Analog IC Design Lab 08
Negative Feedback

PART 1: Feedback with Behavioral OTA

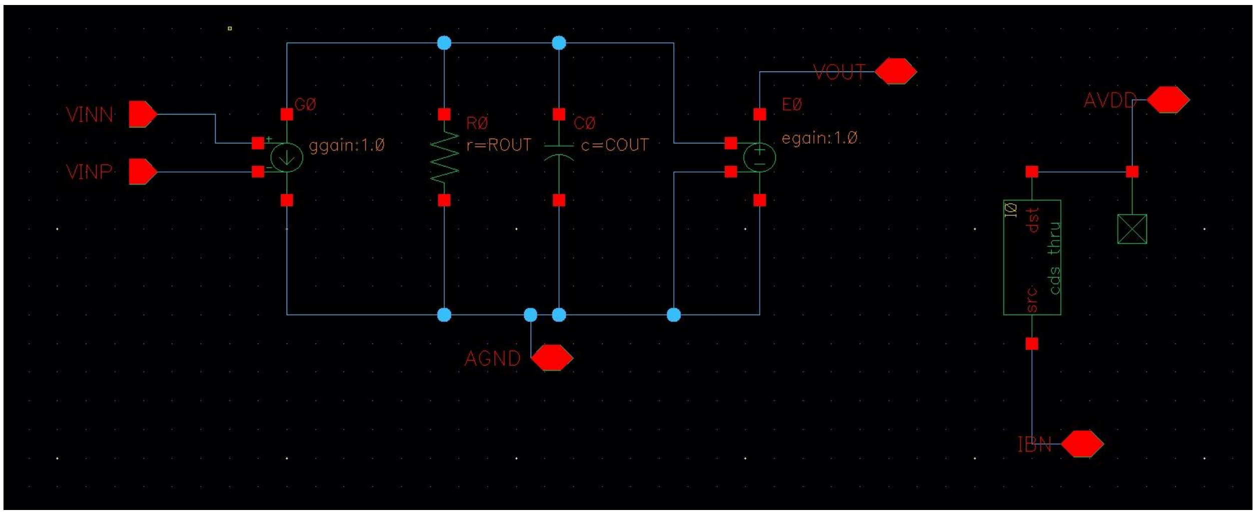

Figure 1 Schematic behavioral.

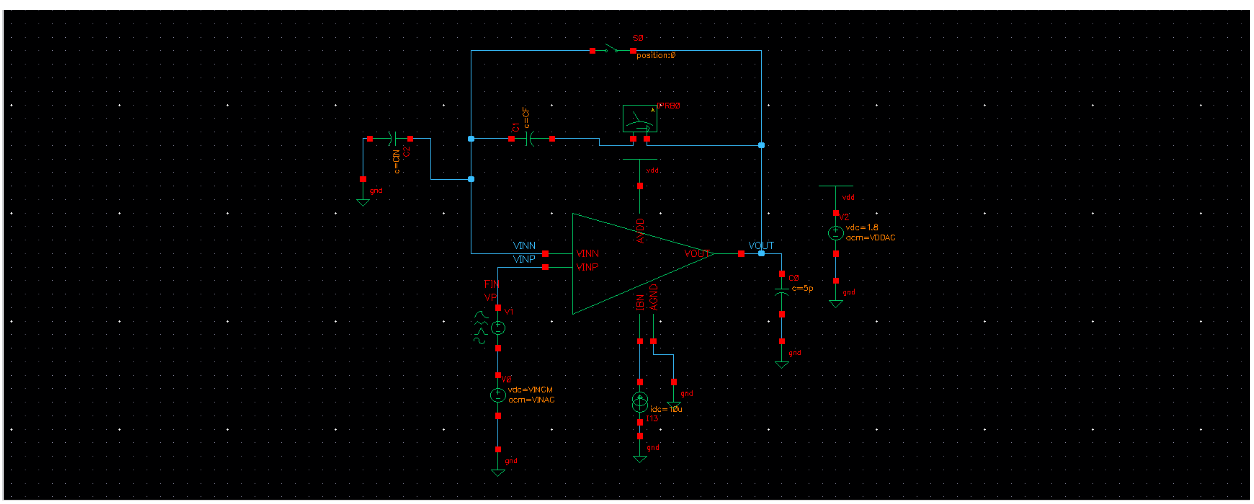

Figure 2 Schematic testbench.

- Set the simulation parameters as below. Note that we set the DC gain and unity gain frequency (GBW) like those of the 5T OTA designed in the previous lab.
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Description	Variable	Value
Feedback capacitance	CF	4p
Input capacitance	CIN	4p, 12p
Load capacitance	CL	as in Lab 07

Transconductance of behavioral model	GM	as in Lab 07
DC gain of behavioral model	Av	as in Lab 07
UGF of behavioral model	wu[1]	as in Lab 07
Output cap of behavioral model	COUT	GM/wu
Output res of behavioral model	ROUT	Av/GM
AC stimulus magnitude	VINAC	1
Transient stimulus peak	VP	50m
Transient stimulus frequency	FIN	1k
Bias current	IB	as in Lab 07
CM input voltage	VICM	At the middle of the CMIR

From LAB07 $GM = 206\mu S\ \ A_V = 70.73 \quad W_U = 6.429MHZ$

Closed loop gain vs frequency

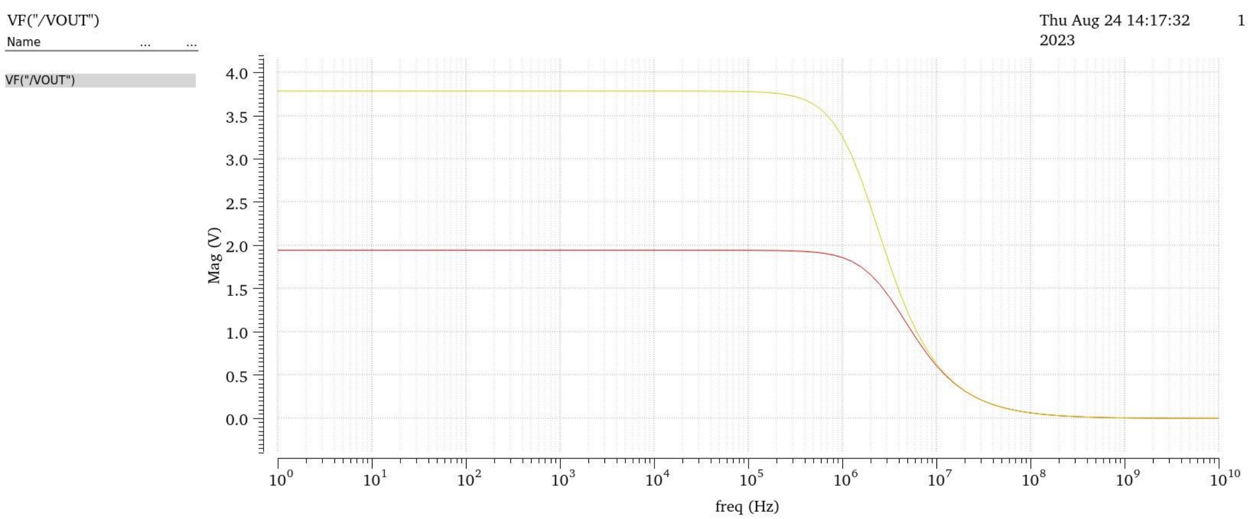


Figure 3 plot VOUT vs frequency.

