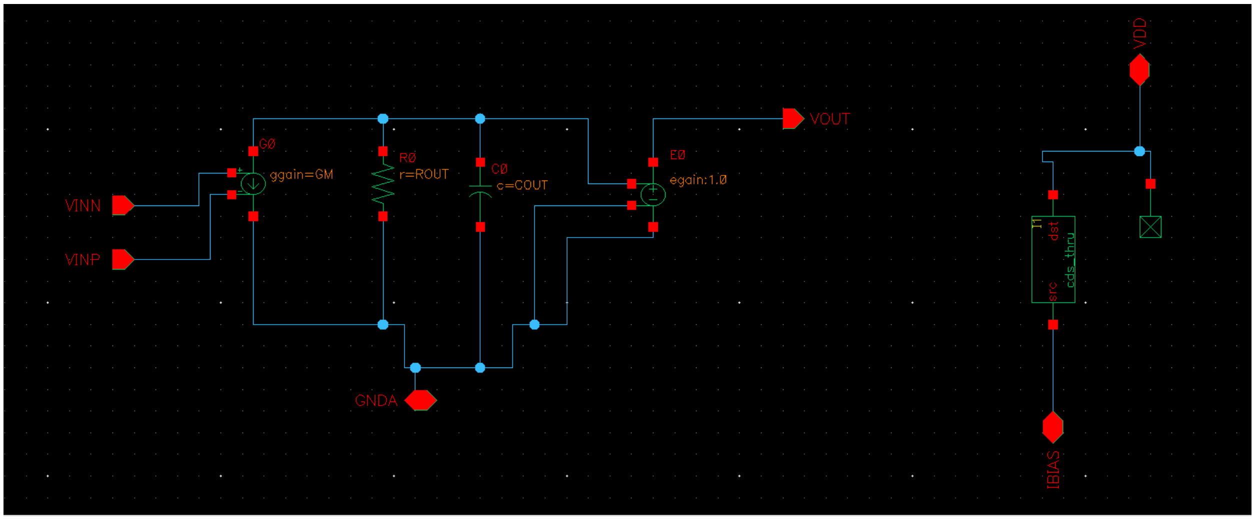
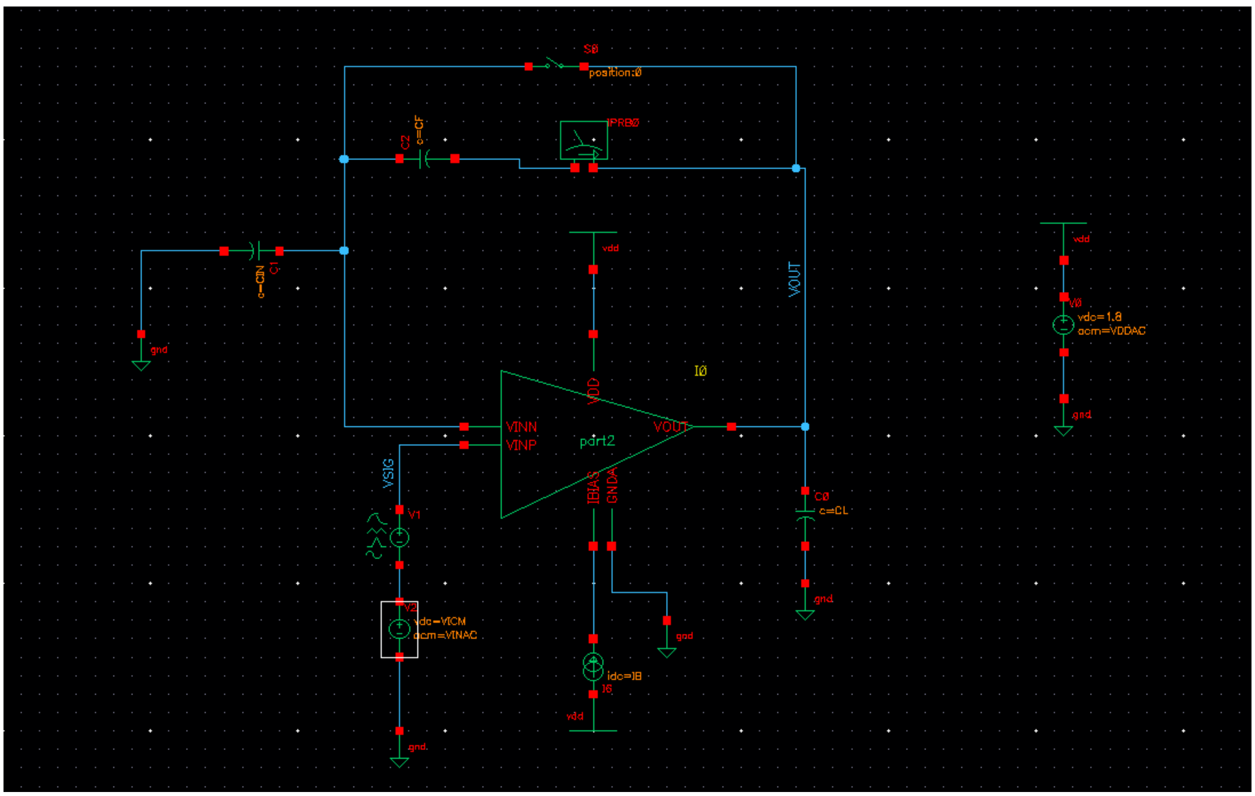
PART 1: Feedback with Behavioral OTA

