Design assignment-2

2-stage OTA

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of —
given with.

$V_{tn} = 0.37V$ $V_{tp} = 0.39V$ $\mu_n C_{ox} = 230 \mu A/V^2$ $\mu_p C_{ox} = 109 \mu A/V^2$

$V_{dd} = 1.8V$ $L_{min} = 0.18\mu m$, $W_{min} = 0.27\mu m$

assumptions

$V_{OD} = 200mV$.

(DC gain) $A_{DC} \geq 1000$ or 60dB.

Slew rate $\geq 10 V/\mu sec$

$C_L = 5pF$.

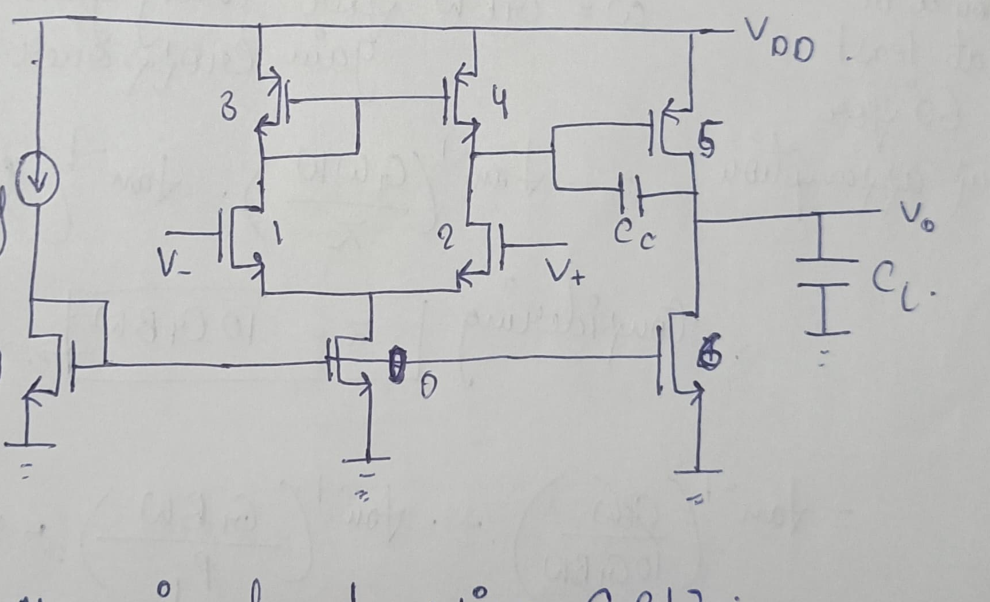
Specifications

Phase margin (PM) $\geq 60°$

GBW = 5MHz.

ICMR(+) = 1.6V.

ICMR(−) = 0.8V.



→ $\left(\frac{W}{L}\right)$ of M_1, M_2 is found using GBW.
→ $\left(\frac{W}{L}\right)$ of M_3, M_4 is found using ICMR (+).
→ $\left(\frac{W}{L}\right)$ of of M_0 is found using ICMR (−)
→ I_S is found using Slew rate.
→ $\left(\frac{W}{L}\right)$ of M_5 using phase Margin & zero Location

→ (W/L) of M_7 by M_5 (related)

→ C_c using C_2 & phase Margin.

I. Calculations

for $PM \geq 60^\circ$; $C_c \geq 0.22 C_L$.

Since OTA is 2nd order System its tf can be of type

$$\frac{V_o}{V_{in}} = \frac{A_{DC}(1 - s/z)}{(1 + s/P_1)(1 + s/P_2)}.$$

P_1, P_2 → poles of system

z → zero of system.

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

Should be at least 60° for our assumption

$\omega = GBW$ for unity gain or is gain cross over frequency.

