LAB 10 :
NOISE SIMULATION

ITI_ANALOG_IC_DESIGN

Analog IC Design

Lab 10

Noise Simulation

PART 1: LPF AC Noise Analysis

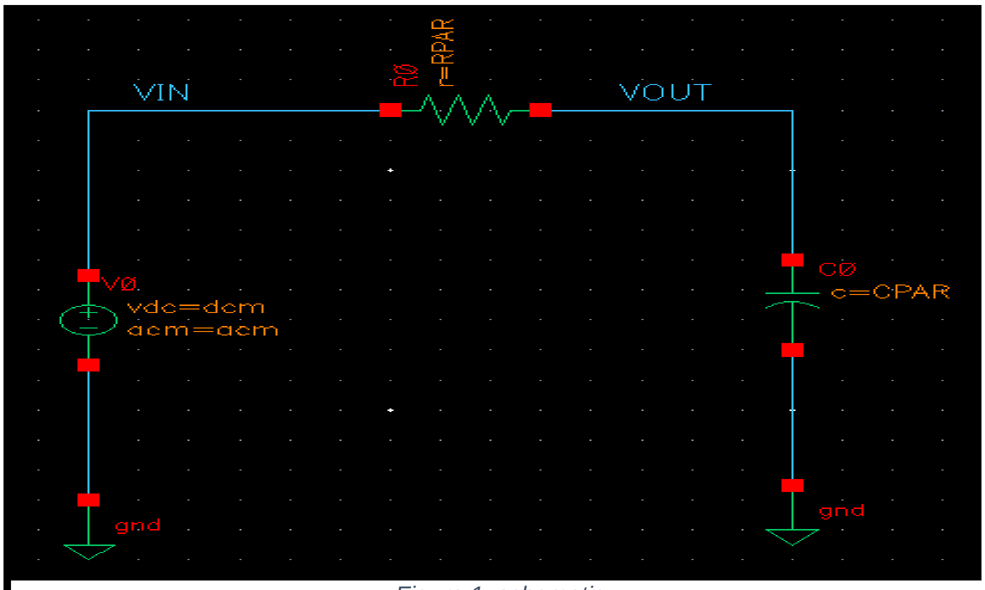


Figure 1: schematic

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

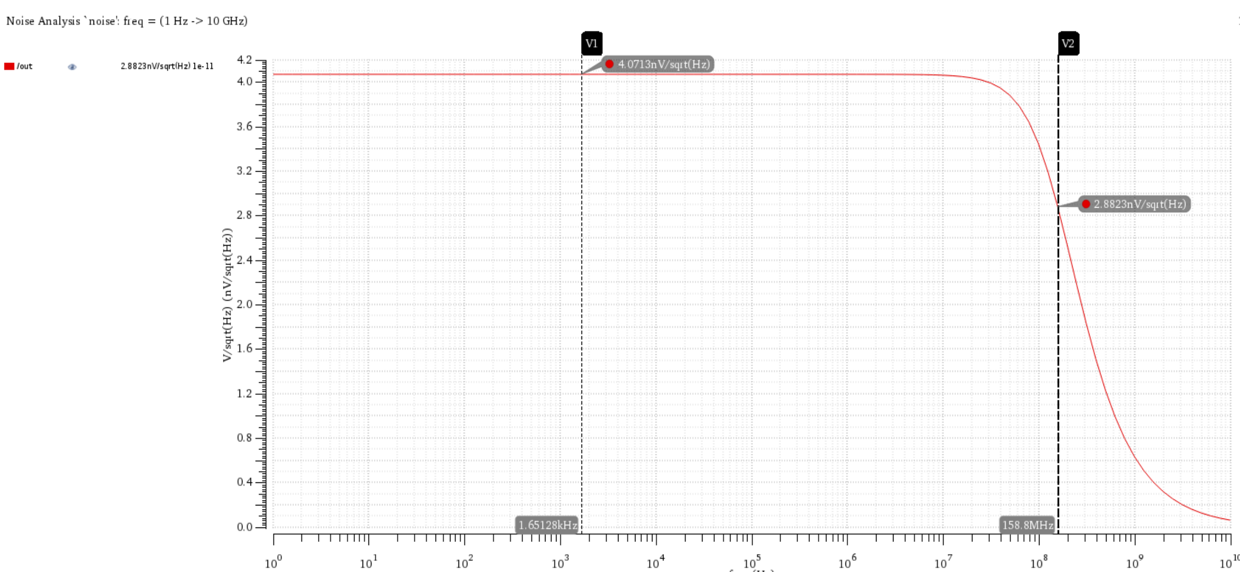


Figure 2: output noise vs freq Voltage and BW annotated

Lab 10 : NOISE SIMULATION

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

Test	Output	Nominal	Spec	Weight	Pass/Fail
lab_10_noise:part1:1	RMS	64.32u			
lab_10_noise:part1:1	BW	158.8M			

