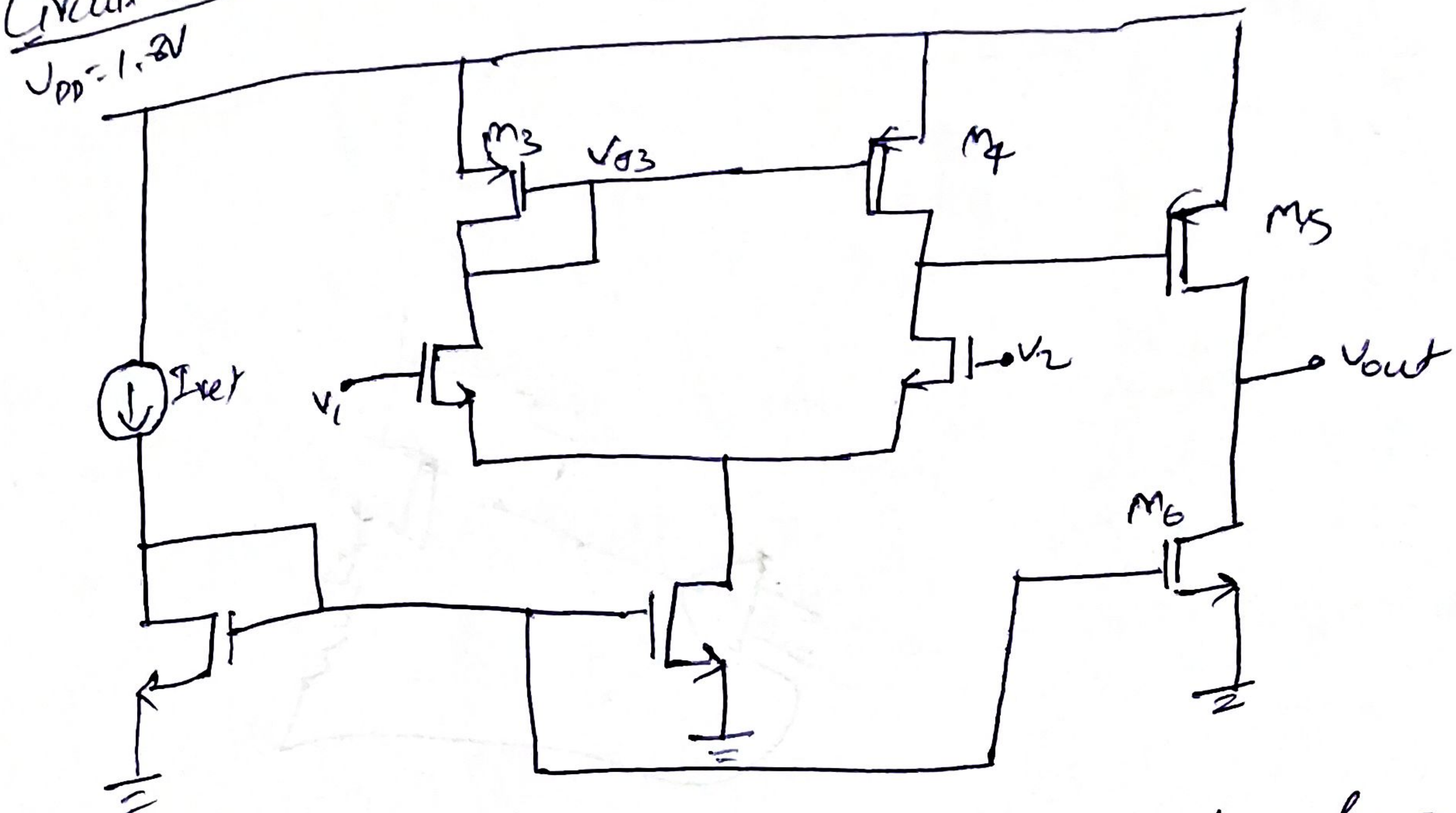
Name: Anshuman Mondal
Roll No:- 230102009
Branch: ECE

EE-206

OTA Assignment

Circuit Diagram: (2 stage OTA analysis-AC)

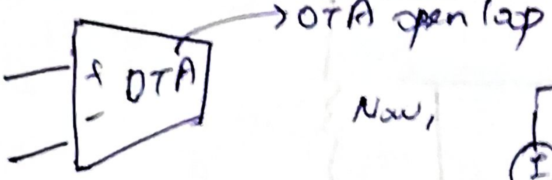


* Calculations: $V_2 \rightarrow$ is the AC signal of 50 μV amplitude & 0.9 VDC (off-set)

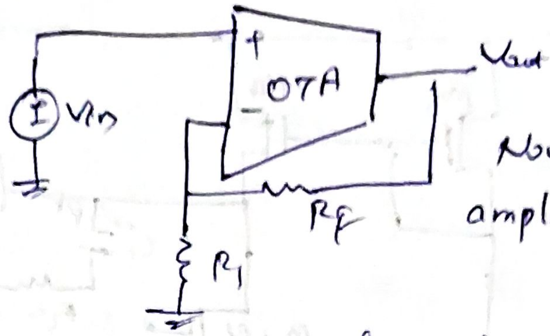
$V_1 = 0.9$ Vdc, 50 μV opposite phase (180° out of phase)

{for maximum swing, the output doesn't clip}

* Closed loop:



