



Exercise 5

Table 5.1

Parameter Symbol	Parameter Description	Typical Parameter Value		Units
		n-Channel	p-Channel	
V_{T0}	Threshold voltage($V_{BS}=0$)	0.7	-0.8	V
K	Transconductance parameter(in saturation)	134	50	$\mu\text{A}/\text{V}^2$
γ	Bulk threshold parameter	0.45	0.4	$\text{V}^{1/2}$
λ	Channel length modulation parameter	0.1	0.2	V^{-1}
$2 \phi_F $	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 $10\mu\text{A}$. Use Table 5.1 for device model information. $V_{bs}=0$ V.

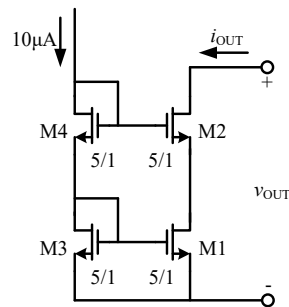


Fig 5.1

Answer:

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

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

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

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

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

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

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 V_t)

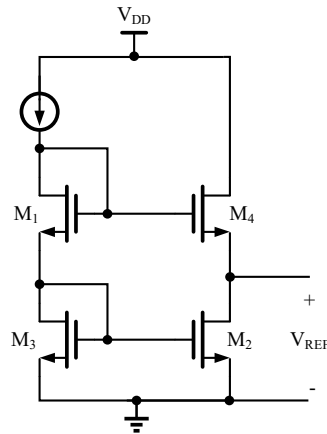


Figure 5.2

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 $\gamma=0$. Using the model parameters in Table 5.1,

- Calculate the voltage V_b when $V_X=V_Y$.
- If V_b is 100mV smaller than the value in (a), calculate the deviation of I_{out} from $300 \mu A$.

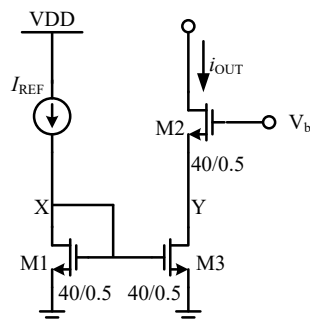


Figure 5.3

Answer:

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

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

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

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.

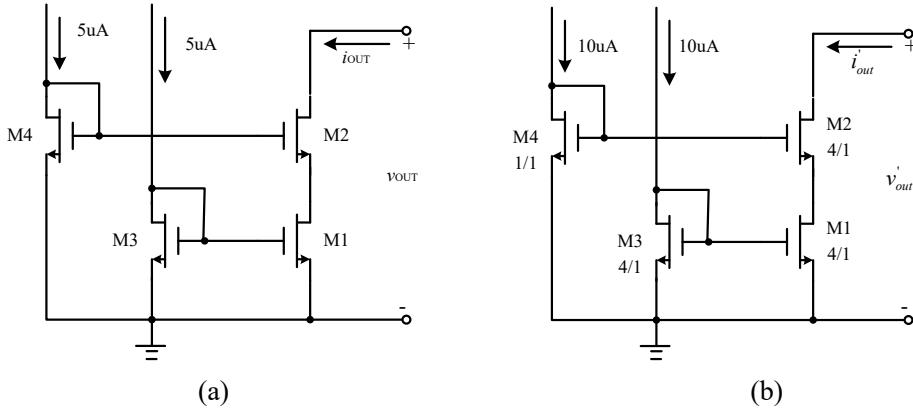


Figure 5.4

Answer:

$$(a) \quad V_{GS1} = V_{GS3}, V_{GS2} = V_{GS4}, I_3 = I_4 = 5\mu A, I_{out} = 10\mu A, \text{ we must have } \left(\frac{W}{L} \right)_1 = 2 \times$$

$$\left(\frac{W}{L} \right)_3, \left(\frac{W}{L} \right)_3 = 2/1.$$

$$\text{In (b)} \quad i_3 = i_4 = 10\mu A = i_1, \quad \left(\frac{W}{L} \right)_4 \times V_{Dsat4}^2 = \left(\frac{W}{L} \right)_1 \times V_{Dsat1}^2, V_{Dsat4} = 2 \times V_{Dsat1}$$

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

$$\text{In (a)} \quad I_3 = I_4 = 5\mu A = 2 \times I_1, \quad \left(\frac{W}{L} \right)_4 \times V_{Dsat4}^2 = \frac{1}{2} \left(\frac{W}{L} \right)_1 \times V_{Dsat1}^2$$

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