ITI

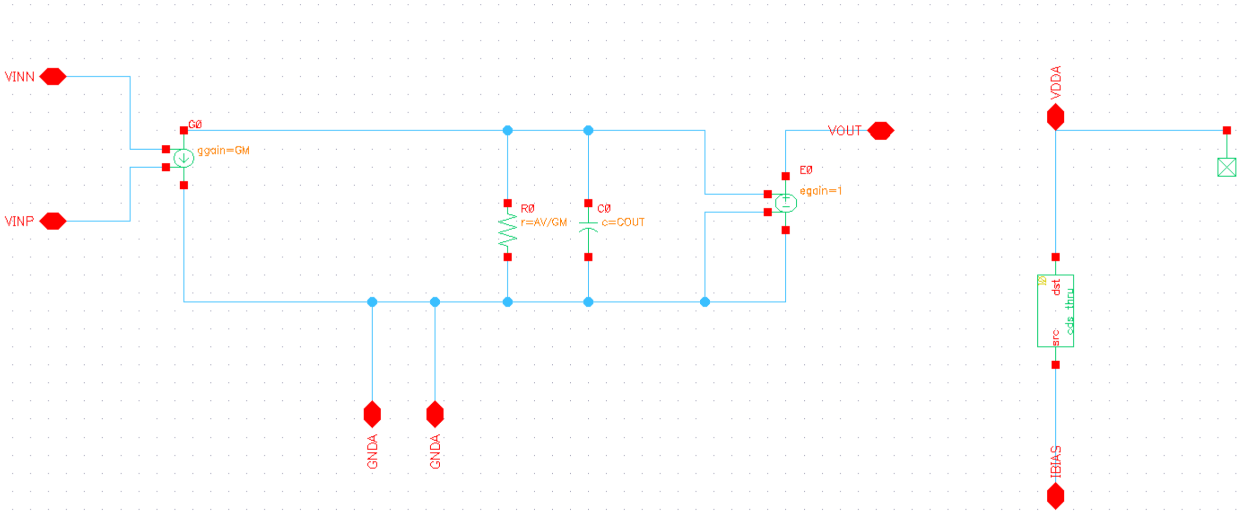
LAB08

Negative Feedback

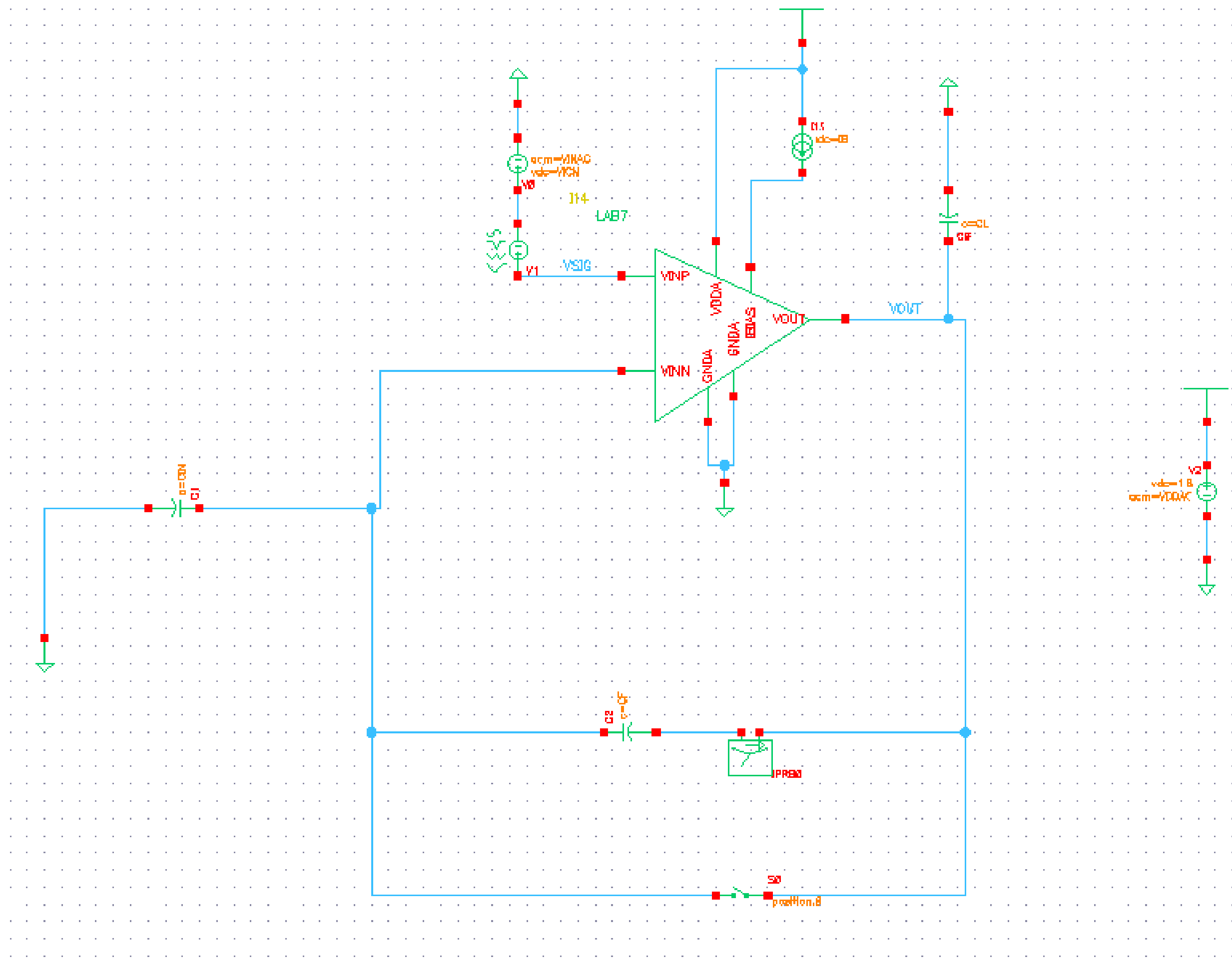
Contents

PART 1: Feedback with Behavioral OTA

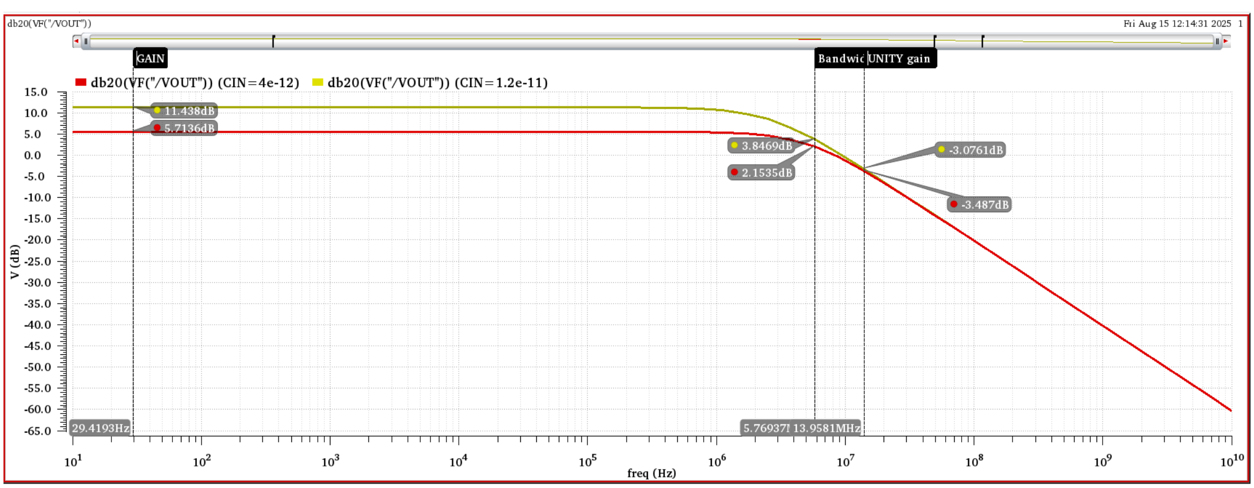
Behavioral schematic



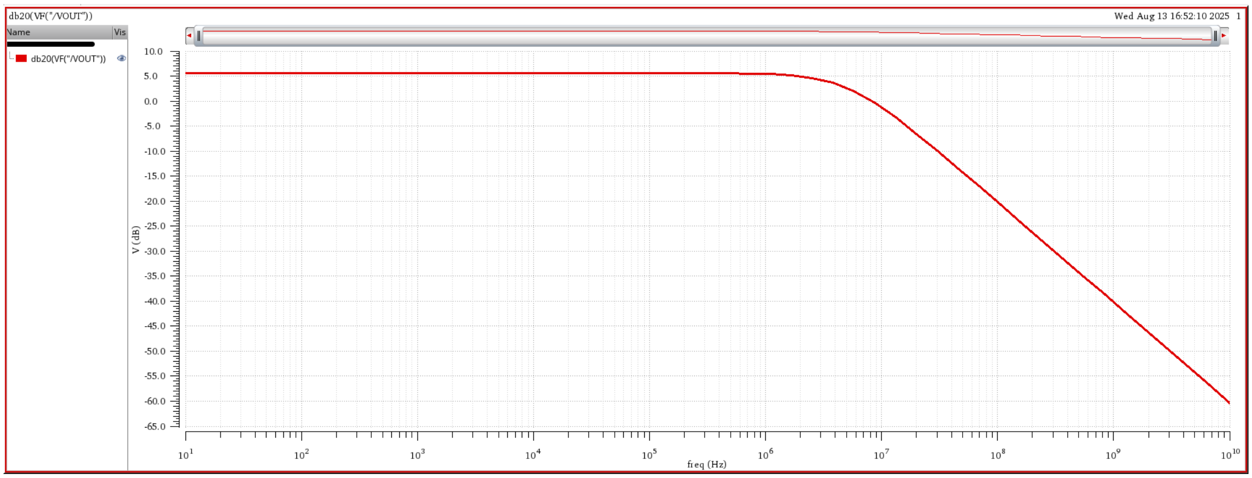
Schematic



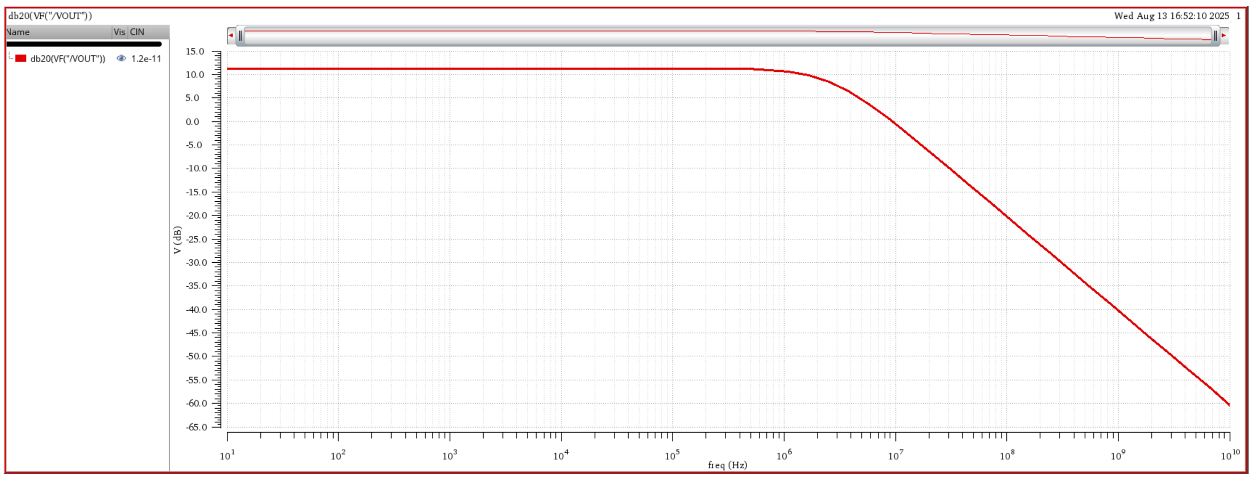
VOUT in dB



VOUT in dB at Cin= 4pF



VOUT in dB at Cin= 4pF



DC gain, BW, and GBW

Simulation values

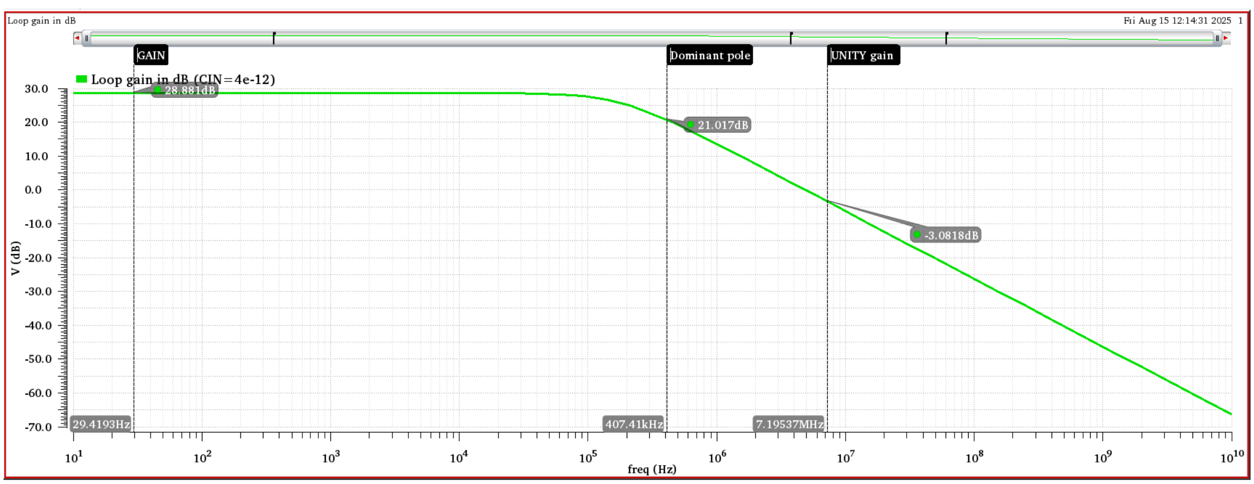
Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI:LAB8:1	db20(VF("/VOUT"))				
1	ITI:LAB8:1	ymax(dB20(VF("/VOUT")))	5.714			
1	ITI:LAB8:1	ymax(mag(VF("/VOUT")))	1.931			
1	ITI:LAB8:1	bandwidth(VF("/VOUT") 3 "lo...	5.142M			
1	ITI:LAB8:1	gainBwProd(VF("/VOUT"))	9.951M			
Parameters: CIN=12p						
2	ITI:LAB8:1	db20(VF("/VOUT"))				
2	ITI:LAB8:1	ymax(dB20(VF("/VOUT")))	11.44			
2	ITI:LAB8:1	ymax(mag(VF("/VOUT")))	3.732			
2	ITI:LAB8:1	bandwidth(VF("/VOUT") 3 "lo...	2.659M			
2	ITI:LAB8:1	gainBwProd(VF("/VOUT"))	9.95M			

