2 STAGE OTA DC CALCULATIONS

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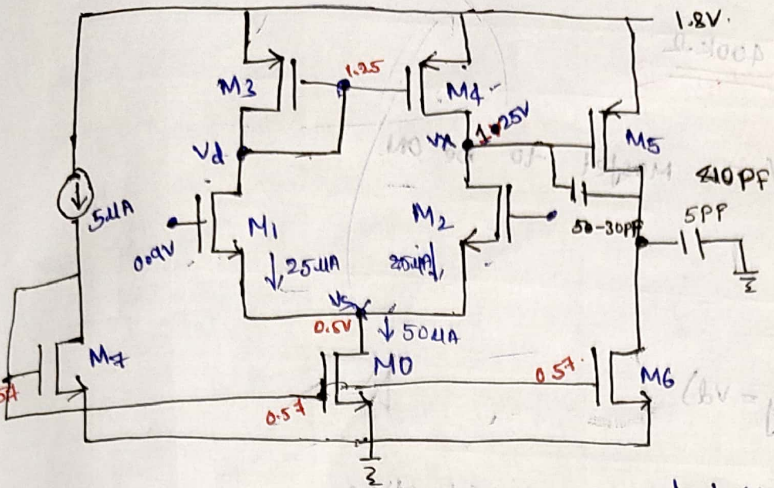


Given

$(V_{th})_n = 0.37V$.

$(V_{th})_p = 0.39V$

$\mu_n C_{ox} = 230\ \mu A/V^2$

$\mu_p C_{ox} = 100\ \mu A/V^2$

$L_{min} = 0.18\ \mu m$

$W_{min} = 0.27\ \mu m$

$\lambda = 0.1$ for $L = 0.18\ \mu m$

Given The overdrive for initial calculations $V_{gs} - V_{th} = 0.2V$.

1) FOR M_0

$I_D = 50\mu A$ (Let us consider)

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{gs}-V_{th})^2$$

$$50\mu = \frac{1}{2}(230\mu)\left(\frac{W}{L}\right)(0.2)^2$$

$$\boxed{\left(\frac{W}{L}\right)_{M_0} = \frac{10}{23(0.2)^2} = 10.87}$$

For design in Ltspice I considered $L = 5 \times 0.18\ \mu m = 0.9\ \mu m$ for all the Mosfets of stage 1.

$$\boxed{g_m = \frac{2I_D}{V_{gs}-V_{th}} = \frac{2(50\mu)}{0.2} = 500\ \mu S.}$$

r_o (due to channel length modulation) $= \frac{1}{\lambda I_D} = \frac{1}{0.1 \times 50\mu} = 200\ K\Omega$

2) FOR M_1 and M_2

For M_1 to be in saturation

$V_{gs} > V_{th}$

$0.9 - V_s > 0.37$

$V_s < 0.53$

To get max gain, gm needs to be high, ⇒ $V_{gs} - V_{th}$ must be low

So I considered max V_s of 0.5

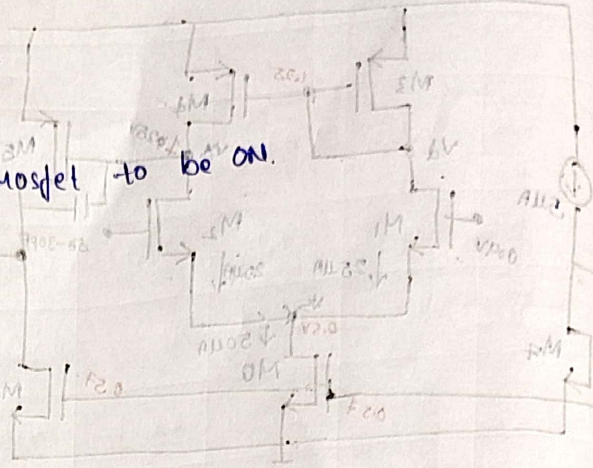
Then $25\mu = \frac{1}{2}(230\mu)\left(\frac{W}{L}\right)(0.9-0.5-0.37)^2$

$$\boxed{\left(\frac{W}{L}\right) = \frac{50}{23(0.03)^2} = 241.55}$$

$$\boxed{g_m = \frac{2(25\mu)}{0.03} = 1666.6\ \mu S}$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.1(25\,\mu A)} = 400\,k\Omega$$

$$(r_o)_{M_1} = (r_o)_{M_2} = \underline{\underline{400\,k\Omega}}$$



3) For M_3 and M_4.

To be in saturation / The Mosfet to be ON.

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

$$1.8 - V_g > 0.39$$

$$V_g < 1.41 \quad (\because V_g = V_d)$$

$$V_d < 1.41$$

and, with the V_d, M_1 must also be in Saturation

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

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

$$V_d > 0.9 - 0.37$$

$$V_d > 0.53$$

$$V_d \in (0.53, 1.41)$$

Let us consider $V_d = 1.25\,V$

then, $25\,\mu = \frac{1}{2}(\mu_p C_{ox})\left(\frac{W}{L}\right)(V_{sg} - V_{thp})^2$

$$\cancel{25\mu} = \frac{1}{2}(\cancel{100\mu})\left(\frac{W}{L}\right)(1.8 - 1.25 - 0.39)^2$$

$$\boxed{\left(\frac{W}{L}\right) = \frac{1}{2(0.16)^2} = 19.53}$$

$$\boxed{g_m = \frac{2I_D}{V_{sg} - V_{thp}} = \frac{2(25\mu)}{0.16} = 312.5\,\mu S}$$

$$(r_o)_{M_1} = (r_o)_{M_2} = \underline{\underline{400\,k\Omega}}$$

4) For M_5 (Let us consider a current of 100 μA is flowing in stage 2.)

