Analog IC Design Lab
08
Negative Feedback

PART 1: Feedback with Behavioral OTA

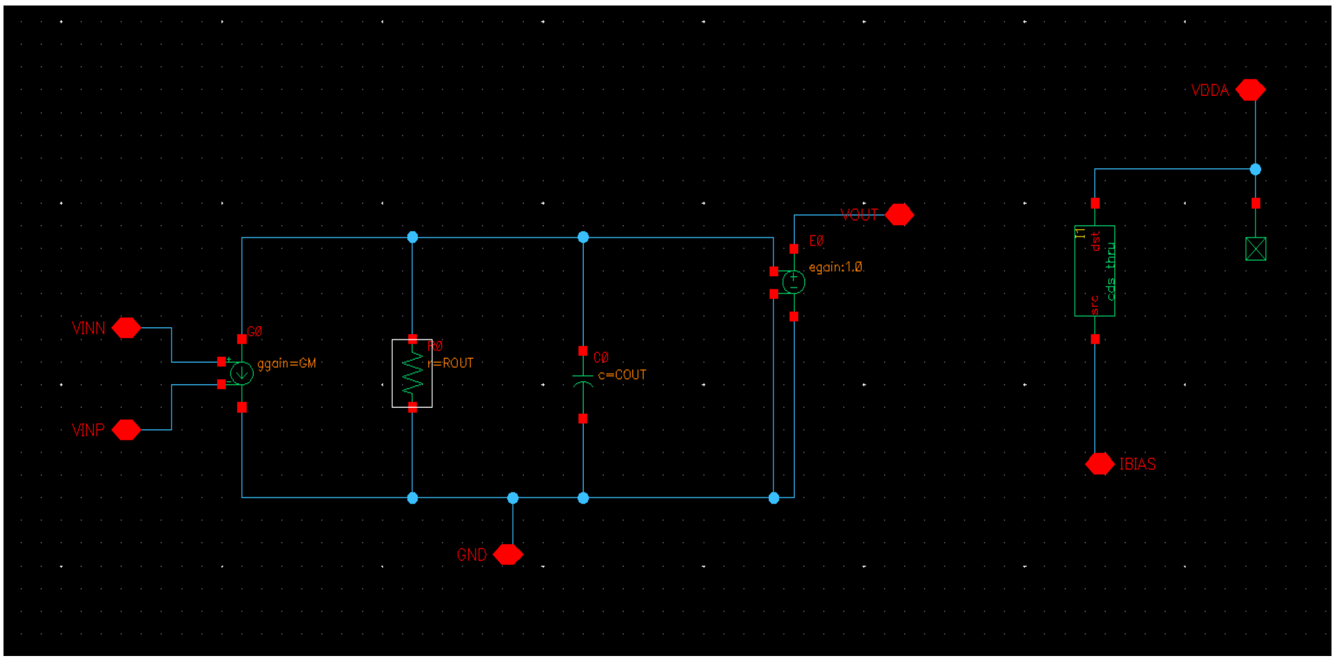
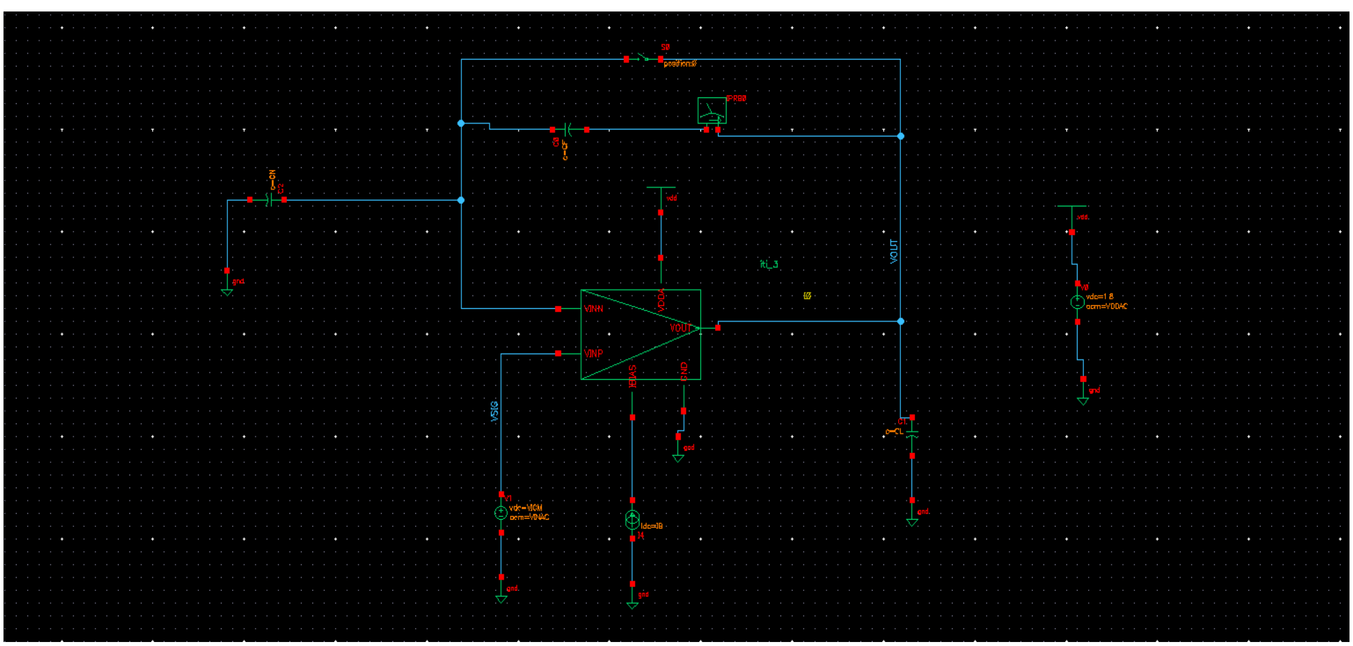


Figure 1:schematic



1) Closed loop gain vs frequency:

