Assignment -7

ICMR = 0.3 - 0.8

output swing > 1V

SR ≥ 10V/μs

Power < 1mW

C_L = 1pF , GBW > 10MHz

$\mu_n C_{ox}$ = 300μ $\mu_p C_{ox}$ = 65μ

L = 0.54μm

$C_c \geq 0.22 C_L \Rightarrow C_c \geq 0.22(1pF) \Rightarrow C_c \geq 0.22pF$

$\boxed{C_c = 2pF}$

$\Rightarrow SR > 10V/\mu s \Rightarrow I_{ss} > (2pF)(10V/\mu s)$

$\Rightarrow \boxed{I_{ss} > 20\mu A}$

For MOSFET 1

we use GBW to find g_{m_1}

$\frac{g_{m_1}}{C_c} = GBW = 2\pi \times 10 \times 10^6 \Rightarrow g_{m_1} = 2\pi \times 10^7 \times 20 \times 10^{-6} \times 10^{-12}$

$= 40\pi \times 10 \times 10^{-12}$

$= 400\pi \times 10^{-12}$

$= \cancel{4\pi \times 10^{-10}}$

$= 1.25 \times 10^{-4}$

$= 125.663\mu S$

$$\left(\frac{W}{L}\right)_1 = \frac{gm^2}{2\left(\frac{I_{ss}}{2}\right)(\mu p\, Cox)} = \frac{(125.663\times10^{-6})^2}{(20\times10^{-6})(65\times10^{-6})}$$

$$\boxed{\left(\frac{W}{L}\right)_1 = 12.147} = \left(\frac{W}{L}\right)_2$$

~~$\Rightarrow$ Vin min $\Rightarrow$ $V_{ss} + V_{gs_3} + V_{sg_3} + V_{OV1}$~~

~~$= 0 + V_{gs_3} + (V_{OV_1} + V_{T_1}) + V_{OV_1}$~~

~~$V_{SG} - V_T = V_{OV}$ $= V_{gs_3} - V_{Th_1}$~~

~~For MOSFET-1 $\Rightarrow$ $V_{sd_1} > V_{sg_1} - |V_{TP}|$~~

~~$-V_{d_1} > -V_{g_1}$~~

For MOSFET 1 $\Rightarrow$ $V_{sd_1} > V_{sg_1} - |V_{TP}|$

From ICMR minimum $V_{d_1} < V_g + |V_{TP}|$

we will find

$V_g > V_{d_1} - |V_{TP}|_1$

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

minimum gate voltage

$$V_g > V_{gs_3\,sat} - |V_{TP}|_1$$

$$0.3 = V_{gs_3\,sat} - (V_{TP}).$$

Threshold voltge assumy 0.45

$0.3 = V_{gs3} - 0.45 \Rightarrow \boxed{V_{gs3} = 0.75}$

$$I_{D_3} = \frac{\mu_n C_{ox}}{2} \left(\frac{W}{L}\right)_3 (0.75 - 0.45)^2$$

$$\left(\frac{W}{L}\right)_3 = \frac{10 \times 10^{-6} \times 2}{300 \times 10^{-6} \times (0.3)^2} = 0.74$$

$$\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 0.74$$

$\Rightarrow$ From ICMR maximum we will find $\left(\frac{W}{L}\right)_{5,6}$

$\Rightarrow$ I am assuming MOSFET 5 and 6 are same

$$V_{in(max)} = V_{dd} - V_{ov5} - V_{ov6} - V_{sg1}$$

$$V_{ov5} = V_{ov6}$$

$$V_{sg1} = \sqrt{\frac{2(10 \times 10^{-6})}{65 \times 10^{-6} \times (12.147)}} + 0.45$$

$$\boxed{V_{sg1} = 0.609}$$

$V_{in\,max} = 0.8 = 1.8 - 2V_{OV} - 0.609$

$$\boxed{V_{OV\,5,6} = 0.1955}$$

$\Rightarrow$ calculating $\left(\frac{W}{L}\right)_5$

$$20\times10^{-6} = \frac{1}{2}(65\times10^{-6})\left(\frac{W}{L}\right)_5 (0.1955)^2$$

$$\boxed{\left(\frac{W}{L}\right)_{5,6} = 16.101}$$

$\Rightarrow$ unity gain freq (GBW)

$$\omega_{unity} = \frac{g_{m1}}{C_C}$$

$$\text{second pole} = \frac{g_{m8}}{C_L}$$

The phase margin is optimized when

$$\omega_{P_2} \geq 2.2\,\omega_{unity}$$

$$\frac{g_{m8}}{C_L} = 2.2\frac{g_{m4}}{C_C}$$

$$\Rightarrow g_{m8} = 2.2\,g_{m4}\left(\frac{C_L}{C_C}\right)$$

$\Rightarrow \quad g_{m8} = (2.2)\left(\sqrt{2 I_d (300\times10^{-6})(0.74)}\right)\left(\frac{1}{2}\right)$

$= (2.2)\,(\quad)\left(\frac{1}{2}\right)$

$g_{m8} = 0.00007329$

$\boxed{g_{m8} = 73.29\,\mu s}$

$\Rightarrow \left(\frac{W}{L}\right)_8 = \dfrac{g_{m8}^2}{(2 I_d)(\mu_n C_{ox})}$

we dont know I_{d8}

so we should use some other method

$\Downarrow$

For MOSFET 4 & 8

same V_{dsat}

$\dfrac{g_{m4}}{g_{m8}} = \dfrac{(W/L)_4}{\left(\frac{W}{L}\right)_8} = \dfrac{0.74}{\left(\frac{W}{L}\right)_8} = \dfrac{66.633\,\mu s}{73.29}$