Hand analysis:

$V_n = \sqrt{4KTR}$ = 4.07 nV/ $\sqrt{HZ}$

BW= $\frac{1}{2\pi \times RC} = 159.1549\ MHZ$

RMS= $\sqrt{\frac{KT}{C}} = 64.36\ uV$

	V_n	BW	RMS
Simulation	4.0713 nV/ $\sqrt{HZ}$	158.8 MHZ	64.32 uV
Hand analysis	4.07 nV/ $\sqrt{HZ}$	159.1549 MHZ	64.36 uV

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

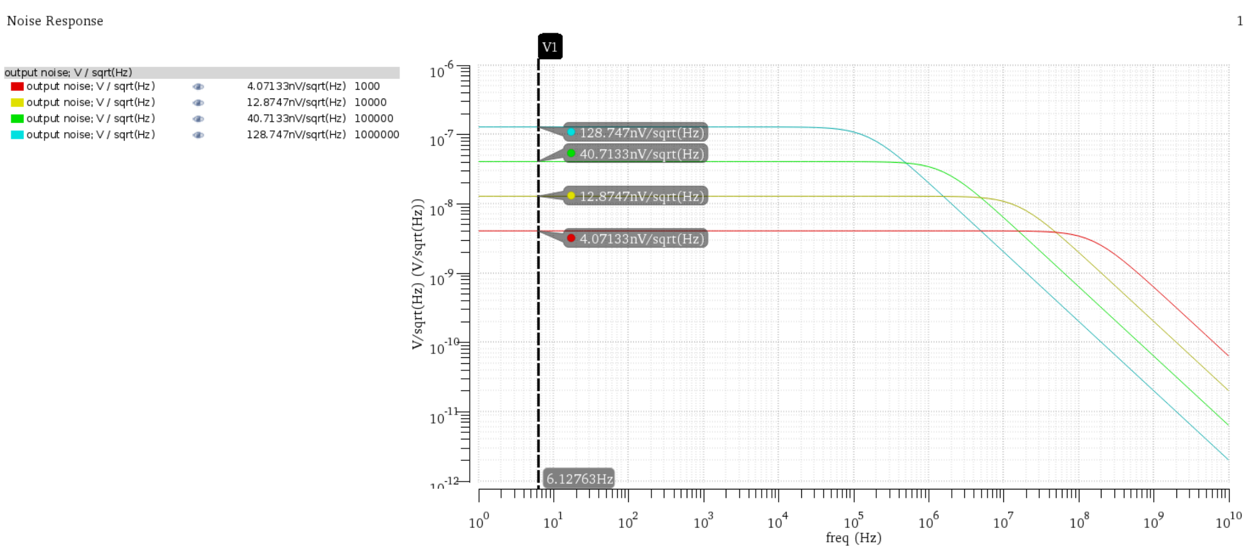


Figure 3: Vn VS 4 VALUES OF R

COMMENT

When R increases, the noise density also increases. This is expected because the thermal noise spectral density is given by $V_n = \sqrt{4KTR}$, so larger R directly raises V_n

11)Calculate the rms noise using the calculator. Comment on the results.

Parameters: RPAR=1k						
1	lab_10_noise:part1:1	RMS	64.32u			
1	lab_10_noise:part1:1	BW	158.8M			
Parameters: RPAR=10k						
2	lab_10_noise:part1:1	RMS	64.62u			
2	lab_10_noise:part1:1	BW	15.88M			
Parameters: RPAR=100k						
3	lab_10_noise:part1:1	RMS	64.65u			
3	lab_10_noise:part1:1	BW	1.588M			
Parameters: RPAR=1M						
4	lab_10_noise:part1:1	RMS	64.66u			
4	lab_10_noise:part1:1	BW	158.8k			

Figure 4: rms and BW from simulation

COMMENT

The calculated RMS output noise voltage remains approximately constant as expected despite the change in the resistor value R because there is no dependence for rms on R where RMS= $\sqrt{\frac{KT}{C}}$, but BW decrease because it depends on R values where BW= $\frac{1}{2\pi \times RC}$.

PART 2: LPF Transient Noise Analysis

3) Report the noise output waveform. Annotate the min and max values.

