OPAMP DESIGN PROJECT
EE3002

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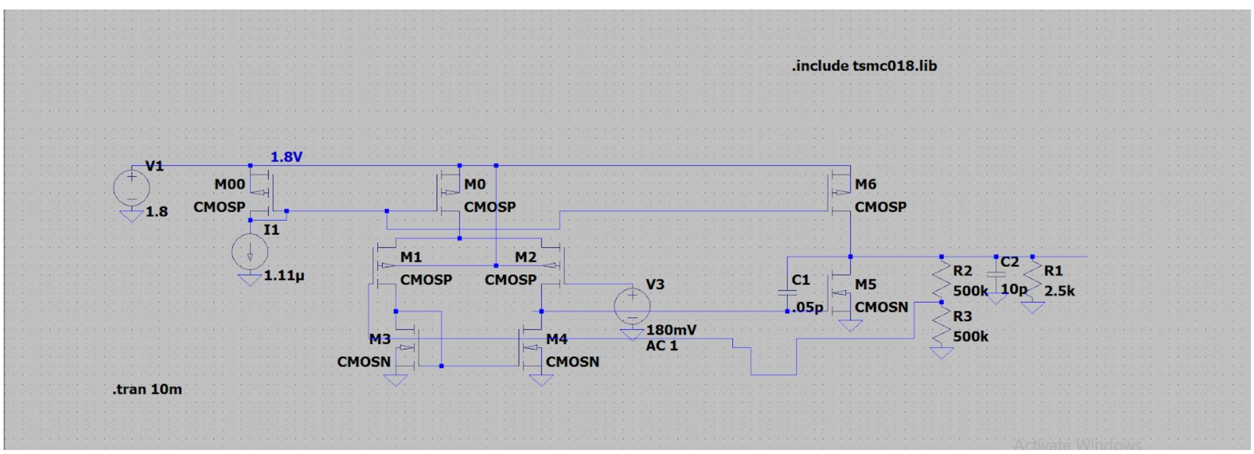
EE17B156

AIM:

The aim of this project is to design an op amp using MOSFETS for gain 2 Amplifier operation having:

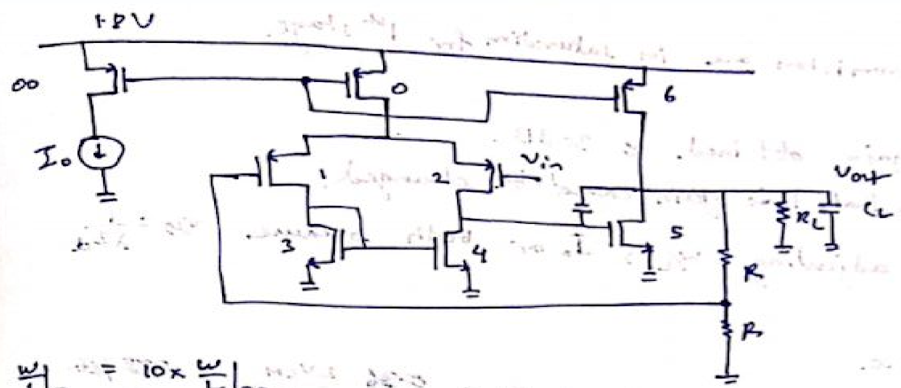
1. Closed Loop 3db Bandwidth of 5MHz
2. Phase margin>60 degrees
3. Capacitive load =10pf
4. Resistive load=2.5kΩ

Circuit Diagram:



Above is the circuit diagram at closed loop operation.

Hand Calculations:



$\frac{W}{L}\Big|_0 = 10\times \frac{W}{L}\Big|_{00}$

Initially; gate overdrive Voltage = 200mV ⇒ $V_{GS} - V_{Tn} = 0.2$

$V_{S3} = 0.57\ V.$

∴ $V_{CM} \gtrsim 0.18\ V$

However. if V_{CM} is too high $V_{out}\ DC = 2\times V_{CM}$ will be high

∵ $R_L = 2.5k$, a high current must flow through M_6

⇒ high W/L for M_6.

