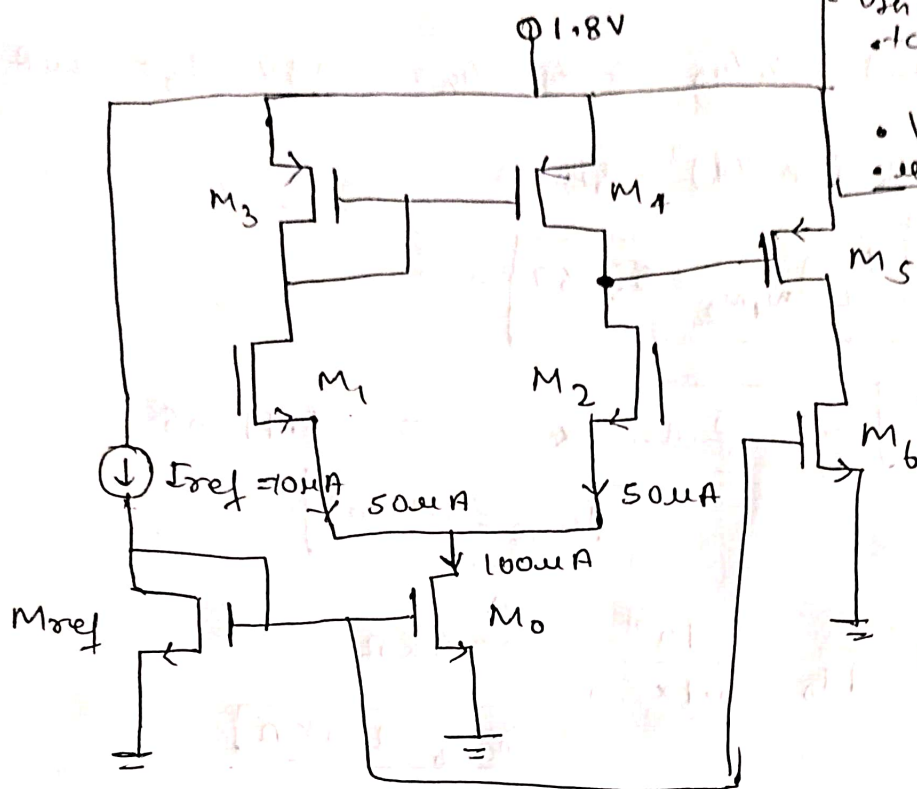


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## 2-Stage OTA



- $I_n = 0.1$   $I_p = 0.05$
  - $V_{thn} = 0.37V$   $V_{thp} = 0.39V$   
taking overdrive voltage as  $0.2V$
  - $V_{dd} = 1.8V$
  - $\mu_{n,ox} = 230 \mu A/V^2$ ,  $\mu_{p,ox} = 100 \mu A/V^2$
- 
- $I_{ref} = 10 \mu A$

for Mrf

$$\frac{\sin \cos \omega}{2L} (V_{gs} - V_{th})^2 = 10 \mu A$$

$$\left(\frac{\omega}{L}\right)_{\text{ref}} = \frac{2 \times 10^{-4} \text{ A}}{230 \times 10^6 \times (0.2)^2}$$

$$\left(\frac{w}{L}\right)_{M_{ref}} = 2.17$$

$$g_{m_{ref}} = \sqrt{2 \times I_D \times \ln 10 \times \frac{W}{L}} = \sqrt{2 \times 10 \times 10^{-6} \times 230 \times 10^{-6} \times 2.17}$$

$$g_{m_{ref}} = 99.9 \mu\text{A/V}$$

$$(r_{on})_{mref} = \frac{10^6}{0.1 \times 10} = 1 M\Omega$$

for Mo

$$(V_{GS} - V_{th}) = 0.2 \text{ V} \quad I_D = 100 \mu\text{A}$$

$$\frac{\frac{W}{L}}{2t} \cdot \frac{\left(\frac{W}{L}\right)_{m0}}{\left(\frac{W}{L}\right)_{mref}} = \frac{I_{m0}}{I_{ref}} = \frac{100 \mu A}{10 \mu A} = 10$$

$$\left(\frac{\omega}{L}\right)_{m_0} = 10 \times 2.17$$

$$\left(\frac{w}{L}\right)_{m_0} = 21.7$$

$$(g_m)_{m_0} = \sqrt{2 I_0 \sin \alpha \times \frac{\omega}{T}} = 999 \mu/\Omega = 1 \text{ m}/\Omega = 10^{-3}/\Omega$$

