10 TΩ and 100 TΩ Resistance Comparison between NIST and AIST

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Abstract — **We report the results of a comparison of 10 TΩ and 100 TΩ high resistance standards between the National Institute of Standards and Technology (NIST) and the National Institute for Advanced Industrial Science and Technology (AIST). Three standard resistors were hand carried between both laboratories, a 100 TΩ from NIST and a 10 TΩ and 100 TΩ from AIST. The two laboratories agreed to within 100 x 10^{-6} at 10 TΩ and 500 x 10^{-6} at 100 TΩ. The comparison results have given both laboratories an external check of their measurement systems and scaling processes to 100 TΩ.**

Index Terms — **high resistance, standard resistor, dual source bridge, voltage injection, uncertainty.**

I. INTRODUCTION

High value standard resistors are of interest for many measurements where small currents, leakage of insulators, or purity of materials are of concern. Interest from National Institute of Standards and Technology (NIST) and National Institute for Advanced Industrial Science and Technology (AIST) industrial collaborators in recent years has motivated us to compare high resistance standards from 100 MΩ to 100 TΩ and provided an opportunity to further evaluate our high resistance scaling and traceability from the quantized Hall resistance (QHR) i=2 plateau of $R_{K\text{-}90}/2$ = 12906.4035 Ω. In 2016, we compared high resistance standards of nominal values from 100 MΩ to 10 TΩ which provided insight to make the 10 TΩ and 100 TΩ comparison in 2017 reported in this paper.

The first part of the comparison involved the assembly and measurement of a 100 TΩ standard resistor at NIST, which was then hand carried to AIST for measurement. After several weeks of measurements at AIST, the 100 TΩ NIST standard resistor, as well as AIST 10 TΩ and 100 TΩ standard resistors, were hand-carried to NIST for measurements over several months. Finally, the AIST 10 TΩ and 100 TΩ standard resistors were hand-carried back to AIST.

II. MEASUREMENT SYSTEMS

The high resistance measurement systems and scaling techniques used at both of our national metrology institutes (NMI) have some similarities but also have some features unique to each NMI. The high resistance bridges used at NIST and AIST for this comparison are similar to a Wheatstone bridge, either a dual source bridge (DSB) [1, 2] or a voltage injection type Wheatstone bridge (VIWB) [3].

NIST has several dual source bridges where low-impedance programmable dc sources (V_1, V_2) in place of two of the resistive ratio arms and the bridge voltage source of a conventional Wheatstone bridge. High resistance standards (≥ 1 MΩ) (R_X, R_S) are used in the other two ratio arms. When the bridge is balanced, the unknown resistor value (R_X) can be determined as

$$R_X = R_S\,(V_1/V_2). \tag{1}$$

The technique has been used for many years at NIST as well as at other NMIs since first introduced by Henderson at the National Physical Laboratory (NPL) [1]. With the DSB, NIST uses guarded Hamon transfer standards and the substitution technique to build-up from 1 MΩ to 10 TΩ in decade steps of 1:10 [4, 5]. The guarded Hamon transfer standards can be configured in 1:10 or 1:100 ratios during the build-up process, providing redundant paths from lower to higher decades of resistance. High resistance measurements at up to 1000 V can be made with the DSB.

AIST mainly uses a VIWB for calibration service and also use a DSB to evaluate standard resistors. The VIWB is a Wheatstone bridge with an additional voltage source at the midpoint of the bridge to get equilibrium by injecting voltage. By measuring this injected voltage, a resistor ratio, R_X/R_S, is measured. The VIWB has a single main voltage source and a resistive voltage divider which consists of eleven 100 kΩ resistors. The main voltage, 110 V, is divided by this resistive voltage divider and then 100 V and 10 V are applied to R_X and R_S, respectively, for 1:10 measurement. The divider ratio of it is calibrated before the main measurement. The voltage dependence of the resistive divider is evaluated up to 1100 V, the maximum test voltage of the VIWB is 1000 V.

III. 10 TΩ AND 100 TΩ RESULTS

The assembly of a compact 100 TΩ standard resistor at NIST a month before hand-carrying it to AIST was problematic. The resistance element had been aged for over a year, but the mounting in a shielded enclosure induced an initial drift of 153 x 10^{-6}/d for the initial measurements at NIST. The resistor drift rate slowed to 54 x 10^{-6}/d during the several weeks of measurements at AIST which included test of voltage and humidity dependence and measurements with both the VIWB

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and DSB. The drift rate had slowed to 16 x 10^{-6}/d for the final measurements at NIST. Both NMIs made measurements at 100 V to 500 V. Voltage dependence of this resistor was negligible compared to the drift rate. Figure 1 shows test at 250 V. Error bars are the expanded uncertainties (k = 2) of 700 x 10^{-6} for NIST and 1200 x 10^{-6} for AIST.