∴ We keep $V_{CM} = 0.18V$ & decrease gate overdrive Voltage

Let $V_{G3} = 0.54\ V$

∵ if we keep L v.small, small channel effects increase & r_{ds} decreases; we shall keep $L = 1.8\mu$ for proper current mirroring. $(10\times L_{min})$

Simplest case; $\frac{W}{L}\Big|_{00} = 1 \Rightarrow W_{00} = 1.8\mu$

$\frac{W}{L}\Big|_0 = 10 \Rightarrow W = 18\mu$

$\frac{W}{L}\Big|_1 = \frac{W}{L}\Big|_2 = 5 \Rightarrow W = 9\mu$

$\frac{W}{L}\Big|_3 = \frac{W}{L}\Big|_4 = 5\times\frac{10}{23} = 2.174\mu$

∴ $I_{d3} \simeq 4.5\mu A \Rightarrow I_0 = 0.9\mu A$, but for $V_G = 0.54\ V$,

The simulation requires passing of $1.11\mu A$ & $I_{d3} = 5\mu A$

1, 2, 3, 4 are in saturation.

$5\mu = \frac{1}{2}\times 100\times 5\times (V_{SG} - V_{Tp})^2$

$\Rightarrow V_{D0} = 711\ mV$

$V_{S0} = 1.268V \quad \therefore V_{D0} < V_{S0} \Rightarrow$ (saturation)

∴ all transistors are in saturation for 1st stage.

1st stage gain obtained ≈ 30dB.

It is seen that this gain cannot be changed by merely adjusting W/L, I_o or both because $r_{ds} = \frac{1}{\lambda I_d}$

Assume R = ∞.

∴ for V_{CM} input; current through R1 = $\frac{2V_{CM}}{R_1}$ = 144 μA

for M5;

$V_G = 0.54$ V

$V_D = 0.36$ V

∴ V_D > $V_G - V_{Tn}$ = 0.17V ⇒ saturation.

current through M5 depends on $(W/L)_5$.

Miller zero of open loop transfer function lies @ $\frac{g_{m2}}{C} = \frac{g_{m5}}{C}$

While ~~dominant pole of~~ Unity gain frequency Open loop TF lies @ $\frac{g_{m1}}{C} = \frac{g_{m1}}{C}$

∴ $g_{m2} \gg g_{m}$, Let $g_{m2} = 10\, g_{m1}$ ⇒ $(W/L)_5 = 10\,(W/L)_4$

(Aβ) DC gain = $g_{m1} R_{o1} \times g_{m5} (R_{o2} \parallel R_L) \times \frac{1}{2}$

$$\omega_d = \frac{1}{g_{m5} R_{o2} C \; R_{o1}}$$

$$\omega_2 = \frac{g_{m5}}{C}$$

ω_U = $\frac{g_{m1}}{C}$ for A; for Aβ; $\omega_U = \frac{g_{m1}}{2C}$

Let C = 1pF & $(W/L)_6$ = (200μ : 1.8μ)

(1)

But in this case Open loop gain (A) is ≈ 32dB, it is smaller than the specification. ∴ we increase $(W/L)_5 = 100\,(W/L)_4$.

⇒ W_5 = 217.4μ

L_5 = 1.8μ

To match the current through M6 & currents through M5 & R_C @ $V_{o_{cm_{DC}}} = 0.36\,V$; a parametric sweep was performed for W_6, keeping $L_6 = 1.0\,\mu$, this value turned out to be $W_6 = 662\,\mu m$, $I_{d_6} = 538\,\mu A$ & $I_{d_4} = 393\,\mu A$.

The DC gain increased to $\approx$ 44 dB. (2)

(1)
before;

$g_{m5} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 = 472\,\mu S$

$g_{m1} = 47.2\,\mu S$

$$\left.\begin{aligned} g_{ds_5} = 1/r_{ds_5} &= 38.61\,\mu \\ g_{ds_6} = 1/r_{ds_6} &= 130\,\mu \end{aligned}\right\} \quad R_{o2} = \frac{1}{g_{ds_5} + g_{ds_6}}$$

$$\left.\begin{aligned} g_{ds_1} = 1/r_{ds_1} &= 2.71\,\mu \\ g_{ds_2} = 1/r_{ds_2} &= 0.44\,\mu \end{aligned}\right\} \quad R_{o1} = \frac{1}{g_{ds_2} + g_{ds_1}}$$

$$\therefore \text{ gain DC} = 47.2 \times 472 \times \frac{1}{168.61} \times \frac{1}{2.71 + 0.44} \approx 41 \Rightarrow 20\log(41) = \underline{\underline{32\,dB}}$$

