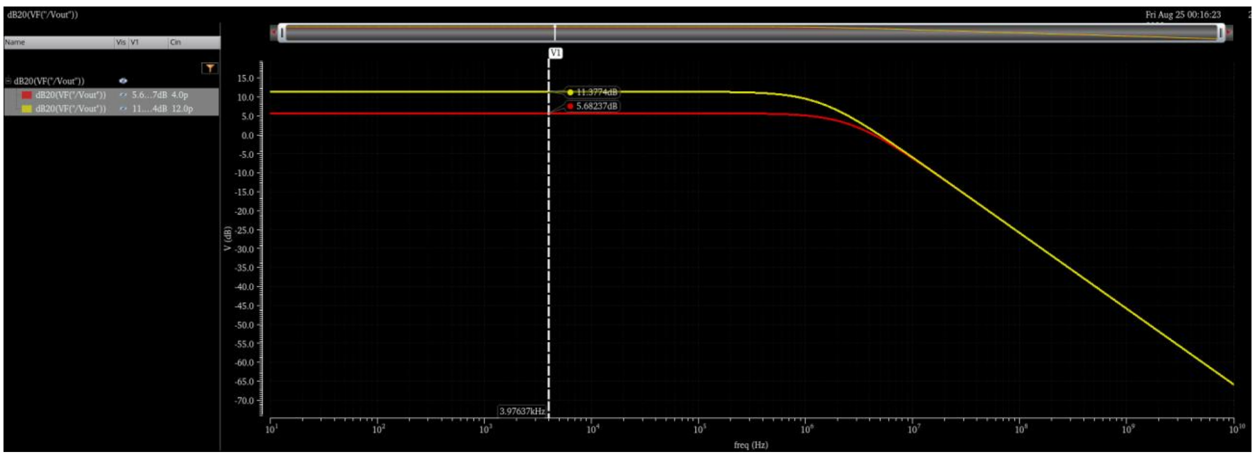
Analog IC Design

Lab 8

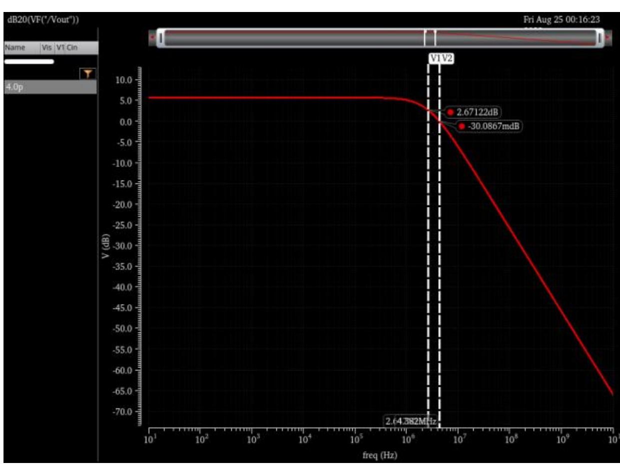
PART 1: Feedback with Behavioral OTA

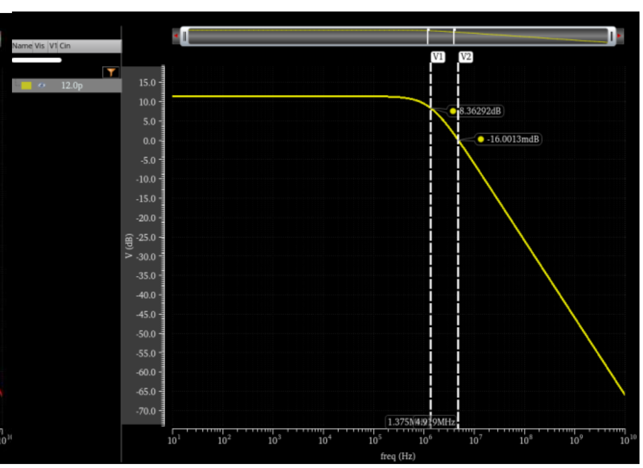
Closed Loop Gain vs Frequency

Overlaid Results (DC gain shown)

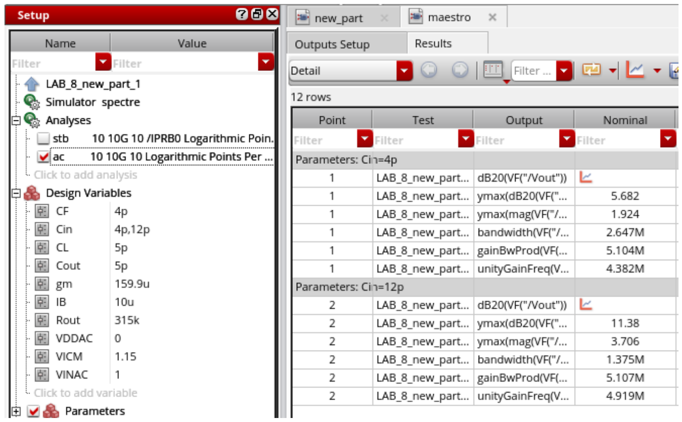


Results (BW & UGF shown)