$\dfrac{0.74}{\left(\frac{W}{L}\right)_8} = 0.909$

$\Rightarrow \left(\frac{W}{L}\right)_8 = 0.814$

$$I_8 = \frac{g_{m8}^2}{2\mu_n C_{ox}\left(\frac{W}{L}\right)_8} = \frac{(73.29\times10^{-6})^2}{2(300\times10^{-6})(0.814)}$$

$$I_8 = 0.00001099$$

$$\boxed{I_8 = 10.998\,\mu A}$$

FOR MOSFET 7

$$\frac{\left(\frac{W}{L}\right)_7}{\left(\frac{W}{L}\right)_8} = \frac{I_7}{I_8} = \frac{10.998\times10^{-6}}{20\times10^{-6}}$$

$$\boxed{\left(\frac{W}{L}\right)_7 = 8.853}$$

M_5 & M_6 (Biasing)

$M_5 \Rightarrow \quad V_{sg5} - |V_{thp}| = V_{ov} = 0.1955$

$$V_s - V_{g5} - 0.45 = 0.1955$$

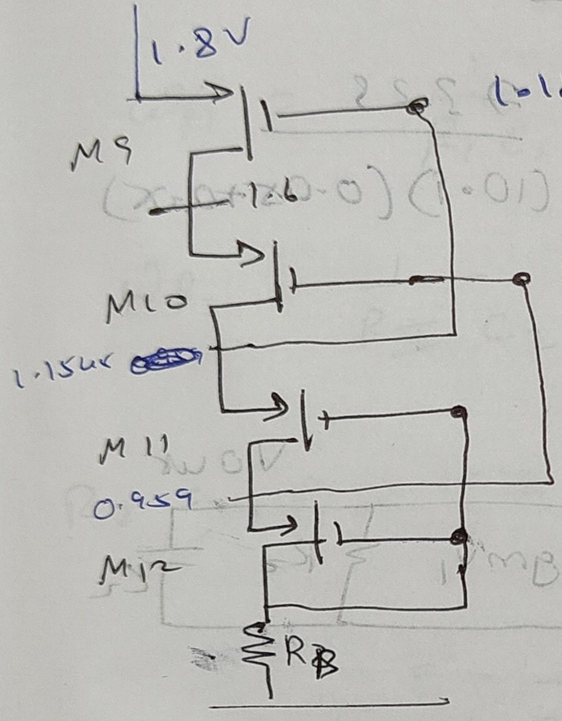
$$V_g = 1.8 - 0.45 - 0.1955$$

$$\boxed{V_{g5} = 1.1545\,V}$$

$\cancel{V_{g6}} = V_{OV6} = V_{SG6} - V_{TH}$

$0.1955 = (1.8 - 0.1955) - V_{g6} - 0.45$

$\boxed{V_{g6} = 0.959\,V}$



Lets assume I through this is I_q

⟹ Power consumption

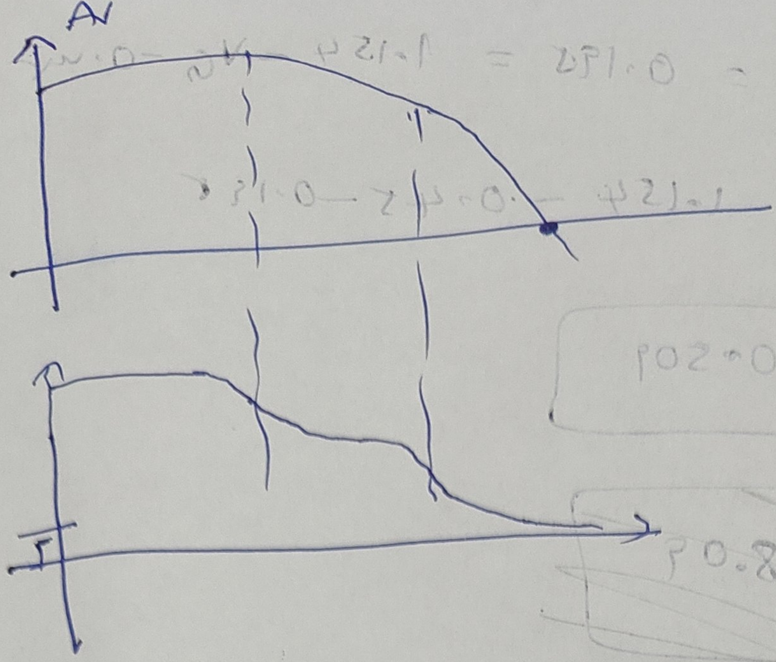
$= (I_q + 20\times10^{-6} + 10.998\times10^{-6})(1.8)$

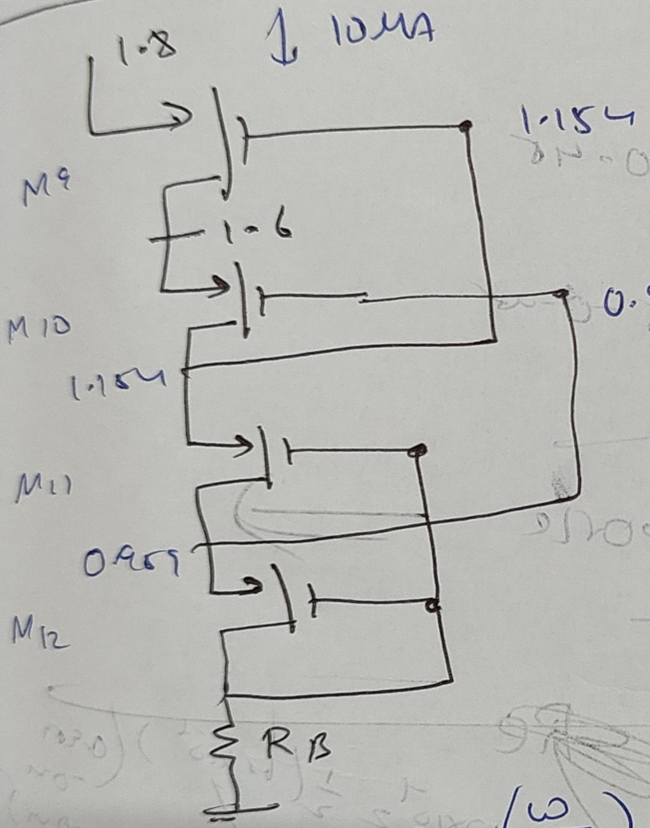
$= 55.796\,\mu W + (I_3)(1.8)$

$I_q(1.8) + 55.796\,\mu W \leq 1000\,\mu W$

$I_q(1.8) \leq 994.204\,\mu W$

$I_q \leq 524.557\,\mu W$





M9 ⇒ suppose Id i assum

$$10\,\mu A = \frac{1}{2}(65\times10^{-6})\left(\frac{W}{L}\right)(0.2)^2$$

$$\boxed{\left(\frac{W}{L}\right)_9 = 7.69}$$

M10 ⇒

$$10\times10^{-6} = \frac{1}{2}(65\times10^{-6})\left(\frac{W}{L}\right)(1.6-0.959-0.45)^2$$

