Group 3 Lab report
Experiment 2: Noise Measurements

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September 19, 2023

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1 Introduction

The objective of this experiment was to measure the noise spectra emitted by a resistor, followed by analysis of different noise types, temperature dependent noise levels, and noise mitigation[1]. This was to be accomplished via a spectrum analyser and analysing the noise levels at room temperature (293 K) and liquid nitrogen (77 K). Specifically, we sought to observe the Johnson-Nyquist noise[2] and see how we could minimise it.

1.1 Johnson-Nyquist Noise

Johnson-Nyquist noise occurs due to thermal agitation of the electric charges in a conductor coupled to a thermal environment[1, 2]. This noise only depends on the temperature in Kelvin, T, and the bandwidth Δf. By probing at a constant bandwidth, we observe that $N \propto T$.

$$N = k_B T \Delta f \tag{1}$$

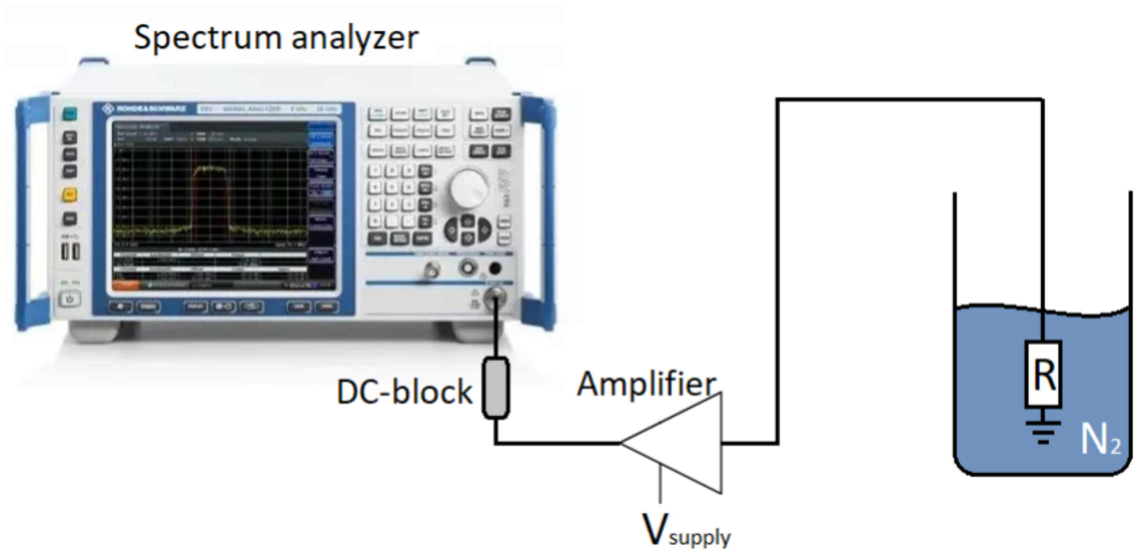
2 Method

For this experiment, we conducted 6 different measurements using a spectrum analyser. Specifically, we used the FSV40-N spectrum analyser, which can observe frequencies from 9 kHz to 40 GHz. Then, we measure the Johnson-Nyquist noise via a spectrum analyser. Recommended settings for the spectrum analyser are shown here:

Parameters	Set values
Mode	Spectrum
Reference Level	173 pW
Attenuation	0 dB
Sweep time	100 ms
Resolution Bandwidth	2 MHz
Video Bandwidth	10 kHz
Frequency	6 GHz
Span	0 Hz

Here, the resolution bandwidth is the minimum bandwidth over which two signals are still separable, whereas the video bandwidth can be thought of as a low pass filter which filters noise. Only the resolution bandwidth reduces the noise floor; the video bandwidth only reduces the noise on the trace.

