Analog IC Design

Lab 08

Negative Feedback

PART 1: Feedback with Behavioural OTA

1) Closed loop gain vs frequency.

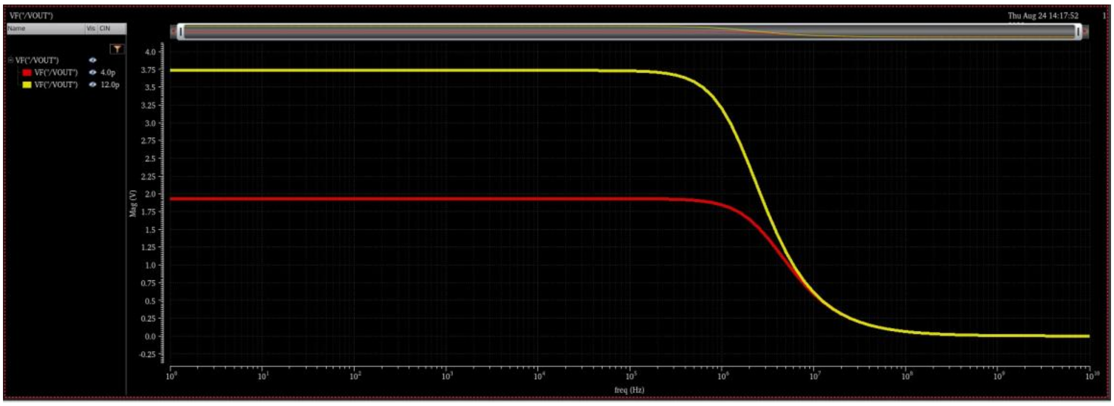

Figure 1 Vout in dB.

Point	Test	Output	Nominal
Filter	Filter	Filter	Filter
Parameters: CIN=4p			
1	Lab7_LAB8_1	VF("/VOUT")	
1	Lab7_LAB8_1	ymax(dB20(VF("...	5.717
1	Lab7_LAB8_1	ymax(mag(VF("/...	1.931
1	Lab7_LAB8_1	bandwidth(VF("/...	3.211M
1	Lab7_LAB8_1	gainBwProd(VF(...	6.217M
Parameters: CIN=12p			
2	Lab7_LAB8_1	VF("/VOUT")	
2	Lab7_LAB8_1	ymax(dB20(VF("...	11.45
2	Lab7_LAB8_1	ymax(mag(VF("/...	3.735
2	Lab7_LAB8_1	bandwidth(VF("/...	1.663M
2	Lab7_LAB8_1	gainBwProd(VF(...	6.226M

Figure 2 the DC gain, the bandwidth, and the unity gain frequency

Hand analysis:

$$\beta = \frac{\mathrm{Cf}}{\mathrm{Cin} + \mathrm{Cf}} = 0.5 \rightarrow \mathrm{Cin}\ 4\mathrm{p}\,, 0.25 \rightarrow \mathrm{Cin}\ 12\mathrm{p}$$

$$AOL = 56.8 \text{ (LAST LAB)}$$

$$ACL = \frac{AOL}{1 + \beta * AOL} = \frac{56.8}{1 + 0.5 * 56.8} = 1.932 = 5.72 \text{ dB}, \text{Cin } 4p$$

$$ACL = \frac{AOL}{1 + \beta * AOL} = \frac{56.8}{1 + 0.25 * 56.8} = 3.74 = 11.45dB, \text{Cin } 12p$$

Bandwidth:

$BW\_OL = 107\ KHZ$ (Last Lab)

$BW\_CL = BW\_OL * (1 + \beta * AOL) = 107K * (1 + 0.5 * 56.8) = 3.146MHZ$, Cin 4p

$BW\_CL = BW\_OL * (1 + \beta * AOL) = 107K * (1 + 0.25 * 56.8) = 1.626MHZ$, Cin 12p

GBW:

$$GBW = BW * ACL = 3.211M * 1.932 = 6.2\ M$$

$$GBW = BW * ACL = 1.663M * 3.74 = 6.22\ M$$

	Hand Analysis		Simulation	
Cin	4p	12p	4p	12p
DC Gain	1.932	3.74	1.931	3.735
BW	$3.146M$	$1.626M$	3.211M	1.663M
GBW	6.2 M	6.22 M	6.2M	6.23M

Feedback factor is a capacitive divider so the increasing in Cin decreases the feedback factor which increase the CL gain that increases BW, but GBW isn't change with Cin as when the gain decrease the bandwidth increase by the same ratio (with a little variation with OL gain as its value is finite).