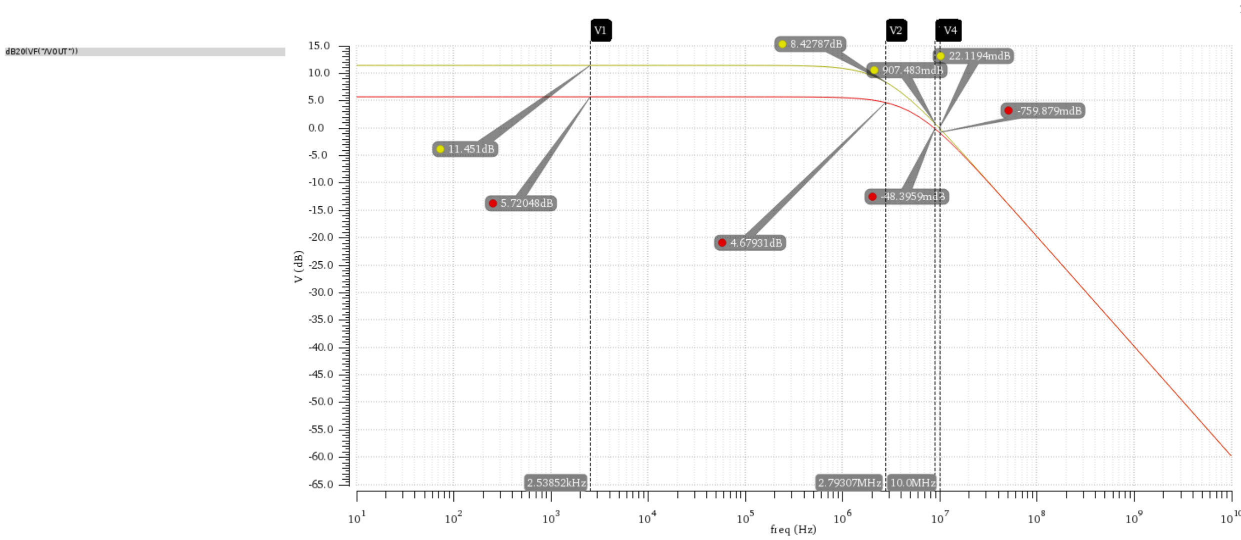


Figure 2:VOUT vs FREQ (in db)

VALUES FROM SIMULATION:

CF	4p
CL	5p
CN	4p,12P
COUT	5p
GM	0.000326944
IB	10u
ROUT	174k

Point	Test	Output	Nominal
Parameters: CN=4p			
1	iti_cadence_lab8:iti_4:1	Gain db	5.72
1	iti_cadence_lab8:iti_4:1	Gain mag	1.932
1	iti_cadence_lab8:iti_4:1	BW	5.39M
1	iti_cadence_lab8:iti_4:1	GBW	10.44M
1	iti_cadence_lab8:iti_4:1	PLOT	
Parameters: CN=12p			
2	iti_cadence_lab8:iti_4:1	Gain db	11.45
2	iti_cadence_lab8:iti_4:1	Gain mag	3.737
2	iti_cadence_lab8:iti_4:1	BW	2.787M
2	iti_cadence_lab8:iti_4:1	GBW	10.44M
2	iti_cadence_lab8:iti_4:1	PLOT	

HAND ANALYSIS:

GAIN = 1+ $\frac{C_{in}}{C_F}$

SO, At $C_{in} = 4p$, GAIN =2 =6 dB

At $C_{in} = 12p$, GAIN =4=12 dB

BW = $\frac{1}{2\pi \times R_{out} \times C_{out}}(1 + Beta \times GAIN_{OL}) = \frac{1}{2\pi \times R_{out} \times C_{out}}(1 + \frac{C_F}{C_{in}+C_F} GM\ R_{out})$

At $C_{in} = 4p$, BW=5.2MHZ

At $C_{in} = 12p$,BW =2.6 MHZ

GBW = BW*GAIN

SO, At $C_{in} = 4p$, GBW =10.4 MHZ

At $C_{in} = 12p$, GBW=10.4 MHZ

	GAIN	BW	GBW	GAIN	BW	GBW
		CIN=4p			CIN=12p	
FROM SIMULATION	1.932	5.39 MHZ	10.44 MHZ	3.737	2.787 MHZ	10.44 MHZ
FROM HAND ANALYSIS	2	5.2MHZ	10.4 MHZ	4	2.6 MHZ	10.4 MHZ

Comment:

- *The bandwidth decreases as CIN increases, which is expected because the feedback factor (β) changes with CIN.* And *The results validate the expected behavior of negative feedback: Higher gain → Lower bandwidth (inverse relationship). GBW remains unchanged, confirming the amplifier's fundamental performance limit and small discrepancies between simulation and hand analysis are likely due to model approximations.*

2) loop gain vs frequency:

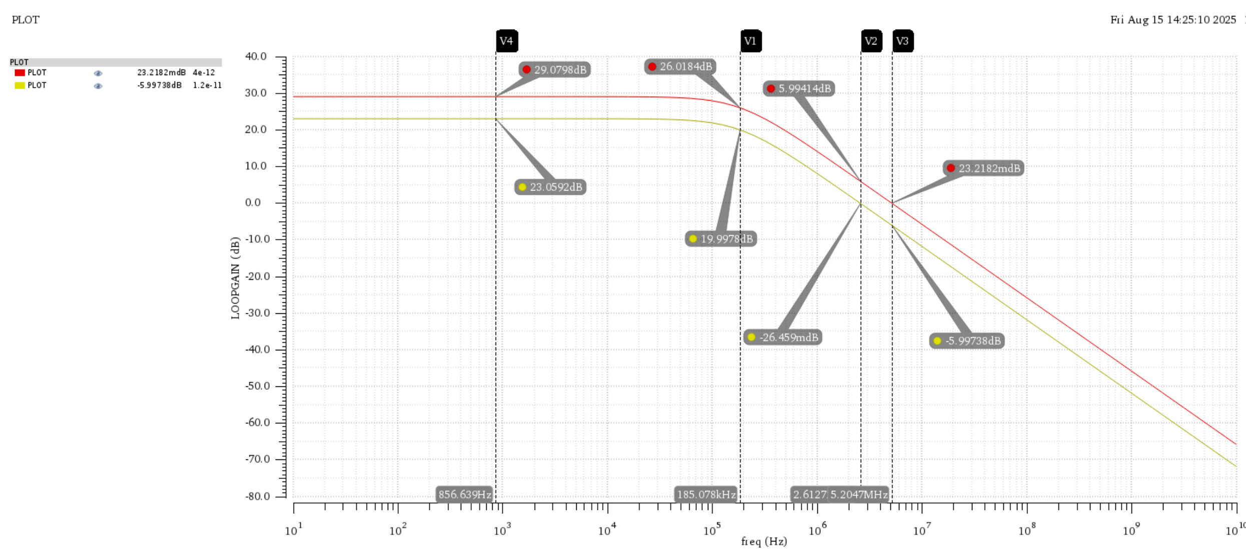


Figure 3: loop gain vs freq (in db)