Now,



Now considering infinite amplification,

$V_P = V_- = V_{in}$

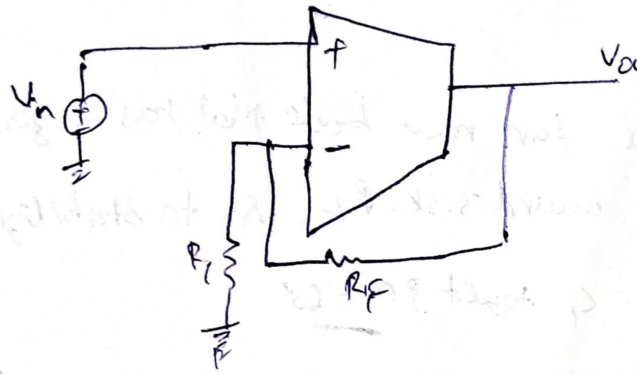
So, applying KCL at V_-

we get, $\frac{V_- - V_{out}}{R_F} + \frac{V_-}{R_1} = 0 \Rightarrow \frac{V_{out}}{V_-} = \frac{R_1 + R_F}{R_1} = \boxed{1 + \frac{R_F}{R_1}}$

So, if $R_F = R_1$ we get 2 & $\boxed{R_F = R_1 = 10.2k\Omega}$

but the OTA, we have designed has a finite A

i.e., $\underline{4862.95} \approx 73dB$



$V_P = V_{in}$

$V_{out} = (V_P - V_-)A$

$\Rightarrow V_{out} - A\,V_{in} = -AV_-$

$\Rightarrow \boxed{V_- = \frac{A V_{in} - V_{out}}{A}}$

So, using KCL at V_-

$$\frac{\left(\frac{AV_{in} - V_{out}}{A}\right)}{R_1} + \frac{\left(\frac{AV_{in} - V_{out}}{A}\right) - V_{out}}{R_F} = 0 \Rightarrow \frac{V_{in}}{R_1} + \frac{V_{in}}{R_F} = V_{out}\left[\frac{1}{AR_1} + \frac{1}{R_F} + \frac{1}{AR_F}\right]$$

$$V_{in}\left(\frac{R_1 + R_F}{R_1 R_F}\right) = V_{out}\left[\frac{R_F + AR_1 + R_1}{AR_1R_F}\right]$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{A(R_1 + R_F)}{AR_1 + R_1 + R_F} = \left(1 + \frac{R_F}{R_1}\right)\left[\frac{A}{(A+1) + \frac{R_F}{R_1}}\right]$$

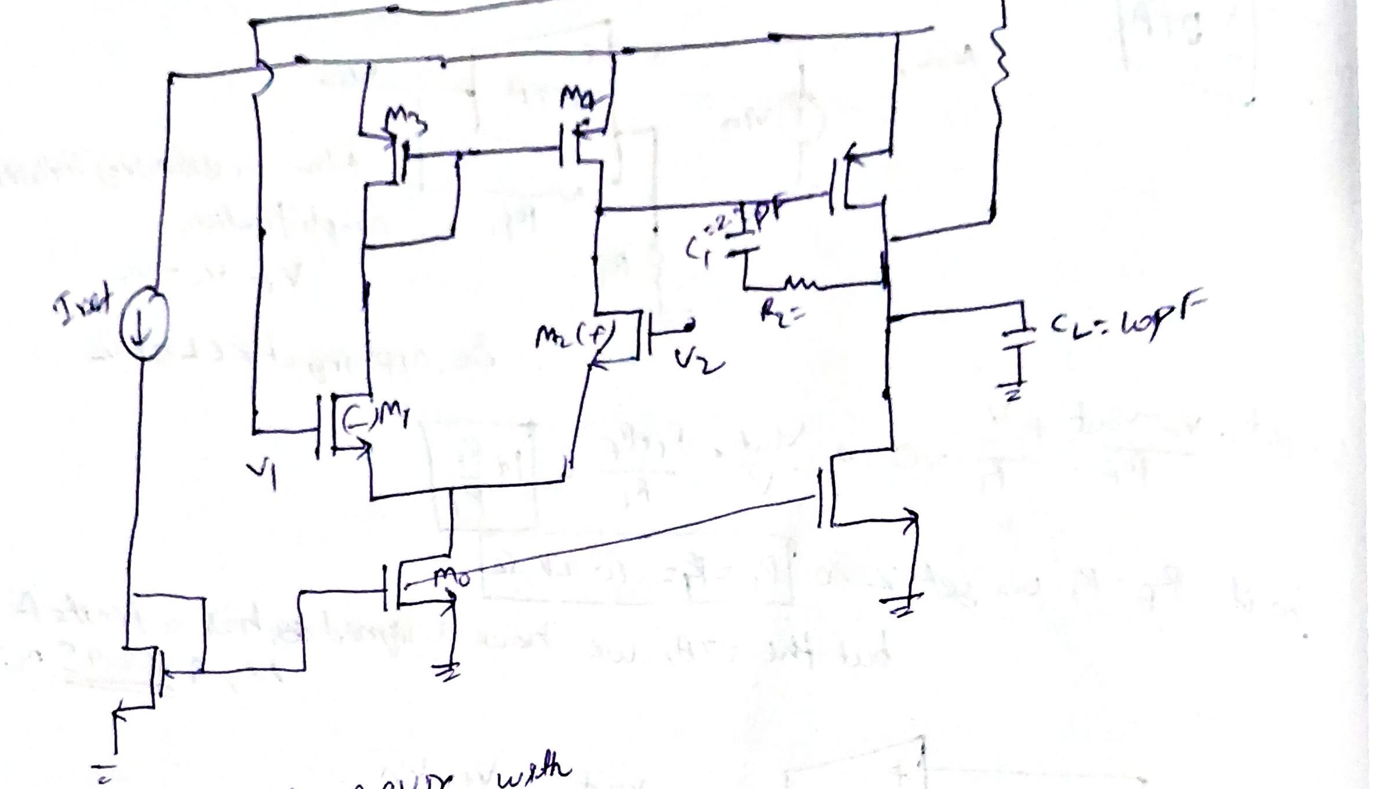
for closed loop system, Gain $= \frac{G}{1+GH} = \frac{4862.95}{1 + 4862.95(0.5)}$

$\boxed{H = \left(1 + \frac{R_F}{R_1}\right)^{-1}}$

$= 0.5$

$= \boxed{1.99}$

Closed loop circuit Diagram:



$V_1 = 0.9V\,DC$, $V_2 = 0.9V\,DC$ with

Taken, $C_1 = 2.2pF$, $C_L = 10pF$, poles are far now bode plot has a zero due to which i got a PM ~ 20° around $3.3K = R_Z$ so to stabilize it I adjusted R_Z in series with C_1 to get PM = 60°

I chose $\boxed{R_Z = 3.75K\Omega}$ for which I have my phase margin ≈ 60° (observed)

Bandwidth observed (f_{3dB}) ≈ $\boxed{9.49MHz}$

* Location of dominant poles of the system:

$$\omega_p = \frac{1}{AC_1\,(r_{o5} \| r_{o6})} = \frac{10^{12} \times 10^{-6}}{33.864 \times 2.2 \times 0.33}$$

$$= 10^6 \times 0.0406$$

$$= \boxed{40.6KHz}$$

A_2 (practical) $= \frac{48629.5}{1436}$

$= \boxed{33.864}$

$r_{o5} = r_{o6} \cong 0.667M\Omega$

~~Closed lo~~

Closed Loop:

Theoretical gain of overall circuit ≈ 1.99

Gain needed $= 2$

Practical gain

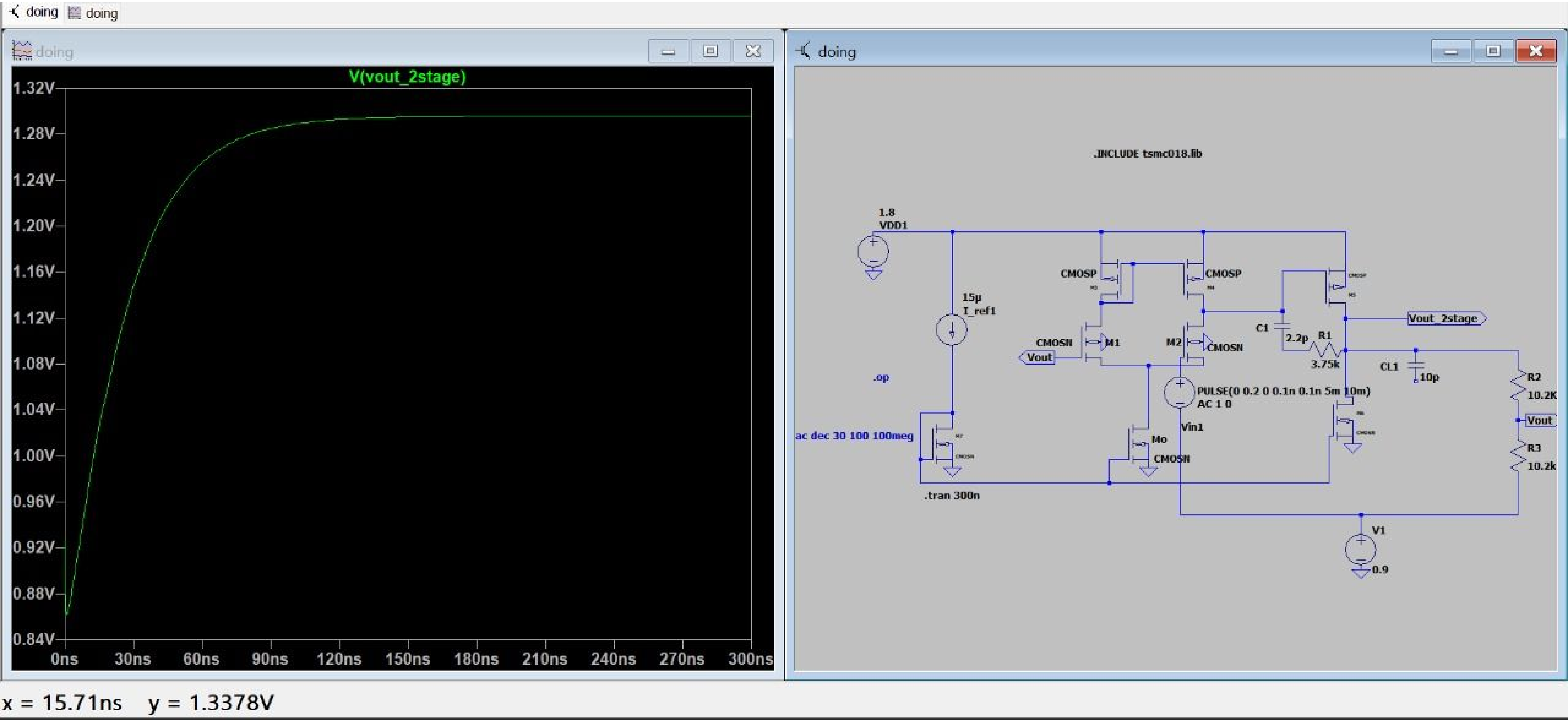
observed from simulation $= \frac{19.65\,mV}{10\,mV}$ $\qquad \frac{V_{out}(PP)}{V_{in}\,PP}$

