Analog IC Design
Lab 10

Noise Simulation

PART 1: LPF AC Noise Analysis

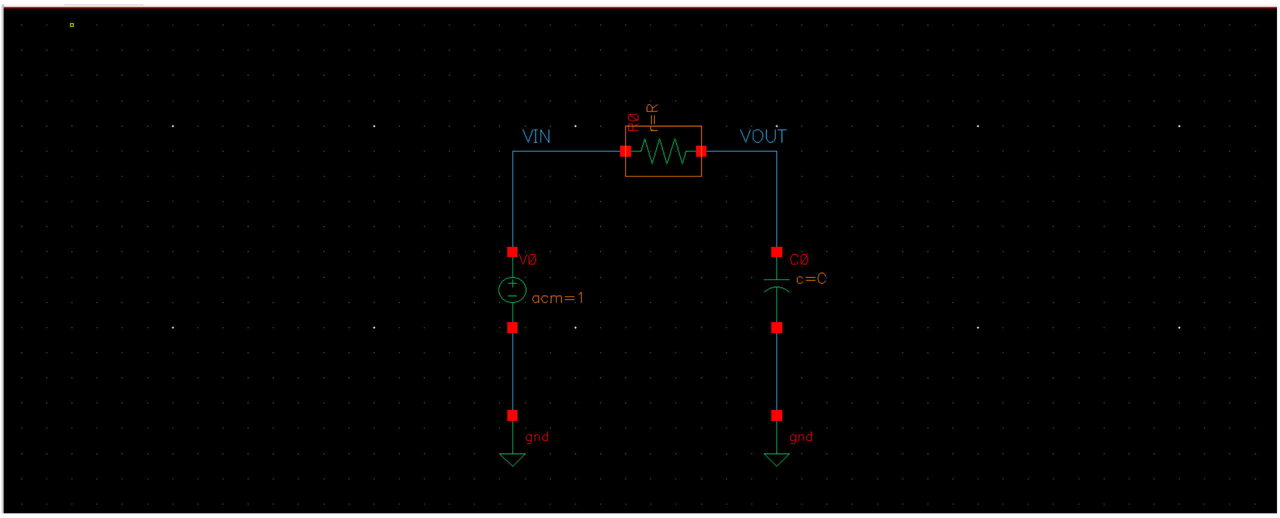


Figure 1 Low pass filter schematic.

Report output noise vs frequency. Annotate voltage noise density and bandwidth in the plot.

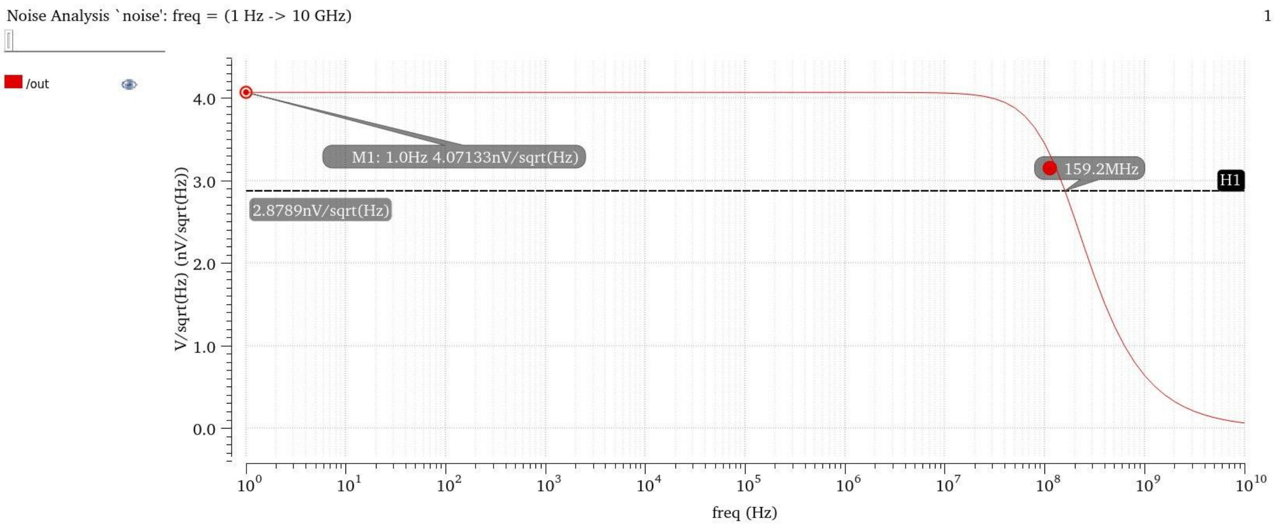
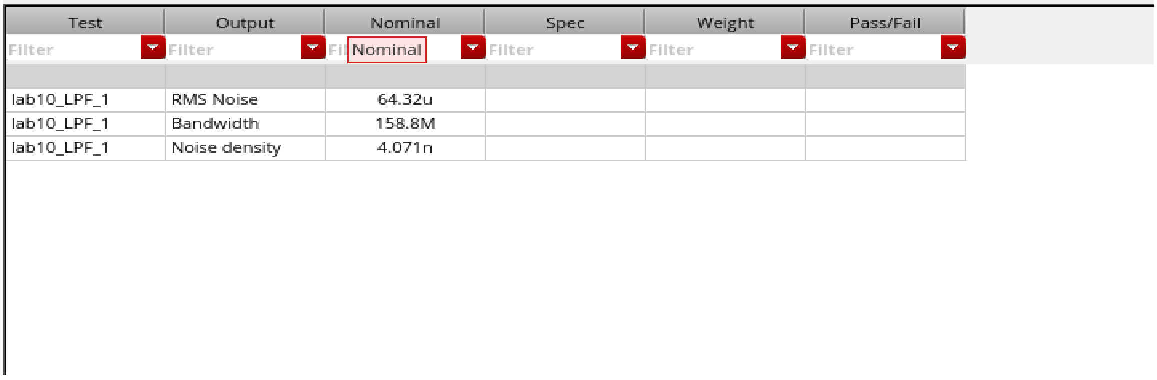