The value of V_x must be choosen such that M_2, M_4 and M_5 must be on / In saturation.

$$(V_{sg})_5 > (V_{th})_p \qquad (V_{sd})_4 > (V_{sg})_4 - (V_{th})_p$$

$$1.8 - V_x > 0.39 \qquad -\cancel{V_d} > -V_g - (V_{th})_p$$

$$V_x < 1.41 \;-(1) \qquad V_g + V_{tp} > V_{\cancel{d}}$$

$$V_{\cancel{d}} < 1.25 + 0.39$$

and $V_x > 0.53 \;-(3)$ $\qquad V_{\cancel{x}} < 1.64 \;-(2)$

To satisfy all (1), (2), (3) $V_X \in (0.53, 1.41)$

But, the phase margin and bandwidth of the overall gain of this design depends on 2nd stage gain i.e $(g_m)_5$

If we consider $(g_m)_5$ very high then overall gain increases but it reduces PM and bandwidth.

$\Rightarrow$ To get a PM of 50-70.

$(g_m)_5$ considered 6-10 x

Let us consider ~~$V_X = 1.00V$~~ $V_X = 1.25V$

Then $100\mu = \frac{1}{2}(100\mu)\left(\frac{W}{L}\right)_5 (1.8 - 1.25 - 0.39)^2$

~~$\boxed{\left(\frac{W}{L}\right)_5 = \frac{2}{(0.41)^2} = 11.9}$~~ $\left(\frac{W}{L}\right)_5 = \frac{2}{(0.16)^2} = 78.125$

~~$g_{m5} = \frac{2(100\mu)}{0.41} = 487.8\mu S$~~ $g_{m5} = \frac{2(100\mu)}{0.16} = 1250\mu S$

$(r_o)_6 = (r_o)_5 = \frac{1}{\lambda I_D} = \frac{1}{0.1 \times 100\mu} = 100 K\Omega$

5) For M_7.

$\frac{(I_D)_7}{\left(\frac{W}{L}\right)_7} = \frac{(I_D)_{M0}}{\left(\frac{W}{L}\right)_{M0}}$ (For same overdrive)

$\frac{5\mu}{\left(\frac{W}{L}\right)_7} = \frac{10\ \cancel{50\mu A}}{10.87}$

$\boxed{\left(\frac{W}{L}\right)_7 = \frac{10.87}{10} = 1.087}$

$\therefore (V_{gs} - V_{th})_7 = 0.2$

$V_g - 0 - 0.37 = 0.2$

$\boxed{V_g = 0.57}$

$g_{m7} = \frac{2(5\mu)}{0.2} = 50\mu S$

$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.1(5\mu)} = 2M\Omega$

6) For M_6.

$100\mu = \frac{1}{2}(230\mu)\left(\frac{W}{L}\right)(0.2)^2$ ($\because V_{gs} - V_{th} = 0.57 - 0.37 = 0.2$)

$\boxed{\left(\frac{W}{L}\right)_6 = \frac{20}{23(0.2)^2} = 21.74}$

$g_{m6} = \frac{2(100\mu)}{0.2} = 1000\mu S$

For M_5 and M_6, I have considered $L = 0.18\mu m$ as $\lambda = 0.1$ which depends on L value.

Scanned with OKEN Scanner

Final Designed Values: $V_{DD} = 1.8V$; $I_{ref} = 5\mu A$; $V_{incm} = 0.9V$

$\frac{V_{dd}}{2} = 20\mu V$

Parameters	M0	M1	M2	M3	M4	M5	M6	M7
$V_{gs} - (V_{th})_n$ / $V_{sg} - (V_{th})_p$	0.2V	0.08V	0.08V	0.16V	0.16V	0.16V	0.2	0.2
$(\frac{W}{L})$	10.869	241.54	241.54	19.5	19.5	78.125	21.739	1.0869
g_m	500µS	1666.6µS	1666.6µS	312.5µS	312.5µS	1250µS	1000µS	50µS
r_o	200kΩ	400kΩ	400kΩ	400kΩ	400kΩ	100kΩ	100kΩ	2MΩ
I_D	50µA	25µA	25µA	25µA	25µA	100µA	100µA	5µA
W	9.78µm	0.22mm	0.22mm	17.55µm	17.55µm	14.06µm	3.91µm	0.98µm
L	0.9µm	0.9µm	0.9µm	0.9µm	0.9µm	0.18µm	0.18µm	0.9µm

Theoretical values:

stage 1 gain $= g_{m1}(r_{o2} \| r_{o2}) = 1666.6 \times 10^{-6}(200 \times 10^3) = 333.32 = 50.457\,dB$

stage 2 gain $= g_{m5}(r_{o5} \| r_{o6}) = 1250 \times 10^{-6}(50k\Omega) = 62.5$

Total gain $= 333.32 \times 62.5 = 20832.5 = 86.4\,dB$ (Total)

Observed values from LT spice:

For stage 1 $A_V = \frac{1.184334 - 1.176524}{40\mu} = 195.125 = 45.8\,dB$

~~For sta~~ Total gain at stage 2:

$A_V = \frac{0.9881 - 0.7753V}{40\mu V} = \frac{0.2128}{40\mu V} = \boxed{5320} = 74.5\,dB$

power consumed:

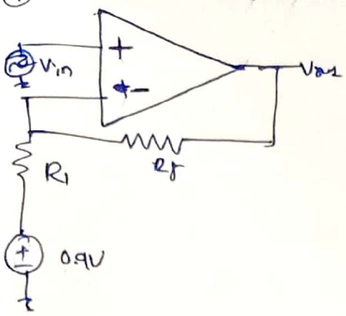
$P = IV$

$= (5\mu A + 50\mu A + 100\mu A)(1.8V)$

$= 279\mu W$

$= 0.279\,mW$

① Non Inverting amplifier of gain 2.



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

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

$$R_f = R_1$$

I have considered $R_f = R_1 = 10\,k\Omega$

We have connected 0.9V DC to R_1 because to provide biasining to the MOSFET'S.

