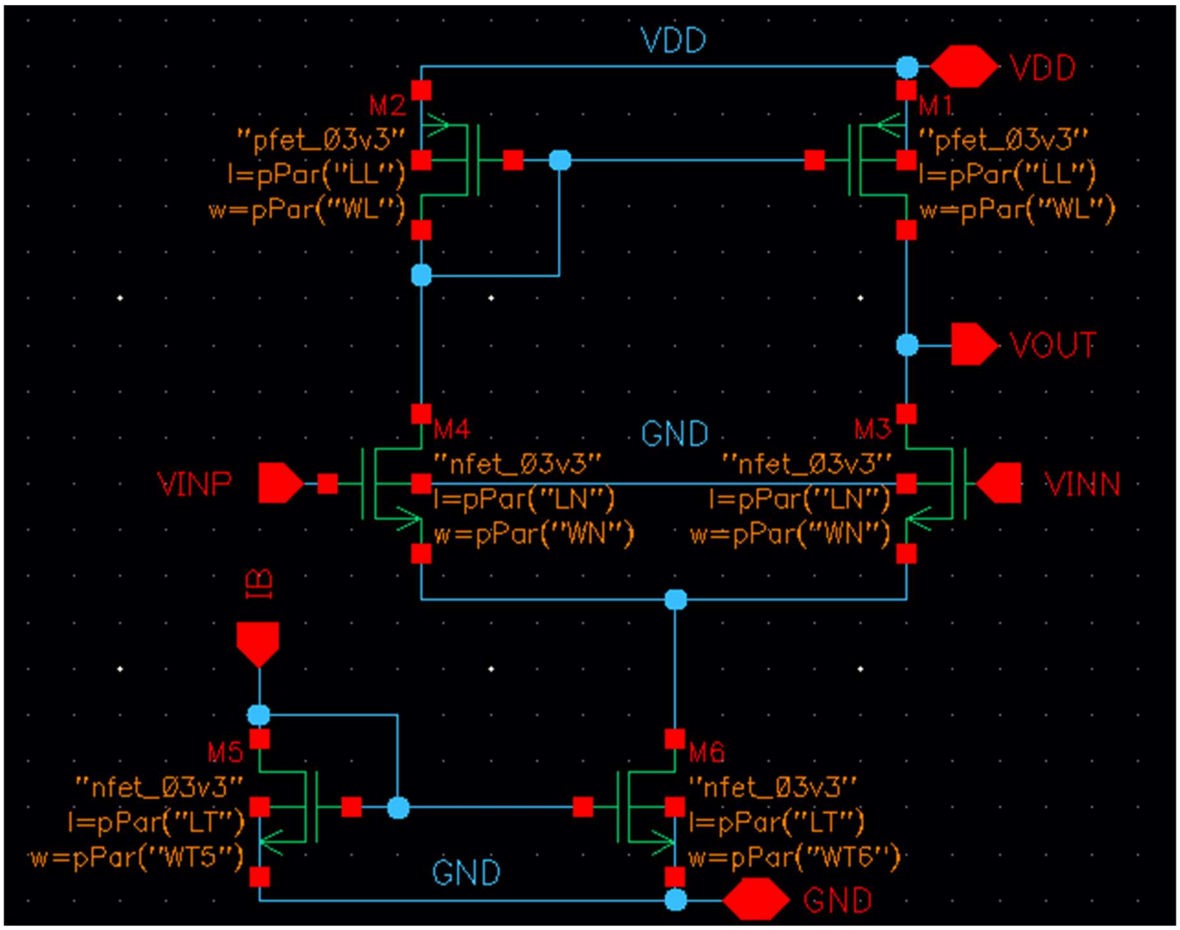
Analog IC Design

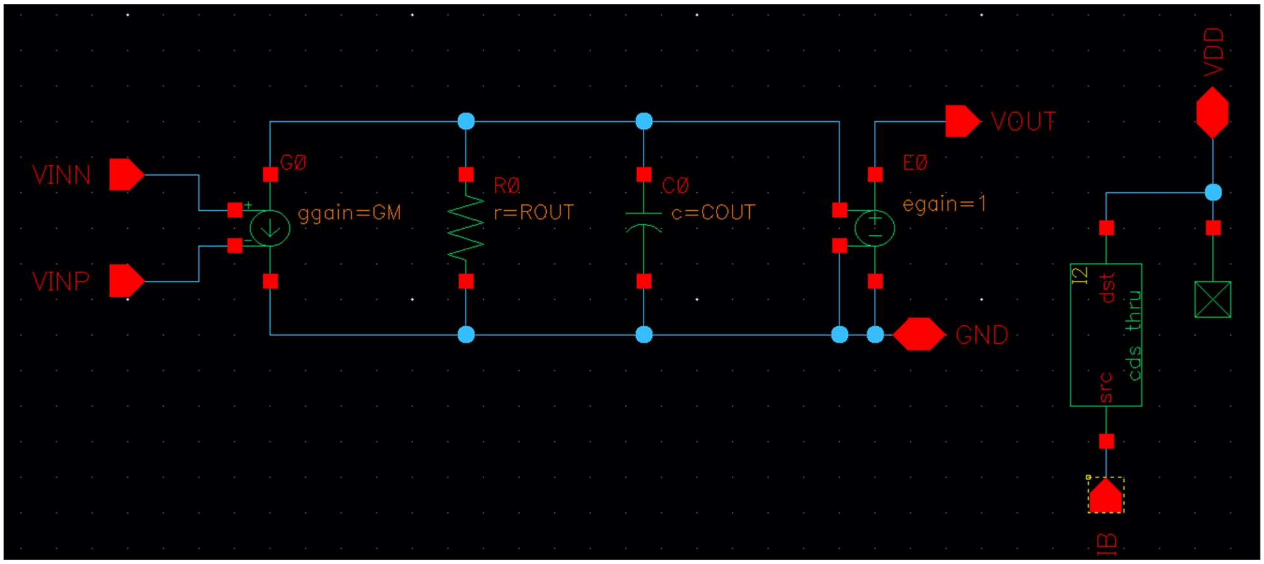
Lab 08

Negative Feedback

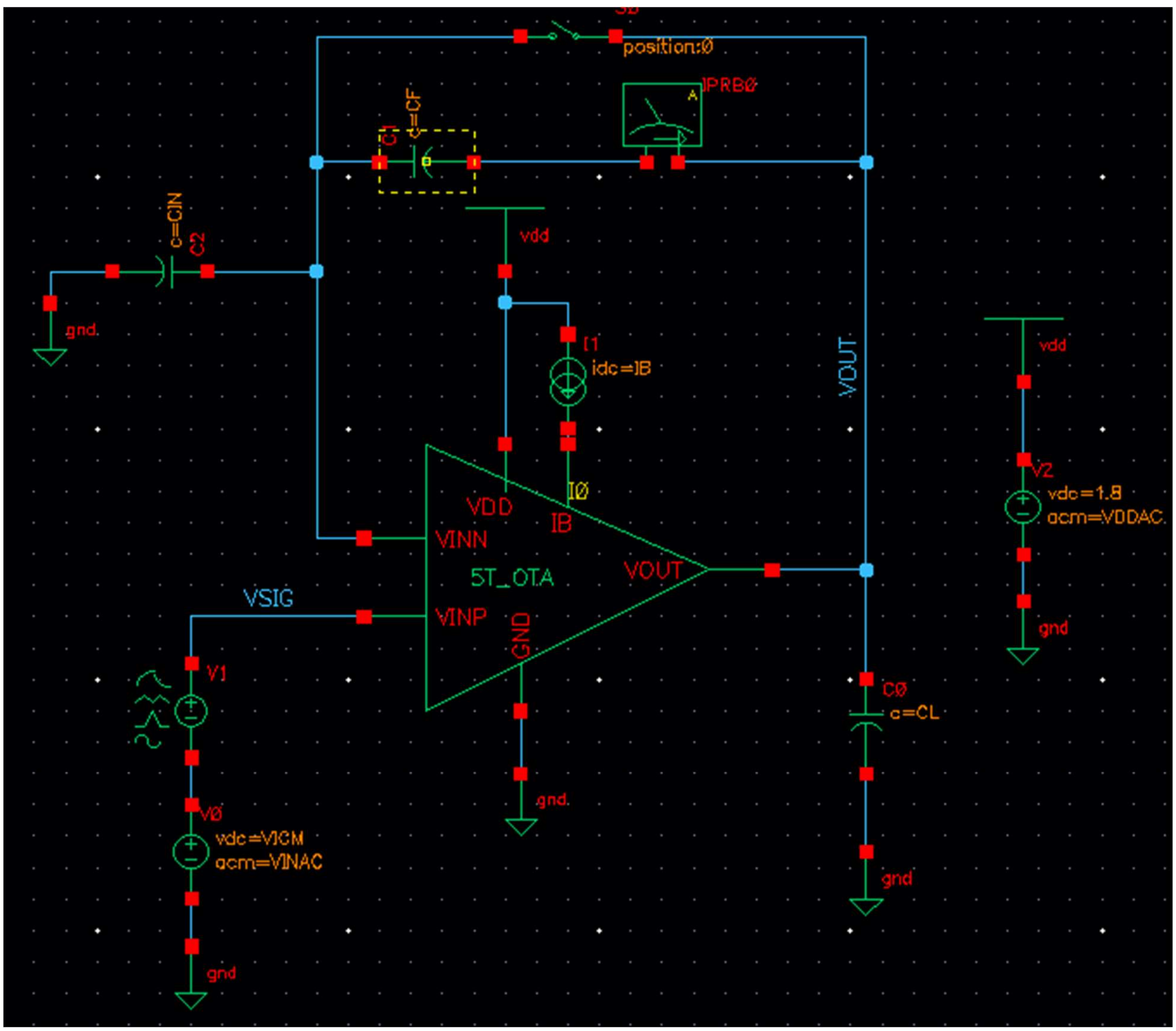
PART 1: Feedback with Behavioral OTA



Transistor	gm/ID	Length	Width	Function
M3 and M4	15	440nm	18um	Input pair
MI and M2	10	320nm	9.92um	current mirror load
M5 and M6	10	1um	4.89um and 19.57um	tail current source