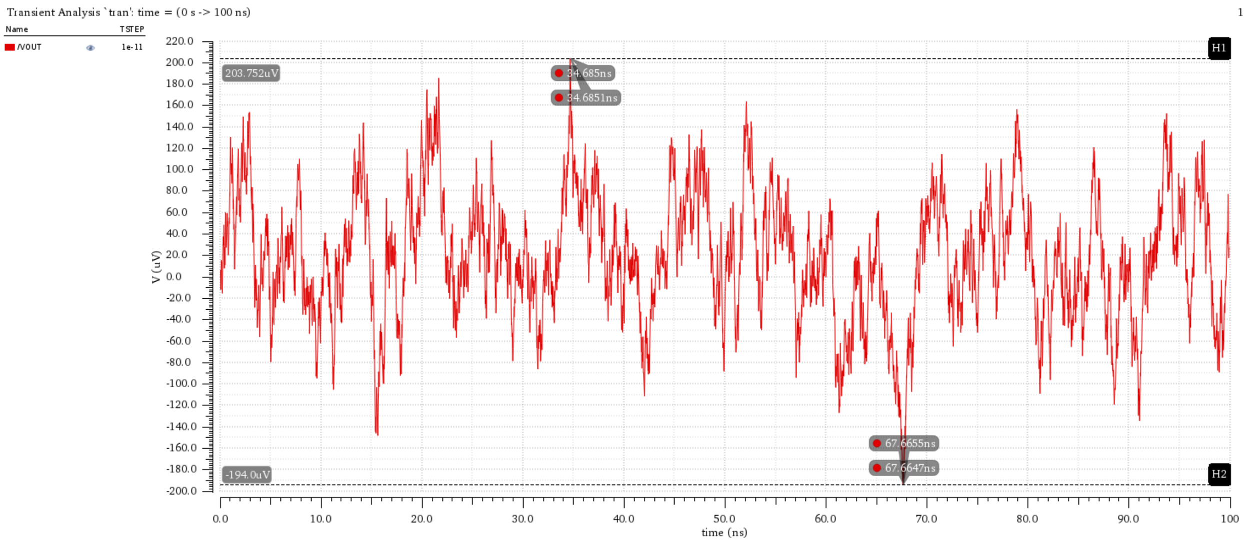


Figure 6: Noise output waveform

Test	Output	Nominal
lab_10_noise:part1:1	Y_MAX	203.8u
lab_10_noise:part1:1	Y_MIN	-194.2u

Figure 5: Y_MAX and Y_MIN from simulation

4) Use the rms function in the calculator to calculate the rms noise Compare it to the value calculated in Part 1.

Expression	Value
rms(v("/VOUT"...	60.88E-6

	RMS
PART 1	64.32 uV
PART 2	60.88 uV

5) Repeat the simulation with TSTEP = TAU/10. Does the calculated rms noise increase or decrease? Why?

lab_10_noise:part1:1	rms	61.59u			

- The simulated RMS noise result shows an increase, which is not the expected trend. Normally, increasing T_STEP should lower the maximum noise frequency (Fmax) and therefore reduce the RMS noise value. The observed increase is likely due to a limitation or artifact of the simulation setup/machine

7) Report the rms noise vs iteration.