Simulation Values



Hand Analysis

1) ACL Calculation

- $\beta = \frac{\frac{1}{sC_{in}}}{\frac{1}{sC_{in}}+\frac{1}{sC_F}} = \frac{1}{1+\frac{C_{in}}{sC_F}}$ → $\beta_{\text{Cin=4p}} = 0.5$ & $\beta_{\text{Cin=12p}} = 0.25$
- AOL = Gm*Rout = (159.9u)*(315k) = 50.37
- $ACL = \frac{AOL}{1+\beta AOL}$ → $ACL_{\text{Cin=4p}} = 1.924$ & $ACL_{\text{Cin=12p}} = 3.706$

2) Bandwidth

- BW = BW_{OL}*(1+LG) & BW_{OL} = 101.1KHz (as calculated in the last lab)
- $BW_{\text{Cin=4p}}$ = (101.1k)*(1+0.5*50.37) = 2.647MHz
- $BW_{\text{Cin=12p}}$ = (101.1k)*(1+0.25*50.37) = 1.374MHz

3) Unity Gain Frequency

- UGF = GBW = ACL*BW
- $UGF_{\text{Cin=4p}}$ = 5.10MHz & $UGF_{\text{Cin=12p}}$ = 5.092MHz

4) Comparison

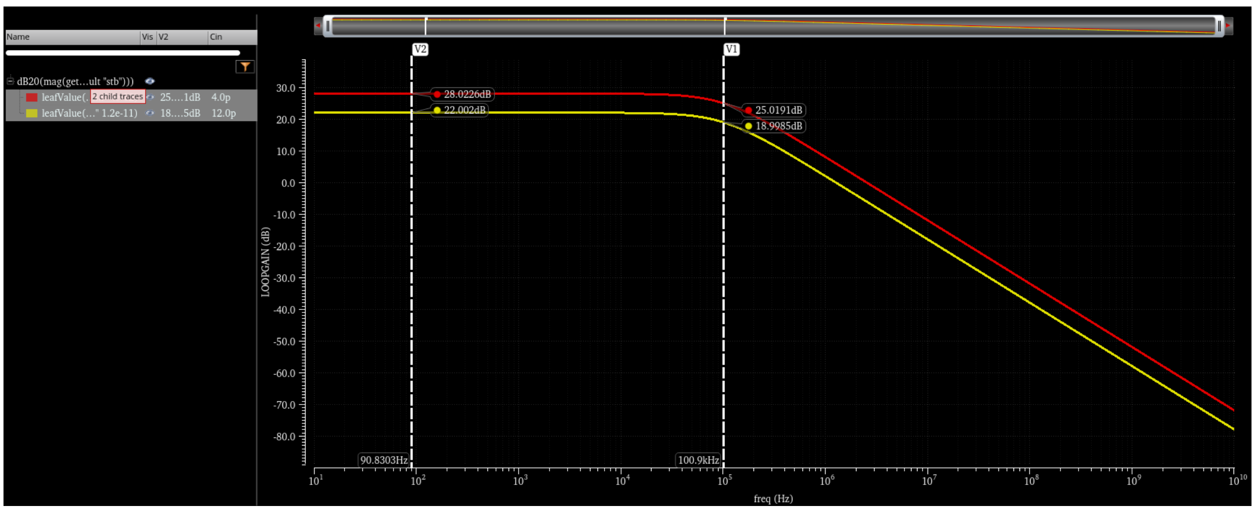
	Simulation (Cin = 4p)	Hand Analysis (Cin = 4p)	Simulation (Cin = 12p)	Hand Analysis (Cin = 12p)
DC Gain	1.924	1.924	3.706	3.706
Bandwidth	2.647MHz	2.647MHz	1.374MHz	1.374MHz
GBW	5.104MHz	5.10MHz	5.107MHz	5.092MHz

5) Comments

- Higher input capacitance in the feedback network gives higher closed loop gain, due to having a higher β and the gain is inversely proportional with β.
- Higher input capacitance in the feedback network gives lower bandwidth extension, due to having a lower β.
- Note that GBW for both capacitors are nearly equal.