VALUES FROM SIMULATION:

Point	Test	Output	**Nominal**
Parameters: CN=4p			
1	iti_cadence_lab8:iti_4:1	PLOT	
1	iti_cadence_lab8:iti_4:1	UGF	5.24M
1	iti_cadence_lab8:iti_4:1	YMAX mag	28.44
1	iti_cadence_lab8:iti_4:1	YMAX db	29.08
Parameters: CN=12p			
2	iti_cadence_lab8:iti_4:1	PLOT	
2	iti_cadence_lab8:iti_4:1	UGF	2.613M
2	iti_cadence_lab8:iti_4:1	YMAX mag	14.22
2	iti_cadence_lab8:iti_4:1	YMAX db	23.06

HAND ANALYSIS:

GAIN LG $= \frac{C_F}{C_{in}+C_F} GM\ R_{out)}$

SO, At $C_{in} = 4p$, GAIN =28.44

At $C_{in} = 12p$, GAIN =14.22

BW = $\frac{1}{2\pi \times R_{out} \times C_{out}}$

At $C_{in} = 4p$, BW=182.936 KHZ

At $C_{in} = 12p$, BW =182.936 KHZ

GBW = BW*GAIN

SO, At $C_{in} = 4p$, GBW =5.2 MHZ

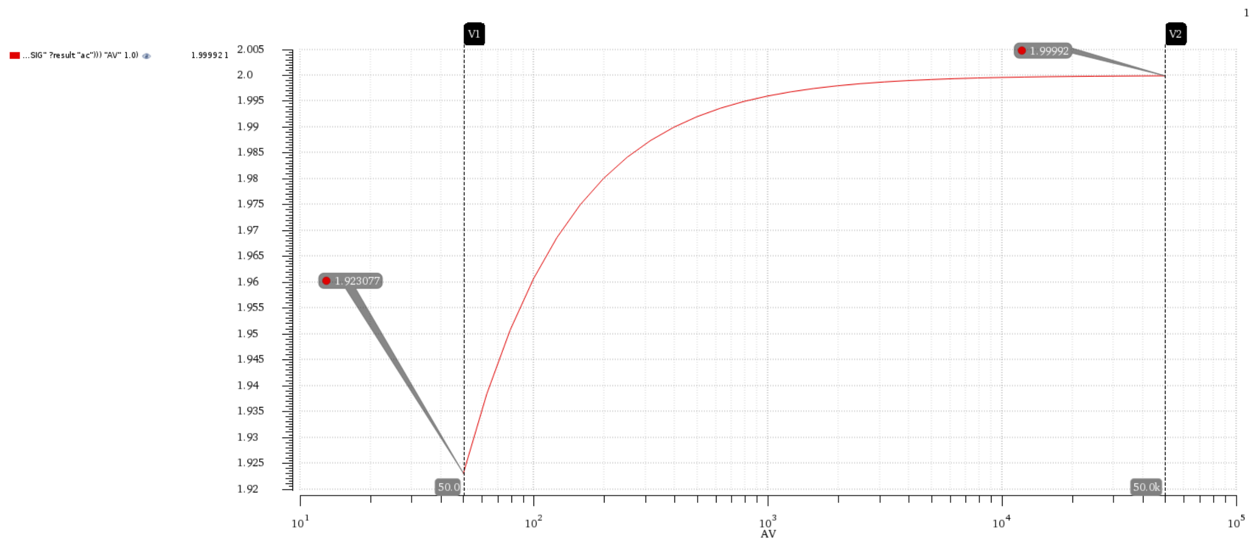
At $C_{in} = 12p$, GBW=2.6 MHZ

	GAIN	BW	GBW	GAIN	BW	GBW
	CIN=4p			CIN=12p		
FROM SIMULATION	28.44	185.078KHZ	5.24 MHZ	14.22	185.0.78K HZ	2.613 MHZ
FROM HAND ANALYSIS	28.44	182.936 KHZ	5.2 MHZ	14.22	182.936 KHZ	2.6 MHZ

Comment:

- *The results show how increasing CIN reduces the feedback factor (β), which directly decreases the loop gain (LG = Aβ). While the closed-loop gain halves (28.44 to 14.22), the unity-gain frequency (where |LG|=1) also drops proportionally (5.2MHz to 2.6MHz), the bandwidth remains constant at ~185kHz regardless of CIN value. This confirms β's role in setting both the loop gain magnitude and frequency response in the feedback system.*

3)Gain Desensitization:



Calculate the percentage change in closed loop gain=$\frac{1.99992-1.923077}{1.923077}\times 100 = 3.9958\,\%$

Negative feedback dramatically reduces the impact of open-loop gain variations, keeping the closed-loop gain within ~4% error d. This proves the robustness of feedback systems in real-world applications in the end l Feedback makes amplifiers immune to gain variations.