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

Considering $\boxed{z = 10\,GBW}$ → for zero to be far apart.

$$= \tan^{-1}\left(\frac{\cancel{GBW}}{10\cancel{GBW}}\right) - \tan^{-1}\left(\frac{GBW}{P_1}\right) - \tan^{-1}\left(\frac{GBW}{P_2}\right).$$

as we know $\boxed{GBW} = \dfrac{g_{m1}}{C_c}$

$\boxed{z} = \dfrac{g_{m6}}{C_c}$ $\quad\boxed{P_2} = \dfrac{g_{m6}}{C_{OL}}$

$\boxed{A_{DC}} = (g_{m1} g_{m6}) R_2 R_1$ $\quad \boxed{P_1} = \dfrac{1}{g_{m6}\underbrace{(r_{o6}||r_{o7})}_{R_1} g_{m1}\underbrace{(r_{o2}||r_{o4})}_{R_2} C_c}$

$R_1 \cdot R_2 = (r_{o2}||r_{o4})(r_{o6}||r_{o7})$

$$= -\tan^{-1}\left(\frac{1}{10}\right) - \tan^{-1}\left(\frac{g_{m1}}{\cancel{C_c}} \times \frac{g_{m6} R_1 R_2 \cancel{C_c}}{}\right) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$\nearrow 90^\circ$$

$$-180^\circ + PM = -\tan^{-1}\left(\frac{1}{10}\right) - \tan^{-1}(A_{DC}) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

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

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

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

$$24.29 = \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$\frac{GBW}{P_2} = 0.4513 \Rightarrow P_2 = 2.2\,GBW$$

$$z = 10\,GBW.$$

$$\frac{g_{m6}}{\cancel{C_c}} = 10\frac{g_{m1}}{\cancel{C_c}}$$

$$\frac{g_{m6}}{C_L} \geq 2.2\frac{g_{m1}}{C_c}$$

$$\frac{10\cancel{g_{m1}}}{C_L} \geq 2.2\frac{\cancel{g_{m1}}}{C_c}$$

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

as $C_L = 10pF$.

$C_c \geq 2.2pF$.

Let $C_c = 3pF$.

$$\text{Slew rate} = \frac{I_s}{C_c}.$$

$$I_s = 10\ V/\mu s \times 3\,pf = 30\mu A.$$

So for M_1 & M_2.

$$g_{m_1} = GBW \cdot C_c \cdot 2\pi = 5\times10^{6} \times 3\times10^{-12} \times 2\pi.$$

$$= 94.24\times10^{-6}\ s = 94.24\ \mu s$$

$$I_s = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{OD})^2.$$

$$g_{m_1} = \sqrt{2 I_s \mu_n C_{ox}\left(\frac{W}{L}\right)_1}.$$

$$\frac{g_{m_1}^2}{2 I_s \mu_n C_{ox}} = \left(\frac{W}{L}\right)_1.$$

$$\left(\frac{W}{L}\right)_{1,2} = \frac{(94.24\,\mu)^2}{230\times 2\times 30\times10^{-6}}.$$

$$= \frac{8881.1776\times \cancel{10^{-12}}}{\cancel{10^{-6}}\times230\times 2\times 30\times \cancel{10^{-6}}} = 1.287$$

$$\approx 2.$$

So for M_3 & M_4.

$$\left(\frac{W}{L}\right)_{3,4} = \frac{2 I_{D_3}}{\mu_p C_{ox}\left[V_{DD} - ICMR(+) - V_{t_3} + V_{t_1}\right]^2}$$

$$= \frac{30\times\cancel{10^{-6}}}{100\times\cancel{10^{-6}}\left[1.8 - 1.6 - 0.39 + 0.37\right]^2}$$

$$= 9.259$$

$$\approx 10.$$

Since $ICMR(+) = V_{DD} - \sqrt{\frac{I_s}{\beta_3}} - V_{t3_{max}} + V_{t1_{min}}$