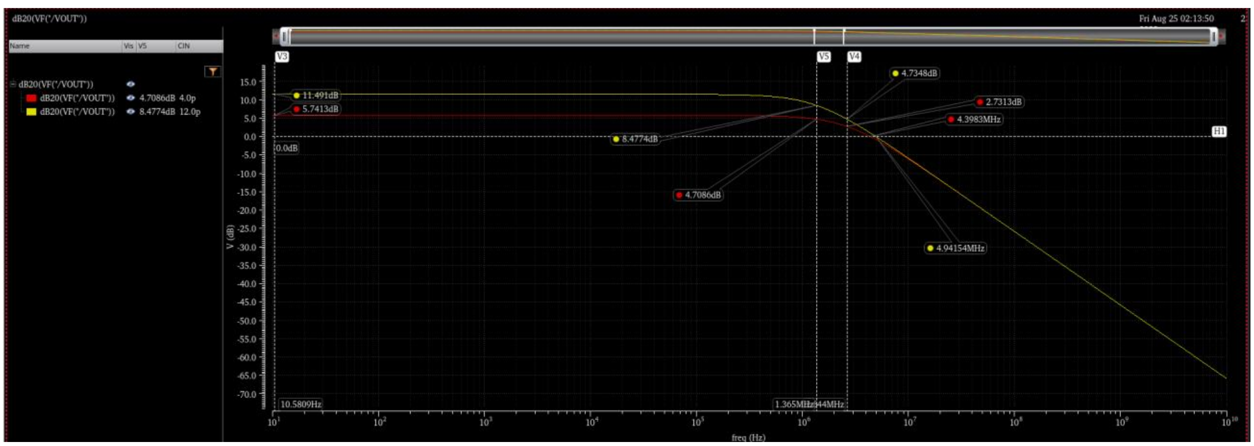




CF	4p
CIN	4p,12p
CL	5p
COUT	GM/wu
GM	162.9u
IB	10u
ROUT	AV/GM
VDD...	0
VICM	1.15
VINAC	1
AV	61.2
wu	32.17M

1 Closed loop gain vs frequency.

1.1 Plot Vout in dB for the two values of CIN (4pF and 12pF). Indicate the DC gain, the bandwidth, and the unity gain frequency in the plot



1.2

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter	Filter
Parameters: CIN=4p						
1	lab7_TEST_benc...	ymax(dB20(VF("...	5.741			
1	lab7_TEST_benc...	ymax(mag(VF("/...	1.937			
1	lab7_TEST_benc...	bandwidth(VF("/...	2.646M			
1	lab7_TEST_benc...	gainBwProd(VF(...	5.138M			
1	lab7_TEST_benc...	unityGainFreq(V...	4.423M			
Parameters: CIN=12p						
2	lab7_TEST_benc...	ymax(dB20(VF("...	11.49			
2	lab7_TEST_benc...	ymax(mag(VF("/...	3.755			
2	lab7_TEST_benc...	bandwidth(VF("/...	1.366M			
2	lab7_TEST_benc...	gainBwProd(VF(...	5.141M			
2	lab7_TEST_benc...	unityGainFreq(V...	4.951M			

1.3 COMPARE THE DC GAIN, BW, AND GBW WITH HAND ANALYSIS IN A TABLE

$C_{in} = 4P$: $\left(\frac{1}{\beta} = 1 + \frac{4}{4} = 2,\ \beta = \frac{1}{2}\right)$

A_v: Gain $= \frac{A_{OL}}{1+\beta A_{OL}} = \frac{61{,}2}{1+61{,}2 \times \frac{1}{2}}$

$= 1{,}937 = 5{,}74\ db$

$BW_{CL} = (1+\beta A_{OL}) BW_{OL} = \left(1+\frac{61{,}2}{2}\right)\frac{32{,}17 \times \frac{10^6}{2\pi}}{61{,}2}$

$= 2{,}64M$

$GBW = A_V \times BW_{CL}$

$= 5{,}11\ M$

$C_{in} = 12P$, $\frac{1}{\beta} = 1 + \frac{12}{4} = 4$, $\beta = \frac{1}{4}$

$A_V = \text{gain} = \frac{A_{OL}}{1+\beta A_{OL}} = \frac{61{,}2}{1+61{,}2 \times \frac{1}{4}} = 3{,}75$

$= 11{,}49\ db$

$BW_{CL} = \left(1 + \frac{61{,}2}{4}\right)\frac{32{,}17 \times 10^6 / 2\pi}{61{,}2} = 1{,}36\ M$

$GBW = A_V \times BW_{CL} = 5{,}11\ M$

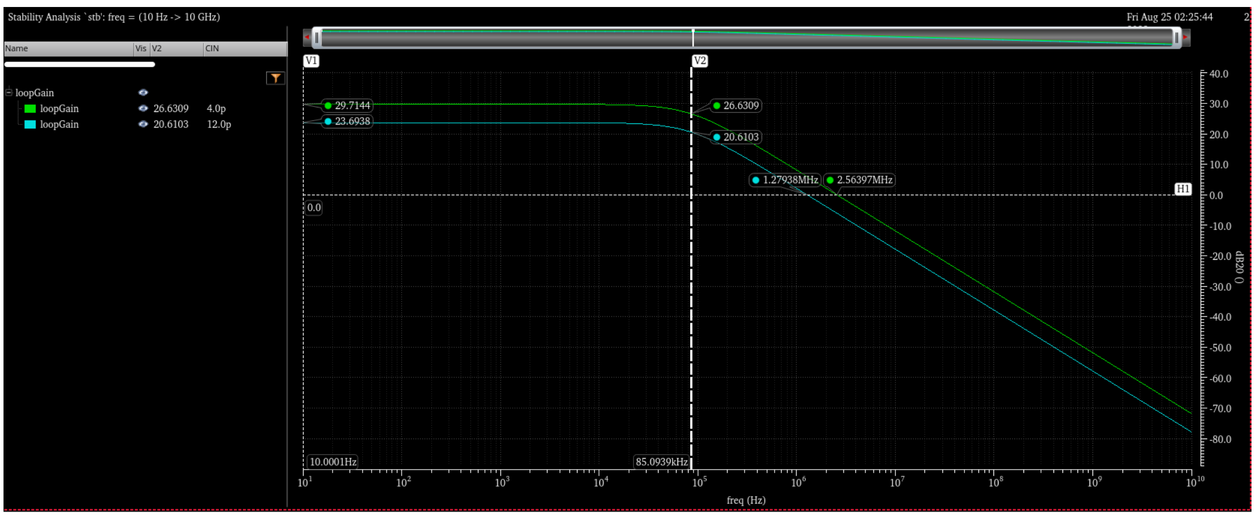
	4p		12p	
	SIM	ANALYTICAL	SIM	ANALYTICAL
Av(db)	5.741	5.74	11.49	11.49
Av	1.937	1.937	3.755	3.75
BW	2.646M	2.64M	1.366M	1.36M
GBW	5.138M	5.11M	5.141M	5.11M
UGF	4.423M	5.11M	4.951M	5.11M

1.4 COMMENT ON THE DIFFERENCE BETWEEN THE RESULTS FOR THE TWO VALUES OF CIN.

As CIN increased, beta decreased so the gain increased, but as GBW is constant so BW decreased.