First, we measure over different frequencies, sweeping from 0 to 12 GHz. Next, we measure the noise level over a 100 ms time interval at 6 GHz. This measurement is then repeated with a 50 Ω resistor, which is then replaced by a 40 dB amplifier. Finally, we measure with both the resistor and the amplifier attached. So far, all measurements have happened at room temperature, which we take to be 298 K. However, for the final experiment, we repeat the measurement with both the resistor and the amplifier in a liquid nitrogen bath. This gives us a second measurement at approximately 298 K, with which we can compare equation 1. The final setup is shown here:



2.1 Amplifiers

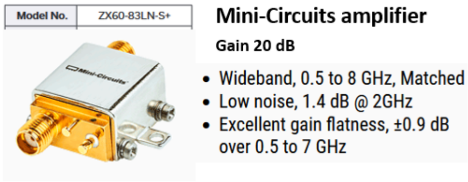
For our experiment, we use 2 20 dB amplifiers connected one after the other. These amplifiers are identical, hence the order does not matter, however, it is quite essential for multi-amplifier setups. For a 2 amplifier setup, the power output is

$$P_{\text{out}} = G_1 G_2 k_B \left(T + T_{N_1} + \frac{T_{N_2}}{G_1} \right) \Delta f \tag{2}$$

We can rewrite this equation to get the temperature instead:

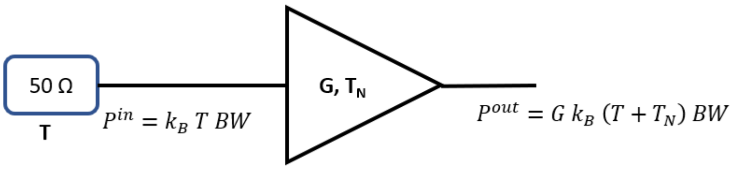
$$T = \frac{P_{\text{out}}}{G_1 G_2 k_B \Delta f} - T_{N_1} - \frac{T_{N_2}}{G_1} \tag{3}$$

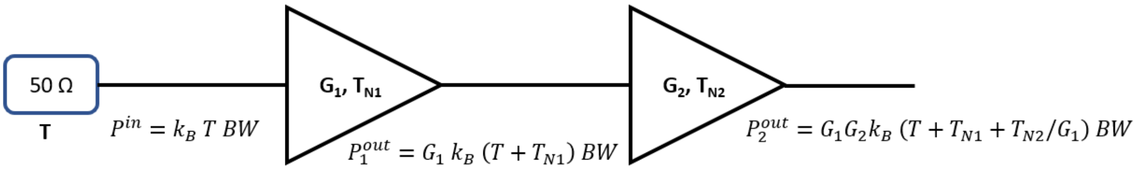
As such, the noise temperature for the first amplifier determines most of the noise. The details for our amplifiers are given below:



1.3 dB noise figure at 6GHz is equivalent to 102 K noise temperature

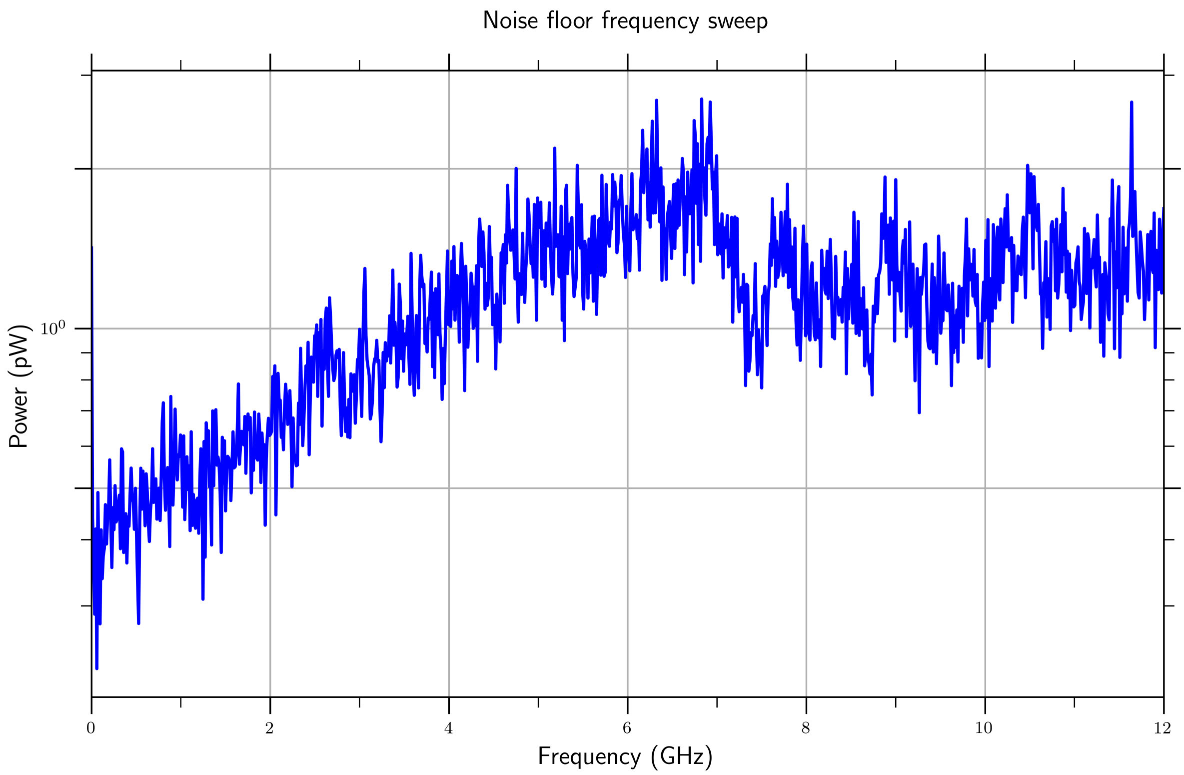
$\boxed{G_1 = G_2 = 100}$ $\boxed{T_{N1} = T_{N2} = 102\ K}$





