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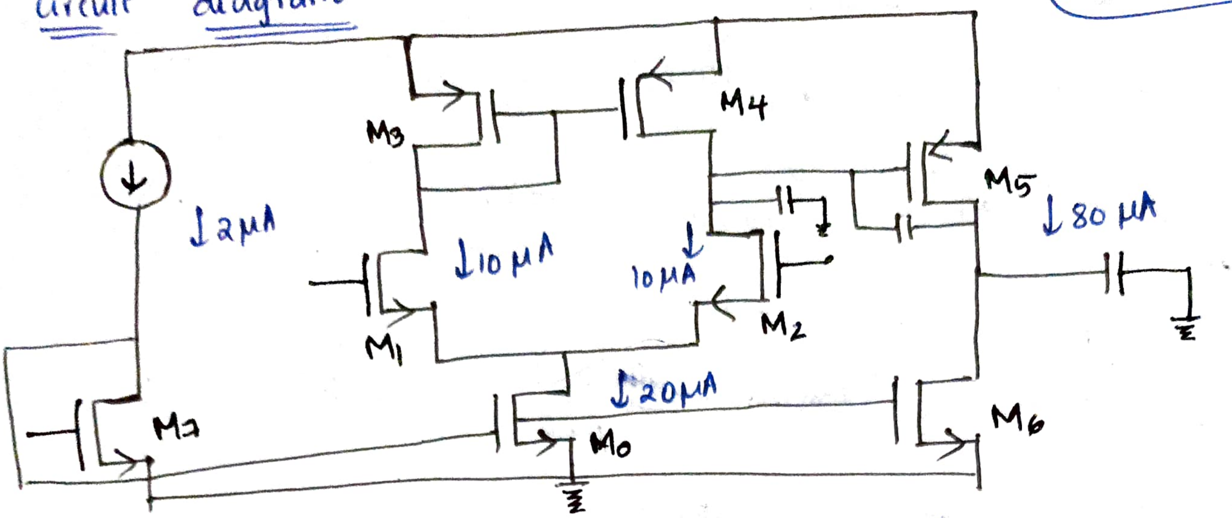
2 stage OTA

Circuit diagram



$I_{ref} = 2\mu A$ Tail current $= 2 \times 10 = 20\mu A$

Given

$(V_{th})_n = 0.37V$
$(V_{th})_p = 0.39V$
$\mu_n C_{ox} = 230 \mu A/V^2$
$\mu_p C_{ox} = 100 \mu A/V^2$

$l_{min} = 0.18 \mu m$
$W_{min} = 0.27 \mu m$
$\lambda = 0.1$ for 180nm technology
$L_{min} = 0.18 \mu m$

considering $V_{gs} - V_{th} = 200mV$ initially

$L = 5 \times 0.18 \mu m = 0.9 \mu m \approx 1 \mu m$ (for all)

$$\frac{(I)_0}{(W/L)_0} = \frac{I_{ref}}{(W/L)_{ref}}$$

$$\frac{20}{(W/L)_0} = \frac{2}{2}$$

$$\boxed{(W/L)_0 = 20}$$

For M_1 and M_2

For M_1 to be in saturation

$V_{gs} > V_{th}$

$0.9 - V_s > 0.37$

$\boxed{V_s < 0.53}$

As $g_m = \frac{2I_D}{V_{gs} - V_{th}}$

For max gain, high $g_m \Rightarrow$ low $V_{gs} - V_{th}$

let ~~$V_s = 0.2V$~~

$V_s = 0.33V$

Then,

$$10\mu = \frac{1}{2}(230\mu)\left(\frac{W}{L}\right)_{M_1} (0.9 - 0.33 - 0.37)^2$$

$$10 = \frac{1}{2}(230)\left(\frac{W}{L}\right)_{M_1} (0.2)^2$$

$$\left(\frac{W}{L}\right)_{M_1} = \frac{10}{115(0.2)^2} = 2.1739$$

$$\left(\frac{W}{L}\right)_{M_1} = \left(\frac{W}{L}\right)_{M_2} = 2.1739$$

To ~~get max~~ ~~swi~~ $(g_m)_{M_1} = \dfrac{2(10\mu)}{0.2} = 100\,\mu S$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.1(10\mu)} = 1000\,k\Omega$$