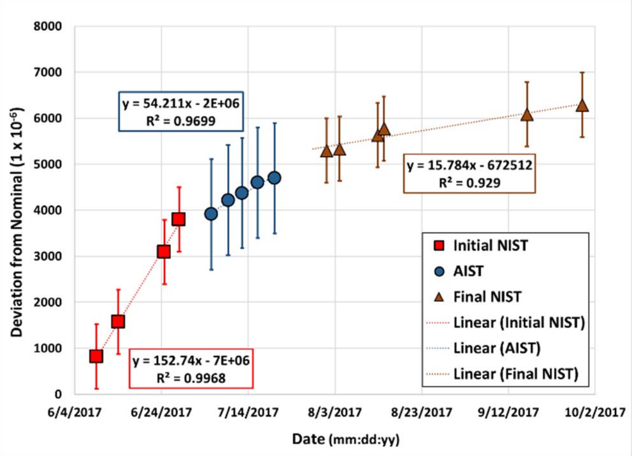

Fig. 1. Newly constructed NIST 100 TΩ resistor measured at NIST - AIST - NIST. Despite the large and decreasing drift rate for this standard resistor, NIST and AIST agreed within the expanded uncertainties (k = 2) of 700 x 10^{-6} for NIST and 1200 x 10^{-6} for AIST. Shown are measurements at 250 V and error bars are the expanded uncertainties (k = 2).

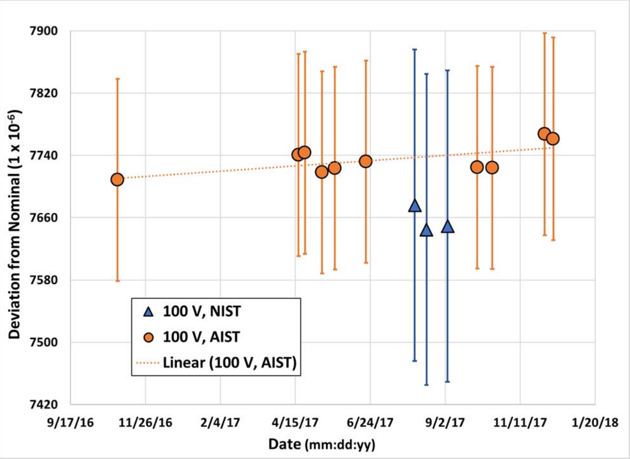

Fig. 2. The AIST 10 TΩ resistor measured at AIST - NIST - AIST. NIST and AIST agreed within the expanded uncertainties (k = 2) of 200 x 10^{-6} for NIST and 130 x 10^{-6} for AIST. Shown are measurements at 100 V and error bars are the expanded uncertainties (k = 2).

The AIST 10 TΩ and 100 TΩ standard resistors used for the latter part of the comparison were well-aged and had much smaller drift rates of 0.097 x 10^{-6}/d (35 x 10^{-6}/yr) for the 10 TΩ and 1.285 x 10^{-6}/d (469 x 10^{-6}/yr) for the 100 TΩ. Fig. 2 and Fig. 3 show the measurements for the 10 TΩ and 100 TΩ AIST standard resistors. The NIST measurements of the 100 TΩ standard resistor are corrected for the voltage dependence of the 10 TΩ standard resistor used in the R_S arm of the DSB.

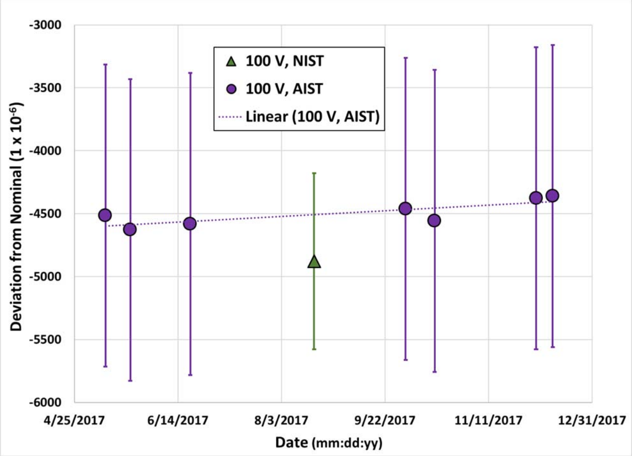

Fig. 3. The AIST 100 TΩ resistor measured at AIST - NIST - AIST. NIST and AIST agreed within the expanded uncertainties (k = 2) of 700 x 10^{-6} for NIST and 1200 x 10^{-6} for AIST. Shown are measurements at 100 V and error bars are the expanded uncertainties (k = 2).

IV. CONCLUSION

10 TΩ and 100 TΩ standard resistors were compared between NIST and AIST. Despite the large initial drift of the NIST 100 TΩ standard resistor, we were able to complete the initial part of the comparison at AIST and agreed within the expanded uncertainties (k = 2) of 700 x 10^{-6} for NIST and 1200 x 10^{-6} for AIST. Agreement was better for the latter part of the comparison where the well-aged AIST 10 TΩ and 100 TΩ standard resistors were measured at NIST and finally at AIST. At 10 TΩ, the two NMIs agree well within the expanded uncertainties (k = 2) of 200 x 10^{-6} for NIST and 130 x 10^{-6} for AIST. The two laboratories agreed to within 100 x 10^{-6} at 10 TΩ and 500 x 10^{-6} at 100 TΩ. The care taken to hand-carry the standard resistors, rather than transport by air freight, minimized transport time and reduced exposure to mechanical shocks and thermal changes; contributing to a successful comparison.

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