EE537 Circuit Simulation Lab
Experiment 8

Name: <Satyam Singh>
ID Number: <2023EEM1026> November 7, 2023

1 Design of an inverting amplifier using a two stage OTA

Design an inverting amplifier using a 2 stage miller compensated OTA. Fig. 1 shows the schematic of the inverting amplifier to be designed.

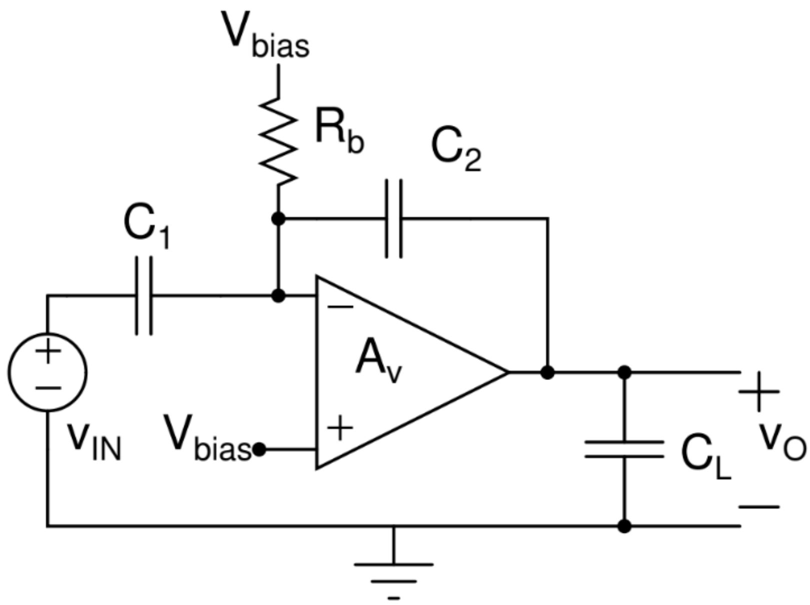

Figure 1: Inverting amplifier with capacitive voltage feedback

Target specification:

Spec.	Value
Midband gain	20 dB
Bandwidth	> 1 MHz
Input capacitance	1 pF
Load capacitance	10 pF
Slew rate	$\geq 10\ V/\mu s$
Gain error	0.1 %
Phase margin	$\geq 65\ ^\circ$
Operating temperature range	0 °C to 70 °C

1.1 Implement the 2 stage using a miller compensated 2 stage OTA. Show the calculations used for all the specifications and detailed design procedure.

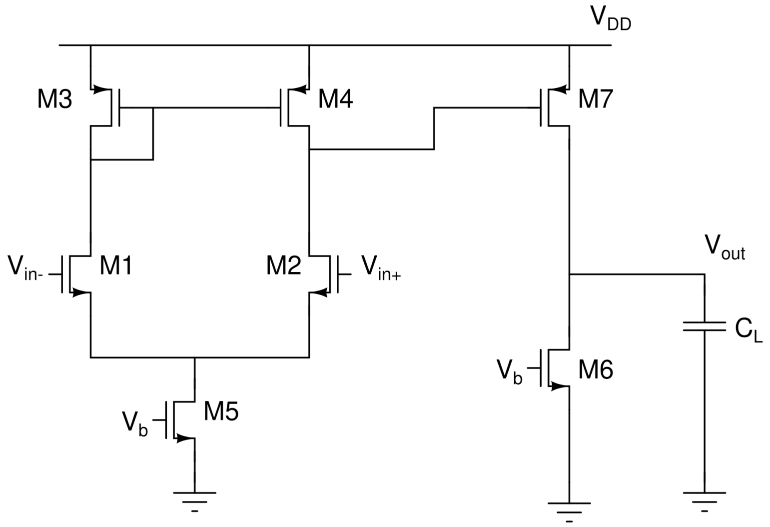

Figure 2: Two stage uncompensated OTA

A typical differential-frequency response of an op-amp is given by:

$$A_v(s) = \frac{A_{vo}}{(\frac{s}{p_1}-1)(\frac{s}{p_2}-1)(\frac{s}{p_3}-1).......} \tag{1}$$

where p1, p2, p3 are the poles of the operational amplifier open-loop transfer.