2) Loop gain vs frequency.

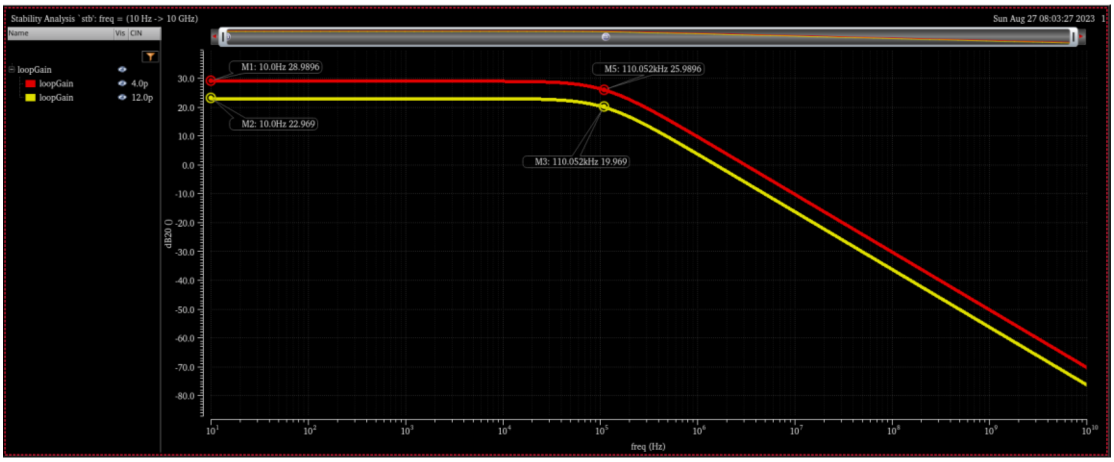

Figure 3 loop gain in dB

Point	Test	Output	Nominal
Filter	Filter	Filter	Filter
Parameters: CIN=4p			
1	Lab7_LAB8_1	ymax(db20(getD...	28.99
1	Lab7_LAB8_1	ymax(mag(getD...	28.15
1	Lab7_LAB8_1	unityGainFreq(...	3.114M
Parameters: CIN=12p			
2	Lab7_LAB8_1	ymax(db20(getD...	22.97
2	Lab7_LAB8_1	ymax(mag(getD...	14.08
2	Lab7_LAB8_1	unityGainFreq(...	1.555M

Figure 4 the DC loop gain, the dominant pole, and the unity gain frequency

Hand Analysis

$$\beta = \frac{\mathrm{Cf}}{\mathrm{Cin} + \mathrm{Cf}} = 0.5 \rightarrow \mathrm{Cin}\ 4\mathrm{p}\,, 0.25 \rightarrow \mathrm{Cin}\ 12\mathrm{p}$$

$$AOL = 56.8\ (\mathrm{LAST\ LAB})$$

$$ALG = \beta * AOL = 28.4 = 29dB \text{ for Cin 4p}$$

$$GBW = \mathrm{BW} * ALG = 110\mathrm{k} * 28.4 = 3.124\ \mathrm{M}HZ$$

$$ALG = \beta * AOL = 14.2 = 23\ dB \text{ for Cin 12p}$$

$$GBW = \mathrm{BW} * ALG = 110\mathrm{k} * 14.2 = 1.562\ \mathrm{M}HZ$$

	Hand Analysis		Simulation	
Cin	4p	12p	4p	12p
DC Gain	28.4	14.2	28.15	14.08
GBW	3.124M	1.562M	3.114M	1.555M

Feedback factor is a capacitive divider so the increasing in Cin decreases the feedback factor which increase the CL gain that increases GBW and that is because the BW is constant in the CL (with a little variation with OL gain as its value is finite).