(2)
expected now

$$\left.\begin{aligned} g_{ds_5} &= 386\,\mu S \\ g_{ds_6} &= 30\,\mu S \end{aligned}\right\} \Rightarrow R_{o2} = 2.4\,k\Omega$$

$g_{ds_1} = 2.71\,\mu$
$g_{ds_2} = 0.44\,\mu$

$$\therefore \text{ DC gain} = 47.2 \times 4720 \times \frac{1}{416} \times \frac{1}{3.15} = 170 \Rightarrow 20\log(170) = \underline{\underline{44\,dB}}$$

- It remains to determine C to satisfy bandwidth & P.M constraint.

$$\cancel{5\,MHz = \frac{\omega_u}{2\pi} = \frac{1}{2\pi} \times \frac{47.2\,\mu}{2C} \Rightarrow C = \frac{1.5\,pF}{2} = 0.75\,pF = C_{max}}$$

$$\therefore 5\,MHz = \frac{\omega_u}{2\pi} = \frac{1}{2\pi} \times \frac{472\,\mu}{2C} \Rightarrow C = 0.75\,pF = C_{max}$$

Assuming that poles are far apart;

i.e $C_c >> C_1$ [C_c cannot be $>> C_2$ ∵ $C_{max} = 0.75p$]

$$P.M = \phi_M = 180^\circ + \angle A\beta = 180^\circ - \tan^{-1}\left(\frac{\omega_u}{P_1}\right) - \tan^{-1}\left(\frac{\omega_u}{P_2}\right) - \tan^{-1}\left(\frac{\omega_u}{\omega_z}\right)$$

$$\cancel{= 180^\circ - \tan^{-1}\left(\frac{\omega_u}{\omega_{P_1}}\right)}$$

$$= 180^\circ - 90^\circ - \tan^{-1}\left(\frac{1}{20}\right) - \tan^{-1}\left(\frac{1}{200}\right)$$

$$= \underline{86.85^\circ}.$$

But we want PM to be within 60° & 80°.

∴ we must decrease C

for $C = 0.05$ pf;

$\omega_{P_2} \approx 20\text{ MHz} \times 2\pi$ (Simulation)

$\omega_{P_1} = 83.2\text{ kHz} \times 2\pi = 2\pi\left(\frac{47.2}{4720 \times 0.05} \times 416\right)$ rad/s

