DESIGN OF 2-STAGE OTA.

- Technology used : TSMC 0.18 μm
- Given values :

$V_T)_n = 0.37\,V$ $\quad$ $V_{dd} = 1.8\,V$

$V_T)_p = 0.39\,V$ $\quad$ $L_{min} = 0.18\,\mu m$

$W_{min} = 0.27\,\mu m$

$\mu_n C_{ox} = 230\,\mu A/V^2$

$\mu_p C_{ox} = 100\,\mu A/V^2$

- Specifications :

1) DC gain $\geq$ 40 dB.

2) GBW = 20 MHz.

3) PM $\geq 60°$.

4) Slew rate = 25 V/μsec.

5) ICMR(+) = 1.6 V

6) ICMR(−) = 0.8 V

7) C_L = 5 pF. $\quad$ 8) Let; L = 500 nm {for all mosfets}.

- For phase margin $\geq 60°$.

say : PM = 60°

$C_c \geq 0.22\,C_L$.

$C_c \geq 0.22 \times 5$

$C_c \geq 1.1\,pF$.

$\therefore$ let; $\boxed{C_c = 1.2\,pF}$

• Diagram:

Names of transistors / MOSFETS:

M_{1-2} = Input differential pair.

M_{3-4} = current mirror active loads.

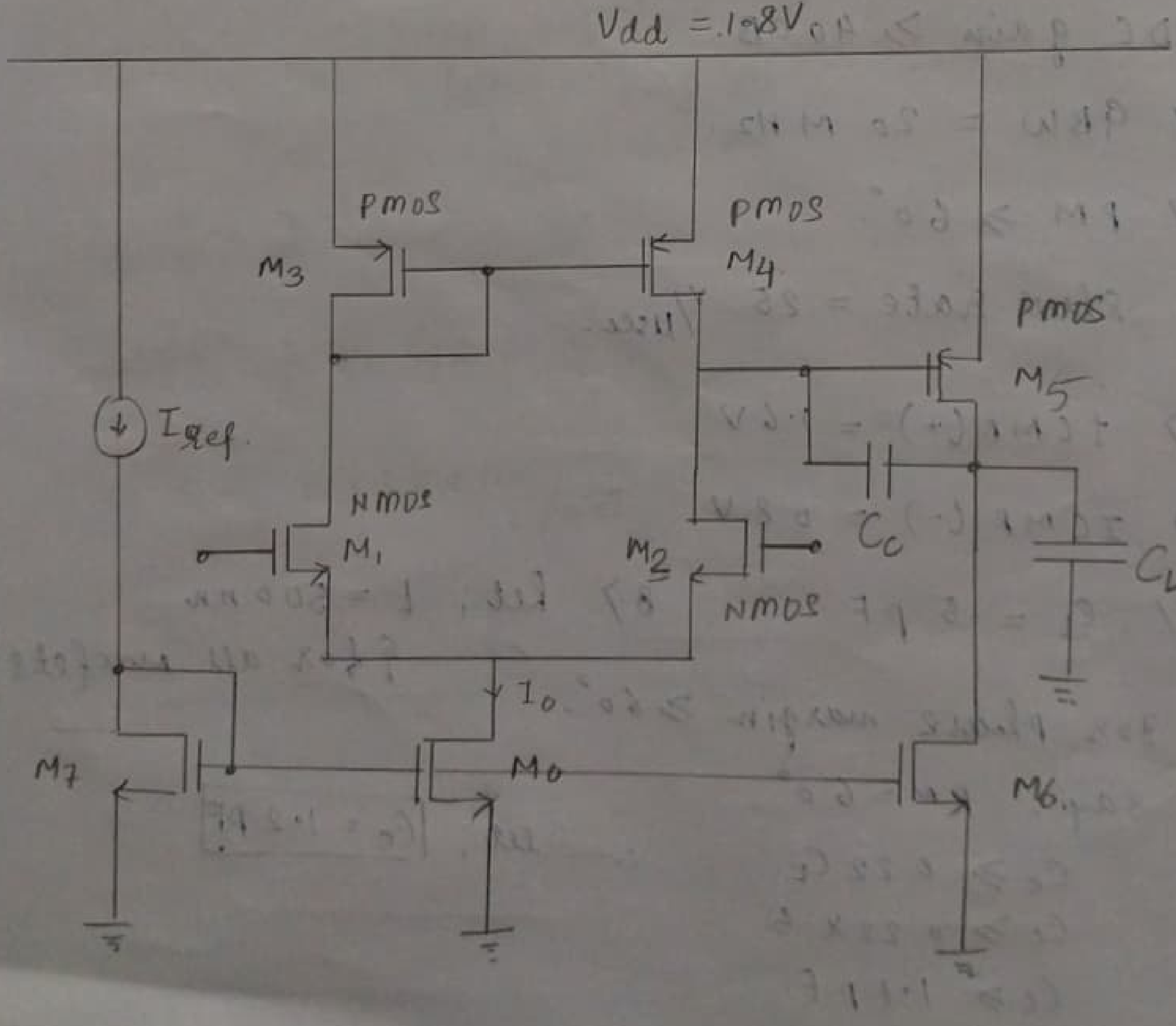
M_0 = Input stage current Source.

