EE206 - 2 STAGE OTA DESIGN ASSIGNMENT

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Technology used: TSMC 0.18 μm

Data: $V_{Tn} = 0.37V$ $\mu_n C_{ox} = 230 \mu A/V^2$ $V_{dd} = 1.8V$ $W_{min} = 0.27 \mu m$

$V_{Tp} = 0.39V$ $\mu_p C_{ox} = 100 \mu A/V^2$ $L_{min} = 0.18 \mu m$

Specifications: (Chosen & given)

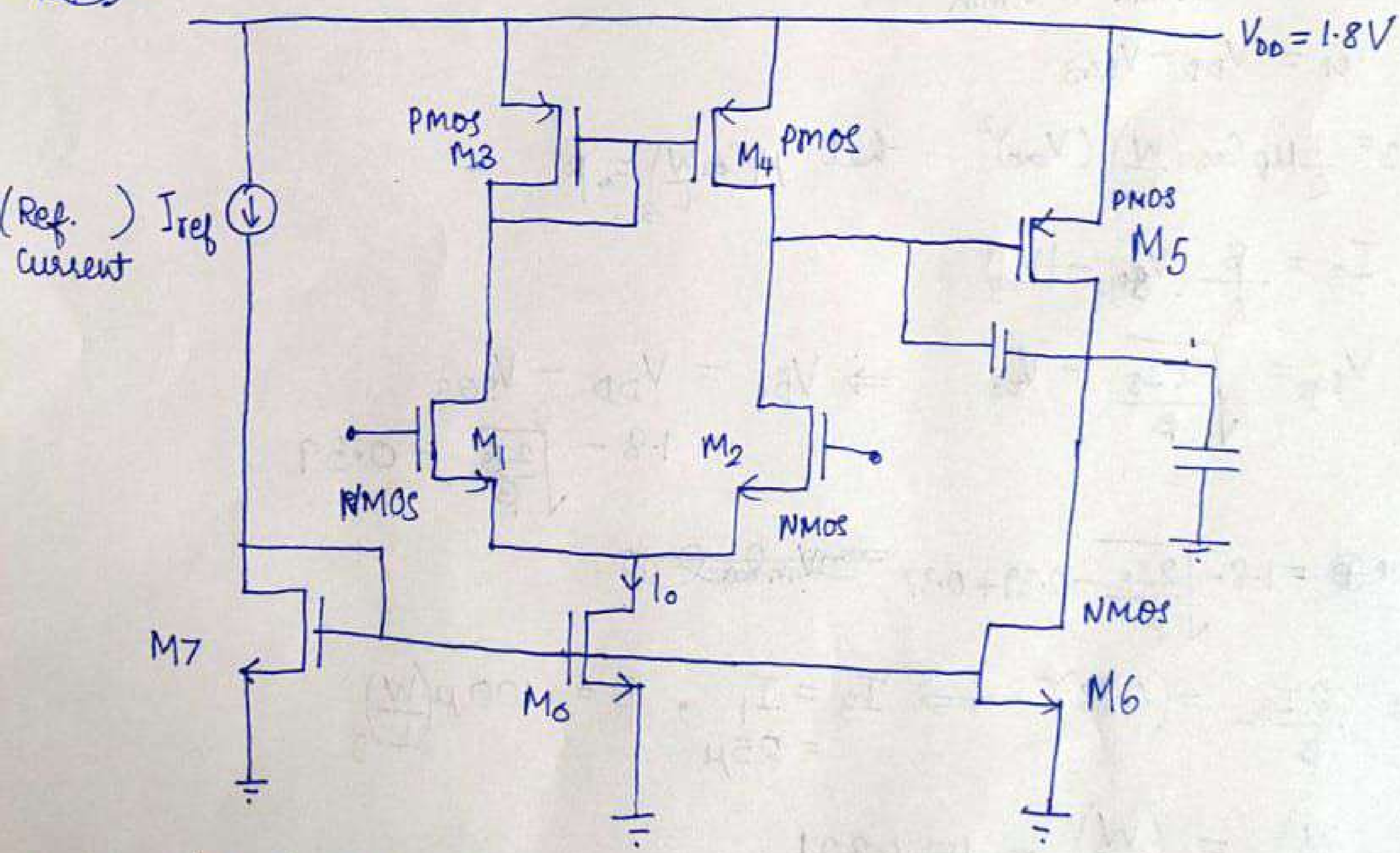
1. DC gain ≥ 40 dB
2. Non-inverting gain = 2
3. GBW = 10 MHz
4. PM ≥ 60°
5. Slew Rate = 20 V/μs
6. ICMR+ = 1.6V
7. ICMR− = 0.8V
8. $C_L = 10pF$
9. $V_{dd} = 1.8 V$
10. $I_{ref} = I_0/10$