as $ICMR(+) - V_{t,min} < V_{G3}$

$$V_{G3} = V_{DD} - V_{OD_3} - V_{tp}$$

for M_0 & M_7

$$V_{D(sat)_0} = ICMR(-) - V_{SS} - \sqrt{\frac{I_s}{\beta_1}} - V_{th,max}$$

$\therefore$ $ICMR(-) - V_{OD_1} - V_{th,max} = V_{d\,Sat_0}$

$(V_{SS} = 0)$

$$V_{D(Sat)_S} = 0.8 - 0.319 - 0 - 0.38$$

$$= 0.1$$

$$\left(\frac{W}{L}\right)_0 = \frac{2 I_s}{\mu_n C_{ox} (V_D Sat_0)^2} = \frac{2 \times 30}{230 \times (0.1)^2}$$

$$= 26.0$$

$$\left(\frac{W}{L}\right)_{0,7} = 26. \qquad \sim 26.$$

for M_5

$$g_{m_5} = 10 g_{m_1} := 942.4\,\mu.$$

$$g_{m_4}^2 = 2 I_4 \mu_p C_{ox} \left(\frac{W}{L}\right)_4.$$

$$g_{m_4} = \sqrt{2 \times 1.5 \times 100 \times 10 \times 10^{-6} \times 10^{-6}}.$$

$$= 173.2\,\mu$$

Since M_4 & M_5 have equal overdrives.

$$\left(\frac{W}{L}\right)_5 = \frac{g_{m6} \times \left(\frac{W}{L}\right)_4}{g_{m4}}.$$

$$\left(\frac{W}{L}\right)_5 = \frac{942.4 \times \cancel{10^{-6}} \times 10}{173.2 \times \cancel{10^{-6}}}.$$

$$= 54.41.$$

$$\sim 55.$$

for M_6: $I_5 = \frac{\left(\frac{W}{L}\right)_5 \times I_4}{\left(\frac{W}{L}\right)_4} = \frac{55 \times 15 \times 10^{-6}}{10}.$

equal to I_6

$$= 82.5 \mu A.$$

$$\left(\frac{W}{L}\right)_6 = \frac{I_7 \times \left(\frac{W}{L}\right)_0}{I_0} = \frac{82.5 \times \cancel{10^{-6}} \times 26}{30 \times \cancel{10^{-6}}}$$

$$= 71.5 \sim 72.$$

Here for No Systematic offsets.

$$\frac{2 \times (W/L)_6}{(W/L)_0} = \frac{(W/L)_5}{(W/L)_4} \text{ is satisfied}$$

$$= 5.5.$$

$I_{dc} = 30\,\mu A$ $\qquad C_c = 3\,pF$ $\qquad C_L = 10\,pF$

Since $L_{min} = 180$ nm.