Figure 2 Plot noise vs frequency.

From the above graph the noise density= 4.07 $^{nV}/_{\sqrt{HZ}}$

And the bandwidth is 159.2 MHZ.

Calculate rms output noise using rms noise function in the calculator.



Test	Output	Nominal	Spec	Weight	Pass/Fail
lab10_LPF_1	RMS Noise	64.32u			
lab10_LPF_1	Bandwidth	158.8M			
lab10_LPF_1	Noise density	4.071n			

Figure 3 Results from simulator.

Hand analysis:

$$Noise\ density = \sqrt{\frac{R}{1K}} * 4\frac{nV}{\sqrt{HZ}} = 4\frac{nV}{\sqrt{HZ}}$$

$$Bandwidth = \frac{1}{2 * \pi * R * C} = 159.155MHZ.$$

$$RMS_{Noise} = \sqrt{\frac{1p}{C}} * 64\mu = 64\mu V_{rms}.$$

	Simulation	Analytical
Noise density	4.071 n	4 n
Bandwidth	158.8 M	159.155 M
RMS Noise	64.32 μ	64 μ

Run parametric sweep for RPAR = 1k, 10k, 100k, 1000k.

Plot output noise overlaid on the same plot. Using log-scale for y-axis. Comment on the results.

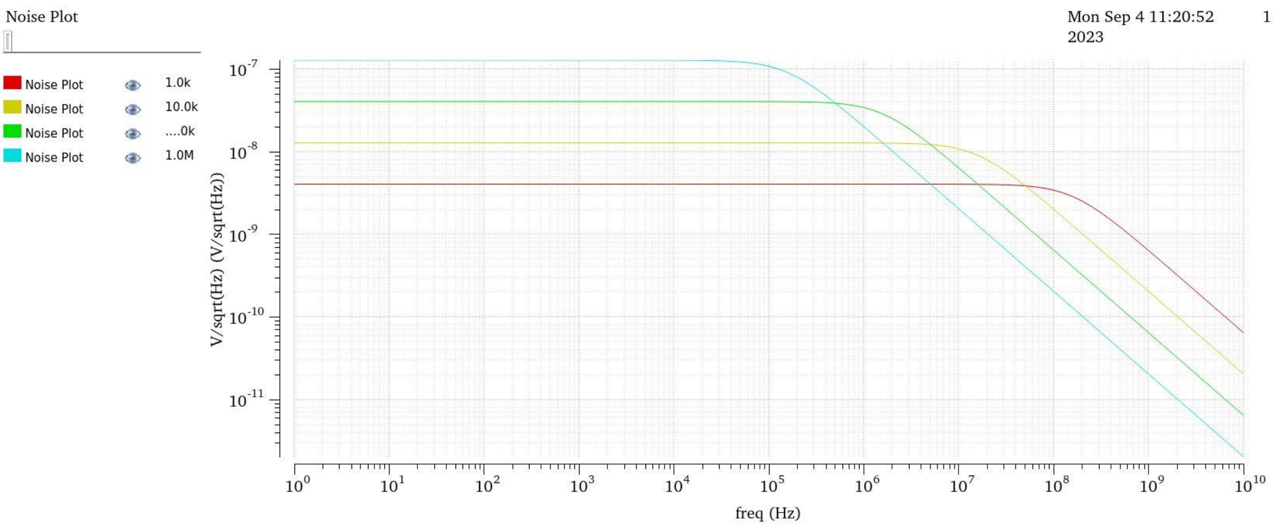


Figure 4 Parametric noise Plot.

Comment: As shown from previous analysis that by increasing resistance noise density increases also due to increasing thermal noise value but bandwidth decreases, When the resistance is multiplied by 10 the noise density is multiplied by $\sqrt{10}$.

<u>Calculate the rms noise using the calculator. Comment on the results</u>

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter	Filter
Parameters: R=1K						Search History
1	lab10_LPF_1	RMS Noise	64.32u			
1	lab10_LPF_1	Bandwidth	158.8M			
1	lab10_LPF_1	Noise density	4.071n			
1	lab10_LPF_1	Noise Plot				
Parameters: R=10K						
2	lab10_LPF_1	RMS Noise	64.62u			
2	lab10_LPF_1	Bandwidth	15.88M			
2	lab10_LPF_1	Noise density	12.87n			
2	lab10_LPF_1	Noise Plot				
Parameters: R=100K						
3	lab10_LPF_1	RMS Noise	64.65u			
3	lab10_LPF_1	Bandwidth	1.588M			
3	lab10_LPF_1	Noise density	40.71n			
3	lab10_LPF_1	Noise Plot				
Parameters: R=1M						
4	lab10_LPF_1	RMS Noise	64.66u			
4	lab10_LPF_1	Bandwidth	158.8K			
4	lab10_LPF_1	Noise density	128.7n			
4	lab10_LPF_1	Noise Plot				

Figure 5 parametric results from simulators.