$$(g_m)_{m_0} = 10^{-3} / \Omega$$

$$r_o = \frac{1}{\lambda n I_D} = \frac{10^6}{0.1 \times 100} = 10^5 \Omega$$

for  $M_1, M_2$

$$(V_{gs} - V_{th}) = 5\% V_{DD} \Rightarrow V_{gs} - V_{th} = 0.09V \quad I_D = 50 \mu A$$

$$\mu_n C_{ox} \frac{W}{2L} \times (V_{gs} - V_{th})^2 = 50 \mu A$$

$$\boxed{\left(\frac{W}{L}\right)_{M_1, M_2} = 53.67}$$

$$g_{m1,2} = \sqrt{2 I_D \frac{W}{L} \mu_n C_{ox}} = 1.11 \text{ mS}$$

$$\boxed{g_{m1,2} = 1.11 \text{ mS}}$$

$$r_{o1,2} = \frac{1}{\lambda I_D} = \frac{10^6}{0.1 \times 50} = 200 \text{ k}\Omega$$

$$\boxed{(r_o)_{1,2} = 200 \text{ k}\Omega}$$

for  $M_3, M_4$

$$(V_{gs} - V_{th}) = 0.2V \quad I_D = 50 \mu A$$

$$\mu_p C_{ox} \frac{W}{2L} (V_{gs} - V_{th})^2 = 50 \mu A$$

$$\left(\frac{W}{L}\right)_{3,4} = \frac{100 \mu A}{(0.2)^2 \times 100 \mu A/V^2}$$

$$\boxed{\left(\frac{W}{L}\right)_{3,4} = 25}$$

$$\boxed{g_{m3,4} = \sqrt{2 I_D \frac{W}{L} \mu_p C_{ox}} = 0.5 \text{ mS}}$$

$$r_o = \frac{1}{\lambda I_D} = \frac{10^6}{0.05 \times 50} = 400 \text{ k}\Omega$$

$$\boxed{(r_o)_{3,4} = 400 \text{ k}\Omega}$$

$$\begin{aligned}\text{gain of 1st stage} &= g_{m1} (r_{o4} || r_{o2}) \\ &= 1.11 \times 10^{-3} (400k || 200k) \\ &= 1.11 \times 10^{-3} \times 133.3k \times 10^3\end{aligned}$$

$$A_{v1} = 148$$

for M<sub>6</sub>  $I = 200 \mu A$ ,  $V_{gs} - V_{th} = 0.2V$

$$\frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_{ref}} = \frac{200 \mu A}{10 \mu A}$$

$$\left(\frac{W}{L}\right)_6 = 42$$

$$g_{m6} = \sqrt{2I_D \times \mu_n C_{ox} \frac{W}{L}} = \sqrt{2 \times 200 \times 230 \times 42 \times 10^{-6}}$$

$$g_{m6} = 1.965 \text{ mS}$$

$$r_o = \frac{1}{\lambda I_D}$$

$$r_{o6} = 50k\Omega$$

for M<sub>5</sub>  $I = 200 \mu A$ ,  $V_{sg} - V_{th} = 0.2V$ ,  $\mu_p C_{ox} = 100 \mu A/V^2$

$$\frac{\mu_p C_{ox} W}{2L} (V_{sg} - V_{th})^2 = 200 \mu A$$

$$\left(\frac{W}{L}\right)_5 = 100$$

$$g_{m5} = \sqrt{2I_D \times \mu_p C_{ox} \frac{W}{L}} = \sqrt{2 \times 200 \times 100 \times 100 \times 10^{-6}}$$

$$g_{m5} = 2 \text{ mS}$$

$$r_o = \frac{1}{\lambda I_D} = \frac{10^6}{0.05 \times 200}$$

$$r_{o5} = 100k\Omega$$

$$\text{gain 2nd stage} = g_{m5} (r_{o5} || r_{o6}) = 2 \times 10^{-3} (100k || 50k)$$

$$A_{v2} = 66.6$$



Table for  $\frac{W}{L}$ ,  $g_m$ ,  $r_o$ ,  $V_{GS} - V_{th}$ ,  $I_D$

• Calculated Values.

