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A COMPARISON OF 1 TΩ AND 10 TΩ HIGH RESISTANCE STANDARDS BETWEEN NIST AND SANDIA

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Abstract

NIST-built 10 TΩ and commercial 1 TΩ standard resistors were hand carried between NIST and Sandia for a high resistance comparison. The comparison tested the ruggedness of the new NIST-built standard resistors, provided a check of the scaling between the two laboratories, supported measurements to reestablish NIST calibration services at 10 TΩ and 100 TΩ, and demonstrated the possibility of establishing a NIST high resistance measurement assurance program (MAP). The comparison has demonstrated agreement on the order of 0.07 % which is within the expanded uncertainties (coverage factor = 2) of NIST and Sandia at 1 TΩ and 10 TΩ.

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Introduction

A comparison of high resistance standards at 1 TΩ and 10 TΩ was made between the National Institute of Standards and Technology (NIST) and Sandia***. The comparison used commercially available 1 TΩ standard resistors and NIST-built 10 TΩ standard resistors. Several objectives were accomplished by this comparison. The new NIST-built 10 TΩ transport standards were constructed using fabrication techniques developed at NIST. Measurements made during this comparison were used to evaluate the new resistor design by subjecting the resistors to the handling they would receive when transported between standards laboratories. The measurements also provided a check of the dissemination of the ohm from NIST to a high-level standards laboratory. Transfer of the U.S. representation of the ohm[1] from NIST to Sandia are typically done at the 1 Ω level, twelve and thirteen decades of resistance lower than the 1 TΩ and 10 TΩ resistance levels measured in this comparison. The transfer provided a check of the scaling process in the high resistance range for NIST and Sandia. The comparison was also valuable to the effort to re-establish NIST calibration services at 10 TΩ and 100 TΩ. Calibration of the new NIST 10 TΩ standards by a second standards laboratory serves as a check where there is no recent history or control charts for those standards at NIST. The success of this comparison also demonstrated the possibility of establishing a NIST measurement assurance program (MAP) in the high resistance range similar to the MAP services offered by NIST at the 1 Ω and 10 kΩ decades of resistance.

Standards

Five standard resistors were used during the comparsion. Three commercial standards were used at the 1 TΩ level and two NIST-built standards were used at the 10 TΩ level. Two of the three 1 TΩ standards were provided by NIST and the third was provided by Sandia. The two NIST standards were acquired from two different commercial manufacturers of high resistance standards. Table 1 lists the resistor identification, nominal value, resistor owner, and manufacturer. The notation used to identify the resistors consists of four parts: the nominal value (1T or 10T), the lab that provided the standard (N for NIST, S for Sandia), an unique number (1 through 5), and a letter (A, B, or C) to differentiate the physical design of the resistor. Resistors designated A and B are of commercial design and fabrication and resistor C is of NIST design and fabrication.

***In this paper, "Sandia" denotes the U. S. Department of Energy Primary Standards Laboratory, operated by Sandia National Laboratories.

DISCLAIMER

Identification	Nominal Value (TΩ)	Resistor Owner	Manufacturer
1TN1A	1	NIST (N)	Commercial - A
1TN2B	1	NIST (N)	Commercial - B
1TS3B	1	Sandia (S)	Commercial - B
10TN4C	10	NIST (N)	NIST - C
10TN5C	10	NIST (N)	NIST - C

Table 1. Identification, nominal value, resistor owner, and resistor manufacturer for 1 TΩ and 10 TΩ standard resistors measured during NIST and Sandia comparison.

The NIST-built standards were fabricated utilizing techniques developed to construct transport standards for an international comparison at 10 MΩ and 1 GΩ [(2)]. Wirewound resistance elements are not practical for standard resistors greater than 100 MΩ. Precious-metal-oxide (PMO) film resistors were used as the resistance elements for construction of all NIST standard resistors at the 1 GΩ decade of resistance and above. The PMO film resistor elements were heat-treated for over 100 hours at approximately 125 °C to accelerate the aging process by reducing short-term drift and making the resistors more stable in a shorter period of time. After heat treatment, the resistance elements were hermetically sealed in a metal-insulator-metal canisters as shown in Fig. 1. The metal-insulator-metal canister was developed to hermetically seal the 10 TΩ PMO film resistors. This allows the metal canister halves to be driven at separate guard potentials nominally equal to the resistor termination potentials, suppressing leakage currents across the glass-to-metal seals. Finally, the metal-insulator-metal canisters are shock mounted in permanent shielded enclosures with coaxial resistor terminations.