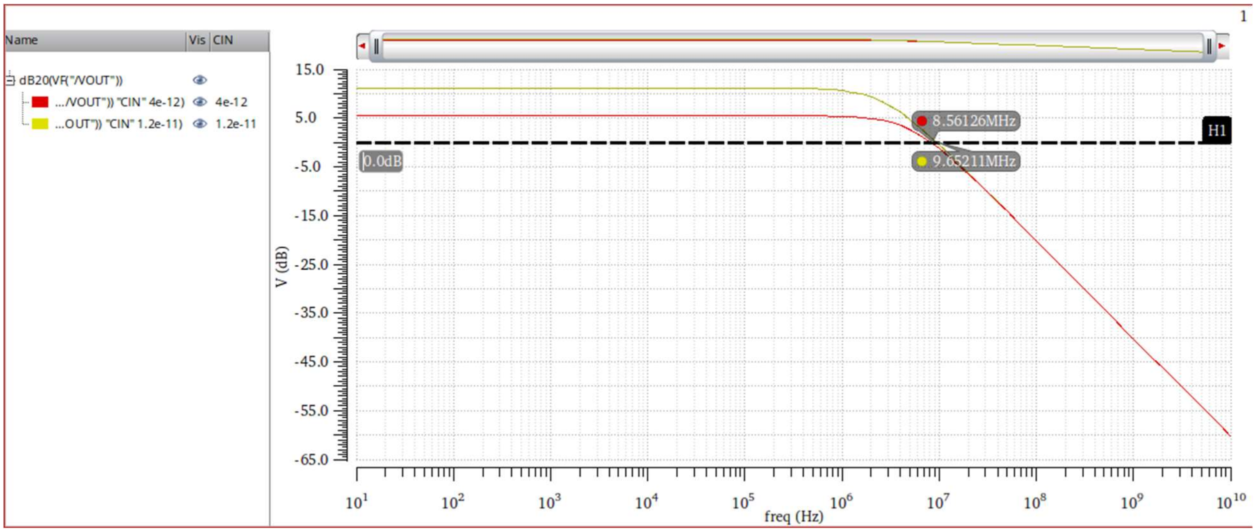


VINN
VINP
GØ
ggain=GM
RØ
r=ROUT
CØ
c=COUT
EØ
egain=1
VOUT
GND
VDD
I2
dst
src
cds_thru
IB



position:Ø
IPRBØ
C1
c=CF
c=CIN
C2
gnd
vdd
I1
idc=IB
VOUT
VDD
IB
IØ
VINN
5T_OTA
VOUT
VSIG
VINP
GND
V1
VØ
vdc=VICM
acm=VINAC
CØ
c=CL
V2
vdc=1.8
acm=VDDAC

1) Closed loop gain vs frequency.



Point	Test	Output	Nominal
Parameters: CIN=4p			
1	Lab_08:TEST_BENCH_OTA:1	Gain_dB	5.68
1	Lab_08:TEST_BENCH_OTA:1	Gain	1.923
1	Lab_08:TEST_BENCH_OTA:1	BW	5.195M
1	Lab_08:TEST_BENCH_OTA:1	GBW	10.02M
Parameters: CIN=12p			
2	Lab_08:TEST_BENCH_OTA:1	Gain_dB	11.37
2	Lab_08:TEST_BENCH_OTA:1	Gain	3.704
2	Lab_08:TEST_BENCH_OTA:1	BW	2.701M
2	Lab_08:TEST_BENCH_OTA:1	GBW	10.03M

Compare the DC gain, BW, and GBW with hand analysis in a table.

$$\beta = \frac{CF}{CF+CIN} = 0.5,\ 0.25$$

$$Av = \frac{Avol}{1+\beta * Avol} = 1.923\ ,3.703 = 5.67dB, 11.372dB$$

$$BW = (1+\beta A_{vOL}) * BW_{OL} = \frac{1+\beta * Avol}{2\pi Rout * Cout} = 5.197M, 2.698M$$