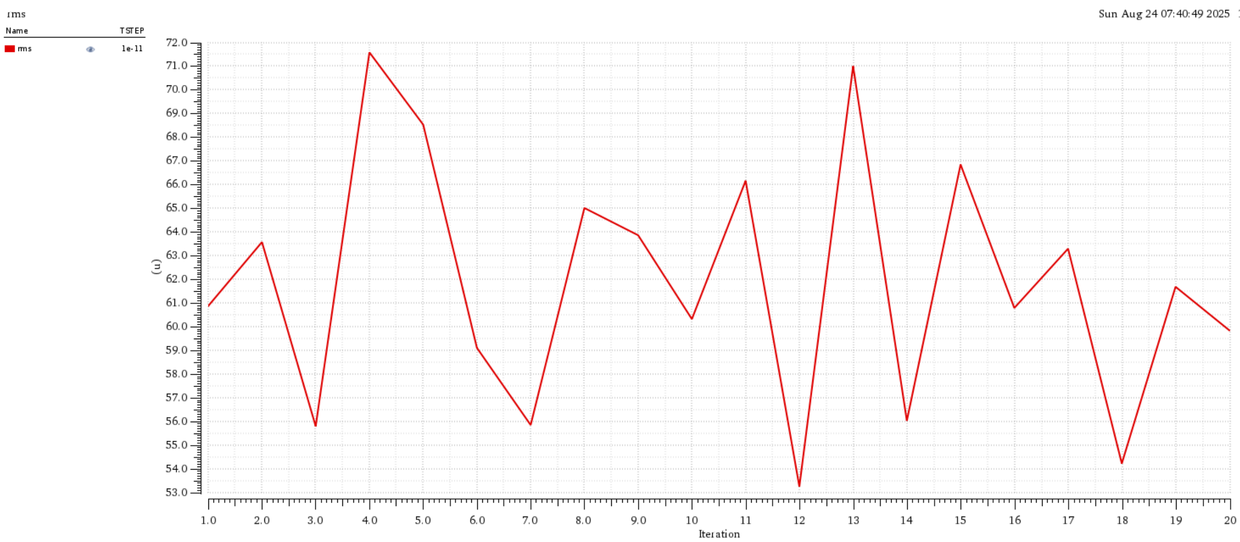


Figure 7: rms VS iteration

8) 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.

lab_10_noise:part1:1	AVERAGE	61.97u			

	RMS
PART 1	64.32 uV
PART 2	60.88 uV
AVERAGE	61.97 uV

PART 3: 5T OTA AC Noise Analysis

1) Create a new testbench. Connect the 5T OTA you designed in Lab 07 in unity-gain buffer configuration. Similar to Part 1, run ac noise analysis.

