

# Lab 8

Feedback Amplifier

# Part 1: Feedback with Behavioral OTA

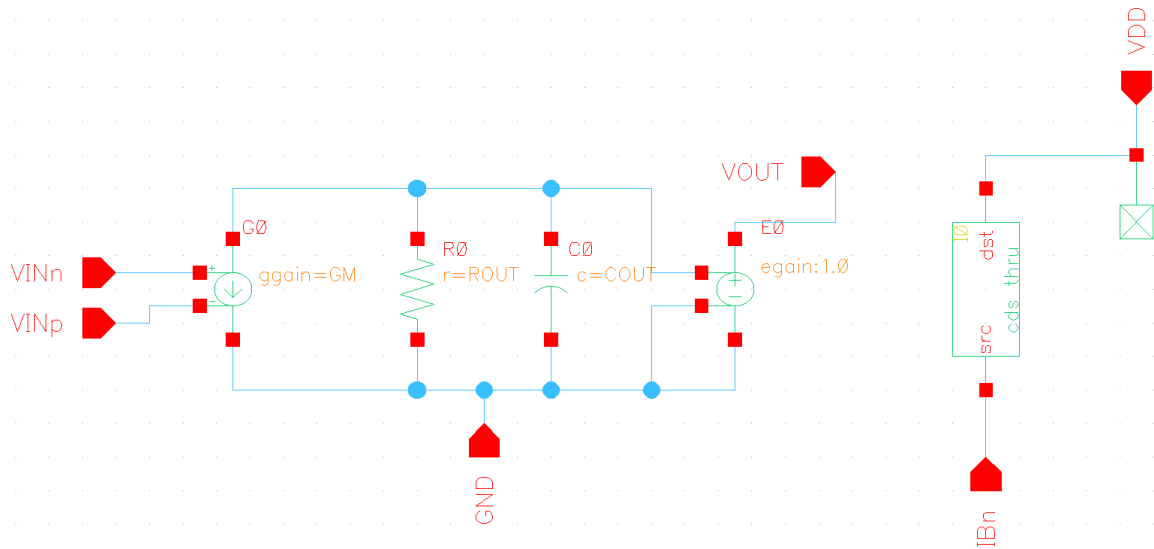


Figure 1 Behavioral Model Schematic

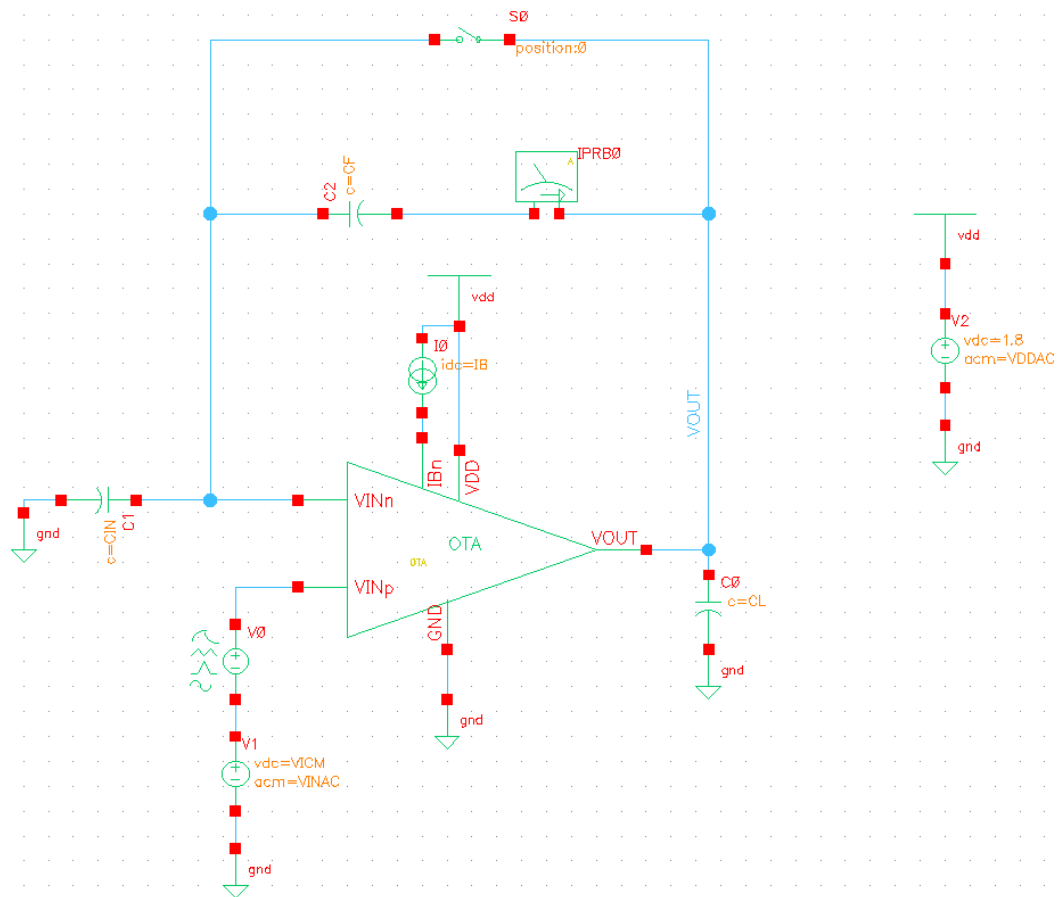


Figure 2 Testbench Schematic

## 1.1 Closed Loop Gain vs Frequency:

VF("/VOUT")

Fri Aug 15 12:32:02 2025 1

VF("/VOUT")			
VF("/VOUT")		1.9281V	4e-12
VF("/VOUT")		3.7223V	1.2e-11

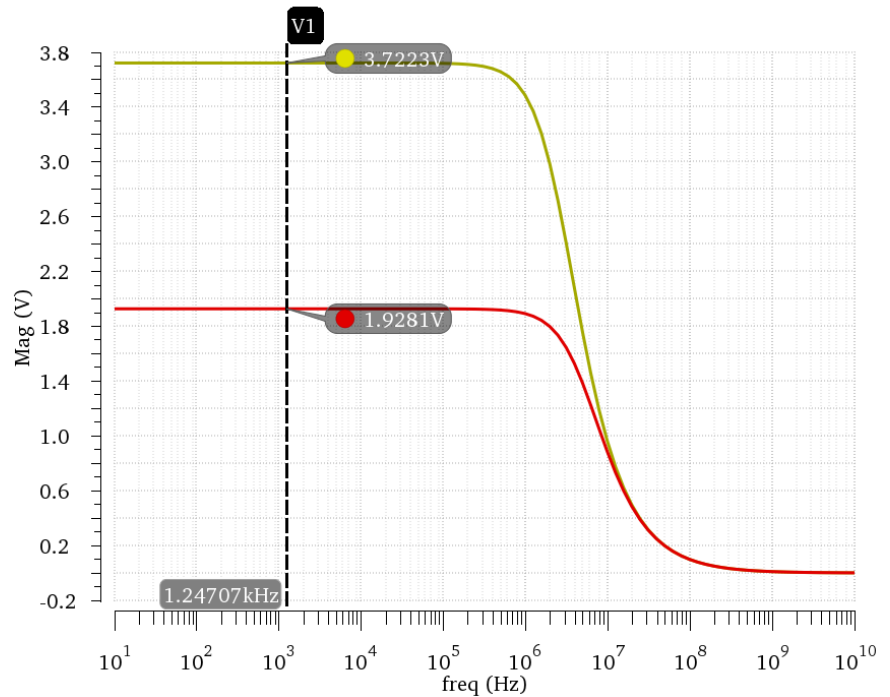


Figure 3 DC Gain in Mag

dB20(VF("/VOUT"))

Fri Aug 15 15:40:33 2025 1

dB20(VF("/VOUT"))			
dB20(VF("/VOUT"))		...0255dB	4e-12
dB20(VF("/VOUT"))		...4163dB	1.2e-11

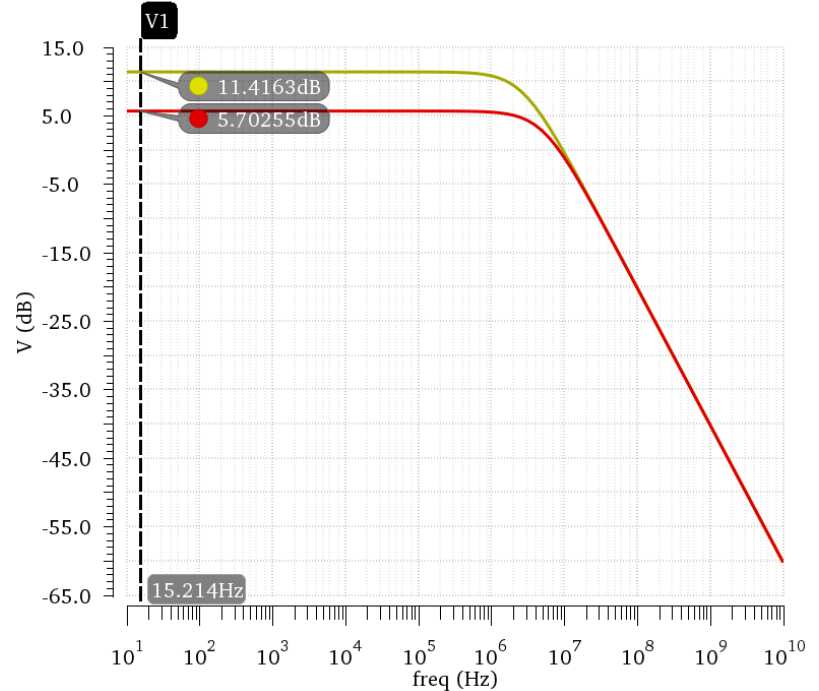


Figure 4 DC Gain in dB

dB20(VF("/VOUT"))

dB20(VF("/VOUT"))  
 dB20(VF("/VOUT")) ...9474dB 4e-12  
 dB20(VF("/VOUT")) ...8682dB 1.2e-11