$$A_{vo} = -gm_1 gm_7 (r_{o2}||r_{o4})(r_{o6}||r_{o7}) \tag{2}$$

For the uncompensated op-amp, the location of poles is given by:

$$p1 = \frac{-1}{(r_{o2}||r_{o4})C_{o1}} \tag{3}$$

where C_{o1} is the sum of parasitic capacitances of M2 and M4 at their drain terminals.

$$p2 = \frac{-1}{(r_{o6}||r_{o7})(C_{o2}+C_L)} = \frac{-1}{(r_{o6}||r_{o7})C_L} \tag{4}$$

where C_{o2} is the sum of parasitic capacitances of M6 and M7 at their drain terminals and the load capacitance.

For stability phase margin of the closed-loop system should be at least greater than 45°. Phase margin is less than 45° in this case hence, the op-amp should be compensated before using it in a closed-loop configuration.

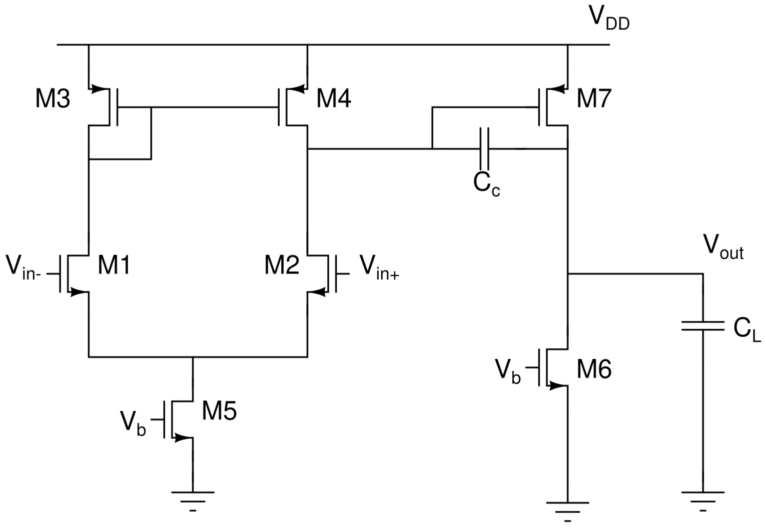

Figure 3: Two stage miller compensated OTA

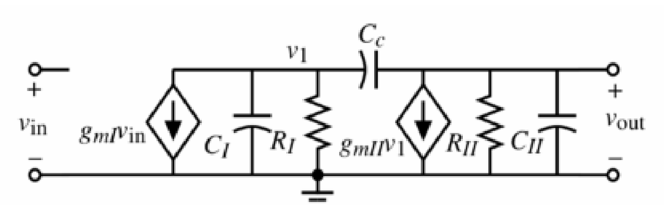

Figure 4: small signal of Two stage miller compensated OTA

The overall transfer function is given by:

$$\frac{V_{out}(s)}{V_{in}} = \frac{(g_{mI})(g_{mII})(R_I)(R_{II})(1 - sC_c/g_{mII})}{1 + s[R_I(C_I + C_c) + R_{II}(C_{II} + C_c) + g_{mII}R_IR_{II}C_c] + s^2R_IR_{II}[C_IC_{II} + C_cC_I + C_cC_{II}]} \tag{5}$$

where,

$$g_{mI} = g_{m1}, g_{mII} = g_{m7}, R_I = (r_{o2}||r_{o4}), R_{II} = (r_{o6}||r_{o7}), C_I = C_{o1}, C_{II} = C_{o2} + C_L = C_L \tag{6}$$

$$p1 = \frac{-1}{g_{m7}(r_{o2}||r_{o4})(r_{o6}||r_{o7})C_c} \tag{7}$$

$$p2 = \frac{-g_{m7}}{C_L} \tag{8}$$

$$z1 = \frac{g_{m7}}{C_c} \tag{9}$$

By using the miller compensation we have done the pole splitting due to which the pole p1 moves closer to the origin and the pole p2 moves away from the origin.