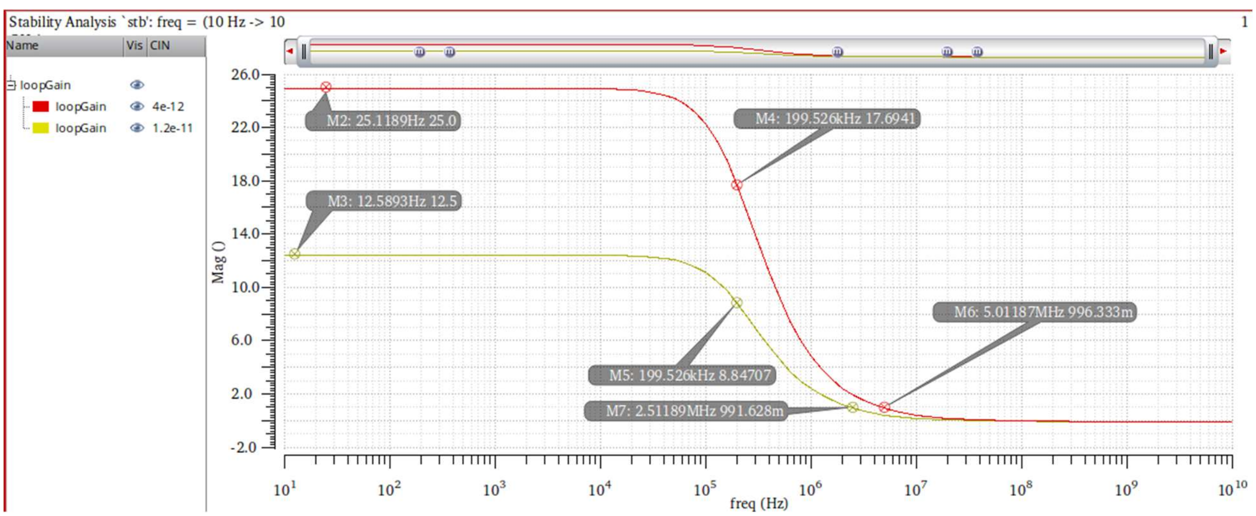
$$GBW = A_v * BW = 9.992M\ , 9.993M$$

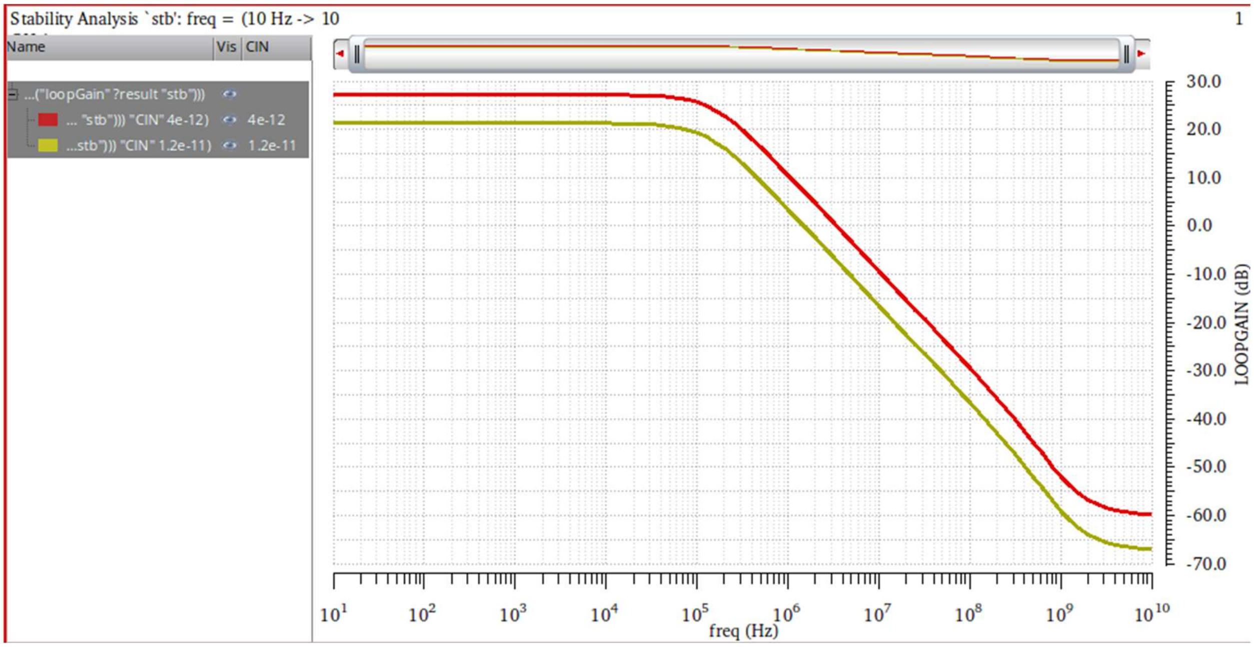
	Analytically		simulation	
	CIN=4P	CIN=12P	CIN=4P	CIN=12P
DC Gain	1.923	3.703	1.923	3.704
BW	5.197M	2.698M	5.195M	2.70M
GBW	9.992M	9.993M	10.02M	10.03M

<u>Comment on the difference between the results for the two values of CIN.</u>

In case of $C_{IN} = 4\ pF$ we had smaller gain and higher BW than in case of CIN =12 pF, that's because in case of 4 pF we had larger β which is inversely, proportional to the gain and directly proportional to the BW.

2) Loop gain vs frequency





Point	Test	Output	Nominal
Parameters: CIN=4p			
1	Lab_08:TEST_BENCH_OTA:1	Gain_dB	5.68
1	Lab_08:TEST_BENCH_OTA:1	Gain	1.923
1	Lab_08:TEST_BENCH_OTA:1	BW	5.195M
1	Lab_08:TEST_BENCH_OTA:1	GBW	10.02M
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain	25
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_dB	27.96
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_BW	199.4k
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_UGF	4.997M
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_GBW	4.998M
Parameters: CIN=12p			
2	Lab_08:TEST_BENCH_OTA:1	Gain_dB	11.37
2	Lab_08:TEST_BENCH_OTA:1	Gain	3.704
2	Lab_08:TEST_BENCH_OTA:1	BW	2.701M
2	Lab_08:TEST_BENCH_OTA:1	GBW	10.03M
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain	12.5
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_dB	21.94
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_BW	199.4k
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_UGF	2.495M
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_GBW	2.499M

Compare DC LG and GBW with hand analysis in a table.

$$\text{DCLG} = \beta \text{AvOL} = 27.95\text{dB} ,21.93\text{dB}$$

$$\text{BW} = \text{BWOL}= \frac{1}{2\pi Rout * Cout} = 199.3\text{K}$$

$$GBW = DC\ LG * BWLG = 4.98\text{M},2.492\text{M}$$

	Analytically		simulation	
	CIN=4P	CIN=12P	CIN=4P	CIN=12P
DC Gain	27.95	21.93	27.9	21.94
BW	199.3K		199.4K	
GBW	4.98M	2.492M	4.99M	2.495M

