NMOS

$\beta_{eff} = 3.14107m$

$= 3141.07\mu$

$\mu_n C_{ox} = \frac{3141.07}{10}$

$= 314.019\mu$

$\boxed{\mu_n C_{ox} = 330\mu}$

PMOS

$\beta_{eff} = 1.6081m$

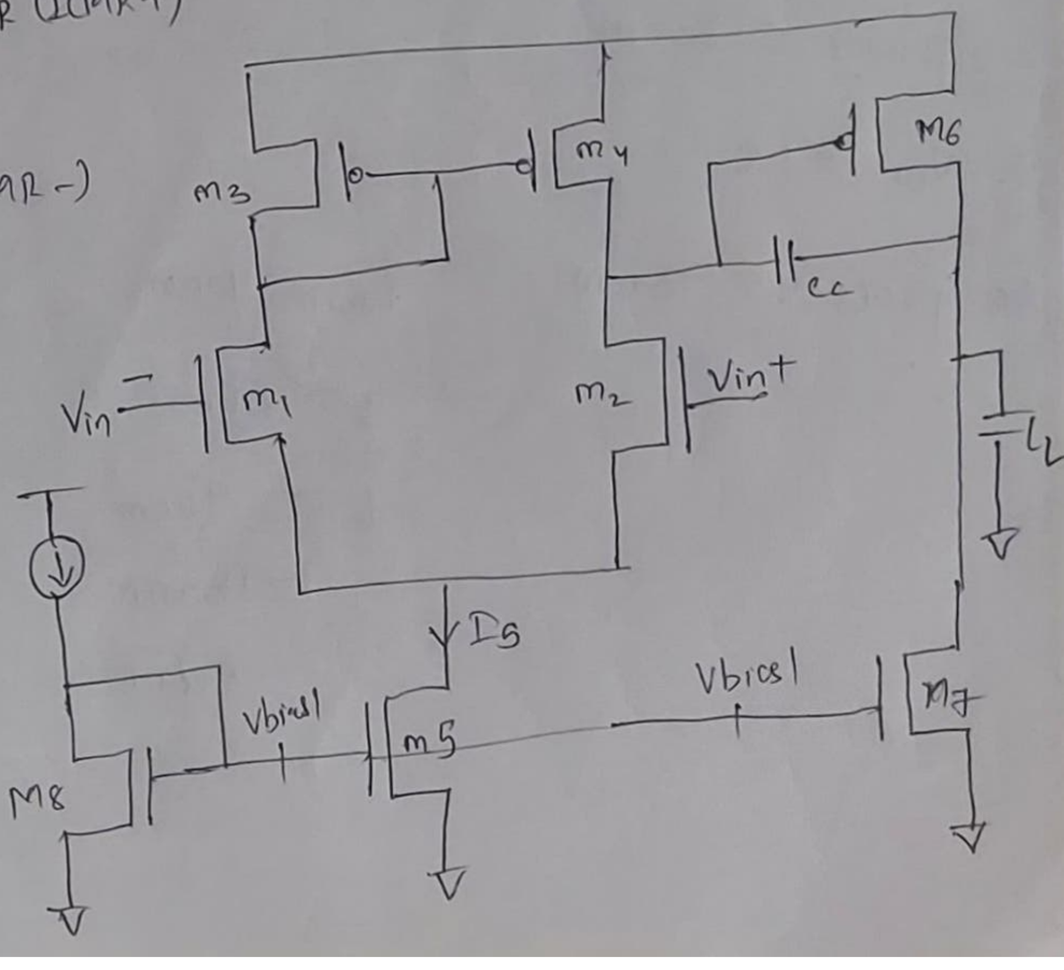
$= 1608.1$

$\mu_p C_{ox} = \frac{1608.1}{10}$

$= 160.81$

$\boxed{\mu_p C_{ox} = 170\mu}$

1. M_1 & M_2 ⇒ GBW product
2. M_3 & M_4 ⇒ Max ICMR (ICMR+)
3. I_5 = slew rate
4. M_5 = min ICMR (ICMR−)
5. C_C = phase Margin



