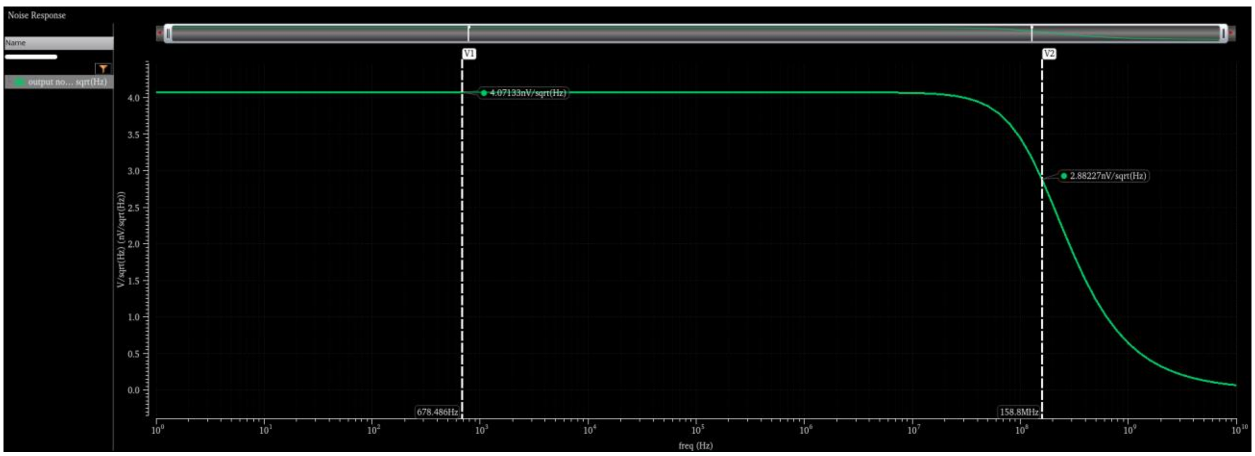
Analog IC Design

Lab 10

PART 1: LPF AC Noise Analysis

R = 1kΩ & C = 1pF

Output Noise vs Frequency



bandwidth(getData("/out" ?result "n...

	Expression	Value	Expression	Value
1	bandwidth(getD...	158.8E6	rmsNoise(1 10G)	64.32E-6

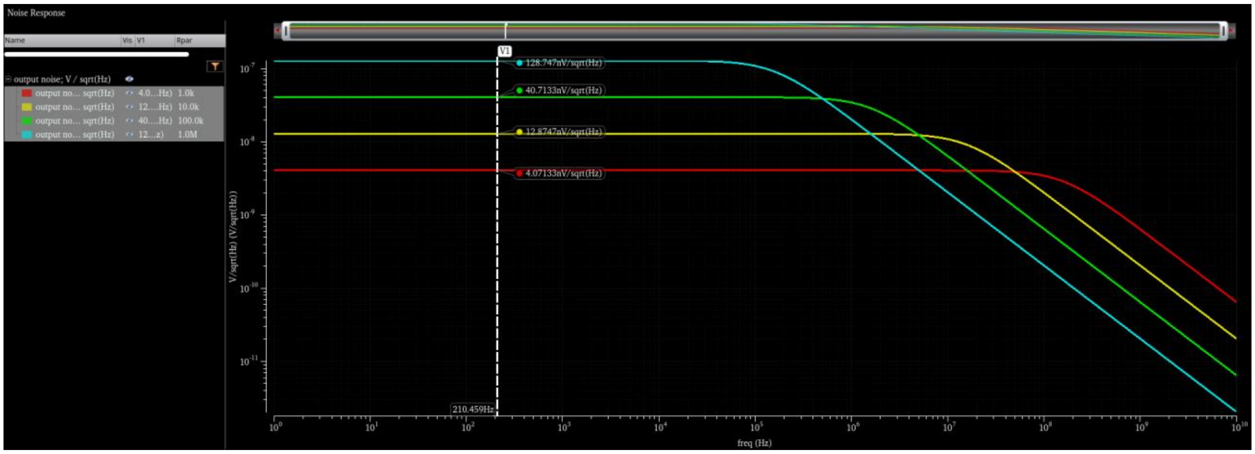
Hand Analysis

- $V_n^2(f) = 4KTR = 4(4.14 * 10^{-21})(1k) = 1.66 * 10^{-17} \rightarrow V_n(f) = 4.069 \frac{nv}{\sqrt{Hz}}$
- $V_{nrms}^2 = \frac{KT}{C} = \frac{4.14*10^{-21}}{1p} \rightarrow V_{nrms} = 64.34\mu V$
- $BW = \frac{2}{4\pi RC} = 159.2MHz$