3) Gain Desensitization.

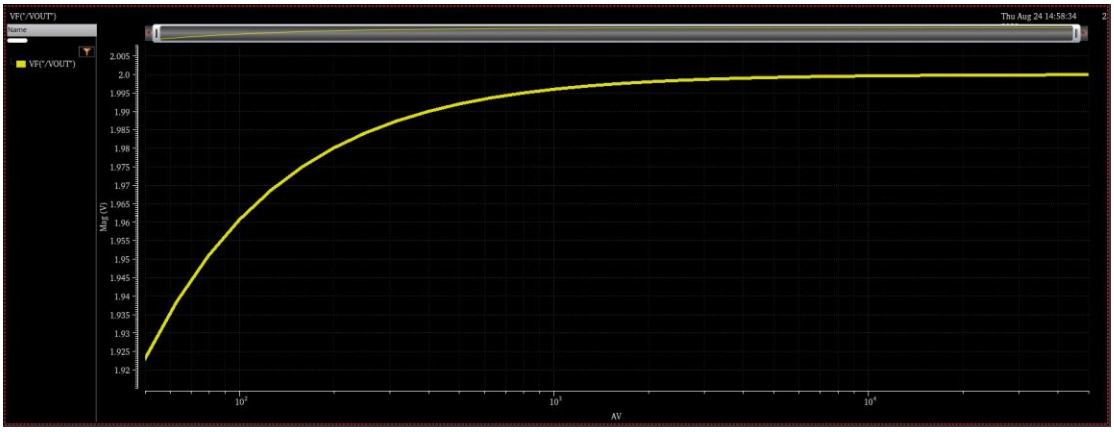

Figure 5 closed loop DC gain VS Av

At AV = $50K$ (MAX) , ACL = 2($ideal$ case).

At AV = 5 (MIN) , ACL = 1.923.

$$percentage\ change = \frac{2-1.923}{2} * 100 = 3.85\%.$$

When we have a large open loop gain that make closed-loop gain only depend on capacitive divider loads and not affected by variations of open loop gain, which make a stable gain with PVT variations.