② For poles and zeroes location to be fixed. And Phase margin Miller capacitance used for compensation $\boxed{C_c = 5P}$

$C_c = 0.22\, C_L.$

$$\Rightarrow C_L = \frac{C_c}{0.22} = \frac{5P}{0.22} = 22.72PF.$$

$$\boxed{C_L = 22.72pF}$$

$$\Rightarrow R_Z = \frac{1}{g_{M_5}} = \frac{1}{1250\,\mu s} = 800\,\Omega$$

But for getting a phase margin of 60° I have tuned the Capacitors and Resistors.

Final values to get 60° PM:

$C_c = 5P$

$C_L = 22.72PF$

$R_Z = 6K\Omega$.

<u>From Simulation:</u>

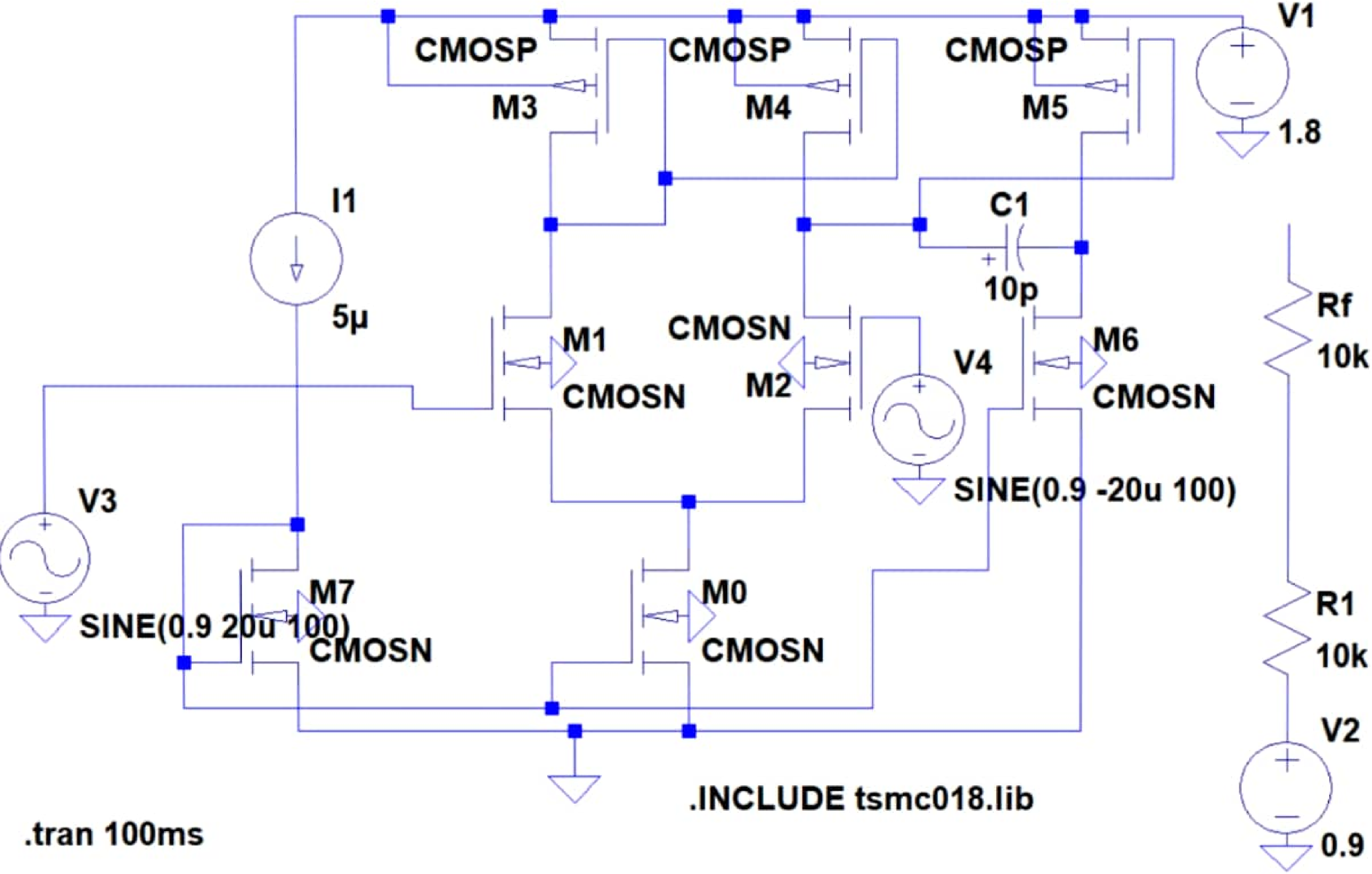
Frequency at 0dB $\omega_{gc} = 27.97\,MHz$.

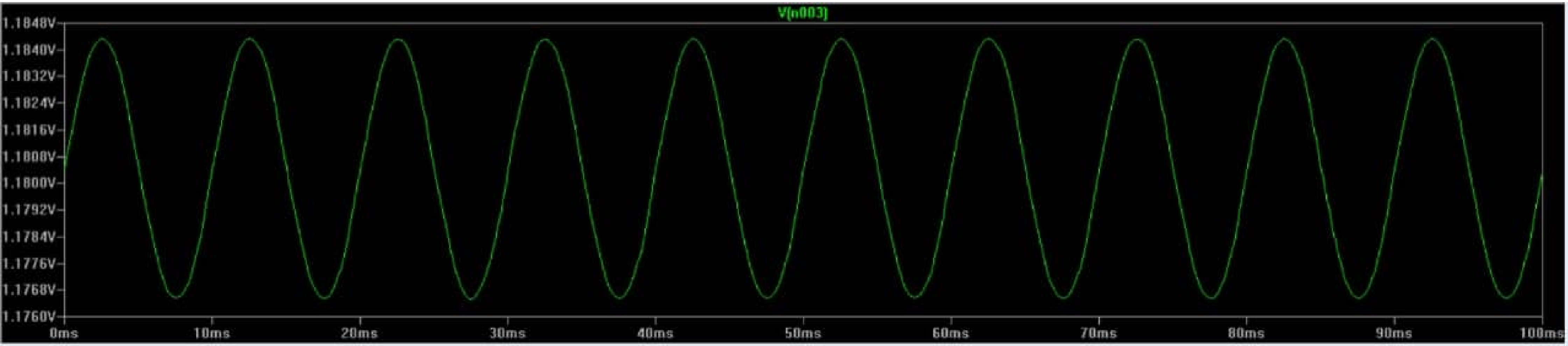
At that ω_{gc} phase of open loop circuit $G(s)H(s) \overset{=1}{} = -119.37$.