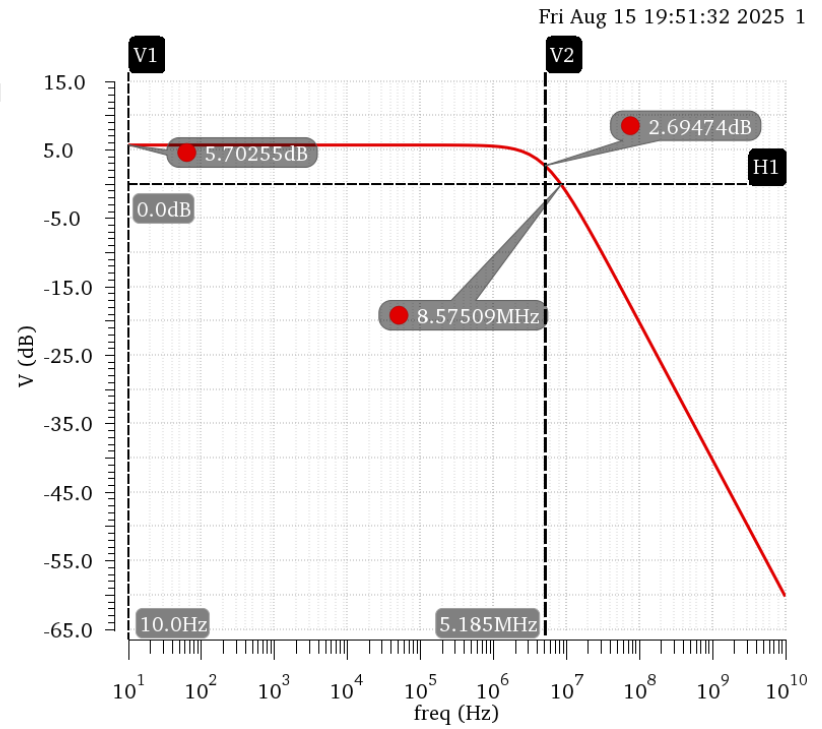


Figure 5 Gain Bode Plot Annotated  $C_{IN} = 4\text{pF}$

dB20(VF("/VOUT"))

dB20(VF("/VOUT")) ...0482dB 1.2e-11

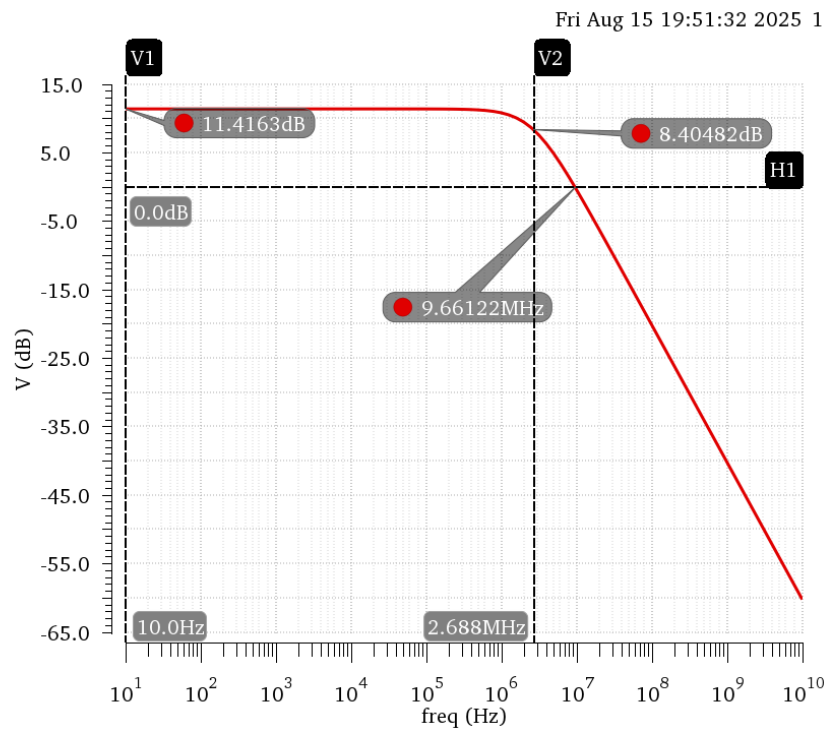


Figure 6 Gain Bode Plot Annotated  $C_{IN} = 12\text{pF}$

	CIN = 4pF	CIN = 12pF
DC Gain (dB)	5.703	11.42
DC Gain	1.928	3.722
BW	5.19E+06	2.69E+06
UGF	8.61E+06	9.69E+06
GBW	10E+06	10E+06

Table 1 Results from Simulation

## Hand Analysis:

Open Loop Parameters from Last Lab:

$$A_{OL} \approx 53, \quad BW_{OL} = 191\text{KHz}, \quad GBW \approx 10.12\text{MHz}$$

$$\beta = \frac{Z_{in}}{Z_{in} + Z_f} = \frac{C_f}{C_f + C_{in}} = \frac{1}{2}, \quad \frac{1}{4} \quad (\text{For Both Values of } C_{in})$$

$$DC \text{ Gain} = A_{CL} = \frac{A_{OL}}{1 + \beta A_{OL}} = 1.927, \quad 3.72$$

$$BW_{CL} = (1 + \beta A_{OL}) BW_{OL} = 5.25\text{MHz}, \quad 2.721\text{MHz}$$

$$GBW_{CL} = 10.1167\text{MHz}, \quad 10.122\text{MHz}$$

	CIN = 4pF		CIN = 12pF	
	Simulation	Analytic	Simulation	Analytic
DC Gain (dB)	5.703	5.698	11.42	11.41
DC Gain	1.928	1.9272	3.722	3.72
BW	5.19E+06	5.25E+06	2.69E+06	2.72E+06
GBW	1.00E+07	1.01E+07	1.00E+07	1.01E+07

Analytic Results Agree with simulated ones in both cases of the input capacitor!

## 1.2 Loop Gain vs Frequency:

VF("/VOUT")

Fri Aug 15 12:32:02 2025 1

VF("/VOUT")

VF("/VOUT")	1.9281V	4e-12
VF("/VOUT")	3.7223V	1.2e-11

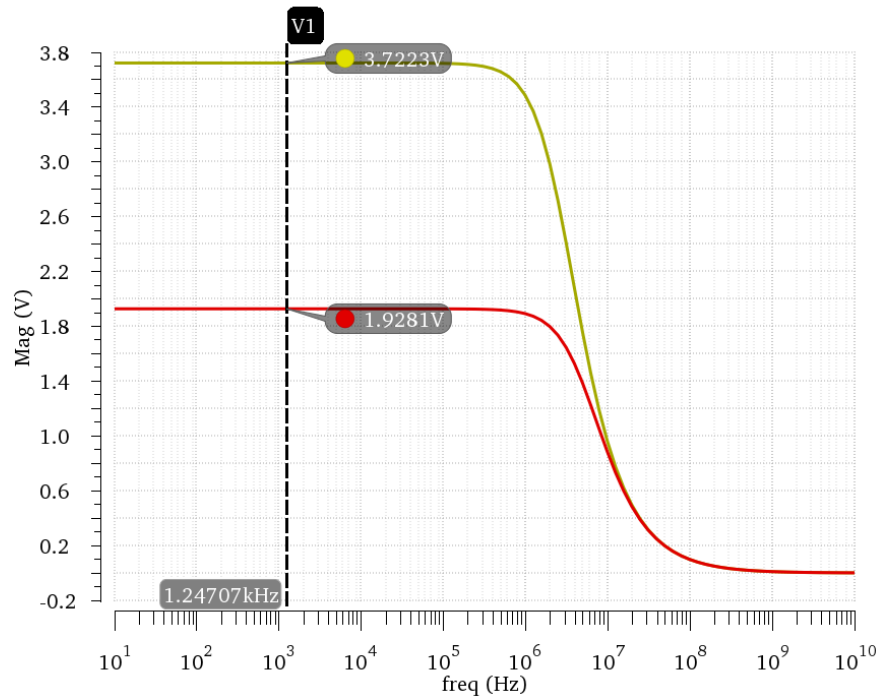


Figure 7 LG Overlaid in Mag

dB20(mag(getData("loopGain" ?result "stb")))

Fri Aug 15 12:57:25 2025 1

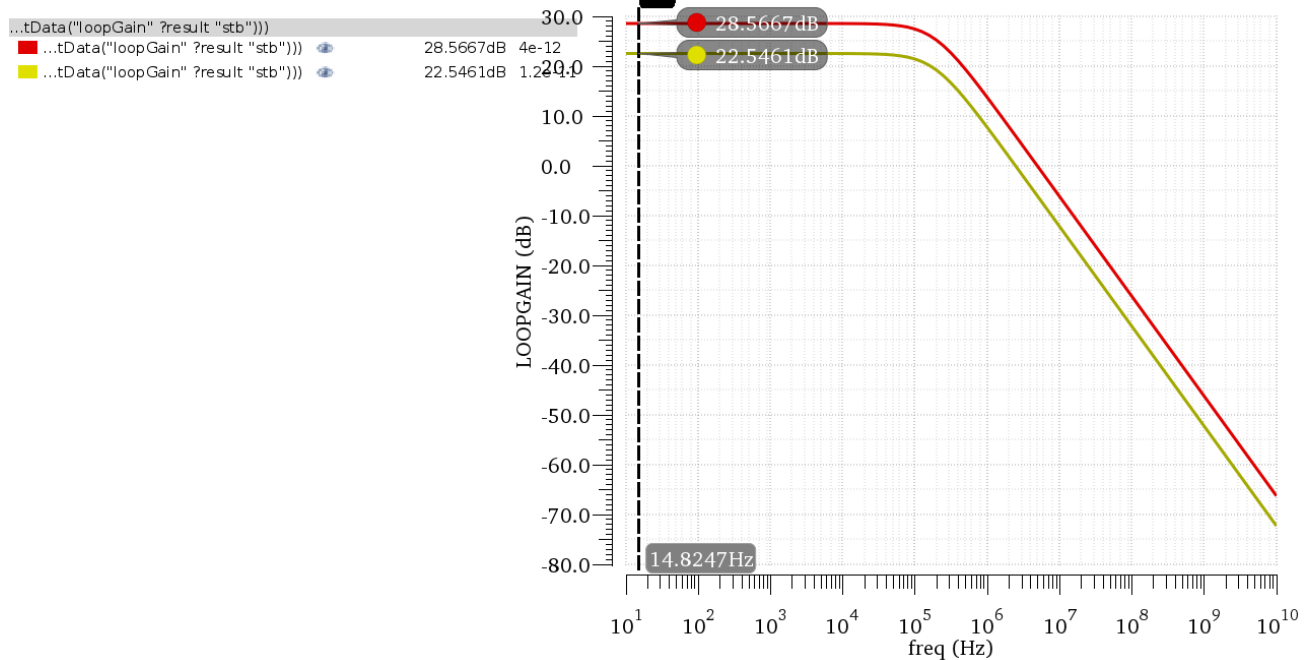


Figure 8 LG Overlaid in dB

dB20(mag(getData("loopGain" ?result "stb")))