Comment:

The rms noise is almost the same for all values of R because noise in RC circuits is independent on the value of R, noise density is multiplied by $\sqrt{10}$.

PART 2: LPF Transient Noise Analysis

<u>Report the noise output waveform. Annotate the min and max values.</u>

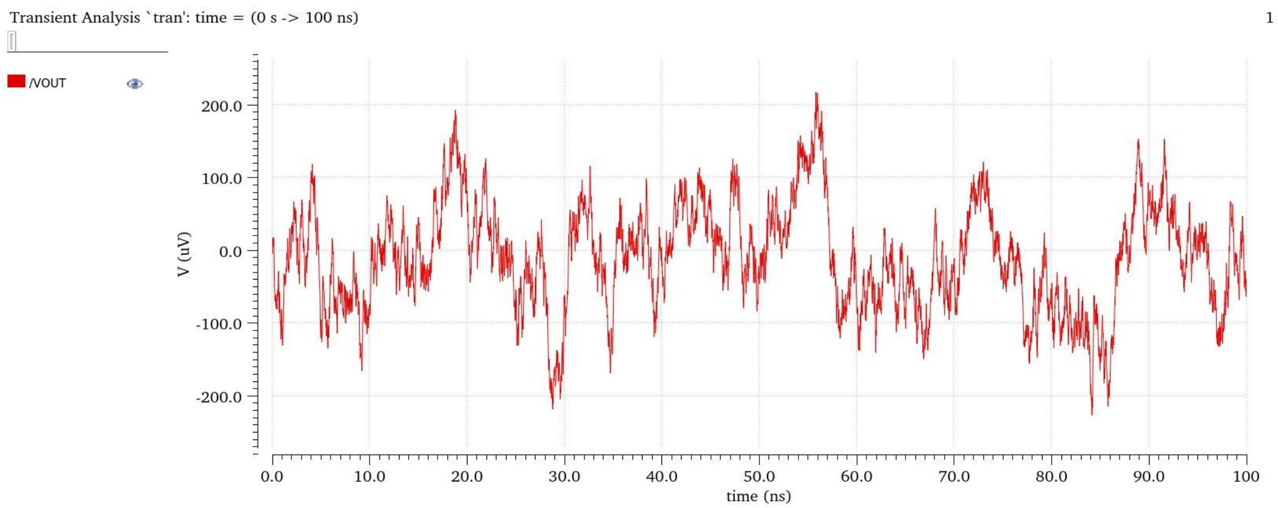


Figure 6 Plot output noise.

Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter
lab10_LPF_1	TRANS_PLOT				
lab10_LPF_1	MIN	-226.7u			
lab10_LPF_1	MAX	218u			

Figure 7 MAX and MIN.

<u>Use the rms function in the calculator to calculate the rms noise. Compare it to the value calculated in Part 1.</u>

Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter
lab10_LPF_1	MIN	-226.7u			
lab10_LPF_1	MAX	218u			
lab10_LPF_1	RMS	73.04u			

Figure 8 RMS from simulator.

The RMS noise increased as in part 1 was equal to 73.04μ.

<u>Repeat the simulation with TSTEP = TAU/10.</u>

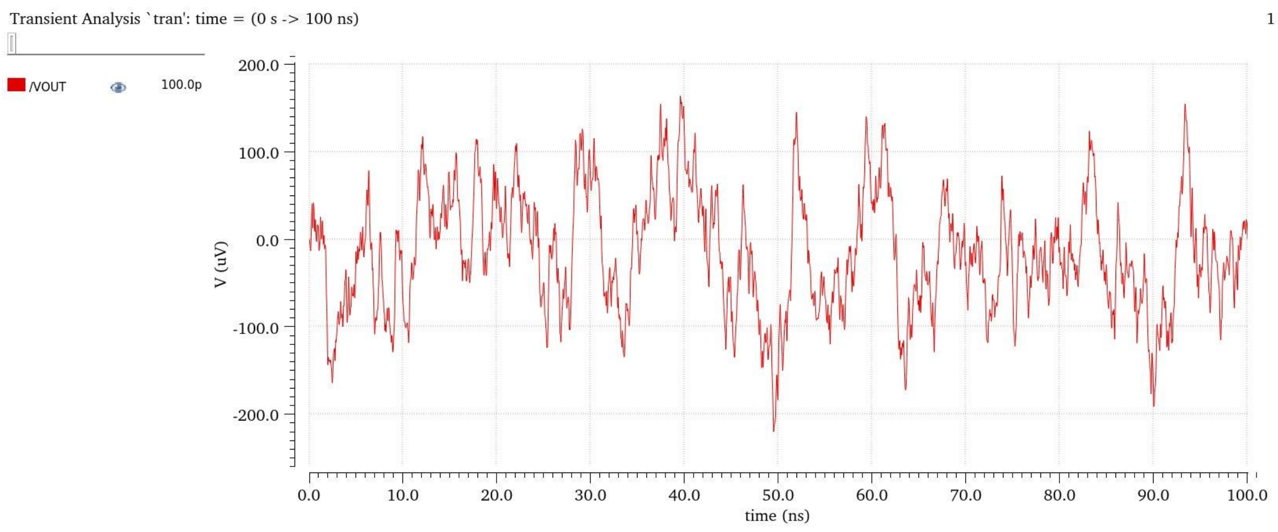


Figure 9 output noise plot.