PART 2: Feedback with Real 5T OTA

1. Closed loop gain vs frequency.

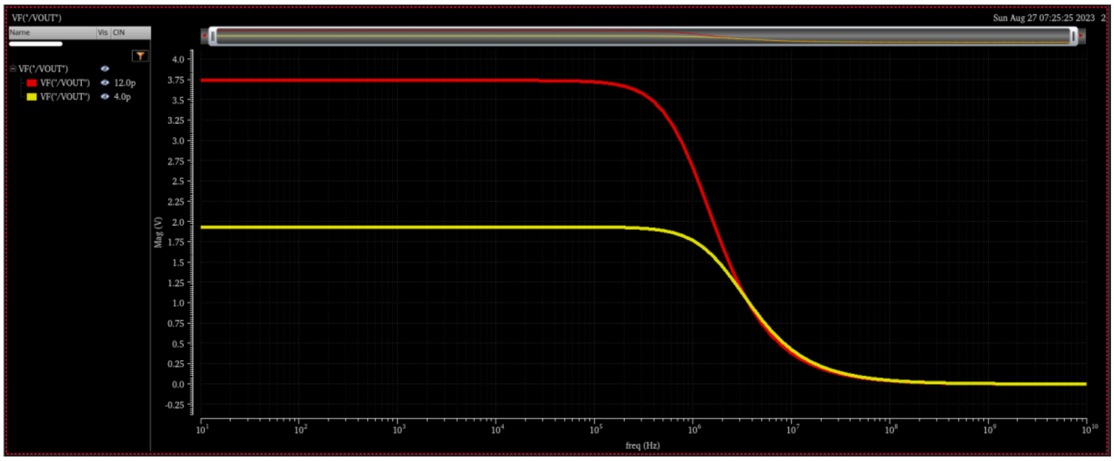

Figure 6 Vout in dB

Point	Test	Output	Nominal
Parameters: CIN=4p			
1	Lab7_LAB8_1	VF("/VOUT")	
1	Lab7_LAB8_1	ymax(dB20(VF("...	5.728
1	Lab7_LAB8_1	ymax(mag(VF("/...	1.934
1	Lab7_LAB8_1	bandwidth(VF("/...	2.253M
1	Lab7_LAB8_1	gainBwProd(VF(...	4.368M
1	Lab7_LAB8_1	ymax(db20(getD...	28.78
1	Lab7_LAB8_1	ymax(mag(getD...	27.49
1	Lab7_LAB8_1	unityGainFreq(...	2.192M
Parameters: CIN=12p			
2	Lab7_LAB8_1	VF("/VOUT")	
2	Lab7_LAB8_1	ymax(dB20(VF("...	11.45
2	Lab7_LAB8_1	ymax(mag(VF("/...	3.737
2	Lab7_LAB8_1	bandwidth(VF("/...	1.019M
2	Lab7_LAB8_1	gainBwProd(VF(...	3.817M
2	Lab7_LAB8_1	ymax(db20(getD...	22.92
2	Lab7_LAB8_1	ymax(mag(getD...	14
2	Lab7_LAB8_1	unityGainFreq(...	956.8K

Figure 7 the DC gain, the bandwidth, and the unity gain frequency

Results	Part 1		Part 2	
CIN	4p	12p	4p	12p
DC gain	1.931	3.735	1.934	3.737
DC gain (dB)	5.717	11.45	5.728	11.45
bandwidth	3.211M	1.663M	2.253M	1.019M
unity gain frequency	6.217M	6.226M	4.368M	3.817M

In the real OTA there is a loading effect which affect the BW that affect the GBW, as the feedback capacitance contributes loading effect increases total capacitance that decreases BW.

2. Loop gain vs frequency.

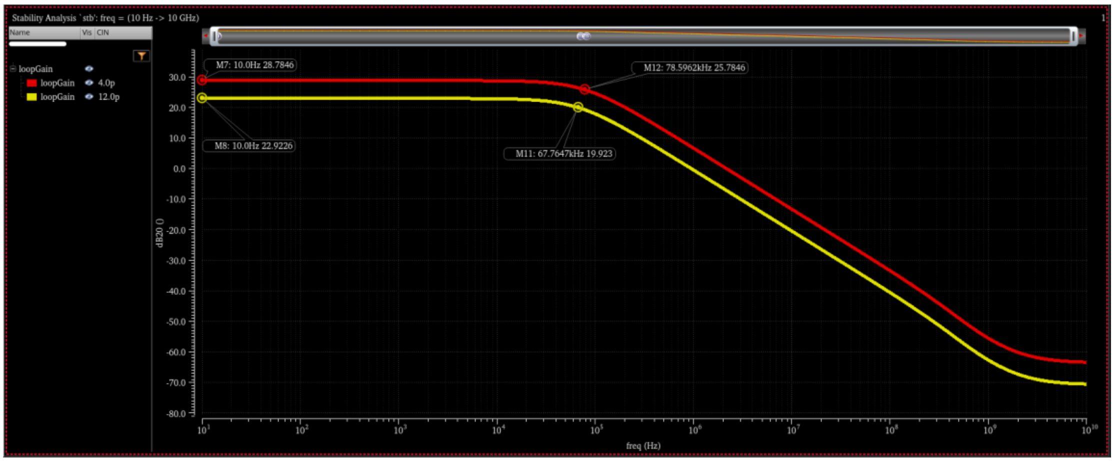

Figure 8 loop gain in dB

Point	Test	Output	Nominal
Filter	Filter	Filter	Filter
Parameters: CIN=4p			
1	Lab7_LAB8_1	ymax(db20(getD...	28.78
1	Lab7_LAB8_1	ymax(mag(getD...	27.49
1	Lab7_LAB8_1	unityGainFreq(...	2.192M
Parameters: CIN=12p			
2	Lab7_LAB8_1	ymax(db20(getD...	22.92
2	Lab7_LAB8_1	ymax(mag(getD...	14
2	Lab7_LAB8_1	unityGainFreq(...	956.8K