Fri Aug 15 19:51:32 2025 1

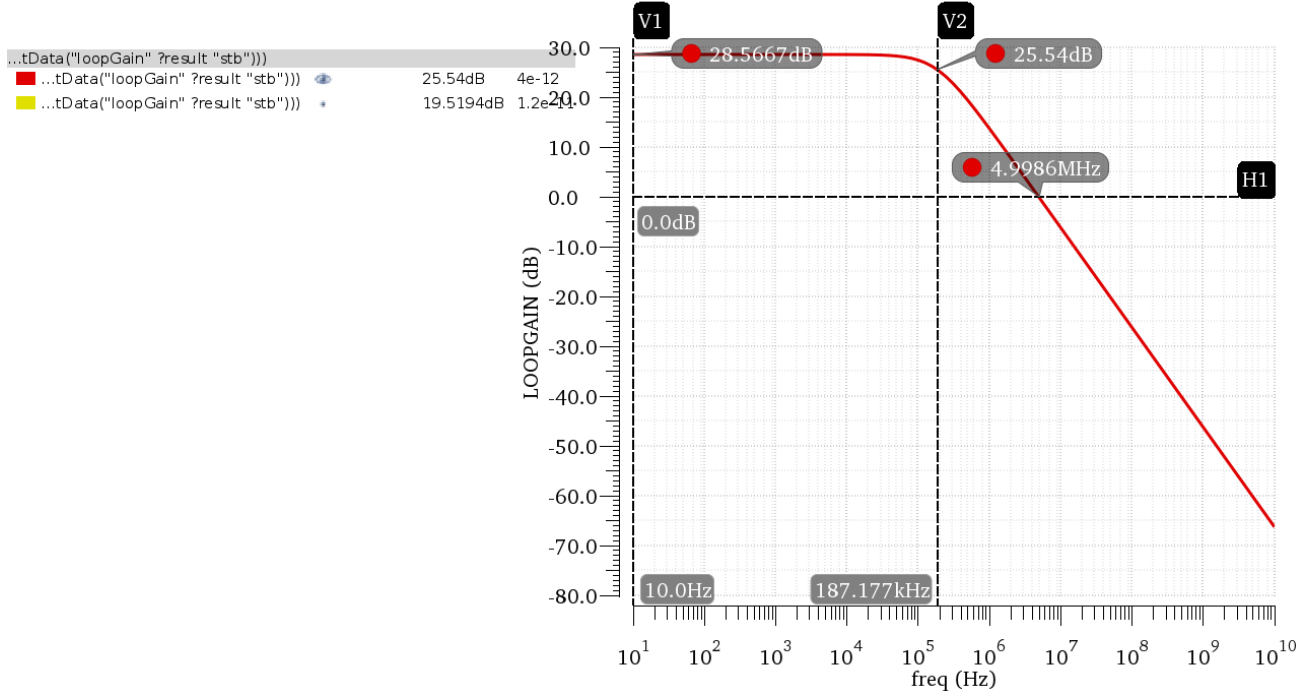


Figure 9 LG Bode Plot Annotated  $C_{IN} = 4pF$

dB20(mag(getData("loopGain" ?result "stb")))

Fri Aug 15 19:51:32 2025 1

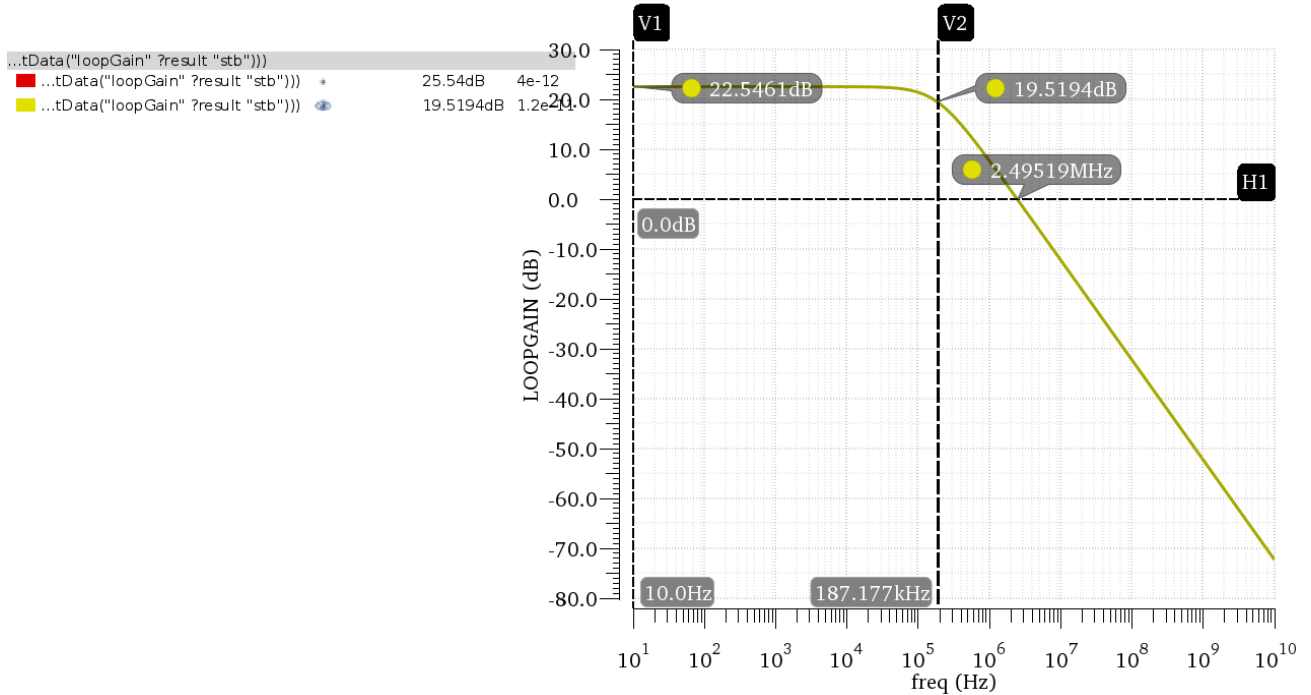


Figure 10 LG Bode Plot Annotated  $C_{IN} = 12pF$

	CIN = 4pF	CIN = 12pF
DC LG (dB)	28.57	22.55
DC LG	26.81	13.41
BW	187.17 KHz	187.17 KHz
UGF	5 MHz	2.5 MHz

Table 2 Results from Simulation

## Hand Analysis:

Open Loop Parameters from Last Lab:

$$A_{OL} \approx 53, \quad BW_{OL} = 191 \text{ KHz}, \quad GBW \approx 10.12 \text{ MHz}$$

$$\beta = \frac{Z_{in}}{Z_{in} + Z_f} = \frac{C_f}{C_f + C_{in}} = \frac{1}{2}, \frac{1}{4} \quad (\text{For Both Values of } C_{in})$$

$$DC \text{ LG} = LG = \beta A_{OL} = \mathbf{26.5, 13.25 \rightarrow 28.465 \text{ dB}, 22.444 \text{ dB}}$$

$$BW_{LG} = BW_{OL} = \mathbf{191 \text{ KHz}}$$

$$\omega_u = GBW_{LG} = \mathbf{5.0615 \text{ MHz}, 2.53 \text{ MHz}}$$

	CIN = 4pF		CIN = 12pF	
	Simulation	Analytic	Simulation	Analytic
DC LG (dB)	28.57	28.465	22.55	22.444
DC LG	26.81	26.5	13.41	13.25
BW	187.17 KHz	191 KHz	187.17 KHz	191 KHz
UGF	5 MHz	5.0615 MHz	2.5 MHz	2.53 MHz

Analytic Results Agree with simulated ones in both cases of the input capacitor!



### 1.3 Gain Desensitization:

To sweep the gain, I can either sweep GM or ROUT, I tried both and both resulted in similar results:

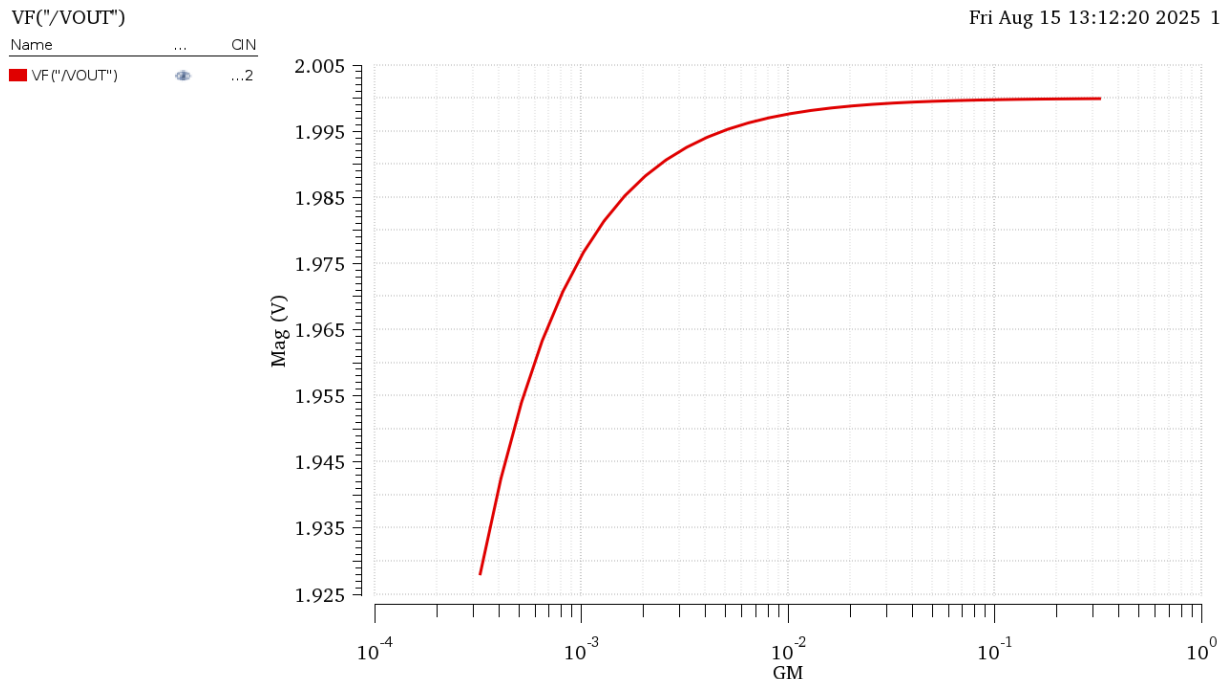


Figure 11 Gain Sweeping GM

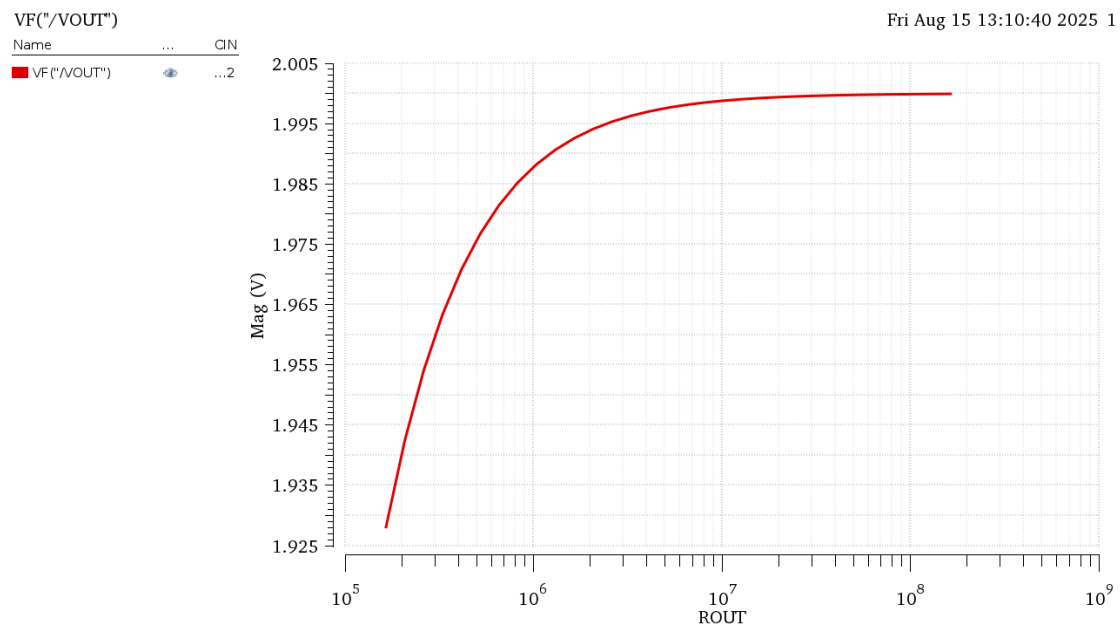


Figure 12 Gain Sweeping ROUT

$$A_{CL}\% = \frac{1.99982 - 1.928}{1.928} * 100 = 3.725\%$$

The Gain is much closer to its ideal value now (Ideal Value = 2) as we increase the Open Loop gain of the amplifier it easier to approximate closed loop gain as  $\frac{1}{\beta}$ .