Loop Gain vs Frequency

Overlaid Results (DC loop gain & BW shown)



ymax(mag(getData("loopGain" ?res...

	Cin	unityGain... "stb")))	ymax(mag..."stb")))	ymax(dB2...stb"))))
1	4.000E-12	2.550E6	25.18	28.02
2	12.00E-12	1.271E6	12.59	22.00

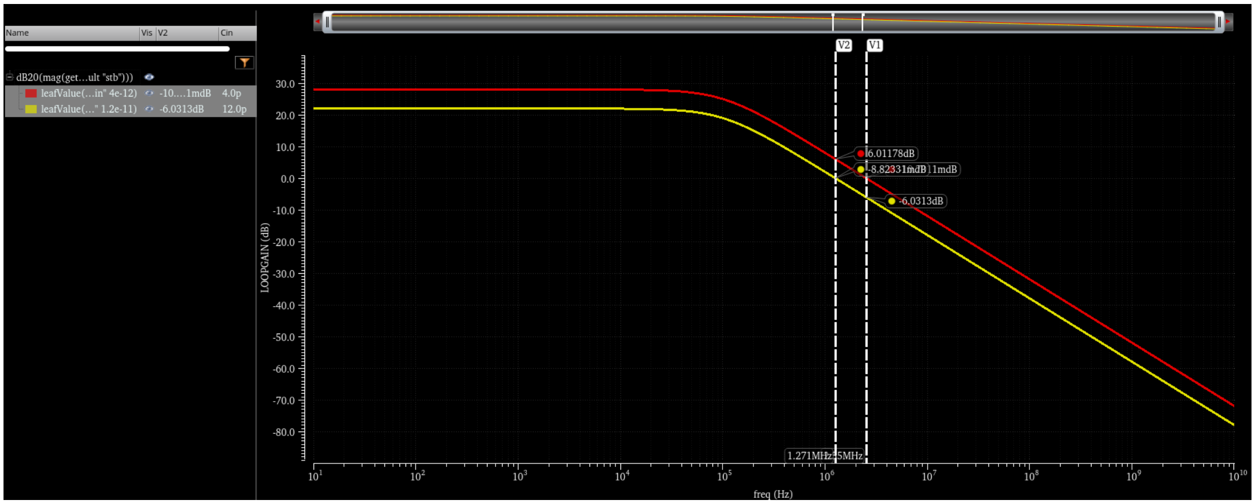
gainBwProd(mag(getData("loopGai...

	Cin	gainBwPr..."stb")))
1	4.000E-12	2.547E6
2	12.00E-12	1.273E6

bandwidth(mag(getData("loopGain"...

	Cin	bandwidt... "low")
1	4.000E-12	100.9E3
2	12.00E-12	100.9E3

Results (UGF shown)



Hand Analysis

1) Loop Gain

- LG = $\beta * AOL$
- $LG_{\text{Cin=4p}}$ = (0.5)*(50.37) = 25.2 & $LG_{\text{Cin=12p}}$ = (0.25)*(50.37) = 12.6

2) GBW

- GBW = LG*BW_{OL}
- $GBW_{\text{Cin=4p}}$ = (101.1k)*(25.2) = 2.548MHz
- $GBW_{\text{Cin=12p}}$ = (101.1k)*(12.6) = 1.274MHz

3) Comparison

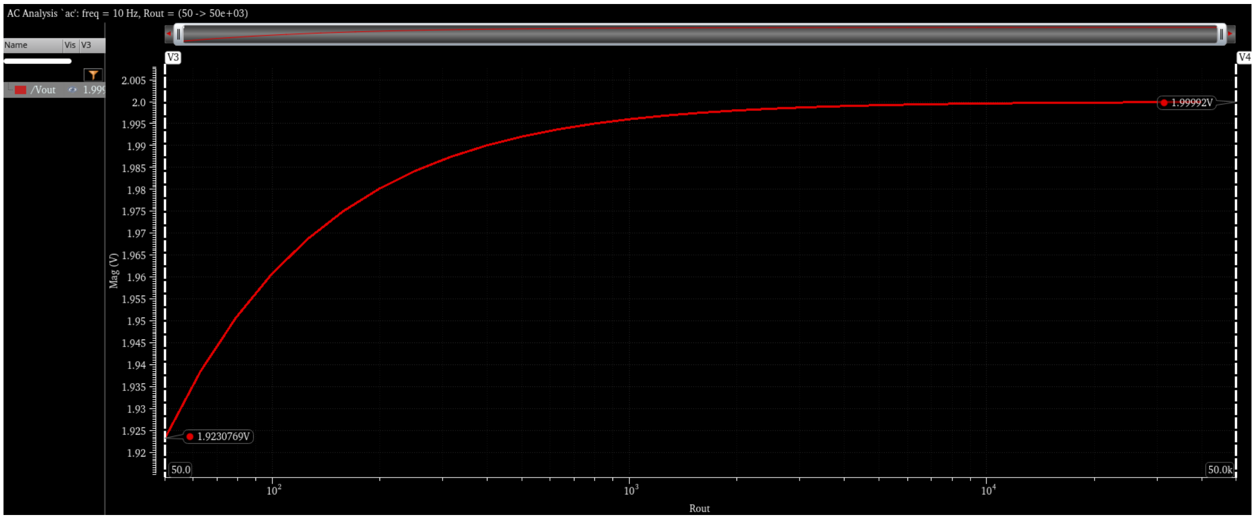
	Simulation (Cin = 4p)	Hand Analysis (Cin = 4p)	Simulation (Cin = 12p)	Hand Analysis (Cin = 12p)
Loop Gain	25.18	25.2	12.59	12.6
GBW	2.547MHz	2.548MHz	1.273MHz	1.274MHz