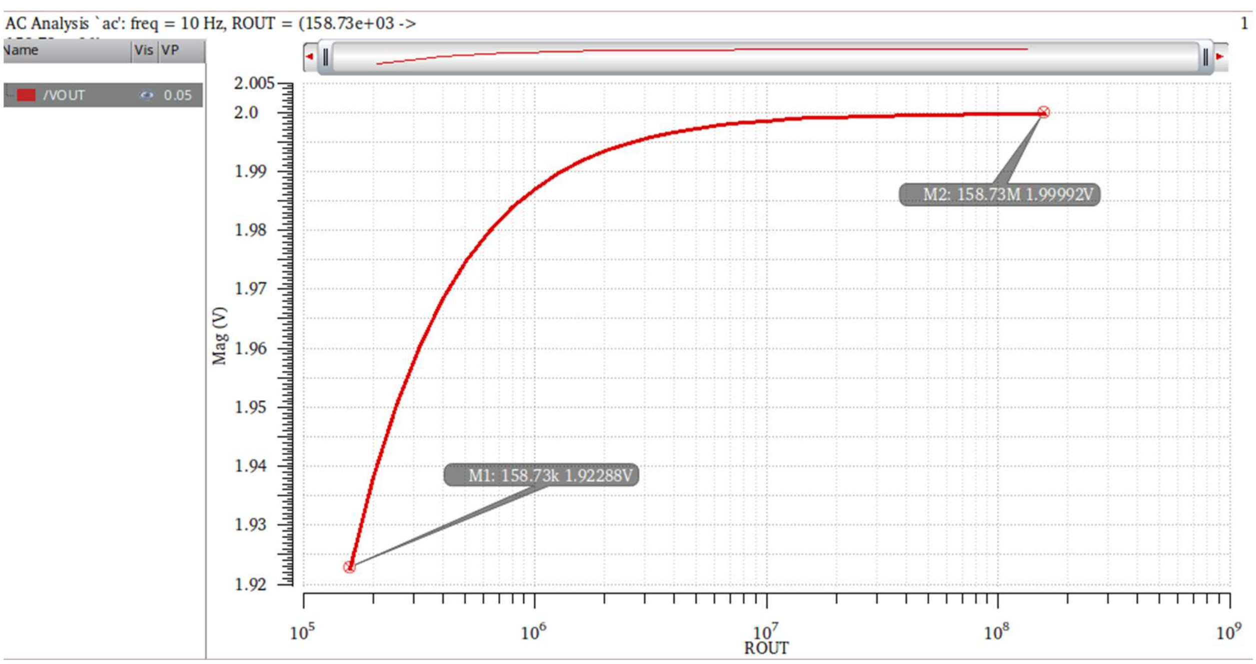
• Comment on the differences between the results for the two values of CIN.

Changing the value of CIN changes the value of β which changes the values of DCLG and LG GBW. LG BW didn't change as changing β doesn't affect it.

3) Gain Desensitization

Plot closed loop DC gain (magnitude at 10Hz, not dB) vs Av.

I did a sweep on ROUT because AV is a fixed number not linked to a variable.



Calculate the percent change in closed loop gain (magnitude, not dB). Note that open loop gain (Av) changes by three orders of magnitude (60dB). Comment.

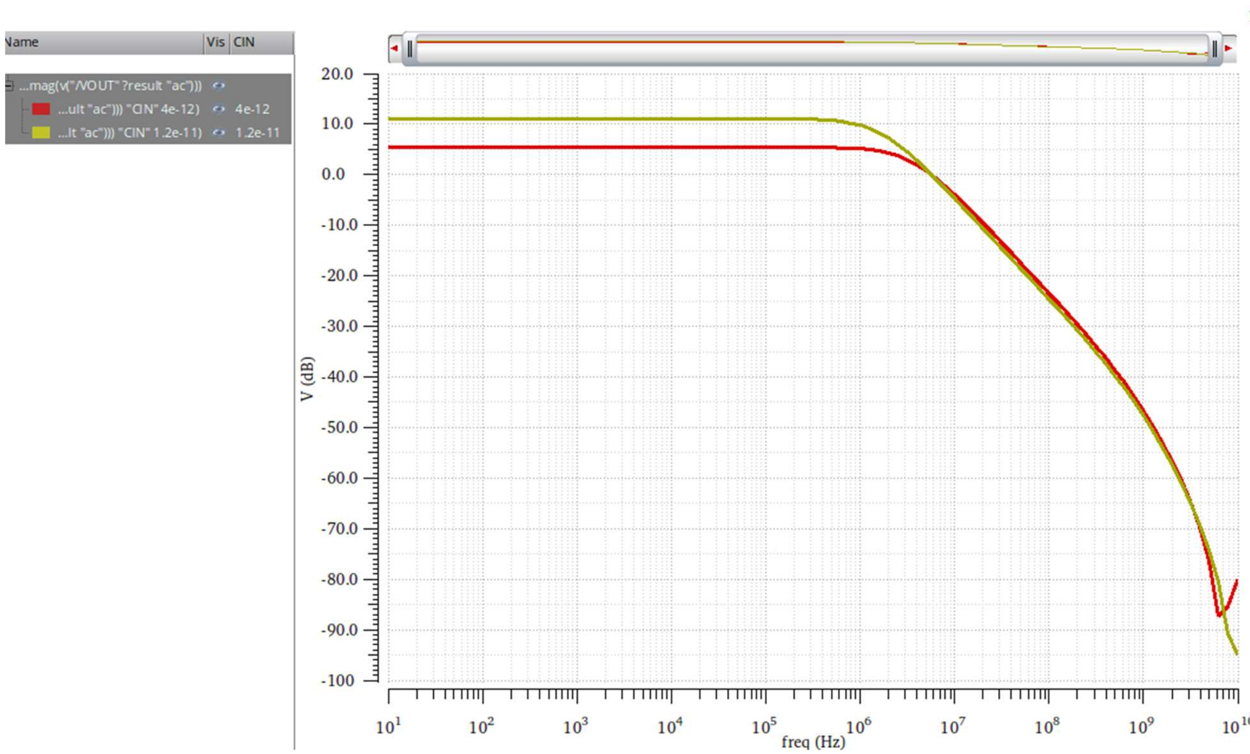
$$\text{Percent Change} = \frac{Max - Min}{Ideal} * 100 = 3.842\%$$

- Large variations in open-loop gain have almost no effect on closed-loop gain. The larger the open-loop gain.
- the more accurate the closed-loop gain will be and the closer it will be to the ideal value.

PART 2: Feedback with Real 5T OTA

1. Closed loop gain vs frequency.

Repeat what you did in Part 1 (Closed loop gain vs frequency).