The percentage change would be even if we calculate for higher gains like the case of CIN = 4pF

## Part 2: Feedback with Real 5T OTA

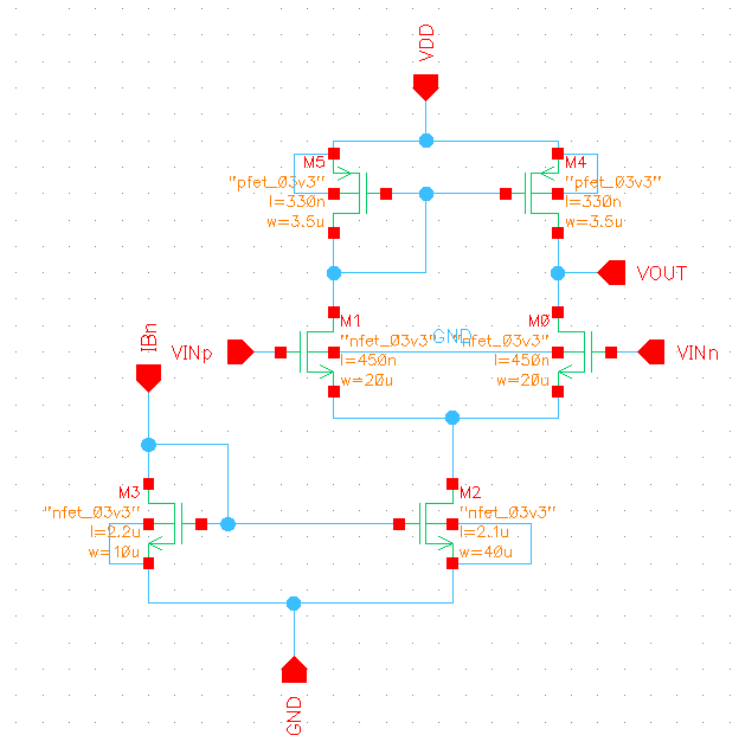


Figure 13 Real OTA Schematic

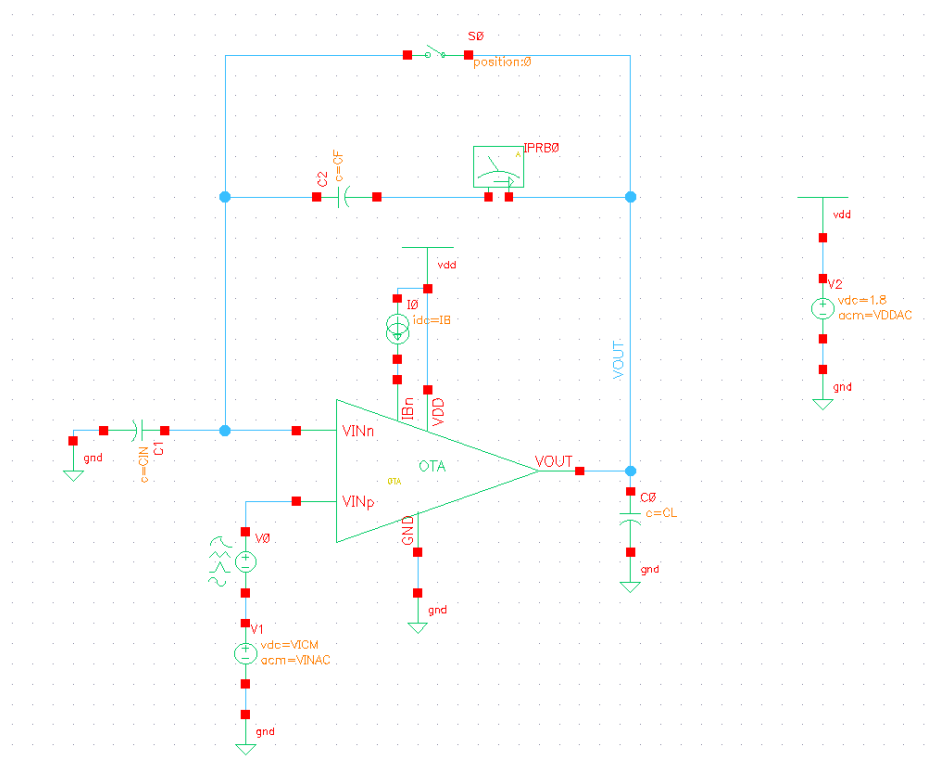


Figure 14 TB Schematic (Same as Part 1)

## 2.1 Closed Loop Gain vs Frequency:

VF("/VOUT")

Fri Aug 15 13:28:37 2025 1

VF("/VOUT")

VF("/VOUT")	...	279V	4e-12
VF("/VOUT")	...	255V	1.2e-11

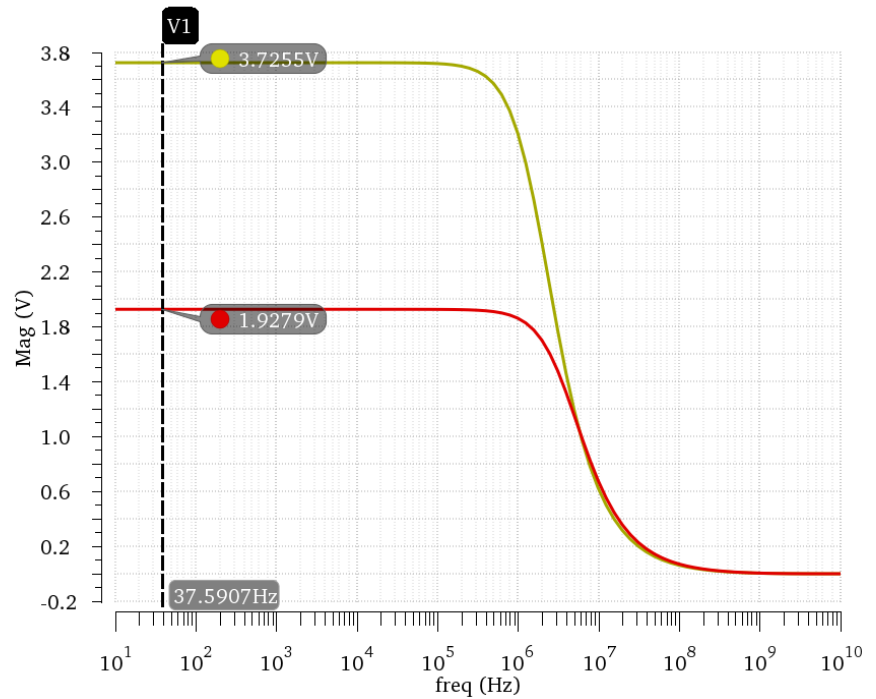


Figure 15 Gain in Mag

dB20(VF("/VOUT"))

Fri Aug 15 13:28:37 2025 1

dB20(VF("/VOUT"))

dB20(VF("/VOUT"))	...	5.70174dB	4e-12
dB20(VF("/VOUT"))	...	11.4238dB	1.2e-11

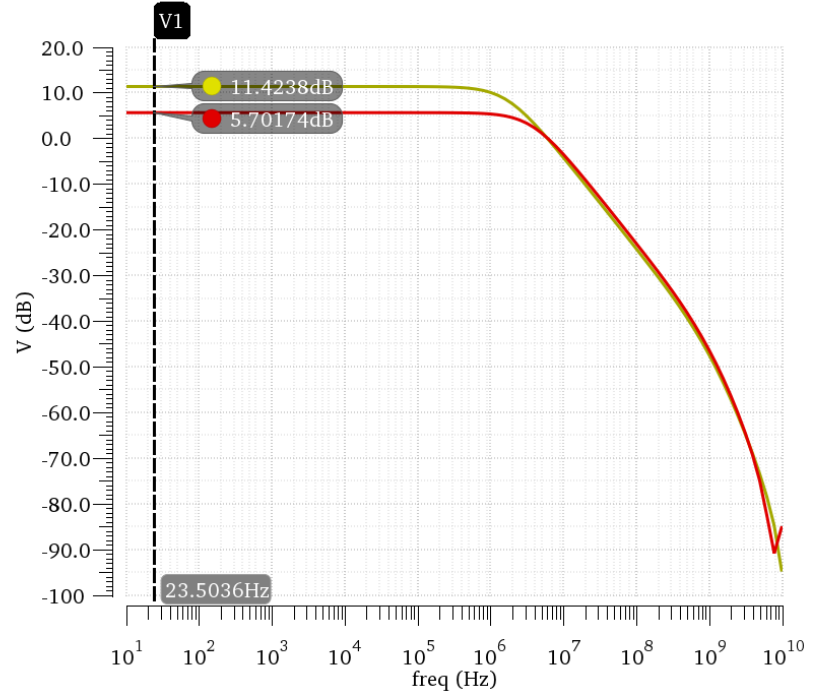


Figure 16 Gain in dB

dB20(VF("/VOUT"))

Sat Aug 16 07:19:38 2025 1

dB20(VF("/VOUT"))			
dB20(VF("/VOUT"))	5.2105dB	4e-12	
dB20(VF("/VOUT"))	9.429dB	1.2e-11	

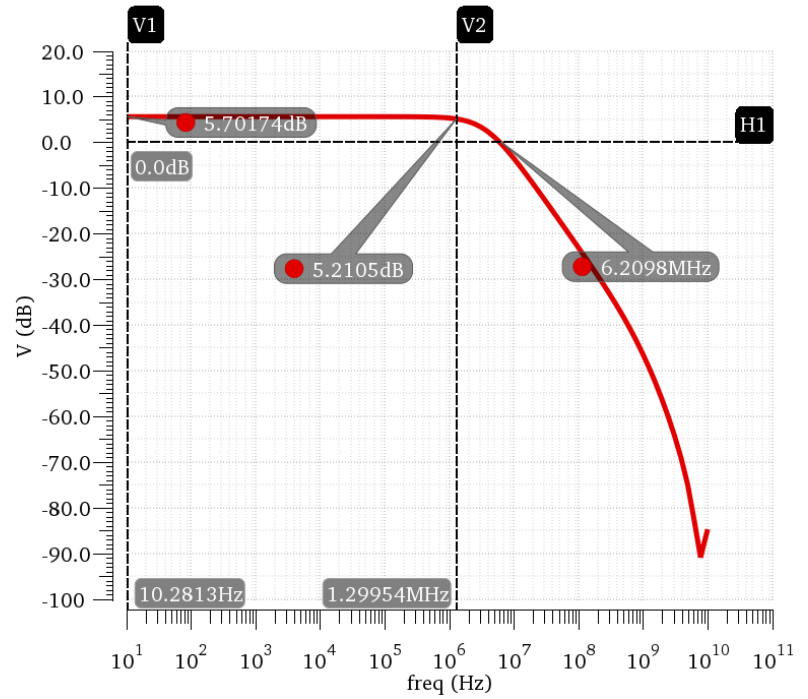


Figure 17 DC LG Bode Plot Annotated at  $C_{IN} = 4pF$

dB20(VF("/VOUT"))