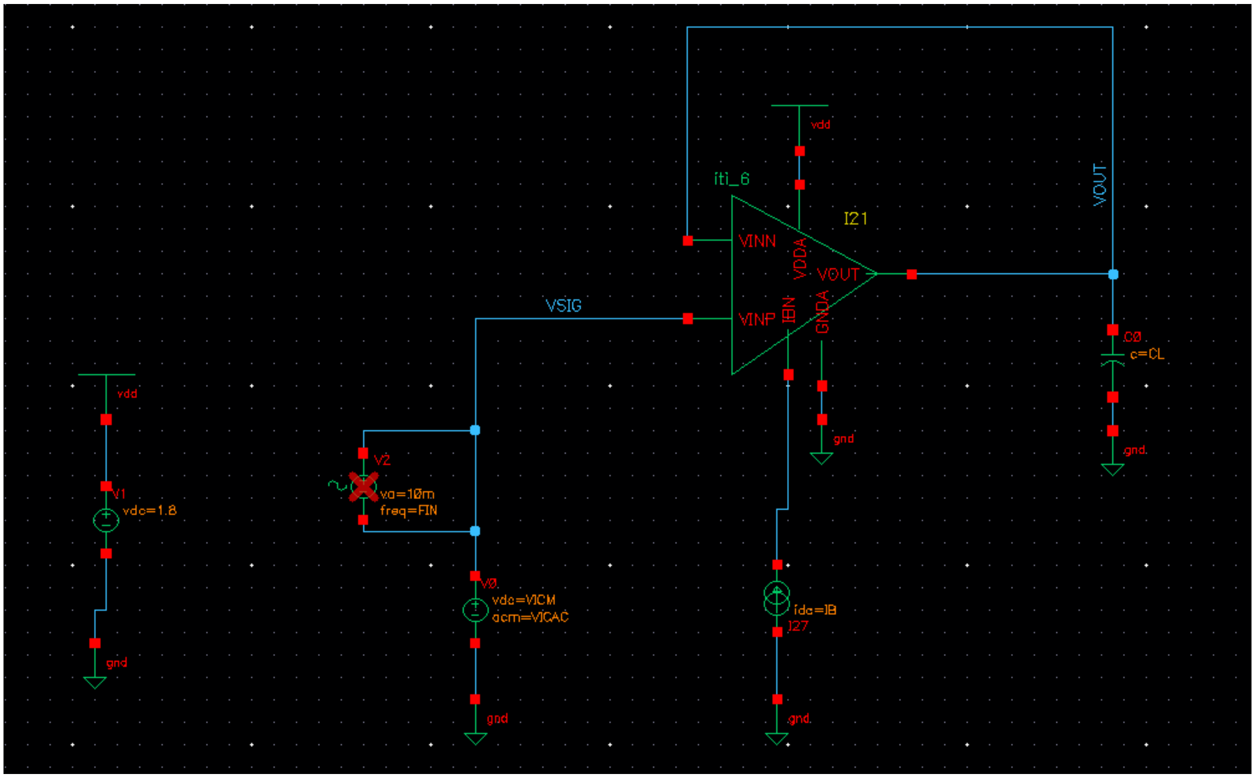


Figure 8:SCHEMATIC

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

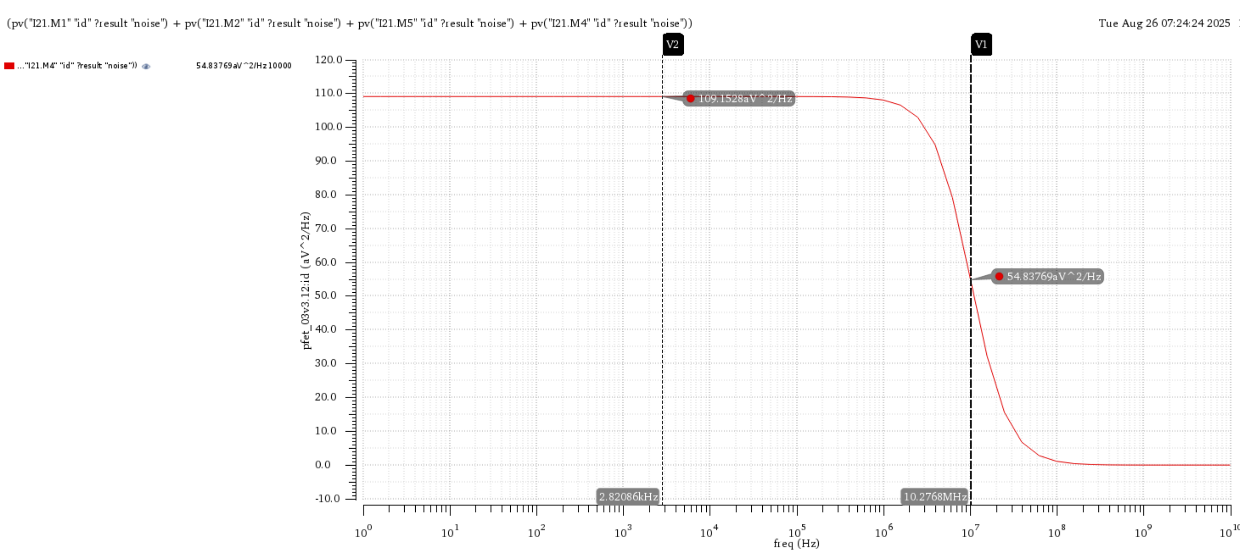


Figure 9: output thermal noise VS freq

Hand analysis:

Assume $\gamma = 2/3$

From lab 7: $gm_n = 320\text{uS}$, $gm_p = 200\text{uS}$, CL= 5p

$\overline{V_{nout}^2} = \frac{8KT\gamma}{gm_n}(1 + \frac{gm_p}{gm_n})$ =108.517 aV^2/ HZ

BW =GBW =$\frac{gm_n}{2\pi \times CL}$ =10.1859 MHZ

	$\overline{V_{nout}^2}$	BW
Simulation	109.1528 aV^2/ HZ	10.2768 MHZ
Hand analysis	108.517 aV^2/ HZ	10.1859 MHZ

3) Report total output noise (thermal + flicker) vs frequency. Estimate the Flicker noise corner.