Comment:

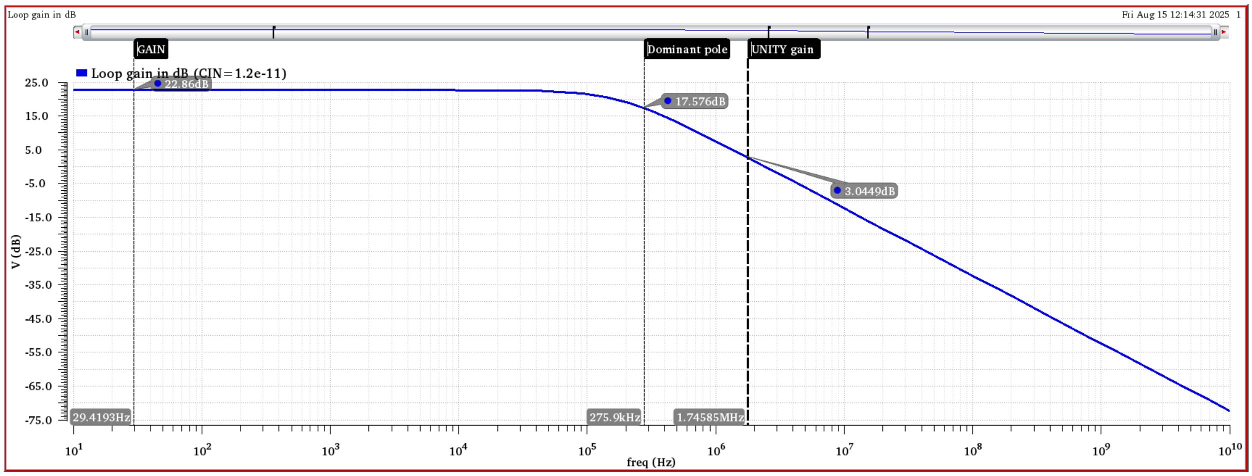
- When CIN is increased, it slows down the dominant pole of the circuit. This reduction in pole frequency causes the amplifier to respond more slowly at higher frequencies, which in turn allows the loop gain to reach a higher peak at lower frequencies. As a result, ymax(dB20(VF("/VOUT"))) increases, and the bandwidth decreases. Despite these changes, the gain-bandwidth product remains nearly constant because the increase in gain is balanced by the decrease in bandwidth.

Loop gain vs frequency

Loop gain at Cin=4pF



Loop gain at Cin=12pF

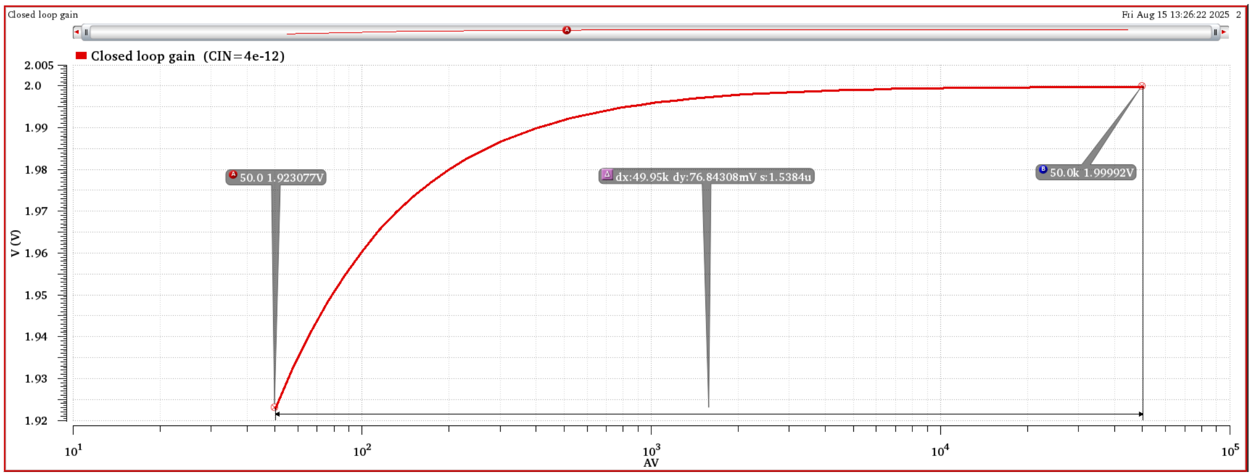


Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI:LAB8:1	unityGainFreq(mag(getData(...	5.125M			
1	ITI:LAB8:1	ymax(mag(getData("loopGai...	27.8			
1	ITI:LAB8:1	ymax(dB20(getData("loopGa...	28.88			
1	ITI:LAB8:1	Loop gain in dB				
Parameters: CIN=12p						
2	ITI:LAB8:1	unityGainFreq(mag(getData(...	2.48M			
2	ITI:LAB8:1	ymax(mag(getData("loopGai...	13.9			
2	ITI:LAB8:1	ymax(dB20(getData("loopGa...	22.86			
2	ITI:LAB8:1	Loop gain in dB				

Comment:

The larger input capacitance slows down the dominant pole of the circuit. This causes the unity gain frequency to decrease because the circuit cannot respond as quickly at higher frequencies. At the same time, the maximum loop gain increases. The larger CIN allows the loop to reach a higher peak gain at lower frequencies due to the slowed dominant pole, while the bandwidth is reduced. Overall, the gain-bandwidth tradeoff is evident: higher peak gain accompanies a lower unity gain frequency, preserving the circuit's overall frequency response characteristics.

Gain Desensitization.