Sat Aug 16 07:19:38 2025 1

dB20(VF("/VOUT"))			
dB20(VF("/VOUT"))	5.2105dB	4e-12	
dB20(VF("/VOUT"))	9.429dB	1.2e-11	

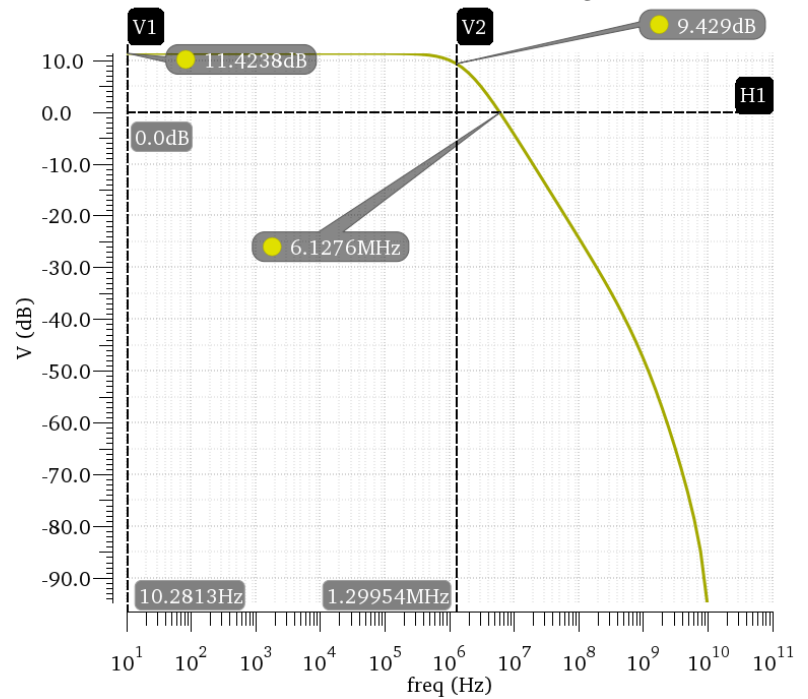


Figure 18 DC LG Bode Plot Annotated at  $C_{IN} = 12pF$

	CIN = 4pF		CIN = 12pF	
	Behavioral	5T OTA	Behavioral	5T OTA
<b>DC Gain (dB)</b>	5.703	5.702	11.42	11.42
<b>DC Gain</b>	1.928	1.928	3.722	3.726
<b>BW</b>	5.19E+06	3.76E+06	2.69E+06	1.70E+06
<b>GBW</b>	1.00E+07	7.27E+06	1.00E+07	6.37E+06

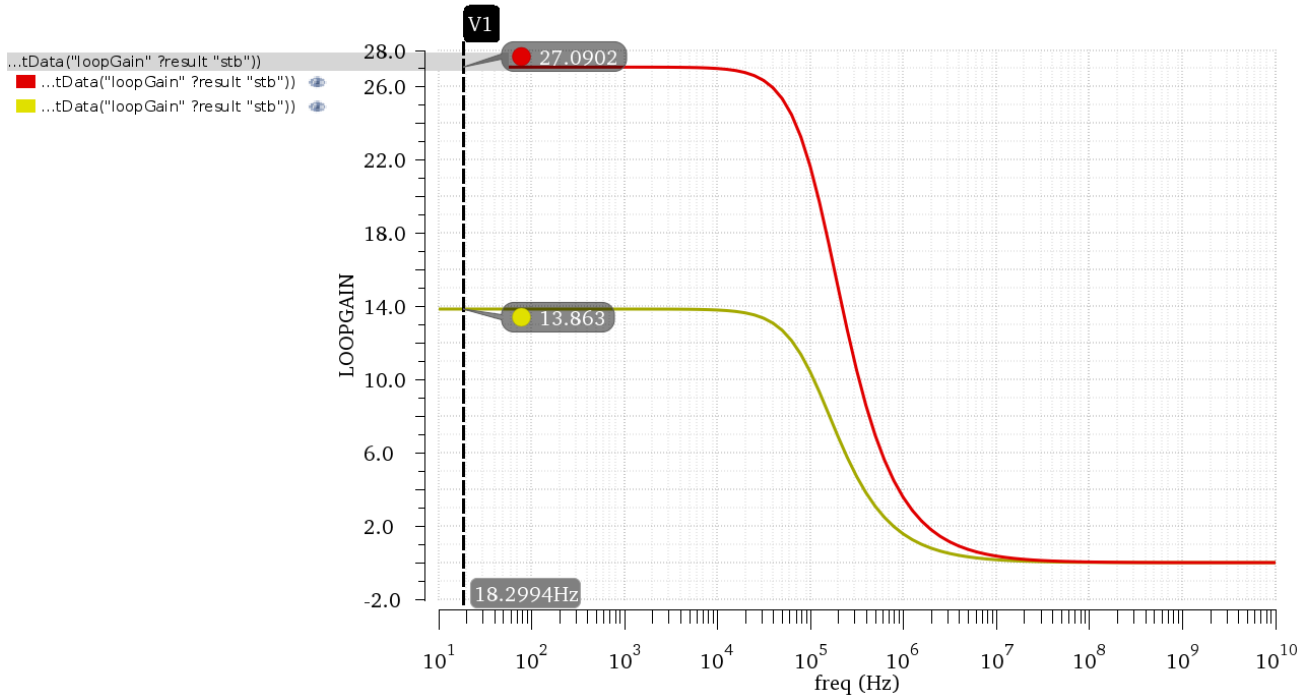
### **The Bandwidth and consequently the GBW are much smaller than Part 1:**

The bandwidth in the OTA is much smaller because the Behavioral model took only CL in consideration when calculating the bandwidth due to the buffer in the behavioral model making  $R_{OUT} = \infty$  thus the effect of the loading effect is not seen. While in the real OTA, the  $R_{OUT}$  seen in the actual  $R_{OUT}$  of the amplifier thus contributing to the pole of the output node making it smaller.

## 2.2 Loop Gain vs Frequency:

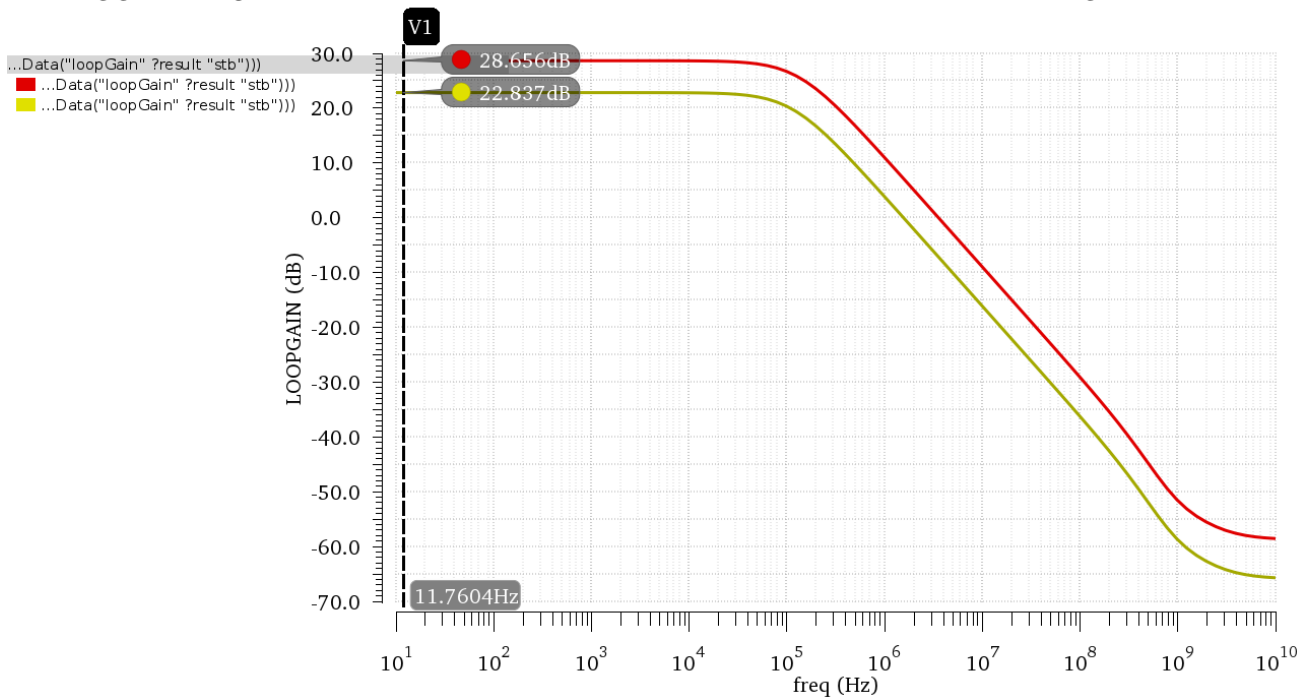
mag(getData("loopGain" ?result "stb"))

Fri Aug 15 13:30:36 2025 1



dB20(mag(getData("loopGain" ?result "stb")))

Fri Aug 15 13:30:36 2025 1



dB20(mag(getData("loopGain" ?result "stb")))