Thumb Rule for PM ≥ 60° : $C_c \geq 0.22 C_L$

$\geq 2.2pF$

Choosing $[C_c = 2.5pF]$

Diagram:



M_{1-2}: Input differential pair

M_{3-4}: Current mirror active loads

M_5: Stage 2 Amplifier

M6: Stage 2 current source

M7: Current mirror MOSFET

M0: Input stage current source

1. Slew Rate $= \frac{I_o}{C_c}$ $\Rightarrow \cancel{\left[I_o = 16.67 \text{V}/\mu s \times 3\text{pF} = 50\mu A\right]}$ $I_o = 20\,\text{V}/\mu s \times 2.5\text{pF}$ $\left[I_o = 50\mu A\right]$

2. $g_{m1} = GBW \times 2\pi \times C_c = 10\,\text{MHz} \times 2\pi \times 2.5\text{pF} = 157.08\,\mu A/V^2$

$$\left(\frac{W}{L}\right)_1 = \frac{g_{m1}^2}{\mu_n C_{ox} 2 I_D} \qquad I_D = \frac{I_o}{2} = \frac{50}{2} = 25\mu A$$

$$= \frac{(157.08)^2}{230 \times 2 \times 25} = 2.14557 \quad \Rightarrow \left[\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 2.14557\right]$$

3. For M_3, M_4 (using ICMR(+))

M_3 is always in saturation $\because$ G, D connected.

$\therefore$ To keep M_1 in saturation.

$$V_{D1} \geq V_{g1} - V_{t1}$$

$$V_{G1} \leq V_{D1} + V_{t1}$$

$$V_{in\,max} \leq V_{D1\,min} + V_{t1\,min}$$

$$V_{D1} = V_{DD} - V_{SG3}$$

$$I_3 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_3 (V_{ov})^2 \quad \text{Let } \mu_p C_{ox}\left(\frac{W}{L}\right)_3 = \beta$$

$$\Rightarrow I_3 = \frac{\beta}{2}(V_{sg_3} - |V_{t3}|)^2$$

$$V_{sg_3} = \sqrt{\frac{2I_3}{\beta}} + V_{t3} \quad \Rightarrow V_{D1} = V_{DD} - V_{SG3}$$

$$= 1.8 - \sqrt{\frac{2I_3}{\beta}} - 0.39$$

$$\Rightarrow \text{ICMR}(+) = 1.8 - \sqrt{\frac{2I_3}{\beta}} - 0.39 + 0.37$$

$$\Rightarrow \frac{2I_3}{\beta} = (0.18)^2 \Rightarrow I_3 = I_1 = 25\mu, \quad \beta = 100\mu\left(\frac{W}{L}\right)_3$$

$$\Rightarrow \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 15.4321$$

4. $\left(\frac{W}{L}\right)_{M_0}$ using ICMR$^{\ominus}$

$V_{D0} \geq V_{G0} - V_{th}$

$V_{D0} = V_{in} - V_{gs1}$

$= V_{Dsat}$

$V_{in} \geq V_{gs1} + V_{Dsat}$

$\Rightarrow ICMR^{\ominus} = V_{gs1} + V_{Dsat}$

$$I_{D0} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_0 [V_{Dsat}]^2 = I_0$$