Transistors	$W/L$	$g_m$ (mS)	$r_o$ (k $\Omega$ )	$V_{GS} - V_{th}$ (PMOS) $V_{GS} - V_{th}$ (NMOS) (V)	$I_D$ ( $\mu$ A)
$M_{ref}$	2.17	0.1	$10^3$	0.2	10
$M_0$	21.7	1	100	0.2	100
$M_1$	53.67	1.11	200	0.09	50
$M_2$	53.67	1.11	200	0.09	50
$M_3$	25	0.5	400	0.2	50
$M_4$	25	0.5	400	0.2	50
$M_5$	100	2	100	0.2	200
$M_6$	42	1.96	50	0.2	200

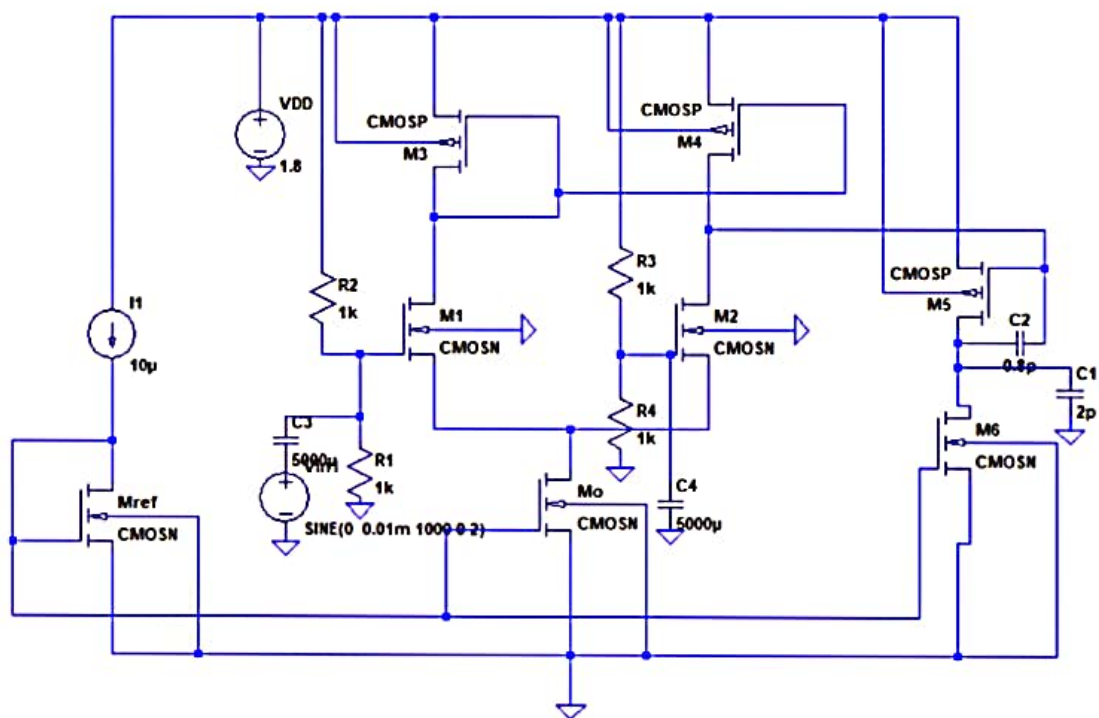
• Simulated Values

Transistors	$W/L$	$g_m$ (mS)	$r_o$ (k $\Omega$ )	$V_{GS} - V_{th}$ (PMOS) $V_{GS} - V_{th}$ (NMOS)	$I_D$ ( $\mu$ A)
$M_{ref}$	2.22	0.101	$1.2 \times 10^3$	0.194	10
$M_0$	23.3	1.02	63.69	0.19	99.9
$M_1$	67.9	0.959	161	0.059	50
$M_2$	67.9	0.959	161	0.059	50
$M_3$	25	0.36	283	0.258	50
$M_4$	25	0.36	283	0.258	50
$M_5$	100	1.49	86.206	0.26	206
$M_6$	46.67	2.09	61.3	0.193	206