Sat Aug 16 07:19:38 2025 1

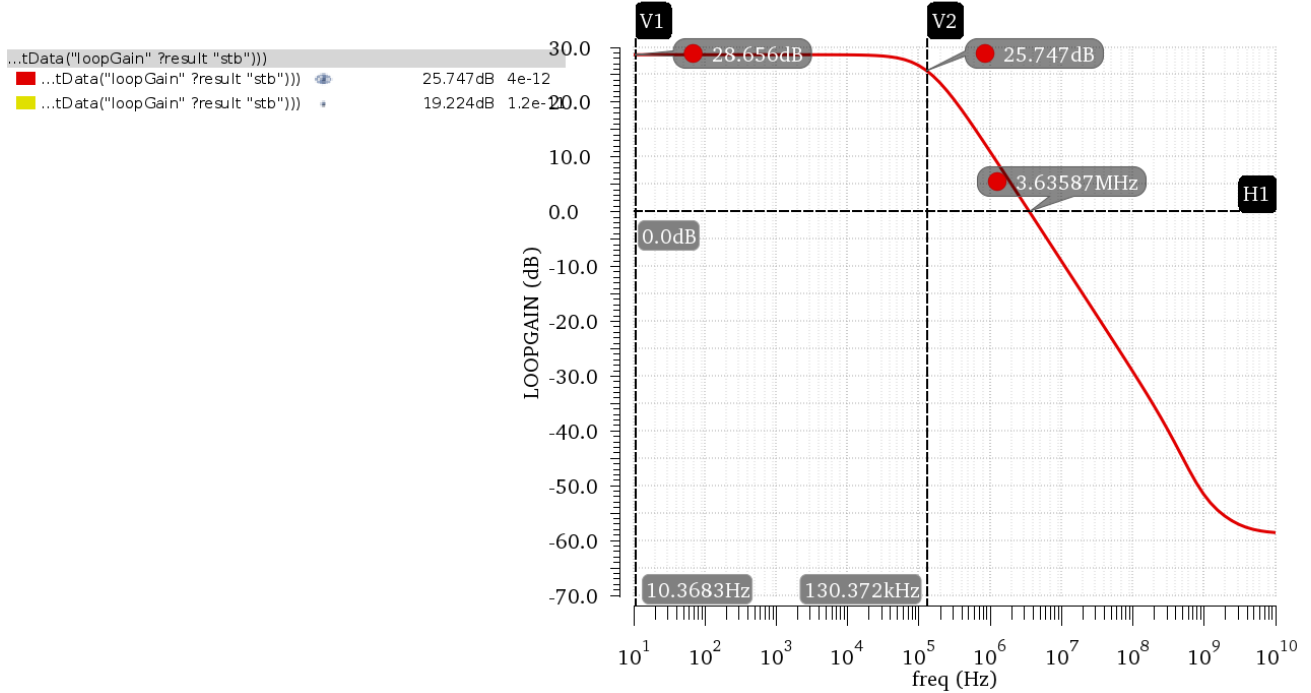


Figure 21 LG Bode Plot Annotated at  $C_{IN} = 4pF$

LG dB

Sat Aug 16 07:19:38 2025 1

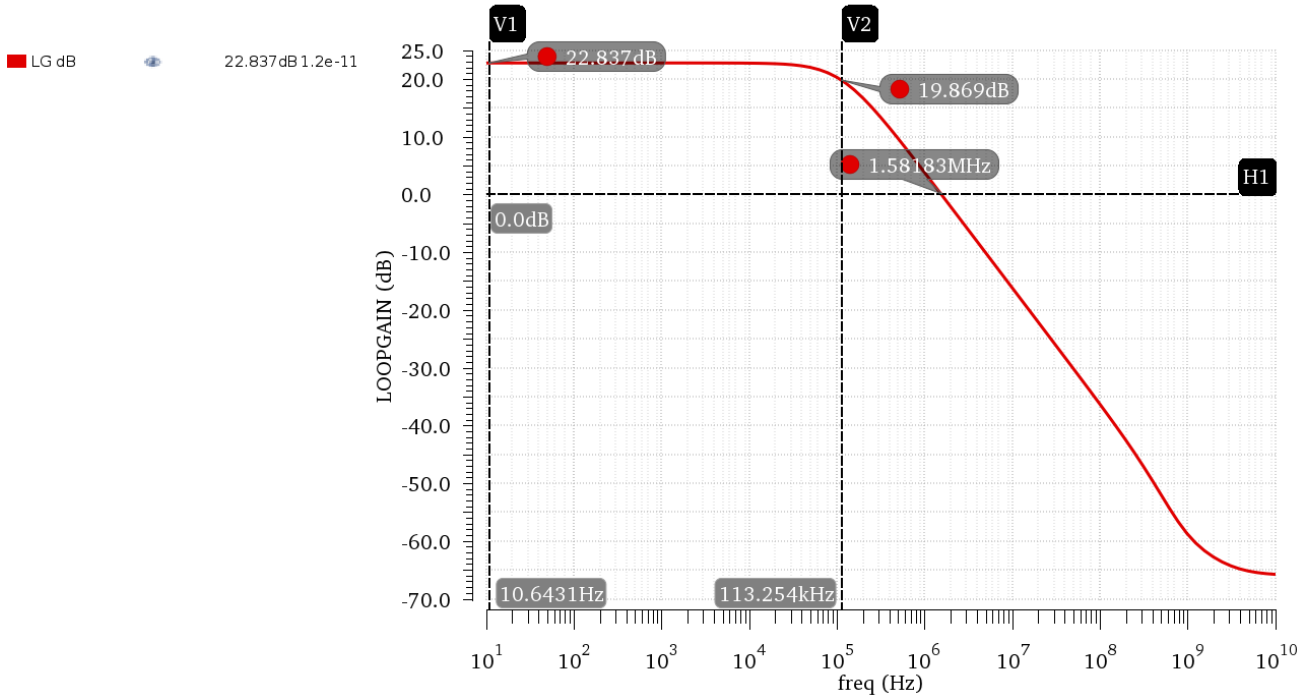


Figure 22 LG Bode Plot Annotated at  $C_{IN} = 12pF$

	CIN = 4pF		CIN = 12pF	
	Behavioral	5T OTA	Behavioral	5T OTA
<b>DC LG (dB)</b>	28.57	28.66	22.55	22.84
<b>DC LG</b>	26.81	27.09	13.41	13.86
<b>BW</b>	187.17 KHz	1.34E+05	187.17 KHz	1.15E+05
<b>UGF</b>	5 MHz	3.66E+06	2.5 MHz	1.58E+06

### UGF is much smaller than in Part 1:

Due to the same reason stated previously, The buffer isolated Rout from seeing the loading effect thus only CL contributed to the Pole, but in the real OTA at the output node the loading effect of the added capacitors is seen such that the capacitance seen is  $C_L + (C_{in} // C_f)$  Contributing to a lower bandwidth thus a lower UGF.



## 2.3 Gain Desensitization:

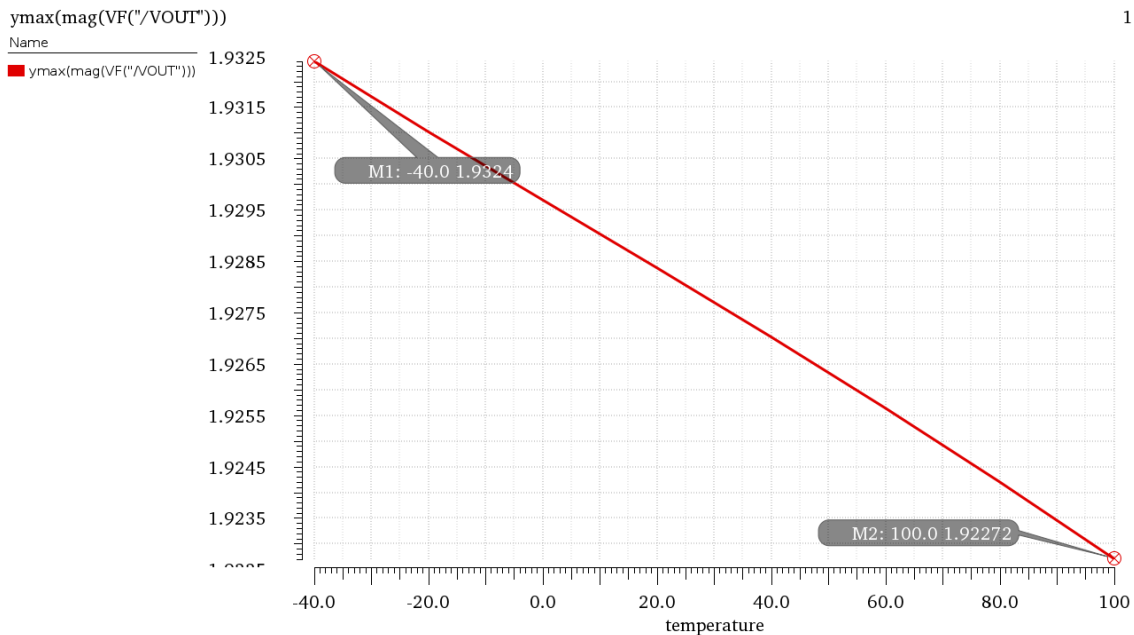


Figure 23 ACL in Mag vs Temp (Extreme Points Annotated)

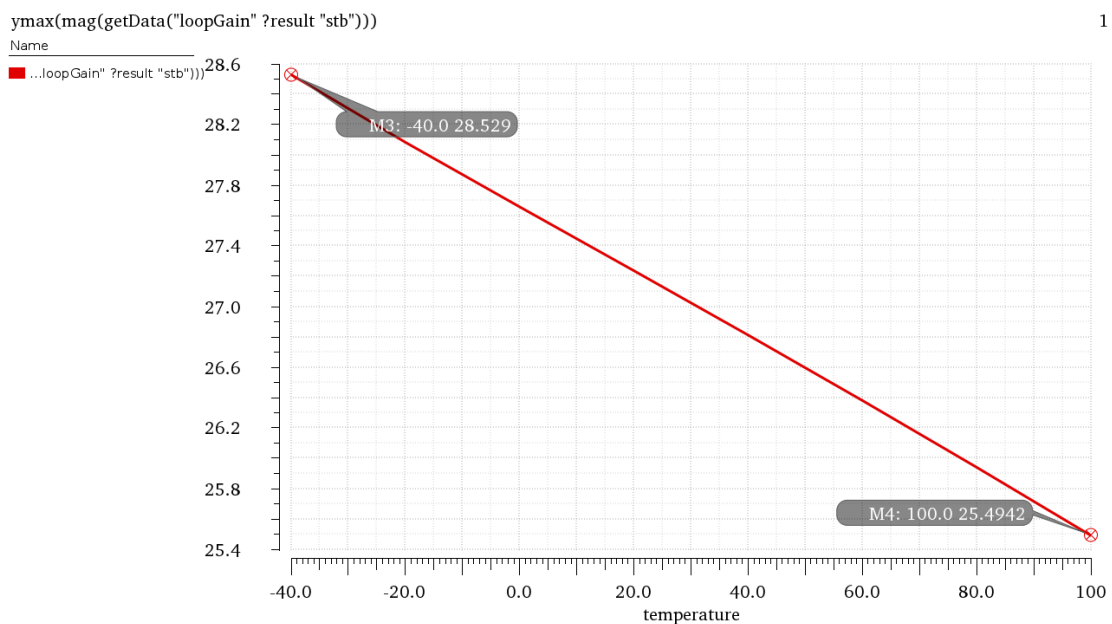


Figure 24 LG in Mag vs Temp (Extreme Points Annotated)

$$A_{CL}\%_{temp} = \frac{1.9324 - 1.9227}{1.928} * 100 = 0.5\%, \quad LG\%_{temp} = \frac{28.529 - 25.4942}{27.09} * 100 = 11.2\%$$

The percentage change in LG is much more pronounced than the percentage change of ACL, as ACL depends on the ratio of capacitances (Which isn't affected by temperature much) much more heavily due to the big gain of AOL while LG depends on AOL which depends on the active components of the circuit whose parameters change heavily by temperature and process variations. This demonstrates the importance of feedback in desensitizing against PVT.