PART 2: Feedback with Real 5T OTA:

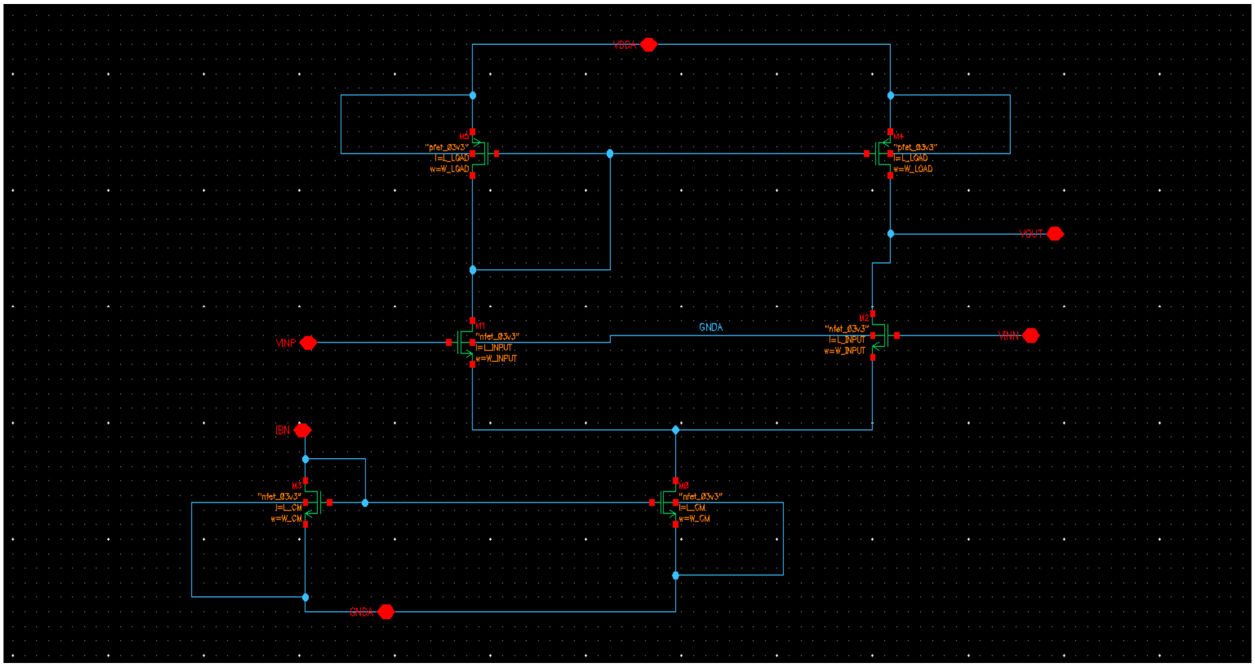
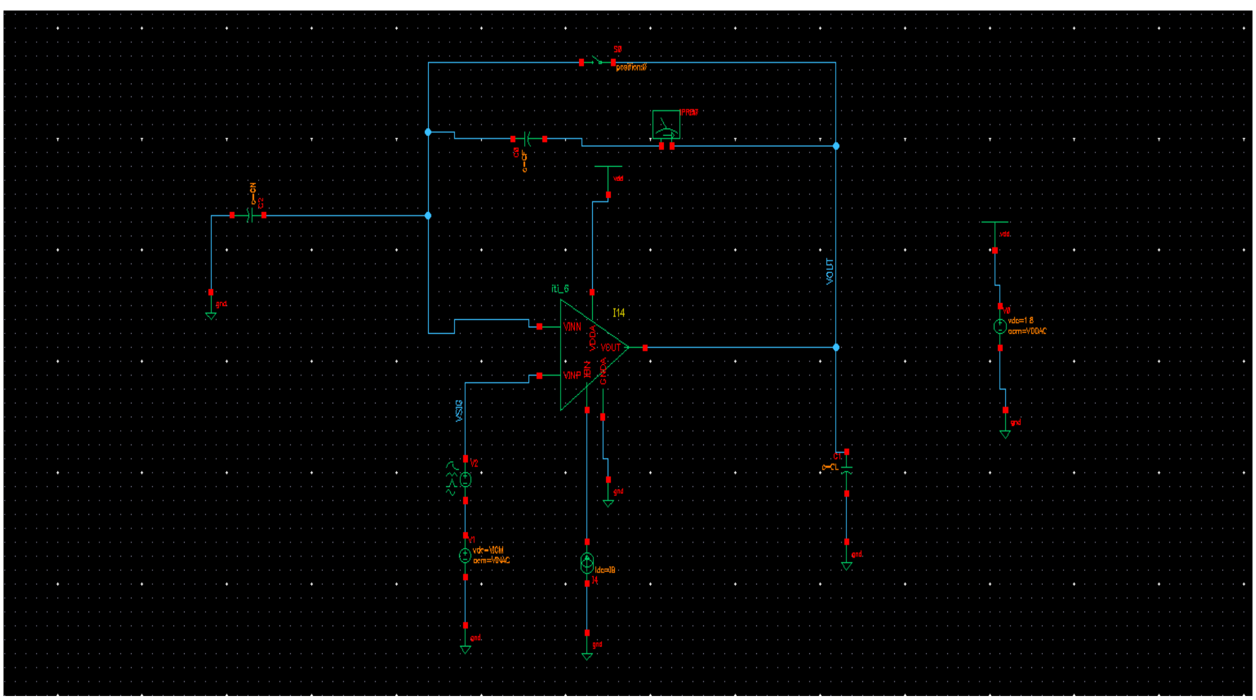


Figure 4: schematic



1) Closed loop gain vs frequency:

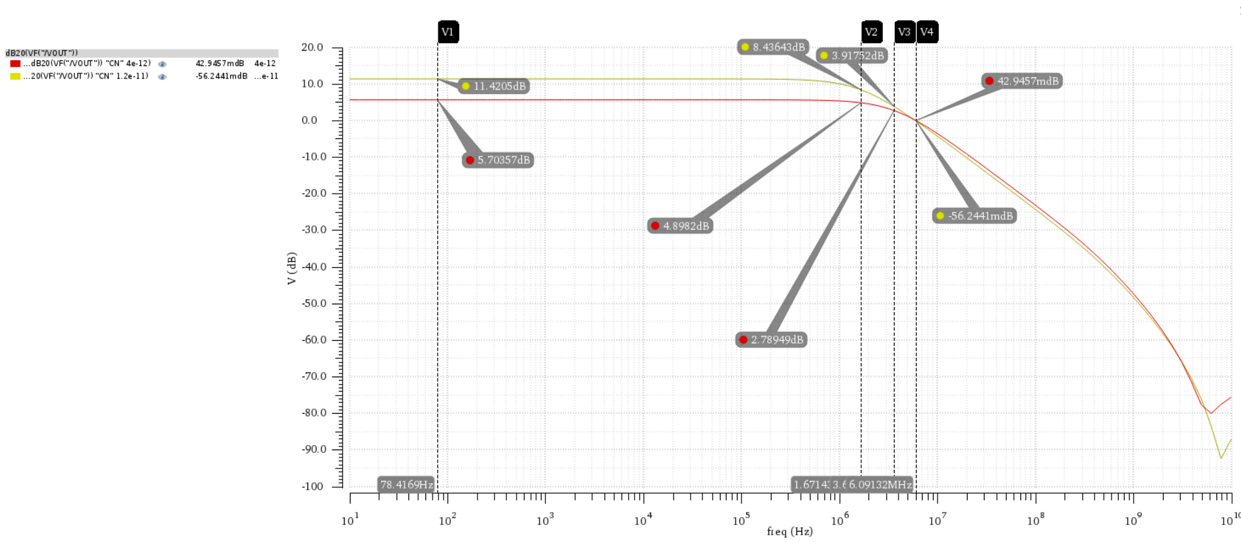


Figure 5:VOUT vs FREQ (in db)

