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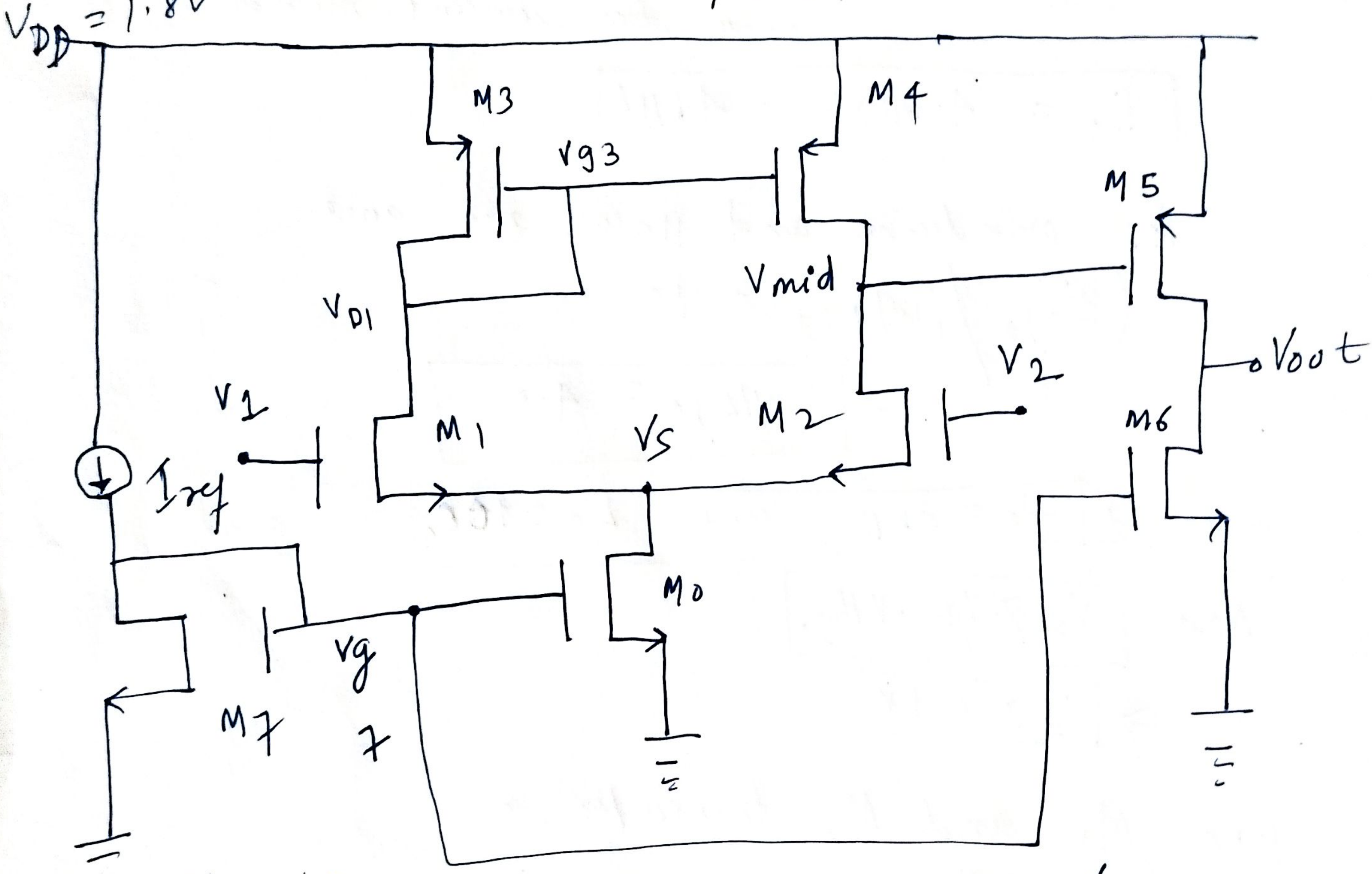
* EE-206 :→

OTA - Assignment :→

* Circuit diagram :→

* Open-Loop :→



* Calculations :→

V_2 = AC signal of 0.1 mV amplitude and 0.9 V dc

V_1 = 0.9 V dc → (for maximum swing)