$$\Rightarrow \left(\frac{W}{L}\right) = \frac{2\times10\times10^{-6}}{(65\times10^{-6})(1.6-0.959-0.45)^2}$$

$$\boxed{\left(\frac{W}{L}\right)_{10} = 8.43}$$

For MOSFET 11

$V_{SD} = 1.154 - 0.959 = 0.195 = 1.154 - V_G - 0.45$

$V_G = 1.154 - 0.45 - 0.195$

$\boxed{V_G = 0.509}$

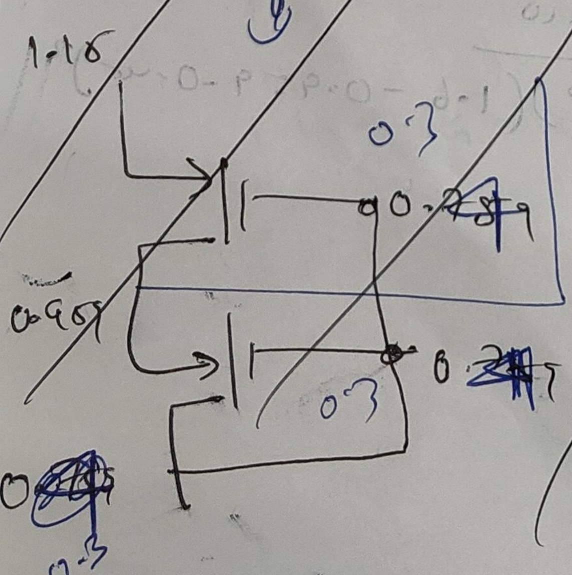
~~For MOSF~~ $\cancel{\left(\frac{W}{L}\right)_{11} = 8.09}$

For MOSFET 12

$V_{SD} = 0.959 - 0.509 = 0.45$

~~$V_{SG} - V_{TH}$~~ $= V_{SG} - V_{TH} = 0.45 + 0.45$

Then This wont work →

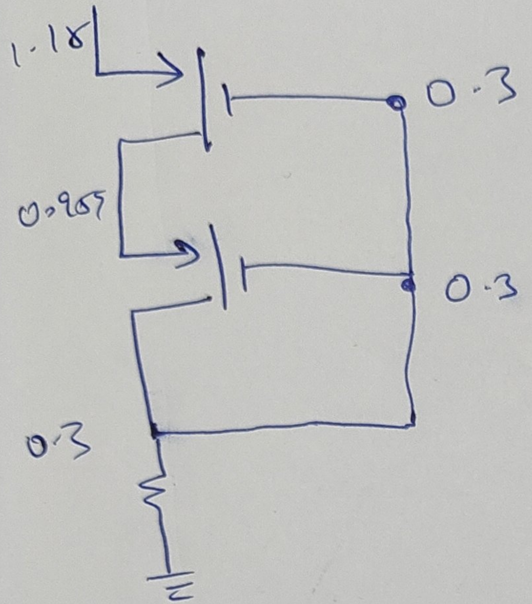


$10\times10^{-6} = \frac{1}{2}(65\times10^{-6})\left(0.959 - 0.45 - 0.45\right)$

→ Revised Value

$10\times10^{-6} = \frac{1}{2}(65\times10^{-6})\left(\frac{W}{L}\right)_{11}\left(1.15 - 0.239 - 0.45\right)$

Revised



$M_{11} \Rightarrow \left(\frac{W}{L}\right)_{11} = \frac{2 \times 10 \times 10^{-6}}{(1.15 - 0.3 - 0.45)^2}$

$\left(\frac{W}{L}\right)_{11} = 1.92$

$M_{12} \Rightarrow \left(\frac{W}{L}\right)_{12} = \frac{2 \times 10 \times 10^{-6}}{65 \times 10^{-6}\,(0.95 - 0.3 - 0.45)^2}$

$\boxed{\left(\frac{W}{L}\right)_{12} = 7.69}$

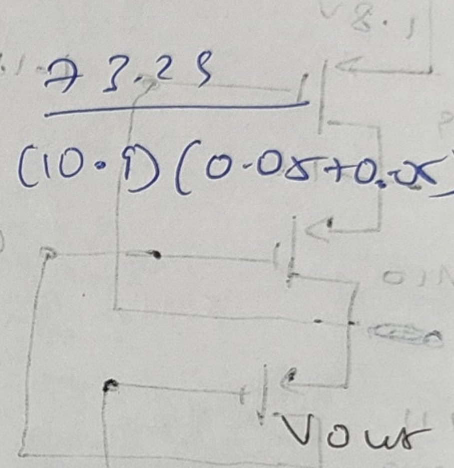
gain → $A_v = -g_{m1}(r_{o2} \| r_{o4})$