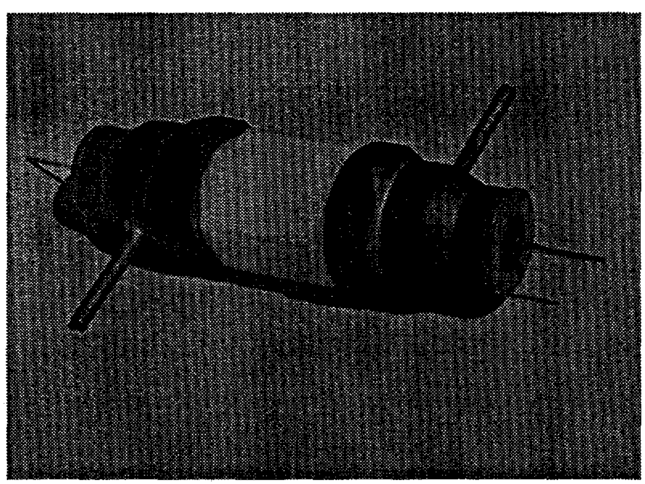

Fig. 1. Metal-insulator-metal canister design used to hermetically seal PMO resistance elements. The glass-to-metal seals at the end insulate the canister from the resistance element terminations. Canister ends can be driven at a guard potential by the shields of coaxial connectors on container (not shown).

Measurement Systems

The measurement systems used to provide calibration services at NIST and Sandia were used to make these measurements. Both laboratories use digital teraohmmeter[3] systems to provide calibration services at 1 TΩ to customers. Sandia also uses the same system for calibrations at the 10 TΩ level. At the time of this comparison, NIST did not offer regular calibration services at 10 TΩ. NIST is implementing a programmable voltage source technique[4,5] to provide this service.

The teraohmmeter instrument uses an analog integrator technique to measure resistances by forming a resistor-capacitor network with the test resistor and an internal fixed air capacitor. A block diagram of the teraohmmeter is shown in Fig. 2. When switch S is opened, the DC source charges the RC network formed by the internal air capacitor, C, and the test resistor, R_X. The output voltage, V_0, is monitored by a level comparator circuit. The time, Δt, required for the output voltage to change by ΔV_0 is measured by the counter circuit. The value of the test resistor, R_X, can then be determined from the test voltage, V_i, the change in output voltage, V_0, the capacitance, C, and the measured time, Δt, as

$$R_X = -\left(\frac{1}{C}\right)\left(\frac{V_i}{\Delta V_0}\right)\Delta t.$$

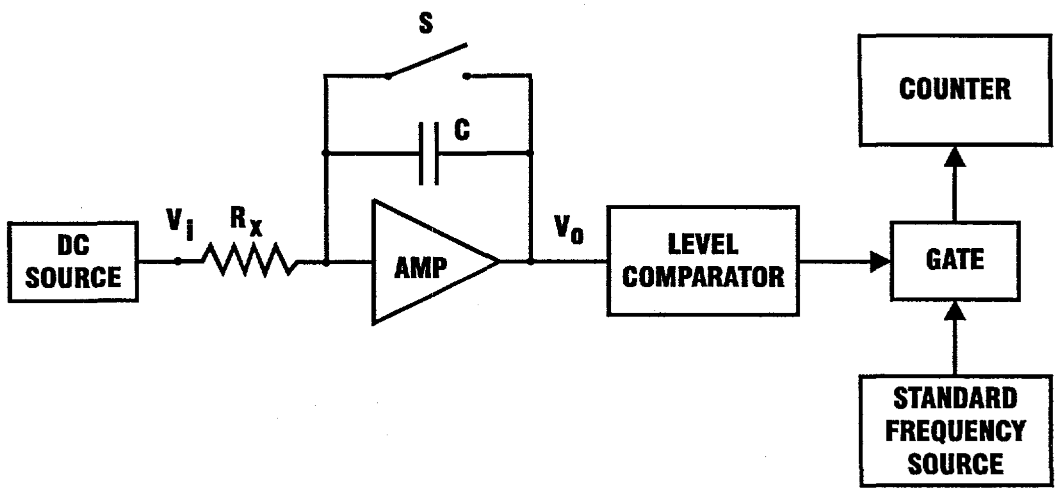

Fig. 2. Block diagram of teraohmmeter system.