Calculations:

$$A_v(s) = \frac{-A_{vo}(s/z1 - 1)}{(s/p1 + 1)(s/p2 + 1)} \tag{10}$$

$$PM = 180^\circ - tan^{-1}(\omega/p1) - tan^{-1}(\omega/p2) - tan^{-1}(\omega/z1) \tag{11}$$

considering $\omega_z >> \omega_u$

$$65^\circ = 180^\circ - 90^\circ - tan^{-1}(\omega/p2) \tag{12}$$

$$\omega_{p2} = 2.2\omega_u \tag{13}$$

To get the phase margin=75°, ω_{p2}=4ω_u and ω_z=10 ω_u For unity gain bandwidth, ω_u

$$(\frac{A_{vo}}{1+s/p1})(\frac{C_2}{C_1+C_2}) = 1 \tag{14}$$

On solving the above equation we get

$$\omega_u = \frac{g_{m1}}{C_c}(\frac{C_2}{C_1+C_2}) \tag{15}$$

Given, C1=1pF and C2=100fF

$$\omega_z = 10\omega_u \tag{16}$$

$$\frac{g_{m7}}{C_c} = 10\frac{g_{m1}}{C_c}(\frac{C_2}{C_1+C_2}) \tag{17}$$

$$g_{m1} = g_{m7} \tag{18}$$

$$\omega_{p2} = 4\omega_u \tag{19}$$

$$\frac{g_{m7}}{C_L} = 4\frac{g_{m1}}{C_c}(0.1) \tag{20}$$

$$C_c = 0.4C_L \tag{21}$$

Given that C_L=10pF then C_c=4pF Slew rate is given by:

$$10V/\mu s = \frac{I_{D5}}{C_c} \tag{22}$$

From there we get: I_{D5}=40μ A similarly,

$$10V/\mu s = \frac{I_{D6}}{C_c+C_L} \tag{23}$$

$$I_{D6} = 140\mu A \tag{24}$$

Calculations of W/L: Taking the values of $\mu n C_{ox}$=300μ and V_{ov}=100mV

$$(W/L)_5 = \frac{I_{D5}}{0.5\mu_n C_{ox}(V_{ov})^2} = 80/3 \tag{25}$$

$$(W/L)_6 = \frac{I_{D6}}{0.5\mu_n C_{ox}(V_{ov})^2} = 280/3 \tag{26}$$

$$I_{D5} = I_{D1} + I_{D2} \tag{27}$$

$$I_{D1} = I_{D2} = 20\mu A \tag{28}$$

$$(W/L)_{1,2} = \frac{I_{D1,2}}{0.5\mu_n C_{ox}(V_{ov}^2)} = 40/3 \tag{29}$$

$$(W/L)_7 = 2(W/L)_6 = 560/3 \tag{30}$$

$$(W/L)_{3,4} = 2(W/L)_{1,2} = 80/3 \tag{31}$$

1.2 Show all the plots required to verify the achieved specifications

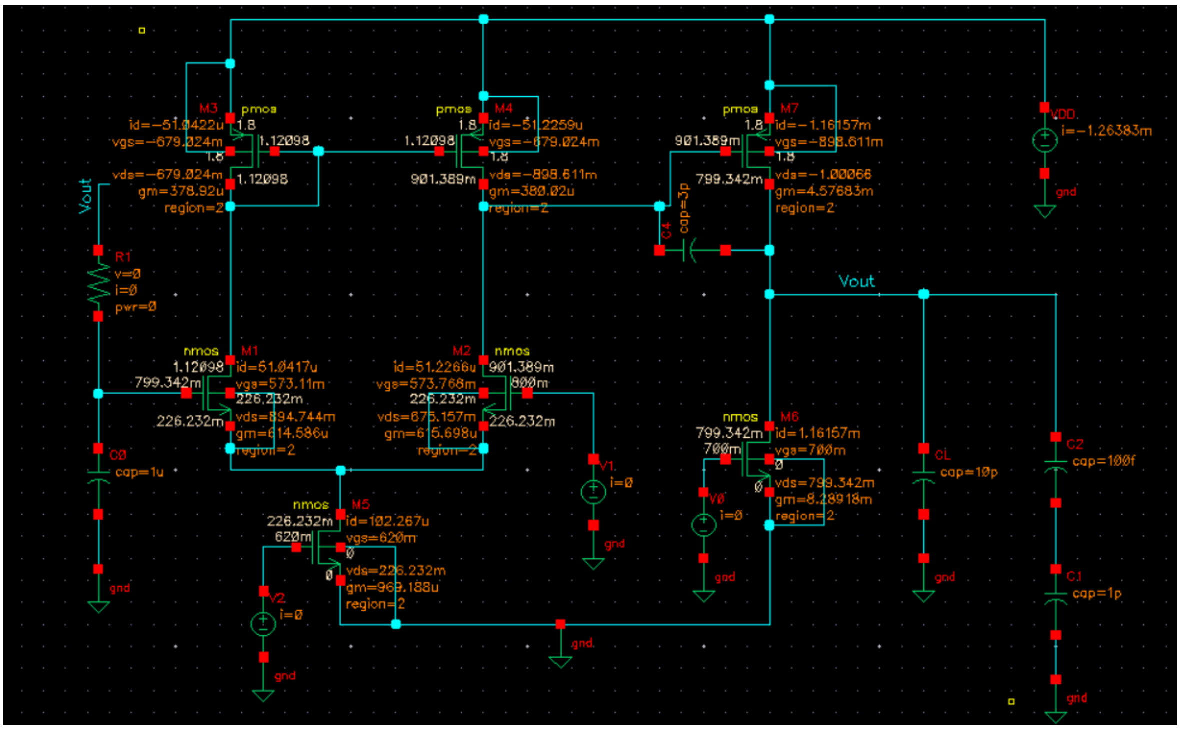

Figure 5: schematic to perform open loop gain of OTA

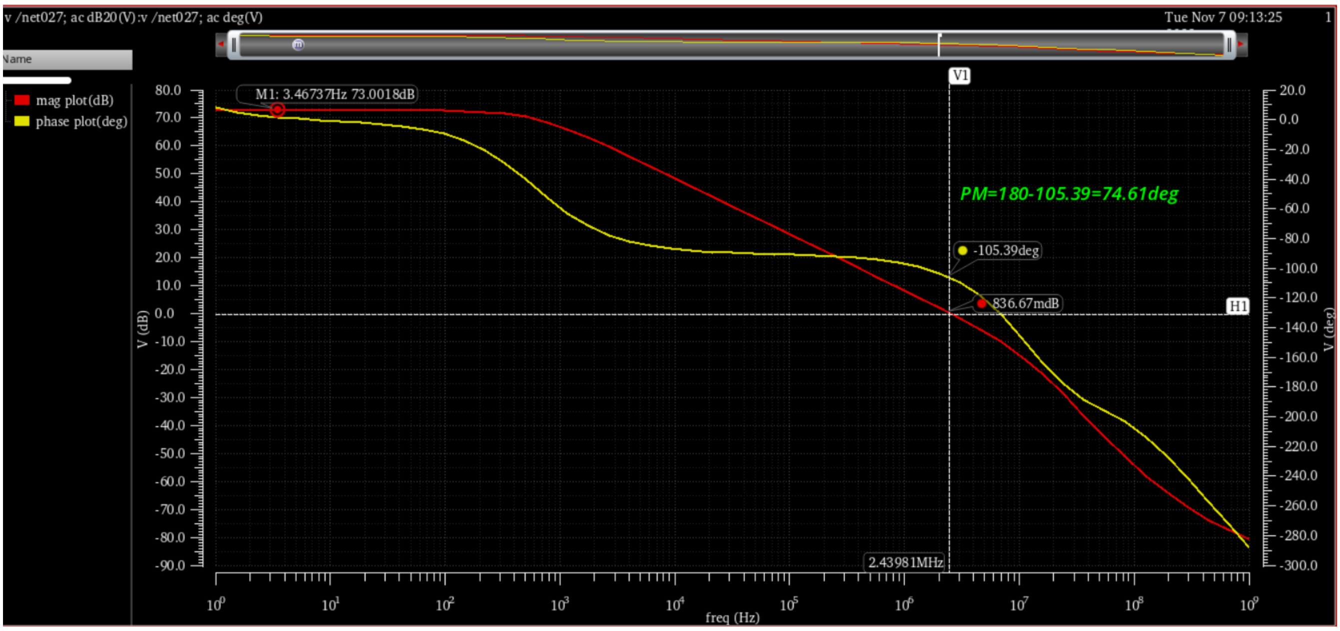

Figure 6: plot of open loop gain and phase

loop gain=73.0018dB and phase margin=74.61°

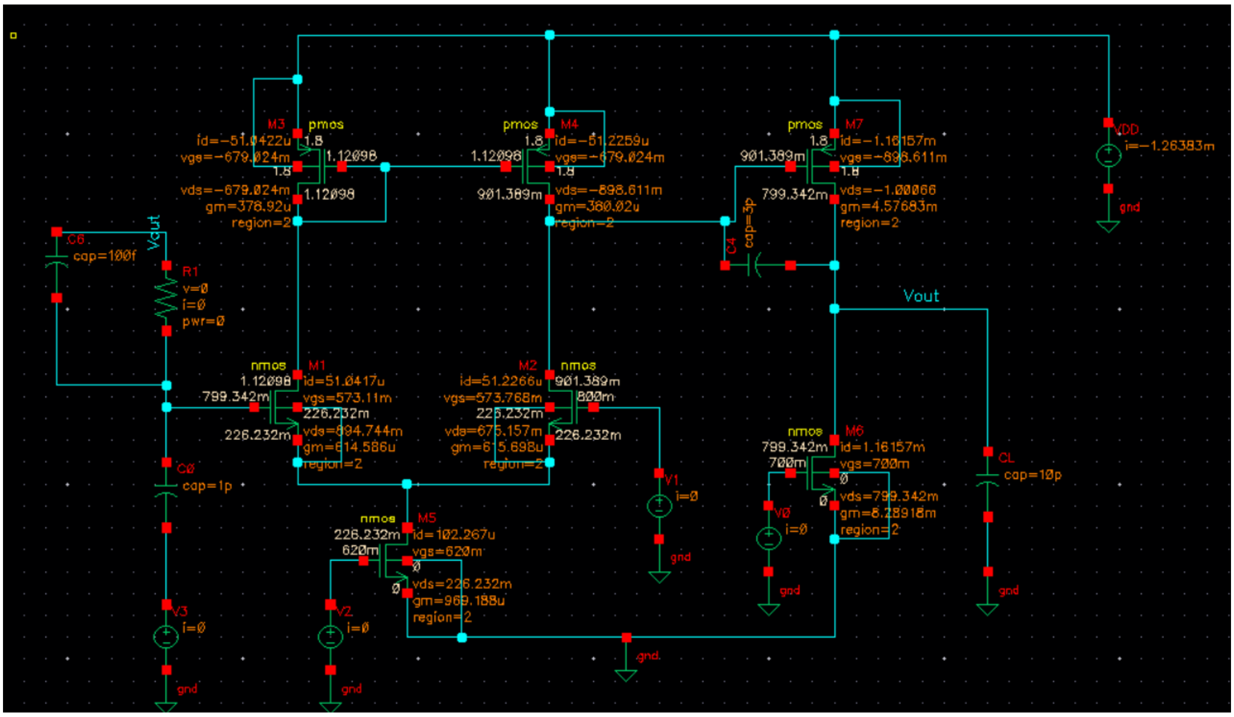

