Design of a Miller compensated Two stage Op-amp with a single-ended output.

Input Stage	nMOS
Load	R=20k Ω C=5pF

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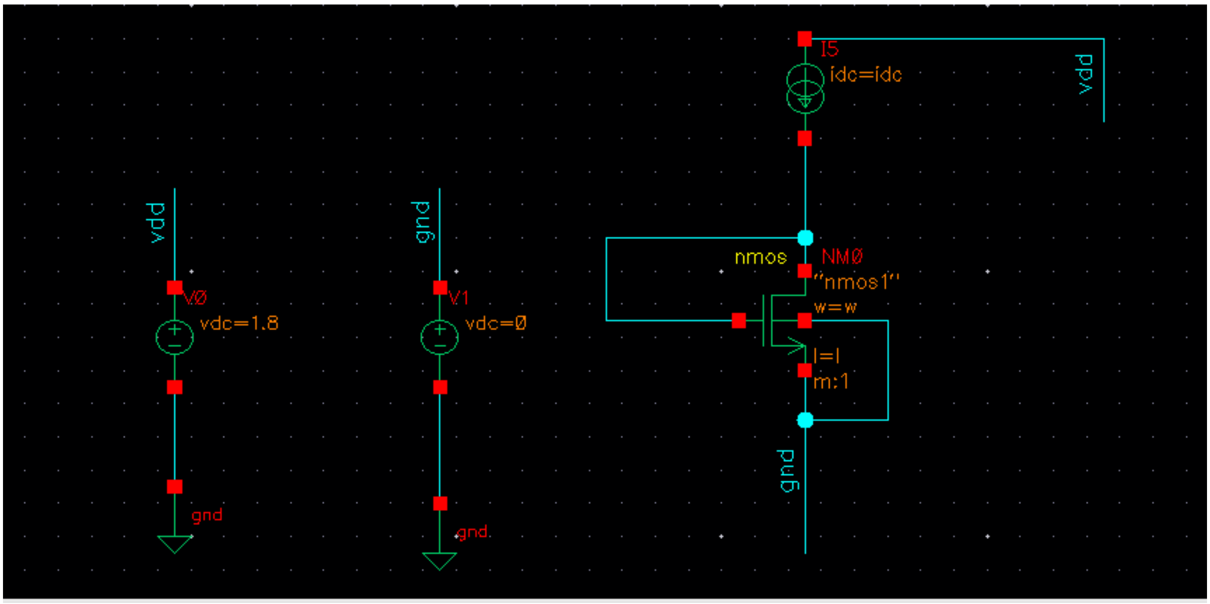
CHARACTERISATION OF nMOS



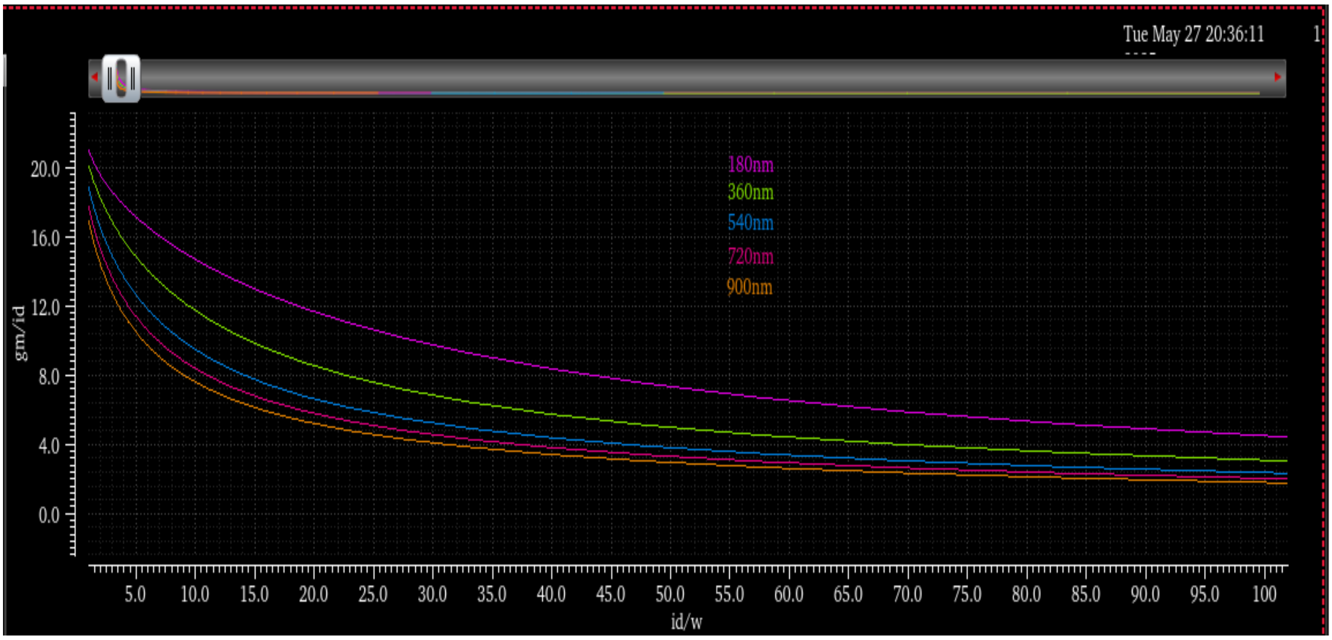
For characterisation of nMOS and pMOS, I varied the Idc and extracted the parameters such as gm/id, gds, gm, cgg, vgs, vds.

