

Some Noise Falls When You Measure Longer, and Some Does Not

— At $1\text{ k}\Omega$ Thermal and Shot Change Places at $51.70\mu\text{A}$ — White Noise Falls as $\tau^{-1/2}$ While $1/f$ Stays Flat —

[Paper 312]

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— *From thinking to syncing.* —

Abstract

The phrase “too much noise” names several quantities with different mechanisms. This paper asks whether measuring longer always lowers it—the answer is some of it does not fall. No new mathematical theorem and no new law is claimed. First, thermal noise is fixed by the resistance alone. At 300 K , 50Ω gives 0.910 and $1\text{ k}\Omega$ gives $4.070\text{ nV}/\sqrt{\text{Hz}}$ (Section 2). Second, shot noise is fixed by the current alone. At $1\text{ k}\Omega$ the two change places at $51.70\mu\text{A}$ (Section 3). Third, this is the core of the paper. White noise falls as $\tau^{-1/2}$, while $1/f$ stays perfectly flat (Section 4). Fourth, at $\tau = 1000\text{ s}$ they differ by a factor of 31.6 (Section 4). Fifth, “noise” is four things, and each needs a different remedy (Section 5). Sixth, the separator is whether averaging lowers it (Section 6).

Scope of this paper (scope note): No new mathematical theorem and no new law is claimed——Johnson–Nyquist thermal noise, Schottky’s shot noise, $1/f$ noise and the Allan variance are all standard. We do not build a theory of noise——all we use is two formulas and one crossing point. We do not discuss the origin of $1/f$ ——why $1/f$ arises is unsettled and we do not enter it. We quote only its behaviour under the Allan variance. We do not treat estimation——extracting signal from noise was treated in Paper 106. This paper looks only at the floor, before extraction. We do not discuss instrument design——amplifier noise figure, shielding and grounding are not treated. We claim no accuracy for representative values—— $T = 300$ K is a value for showing orders. Relation to earlier papers: Paper 78 showed friction and dissipation to be coarse-graining, and wrote via the fluctuation–dissipation theorem that thermal noise and friction are two faces of one coupling——this paper does not enter that mechanism and treats only the height of the floor and how it falls with time. 78 asks why it is there; this paper asks which one acts. Paper 106 extracted signal from noise with Wiener’s filter——this paper counts what is being extracted from. Paper 266 stated explicitly that Johnson–Nyquist thermal noise and the Nyquist of sampling are the same name on different work——the Nyquist here is the former. Paper 252 counted four quantities called “information”——this paper counts four called “noise”. The same form. Paper 255 showed that accuracy is two things and that repetition lowers only one——this paper exhibits a noise that repetition does not lower. 255’s “scatter falls as $\sigma/\sqrt{n}$ ” has an exception. What is added is computing thermal noise for three resistances, putting the thermal–shot crossing at $51.70\mu\text{A}$, tabulating how white and $1/f$ part company under the Allan variance, and listing four noises with their remedies.

1. Notation and the Question

Setting: Consider the noise that sets a measurement’s floor. $k_B = 1.380649 \times 10^{-23}$ J/K, $q = 1.602176634 \times 10^{-19}$ C, $T = 300$ K.

Observation 1.1

Repeat a measurement and the scatter falls as $\sigma/\sqrt{n}$ ——as Paper 255 wrote. This paper looks for the exception.

Question: Does measuring longer always lower the noise?

2. Thermal Noise Is Fixed by the Resistance Alone

Setting: Johnson–Nyquist thermal noise is $v_n = \sqrt{4k_B T R}$ per unit bandwidth.

Check 2.1:

$R \text{ } [\Omega]$	$v_n \text{ } [\text{nV}/\sqrt{\text{Hz}}]$
50	0.910
1000	4.070
10^6	128.716

Observation 2.2

A factor of 20000 in R gives only **141.4** in v_n —because of the square root.

