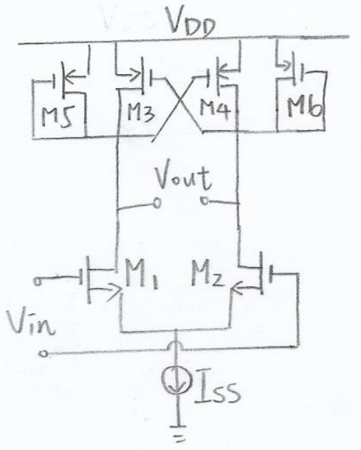
Q1

(a)



$\lambda = \gamma = 0$

assume $g_{m1} = g_{m2}$

$g_{m3,4} = 0.75\, g_{m5,6}$

$$\overline{V_{n,out}^2} = 4kT\gamma\,(g_{m1} + g_{m3} + g_{m5}) \times 2 \times R_{out}^2$$

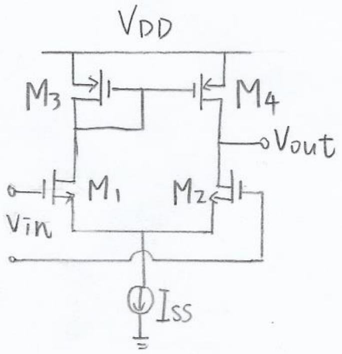
$$|A_V|^2 = (g_{m1,2})^2 R_{out}^2$$

$$\overline{V_{n,in}^2} = \frac{\overline{V_{n,out}^2}}{A_V^2} = \frac{4kT\gamma\,(g_{m1}+g_{m3}+g_{m5})\times 2\times \cancel{R_{out}^2}}{g_{m1}^2 \times \cancel{R_{out}^2}}$$

$$= 4kT\gamma\left(\frac{1}{g_{m1}} + \frac{g_{m3}+g_{m5}}{g_{m1}^2}\right)\times 2$$

$$= 4kT\gamma\left(\frac{2}{g_{m1}} + \frac{3.5\,g_{m5}}{g_{m1}^2}\right)$$

(b)



$\gamma = 0$

assume $g_{m1} = g_{m2}$

$g_{m3} = g_{m4}$

$$\overline{V_{n,out}^2} = \overline{I_{n,out}^2} \cdot R_{out}^2$$

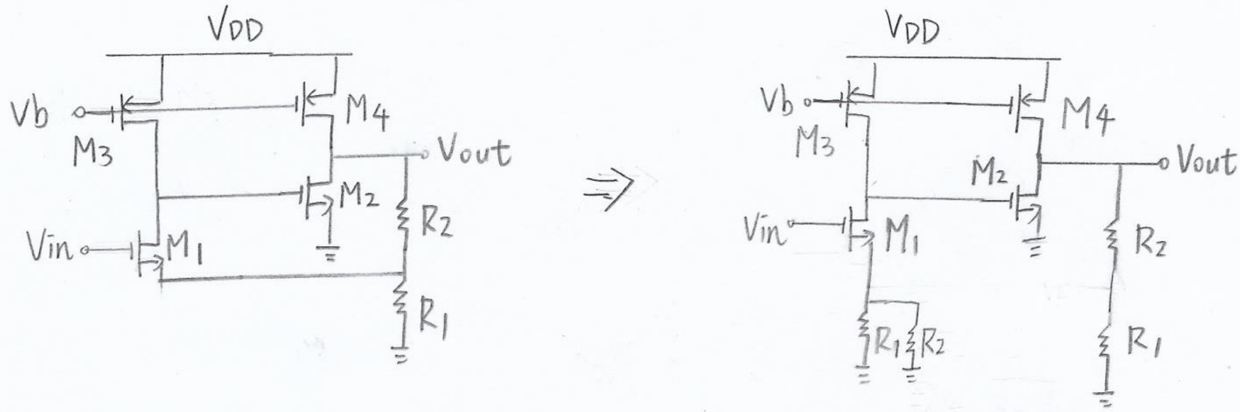
$$= 4kT\gamma\,(g_{m1} + g_{m2} + g_{m3} + g_{m4}) \cdot R_{out}^2$$

$$= 4kT\gamma\,(2g_{m1} + 2g_{m3}) \cdot R_{out}^2$$

$$\overline{V_{n,in}^2} = \frac{\overline{V_{n,out}^2}}{A_V^2} = \frac{4kT\gamma\,(2g_{m1}+2g_{m3})\cdot \cancel{R_{out}^2}}{g_{m1}^2 \cdot \cancel{R_{out}^2}}$$

$$= 4kT\gamma\left(\frac{2}{g_{m1}} + \frac{2g_{m3}}{g_{m1}^2}\right)$$

Q2



$$A_{v,\text{open loop}} = \frac{g_{m1} r_{o3}}{1+g_{m1}(R_1 /\!/ R_2)} \cdot g_{m2} \cdot \left[r_{o2} /\!/ r_{o4} /\!/ (R_2+R_1) \right]$$