## 2.4 Transient Analysis:

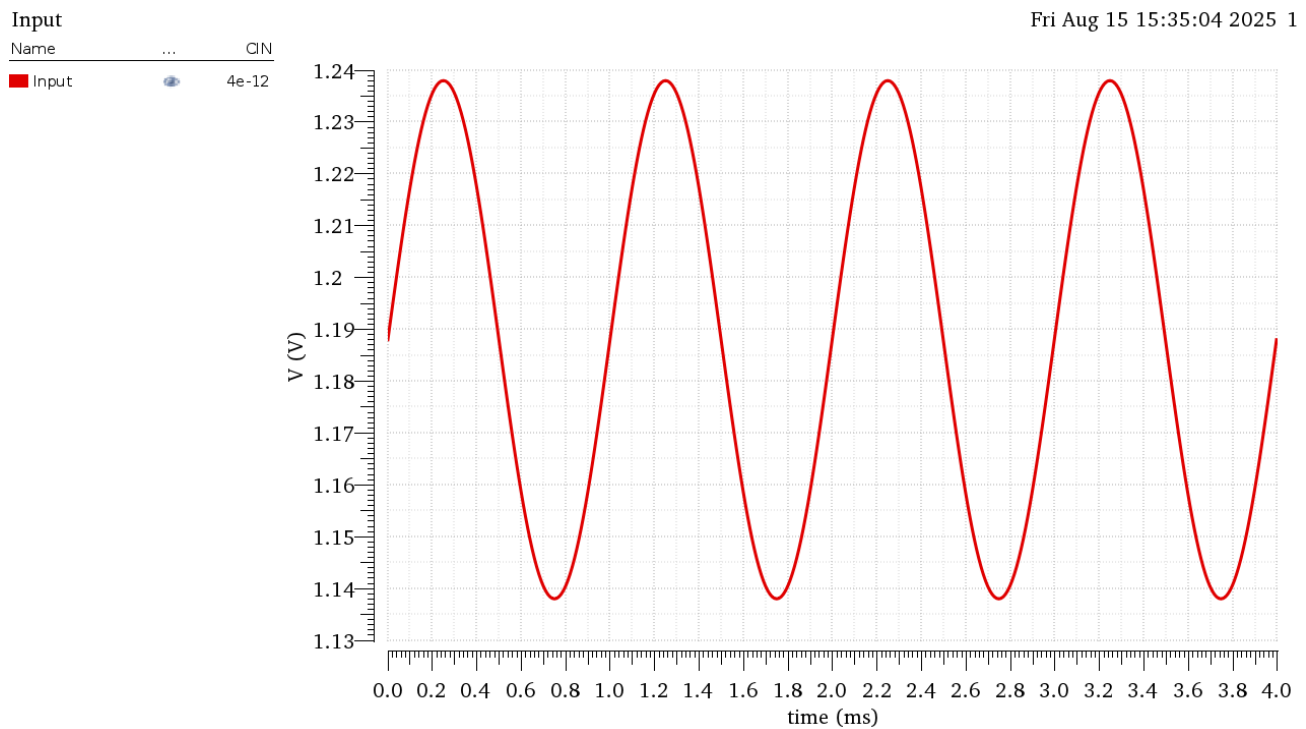


Figure 25 Input Signal

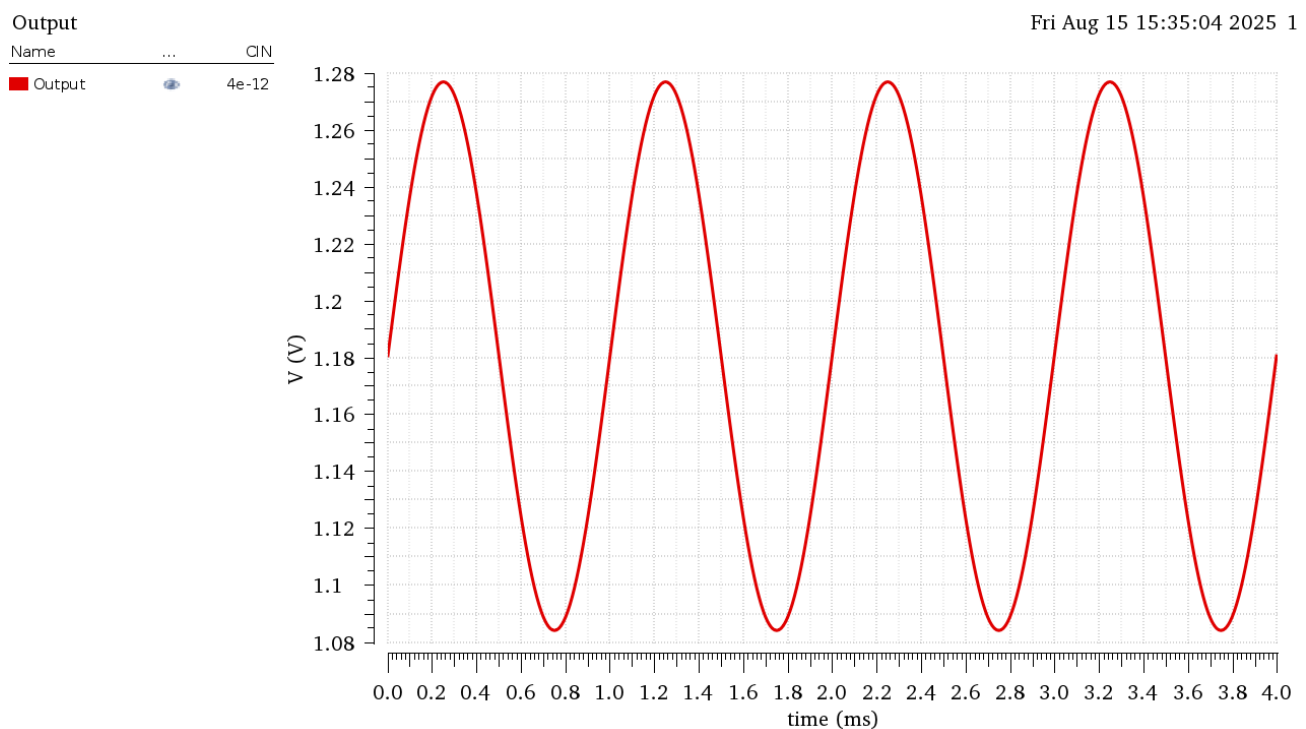
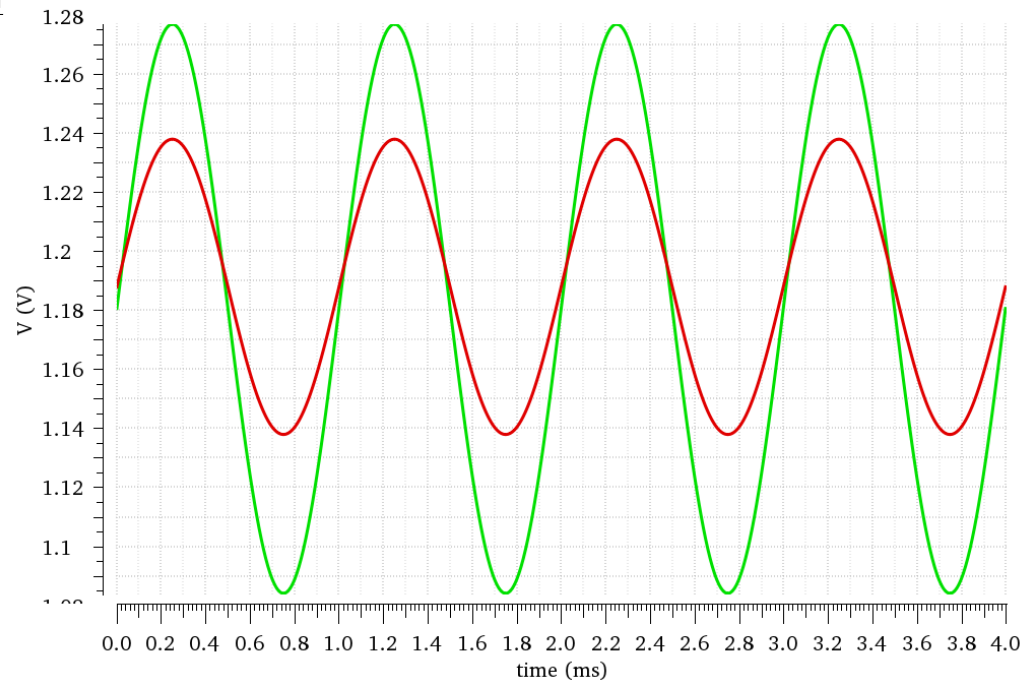


Figure 26 Output Signal


## Input

Name	...	QIN
Input		4e-12
Output		4e-12
VID		4e-12

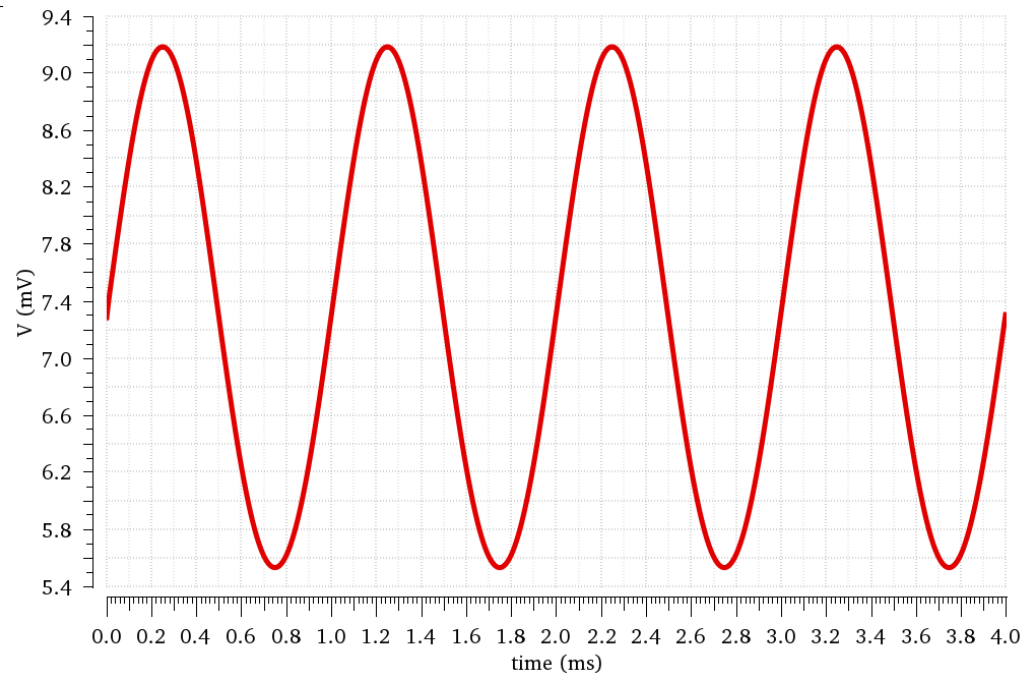
Fri Aug 15 15:35:04 2025 1

Figure 27  $V_{in}$  and  $V_{out}$  Overlaid (To Showcase Gain)

## VID

Name	...	QIN
VID		4e-12

Fri Aug 15 15:35:04 2025 1

Figure 28 Error ( $V_P - V_N$ )

	VIN	VOUT	VID
Peak to Peak (V)	1.00E-01	1.93E-01	3.66E-03

$$\frac{V_{OUT}}{V_{err}} = \frac{193m}{3.66m} = 52.732 = A_{OL}$$

The relationship between the Output Voltage and Error Voltage or the Differential Input voltage of the amplifier is the Open Loop Gain.