M_5 = Stage 2 amplifier

M_6 = Stage 2 current Source.

M_7 = Current mirror MOSFET.

• reference current: I_{ref}.



1.) Calculating I_0 using Slew rate:

$$S.R = \frac{I_0}{C_c}$$

$$25 \ V/\mu sec = \frac{I_0}{1.2 pF}$$

$$\boxed{I_0 = 30 \ \mu A}$$

2.) Calculating M_1 and M_2 : {using GBW}

- $g_{m_1} = GBW \times 2\pi \times C_c$

$$g_{m_1} = 20 \ MHz \times 2\pi \times 1.2 pF$$

$$g_{m_1} = 150.8 \ \mu A/V^2$$

$$\because \left(\frac{W}{L}\right)_1 = \frac{g_{m_1}^2}{\mu_n C_{ox} \times 2 I_D}$$

here $I_D = I_1$.

$I_1 = I_0/2$.

$I_1 = 15 \mu A$

$$\left(\frac{W}{L}\right)_1 = \frac{g_{m_1}^2}{\mu_n C_{ox} \times 2 I_D}$$

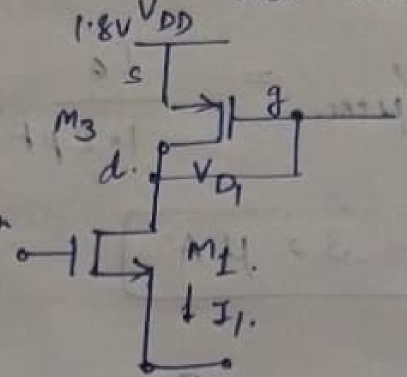
$$= \frac{150.8^2}{230 \times 30}$$

$$= 3.29$$

$$\therefore \boxed{\left(\frac{W}{L}\right)_1 = 3.3} \text{ and } \boxed{\left(W/L\right)_2 = 3.3}$$

3.) For M_3 and M_4: { using $ICMR(+)_{max}$ }.

M_3: always in saturation { gate and drain are connected }.



- To keep M_1 in saturation:

$V_{D_1} \geq V_g - V_t)_1$.

$V_g \leq V_{D_1} + V_t)_1$.

$V_{in})_{max} \leq V_{D_1})_{min} + V_t)_{1\,min}$ — (1).

$V_D)_1 = V_{DD} - V_{sg})_3$.

$$I_3 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_3 (\Delta V)^2 \quad \{ I_1 = I_3 \}.$$

$$I_3 = \frac{\beta}{2}(\Delta V)^2.$$

$$I_3 = \frac{\beta}{2}(V_{sg} - |V_t|)^2.$$

$$V_{sg} = \sqrt{\frac{2I_1}{\beta}} + |V_t|_3.$$

$$\therefore V_{D_1} = 1.8 - \sqrt{\frac{2I_1}{\beta}} - |V_t|_3.$$

and
$$V_{in})_{max} \leq 1.8 - \sqrt{\frac{2I_3}{\beta}} - |V_t|_3 + V_{t1})_{min}$$

