Design for 2 stage opamp

Specification :

DC Gain $> 60\,dB$

GBW = 5 MHz

Process = 180 nm

PM $\geq 60^\circ$

Slew Rate $\geq 10V/\mu sec$

ICMR(+) = 1.6V

ICMR(-) = 0.8 V

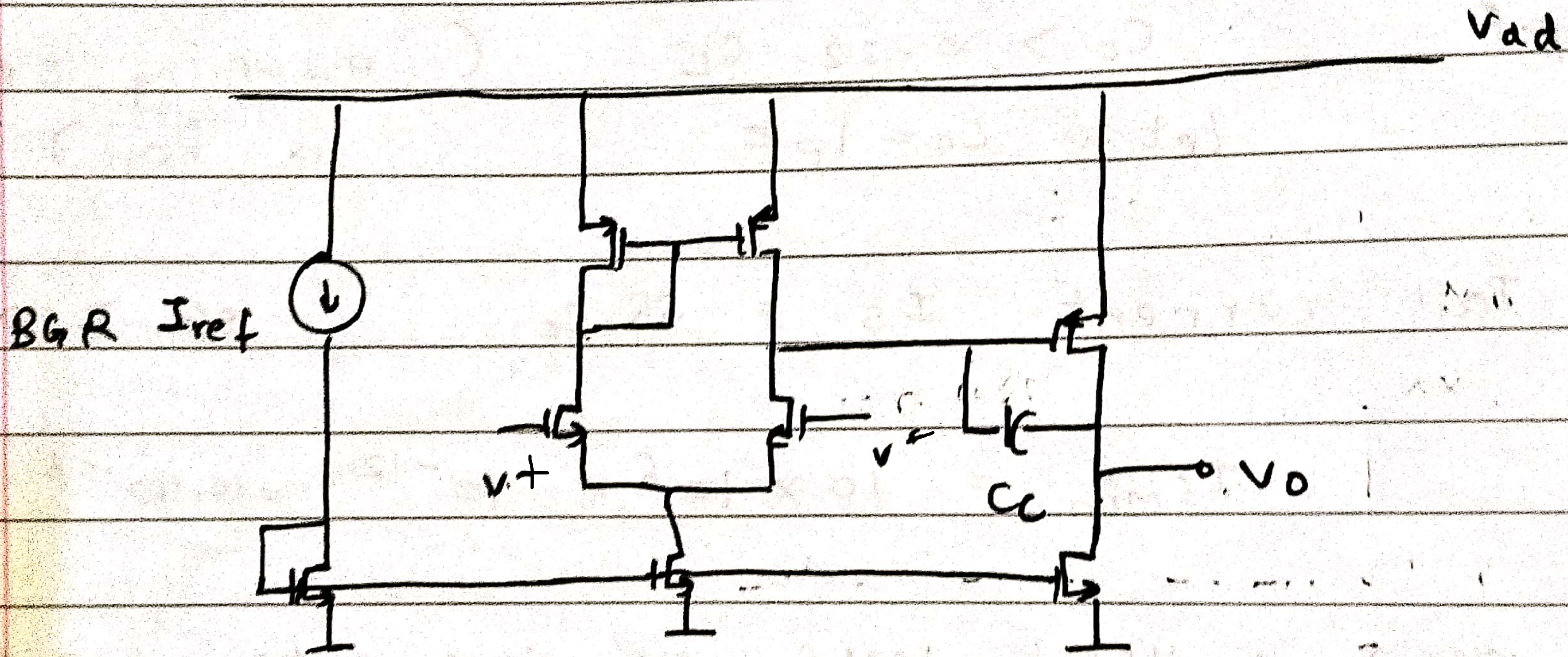
C_L = 10pF

Vdd = 1.8V

$\mu_n C_{ox} = 246.74\ \mu A/V^2$

$\mu_p C_{ox} = 92.75\ \mu A/V^2$

Circuit diagram,



Method of Design :

- $\frac{W}{L}$ of $M_3\ M_4$ is found using ICMR+
- $\frac{W}{L}$ of $M_1\ M_2$ is found using GBW
- I_5 is found using slew rate
- W/L of M_5 found using ICMR (-)
- W/L of M_6 using phase margin & zero location
- W/L of M_7 by M_5 (related)
- C_c using C_L and phase margin.

Calculation.