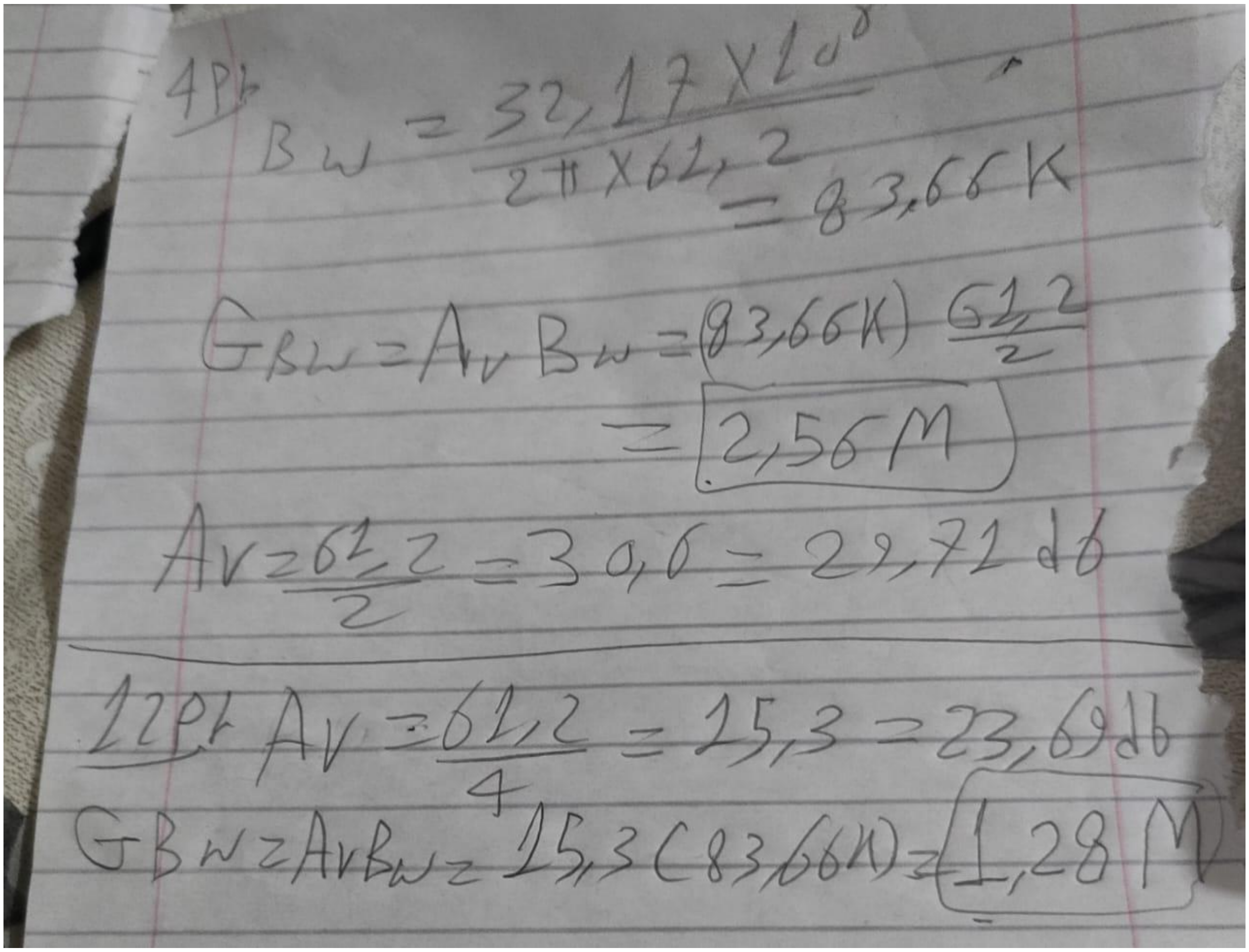
2 LOOP GAIN VS FREQUENCY.

2.1 PLOT LOOP GAIN IN DB FOR THE TWO VALUES OF CIN. ANNOTATE THE DC LOOP GAIN, THE DOMINANT POLE, AND THE UNITY GAIN FREQUENCY IN THE PLOT.



Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter	Filter
Parameters: CIN=4p						
1	lab7_TEST_benc...	unityGainFreq(...	2.572M			
1	lab7_TEST_benc...	ymax(mag(getD...	30.6			
1	lab7_TEST_benc...	ymax(dB20(mag...	29.71			
1	lab7_TEST_benc...	gainBwProd(ma...	2.569M			
Parameters: CIN=12p						
2	lab7_TEST_benc...	unityGainFreq(...	1.283M			
2	lab7_TEST_benc...	ymax(mag(getD...	15.3			
2	lab7_TEST_benc...	ymax(dB20(mag...	23.69			
2	lab7_TEST_benc...	gainBwProd(ma...	1.284M			