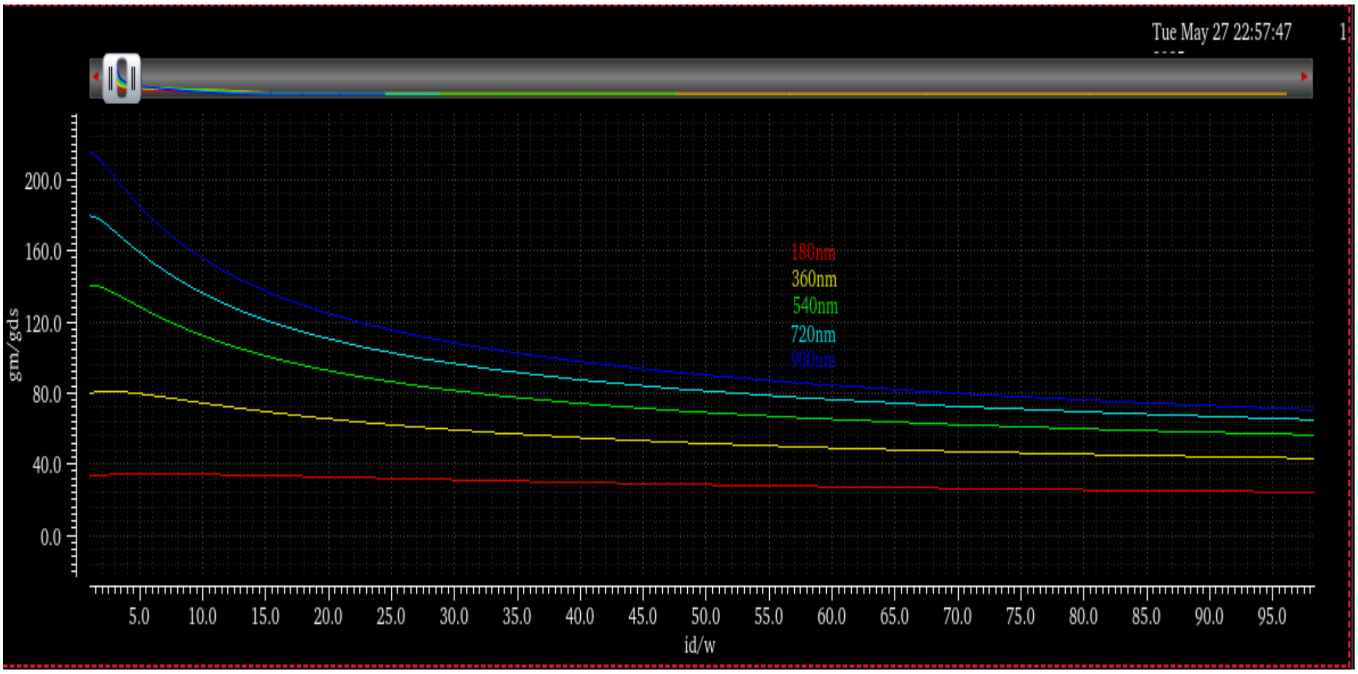
- From these parameters I tried to get width independent graphs which are (gm/id vs id/w), (gm/gds vs id/w), (gds/id vs id/w).