1. Dc gain = 1000

$= 20 \log 1000$

$= 60dB$

2. GBW = 30MHz

3. PM ≥ 60°

4. Slew rate = 20V/μ.sec

5. ICMR (+) = 1.2

6. ICMR (−) = 0.5

7. $C_L = 2pF$

8. power ≤ 300μw

9. $V_{DD} = 1.8$

10. process = 90nm

$L_{min} = 90nm$

$L \geq 2.L_{min}$

$L \geq 2.90nm$

$\therefore L \geq 180nm$

$L = 500nm$

1. $L = 500nm$

2. $C_c \geq 0.22 C_L$

$C_c \geq 0.22 \times 2pF$

$C_c \geq 0.44 pF$

$C_c \geq 440 fF$ (for $PM \geq 60°$)

$\boxed{C_c = 800 fF}$ (for Design purpose)

3. $\text{Slew rate} = \frac{I_5}{C_c}$

$I_5 = S_R \cdot C_c$

$I_5 = 20 V/\mu sec \times 800 fF$

$I_5 = 16 \mu A$

$\boxed{I_5 = 20 \mu A}$

Design of M_1 & M_2

$gm_1 = GBW \times C_c \times 2\pi$

$= 30 MHz \times 800 fF \times 2\pi$

$= 150.79 \mu$

$\boxed{gm_1 = 160 \mu}$

$$I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)\cdot(V_{gs}-V_t)^2$$

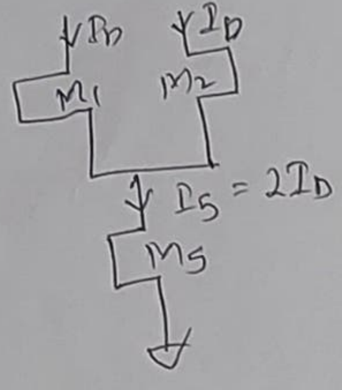
$$g_m = \frac{\partial I_D}{\partial V_{gs}} = \frac{\mu_n C_{ox}}{\cancel{2}}\left(\frac{W}{L}\right)\cdot \cancel{2}(V_{gs}-V_t)$$

$$g_m = \mu_n C_{ox}\left(\frac{W}{L}\right)\cdot(V_{gs}-V_t)$$

Squaring on both side

$$g_m^2 = \left[\mu_n C_{ox}\left(\frac{W}{L}\right)\right]^2\cdot(V_{gs}-V_t)^2$$

$$g_m^2 = \underbrace{\left[\mu_n C_{ox}\left(\frac{W}{L}\right)\right]^2\cdot\frac{(V_{gs}-V_t)^2}{2}}_{I_D}\times 2$$



$$g_m^2 = 2 I_D \mu_n C_{ox}\left(\frac{W}{L}\right)$$

$$\left(\frac{W}{L}\right) = \frac{g_m^2}{\mu_n C_{ox}\, 2 I_D} \quad (\because 2I_D = I_5)$$

$$\left(\frac{W}{L}\right)_{1,2} = \frac{g_{m1}^2}{\mu_n C_{ox}\cdot I_5}$$

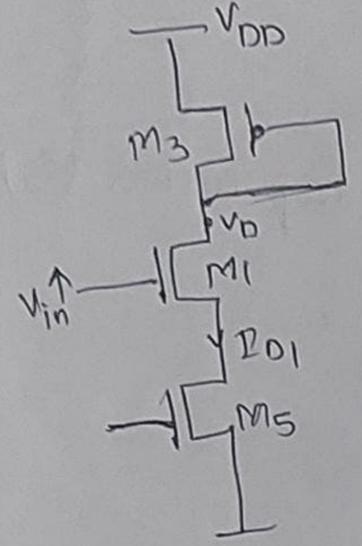
$$= \frac{1.60^2}{330\mu \times 20}$$

$$= 3.878$$

$$\left(\frac{W}{L}\right)_{1,2} = 4$$

Tunning $\left(\frac{W}{L}\right)_{1,2} = 7$

Design of M_3, M_4



⇒ For a MOSFET to use as an amplifier, All the devices are/should be in Saturation region