Point	Test	Output	Nominal
Parameters: CIN=4p			
1	Lab_08:TEST_BENCH_OTA:1	Gain_dB	5.85
1	Lab_08:TEST_BENCH_OTA:1	Gain	1.961
1	Lab_08:TEST_BENCH_OTA:1	BW	3.642M
1	Lab_08:TEST_BENCH_OTA:1	GBW	7.159M
Parameters: CIN=12p			
2	Lab_08:TEST_BENCH_OTA:1	Gain_dB	11.53
2	Lab_08:TEST_BENCH_OTA:1	Gain	3.77
2	Lab_08:TEST_BENCH_OTA:1	BW	1.655M
2	Lab_08:TEST_BENCH_OTA:1	GBW	6.256M

$$\beta = \frac{CF}{CF+CIN} = 0.5,\ 0.25$$

$$Av = \frac{Avol}{1+\beta * Avol} = 1.923\ , 3.703 = 5.67dB, 11.372dB$$

$$BW = (1+\beta A_{vOL}) * BW_{OL} = \frac{1+\beta * Avol}{2\pi Rou\ *(CL(CF(CIN||CF)))} = 3.7M, 1.7M$$

$$GBW = A_v * BW = 7.2M\ , 6.3M$$

	Analytically		simulation	
	CIN=4P	CIN=12P	CIN=4P	CIN=12P
DC Gain	1.923	3.703	1.96	3.77
BW	3.7M	1.7M	3.6M	1.6M
GBW	7.2M	6.3M	7.1M	6.2M

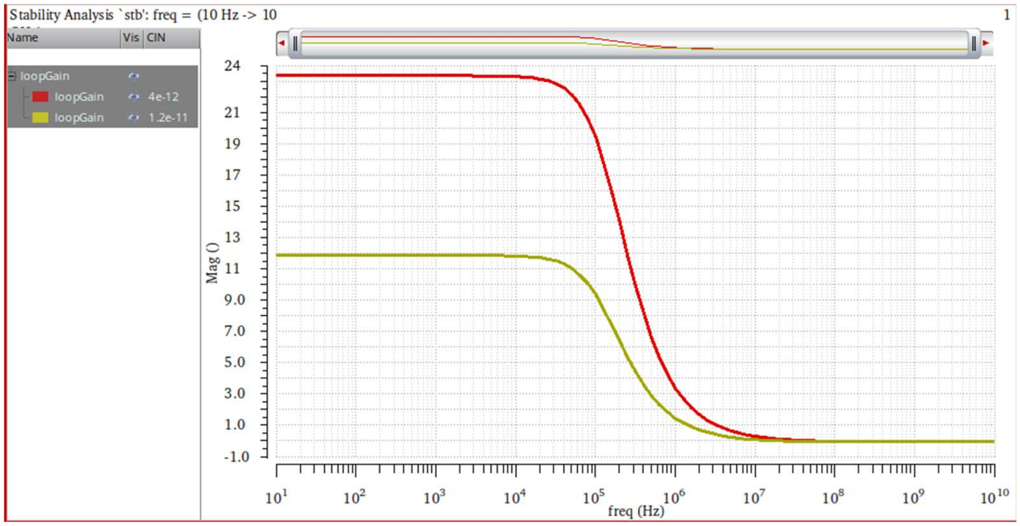
Compare between the results you obtained here and the results in Part 1 in a table.

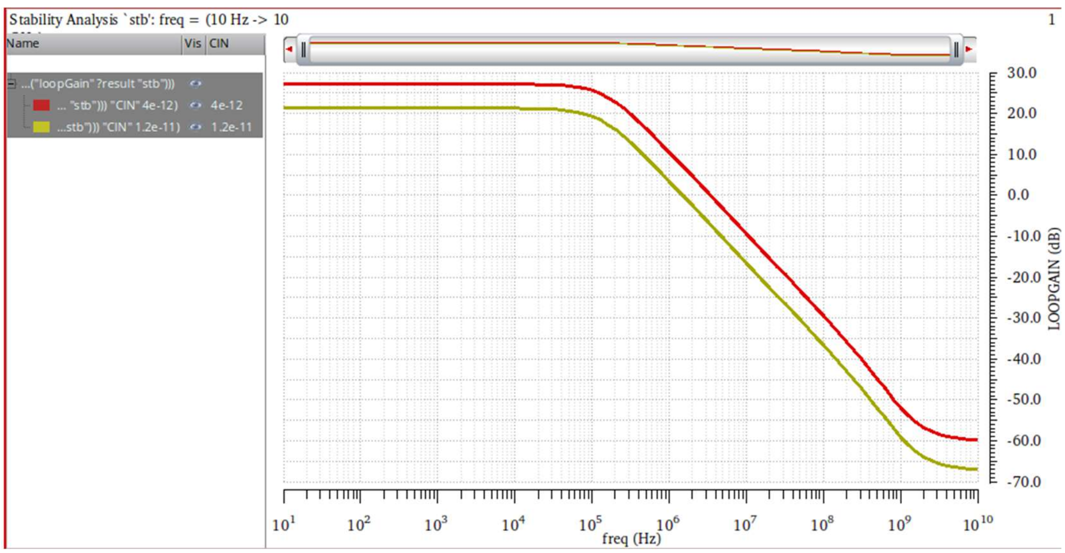
	PART1		PART2	
	CIN=4P	CIN=12P	CIN=4P	CIN=12P
DC Gain	1.923	3.704	1.96	3.77
BW	5.195M	2.70M	3.6M	1.6M
GBW	10.02M	10.03M	7.1M	6.2M

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

Because in part 1 $BW = \frac{1}{2\pi Rou\ *Cout}$ and $Cout \approx 5\ pF$ while in part 2 we had $\frac{1+\beta*Avol}{2\pi Rout*(CL(CF(CIN||CF)))}$ which is larger than the Cout of part 1, and larger capacitance means lower BW for a given resistance and that's why the BW in part 2 is smaller than in part 1 and the gain didn't change which results in a smaller GBW.

