EECS 140 Fall 2001

Suggested Solutions for Mid-term Exam.

1 a) $I_{D1} = I_{D2} = I_{D6} = I_B/2$

$I_{D8} = N I_B/2$

$\Delta V_n = \sqrt{I_B / K_n' \frac{W}{L}}$ $\qquad n = 1, 2, \cancel{3}, \cancel{4}, \cancel{5}, 6, \cancel{7}, 8$

$\Delta V_9 = \sqrt{I_B / \frac{K_n'}{2}\frac{W}{L}}$

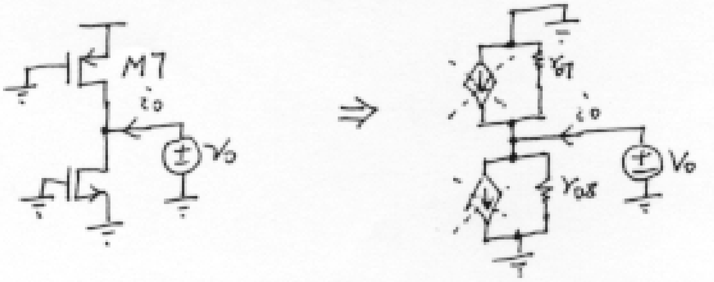
$\Delta V_p = \sqrt{I_B / K_p' \frac{W}{L}}$ $\qquad p = 3, 4, 5, 7$

b) $V_{SS} + \Delta V_9 + V_{T1,2} + \Delta V_{1,2} < V_{Icm} < V_{DD} - |V_{T3,4}| - |\Delta V_{3,4}| + V_{T1,2}$

c) $V_{SS} + \Delta V_8 \leq V_O \leq V_{DD} - |\Delta V_7|$

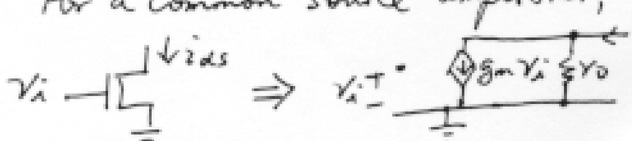
d) $\because$ $R_{out} = \frac{v_o}{i_o}\Big|_{v_{in}=0}$

$\therefore$ The small signal model becomes.



$\therefore$ $R_{out} = r_{o7} // r_{o8}$ #

e). For a common source amplifier,

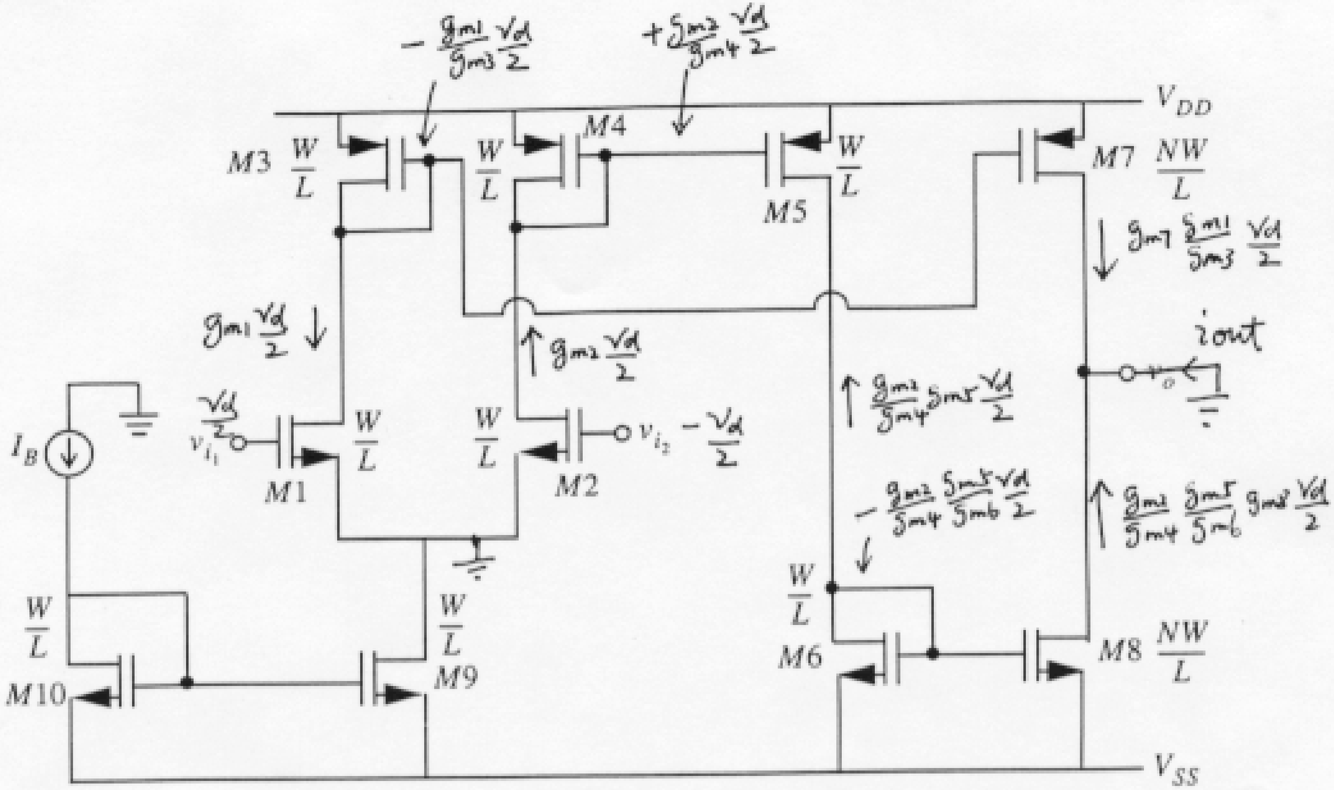


$\Rightarrow$ $i_{ds} = g_m v_i$ if $r_o >> \frac{1}{g_m}$

For differential mode input, $v_{i1} = \frac{v_d}{2}$, $v_{i2} = -\frac{v_d}{2}$, and the drain of M9 is a.c. grounded (i.e. d.c. voltage is constant).