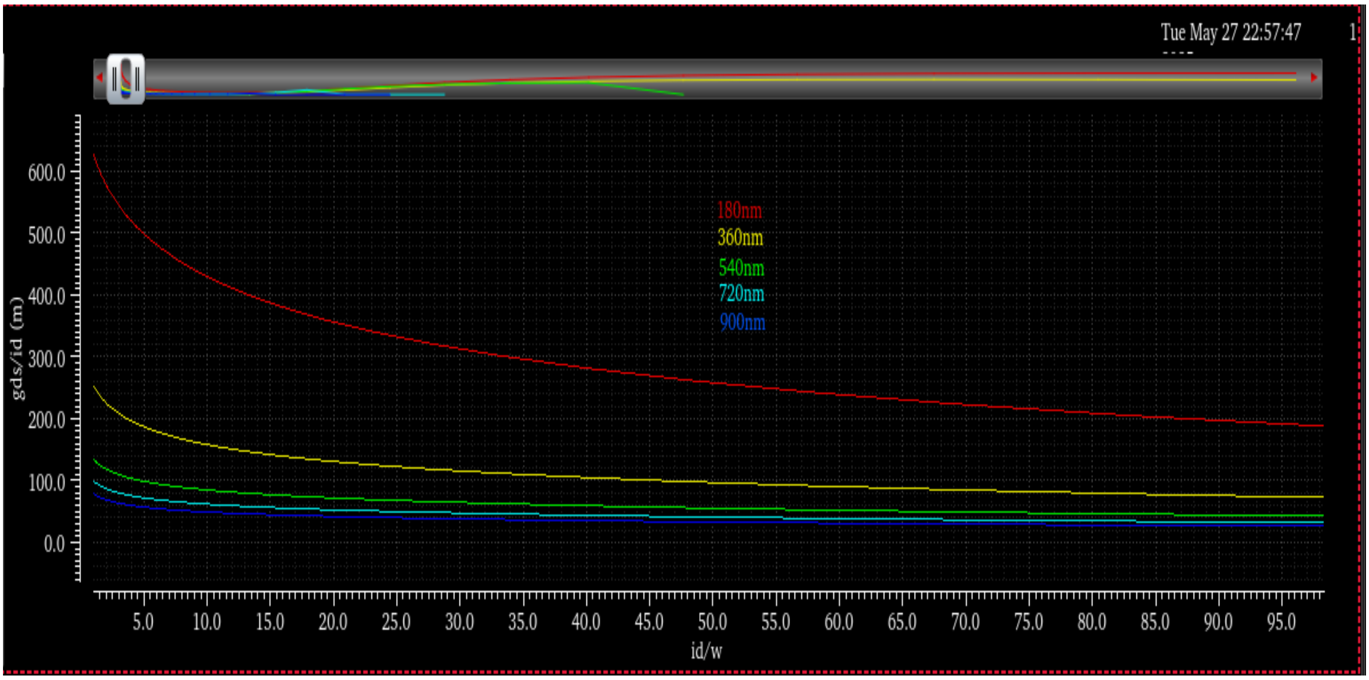
- I have generated these graphs for different lengths.

- The lengths that I have chosen to generate these graphs are. 1. L=180nm 2. L=360nm 3. L=540nm 4. L=720nm 5. L=900nm