Figure 7: schematic for closed loop configuration of OTA

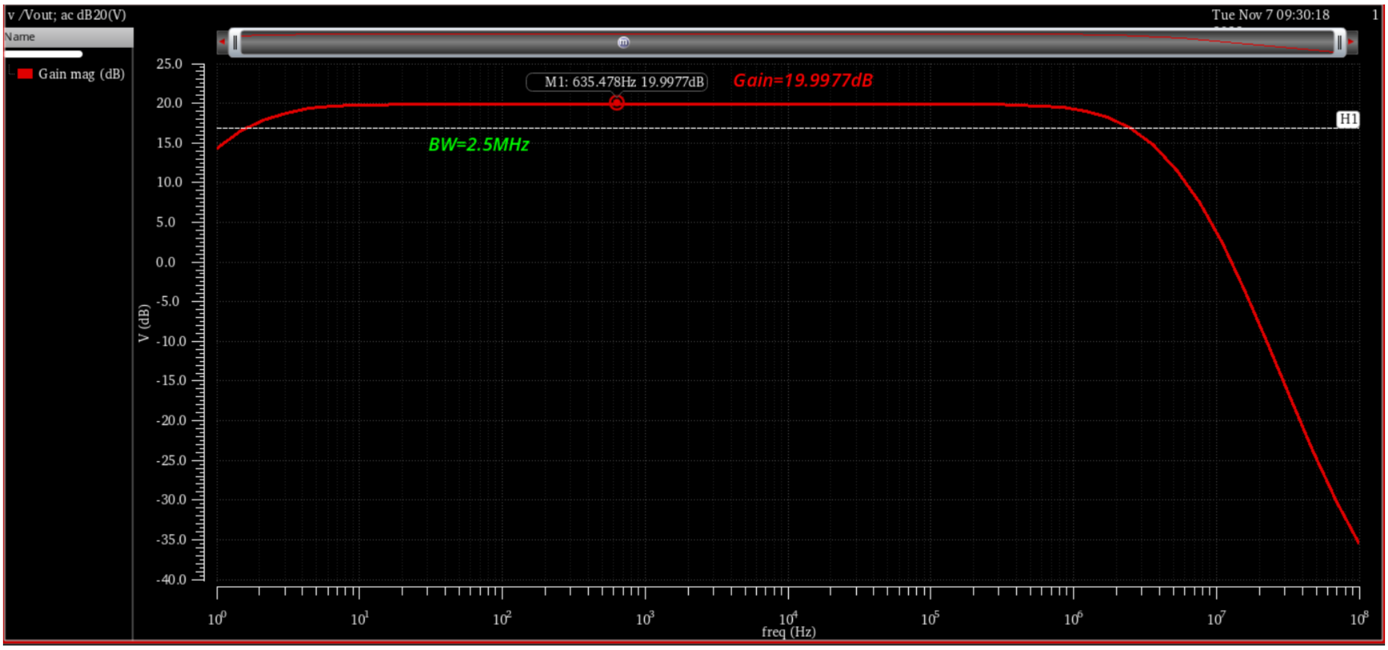

Figure 8: plot of closed loop gain

Bandwidth=2.5MHz and mid-band gain=19.9977dB

Calculation of % gain error:

$$A_{CL} = \frac{A}{1 + A\beta} \tag{32}$$

$$\Delta A_{CL} = \frac{-1}{\beta(1 + A\beta)} \tag{33}$$

$$\%gainerror = \frac{\Delta A_{CL}}{A_{CL}} * 100 = \frac{1}{A\beta} * 100 \tag{34}$$

loop gain, Aβ=73.0018dB=4466.83

$$\%gainerror = \frac{1}{4466.83} * 100 = 0.0223\% \tag{35}$$