* For M_7 transistor :→

Assuming 0.1V overdrive for M_7 we get,

Iref choosing as 4.6 μA

$$\Rightarrow \boxed{I_{ref} = \frac{\mu_n C_{ox}}{2} \left(\frac{W}{L}\right)_7 (V_{gs} - V_{th})^2}$$

$\Rightarrow 4.6\mu A = \frac{230\mu}{2}\left(\frac{W}{L}\right)_7 (0.1)^2$

$\Rightarrow \boxed{\left(\frac{W}{L}\right)_7 = 4}$ $\Rightarrow \boxed{L_7 = 900n \quad \Rightarrow W_7 = 3.6u}$

* **For** M_0 **transistor** :-

The tail current is 10 times that of ~~over~~ ~~do~~ current mirror.

$\boxed{I_0 = 4.6\mu \times 10 = 46\mu A}$

As overdrive and $\mu_n C_{ox}$ are same

$\left(\frac{W}{L}\right)_0 / (W/L)_7 = 10$

$\Rightarrow \boxed{(W/L)_0 = 40}$

$\Rightarrow \boxed{W_0 = 36u \text{ and } L_0 = 900n}$

Now, $\boxed{V_s > (V_{gs} - V_{th})_0}$

$\Rightarrow \boxed{V_s > 0.1V}$

For M_1 **and** M_2 **transistor** :-

$\boxed{I_1 = I_2 = 46/2\ \mu A = 23\mu A}$

Choosing its overdrive also to be 0.1V we get,

$(W/L)_1 / (W/L)_0 = \frac{1}{2}$ as $I_1 = I_2 = \frac{I_0}{2}$ and other parameters except (W/L) is same

$\Rightarrow (W/L)_1 = (W/L)_2 = 20$

$\Rightarrow \boxed{W_1 = W_2 = 18u}$ $\boxed{L_1 = L_2 = 900n}$

Now, $V_{g_{1s}} - V_{th_1} = 0.1V$

$\Rightarrow 0.9V - V_S - 0.37V = 0.1V$

$\Rightarrow \boxed{V_S = 0.9V - 0.37 - 0.1V}$

$\Rightarrow \boxed{V_S = 0.43V} > 0.1V$

So, Mo is in saturation (proved.).

Now, $V_{D1} > (V_{gs} - V_{th})_1$

$\Rightarrow \boxed{V_{D1} > 0.1V}$

* for M_3 and M_4 transistor :-

$\boxed{I_3 = I_4 = 23\mu A}$

Now, $I_3 = \frac{\mu_p C_{ox}}{2} (W/L)_3 (V_{sg} - V_{th})_3^2$

$\Rightarrow \frac{23\mu A}{50\mu} = (W/L)_3 (V_{sg} - V_{th})_3^2$

$\boxed{\text{taking } (W/L)_3 = 4}$ we get,

$\Rightarrow \boxed{(V_{sg} - V_{th})_3 = 0.339V}$

from here $(V_{sg} - V_{th})_3 = (V_{sg} - V_{tp})_4 = 0.339V$

and W_3 and W_4 and $L_3 = L_4 = 900n$

$W_3 = 3.6u$, $W_4 = 3.6u$

Now, for M_3 to be on, $\boxed{V_{sg} > |V_{tp}|}$

$\Rightarrow 1.8V - |V_{tp}| > V_g$

$\Rightarrow 1.8V - 0.39V > V_g$ $\Rightarrow \boxed{1.41V > V_{D1}}$

Now we get

$(V_{sg} - V_{th})_3 = 0.339$

$\Rightarrow 1.8V = 0.339 + V_{D1} + 0.39$

$\Rightarrow \boxed{V_{D1} = 1.071V}$

It satisfies as $V_{D1} > 0.1V$ and $V_{D1} > 1.41V$

So, $\boxed{M_3,\ M_4 \text{ and } M_1 \text{ and } M_2 \text{ are in saturation}}$

Practically, due to body effect and due to finite Rout impedance of M_0,

$\boxed{\left(\frac{W}{L}\right)_7 = \frac{3.450}{0.90} \text{ but all other parameters are same.}}$

So, gain due to first stage $= g_{m_2}(r_{ON_2} \| r_{OP_4})$

(taken from log file attached at end)