2.2 COMPARE DC LG AND GBW WITH HAND ANALYSIS IN A TABLE



4Pf $B_W = \frac{32,17 \times 10^8}{2\pi \times 61,2} = 83,66K$

$G_{BW} = A_v B_w = (83,66K)\frac{61,2}{2} = \boxed{2,56M}$

$A_v = \frac{61,2}{2} = 30,6 = 29,71\ db$

12Pf $A_v = \frac{61,2}{4} = 15,3 = 23,69\ db$

$GBW = A_v B_w = 15,3(83,66K) = \boxed{1,28\ M}$

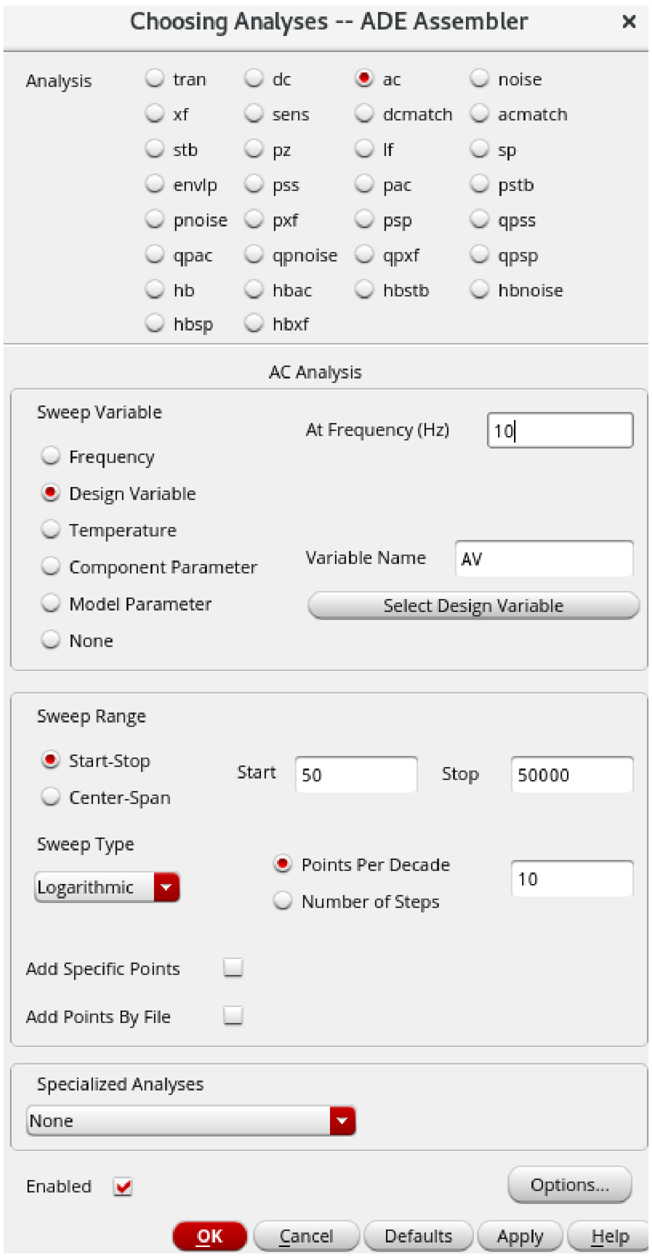
	4p		12p	
	SIM	ANALYTICAL	SIM	ANALYTICAL
Av(db)	29.71 db	29.71 db	23.69 db	23.69 db
Av	30.6	30.6	15.3	15.3
GBW	2.569M	2.56M	1.284M	1.28M
UGF	2.572M	2.56M	1.283M	1.28M

2.3 COMMENT ON THE DIFFERENCES BETWEEN THE RESULTS FOR THE TWO VALUES OF CIN.

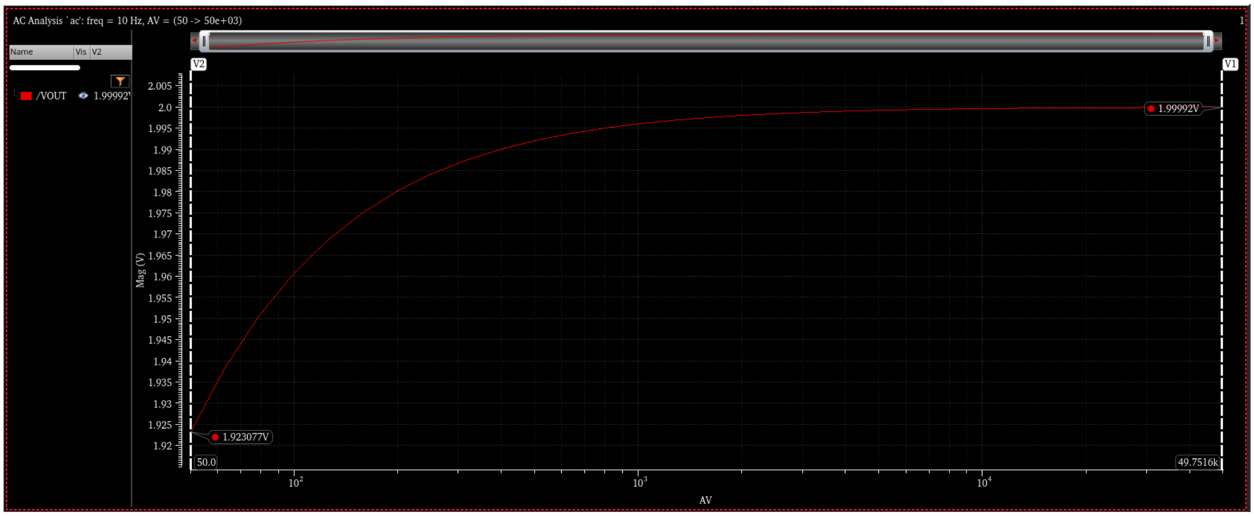
BW doesn't depend on $\boldsymbol{\beta}$ change, so when we change $\boldsymbol{\beta}$ we only change the gain, so the GBW also changes.

3 Gain Desensitization. Study the variation of closed loop gain with the variation of open loop gain

3.1 Set AC simulation to sweep design variable (Av = open loop gain of the behavioral OTA) = 50:50000, logarithmic, 10 points/decade. Set the AC simulation frequency at 10 Hz (single frequency point).



3.2 PLOT CLOSED LOOP DC GAIN (MAGNITUDE AT 10HZ, NOT DB) VS AV.



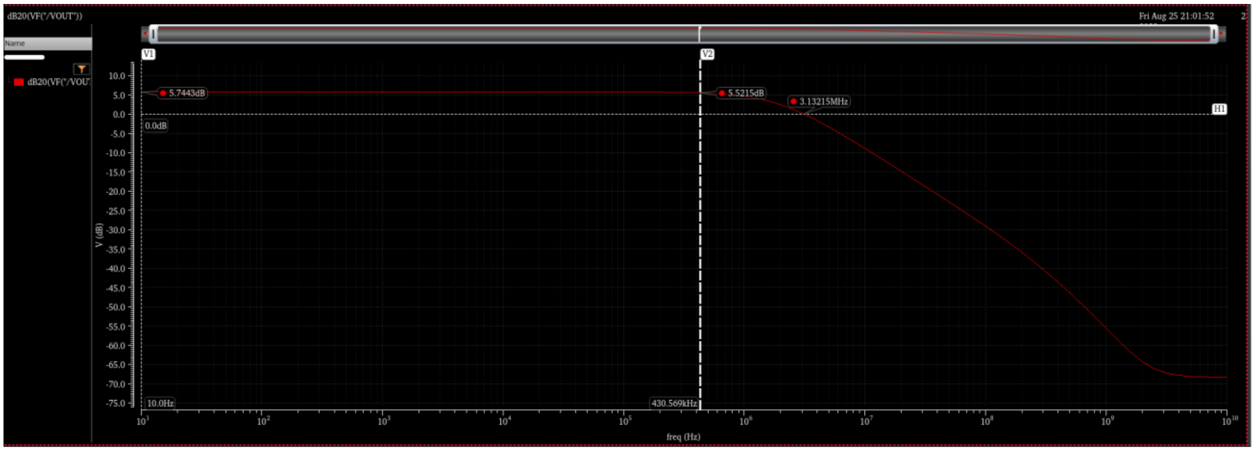
3.3 CALCULATE THE PERCENT CHANGE IN CLOSED LOOP GAIN (MAGNITUDE, NOT DB). NOTE THAT OPEN LOOP GAIN (AV) CHANGES BY THREE ORDERS OF MAGNITUDE (60 DB). COMMENT.