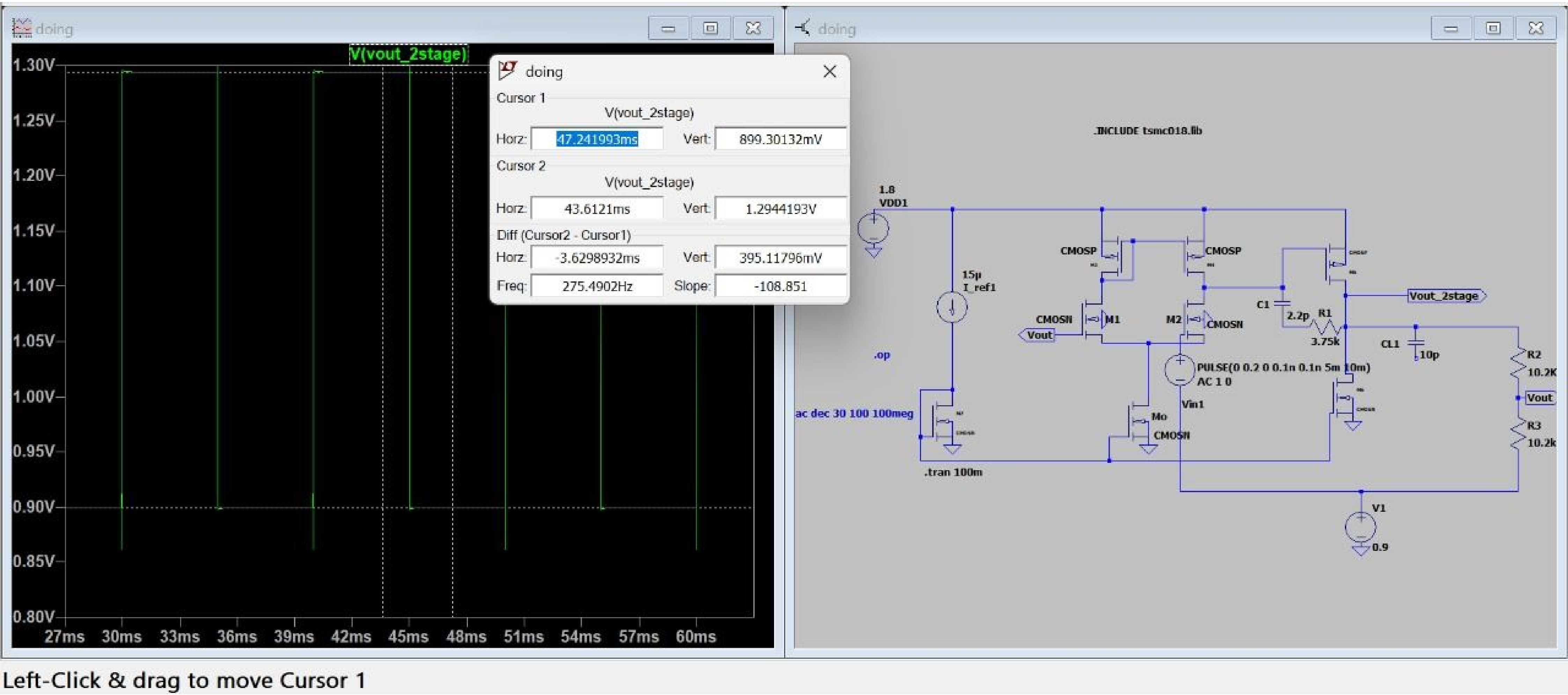
$\approx \boxed{1.965}$

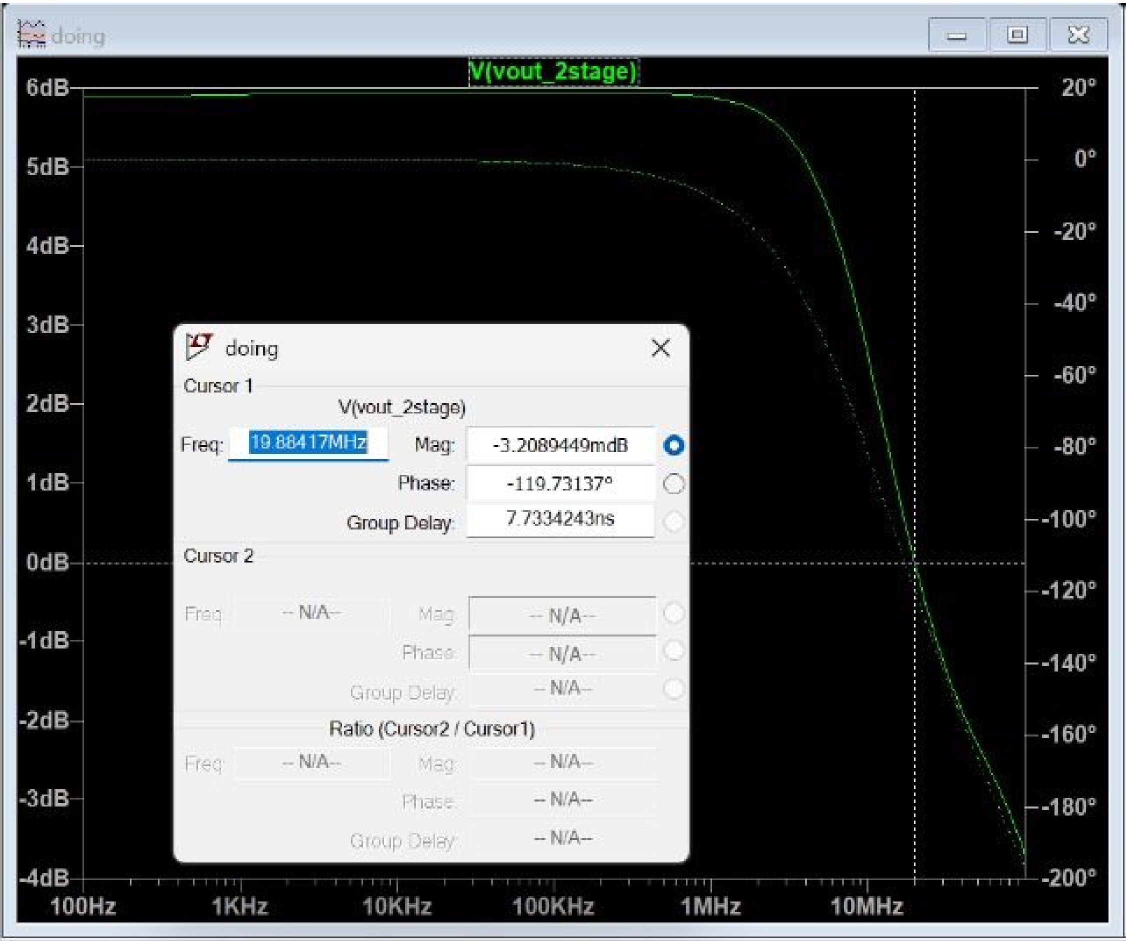
∴ error $= -1.256\%$