4) Comments

- Higher input capacitance in the feedback network gives lower loop gain, due to having a lower β (LG = βAOL)
- Both capacitors have the same BW, because β doesn't affect the LG poles (shifts the curve up or down)

Gain Desensitization

Closed Loop DC Gain vs Av



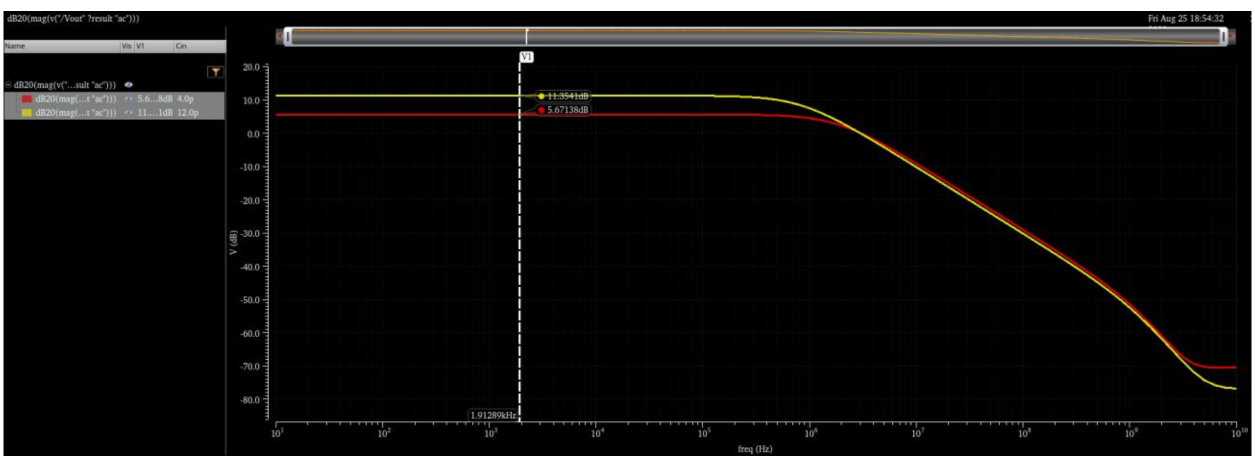
Comments

- Percentage of change in A_{CL} = $\frac{2-1.923}{2} * 100 = 3.85\%$
- Despite the huge change in open loop gain (3 order of magnitude), the change in closed loop is small. This reflects that negative feedback provides stable, linear, and accurate gain.

