High Resistance Measurements with a Two-Terminal Cryogenic Current Comparator

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Abstract **— The aim of this paper is to describe the set-up of a new two-terminal cryogenic current comparator (CCC) at the *Instituto Nacional de Tecnología Industrial* (INTI), Argentina. This new bridge improves our uncertainties in high value resistor measurements up to four hundred times in the best situation. Expanded uncertainties of 0.01 µΩ/Ω can be obtained to resistors of 1 MΩ or 10 MΩ and 1 µΩ/Ω to 1 GΩ resistors.**

Index Terms **— Current comparators, measurement techniques, resistance measurement, superconducting quantum interference device (SQUID).**

I. Introduction

In 1972, I. K. Harvey developed the first cryogenic current comparator [1]. It was a two-terminal CCC used for the measurement of resistance ratio. The same idea was then adapted to measure 100 MΩ resistors [2] against the QHR and to scale from QHR or 10 kΩ standards up to 1 GΩ [3] – [4].

In this work we use the system explained at reference [3]. It is the result of an international project heading by the National Institute of Standards and Technology of USA (NIST), with the collaboration of the national institutes of metrology of Mexico (Centro Nacional de Metrología - CENAM), Australia (National Measurement Institute - NMI) and Argentina (INTI). We describe the set-up of the CCC and present some obtained result.

II. System overwied

Fig. 1 shows a schematic diagram of the bridge. Each resistor to be compared is connected in series with a winding forming the two arms of the bridge. A direct voltage source is connected in parallel. The magnetic fluxes produced by the windings have opposite direction and the flux difference is measured with a dc Superconducting Quantum Interference Device (SQUID). The bridge is balanced using the SQUID output voltage to drive a third winding. This bridge has five ratio windings: one of 3100 turns, another of 310, two of 31 and one of 4 turns. This configuration allows ratios of 1:1, 1:10, 1:100 and QHR to 100 kΩ or 10 MΩ. The 4 turns winding is superconductive and the others are resistive. The winding's resistance helps to decrease the effect of the self-resonance of the CCC [2]. On the other hand, because the standard resistors are used as two terminal elements, the resistance of each winding has to be measured to make corrections. It introduces a lower limit to the value of the standard resistor. The following equations show the magnetic circuit in balance and the solution for the value of the primary resistor

$$I_1 \cdot N_1 = I_2 \cdot N_2 + I_F \cdot N_F \quad (1)$$

$$I_1 = \frac{V}{R_1 + r_{w1}} \quad I_2 = \frac{V}{R_2 + r_{w2}} \quad (2)$$

$$R_1 = \frac{V \cdot N_1}{\frac{V}{R_2 + r_{w2}} N_2 + I_F \cdot N_F} - r_{w1} \,. \quad (3)$$

In these equations $R_{1,2}$ are the resistors to be compared and $I_{1,2}$ are the currents in each one. $N_{1,2}$ and $r_{w1,2}$ are the number of turns and the resistance of each winding respectively. V is the applied voltage and I_F is the feedback current flowing throw a winding with N_F turns.

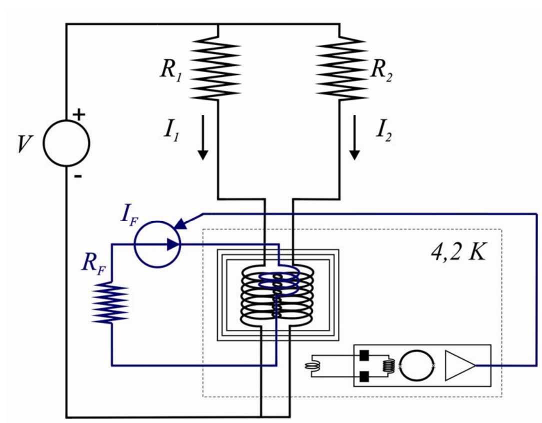

Fig. 1. Schematic diagram of the two-terminal CCC.

