习 题 5

Table 5.1

		Typical Parameter Value		
Parameter	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}
$2\|\phi_F\|$	Surface potential at strong inversion	0.9	0.8	V

5.1 Figure 5.1 shows an n-channel input differential amplifier, with the parameters shown in table 5.1. Consider I_{ss}=100μA(the drain current of M5), and $W_1/L_1=W_2/L_2=W_3/L_3=W_4/L_4=W_5/L_5=1$. Assuming all the channel lengths are equal to 1μm, and V_{DD}=5V.

(a) Calculate the differential transconductance g_{md} and the differential voltage gain A_v

(b) Calculate the maximum (V_{IC}(max)) and the minimum input common-mode voltages (V_{IC}(min)), and the input common mode voltage range (ICMR)

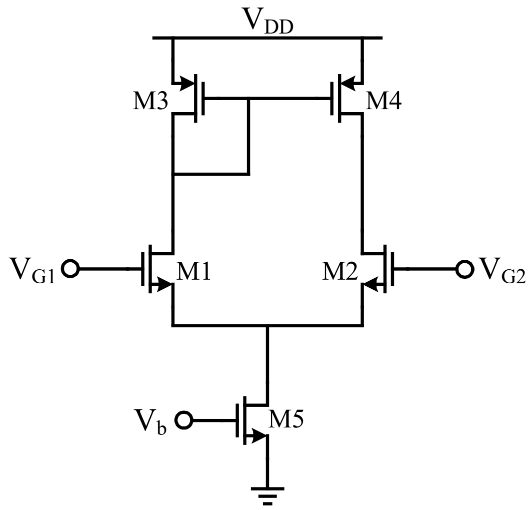


Figure 5.1

解：

(a)

$$\left(\frac{W}{L}\right)_1=\left(\frac{W}{L}\right)_2=\left(\frac{W}{L}\right)_3=\left(\frac{W}{L}\right)_4=1$$

$$g_{md}=g_{m1}=g_{m2}=\sqrt{K_n{}'\left(\frac{W}{L}\right)_1 I_{SS}}=115.76\mu S$$

$$A_v=\frac{g_{m2}}{g_{ds2}+g_{ds4}}=\frac{2g_{m2}}{(\lambda_2+\lambda_4)I_{SS}}=7.72V/V$$

(b)

$$V_{IC}(max)=V_{DD}+V_{T1}-V_{T3}-V_{dsat3}$$

$$= V_{DD} + V_{T1} - V_{T3} - \sqrt{\frac{I_{SS}}{K_P^{'}(W/L)_3}} = 3.49V$$

$$V_{IC}(\min) = V_{SS} + V_{T1} + V_{dsat1} + V_{dsat5}$$

$$= V_{SS} + V_{T1} + \sqrt{\frac{I_{SS}}{K_N'(W/L)_1}} + \sqrt{\frac{2I_{SS}}{K_N'(W/L)_5}} = 2.79V$$

$$ICMR = V_{IC}(max) - V_{IC}(min) = 0.7V$$

5.2 Find the value of the unloaded differential-transconductance, g_{md}, and the unloaded differential-voltage gain, A_v, for the p-channel input differential amplifier of Figure 5.3 when I_{SS}=10μA and I_{SS}=1μA. What is the slew rate of the differential amplifier if a 100 pF capacitor is attached to the output? Assuming W1/L1=W2/L2=W3/L3=W4/L4=1, and all the channel lengths are equal to 1μm. Use the transistor parameters of Table 5.1.