phase margin = $180 + \phi$

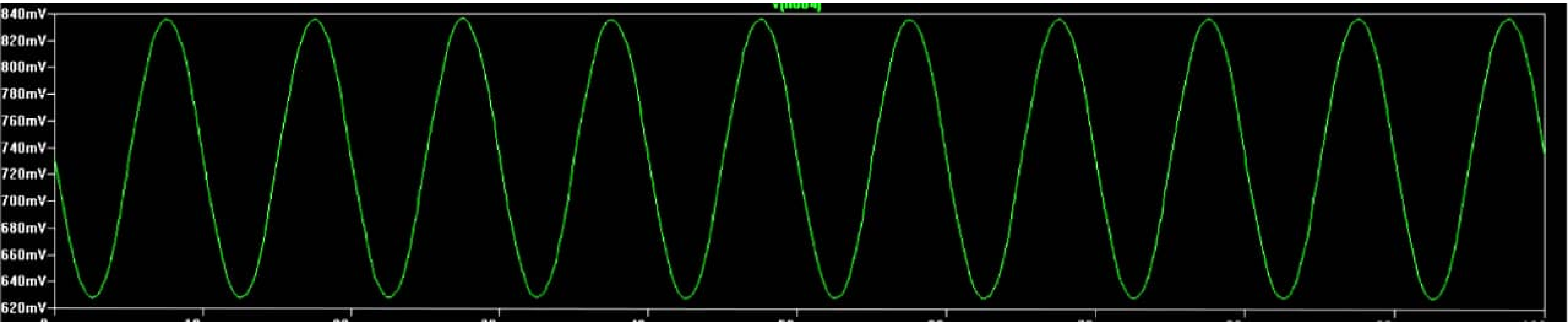
$= 180 - 119.37$

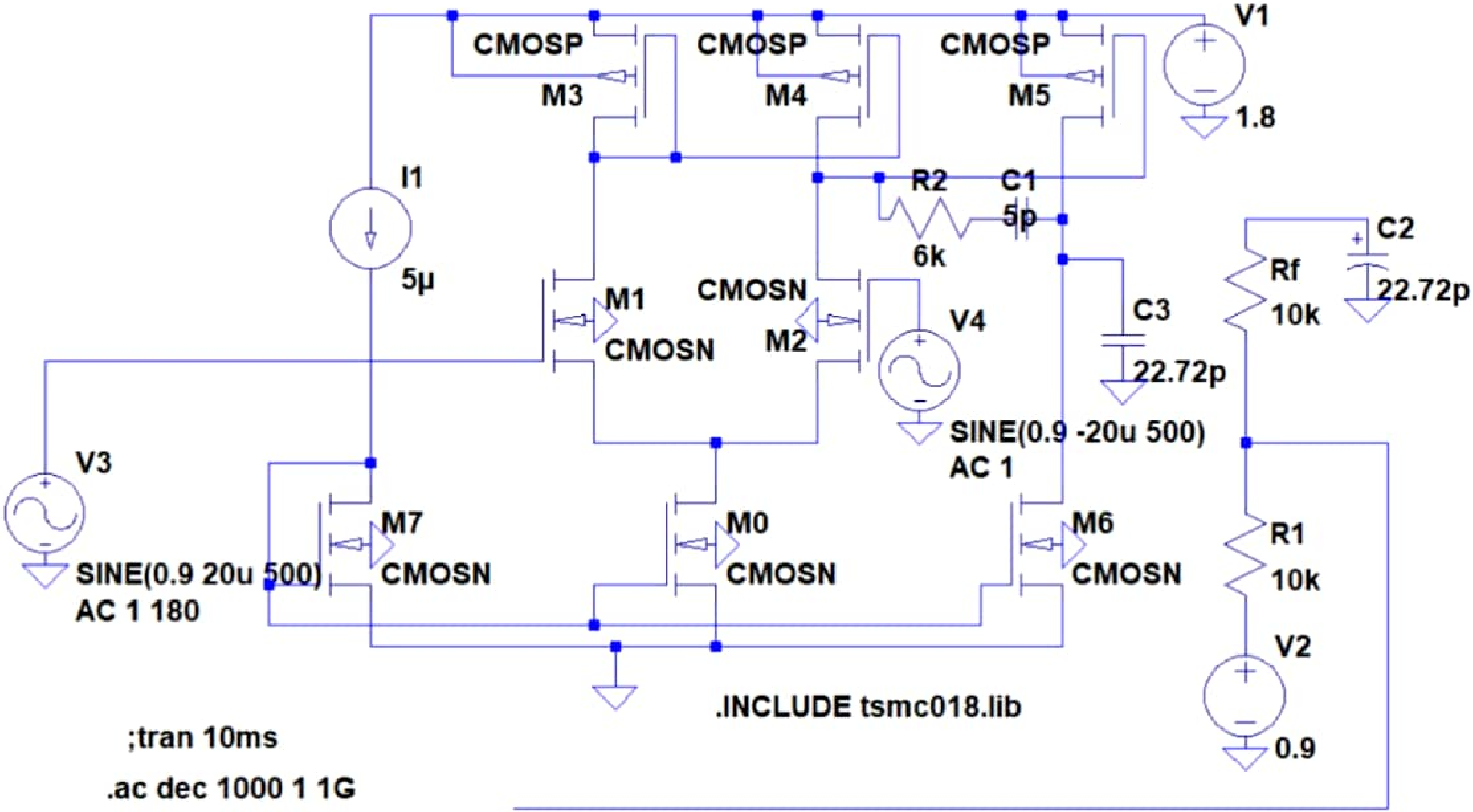
$$\boxed{PM = 60.63^\circ}$$


V1
1.8
CMOSP
M3
CMOSP
M4
CMOSP
M5
I1
5µ
C1
10p
Rf
10k
M1
CMOSN
CMOSN
M2
V4
M6
CMOSN
SINE(0.9 -20u 100)
V3
SINE(0.9 20u 100)
M7
CMOSN
M0
CMOSN
R1
10k
V2
0.9
.INCLUDE tsmc018.lib
.tran 100ms

