Table 6.1

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 ± 10%	50.0 ± 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

5.1 Calculate the differential transconductance g_{md} and the differential voltage gain A_v of an n-channel input differential amplifier shown in Figure 5.1 , with the parameters shown in table 6.1. Consider I_{ss}=100μA(the drain current of M5), and $W_1/L_1=W_2/L_2=W_3/L_3=W_4/L_4=1$. Assuming all the channel lengths are equal to 1μm, and V_{DD}=5V. If $W_1/L_1=W_2/L_2=10W_3/L_3=10W_4/L_4=10$, repeat the calculation

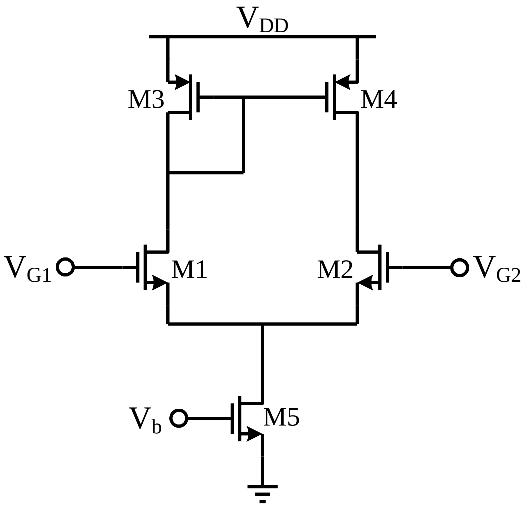


Figure 6.1

解：

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

$$g_{md}=g_{m1}=g_{m2}=\sqrt{K_n'\left(\frac{W}{L}\right)_1 I_{SS}}=104.9\mu S$$

$$A_v=\frac{g_{m2}}{g_{ds2}+g_{ds4}}=\frac{2g_{m2}}{(\lambda_2+\lambda_4)I_{SS}}=23.31V/V$$

$$b)\ \left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 10\left(\frac{W}{L}\right)_3 = 10\left(\frac{W}{L}\right)_4 = 10$$

$$g_{md} = g_{m1} = g_{m2} = \sqrt{K_n'\left(\frac{W}{L}\right)_1 I_{SS}} = 331.7\mu S$$

$$A_v = \frac{g_{m2}}{g_{ds2}+g_{ds4}} = \frac{2g_{m2}}{(\lambda_2+\lambda_4)I_{SS}} = 73.71V/V$$

5.2 Calculate the maximum(V_{IC}(max)) and the minimum input common-mode voltages (V_{IC}(min)), and the input common mode voltage range (ICMR) of an n-channel input differential amplifier shown in Figure 6.1, with the parameters shown in table 6.1. Assume all MOSFETs are in saturation, all the (W/L)s are equal to 10μm/1μm, I_{SS}=10μA, and V_{DD}=5V.

解：

The maximum input common-mode input is given by

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

or, $$V_{IC}(\max) = V_{DD} + V_{T1} - V_{T3} - \sqrt{\frac{I_{SS}}{K_P'(W/L)_3}} = \underline{4.86\ V}$$

The minimum input common-mode input is given by

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

or, $$V_{IC}(\min) = V_{SS} + V_{T1} + \sqrt{\frac{I_{SS}}{K_N'(W/L)_1}} + \sqrt{\frac{2I_{SS}}{K_N'(W/L)_5}} = \underline{0.93\ V}$$

So, the input common-mode range becomes

$$ICMR = V_{IC}(\max) - V_{IC}(\min) = \underline{3.93\ V}$$

5.3 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 6.3 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 6.1.

