Table 7.1

Parameter Symbol	Parameter Description	Typical Parameter Value n-Channel	p-Channel	Units
V_{T0}	Threshold voltage ($V_{BS}=0$)	0.7 ± 0.15	−0.7 ± 0.15	V
K'	Transconductance parameter (in saturation)	110.0 ± 10%	50.0 ± 10%	$\mu A/V^2$
γ	Bulk threshold parameter	0.4	0.57	$V^{1/2}$
λ	Channel length modulation parameter	0.04 ($L = 1\ \mu m$) 0.01 ($L = 2\ \mu m$)	0.05 ($L = 1\ \mu m$) 0.01 ($L = 2\ \mu m$)	V^{-1}
$2\|\phi_F\|$	Surface potential at strong inversion	0.7	0.8	V

7.1 In the op amp of Fig 7.1, $(W/L)_{1\text{-}8}=100/0.5$, $I_{SS}=1mA$, 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}?

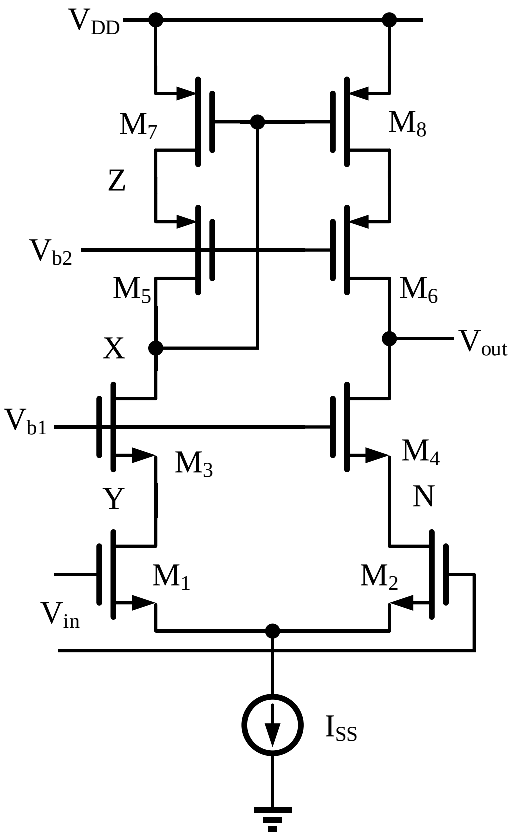


Fig 7.1

解：

(a)

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

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

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

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

(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

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

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

且有$V_N = V_{b1} - V_{GS4}$

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

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

(d)

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

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

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

7.2 Suppose the circuit of Fig 7.2 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, λ=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.

