

Design for 2 stage opamp

Specification :

DC Gain $> 60 \text{ dB}$

GBW = 5 MHz

Process = 180 nm

PM $\pi/60^\circ$

Slew Rate $7.1 \text{ V}/\mu\text{sec}$

|CMRR(+)| = 1.6 V

|CMRR(-)| = 0.8 V

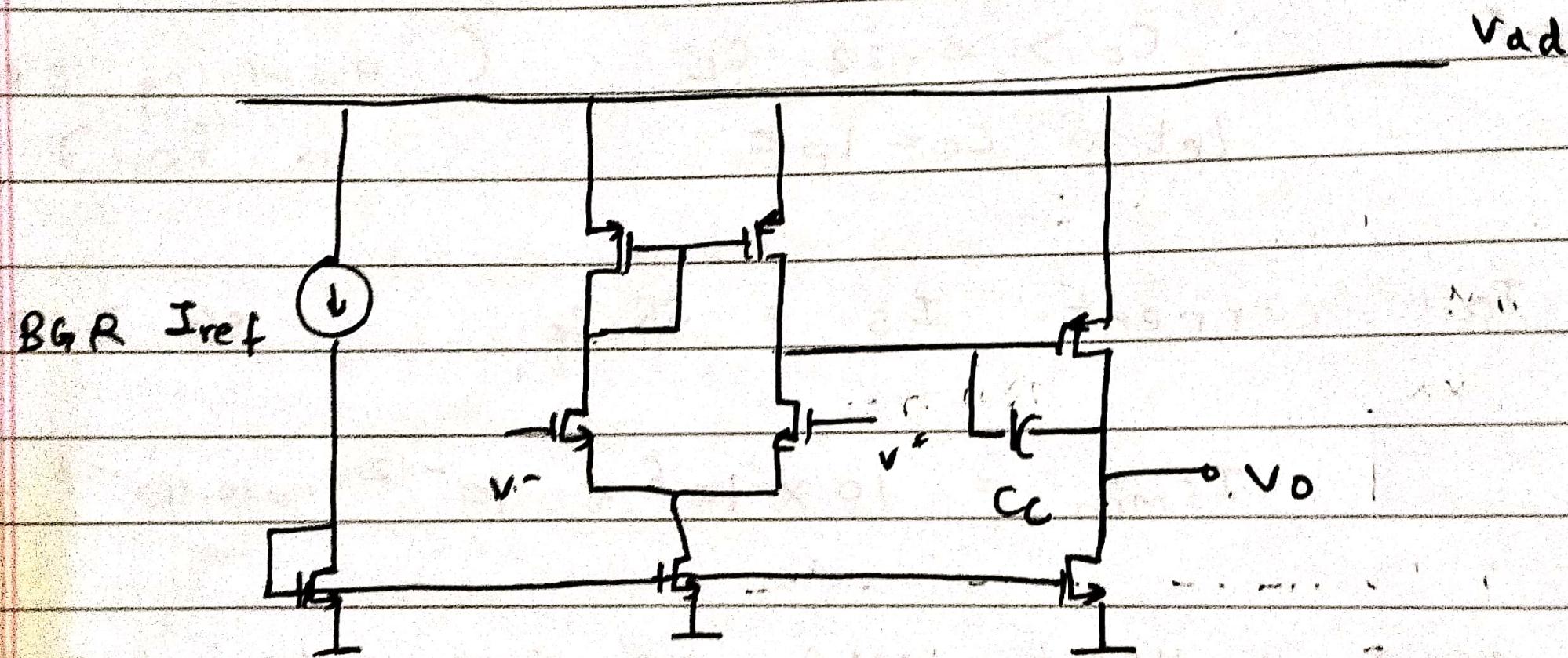
$C_L = 10 \text{ pF}$

$V_{dd} = 1.8 \text{ V}$

$\mu_n C_{ox} = 246.74 \text{ nA/V}^2$

$\mu_p C_{ox} = 92.75 \text{ nA/V}^2$

Circuit diagram,



Method of Design :

- $\frac{\omega}{L}$ of $M_3 M_4$ is found using ICMR+
- $\frac{\omega}{L}$ of $M_1 M_2$ is found using GBW
- I_S is found using slew rate
- WIL of M_S found using ICMR (-)
- WIL of M_6 using phase margin & zero location
- WIL of M_7 by M_S (related)
- C_C using C_L and phase margin.