Graphs for nMOS

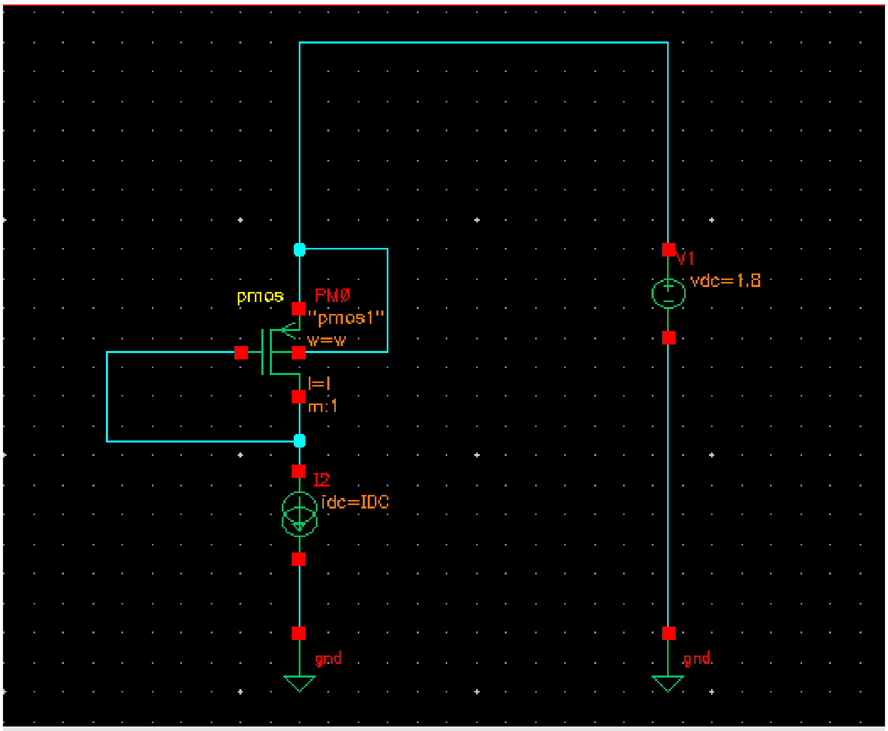




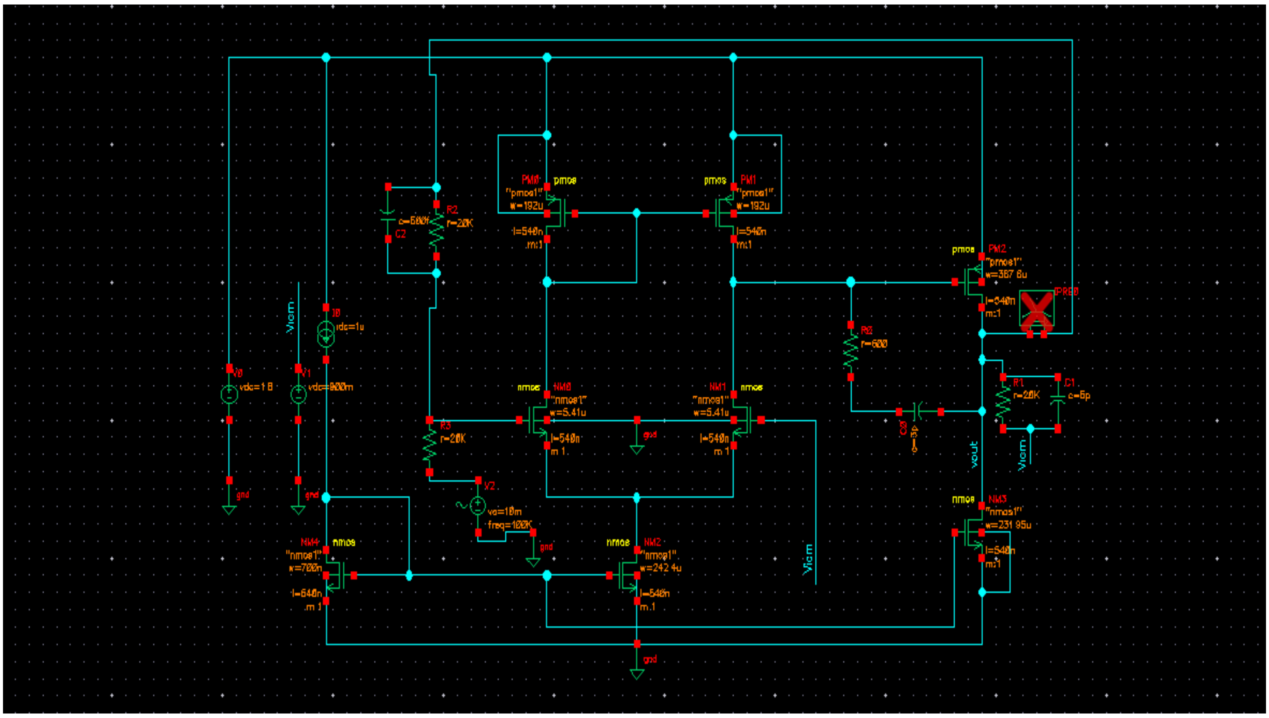


Out of these length I have chosen one(l=540nm) due to design requirements (I have explained in detail ahead).

Similarly, characterization of pMOS is also done.