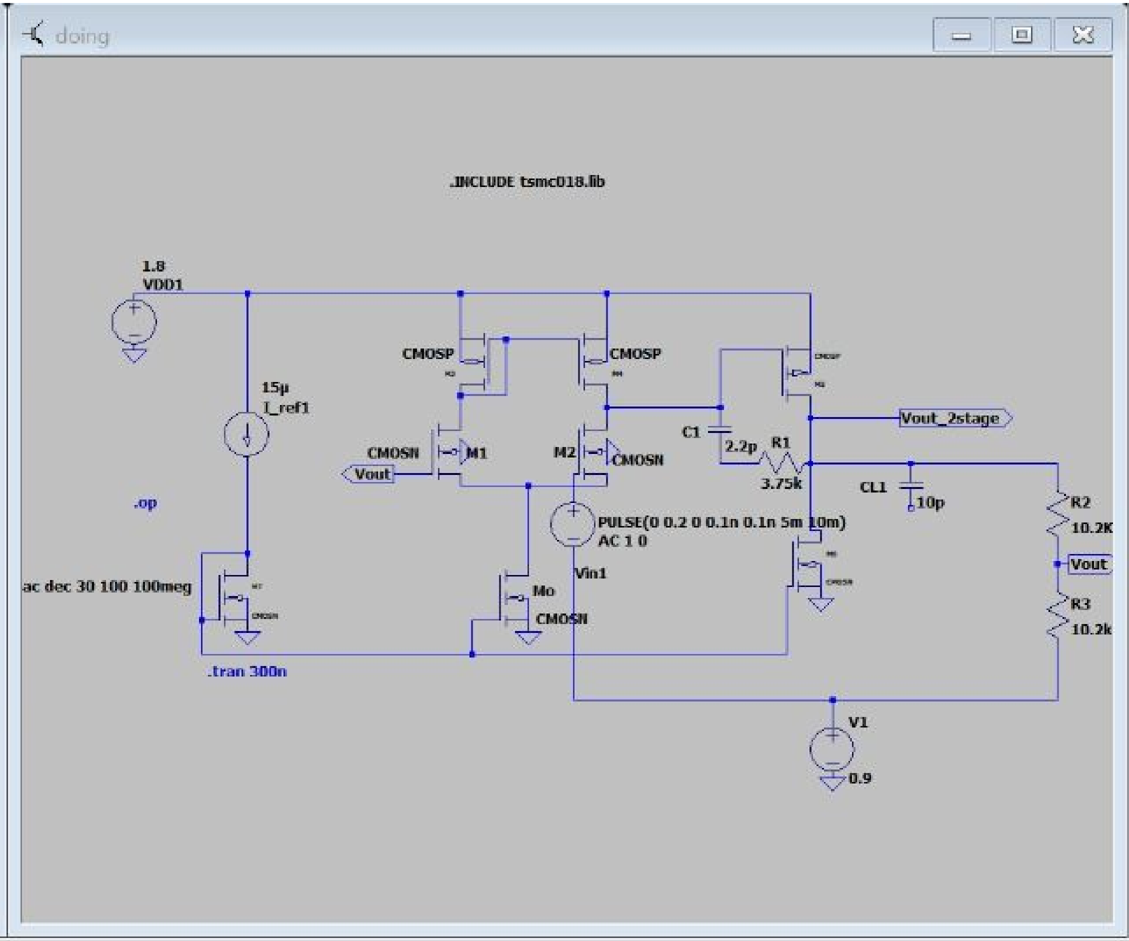
for 0.2V step input, observed $V_{out} = |898 - 1294.92| = 396\,mV$, Gain $= 1.98$