From the graph the value of the mismatch $=\frac{1.99992-1.923077}{1.923077}\times 100$

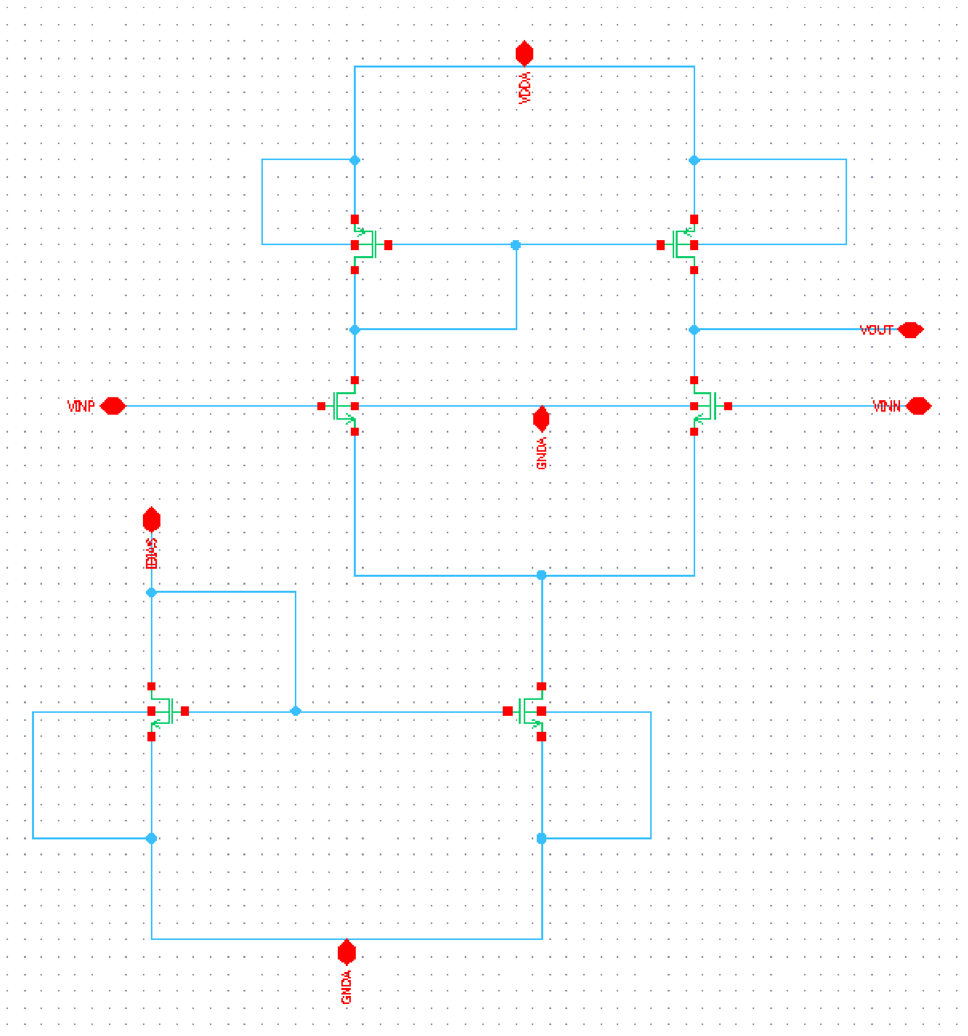
Mismatch = 4%

Comment:

Even though the open-loop gain changes dramatically by three orders of magnitude (60 dB), the closed-loop gain changes much less, only about 4%. This is because the feedback stabilizes the gain, the closed-loop gain depends primarily on the feedback network, not the absolute value of the open-loop gain. The large change in open-loop gain mainly affects the precision and stability of the closed-loop response rather than its nominal value, which demonstrates the robustness of feedback in controlling gain.

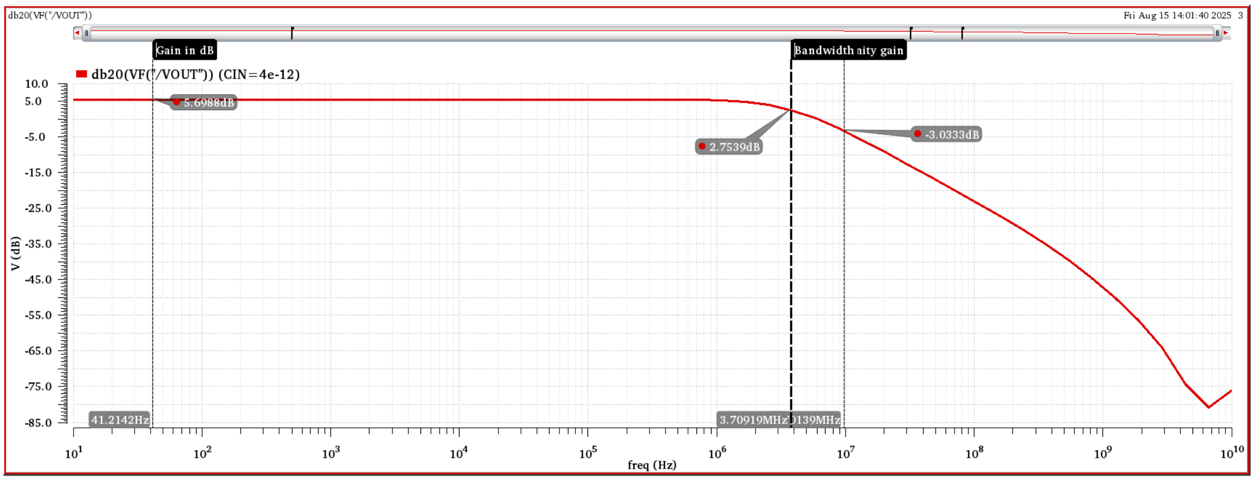
PART 2: Feedback with Real 5T OTA

Schematic

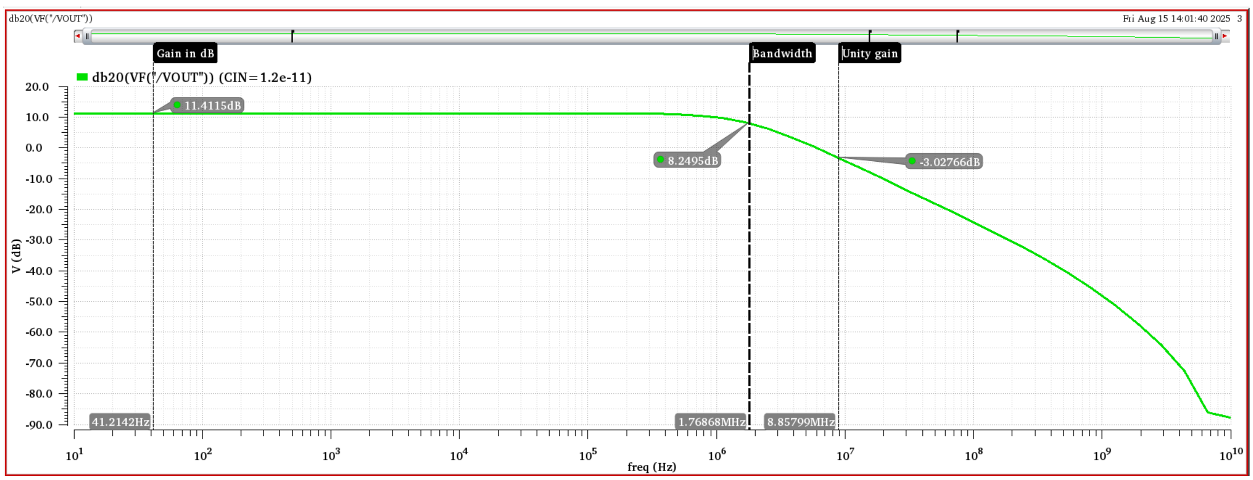


VOUT in dB

VOUT in dB at Cin= 4pF



VOUT in dB at Cin= 12pF



Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI:LAB8:1	db20(VF("/VOUT"))				
1	ITI:LAB8:1	ymax(dB20(VF("/VOUT")))	5.699			
1	ITI:LAB8:1	ymax(mag(VF("/VOUT")))	1.927			
1	ITI:LAB8:1	bandwidth(VF("/VOUT") 3 "lo...	3.762M			
1	ITI:LAB8:1	gainBwProd(VF("/VOUT"))	7.266M			
Parameters: CIN=12p						
2	ITI:LAB8:1	db20(VF("/VOUT"))				
2	ITI:LAB8:1	ymax(dB20(VF("/VOUT")))	11.41			
2	ITI:LAB8:1	ymax(mag(VF("/VOUT")))	3.72			
2	ITI:LAB8:1	bandwidth(VF("/VOUT") 3 "lo...	1.709M			
2	ITI:LAB8:1	gainBwProd(VF("/VOUT"))	6.374M			