$$(r_o)_{M_1} = (r_o)_{M_2} = 1000\,k\Omega$$

③ For <u>M3 and M4</u>

M3 should be on and M1 should be in saturation

$$(V_{sg})_3 > (V_{th})_p$$

$$1.8 - (V_g)_3 > 0.39$$

$$(V_g)_3 < 1.41 \qquad\qquad (V_g)_3 = (V_d)_1$$

$$(V_d)_1 < 1.41V$$

and M1 saturation

$$(V_{ds})_1 > (V_{gs})_1 - (V_{th})_n$$

$$(V_d)_1 > (V_g)_1 - (V_{th})_n$$

$$V_d > 0.9 - 0.37$$

$$(V_d)_1 > 0.53$$

$$(V_d)_1 \in (0.53, 1.41) \Rightarrow \boxed{(V_d)_1 = \cancel{1.4V}\ 1.02V}$$

Then,

$$10\mu = \frac{1}{2}(\mu_p C_{ox})\left(\frac{W}{L}\right)_{M_3} (V_{sg} - V_{tp})^2$$

$$10\mu = \frac{1}{2}(100\mu)\left(\frac{W}{L}\right)_{M_3} (1.8 - 1.02 - 0.39)^2$$

$$\left(\frac{W}{L}\right)_{M_3} = \frac{2}{10(0.39)^2} = 1.314$$

$$g_m = \frac{2I_D}{V_{sg} - V_{tp}} = \frac{2(10\mu)}{0.39} = 51.3\,\mu S$$

$$(r_o)_{M3} = (r_o)_{M4} = \frac{1}{\lambda I_D} = 1000\,K\Omega$$

④ For M5 (consider 80 μA in stage 2)

M4 in saturation

M_5 on $(V_{sg})_5 > (V_{th})_p$

$1.8 - (V_g)_5 > 0.39$

$(V_g)_6 < 1.41$

$(V_{sd})_4 > (V_{sg})_4 - (V_{th})_p$ $\quad [(V_d)_4 = (V_g)_5]$

$-(V_g)_5 > -(V_g)_4 - V_{tp}$ $\quad 1.25 + 0.39$

$(V_g)_5 < 1.64V$

and $(V_g)_5 > 0.53$

$(V_g)_5 \in (0.53, 1.41)$

$(V_g)_5 = 1.02V$

$$80\mu = \frac{1}{2}(100\mu)\left(\frac{W}{L}\right)_5 (1.8 - 1.02 - 0.39)^2$$

$$\left(\frac{W}{L}\right)_5 = 1.314 \times 8 = 10.512$$

$$(g_m)_5 = \frac{2(80\mu)}{0.39} = 410.25\,\mu S$$

$$(r_o)_5 = (r_o)_6 = \frac{1}{\lambda I_D} = \frac{1}{0.1 \times 80\mu} = 125\,K\Omega$$

⑤ For M6

$$\frac{(I)_6}{(W/L)_6} = \frac{(I)_{ref}}{(W/L)_{ref}}$$

$$\frac{80}{(W/L)_6} = \frac{2}{2}$$

$$(W/L)_6 = 80$$

$r_o = \cancel{\frac{1}{\lambda I_D}}$ $\quad (g_m)_6 = \cancel{2(80\mu)}$

Tabular form considering $\lambda = 0.1$

Transistor		W/L	gm	overdrive	r_o	I_D
NMOS	M_1	2.1739	100µS	0.2V	1000kΩ	20µA
	M_2	2.1739	100µS	0.2V	1000kΩ	
PMOS	M_3	1.314	51.3µS	0.39V	1000kΩ	20µA
	M_4	1.314	51.3µS	0.39V	1000kΩ	
PMOS	M_5	10.512	410.25µS	0.39V	125kΩ	80µA
NMOS	M_6	80	~~1018223µS~~ 1777µS	~~0.08 0.2V~~ 0.09V	125kΩ	80µA
tail	M_0	20	444.4µS	0.09V	500kΩ	40µA
reference	M_7	~~20~~ 2	44.44µS	0.09V	5000kΩ	2µA