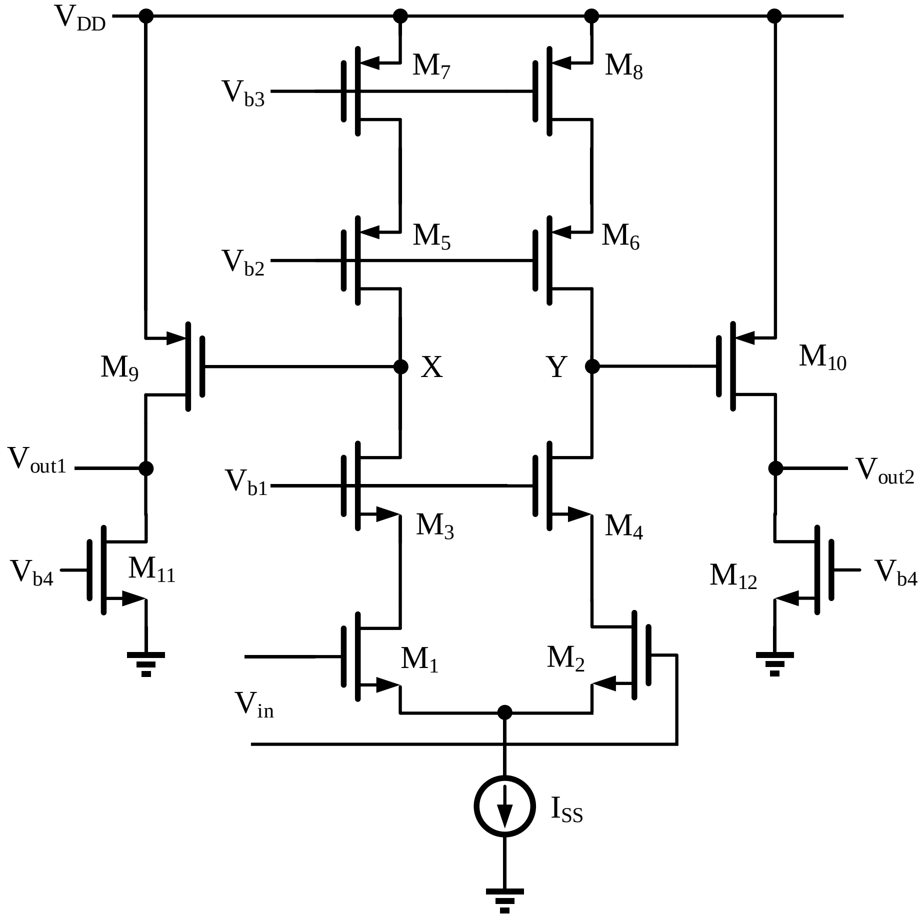


Fig 7.2

解：

(a)

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

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

(b)

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

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

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

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

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

(c)

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

7.3 Consider the amplifier of Fig 7.3, where $(W/L)_{1-4}$=50/0.5 and $I_{SS}=I_1$=0.5mA. **λp=0.2 and λn=0.1**.（此题图有所修改，在答案最后）

(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?

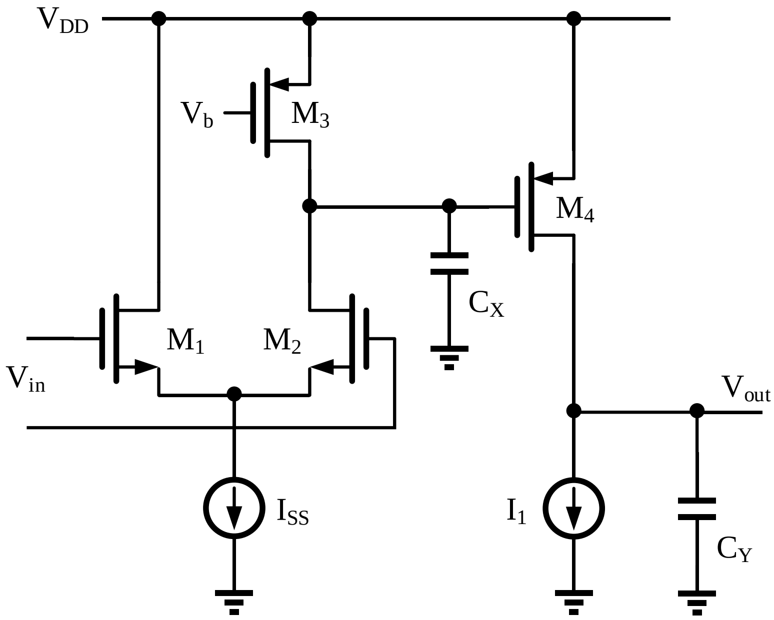


Fig 7.3

解：

(a)

$$r_{o3}=\frac{1}{\lambda_pI_{D3}}=20k\Omega,\ r_{o2}=\frac{1}{\lambda_nI_{D2}}=40k\Omega$$

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

$$g_{m4}=\sqrt{2I_1K_n\left(\frac{W}{L}\right)_4}=3.3\times10^{-3}$$

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

$$g_{m2} = \sqrt{I_{SS}K_n\left(\frac{W}{L}\right)_4} = 2.35\times10^{-3}$$

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

所以增益交点对应频率为：$20\log\frac{\omega_1}{\omega_{px}} = 29.9$，$\omega_1 = 4.69\times10^9 rad/s$