	Simulation	Hand Analysis
Noise Density $\left(\frac{nv}{\sqrt{Hz}}\right)$	4.071	4.069
Noise RMS (µV)	64.32	64.34
Bandwidth (MHz)	158.8	159.2

Parametric Sweep (R = 1k, 10k, 100k, 1000k)

Output Noise vs Frequency (Log. Scale)



Comment: Noise density is directly proportional with resistance (R) and noise bandwidth is inversely proportional with resistance.

RMS Noise

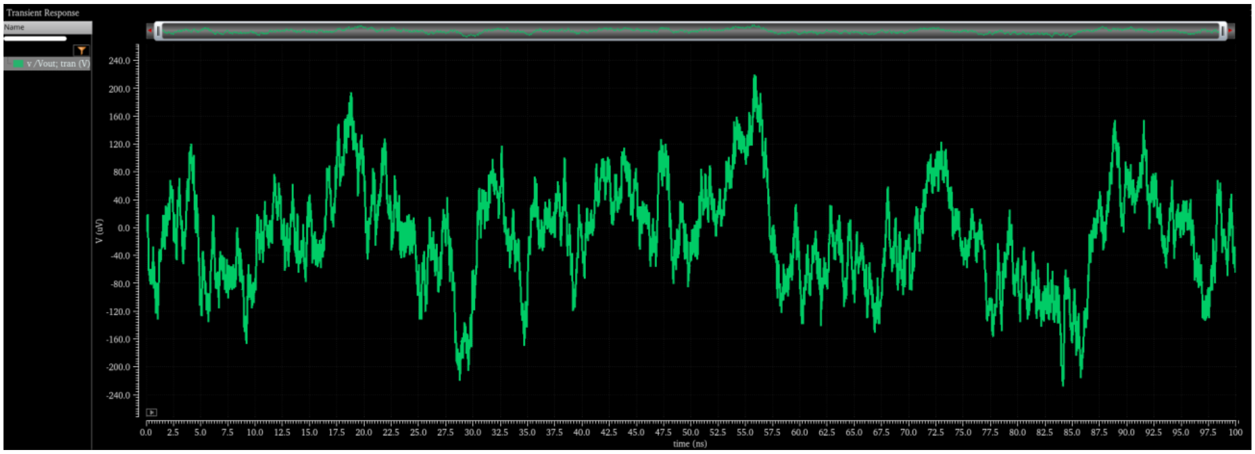
rmsNoise(1 10G)

	Rpar	rmsNoise(1 10G)
1	1.000E3	64.32E-6
2	10.00E3	64.62E-6
3	100.0E3	64.65E-6
4	1.000E6	64.66E-6

Comment: RMS noise is independent of resistance. Increasing R increases the density but reduces the BW; thus, the total integrated noise (area under the curve) is unchanged.

PART 2: LPF Transient Noise Analysis

Output Waveform ($T_{step} = \tau/100$)



ymin(vtime('tran "/Vout")) ymax(vti...

	Expression	Value	Expression	Value	Expression	Value
1	ymin(vtime('tran...	-226.7E-6	ymax(vtime('tra...	218.0E-6	rms(vtime('tran ...	73.04E-6