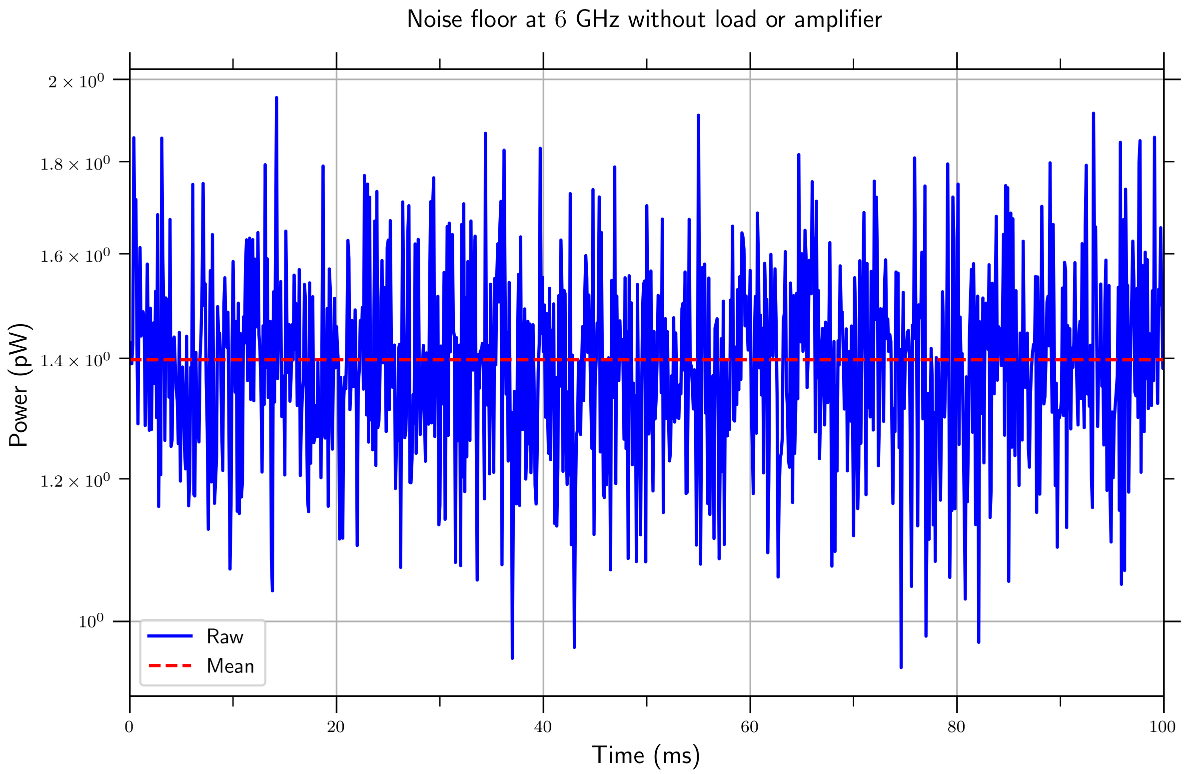
3 Results

3.1 Noise floor sweep from 0 to 12 GHz without load or amplifier



3.2 Noise floor measurements at 6 GHz without load or amplifier

3.2.1 Raw data with the mean highlighted



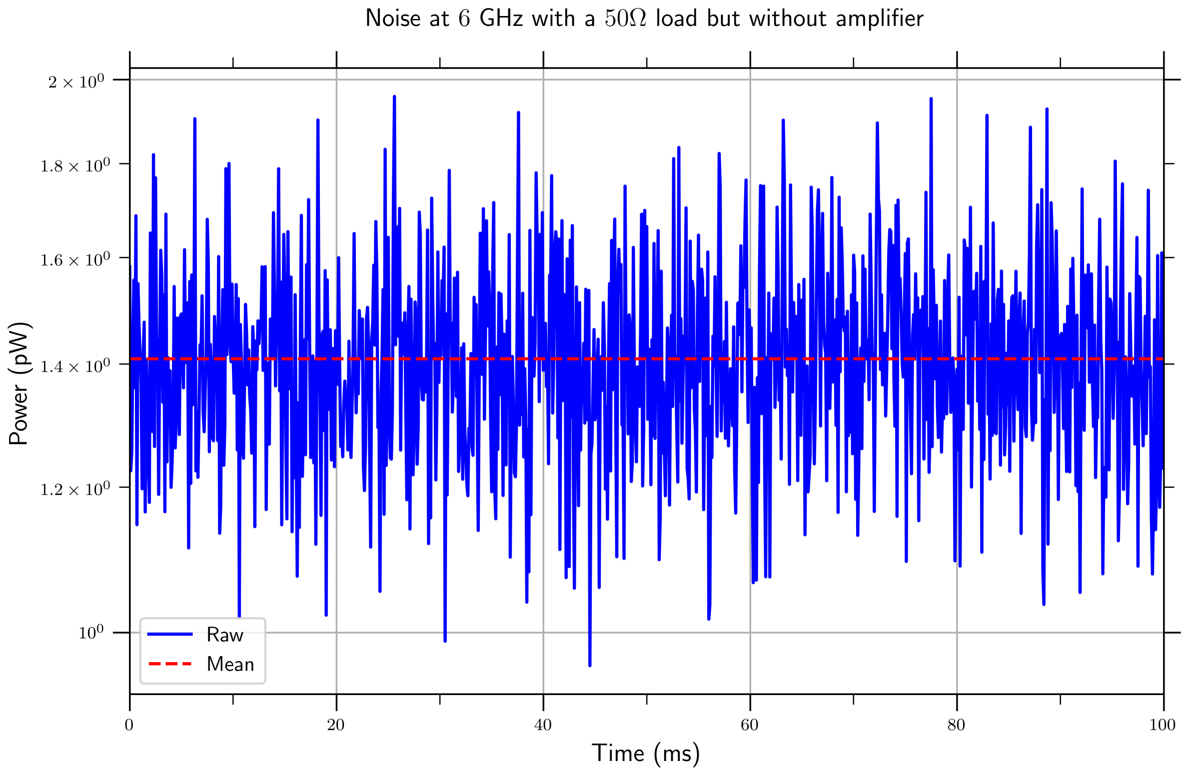
3.2.2 Noise analysis

The actual average power is 1.397 pW. The noise level calculated via root mean square is 1.407 pW. The noise level calculated via peak-to-peak is 1.011 pW.

