Exercise 4

Table 4.1

		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 For the circuit in Fig.4.1(a) assume that there are no capacitance parasitics associated with M1. The voltage source v_{in} is a small-signal value, whereas voltage source V_{DC} has a dc value of 3 V. Design M1 to achieve the asymptotic frequency response shown in Fig.4.1(b).

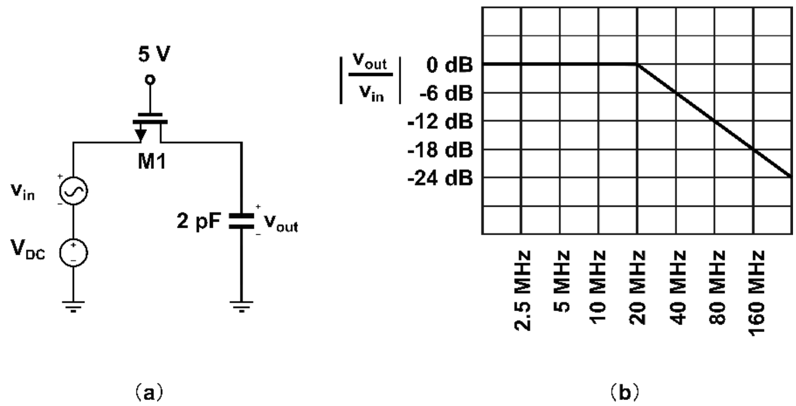


Fig.4.1

Answer:

$f(-3dB) = 20MHz$,thus $\omega = 40\pi M$ rad/s.Note that since no dc current flows through the transistor, the dc value of the drain-source voltage is zero.

$$r_{ON} = \frac{L}{KW(V_{GS}-V_T)}, \text{then } \frac{1}{RC} = \frac{KW(V_{GS}-V_T)}{LC} \text{ find } \frac{W}{L} = \frac{C \times 40\pi \times 10^6}{K(V_{GS}-V_T)}$$

$$V_T = V_{T0} + \gamma\left(\sqrt{|2\varphi_F| + |v_{bs}|} - \sqrt{|2\varphi_F|}\right) = 0.7 + 0.45 \times \left(\sqrt{0.9+3} - \sqrt{0.9}\right) = 1.16$$

$$\frac{W}{L} = \frac{2 \times 10^{-12} \times 40\pi \times 10^{6}}{134 \times 10^{-6} \times (2 - 1.16)} = 2.23$$

Vt=0.7， w/l=2.88

4-2 Fig.4.2 illustrates a source-degenerated current source. M1 with W/L=2u/1u, I_D = 10uA.

(a) Using Table 4.1 model parameters, calculate the output resistance at the given current bias. Ignore the body effect.

(b) Calculate the minimum output voltage required to keep the device in saturation.

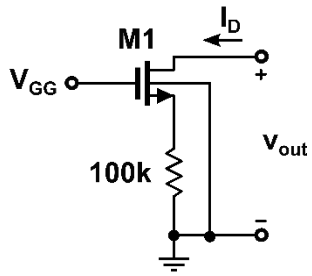
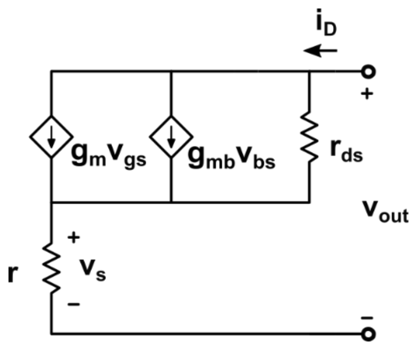


Fig.4.2

Answer:

The small-signal model if this circuit is shown below



(a) $V_S = I_D \times r = 1\text{V}, r_{out} = r + r_{ds} + [(g_m + g_{mb})r_{ds}]r.$

$$g_m = \sqrt{2 \times \frac{KW}{L} I_D} = 73.2 \times 10^{-6}$$

$$g_{mb} = g_m \frac{\gamma}{2(2|\Phi_F| + V_{SB})^{\frac{1}{2}}} = 11.9 \times 10^{-6}$$

$$g_{ds} = \lambda I_D = 1 \times 10^{-6}$$

$$r_{ds} = \frac{1}{g_{ds}} = 1 \times 10^{6}$$

thus $r_{out} = 9.61 \times 10^{6}$

(b) $V_T = V_{T0} + \gamma\left(\sqrt{|2\varphi_F| + |v_{bs}|} - \sqrt{|2\varphi_F|}\right) = 0.89\,V.\, V_{GS} = \left(\sqrt{2 \times \frac{L}{KW} I_D} + V_T\right) =$ $1.16V.\, V_{GG} = V_{GS} + V_S = 2.16\ V\ , V_{out} > V_{GG} - V_T =\ 1.27V$

4-3 Calculate the output resistance and the minimum output voltage, while maintaining all devices in saturation, for the circuits shown in Fig.4.3. Assume that i_{OUT} is actually 10μA. Use Table 4.1 for device model information.

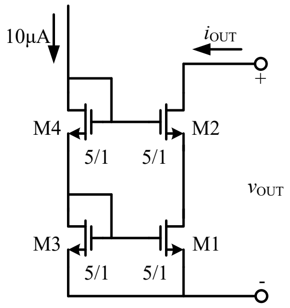


Fig .4.3

Answer:

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

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

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

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

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

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

4-4 A reference circuit is shown in Fig.4.4, assume that $(W/L)_1=(W/L)_2=(W/L)_3=4$, $(W/L)_4=1$, please derive a symbolic expression of V_{REF}.（已知各管处于饱和区且各管阈值电压为V_{Ti}）

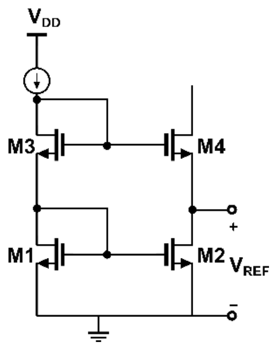


Fig.4.4

Answer:

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

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

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

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

$V_{REF} = V_{T1}$

4-5 As the circuits shown in Fig.4.5, 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 μA.

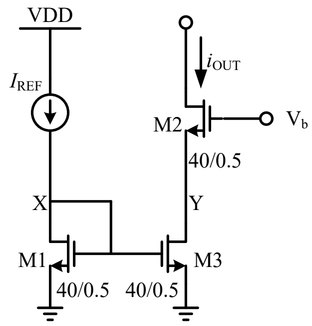


Fig.4.5

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

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

4-6 Design M3 and M4 of Fig.4.6(a) so that the output characteristics are identical to the circuit shown in Fig.4.6(b). It is desired that i_{OUT} is ideally 10uA.

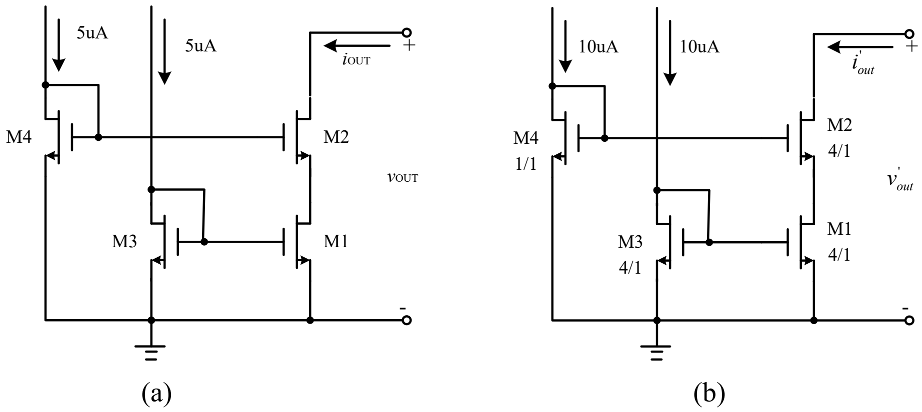


Fig.4.6

(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）$i_3 = i_4 = 10uA = i_1$, $\left(\frac{W}{L}\right)_4 \times V_{Dsat4}^2 = \left(\frac{W}{L}\right)_1 \times V_{Dsat1}^2, V_{Dsat4} = 2 \times V_{Dsat1}$

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

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

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