	Noise Simulation	Transient Simulation
RMS Noise (μV)	64.32	73.04

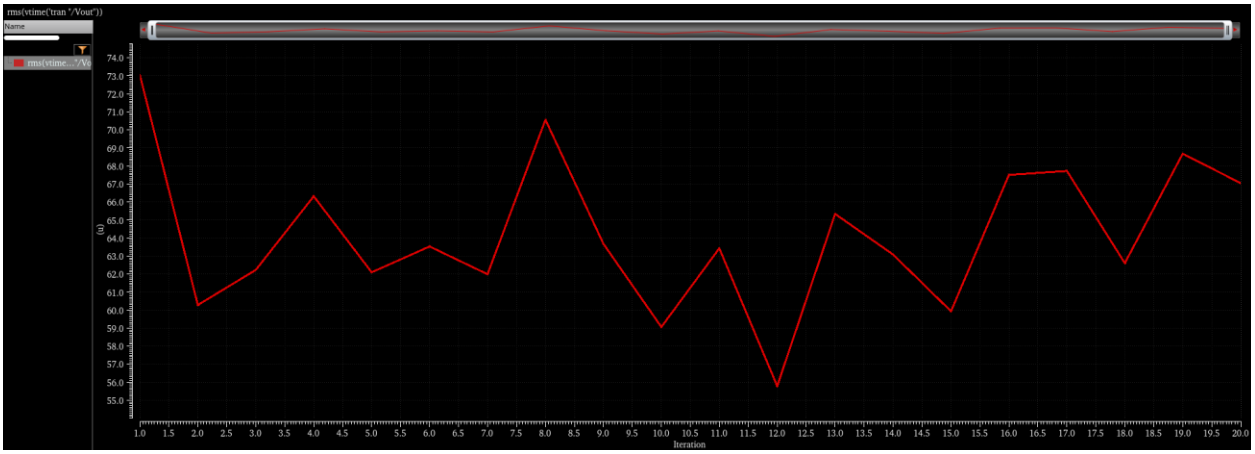
$T_{step} = \tau/10$

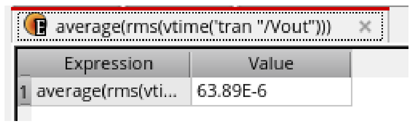
rms(vtime('tran "/Vout"))

	Expression	Value
1	rms(vtime('tran ...	68.92E-6

Comment: RMS noise decreased when the step increased (68.92 < 73.04), because we reduced the frequency window (lower area under the curve).