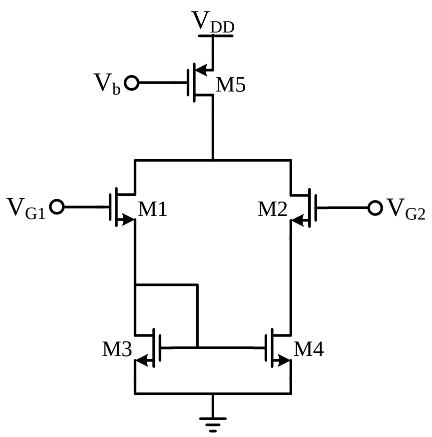


Figure 6.3

解：

a) Given I_{SS}=10μA,

$$g_{md} = g_{m1} = g_{m2} = 22.36\mu S$$

$$A_v = \frac{g_{m1}}{g_{ds2} + g_{ds4}} = \frac{2g_{m1}}{(\lambda_1 + \lambda_2)I_{SS}} = 49.69V/V$$

Given I_{SS}=1μA

$$g_{md} = g_{m1} = g_{m2} = 7.07\mu S$$

$$A_v = \frac{g_{m1}}{g_{ds2} + g_{ds4}} = \frac{2g_{m1}}{(\lambda_1 + \lambda_2)I_{SS}} = 157.11V/V$$

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

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

5.4 In the circuit of Fig 6.4, 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 **λ≠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?

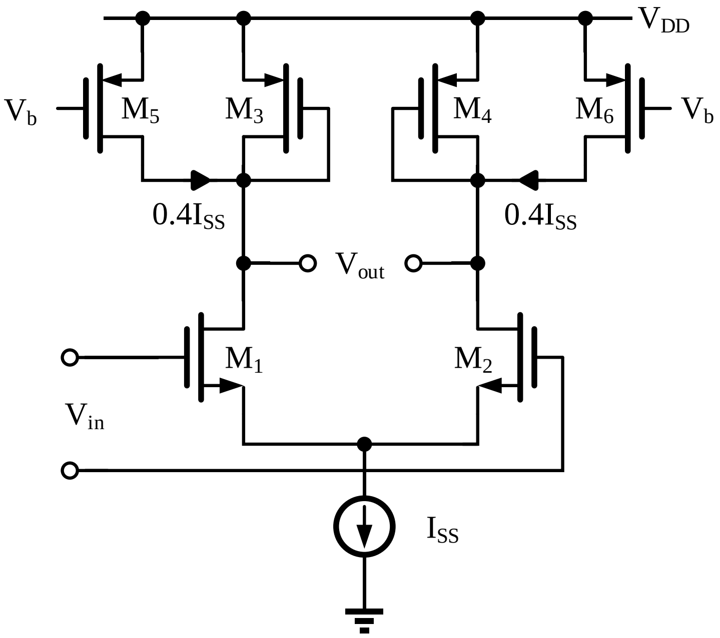


Figure 6.4

解：

a) $A_V \approx -\dfrac{g_{m1}}{g_{m3}} = \sqrt{\dfrac{\mu_n I_{D1}}{\mu_p I_{D3}}} = \sqrt{\dfrac{110\times 0.5 I_{SS}}{50\times 0.2\dfrac{I_{SS}}{2}}} = -3.32$

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

$$V_b = V_{DD} - V_{SG5} = V_{DD} - |V_{TH}| - \sqrt{\frac{2I_{D5}}{\mu_p C_{ox}\frac{W}{L}}} = 1.9V$$

c)

$$\left(V_{out1,2}\right)_{\max} = \min\left(V_b + |V_{TH,P}|, V_{DD} - |V_{TH,P}|\right) = \min\left(1.9+0.7, 3-0.7\right) = 2.3V$$