The signal-to-noise ratio calculated via root mean square is 0.9930. The signal-to-noise ratio calculated via peak-to-peak is 1.382.

3.3 Noise measurements at 6 GHz with a 50Ω load but no amplifier

3.3.1 Raw data with the mean highlighted



3.3.2 Noise analysis

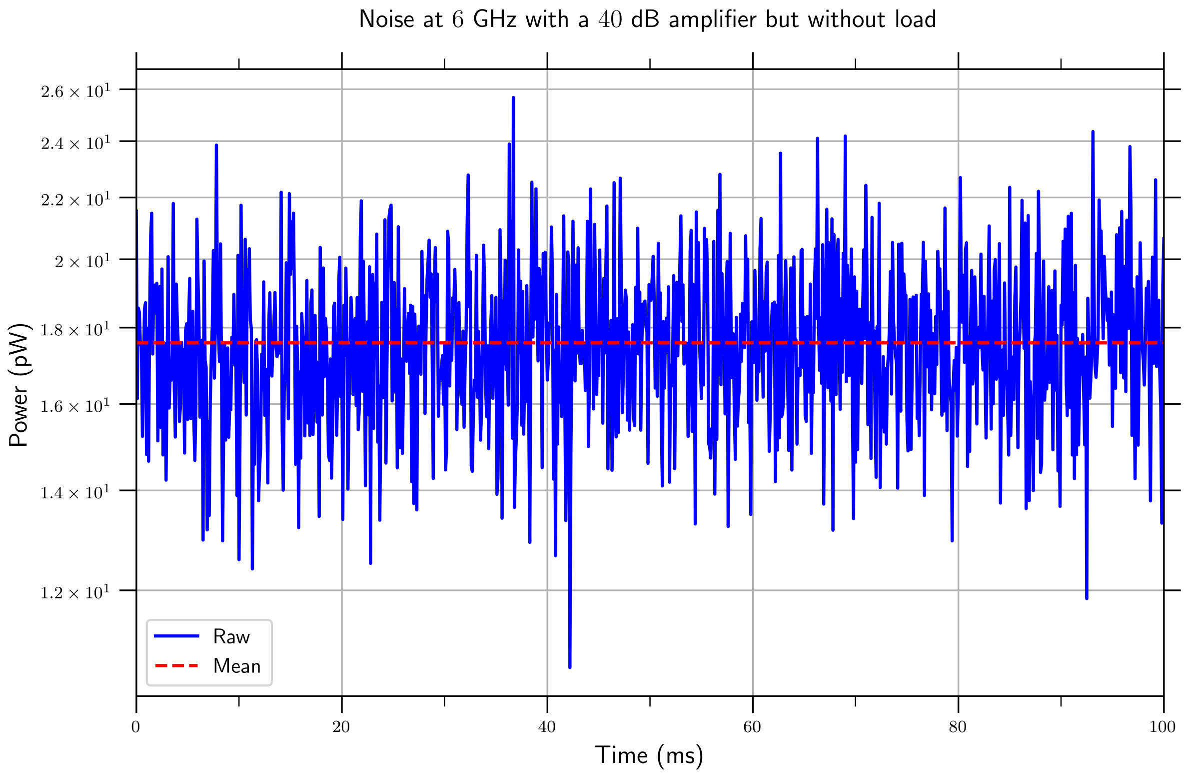
The expected power is $k_B T \Delta f = k_B \times 298\,\mathrm{K} \times 2\,\mathrm{MHz} \approx 8.229\,\mathrm{fW}$.

However, the average power is $1.410\,\mathrm{pW}$. The noise level calculated via root mean square is $1.420\,\mathrm{pW}$. The noise level calculated via peak-to-peak is $0.9987\,\mathrm{pW}$.

The signal-to-noise ratio calculated via root mean square is 0.9929. The signal-to-noise ratio calculated via peak-to-peak is 1.411.