Gain of 1st stage

$$(A_v)_1 = \frac{1.7mV - (-1.7mV)}{20\mu} = \frac{3.4mV}{20\mu} = 170 = 44.6dB$$

2nd stage

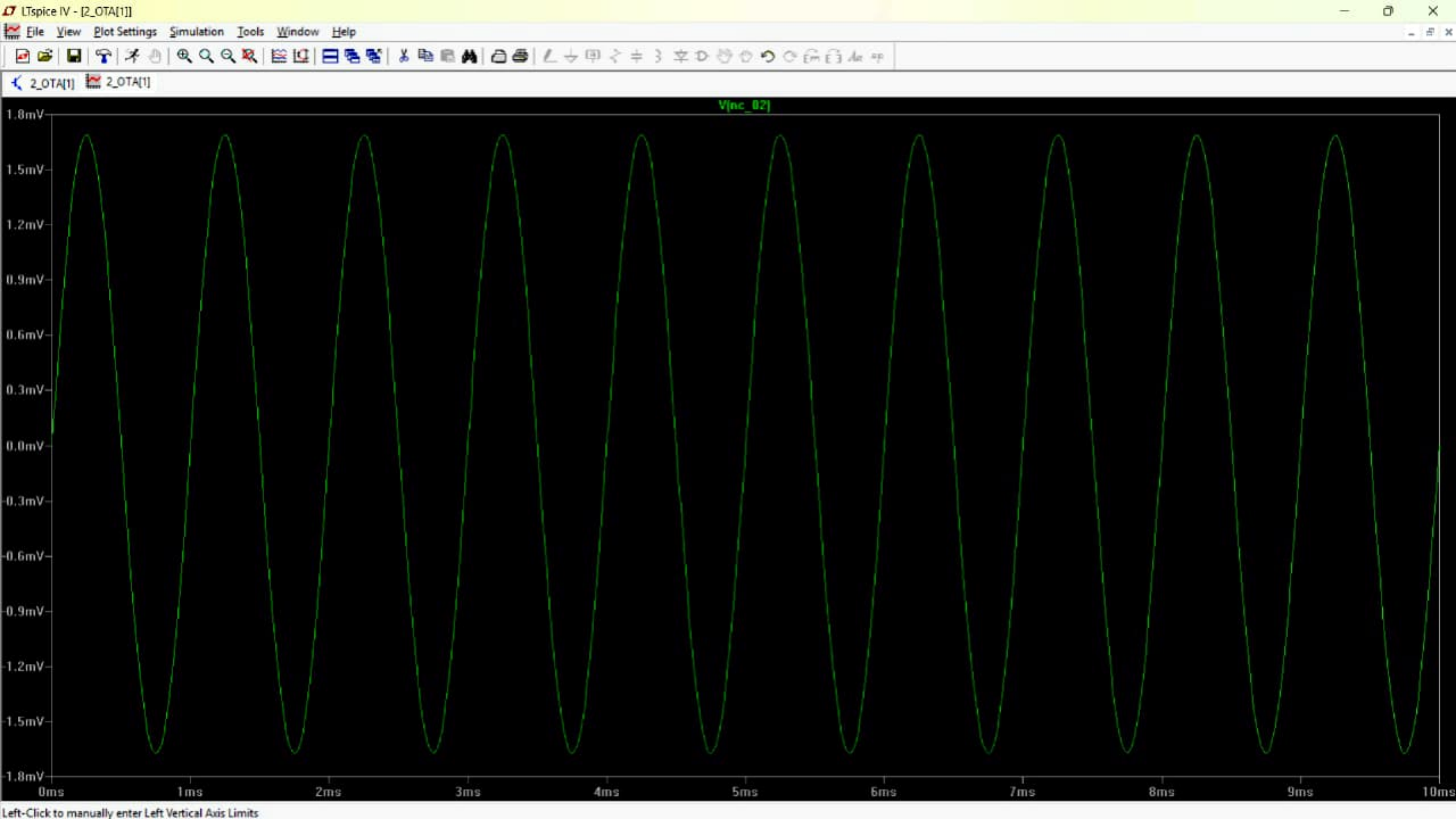
$$(A_v)_2 = \frac{30mV - (-30mV)}{20\mu} = \frac{60mV}{20\mu} = 3000 = 69.54dB$$