Considering $L = 180$ nm

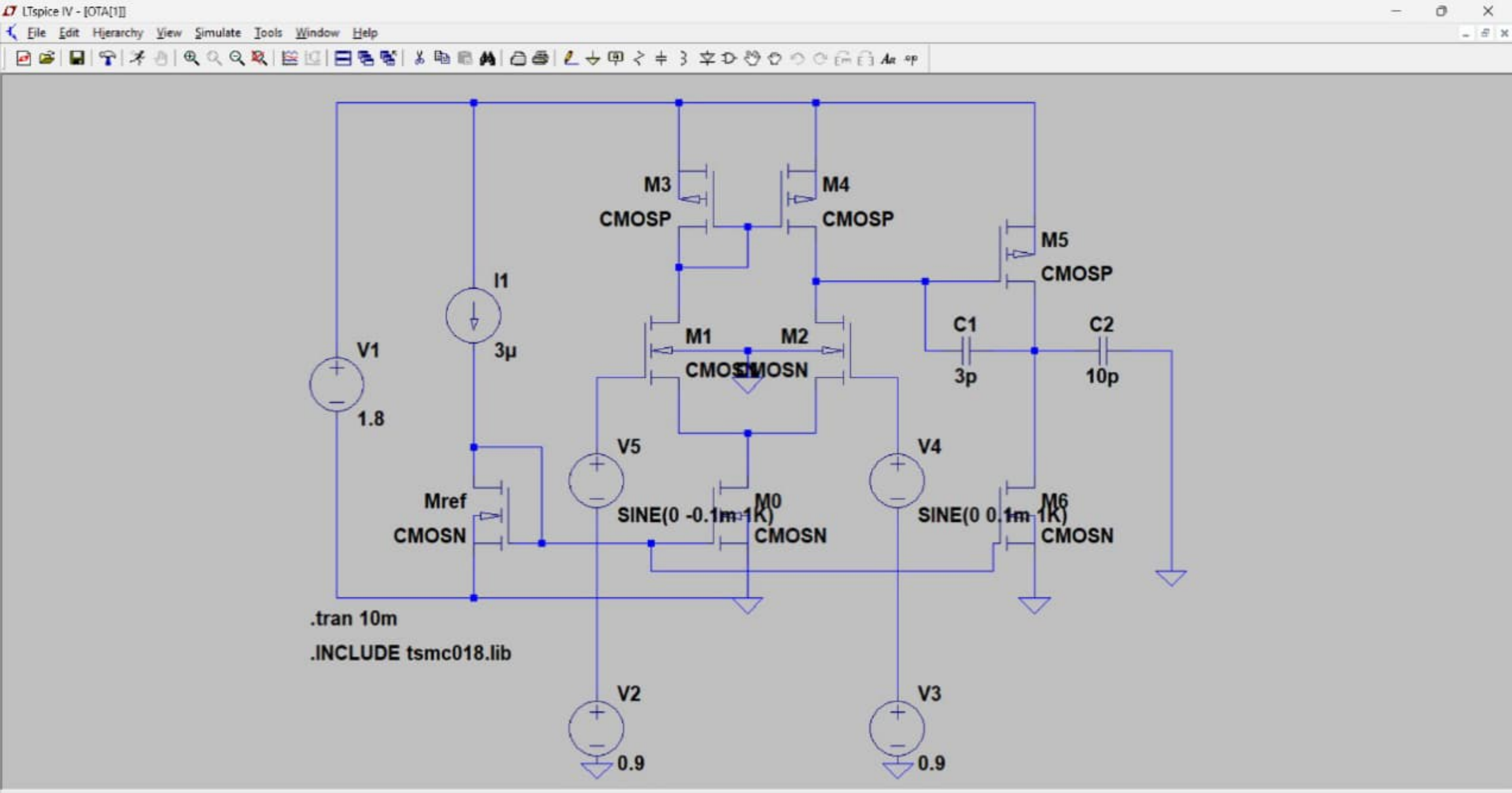
Initial Values.

$M_{1,2}$ $g_{m_{1-2}} =$	$W = 3600$ nm	$L = 180$ nm	$r_{o_{1-2}} =$
$M_{3,4}$ $g_{m_{3-4}} =$	$W = 1.8\,\mu m$	$L = 180$ nm	$r_{o_{3-4}} =$
M_0 $g_{m_0} =$	$W = 4.680\,\mu m$	$L = 180$ nm	$r_{o_0} =$
M_5 $g_{m_5} =$	$W = 9.9\,\mu m$	$L = 180$ nm	$r_{o_5} =$
M_6 $g_{m_6} =$	$W = 12.96\,\mu m$	$L = 80$ nm	$r_{o_6} =$
M_7	$W = 4.680\,\mu m$	$L = 180$ nm	