II. Set-up & Results

The probe of the CCC and its electronics were manufactured at NIST. During the journey from NIST to INTI the probe was damaged. At INTI we made a new superconducting external lead shield because the original had been totally broken. We needed to fix some wires and connectors too. Especial care was taken in the system installation: the multimeter and the electronic of the SQUID were connected to an isolated and filtered power supply. The computer was connected to an independent source and the

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communication (via GPIB and a relay card) was isolated using external optical devices. All the system was connected in a single point to a low-resistance ground connection. A temperature isolated metal box was made to hold the standard resistors; we included in one of its sides a connection panel with UHF connectors. The link from each terminal of the resistor to the CCC was coaxial with an isolation resistance of 10 TΩ between the inner and the outer conductors. This last one can be connected to ground or to a guard voltage to drive the leakage current outside the CCC.

We found a strong and unexpected dependence of the measurements with the voltage source. After some test, we found that the origin of this effect was noise coupled to the ground system. A digital board is used to generate the voltage source. We totally shielded this board and the system noise decreased. Fig. 2 shows the results for a 10 MΩ resistor compared with a 1 MΩ standard at different voltages before and after the repairs.

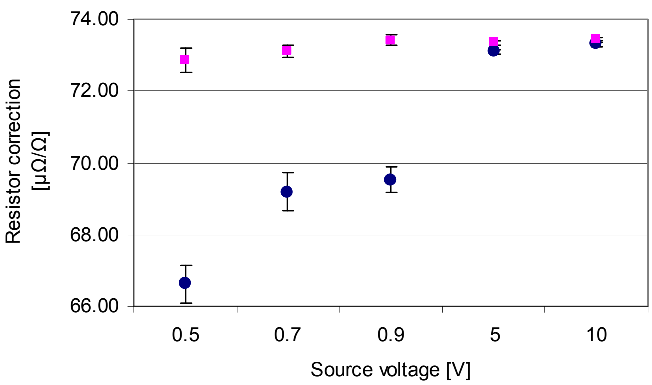

Fig. 2. Relative difference at nominal value for a 10 MΩ resistor measured at different voltages before the repairs (circle) and after (square). Bars indicate the expanded uncertainty (k=2).

In Table 1 the expanded uncertainties of the Calibration and Measurement Capabilities (CMCs) declared at KCDB and the expected uncertainties using the CCC [4] are compared. The CMCs uncertainties were obtained with an active arm bridge. Finally, fig. 3 shows the results for a 10 MΩ resistor compared with a 1 MΩ resistor at 10 V with two different ratio windings.

Table 1. Comparison of the expanded uncertainty of the Calibration and Measurement Capabilities (CMCs) declared at KCDB and the expected uncertainty with the two-terminal CCC.

Resistor value	Expanded uncertainty CMCs	Expanded uncertainty CCC
100 kΩ	1 μΩ/Ω	0.08 μΩ/Ω
1 MΩ	2.5 μΩ/Ω	0.01 μΩ/Ω
10 MΩ	4 μΩ/Ω	0.01 μΩ/Ω
100 MΩ	7 μΩ/Ω	0.1 μΩ/Ω
1 GΩ	10 μΩ/Ω	1 μΩ/Ω

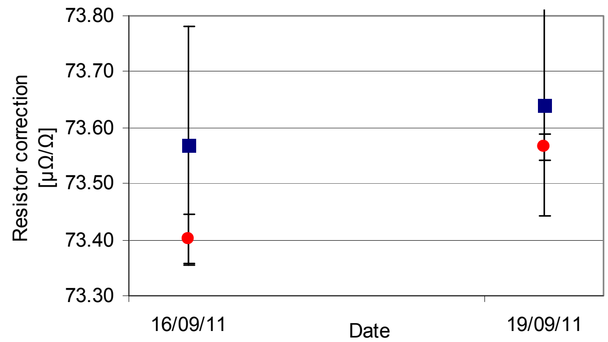

Fig. 3. Two days measurements of a 10 MΩ resistor at 10 V. The windings ratio used were 3100/310 (circle) and 310/31 (square). Bars indicate the expanded uncertainty (k=2).

VI. Conclusion

First measurements show an improvement from ten to four hundred times in the uncertainties obtained with previous methods, depending of the range of resistors. The results show a good agreement within the stability of each resistor. More result will be shown at the conference.

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