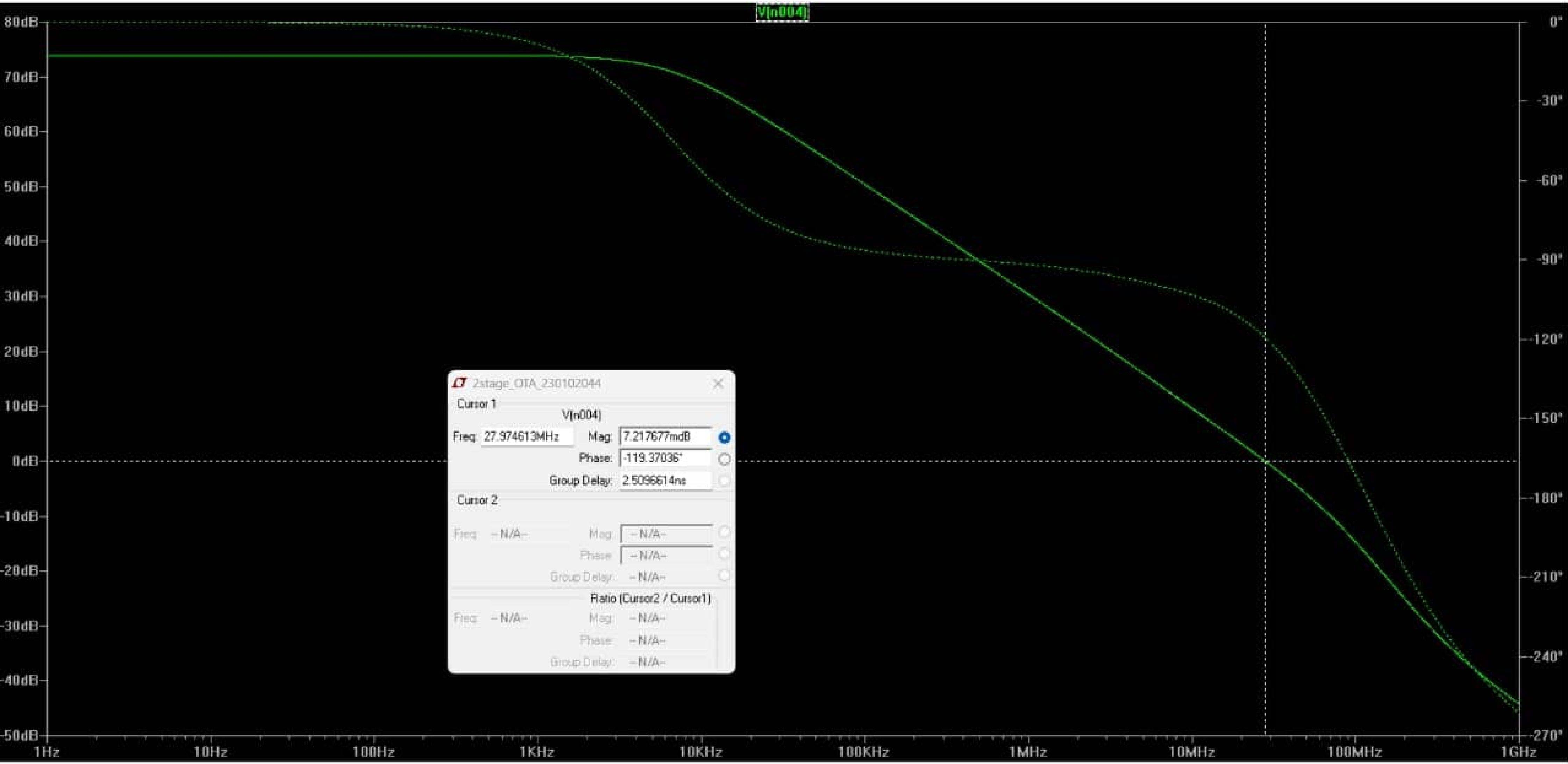


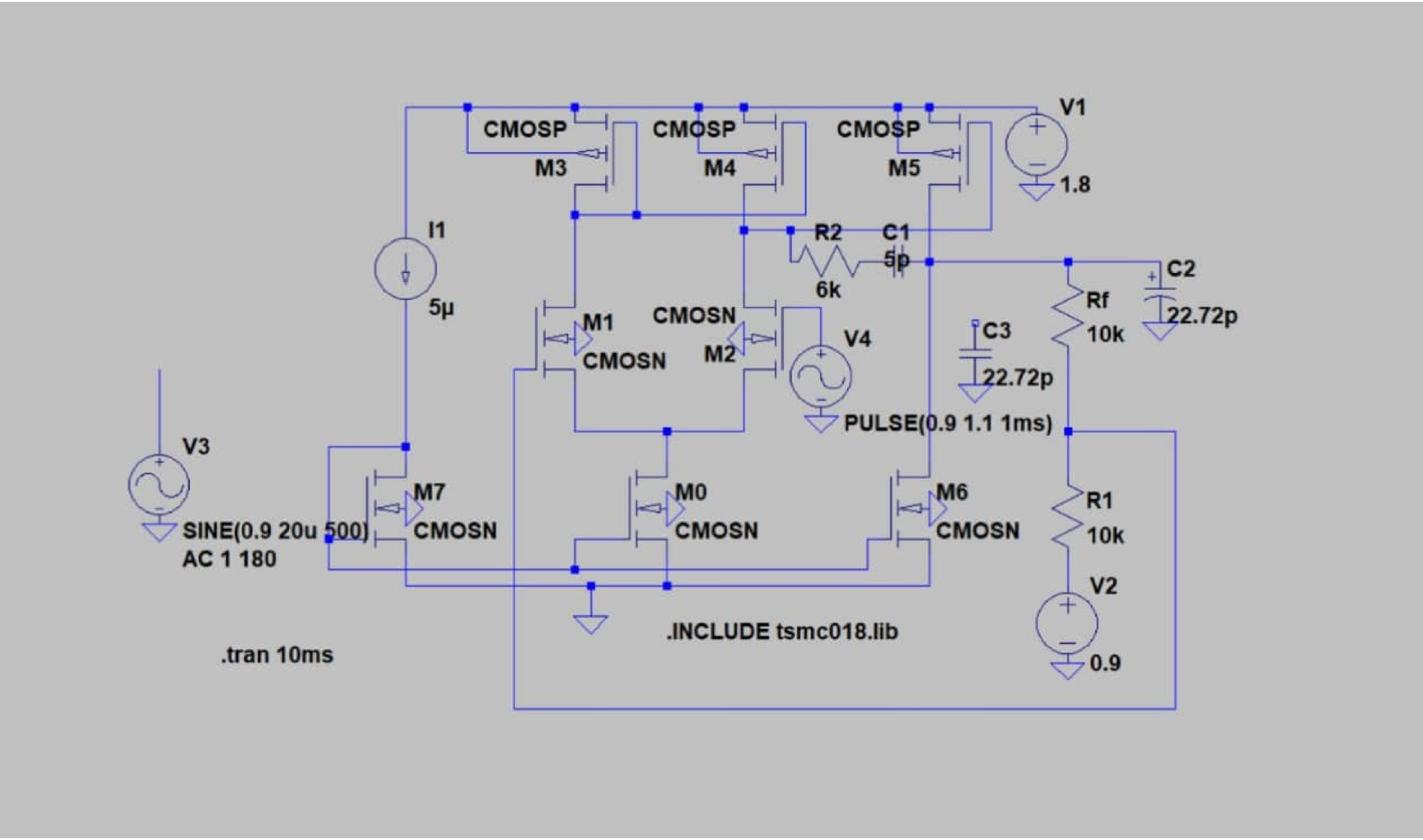
V(n003)
1.1848V
1.1840V
1.1832V
1.1824V
1.1816V
1.1808V
1.1800V
1.1792V
1.1784V
1.1776V
1.1768V
1.1760V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
100ms