3.4 Noise measurements at 6 GHz with an amplifier but no load

3.4.1 Raw data with the mean highlighted



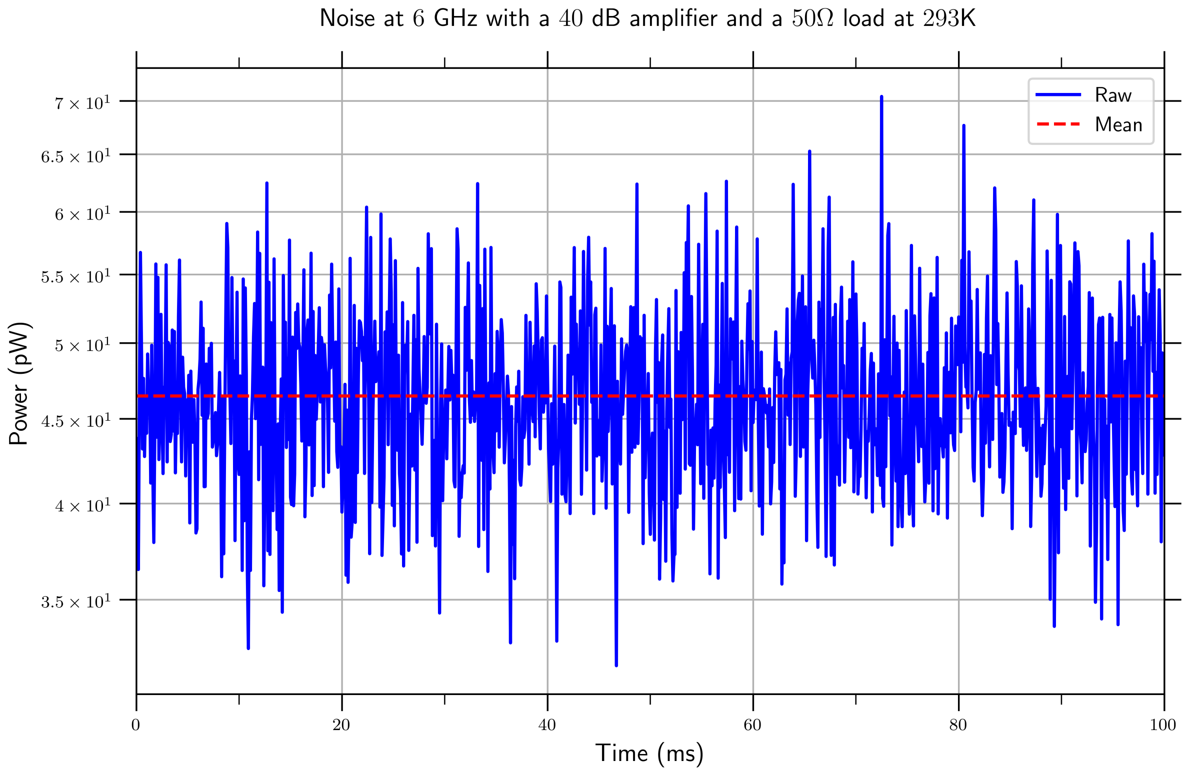
3.4.2 Noise analysis

The average power is 17.58 pW. The noise level calculated via root mean square is 17.71 pW. The noise level calculated via peak-to-peak is 15.01 pW.

The signal-to-noise ratio calculated via root mean square is 0.9927. The signal-to-noise ratio calculated via peak-to-peak is 1.171.

3.5 Noise measurements at $6\,\mathrm{GHz}$ with a $40\,\mathrm{dB}$ amplifier and a $50\,\Omega$ load at $293\,\mathrm{K}$

