## 习 题 8

Table 8.1

| Parameter | Parameter Description | Typical Parameter Value | | Units |
|---|---|---|---|---|
| | | n-Channel | p-Channel | |
| $V_{T0}$ | Threshold voltage($V_{BS}$=0) | 0.7 | -0.7 | V |
| K | Transconductance parameter(in saturation) | 110 | 50 | $\mu A/V^2$ |
| $\gamma$ | Bulk threshold parameter | 0.4 | 0.57 | $V^{1/2}$ |
| $\lambda$ | Channel length modulation parameter | 0.01 | 0.01 | $V^{-1}$ |
| $2|\phi_F|$ | Surface potential at strong inversion | 0.7 | 0.8 | V |

8.1 In the op amp of Fig 8.1, $(W/L)_{1-8}$=100/0.5, $I_{SS}$=1mA, and $V_{b1}$=1.7V. Assume that $\gamma=\lambda=0$. $V_{DD}$=3V.

(a) What is the maximum allowable input CM level?

(b) What is $V_X$?

(c) What is the maximum allowable output swing if the gate of $M_2$ is connected to the output? (make sure that M2 and M4 work in saturation region)
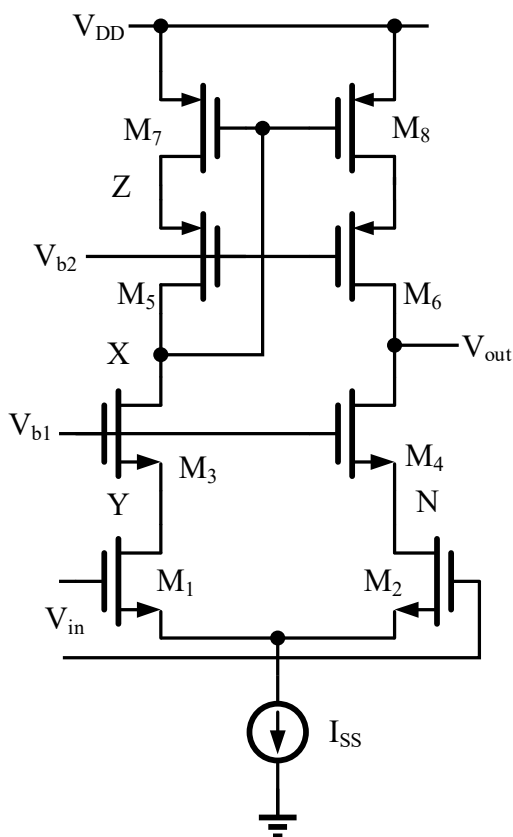
(d) What is the acceptable range of $V_{b2}$?



Fig 8.1

解：

(a)

$$V_{in,CM,\max} = V_Y + V_{TH1} = V_{b1} - V_{GS3} + V_{TH1}$$

$$= V_{b1} - V_{OD3} - V_{TH3} + V_{TH1} = V_{b1} - V_{OD3}$$

$$V_{OD3} = V_{GS3} - V_{TH} = \left( \frac{2I_{D3}}{K_n \left( \dfrac{W}{L} \right)_3} \right)^{\frac{1}{2}} = 0.213\,\mathrm{V}$$

$$V_{in,CM.\max} = 1.7 - 0.213 = 1.487V$$

(b)

$$\frac{1}{2}I_{SS} = \frac{1}{2}K_p \left( \frac{W}{L} \right)_7 \left( V_{DD} - V_X - |V_{TH7}| \right)^2$$

解得 $V_X = 1.984V$

(c)

M2 和 M4 均工作在饱和区，所以

$$V_{out} - V_{TH} \leq V_N$$

$$V_{out} \geq V_{b1} - V_{TH}$$

且有 $V_N = V_{b1} - V_{GS4}$

整理得 $V_{b1} - V_{TH} \leq V_{out} \leq V_{b1} - (V_{GS4} - V_{TH})$

所以 $\Delta V_{swing} = 2V_{TH} - V_{GS4} = 2V_{TH} - V_{GS3} = 1.4 - 0.913 = 0.487V$