[1] Note that $\omega_u = 2\pi f_u = 2\pi \times GBW$.

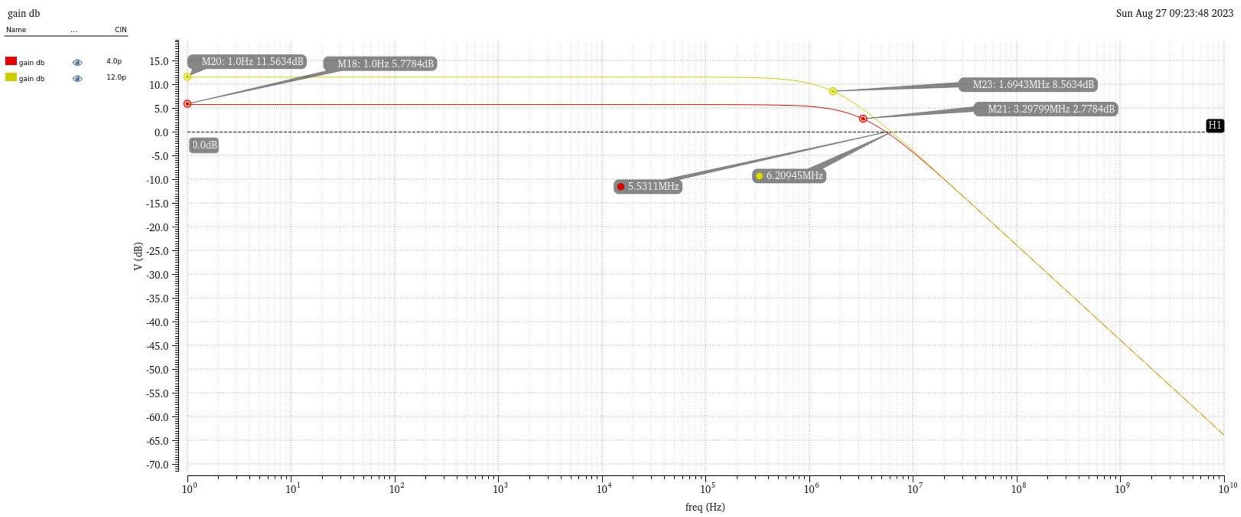
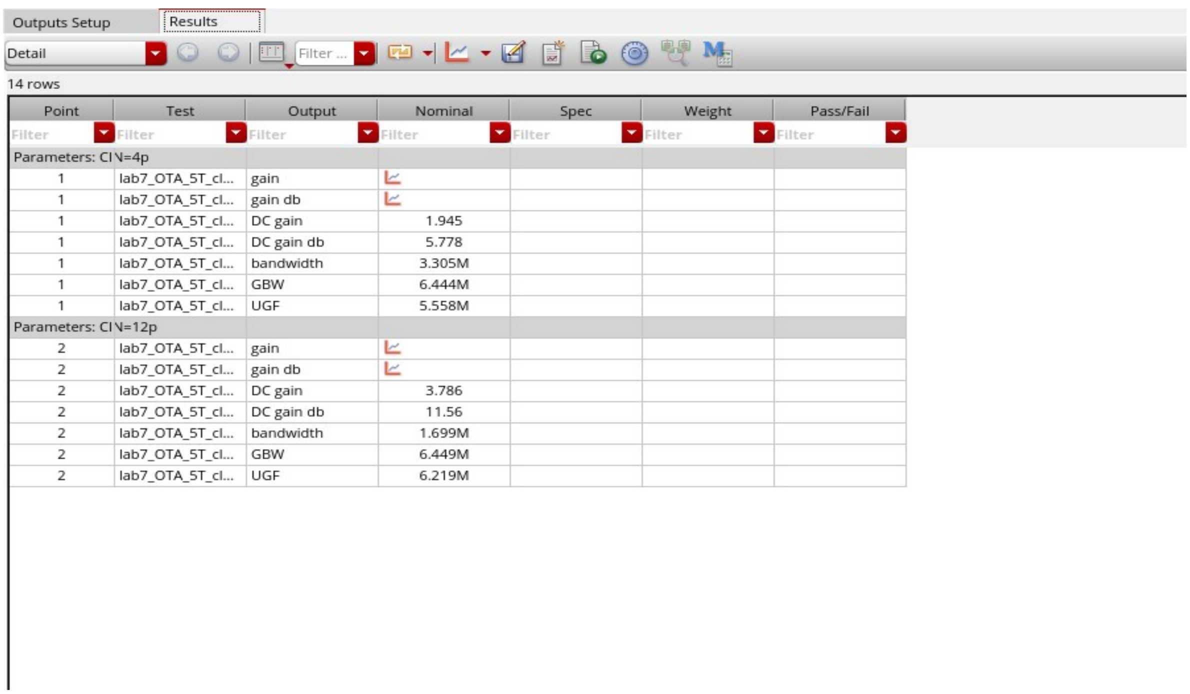


Figure 4 plot VOUT in dB vs frequency .



Outputs Setup | Results

Detail

14 rows

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	lab7_OTA_5T_cl...	gain				
1	lab7_OTA_5T_cl...	gain db				
1	lab7_OTA_5T_cl...	DC gain	1.945			
1	lab7_OTA_5T_cl...	DC gain db	5.778			
1	lab7_OTA_5T_cl...	bandwidth	3.305M			
1	lab7_OTA_5T_cl...	GBW	6.444M			
1	lab7_OTA_5T_cl...	UGF	5.558M			
Parameters: CIN=12p						
2	lab7_OTA_5T_cl...	gain				
2	lab7_OTA_5T_cl...	gain db				
2	lab7_OTA_5T_cl...	DC gain	3.786			
2	lab7_OTA_5T_cl...	DC gain db	11.56			
2	lab7_OTA_5T_cl...	bandwidth	1.699M			
2	lab7_OTA_5T_cl...	GBW	6.449M			
2	lab7_OTA_5T_cl...	UGF	6.219M			

Figure 5 Results from simulator.

Hand analysis:

DC gain:

- $C_{in} = 4pF \quad \beta = \frac{C_f}{C_{in}+c_f} = 0.5 \, , A_{OL} \, from \, previous \, lab = 70.73 \, so$

  $$A_{CL} = \frac{A_{OL}}{1+\beta A_{OL}} = \frac{70.73}{1+0.5*70.73} = 1.945 = 5.778 \, dB.$$

- $C_{in} = 12pF \quad \beta = \frac{C_f}{C_{in}+c_f} = 0.25 \, , A_{OL} \, from \, previous \, lab = 70.73 \, so$

  $$A_{CL} = \frac{A_{OL}}{1+\beta A_{OL}} = \frac{70.73}{1+0.25*70.73} = 3.786 = 11.56 \, dB.$$

Bandwidth:

- $C_{in} = 4pF \quad \beta = \frac{C_f}{C_{in}+c_f} = 0.5\,, A_{OL}\ from\ previous\ lab = 70.73\ and\ W_{OL} = 90.66KHZ.$