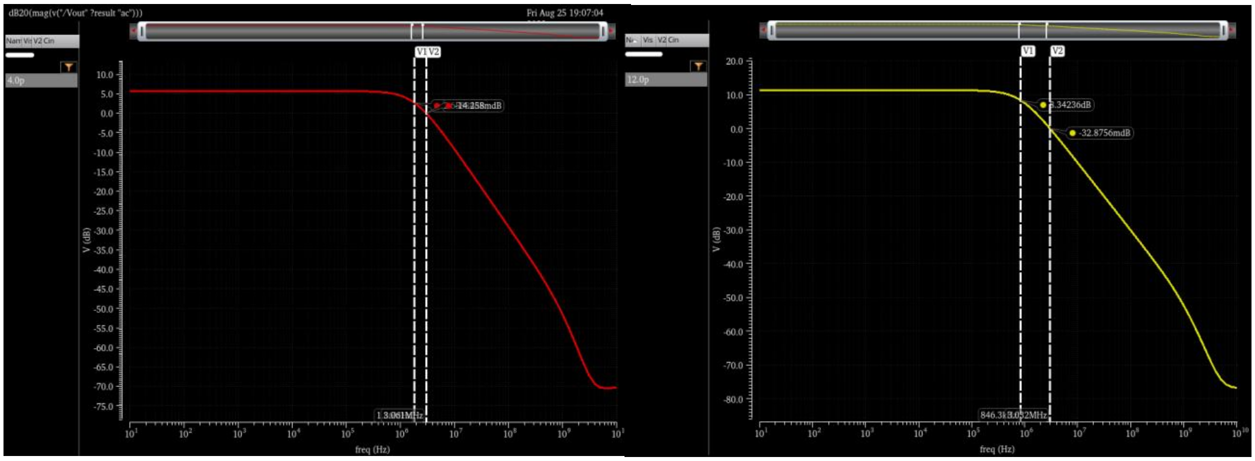
PART 2: Feedback with Real 5T OTA

Closed Loop Gain vs Frequency

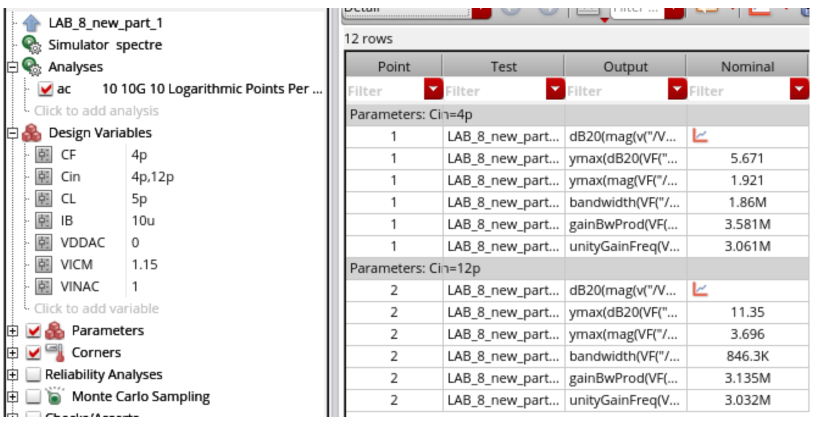
Overlaid Results (DC gain shown)



Results (BW & UGF shown)



Simulation Values



LAB_8_new_part_1
Simulator spectre
Analyses
ac 10 10G 10 Logarithmic Points Per ...
Click to add analysis
Design Variables

CF	4p
Cin	4p,12p
CL	5p
IB	10u
VDDAC	0
VICM	1.15
VINAC	1

Click to add variable
Parameters
Corners
Reliability Analyses
Monte Carlo Sampling

12 rows

Point	Test	Output	Nominal
Parameters: Cin=4p			
1	LAB_8_new_part...	dB20(mag(v("/V...	
1	LAB_8_new_part...	ymax(dB20(VF("...	5.671
1	LAB_8_new_part...	ymax(mag(VF("/...	1.921
1	LAB_8_new_part...	bandwidth(VF("/...	1.86M
1	LAB_8_new_part...	gainBwProd(VF(...	3.581M
1	LAB_8_new_part...	unityGainFreq(V...	3.061M
Parameters: Cin=12p			
2	LAB_8_new_part...	dB20(mag(v("/V...	
2	LAB_8_new_part...	ymax(dB20(VF("...	11.35
2	LAB_8_new_part...	ymax(mag(VF("/...	3.696
2	LAB_8_new_part...	bandwidth(VF("/...	846.3K
2	LAB_8_new_part...	gainBwProd(VF(...	3.135M
2	LAB_8_new_part...	unityGainFreq(V...	3.032M

Hand Analysis

5) ACL Calculation

- No change in ACL → $ACL_{\text{Cin=4p}} = 1.924$ & $ACL_{\text{Cin=12p}} = 3.706$

6) Bandwidth

- BW = $BW = \frac{1+\beta AOL}{2\pi * Rout * \left[CL + \frac{C_F * C_{in}}{C_F + C_{in}}\right]}$
- $BW_{\text{Cin=4p}}$ = 1.89MHz & $BW_{\text{Cin=12p}}$ = 858.5KHz

7) Unity Gain Frequency

- UGF = GBW = ACL*BW
- $UGF_{\text{Cin=4p}}$ = 3.636MHz & $UGF_{\text{Cin=12p}}$ = 3.181MHz

Hand Analysis vs Simulation

1) Cin = 4pF

	Simulation	Hand Analysis
DC Gain	1.924	1.924
Bandwidth (MHz)	1.86	1.89
GBW (MHz)	3.581	3.636
UGF (MHz)	3.061	3.636

