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

Input Stage	NMOS
Load	Capacitance = 2 pF

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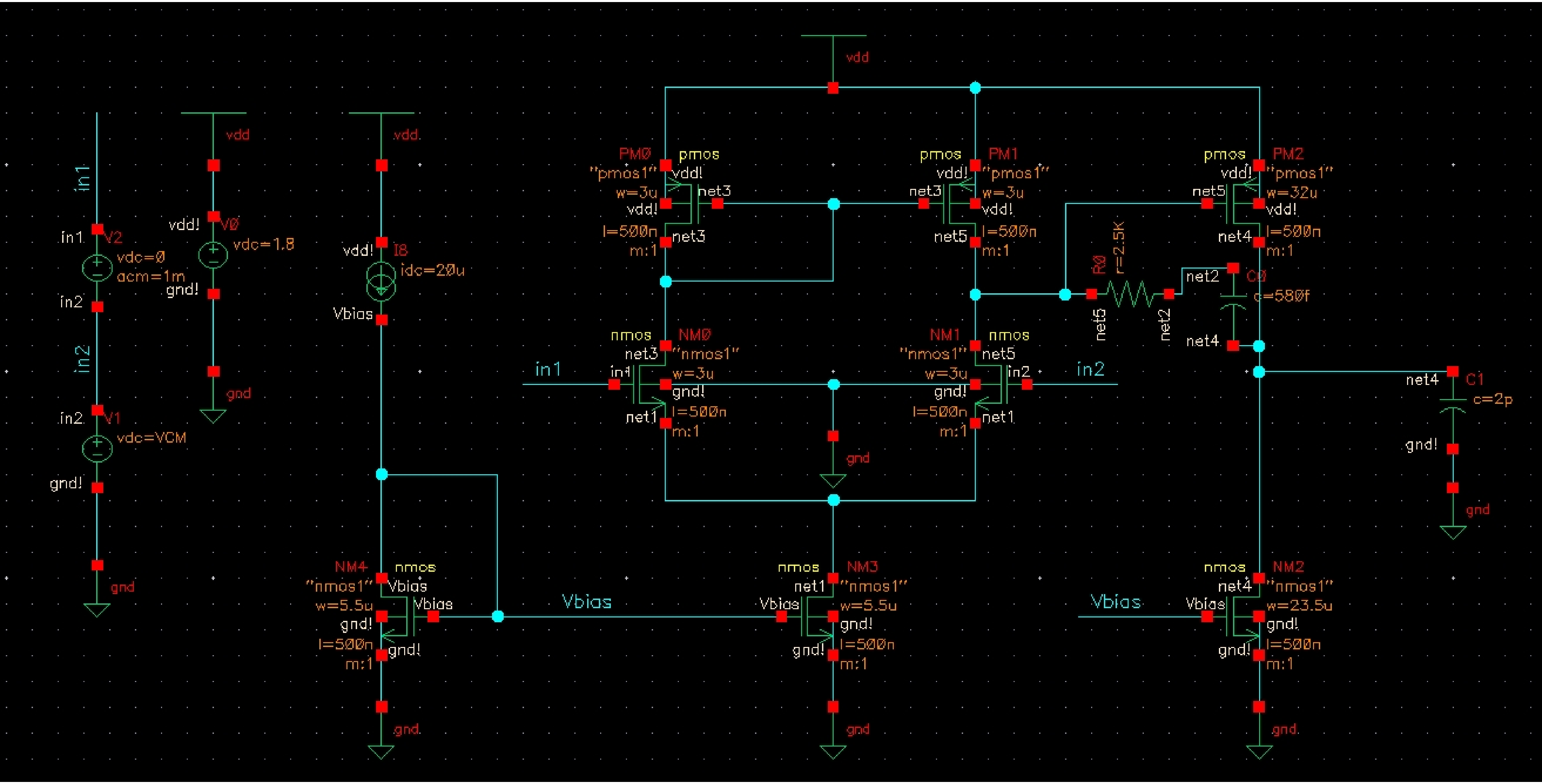