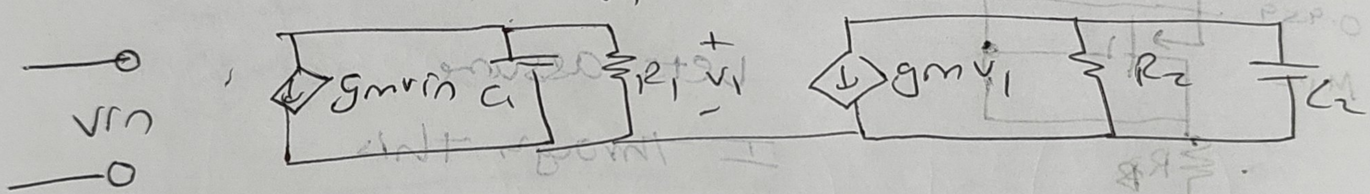
$$= \frac{-g_{m1}}{I_d(\lambda_p+\lambda_n)} =$$

$$\frac{g_{m1}}{I(\lambda_n+\lambda_p)} * \frac{g_{m8}}{I(}$$

Net gain → $\frac{125.663}{10(0.05+0.08)} \times \frac{73.29}{(10.9)(0.08+0.08)}$

$\Rightarrow 78.536\ dB$





$$g_{m1} v_{in} = \frac{v_1}{R_1} + C_1 \frac{dv_1}{dt}$$

$$v_1 = g_{m1} v_{in} \left(\frac{R_1}{1+sR_1C_1} \right)$$

$$\Rightarrow g_{m2} v_1 = \frac{V_{out}}{R_2} + C_2 \frac{dV_{out}}{dt}$$

$$V_{out} = g_{m2} v_1 \left(\frac{R_2}{1+sR_2C_2} \right)$$

$$\Rightarrow \frac{V_{out}}{v_{in}} = \frac{g_{m1} g_{m2} R_1 R_2}{(1+sR_1C_1)(1+sR_2C_2)}$$

$$\omega p_1 = \frac{1}{R_1 C_1}$$

$$R_1 = r_{o2} \| r_{o4} = \frac{1}{(10\times10^{-6})(0.05+0.05)} = 10^6$$

~~Cgd2 + Cgd4 + Cgs8 + Cgs...~~

$$\omega p_1 = \frac{1}{R_1 C_1}$$

$$\omega p_2 = \frac{1}{R_{II} C_2}$$

$$R_2 = r_{o7} \| r_{o8} = \frac{1}{g_{ds7} + g_{ds8}}$$

$$\frac{1}{10^{-6}(10.9)(0.\cancel{1})} \quad 9.17\times10^5$$

C_1 would be in Femto Farad

Lets assume $15\,fF$

C_2 is $C_L = 1PF$

$$\omega p_1 = \frac{1}{2\pi(10^6)(15\times10^{-15})} = \frac{6.67\times10^7}{2\pi}$$

$= 10610329.54$ Hz

$= 10.61\times10^6$ Hz

$$\omega p_2 = \frac{1}{2\pi (9.17 \times 10^8)(10^{-12})} = 173560.46$$

$$\approx 17.35 \times 10^4 \ Hz$$

$$GBW = (78.536 dB)(17.35 \times 10^4)$$

~~ga~~ gain dominant pole

$$= 1465883577 \ Hz$$

$$= 14.65 \times 10^8 = 1.465 \ GHz$$

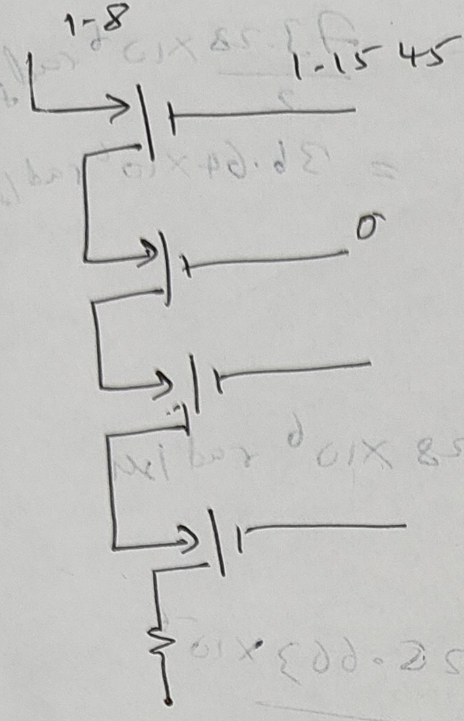
phase margin

$$\angle H(s) = -\tan^{-1}\left(\frac{\omega}{\omega p_1}\right) - \tan^{-1}\left(\frac{\omega}{\omega p_2}\right)$$

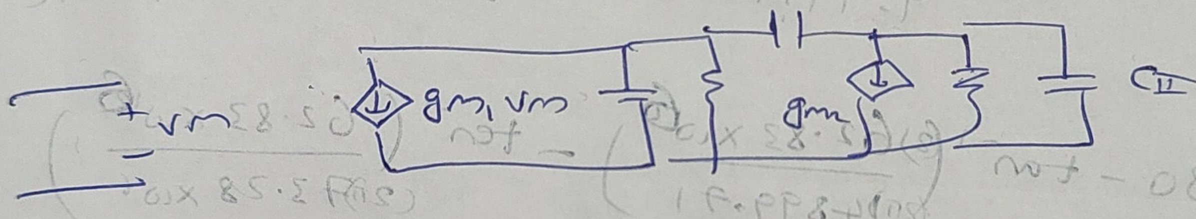
$-180 + PM$

$$PM = 180 - \tan^{-1}\left(\frac{1.465 \times 10^9}{10.61 \times 10^6}\right) - \tan^{-1}\left(\frac{1.465 \times 10^9}{17.35 \times 10^4}\right)$$

$$\boxed{PM = 0.4217}$$



with compensation capacitor



$$\omega p_1 = \frac{1}{g_{m2} R_1 R_2 C_c} = \frac{(\lambda_n+\lambda_p) I_2 \; (\lambda_n+\lambda_p) I_8}{g_{m8} \cdot C_c}$$

$$\omega p_2 = \frac{g_{m8}}{C_2}$$

$$\omega_z = \frac{g_{m2}}{C_c}$$

$$\omega p_1 = \frac{(0.1)(10\times10^{-6})(0.1)(10.92\times10^{-6})}{(73.29\times10^{-6})(2\times10^{-12})}$$

$$= \frac{14899.71}{2} \text{ rad/sec} \cong 7.449\times10^{3} \text{ rad/s}$$

$$\omega_{Z_1} = \frac{g_{m8}}{C_C} = \frac{73.28\times10^{-6}}{2\times10^{-12}} = \frac{73.28\times10^{6}}{2} \text{ rad/sec}$$