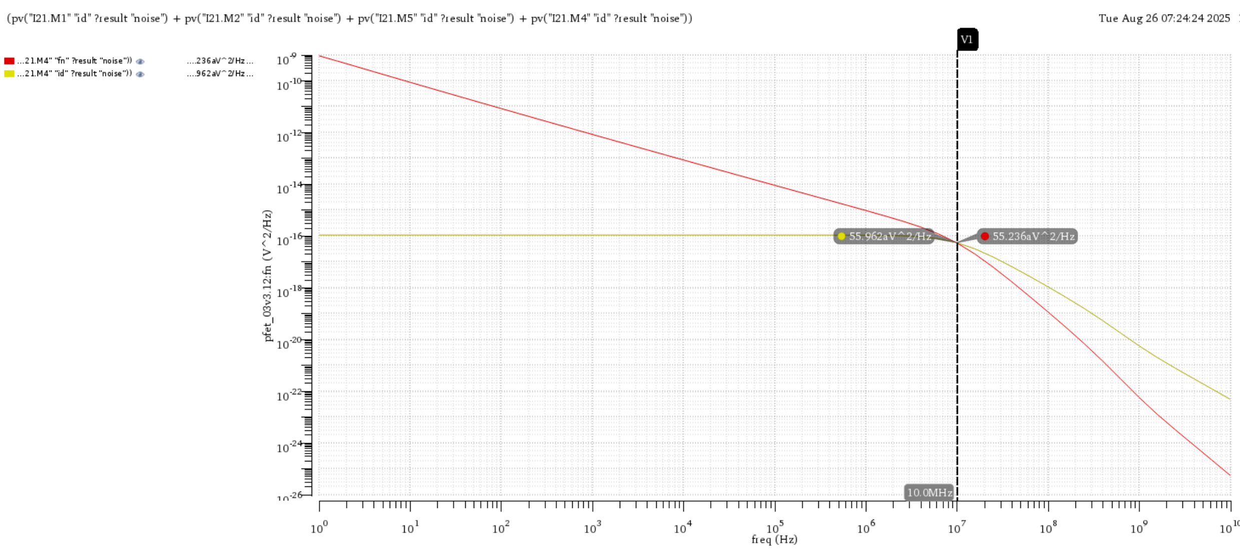


Figure 10:thermal and flicker noise VS freq

The flicker noise corner frequency (fc): is the frequency at which the flicker (1/f) noise spectral density equals the thermal (white) noise spectral density.

Flicker corner ≈ 10 MHZ

4) Calculate rms output noise (calculate the rms noise due to thermal noise only using Noise Summary.

```
Device      Param     Noise Contribution      % Of Total

/I21/M2     fn        6.2516e-05              35.94
/I21/M1     fn        6.20955e-05             35.46
/I21/M5     fn        2.53055e-05             5.89
/I21/M4     fn        2.51117e-05             5.80
/I21/M2     id        2.3342e-05              5.01
/I21/M1     id        2.32691e-05             4.98
/I21/M4     id        1.95629e-05             3.52
/I21/M5     id        1.81707e-05             3.04
/I21/M3     fn        4.58605e-06             0.19
/I21/M3     id        3.26239e-06             0.10
/I21/M0     fn        2.22916e-06             0.05
/I21/M0     id        1.98772e-06             0.04

Integrated Noise Summary (in V) Sorted By Noise Contributors
Total Summarized Noise = 0.000104283
Total Input Referred Noise = 0.00263586
The above noise summary info is for noise data with  FIN = 10000.0
```

I will neglect thermal noise for M0,M3 (tail CM)

RMS = $\sqrt{id_1^2 + id_2^2 + id_4^2 + id_5^2}$ ≈42.2 uV

Hand analysis:

RMS = $\sqrt{BW \times \overline{V_{nout}^2} \times \frac{\pi}{2}}$ ≈ 41.67 uV

5) Compare the simulation results (noise density, bandwidth, and rms) with hand analysis.

	$\overline{V_{nout}^2}$	BW	RMS
Simulation	109.1528 aV^2/ HZ	10.2768 MHZ	42.2 uV
Hand analysis	108.517 aV^2/ HZ	10.1859 MHZ	41.67 uV

PART 4: 5T OTA Transient Noise Analysis

1) Create a new simulation configuration. Keep the 5T OTA connected in unity-gain buffer configuration.

