Table 6.1

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

$* K = \mu C_{OX}$

6.1 Calculate the differential transconductance g_{md} and the differential voltage gain A_v of an n-channel input differential amplifier shown in Figure 6.1 , 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

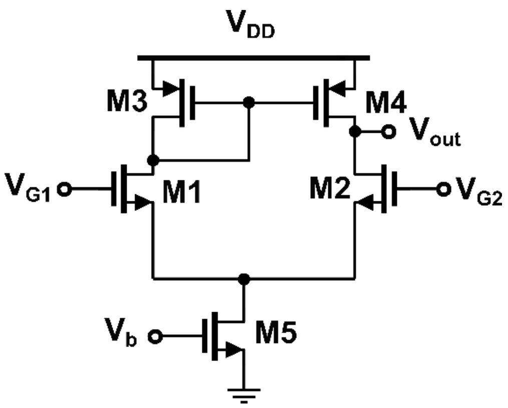


Figure 6.1

Answer:

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

$$g_{md} = g_{m1} = g_{m2} = \sqrt{2 \times K_n \left(\frac{W}{L}\right)_1 \frac{I_{SS}}{2}} = 115.8\mu S$$

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

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

$$g_{md} = g_{m1} = g_{m2} = \sqrt{2 \times K_n \left(\frac{W}{L}\right)_1 \frac{I_{SS}}{2}} = 366.1\mu S$$

$$A_v = \frac{g_{m2}}{g_{ds2} + g_{ds4}} = \frac{2g_{m2}}{(\lambda_2 + \lambda_4)I_{SS}} = 24.4V/V$$

6.2 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 $(W/L)_i$ are equal to 10μm/1μm, I_{SS}=10μA, and V_{DD}=5V.

Answer:

The maximum input common-mode input is given by

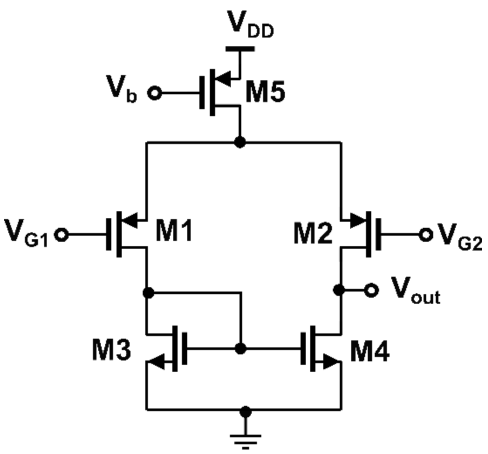
$$V_{(IC)}(max) = V_{DD} + V_{T1} - V_{T3} - V_{GS3} = V_{DD} + V_{T1} - V_{T3} - \sqrt{\frac{I_{SS}}{K_P\left(\frac{W}{L}\right)_3}} = 4.76V$$

The minimum input common-mode input is given by

$$V_{(IC)}(min) = V_{SS} + V_{T1} + V_{GS3} + V_{GS5} = V_{SS} + V_{T1} + \sqrt{\frac{I_{SS}}{K_n\left(\frac{W}{L}\right)_3}} + \sqrt{\frac{2 \times I_{SS}}{K_n\left(\frac{W}{L}\right)_5}} = 0.91V$$

So, the input common-mode range becomes
$ICMR = V_{(IC)}(max) - V_{(IC)}(min) = 3.85V$

6.3 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 $W_1/L_1=W_2/L_2=W_3/L_3=W_4/L_4=1$, and all the channel lengths are equal to 1μm. Use the transistor parameters of Table 6.1.



Answer:

Figure 6.3

Given I_{SS}=10μA,

$$g_{md} = g_{m1} = g_{m2} = \sqrt{2 \times K_p \left(\frac{W}{L}\right)_1 \frac{I_{SS}}{2}} = 22.36\mu S$$

$$A_v = \frac{g_{m1}}{g_{ds2} + g_{ds4}} = \frac{2g_{m1}}{(\lambda_1 + \lambda_2)I_{SS}} = 14.9V/V$$

Given I_{SS}=1μA

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

$$A_v = \frac{g_{m1}}{g_{ds2} + g_{ds4}} = \frac{2g_{m1}}{(\lambda_1 + \lambda_2)I_{SS}} = 47.13V/V$$

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

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

Slew rate can be given as

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

For $I_{SS} = 10uA$ and$C_L = 100pF$

$$SR = 0.1V/us$$

For $I_{SS} = 1uA$ and$C_L = 100pF$

$$SR = 0.01V/us$$

6.4 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?

