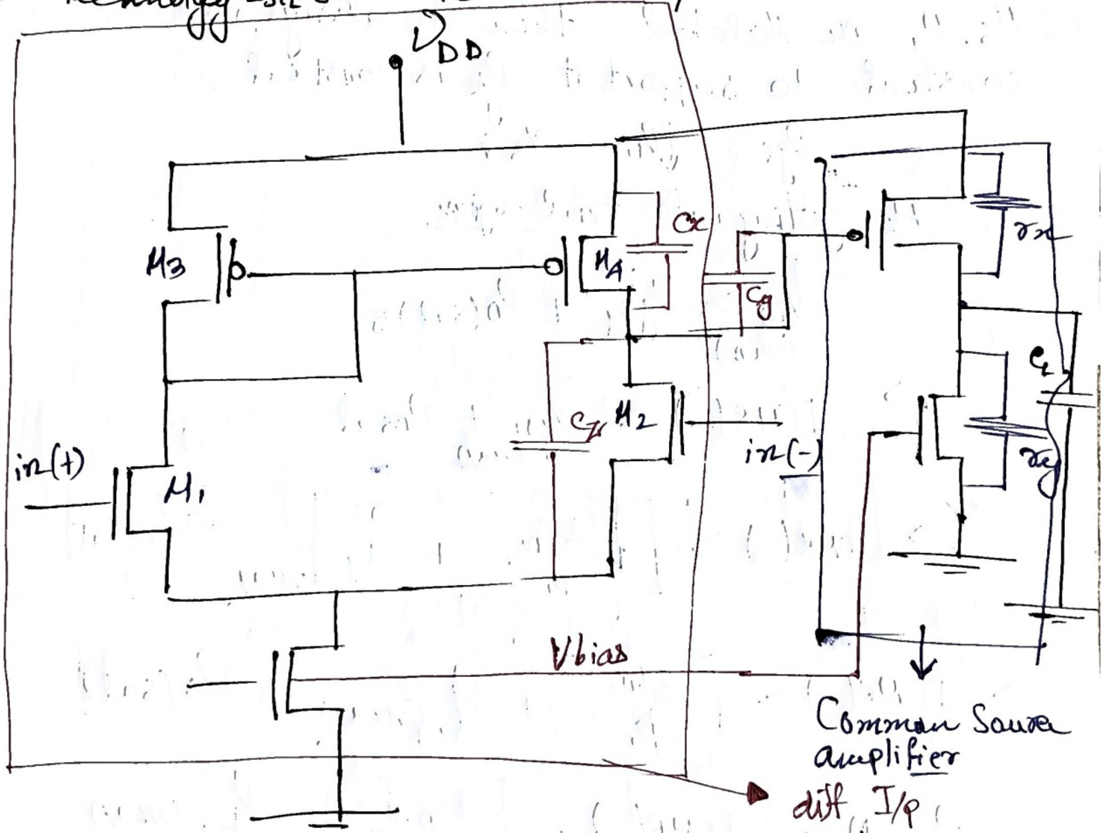
Design specifications:

1. DC gain = 60dB
2. Phase Margin = 60°
3. slew rate = 20V/μsec.
4. Power supply = 1.8V
5. Input common Mode ratio (+) = 1.6V
6. Input common Mode ratio (−) = 0.8V
7. Length = 180nm
8. Technology = SCL 180nm

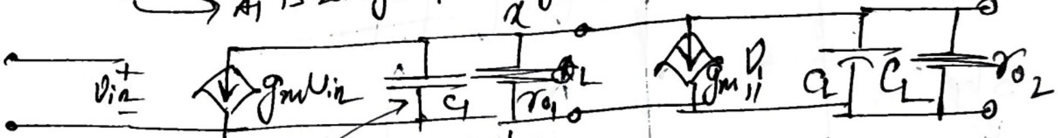
~~(9) GBW = 30MHz.~~
~~(10) power = 300μW.~~



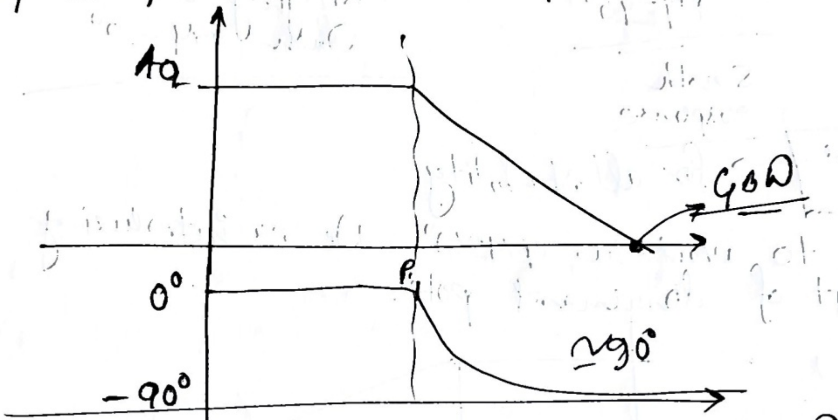
$$r_{o_2} = r_x \parallel r_y$$
$$C_1 = C_x \parallel C_y \parallel C_z$$

$C_L = C_2$

$\rightarrow$ A_1 is single pole system.



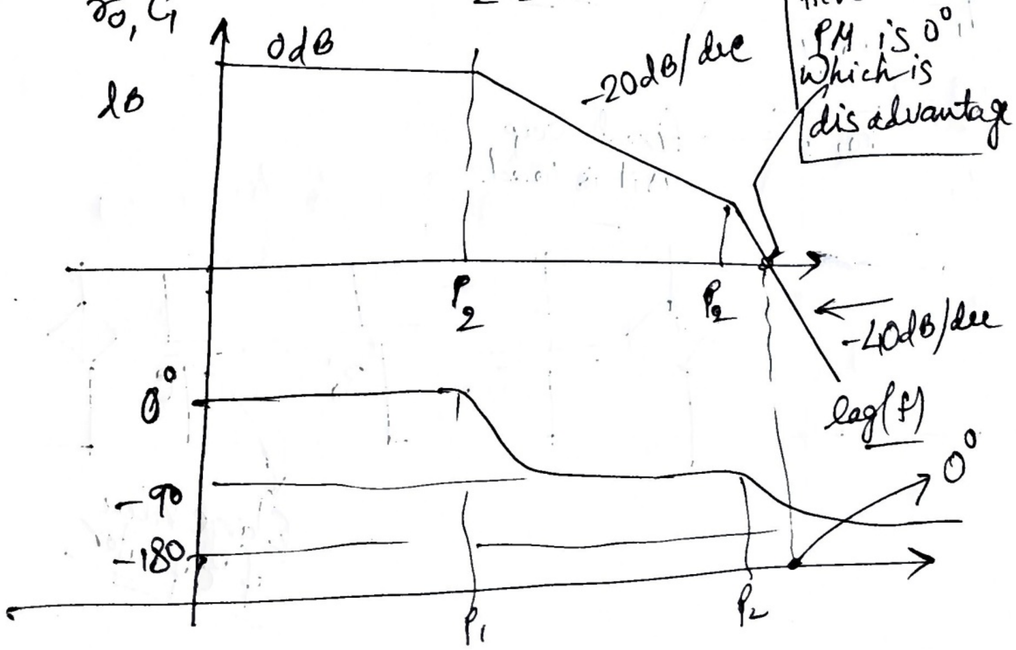
* This parasitic capacitor is gate cap. of M_y, drain source capacitor of M_x, drain source capacitor of M_Z.