$= -3.95 \times 10^{-4} \times [258397.9328]$

$= -102.06$

Practically coming, gain of first stage as $= -101.0204$

$\boxed{\text{Error} = -1.02\%}$

Practically,

$$\boxed{V_{D1} = V_{mid} = 0.922\ V}$$

due to body effect V_{th} varies

* For M_6 transistor :-

choosing, $I_6 = 23\ \mu A$

as $\boxed{V_{g7} = V_{g6}}$

So, $(V_{gs} - V_{th})_6 = 0.1V$

$\Rightarrow 23\ \mu A = 115\mu \times (W/L)_6 \times (0.1)^2$

$\Rightarrow (W/L)_6 = 20$

$$\Rightarrow \boxed{L_6 = 900n \quad W_6 = 18U}$$

Practically $\boxed{W_6 = 16.65U \text{ and } L_6 = 900\ n}$
as finite r_{ON} so, variations are arising.

I_6 also practically
coming up as $\underline{22.9\ \mu A}$.

$V_{out} > (V_{gs} - V_{th})_6$

$$\boxed{V_{out} > 0.1V}$$

* For $M5$ transistor :-

$(V_{sg} - V_{th})_5 = V_s - V_{mid} - V_{th}$
$= 1.8 - 1.071 - 0.39$
$= 0.339V$

$I_5 = 23\mu A$

$\Rightarrow 23\mu A = \frac{\mu_p C_{ox}}{2} \left(\frac{W}{L}\right)_5 (0.339)^2$

$\Rightarrow \left(W/L\right)_5 = 4$

and it satisfied $\boxed{V_{SD} > V_{sg} - V_{th}}$

$\Rightarrow \boxed{\begin{matrix} W_5 = 3.6u \\ L_5 = 900n \end{matrix}}$ $\boxed{V_{out} = 0.94V}$

So, M5 and M6 in saturation

Gain for Second stage :-

(taken from log file) $gm_5 \times (ro_{P5} \,||\, ro_{N6})$
$= -9.14 \times 10^{-5} \times (279329.608)$
$= -25.530$

Practically open loop gain of OTA I got is $\underline{2366.199}$.

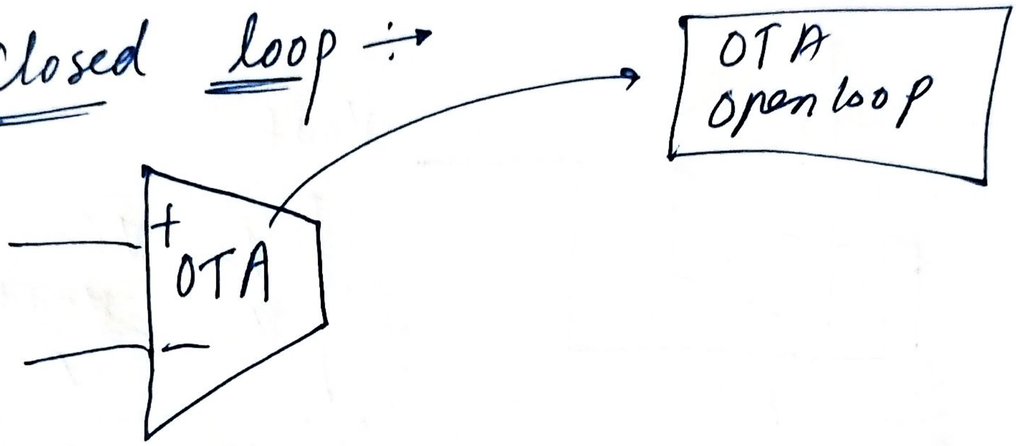
and first stage practically is $\underline{101.0204}$

So, gain for second stage practically is $\underline{23.4229}$.