Overall gain → 114.14dB

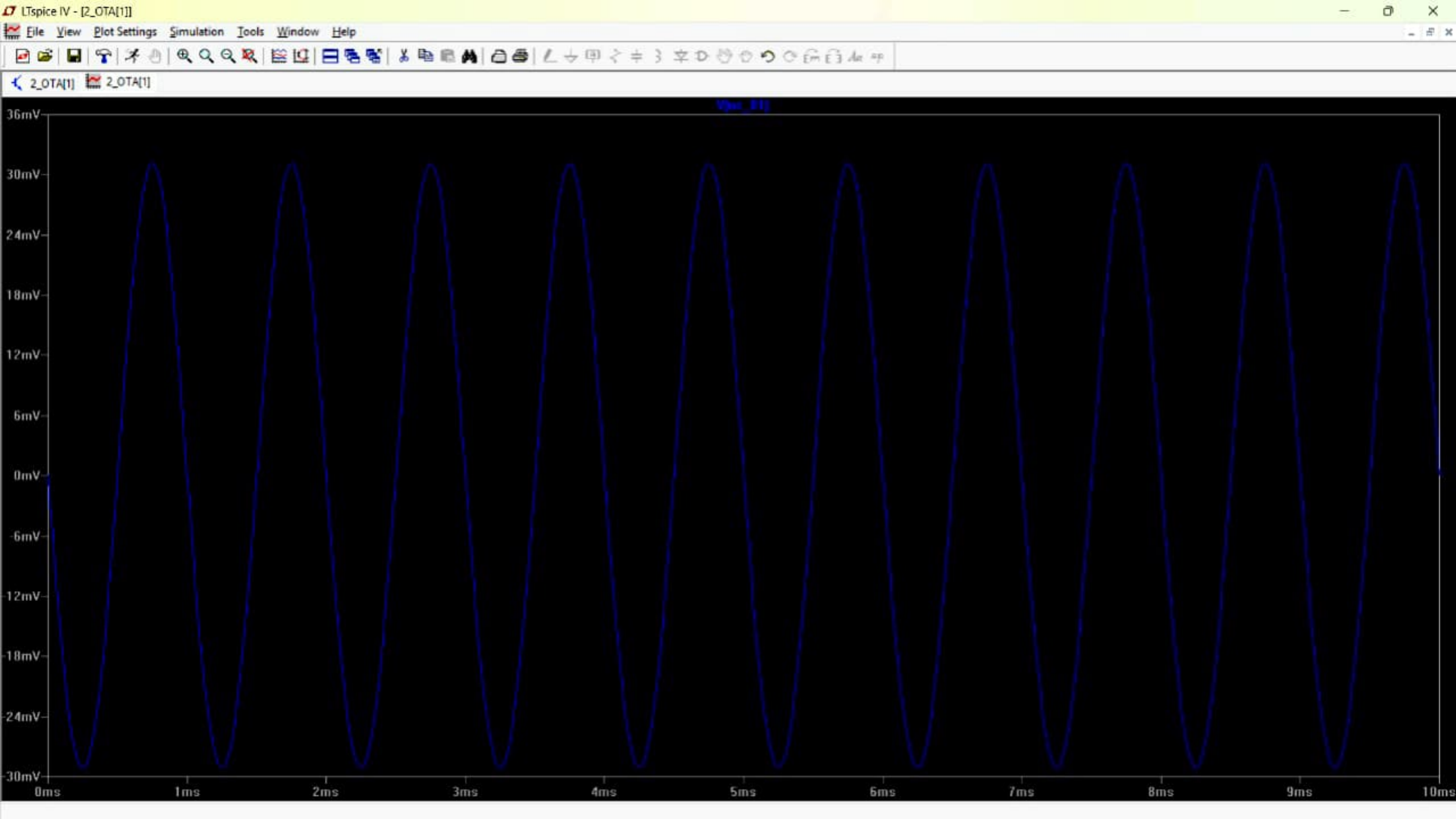
Power consumed → $20 + 2 + 80 = 102\mu A$