parameter	Part1 Cin=4pF	Part1 Cin=12pF	Part2 Cin=4pF	Part2 Cin=12pF

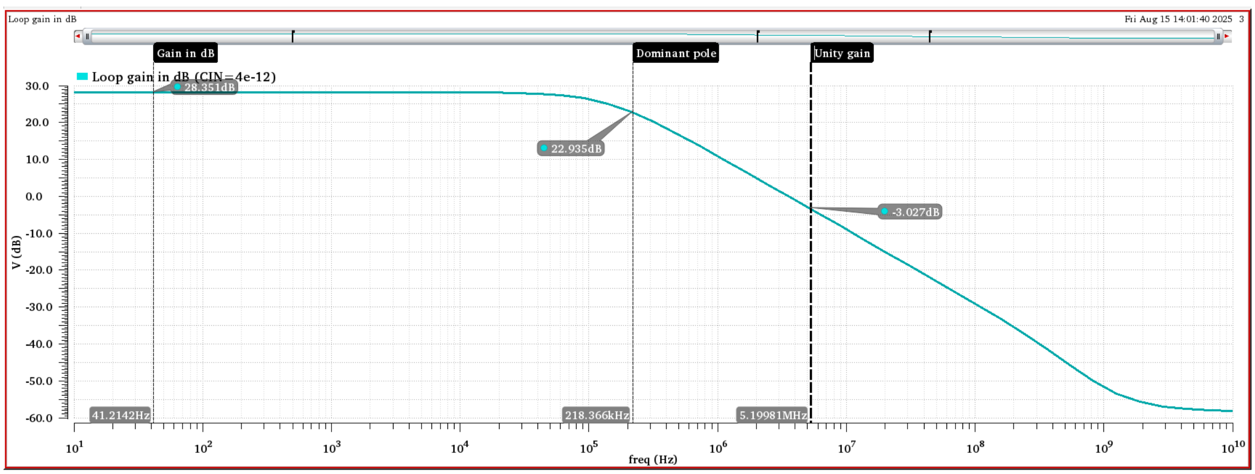
ymax(dB20(VF("/VOUT")))	5.714	11.42	5.699	11.41
ymax(mag(VF("/VOUT")))	1.931	3.732	1.927	3.72
bandwidth(VF("/VOUT") 3 "low")	5.142M	2.659M	3.762M	1.709M
gainBwProd(VF("/VOUT"))	9.951M	9.95M	7.266M	6.374M

Comment:

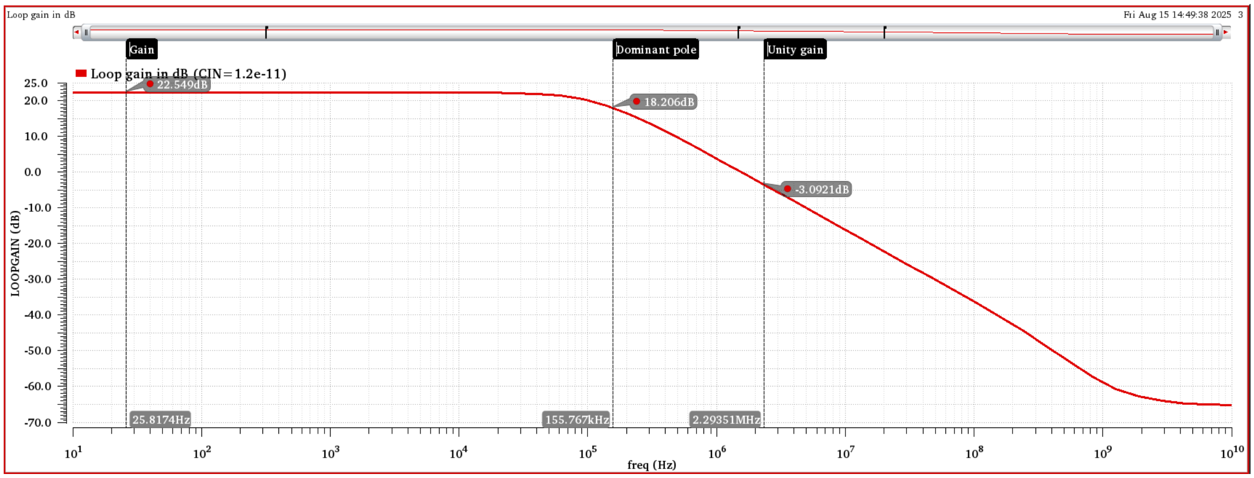
In Part 2, the actual 5-transistor OTA exhibits significantly lower bandwidth and GBW compared to the behavioral model in Part 1 because real devices introduce non-ideal effects absent in the ideal model. Parasitic capacitances, finite transconductance, this shifts the dominant pole to a much lower frequency and accelerate gain roll-off, thereby reducing both bandwidth and GBW.

Loop gain vs frequency

Loop gain at Cin=4pF



Loop gain at Cin=12pF



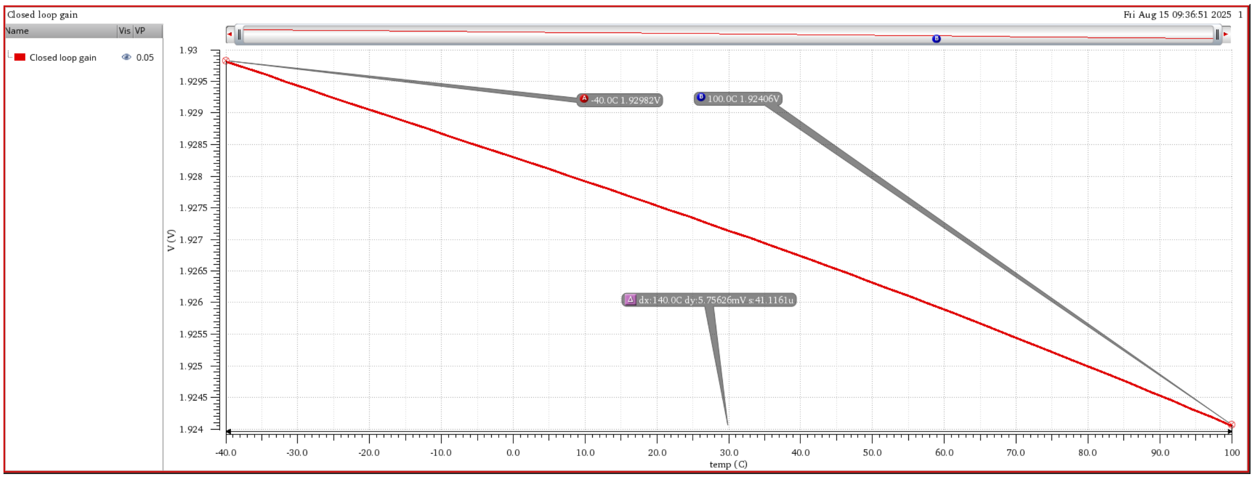
Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI:LAB8:1	unityGainFreq(mag(getData("loopGain" ?result "stb")))	3.667M			
1	ITI:LAB8:1	ymax(mag(getData("loopGain" ?result "stb")))	26.15			
1	ITI:LAB8:1	ymax(dB20(getData("loopGain" ?result "stb")))	28.35			
1	ITI:LAB8:1	Loop gain in dB				
Parameters: CIN=12p						
2	ITI:LAB8:1	unityGainFreq(mag(getData("loopGain" ?result "stb")))	1.604M			
2	ITI:LAB8:1	ymax(mag(getData("loopGain" ?result "stb")))	13.41			
2	ITI:LAB8:1	ymax(dB20(getData("loopGain" ?result "stb")))	22.55			
2	ITI:LAB8:1	Loop gain in dB				