∴ $\angle A\beta = 104.3^\circ \Rightarrow \phi_M = 75.7^\circ$

Scanned by CamScanner

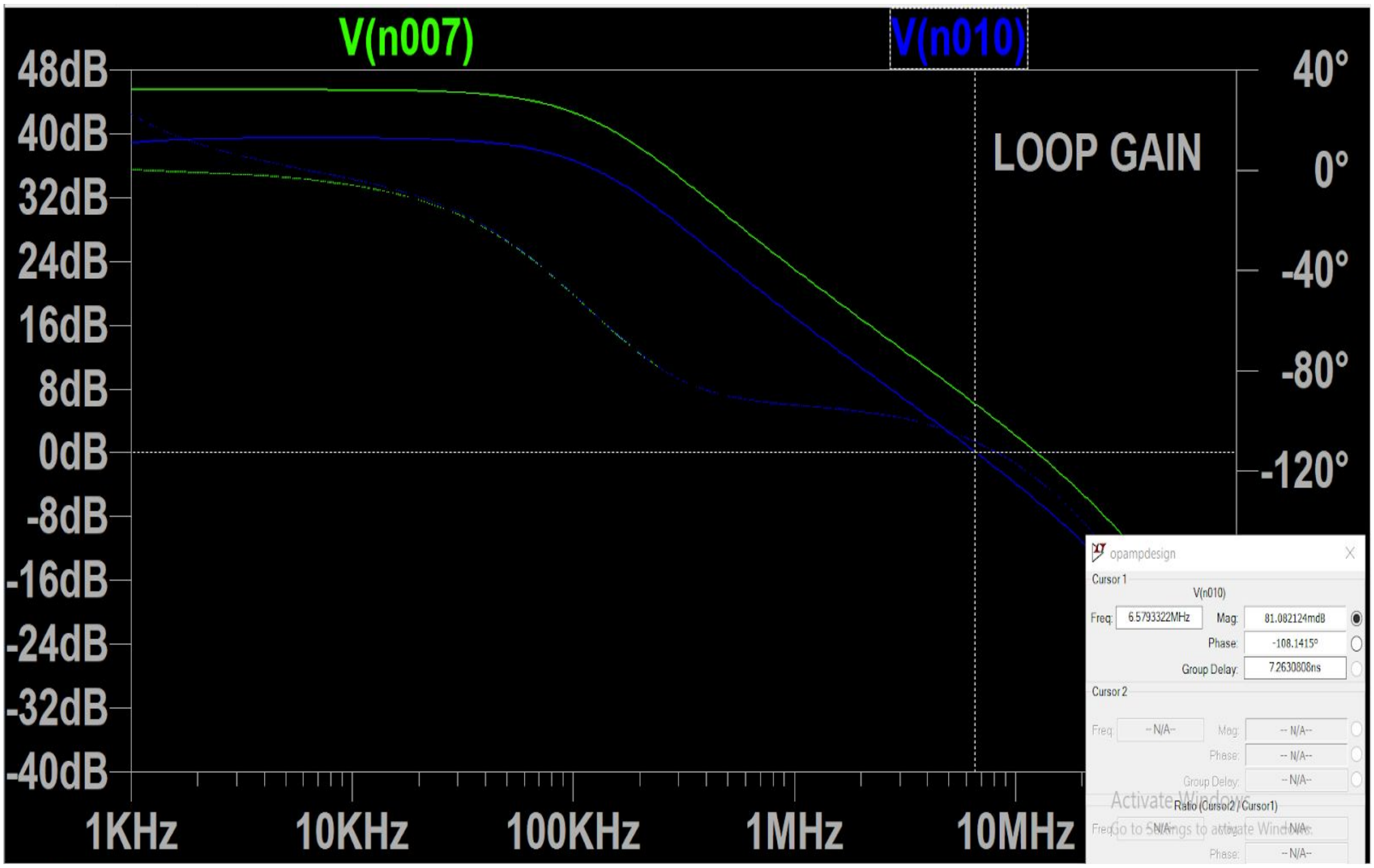
MOSFET	gm calculated	Vgs-Vt calculated	Id calculated	gm simulated	Vgs-Vt	Id	gds
M0	150.6μA	0.15V	8μA	205μS	0.1431V	10.2μA	74.65μS
M1	47.22μS	0.257V	4μA	48.7μS	0.426V	5.063μA	2.74μS
M2	47.22μS	0.257V	4μA	48.7μS	0.425V	5.06μA	2.74μS
M3	47.22μS	0.17V	4μA	50.9μS	0.1708V	5.063μA	0.391μS
M4	47.22μS	0.17V	4μA	50.9μS	0.1706V	5.06μA	0.391μS
M5	4722.μS	0.17V	401μA	4.49mS	0.1706	393μA	0.386mS
M6	9.3mS	0.15V	545μA	7.57mS	0.1432V	538μA	0.038mS