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

$$1.6 = 1.8 - \sqrt{\frac{2I_3}{\mu_p C_{ox}(W/L)_3}} - 0.02.$$

$$\frac{2I_3}{\mu_p C_{ox}(W/L)_3} = (0.18)^2.$$

$$\left(\frac{W}{L}\right)_3 = \frac{2 \times 15}{100 \times (0.18)^2}$$

$$\boxed{\left(W/L\right)_3 = 9.23}$$

$$\therefore \boxed{\left(W/L\right)_4 = 9.23}$$

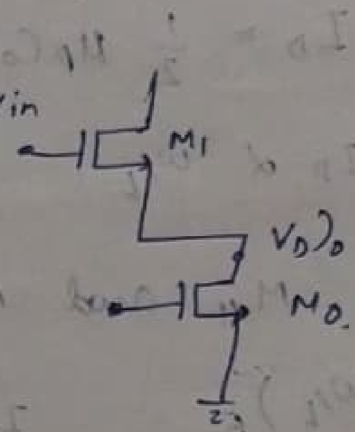
4) For M_0 calculation: {using ICMR (−)}

$V_D)_0 > V_g)_0 - V_t)_n$

$V_D)_0 = V_{in} - V_{gs})_1$

$\therefore V_D)_0 \geq \underbrace{V_D)_{sat}}$

value required for keeping M_0 in saturation.



$\therefore V_{in} \geq V_{gs1} + V_D)_{sat} \Rightarrow ICMR(-) = V_{gs1} + V_D)_{sat}$

$$I_D)_0 = \frac{1}{2}\mu_n C_{ox} \left(W/L\right)_0 \left(V_D)_{sat}\right)^2$$

$$30 = \frac{1}{2} \times 230 \times \left(\frac{W}{L}\right)_0 \times (0.23)^2$$

$$\boxed{\left(W/L\right)_0 = 4.9}$$

$$0.8 = \sqrt{\frac{2 I_{D1}}{\beta_1}} + V_t + V_D)_{sat}$$

$$V_D)_{sat} = 0.8 - \sqrt{\frac{2 I_{D1}}{\beta_1}} - V_t$$

$$= 0.8 - \sqrt{\frac{2 \times 15}{230 \times 3.3}} - 0.37$$

$$\boxed{V_D)_{sat} = 0.23}$$

5) M_6 :

60° Phase Margin:

$g_{m5} \geq 10 \times g_{m1}$.

$g_{m5} \geq 10 \times 150.8$

$$\boxed{g_{m5} = 1508 \ \mu V/A^2}$$

$\because \ I_D = \frac{1}{2} \mu_p C_{ox} (W/L)(V_{gs} - V_{th})^2$

$I_D \propto W/L$

For M_4 and M_5 :

$$\frac{(W/L)_5}{(W/L)_4} = \frac{I_5}{I_4} = \frac{g_m)_5}{g_m)_4}.$$

$$g_{m4} = \sqrt{\mu_p C_{ox} \left(\frac{W}{L}\right) 2 I_D}$$

$$= \sqrt{100 \times 9.3 \times 2 \times 15}$$

$$= 167.$$

$$(W/L)_5 = \frac{1508}{167} \times 9.3$$

$$\boxed{W/L)_5 = 84}$$

for I_5:

$$\frac{I_5}{I_4} = \frac{(W/L)_5}{(W/L)_4}$$

$$I_5 = \frac{84}{9.23} \times 15$$

$$\boxed{I_5 = 136.5\ \mu A}$$ {stage 2 current}

and $\frac{I_6}{I_0} = \frac{(W/L)_6}{(W/L)_0}$ } lower current sources.

$$(W/L)_6 = \frac{136.5}{30} \times 4.9$$

$$\boxed{(W/L)_6 = 22.3}$$

6) $I_{ref} = 1/10\ I_0$

$= 1/10 \times 30\ \mu A = 3\ \mu A$.

$$\therefore (W/L)_7 = \frac{1}{10} \times (W/L)_0$$

$$(W/L)_7 = 1/10 \times 4.9$$

$$\boxed{(W/L)_7 = 0.49}$$

a)

MOSFET	(W/L)	L	W
M_{1-2}	3.3	500 nm	1650 nm
M_{3-4}	9.23	500 nm	4615 nm
M_5	84.[illegible]	500 nm	42000 nm
M_6	22.3	500 nm	11150 nm
M_0	4.9	500 nm	2450 nm
M_7	0.49	1000 nm	490 nm

b) Power Drawn: current drawn × V_{supply}.

$\Rightarrow (I_7 + I_0 + I_6) \times V_{DD}$;

$\Rightarrow (30 + 136.5 + 3)\ \mu A \times 1.8$

$\Rightarrow 305.1\ \mu W$

$\Rightarrow 0.305\ mW$.

c) DC gain:

Net gain: 76 dB.

Stage 1 (differential stage): 41.2 dB.