Does the calculated rms noise increase or decrease? Why?

Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter
lab10_LPF_1	TRANS_PLOT				
lab10_LPF_1	MIN	-219.9u			
lab10_LPF_1	MAX	163.7u			
lab10_LPF_1	RMS	68.92u			

Figure 10 results from simulator.

The rms noise decrease slightly than that of TAU/10.

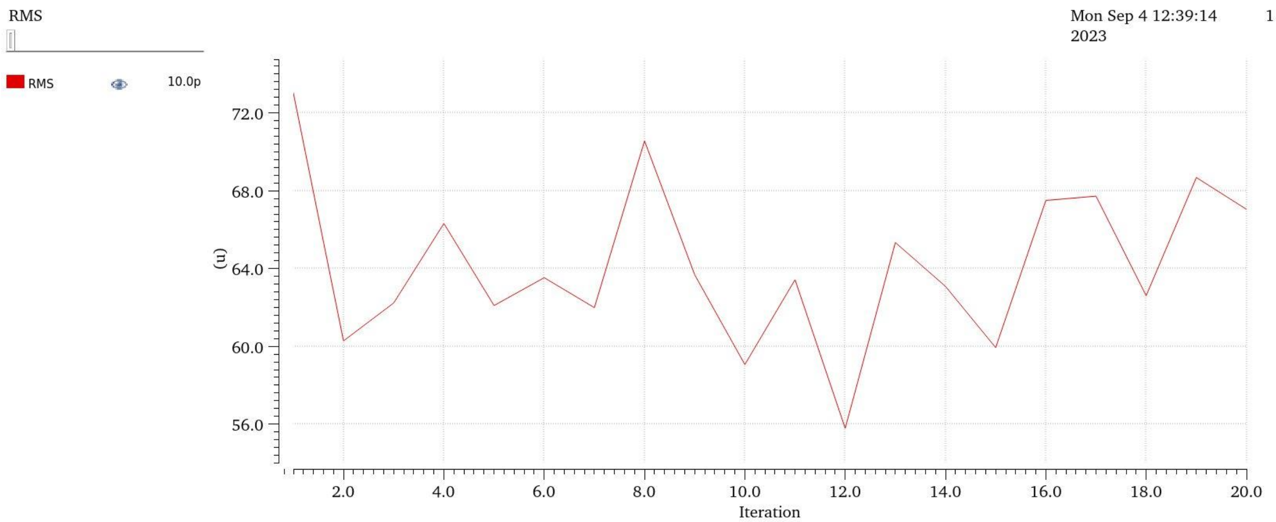


Figure 11 plot RMS Iteration.

Use the calculator to calculate the average rms noise. Compare the calculated value with the rms noise previously obtained in Part 1 and Part 2.

average(leafValue(RMS "TSTEP" 1e-...

	Expression	Value
1	average(leafVal...	63.89E-6

Figure 12 Average od RMS.

	Part 1	Part 2
Average RMS	64.32μ	63.89μ

PART 3: 5T OTA AC Noise Analysis

Report output noise vs frequency. Annotate noise density and bandwidth in the plot.Compare the simulation results with hand analysis

This graph shows the total noise which is the flicker noise and thermal noise which is clear that the graph takes the shape of the flicker noise as it decays with frequency and the thermal noise is white noise which here acts as an offset.

So, I want to get the bandwidth, so I got it from the thermal noise.