$$= 36.64\times10^{6} \text{ rad/sec}$$

$$\omega_{P_2} = \frac{-g_{m8}}{C_L}$$

$$= \frac{73.28\times10^{-6}}{10^{-12}} = 73.28\times10^{6} \text{ rad/sec}$$

$$GBW = \frac{g_{m1}}{2\pi C_c} = \frac{125.663\times10^{-6}}{2\times10^{-12}}$$

$$9.99 MHz = 62.8315\times10^{6} \text{ rad/sec}$$

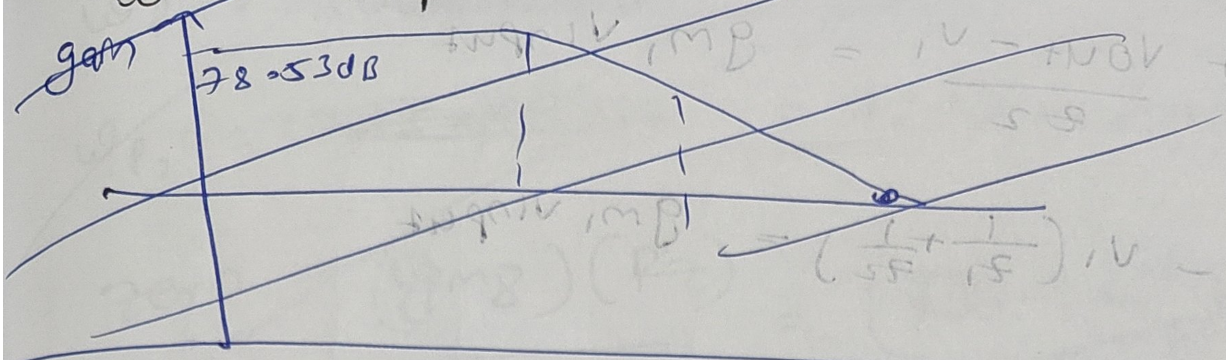
$$PM = 180 - \tan^{-1}\left(\frac{(2)\,62.83\times10^{6}}{(2\pi)\,4899.71}\right) - \tan^{-1}\left(\frac{62.83\times10^{6}}{(2\pi)\,73.28\times10^{6}}\right)$$

$$- \tan^{-1}\left(\frac{62.83\times10^{6}}{(2\pi)\,36.64\times10^{6}}\right)$$

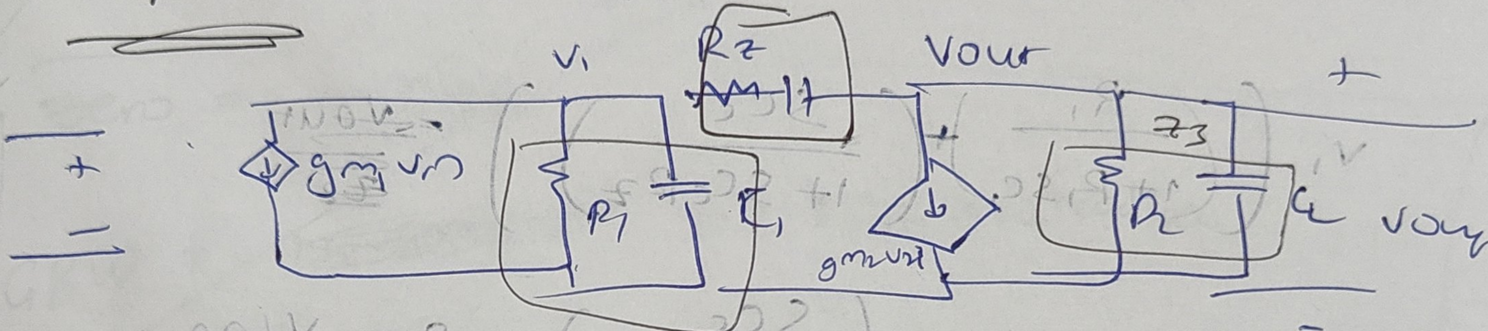
$$\boxed{\cancel{PM = 66.9642}}$$

$$\boxed{PM = 67.029}$$

~~with compen~~



Compensation + Resistor z_2



$$\frac{0-V_1}{z_1} + \frac{V_{out}-V_1}{z_2} = g_{m1} v_{in} \quad — ①$$

$$z_1 \Rightarrow \quad \frac{1}{z_1} = \frac{1}{R_1} + sC_1 = \frac{1+R_1 sC_1}{R_1}$$

$$z_1 = \frac{R_1}{1+R_1C_1 s}$$

$$z_2 \Rightarrow \quad R_z + \frac{1}{sC_c}$$

$$z_3 \Rightarrow \quad z_3 = \frac{R_2}{1+R_2C_L s}$$

$$\frac{V_1 - V_{out}}{z_2} + \frac{0 - V_{out}}{z_3} = g_{m2} V_1 \quad — ②$$

$$V_1\left(\frac{1}{z_2} - g_{m2}\right) = V_{out}\left(\frac{1}{z_2} + \frac{1}{z_3}\right)$$

$$\frac{0 - V_1}{z_1} + \frac{V_{out} - V_1}{z_2} = gm_1 V_{input}$$

$$\frac{V_{out}}{z_2} - V_1\left(\frac{1}{z_1} + \frac{1}{z_2}\right) = gm_1 V_{input}$$

$$V_1\left(\frac{1}{z_1} + \frac{1}{z_2}\right) = \frac{V_{out}}{z_2} - gm_1 V_{input}$$

$$V_1\left(\left(\frac{R_1}{1 + R_1 s C_1}\right) + \left(\frac{sC_c}{1 + sC_c R_z}\right)\right) = \cancel{\frac{V_{out}}{z_2}}$$

$$= V_{out}\left(\frac{sC_c}{1 + sC_c R_z}\right) - gm_1 V_{input}$$

$$\frac{V_{out}\left(\frac{1}{z_2} + \frac{1}{z_3}\right)}{\boxed{\left(\frac{1}{z_2} - gm_8\right)}} \quad \left(R_1 + sC_c R_z R_1 + sC_c + s^2 C_c R_1 C_1\right.$$