Figure 9 the DC loop gain, the dominant pole, and the unity gain frequency

Results	Part 1		Part 2	
CIN	4p	12p	4p	12p
DC gain	28.15	14.08	27.49	14
DC gain (dB)	28.99	22.97	28.78	22.92
dominant pole	110k	110k	78.6k	67.8k
unity gain frequency	3.114M	1.555M	2.192M	956.8k

The Negative Feedback make a loading effect at the output node and feedback capacitance contributes loading effect which decrease the BW which decrease the UGF.

3. Gain Desensitization.

Name	Type	Details	Value
	expr	VF("/VOUT")	
	expr	ymax(dB20(VF("/VOUT")))	5.724
	expr	ymax(mag(VF("/VOUT")))	1.933
	expr	bandwidth(VF("/VOUT") 3 "low")	2.749M
	expr	gainBwProd(VF("/VOUT"))	5.326M
	expr	ymax(db20(getData("loopGain" ?result "stb")))	28.66
	expr	ymax(mag(getData("loopGain" ?result "stb")))	27.11
	expr	unityGainFreq(mag(getData("loopGain" ?result "stb")))	2.665M

Figure 10 T= -40

Name	Type	Details	Value
	expr	VF("/VOUT")	
	expr	ymax(dB20(VF("/VOUT")))	5.727
	expr	ymax(mag(VF("/VOUT")))	1.934
	expr	bandwidth(VF("/VOUT") 3 "low")	2.298M
	expr	gainBwProd(VF("/VOUT"))	4.453M
	expr	ymax(db20(getData("loopGain" ?result "stb")))	28.77
	expr	ymax(mag(getData("loopGain" ?result "stb")))	27.45
	expr	unityGainFreq(mag(getData("loopGain" ?result "stb")))	2.237M

Figure 11 T= 20

Name	Type	Details	Value
	expr	VF("/VOUT")	
	expr	ymax(dB20(VF("/VOUT")))	5.733
	expr	ymax(mag(VF("/VOUT")))	1.935
	expr	bandwidth(VF("/VOUT") 3 "low")	1.859M
	expr	gainBwProd(VF("/VOUT"))	3.605M
	expr	ymax(db20(getData("loopGain" ?result "stb")))	28.94
	expr	ymax(mag(getData("loopGain" ?result "stb")))	27.99
	expr	unityGainFreq(mag(getData("loopGain" ?result "stb")))	1.812M

Figure 12 T= 100

DC CL Gain

At T= 27 , $A_{CL} = 1.934$

At T= -40 , $A_{CL} = 1.933$, percent change $= \frac{1.934-1.933}{1.934} * 100 = 0.05\%$

At T= 20 , $A_{CL} = 1.935$, percent change $= \frac{1.935-1.934}{1.934} * 100 = 0.05\%$

At T= 100 , $A_{CL} = 1.935$, percent change $= \frac{1.935-1.933}{1.934} * 100 = 0.05\%$

DC loop gain

At T= 27 , $A_C = 27.49$

At T= -40 , $A_L = 27.11$, percent change $= \frac{27.49-27.11}{27.49} * 100 = 1.4\%$

At T= 20 , $A_L = 27.45$, percent change $= \frac{27.49-27.45}{27.49} * 100 = 0.145\%$

At T= 100 , $A_L = 27.99$, percent change $= \frac{27.49-27.99}{27.49} * 100 = 1.8\%$

The CL_Gain is insensitive to temperature change, as it depend on a retio.

4.Transient analysis.

Plot the input signal, the output signal, and the differential input signal of the OTA (VP – VN).