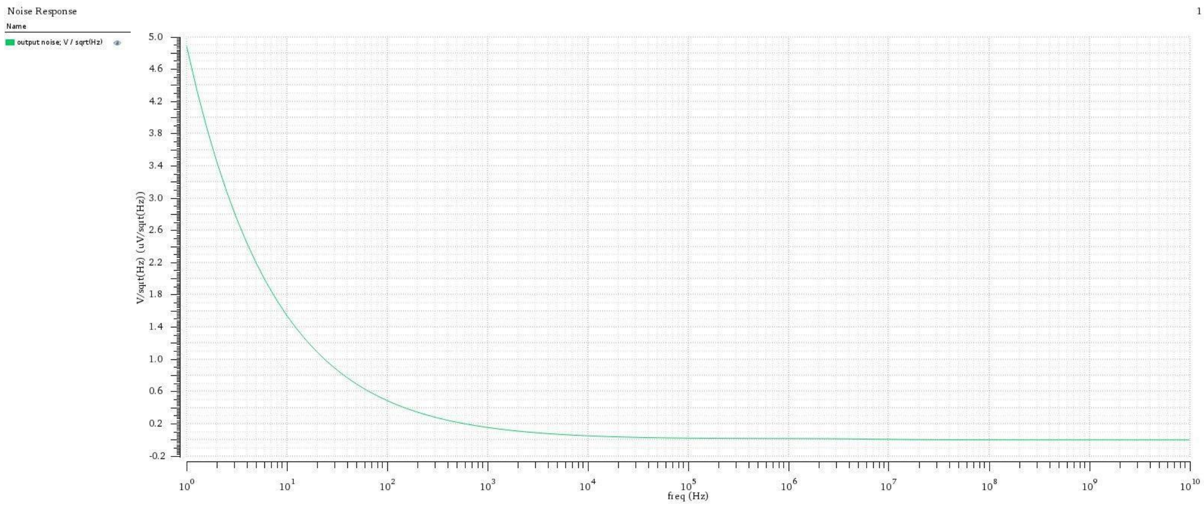


Figure 13 Output noise plot.

The thermal noise graph.

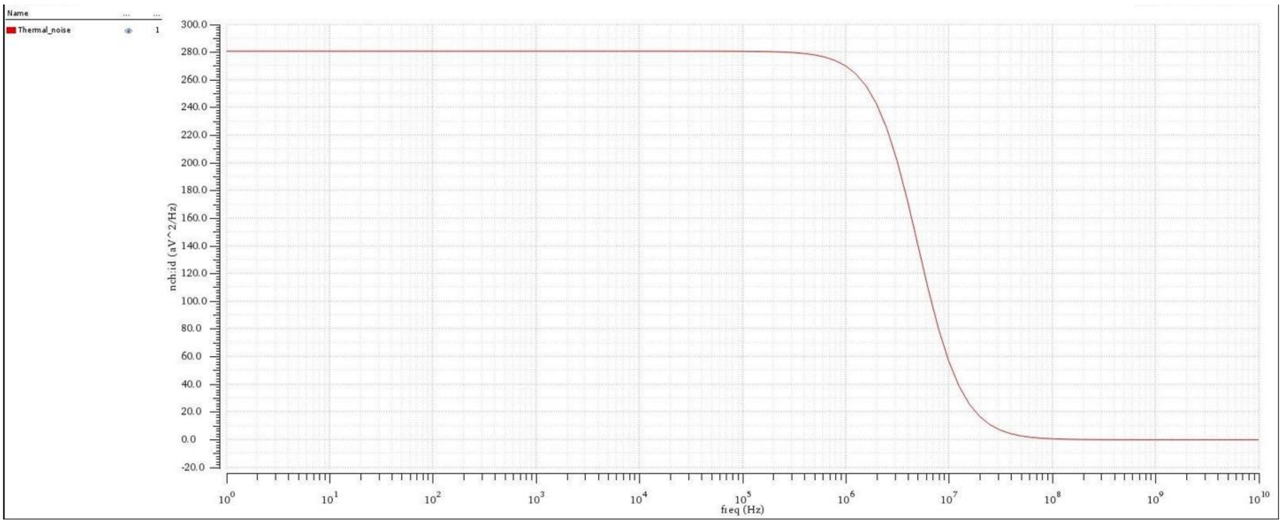


Figure 14 thermal noise plot.

Then the thermal noise in dB.

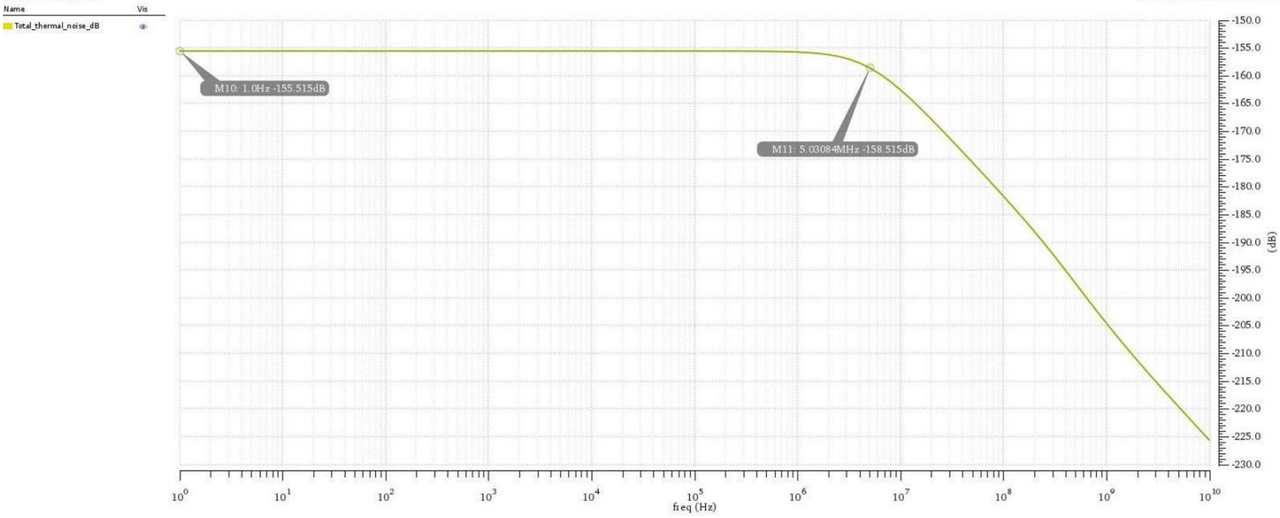


Figure 15 thermal noise in dB

From this graph thermal noise = 16.759 $\frac{nV}{\sqrt{HZ}}$

Here it's clear that the bandwidth is equal to 5 MHZ.