$V = 1.8V$

Power $= 183\mu W$

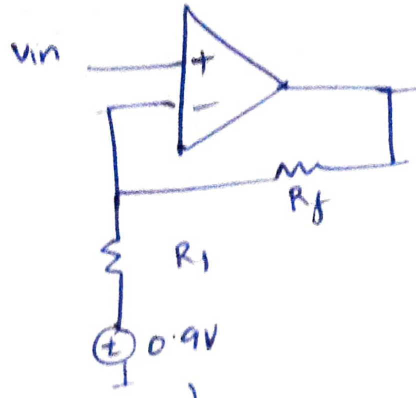


LTspice IV - [2_OTA[1]]
File View Plot Settings Simulation Tools Window Help
2_OTA[1]
2_OTA[1]
V(nc_02)
1.8mV
1.5mV
1.2mV
0.9mV
0.6mV
0.3mV
0.0mV
-0.3mV
-0.6mV
-0.9mV
-1.2mV
-1.5mV
-1.8mV
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
Left-Click to manually enter Left Vertical Axis Limits



LTspice IV - [2_OTA[1]]
File
View
Plot Settings
Simulation
Tools
Window
Help
2_OTA[1]
2_OTA[1]
36mV
30mV
24mV
18mV
12mV
6mV
0mV
-6mV
-12mV
-18mV
-24mV
-30mV
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms

(c) Non-inverting amplifier of gain 2



DC supply (bias), to M1.

$1 + \frac{R_f}{R_1} = 2$

$\frac{R_f}{R_1} = 1$

$R_f = R_1$

I considered $R_f = R_1 = 5K\Omega$

(I got gain around 5.98dB)

Gain $= 20\log(2) = 6dB$.

(c) For phase margin ($55° - 70°$), tune the following.

→ Miller capacitor used for compensation (C_c) = 4pF

Load capacitor (C_L) = 18.18pF = $\frac{C_c}{0.22}$

~~R_z (for zero) = 10K~~

This ensures that pole 1 (dominant pole) due to C_c and pole due to C_L are far apart from each other.

$R_z = \frac{1}{4mS} = \frac{1}{410.28}\mu S = 3K\Omega$

→ To get around 60°, I have tuned the C_c, C_L, R_z.

Final values (To get 62°)

$C_c = 4pF$

$C_L = 18.18pF$

$R_z = 10K\Omega$

→ From simulation

Freq at 0dB (ω_{gc} = 3.9 MHz)

