EE-719

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1a)

$(V_{OP})_{max} = (63\times 4 I_{LSB} + I_{LSB} + 2I_{LSB})R_L$, when all switches are ON. $(b_0, b_1, t_1, t_2, \dots t_n)$

$= 255 I_{LSB} \times R_L$

$R_L = (25 + r) = 25+8 = 33\,\Omega$

$(V_{ON})_{min} = 0$, when all switches are OFF $(\bar{b}_0, \bar{b}_1, \bar{t}_1, \bar{t}_2, \dots, \bar{t}_n)$

$(V_{out})_{max} = (V_{OP})_{max} - (V_{ON})_{min}$

$= 255 I_{LSB} \times R_L$

$(V_{OP})_{min} = 0$

$(V_{ON})_{max} = 255 I_{LSB} \times R_L$

$(V_{out})_{min} = (V_{OP})_{min} - (V_{ON})_{max}$

$= -255 I_{LSB} \times R_L$

$\therefore V_{FS} = (V_{out})_{max} - (V_{out})_{min}$

$V_{FS} = 510 I_{LSB} \times R_L \longrightarrow (1)$

But given $V_{FS} > 0.8 V_{PP}$

Assume $V_{PP} = 1V$

$510 I_{LSB} \times 33 > 0.8(1)$

$I_{LSB} > \frac{0.8}{510\times 33} = 47.534 \mu A \longrightarrow (2)$

Under proper biasing, the differential pair txors (M_1 & M_2) should operate in saturation.

Under saturation condition

$$(V_{SD})_{M_{1,2}} > (V_{SG})_{M_{1,2}} - |V_{tp}|_{M_{1,2}}$$

$$(V_D)_{M_{1,2}} < (V_g)_{M_{1,2}} + |V_{tp}|_{M_{1,2}} < (V_s)_{M_{1,2}} \longrightarrow (3)$$

Under worst case condition

$$255 I_{LSB} \times R_L < (V_g)_{M_{1,2}} + |V_t|_{M_{1,2}}$$

Assume $V_{tp} = -0.45V$ & $(V_g)_{M_{1,2}} = 0.35V = 0.35V$

then

$$I_{LSB} < \frac{0.35 + |-0.45|}{255 \times 33} = \frac{0.80}{255 \times 33} = 95.06 \mu A$$
$$= 95.06 \mu A$$

$$I_{LSB} < 95.06 \mu A \longrightarrow (4)$$

from (2) & (4)

$$47.534 \mu A < I_{LSB} < 95.06 \mu A$$

let $\underline{I_{LSB} = 50 \mu A}$

from (1)

$$V_{FS} = 510 \times 33 \times 50 \times 10^{-6}$$

$$\underline{V_{FS} = 0.8415V}$$

For both txors to operate in saturation,

$$V_{DMB_1} < (V_G)_{MB_1} + |V_{tp}|_{MB_1}$$

$$V_{SM_{1,2}} < V_{DD} - (V_{SDsat})_{MB_1} - (V_{SDsat})_{MB_2} \longrightarrow (5)$$

since both M_{B_1} & M_{B_2} have same drain current & assuming they have same aspect ratios,

$$(V_{SDsat})_{MB_1} = (V_{SDsat})_{MB_2} = (V_{SDsat})_{MB}$$

from (1) & (5)

$$(V_S)_{M_{1,2}} + (V_{tp})_{M_{1,2}} < V_{DD} - 2(V_{Dsat})_{MB}$$

$$0.35 + 0.45 < 1.2 - 2(V_{Dsat})_{MB}$$

$$\Rightarrow (V_{Dsat})_{MB} < 200mV$$

Let $V_{DsatMB} = 100mV$

also $V_{B_1} = V_{DD} - |V_{tp}| - V_{DsatB}$

$= 1.2 - |-0.45| - 0.1$

$\underline{V_{B_1} = 0.65V} \longrightarrow (6)$

&

$V_{B_2} = V_{DD} - V_{SDsatB_1} - V_{SDsatB_2} - |V_{tp}|$

$= 1.2 - 0.10 \times 2 - 0.45$

$= 1.2 - 0.2 - 0.45$

$\underline{V_{B_2} = 0.55V} \longrightarrow (7)$

$$I_{LSB} = \frac{\mu_p C_{ox}}{2} \frac{W_B}{L_B} (V_{SDsatMB})^2$$

$$\frac{W_B}{L_B} = \frac{2 I_{LSB}}{\mu_p C_{ox} (V_{SDsatMB})^2} = \frac{2 \times 50 \times 10^{-6}}{140 \times 10^{-6} \times (0.1)^2} = \frac{500}{7}$$

$$\therefore \frac{W_{MB_1}}{L_{MB_1}} = \frac{W_{MB_2}}{L_{MB_2}} = \frac{500}{7} \rightarrow (8)$$

from (1) & (5)