(d)

$$V_Z < V_X + V_{TH}, \text{ 且 } V_{b2} = V_Z - |V_{GS5}|, \text{ 所以}$$

$$V_{b2} < V_X + V_{TH} - |V_{GS5}| = 1.984 + 0.7 - 1.016 = 1.668V$$

且 $V_{b2} > V_X - V_{TH} = 1.984 - 0.7 = 1.284V$

8.2 Suppose the circuit of Fig 8.2 is designed with $I_{SS}$ equal to 1mA, $I_{D9}$-$I_{D12}$ equal to 0.5mA, and (W/L)$_{9\text{-}12}$=100/0.5. $V_{DD}$=3V, $\lambda$=0.

(a) What CM level is required at X and Y?

(b) If $I_{SS}$ requires a minimum voltage of 400mV, choose the minimum dimensions of $M_1$-$M_8$ to allow a peak-to-peak swing of 200mV at X and at Y, assume that $M_1$-$M_4$ are of the same size and $M_5$-$M_8$ are of the same size.

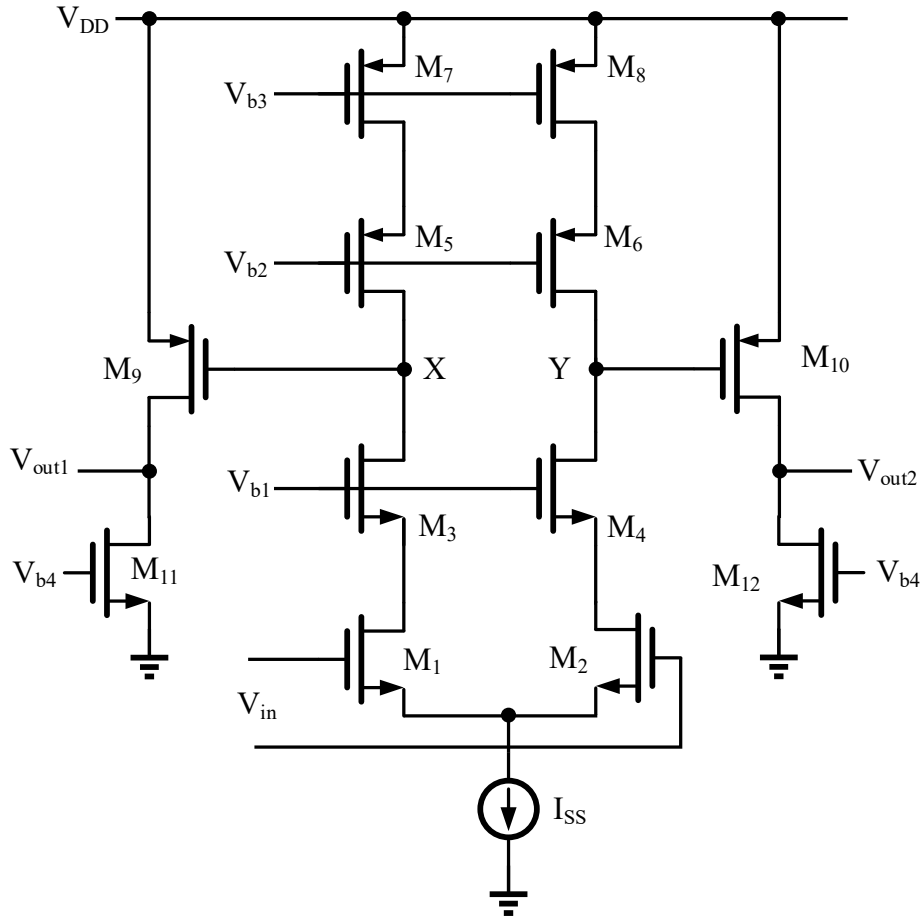(c) Give the expression of the overall voltage gain.