At that ω_{gc} phase of open loop (GH) = −118°

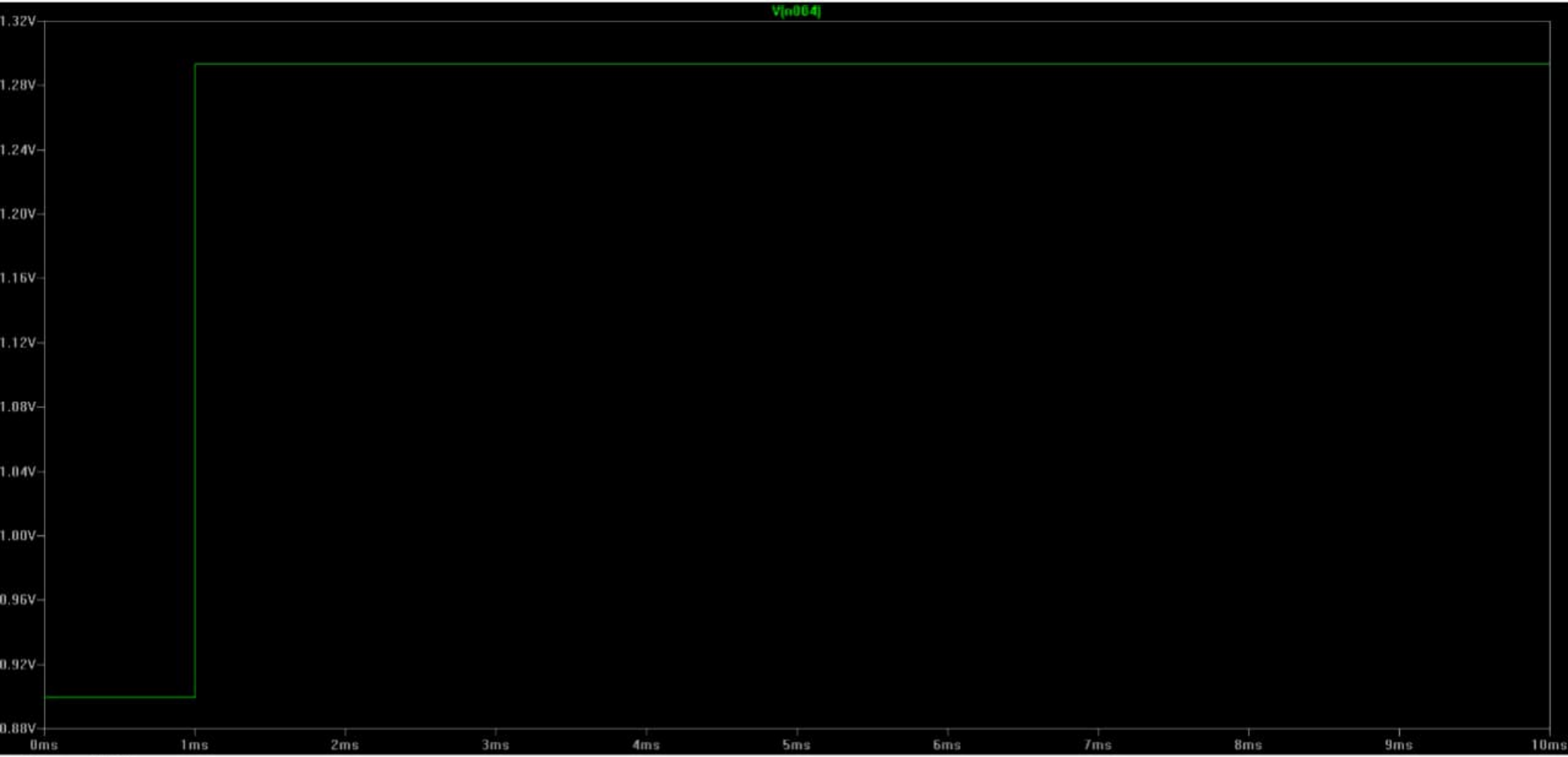
(in unity gain feedback)