'DC' analysis was attached in DC simulation file, previously uploaded

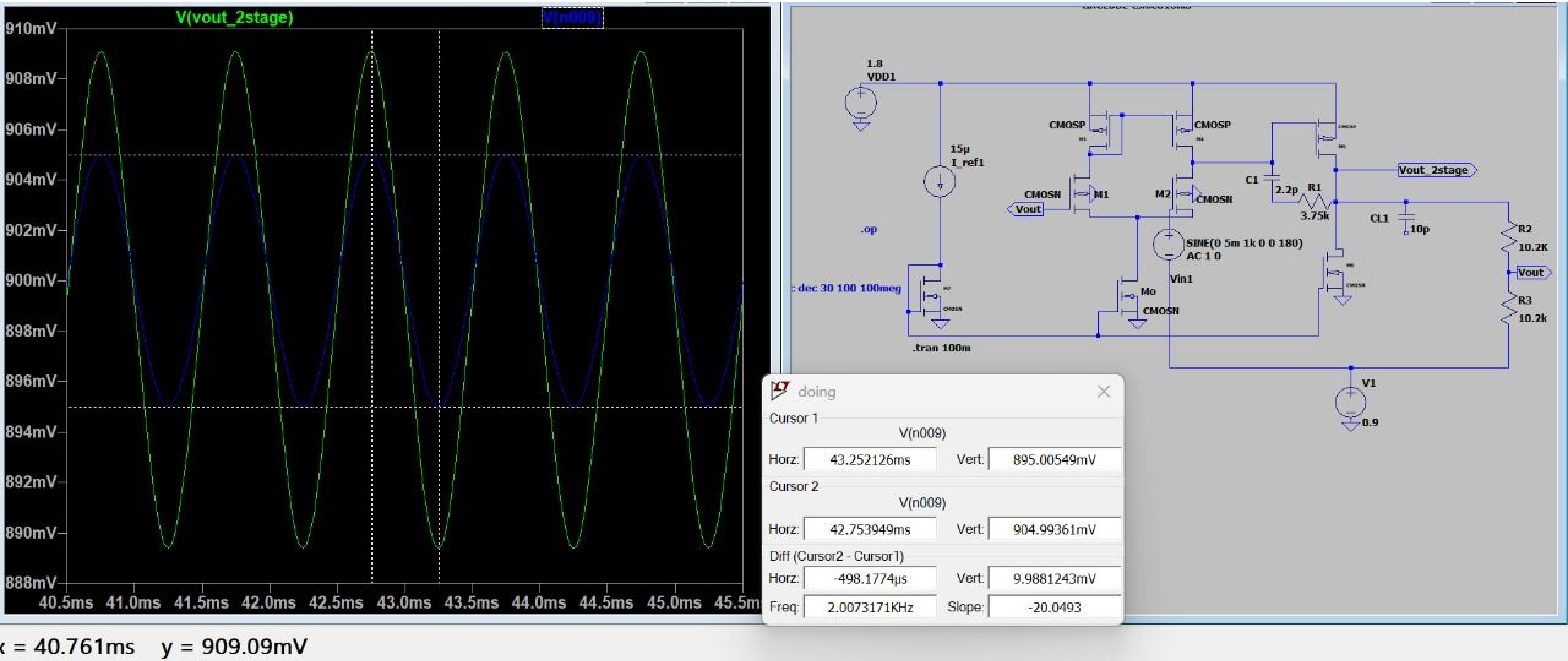

doing
doing
doing
V(vout_2stage)
1.32V
1.28V
1.24V
1.20V
1.16V
1.12V
1.08V
1.04V
1.00V
0.96V
0.92V
0.88V
0.84V
0ns
30ns
60ns
90ns
120ns
150ns
180ns
210ns
240ns
270ns
300ns
doing
.INCLUDE tsmc018.lib
1.8
VDD1
15μ
I_ref1
CMOSP
CMOSP
CMOSN
M1
M2
CMOSN
Vout
.op
C1
2.2p
R1
3.75k
CL1
10p
Vout_2stage
R2
10.2K
Vout
R3
10.2k
PULSE(0 0.2 0 0.1n 0.1n 5m 10m)
AC 1 0
Vin1
Mo
CMOSN
ac dec 30 100 100meg
.tran 300n
V1
0.9
x = 15.71ns y = 1.3378V


doing
V(vout_2stage)
1.30V
1.25V
1.20V
1.15V
1.10V
1.05V
1.00V
0.95V
0.90V
0.85V
0.80V
27ms 30ms 33ms 36ms 39ms 42ms 45ms 48ms 51ms 54ms 57ms 60ms
Cursor 1
V(vout_2stage)
Horz: 47.241993ms Vert: 899.30132mV
Cursor 2
V(vout_2stage)
Horz: 43.6121ms Vert: 1.2944193V
Diff (Cursor2 - Cursor1)
Horz: -3.6298932ms Vert: 395.11796mV
Freq: 275.4902Hz Slope: -108.851
.INCLUDE tsmc018.lib
1.8
VDD1
15µ
I_ref1
CMOSP
CMOSP
CMOSN
M1
M2
CMOSN
Vout
C1
2.2p
R1
3.75k
CL1
10p
Vout_2stage
R2
10.2K
Vout
R3
10.2k
.op
PULSE(0 0.2 0 0.1n 0.1n 5m 10m)
AC 1 0
Vin1
Mo
CMOSN
ac dec 30 100 100meg
.tran 100m
V1
0.9
Left-Click & drag to move Cursor 1