Finally $\Rightarrow$

$$\boxed{A_{DC} \frac{\left(1 - \frac{s}{z}\right)}{\left(1 + \frac{s}{p_1}\right)\left(1 + \frac{s}{p_2}\right)} \qquad \omega p_1 = \frac{1}{R_1 C_1} \qquad \omega p_3 \qquad \omega p_2 = \frac{1}{R_2 C_2}}$$

but

$$\text{zero} = \frac{(gm_8)(R_z)}{C_c}$$

freq response without compensation

=> when the series resistance is connected with miller capacitor

=> The nulling Resistor Introduced a weak 3rd pole & it pushes the Right half plane zero away from the system

$$P_3(new) = -G_{m8}\left(\frac{1}{C_C} + \frac{1}{C_1} + \frac{1}{C_L}\right)R_z$$

$$Z_1 = \frac{1}{\left(R_z - \frac{1}{g_{m8}}\right)C_C}$$

$$R_z \geq \frac{1}{g_{m8}}$$

=> If this is not taken as it would lie in left half of s-plane providing phase lead instead of phase lag

=> This would result the total phase lag of 180° degree

=> unstability

$\omega P_1 =$

$$R_3 = \frac{1}{g_{m8}} = \frac{1}{73.28\times10^{-6}} = 13.646\times10^{3}\,\Omega$$

$$P_3\,new = -\frac{(73.28\times10^{-6})}{}(13.646\times10^{3})\left[\frac{1}{2\times10^{-12}} + \frac{1}{1\times10^{-12}} + \frac{1}{15\times10^{-12}}\right]$$

$$= 68.16\times10^{12}\,rad/sec$$

$$PM = 180 - \tan^{-1}\left(\frac{GBW}{\omega P_1}\right) - \tan^{-1}\left(\frac{GBW}{\omega P_2}\right) - \tan^{-1}\left(\frac{GBW}{\omega Z}\right)$$