--- BSIM3 MOSFETS ---

Name:	m5	m4	m3	m6	mref
Model:	cmosp	cmosp	cmosp	cmosn	cmosn
Id:	-2.06e-04	-5.00e-05	-5.00e-05	2.06e-04	1.00e-05
Vgs:	-6.80e-01	-6.80e-01	-6.80e-01	6.05e-01	6.05e-01
Vds:	-1.17e+00	-6.80e-01	-6.80e-01	6.31e-01	6.05e-01
Vbs:	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Vth:	-4.20e-01	-4.22e-01	-4.22e-01	4.12e-01	4.11e-01
Vdsat:	-2.07e-01	-2.06e-01	-2.06e-01	1.50e-01	1.50e-01
Gm:	1.49e-03	3.64e-04	3.64e-04	2.09e-03	1.01e-04
Gds:	1.16e-05	3.53e-06	3.53e-06	1.63e-05	8.21e-07
Gmb:	4.69e-04	1.15e-04	1.15e-04	5.86e-04	2.83e-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:	5.72e-14	1.43e-14	1.43e-14	3.46e-14	1.65e-15
Cgdov:	5.72e-14	1.43e-14	1.43e-14	3.46e-14	1.65e-15
Cgbov:	8.41e-19	8.41e-19	8.41e-19	8.66e-19	8.66e-19
dQgdVgb:	6.43e-13	1.61e-13	1.61e-13	3.24e-13	1.55e-14
dQgdVdb:	-5.61e-14	-1.41e-14	-1.41e-14	-3.38e-14	-1.61e-15
dQgdVsb:	-5.72e-13	-1.43e-13	-1.43e-13	-2.75e-13	-1.31e-14
dQddVgb:	-2.70e-13	-6.75e-14	-6.75e-14	-1.36e-13	-6.50e-15
dQddVdb:	5.66e-14	1.42e-14	1.42e-14	3.42e-14	1.63e-15
dQddVsb:	2.81e-13	7.03e-14	7.03e-14	1.35e-13	6.41e-15
dQbdVgb:	-1.04e-13	-2.59e-14	-2.59e-14	-5.15e-14	-2.46e-15
dQbdVdb:	8.35e-17	-2.37e-17	-2.37e-17	2.63e-17	6.75e-19
dQbdVsb:	-4.75e-14	-1.19e-14	-1.19e-14	-2.89e-14	-1.36e-15

Name:	m0	m2	m1
Model:	cmosn	cmosn	cmosn
Id:	9.99e-05	5.00e-05	5.00e-05
Vgs:	6.05e-01	5.67e-01	5.67e-01
Vds:	3.33e-01	7.87e-01	7.87e-01
Vbs:	0.00e+00	-3.33e-01	-3.33e-01
Vth:	4.13e-01	5.08e-01	5.08e-01
Vdsat:	1.49e-01	7.58e-02	7.58e-02
Gm:	1.02e-03	9.59e-04	9.59e-04
Gds:	1.57e-05	6.21e-06	6.21e-06
Gmb	2.85e-04	2.42e-04	2.42e-04
Cbd:	0.00e+00	0.00e+00	0.00e+00
Cbs:	0.00e+00	0.00e+00	0.00e+00
Cgsov:	1.73e-14	5.03e-14	5.03e-14
Cgdov:	1.73e-14	5.03e-14	5.03e-14
Cgbov:	8.66e-19	8.66e-19	8.66e-19
dQgdVgb:	1.63e-13	4.27e-13	4.27e-13
dQgdVdb:	-1.72e-14	-4.93e-14	-4.93e-14
dQgdVsb:	-1.38e-13	-3.44e-13	-3.44e-13
dQddVgb:	-6.86e-14	-1.76e-13	-1.76e-13
dQddVdb:	1.74e-14	4.97e-14	4.97e-14
dQddVsb:	6.74e-14	1.61e-13	1.61e-13
dQbdVgb:	-2.54e-14	-7.36e-14	-7.36e-14
dQbdVdb:	-3.15e-16	9.10e-17	9.10e-17
dQbdVsb:	-1.46e-14	-2.82e-14	-2.82e-14