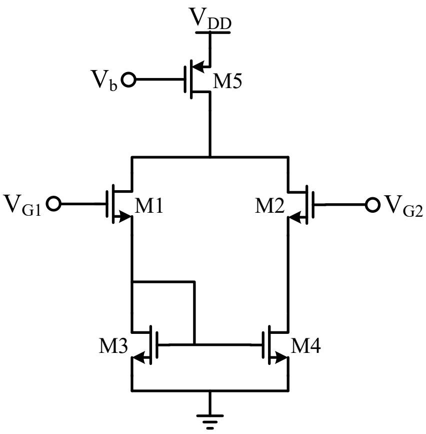


Figure 5.3

解：

a) Given I_{SS}=10μA,

$$g_{md} = g_{m1} = g_{m2} = 36.6\mu S$$

$$A_v = \frac{g_{m1}}{g_{ds2} + g_{ds4}} = \frac{2g_{m1}}{(\lambda_1 + \lambda_2)I_{SS}} = 36.6V/V$$

Given I_{SS}=1μA

$$g_{md} = g_{m1} = g_{m2} = 11.6\mu S$$

$$A_v = \frac{g_{m1}}{g_{ds2} + g_{ds4}} = \frac{2g_{m1}}{(\lambda_1 + \lambda_2)I_{SS}} = 115.8V/V$$

b) Slew rate can be given as

$$SR = \frac{I_{SS}}{C_L}$$

For $I_{SS} = 10\ \mu A$ and $C_L = 100$ pF

$$SR = \frac{I_{SS}}{C_L} = \underline{0.1\ \text{V/µs}}$$

For $I_{SS} = 1\ \mu A$ and $C_L = 100$ pF

$$SR = \frac{I_{SS}}{C_L} = \underline{0.01\ \text{V/µs}}$$

5.3 In the circuit of Fig 5.4, assume that I_{SS}=1mA, V_{DD}=3V and W/L=50/0.5 for all the transistors. And $I_{D5}=I_{D6}=0.8(I_{SS}/2)$. Assuming $\boldsymbol{\lambda \neq 0}$.

(a) Determine the voltage gain.

(b) Calculate V_b.

(c) If I_{SS} requires a minimum voltage of 0.4V, what is the maximum differential output swing?

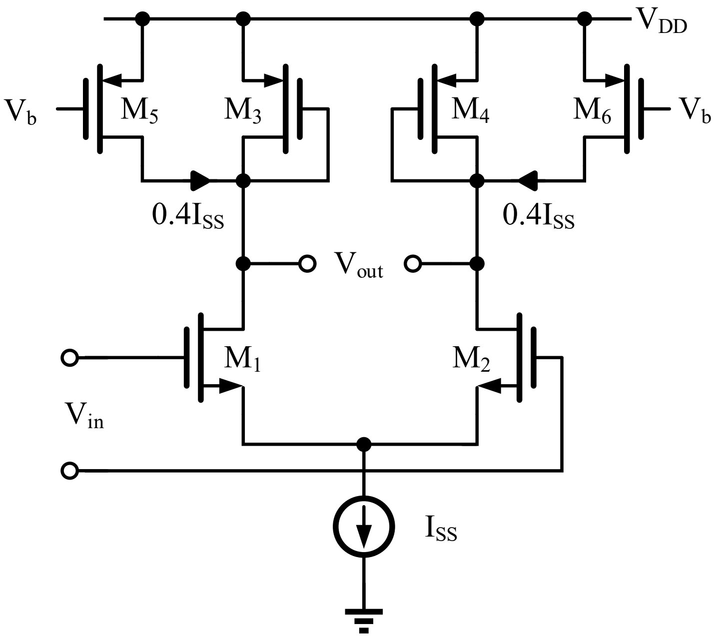


Figure 5.4

解：

a) $$A_V \approx -\frac{g_{m1}}{g_{m3}} = \sqrt{\frac{\mu_n I_{D1}}{\mu_p I_{D3}}} = \sqrt{\frac{134 \times 0.5 I_{SS}}{50 \times 0.2 \frac{I_{SS}}{2}}} = -3.66$$

b) $$I_{D5} = I_{D6} = 0.8\frac{I_{SS}}{2} = 0.4mA$$

$$V_b = V_{DD} - V_{SG5} = V_{DD} - |V_{TH}| - \sqrt{\frac{2I_{D5}}{\mu_p C_{ox}\frac{W}{L}}} = 1.8V$$

c)

$$\left(V_{out1,2}\right)_{\max} = \min\left(V_b + |V_{TH,P}|, V_{DD} - |V_{TH,P}|\right) = \min(1.9+0.8, 3-0.8) = 2.2V$$