$$\Rightarrow ICMR^{\ominus} = 0.8V = V_{ov} + V_{tn} + V_{Dsat}$$

$$= \sqrt{\frac{2I_{D1}}{\beta_1}} + 0.37 + V_{Dsat}$$

$$\Rightarrow V_{Dsat} = 0.8 - \sqrt{\frac{2I_{D1}}{\beta_1}} - 0.37$$

$$= 0.8 - \sqrt{\frac{2 \times 25}{230 \times 2.14557}} - 0.37$$

$$V_{Dsat} = 0.1117\ V$$

$$\Rightarrow I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_0 (V_{Dsat})^2$$

$$50 = \frac{1}{2} \times 230 \times \frac{W}{L} \times 0.0124$$

$$\boxed{\left(\frac{W}{L}\right)_0 = 34.85}$$

5. $M_5 : 60° = PM$

$g_{m5} \geq 10 \cdot g_{m1}$ $\quad g_{m5} \geq 1570.8\ \mu A/V^2$.

$I_D \propto \frac{W}{L} \propto g_m$. $\quad \therefore \left(\frac{W}{L}\right)_5 = \frac{g_{m5}}{g_{m4}} \times \left(\frac{W}{L}\right)_4$

$$g_{m4} = \mu_p C_{ox}\left(\frac{W}{L}\right)_4 \cdot (V_{gs} - V_{th})$$

$$= \sqrt{2 \cdot I_D \cdot \mu_p C_{ox}\left(\frac{W}{L}\right)_4} = \sqrt{2 \times 25 \times 100 \times 15.4321} = 277.77\ \mu A/V^2$$

$$\Rightarrow \left(\frac{W}{L}\right)_5 = \frac{1570.8}{277.77} \times 15.4321 = \boxed{87.27 = \left(\frac{W}{L}\right)_5}$$

6. $I_5 = \frac{(W/L)_5}{(W/L)_4} \times I_4 = 141.38\mu A$

$$\frac{I_6}{I_0} = \frac{(W/L)_6}{(W/L)_0} \Rightarrow \frac{141.38}{50} \times 34.85 = \left[98.54 = \left(\frac{W}{L}\right)_6\right]$$

7. $I_{ref} = \frac{I_0}{10} = 5\mu A$

$$\left(\frac{W}{L}\right)_7 = \frac{\left(\frac{W}{L}\right)_0}{10} = \left[3.485 = \left(\frac{W}{L}\right)_7\right]$$

⇒ Summary of (W/L) values:

$\left(\frac{W}{L}\right)_0 = 34.85$, $\left(\frac{W}{L}\right)_{1,2} = 2.14557$, $\left(\frac{W}{L}\right)_{3,4} = 15.4321$,

$\left(\frac{W}{L}\right)_5 = 87.27$, $\left(\frac{W}{L}\right)_6 = 98.54$, $\left(\frac{W}{L}\right)_7 = 3.485$

* Simulated Values:

* Other values:

$C_L = 10pF \quad C_c = 2.5pF \quad C_1 = 100\mu F$

* Gain=2 in Feedback

$\therefore 1 + \frac{R_f}{R_{in}} = 2 \Rightarrow \underset{R_1}{R_f} = \underset{R_2}{R_{in}} = 10k\Omega$.