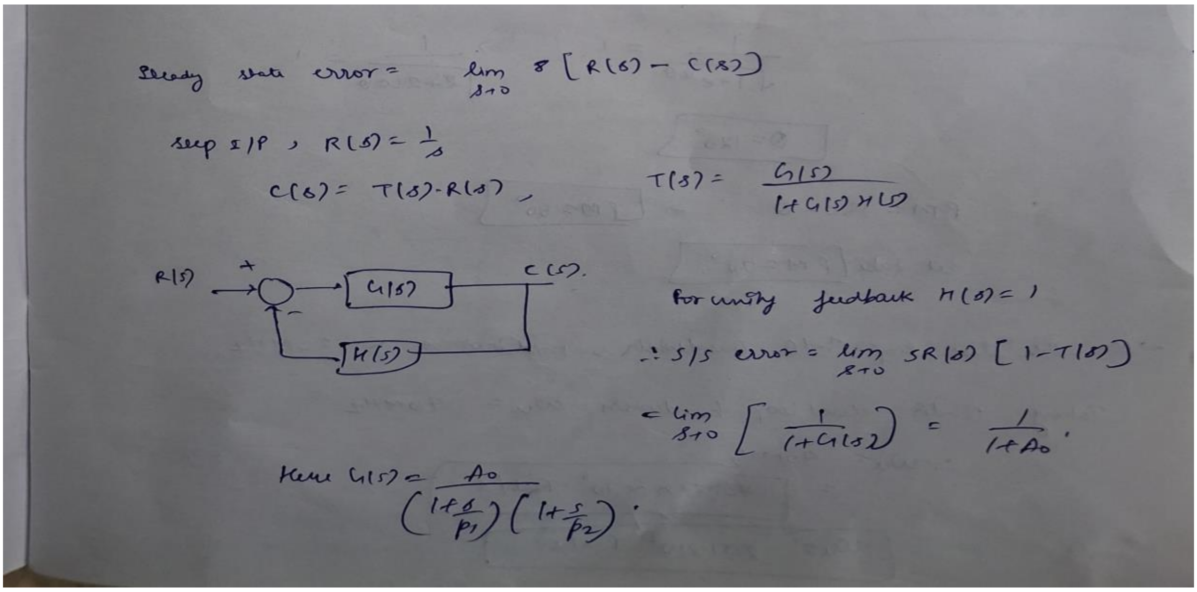
Transistor level Schematic



Design Methodology

Conditions for designing the circuit

- When the step input is applied to the closed loop system output must settle to the desired value with less than 0.1 % error.
- Closed loop frequency response must not exhibit any peaking.
- The closed loop 3dB bandwidth must be greater than 20MHz.



Given error < 0.1 %.

$\therefore \frac{1}{1+A_0} < \frac{0.1}{100}$

$\frac{1}{1+A_0} < \frac{1}{1000}$ $\therefore$ $\boxed{A_0 > 1000}$

Assume $\boxed{A_0 = 1500}$

For Phase Margin:

By miller compensation, poles are far apart and it is acting as a first order system hence, at unity gain bandwidth loop gain has magnitude 1 & a phase θ.

$\therefore LG = 1 e^{j\theta}$.

Close loop $= \frac{LG}{1+LG} = \frac{1e^{j\theta}}{1+1e^{j\theta}}$

For no peaking, $|\text{close loop}| \leq 1$

$\therefore \left| \frac{1e^{j\theta}}{1+e^{j\theta}} \right| \leq 1$

$\frac{1}{\sqrt{1+e^{j2\theta}}} = 1 \Rightarrow \frac{1}{\sqrt{2+2\cos\theta}} = 1$

$\boxed{\theta = 120^\circ}$

$\therefore PM = 180 - \theta \Rightarrow \boxed{PM = 60^\circ}$

let take $\boxed{PM = 70^\circ}$

→ Also, the close loop 3-dB Bandwidth, must not be < 20MHz.

Taking 3-dB closed loop bandwidth $\omega_u = 40MHz$

$\therefore \omega_u = 40MHz$

$= \boxed{40 \times 2 \times \pi \times 10^6 \text{ Rad/s}}$

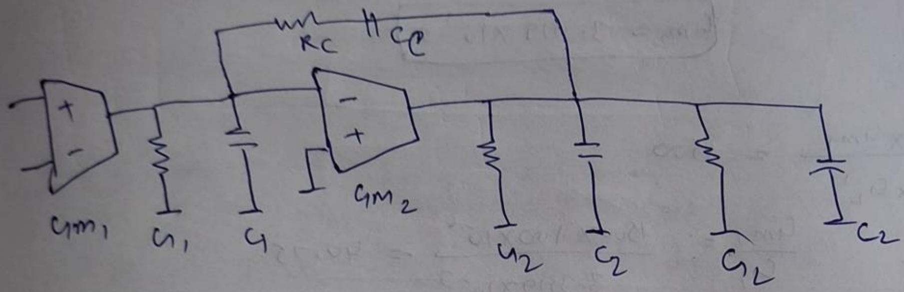
$\boxed{\omega_u = 2.51 \times 10^8 \text{ Rad/s}}$

$\omega_u = \beta A_o p_1$

$\omega_u = A_o p_1$ $\qquad [\beta = 1, \quad A_o = 1500]$

$$p_1 = \frac{\omega_u}{A_o} = \frac{2.51\times10^8}{1500} = 0.167\times10^6$$

$$\boxed{p_1 = 0.1675\times10^6 \text{ Rad/sec}}$$



$$PM = 180 + \left[-90 - \tan^{-1}\left(\frac{\omega_u}{p_2}\right)\right]$$

$$PM = 90 - \tan^{-1}\left(\frac{\omega_u}{p_2}\right)$$

$$70 = 90 - \tan^{-1}\left(\frac{\omega_u}{p_2}\right)$$

$$\frac{\omega_u}{p_2} = 0.3639.$$

$\therefore \omega_u = 0.3639\times p_2 \Rightarrow \boxed{p_2 = 6.9038\times10^8 \text{ rad/sec}}$