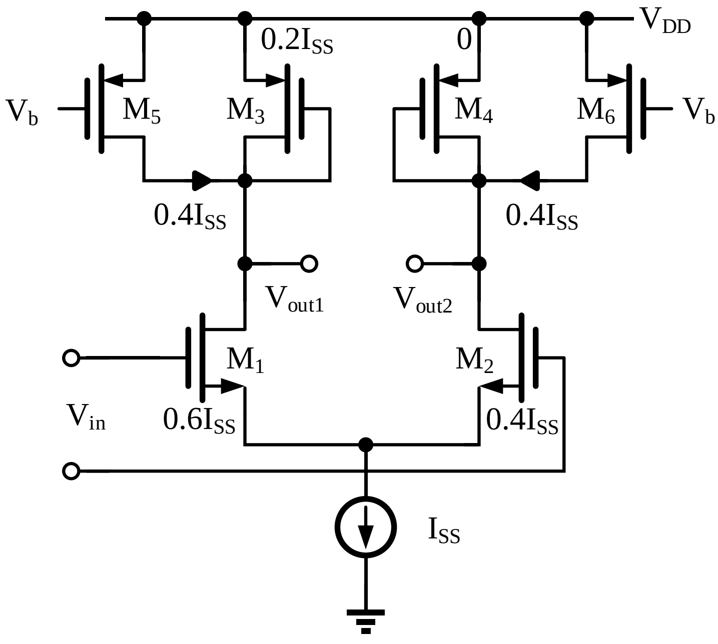
$$\left(V_{out1,2}\right)_{\min} = \max\left(V_{Iss\min} + V_{GS1}\big|_{I_D=0.6I_{SS}} - V_{TH,N}, V_{DD} - V_{SG3}\big|_{I_D=0.2I_{SS}}\right)$$

$$V_{GS1}\big|_{I_D=0.6I_{SS}} = V_{TH,N} + \sqrt{\frac{2\times 0.6I_{SS}}{\mu_n C_{ox}\frac{W}{L}}} = 0.7+0.33 = 1.03V$$

$$V_{SG3}\big|_{I_D=0.2I_{SS}} = |V_{TH,P}| + \sqrt{\frac{2\times 0.2I_{SS}}{\mu_p C_{ox}\frac{W}{L}}} = 0.7+0.28 = 0.98V$$

$$\left(V_{out1,2}\right)_{\min} = \max\left(0.4+1.03-0.7, 3-0.98\right) = 2.02V$$

$$V_{out,swing} = 2\left(2.3-2.02\right) = 0.56V$$



5.5 The circuit shown in Figure 6.5 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 6.1,

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 $v_{in} = v_1 - v_2$.

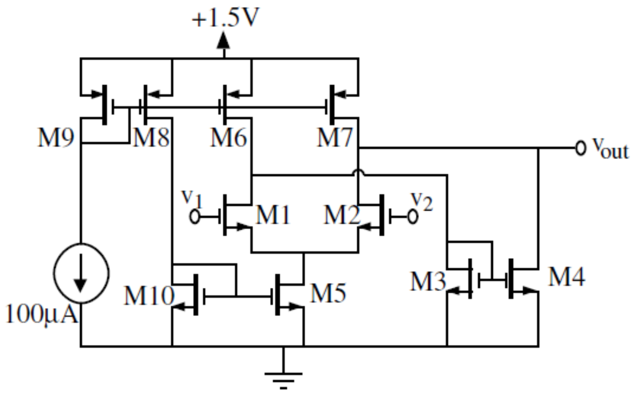


Figure 6.5

解：

a) $v_{1(\max)} = V_{GS3} + V_{TN} = 0.7 + \sqrt{\dfrac{2 \bullet 50}{110 \bullet 100}} + 0.7 = 1.495V$

$$v_1(\min) = 0 + V_{DS5}(\text{sat}) + V_{GS1}(50\mu A) = \sqrt{\frac{2 \cdot 100}{110 \cdot 100}} + \left(\sqrt{\frac{2 \cdot 50}{110 \cdot 100}} + 0.7\right)$$

$$= 0.1348 + 0953 + 0.7 = 0.9302V \Rightarrow \boxed{v_1(\min) = 0.9302V}$$

b) $V_{ICMR} = v_{1(\max)} - v_{1(\min)} = 1.495 - 0.9302 = 0.5648V$

c) $A_v = g_{m1} \times (r_{o2} // r_{o4} // r_{o7}) = 116.5V/V$

5.6 In the circuit of Fig 5.6, 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 $\boldsymbol{\lambda \neq 0}$.

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.