Phase margin $= 180 + \phi$

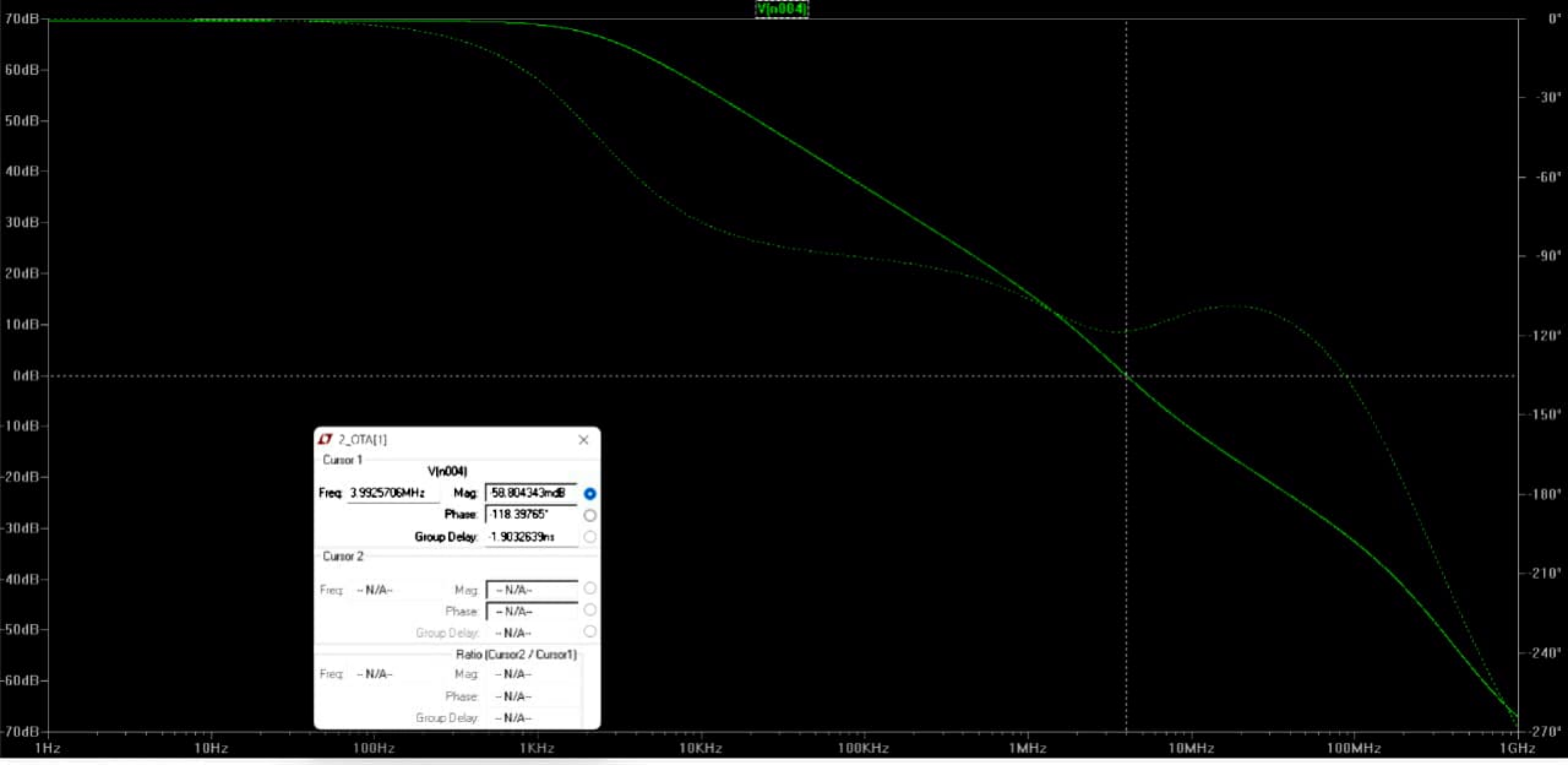
$= 180 - 118°$

$\boxed{PM = 62°}$ ✓

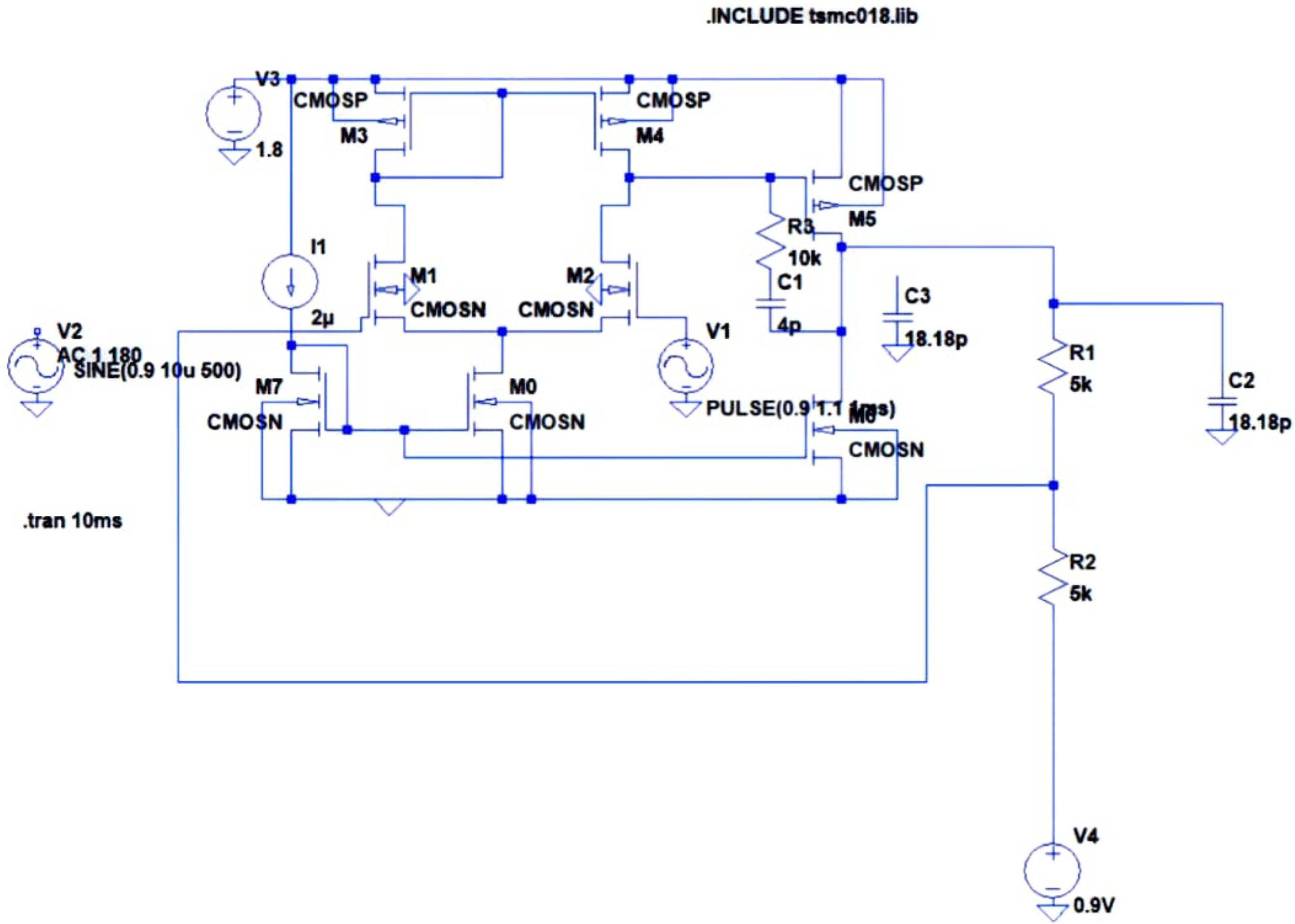
8dB
7dB
6dB
5dB
4dB
3dB
2dB
1dB
0dB
-1dB
-2dB
-3dB
-4dB
-5dB
-6dB
-7dB
-8dB
-9dB
-10dB
-11dB
-12dB
-13dB
-14dB
-15dB
-16dB
-17dB
-18dB
-19dB
-20dB
0°
-30°
-60°
-90°
-120°
-150°
-180°
-210°
-240°
-270°
-300°
-330°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz



x = 3.54ms y = 1.3004V



V(n004)
70dB
60dB
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
0°
-30°
-60°
-90°
-120°
-150°
-180°
-210°
-240°
-270°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
2_OTA[1]
Cursor 1
V(n004)
Freq: 3.9925706MHz
Mag: -58.804343mdB
Phase: -118.39765°
Group Delay: -1.9032639ns
Cursor 2
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--
Ratio (Cursor2 / Cursor1)
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--


.INCLUDE tsmc018.lib
V3
1.8
CMOSP
M3
CMOSP
M4
CMOSP
M5
R3
10k
C1
4p
I1
2µ
M1
CMOSN
M2
CMOSN
V1
PULSE(0.9 1.1 1ms)
C3
18.18p
R1
5k
C2
18.18p
V2
AC 1 180
SINE(0.9 10u 500)
M7
CMOSN
M0
CMOSN
M6
CMOSN
.tran 10ms
R2
5k
V4
0.9V