GM values and the device sizes.

$$p_1 = \frac{G_1}{C_1 + C_c\left[1 + \frac{G_{m2}}{G_2'}\right]} = \frac{G_1}{C_c \frac{G_{m2}}{G_2'}}$$

$$p_2 = \frac{G_2' + G_{m2}\left[\frac{C_c}{C_c + C_1}\right]}{C_L' + \frac{C_c C_1}{C_c + C_1}} = \frac{G_2' + G_{m2}}{C_L'}$$

assuming $C_c \gg C_1$, $C_L' \gg C_1$, $C_L \gg C_2$,

$$\boxed{C_L' \approx C_L + C_2 \approx C_L = 5pF}$$

$G_L' = G_L + G_2$

assume $G_L = G_2$, $G_L' = 2G_L$ $= 2 \times G_L = 100 \times 10^{-6}$.

$P_2 = \frac{G_L' + G_{m2}}{C_L'} \Rightarrow G_{m2} = P_2 C_L' - G_L'$

$= 6.9038 \times 10^8 \times 5 \times 10^{-12} - 100 \times 10^{-6}$

$$\boxed{G_{m2} = 3.3519 \times 10^{-3}\ S}$$

$A_0 = \frac{G_{m1} \times G_{m2}}{G_1 \times G_L'} = 1500$

$\frac{G_{m1}}{G_1} = \frac{1500 \times 100 \times 10^{-6}}{3.3519 \times 10^{-3}} = 44.75.$

$G_L = G_2$ is choosen, as generally G_2 has smaller value than G_L

& by equating we get worst case scenario.

$$\omega_u = \frac{G_{m1}}{G_1} \times \frac{G_{m2}}{G_L'} \times \frac{G_L'}{C_c \times \frac{G_{m2}}{G_L'}}$$

$$\boxed{\omega_u = \frac{G_{m1}}{C_c}}$$

$\omega_u = \frac{G_{m1}}{C_c}$ assuming $C_c = 3pF$

as $C_c < C_L'$.

$G_{m1} = \omega_u \times C_c$

$= 2.513 \times 10^8 \times 3 \times 10^{-12}$

$$\boxed{G_{m1} = 7.54 \times 10^{-4}\ S}$$

Also, $\frac{G_{m1} \times G_{m2}}{G_1 \times G_L'} = A_0 \Rightarrow G_1 = \frac{G_{m1} \times G_{m2}}{A_0 \times G_L'} = \frac{7.54 \times 10^{-4} \times 3.35 \times 10^{-3}}{1500 \times 100 \times 10^{-6}}$

$$\boxed{G_1 = 16.84 \mu S}$$

Now, $G_{m1} = 7.54 \times 10^{-4}\,S \approx 754\,\mu S$

$G_1 = 16.84\,\mu S$

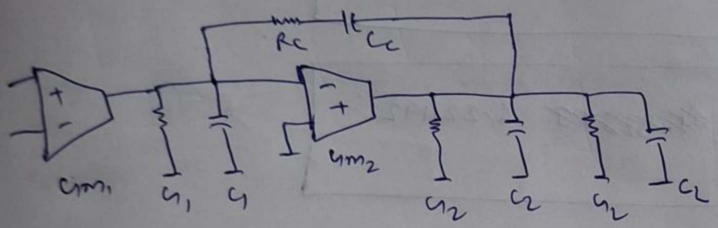
$G_{m2} = 3.35 \times 10^{-3}\,S$

$G_2' = (50+50)\,\mu S = 100\,\mu S$

$C_2' = 5pF$

$C_c = 3pF$

$R_c = 3\mathrm{k}\Omega$.



Now fixing W/L of all transistors.

Stage-1

$$\frac{G_{m1}}{G_1} = \frac{G_m(M_1, M_2)}{G_{dsn} + G_{dsp}}$$ (assuming $G_{dsn} \approx G_{dsp}$).

$$\frac{G_{m1}}{G_1} \approx \frac{G_m(M_1, M_2)}{2 G_{dsn}}$$

$$\frac{G_m(M_1, M_2)}{G_{dsn}} = 2 \times \left(\frac{G_{m1}}{G_1}\right) = \frac{2 \times 7.54 \times 10^{-4}}{16.84 \times 10^{-6}}$$

$$\left(\frac{G_m}{G_{ds}}\right)_{M_1, M_2} = 89.55.$$

Now, we will check which length is able to give this much of gain.

