Op Amp

Specification:

DC Gain = 1000 = 60 DB

GBW = 50 MHz.

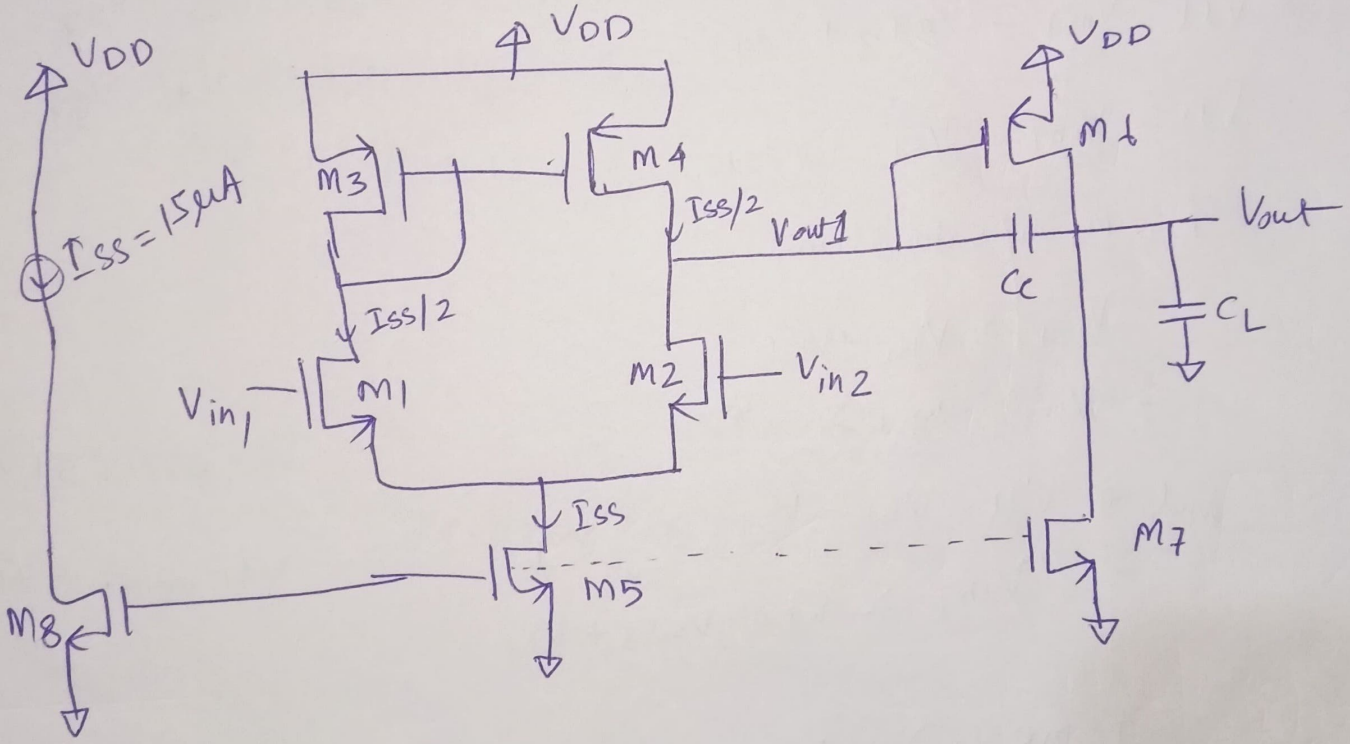
Phase margin ≃ 60°

C_L = 1PF, Slew Rate = 30 V/µs.

Power = 400 µW

ICMR (+) = 1.6 V.

ICMR (−) = 0.8 V.



L = 500 nm

$\Rightarrow C_c \geq 0.22 C_L \Rightarrow C_c \geq 0.22 \times 10^{-12} F \Rightarrow \boxed{C_c \geq 220\,fF}$

$\boxed{C_c = 500\,fF}$

$\Rightarrow I_{ss} = C_c SR \Rightarrow I_{ss} = 500 \times 10^{-15} \times 30 \times 10^{6} = 15 \times 10^{-6} = \boxed{15\,\mu A}$

M_1, M_2

$\rightarrow (GBW) = \frac{g_m}{C_c} \Rightarrow 2\pi \times (GBW)_f \times C_c = g_{m1} \Rightarrow g_{m1} = 2\pi (50 \times 10^6) \times 500 \times 10^{-19}$