VALUES FROM SIMULATION:

Parameters: CN=4p			
1	iti_cadence_lab8:iti_4:1	GAIN db	5.704
1	iti_cadence_lab8:iti_4:1	GAIN mag	1.928
1	iti_cadence_lab8:iti_4:1	BW	3.715M
1	iti_cadence_lab8:iti_4:1	GBW	7.18M
Parameters: CN=12p			
2	iti_cadence_lab8:iti_4:1	GAIN db	11.42
2	iti_cadence_lab8:iti_4:1	GAIN mag	3.724
2	iti_cadence_lab8:iti_4:1	BW	1.682M
2	iti_cadence_lab8:iti_4:1	GBW	6.28M

GAIN = $1+\frac{C_{in}}{C_F}$

SO, At $C_{in} = 4p$, GAIN =2 =6 dB

At $C_{in} = 12p$, GAIN =4=12 dB

Cout = (CF//CIN)+CL

BW = $\frac{1}{2\pi \times R_{out} \times C_{out}}(1 + Beta \times GAIN_{OL}) = \frac{1}{2\pi \times R_{out} \times C_{out}}(1 + \frac{C_F}{C_{in}+C_F} GM\ R_{out})$

At $C_{in} = 4p$, BW=3.847MHZ

At $C_{in} = 12p$, BW =1.74 MHZ

GBW = BW*GAIN

SO, At $C_{in} = 4p$, GBW =7.694 MHZ

At $C_{in} = 12p$, GBW=6.96 MHZ

	GAIN	BW	GBW	GAIN	BW	GBW
	CIN=4p			CIN=12p		
FROM SIMULATION	1.928	3.715 MHZ	7.18 MHZ	3.724	1.682 MHZ	6.28 MHZ
FROM HAND ANALYSIS	2	3.847MHZ	7.694 MHZ	4	1.74MHZ	6.96 MHZ

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

	GAIN	BW	GBW	GAIN	BW	GBW
	CIN=4p			CIN=12p		
Part 1	1.932	5.39MHZ	10.44MHZ	3.737	2.787MHZ	10.44 MHZ
Part 2	1.928	3.715 MHZ	7.18 MHZ	3.724	1.682 MHZ	6.28 MHZ

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

- Yes, the real 5T OTA shows significantly lower bandwidth (BW) and gain-bandwidth product (GBW) compared to Part 1's behavioral model. This degradation occurs because
  Output Loading Dominates: The real OTA faces Cout = (CF||CIN) + CL, adding parasitic capacitance that Shifts the dominant pole to lower frequencies Directly reduces both BW and GBW

2) loop gain vs frequency:

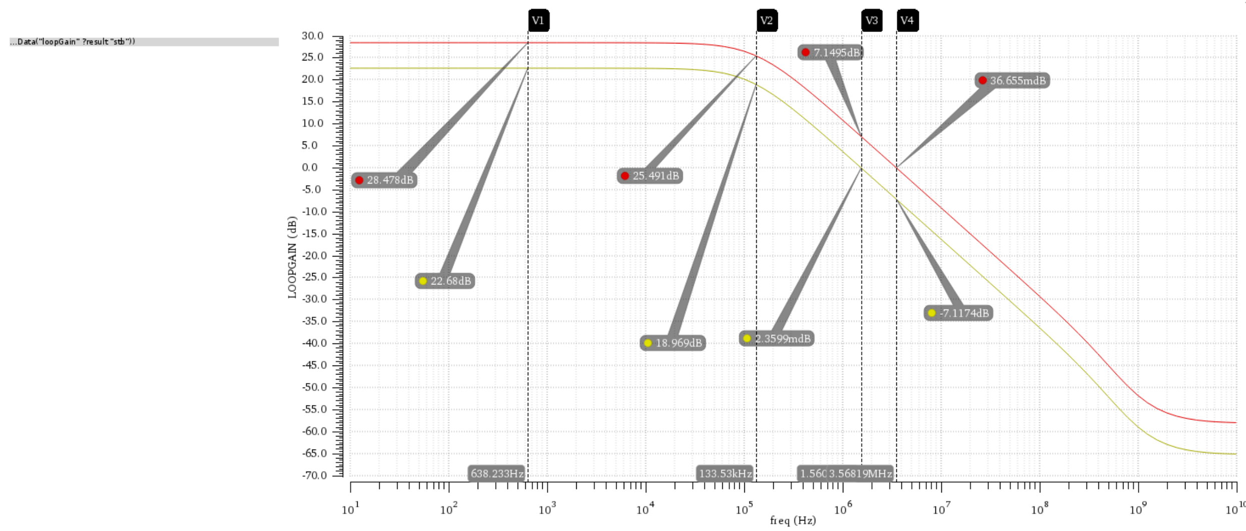


Figure 6:: loop gain vs freq (in db)

VALUES FROM SIMULATION:

Parameters: CN=4p			
1	iti_cadence_lab8:iti_4:1	UGF	3.607M
1	iti_cadence_lab8:iti_4:1	GAIN mag	26.54
1	iti_cadence_lab8:iti_4:1	GAIN db	28.48
Parameters: CN=12p			
2	iti_cadence_lab8:iti_4:1	UGF	1.564M
2	iti_cadence_lab8:iti_4:1	GAIN mag	13.61
2	iti_cadence_lab8:iti_4:1	GAIN db	22.68

HAND ANALYSIS:

GAIN LG = $\frac{C_F}{C_{in}+C_F} GM\ R_{out})$

SO, At $C_{in} = 4p$, GAIN =28.44

At $C_{in} = 12p$, GAIN =14.22

Cout = (CF//CIN)+CL

BW = $\frac{1}{2\pi \times R_{out} \times C_{out}}$

At $C_{in} = 4p$, BW=130.669 KHZ

At $C_{in} = 12p$, BW =114.335 KHZ

GBW = BW*GAIN

SO, At $C_{in} = 4p$, GBW =3.716 MHZ

At $C_{in} = 12p$, GBW=1.626 MHZ

	GAIN	BW	GBW	GAIN	BW	GBW
		CIN=4p			CIN=12p	
FROM SIMULATION	26.54	133.53KHZ	3.607 MHZ	13.62	116.831K HZ	1.564 MHZ
FROM HAND ANALYSIS	28.44	130.669 KHZ	3.716 MHZ	14.22	114.335 KHZ	1.626 MHZ

	GAIN	BW	GBW	GAIN	BW	GBW
		CIN=4p			CIN=12p	
Part 1	28.44	185.078KHZ	5.24 MHZ	14.22	185.0.78K HZ	2.613 MHZ
Part 2	26.54	133.53KHZ	3.607 MHZ	13.62	116.831K HZ	1.564 MHZ

Comment:

- the real 5T OTA shows significantly lower bandwidth (BW) and gain-bandwidth product (GBW/UGF) compared to Part 1's behavioral model. This degradation occurs because Output Loading Dominates: The real OTA faces Cout = (CF||CIN) + CL, adding parasitic capacitance that Shifts the dominant pole to lower frequencies Directly reduces both BW and GBW

3) GAIN DE sensitization:

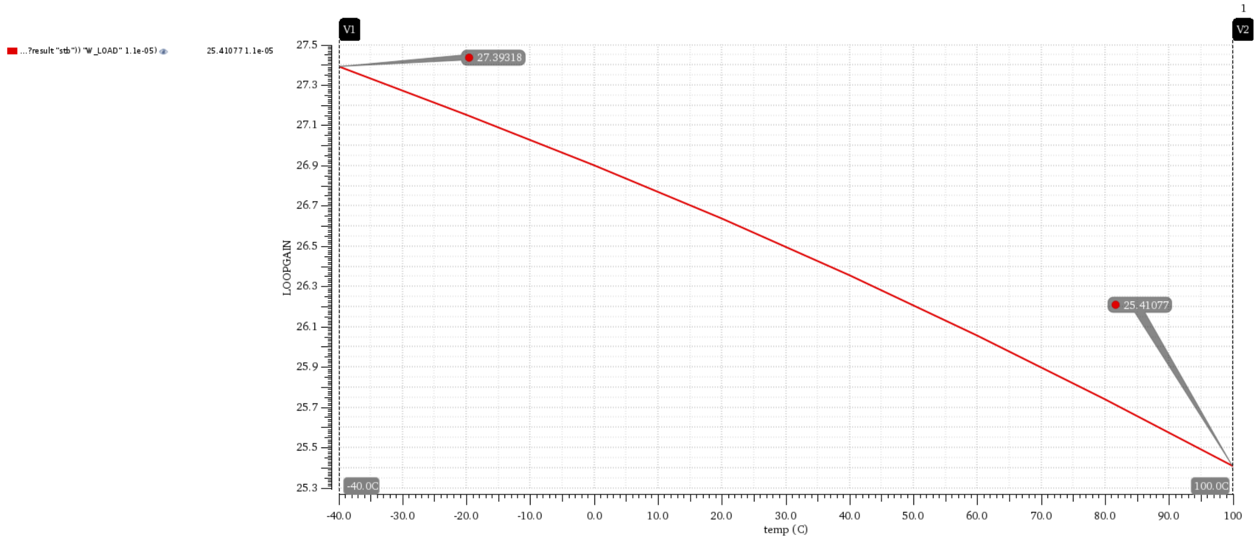


Figure 7:loop gain vs temp

Calculate the percentage change in loop gain= $\frac{25.41077-27.39318}{27.39318} \times 100 = -7.2368\ \%$

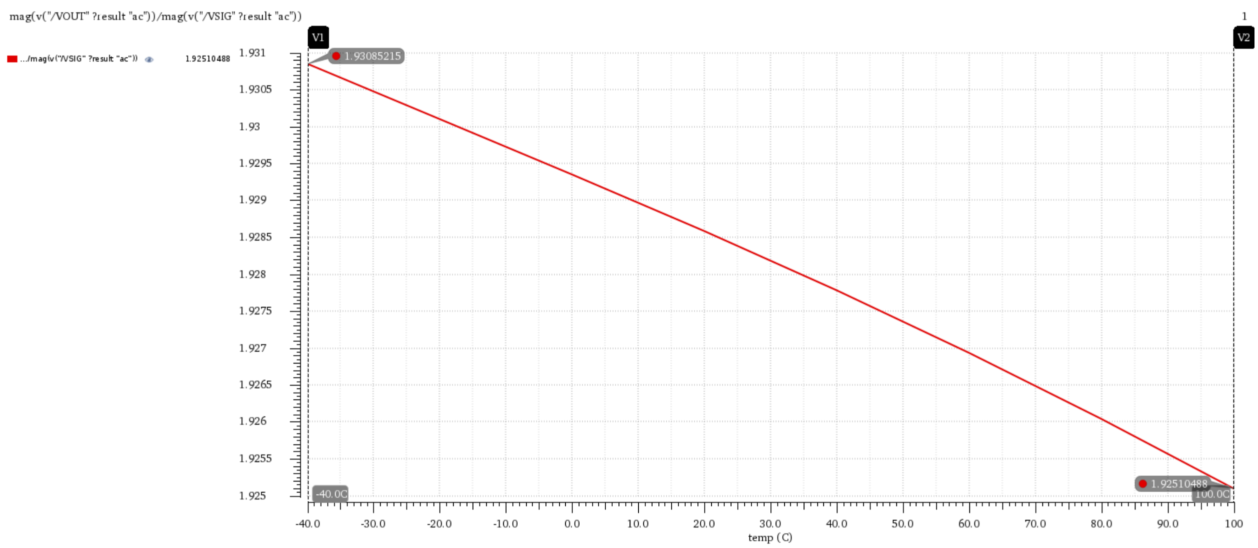


Figure 8: CL gain VS temp

Calculate the percentage change in closed loop gain= $\frac{1.92510488-1.93085215}{1.93085215} \times 100 = -0.297\ \%$