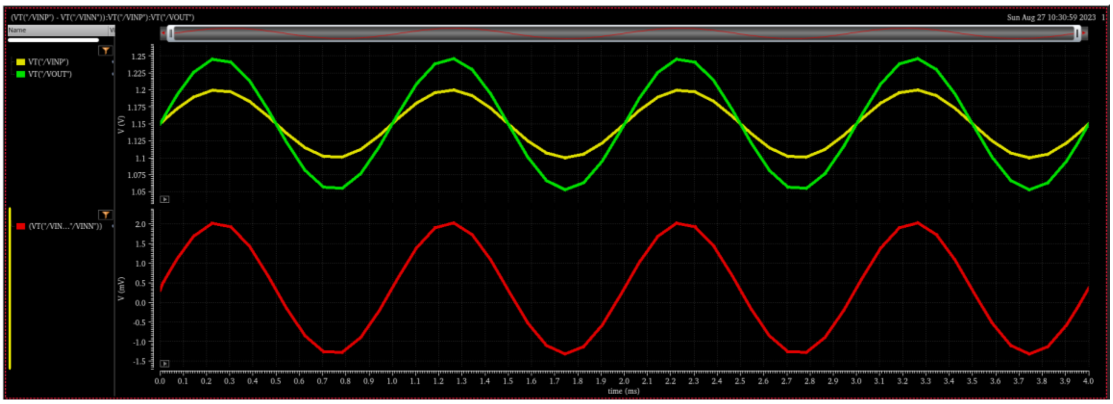

Figure 13 signals of the OTA

	expr	peakToPeak(VT("/VINP"))	99.76m
	expr	peakToPeak(VT("/VOUT"))	193m
	expr	peakToPeak((VT("/VINP") - VT("/VINN")))	3.34m

The relation between the output and the differential input is nearly the open loop gain

$$A_{OL} = \frac{V_{OUT}}{V_{DIF}} = \frac{193}{3.34} = 57.8$$

DC GAIN = 56.9

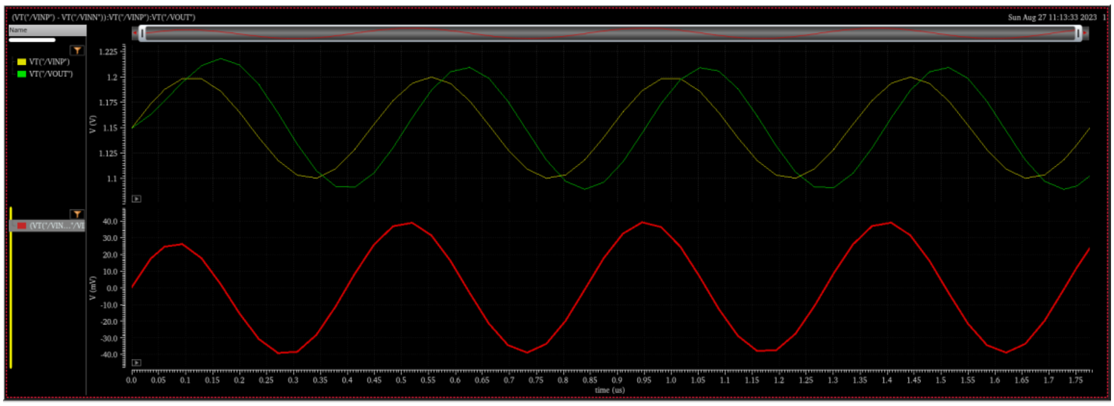

Figure 14 transient analysis with FIN = CL bandwidth

	expr	peakToPeak(VT("/VINP"))	99.66m
	expr	peakToPeak(VT("/VOUT"))	128.8m
	expr	peakToPeak((VT("/VINP") - VT("/VINN")))	78.45m

The relation between the output and the input signal and (VP – VN) is nearly the closed loop gain

$$\frac{V_{OUT}}{V_{in}} = \frac{128.8}{99.66} = 1.3$$

$$\frac{V_{OUT}}{V_{DIF}} = \frac{128.8}{78.45} = 1.64$$

$$A_{CL} = 1$$

FIN	1 KHz	CL_BW
Input	99.76m	99.66m
Output	193m	128.8m

Diff	3.34m	78.45m