$\Rightarrow g_m = 157.142\ \mu F/s$

$\therefore g_{m_1} \approx 160\mu = g_{m_2}$

and, $g_{m_1} = \sqrt{2\beta I_1} \Rightarrow \frac{g_m^2}{2I_1} = \mu C_{ox}\left(\frac{W}{L}\right)_{1,2}$

$\Rightarrow \left(\frac{W}{L}\right)_{12} = \frac{160 \times 160 \times 10^{-12}}{15 \times 10^{-6} \times 310 \times 10^{-6}} = 5.505$

$\therefore \left(\frac{W}{L}\right)_{12} \approx 6.$

M_3, M_4

$V_{dd} - V_{in_1} = V_{sd_3} + V_{dg_1}$

$V_{dg} = V_{ds} + V_{sg}$

$V_{dg} = V_{ds} - V_{gs}$

$\therefore V_{dd} - V_{in_1} = V_{sd_3} + V_{ds_1} - V_{gs_1}$

For M_1 in saturation:-

$V_{ds_1} \geq V_{gs_1} - V_{t_1}$

$\Rightarrow V_{ds_1} - V_{gs_1} \geq -V_{t_1}$

and $\Rightarrow V_{dd} - V_{in_1} - V_{sd_3} \geq -V_{t_1}$

$\Rightarrow V_{in_1} \leq V_{dd} - V_{sd_3} + V_{t_1}$

$V_{t_3\,max} = 510mV$

$V_{t_1\,min} = 470mV.$

$ICMR(+) = V_{dd} + V_{t_1,min} - \left(V_{t_3,max} + \sqrt{\frac{2I_3}{\mu_p C_{ox}\left(\frac{W}{L}\right)}}\right)$

$ICMR(+) = V_{dd} + V_{t_1\,min} - V_{t_3\,max} - \sqrt{\frac{2I_3}{\mu_p C_{ox}\left(\frac{W}{L}\right)}}$

$\therefore \sqrt{\frac{2I_3}{\mu_p C_{ox}\left(\frac{W}{L}\right)_{min}}} = V_{dd} + V_{t_1\,min} - V_{t_3 max} - ICMR(+)$

$= 1800 - 470$

$\left(\frac{W}{L}\right)_{3\,min} = \frac{15 \times 10^6}{160 \times 160 \times 60} = 9.765 \Rightarrow \left(\frac{W}{L}\right)_3 \geq 9.765$

So, $\left(\frac{W}{L}\right)_{3,4} \approx 12$

$$g_{m3} = \sqrt{2 \times \mu_p C_{ox} \left(\frac{W}{L}\right)_3 \times I_D} = \sqrt{15 \times 10^6 \times 60 \times 10^6 \times 12}$$

$$= 10^{-6} \sqrt{15 \times 12 \times 60}$$

$$\boxed{g_{m3} = 103.92\ \mu}$$

For M_5, M_8 :-

$$V_{in} = V_{gs1} + V_{ds5}$$

$$V_{ds5} \geq V_{gs5} - V_{t5}$$

$$V_{in1} - V_{gs1} \geq V_{gs5} - V_{t5}$$

$$V_{t1,max} = 590mV$$

$$V_{in1} \geq V_{gs1} + V_{gs5} - V_{t5}$$

$$ICMR(-) = (V_{gs1} + V_{gs5} - V_{t5})_{max} = V_{t1,max} + \sqrt{\frac{I_{SS}}{\mu_n C_{ox}\left(\frac{W}{L}\right)}}$$

$$+ V_{t5,max} + \sqrt{\frac{2 I_{SS}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_{5min}}} - V_{t5,min}$$

or

$$ICMR(-) = V_{gs1,max} + (V_{gs5} - V_{t5})_{max} = V_{t1,max} + \sqrt{\frac{I_{SS}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}}$$

$V_{gs5} - V_{t5} = V_{ds5}$

$$\therefore V_{ds5} = 800m - 590m - \sqrt{\frac{15 \times 10^{-6}}{310 \times 10^{-6} \times 6}}$$

$$= 210m - 89.3m = 120.2m$$

$$I_{SS} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_5 (V_{gs} - V_t)^2 \Rightarrow \frac{2 I_{SS}}{\mu_n C_{ox}} = \left(\frac{W}{L}\right)_{5\,min} \times (V_{gs} - V_t)^2_{max}$$

$$\Rightarrow \left(\frac{W}{L}\right)_{5min} = \frac{2 \times 15 \times 10^{-6}}{310 \times 10^{-6}} \times \frac{1}{(V_{ds5})^2} = \frac{30}{310} \times \frac{10^6}{(120.2)^2} = 6.698$$

$$\therefore \boxed{\left(\frac{W}{L}\right)_5 \geq 6.698} \Rightarrow \boxed{\left(\frac{W}{8}\right)_{5,8} = 8}$$