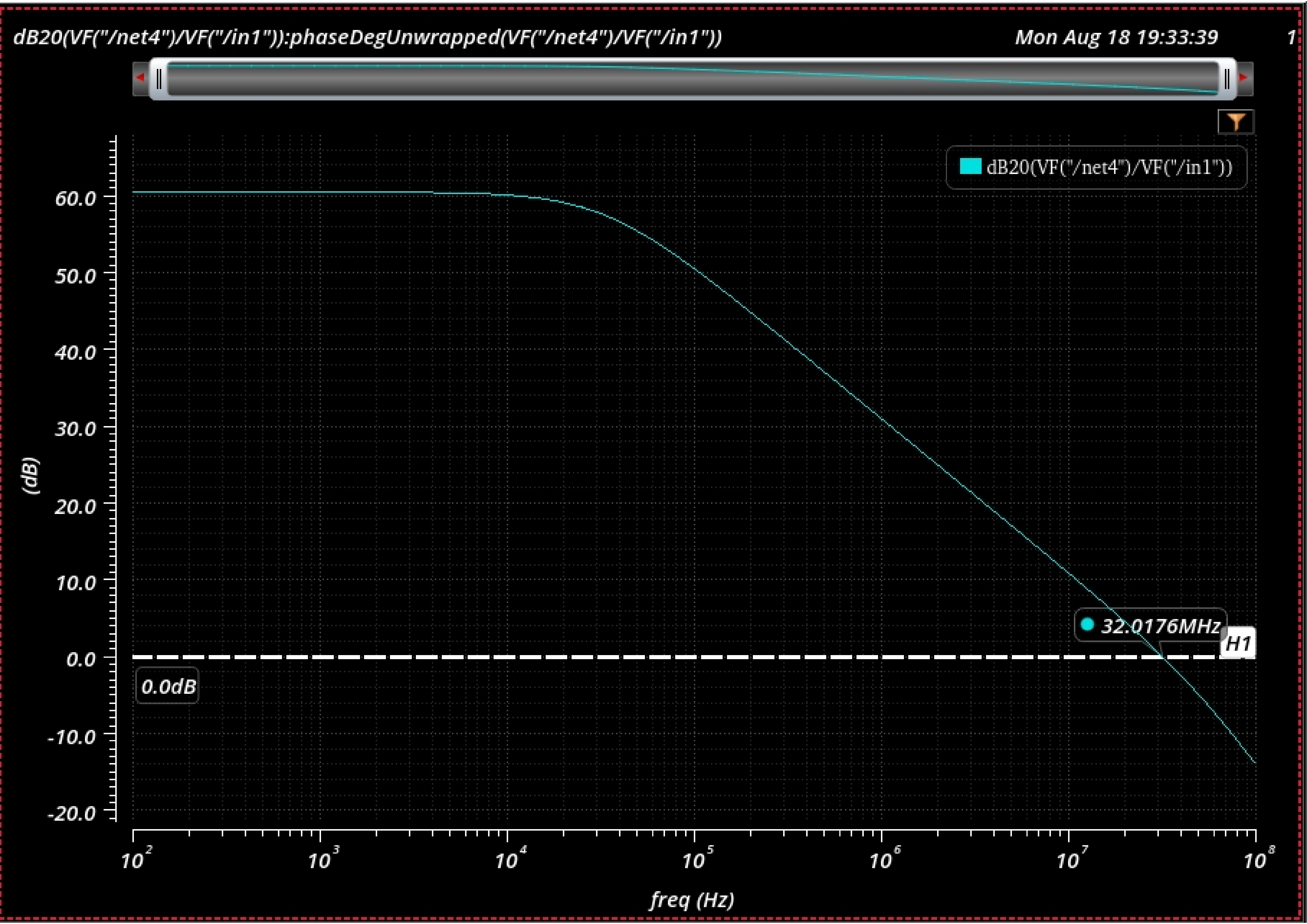
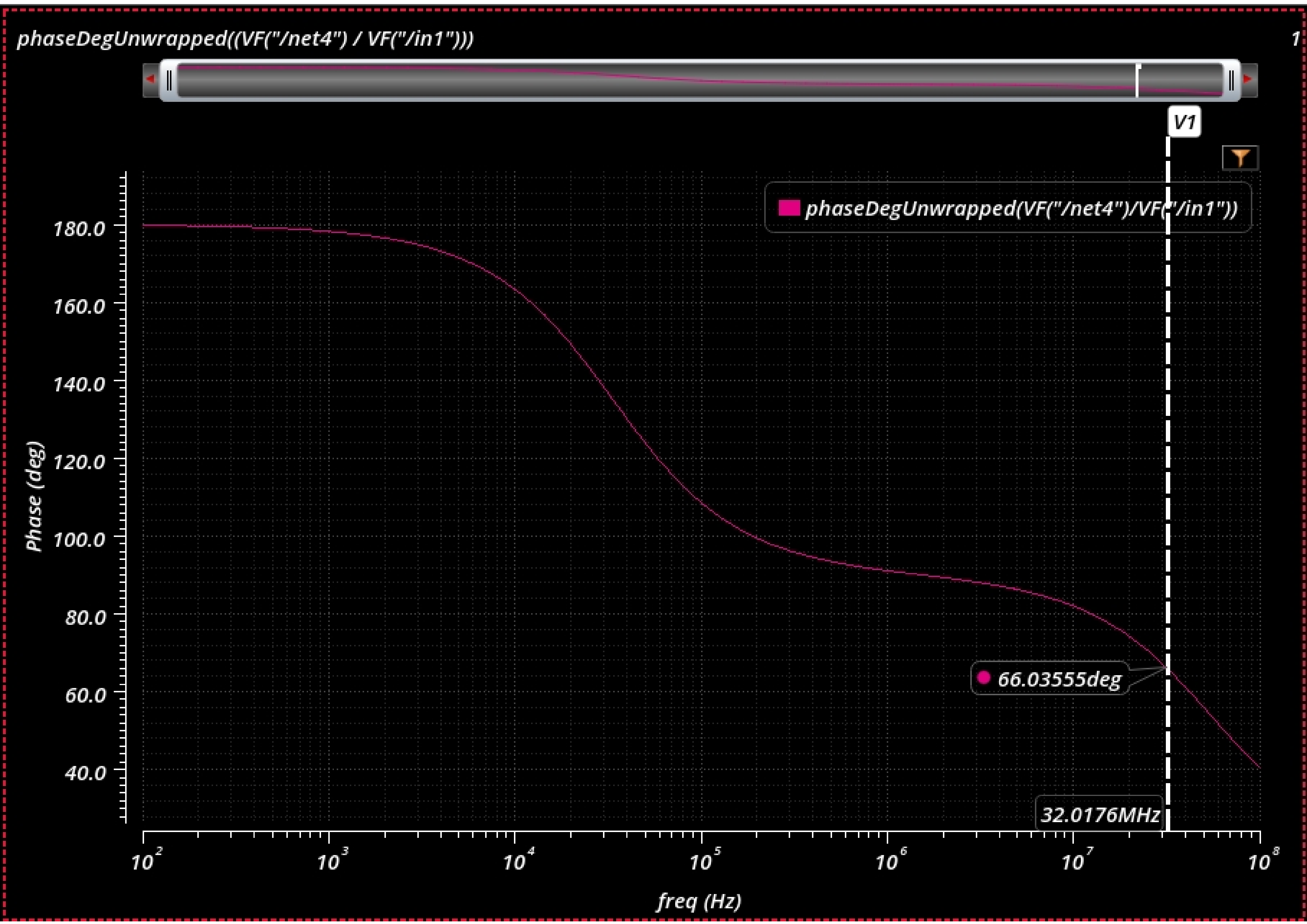
MVLSI IIT KANPUR