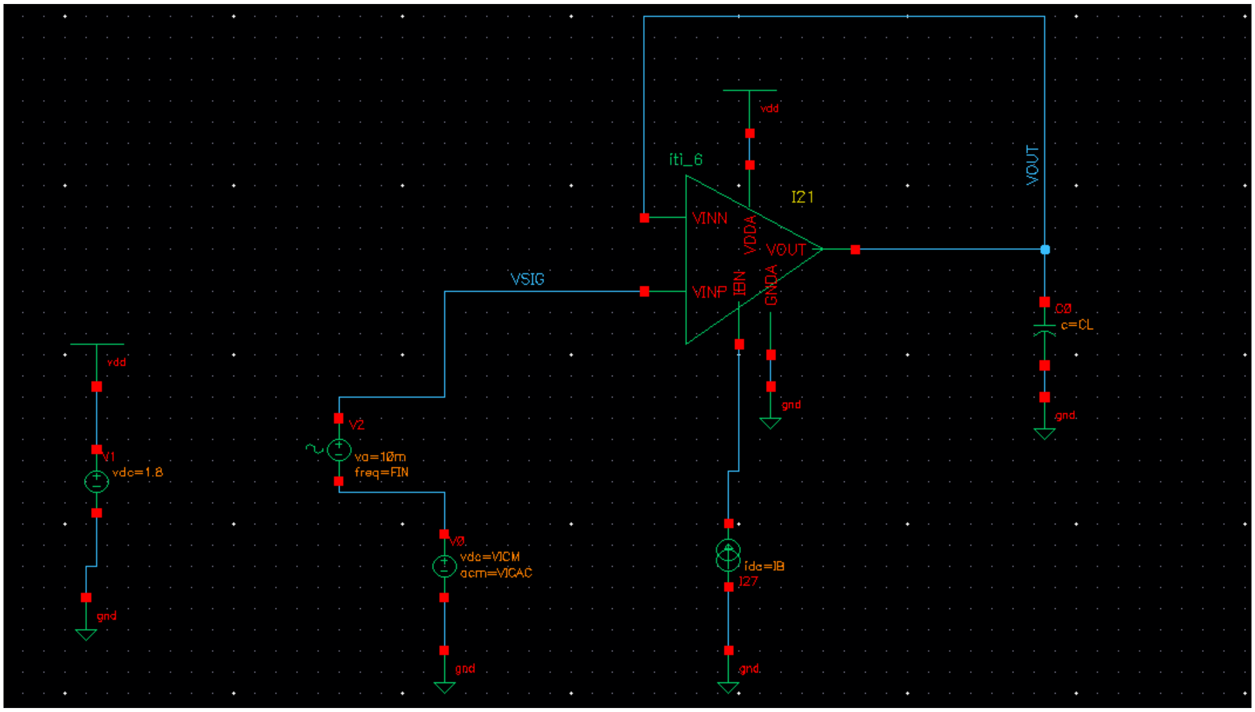
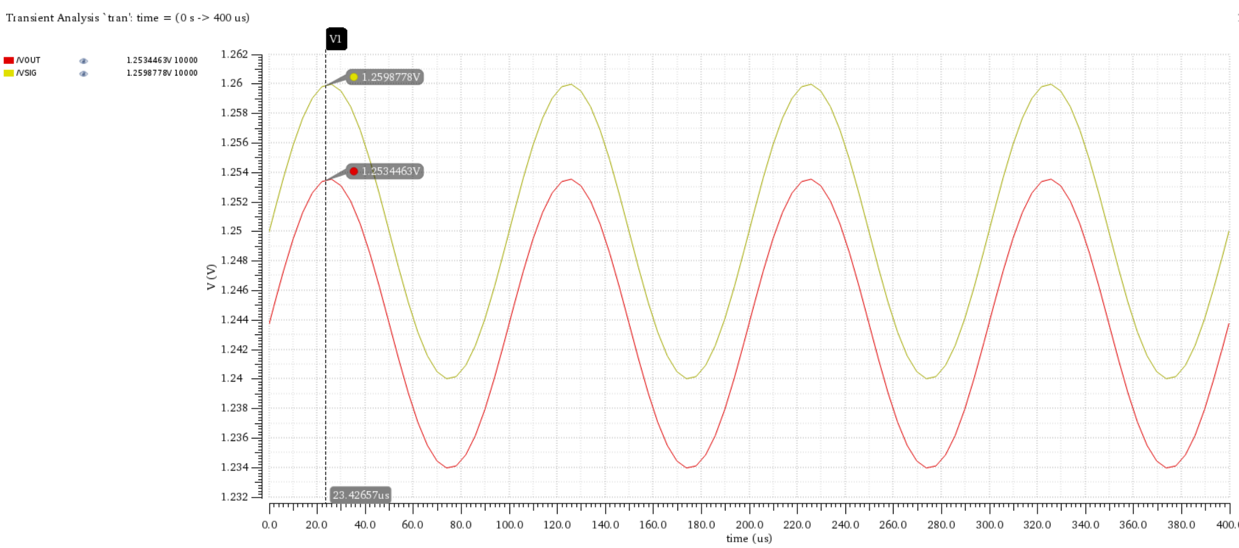


Figure 11:SCHEMATIC

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



VOUT is approximately equal to VIN, confirming basic buffer operation. The small error exists because the OTA's finite open-loop gain (AOL is not =∞) prevents it from being an ideal buffer .

6) Report the "noisy" output waveform (zoom-in to highlight the noise). Notice that output signal and noise are superimposed.

