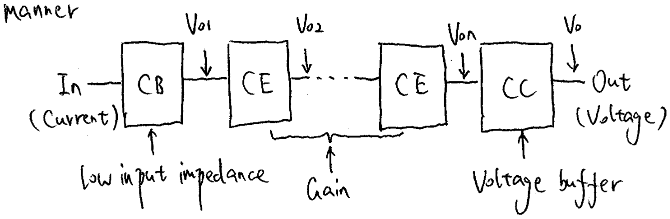
Spring 2001 EE105 Homework #12 Solution

by Xuesong Jiang

12.1. The multistage amplifier will have stages cascaded in the following manner



The transresistance of the CB stage:

$$|R_m| = \left|\frac{V_{o1}}{I_{in}}\right| = |A_i| \cdot (R_{out\_CB} \| R_{in\_CE}) = 1 \cdot \frac{400k\Omega \cdot 100k\Omega}{400k\Omega + 100k\Omega} = 80\ k\Omega$$

The voltage gain of the CE stage: (one stage)

$$|A_v| = \left|\frac{V_{o2}}{V_{o1}}\right| = |G_m \cdot (R_{out\_CE} \| R_{in\_CE})| = 4mS \cdot 80k\Omega = 320$$

The voltage gain of CC stage:

$$|A_v| = \left|\frac{V_o}{V_{on}}\right| = |A_v| \cdot \frac{R_L}{R_{out\_cc} + R_L} = 1 \cdot \frac{100\Omega}{100\Omega + 100\Omega} = 0.5$$

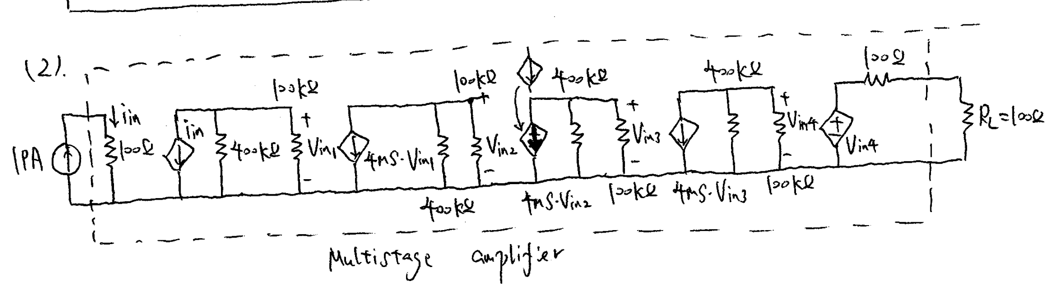
The overall transresistance is

$$|R_{m\_all}| = \left|\frac{V_o}{I_{in}}\right| = |R_m \cdot A_v^n \cdot A_{v\text{-}cc}| = |80k\Omega \cdot 320^n \cdot 0.5| > \frac{1V}{1pA} = 10^{12}\ \Omega$$

$\therefore\ n \geq 3$

(1) **At least 5 building blocks are needed for the multistage amplifier**

(2).



(3). The overall transresistance :

$$|R_{m\_all}| = |80k\Omega \cdot 320^3 \cdot 0.5| = \boxed{1.31 \times 10^{12}\ \Omega}$$

12.2. (1) $I_o = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS1} - V_{Tn})^2 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{DS1\_sat})^2$

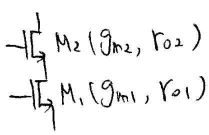
$$V_{b2} = V_{GS2} + V_{DS1} = (V_{Tn} + \underbrace{V_{GS2} - V_{Tn}}_{V_{DS2\_sat} = V_{DS1\_sat}}) + 2V_{DS1\_sat} = V_{Tn} + 3V_{DS1\_sat}$$

$$1.9V = 0.7V + 3 \cdot V_{DS1\_sat} \Rightarrow V_{DS1\_sat} = 0.4V$$

$$V_{b1} = V_{GS1} = V_{Tn} + V_{DS1\_sat} = \boxed{1.1V}$$

$$\therefore \frac{W}{L} = \frac{2I_o}{\mu_n C_{ox}(V_{DS1\_sat})^2} = \frac{2 \cdot 1mA}{50\mu A/V^2 \cdot (0.4V)^2} = \boxed{250}$$