vdd
in1
V2
vdc=0
acm=1m
in2
V1
vdc=VCM
gnd!
gnd
vdd!
V0
vdc=1.8
I8
idc=20u
Vbias
PM0
pmos
"pmos1"
w=3u
l=500n
m:1
net3
PM1
w=3u
net5
PM2
w=32u
net4
R0
r=2.5K
net2
C0
c=580f
NM0
nmos
"nmos1"
net1
NM1
in2
in1
C1
c=2p
NM4
w=5.5u
NM3
NM2
w=23.5u


dB20(VF("/net4")/VF("/in1")):phaseDegUnwrapped(VF("/net4")/VF("/in1"))
Mon Aug 18 19:33:39
dB20(VF("/net4")/VF("/in1"))
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
(dB)
32.0176MHz
H1
0.0dB
10^2
10^3
10^4
10^5
10^6
10^7
10^8
freq (Hz)



phaseDegUnwrapped((VF("/net4") / VF("/in1")))
V1
phaseDegUnwrapped(VF("/net4")/VF("/in1"))
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
Phase (deg)
66.03555deg
32.0176MHz
10^2
10^3
10^4
10^5
10^6
10^7
10^8
freq (Hz)

Outputs

	Name/Signal/Expr	Value	Plot	Save
1	dB20(VF("/net4")/VF("/in1"))	wave	☑	☐
2	phaseDegUnwrapped(VF("/net4")/VF("/in1"))	wave	☑	☐
3	ymax(dB20((VF("/net4") / VF("/in1"))))	60.4605	☑	☐

⇒ Specs.

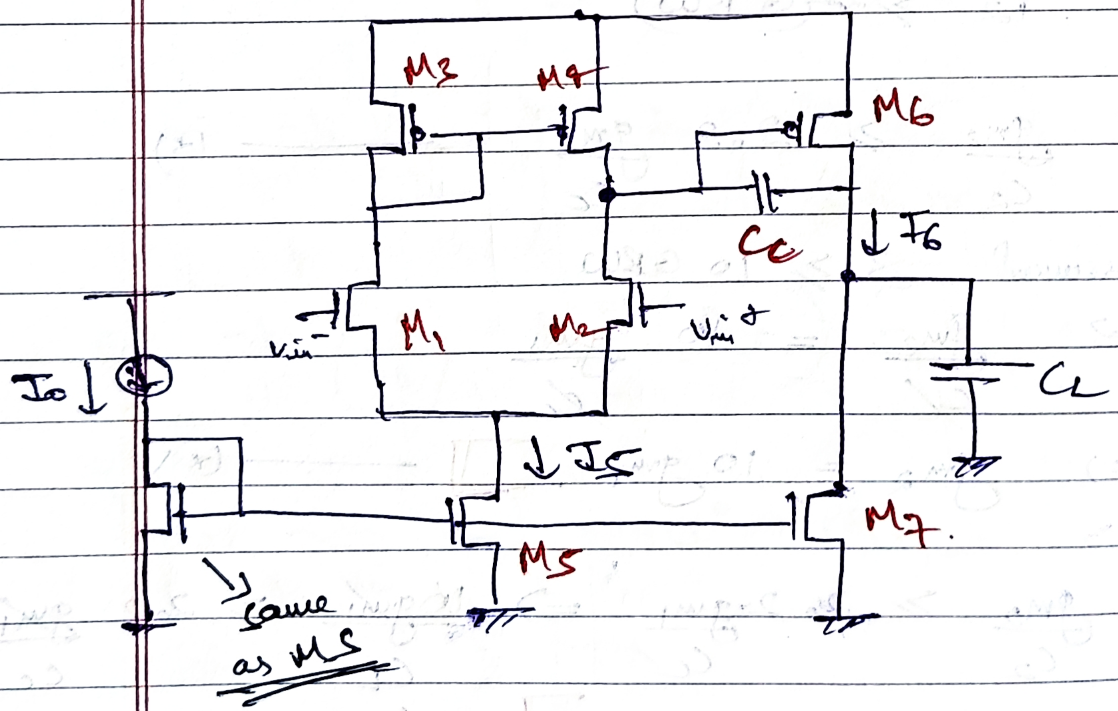
- DC gain = 1000 ⇒ $20\log_{10}(1000)$ ⇒ 60dB
- GBW = 30 MHz
- PM ≥ 60°.
- Slew Rate = 20 $\frac{V}{\mu S}$.