  $W_{CL} = W_{OL} * (1 + \beta A_{OL}) = 90.66K * (1 + 0.5 * 70.73) = 3.297MHZ.$
- $C_{in} = 12pF \quad \beta = \frac{C_f}{C_{in}+c_f} = 0.25\,, A_{OL}\ from\ previous\ lab = 70.73\ and\ W_{OL} = 90.66KHZ$

  $W_{CL} = W_{OL} * (1 + \beta A_{OL}) = 90.66K * (1 + 0.25 * 70.73) = 1.694MHZ.$

GBW:

- $C_{in} = 4pF \quad GBW = gain * bandwidth = 1.945 * 3.297M = 6.413MHZ$
- $C_{in} = 12pF \quad GBW = gain * bandwidth = 3.786 * 1.694M = 6.413MHZ$

	Simulation $C_{IN} = 4p$	Hand analysis $C_{IN} = 4p$	Simulation $C_{IN} = 12p$	Hand analysis $C_{IN} = 12p$
DC gain	1.945	1.945	3.786	3.786
DC gain dB	5.778	5.778	11.56	11.56
Bandwidth	3.305M	3.297M	1.699M	1.694M
GBW	6.444M	6.413M	6.449M	6.413M

• Comment on the difference between the results for the two values of CIN.

As shown from previous analysis that by increasing capacitance the value of feedback factor decreases due to capacitive divider which increases the value of closed-loop gain, but cannot reach to ideal value of closed-loop gain because open-loop gain is a finite gain, but GBW is the same in two cases because as gain decrease bandwidth increase by the same ratio which keep GBW constant.

Loop gain vs frequency

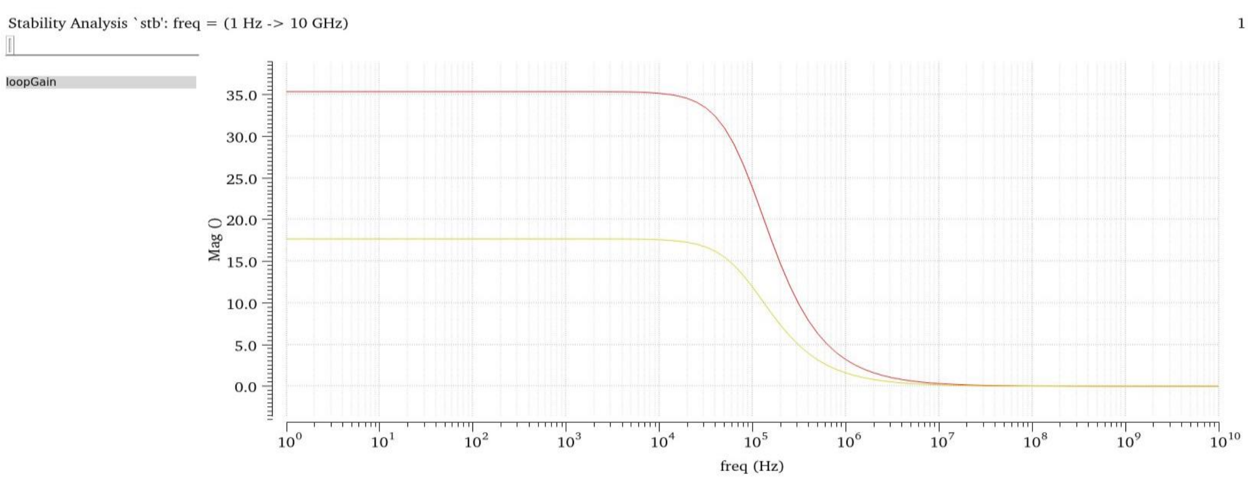


Figure 6 plot Vout vs frequency in STB analysis.

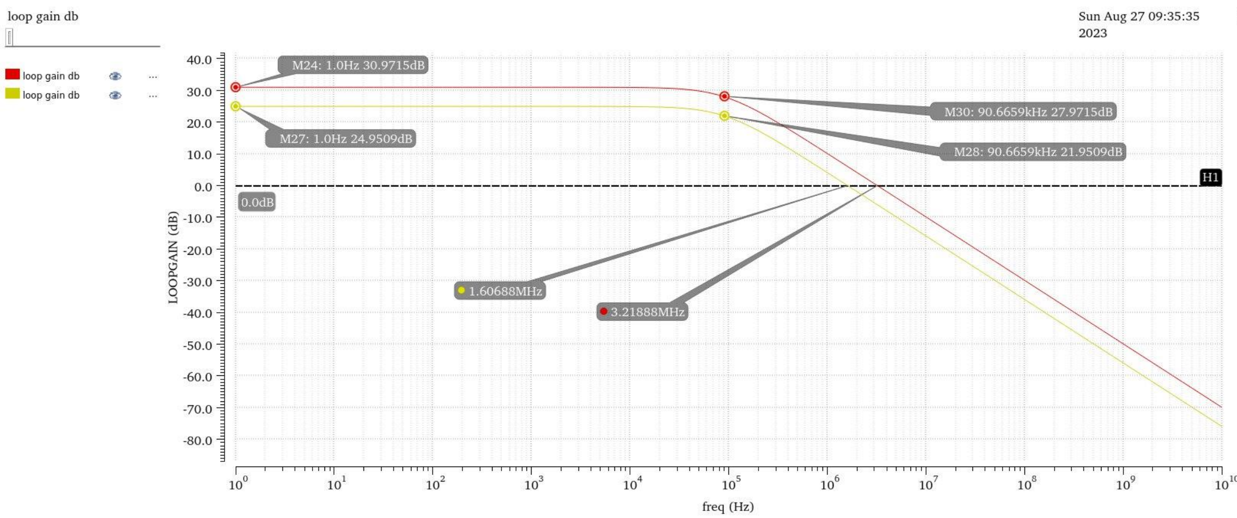
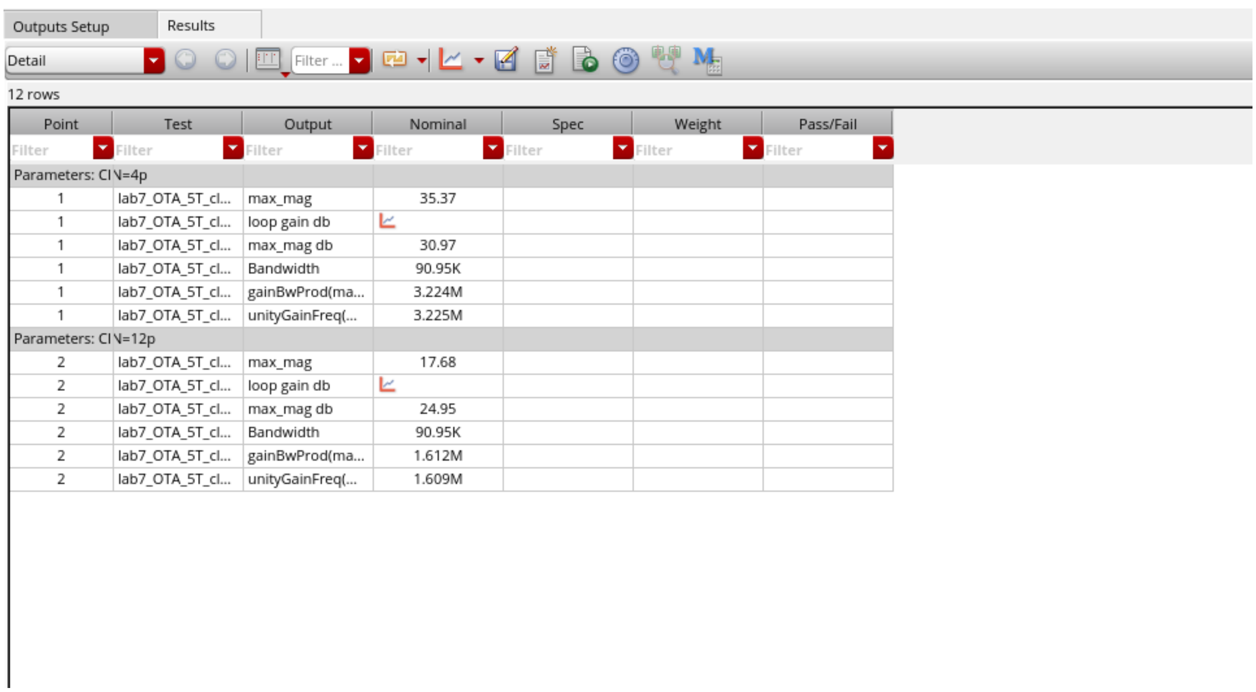