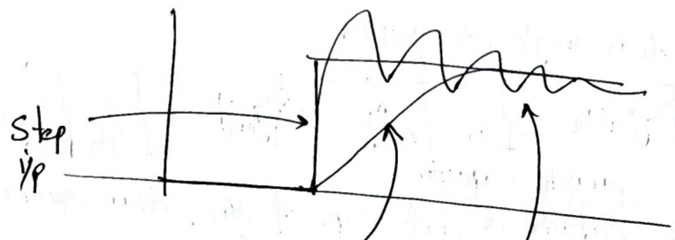


Near -90° PM is consider as a safe PM. at GBW Which is advantage

$r_{o2} \rightarrow \boxed{r_x \| r_y}$

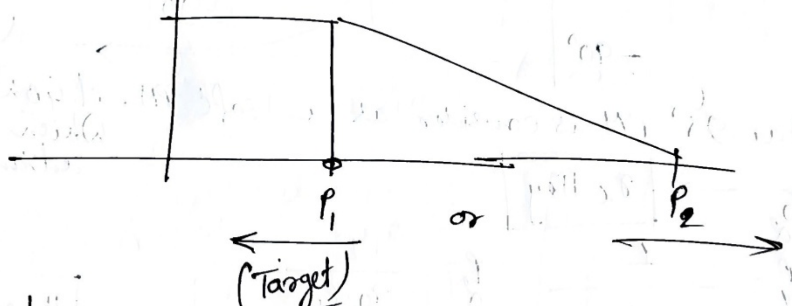
$P_1 = \dfrac{1}{r_{o1} C_1}$ $\qquad P_2 = \dfrac{1}{r_{o2} C_L}$





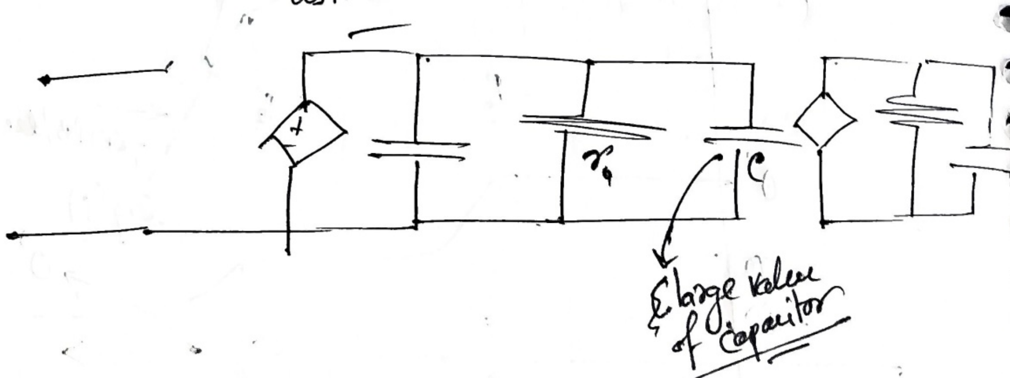
$\boxed{PM \geq 45^\circ}$ → for all stability

(*) Here to avoid the $PM \simeq 0^\circ$ We are introducing concept of dominant pole.

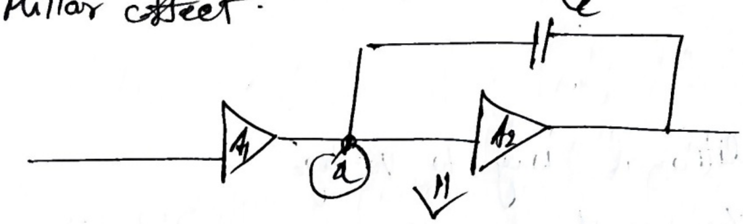


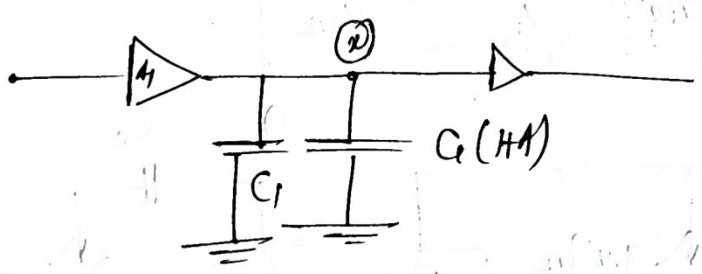
$$P_1 = \frac{1}{r_{o1} C_1}$$

$$P_2 = \frac{1}{r_{o2} C_2}$$ ← fixed cap as it is load.



To avoid that big capacitance we introduces Millar effect.

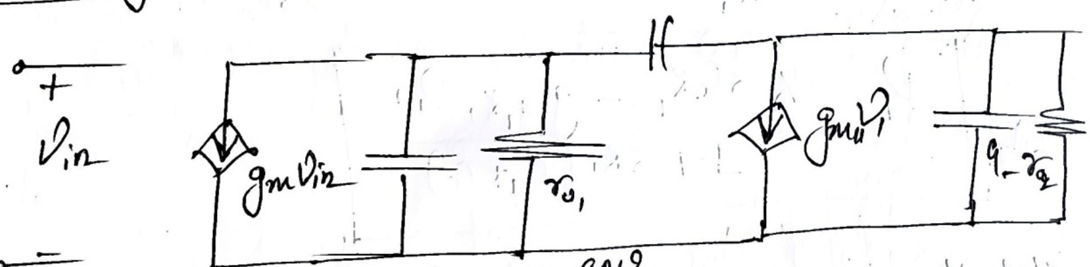




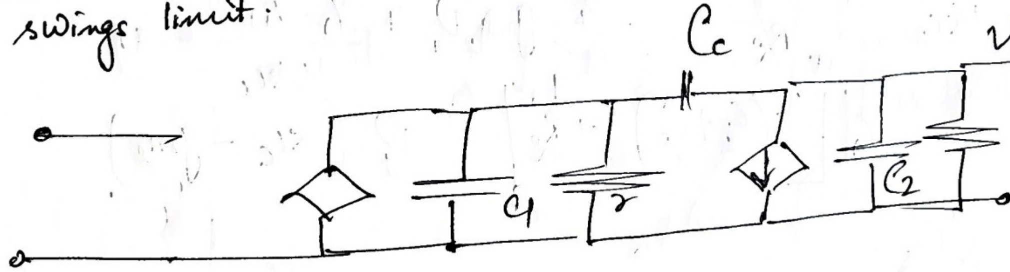
$$\therefore \quad \rho_1 = \frac{1}{r_{o_1}\left(C_1 + C_1(1+A)\right)}.$$

Small signal Model

$C_c \leftarrow$ Compensation capacitor



Terms
- Phase Margin — pole, zeros, GBW
- slew rate
- swings limit.