RMS Noise vs Iteration

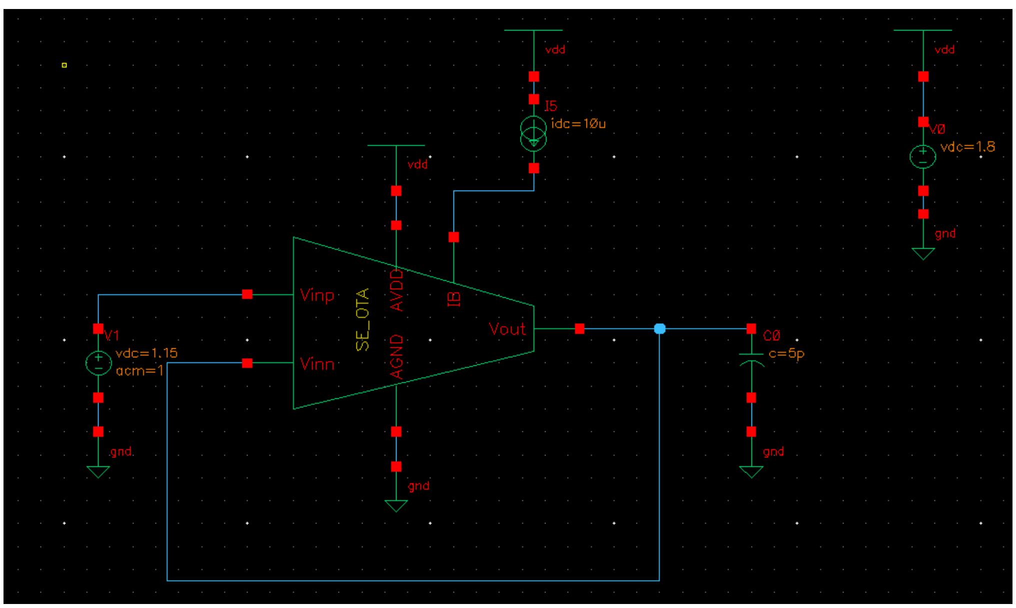




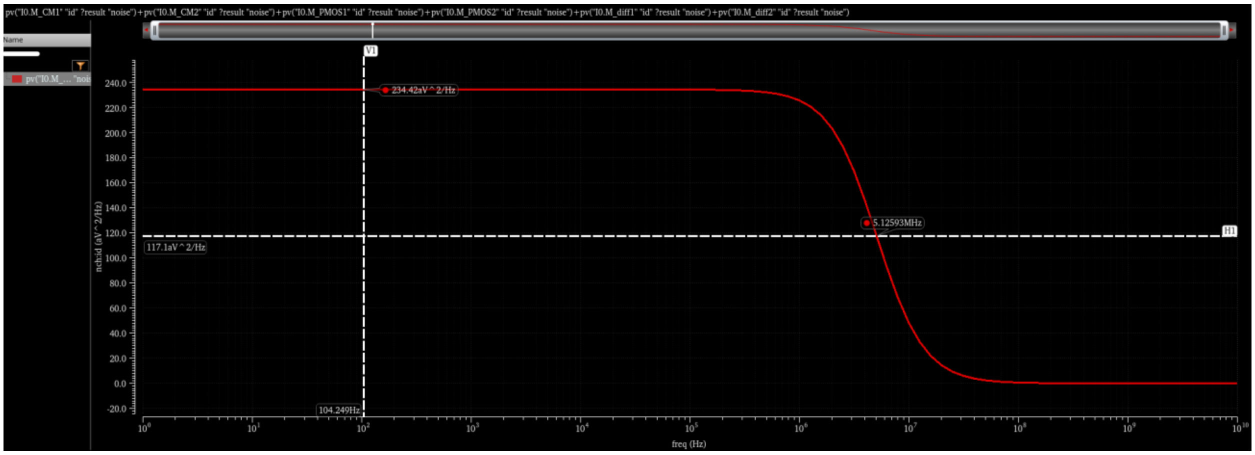
	Noise Simulation	Transient (1iteration)	Transient (avg. 20 iterations)
RMS Noise (μV)	64.32	73.04	63.89

PART 3: 5T OTA AC Noise Analysis

Schematic



Output Thermal Noise vs Frequency



- $V_{out}^2(f) = 234.42a \rightarrow V_{out}(f) = 15.3\frac{nV}{\sqrt{Hz}}$
- BW = 5.13MHz

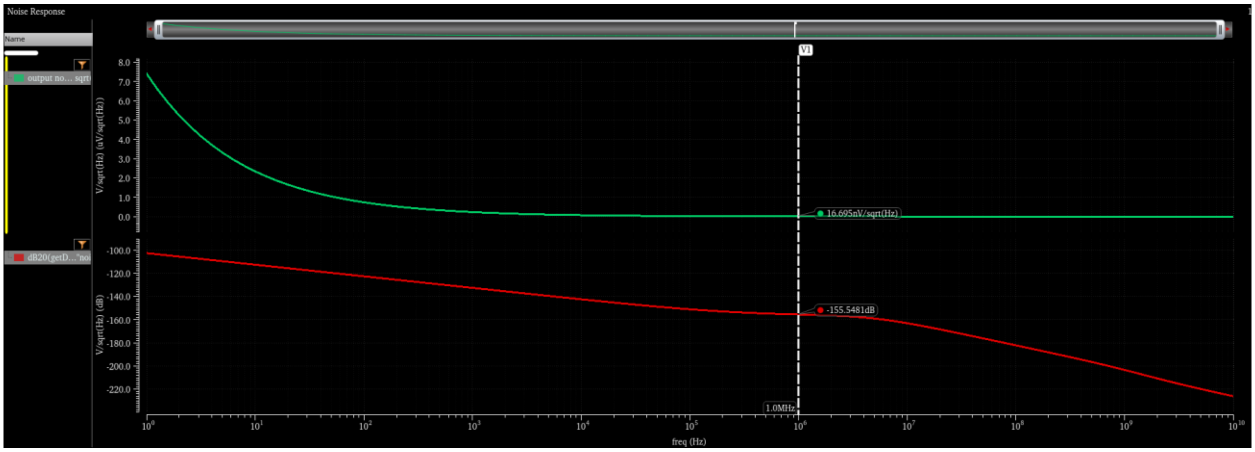
Hand Analysis

	Name	Value
1	I0.M_PMOS1:gm	66.21E-6
2	I0.M_diff1:gm	162.5E-6
3	I0.M_PMOS1:rout	629.6E3
4	I0.M_diff1:rout	623.7E3