Observation 2.3

No current appears here. Pass no current at all and a resistance still carries noise—in the language of Paper 78, where there is friction there is fluctuation.

Observation 2.4

And no frequency appears. The same magnitude at every frequency—white—this property is what acts in Section 4.

3. Shot Noise Is Fixed by the Current Alone

Setting: Schottky's shot noise is $i_n = \sqrt{2qI}$ per unit bandwidth. It comes from charge being discrete.

Check 3.1:

$I \text{ } [\text{A}]$	$i_n \text{ } [\text{A}/\sqrt{\text{Hz}}]$
10^{-6}	5.6607×10^{-13}
10^{-3}	1.7901×10^{-11}
1	5.6607×10^{-10}

Observation 3.2

No temperature appears here. At absolute zero shot noise does not vanish—it comes not from heat but from being made of grains.

Check 3.3: Setting the two equal: $2qIR^2 = 4k_BTR$ gives $I = 2k_BT/(qR)$.

$R [\Omega]$	Crossing current I
1000	$5.1704 \times 10^{-5} \text{ A} = \mathbf{51.70\mu\text{A}}$

Observation 3.4

Below $51.70\mu\text{A}$ thermal noise sets the floor; above it shot noise does. In one circuit, changing only the current changes which one rules—which is “the noise of that circuit” is not settled by the circuit.

Observation 3.5

And both are white. The mechanisms differ (heat on one side, discreteness on the other) yet their behaviour in time is identical—so far, averaging lowers both.

4. The Core: Some Noise Does Not Fall Under Averaging

Setting: The Allan variance averages over a time τ and looks at the scatter of the differences between adjacent averages. Each kind of noise carries its own τ dependence.

Check 4.1: Relative values, with $\tau = 1$ set to 1.

τ [s]	White noise $\propto \tau^{-1/2}$	$1/f$ noise
1	1.00000	1.00000
10	0.31623	1.00000
100	0.10000	1.00000
1000	0.03162	1.00000

Observation 4.2

This is the core of the paper. The right column does not move—a factor of 1000 in τ and it falls not at all.

Observation 4.3

At $\tau = 1000$ s they differ by a factor of **31.6**. They began equal, and the longer one measures the wider the gap—over short times they cannot be told apart.

Observation 4.4

So Paper 255's “scatter falls as $\sigma/\sqrt{n}$ ” has an exception. When $1/f$ is the floor, more repetitions do not lower it—beside 255's “bias does not vanish with repetition” stands a second thing that does not vanish.

Check 4.5: The four side by side.

Noise	Spectrum	Allan τ dependence
Thermal	white	$\tau^{-1/2}$
Shot	white	$\tau^{-1/2}$
$1/f$	$\propto 1/f$	flat
Random walk	$\propto 1/f^2$	$\tau^{+1/2}$ (it rises)

Observation 4.6

The fourth row rises. Measuring longer makes it worse——so an optimal measuring time exists.

Observation 4.7

A point to write honestly——this paper does not explain why $1/f$ arises. Its origin is still unsettled in general, and different mechanisms are proposed for different systems——all we use is the measured fact of its τ dependence.

5. “Noise” Is Four Things, Each Needing a Different Remedy

Check 5.1:

Noise	Fixed by	Removable?	What works
Thermal	R and T	cooling lowers it	lower the resistance, cool
Shot	I alone	cooling does nothing	lower the current
$1/f$	device and process	averaging does nothing	modulate up in frequency
Interference	environment	removable in principle	shield, ground, differential

Observation 5.2

All four need different remedies. Cooling works only on the first row and measuring longer does nothing for the third——lump them under “reduce the noise” and you reach for the wrong tool.

Observation 5.3

The third row’s remedy is peculiar. $1/f$ is large at low frequency, so one moves the signal up instead——not reducing the noise but escaping to where it is small.

Observation 5.4

Paper 252 wrote that “information” is four quantities needing different things. Noise has the same shape—one word covering four quantities, with only the remedies splitting into four.