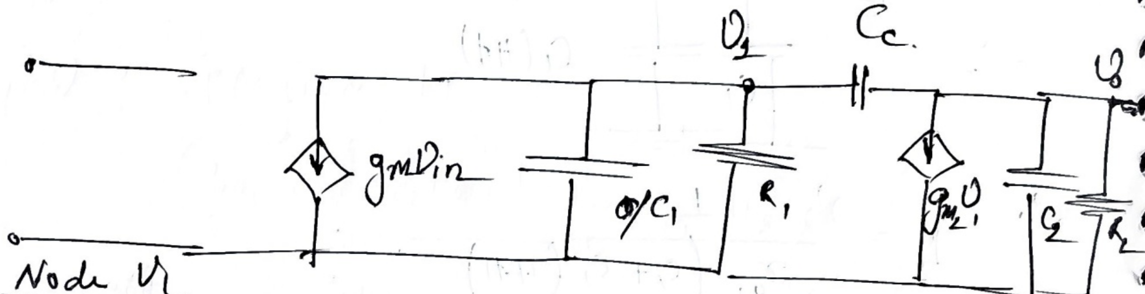
Miller Theorem has two disadvantage

① pole splitting

② zeros

So, To find traditional way to voltage

$$\boxed{\frac{V_1}{V_{in}} \times \frac{V_0}{V_1} = \frac{V_0}{V_{in}}}$$



Node V_1

$$\frac{V_1}{1/sC_1} + \frac{V_1}{R_1} + g_m V_{in} + \frac{V_1 - V_0}{1/sC_c} = 0$$

$$\boxed{V_1 = \frac{V_0\, sC_cR_1 - g_{m_1} R_1 V_{in}}{1 + sR_1(C_1 + C_c)}}$$

Node V_0

$$\frac{V_0}{1/sC_2} + \frac{V_0}{R_2} + g_{m_2} V_1 + \frac{V_0 - V_1}{1/sC_c} = 0$$

$$V_0\left[s(C_2 + C_c) + \frac{1}{R_2}\right] = V_1\left(sC_c - g_{m_2}\right)$$

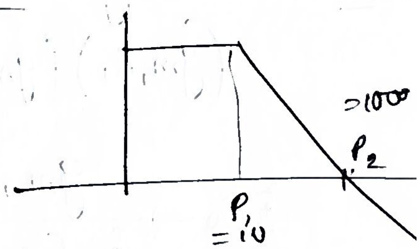
$$V_0 \left[s(C_2+C_c) + 1/R_2 \right] = \frac{(V_0 sC_c R_1 - g_{m1} R_1 V_{in})(sC_c - g_{m2})}{1 + s(C_1+C_c)R_1}$$

$$\frac{V_0}{V_{in}} = \frac{g_{m1} R_1 g_{m2} R_2 \left(1 - \frac{sC_c}{g_{m2}}\right)}{s^2\left[R_1R_2(C_1C_2 + C_1C_c + C_2C_c) + s\left(R_2(C_c+C_2) + R(C_c+C_1) + C_c g_{m2} R_1R_2\right]\right.}$$

As We Know for any std 2pole system $+1$ and one zero is

$$\frac{V_0}{V_{in}} = \frac{A_{0e}(1 - s/Z)}{(1+s/P_1)(1+s/P_2)}$$

$A_{0e} \rightarrow$ DC gain of OP AMP



$$= \frac{A_{0e}(1 - s/Z)}{1 + s\left(\frac{1}{P_1} + 1/P_2\right) + s^2(1/P_1P_2)}$$

↑ dominant pole

so, $s\left(\frac{1}{P_1} + 1/P_2\right) \simeq s(1/P_1)$

$\boxed{1/P_1 \rightarrow \text{Co-eff of } s}$

$$\therefore \boxed{P_1 = \frac{1}{R_2(C_c+C_2) + R_1(C_c+C_1) + \underbrace{C_c g_{m2} R_1 R_2}_{\text{large}}}}$$

$\text{Coeff } s^2 \Rightarrow \frac{1}{P_1} \; 1/P_1P_2$

$$\simeq \boxed{P_1 \simeq \frac{1}{C_c g_{m2} R_1 R_2}}$$

$$P_1P_2 = \frac{1}{R_1R_2(C_1C_2 + C_1C_c + C_2C_c)}$$

$$P_2 = \left[\frac{\cancel{R_2(C_c+C_2) + R_1(C_1+C_c)} + C_c g_{m2} \cancel{R_1R_2}}{\cancel{R_1R_2}(C_1C_2 + C_1C_c + C_2C_c)}\right]$$

$$= \frac{C_c g_{m2}}{\underbrace{C_1C_2}_{\text{small}} + \underbrace{C_1C_c}_{\text{small}} + C_2C_c} \simeq \frac{C_c g_{m2}}{C_c C_2} \simeq \boxed{g_{m2}/C_2 = P_2}$$

$C_1 \rightarrow$ parasitic cap

$C_c \rightarrow$ Comp. cap

$C_2 \rightarrow$ load cap

Zero location

$$1 - \frac{sC_c}{g_{m2}} = 0$$

$$\boxed{s = \frac{g_{m2}}{C_c}}$$

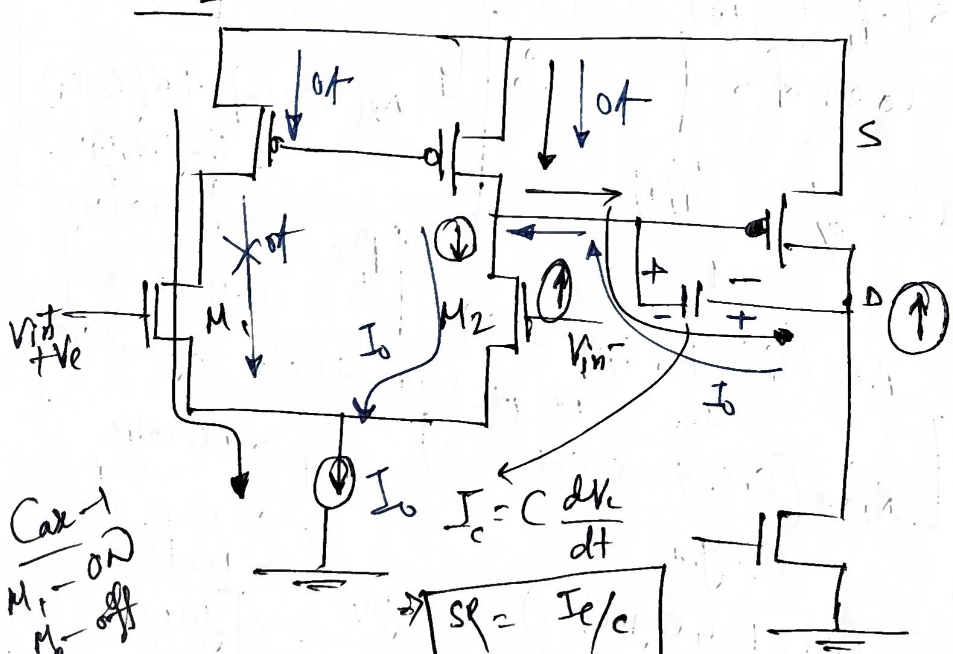
$$A_{dc} = (s=0) = g_{m1} g_{m2} R_1 R_2$$