## Using $F_{IN}=BW=134\text{KHz}$

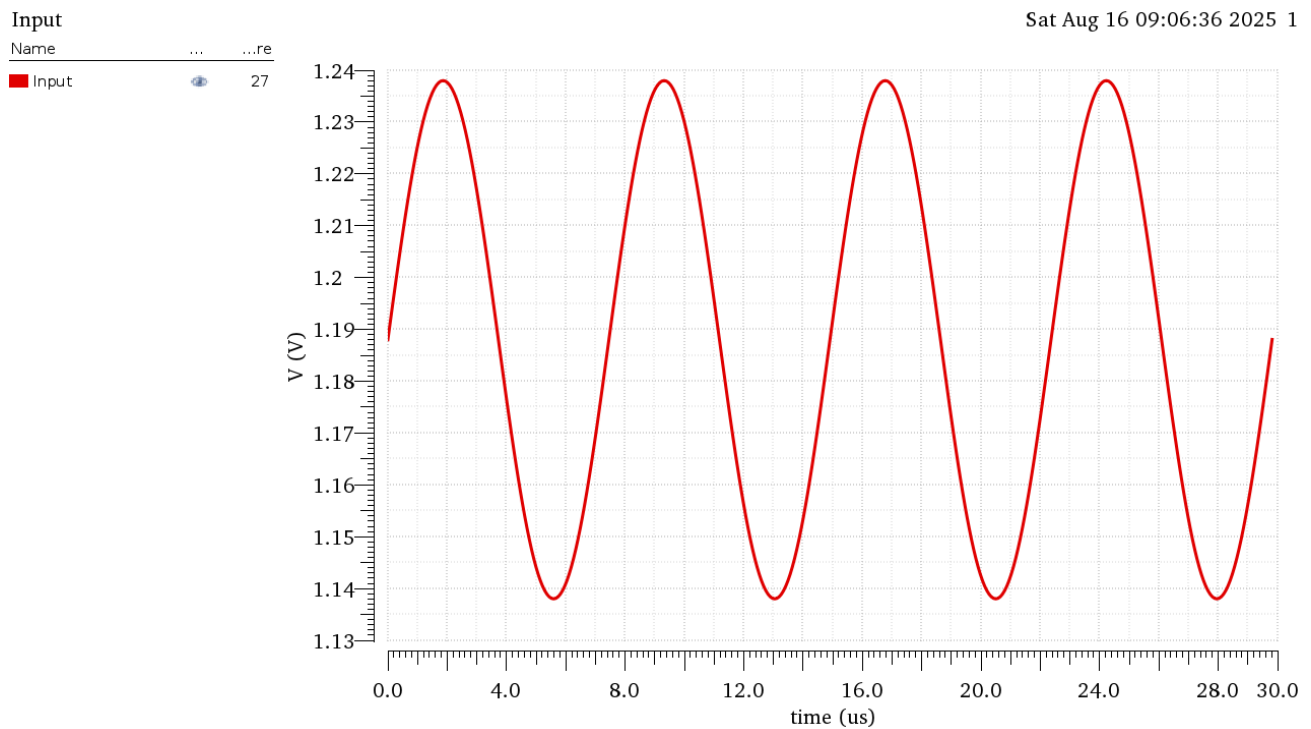


Figure 29 Input Signal at  $F_{IN}=134\text{KHz}$

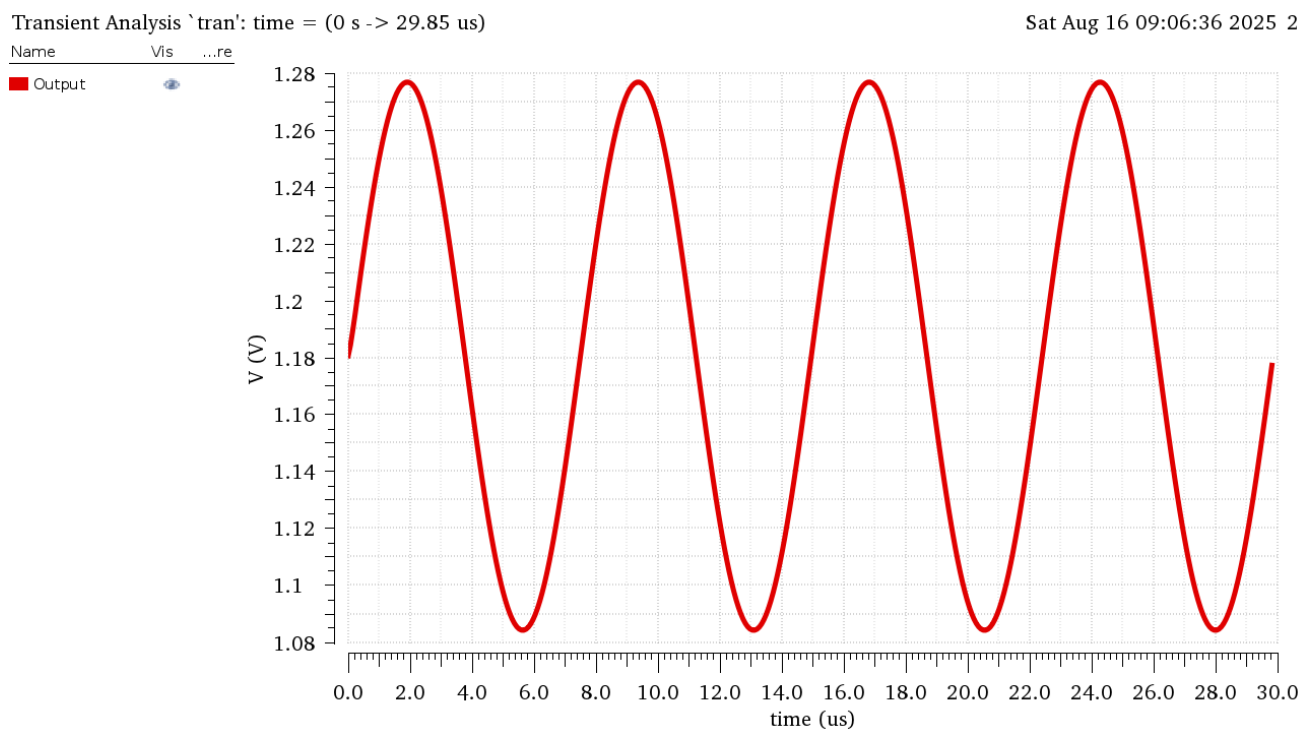
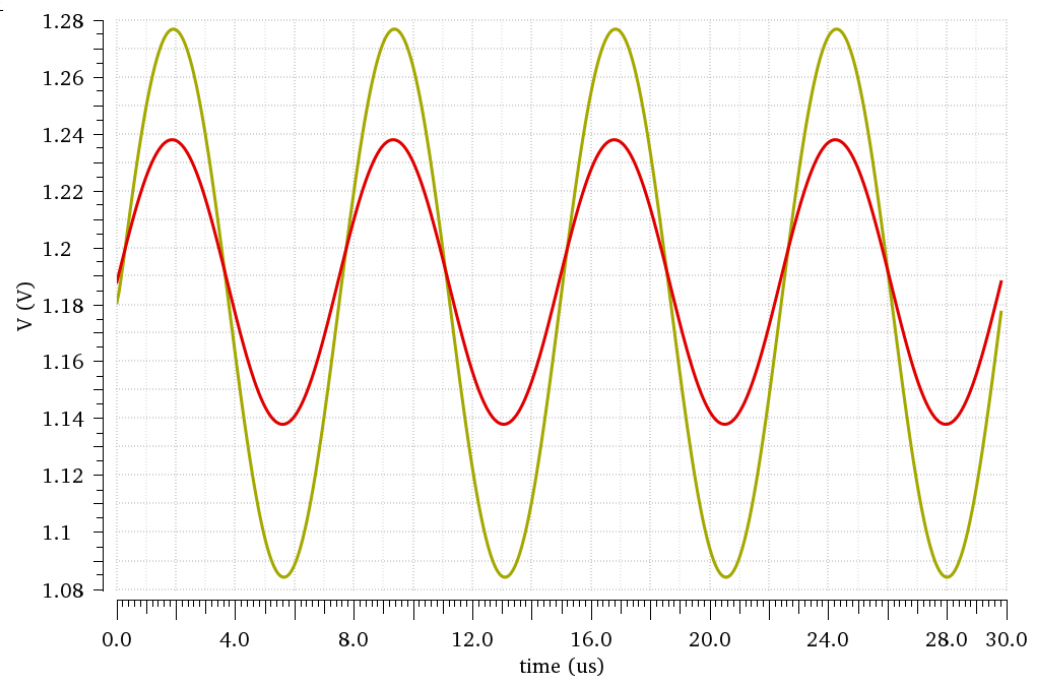


Figure 30 Output Signal at  $F_{IN}=134\text{KHz}$

## Input

Sat Aug 16 09:06:36 2025 1

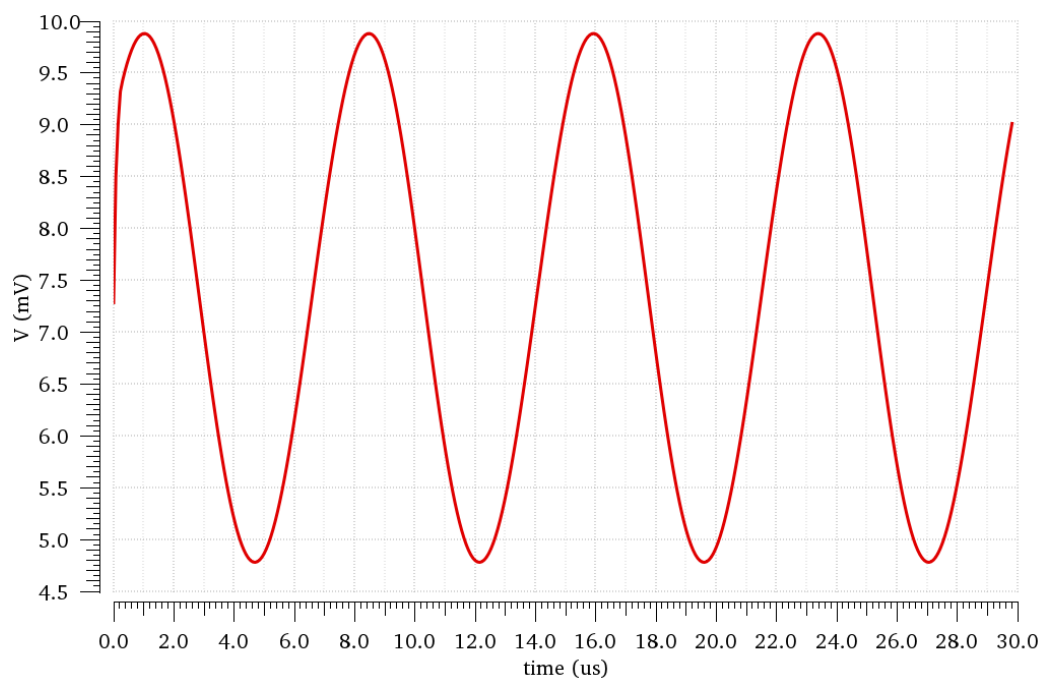
Name	...	...re
Input		
Output		

Figure 31 Vout and Vin Overlaid  $F_{IN}=134\text{KHz}$ 

## VID

Sat Aug 16 09:06:36 2025 3

Name	...	...re
VID		27

Figure 32 Verror at  $F_{IN}=134\text{KHz}$

	VIN	VOUT	VID
Peak to Peak (V)	1.00E-01	1.93E-01	5.10E-03

$$\frac{V_{OUT}}{V_{err}} = \frac{193m}{5.1m} = 37.671 = \frac{52.732}{\sqrt{2}} = \frac{A_{OL}}{\sqrt{2}}$$

The relationship between the Output Voltage and Error Voltage or the Differential Input voltage of the amplifier is the Open Loop Gain divided by root 2 as the Input signal is at the cutoff frequency.