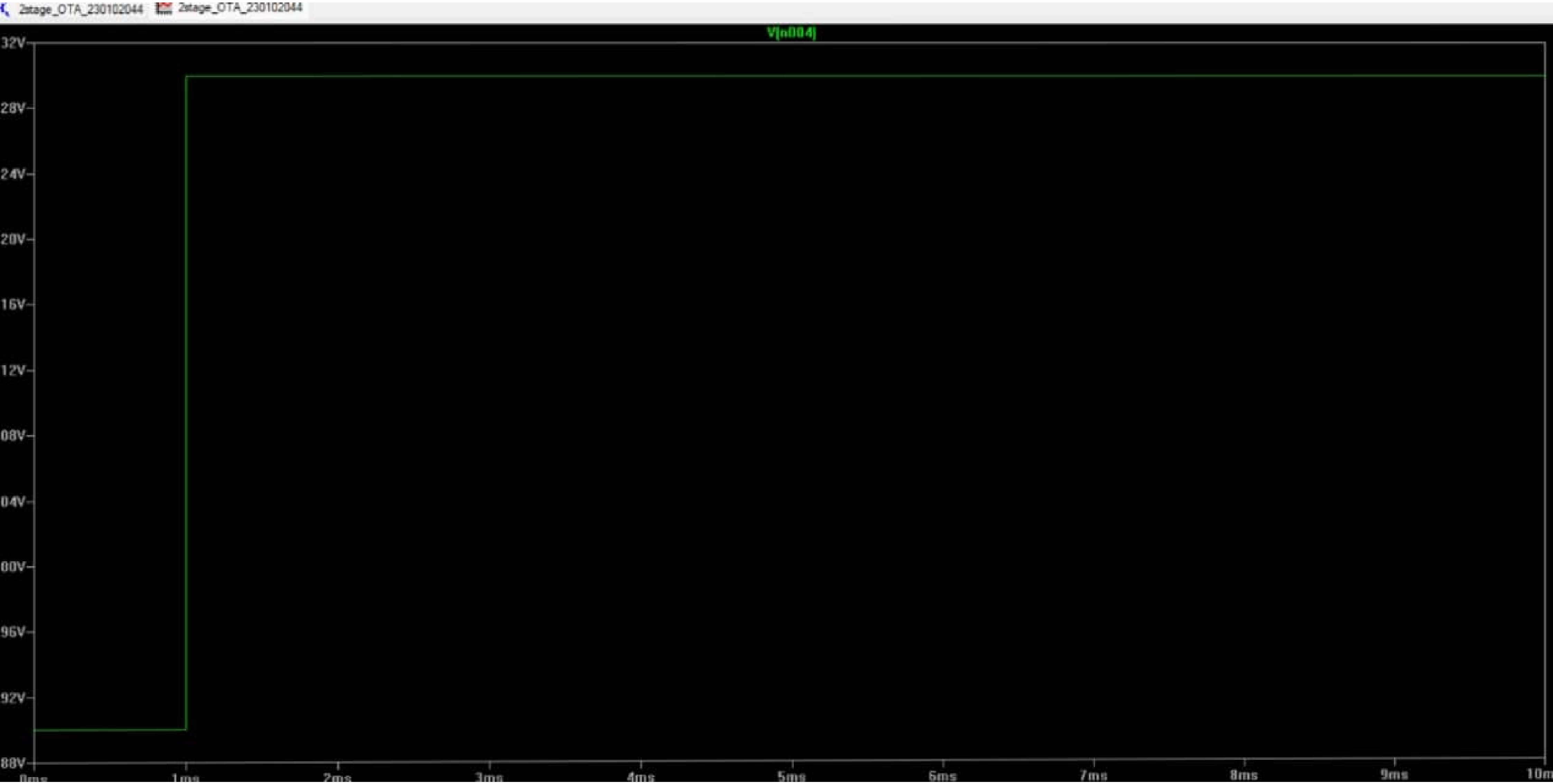

840mV
820mV
800mV
780mV
760mV
740mV
720mV
700mV
680mV
660mV
640mV
620mV



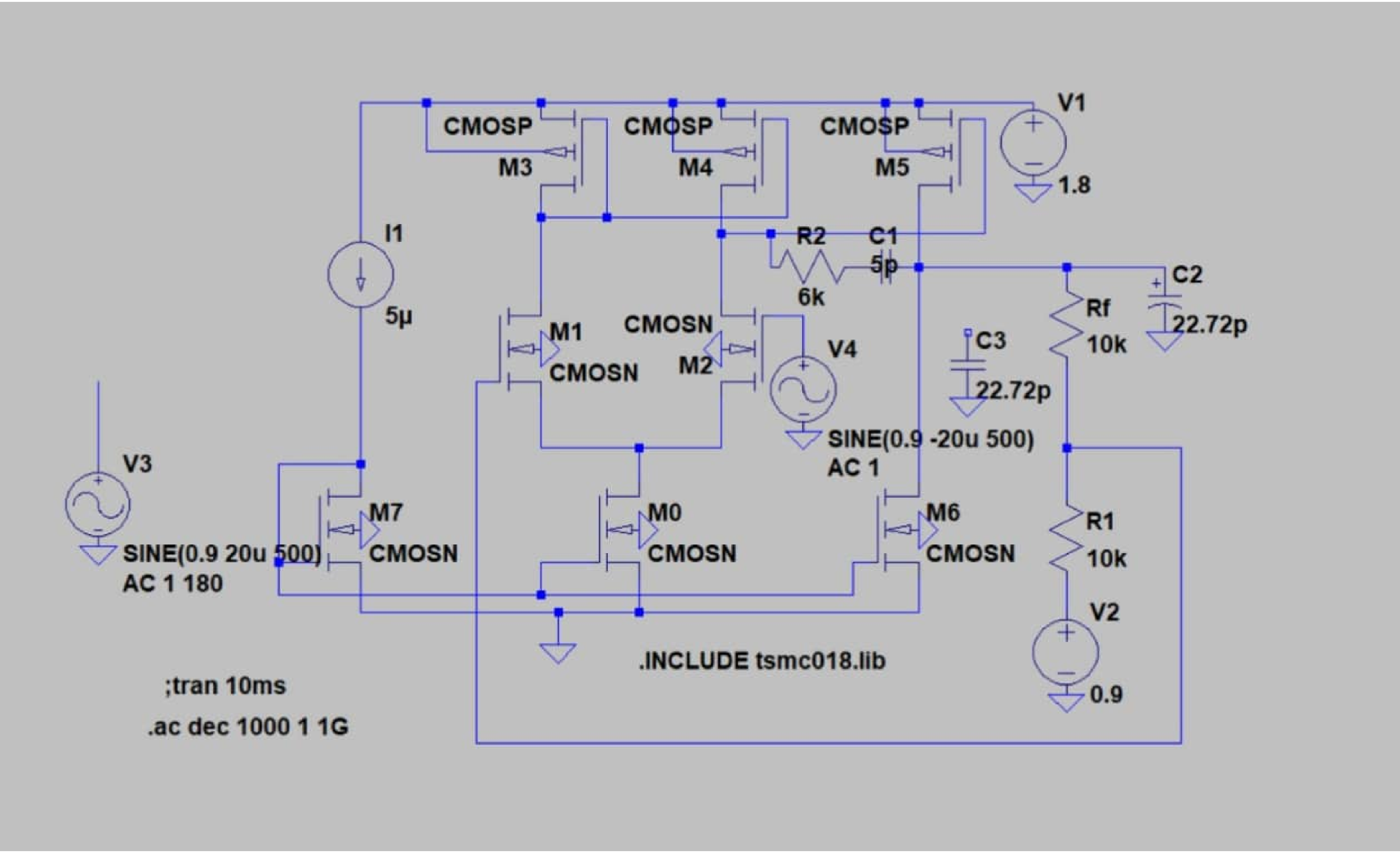
V1
1.8
CMOSP
M3
CMOSP
M4
CMOSP
M5
I1
5µ
R2
6k
C1
5p
C2
22.72p
Rf
10k
C3
22.72p
M1
CMOSN
CMOSN
M2
V4
SINE(0.9 -20u 500)
AC 1
V3
SINE(0.9 20u 500)
AC 1 180
M7
CMOSN
M0
CMOSN
M6
CMOSN
R1
10k
V2
0.9
.INCLUDE tsmc018.lib
;tran 10ms
.ac dec 1000 1 1G