GBW :- DC gain $\times P_1$

$$= (g_{m1} R_1)(g_{m2} R_2) \times \frac{1}{g_{m2} R_1 \, g R_2 C_c}$$

$$= \frac{g_{m1}}{C_c}$$

Slew rate :- How much quickly o/p can change w.r.t Vin



$$\boxed{SR = I_c / c}$$

Case - II $M_2 \rightarrow ON$

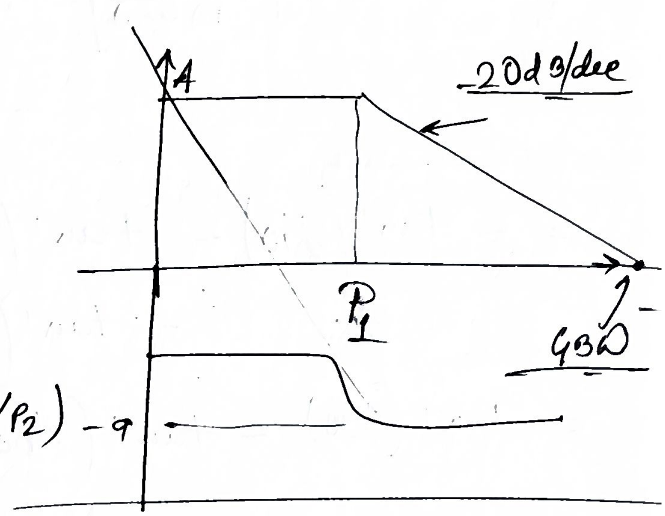
$M_1 \rightarrow off.$

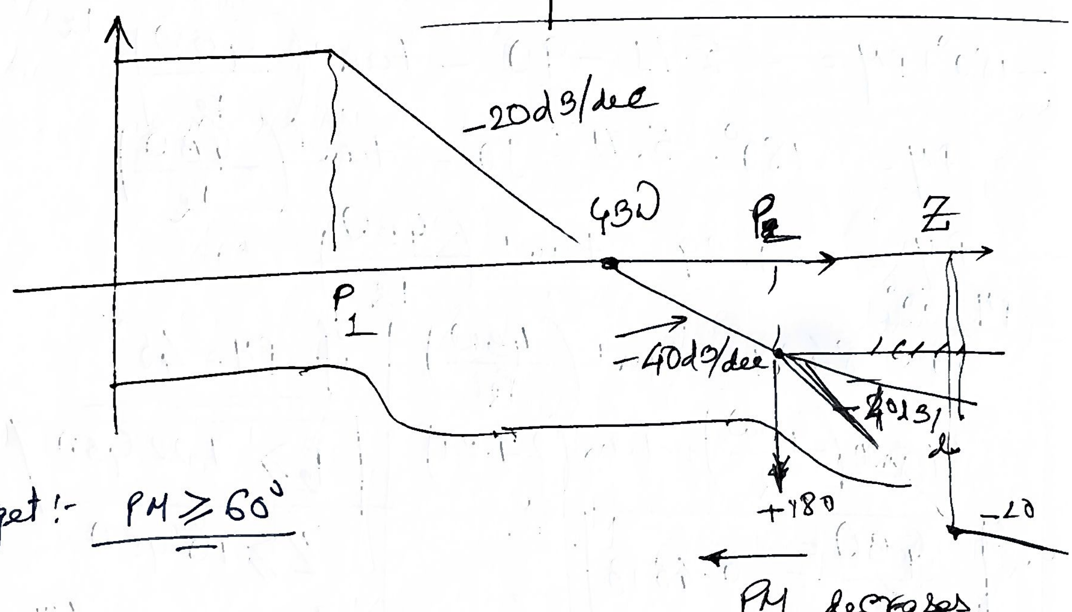
Phase Margin :-

$$\boxed{Z \geqslant 10\,GBW} \rightarrow (1)$$

$\rightarrow$ Assumption

$$\angle \frac{V_0}{V_{in}} = -\tan^{-1}\left(\omega/z\right) - \tan^{-1}\left(\omega/P_1\right) - \tan^{-1}\left(\omega/P_2\right)$$





Target :- $PM \geq 60^\circ$

$$\frac{\angle V_0}{\angle V_{in}} = -\tan^{-1}\left(\frac{\omega}{\cancel{Z}}\right) - \tan^{-1}\left(\frac{\omega}{P_1}\right) - \tan^{-1}\left(\frac{\omega}{P_2}\right)$$

$$\boxed{PM = +180^\circ + \angle G\,(j\omega_{gc})}$$

$$\boxed{Z \geqslant 10\,GBW}$$

$$\angle G(j\omega_{gc}) = -180^\circ + PM$$

$$\Rightarrow \angle \frac{V_0}{V_{in}} = -\tan^{-1}\left(\frac{\omega}{Z}\right) - \tan^{-1}\left(\frac{\omega}{P_1}\right) - \tan^{-1}\left(\frac{\omega}{P_2}\right)$$

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

$$\angle\frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{GBW}{10\,GBW}\right) - \tan^{-1}\left(\frac{g_{m1}R_1 g_{m2}R_2 \cancel{C_c}}{\cancel{C_c}}\right) - \tan^{-1}\left(\frac{g_m C_L}{C_c\, g_{m2}}\right)$$

$$= -\tan^{-1}(1/10) - \tan^{-1}(g_{m1}g_{m2}R_1R_2) - \tan^{-1}\left(\frac{g_m C_L}{C_L\, g_{m2}}\right)$$

$$= -\tan^{-1}(1/10) - \tan^{-1}(A_{DC}) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$-180^\circ + PM = -5.71 - 90 - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$PM = 180^\circ - 5.71 - 90^\circ - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$PM = 84.29 - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

if $PM = 60^\circ$

$$60 = 84.29 - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$\left(\frac{GBW}{P_2}\right) = \tan(24.29)$$

$$\boxed{\frac{GBW}{P_2} = 0.4513}$$

$$P_2 = \frac{GBW}{0.4513}$$

$$\boxed{P_2 = 2.2\,GBW}$$

$$\frac{g_{m2}}{C_2} \geq (2.2)\frac{g_{m1}}{C_c}$$

$$\frac{10\,\cancel{g_{m1}}}{C_2} \geq (2.2)\frac{\cancel{g_{m1}}}{C_c}$$

if $PM = 45^\circ$

$$\boxed{P_2 \geq 1.22\,GBW}$$

$$Z \geq 10\,GBW$$

$$\frac{g_{m2}}{\cancel{C_c}} \geq 10\frac{g_{m1}}{\cancel{C_L}}$$

$$\boxed{g_{m2} \geq 10\,g_{m1}}$$

$$\boxed{\frac{10}{C_2} \geq 2.2\,C_L}$$

[illegible] $\geq$ 0.