⇒ Since, M_3 is diode connected region, So M_3, always will be in Saturation region

⇒ If we increas $V_{in} \uparrow$, M_1 enters into triode/linear region

⇒ For, M_1 to be in saturation, then Vd of M_1 should be greater than $v_g - v_{t1}$ (gate voltage - Threshold voltage) (of M_1)

$$\therefore V_d > V_g - V_{t1}$$

$$\therefore V_d > V_g - V_{t1}$$

$$V_g < V_{D1} + V_{t1}$$

$$V_{in} < V_{D1} + V_{t1} \quad (\because V_g = V_{in}) \rightarrow (\text{gate voltage} = V_{in})$$

$$V_{in} \leq V_{D1} + V_{t1}$$

For,

$$V_{in(max)} = V_{D1} + V_{t1} \quad \text{——} \quad (1)$$

$$I_3 = \frac{\mu_p C_{ox} \left(\frac{W}{L}\right)}{2} (V_{gs} - V_t)^2$$

$$= \frac{\beta}{2}(v_{gs} - |v_t|)^2 \quad \left(\because \beta = \mu_p C_{ox}\left(\frac{w}{L}\right)\right)$$

$$\Rightarrow v_{gs} = \sqrt{\frac{2I_3}{\beta}} + |v_{t3}|$$

$$V_{D1} = V_{DD} - V_{gs3} \quad (\because v_{gs3} = \text{voltage drop accross } M_3)$$

$$V_{D1} = V_{DD} - \left[\sqrt{\frac{2I_3}{\beta_1}} + |V_{t3}|\right] \text{ — } ②$$

from eq^n ①

$$V_{in(max)} \leq \underbrace{V_{D1} + V_{t1}}_{min} \quad \text{(minimum value of } V_{D1} \text{ \& } V_{t1} \text{ is equal to } V_{in} \text{ max)}$$

$$ICMR+ \leq V_{D1min} + V_{t1min} \quad (\because V_{in(max)} = ICMR+)$$

$$ICMR+ \leq \left[V_{DD} - \left[\sqrt{\frac{2I_{D3}}{\beta}} + |v_{t3}|\right]\right]_{(min)} + V_{t1(min)}$$

↑ from eq^n – ②

$$ICMR+ \leq V_{DD} - \sqrt{\frac{2I_{D3}}{\beta}} - |V_{t3}|_{max} + V_{t1min}$$

If Vt_3 is maximum then only the V_{D1} will be minimum

$$\frac{2I_{D3}}{\beta} = \left(V_{DD} - (ICMR_{max}) - |Vt_3|_{max} + Vt_{1min}\right)^2$$

$$\frac{2I_{D3}}{\mu_p C_{ox}\left(\frac{W}{L}\right)_{3,4}} = \left(V_{DD} - ICMR_{max} - |Vt_3|_{max} + Vt_{1min}\right)^2$$

$$\left(\frac{W}{L}\right)_{3,4} = \frac{2I_{D3}}{\mu_p C_{ox}\left(V_{DD} - ICMR_{max} - |Vt_3|_{max} + Vt_{1min}\right)^2}$$

$V_{DD} = 1.8$

$I_{D3} = \frac{I_{D5}}{2} = \frac{20}{2} = 10\mu$

$\mu_p C_{ox} = 170\mu$

$ICMR + = 1.2$

$Vt_3(max) = 0.19\mu$

$Vt_3(min) = 0.22\mu$

$Vt_1(max) = 0.3\mu$

⇒ For M_3 & M_4 V_{th} value can be taken by using arbitary value - 10μ, 5μ (or) 15μ