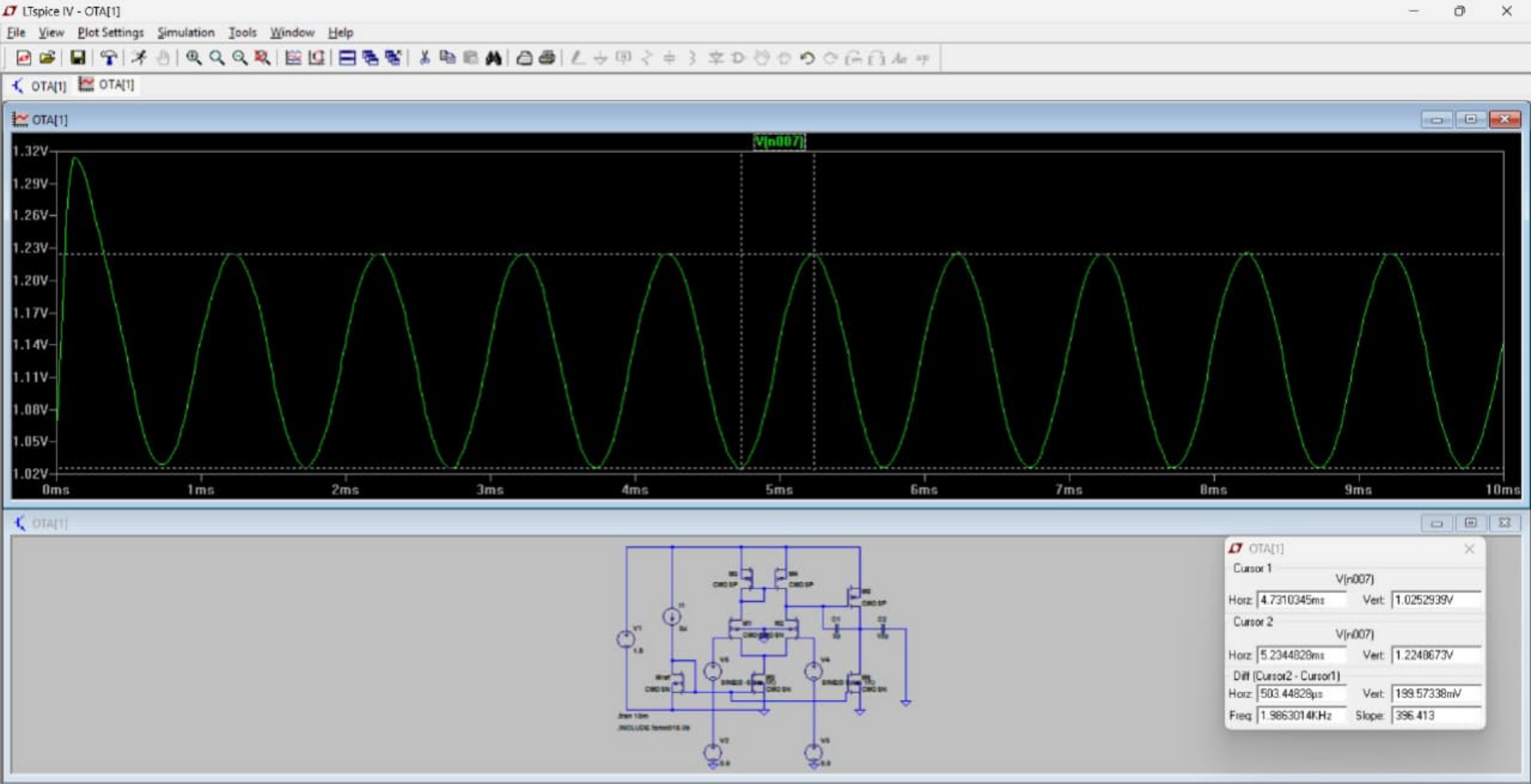
for these values I got gain of 55dB after fine tuning it.