$((1.99 - 1.92)/1.92) * 100$=3.64%, close loop gain is so stable with the changes in open loop gain so the gain is desensitized.

PART 2: Feedback with Real 5T OTA

1 CLOSED LOOP GAIN VS FREQUENCY.

1.1 REPEAT WHAT YOU DID IN PART 1 (CLOSED LOOP GAIN VS FREQUENCY).



1.2 COMPARE BETWEEN THE RESULTS YOU OBTAINED HERE AND THE RESULTS IN PART 1 IN A TABLE

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter	Filter
Parameters: CL=4p						
1	lab7_TEST_benc...	ymax(dB20(VF("...	5.744			
1	lab7_TEST_benc...	ymax(mag(VF("/...	1.937			
1	lab7_TEST_benc...	bandwidth(VF("/...	1.886M			
1	lab7_TEST_benc...	gainBwProd(VF(...	3.663M			
1	lab7_TEST_benc...	unityGainFreq(V...	3.134M			
1	lab7_TEST_benc...	dB20(VF("/VOUT...				
Parameters: CL=12p						
2	lab7_TEST_benc...	ymax(dB20(VF("...	11.49			
2	lab7_TEST_benc...	ymax(mag(VF("/...	3.754			
2	lab7_TEST_benc...	bandwidth(VF("/...	852K			
2	lab7_TEST_benc...	gainBwProd(VF(...	3.206M			
2	lab7_TEST_benc...	unityGainFreq(V...	3.094M			
2	lab7_TEST_benc...	dB20(VF("/VOUT...				

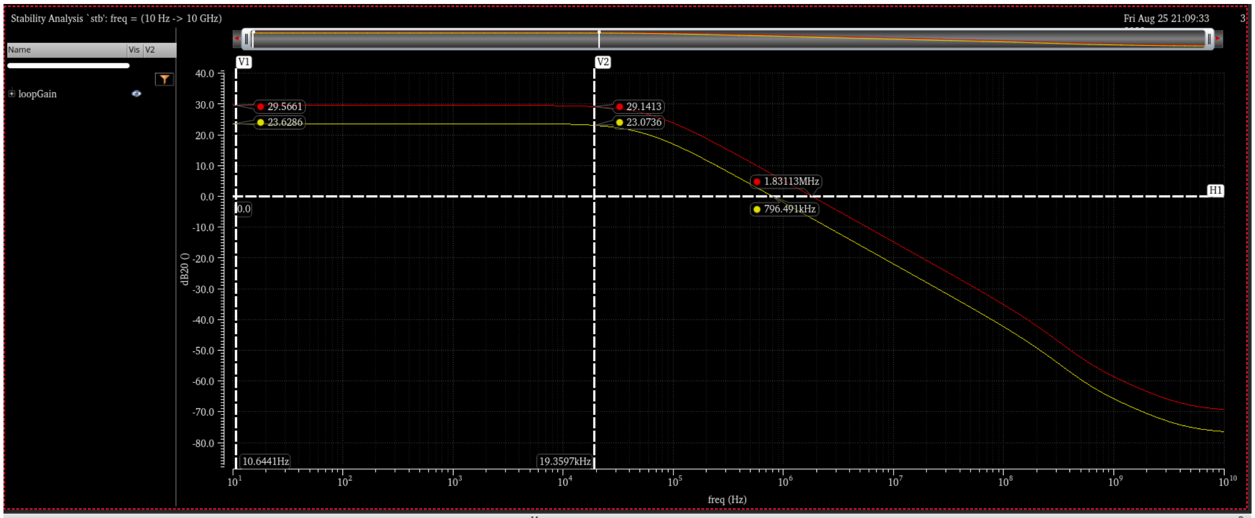
	4p		12p	
	Part1	Part2	Part1	Part2
Av(db)	5.741	5.774	11.49	11.49
Av	1.937	1.937	3.755	3.754
BW	2.646M	1.886M	1.366M	852K
GBW	5.138M	3.663M	5.141M	3.206M
UGF	4.423M	3.134M	4.951M	3.094M

1.3 You will notice that the bandwidth, and consequently the GBW are much smaller than Part 1. Why? Comment

Because in part2 there is no buffer like part1, so the capacitance increases (because of Cf and this can be expected using Miller's theorem) so GBW decreases.

2 Loop gain vs frequency.

2.1 Repeat what you did in Part 1 (Loop gain vs frequency).



2.2 Compare between the results you obtained here and the results in Part 1 in a table.

1	lab7_TEST_benc...	unityGainFreq(...	1.842M			
1	lab7_TEST_benc...	ymax(mag(getD...	30.08			
1	lab7_TEST_benc...	ymax(dB20(mag...	29.57			
1	lab7_TEST_benc...	gainBwProd(ma...	1.824M			
Parameters: CIN=12p						
2	lab7_TEST_benc...	unityGainFreq(...	796.7K			
2	lab7_TEST_benc...	ymax(mag(getD...	15.19			
2	lab7_TEST_benc...	ymax(dB20(mag...	23.63			
2	lab7_TEST_benc...	gainBwProd(ma...	800K			