So, from graph, I got $\boxed{l = 540\,nm}$

So, for all transistors we fix $\boxed{L = 540\,nm}$.

Using the look up table generated,

from the graph $\frac{g_m}{g_{ds}}$ vs $\frac{I_d}{W}$, we got to know the value of $\frac{I_D}{W}$ for $\frac{g_m}{g_{ds}} = 89.55$.

for $\frac{gm}{gds} = 89.55$, $\boxed{\text{we get } \frac{ID}{W} = \cancel{[illegible]}}$ 22.387

Now, we know $\frac{ID}{W}$, & from the graph of $\frac{gm}{ID}$ vs $\frac{ID}{W}$, we can know the value of $\frac{gm}{ID}$ corresponding to $\boxed{\frac{ID}{W} = \cancel{[illegible]} \; 22.387}$

$$\boxed{\frac{gm}{ID} = \cancel{[illegible]} \; 6.221192}$$

$$\boxed{\left(\frac{gm}{ID}\right)_{M_1, M_2} = \cancel{[illegible]} \; 6.221192}$$

$$(ID)_{M_1, M_2} = \frac{(gm)(M_1, M_2)}{6.221192 \; \cancel{[illegible]}} = \frac{7.54 \times 10^{-4}}{\cancel{[illegible]} \; 6.221192}$$

$$\boxed{(ID)_{M_1, M_2} = \cancel{[illegible]}} \quad \boxed{121.2 \mu A}$$

Also, $\left(\frac{ID}{W}\right)_{M_1, M_2} = \cancel{[illegible]}. \boxed{22.387}$

$$(W)_{M_1, M_2} = \frac{(ID)_{M_1, M_2}}{\cancel{[illegible]} \; 22.387} = \frac{\cancel{[illegible]} \; 121.2 \mu A}{\cancel{[illegible]} \; 22.387}$$

$$\boxed{(W)_{M_1, M_2} = \cancel{[illegible]}} \quad \boxed{5.41 \mu m}$$

$$\boxed{\begin{array}{l} W_{m_1} = \cancel{[illegible]} \; 5.41 \mu m \\ L_{m_1} = \cancel{[illegible]} \; 540 \text{ nm} \end{array}} \qquad \boxed{\begin{array}{l} W_{m_2} = \cancel{[illegible]} \; 5.41 \mu m \\ L_{m_2} = \cancel{[illegible]} \; 540 \text{ nm.} \end{array}}$$

Now, for stage-2

$(g_m)_{M_5} \rightarrow$ Transconductance of pmos M_5

$$\frac{g_{m2}}{C_2'} = \frac{(g_m)_{M_5}}{2(2C_{dsp})}$$

$C_2' = 2C_2$

$C_2 = C_{dsp} + C_{dsn}$

assuming $C_{dsp} = C_{dsn}$.

$$\left(\frac{g_m}{C_{ds}}\right)_{p\,(M_5)} = 4\left(\frac{g_{m2}}{C_2'}\right)$$

$$\left(\frac{g_m}{g_{ds}}\right)_5 = \frac{4\times 3.35\times10^{-3}}{100\times10^{-6}} = 134.$$

Now from $\left(\frac{g_m}{g_{ds}}\right)_{pmos} = 134$, length $=$ 540nm satisfies the gain condition.

from $\frac{g_m}{g_{ds}}$ vs $\frac{I_D}{W}$ graph we see which value of $\frac{I_D}{W}$, $\frac{g_m}{g_{ds}} = 134$.

→ So, for $\left(\frac{g_m}{g_{ds}}\right)_{pmos} = 134$, $\boxed{\frac{I_D}{W} = 0.630095}$

→ Now from $\left(\frac{g_m}{I_D}\right)$ vs $\left(\frac{I_D}{W}\right)$, for $\frac{I_D}{W} = 0.630095$

we have $\frac{g_m}{I_D} = 14.443$

$$\therefore \boxed{\left(\frac{g_m}{I_D}\right)_{pmos} = 14.443}$$

$$\therefore (I_D)_{M_5} = \frac{(g_m)_{M_5}}{14.443} = \frac{3.35\times10^{-3}}{14.443}$$