$\therefore \boxed{C_c \geq 0.22 C_L}$

Design procedure

~~Deg~~

DC gain = 1000 = 60 dB

GBW = 30 MHz

PM ≥ 60°

slew rate = 20 V/μsec

Input common Mode ratio (+) (ICMR) = 1.6 V

ICMR(−) = 0.8 V

C_L = 2 pF

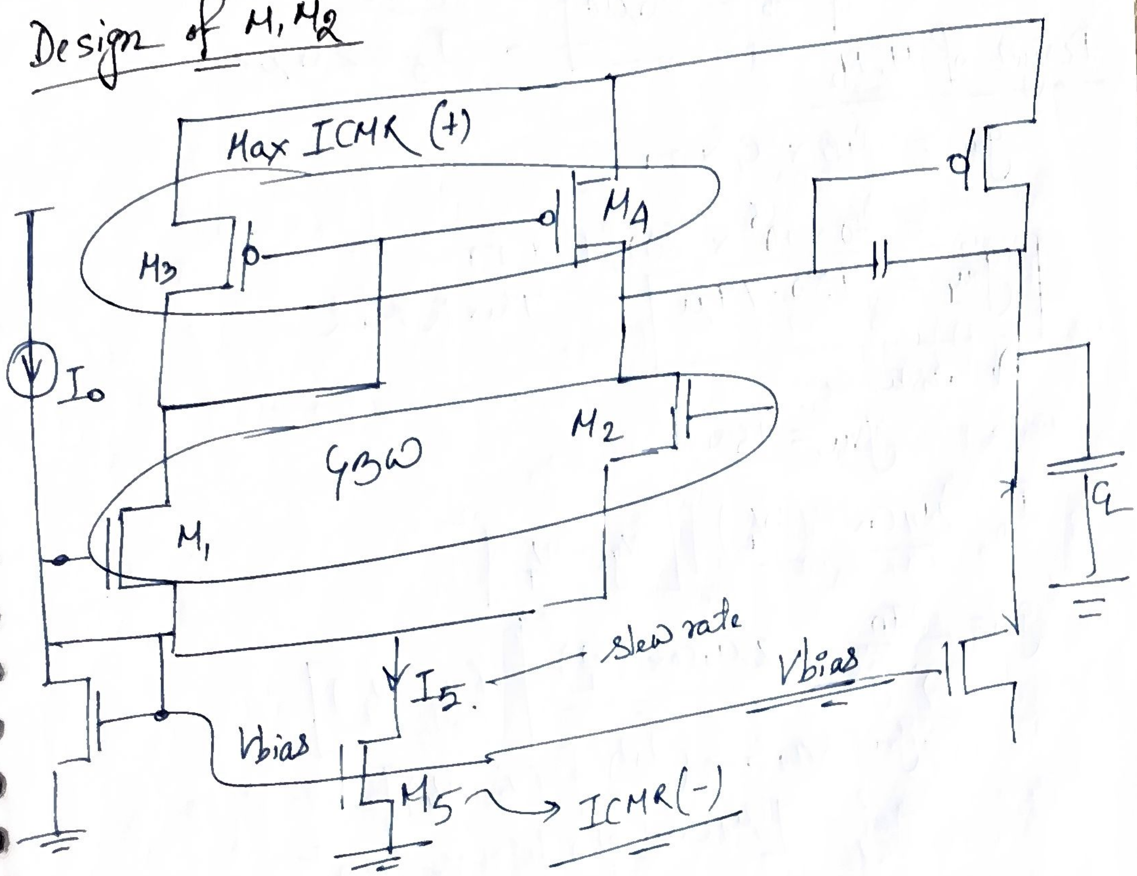
Power ≤ 300 μW.

V_{DD} = 1.8 V
process Tech = 180 nm

L_min = 180 nm

L = 500 nm
channel length

Design of M_1, M_2



① $L = 500nm$ Assume $\underline{C_L = 2pF}$

② $C_c \geq 0.22\, C_L$

$C_c \geq 0.22 \times 2pF$

$C_c \geq 0.44pF$

$\boxed{C_c \geq 440fF}$

$\boxed{C_c = 800fF}$

③ $SR = 20V/\mu sec. = \frac{I_5}{C_c}$

$I_5 = \frac{20V}{\mu sec} \times 800fF$

$\boxed{I_5 = 16\mu A}$ Min

$I_5 = 20\mu A$

Design of M_1, M_2

$g_{m_1} = GB \times C_c \times 2\pi$

$= 30 \times 10^6 \times 800fF \times 2\pi$

$\boxed{g_{m_1} = 150.79\mu}$ This is Min

We assume,

$\underline{g_{m_1} = 160}$

$I_D = \frac{\mu_n C_{ox}}{2} (W/L) [V_{gs} - V_T]^2$

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

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

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

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

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

for M_1, M_2

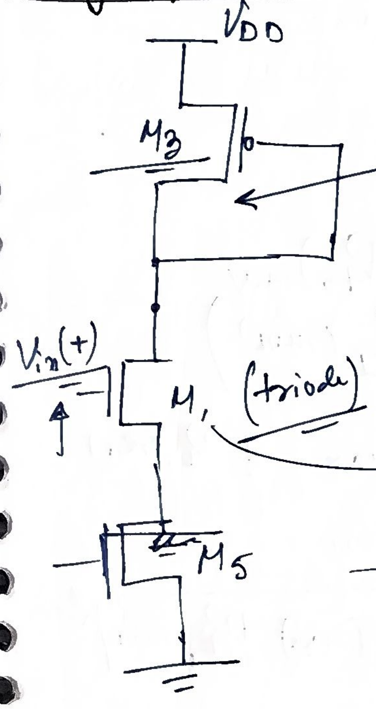
$2I_D = I_5$.

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

$$= \frac{160^2}{300 \times 20} \simeq 4.266$$

use $\boxed{\left(W/L\right)_{1,2} = 5}$

Design of M_3, M_4



diode connected MOSFET

$M_3 \rightarrow$ ON always

as it is in saturation

for saturation

$V_{DS} \geq V_{gs} - V_{TH}$

$V_{DS} \leq \uparrow V_{gs} - V_{TH}$

M_1 enters to linear region as it is $V_{gs}\uparrow$

for M_1 to be in saturation

$$V_g < V_D + V_{Th}$$

$$V_{in} \leq V_{D_1} + V_{Th}$$

$$\boxed{(V_{in})_{max} \leq V_{D_1} + V_{Th}} \quad (1)$$

$V_{D_1} = V_{DD} - V_{sg3}$

$$I_{D_3} = \frac{\mu_p C_{ox} (W/L)}{2} (V_{gs} - V_{Th})^2$$

$$= \frac{\beta}{2} (V_{gs} - |V_T|)^2$$

$$V_{gs} = \sqrt{\frac{2 I_3}{\beta_3}} + |V_{t3}|.$$

$$V_{D_1} = V_{DD} - \left[\sqrt{\frac{2I_3}{\beta}} + |V_{t3}| \right]$$

$$\boxed{V_{in(max)} \leq V_{D_1} + V_{t_1}}$$

$$\Rightarrow ICMR(+) \leq V_{D_1(min)} + V_{t_1(min)}$$

$$V_{in(max)} \leq V_{D_1(min)} + (V_{t_1})_{min}$$

$$ICMR(+) \leq V_{DD} - \sqrt{\frac{2I_{D_3}}{\beta_3}} - |V_{t3}|\Big|_{max} + V_{t_1 min}$$

$$\boxed{\begin{array}{l} \mu_p C_{ox} = 60\mu \\ \mu_n C_{ox} = 300\mu \end{array}}$$ By simulation

$$\frac{2I_3}{\beta_3} = \left(V_{DD} - ICMR(max) - (V_{t3})_{max} + V_{t_1(min)} \right)^2$$

$$\frac{2I_D}{\mu_p C_{ox} \left(\frac{W}{L}\right)_{3,4}} = V_{DD} - ICMR - (V_{t3})_{max} + V_{t_1(min)}$$

$$\left(W/L\right)_{3,4} = \frac{2I_{D3}}{\mu_p C_{ox} \left[V_{DD} - ICMR + V_{t_3(max)} + V_{t_1 min} \right]^2}$$

$V_{t_1} \longrightarrow$ Threshold voltage of M_1

for Simulation,

$V_{DD} = 1.8V$

$I_{D_3} = \frac{I_{05}}{2} = 10\mu$

$\mu_p C_{ox} = 60\mu$

$ICMR(+) = 1.6V$

$V_{t_3}(+) = 0.57\mu V$

$V_{t_1} = 0.47\mu V.$

$$\therefore (W/L)_{3,4} = \frac{2 \times 10 \times 10^{-6}}{60 \times 10^{-6} \left[1.8 - 1.6 - 0.57 + 0.47 \right]^2}$$

$$(W/L)_{3,4} = 13.02$$

Assume $\boxed{(W/L)_{3,4} = 14}$

$V_D(sat) \geq 0.8 - 0.115 \times 4 - 0.59$

$\geq 94.6mV.$

for Safety Margin $V_D(sat)$ Assume $= (105mV)$

$$\left(\frac{W}{L}\right)_5 = \frac{2 \times 20 \times 10^{-6}}{301 \times 10^{-6} \times (105\,mV)^2}$$