b)The Two resistors for K=2, R= 500k >>rds5||rds6

c) DC gain = 45 db

d)Power consumption=986.2 μW

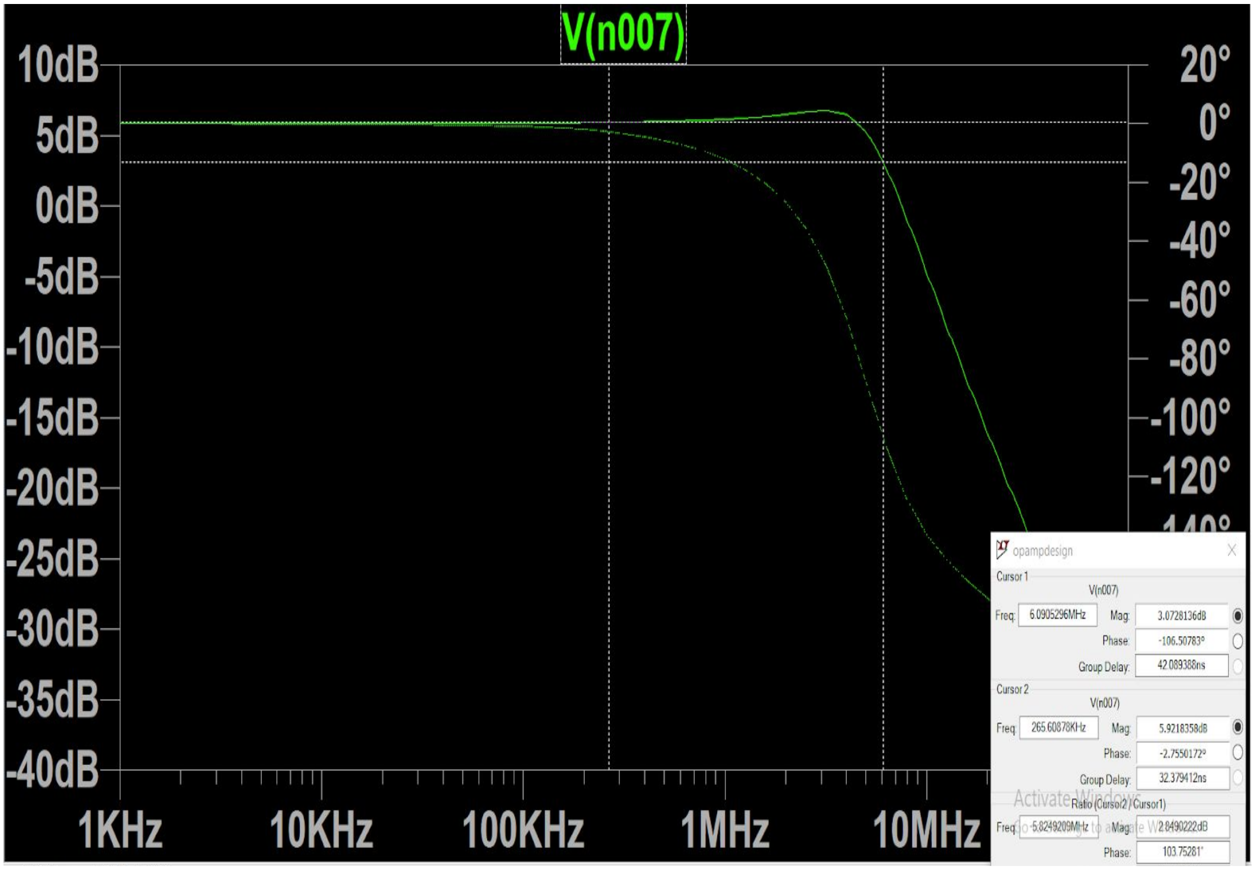
Loop Gain: Green curve opamp gain . Blue curve loop gain =Aβ