2) Cin = 12pF

	Simulation	Hand Analysis
DC Gain	3.696	3.706
Bandwidth (KHz)	846.3	858.5
GBW (MHz)	3.135	3.181
UGF (MHz)	3.032	3.181

Behavioral OTA vs Real OTA

1) Cin = 4pF

	Behavioral OTA	Real OTA
DC Gain	1.924	1.921
Bandwidth (MHz)	2.647	1.86
GBW (MHz)	5.104	3.581
UGF (MHz)	4.382	3.601

2) Cin = 12pF

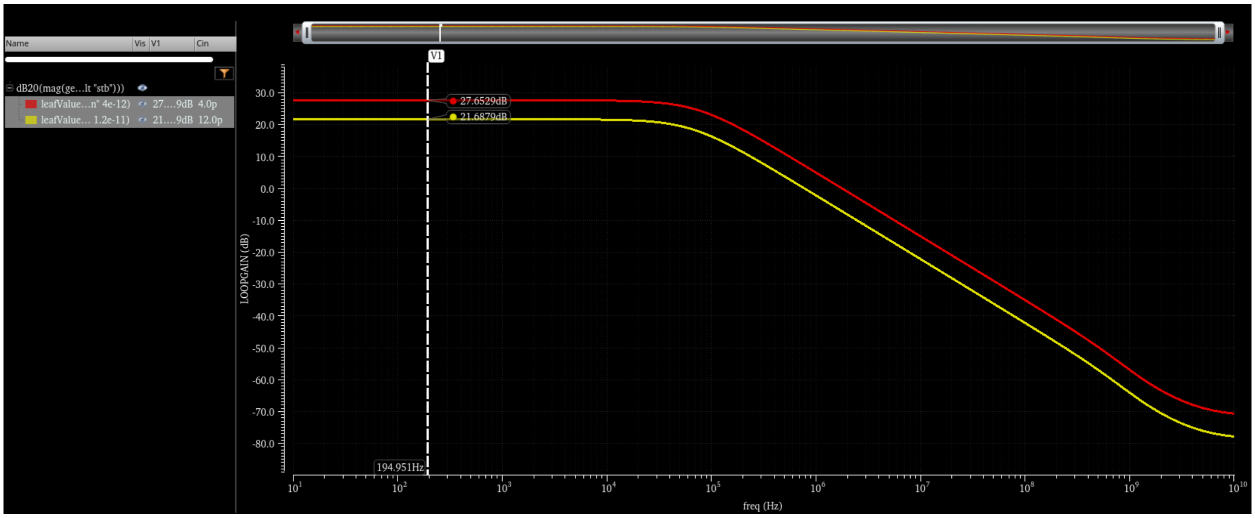
	Behavioral OTA	Real OTA
DC Gain	3.706	3.696
Bandwidth (MHz)	1.375	0.8463
GBW (MHz)	5.107	3.135
UGF (MHz)	4.919	3.032

3) Why are BW & GBW much smaller than Part 1?

For ideal OTA, bandwidth is not affected by load capacitance. However, for real OTA, there is a loading effect causing a decrease in bandwidth.

Loop Gain vs Frequency

Overlaid Results



ymax(mag(getData("loopGain" ?res...

	Cin	ymax(mag..."stb")))	ymax(dB2...stb"))))	unityGain..."stb"))))	gainBwPr...stb"))))
1	4.000E-12	24.13	27.65	1.768E6	4.793E6
2	12.00E-12	12.15	21.69	711.8E3	2.548E6

Hand Analysis

1) **Loop Gain**

- No change in LG → $LG_{\mathrm{Cin=4p}}$ = 25.2 & $LG_{\mathrm{Cin=12p}}$ = 12.6

2) **GBW**

- GBW = $\frac{\beta * AOL}{2\pi * Rout * \left[CL + \frac{C_F * C_{in}}{C_F + C_{in}}\right]}$
- $GBW_{\mathrm{Cin=4p}}$ = 1.817MHz & $GBW_{\mathrm{Cin=12p}}$ = 795.1KHz

Hand Analysis vs Simulation

1) **Cin = 4pF**

	Simulation	Hand Analysis
Loop Gain	24.13	25.2
GBW (MHz)	4.793	1.817
UGF (MHz)	1.768	1.817

2) Cin = 12pF

	Simulation	Hand Analysis
Loop Gain	12.15	12.6
GBW (MHz)	2.548	0.795
UGF (KHz)	711.8	795.1