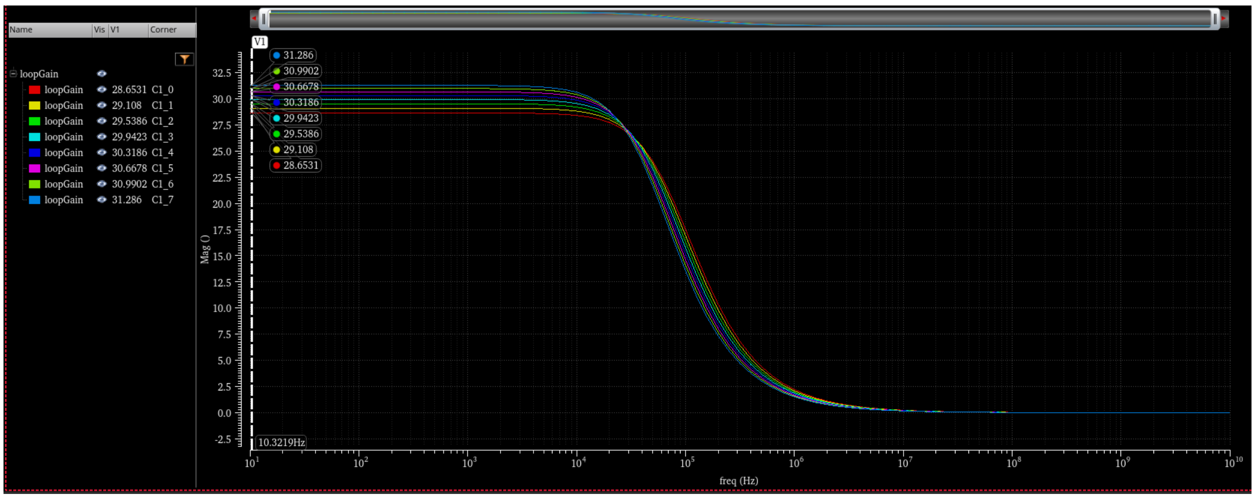
	4p		12p	
	PART1	PART2	PART1	PART2
Av(db)	29.71 db	29.57 db	23.69 db	23.63 db
Av	30.6	30.08	15.3	15.19
GBW	2.569M	1.842M	2.569M	800K
UGF	2.572M	1.842M	2.572M	796.7K

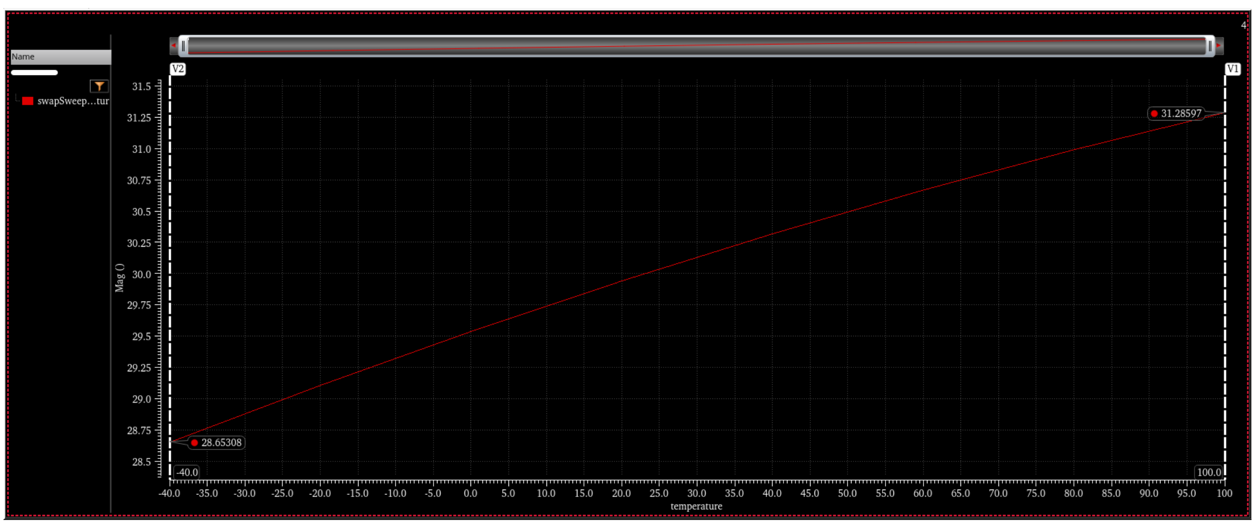
2.3 YOU WILL NOTICE THAT THE UNITY GAIN FREQUENCY IS MUCH SMALLER THAN PART 1. WHY? COMMENT.

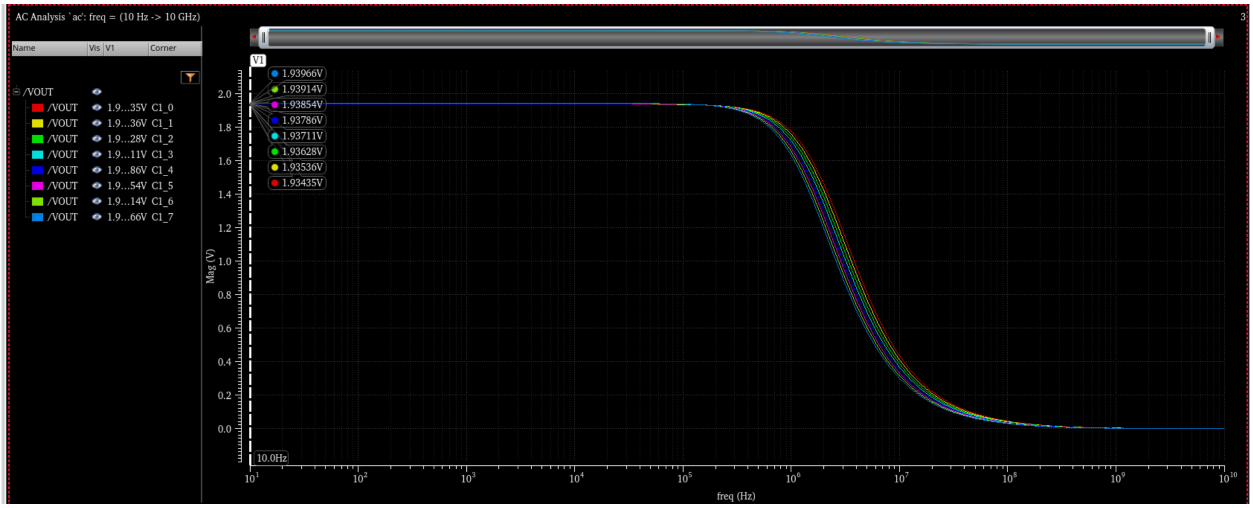
Because in part2 there is no buffer like part1, so the capacitance increases (because of Cf and this can be expected using Miller's theorem), so UGF decreases.