2. Loop gain vs frequency





Point	Test	Output	Nominal
Parameters: CIN=4p			
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain	23.41
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_dB	27.39
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_BW	148.6k
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_UGF	3.519M
1	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_GBW	3.485M
Parameters: CIN=12p			
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain	11.92
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_dB	21.52
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_BW	127.8k
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_UGF	1.53M
2	Lab_08:TEST_BENCH_OTA:1	Loop_Gain_GBW	1.526M

$$\text{DCLG} = \beta \text{AvOL} = 27.95\text{dB}\ ,21.93\text{dB}$$

$$\text{BW} = BWOL = \frac{1}{2\pi Rout*(CL(CF(CIN||CF)))} = 148.7\text{K},127.95\text{K}$$

$$GBW = DC\ LG * BWLG = 3.55\text{M},1.58\text{M}$$

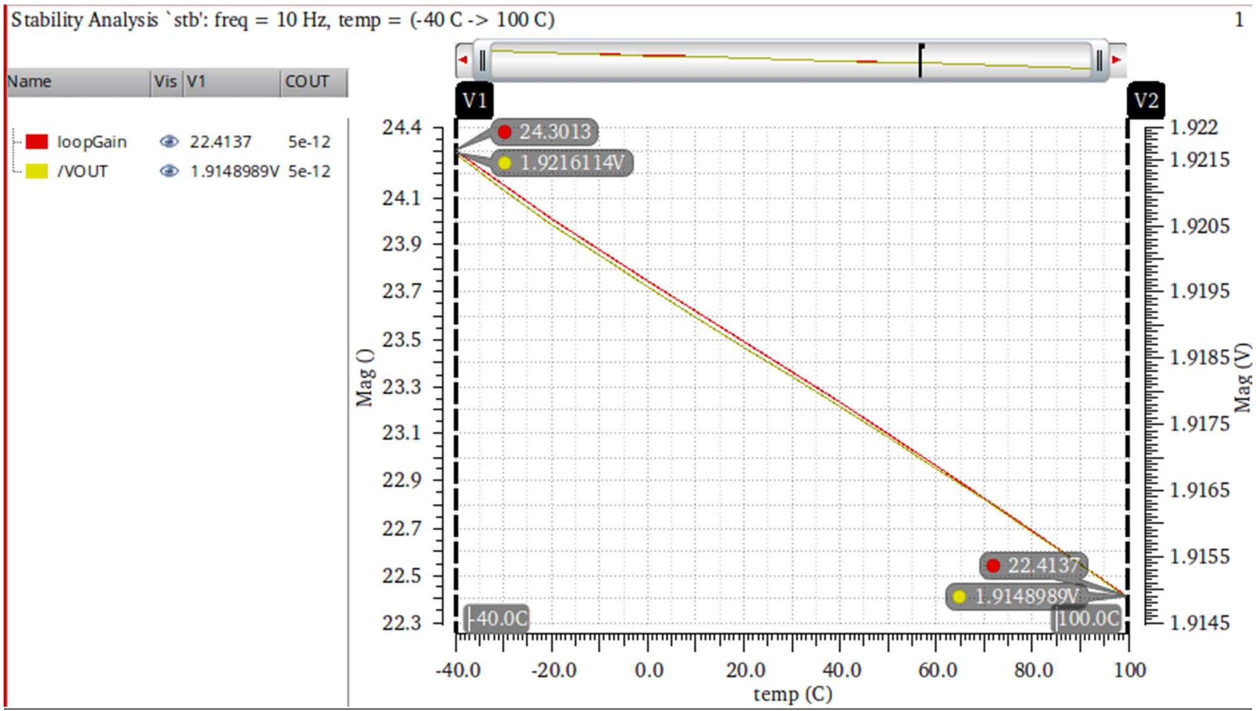
	Analytically		simulation	
	CIN=4P	CIN=12P	CIN=4P	CIN=12P
DC Gain	1.923	3.703	23.4	11.92
BW	148.7K	127.9K	148.6K	127.8K
GBW	3.55M	1.58M	3.48M	1.52M

	PART1		PART2	
	CIN=4P	CIN=12P	CIN=4P	CIN=12P
DC Gain	27.9	21.94	23.4	11.92
BW	199.4K		148.6K	127.8K
GBW	4.99M	2.495M	3.48M	1.52M

Because the feedback loop loads the circuit and increases its output capacitance which reduces its BW and eventually reduces its GBW and UGF

3. Gain Desensitization.

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.