Figure 7 plot loop gain vs frequency in STB analysis.



Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	lab7_OTA_5T_cl...	max_mag	35.37			
1	lab7_OTA_5T_cl...	loop gain db				
1	lab7_OTA_5T_cl...	max_mag db	30.97			
1	lab7_OTA_5T_cl...	Bandwidth	90.95K			
1	lab7_OTA_5T_cl...	gainBwProd(ma...	3.224M			
1	lab7_OTA_5T_cl...	unityGainFreq(...	3.225M			
Parameters: CIN=12p						
2	lab7_OTA_5T_cl...	max_mag	17.68			
2	lab7_OTA_5T_cl...	loop gain db				
2	lab7_OTA_5T_cl...	max_mag db	24.95			
2	lab7_OTA_5T_cl...	Bandwidth	90.95K			
2	lab7_OTA_5T_cl...	gainBwProd(ma...	1.612M			
2	lab7_OTA_5T_cl...	unityGainFreq(...	1.609M			

Figure 8 results from simulators.

DC loop gain Hand analysis:

- $C_{in} = 4pF \quad \beta = \frac{C_f}{C_{in}+c_f} = 0.5\, , A_{OL}\ from\ previous\ lab = 70.73\ so$

  $A_{LG} = \beta * A_{OL} = 0.5 * 70.73 = 35.37 = 30.97dB$
- $C_{in} = 12pF \quad \beta = \frac{C_f}{C_{in}+c_f} = 0.25\, , A_{OL}\ from\ previous\ lab = 70.73\ so$

  $A_{LG} = \beta * A_{OL} = 0.25 * 70.73 = 17.68 = 24.95dB$

GBW loop gain Hand analysis:

- $C_{in} = 4pF \quad GBW = bandwidth * A_{LG} = 90.66K * 35.37 = 3.21MHZ$
- $C_{in} = 12pF \quad GBW = bandwidth * A_{LG} = 90.66K * 17.68 = 1.603MHZ$

	Simulation $C_{IN} = 4p$	Hand analysis $C_{IN} = 4p$	Simulation $C_{IN} = 12p$	Hand analysis $C_{IN} = 12p$
DC gain	35.37	35.37	17.68	17.68
GBW	3.224M	3.21M	1.612M	1.603M

• Comment on the differences between the results for the two values of CIN.

As shown from previous analysis that by increasing capacitance the value of feedback factor decreases due to capacitive divider which increases the value of closed-loop gain but cannot reach to ideal value of closed-loop gain because open-loop gain is a finite gain, which increase GBW because BW of LG is constant as open-loop BW.

Gain Desensitization

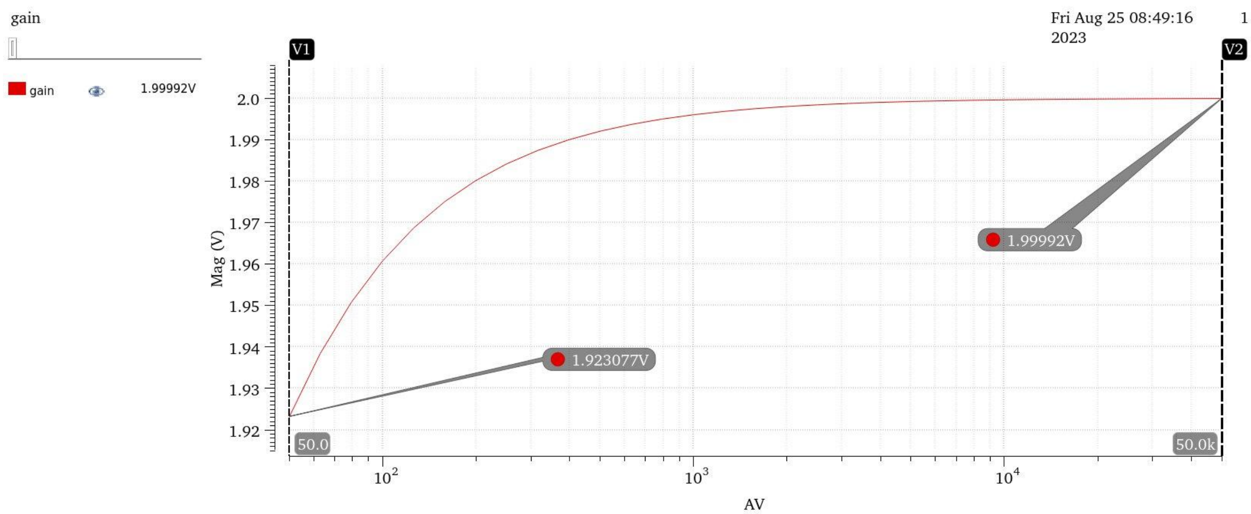


Figure 9 Plot VOUT vs open loop gain.

At $A_{OL} = 50K \quad A_{CL} = 2(ideal)$.

At $A_{OL} = 5 \quad A_{CL} = 1.923$.

$$percentage\ change = \frac{A_{CL\_ideal} - A_{CL\_Actual}}{A_{CL\_Ideal}} * 100 = 4\%.$$

Comment: from previous analysis as shown that closed-loop gain not affected by variations of open-loop gain, and only depend on capacitive divider loads so this give a stable gain with PVT variations.