In this graph this is the noise in dB and here is the bandwidth annotated.

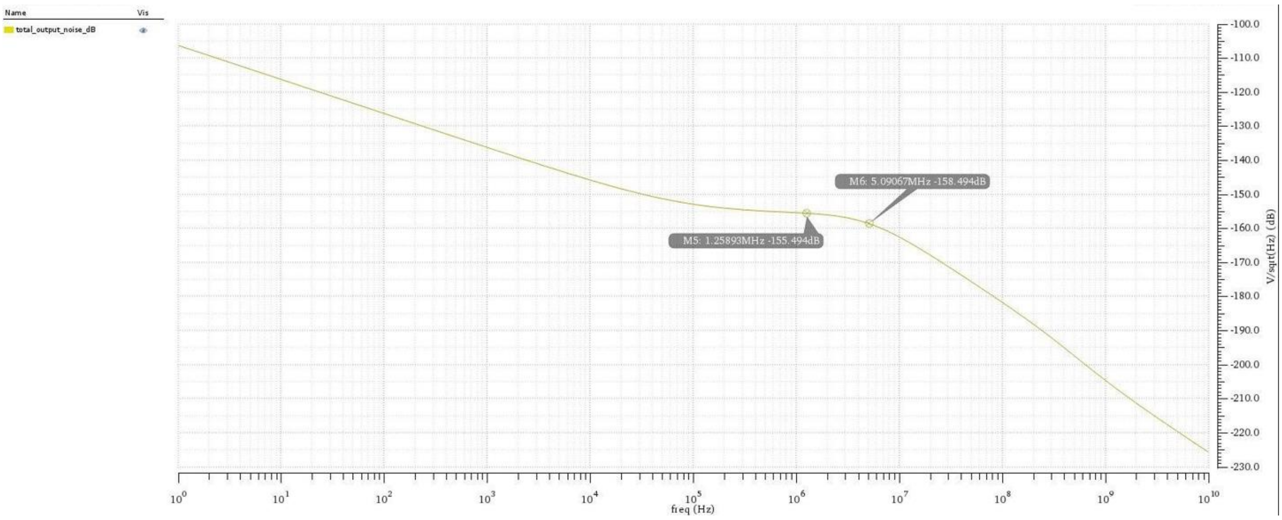


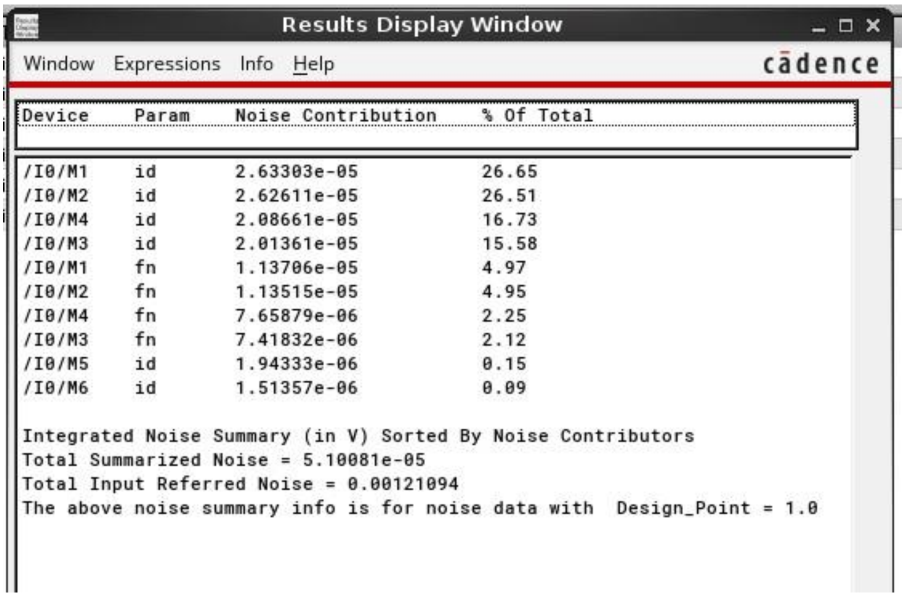
Figure 16 Corner Frequency.

<u>Calculate rms output noise (calculate the rms noise due to thermal noise only using Noise Summary).</u>

Test	Output	Nominal	Spec	Weight	Pass/Fail
Lab_10:part3_ota:1	output noise; V / sqrt(Hz)				
Lab_10:part3_ota:1	Thermal_noise				
Lab_10:part3_ota:1	thermal_noise_dB				
Lab_10:part3_ota:1	total_thermal_noise				
Lab_10:part3_ota:1	total_thermal_noise_db				
Lab_10:part3_ota:1	rmsNoise(1 1e+10)	51.01u			

This is the total output rms noise.

Figure 17 RMS Noise Result.