parameter	**Part1 Cin=4pF**	**Part1 Cin=12pF**	**Part2 Cin=4pF**	**Part2 Cin=12pF**
unityGainFreq(mag(getData("loopGain" ?result "stb")))	$5.125M$	$2.48M$	$3.667M$	$1.604M$
ymax(mag(getData("loopGain" ?result "stb")))	27.8	13.9	26.15	13.41
ymax(dB20(getData("loopGain" ?result "stb")))	28.88	22.86	28.35	22.55

Comment:

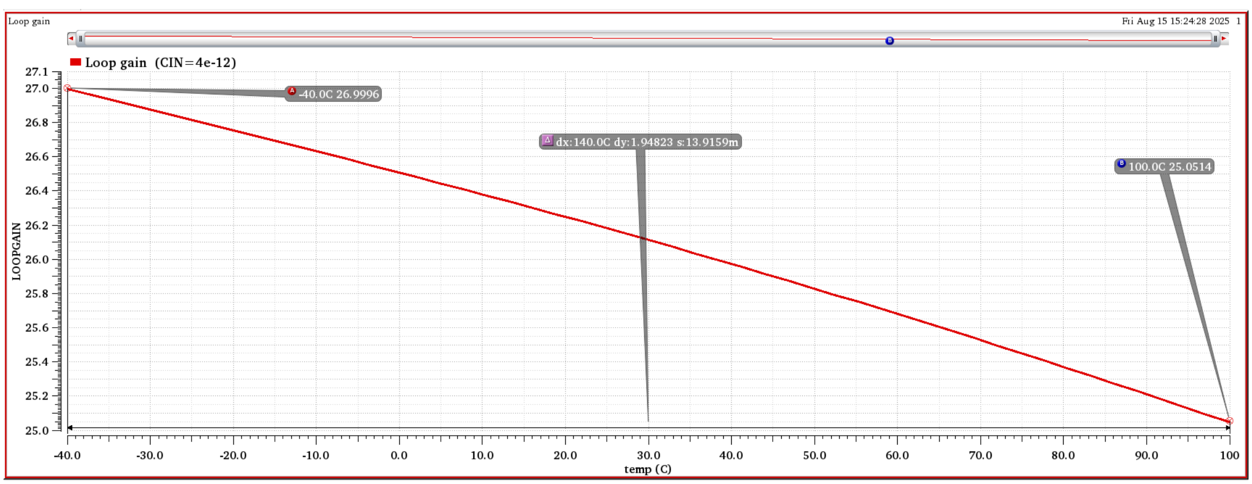
The unity gain frequency in Part 2 is much smaller than in Part 1 because the actual 5-transistor OTA includes parasitic capacitances and additional poles from the transistor stages, which lower the dominant pole frequency and increase high-frequency attenuation. These non-idealities are absent in the behavioral model, resulting in a higher unity gain frequency in Part 1.

Gain Desensitization



The percentage of the change $\frac{1.92406-1.92982}{1.92982} \times 100$

Change= -0.3%

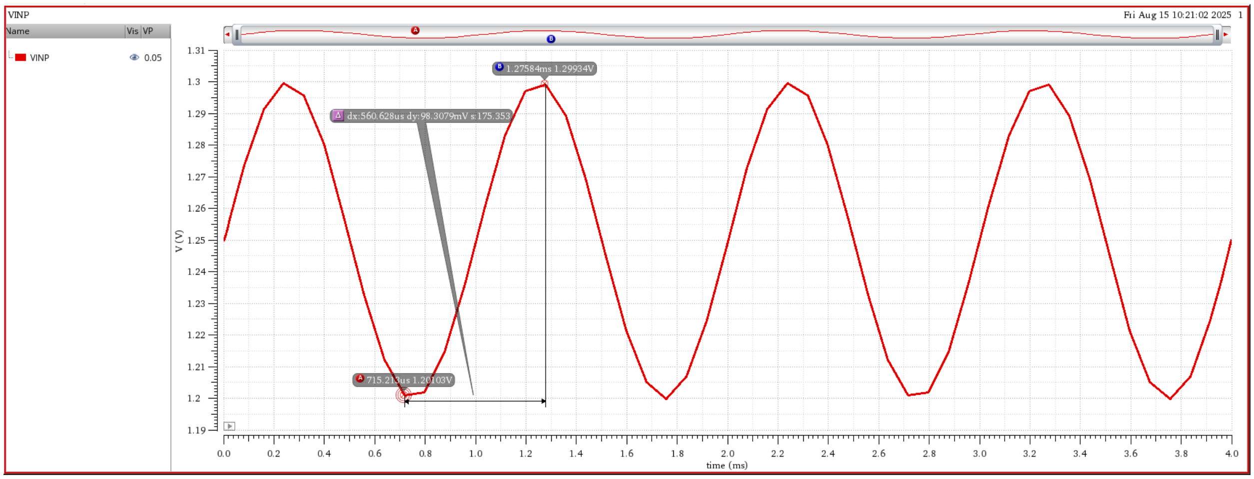


The percentage of the change $\frac{25.0514-26.9996}{25.0514} \times 100$

Change= -7.78%

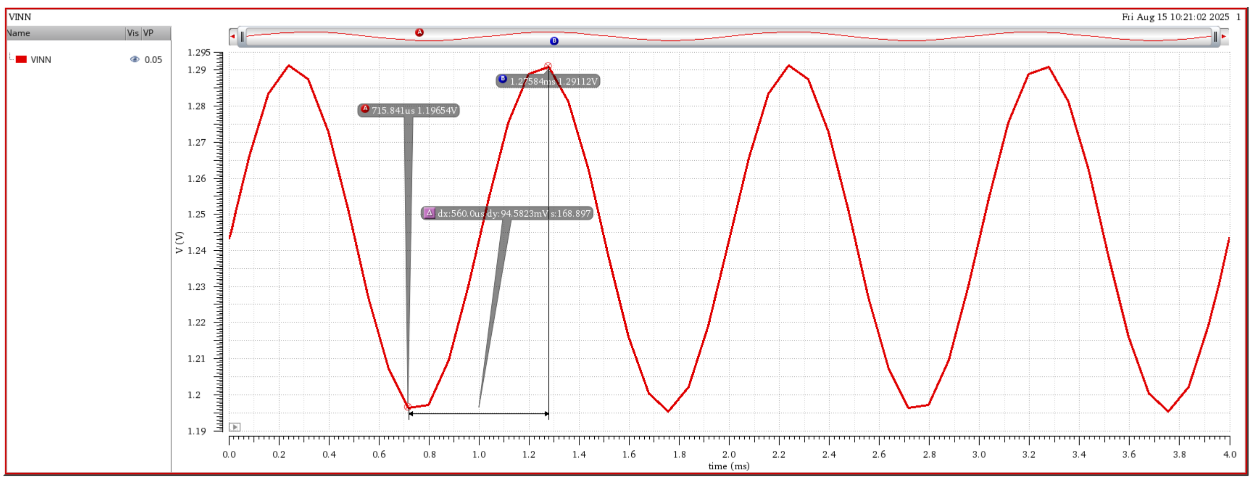
Transient analysis

VINP(FIN=1KHz)