Resistance Scaling

The U. S. representation of the ohm is defined by the quantized Hall resistance[6] standard at NIST. Figure 3 shows the dissemination of the U. S. ohm from the i = 2 quantized Hall resistance value of 12 906.4 Ω to the 1 TΩ and 10 TΩ levels of resistance compared by NIST and Sandia. Many systems and techniques including cryogenic current comparators[7], Hamon transfer standards[8], teraohmmeters, and automated resistance bridges are used for resistance scaling. NIST calibration services transfer the U. S. ohm to Sandia at the 1 Ω decade of resistance. The comparison of 1 TΩ and 10 TΩ resistance standards provided a check of the scaling techniques to these decades of resistance for both NIST and Sandia.

NIST and Sandia scale to the 10 GΩ and 10 MΩ decades of resistance, respectively, with Hamon transfer standards. At resistance levels of 10 GΩ and above, NIST compares test resistors to a 10 GΩ standard resistor with the teraohmmeter. Check standards are maintained and measured at resistance levels of 10 GΩ and above to provide quality control for the calibration service. Similarly, Sandia uses a 10 MΩ standard with the teraohmmeter and also maintains and measures check standards at all the decades where resistors are calibrated. Both laboratories rely on the internal ratio of the teraohmmeter to scale to the 1 TΩ and 10 TΩ decades of resistance. The teraohmmeter's internal ratio errors are included in the uncertainty analysis as a Type B uncertainty[1].

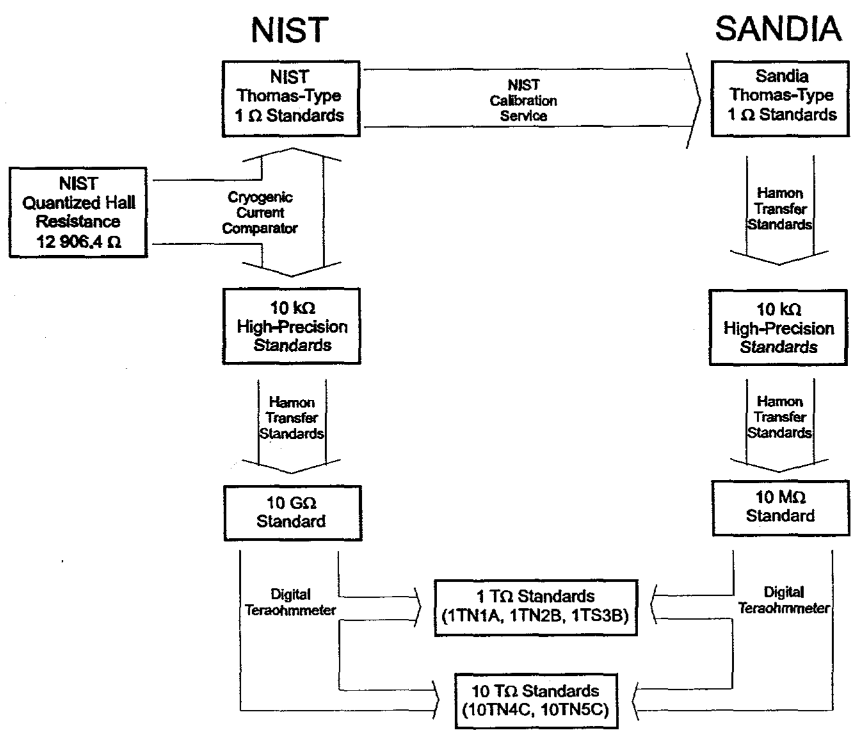

Fig. 3. Traceability of NIST and Sandia calibration of 1 TΩ and 10 TΩ standards in terms of the U. S. ohm. The NIST calibration service transfers the U. S. ohm to Sandia at the 1 Ω decade of resistance. Scaling techniques transfer the U. S. ohm to higher decades of resistance at NIST and Sandia.

Comparison

The measurements were made over a period of three months. The four NIST resistors involved in the comparsion were measured at NIST and then hand-carried to Sandia the week of the NCSL Conference in 1998. During the week of the conference, the 10 TΩ standards were measured at Sandia and then hand-carried back to NIST once the measurements were completed. The 10 TΩ standards were then remeasured at NIST. The two 1 TΩ standard resistors provided by NIST remained at Sandia and were measured along with a Sandia check standard. These three resistors were later hand-carried to NIST and measured. Finally, the Sandia check standard was hand-carried back to Sandia and remeasured upon return concluding the comparison

Figure 4 shows the differences between the NIST and Sandia measurements of the 1 TΩ and 10 TΩ standard resistors. Differences for the 1 TΩ standard resistors are reported at 100 V, 250 V, and 500 V. Differences for the 10 TΩ standard resistors are reported only at 500 V since the 10 TΩ standard resistors have very small voltage coefficients, 0.4 x 10^{-6}/V and 0.8 x 10^{-6}/V, respectively. The 10 TΩ transport standards, having recently been assembled, were drifting at a decreasing rate, therefore, the differences shown in Fig. 4 for the 10 TΩ transport standards are based on a second-order fit to the NIST data before and after the resistors were measured by Sandia.