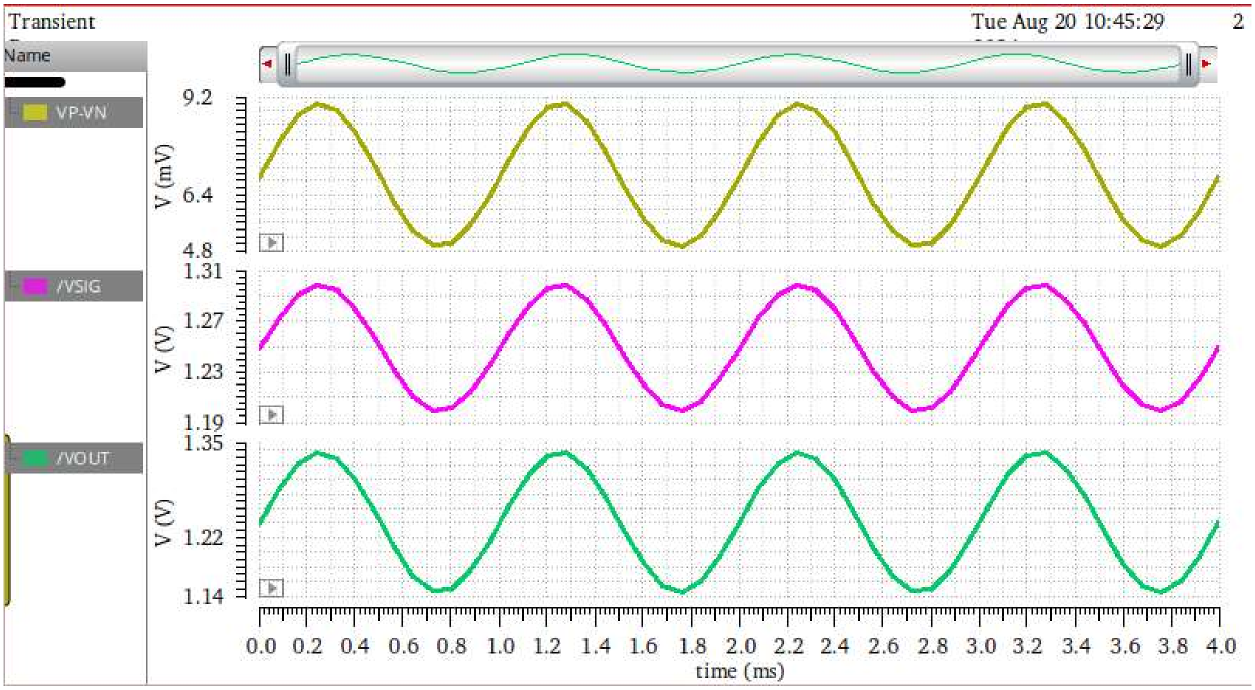
$$\text{Percent Change in LG} = \frac{24.3013- \quad .4137}{23.41} * 100 = 8.063\%$$

$$\text{Percent Change in } Av_{CL} = \frac{1.9216114 - 1.9148989}{2} * 100 = 0.335\%$$

The percent change in Closed-loop gain << The percent change in LG and this is demonstrates the concept of gain desensitization by feedback. This is because Avcl= $\frac{Avol}{1+\beta * Avol}$ which means if AOL is large enough we can use the approximation

$ACL = 1/\ \beta$ which is a constant and doesn't depend on any variations.

4. Transient analysis.

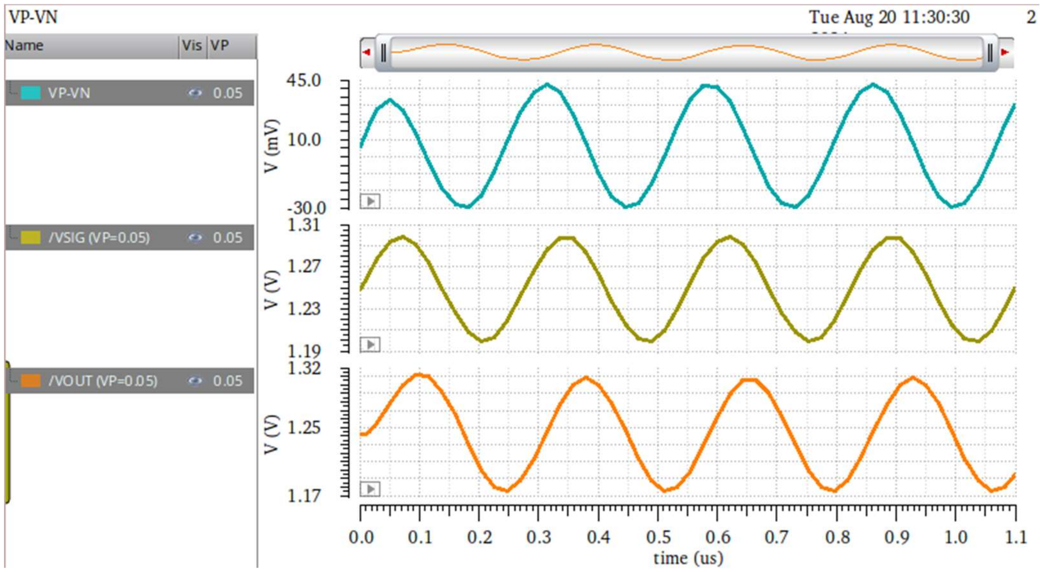


Lab_08:TEST_BENCH_OTA:1	OUTPUT	
Lab_08:TEST_BENCH_OTA:1	INPUT	
Lab_08:TEST_BENCH_OTA:1	VP-VN	
Lab_08:TEST_BENCH_OTA:1	PTP_IN	99.8m
Lab_08:TEST_BENCH_OTA:1	PTP_OUT	191.4m
Lab_08:TEST_BENCH_OTA:1	PTP_VP ? VN	4.11m

relation between Output and VP-VN $= \frac{vout}{VP - VN} = \frac{191.4}{4.11} = 46.5 \approx Av_{OL}$

$$Av_{OL} = \frac{vout}{vdiff} \text{ and } VP - V_N = V_{diff}.$$

<u>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)</u>



Test	Output	Nominal
Lab_08:TEST_BENCH_OTA:1	OUTPUT	
Lab_08:TEST_BENCH_OTA:1	INPUT	
Lab_08:TEST_BENCH_OTA:1	VP-VN	
Lab_08:TEST_BENCH_OTA:1	PTP_IN	99.78m
Lab_08:TEST_BENCH_OTA:1	PTP_OUT	136.7m
Lab_08:TEST_BENCH_OTA:1	PTP_VP ? VN	72.28m

relation between Output and VP-VN $= \frac{vout}{VP - VN} = \frac{136.7}{72.28} = 1.89$

	Part1	Part2
In	99.8m	99.78m
Out	191.4m	136.7m
VP-VN	4.11m	72.28m