Table 4.1

Parameter Symbol	Parameter Description	Typical Parameter Value n-Channel	Typical Parameter Value p-Channel	Units
V_{T0}	Threshold voltage ($V_{BS} = 0$)	0.7 ± 0.15	-0.7 ± 0.15	V
K'	Transconductance parameter (in saturation)	$110.0 \pm 10\%$	$50.0 \pm 10\%$	$\mu A/V^2$
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

4.1 Calculate the output resistance and the minimum output voltage, while maintaining all devices in saturation, for the circuits shown in Figure 4.1. Assume that i_{OUT} is actually 10μA. Use Table 4.1 for device model information.

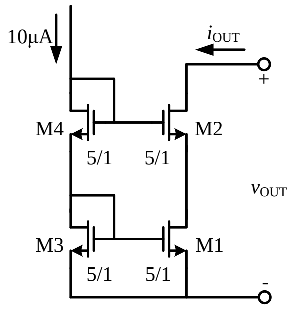

Fig 4.1

解:

$$V_{GS3} = V_{G3} = \sqrt{\frac{2i_D}{\beta}} + V_T = \sqrt{\frac{2 \times 10 \times 10^{-6}}{5 \times 110 \times 10^{-6}}} + 0.7 = \sqrt{\frac{20}{550}} + 0.7 = 0.891$$

$V_{SB2} = V_{G3} = 0.891$

$V_{DS1} = V_{G3} + V_{GS4} - V_{GS2}$ because all devices are matched.

$$g_{m2} = g_{m4} \cong \sqrt{(2K'W/L)|I_D|} = \sqrt{2\times 110\times10^{-6} \times5/1 \times 10\times10^{-6}} = 104.9 \times10^{-6}$$

$$g_{mbs2} = g_{mbs4} = g_{m2}\frac{\gamma}{2(2|\phi_F| + V_{SB})^{1/2}} = 104.9 \times10^{-6}\frac{0.4}{2(0.7 + 0.891)^{1/2}} = 16.63\times10^{-6}$$

$$r_{out} = \frac{v_{out}}{i_{out}} = r_{ds1} + r_{ds2} + [(g_{m2} + g_{mbs2})r_{ds2}]\, r_{ds1}$$

$$g_{ds1} = g_{ds2} \cong I_D\,\lambda = 10\times10^{-6} \times 0.04 = 400\times10^{-9}$$

$$r_{ds1} = r_{ds2} = \frac{1}{g_{ds}} = 2.5\times10^{6}$$

$$r_{out} = 2.5\times10^{6} + 2.5\times10^{6} + [(104.9 \times10^{-6} + 16.63\times10^{-6})\, 2.5\times10^{6}]\, 2.5\times10^{6}$$

$$r_{out} = 764\times10^{6}$$

$$v_{out(\min)} = V_{GS3} + V_{GS4} - V_{T2} = V_{GS3} + \sqrt{\frac{2i_D}{\beta}} + V_{T4} - V_{T2}$$

$$= V_{GS3} + \sqrt{\frac{2i_D}{\beta}} = 0.891 + \sqrt{\frac{2\times10\times10^{-6}}{5\times110\times10^{-6}}} = 1.082\text{V}$$

4.2 Design M3 and M4 of Figure 4.2(a) so that the output characteristics are identical to the circuit shown in Figure 4.2(b). It is desired that i_{OUT} is ideally 10uA.