$= 12.09$

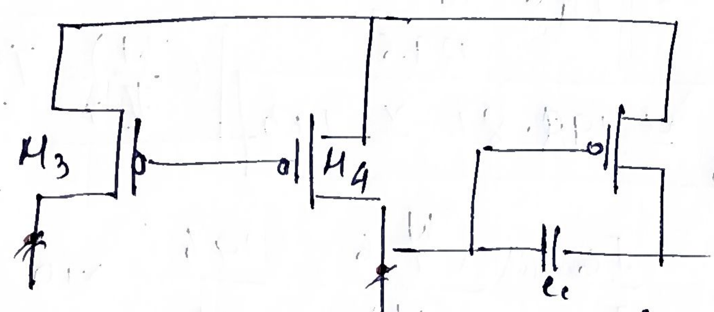
$$\boxed{\left(\frac{W}{L}\right)_5 \simeq 12}$$

Design of M_6

for $60°$ PM $\boxed{g_{m6} \geq 10 g_{m1}}$

$g_{m6} \geq 10 \times (160\mu)$

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



$M_3 \to M_4 \to$ Current Mirror, it means, $(V_{g3} = V_{g4})$; $(V_{D3} = V_{D4})$

$(V_{S3} = V_{S4})$; $\therefore V_{gs3} = V_{gs4}$ and $V_{SD3} = V_{SD4}$

$\therefore$ Now, $V_{g6} = V_{D4} = V_{D3} = V_{g3}$

$\therefore V_{SD6} = V_{SD4}$

also, $V_{gs3} = V_{gs4} = V_{gs6}$

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

$$\therefore \left(\frac{W}{L}\right) \propto I_D$$

$$\left(\frac{W}{L}\right)_4 = 13 \text{ or } 14$$

$$\frac{(W/L)_6}{(W/L)_4} = \frac{I_{D6}}{I_{D4}} = \frac{g_{m6}}{g_{m4}}$$

$$g_{m4} = \sqrt{\mu_p C_{ox} \left(\frac{W}{L}\right) 2 I_D}$$

$$= \sqrt{60 \times 14 \times 2 \times 10}$$

$$= 129.61$$

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

$$= 14 \times \frac{1600}{129.61}$$

$$\boxed{\left(\frac{W}{L}\right)_6 \simeq 192.82 \simeq 193} \quad \boxed{\left(\frac{W}{L}\right)_7 = 75}$$

Design M_7

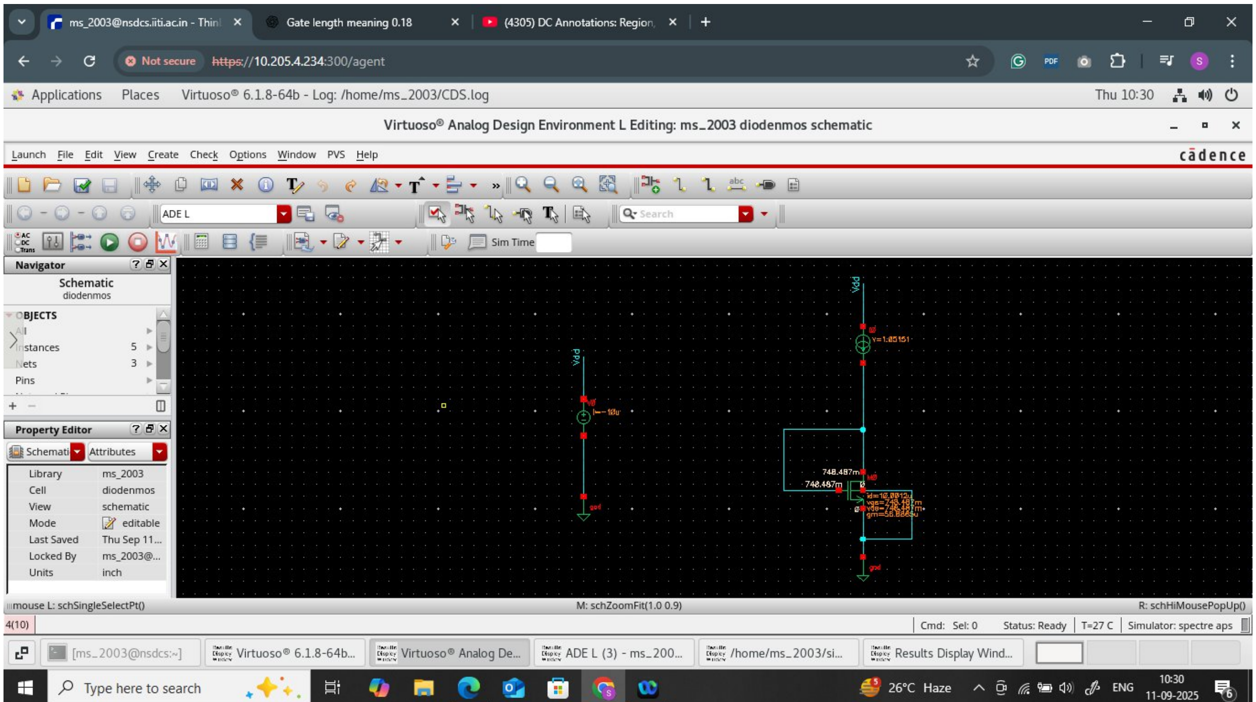
$$\frac{I_6}{I_4} = \frac{(W/L)_6}{(W/L)_4} = \frac{194}{14} \times 10$$

$$\Rightarrow \boxed{I_6 = 124.28} \simeq 125$$

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

$$\cancel{\Rightarrow I_7 = \frac{(W/L)_7}{(W/L)_5} \times I_5} = \frac{125}{20} \times 12 = \frac{125}{20} \times 12$$