#
- VDD = 1.8 V
- Process = 180 nm

#
- ICMR(+) ⇒ 1.6 V.
- ICMR(−) ⇒ 0.9 V.
- C_L = 2pf.
- Power ≤ 300 μW.

we take L ≥ 2 Lmin here Lmin = 180nm (tech)
thus we use L = 500 nm.

CKT.



M_3, M_4 from ICMR(+)

M_1, M_2 from GBW

I_5 from slew rate.

M_5 from ICMR(−).

$\boxed{L = 500\ nm}$ #

Since $PM \geq 60°$ then $C_c \geq 0.22\, C_L \rightarrow 2pF.$

$\Rightarrow C_c \geq 0.44\ pF.$

$\Rightarrow C_c \geq 440\ fF$

Thus using $\boxed{C_c = 800\ fF.}$ #

Since $SR = 20 \dfrac{V}{\mu s} = \dfrac{I_5}{C_c} \Rightarrow \dfrac{I_5}{800\ fF}$

$\Rightarrow I_5 = \left(20 \dfrac{V}{\mu s}\right)(800\ fF)$

$\Rightarrow I_5 = 16\ \mu A.$

Thus $\Rightarrow$ faimen $\boxed{I_5 = 20\ \mu A.}$ #

Design of M_1, M_2

$g_{m1} = (GB)(2\pi)\, C_c.$

$= (30\ MHz)(2\pi)(800\ fF)$

$\Rightarrow g_{m1} = 150.79\ \mu\left(\dfrac{A}{V}\right)$

Thus, $\boxed{g_{m1} = 160\ \dfrac{\mu A}{V}}$ #

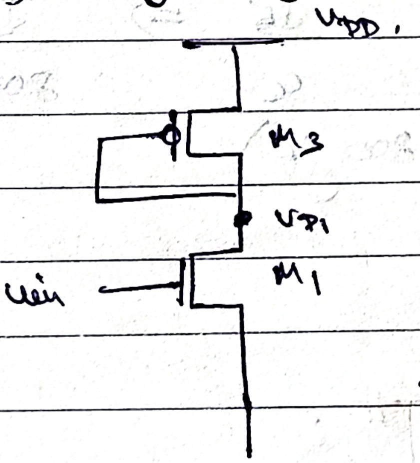
now, $\left(\frac{W}{L}\right) = \frac{g_m^2}{(\mu_n C_{ox})(2I_D)}$

here $I_D = \frac{I_S}{2} \Rightarrow 10\,\mu A$.

$$\Rightarrow \left(\frac{W}{L}\right) = \frac{(160\,\mu)^2}{(\cancel{300\,\mu}\ 360)(20\,\mu)} = \cancel{4.26}\ 3.555.$$

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

→ Design M_3, M_4.
drawing only half ckt.



then if $V_{in}\uparrow$ then M_1 might enter triode thus,
$V_{D1} \geq V_{g1} - V_{th1}$

$\Rightarrow V_{g1} \leq V_{D1} + V_{th1}$

$\Rightarrow V_{in} < V_{D1} + V_{th1}$

$\Rightarrow V_{in\,max} = V_{D1} + V_{th1}$ ——— (*)