PART 2: Feedback with Real 5T OTA

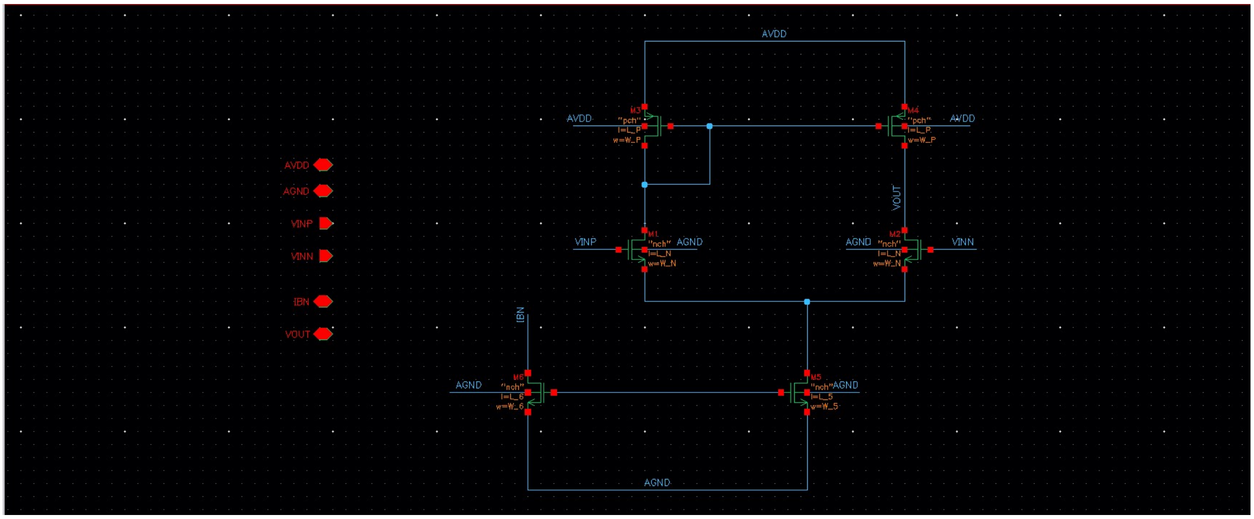


Figure 10 schematic of 5T-OTA.

Closed loop gain vs frequency

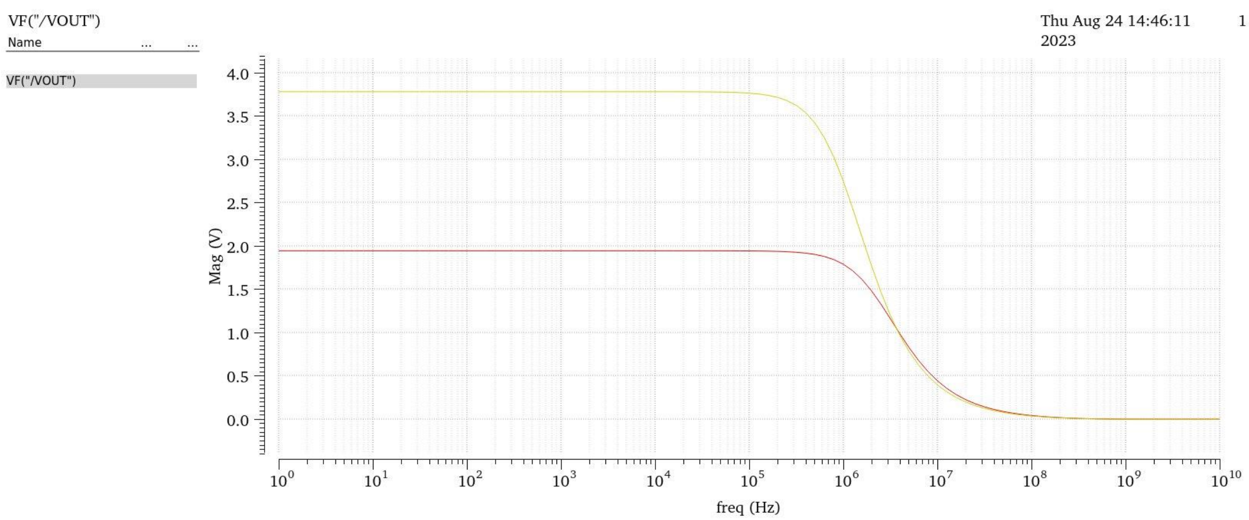


Figure 11 plot VOUT vs frequency.

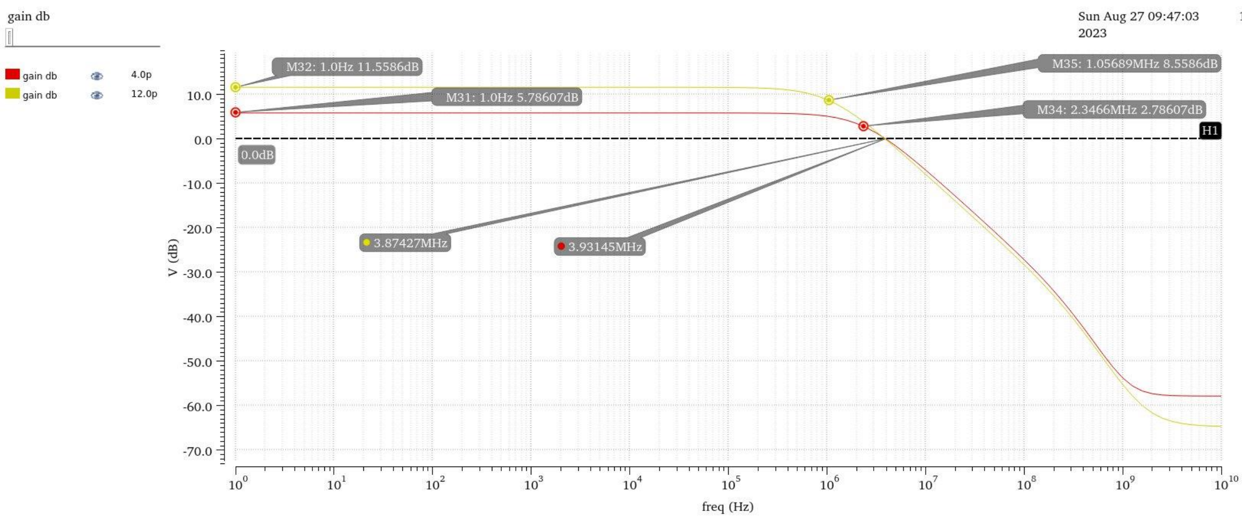
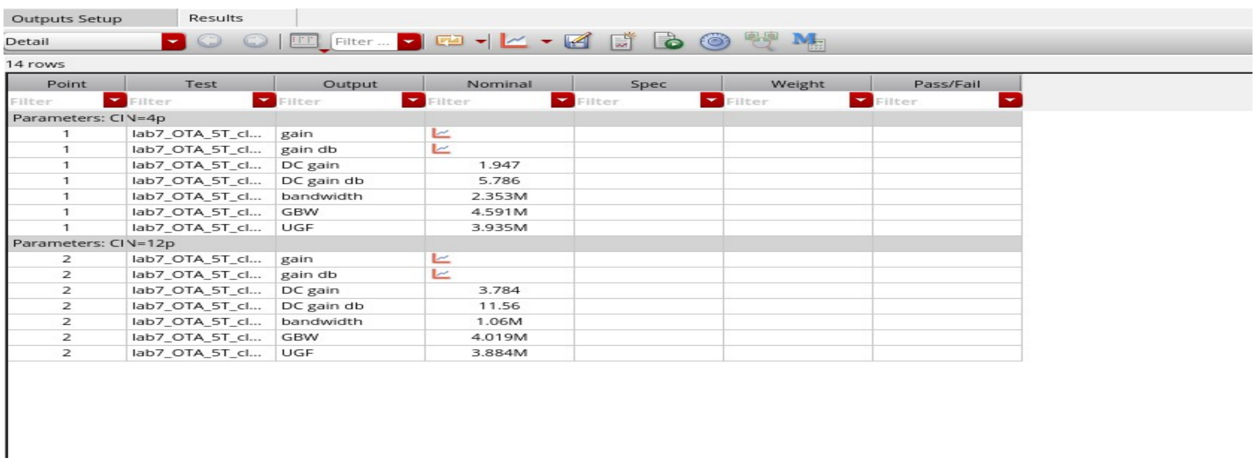


Figure 12 plot VOUT vs frequency in db.