Fig 8.2

解：

(a)

$$|V_{GS9}| = |V_{TH}| + \left[ \frac{2I_{D9}}{K_p \left( \frac{W}{L} \right)_9} \right]^{\frac{1}{2}} = 1.016V$$

$$V_{XY,CM} = V_{DD} - |V_{GS9}| = 1.984V$$

(b)

$V_X$摆幅为200mV，所以$V_{Xmax}$=2.084V，$V_{Xmin}$=1.884V

$$V_{OD7} = V_{OD5} = \frac{V_{DD} - V_{X\max}}{2} = 0.458V$$

$$V_{OD1} = V_{OD3} = \frac{V_{X\min} - V_{ISS}}{2} = 0.742V$$

$$\left(\frac{W}{L}\right)_{5-8} = \frac{I_{SS}}{K_p V_{OD5,7}^2} = 95.35$$

$$\left(\frac{W}{L}\right)_{1-4} = \frac{I_{SS}}{K_n V_{OD1,3}^2} = 16.51$$

(c)

$$A_V = g_{m1}\left(g_{m3}r_{o3}r_{o1} // g_{m5}r_{o5}r_{o7}\right)g_{m9}\left(r_{o9} // r_{o11}\right)$$

8.3 Consider the amplifier of Fig 8.3, where $(W/L)_{1-4}=50/0.5$ and $I_{SS}=I_1=0.5mA$. **λp=0.2 and λn=0.1**.

(a) Estimate the poles at nodes X and Y by multiplying the small-signal resistance and capacitance to ground. Assume that $C_X=C_Y=0.5pF$. What is the phase margin for unity-gain feedback?

(b) If $CX=0.5pF$, what is the maximum tolerable value of CY that yields a phase margin for 60° for unity-gain feedback?
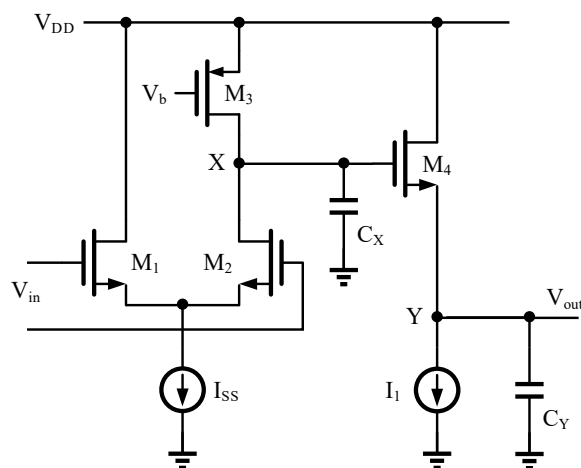


Fig 8.3

解：

(a)

$$r_{o3} = \frac{1}{\lambda_p I_{D3}} = 20k\Omega, \quad r_{o2} = \frac{1}{\lambda_n I_{D2}} = 40k\Omega$$

$$\omega_{px} = \frac{1}{C_X\left(r_{o2} // r_{o3}\right)} = 150\times10^6 \, rad/s$$

$$g_{m4} = \sqrt{2I_1 K_n\left(\frac{W}{L}\right)_4} = 3.3\times10^{-3}$$

$$\omega_{py} = \frac{1}{C_Y\left(g_{m4}\right)^{-1}} = 6.6\times10^9 \, rad/s$$

$$g_{m2} = \sqrt{I_{SS} K_n \left(\frac{W}{L}\right)_4} = 2.35 \times 10^{-3}$$

低频增益为：$g_{m2}(r_{o2} // r_{o3}) = 31.33 \rightarrow 29.9 dB$ （增益转换为 dB 模式）

所以增益交点对应频率为：$20\log \dfrac{\omega_1}{\omega_{px}} = 29.9$，$\omega_1 = 4.69 \times 10^9 rad / s$

$$PM = 180^o - \tan^{-1} \frac{\omega_1}{\omega_{px}} - \tan^{-1} \frac{\omega_1}{\omega_{py}} = 56.43^o$$

(b)

$$PM = 180^o - \tan^{-1} \frac{\omega_1}{\omega_{px}} - \tan^{-1} \frac{\omega_1}{\omega_{py}} = 60^o$$