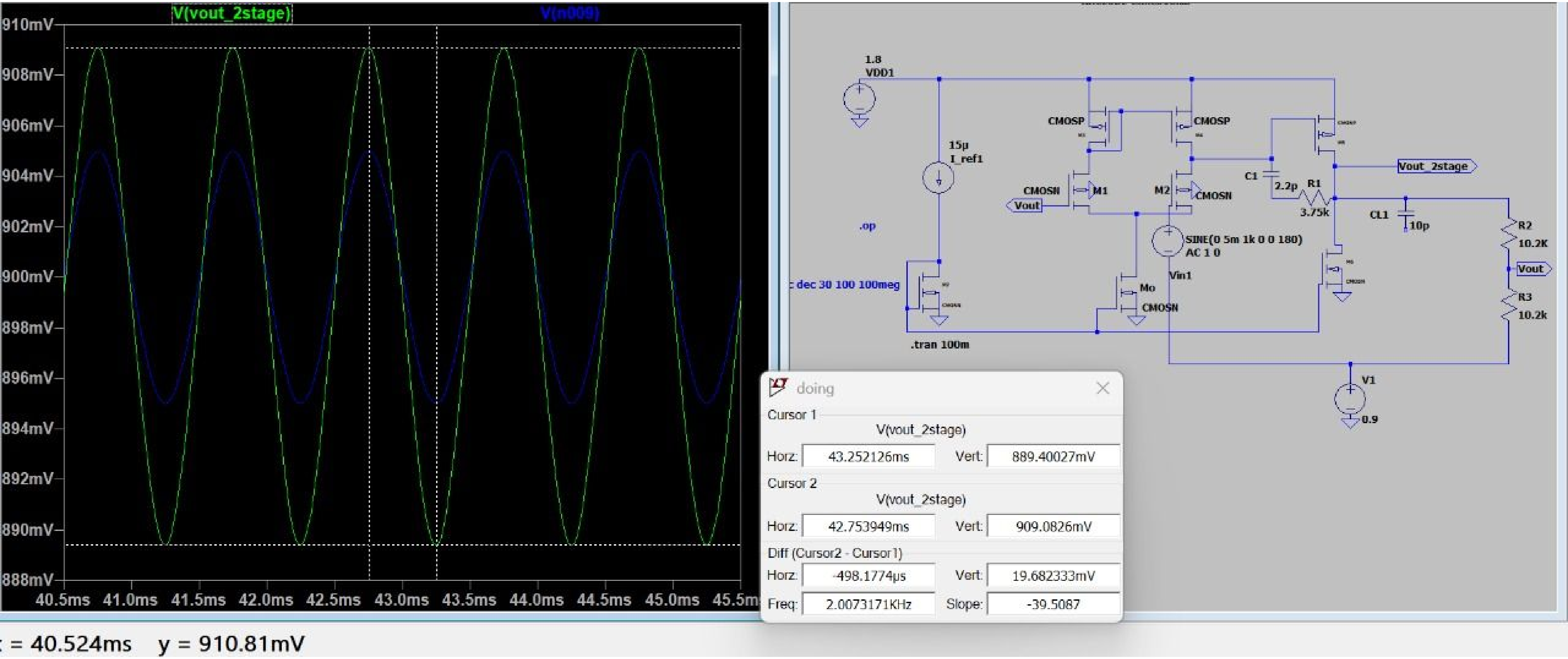




x = 5.672KHz y = 4.077dB, -22.308°



V(vout_2stage)
V(n009)
910mV
908mV
906mV
904mV
902mV
900mV
898mV
896mV
894mV
892mV
890mV
888mV
40.5ms 41.0ms 41.5ms 42.0ms 42.5ms 43.0ms 43.5ms 44.0ms 44.5ms 45.0ms 45.5m
1.8
VDD1
15µ
I_ref1
CMOSP
CMOSP
CMOSN
M1
M2
CMOSN
Vout
.op
C1
2.2p
R1
3.75k
CL1
10p
Vout_2stage
R2
10.2K
Vout
R3
10.2k
SINE(0 5m 1k 0 0 180)
AC 1 0
Vin1
Mo
CMOSN
: dec 30 100 100meg
.tran 100m
V1
0.9
doing
Cursor 1
V(n009)
Horz: 43.252126ms Vert: 895.00549mV
Cursor 2
V(n009)
Horz: 42.753949ms Vert: 904.99361mV
Diff (Cursor2 - Cursor1)
Horz: -498.1774µs Vert: 9.9881243mV
Freq: 2.0073171KHz Slope: -20.0493
x = 40.761ms y = 909.09mV


V(vout_2stage)
V(n009)
910mV
908mV
906mV
904mV
902mV
900mV
898mV
896mV
894mV
892mV
890mV
888mV
40.5ms 41.0ms 41.5ms 42.0ms 42.5ms 43.0ms 43.5ms 44.0ms 44.5ms 45.0ms 45.5ms
1.8
VDD1
15µ
I_ref1
CMOSP
CMOSP
CMOSN
M1
M2
CMOSN
Vout
C1
2.2p
R1
3.75k
CL1
10p
R2
10.2K
Vout
R3
10.2k
Vout_2stage
.op
SINE(0 5m 1k 0 0 180)
AC 1 0
Vin1
Mo
CMOSN
dec 30 100 100meg
.tran 100m
V1
0.9
doing
Cursor 1
V(vout_2stage)
Horz: 43.252126ms
Vert: 889.40027mV
Cursor 2
V(vout_2stage)
Horz: 42.753949ms
Vert: 909.0826mV
Diff (Cursor2 - Cursor1)
Horz: -498.1774µs
Vert: 19.682333mV
Freq: 2.0073171KHz
Slope: -39.5087
x = 40.524ms y = 910.81mV

```
Name:        m3          m4          m5
Model:      cmosp       cmosp       cmosp
Id:       -1.95e-05   -1.95e-05   -1.59e-05
Vgs:      -6.22e-01   -6.22e-01   -6.46e-01
Vds:      -6.22e-01   -6.46e-01   -9.01e-01
Vbs:      -1.37e-01   -1.38e-01   -1.41e-01
Vth:      -3.81e-01   -3.81e-01   -3.79e-01
Vdsat:    -1.88e-01   -1.88e-01   -2.05e-01
Gm:        1.54e-04    1.55e-04    1.13e-04
Gds:       1.47e-06    1.44e-06    9.46e-07
Gmb        4.19e-05    4.19e-05    3.06e-05
Cbd:       0.00e+00    0.00e+00    0.00e+00
Cbs:       0.00e+00    0.00e+00    0.00e+00
Cgsov:     6.43e-15    6.43e-15    4.29e-15
Cgdov:     6.43e-15    6.43e-15    4.29e-15
Cgbov:     8.41e-19    8.41e-19    8.41e-19
dQgdVgb:   7.28e-14    7.28e-14    4.85e-14
dQgdVdb:  -6.34e-15   -6.34e-15   -4.21e-15
dQgdVsb:  -6.60e-14   -6.60e-14   -4.41e-14
dQddVgb:  -3.03e-14   -3.03e-14   -2.02e-14
dQddVdb:   6.39e-15    6.39e-15    4.25e-15
dQddVsb:   3.06e-14    3.06e-14    2.04e-14
dQbdVgb:  -1.21e-14   -1.21e-14   -8.08e-15
dQbdVdb:  -1.52e-17   -1.17e-17    2.95e-18
dQbdVsb:  -1.70e-15   -1.69e-15   -1.03e-15


Total elapsed time: 0.135 seconds.
```

Semiconductor Device Operating Points:

--- BSIM3 MOSFETS ---

Name:	m1	m2	mo	m7	m6
Model:	cmosn	cmosn	cmosn	cmosn	cmosn
Id:	1.95e-05	1.95e-05	3.90e-05	1.50e-05	1.59e-05
Vgs:	6.57e-01	6.58e-01	5.85e-01	5.85e-01	5.85e-01
Vds:	9.36e-01	9.12e-01	2.42e-01	5.85e-01	8.99e-01
Vbs:	-2.42e-01	-2.42e-01	5.71e-02	9.06e-02	1.06e-01
Vth:	4.82e-01	4.82e-01	3.96e-01	3.84e-01	3.78e-01
Vdsat:	1.45e-01	1.45e-01	1.44e-01	1.50e-01	1.53e-01
Gm:	2.11e-04	2.11e-04	4.03e-04	1.49e-04	1.54e-04
Gds:	1.41e-06	1.42e-06	1.20e-05	1.24e-06	1.06e-06
Gmb	5.39e-05	5.40e-05	1.05e-04	3.69e-05	3.74e-05
Cbd:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Cbs:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Cgsov:	3.62e-15	3.62e-15	7.24e-15	2.41e-15	2.41e-15
Cgdov:	3.62e-15	3.62e-15	7.24e-15	2.41e-15	2.41e-15
Cgbov:	8.66e-19	8.66e-19	8.66e-19	8.66e-19	8.66e-19
dQgdVgb:	3.36e-14	3.36e-14	6.85e-14	2.28e-14	2.28e-14
dQgdVdb:	-3.53e-15	-3.53e-15	-7.53e-15	-2.36e-15	-2.36e-15
dQgdVsb:	-2.85e-14	-2.85e-14	-5.85e-14	-1.97e-14	-1.97e-14
dQddVgb:	-1.43e-14	-1.43e-14	-2.90e-14	-9.53e-15	-9.53e-15
dQddVdb:	3.57e-15	3.58e-15	7.60e-15	2.39e-15	2.38e-15
dQddVsb:	1.37e-14	1.37e-14	2.78e-14	9.19e-15	9.15e-15
dQbdVgb:	-5.12e-15	-5.11e-15	-1.06e-14	-3.70e-15	-3.72e-15
dQbdVdb:	7.45e-18	7.26e-18	-4.33e-16	2.43e-19	6.43e-18
dQbdVsb:	-2.43e-15	-2.43e-15	-4.38e-15	-1.11e-15	-9.77e-16

Name:	m3	m4	m5
Model:	cmosp	cmosp	cmosp
Id:	-1.95e-05	-1.95e-05	-1.59e-05
Vgs:	-6.22e-01	-6.22e-01	-6.46e-01
Vds:	-6.22e-01	-6.46e-01	-9.01e-01
Vbs:	-1.37e-01	-1.38e-01	-1.41e-01
Vth:	-3.81e-01	-3.81e-01	-3.79e-01
Vdsat:	-1.88e-01	-1.88e-01	-2.05e-01
Gm:	1.54e-04	1.55e-04	1.13e-04
Gds:	1.47e-06	1.44e-06	9.46e-07
Gmb	4.19e-05	4.19e-05	3.06e-05
Cbd:	0.00e+00	0.00e+00	0.00e+00
Cbs:	0.00e+00	0.00e+00	0.00e+00
Cgsov:	6.43e-15	6.43e-15	4.29e-15
Cgdov:	6.43e-15	6.43e-15	4.29e-15
Cgbov:	8.41e-19	8.41e-19	8.41e-19
dQgdVgb:	7.28e-14	7.28e-14	4.85e-14
dQgdVdb:	-6.34e-15	-6.34e-15	-4.21e-15
dQgdVsb:	-6.60e-14	-6.60e-14	-4.41e-14
dQddVgb:	-3.03e-14	-3.03e-14	-2.02e-14
dQddVdb:	6.39e-15	6.39e-15	4.25e-15
dQddVsb:	3.06e-14	3.06e-14	2.04e-14
dQbdVgb:	-1.21e-14	-1.21e-14	-8.08e-15
dQbdVdb:	-1.52e-17	-1.17e-17	2.95e-18
dQbdVsb:	-1.70e-15	-1.69e-15	-1.03e-15

Total elapsed time: 0.097 seconds.

Semiconductor Device Operating Points:

--- BSIM3 MOSFETS ---

Name:	m1	m2	mo	m7	m6
Model:	cmosn	cmosn	cmosn	cmosn	cmosn
Id:	1.95e-05	1.95e-05	3.90e-05	1.50e-05	1.59e-05
Vgs:	6.57e-01	6.58e-01	5.85e-01	5.85e-01	5.85e-01
Vds:	9.36e-01	9.12e-01	2.42e-01	5.85e-01	8.99e-01
Vbs:	-2.42e-01	-2.42e-01	5.71e-02	9.06e-02	1.06e-01
Vth:	4.82e-01	4.82e-01	3.96e-01	3.84e-01	3.78e-01
Vdsat:	1.45e-01	1.45e-01	1.44e-01	1.50e-01	1.53e-01
Gm:	2.11e-04	2.11e-04	4.03e-04	1.49e-04	1.54e-04
Gds:	1.41e-06	1.42e-06	1.20e-05	1.24e-06	1.06e-06
Gmb	5.39e-05	5.40e-05	1.05e-04	3.69e-05	3.74e-05
Cbd:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Cbs:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Cgsov:	3.62e-15	3.62e-15	7.24e-15	2.41e-15	2.41e-15
Cgdov:	3.62e-15	3.62e-15	7.24e-15	2.41e-15	2.41e-15
Cgbov:	8.66e-19	8.66e-19	8.66e-19	8.66e-19	8.66e-19
dQgdVgb:	3.36e-14	3.36e-14	6.85e-14	2.28e-14	2.28e-14
dQgdVdb:	-3.53e-15	-3.53e-15	-7.53e-15	-2.36e-15	-2.36e-15
dQgdVsb:	-2.85e-14	-2.85e-14	-5.85e-14	-1.97e-14	-1.97e-14
dQddVgb:	-1.43e-14	-1.43e-14	-2.90e-14	-9.53e-15	-9.53e-15
dQddVdb:	3.57e-15	3.58e-15	7.60e-15	2.39e-15	2.38e-15
dQddVsb:	1.37e-14	1.37e-14	2.78e-14	9.19e-15	9.15e-15
dQbdVgb:	-5.12e-15	-5.11e-15	-1.06e-14	-3.70e-15	-3.72e-15
dQbdVdb:	7.45e-18	7.26e-18	-4.33e-16	2.43e-19	6.43e-18
dQbdVsb:	-2.43e-15	-2.43e-15	-4.38e-15	-1.11e-15	-9.77e-16