Results Display Window

Window Expressions Info Help cādence

Device	Param	Noise Contribution	% Of Total
/I0/M1	id	2.63303e-05	26.65
/I0/M2	id	2.62611e-05	26.51
/I0/M4	id	2.08661e-05	16.73
/I0/M3	id	2.01361e-05	15.58
/I0/M1	fn	1.13706e-05	4.97
/I0/M2	fn	1.13515e-05	4.95
/I0/M4	fn	7.65879e-06	2.25
/I0/M3	fn	7.41832e-06	2.12
/I0/M5	id	1.94333e-06	0.15
/I0/M6	id	1.51357e-06	0.09

Integrated Noise Summary (in V) Sorted By Noise Contributors
Total Summarized Noise = 5.10081e-05
Total Input Referred Noise = 0.00121094
The above noise summary info is for noise data with Design_Point = 1.0

Figure 18 noise summery.

The rms noise due to thermal noise only is equal to:

$$100\% - (4.97\% + 4.95\% + 2.25\% + 2.12\%) * TOTAL\ NOISE = 43.72\ u$$

<u>Compare the simulation results (noise density, bandwidth, and rms) with hand analysis.</u>

$$gamma = \frac{3}{4} \rightarrow g_{m1} = 157.3\ u \rightarrow g_{m3} = 92.54\ u \rightarrow B = 1$$

noise density $= VOUT_{RMS} = \sqrt{\frac{8KT\gamma}{gm_1} * (1 + \frac{gm_3}{gm_1})} = 14.93 \frac{nV}{\sqrt{HZ}}$

1

$$Bandwith = \frac{1}{2*\pi*R_{OUT}*C_L} * (1 + \beta A_{OL}) = 5.09MHZ$$

$$RMS_{Noise} = \sqrt{VOUT_{RMS}^2 * BW * \frac{\pi}{2}} = 42.216\mu.$$

	Simulation	Analytical
BW	5.03 MHz	5.09MHz
Noise density	14.759 n	14.93 n
Rms noise (thermal)	43.72 u	42.216 u

PART 4: 5T OTA Transient Noise Analysis

<u>Plot input and output overlaid and make sure they match well (verify that the circuit behaves as a buffer).</u>

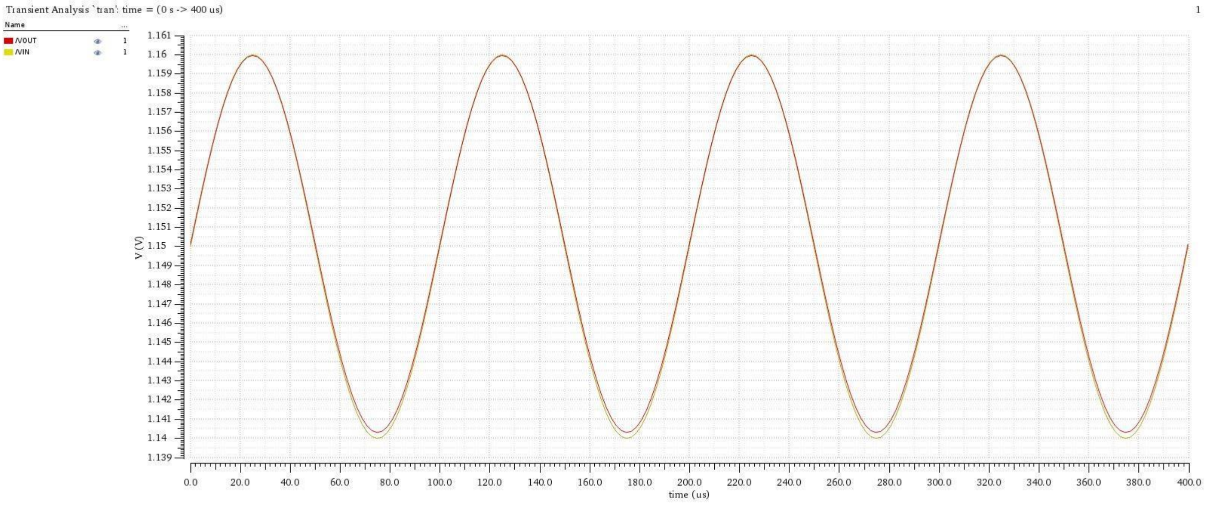


Figure 19 Transient PLOT.

the output signal is almost equal to the input signal, but it has some slight errors due to the finite gain of the 5T-OTA.

<u>Report the "noisy" output waveform. Notice that output signal and noise are superimposed.</u>