- $V_{out}^2(f) = \frac{8KT\gamma}{gm_{diff}}\left(1 + \frac{gm_{load}}{gm_{diff}}\right) * Av^2 = \frac{8(4.14*10^{-21})\left(\frac{2}{3}\right)}{162.5*10^{-6}}\left(1 + \frac{66.2}{162.5}\right) * 1^2 = 191.2aV$
- $V_{out}(f) = 13.8\frac{nV}{\sqrt{Hz}}$
- $BW_{OL} = \frac{1}{2\pi RC_L} = \frac{1}{2\pi(ro_{diff}||ro_{load})C_L} = \frac{1}{2\pi(313.3k)(5p)} = 101.6kHz$
- $GBW_{OL} = 50 * 101.6k = 5.08MHz$
- $GBW_{OL} = GBW_{CL} = 1 * 5.08M \rightarrow B_N = 5.08MHz$

	Transient Simulation	Hand Analysis
Noise density $\left(\frac{nV}{\sqrt{Hz}}\right)$	15.3	13.8
Bandwidth (MHz)	5.13	5.08

Total Output Noise (Thermal + Flicker) vs Frequency



Flicker noise corner ≈ 1MHz

RMS Output Noise

Device	Param	Noise Contribution	% Of Total
/I0/M_diff2	id	6.59705e-10	23.98
/I0/M_diff1	id	6.56537e-10	23.87
/I0/M_PMOS2	fn	3.04181e-10	11.06
/I0/M_PMOS2	id	3.02605e-10	11.00
/I0/M_PMOS1	fn	2.89702e-10	10.53
/I0/M_PMOS1	id	2.70422e-10	9.83
/I0/M_diff2	fn	1.33622e-10	4.86
/I0/M_diff1	fn	1.29858e-10	4.72
/I0/M_CM2	id	2.1769e-12	0.08
/I0/M_CM1	id	1.48858e-12	0.05
/I0/M_PMOS2	rs	9.03722e-14	0.00
/I0/M_PMOS1	rs	8.16347e-14	0.00
/I0/M_CM1	fn	4.55001e-14	0.00
/I0/M_CM2	fn	2.16432e-14	0.00
/I0/M_PMOS2	rd	8.20984e-17	0.00
/I0/M_PMOS1	rd	2.84565e-17	0.00
/I0/M_diff1	rs	0	0.00
/I0/M_diff1	rd	0	0.00
/I0/M_diff2	rs	0	0.00
/I0/M_diff2	rd	0	0.00

Integrated Noise Summary (in V^2) Sorted By Noise Contributors
Total Summarized Noise = 2.75054e-09
Total Input Referred Noise = 2.1636e-06
The above noise summary info is for noise data

- Output thermal noise = $V_{rms}^2 = \sum id = 1.89nV$
- Output RMS thermal noise = 43.47μV