For M_6

$g_{m6} \geq 10 g_{m1} \Rightarrow g_{m6} = 10 g_{m1} = 1600\mu$

$V_{gs,3} = V_{gs,4} \approx V_{gs,6} \Rightarrow \dfrac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} = \dfrac{I_6}{I_4}$

$I_p = \dfrac{\mu_n C_{ox}}{2}\left(\dfrac{W}{L}\right)(V_{gs}-V_t)^2$, $g_m = \mu_n C_{ox}\left(\dfrac{W}{L}\right)(V_{gs}-V_t)$.

$\Rightarrow \dfrac{g_{m6}}{g_{m4}} = \dfrac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} \Rightarrow \left(\dfrac{W}{L}\right)_{6,min} = \dfrac{1600\mu \times 12}{g_{m4}}$.

and $g_{m4} = \sqrt{2\beta I} = \sqrt{2 \times \mu_p C_{ox}\left(\frac{W}{L}\right)_4 \times 7.5 \times 10^{-6}}$

$= \sqrt{15 \times 10^{-6} \times 60 \times 10^{-6} \times 12} = \sqrt{10800 \times 10^{-12}} = 103.9 \times 10^{-6}$

$\therefore \boxed{g_{m4} = 104\mu}$

$\left(\dfrac{W}{L}\right)_{6,min} = \dfrac{1600\mu \times 12}{104\mu} = 184.615$

$\therefore \boxed{\left(\dfrac{W}{L}\right)_6 = 190}$

For M_7

$\dfrac{I_6}{I_4} = \dfrac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} = \dfrac{190}{12} \Rightarrow I_6 = \dfrac{190}{12} \times 7.5 \times 10^{-6}$.

$\therefore \boxed{I_6 = 118.75\mu}$

$\dfrac{I_5}{I_7} = \dfrac{\left(\frac{W}{L}\right)_5}{\left(\frac{W}{L}\right)_7} \Rightarrow \dfrac{15\mu A}{118.75\mu A} = \dfrac{8}{\left(\frac{W}{L}\right)_7} \Rightarrow \left(\dfrac{W}{L}\right)_7 = \dfrac{8 \times 118.75}{15}$

$\therefore \left(\dfrac{W}{L}\right)_7 = 63.33 \Rightarrow \boxed{\left(\dfrac{W}{L}\right)_7 = 64}$

$M_5, M_8 \Rightarrow \frac{4\mu}{0.5\mu}$, $M_6 = \frac{95\mu}{0.5\mu}$

$M_3, M_4 \Rightarrow \frac{6\mu}{0.5\mu}$, $M_7 = \frac{32\mu}{0.5\mu}$

$M_1, M_2 \Rightarrow \frac{3\mu}{0.5\mu}$

Result 1: [$C_c = 250$ fF]

- BW ≈ 53 MHz ✗
  Gain ≈ 64 dB ✓
  $\theta = -127°$
  PM = 53° (✗)

Result 2: [$C_c = 230$ fF]

$\theta = -130°$, BW = 57 MHz, Gain ≈ 64dB ✓

PM = $\theta + 180° = 180 - 130 = 50°$ ✗

observed, $g_{m1,2} = 117.7\mu$ → Increased to 146μ $\left[\text{new}\left(\frac{W}{L}\right)_{1,2} = \frac{8.5\mu}{0.5\mu}\right]$

observed $g_{m3,4} = 87.9\mu$ → increased to 95μ → then gain drastically dropped to 4.2 dB.

For M_5, M_7, M_8 → increase L to 1 µm → Gain ↑ by 3dB. ($\frac{W}{L}$ same)
from 65dB to 68dB
→ BW ↑
→ But Phase margin ↓ (~95°)

→ ~~So, M6 has~~

So, need to move P_2 to right $\Rightarrow g_{m6}$ has to be ↑

$$g_{m6} = \sqrt{2\beta I}$$

↓

limit reached,

↓

→ can not go beyond 100μ

→ tried with $L = L_{min} = 180nm$

but r_{o6} dropped and gain dropped to 20dB

⇒ ~~when,~~

→ when, $C_L \rightarrow 15fF$ from 1pF

BW ↑, PM ↑ (~ 64°) ~~***~~

→ when, $C_c \rightarrow 10fF$ from 200fF,

BW ↑ to 190 MHz, ~~but~~

but PM ↓ (~30°)