1. for $PM \geq 60^\circ : C_c \geq 0.22 C_L$

as : $\phi_M = 60^\circ = 180 - \tan^{-1}\left(\frac{\omega}{|P_1|}\right) - \tan^{-1}\left(\frac{\omega}{|P_2|}\right) - \tan^{-1}\left(\frac{\omega}{z_1}\right)$

=> @ GBW (since GBW = open loop UGF).

$$120^\circ = \tan^{-1}\left(\frac{GB}{|P_1|}\right) + \tan^{-1}\left(\frac{GB}{|P_2|}\right) + \tan^{-1}\left(\frac{GB}{z_1}\right)$$

$$= \tan^{-1}[\text{DC Gain}] + \tan^{-1}\left(\frac{GB}{|P_2|}\right) + \tan^{-1}(0.1)$$

$A_v(0) \to \infty$ $[z_1 = 10GB]$

$$24.3^\circ = \tan^{-1}\left(\frac{GB}{|P_2|}\right)$$

$$|P_2| \geq 2.2\, GB$$

$(z_1 \geq 10GB)$ $\frac{g_{m6}}{C_c} \geq 10 \frac{g_{m2}}{C_c}$ => $g_{m6} \geq 10\, g_{m2}$

$\frac{g_{m6}}{C_2} \geq 2.2 \frac{g_{m2}}{C_c}$ => $C_c \geq 0.22 C_L$

$C_L = 10pF$ $C_c \geq 2.2pF$ let $C_c = 3pF$

2. I_S : Slew rate $= \frac{I_S}{C_c}$

$$I_S = SR \cdot C_c = 10V/\mu s \times 3pF = 30\ \mu A$$

3. M_1 & M_2

$$g_{m1} = GBW \cdot C_c \cdot 2\pi = 94.24\ \mu S$$

$$\left(\frac{W}{L}\right)_1 = \frac{g_m^2}{\mu_n C_{ox}\ 2I_D} = 1.2 = \frac{(94.24\mu)^2}{(246.79 \times 30\mu^2)}$$

4. for M_3 M_4

$$\left(\frac{W}{L}\right)_{3,4} = \frac{2 I_{D3}}{\mu_p C_{ox}\left[V_{DD} - ICMR(+) - V_{t3max} + V_{t1min}\right]^2}$$

$V_{t3max} = 0.433V$ $\quad V_{t1min} = 0.31V$

$$\left(\frac{W}{L}\right)_3 = \frac{30}{92.75\left[1.8 - 1.6 - 0.43 + 0.31\right]^2} = 54.55$$

$$\left(\frac{W}{L}\right)_{3,4} = 55$$

since $\quad ICMR(+) = V_{DD} - \sqrt{\frac{I_S}{\beta_3}} - V_{t03max} + V_{t1min}$

as $\quad (ICMR)(+) - V_{t1min} < V_{G3}$

$$V_{G3} = V_{DD} - V_{ov3} - V_{tp}$$

5. for M_5 M_8

$$V_{Dsat5} = ICMR(-) - V_{SS} - \sqrt{\frac{I_5}{\beta_1}} - V_{th1\,max}$$

since $ICMR(-) - V_{ov1} - V_{th1\,max} = V_{dsat5}$
$(V_{SS} = 0)$

$$V_{Dsat5} = 0.8 - 0 - 0.319 - 0.38 = 0.1V$$

$$\left(\frac{W}{L}\right)_5 = \frac{2 I_5}{\mu_n C_{ox} (V_{Dsat5})^2} = \frac{2 \times 30}{246.74 \times (0.1)^2} = 24.31$$

$$\left(\frac{W}{L}\right)_{5,8} = 24$$

6. for M_6

$$g_{m6} = 10\, g_{m1} = 942.4\mu$$

$$g_{m4}^2 = 2 I_4\, \mu_p C_{ox} \left(\frac{W}{L}\right)_4 \Rightarrow g_{m4} = \sqrt{30 \times 92.75 \times 55}$$

$$g_{m4} = 391.20\mu$$

$$\left(\frac{W}{L}\right)_6 = \frac{g_{m6} \times (W/L)_4}{g_{m4}}$$ [since M_4 & M_6 have equal overdrives]

$$= 132.49 \simeq 132$$

7. for M_7 : $I_6 = \frac{(W/L)_6 \times I_4}{\left(\frac{W}{L}\right)_4} = \frac{132 \times 15\mu}{55} = 36\mu A$

$$\left(\frac{w}{l}\right)_7 = \frac{I_7 \times \left(\frac{w}{l}\right)_5}{I_5} = 28.$$

Here for no systematic offset :

$$2 \times \frac{(W/L)_7}{(W/L)_5} = \frac{(W/L)_6}{(W/L)_4}$$ is satisfied

Data :

$I_{dc} = 30\ \mu A$ $\quad C_c = 3pF$ $\quad C_L = 10pF$ $\quad$ Let $L = 500nm$

$M_{1,2}$	$W = 600\ nm$	$L = 500nm$
$M_{3,4}$	$W = 27\ \mu m$	$L = 500nm$
M_5	$W = 12\ \mu m$	$L = 500nm$
M_6	$W = 65\mu$	$L = 500n$
M_7	$W = 14\mu$	$L = 500n$
M_8	$W = 12\mu$	$L = 500n$

Analysis :

Total open loop gain : 65 dB $\quad$ 71.60 dB

GBW = 3dB of closed loop : 5.07 MHz

Phase margin = 63°

Phase margin was expected to be 60°