Outputs Setup | Results

Detail

14 rows

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	lab7_OTA_5T_cl...	gain				
1	lab7_OTA_5T_cl...	gain db				
1	lab7_OTA_5T_cl...	DC gain	1.947			
1	lab7_OTA_5T_cl...	DC gain db	5.786			
1	lab7_OTA_5T_cl...	bandwidth	2.353M			
1	lab7_OTA_5T_cl...	GBW	4.591M			
1	lab7_OTA_5T_cl...	UGF	3.935M			
Parameters: CIN=12p						
2	lab7_OTA_5T_cl...	gain				
2	lab7_OTA_5T_cl...	gain db				
2	lab7_OTA_5T_cl...	DC gain	3.784			
2	lab7_OTA_5T_cl...	DC gain db	11.56			
2	lab7_OTA_5T_cl...	bandwidth	1.06M			
2	lab7_OTA_5T_cl...	GBW	4.019M			
2	lab7_OTA_5T_cl...	UGF	3.884M			

Figure 13 results from simulator.

	Part 1 $C_{IN} = 4p$	Part 2 $C_{IN} = 4p$	Part 1 $C_{IN} = 12p$	Part 2 $C_{IN} = 12p$
DC gain	1.945	1.947	3.786	3.784
DC gain dB	5.778	5.786	11.56	11.56
Bandwidth	3.305M	2.353M	1.699M	1.06M
GBW	6.444M	4.591M	6.449M	4.019M

• You will notice that the bandwidth, and consequently the GBW are much smaller than Part 1. Why?
in part 1 I used an ideal switch which acted as an ideal buffer which had no loading effects which resulted in a much higher BW, however in the real OTA the is a loading effect which was modelled as the Cout, so it did affect the BW and therefore affected the GBW, feedback capacitance contributes loading effect all this increase total capacitance and decrease BW.

Loop gain vs frequency

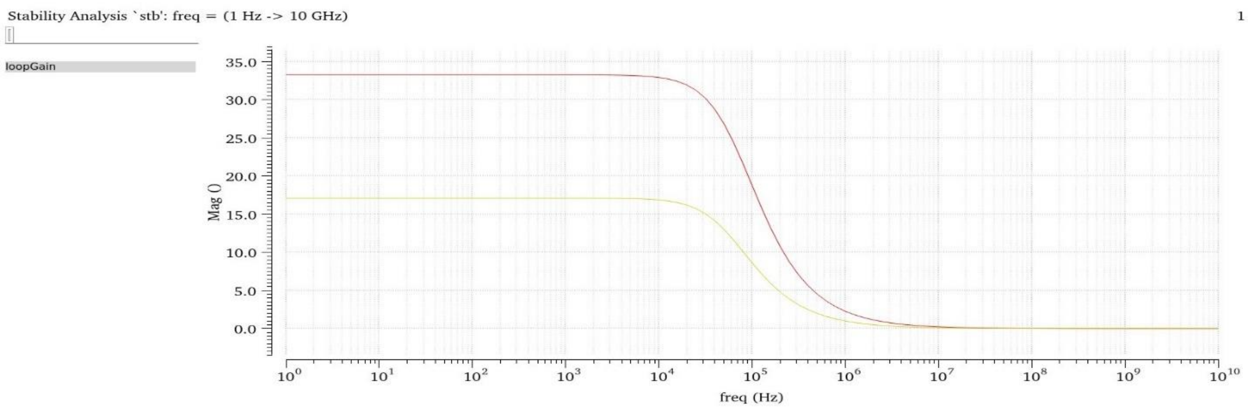


Figure 14 plot loop gain vs frequency.

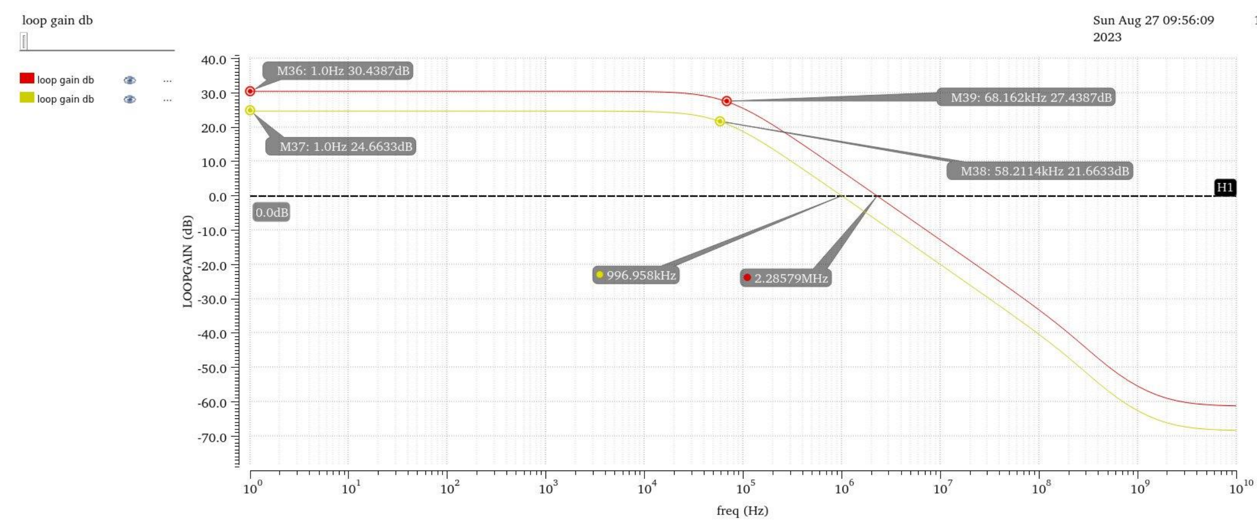


Figure 15 plot loop gain in dB vs frequency and results.

Outputs Setup | Results

Detail

12 rows

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CL=4p						
1	lab7_OTA_5T_cl...	max_mag	33.26			
1	lab7_OTA_5T_cl...	loop gain db				
1	lab7_OTA_5T_cl...	max_mag db	30.44			
1	lab7_OTA_5T_cl...	Bandwidth	68.37K			
1	lab7_OTA_5T_cl...	gainBwProd(ma...	2.28M			
1	lab7_OTA_5T_cl...	unityGainFreq(...	2.3M			
Parameters: CL=12p						
2	lab7_OTA_5T_cl...	max_mag	17.11			
2	lab7_OTA_5T_cl...	loop gain db				
2	lab7_OTA_5T_cl...	max_mag db	24.66			
2	lab7_OTA_5T_cl...	Bandwidth	58.38K			
2	lab7_OTA_5T_cl...	gainBwProd(ma...	1.001M			
2	lab7_OTA_5T_cl...	unityGainFreq(...	997.3K			

Figure 16 results from simulator.