⇒ This value is used only to find the V_{th} value of M_1 & M_3

⇒ These value are taken to compare the variation in V_{th} value of M_1 & M_3

For 10μ length

$V_{cm} = 1.2$ | $V_{cm} = 0.5$

$M_1 = 293.958m = 300m = 0.3\mu$ | $216.766m \simeq 220m = 0.22\mu$

$M_3 = 186.518m \simeq 190m = 0.19\mu$ | $186.518m$

For 5μ length

$M_1 = 294.185m$ | $216.93m$

$M_3 = 186.281m$ | $186.281m$

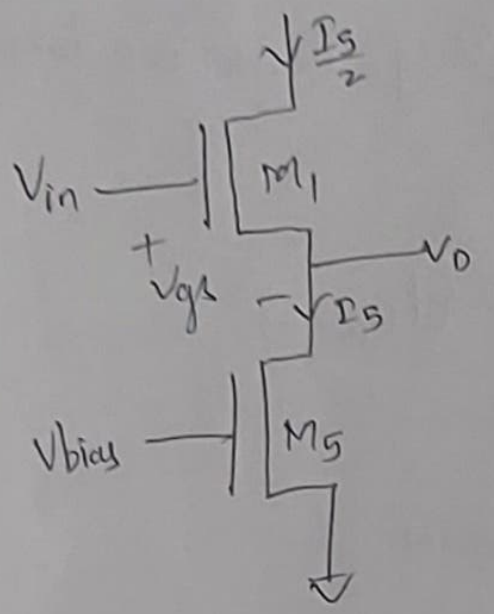
$$\left(\frac{W}{L}\right)_{3,4} = \frac{2 I_{D3}}{\mu_p C_{ox} (V_{DD} - ICMR_{max} - |V_{t3}|_{max} + V_{t1\,min})^2}$$

$$= \frac{2 \times 10}{170 (1.8 - 1.2 - 0.19 + 0.22)^2}$$

$$= 0.296$$

$$\left(\frac{W}{L}\right)_{3,4} \simeq 1$$

6. Design of M_5



⇒ when V_{in} decrease, V_{gs} almost remains constant and V_o decreases

⇒ M_5 to be in saturation

$$V_{DS} > V_{gs} - V_{t_5}$$

⇒ When V_{in} decreases, V_D of M_5 is decreasing then M_5 will enter to triode region

⇒ $V_D = V_{sat}$ → Required for M_5 to be in saturation

Therefore

$$V_{in\,(min)} \geq V_{gs_1} + V_{Dsat_5}$$

$$ICMR- \geq V_{gs_1(max)} + V_{Dsat_5}$$ ($\because$ V_{Dsat} is fixed & V_{gs} is max to calculate ICMR −)

$$ICMR- \geq \left[\sqrt{\frac{2I_{D1}}{\beta_1}} + V_{t_1}\right]_{max} + V_{Dsat_5} \quad \left[\because V_{gs_1} = \sqrt{\frac{2I_{D1}}{\beta_1}} + V_{t_1}\right]$$

$$ICMR- \geq \sqrt{\frac{2I_{D1}}{\beta_1}} + V_{t_1\,(max)} + V_{Dsat_5}$$

→ Body of M_1 connected to ground but source will not be connected to ground. Therefore, threshold voltage of M_1 will vary. Hence, we take maximum threshold voltage of M_1