for gain of 60

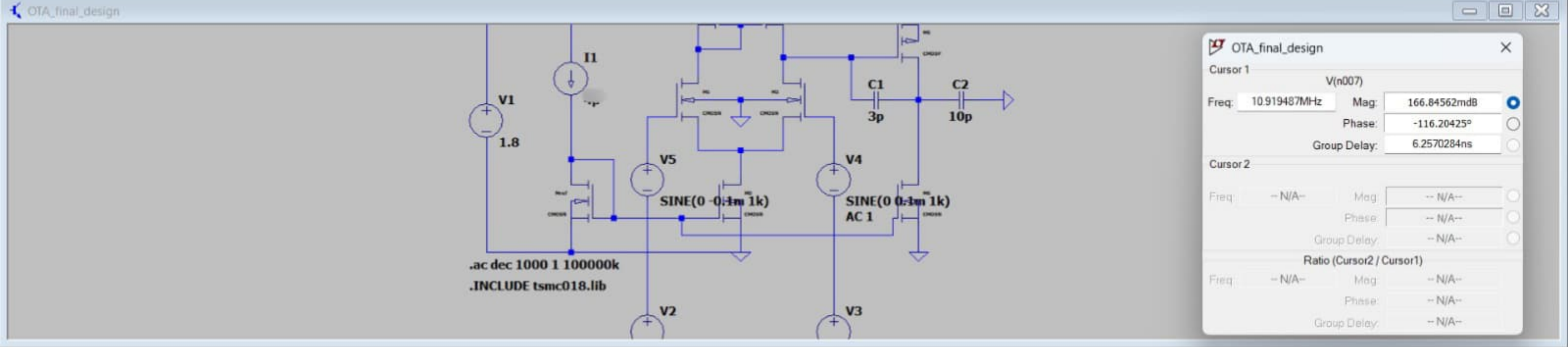
M_{1-2}	$W = 1.8\,\mu m$	$L = 180$ nm
M_{3-4}	$W = 2.2\,\mu m$	$L = 180$ nm
M_0	$W = 8\,\mu m$	$L = 180$ nm
M_5	$W = 25\,\mu m$	$L = 180$ nm
M_6	$W = 23\,\mu m$	$L = 180$ nm
M_7	$W = 5\,\mu m$	$L = 180$ nm



LTspice IV - [OTA[1]]
File Edit Hierarchy View Simulate Tools Window Help
M3
CMOSP
M4
CMOSP
M5
CMOSP
I1
3µ
V1
1.8
M1
M2
C1
3p
C2
10p
V5
V4
Mref
CMOSN
SINE(0 -0.1m 1K)
CMOSN
SINE(0 0.1m 1K)
CMOSN
.tran 10m
.INCLUDE tsmc018.lib
V2
0.9
V3
0.9


LTspice IV - OTA[1]
File View Plot Settings Simulation Tools Window Help
OTA[1]
OTA[1]
OTA[1]
V(n007)
1.32V
1.29V
1.26V
1.23V
1.20V
1.17V
1.14V
1.11V
1.08V
1.05V
1.02V
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
OTA[1]
OTA[1]
Cursor 1
V(n007)
Horz: 4.7310345ms
Vert: 1.0252939V
Cursor 2
V(n007)
Horz: 5.2344828ms
Vert: 1.2248673V
Diff (Cursor2 - Cursor1)
Horz: 503.44828µs
Vert: 199.57338mV
Freq: 1.9863014KHz
Slope: 396.413


OTA_final_design
V(n007)
64dB
56dB
48dB
40dB
32dB
24dB
16dB
8dB
0dB
-8dB
-16dB
-24dB
-32dB
20°
0°
-20°
-40°
-60°
-80°
-100°
-120°
-140°
-160°
-180°
-200°
-220°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz


OTA_final_design
I1
V1
1.8
V5
V4
C1
3p
C2
10p
SINE(0 -0.1m 1k)
SINE(0 0.1m 1k)
AC 1
.ac dec 1000 1 100000k
.INCLUDE tsmc018.lib
V2
V3
OTA_final_design
Cursor 1
V(n007)
Freq: 10.919487MHz
Mag: 166.84562mdB
Phase: -116.20425°
Group Delay: 6.2570284ns
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--

$r_{o1-2} = 4.7\,k\Omega$	$g_{m_{1-2}} = 10^{-5} = 10\,\mu S$
$r_{o_0} = 2.5\,k\Omega$	$g_{m_0} = 2 \times 10^{-5} = 20\,\mu S$
$r_{o_5} = 416\,\Omega$	$g_{m_5} = 0.12 \times 10^{-3} = 0.12\,mS$
$r_{o_{3-4}} = 4.7\,k\Omega$	$g_{m_{3-4}} = 10^{-5} = 10\,\mu S$
$r_{o_6} = 416\,\Omega$	$g_{m_6} = 0.12 \times 10^{-3} = 0.12\,mS$
$r_{o_7} = 3.34\,k\Omega$	$g_{m_7} = 15\,\mu S$