$(I_D)_{M_5} = 231.94\,\mu A$

Also $\left(\frac{I_D}{W}\right)_{M_5} = 0.63096$

$\boxed{\therefore (W)_{M_5} = 367.6\,\mu m}$, $\boxed{L_{M_5} = 540\,nm}$

For no systematic offset

$$\left(\frac{2D}{W}\right)_{m3} = \left(\frac{2d}{W}\right)_{m4} = \left(\frac{2D}{W}\right)_{m5}.$$

Also, we know that $\left(\frac{2D}{W}\right)_{m5} = 0.63096.$

$(2d)_{m1} = (2d)_{m2} = (2d)_{m3} = (2d)_{m4} = 121.2\ \mu A.$

$$\left(\frac{2D}{W}\right)_{m3} = 0.63096.$$

$$(W_{m3}) = \left(\frac{2d_{m3}}{0.63096}\right) = \boxed{192\ \mu m}$$

$\therefore$ $W_{m3} = 192\ \mu m$ $\quad$ $W_{m4} = 192\ \mu m$

$L_{m3} = 540\ nm$ $\quad$ $L_{m4} = 540\ nm$

Now, for M6, M7, M8.

$$\left(\frac{2D}{W}\right)_{m6} = \left(\frac{2D}{W}\right)_{m7} = \left(\frac{2D}{W}\right)_{m8}$$

$(2d)_{m7} = 2(121.2) = 242.4\ \mu A$

$2d_{m8} = 231.95\ \mu A$

$2d_{m6} = 1\ \mu A$

Assuming $(W)_{m6} = 1\ \mu m$

then $(W)_{m7} = 242.4\ \mu m$

then $(W)_{m8} = 231.95\ \mu m$

$\therefore$

M6
$W_{m6} = 1\ \mu m$
$L_{m6} = 540\ nm$

M7
$W_{m7} = 242.4\ \mu m$
$L_{m7} = 540\ nm$

M8
$W_{m8} = 231.95\ \mu m$
$L_{m8} = 540\ nm$

Loop gain (63.4798 dB)

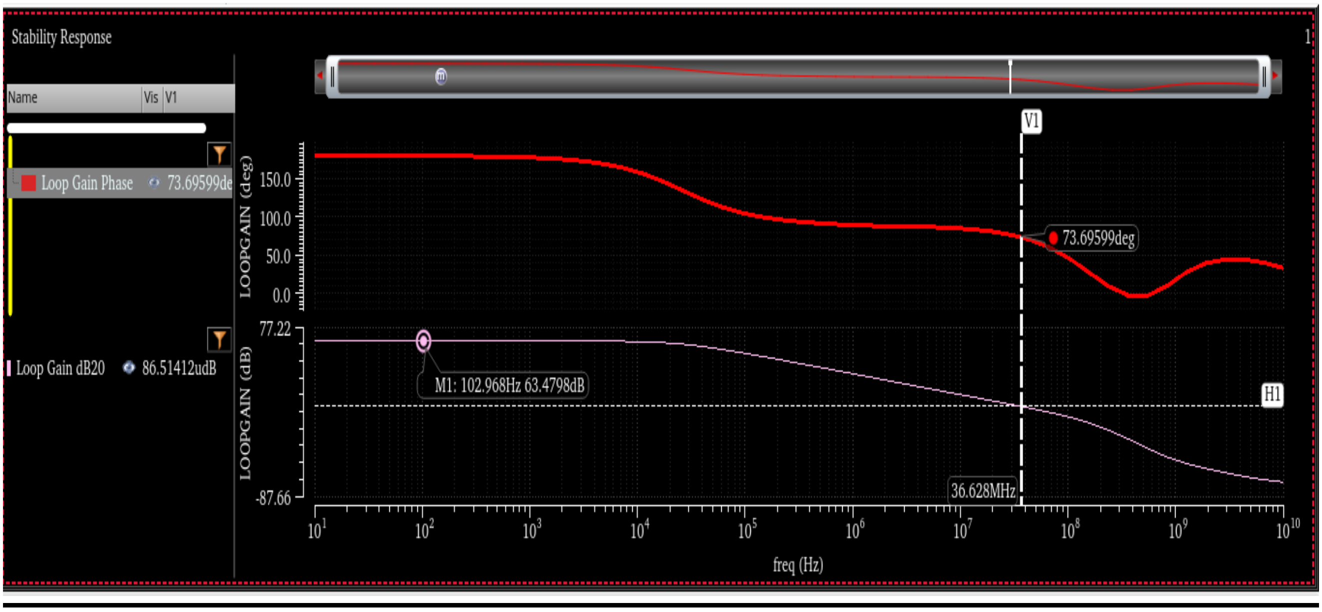


Fig: Simulated plot of loop gain magnitude and phase

Phase Margin (74.004 deg)