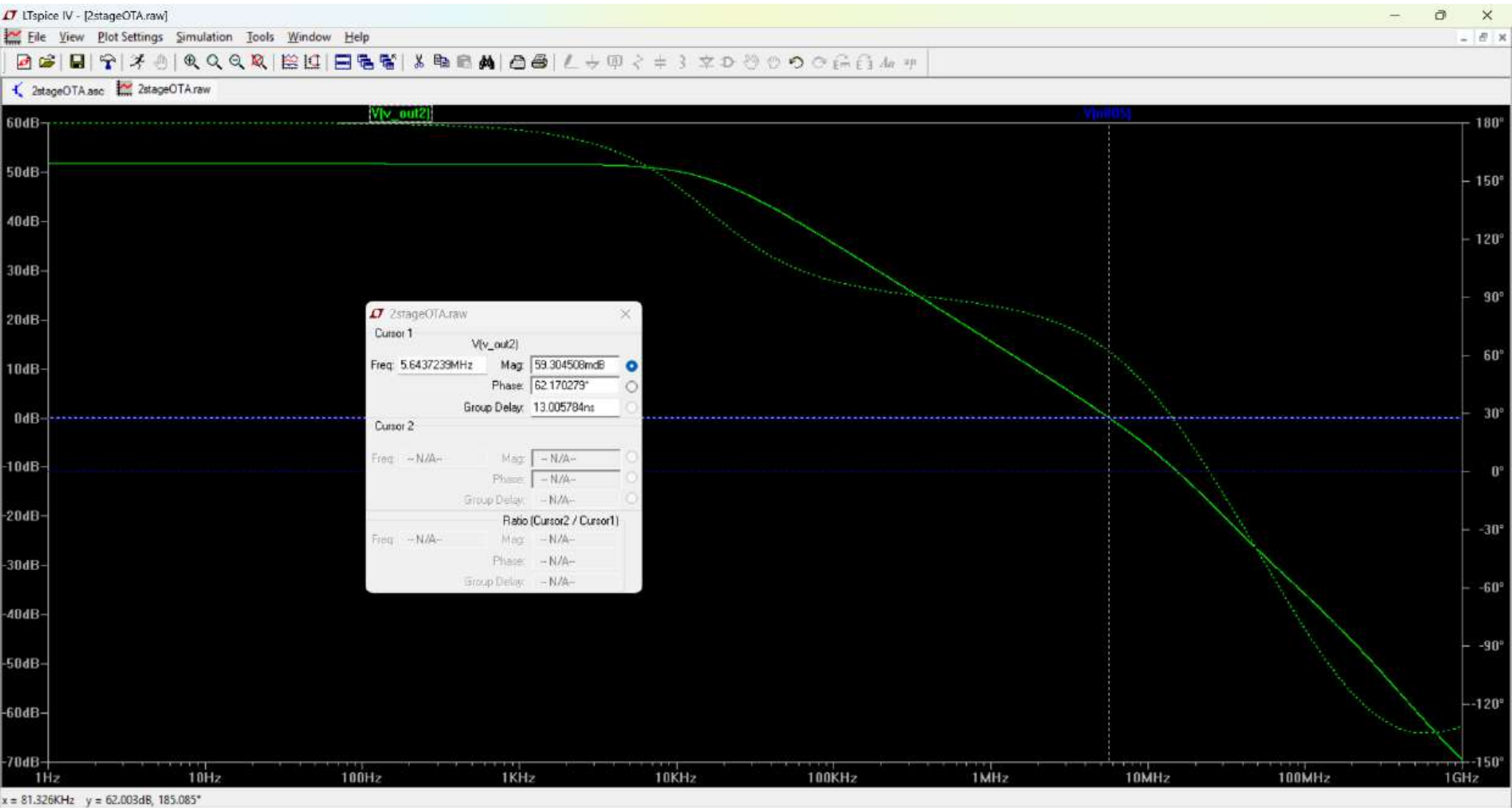
* DC gain = 51.68756 dB
* Power dissipation = $1.8V(50\mu A + 2 \times 1.95 \times 10^{-5} A + 1.18 \times 10^{-4} A)$

$[\text{Power}_{max} = 291\mu W]$

$P_{calc} = 1.8[50\mu A + 141.39\mu A + 5\mu A]$

$[= 353.502\mu W]$

AC Analysis



DC gain = 51.6875 dB

Phase Margin = 62.170279 deg

Transient Analysis