$\therefore 0.8V < V_{SM_{1,2}} < 1V$

~~Also~~

Let $V_{SM_{1,2}} = 0.85V$

$$I_{LSB} = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_{1,2} ((V_{SG})_{M_{1,2}} - |V_{tp}|)^2$$

$$\left(\frac{W}{L}\right)_{M_{1,2}} = \frac{2 \times 50 \times 10^{-6}}{140 \times 10^{-6} \times (0.85 - 0.35 - 0.45)^2}$$

$$\left(\frac{W}{L}\right)_{M_1} = \left(\frac{W}{L}\right)_{M_2} = \frac{2000}{7} \rightarrow (9)$$

Also $INL_{max} = \frac{\sigma_{I_{LSB}}}{2 I_{LSB}} \sqrt{2^N} \cdot LSB \rightarrow (8)\ (10)$

From pelgorm's eqns.,

$$\frac{\sigma_{I_D}^2}{I_D^2} = \frac{4 \sigma_{V_{th}}^2}{(V_{SG} - |V_{th}|)^2} + \frac{\sigma_\beta^2}{\beta^2} \rightarrow (11)$$

$$\sigma_{V_{th}}^2 \approx \frac{A_{V_{th}}^2}{WL} \rightarrow (12)$$

$$\frac{\sigma_\beta^2}{\beta^2} \approx \frac{A_\beta^2}{WL} \rightarrow (13)$$

(13) & (12) in (11)

$$\boxed{\frac{\sigma_{I_{LSB}}}{I_{LSB}} = \sqrt{\frac{4A_{Vth}^2}{W_B L_B (V_{SDsat\,MB})^2} + \frac{A_B^2}{W_B L_B}}} \rightarrow (13)$$

Also given $INL_{max} < 1\,LSB$

$$\frac{\sigma_{I_{LSB}}}{2 I_{LSB}}\sqrt{2^8}\cdot LSB < 1\,LSB$$

$$\frac{\sigma_{I_{LSB}}}{I_{LSB}} < 0.125$$

from (13)

$$\frac{4A_{Vth}^2}{W_B L_B (V_{SDsat\,MB})^2} + \frac{A_B^2}{W_B L_B} < (0.125)^2$$

$$\frac{1}{(0.125)^2}\left[\frac{4(4.6\times10^{-3})^2}{(0.1)^2} + \frac{(0.04)^2}{1}\right] < W_B L_B$$

$$\therefore W_B L_B > 0.644\,\mu m^2 \rightarrow (14)$$

from (8) & (14)

$$\frac{500}{7} L_B^2 > 0.644\,\mu m^2$$

$$\Rightarrow L_B > 0.0949\,\mu m = 94.9\,nm$$

Let $L_{B_1} = L_{B_2} = L_B = 120\,nm$

$$W_{B_1} = W_{B_2} = W_B = \frac{500}{7}\times 120 = 8579\,nm$$
$$= 8.571\,\mu m$$

Given $L_{M_1} = L_{M_2} = L_M = 45nm$ (minimum channel length)

$$\therefore W_{M_1} = W_{M_2} = W_{M_{1,2}} = \frac{2000}{7} \times 45nm$$
$$= 12.857\,\mu m$$

parameters	M_{B1}	M_{B2}	M_1	M_2	V_{FS}	I_{LSB}
width	8.57 µm	8.571 µm	12.857 µm	12.857 µm	0.8415V	50 µA
length	120nm	120nm	45nm	45nm	—	—

1b)

$$\frac{I_{LSB}}{I_{ref}} = \frac{50}{10} = 5$$

$$\frac{W_{MB2}}{L_{MB2}} = \frac{W_{MB1}}{L_{MB1}} = 5\frac{W_{MB4}}{L_{MB4}} = 5\frac{W_{MB3}}{L_{MB3}}$$

Assuming $L_{MB1} = L_{MB2} = L_{MB3} = L_{MB4} = 120nm$ (for better matching)

$$\therefore W_{MB3} = W_{MB4} = \frac{W_B}{5} = 1.7142\,\mu m$$

from (6) & (7)

$$V_{B1} - V_{B2} = 100mV = I_{REF} \times R$$

$$R = \frac{100 \times 10^{-3}}{10 \times 10^{-6}} = 10k\Omega$$

parameter	M_{B3}	M_{B4}	R
width	1.7142 µm	1.7142 µm	10kΩ
length	120nm	120nm	—