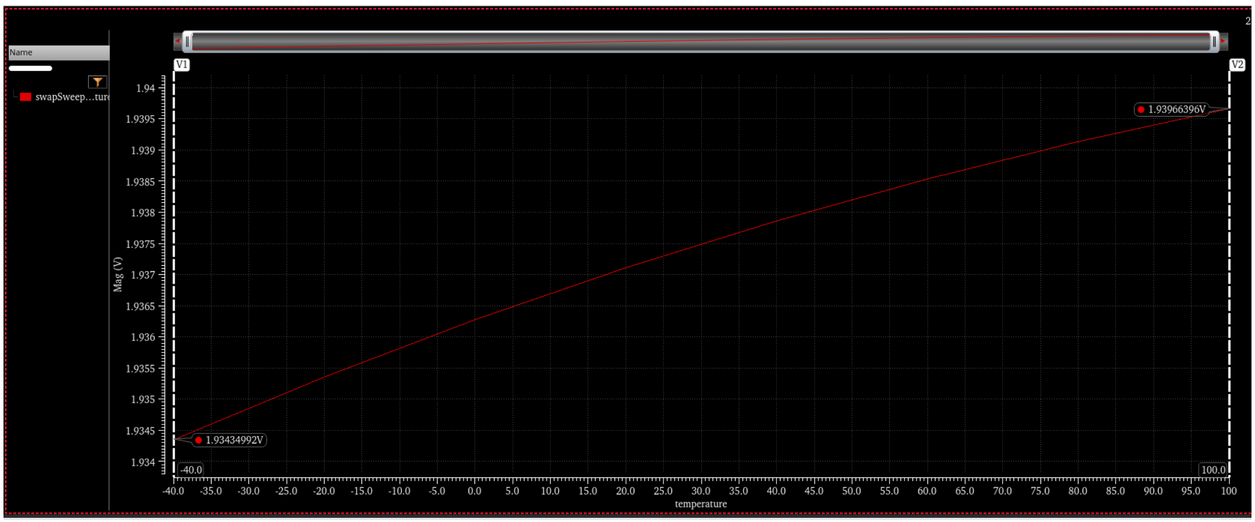
3 GAIN DESENSITIZATION.

Parameter	C1_0	C1_1	C1_2	C1_3	C1_4	C1_5	C1_6	C1_7
temperature	-40	-20	0	20	40	60	80	100









3.1 Compare the percent change in the DC loop gain (from STB) and the DC closed loop gain (from AC) across temperature extremes. Do NOT use dB when calculating percent change. Comment

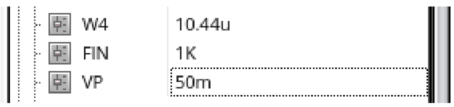
Change in closed loop gain = $\frac{1.939-1.934}{1.934} * 100 = 0.258\%$

Change in loop gain = $\frac{31.286-28.653}{28.653} * 100 = 9.19\%$

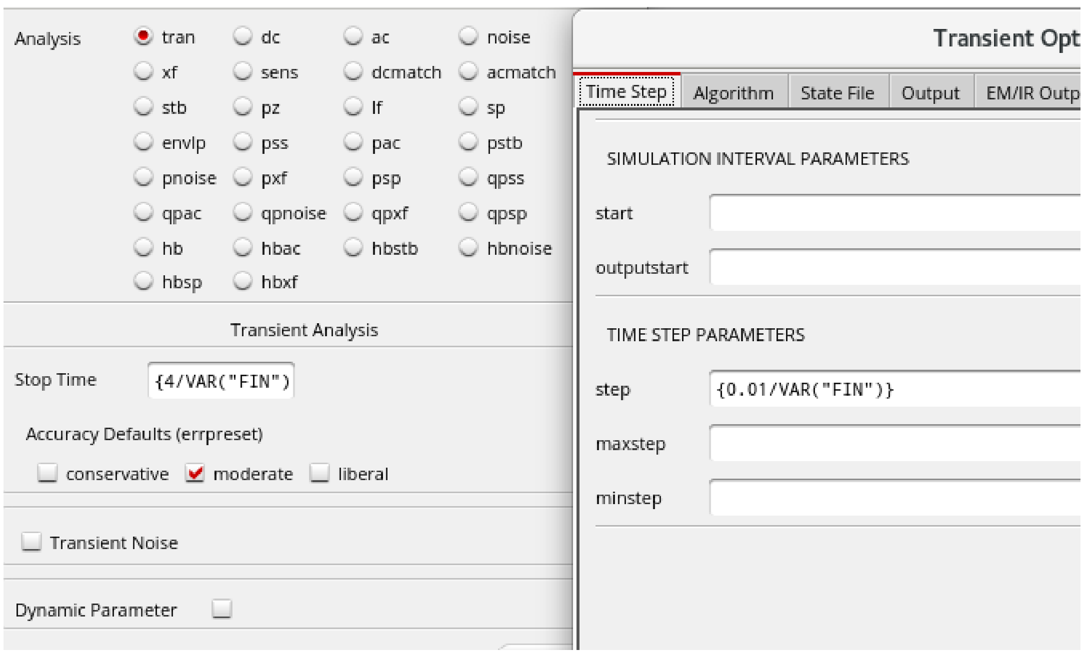
Closed loop gain is robust and stable with the changes in temperature, while the change in loop gain(Aol*β) is much larger.

4 TRANSIENT ANALYSIS.

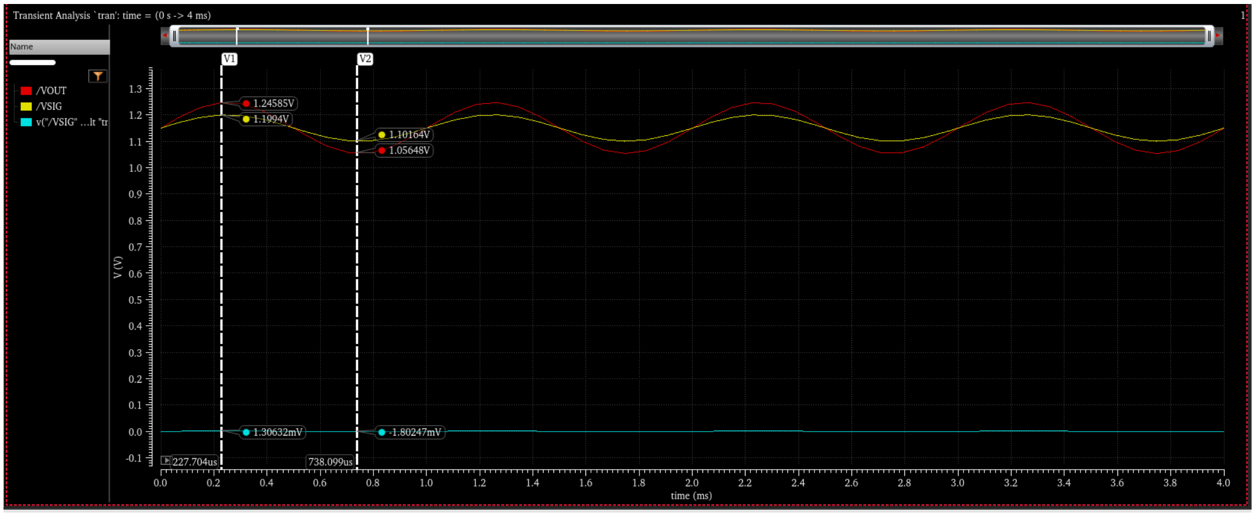
4.1 SET THE TRANSIENT SOURCE TO SINE WAVE WITH FREQUENCY FIN = 1KHZ AND AMPLITUDE VP = 50MV, WHERE FIN AND VP ARE TWO VARIABLES DEFINED IN THE PARAMETERS WINDOW