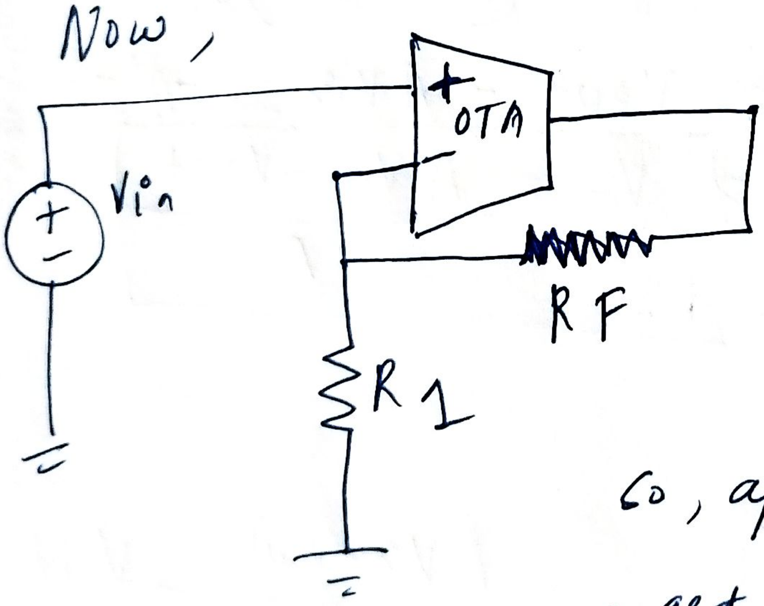
error $= -8.25\%$

Theoretically
total gain is (-102.06×-25.530)
$= 2605.5918$
but practical gain $= 2366.199$
So, error of $\underline{-9.18\ \%}$

* <u>Closed loop</u> :-



Now,



Now considering infinite Amplification
$V_+ = V_- = V_{in}$

So, applying KCL at V_-

we get

$$\frac{V_- - V_{out}}{R_F} + \frac{V_-}{R_1} = 0$$

$$\Rightarrow \boxed{\frac{V_{out}}{V_-} = \frac{R_1 + R_F}{R_1}}$$

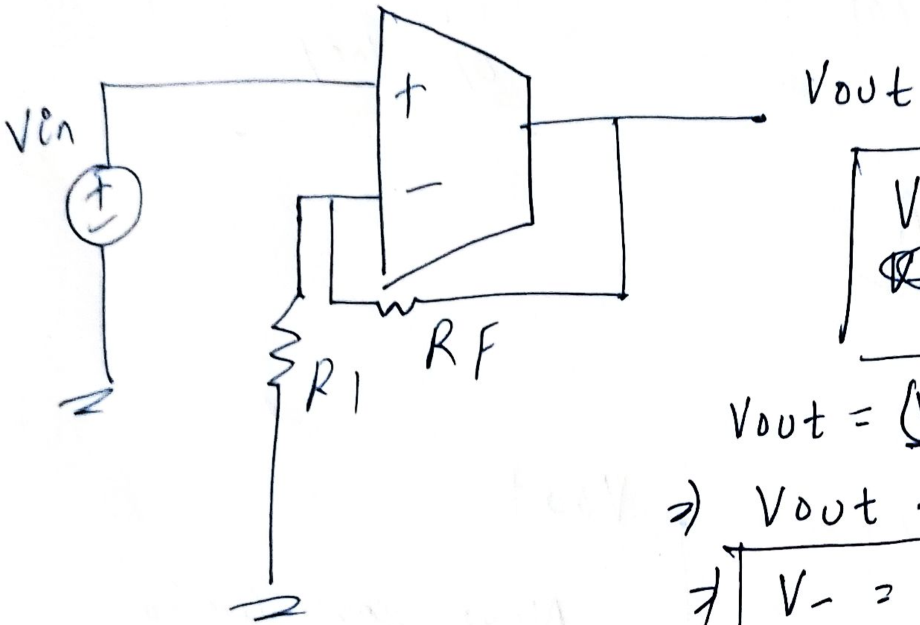
$$\Rightarrow \boxed{\frac{V_{out}}{V_-} = 1 + \frac{R_F}{R_1}}$$

So, if $RF = R1$

we get 2

So, $\boxed{RF = R1 = 20K}$

but the OTA we have designed has a finite A i.e. $\underline{2366.199}$.