$$= 75$$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Launch File Edit View Create Check Options Window PVS Help
Navigator
Schematic
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Property Editor
Library ms_2003
Cell diodenmos
View schematic
Mode editable
Units inch
mouse L: schSingleSelectPt()
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R: schHiMousePopUp()
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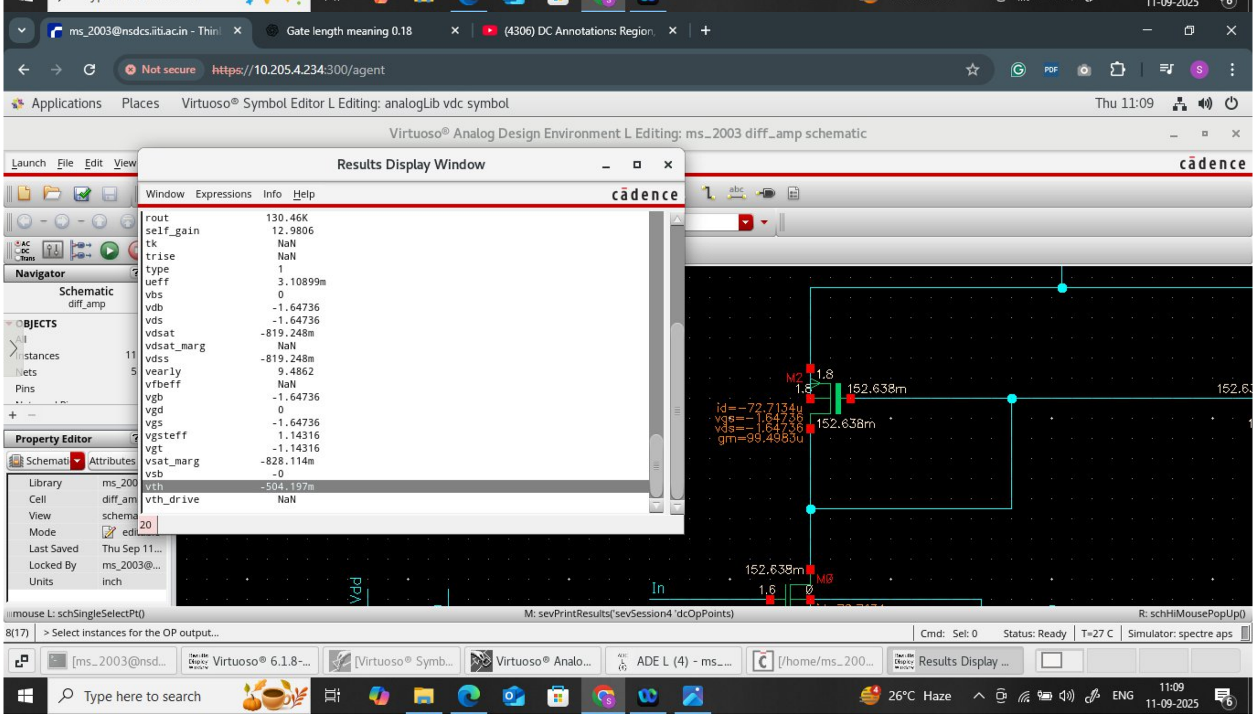
748.487m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Results Display Window
Window Expressions Info Help
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self_gain 12.9806
tk NaN
trise NaN
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ueff 3.10899m
vbs 0
vdb -1.64736
vds -1.64736
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vdsat_marg NaN
vdss -819.248m
vearly 9.4862
vfbeff NaN
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vsb -0
vth -504.197m
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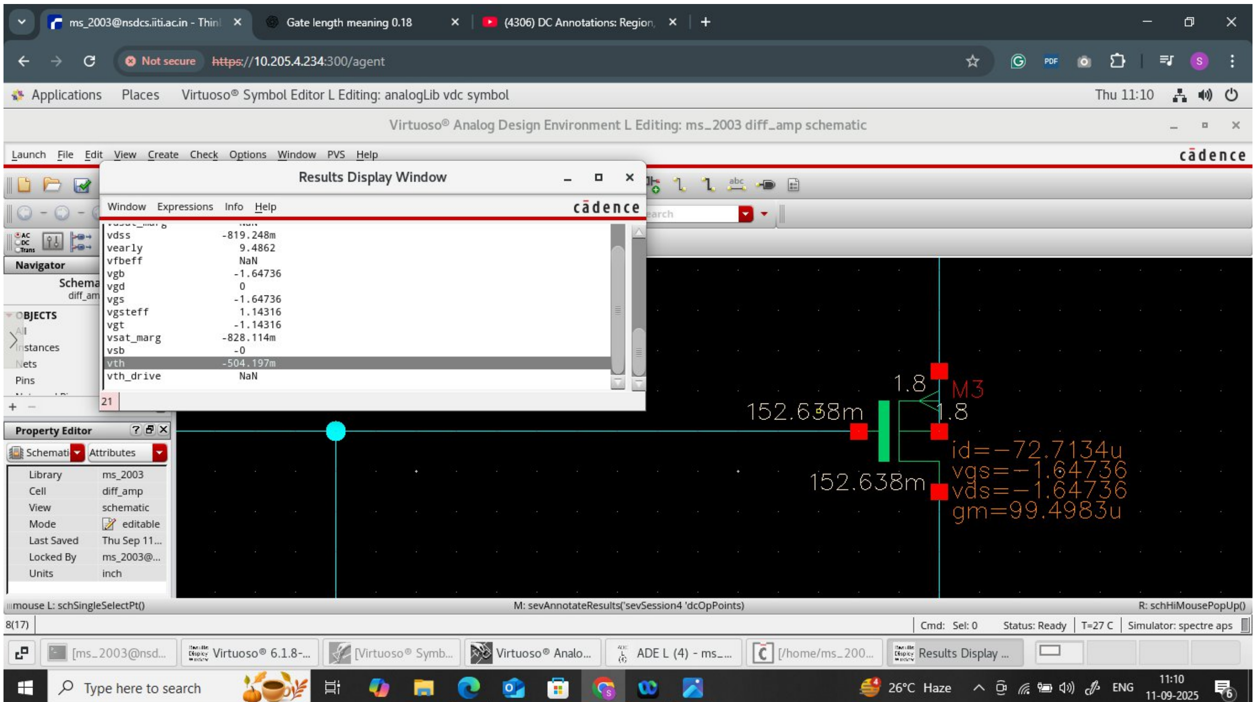
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M3
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1.8
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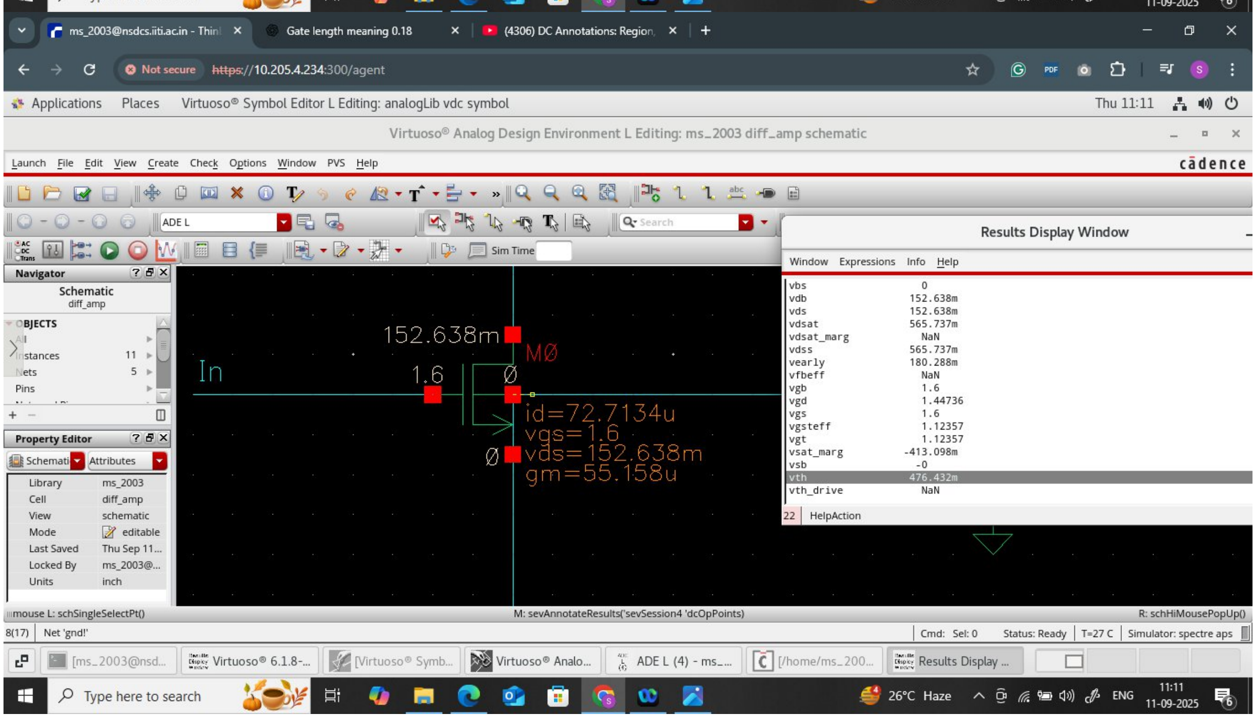
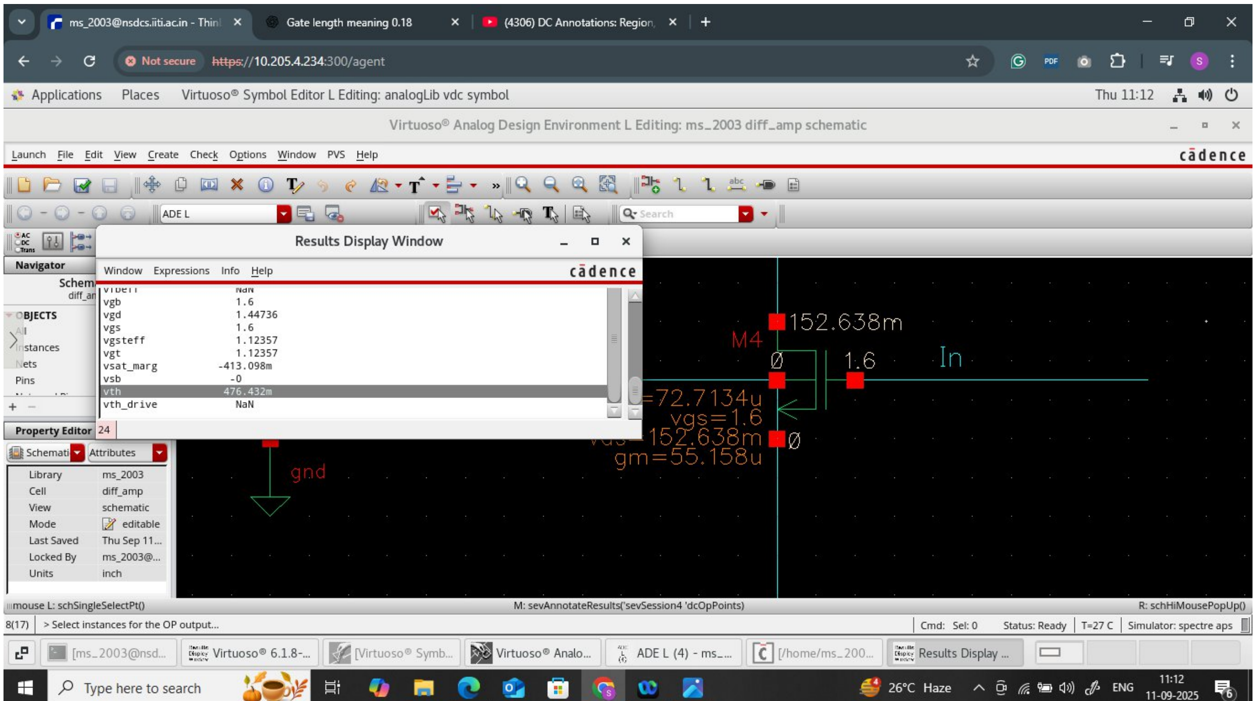
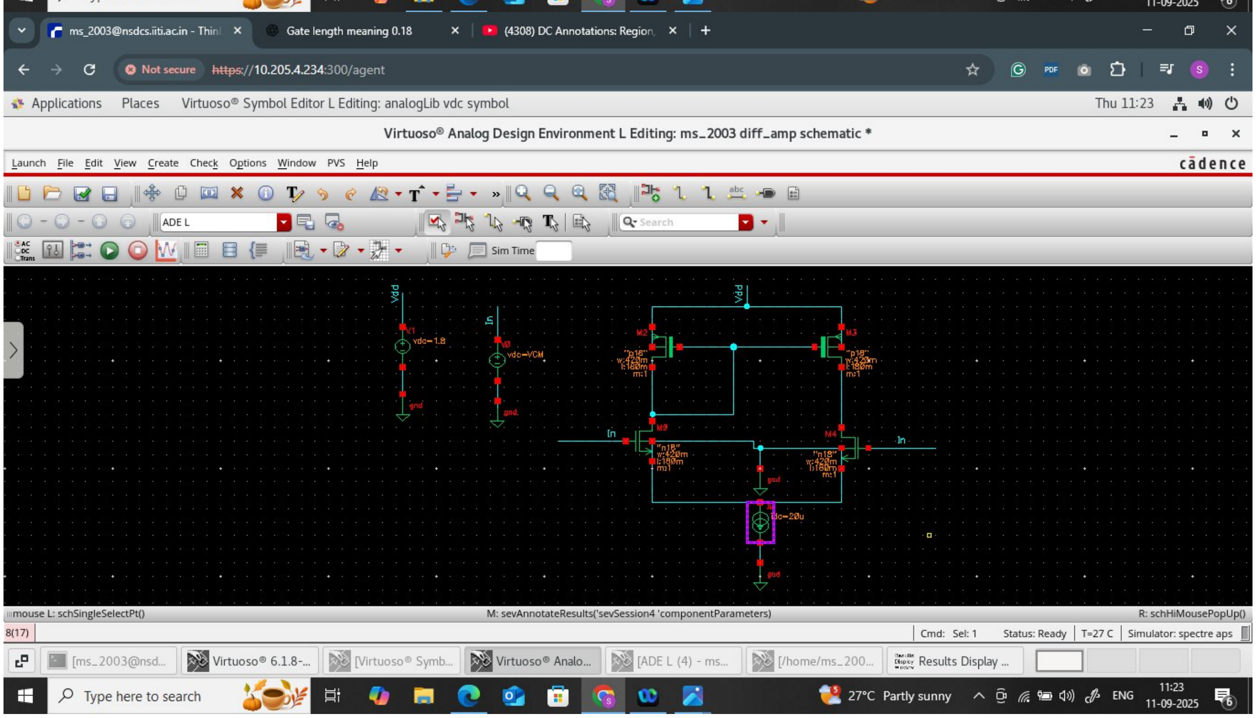
vgs=-1.64736
vds=-1.64736
gm=99.4983u
152.638m