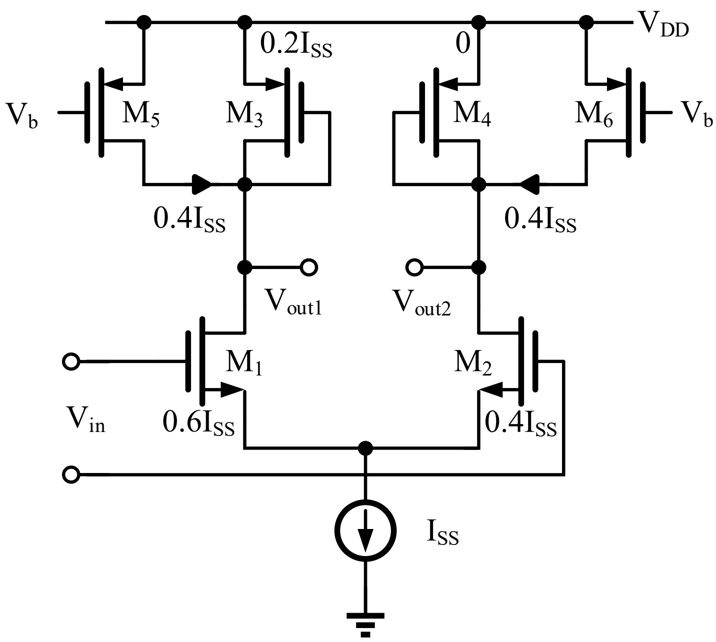
$$\left(V_{out1,2}\right)_{\min} = \max\left(V_{Iss\min} + V_{GS1}\Big|_{I_D=0.6I_{SS}} - V_{TH,N}, V_{DD} - V_{SG3}\Big|_{I_D=0.2I_{SS}}\right)$$

$$V_{GS1}\Big|_{I_D=0.6I_{SS}} = V_{TH,N} + \sqrt{\frac{2\times 0.6I_{SS}}{\mu_n C_{ox}\frac{W}{L}}} = 0.7+0.3 = 1.0V$$

$$V_{SG3}\Big|_{I_D=0.2I_{SS}} = |V_{TH,P}| + \sqrt{\frac{2\times 0.2I_{SS}}{\mu_p C_{ox}\frac{W}{L}}} = 0.8+0.28 = 1.08V$$

$$\left(V_{out1,2}\right)_{\min} = \max(0.4+1-0.7, 3-1.08) = 1.92V$$

$$V_{out,swing} = 2(2.2-1.92) = 0.56V$$



5.4 The circuit shown in Figure 5.5 called a folded-current mirror differential amplifier and is useful for low values of power supply. Assume that all W/L values of each transistor is 100. Using the parameters shown in table 5.1,

a) Find the maximum input common mode voltage, V_{IC}(max) and the minimum input common mode voltage, V_{IC}(min). Keep all transistors in saturation for this problem.

b) What is the input common mode voltage range, ICMR?

c) Find the small signal voltage gain, v_{out}/v_{in}, if $v_{in} = v_1 - v_2$.

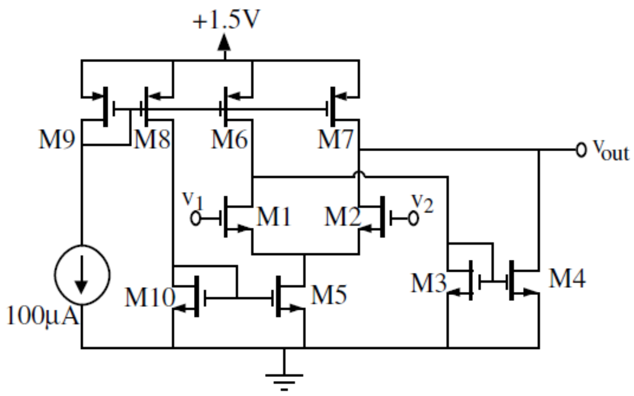


Figure 5.5

解：

a) $v_{1(\max)} = V_{GS3} + V_{TN} = 0.7 + \sqrt{\dfrac{2\bullet 50}{134\bullet 100}} + 0.7 = 1.486V$