& $V_{D1} = V_{DD} - V_{SG3}$ ——— (*)

then,

$$I_D = \frac{\mu_p C_{ox}(W/L)}{2} \cdot (V_{gs} - V_{th})^2.$$

$$\Rightarrow \left(\frac{\beta}{2}\right)(V_{gs} - V_{th})^2.$$

$$\Rightarrow V_{gs} = \sqrt{\frac{2I_3}{\beta_p}} + |V_{th_3}| \quad \text{———} (*)$$

Thus,

$$V_{D_1} = V_{DD} - \left[\sqrt{\frac{2I_3}{\beta_p}} + |V_{th_3}|\right]$$

Since

$$\underbrace{V_{in_{max}}}_{ICMR(+)} \leq V_{D_1} + V_{th_1}$$

$$\Rightarrow ICMR(+) \leq V_{D_{1\,min}} + V_{th_{min}}$$

Thus,

$$ICMR(+) \leq V_{DD} - \sqrt{\frac{2I_3}{\beta_3}} - |V_{th_3}|_{max} + V_{th_{1\,min}}$$

Thus, $\Rightarrow \frac{2I_3}{\beta_3} = \left(V_{DD} - ICMR(+) - |V_{th_3}|_{max} + V_{th_{1\,min}}\right)^2$

$\mu_p C_{ox} = \cancel{60\mu}$ 52μ

$\mu_n C_{ox} = \cancel{300\mu}$ 360μ

$$\Rightarrow \frac{2I_{D_3}}{(\mu_p C_{ox})\left(\frac{W}{L}\right)} = \left(V_{DD} - ICMR(+) - |V_{th_3}|_{max} + V_{th_{1\,min}}\right)^2$$

from sim, diff amp

$$\Rightarrow \left(\frac{W}{L}\right) = \left(\frac{2 I_{D_3}}{\mu_p C_{ox}}\right)\left(\frac{1}{V_{DD} - ICMR(+) - |V_{th_3}|_{max} + V_{th_{1\,min}}}\right)^2$$

$I_{D_3} \rightarrow 10\mu$, $\mu_p C_{ox} \rightarrow 52\mu$, $ICMR(+) \rightarrow 1.6$

thus to find out the values of V_{th} we will have an exact replica of the diff-amp ckt.

Schematic $\Rightarrow$ 3_1_that_2stage_opamp.

Photo $\Rightarrow$ 3_1_1_that_2stage_opamp.

$\Rightarrow$ we use $V_{th_{n\,min}} = \cancel{540}$ mV

$V_{thp\,max} =$ 470 mV.

at $V_{CM} = 1.6$ V.

$V_{th_n} = \cancel{718\,mV}$ $\cancel{507\,mV}$ 637 mV

$|V_{thp}| = +458$ mV

at $V_{CM} = 0.8$ V

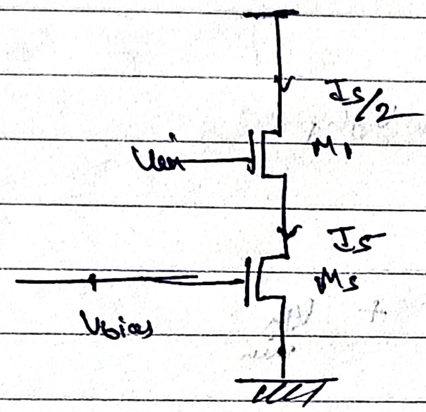
$V_{th_n} = 549$ mV

$|V_{thp}| = +458$ mV.

using these we get

$$\boxed{\left(\frac{W}{L}\right)_{3,4} = \cancel{1.93}\ 5.27 \cong \underline{6}}$$

→ Design of M_5.



if $V_{in} \downarrow$ then $V_{gs_1} \downarrow$ thus, $V_{DS} \downarrow$.

for M_5 in sat.

$$V_{DS} > V_{gs} - V_{th_5}.$$

thus as $V_{DS} \downarrow$ then M_5 goes in triode.