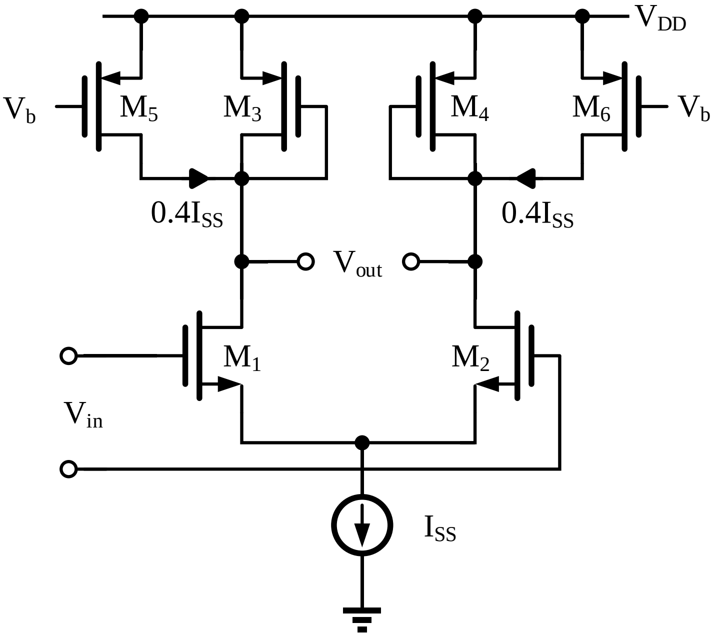


Figure 6.4

Answer:

a) $A_V \approx -\frac{g_{m1}}{g_{m3}} = -\sqrt{\frac{K_n I_{D1}}{K_p I_{D3}}} = -\sqrt{\frac{134\times0.5I_{SS}}{50\times0.2\frac{I_{SS}}{2}}} = -3.66$

b) $I_{D5} = I_{D6} = 0.8\frac{I_{SS}}{2} = 0.4mA, V_b = V_{DD} - V_{SG5} = V_{DD} - |V_{TH}| - \sqrt{\frac{2I_{D5}}{K_p\frac{W}{L}}} = 1.8V$

c)

$(V_{out1,2})max = min(V_b + |V_{TH,P}|, V_{DD} - |V_{TH,P}|) = min(1.8 + 0.8, 3 - 0.8) = 2.2V$

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

$$V_{GS1}\ |_{I_D=0.6I_{SS}} = V_{TH,N} + \sqrt{\frac{2\times0.6I_{SS}}{K_n\frac{W}{L}}} = 0.7 + 0.299 = 0.999V$$

$$V_{SG3}\ |_{I_D=0.2I_{SS}} = |V_{TH,P}| + \sqrt{\frac{2\times0.2I_{SS}}{K_p\frac{W}{L}}} = 0.8 + 0.28 = 1.08V$$

$(V_{out1,2})min = max(0.4 + 0.999 - 0.7, 3 - 1.08) = 1.92V$

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

6.5 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 $V_{in} = V_1 - V_2$.

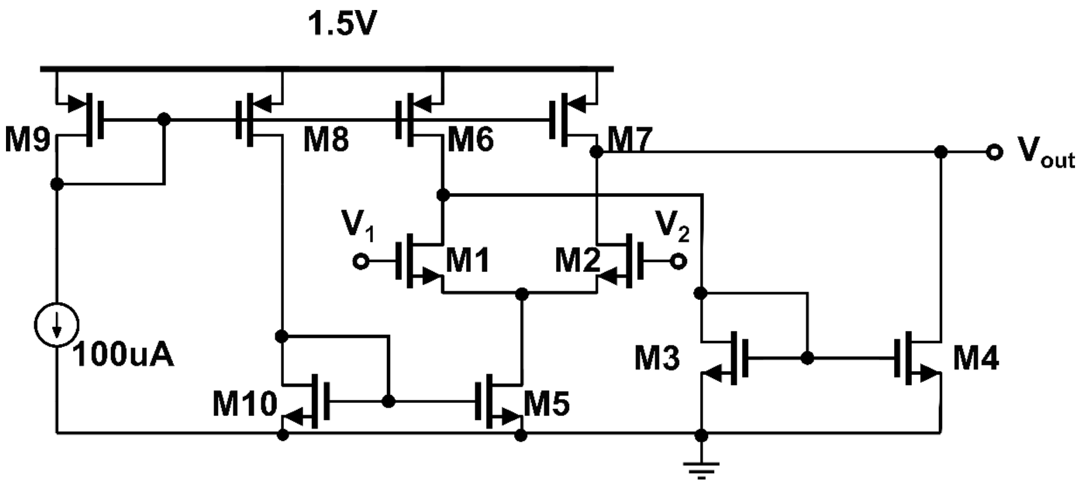


Figure 6.5

Answer:

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

$v_{1(min)} = V_{SS} + V_{GS5} - V_{TN} + V_{GS1} = \sqrt{\frac{2\times 100}{134\times 100}} + (\sqrt{\frac{2\times 50}{134\times 100}} + 0.7)$ = 0.122+0.086+0.7 = 0.908V

b) $V_{ICMR} = v_{1(max)} - v_{1(min)} = 1.486 - 0.908\,V = 0.578V$

c)

$$g_{md} = g_{m1} = g_{m2} = \sqrt{2 \times K_N \left(\frac{W}{L}\right)_1 \frac{I_{SS}}{2}} = 1157.58\mu S$$

$$r_{o4} = r_{o2} = \frac{2}{\lambda_n I_{ss}} = 0.2M\,\Omega$$

$$r_{o7} = \frac{1}{\lambda_p I_{ss}} = 0.05M\,\Omega$$

$$A_v = g_{m1} \times (r_{o2}//r_{o4}//r_{o7}) = 38.586V/V$$

6.6 In the circuit of Fig 10.6, 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 V_{DD} 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.