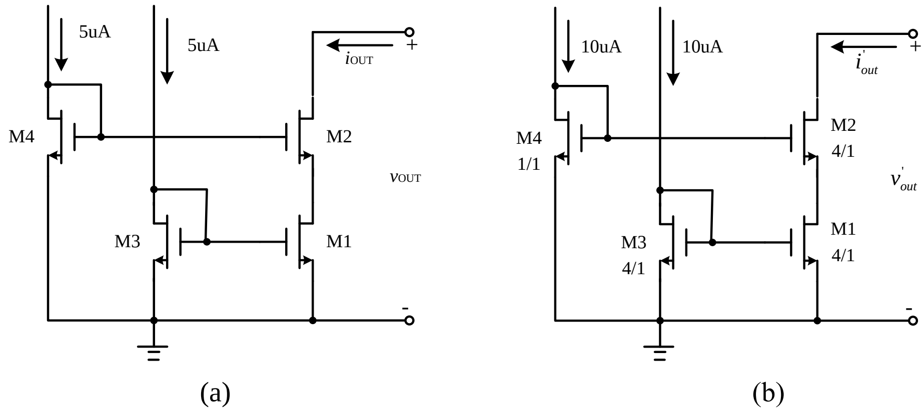

Figure 4.2

解:

For getting $i_{out}^{'} = i_{out} = 10\mu A$

In Fig.4.2a), ∵ $i_3 = i_4 = 5\mu A$

Thus to ensure $i_{out} = 10\mu A$

We must have $\left(\frac{W}{L}\right)_1 = 2\left(\frac{W}{L}\right)_3$

$$\left(\frac{W}{L}\right)_3 = \frac{1}{2}\left(\frac{W}{L}\right)_1 = \frac{1}{2}\cdot\frac{4}{1} = \frac{2}{1}$$

In Fig. 4.2b) $i_4 = i_3 = i_1$

$$\left(\frac{W}{L}\right)_4 \Delta V_4^2 = \left(\frac{W}{L}\right)_1 \Delta V_1^2 \Rightarrow \left(\frac{1}{1}\right)\Delta V_4^2 = \left(\frac{4}{1}\right)\Delta V_1^2$$

$$\therefore \frac{\Delta V_4^2}{\Delta V_1^2} = \frac{4}{1} \Rightarrow \Delta V_4 = 2\Delta V_1$$

$V_{G4} = V_T + 2\Delta V_1$

$V_{G2} = V_{G4} = V_T + 2\Delta V_1$

$\therefore V_{MIN} = 2\Delta V_1$

And we get V_{MIN} in Fig.5.2(a): $V_{MIN} = 2\Delta V_1$

$\therefore V_{G2} = V_{G4} = V_T + 2\Delta V_1$ and $\Delta V_4 = 2\Delta V_1$

In Fig.5.2(a): $i_4 = i_3 = \frac{1}{2} i_1$

$$\left(\frac{W}{L}\right)_4 \Delta V_4^2 = \frac{1}{2}\left(\frac{W}{L}\right)_1 \Delta V_1^2$$

$$\left(\frac{W}{L}\right)_4 = \frac{1}{2}\left(\frac{W}{L}\right)_1 \left(\frac{\Delta V_1}{\Delta V_4}\right)^2$$

For $\left(\frac{\Delta V_4}{\Delta V_1}\right)^2 = 4 \Rightarrow \left(\frac{\Delta V_1}{\Delta V_4}\right)^2 = \frac{1}{4}$

$$\left(\frac{W}{L}\right)_4 = \frac{1}{8}\left(\frac{W}{L}\right)_1 = \frac{1}{8}\cdot\frac{4}{1} = \frac{1}{2}$$

4.3 A reference circuit is shown in figure 4.3, assume that $(W/L)_1=(W/L)_2=(W/L)_3=4$, $(W/L)_4=1$, please calculate the expression of V_{REF}.

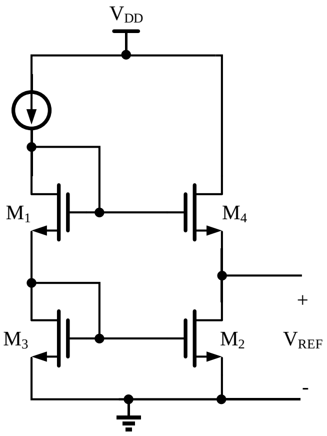

Figure 4.3

解：

V_T

4.4 As the circuits shown in Figure 4.4, I_{REF}=0.3mA and γ=0. Using the model parameters in Table 4.1,

(a)Calculate the voltage V_b when V_X=V_Y;

(b) If V_b is 100mV smaller than the value in (a), calculate the deviation of I_{out} from 300 μ A.