$$\mathrm{v_1(min)} = 0 + \mathrm{V_{DS5}(sat)} + \mathrm{V_{GS1}}(50\mu\mathrm{A}) = \sqrt{\frac{2\cdot 100}{134\cdot 100}} + \left(\sqrt{\frac{2\cdot 50}{134\cdot 100}} + 0.7\right)$$

$$= 0.122 + 0.086 + 0.7 = 0.908\mathrm{V} \Rightarrow \mathrm{v_1(min)} = 0.908\mathrm{V}$$.

b) $V_{ICMR} = v_{1(\max)} - v_{1(\min)} = 1.486 - 0.908 = 0.5784V$

c) $A_v = g_{m1} \times (r_{o2} // r_{o4} // r_{o7}) = 38.67V/V$

5.5 In the circuit of Fig 5.5, assume that I_{SS} = 0.5mA, V_{DD} = 3V, $(W/L)_{1,2}$ = 50/0.5 and $(W/L)_{3,4}$ = 10/0.5. I_{SS} current is provided by NMOS, and its W/L = 50/0.5. Assuming **$\lambda \neq 0$**.

a) Calculate the range of input common mode voltage.

b) If $V_{in,CM}$ = 1.5V, draw a sketch of the small signal differential voltage gain of the circuit when VDD changes from 0 to 3V.

c) If the mismatch threshold voltage of M_1 and M_2 is 1mV, calculate CMRR.

d) If the W_3 = 10μm and W_4 = 11μm, calculate CMRR.

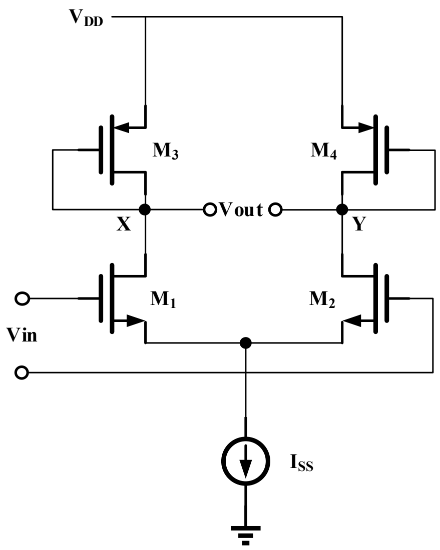


Figure 5.5

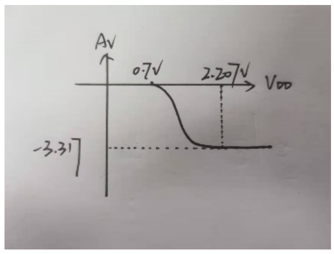
解：

a) $$(V_{in,cm})_{\min} = V_{GS1} + Vod_{ss} = V_{TH1} + \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}(\frac{W}{L})_1}} + \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}(\frac{W}{L})_{SS}}} = 0.7V + 0.19V + 0.27V = 1.16V$$

$$(V_{in,cm})_{\max} = V_{DD} - V_{od3} - V_{TH,P} + V_{TH,N} = V_{DD} - 0.8 + 0.7 - \sqrt{\frac{2I_{D3}}{\mu_p C_{ox}(\frac{W}{L})_3}} = 3V - 0.707V - 0.1 = 2.193V$$

b) 三个标记点：

开启电压$V_{TH,P}$ = 0.8V



增益 $$Av = -\sqrt{\frac{Kn(\frac{W}{L})_1}{Kp(\frac{W}{L})_3}} = -3.66$$

饱和点电压$VDD = V_{in,cm} - V_{TH,N} + V_{GS3} = 1.5V - 0.7V + 0.8V + 0.707V = 2.307V$ [图中数据有误]