	Part 1 $C_{IN} = 4p$	Part 2 $C_{IN} = 4p$	Part 1 $C_{IN} = 12p$	Part 2 $C_{IN} = 12p$
DC gain	35.37	33.26	17.68	17.11
DC gain dB	30.97	30.44	24.95	24.66
Bandwidth	90.95K	68.37K	90.59K	58.38K
GBW	3.224M	2.28M	1.612M	1.001M
UGF	3.225M	2.3M	1.609M	997.3K

• You will notice that the unity gain frequency is much smaller than Part 1. Why? Comment.

The loop gain is nearly unchanged, while BW is affected by the loading which affected the UGF. The negative feedback of the real OTA presented a loading effect, feedback capacitance contributes loading effect all this increase total capacitance which translated in a decrease in the BW, so it led to a decrease in UGF.

Gain Desensitization

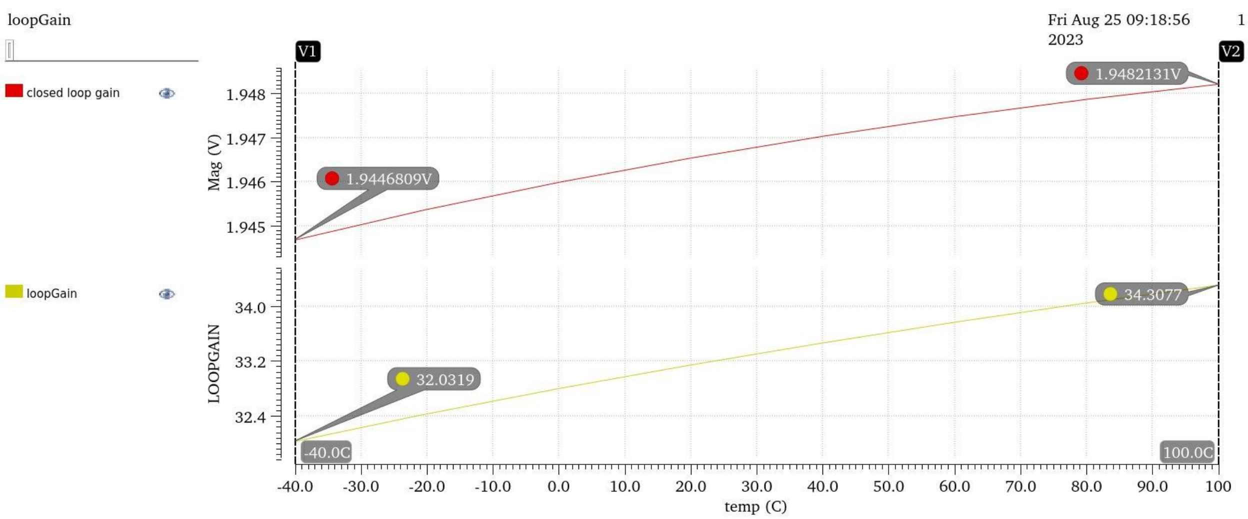


Figure 17 plot closed and open loop gain vs temperature.

For closed loop gain:

At T =-40 $A_{CL} = 1.945$

At $T = 100$ $A_{CL} = 1.948$

$$percentage\ change = \frac{A_{CL\_ideal} - A_{CL\_Actual}}{A_{CL\_Ideal}} = 0.15\%$$

For open loop gain

At T =-40 $A_{OL} = 32.0319$

At $T = 100$ $A_{OL} = 34.3077$

$$percentage\ change = \frac{A_{OL\_ideal} - A_{OL\_Actual}}{A_{OL\_Ideal}} = 6\%$$

Comment: From previous analysis has shown that closed-loop gain is insensitive to temperature change as it depends on ratio of capacitive divider despite loop gain which affected by changing temperature as shown.

Transient analysis

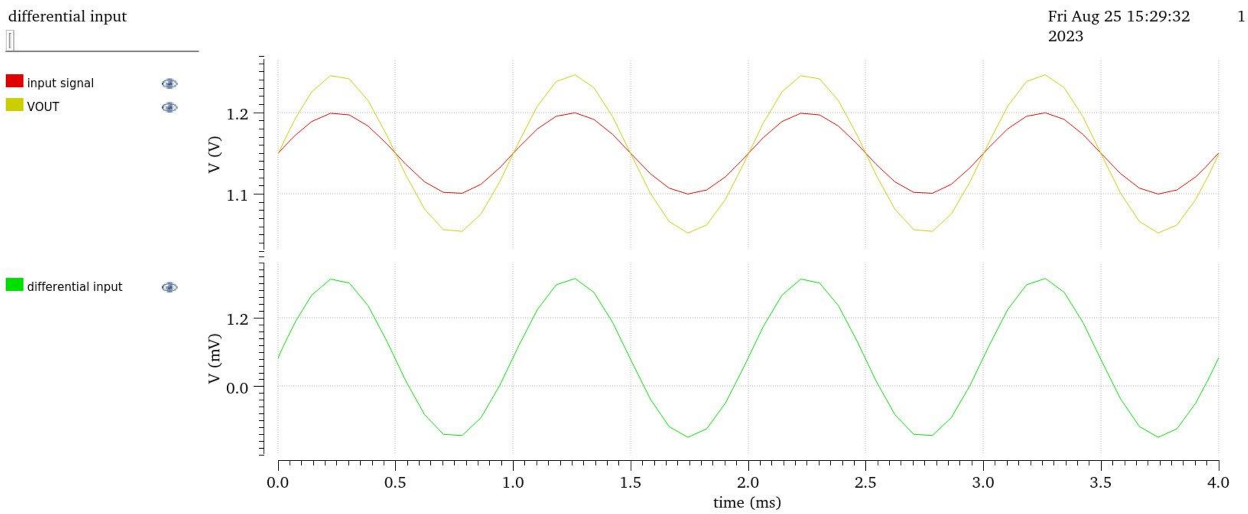
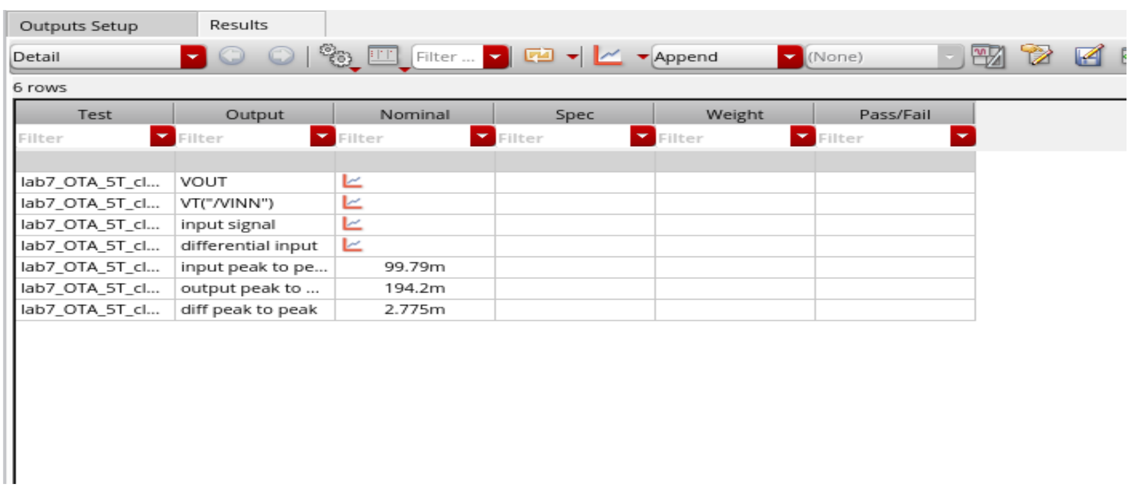


Figure 18 transient analysis.