The comparison has demonstrated agreement between NIST and Sandia at 1 TΩ and 10 TΩ. The difference between NIST and Sandia for the two 10 TΩ standard resistors was less than 600 x 10^{-6} which is well within the expanded uncertainties (coverage factor = 2) of 2000 x 10^{-6} that NIST and Sandia would assign to these measurements. A combined expanded uncertainty of 2828 x 10^{-6} for the 10 TΩ decade of resistance shown in Fig. 4 is the limit of disagreement of measurements at the two laboratories. The difference between NIST and Sandia for two of the three 1 TΩ standard resistors was less than 700 x 10^{-6} which is well within the expanded uncertainties (coverage factor = 2) of 1400 x 10^{-6} and 1333 x 10^{-6} for NIST and Sandia, respectively. The third 1 TΩ standard resistor (ID: 1TN1A) difference ranged from 1000 x 10^{-6} to 1800 x 10^{-6}. The relatively large voltage coefficient of 50 x 10^{-6} (3 to 25 times larger than that of the other two 1 TΩ standard resistors) of standard resistor 1TN1A indicates that it may not be the best resistor for use as a transport standard. A combined expanded uncertainty of 1933 x 10^{-6} for the 1 TΩ decade of resistance is shown in Fig. 4.

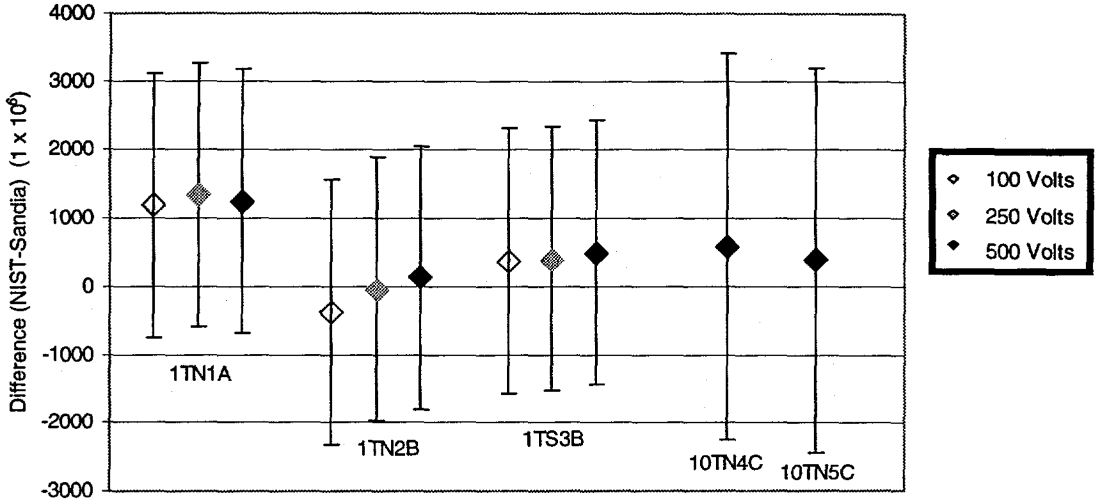

Fig. 4. Differences betweeen NIST and Sandia for measurement of 1 TΩ commercial and 10 TΩ NIST built transport standards. Difference was within the combined expanded uncertainties (coverage factor = 2) for NIST and Sandia of 1933 x 10^{-6} and 2828 x 10^{-6} for 1 TΩ and 10 TΩ measurements, respectively.

Summary

The comparison demonstrates equivalence at 1 TΩ and 10 TΩ between NIST and Sandia within the expanded uncertainties (coverage factor = 2) of both standards laboratories. Transfer of the U. S. ohm from NIST to Sandia is typically done at the 1 Ω level, therefore, this comparison demonstrates that, with careful attention to scaling, the ohm can be disseminated to higher decades of resistance. Field testing of the NIST-built 10 TΩ standard resistors shows their ruggedness and ability to be transported between standards labs, demonstrating that a MAP could be established in the high resistance range. The comparison also benefitted the effort at NIST to extend calibration services to the 10 TΩ and 100 TΩ decades of resistance by providing a check at 10 TΩ where there is no recent history or control charts for those standards at NIST. Further design, construction, evaluation, and characterization of PMO high resistance standards is planned.

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