

Experimental Characterization of Negative Temperature Coefficient Resistor Noise Depending on Polarization Voltage

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Summary:

Negative Temperature Coefficient Resistors (NTC) are a workhorse of temperature measurement when sensitivity is the primary concern. NTC are semicrystalline semiconductor blends and exhibit flicker noise. We report here experiments showing that the NTC noise depends heavily on the polarization voltage.

Keywords: negative temperature coefficient resistor, noise, voltage

Introduction

Resistive temperature sensors are chosen according to a trade-off between low drift and high linearity (resistive temperature detectors - RTD) and high sensitivity (thermistors). While the noise of RTD is the well-known Johnson-Nyquist noise, the noise of thermistors, like most semiconductors, arises from several processes [1] and often must be determined empirically. Many of these phenomena are well-described by Hooge's law, which postulates that the resistivity of the material not only varies due to actual temperature drift (phonon noise) but also because of random fluctuations in carrier density and/or mobility.

The noise in PTC has been connected to carrier mobility fluctuations in the depletion region near the grain interface [2]. Ralph and Schofield have proposed a model without adjustable parameters to predict the noise. However, unlike PTC, the conductivity of NTC is not determined at the grain boundary but by bulk properties [3]. Therefore, the noise generation process is not well understood.

Ryger et al. [4] have measured the noise of negative temperature coefficient resistors and shown that physically smaller devices were noisier than larger ones, in agreement with the empirical Hooge's law. However, these results did not predict well the noise of an NTC used in ABB instruments. The NTC is thermalized at higher temperature (87°C) and voltage (10 V) than the ones used in Ryger's study [4]. Furthermore, the NTC is polarized at constant voltage, as opposed to the 1 kHz in the previous study. Therefore, we investigated the effect of those operating parameters on the NTC noise. Most

parameters were found to have a small effect and therefore we report mainly on the voltage that had by far the largest effect on noise.

Method

Four detector beads were assembled in Wheatstone bridge configuration and immersed in colza oil. The oil provided a higher thermal inertia than in air, and reduced convective currents, which allowed testing the NTC at higher voltage. Extra resistors were added in series with individual beads to balance the bridge and maximize the power supply rejection. The bridge was placed in a Faraday cage and supplied either by an ultra-low-noise voltage source or a battery.

To ensure that the noise was coming from the circuit and not from the amplifier, the signal was recorded via two independent channels. Each channel included a low-noise instrumentation amplifiers (SR 560) with a bandwidth of 0,03 Hz to 100 Hz, and a gain of 50,000. The signal from each amplifier was then digitized by an oscilloscope.

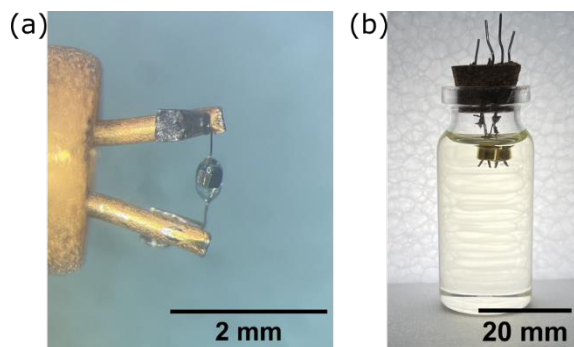


Fig. 1. Experimental setup. (a) Negative temperature coefficient (NTC) resistor, protected by a glass shell. (b) two NTC immersed in an oil bath. Two of these bottles were used to build the Wheatstone bridge.

Signal processing

Assuming the resistance of each NTC is given by $R_0(1 + \epsilon_i)$, with the power spectrum density of ϵ_i given by S_{RR} , we can show that the voltage noise density S_{VV} at the bridge reads:

$$\frac{S_{VV}}{V_b^2} \approx \frac{S_{RR}}{R^2}, \quad (1)$$

with $V_b = \frac{1}{2}U_0$ the voltage on the half bridge. To distinguish between amplifier noise and circuit noise, the cross-spectral density (CSD) from the output of the two amplifiers was used as a proxy of the circuit noise. We note that in all our experiments, the CSD was very similar to the power spectral density the amplified signals, showing that the amplifier noise is negligible. Furthermore, accounting for the PSR offered by the bridge, the voltage source noise was estimated to be of the order of $1 \text{ nV}/\sqrt{\text{Hz}}$, much smaller than the recorded noise ($132 \text{ nV}/\sqrt{\text{Hz}}$).

Results & discussion

The noise density of the NTC was found to be insensitive to the medium temperature. However, we observed that the noise depends on the excitation voltage, as shown in Fig 1:

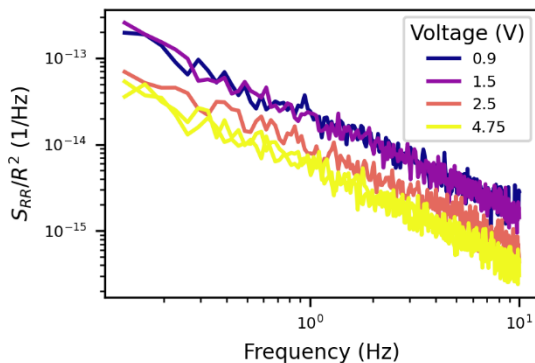


Fig. 2. NTC noise spectral density at various polarization voltages.

The variation of noise density with polarization voltage is shown in Fig. 2:

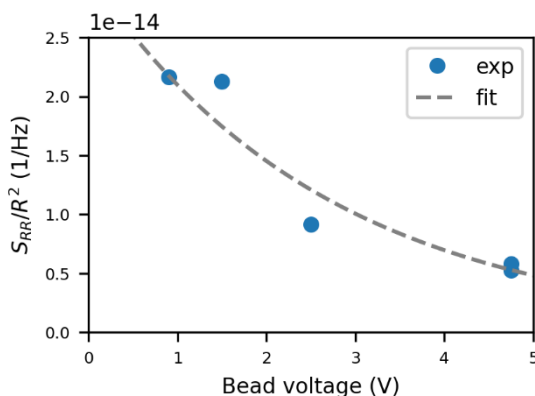


Fig. 3. NTC noise at 1 Hz vs polarization voltage.

Experimental noise levels are well described using the following model:

$$\frac{S_{RR}}{R^2} \approx \frac{A}{f} e^{-\frac{V_b}{V_0}}, \quad (2)$$

with $A = 3 \times 10^{-14}$ and $V_0 = 2.7 \text{ V}$. The value of V_0 suggest that a bandgap mechanism may be at the origin of the noise.

Despite extensive literature review, the authors have not found reports that NTC noise depends on the excitation voltage. Our study suggests that the signal to noise ratio of NTC exponentially increases with the voltage as follows:

$$\text{SNR} \approx \sqrt{\frac{A \beta^2 S_{\theta\theta}}{f T_0^4} e^{\frac{V_b}{V_0}}}, \quad (2)$$

With $S_{\theta\theta}$ the power spectrum density of the temperature signal, T_0 the average temperature of the sensor, and β its temperature coefficient ($R(T) = R_0 e^{\beta/T}$ with R_0 a fictive resistance at infinite temperature). While using elevated voltages can bias the measurement by heating up the medium, and even add noise, for instance due to convection, our study highlights that there is some trade-off in increasing the voltage that might be worth considering for high precision applications.

References

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