$\boxed{V_+ = V_{in}}$

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

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

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

So, KCL at V^-,

$$\frac{\left[\frac{AV_{in} - V_{out}}{A}\right]}{R_1} + \frac{\frac{AV_{in} - V_{out}}{A} - V_{out}}{RF} = 0$$

$$\Rightarrow \frac{V_{in}}{R1} + \frac{V_{in}}{RF} = V_{out}\left[\frac{1}{AR1} + \frac{1}{RF} + \frac{1}{ARF}\right]$$

$$\Rightarrow \cancel{V_{in}\left[\frac{R1+RF}{R1RF}\right]} = \cancel{V_{out}}\left[\cancel{AR1\,(A+1)}\right]$$

$$\Rightarrow V_{in}\left[\frac{R_1+R_F}{\cancel{R_1R_F}}\right] = V_{out}\left[\frac{R_F+AR_1+R_1}{A\cancel{R_1}R_F}\right]$$

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

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

this causing the discrepancy

so, chosen $\boxed{R_F = 21k \text{ and } R_1 = 20k}$

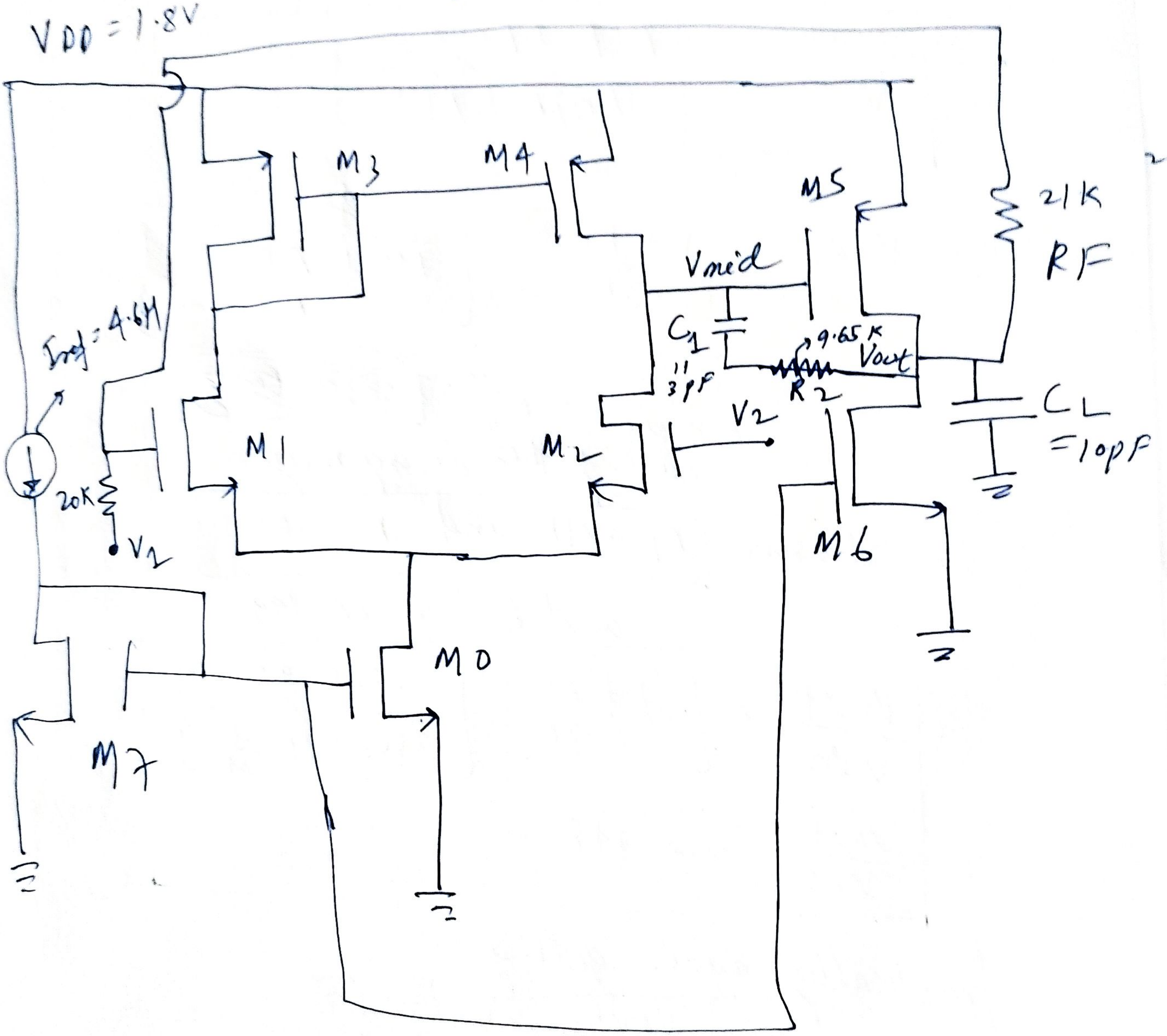
and $A = 2366.199$

$$\Rightarrow \boxed{\frac{V_{out}}{V_{in}} = \left[1+\frac{21}{20}\right]\left[\frac{2366.199}{2367.199+\frac{21}{20}}\right] \\ \Rightarrow \frac{V_{out}}{V_{in}} = 2.048}$$

Practically again getting $\boxed{\frac{V_{out}}{V_{in}} = \cancel{2.035}\ 2.03675}$

$$\boxed{\text{error \%} = -0.5493}$$

Closed-loop circuit diagram :→



$V_1 = 0.9V\ dc$ $V_2 = 0.9V\ dc$ with 0.1m amplitude sine wave

Taken $C_1 = 3pF$ and $C_2 = 10pF$ poles are far apart

Now, bode plot had zero in the middle, which was compromising my phase margin

So, I put a R_2 in series with C_2 to shift my zero and get the required P.M.

First I approximated R_2 as $\frac{1}{g_{m5}}$

(taken from log file) $= \frac{10^5}{9.13}$

$= 10.952K$