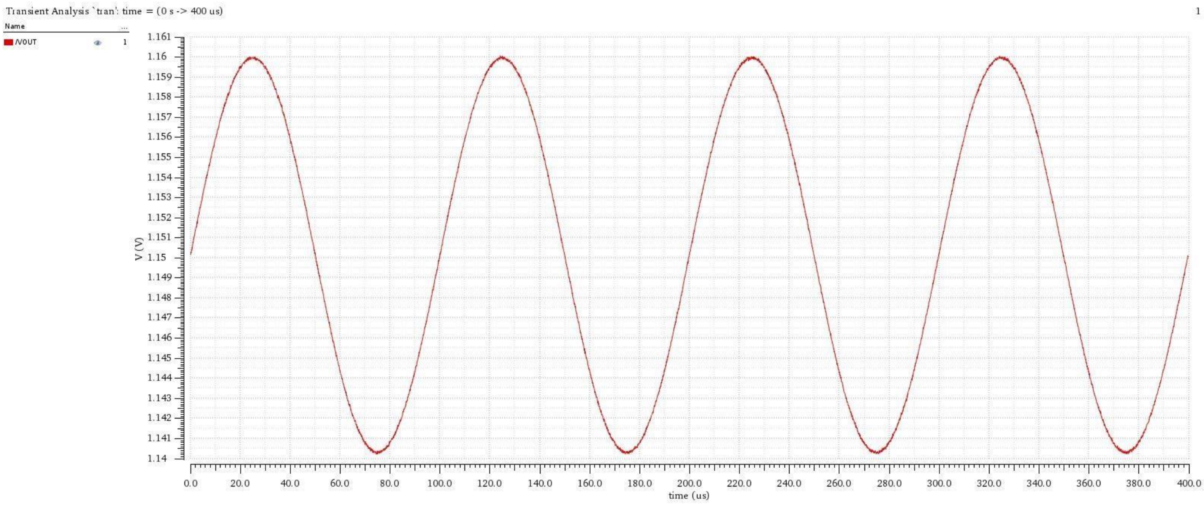


Figure 20 Noisy output.

As we can see that the output signal is noisy here is a closer look.

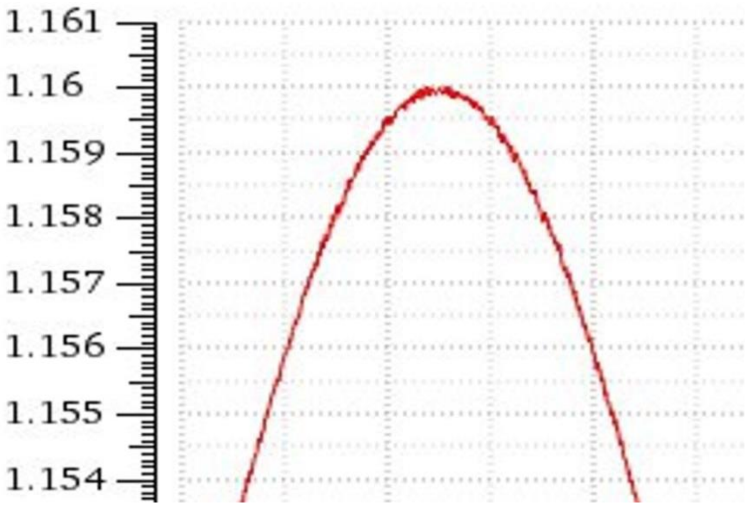


Figure 21 Zoom in Noisy output.

<u>Report the rms noise vs iteration.</u>

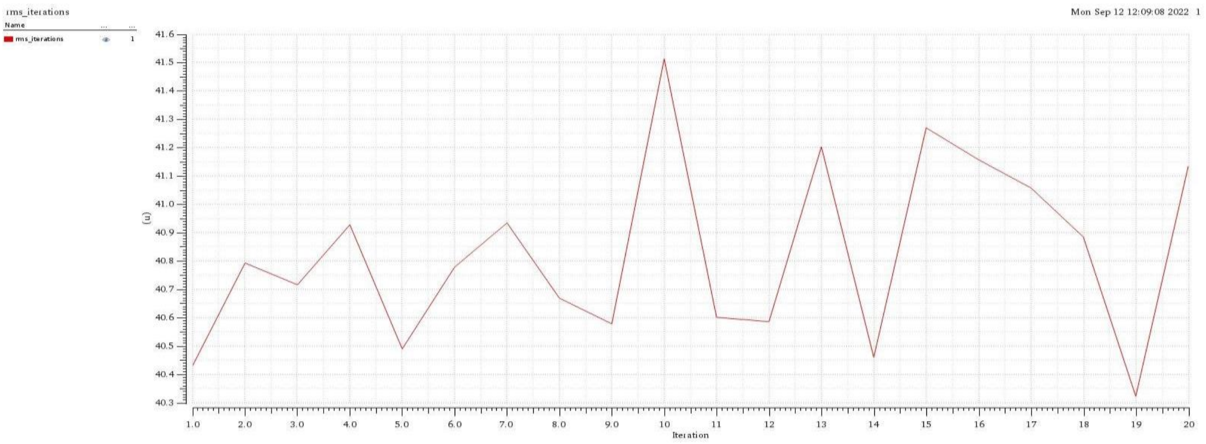


Figure 22 RMS Noise vs Iteration.

<u>Use the calculator to calculate the average rms noise. Compare the calculated value with the rms noise previously obtained in Part 3.</u>

Test	Output	Nominal	Spec	Weight	Pass/Fail
Lab_10:part3_ota:1	VOUT				
Lab_10:part3_ota:1	VIN				
Lab_10:part3_ota:1	Vdiff				
Lab_10:part3_ota:1	rms_iterations				
Lab_10:part3_ota:1	average(rms(Vdiff))	40.83u			

	Part 3	Part 4
Average rms noise	50.01 u 43.72 u (thermal)	40.83u