Test	Output	Nominal	Spec	Weight	Pass/Fail
lab7_OTA_5T_cl...	VOUT				
lab7_OTA_5T_cl...	VT("/VINN")				
lab7_OTA_5T_cl...	input signal				
lab7_OTA_5T_cl...	differential input				
lab7_OTA_5T_cl...	input peak to pe...	99.79m			
lab7_OTA_5T_cl...	output peak to ...	194.2m			
lab7_OTA_5T_cl...	diff peak to peak	2.775m			

Figure 19 results.

As shown that the ration between output voltage to differential voltage is nearly equivalent to open loop gain $A_{OL} = \frac{V_{OUT}}{V_{dif}} = \frac{194.2m}{2.775m} = 69.982. i\ have\ A_{OL} = 70.73$

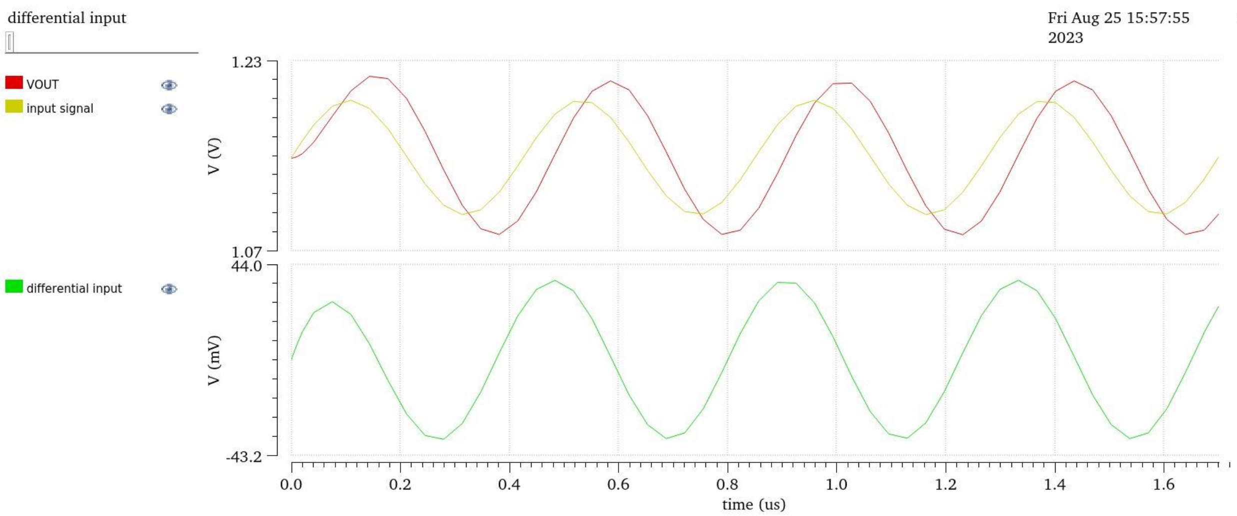
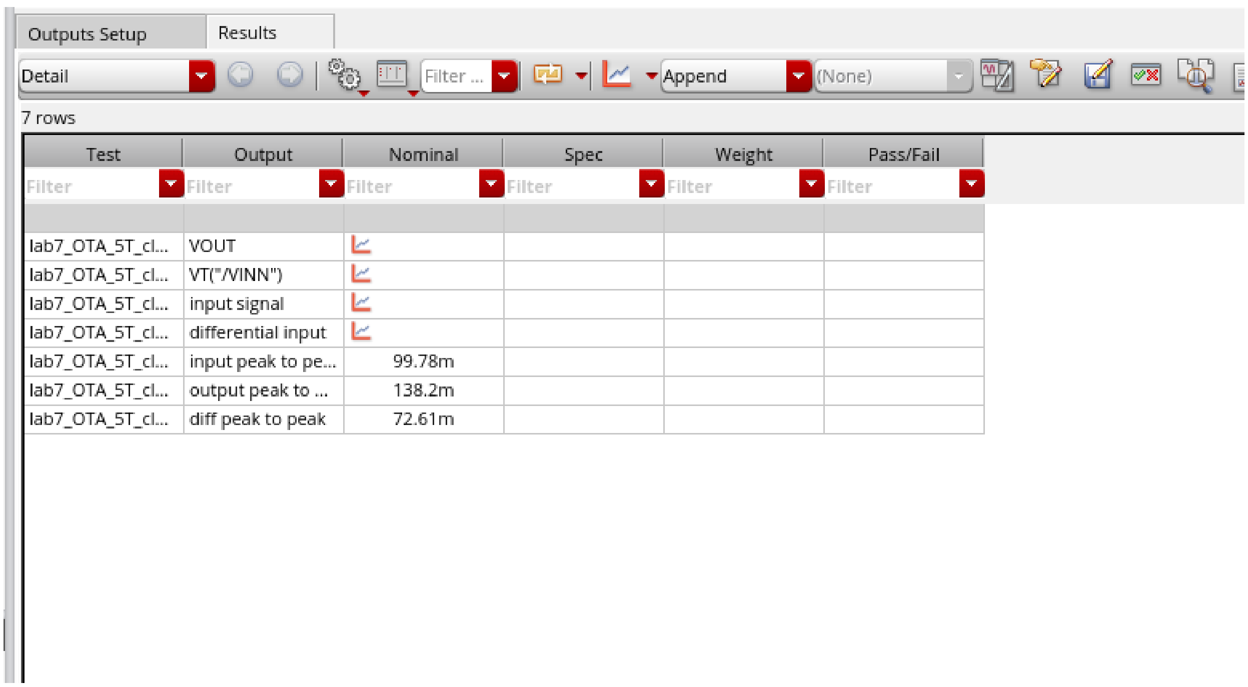


Figure 20 transient plots at FIN equal bandwidth.



Test	Output	Nominal	Spec	Weight	Pass/Fail
lab7_OTA_5T_cl...	VOUT				
lab7_OTA_5T_cl...	VT("/VINN")				
lab7_OTA_5T_cl...	input signal				
lab7_OTA_5T_cl...	differential input				
lab7_OTA_5T_cl...	input peak to pe...	99.78m			
lab7_OTA_5T_cl...	output peak to ...	138.2m			
lab7_OTA_5T_cl...	diff peak to peak	72.61m			

Figure 21 results.

As shown that the ration between output voltage to differential voltage is nearly equivalent to closed loop gain $A_{CL} = \frac{V_{OUT}}{V_{dif}} = \frac{138.2m}{72.61m} = 1.903. i\ have\ A_{CL}. ideal\ equal\ to\ 2$

	FIN=1KHZ	FIN=closed loop bandwidth
Input peak to peak	99.79m	99.78m
Output peak to peak	194.2m	138.2m
Diff peak to peak	2.775m	72.61m