Calculation.

1. for $\text{PM} \geq 60^\circ: C_C \geq 0.22 C_L$

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 $\text{GBW} = \text{open loop UGF}$).

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

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

$$A_V(0) \rightarrow \infty \quad [z_1 = 10GB]$$

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

$$|P_2| > 2.2GB$$

$$(z_1, 10GB) \frac{g_{m6}}{C_C} \geq 10 \frac{g_{m2}}{C_C} \Rightarrow g_{m6} \geq 10 g_{m2}$$

$$\frac{g_{m6}}{C_L} \geq 2.2 \frac{g_{m2}}{C_C} \Rightarrow C_C \geq 0.22 C_L$$

$$C_L = 10 \mu F$$

$$C_C \geq 2.2 \mu F$$

$$\text{let } C_C = 3 \mu F$$

$$2. I_S : \text{slew rate} = \frac{I_S}{C_C}$$

$$I_S = SR \cdot C_C = 10 \mu\text{s} \times 3 \text{ pF} = 30 \text{ mA}$$

3. M₁ & M₂

$$g_m = GBW \cdot C_C \cdot 2\pi = 94.24 \text{ } \mu\text{s}$$

$$\left(\frac{\omega}{L}\right) = \frac{g_m^2}{M_p C_{ox} 2 I_D} = 1.2 = (94.24 \text{ } \mu\text{s})^2 / (246.79 \times 30 \text{ A})$$

4. for M₃ M₄

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

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

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

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

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

$$\text{as } (I_{CMR})(+) - V_{t1min} < V_{G3}$$

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

for M₅ M₈,

$$V_{DSAT5} = -ICMR(-) - V_{SS} - \sqrt{\frac{I_S}{\beta}} - V_{TH, MAX}$$

since

$$ICMR(-) = V_{OV_1} - V_{TH, MAX} = V_{DSAT5}$$

$(V_{SS} = 0)$

$$V_{DSAT5} = 0.8 - 0.319 - 0.38 = 0.1V$$

$$\left(\frac{w}{l}\right)_S = \frac{2I_S}{M_n C_{ox} (V_{DSAT5})^2} = \frac{2 \times 30}{246.74 \times (0.1)^2} = 24.31$$

$$\left(\frac{w}{l}\right)_{S, 8.1} = 24$$

for M₆

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

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

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

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

$$= 132.49 \approx 132$$

for M₇ : $I_6 = (w/l)_6 \times I_4 = \frac{132 \times 154}{1055} = 36MA$

$$\left(\frac{\omega}{l}\right)_7 = I_7 \times \underbrace{\left(\frac{\omega}{l}\right)_S}_{I_S} = 28.$$

Here for no systematic offset :

$$2 \times \frac{(w/l)_7}{(w/l)_S} = \frac{(w/l)_6}{\cancel{(w/l)_4}} \quad \text{is satisfied}$$

Data :

$$I_{DC} = 30 \text{ mA}$$

$$C_C = 3 \text{ pF}$$

$$C_L = 10 \text{ pF} \quad \text{Let } L = 500 \text{ nm}$$

M_{1,2}

$$w = 600 \text{ nm}$$

$$L = 500 \text{ nm}$$

M_{3,4}

$$w = 27 \mu \text{m}$$

$$L = 500 \text{ nm}$$

M₅

$$w = 12 \mu \text{m}$$

$$L = 500 \text{ nm}$$

M₆

$$w = 60 \mu$$

$$L = 500 \text{ nm}$$

M₇

$$w = 14 \mu$$

$$L = 500 \text{ nm}$$

M₈

$$w = 12 \mu$$

$$L = 500 \text{ nm}$$

Analysis :

Total open loop gain : 65 dB 71.6 dB

G_{BW} = 3 dB of closed loop : 5.07 MHz

Phase margin = 63°

Phase margin was expected to be 60°