3.5.1 Raw data with the mean highlighted



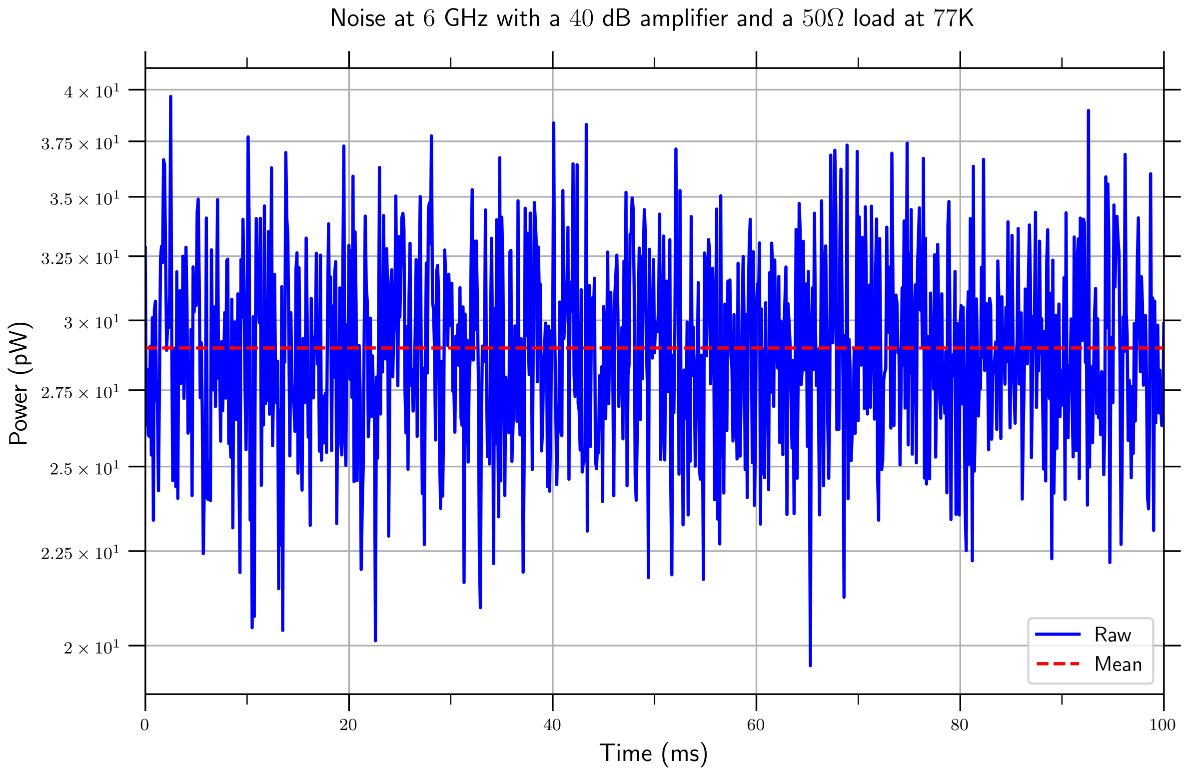
3.5.2 Noise analysis

The average power is $46.45\,\mathrm{pW}$. The noise level calculated via root mean square is $46.79\,\mathrm{pW}$. The noise level calculated via peak-to-peak is $38.51\,\mathrm{pW}$.

The signal-to-noise ratio calculated via root mean square is 0.9927. The signal-to-noise ratio calculated via peak-to-peak is 1.206.

3.6 Noise measurements at $6\,\mathrm{GHz}$ with a $40\,\mathrm{dB}$ amplifier and a $50\,\Omega$ load at $77\,\mathrm{K}$

3.6.1 Raw data with the mean highlighted



3.6.2 Noise analysis

The average power is $28.99\,\mathrm{pW}$. The noise level calculated via root mean square is $29.18\,\mathrm{pW}$. The noise level calculated via peak-to-peak is $20.15\,\mathrm{pW}$.

The signal-to-noise ratio calculated via root mean square is 0.9932. The signal-to-noise ratio calculated via peak-to-peak is 1.438.

4 Conclusion

We get an average power of $28.99\,\mathrm{pW}$. As such, we can back estimate the temperature using equation 3. This gives us a value of

5 References

References

[1] Timm Fabian Mörstedt and Suman Kundu. *Experiment 2: Noise Measurements*. 2023.

[2] H. Nyquist. "Thermal Agitation of Electric Charge in Conductors". In: *Physical Review* 32.1 (July 1, 1928), pp. 110–113. DOI: 10.1103/PhysRev.32.110. URL: https://link.aps.org/doi/10.1103/PhysRev.32.110 (visited on 09/26/2023).