Virtuoso® Analog Design Environment L Editing: ms_2003 diff_amp schematic
Results Display Window
vbs 0
vdb 152.638m
vds 152.638m
vdsat 565.737m
vdsat_marg NaN
vdss 565.737m
vearly 180.288m
vfbeff NaN
vgb 1.6
vgd 1.44736
vgs 1.6
vgsteff 1.12357
vgt 1.12357
vsat_marg -413.098m
vsb -0
vth 476.432m
vth_drive NaN
152.638m
M0
In
1.6
0
id=72.7134u
vgs=1.6
vds=152.638m
gm=55.158u


Virtuoso® Analog Design Environment L Editing: ms_2003 diff_amp schematic
Launch File Edit View Create Check Options Window PVS Help
cādence
Results Display Window
Window Expressions Info Help
vgb 1.6
vgd 1.44736
vgs 1.6
vgsteff 1.12357
vgt 1.12357
vsat_marg -413.098m
vsb -0
vth 476.432m
vth_drive NaN
Library ms_2003
Cell diff_amp
View schematic
Mode editable
Units inch
M4
152.638m
1.6
In
vgs=1.6
gm=55.158u
gnd
mouse L: schSingleSelectPt()
M: sevAnnotateResults('sevSession4 'dcOpPoints)
R: schHiMousePopUp()
> Select instances for the OP output...
Cmd: Sel: 0 Status: Ready T=27 C Simulator: spectre aps
26°C Haze
11:12
11-09-2025


Virtuoso® Analog Design Environment L Editing: ms_2003 diff_amp schematic *
Launch File Edit View Create Check Options Window PVS Help
cādence
Sim Time
mouse L: schSingleSelectPt()
M: sevAnnotateResults('sevSession4 'componentParameters)
R: schHiMousePopUp()
Cmd: Sel: 1 Status: Ready T=27 C Simulator: spectre aps
27°C Partly sunny
11:23
11-09-2025