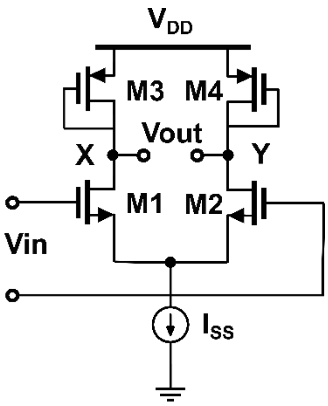


Figure 6.6

Answer:

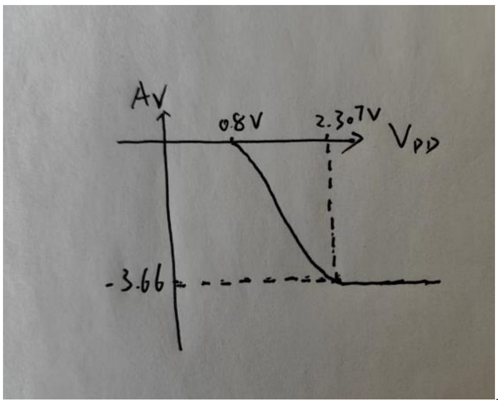
a) $(Vin, cm)\, min = V_{GS1} + V_{odSS} = V_{TH1} + \sqrt{\frac{2ID1}{Kn\left(\frac{W}{L}\right)1}} + \sqrt{\frac{2ISS}{Kn\left(\frac{W}{L}\right)SS}} = 0.7V + 0.193V + 0.273V = 1.166V$

$$(Vin, cm)\, max = V_{DD} - V_{od3} - V_{TH3} + V_{TH1} = V_{DD} - \sqrt{\frac{2ID3}{Kp\left(\frac{W}{L}\right)3}}$$

$$= 3V - 0.707V - 0.8V + 0.7V = 2.193V$$

ICMR=2.193-1.166=1.027V

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$VDD = Vin, cm - VTH, N + VGS3 = 1.5V - 0.7V + 0.8V + 0.707V = 2.307V$

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：

$$i_{D1} = g_{m1}(Vin,cm - Vp)$$
$$i_{D2} = g_{m2}(Vin,cm - Vp)$$
$$Vout1 = -\frac{i_{D1}}{g_{m3}} = -\frac{g_{m1}(Vin,cm - Vp)}{g_{m3}}$$
$$Vout2 = -\frac{i_{D2}}{g_{m4}} = -\frac{g_{m2}(Vin,cm - Vp)}{g_{m4}}$$
$$\frac{g_{m1}}{g_{m3}} = \sqrt{\frac{Kn(\frac{W}{L})1，2}{Kp(\frac{W}{L})3，4}} = \frac{g_{m2}}{g_{m4}}$$
$$\therefore Vout1 = Vout2$$
$$\therefore Acm - dm = 0, CMRR = \infty$$

d)

$$Adm - dm = -g_m R_D$$
$$Acm - dm = \frac{g_m R_D}{1 + 2g_m R_{SS}} - \frac{g_m(R_D + \Delta R_D)}{1 + 2g_m R_{SS}} = -\frac{g_m \Delta R_D}{1 + 2g_m R_{SS}}$$
$$\therefore CMRR = \left|\frac{Adm - dm}{Acm - dm}\right| = \frac{1 + 2g_m R_{SS}}{\Delta R_D / R_D}$$
$$\because RD1 = \frac{1}{g_{m3}}, RD2 = \frac{1}{g_{m4}}$$
$$\therefore \frac{\Delta R_D}{R_D} = \frac{R_D 1 - R_D 2}{RD1} = 1 - \frac{R_D 2}{R_D 1} = 1 - \sqrt{\frac{2Kp(\frac{W}{L})3ID}{2Kp(\frac{W}{L})4ID}} = 1 - \sqrt{\frac{10}{11}} = 0.0465$$
$$g_m = \sqrt{2Kn(\frac{W}{L})1 i_{D1}} = 2.588m\Omega^{-1}$$
$$\lambda = 2 \times 0.1 = 0.2$$
$$Rss = \frac{1}{\lambda ISS} = \frac{1}{0.1 \times 0.5 \times 10^{-3}} = 20k\Omega$$
$$\therefore CMRR = \frac{1 + 2 \times 2.588m\Omega^{-1} \times 20k\Omega}{0.0465} = 2270$$