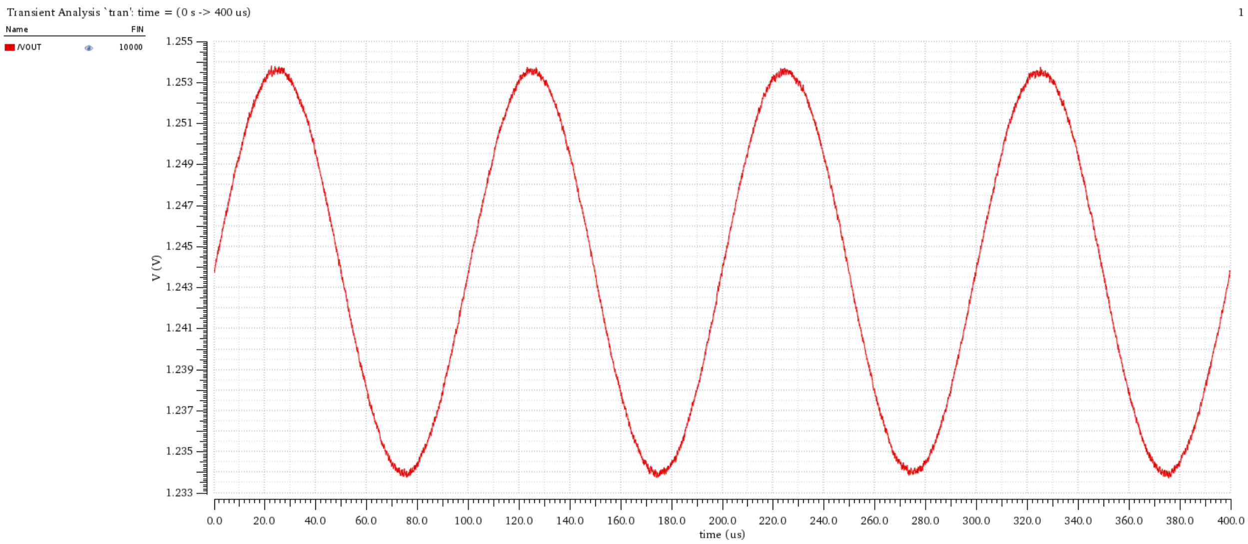


Figure 12:"noisy" output waveform

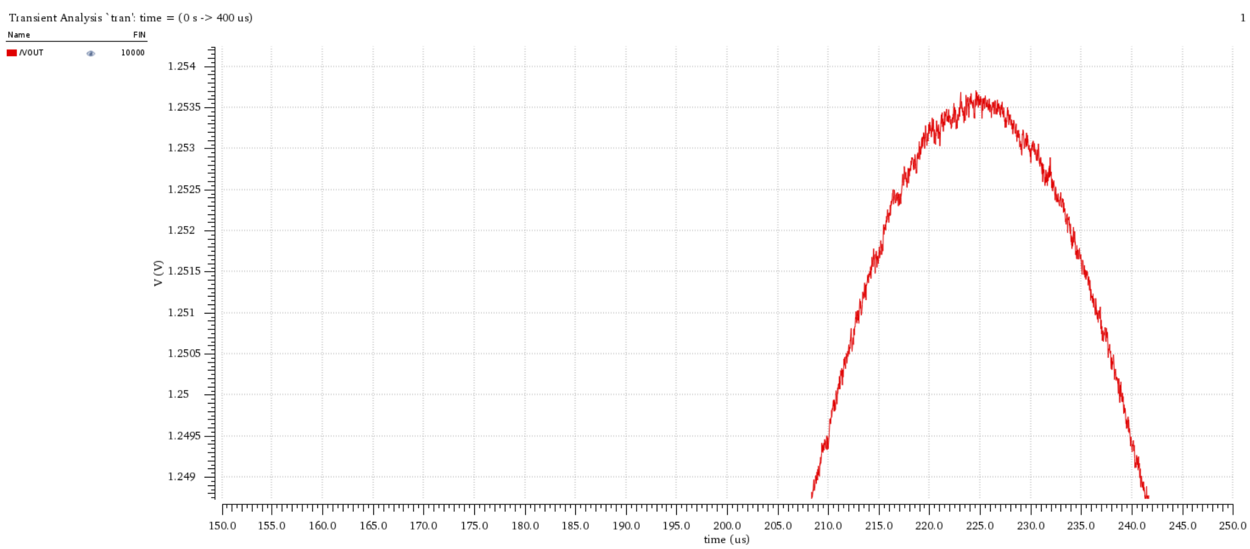


Figure 13:"noisy" output waveform (zoom-in to highlight the noise).

8) Report the rms noise vs iteration.

Figure 14: rms noise VS iteration

9) Use the calculator to calculate the average rms noise. Compare the calculated value with the rms noise previously obtained in Part 3.

	FIN	average...psf")))
1	10.00E3	95.47E-6

	RMS
Part 3	95.47 uV
Part 4	42.2 uV

As expected, the rms noise obtained in Part 4 is larger than in Part 3. In Part 3 we only considered the thermal noise contribution, while in Part 4 both thermal and flicker noise are included, which increases the total noise level.