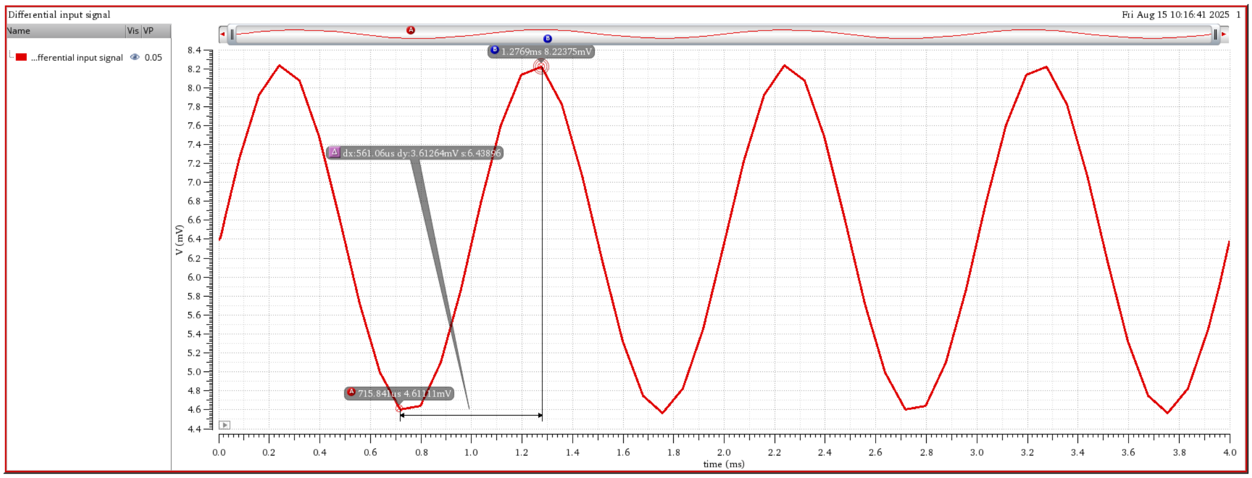
From the graph the peak-to-peak value equals 98.3079mV

VINN(FIN=1KHz)



From the graph the peak-to-peak value equals 94.5823mV

VINP-VINN(FIN=1KHz)



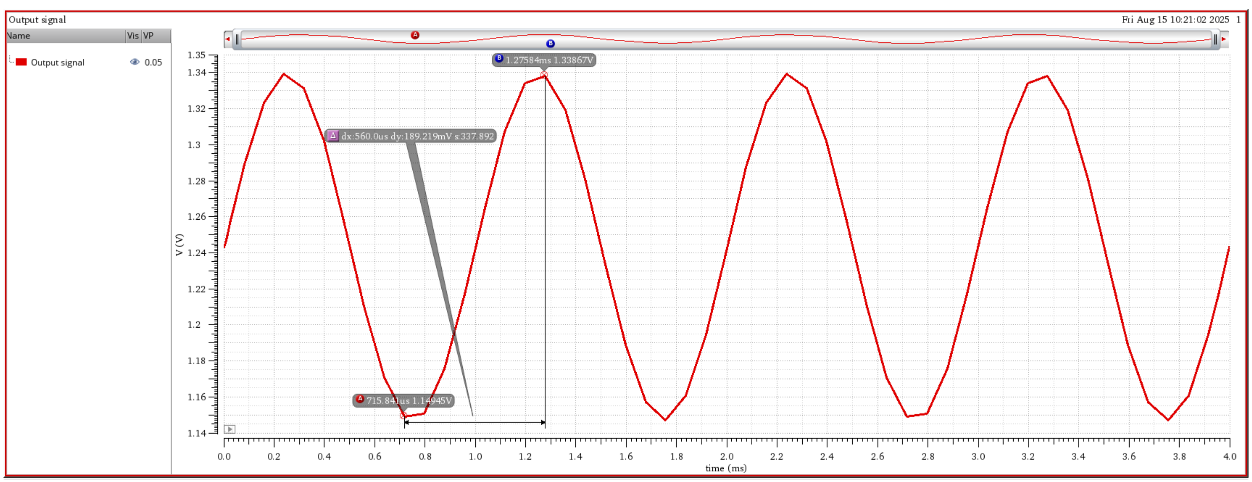
From the graph the peak-to-peak value equals 94.5823mV

Comment: The output voltage is proportional to the difference between the non-inverting and inverting inputs $(V_{INP} - V_{INN})$, scaled by the open-loop gain A_{OL} of the OTA

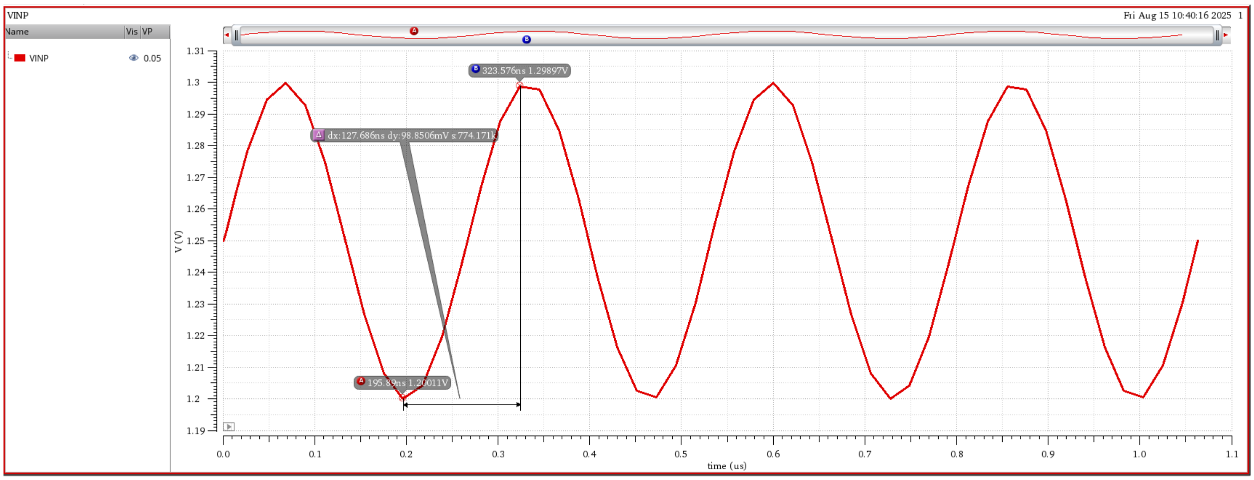
$$V_{out} = A_{OL}(V_{INP} - V_{INN})$$

This means that for a given small differential input, the output changes by a factor equal to the open-loop gain.