Behavioral OTA vs Real OTA

1) Cin = 4pF

	Behavioral OTA	Real OTA
Loop Gain	25.18	24.13
GBW (MHz)	2.547	4.793
UGF (MHz)	2.550	1.768

2) Cin = 12pF

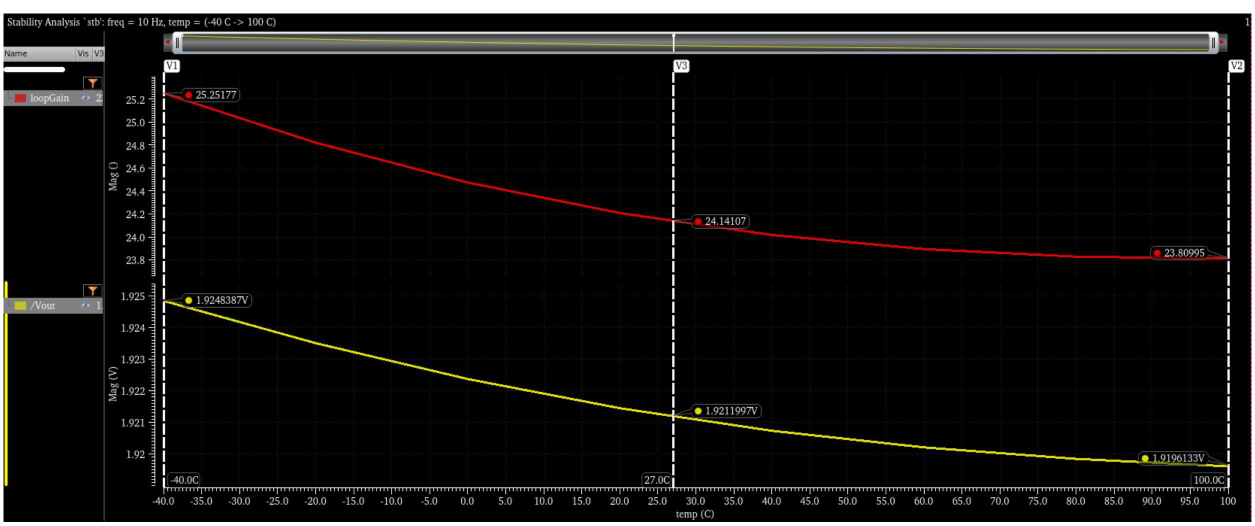
	Behavioral OTA	Real OTA
Loop Gain	12.59	12.15
GBW (MHz)	1.273	2.548
UGF (MHz)	1.271	0.712

3) Why is UGF much smaller than Part 1?

Due to loading effect; the output capacitor affects the circuit pole giving a lower UGF.

Gain Desensitization

Loop Gain & Closed Loop Gain vs Temperature



Percentage of Change

- **Percentage of change in LG:**

$$\Delta LG = \frac{24.14-25.25}{24.14} * 100 : \frac{24.14-23.81}{24.14} * 100 = -4.6\% : 1.37\%$$