(2)



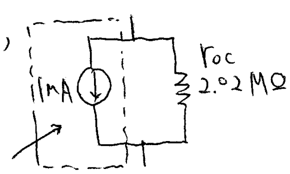
$$R_o = r_{o2}(1 + g_{m2} \cdot r_{o1})$$

$$r_{o2} = r_{o1} = \frac{1}{\lambda \cdot I_D} = \frac{1}{0.05V^{-1} \cdot 1mA} = 20k\Omega$$

$$g_{m2} = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} = \sqrt{2 \times 50\mu A/V^2 \cdot \frac{250}{1} \cdot 1mA} = 0.005S$$

$$\therefore R_o = 20k\Omega \cdot (1 + 0.005S \cdot 20k\Omega) = \boxed{2.02\ M\Omega}$$

(3)



The current source will be used in large signal analysis

(4). If W/L of M_1 and M_2 are doubled and I_o is kept at 1mA.

$r_{o2} = r_{o1}$ won't change, g_{m2} is proportional to $\sqrt{\frac{W}{L}}$, which will be $\sqrt{2}$ times higher

The source resistance of the current source will increase to 1.414 times the original result in (2)

$\boxed{R_o = 2.86\ M\Omega}$ or R_o is increased to $\boxed{\sqrt{2}}\cdot 2.02\ M\Omega$.

(5) If I_o is reduced to 0.5mA, and W/L of M_2 and M_1 remain the same as in part (1).

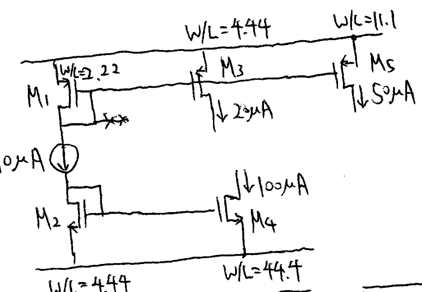
$$r_{o1} = r_{o2} = \frac{1}{\lambda I_o} = \frac{1}{0.05\,V^{-1}\,0.5mA} = 40k\Omega$$

$$g_{m2} = \sqrt{2\mu_n C_{ox}\frac{W}{L} I_o} = 0.005S\cdot\sqrt{\frac{1}{2}} = 3.54mS$$

$$\therefore R_o = 40k\Omega\cdot(1+3.54mS\cdot 40k\Omega) = \boxed{5.74\ M\Omega}$$

The source resistance is increased by a factor of $2\cdot 2\cdot\sqrt{\frac{1}{2}} = \boxed{2.828}$

12.3. (1)



$$V_{DS\_sat\_M1} = 0.6V = \sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} = \sqrt{\frac{2\times 10\mu A}{25\mu A/V^2\cdot\frac{W}{L}}}$$

$$\therefore \left(\frac{W}{L}\right)_{M1} = 2.22,\quad \left(\frac{W}{L}\right)_{M3} = 2\cdot\left(\frac{W}{L}\right)_{M1} = 4.44,\quad \left(\frac{W}{L}\right)_{M5} = 5\cdot\left(\frac{W}{L}\right)_{M1} = 11.1$$

$$\left(\frac{W}{L}\right)_{M2} = \frac{2\cdot I_D}{\mu_n C_{ox}\underbrace{(V_{GS}-V_{TN})^2}_{V_{DS\_sat\_M2}}} = \frac{2\times 10\mu A}{50\mu A/V^2\cdot 0.3V^2} = 4.44$$

$$\left(\frac{W}{L}\right)_{M4} = 10\cdot\left(\frac{W}{L}\right)_{M2} = 44.4$$

(3)

$$r_{oc}(I_o = 20\mu A) = \frac{1}{\lambda_p \cdot I_o} = \frac{1}{0.01V^{-1} \cdot 20\mu A} = \boxed{5M\Omega}$$

$$r_{oc}(I_o = 50\mu A) = \frac{1}{\lambda_p \cdot I_o} = \frac{1}{0.01V^{-1} \cdot 50\mu A} = \boxed{2M\Omega}$$

$$r_{oc}(I_o = 100\mu A) = \frac{1}{\lambda_n \cdot I_o} = \frac{1}{0.01V^{-1} \cdot 100\mu A} = \boxed{1M\Omega}$$