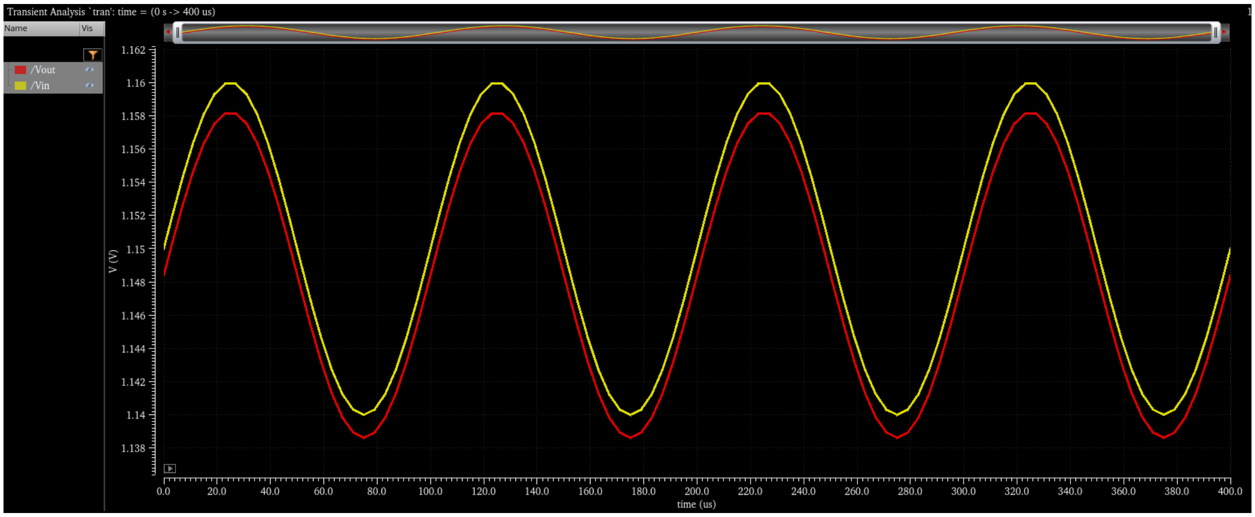
Hand Analysis

- Total noise density ≈ thermal noise density (dominant noise) = $13.8 \frac{nV}{\sqrt{Hz}}$
- BW = 5.08MHz (noise is multiplied with the same transfer function)
- Output RMS thermal noise = $\sqrt{234.42a * \frac{\pi}{2} * f_p = 234.42a * \frac{\pi}{2} * 5.13M}$ = 43.46 μV

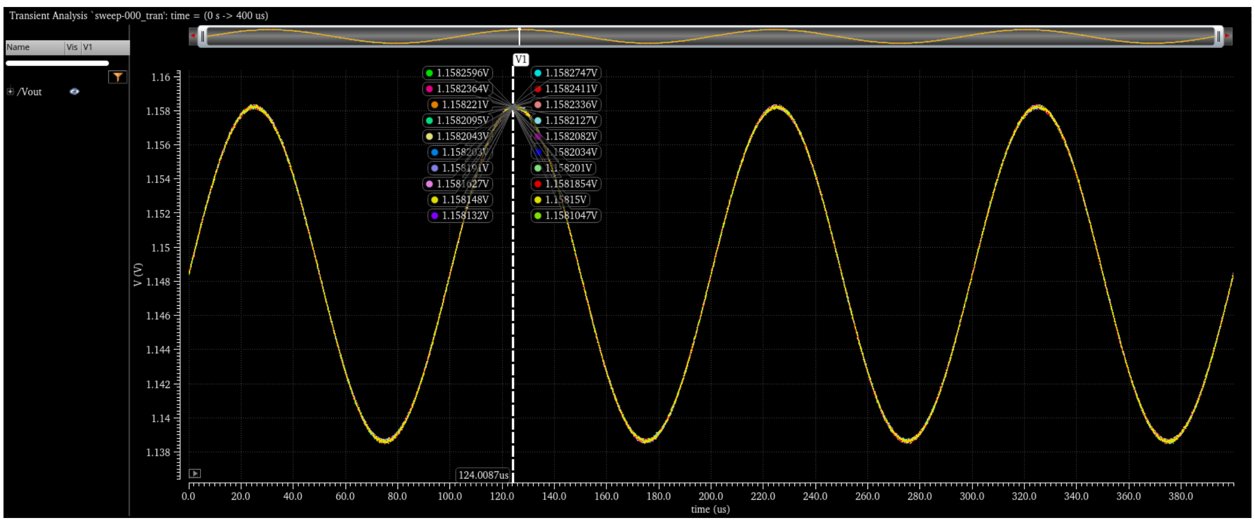
	Simulation	Hand Analysis
RMS Noise (μV)	43.47	43.46