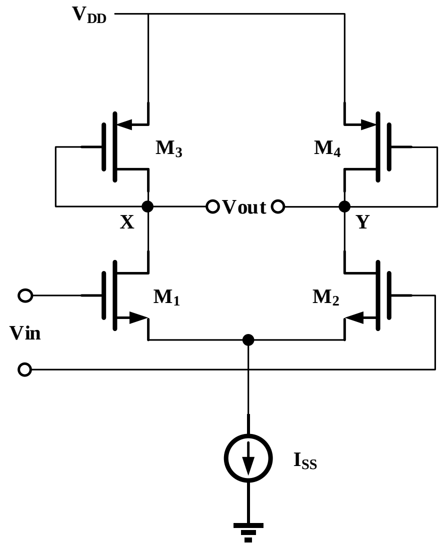


Figure 5.6

解：

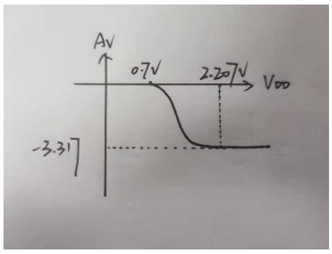
a) $$(V_{in,cm})_{\min} = V_{GS1} + Vod_{ss} = V_{TH1} + \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}(\frac{W}{L})_1}} + \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}(\frac{W}{L})_{SS}}} = 0.7V + 0.213V + 0.302V = 1.215V$$

$$(V_{in,cm})_{\max} = V_{DD} - V_{od3} - V_{TH,P} + V_{TH,N} = V_{DD} - \sqrt{\frac{2I_{D3}}{\mu_p C_{ox}(\frac{W}{L})_3}} = 3V - 0.707V = 2.293V$$

b) 三个标记点：

开启电压$V_{TH,P}$ = 0.7V

增益 $$Av = -\sqrt{\frac{Kn(\frac{W}{L})_1}{Kp(\frac{W}{L})_3}} = -3.317$$



饱和点电压 $VDD = V_{in,cm} - V_{TH,N} + V_{GS3} = 1.5V - 0.7V + 0.7V + 0.717V = 2.217V$

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：

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

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

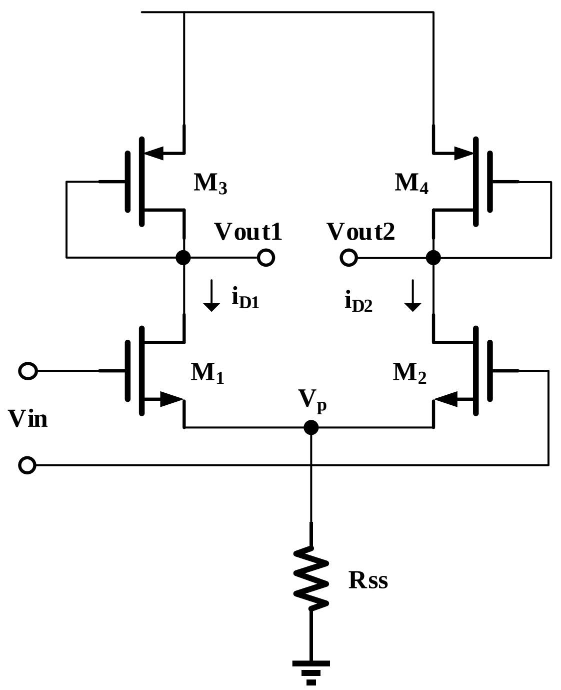
$$Vout1 = -\frac{i_{D1}}{g_{m3}} = -\frac{g_{m1}(V_{in,\,cm} - V_p)}{g_{m3}}$$

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

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

$$\therefore Vout1 = Vout2$$

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



d)

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

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

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

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

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

$$gm = \sqrt{2Kn(\frac{W}{L})_1 I_{D1}} = 2.345m\Omega^{-1}$$

$$Rss = \frac{1}{\lambda I_{SS}} = \frac{1}{0.08 \times 0.5 \times 10^{-3}} = 25k\Omega$$

$$\therefore CMRR = \frac{1 + 2 \times 2.345m\Omega^{-1} \times 25k\Omega}{0.0465} = 2543$$