Rarely Asked Questions

Strange but true stories from the call logs of Analog Devices
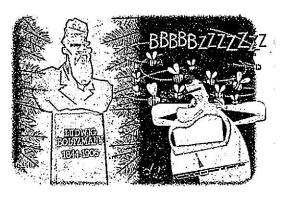
Resistor Noise can be Deafening, and Hard to Reduce

Q. My low-noise amplifier is not low noise enough. What am I doing wrong?

A. It may not be the amplifier causing the trouble; analyze where the noise is actually coming from. A typical operational amplifier circuit contains six uncorrelated noise sources (the smaller ones can usually be disregarded[1]). The amplifier itself has three separate noise sources: a voltage noise source appears differentially across the inputs; and current noise sources appear in series with both inverting and non-inverting inputs. Remarkably often the problem is not the amplifier, though, but the thermal noise generated by one or more of the three resistors that set the amplifier gain and provide bias current compensation. Analog Devices has over sixty types of op amps whose voltage noise is less than that of a 1 kΩ resistor ($4\,nV/\sqrt{Hz}$).

This answer is rarely popular; it is far more satisfactory to blame an imperfect amplifier and replace it with a better one than to admit that there is a fundamental problem with apparently simple components such as resistors. In fact, a remarkably common response to a diagnosis of resistor noise is to seek a source of *"good"* resistors, with *"good"* being defined as without thermal noise.

This is impossible. The basic physics of resistance shows[2] that the random thermal movement of charge carriers in a conductor always produces electrical noise of value $\sqrt{4kTBR}$ where k is Boltzmann's Constant (1.38065×10^{-23} J/K), T is the absolute temperature, B is the bandwidth and R the resistance. (We often express this noise in terms of spectral density, making the voltage noise $\sqrt{4kTR}\;{}^{V}\!/_{\sqrt{Hz}}$).

Such noise is known as thermal noise, or Johnson noise, after John B. Johnson (Bell Telephone Laboratories – 1928), who was the first person to observe it. It might more properly be named Johnson/Nyquist

noise as it was Harry Nyquist (also at Bell Laboratories) who explained the physical basis of Johnson's observation.

So anywhere at all that there is resistance in a circuit, whether it is carrying current or not, there is a noise generator with an output voltage noise spectral density of $\sqrt{4kTR}$. We can reduce the noise by reducing the resistance (this may increase current and/or power consumption), but reducing the temperature is not usually practicable (if we cool a resistor from room temperature (298K) to liquid nitrogen temperature (77K), its noise voltage is still more than half its room temperature value). And, of course, we can't change Boltzmann's Constant because Professor Boltzmann is dead[3].

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[1] *Any noise source less than ⅓ the magnitude of the largest can be ignored for most practical purposes.*

[2] *http://www.physics.utoronto.ca/~phy225h/experiments/thermal-noise/Thermal-Noise.pdf*

[3] *Died 5 September 1906 at Diuno near Trieste, buried Zentralfriedhof, Vienna.*

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