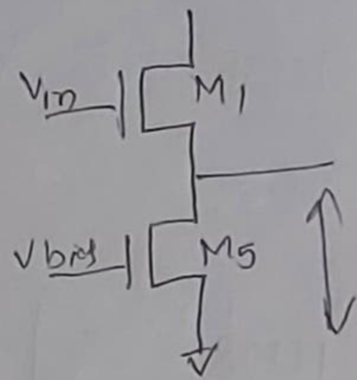
$$V_{DSat5} \geq ICMR_{(-)} - \sqrt{\frac{2I_{D1}}{\beta_1}} - V_{t1(max)}$$

$$V_{DSat} \geq ICMR_{(-)} - \sqrt{\frac{2I_{D1}}{\beta_1}} - V_{t(max)}$$

$$V_{DSat} \geq 0.5 - \sqrt{\frac{2 \times 10\mu}{330 \times 4}} - 0.3 \qquad [V_{tmax} = 0.3\mu]$$

$$V_{DSat} = 0.5 - 0.123 - 0.3$$

$$V_{DSat} = 77mA$$



$$V_{DSat} = 0.5 - \sqrt{\frac{2 \times 10\mu}{330 \times 7}} - 0.3$$

$$= 0.5 - 0.0930 - 0.3$$

100mv > good
100mv < weak

$$\boxed{V_{DSat} = 107mA}$$

Tunning

$$\left(\frac{W}{L}\right)_{1,2} = 7$$

$$\left(\frac{W}{L}\right)_5 = \frac{2I_{D5}}{\mu_n C_{ox} \cdot (V_{Dsat})^2}$$

$$= \frac{2 \times 20\mu}{330\,(107)^2}$$

$$\left(\frac{W}{L}\right)_5 = 10.58$$

$$\boxed{\left(\frac{W}{L}\right)_5 = 11}$$

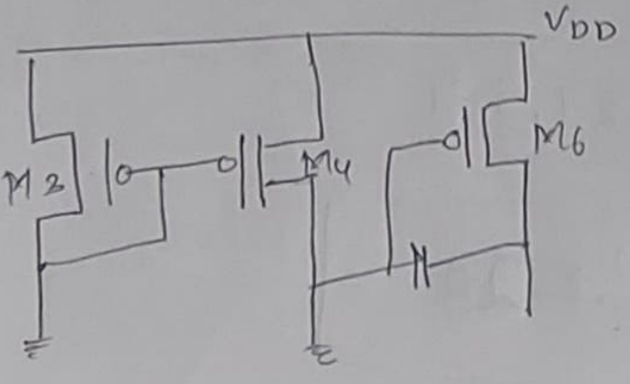
Design of M_6

for 60° PM

$$g_{m6} \geq 10 \cdot g_{m1}$$

$$g_{m6} \geq 10 \cdot 160\mu$$

$$g_{m6} \geq 1600\mu$$



$$\underset{(M_3)}{V_{DS}} = \underset{(M_4)}{V_{DS}} = \underset{(M_6)}{V_{DS}}$$

$$\underset{(M_3)}{V_{gs}} = \underset{(M_4)}{V_{gs}} = \underset{(M_6)}{V_{gs}}$$

$$I_D = \mu_p C_{ox}\left(\frac{W}{L}\right)\frac{[V_{gs} - V_t]^2}{2}$$

$$\frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} = \frac{I_6}{I_4} \quad \Bigg| \quad \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} = \frac{g_{m6}}{g_{m4}} \quad \Bigg| \quad \left(\frac{W}{L}\right)_4 = 1$$

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

$$g_{m4} = \sqrt{170 \times 1 \times 2 \times 10}$$

$$g_{m4} = 58.30\mu$$

$$\left(\frac{W}{L}\right)_6 = \frac{g_{m6}}{g_{m4}} \times \left(\frac{W}{L}\right)_4$$

$$= \frac{1600}{58.30} \times 1$$

$$= 27.44$$

$$\boxed{\left(\frac{W}{L}\right)_6 \simeq 28}$$

Design of M_7

$$\frac{I_6}{I_4} = \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4}$$

$$I_6 = \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} \times I_4$$

$$= \frac{28}{1} \times 10$$

$$\boxed{I_6 = 280\mu A}$$

$$\frac{I_7}{I_5} = \frac{\left(\frac{W}{L}\right)_7}{\left(\frac{W}{L}\right)_5}$$