设 $\omega_{px}$ 不变，解得 $\omega_{py} = 8.43 \times 10^9 rad / s = \dfrac{1}{C_Y (g_{m4})^{-1}}$

解得 $C_Y = 391 fF$

8.4 In the circuit of Fig.8.4, assume that $(W/L)_{1-4} = 100/1$, $C_1 = C_2 = 0.5$ pF, and $I_{SS} = 1$ mA. Calculate the small-signal time constant($\tau$) of the circuit (tips: the transfer function of the amp can be expressed by $\frac{A}{1 + \tau S}$ )
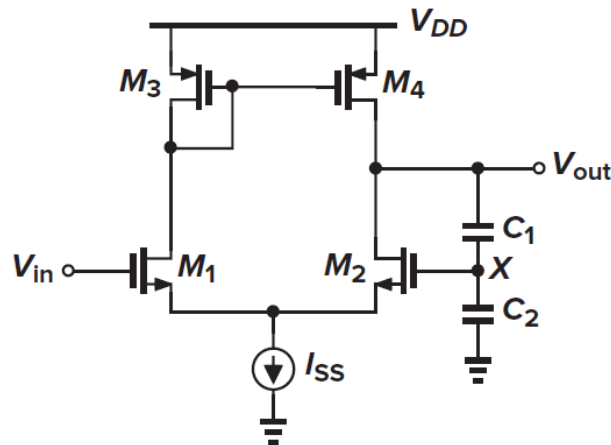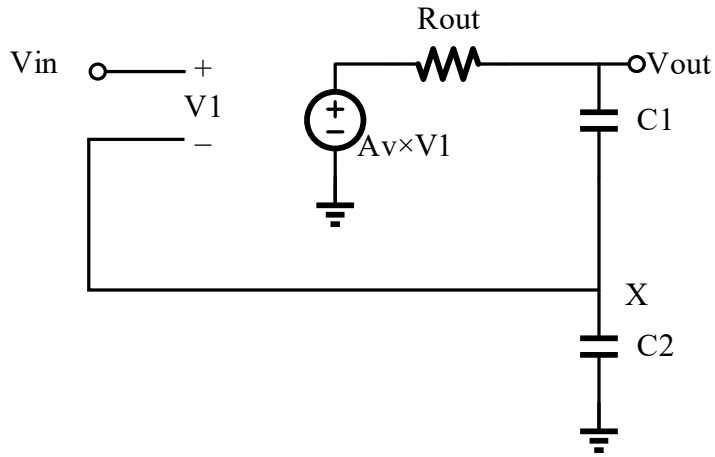


Fig 8.4

解：

$A_v = g_{m1}(r_{o2}//r_{o4}) = 73.7$

$R_{out} = r_{o2}//r_{o4} = 22.2\text{k}$

$V_{in} = V_1 + V_x$

$V_x = V_{out} \dfrac{C_1}{C_1 + C_2}$

$V_{out} = A_v V_1 \left[ \dfrac{\dfrac{1}{C_1//C_2 \cdot S}}{R_{out} + \dfrac{1}{C_1//C_2 \cdot S}} \right] = A_v V_1 \left[ \dfrac{1}{C_1//C_2 \cdot R_{out} \cdot S + 1} \right]$

$\qquad = \dfrac{A_v}{C_1//C_2 \cdot R_{out} \cdot S + 1} \left( V_{in} - V_{out} \dfrac{C_1}{C_1 + C_2} \right)$

$\dfrac{V_{out}}{V_{in}} = \dfrac{\dfrac{A_v}{1 + A_v \dfrac{C_1}{C_1 + C_2}}}{1 + \dfrac{(C_1//C_2)R_{out}S}{1 + A_v \dfrac{C_1}{C_1 + C_2}}}$

$\tau = \dfrac{\dfrac{C_1 C_2}{C_1 + C_2} R_{out}}{1 + A_v \dfrac{C_1}{C_1 + C_2}} = 1.466 \times 10^{-10}$