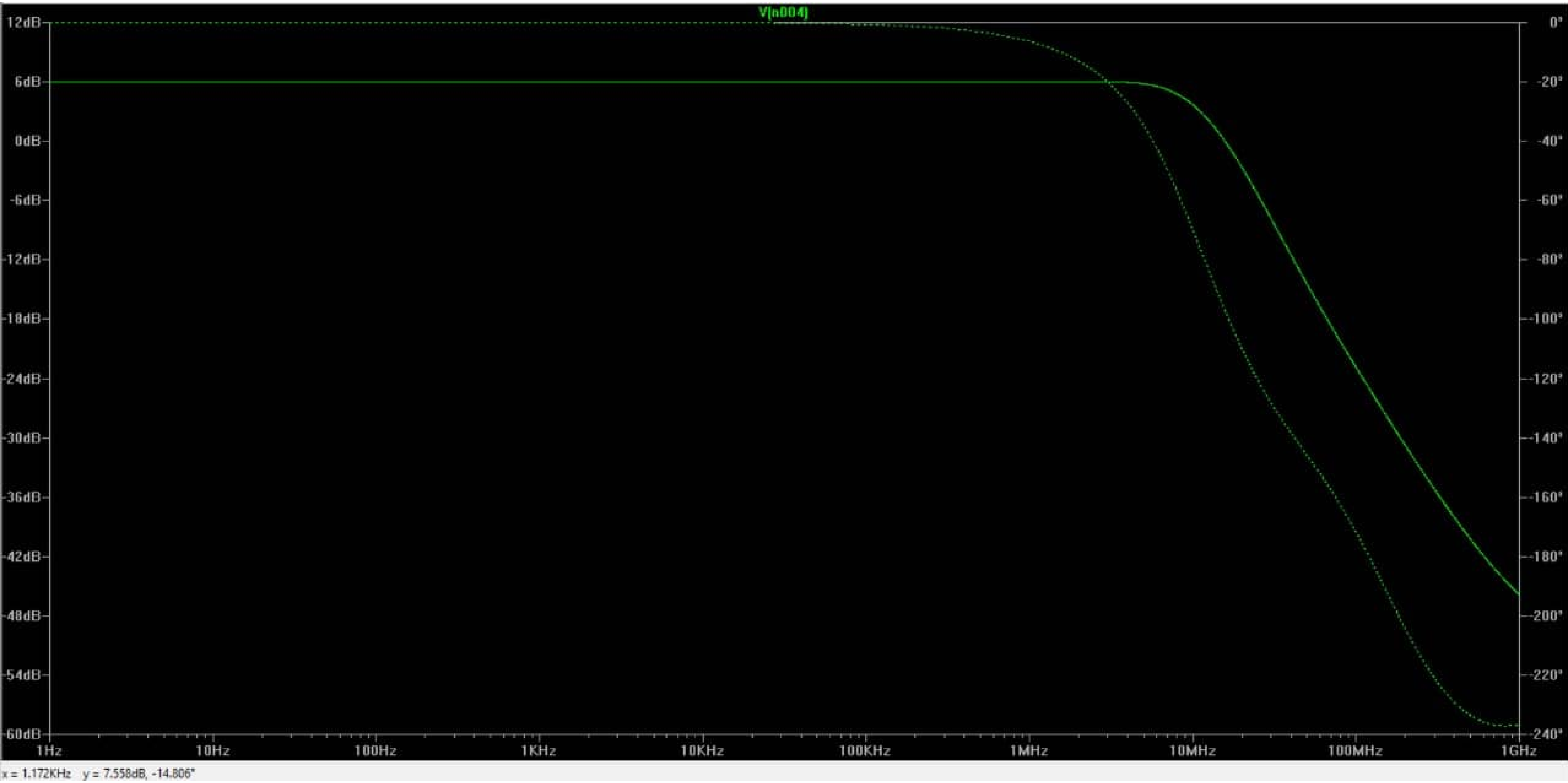

V(n004)
80dB
70dB
60dB
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
0°
-30°
-60°
-90°
-120°
-150°
-180°
-210°
-240°
-270°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
2stage_OTA_230102044
Cursor 1
V(n004)
Freq: 27.974613MHz
Mag: 7.217677mdB
Phase: -119.37036°
Group Delay: 2.5096614ns
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--


V1
1.8
CMOSP
M3
CMOSP
M4
CMOSP
M5
I1
5µ
R2
6k
C1
5p
C2
22.72p
Rf
10k
M1
CMOSN
CMOSN
M2
V4
PULSE(0.9 1.1 1ms)
C3
22.72p
V3
SINE(0.9 20u 500)
AC 1 180
M7
CMOSN
M0
CMOSN
M6
CMOSN
R1
10k
V2
0.9
.INCLUDE tsmc018.lib
.tran 10ms



2stage_OTA_230102044
2stage_OTA_230102044
V(n004)
32V
28V
24V
20V
16V
12V
08V
04V
00V
96V
92V
88V
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10m


V1
1.8
CMOSP
M3
CMOSP
M4
CMOSP
M5
I1
5µ
R2
6k
C1
5p
C2
22.72p
Rf
10k
CMOSN
M1
CMOSN
M2
V4
C3
22.72p
SINE(0.9 -20u 500)
AC 1
V3
SINE(0.9 20u 500)
AC 1 180
M7
CMOSN
M0
CMOSN
M6
CMOSN
R1
10k
V2
0.9
.INCLUDE tsmc018.lib
;tran 10ms
.ac dec 1000 1 1G


V(n004)
12dB
6dB
0dB
-6dB
-12dB
-18dB
-24dB
-30dB
-36dB
-42dB
-48dB
-54dB
-60dB
0°
-20°
-40°
-60°
-80°
-100°
-120°
-140°
-160°
-180°
-200°
-220°
-240°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
x = 1.172KHz y = 7.558dB, -14.806°