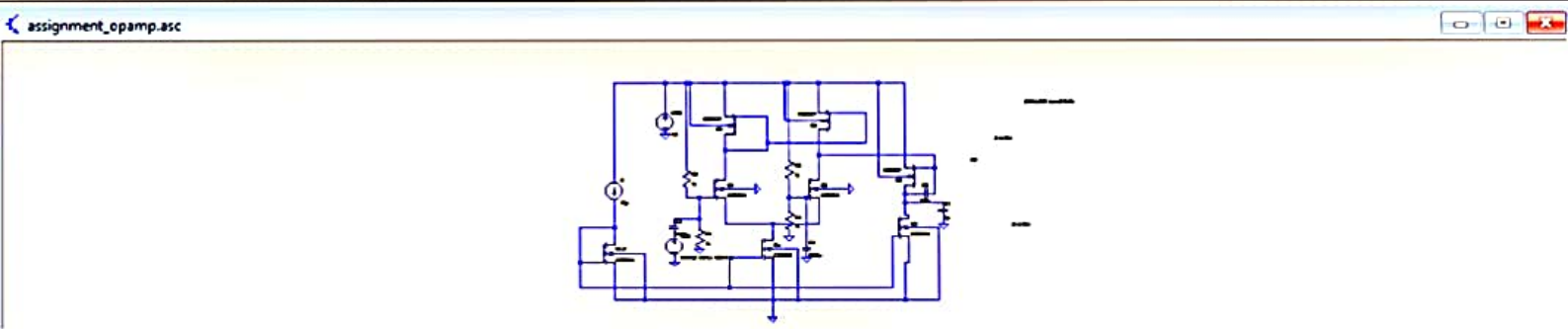
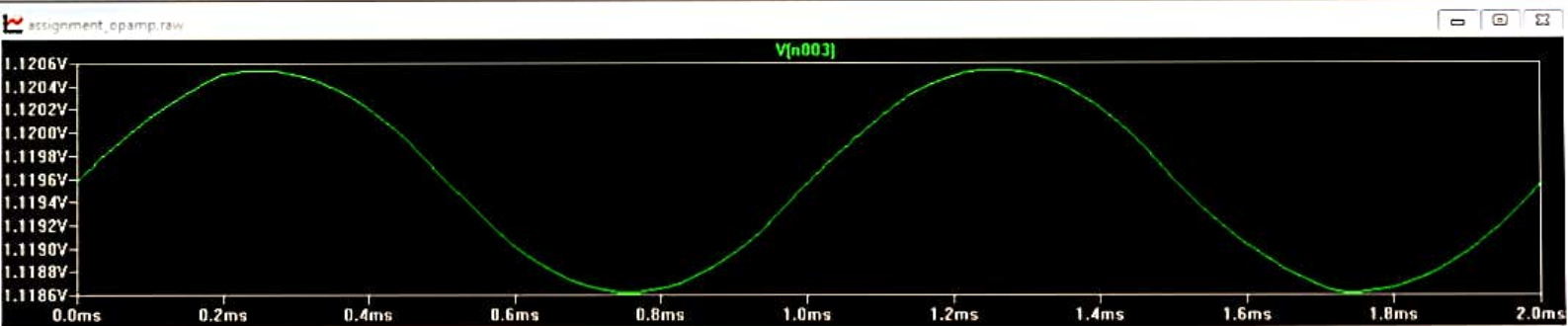
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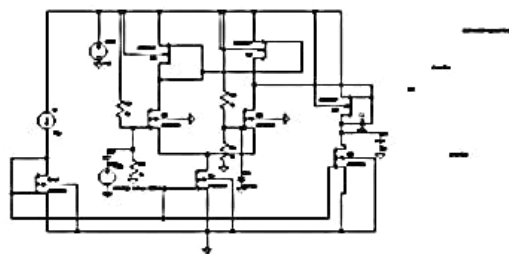
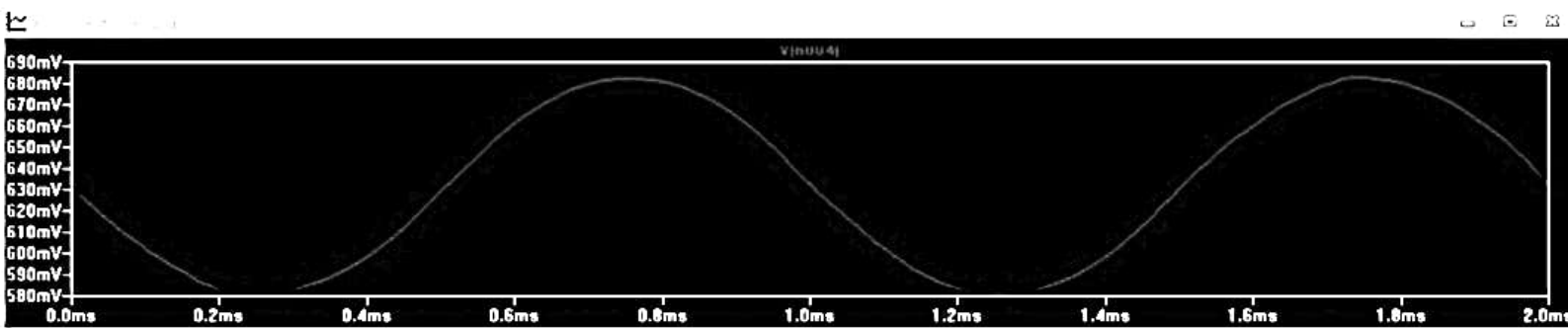
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Simulated gains

$$V_{in} = 0.02 \text{ mV}$$

$$\text{first stage} = \frac{V_{out}}{V_{in}} = \frac{1.12 - 1.118}{0.02} \times 10^3$$

$$A_{v1} = 100$$

$$20 \log(A_{v1}) = 40 \text{ dB}$$

Overall gain (i.e. two stage gain)

$$A = -\frac{(682.35 - 580) \text{ mV}}{0.02 \text{ mV}}$$

$$A = -5117.5$$

$$20 \log(A) = 74.18 \text{ dB}$$

where

$$C_L = 2 \text{ pF}$$

$$C_C = 0.8 \text{ pF}$$