- Across the temperature sweep, the loop gain shows a clear variation, while the closed-loop gain remains nearly constant with only a very small change. This indicates that the circuit keeps stable performance even as device characteristics shift with temperature. The slight movement in the closed-loop response is expected, but overall, the gain stays well controlled and the design demonstrates good robustness over the entire temperature range

4)Transient Analysis:

At Fin =1 k

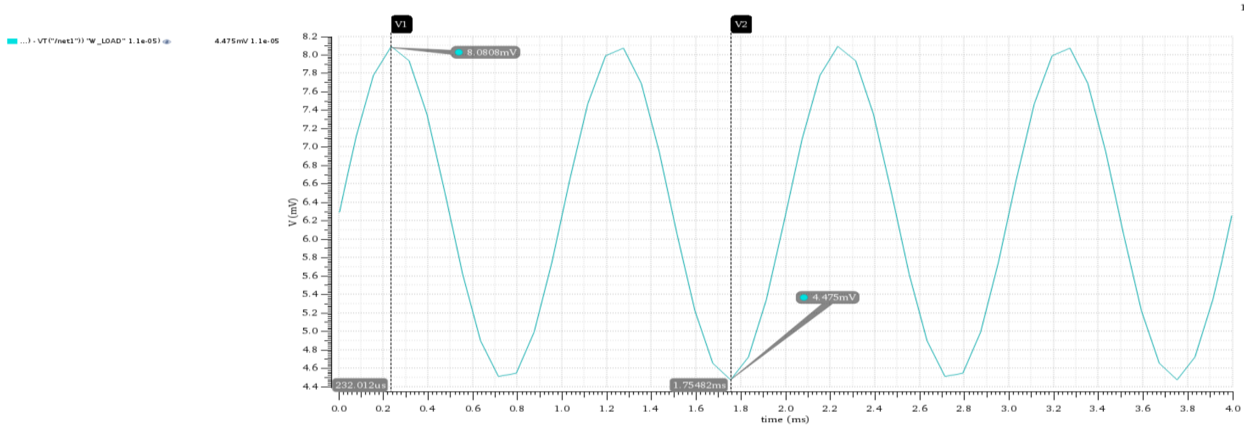


Figure 11:vinn-vinp vs time

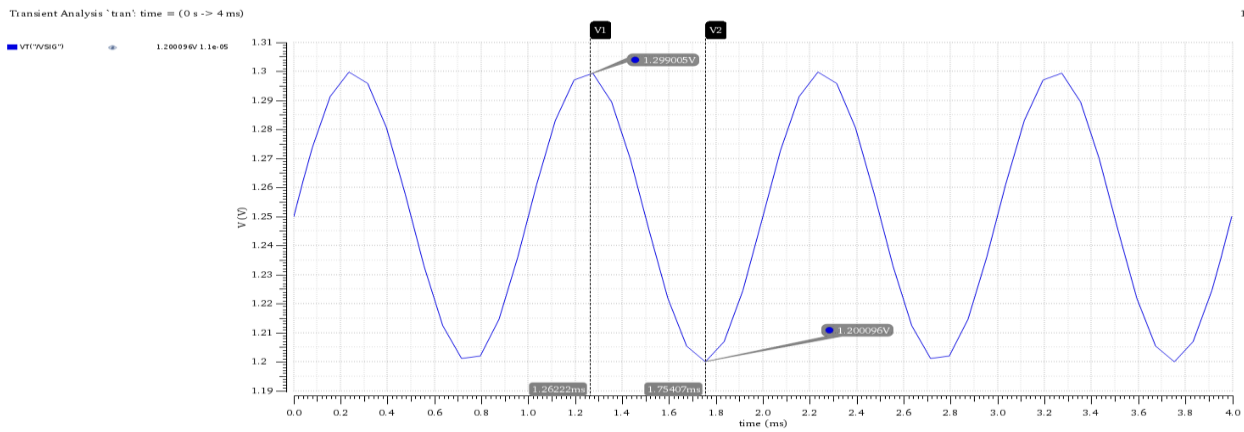


Figure 10: vin vs time

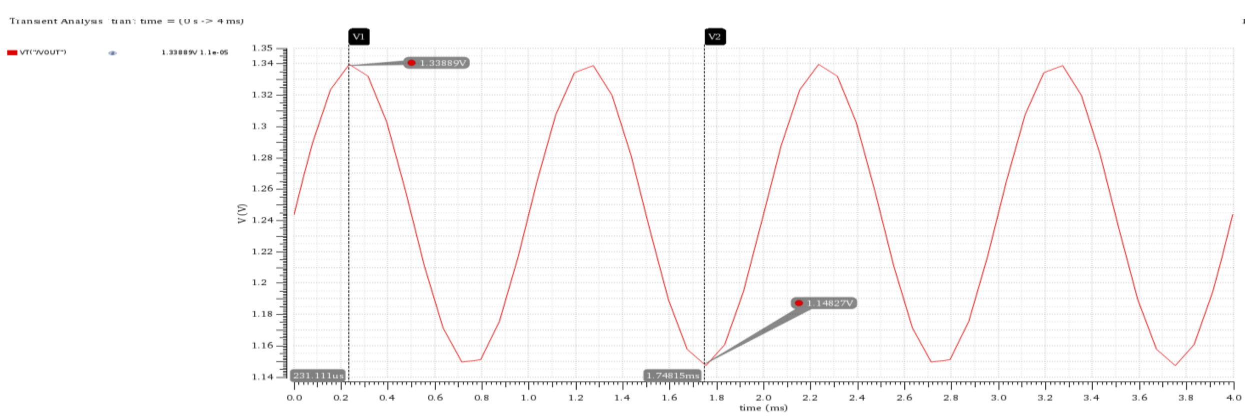


Figure 9: vout vs time

Peak to peak values from simulation:

Test	Output	Nominal
iti_cadence_lab8:iti_4:1	vinn-vinp p-p	3.619m
iti_cadence_lab8:iti_4:1	vin p-p	99.76m
iti_cadence_lab8:iti_4:1	vout p-p	192.3m

$$AOL = \frac{VOUT}{VINN - VINP} = 53.13$$

$$ACL = \frac{VOUT}{VIN} = 1.9276$$

FIN is exactly equal to the closed loop bandwidth

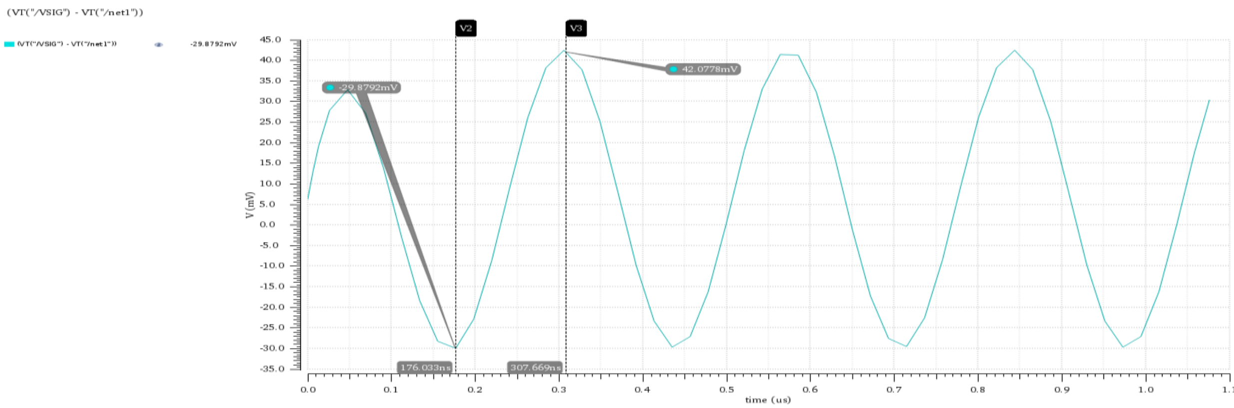


Figure 14: vinn-vinp vs time

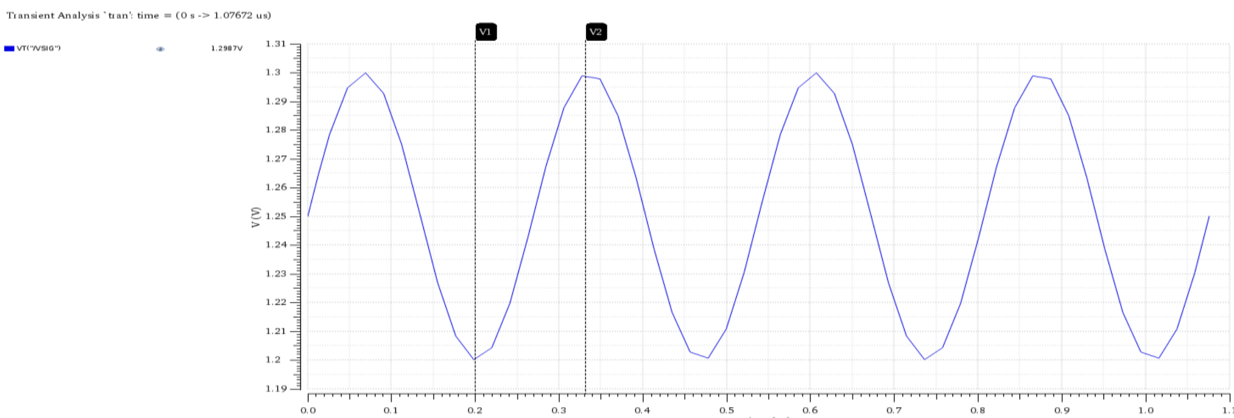


Figure 13: vin vs time

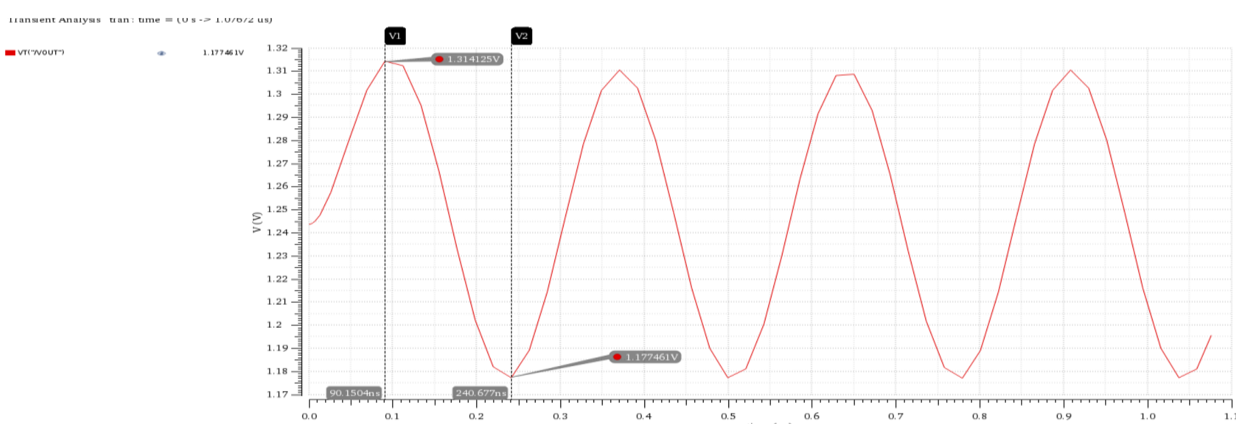


Figure 12: vout vs time

Peak to peak values from simulation:

iti_cadence_lab8:iti_4:1	vinn-vinp p-p	72.41m
iti_cadence_lab8:iti_4:1	vin p-p	99.78m
iti_cadence_lab8:iti_4:1	vout p-p	137.2m

AOL = $\frac{VOUT}{VINN-VINP}$ =1.92129

ACL =$\frac{VOUT}{VIN} = 1.8947$

At FIN = the closed-loop bandwidth, the amplifier can no longer follow the input perfectly because its internal open-loop gain is rolling off. The feedback can’t fully correct the error, so the closed loop gain drops.

By definition, the closed-loop bandwidth is the frequency where the closed-loop gain has fallen by about 3 dB (≈70.7% of its low-frequency value). That’s why you see the gain decrease right at that point.