c) 由于M1和M2的阈值电压失配，因此有： $g_{m1} \neq g_{m2}, g_{m3} \neq g_{m4}$

为了计算$A_{cm\text{-}dm}$有：

$$i_{D1} = g_{m1}(V_{in,cm} - V_p)$$

$$i_{D2} = g_{m2}(V_{in,cm} - V_p)$$

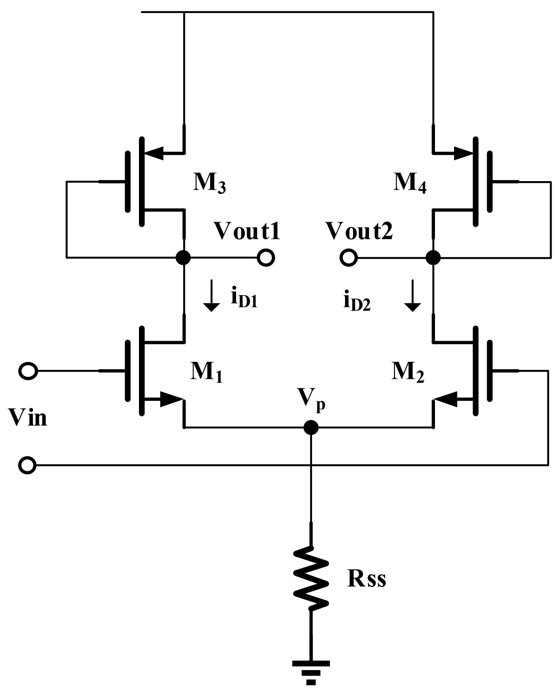
$$Vout1 = -\frac{i_{D1}}{g_{m3}} = -\frac{g_{m1}(V_{in,cm} - V_p)}{g_{m3}}$$

$$Vout2 = -\frac{i_{D2}}{g_{m4}} = -\frac{g_{m2}(V_{in,cm} - V_p)}{g_{m4}}$$

$$\frac{g_{m1}}{g_{m3}} = \sqrt{\frac{Kn(\frac{W}{L})_{1,2}}{Kp(\frac{W}{L})_{3,4}}} = \frac{g_{m2}}{g_{m4}}$$

$$\therefore Vout1 = Vout2$$

$$\therefore A_{cm-dm} = 0, CMRR = \infty$$



d)

$$A_{dm-dm} = -g_m R_D$$

$$A_{cm-dm} = \frac{g_m R_D}{1+2g_m R_{ss}} - \frac{g_m(R_D + \Delta R_D)}{1+2g_m R_{ss}} = -\frac{g_m \Delta R_D}{1+2g_m R_{ss}}$$

$$\therefore CMRR = \left|\frac{A_{dm-dm}}{A_{cm-dm}}\right| = \frac{1+2g_m R_{ss}}{\Delta R_D / R_D}$$

$$\because R_{D1} = \frac{1}{g_{m3}}, R_{D2} = \frac{1}{g_{m4}}$$

$$\therefore \frac{\Delta R_D}{R_D} = \frac{R_{D1} - R_{D2}}{R_{D1}} = 1 - \frac{R_{D2}}{R_{D1}} = 1 - \sqrt{\frac{2K_p(\frac{W}{L})_3 I_D}{2K_p(\frac{W}{L})_4 I_D}} = 1 - \sqrt{\frac{10}{11}} = 0.0465$$

$$gm = \sqrt{2Kn(\frac{W}{L})_1 I_{D1}} = 2.59m\Omega^{-1}$$

$$Rss = \frac{1}{\lambda I_{SS}} = \frac{1}{0.1 \times 0.5 \times 10^{-3}} = 20k\Omega$$

$$\therefore CMRR = \frac{1 + 2 \times 2.59m\Omega^{-1} \times 20k\Omega}{0.0465} = 2248$$