We can find $G_m = \frac{i_{out}}{v_d}\Big|_{v_o=0}$ by using "$i_{ds} = g_m v_i$" and working from $M1 \rightarrow M3 \rightarrow M7$

& $M2 \rightarrow M4 \rightarrow M5 \rightarrow M6 \rightarrow M8$ as indicated in the figure:



Therefore $i_{out} = -\left[g_{m7}\frac{g_{m1}}{g_{m3}}\frac{v_d}{2} + \frac{g_{m2}}{g_{m4}}\frac{g_{m5}}{g_{m6}}g_{m8}\frac{v_d}{2}\right]$

∵ $g_{m1} = g_{m2} = g_{m1,2}$, $Ng_{m3} = g_{m7}$, $g_{m4} = g_{m5}$, $g_{m6}N = g_{m8}$

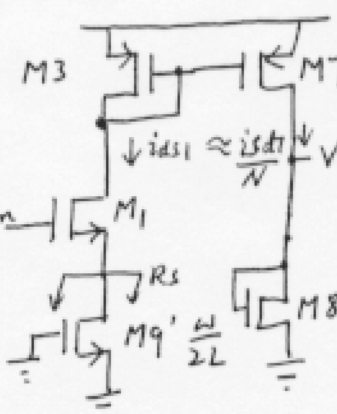
∴ $G_m = -Ng_{m1,2}$ #

f) For common mode input, the circuit is symmetric.

$M1 \to M3 \to M7 \to M8$ vs $M2 \to M4 \to M5 \to M6$

So, $V_{O8} = V_{O6} = V_{G6} = V_{G8}$, ⇒ M8 is diode connected in CM.

Use half circuit technique, we have



Since M9 is shared by the 2 half circuits,

∴ $R_s = 2r_{o9}$

M1 then becomes a CS amplifier with degeneration,

∴ $i_{sd7} \approx i_{ds1}N = G_{m1}V_{icm}N$

$= \frac{g_{m1}}{1 + g_{m1}2r_{o9}} V_{icm}N$

∴ $V_o = i_{ds8}\left(\frac{1}{g_{m8}}\right)$

$= i_{sd7}\left(\frac{1}{g_{m8}}\right) = \frac{g_{m1}N}{g_{m8}(1 + 2g_{m1}r_{o9})}V_{icm}$

∴ $= \frac{V_o}{V_{icm}} = \frac{1}{(1 + 2g_{m1}r_{o9})}$ #

2 a) $I_{out} = I_{ref}$

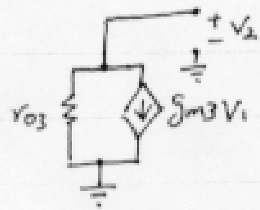
$$V_{GSn} = \sqrt{\frac{2I_{ref}}{k'(\frac{W}{L})}} + V_{Tn} \quad , \quad n = 1, 2, 4, 5$$

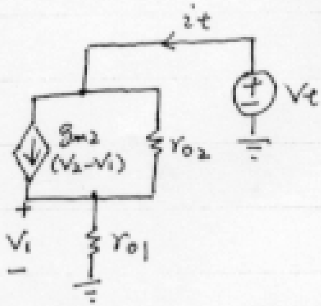
$$V_{Gn} = \sqrt{\frac{2I_B}{k'(\frac{W}{L})}} + V_{Tn} \quad , \quad n = 3, 6$$

b)
$$V_{out\,min} = \Delta V_2 + V_{GS3} = \Delta V_2 + V_{T3} + \Delta V_3$$

$$= \sqrt{\frac{2I_{ref}}{k'(\frac{W}{L})}} + \sqrt{\frac{2I_B}{k'(\frac{W}{L})}} + V_{T3}$$

c) Ignore body effect





$\because \quad \frac{V_2}{r_{o3}} = -g_{m3}V_1$

$\therefore \quad V_2 = -g_{m3}r_{o3}V_1 \qquad ①$

Also, $\frac{V_1}{r_{o1}} = i_t \qquad ②$

$\frac{V_t - V_1}{r_{o2}} + g_{m2}(V_2 - V_1) = i_t \qquad ③$

sub ① + ② into ③ $\quad \frac{V_t}{r_{o2}} + g_{m2}(-g_{m3}r_{o3}r_{o1}i_t) - g_{m2}r_{o1}i_t - \frac{r_{o1}i_t}{r_{o2}} = i_t$

$$\therefore \quad R_{out} = \frac{V_t}{i_t} = r_{o1} + r_{o2} + g_{m2}r_{o1}r_{o2} + g_{m2}g_{m3}r_{o1}r_{o2}r_{o3}$$

$$\approx r_{o1}r_{o2}r_{o3}g_{m2}g_{m3}$$

#

d) Ensure $V_{D4} = V_{D1}$ so that $I_{out} = I_{ref}$ even there is channel length modulation.