$$R_{out,\text{open}} = r_{o4} /\!/ r_{o2} /\!/ (R_2+R_1)$$

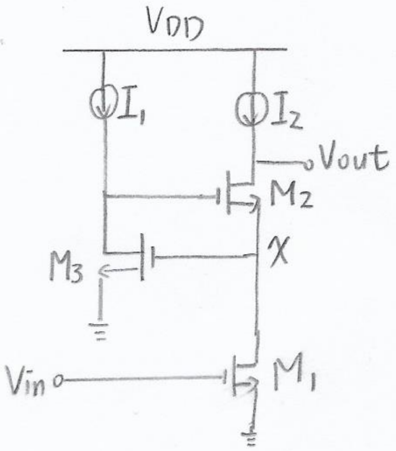
$$\beta = \frac{R_1}{R_1+R_2}$$

$$\text{Loop gain} = \beta A_{v,\text{open loop}} = \frac{R_1}{R_1+R_2} \cdot \frac{g_{m1} r_{o3}}{1+g_{m1}(R_1 /\!/ R_2)} \cdot g_{m2} \cdot \left[r_{o2} /\!/ r_{o4} /\!/ (R_2+R_1) \right]$$

$$A_{v,CL} = \frac{A_{v,\text{open loop}}}{1+\beta A}$$

$$R_{out,CL} = \frac{R_{out,\text{open}}}{1+\beta A}$$

Q3



(a)

$$I_1 = \frac{1}{2}\left(\frac{W}{L}\right)_3 (V_{gs3} - V_{tn3})^2 \mu_n C_{ox}$$

$$V_{G3} = \sqrt{\frac{2I_1}{\left(\frac{W}{L}\right)_3 \mu_n C_{ox}}} + V_{tn3} = V_{G3} = 0.6V$$

$$I_2 = \frac{1}{2}\left(\frac{W}{L}\right)_2 (V_{gs2} - V_{tn2})^2 \mu_n C_{ox}$$

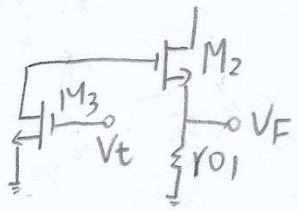
$$V_{g2} = \sqrt{\frac{2I_2}{\left(\frac{W}{L}\right)_2 \mu_n C_{ox}}} + V_{tn2} + V_X = 1.3V$$

(b)

Assume I_1 & I_2 are ideal current source

Loop gain for M_2 & M_3

$\Rightarrow g_{m3} r_{o3}$



$$R_{out,OL} = g_{m2} r_{o2} r_{o1}$$

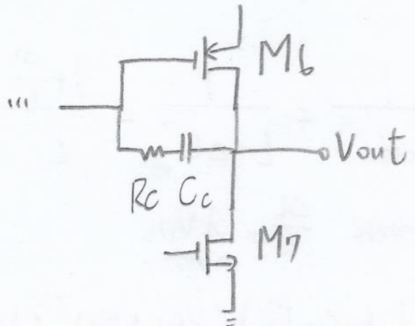
$$R_{out,CL} = (1+\beta A) R_{out} \cong g_{m3} r_{o3} g_{m2} r_{o2} r_{o1}$$

$$A_v = -g_{m1} g_{m2} g_{m3} r_{o1} r_{o2} r_{o3}$$

Q4

(a) The purpose of using C_c is move the interstage pole toward the origin (from $\frac{1}{(r_{o4}//r_{o2})C_{parasitic}}$ to $\frac{1}{(r_{o4}//r_{o2})(r_{o6}//r_{o7})g_{m6}C_c}$) and push the second stage pole away from dominant pole and origin (from $\frac{1}{(r_{o6}//r_{o7})C_L}$ to $\frac{g_{m6}}{C_L}$), but C_c will bring the disadvantage about having a RHP zero $\frac{g_{m6}}{C_c}$ cause unstable

(b)

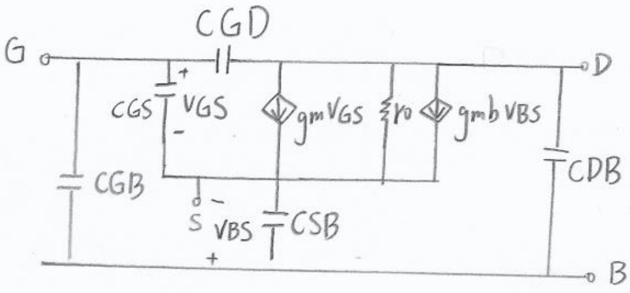


To add a resistor R_c to move the zero from $\frac{g_{m6}}{C_c}$ (RHP) to $\frac{1}{C_c(\frac{1}{g_{m6}}-R_c)}$

if $\frac{1}{g_{m6}} \leq R_c$, then the zero will move to LHP

Q5

(a)



nMOST small signal model

(b)

1. Channel length modulation

⇒ The actual length of the channel gradually decreases as the potential difference between the gate and the drain decreases. When mos at saturation region, the length of Leff decreases, and the current increases.

$V_{DS} < V_{GS} - V_{th}$ $V_{DS} > V_{GS} - V_{th}$

$$\frac{1}{L_{eff}} = \frac{1}{L - \Delta L} = \frac{1 + \frac{\Delta L}{L}}{L}$$

where $\frac{\Delta L}{L} = \lambda V_{DS}$

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_{th})^2 (1 + \lambda V_{DS})$$

λ ⇒ channel length modulation coefficient

⇒ For design, when I_D is at saturation region, the V_{DS} increases or decreases will change r_o, and this phenomenon brings nonlinearity.

2. Body effect

⇒ For nMosT, if $V_B < 0$, more holes are attracted to the substrate connection, leaving negative charge under the gate. Thus, we need higher gate voltage to build the inverse channel.

⇒ For design, when $V_{BS} \neq 0$, then $V_{th} = V_{th0} + \underbrace{\gamma\left(\sqrt{2\phi_f - V_{BS}} - \sqrt{2\phi_f}\right)}_{\text{coffeicient}}$, the coefficient will appear to change I_D.