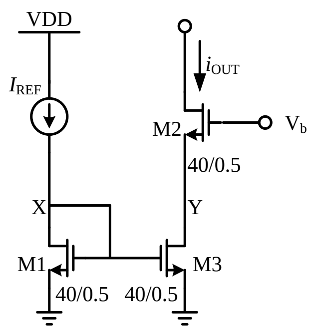

Figure 4.4

解：

a)

$$V_{GS1} = V_T + \sqrt{\frac{2I_{REF}}{K_N'(W/L)_1}} = 0.7 + \sqrt{\frac{2\times 0.3\times 10^{-3}}{80\times 110\times 10^{-6}}} = 0.961V$$

$$V_b = 2V_{GS1} = 1.922V$$

b)

$$\lambda(l = 0.5u) \approx \lambda(l = 1u)\frac{1u}{0.5u} = 0.04\times 2 = 0.08V^{-1}$$

$$I_{out} = I_{REF}\frac{1+\lambda(V_{GS1}+\Delta V_b)}{1+\lambda V_{GS1}}$$

$$\Delta I_{out} = I_{REF}\frac{\lambda\Delta V_b}{1+\lambda V_{GS1}} = 0.3\times 10^{-3}\times\frac{0.08\times(-0.1)}{1+0.08\times 0.961} = -2.229\times 10^{-6}A$$

4.5 Assume that W/L ratios of Figure 4.5 are $(W/L)_1$ = 2μm/1μm and $(W/L)_2$ = $(W/L)_3$ = $(W/L)_4$ =1μm/1μm. Find the dc value of v_{IN} that will give a dc current in M1 of 110μA. Calculate the small signal voltage gain and output resistance using the parameters of Table 4.1. Assume $\lambda=\gamma=0$.

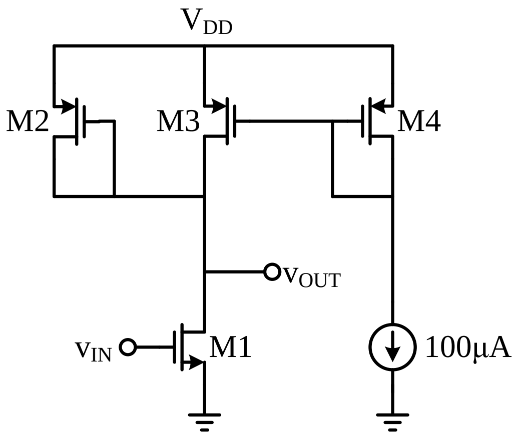

Figure 4.5

Solution:

$$I_{D1} = \frac{1}{2} K'_N (\frac{W}{L})_1 (V_{in} - V_{TH1})^2$$

$$110\mu = \frac{1}{2} \times (110\mu) \times \frac{2}{1} \times (V_{in} - 0.7)^2$$

$$V_{in} = 1.7V$$

$$I_{D3} = I_{D4} = 100\mu A$$

$$I_{D2} = I_{D1} - I_{D3} = 10\mu A$$

$$A_v \cong -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{K'_N}{K'_P} \frac{(W/L)_1}{(W/L)_2} \frac{I_{D1}}{I_{D2}}} = -\sqrt{\frac{110\mu}{50\mu} \times \frac{2}{1} \times \frac{110\mu}{10\mu}} = -6.96V/V$$

$$R_{out} \cong \frac{1}{g_{m2}} = \frac{1}{\sqrt{2K'_P (W/L)_2 I_{D2}}} = \frac{1}{\sqrt{2 \times 50 \times 10^{-6} \times 1 \times 10 \times 10^{-6}}} = 31.6K\Omega$$