4.2 RUN TRANSIENT ANALYSIS. SET THE SIMULATION TIME TO BE {4/FIN} AND THE TIME STEP TO BE {0.01/FIN}



4.3 PLOT THE INPUT SIGNAL, THE OUTPUT SIGNAL, AND THE DIFFERENTIAL INPUT SIGNAL OF THE OTA (VP – VN).



4.4 CALCULATE THE PEAK-TO-PEAK VOLTAGE OF THE PREVIOUS THREE SIGNALS. WHAT IS THE RELATION BETWEEN THE OUTPUT AND (VP – VN)? COMMENT.

lab7_TEST_benc...	(ymax(v("/VOUT" ?result "tran")) - ymin(v("/VOUT" ?result "tran")))	193.2m			
lab7_TEST_benc...	(ymax(v("/VSIG" ?result "tran")) - ymin(v("/VSIG" ?result "tran")))	99.72m			
lab7_TEST_benc...	(ymax((v("/VSIG" ?result "tran") - v("/VINN" ?result "tran"))) - ymin((v("/VSIG" ?result "tran") - v("/VINN" ?result "tran"))))	3.163m			

VOUT -> 193.2 m

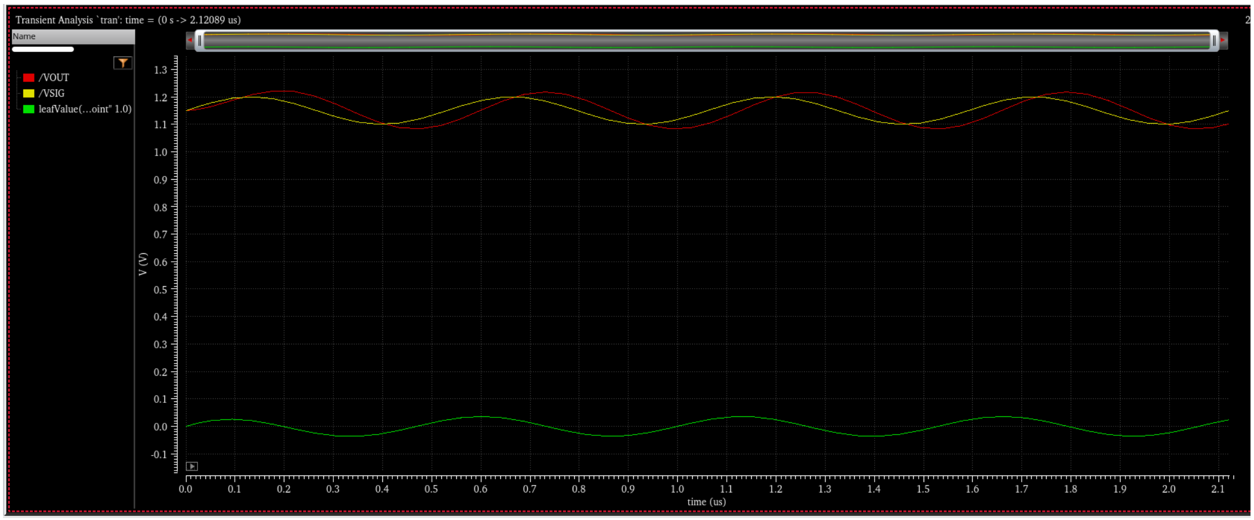
Vsig -> 99.72 m

Vdiff -> 3.163 m

As expected The relation between the output and differential input is the open loop gain at dc gain

$Av = \frac{193.2m}{3.163m}$=61

4.5 REPEAT THE TRANSIENT ANALYSIS WITH FIN EXACTLY EQUAL TO THE CLOSED LOOP BANDWIDTH. PLOT THE INPUT SIGNAL, THE OUTPUT SIGNAL, AND THE DIFFERENTIAL INPUT SIGNAL OF THE OTA (VP – VN)



4.6 CALCULATE THE PEAK-TO-PEAK VOLTAGE OF THE PREVIOUS THREE SIGNALS. WHAT IS THE RELATION BETWEEN THE OUTPUT AND THE INPUT SIGNAL? WHAT IS THE RELATION BETWEEN THE OUTPUT AND (VP – VN)? COMPARE BETWEEN THIS CASE AND THE CASE OF 1KHZ INPUT.

lab7_TEST_benc...	(ymax(v("/VOUT" ?result "tran")) - ymin(v("/VOUT" ?result "tran")))	138.2m			
lab7_TEST_benc...	(ymax(v("/VSIG" ?result "tran")) - ymin(v("/VSIG" ?result "tran")))	99.78m			
lab7_TEST_benc...	(ymax((v("/VSIG" ?result "tran") - v("/VINN" ?result "tran"))) - ymin((v("/VSIG" ?result "tran") - v("/VINN" ?result "tran"))))	72.14m			

VOUT -> 138.2 m

Vsig -> 99.78 m

Vdiff -> 72.14 m

the relation between the output and the input signal: $\frac{138.2}{99.78} = 1.38$ as expected we have an input signal exactly at the pole, so the gain would decreased by 3db ($\frac{1}{\sqrt{2}}$), $\frac{1.93}{\sqrt{2}} = 1.36 \sim 1.38$.

the relation between the output and (VP – VN): $\frac{138.2}{72.14} = 1.91$

The open-loop and closed-loop asymptotes coincide at this high frequency, so we can calculate the decay happened at the point of fin(BWcl) from 3 + 20 log(fin/BWol)=30.06 db = 31.84

$$\frac{61.2}{31.84} = 1.92$$

Compare between this case and the case of 1kHz input:

In the case of 1khz we got the dc gain as the frequency is much smaller than the open loop bandwidth.