but I got a P.M of 103°

So, I meddled and adjusted and at $R_2 = \cancel{9.7K}$ 9.65K I got P.M of 60° (approx)

Bandwidth (3db) = 13.010498 MHz (approx)

Location of dominant pole P_2 :-

$$\frac{1}{A_{v\text{ of second stage}}\, C_1 (r_{oP5} \| r_{oN6})}$$

$$= \frac{10^{12}}{(3 \times 23.4229 \times 279329.608)}$$

$$= \frac{10^{12}}{(3 \times 23.4229 \times 279329.608)}$$

$= \cancel{50.947}$ ~~rad/sec~~

$= 50.947 \times 10^3$ rad/sec

Theoretical :-

$(W/L)_7$	$3.6u/0.9u = 4$
$(W/L)_0$	$36u/9u = 40$
$(W/L)_1$	$18u/9u = 20$
$(W/L)_2$	$18u/9u = 20$
$(W/L)_3$	$3.6u/0.9u = 4$
$(W/L)_4$	$3.6u/0.9u = 4$
$(W/L)_5$	$3.6u/0.9u = 4$
$(W/L)_6$	$18u/0.9u = 20$
Gain of first stage	-102.06
g_{m2}	3.95×10^{-4} → log file
Gain of second stage	~~23.4229~~ → 25.530
g_{m5}	9.14×10^{-4} → log file
Overall gain	2605.5918

Practical :-

$(W/L)_7$	$3.45\mu/0.90 = 3.833$
$(W/L)_0$	$36/9\mu = 40$
$(W/L)_1$	$18\mu/90 = 20$
$(W/L)_2$	$18\mu/90 = 20$
$(W/L)_3$	$3.6\mu/0.90 = 4$
$(W/L)_4$	$3.6\mu/0.90 = 4$
$(W/L)_5$	$3.6\mu/0.9\mu = 4$
$(W/L)_6$	$16.65\mu/0.9\mu = 18.5$
gain of first stage	101.0204
error in first stage (wrt theoretical)	~~8.25%~~ -1.02%
gain of second stage	23.4229
error in second stage (wrt theoretical)	-8.25%
overall gain	2366.199
error in overall gain (wrt theoretical)	-9.18%
C_1	3pF
C_L	10pF
R_2	9.65K
P.M	60° (approx)
Location of dominant pole	50.947×10^3 rad/sec
Power dissipation	$(4.6+46+23)\mu A \times 1.8V = 1.3248 \times 10^{-4} W = 0.13248 mW$

Closed-loop :-

theoretical :-

gain of overall circuit :- 2

practical :-

calculated (with finite A_o) = 2.048

found in LTSpice = 2.03675

error = −0.5493 %

Log file attached with this pdf in teams