Exercise 5

Table 5.1

		Typical Parameter Value		
Parameter Symbol	Parameter Description	n-Channel	p-Channel	Units
V_{T0}	Threshold voltage(V_{BS}=0)	0.7	-0.8	V
K	Transconductance parameter(in saturation)	134	50	$\mu A/V^2$
γ	Bulk threshold parameter	0.45	0.4	$V^{1/2}$
λ	Channel length modulation parameter	0.1	0.2	V^{-1}
$2\lvert\phi_F\rvert$	Surface potential at strong inversion	0.9	0.8	V

$* K = \mu C_{OX}$

4.1 Calculate the output resistance and the minimum output voltage, while maintaining all devices in saturation, for the circuits shown in Figure 5.1. Assume that i_{OUT} is actually 10μA. Use Table 5.1 for device model information. V_{bs}=0 V.

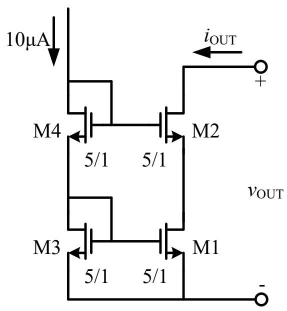


Fig 5.1

Answer:

$$V_{GS3} = V_{GS4} = \left(\sqrt{2 \times \frac{L}{KW} I_D} + V_T\right) = 0.17 + 0.7\ V = 0.87\ \text{V}.$$

$$g_{m2} = g_{m4} = \sqrt{2 \times \frac{KW}{L} I_D} = 115.8 \times 10^{-6}$$

$$r_{out} = r_{ds1} + r_{ds2} + g_{m2} r_{ds1} r_{ds2}.$$

$$r_{ds1} = r_{ds2} = \frac{1}{\lambda I_D} = 1 \times 10^6$$

$$r_{out} = 117.8 \times 10^6$$

$$v_{out} = V_{GS3} + V_{GS4} - V_{T2} = 1.04\ V$$

5.2 A reference circuit is shown in figure 5.2, assume that $(W/L)_1$=$(W/L)_2$= $(W/L)_3$=4, $(W/L)_4$=1, please calculate the symbolic expression of V_{REF}.（已知各管处于饱和区且各管阈值电压为Vt）

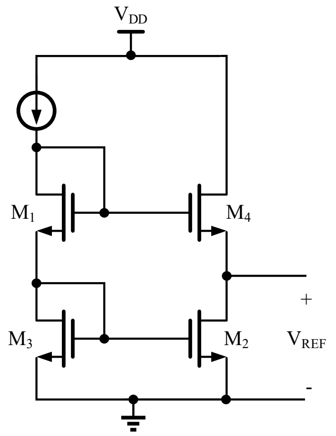


Figure 5.2

Answer:

$$V_{REF} = V_{GS1} + V_{GS3} - V_{GS4}$$

$$V_{REF} = V_{ON1} + V_{T1} + V_{ON3} + V_{T3} - V_{ON4} - V_{T4}$$

$$V_{T3} = V_{T4}$$

$$V_{ON4} = 2 \times V_{ON1} = 2 \times V_{ON3}$$

$$V_{REF} = V_{T1}$$

5.3 As the circuits shown in Figure 5.3, I_{REF}=0.3mA and γ=0. Using the model parameters in Table 5.1,

(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.

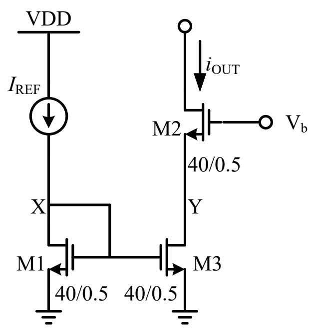


Figure 5.3

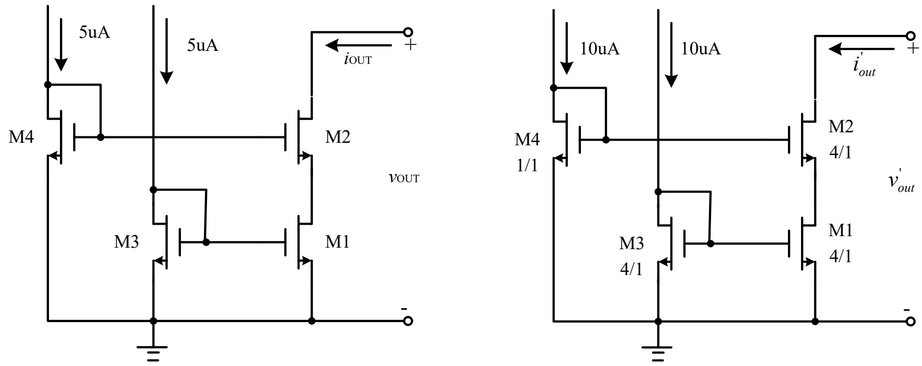
Answer:

(a) $V_{GS1} = \left(\sqrt{2 \times \frac{L}{KW} I_{REF}} + V_T\right) = 0.24 + 0.7 = 0.94\,V.V_b = 2 \times V_{GS1} = 1.88\,V.$

(b) $\lambda(L = 0.5u) = 2 \times \lambda(L = 1u) = 0.2V^{-1}$

$$I_{out} = I_{REF}\frac{1 + \lambda(V_{GS1} + \Delta V_b)}{1 + \lambda V_{GS1}}, \quad \Delta\, I_{out} = I_{REF}\frac{\lambda \Delta V_b}{1 + \lambda V_{GS1}} = -5.05 \times 10^{-6}$$

5.4 Design M3 and M4 of Figure 5.4(a) so that the output characteristics are identical to the circuit shown in Figure 5.4(b). It is desired that i_{OUT} is ideally 10uA.



(a) (b)

Figure 5.4

Answer:

(a) $V_{GS1} = V_{GS3}, V_{GS2} = V_{GS4}. I_3 = I_4 = 5uA,\ I_{out} = 10uA$, we must have $\left(\frac{W}{L}\right)_1 = 2 \times \left(\frac{W}{L}\right)_3, \left(\frac{W}{L}\right)_3 = 2/1.$

In (b) $i_3 = i_4 = 10uA = i_1,\quad \left(\frac{W}{L}\right)_4 \times \mathrm{V}_{\mathrm{Dsat4}}^2 = \left(\frac{W}{L}\right)_1 \times \mathrm{V}_{\mathrm{Dsat1}}^2, \mathrm{V}_{\mathrm{Dsat4}} = 2 \times \mathrm{V}_{\mathrm{Dsat1}}$

$V_{GS4} = V_T + V_{Dsat4}, V_{GS2} = V_T + V_{Dsat4}, V_{out} > V_{GS2} - V_T = V_{Dsat4} = 2 \times V_{Dsat1}$

In (a) $I_3 = I_4 = 5uA = 2 \times I_1,\ \left(\frac{W}{L}\right)_4 \times \mathrm{V}_{\mathrm{Dsat4}}^2 = \frac{1}{2}\left(\frac{W}{L}\right)_1 \times \mathrm{V}_{\mathrm{Dsat1}}^2$

$$because, \quad \frac{V_{Dsat4}}{V_{Dsat1}} = \sqrt{\frac{1}{2} \times \left(\frac{W}{L}\right)_1 / \left(\frac{W}{L}\right)_4} = 2,\ \left(\frac{W}{L}\right)_4 = \frac{1}{8} \times \left(\frac{W}{L}\right)_1 = 1/2$$