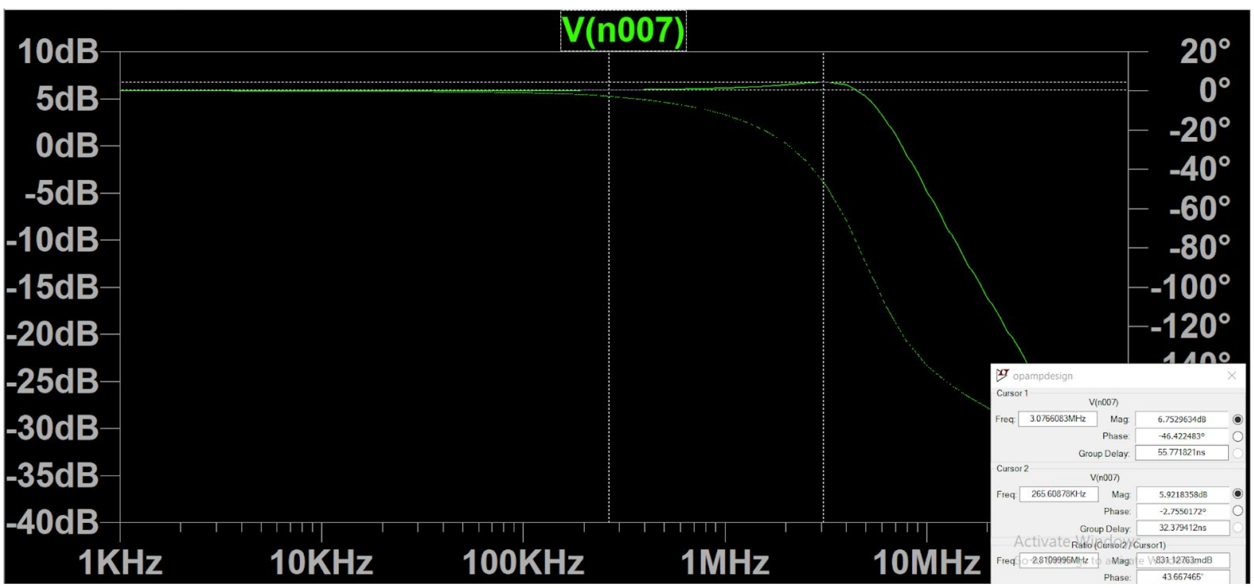


Phase margin=71.8 degrees

Closed Loop gain:

DC gain=5.921db
Bandwidth=6.09MHz



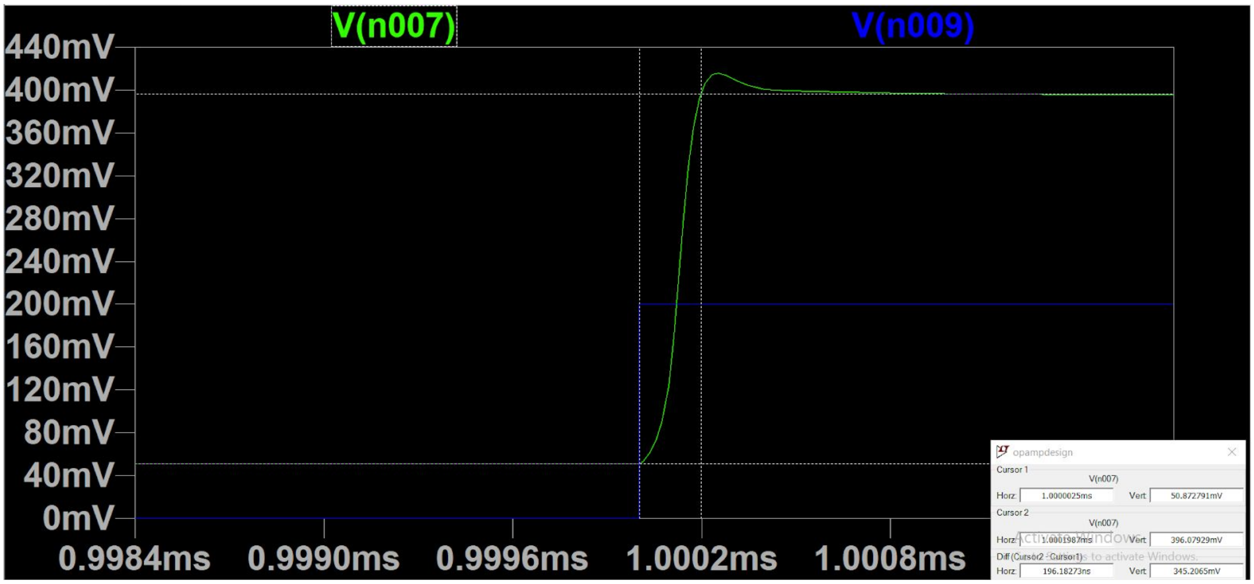


Peaking =0.837dB

Transient Response:

Blue curve : input step

Green curve: output response



trise=196.2 ns

%Overshoot=4.85%

ts=314 ns

FINAL DESIGN:

Designed C = 0.05pf

VCM = 180mV

i0=1.11μA

MOSFET	W	L	W/L
M00	1.8u	1.8u	1
M0	18u	1.8u	10
M1	9u	1.8u	5
M2	9u	1.8u	5
M3	3.91u	1.8u	2.174
M4	3.91u	1.8u	2.174
M5	217.4u	1.8u	120.78
M6	662u	1.0u	662