6. Separator: Whether Averaging Lowers It

Observation 6.1

Separator—whether a longer averaging time lowers it.

	Does it fall?	Why
Thermal and shot (white)	yes	uncorrelated, so it averages as $\sqrt{\tau}$
$1/f$	no	every time scale carries the same fluctuation
Random walk	it rises	it wanders further the longer you wait

Observation 6.2

Why $1/f$ does not fall is said by its own name— $1/f$ is flat on a logarithmic scale. Every decade carries the same power—change the time scale and the view does not change.

Observation 6.3

Paper 190 wrote that “rare” is measured on a logarithmic scale, and Paper 292 that only the logarithm adds. $1/f$ is the noise that is uniform on that scale—so it can be characterised only in the language of logarithms.

Check 6.4: Applying Paper 300’s criteria to thermal and shot noise. Both are white and their formulas look alike—same root?

Criterion	Result
Does the agreement persist under motion?	no. Lower T and only the thermal one goes
Do the same quantities appear?	no. T against q
Does one follow from the other?	no. Equilibrium against non-equilibrium
τ dependence	yes. Both $\tau^{-1/2}$

Observation 6.5

Three noes and one yes. The mechanisms are distinct roots, and the behaviour in time is the same—behaving alike is not sharing a root (Paper 300).

Observation 6.6

And for whoever is measuring, only that one yes matters—to someone lowering a floor, whether it goes as $\tau^{-1/2}$ is the whole question. The distinct roots of mechanism and the shared root of remedy disagree here.

7. Roll Call and Closing

1. **4.070 nV/ $\sqrt{\text{Hz}}$ at 1 k Ω** (Check 2.1): **No current enters.**
2. **20000 in R gives 141.4** (Observation 2.2): **A square root.**
3. **No temperature in shot noise** (Observation 3.2): **It comes from discreteness.**
4. **The crossing is 51.70 μA** (Check 3.3): **Which one rules changes.**
5. **$1/f$ is flat** (Check 4.1): **A factor of 1000 in τ moves nothing.**
6. **A factor of 31.6 at $\tau = 1000$ s** (Observation 4.3): **The gap widens.**
7. **Random walk rises** (Check 4.5): **An optimal measuring time exists.**
8. **Four different remedies** (Check 5.1): **Cooling works on one row.**
9. **$1/f$ can only be escaped** (Observation 5.3): **Modulate up in frequency.**
10. **Three noes, one yes** (Check 6.4): **Distinct mechanisms, same behaviour.**

Closing: The phrase “too much noise” names several quantities with different mechanisms. Thermal noise, $\sqrt{4k_B T R}$, is fixed by resistance and temperature alone and gives **4.070 nV/ $\sqrt{\text{Hz}}$** at 300 K and 1 k Ω —shot noise, $\sqrt{2qI}$, is

fixed by the current alone and contains no temperature (it does not vanish at absolute zero). At $1\text{ k}\Omega$ the two change places at $51.70\mu\text{A}$ —which is “the noise of that circuit” is not settled by the circuit. The core is what happens when one measures longer—under the Allan variance white noise falls as $\tau^{-1/2}$, while $1/f$ stays flat and does not fall at all. At $\tau = 1000\text{ s}$ they differ by a factor of **31.6**. A random walk actually rises—so an optimal measuring time exists. “Noise” is four things, and all four need different remedies—cooling works only on thermal noise, and measuring longer does nothing for $1/f$. For $1/f$ one can only modulate up in frequency and escape. One thing separates them—whether a longer averaging time lowers it. Why $1/f$ does not fall is said by its own name—it is flat on a logarithmic scale, and every decade carries the same power. Change the time scale and the view does not change. One last thing—thermal and shot noise are distinct roots by Paper 300’s criteria (lower T and only one goes) and yet their τ dependence agrees. The distinct roots of mechanism and the shared root of remedy disagree, and to someone lowering a floor only that agreement matters.

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