VOUT(FIN=1KHz)

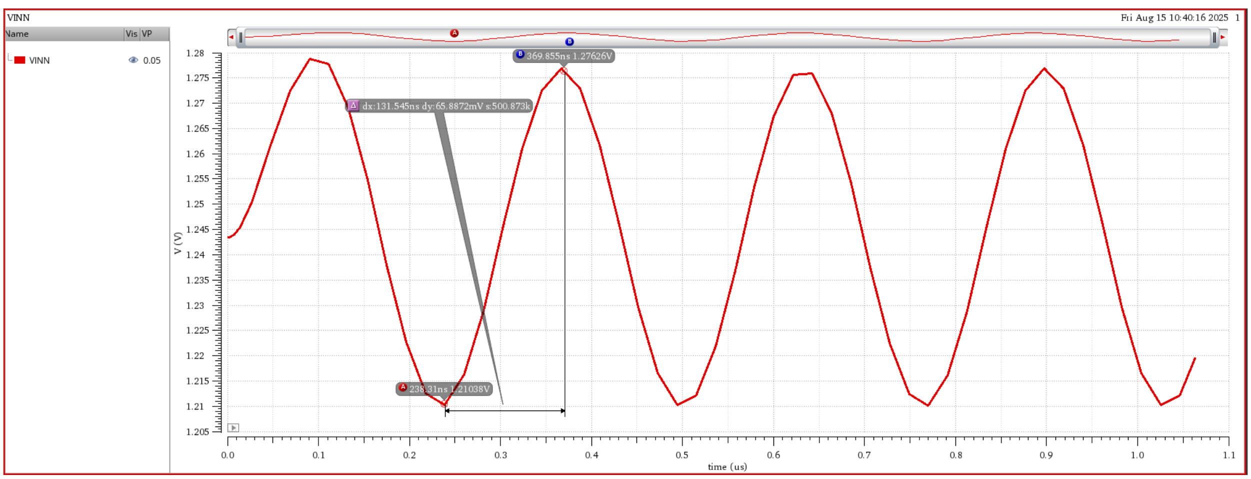


VINP(FIN=3.762MHz)



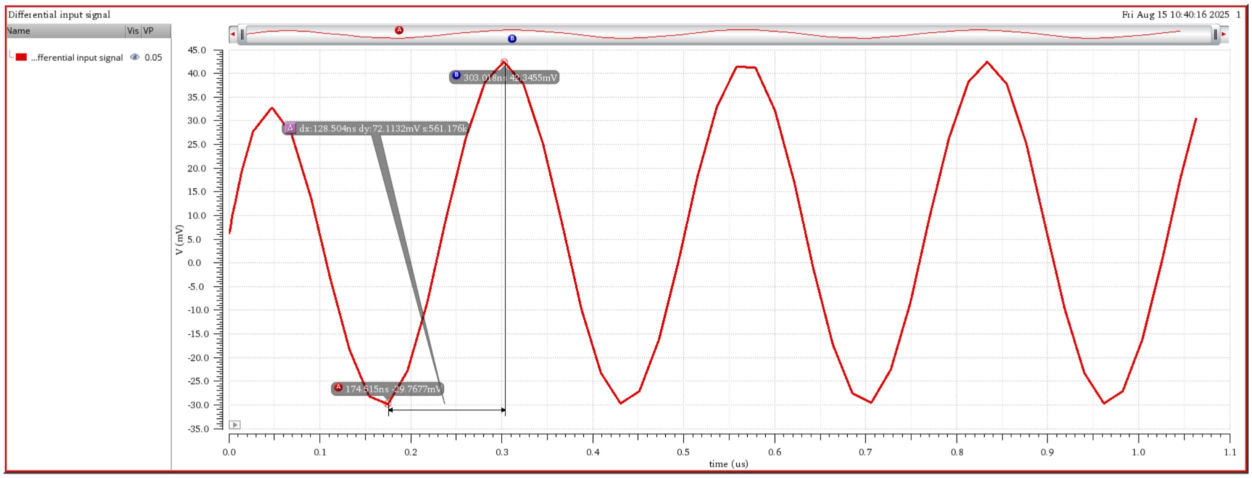
From the graph the peak-to-peak value equals 98.8506mV

VINN(FIN=3.762MHz)



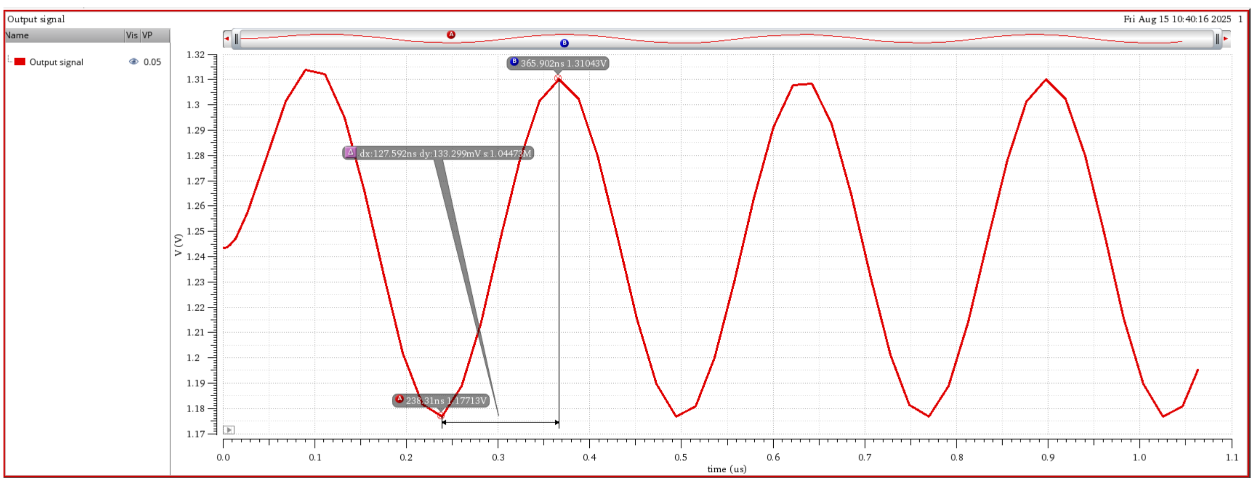
From the graph the peak-to-peak value equals 65.8872mV

VINP-VINN(FIN=3.762MHz)



From the graph the peak-to-peak value equals 72.1132mV

VOUT(FIN=3.762MHz)



From the graph the peak-to-peak value equals 133.299mV

Comment:

At high frequency, the loop gain becomes much less than unity, causing the closed-loop response to collapse to the open-loop response ,which mean that the output is determined by the OTA's intrinsic gain–frequency characteristic rather than the feedback network, and the differential input voltage ($V_{INP} - V_{INN}$) is no longer negligible. Feedback has limited control, resulting in a larger error signal.