thus, $V_{in_{min}} \geq V_{gs_1} + V_{Dsat_5}$ (V_{Dsat_5} above which M_5 in sat).

$$ICMR(-) \geq V_{gs_1\,max} + V_{Dsat_5}.$$

$$\Rightarrow ICMR(-) \geq \left(\sqrt{\frac{2I_D}{\beta_1}} + V_{th_1}\right)_{max} + V_{Dsat_5}.$$

$$V_{Dsat_5} \geq ICMR(-) - \sqrt{\frac{2I_{D_1}}{\beta_1}} - V_{th_1\,max}.$$

$$\Rightarrow V_{Dsat_5} \geq 0.9 - \sqrt{\frac{2\times 10\,\mu}{360\,\mu\times 4}} - 0.7$$ prev page bottom

$\Rightarrow V_{Dsat_5} \geq$ ~~-ve value thus increase~~ ~~(to 1)~~

making $\left(\frac{W}{L}\right)_{1,2} = 6$ #

we get, $V_{Dsat5} = 104\ mV$

Thus, $\left(\frac{W}{L}\right)_5 = \frac{2 I_D}{(\mu_n C_{ox})(V_{Dsat})^2}$ $I_D \to 20\mu$, $\mu_n C_{ox} \to 360\mu$, $V_{Dsat} \to 104\ mV$ $\Rightarrow$ $\boxed{10.27}$

$$\boxed{\Rightarrow \left(\frac{W}{L}\right)_5 = 10.27 \approx 11.}$$ #

Design of M6.

- for PM $\geq 60°$ we made one assumption.

$z \geq 10\ GBW$

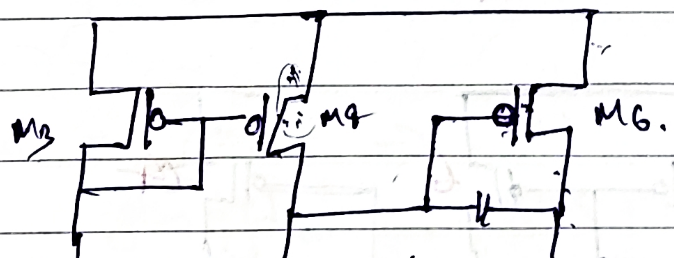
$\Rightarrow g_{m6} \geq 10\, g_{m1} \rightarrow \underbrace{152.4\mu}_{\text{from sim.}}$ $\hookrightarrow$ assume 160μ

Thus,

$\Rightarrow g_{m6} \geq 10 \times 160\mu$

$\Rightarrow g_{m6} \geq 1600\mu.$ ———— $(*)$

Thus,



If proper mirroring then $V_{GS3} = V_{GS4} = V_{GS6}$.

Thus $\frac{(W/L)_6}{(W/L)_4} = \frac{I_6}{I_4} = \frac{g_{m6}}{g_{m4}}$. we have $\underbrace{g_{m4} = 150\mu}_{\text{from sim.}}$

$$\boxed{\Rightarrow \left(\frac{W}{L}\right)_6 = \left(\frac{\overset{1600}{\cancel{g_{m6}}}}{\underset{150}{\cancel{g_{m4}}}}\right)\left(\cancel{\frac{W}{L}}\right)_4^{6} \Rightarrow 64}$$ #

thus,

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

$$\Rightarrow I_6 = \left(\frac{64}{6}\right)(10)$$

$$\Rightarrow I_6 = 106.66\ \mu A.$$

Design of M_7.

thus I_6 flow through M_7.

thus

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

$$\Rightarrow \left(\frac{W}{L}\right)_7 = \left(\frac{106\mu}{20\mu}\right)(11)$$

$$\Rightarrow \left(\frac{W}{L}\right)_7 = 58.3$$

$$\Rightarrow \boxed{\left(\frac{W}{L}\right)_7 = 59}$$