS} - V_{G5} = V_T + \Delta V_5$

$(V_{DD} - \Delta V_3) - (V_{DD} - V_T - \Delta V_{14}) = V_T + \Delta V_5$

$\Delta V_{14} = \Delta V_3 + \Delta V_5$

Choose $\Delta V_3 = \Delta V_5 = \Delta V$

$\Delta V_{14} = 2\Delta V$

$\sqrt{\frac{I_o}{\left(\frac{W}{L}\right)_{14}}} = \sqrt{\frac{4I_o}{\left(\frac{W}{L}\right)_{3,5}}} \Rightarrow \left(\frac{W}{L}\right)_{3,5} = 4$ #

$I_3 = I_4 \Rightarrow \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4$ 4 #

$I_5 = I_6 \Rightarrow \left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6$ 4 #

$(W/L)_5$	4
$(W/L)_6$	4
$(W/L)_7$	4
$(W/L)_8$	4
$(W/L)_9$	8
$(W/L)_{10}$	8
$(W/L)_{12}$	4
$(W/L)_{13}$	2
$(W/L)_{15}$	4
$(W/L)_{16}$	4

NMOS

① $V_{GS12} = V_{GS16} = V_{GS9} = V_{GS10}$

$\Rightarrow \Delta V_{12} = \Delta V_{16} = \Delta V_9 = \Delta V_{10}$ ——(*)

② Also,

$V_{GS12} + V_{GS11} = V_{GS15} + V_{GS8} + \Delta V_{10}$

$\Delta V_{12} + \Delta V_{11} = \Delta V_{15} + \Delta V_8 + \Delta V_{10}$

Using (*), $\Delta V_{11} = \Delta V_{15} + \Delta V_8$

Choose $\Delta V_8 = \Delta V_{15} = \Delta V'$

$\Delta V_{11} = 2\Delta V'$

$$\sqrt{\frac{I_0}{\left(\frac{W}{L}\right)_{11}}} = \sqrt{\frac{4I_0}{\left(\frac{W}{L}\right)_{8,15}}} \Rightarrow \left(\frac{W}{L}\right)_{8,15} = 4$$

$V_{GS7} = V_{GS8} \Rightarrow \left(\frac{W}{L}\right)_7 = \left(\frac{W}{L}\right)_8 = 4$

③ From (*), choose $\Delta V_{12} = \Delta V_{16} = \Delta V_9 = \Delta V_{10} = \Delta V'$

$\therefore \left(\frac{W}{L}\right)_{12} = \left(\frac{W}{L}\right)_{16} = 4$

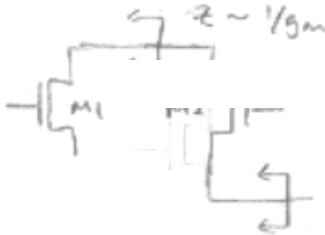
$\left(\frac{W}{L}\right)_9 = \left(\frac{W}{L}\right)_{10} = 8$ ($\because$ of $2I_0$)

(b) Determine the voltage gain of the amplifier. Express your answer in terms parameters (gm_i, ro_i, etc). Ignore body effect.
(13 marks)

$$\text{Gain} = g_{m1} R_{out}$$

$$R_{out} \simeq g_{m6} r_{o6} r_{o4} \,/\!/\, g_{m8} r_{o8} (2 r_{o2} \,/\!/\, r_{10})$$ #

Note that impedance looking into M_2



$$z \sim r_{o2} + \frac{1}{g_{m2}} + g_{m2}(r_{o2})\left(\frac{1}{g_{m2}}\right)$$

$$= 2 r_{o2}.$$

(c) Determine the output swing of the amplifier. Express your answer in terms of Vdd, Vt_i and $Vdsat_i$ of the transistors.
(10 marks)

$$-V_{dd} + v_{dsat10} + v_{dsat8} \leq V_{out} \leq V_{DD} - V_{dsat4} - v_{dsat6}$$

End of Paper