$Z_1 =$

M11 => $\cancel{V_{DS_{sat}} = V_{SG} - |V_{TP}|}$

$\cancel{V_{SD_{sat}} = V_{SG} - |V_{TP}|}$

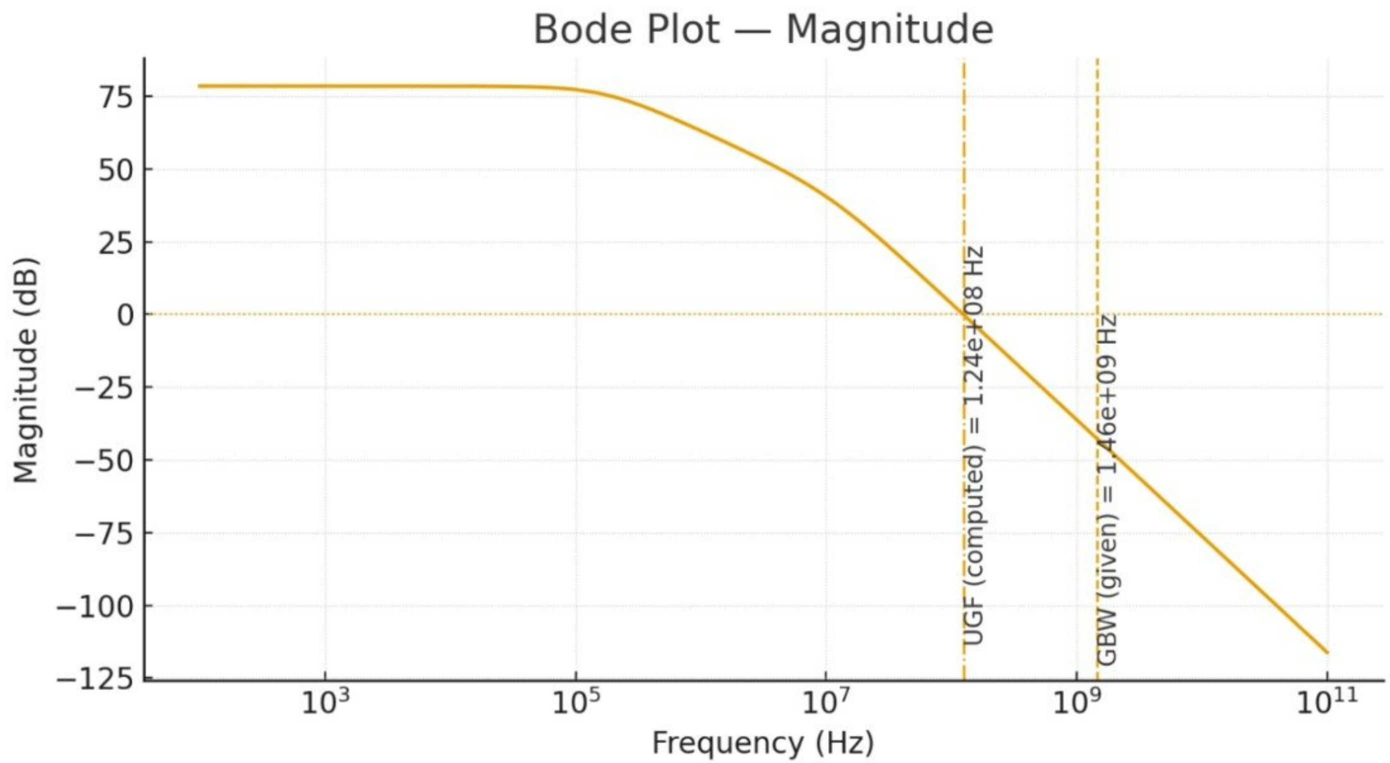
$\cancel{-0.959 - V_X = 1.154} - V_X$

$\cancel{0.959 - 0.154 = 1.154}$

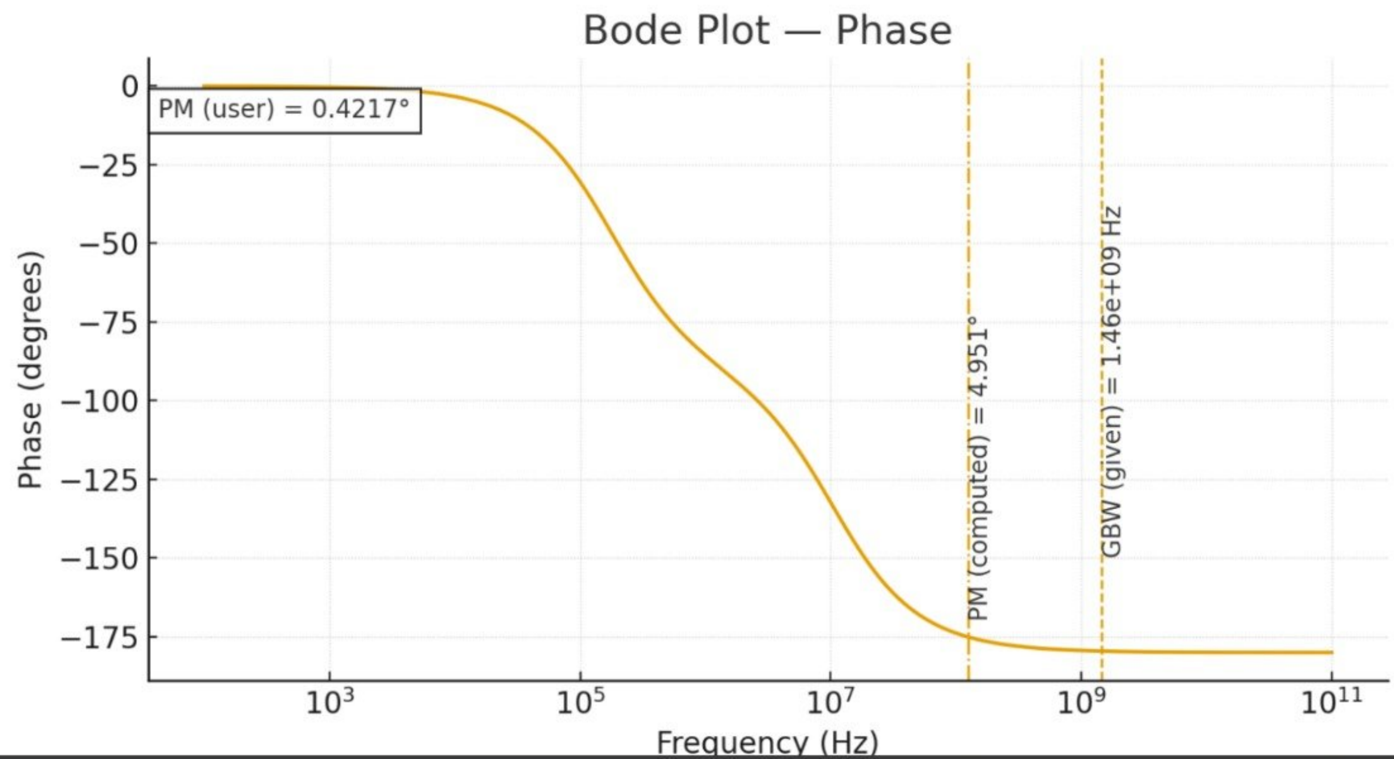
$1.154 - 0.959 =$

$1.18 - V_G - 0.4 = 0.2$

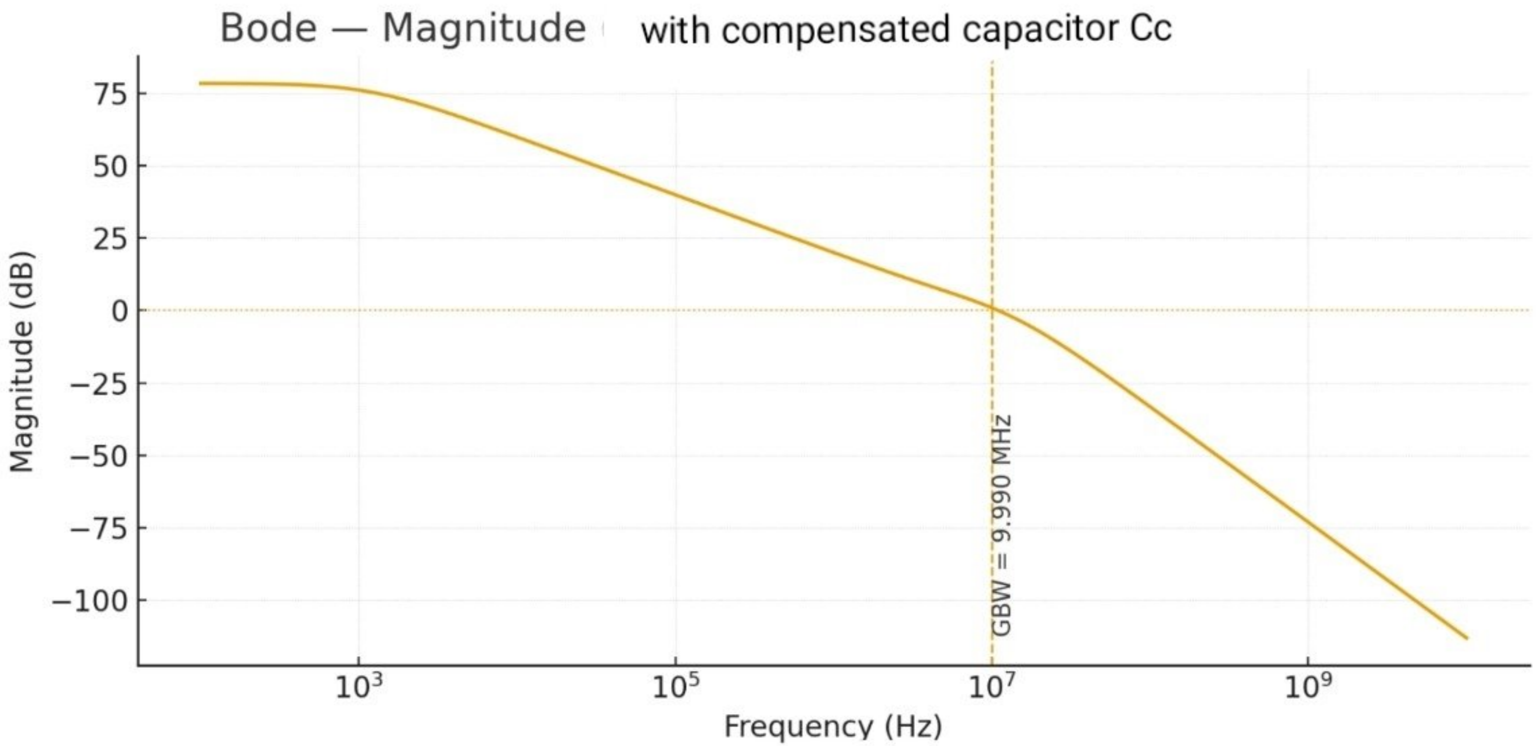
$V_G = 1.18 - 0.6$



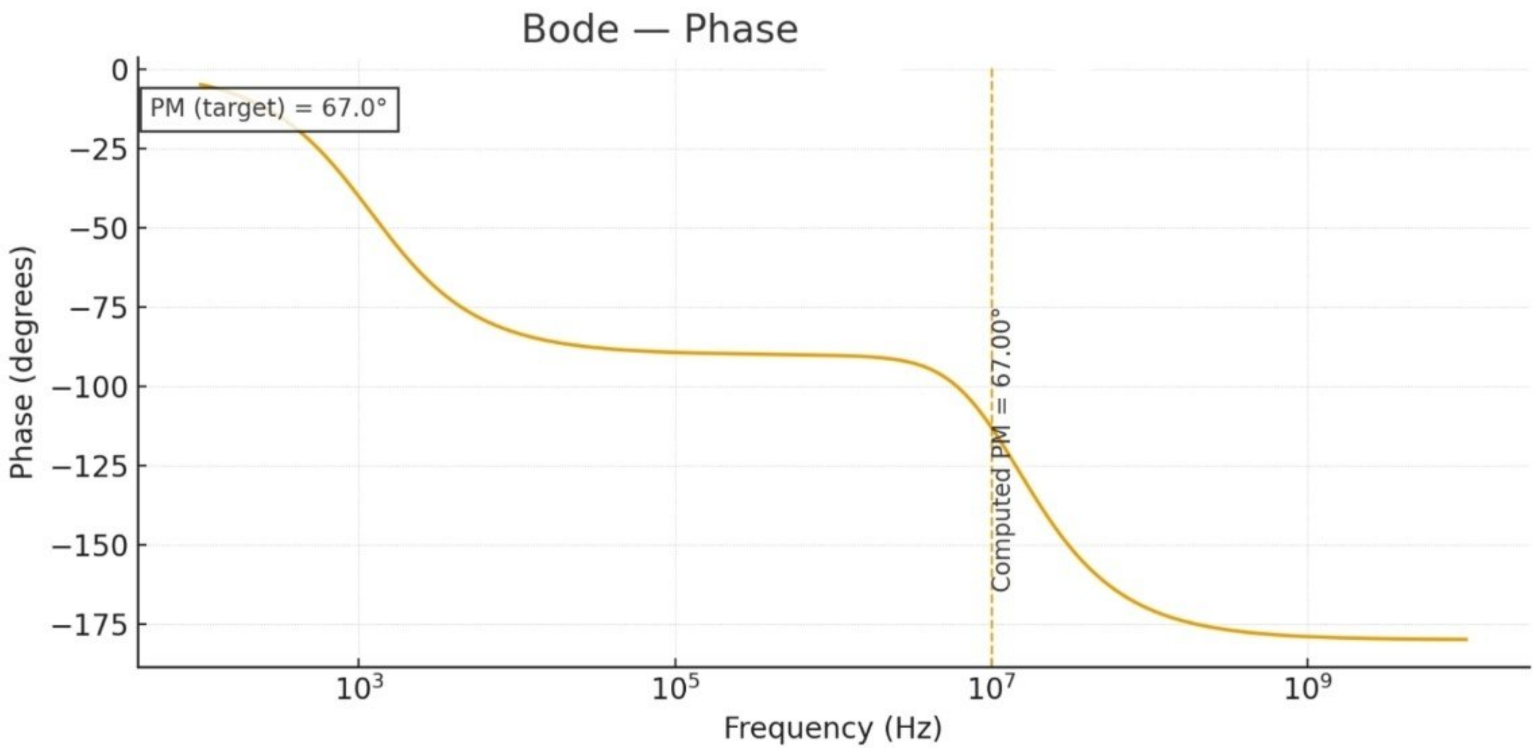
Bode Plot — Magnitude
75
50
25
0
−25
−50
−75
−100
−125
Magnitude (dB)
10^3
10^5
10^7
10^9
10^{11}
Frequency (Hz)
UGF (computed) = 1.24e+08 Hz
GBW (given) = 1.46e+09 Hz



Bode Plot — Phase
PM (user) = 0.4217°
0
−25
−50
−75
−100
−125
−150
−175
Phase (degrees)
10^3
10^5
10^7
10^9
10^{11}
Frequency (Hz)
PM (computed) = 4.951°
GBW (given) = 1.46e+09 Hz



Bode — Magnitude with compensated capacitor Cc
Magnitude (dB)
75
50
25
0
−25
−50
−75
−100
10^3
10^5
10^7
10^9
Frequency (Hz)
GBW = 9.990 MHz



Bode — Phase
Phase (degrees)
PM (target) = 67.0°
0
−25
−50
−75
−100
−125
−150
−175
10^3
10^5
10^7
10^9
Frequency (Hz)
Computed PM = 67.00°