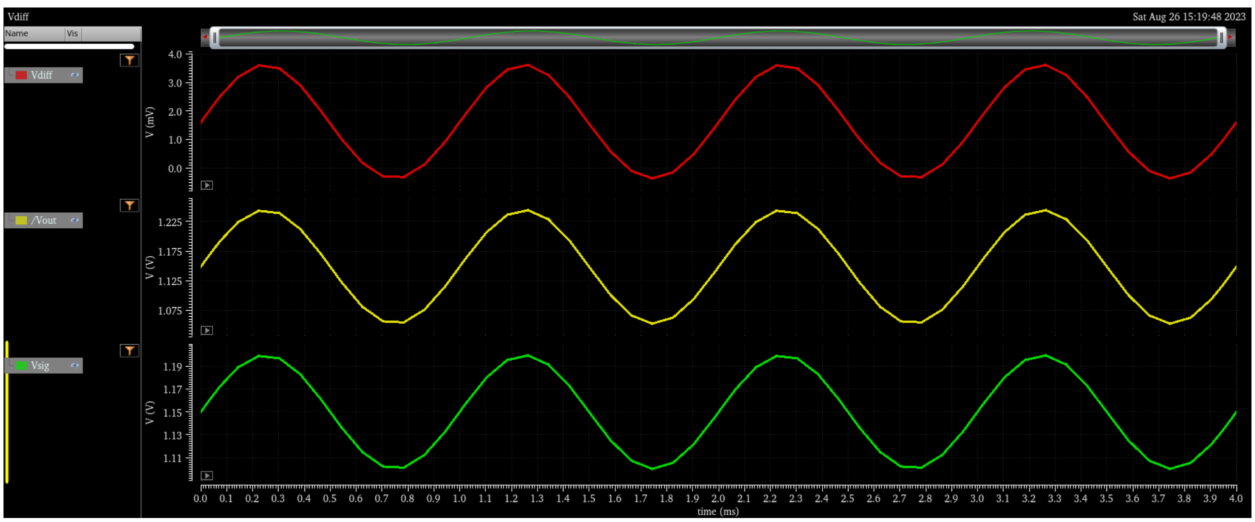
- **Percentage of change in A_{CL}:**

$$\Delta ACL = \frac{1.9212-1.9248}{1.9212} * 100 : \frac{1.9212-1.9196}{1.9212} * 100 = -0.19\% : 0.083\%$$

- **Comment:** Temperature has a higher effect on loop gain, while closed loop gain is more immune to temperature variations.

Transient Analysis

Frequency = 1kHz



Vpp_diff=peakToPeak(Vdiff) Vpp_ou...

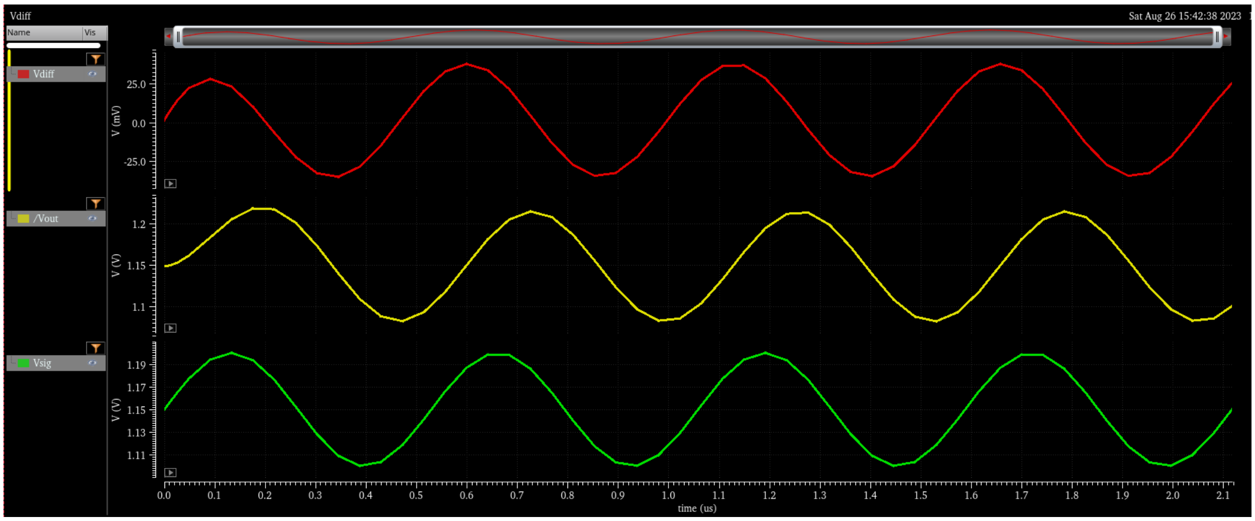
	Expression	Value	Expression	Value	Expression	Value
1	Vpp_diff=peakT...	3.966E-3	Vpp_out=peakT...	191.7E-3	Vpp_sig=peakT...	99.77E-3

What is the relation between the output and (VP – VN)?

Vout = AOL*Vin_diff → $AOL_{simulation} = \frac{Vout}{Vdiff} = \frac{191.7}{3.966} = 48.3 \approx 50.36$ (per ac simulation).

Vout = ACL*Vsig → $ACL_{simulation} = \frac{Vout}{Vdiff} = \frac{191.7}{99.77} = 1.92$

Frequency = 1.89MHz



Vpp_diff=peakToPeak(Vdiff) Vpp_ou...

	Expression	Value	Expression	Value	Expression	Value
1	Vpp_diff=peakT...	72.82E-3	Vpp_out=peakT...	135.8E-3	Vpp_sig=peakTo...	99.67E-3

- **What is the relation between the output and the input signal?**

  $\frac{\text{Vout}}{\text{Vsig}} = \frac{135.8}{99.67} = 1.36$ → Closed loop gain (ACL)

- **What is the relation between the output and the differential signal?**

  $\frac{\text{Vout}}{\text{Vdiff}} = \frac{135.8}{72.82} = 1.86$ → Open loop gain (AOL)

- **Comparison**

  At closed loop bandwidth frequency, the open loop gain has significantly decreased because BW_{ACL} >> BW_{AOL}, so the closed loop gain decreases consequently.