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

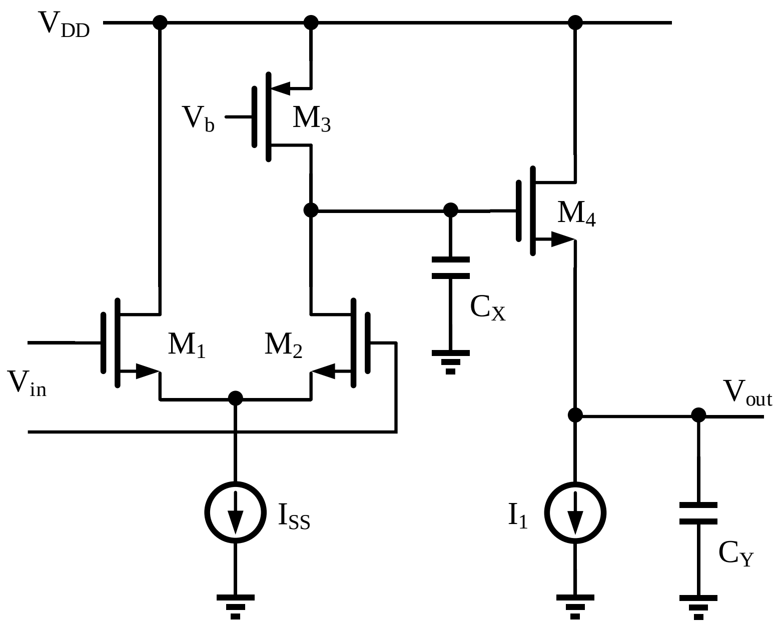
(b)

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

设 ω_{px} 不变，解得 $\omega_{py} = 8.43\times10^9 rad/s = \frac{1}{C_Y\left(g_{m4}\right)^{-1}}$

解得 $C_Y = 391 fF$

此题图应改为：



7.4 In the circuit of Fig.7.4, 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(τ) of the circuit (tips: the transfer function of the amp can be expressed by $\frac{A}{1+\tau S}$)

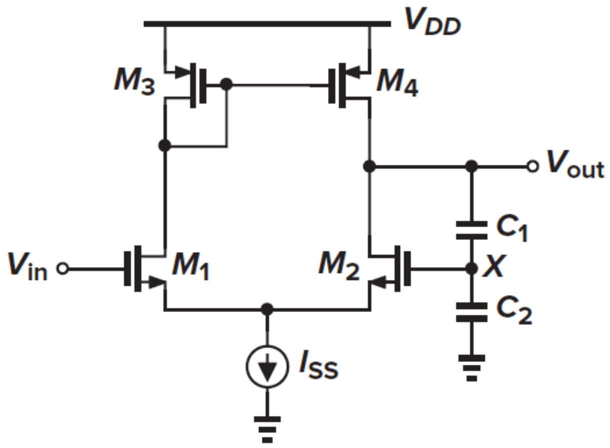
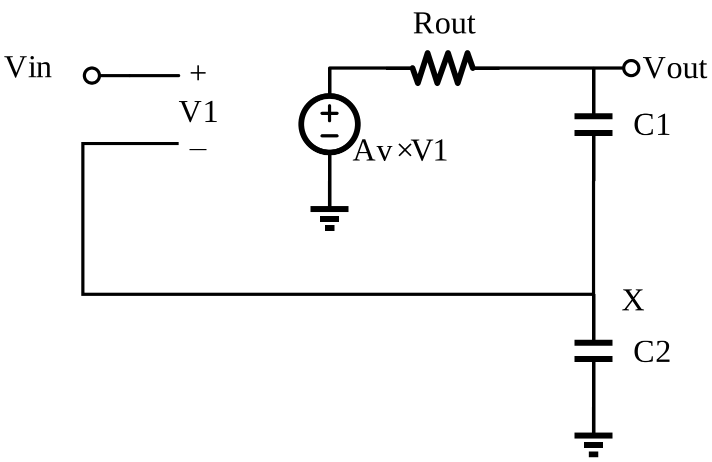


Fig 7.4

解：



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

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

$V_{in} = V_1 + V_x$

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

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

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

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

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