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Short Communication: Improvements to INRIM Johnson Noise Thermometer

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Abstract This paper presents a progress report for the Johnson noise thermometry experiment which is under development at the Istituto Nazionale di Ricerca Metrologica. In order to aim at an uncertainty level better than 10^{-5} and to reduce the measurement time, a new setup has been developed. In particular, several modifications have been applied to the experiment described by Callegaro et al. (Metrologia **46**: 409, 2009) to improve the traceability to voltage, resistance and frequency standards, and new amplifiers have been designed in order to expand the working frequency range up to 20 kHz, with a sensing resistor of 1 kΩ, while maintaining amplifier induced systematic errors to an acceptable level.

Keywords Johnson noise thermometry · Boltzmann constant

1 Introduction

The Johnson noise thermometer (JNT) under development [1] at the Istituto Nazionale di Ricerca Metrologica (INRIM) determines the thermodynamic temperature by measuring the Johnson noise [2] of a sensing resistor, with traceability to voltage, resistance, and frequency standards. The temperature is measured in energy units, and can be converted to SI units (kelvin) with the accepted value of the Boltzmann constant k_B; or, conversely, can be employed to perform measurements at the triple point of water, thus obtaining a determination of k_B [3].

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The 2008 JNT version [1] reached an uncertainty of about 6×10^{-5} at room temperature. The main contributions to the uncertainty came from the ac voltage measurement (performed with a commercial voltmeter), and the temperature measurement (performed with a standard platinum resistance thermometer head, whose resistance was measured by a commercial multimeter).

2 Description of the New JNT

A block schematics of the new JNT is shown in Fig. 1: the sensing resistor $R = 1\,\text{k}\Omega$ generates the noise voltage e_N which is amplified by the two amplifiers A and measured by the two analog-to-digital converters ADC; next, the digitized signals are processed by the PC to obtain the cross-spectral density function between the two channels. In order to have traceability to electrical units, the correlation spectrum analyzer requires inline calibration, which is periodically performed by adding to e_N a calibration signal e_C. This signal has a comb spectrum which spans the measurement bandwidth [4] and is injected in series with e_N by the feedthrough transformer F. e_C is generated by dividing with a two-stage divider chain IVD the output voltage V_AC of the digital-to-analog converter DAC. The following improvements over the 2008 version have been developed:

- The traceability of V_AC is obtained by means of an ac–dc transfer technique, using the multijunction thermal converter MJTC (PTB/IPHT design [5], $400\,\Omega$ heater resistance).
- The traceability to temperature is obtained with a $25.5\,\Omega$ SPRT (Hart Scientific Model 5683-S, quartz-sheath SPRT for $-200\,°\text{C}$ to $480\,°\text{C}$ temperature range) whose resistance is measured by a thermometry bridge (Automatic System

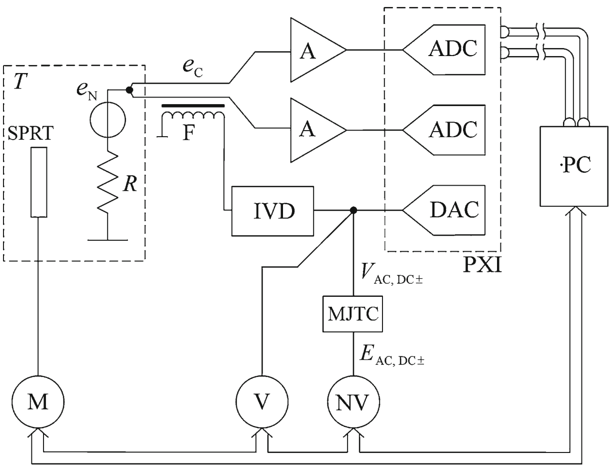

Fig. 1 Block schematics of JNT: e_N is the resistor noise voltage; e_C is the calibration signal, obtained from the DAC output voltage V_AC. During the ac–dc transfer sequence, the DAC generates V_AC, $V_{\text{DC}+}$, $V_{\text{DC}-}$; the corresponding MJTC output voltages E_AC, $E_{\text{DC}+}$, $E_{\text{DC}-}$ are read by the nanovoltmeter NV

Laboratories Model F18) by comparison with a 25 Ω resistance standard (Tinsley Model 5685 ac–dc standard resistor).

- The bandwidth has been extended from (3 to 7) kHz to (3 to 20) kHz.
- A new set of front-end amplifiers, optimized for very low current noise and high gain stability, has been designed. For these amplifiers, with typical device parameters, a sensing resistor of 1 kΩ and a cable capacitance of 80 pF, the estimated (by electrical modeling, see [6,7]) relative temperature measurement error is 8×10^{-7} over the frequency range from 3 kHz to 20 kHz. In contrast to other designs typically employed in JNT, feedback has been used to achieve a gain stability better than 10^{-6} for the whole measurement time, thus reducing the need of frequent gain calibrations.

3 Conclusions

In this paper, we have summarized the various improvements to the INRIM Johnson noise thermometer, which should decrease its uncertainty in the measurement of the thermodynamic temperature and the comparison with the ITS-90 scale as realized at INRIM. The uncertainty of the previous version, about 6×10^{-5}, should drop significantly; the next improvement will be the calibration of IVD and F in the extended frequency bandwidth, for which a dedicated calibration setup is under design.

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