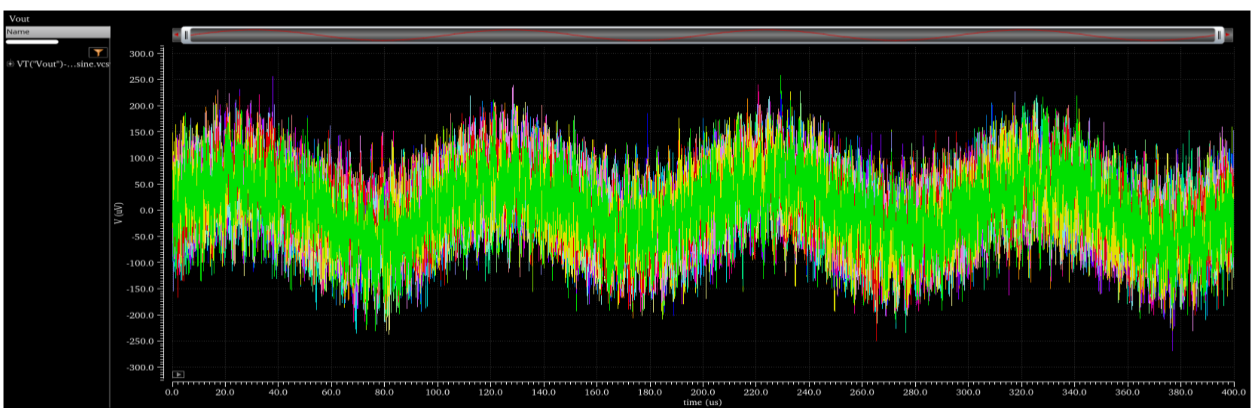
PART 4: 5T OTA Transient Noise Analysis

Input & Output vs Time

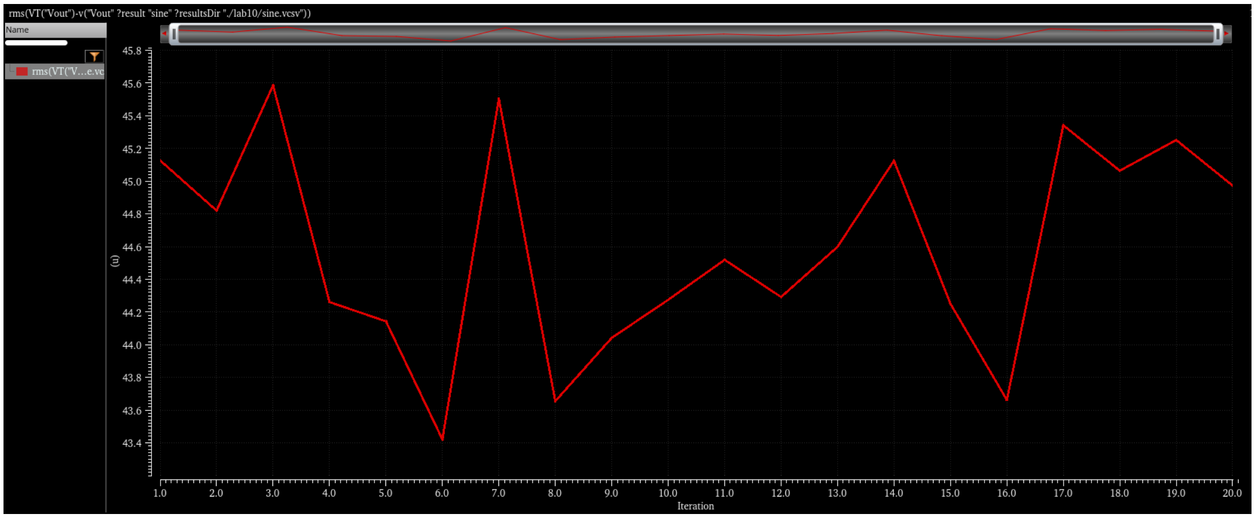


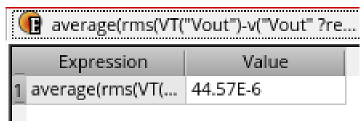
Noisy Output Waveform





RMS Noise vs Iteration





	Part 3 Simulation	Part 4 Simulation
RMS Noise (μV)	43.47	44.57

Comment: Part 4 is the total rms noise, and part 3 is thermal rms noise only.