$$\left(\frac{W}{L}\right)_7 = \frac{I_7}{I_5} \cdot \left(\frac{W}{L}\right)_5$$

$$\left(\frac{W}{L}\right)_7 = \frac{280}{20} \times 11$$

$\left(\frac{W}{L}\right)_7 = 154$

$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_8$

so. $\left(\frac{W}{L}\right)_5$ is 11

Therefore $\left(\frac{W}{L}\right)_8 = 11$

$I_5 = 20\mu A$

$C_c = 880 fF$

$M_1, M_2 \Rightarrow 7 \Rightarrow \frac{3.5}{0.5}$

$M_3, M_4 \Rightarrow 1 \Rightarrow \frac{0.5}{0.5}$

$M_5 \Rightarrow 11 \Rightarrow \frac{5.5}{0.5}$

$M_6 \Rightarrow 28 \Rightarrow \frac{14}{0.5}$

$M_7 \Rightarrow 154 \Rightarrow \frac{77}{0.5}$

$M_8 \Rightarrow 11 \Rightarrow \frac{5.5}{0.5}$

$I_6, I_7 = 280\mu A$

Effect of current (idc) :-

If we increase the current then slew rate ↑ but the gain ↓

because $\frac{gm}{\lambda id}$ If Id is high gain will be ↓

First stage gain contributed by M_1 & M_2

If we Increase M_1 gain will ↑ because $M_1 \propto gm$ (GBW product also ↑)

⇒ To get higher gain & GBW product increase M_1 & M_2

If we need max ICMR then we should make M_3 & M_4 ↑ but that effect M_1 & M_3 cause gain ↓ then we should have to make M_5 ↑

M_6 contribute gain of second stage
M_7 contribute gain of second stage

Cc will not have effect on gain it has effect on GBW

If CC↓ GBW↑
CC↑ GBW↓

Cc also have big impact on slewrate
Cc↑ SR↑
CC↓ SR↓

For ICMR $\Rightarrow 0.5$

$gm_1 = 167.844\mu$

$gds_1 = 2.07644\mu$

$gds_4 = 839.918n$

$= 0.839918$

$gm_6 = 1.25501m$

$= 1255.01\mu$

$gds_6 = 21.7001\mu$

$gds_7 = 57.4821\mu$

$\text{gain} = gm\,(r_{o1} \| r_{o4})$ } standard text book

$$\text{gain} = \frac{gm_1}{gds_1 + gds_4}$$

$$= \frac{167.844}{2.07644 + 0.839918}$$

gain $= 57.55$

gain in dB $= 20\log(57.55)$

gain in dB $= 35.201$

$$\text{gain} = \frac{gm_6}{gds_6 + gds_7}$$

$$= \frac{1255.01}{21.7001 + 57.4821}$$

gain $= 15.84$

gain in dB $= 20\log(15.84)$

gain in dB $= 24.00$

Total gain = gain of first stage + gain of second stage

$= 59.201$

· For ICMR => 1.2

$gm_1 = 181.626\mu$

$gds_1 = 2.76759\mu$

$gds_4 = 915.257n$
$= 0.915257\mu$

$$\text{gain} = \frac{gm_1}{gds_1 + gds_4}$$

$$= \frac{181.626}{2.76759 + 0.915257}$$

$= 49.316$

gain in dB $= 20\log(49.316)$
$= 33.859$

$gm_6 = 1.28827m$
$= 1288.27\mu$

$gds_6 = 22.4588\mu$

$gds_7 = 59.2008\mu$

$$\text{gain} = \frac{gm_6}{gds_6 + gds_7}$$

$$= \frac{1288.27}{22.4588 + 59.2008}$$

$= 15.776$

gain in dB $= 20\log(15.776)$
$= 23.959$

~~Gain~~

Total gain = gain of first stage + gain of second stage
$= 33.859 + 23.957$

Total gain $= 57.81$