A 100 TΩ Guarded Hamon Transfer Standard

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Abstract — **Guarded Hamon transfer standards are used at the National Institute of Standards and Technology (NIST) for scaling to high resistance levels. An improved design for a guarded Hamon transfer standard in the range from 1 TΩ to 100 TΩ is described. Measurements taken to select the primary and guard resistor elements are described, as well as the process used to clean the resistor elements. The selection process for resistor elements focused on choosing the smallest settling times and narrowest range of corrections from nominal value. Key aspects of this guarded Hamon transfer standard are the elimination of charge-storing materials in its connections, selection of resistors to minimize leakage currents, and the hermetic sealing of all the elements inside one enclosure.**

Index Terms **— Measurement, standard resistor, guarded Hamon transfer standard, settling time, scaling.**

I. INTRODUCTION

The National Institute of Standards and Technology (NIST) uses guarded Hamon transfer standards to scale from 1 MΩ to 10 TΩ. These Hamon network standards are used exclusively for scaling at the highest resistance levels, while high resistance cryogenic current comparators (HR-CCC) also are used at resistance levels up to 1 GΩ. In earlier scaling measurements made at 100 TΩ we have used 1:10 and 1:100 bridge ratios to scale from 1 TΩ and 100 TΩ. The 100 TΩ transfer standard described here was designed to verify and improve scaling by providing greater stability than those bridge ratios [1]. Like other NIST-built transfer standards, this standard has internal guard networks to suppress leakage currents flowing from the main resistor network to ground.

II. PRIMARY AND GUARD RESISTOR ELEMENTS

The resistor elements used were thin-film precious metal oxides deposited on alumina substrates. Impurities on the surface could shunt the resistor element, contributing to leakage currents, reduction in the resistance value, and increases in the settling time or resistor-capacitor (RC) time constant. The resistance elements were cleaned, heat treated, purged with inert gas, and hermetically sealed to protect these components from moisture and contamination. The glass-to-metal (hermetic) seals were used to connect and guard the resistor elements, eliminating some charge-storing materials and leakage paths. Designs and construction methods refined in recent years were applied to build a 100 TΩ transfer standard with minimal settling time [2].

Most Hamon transfer standards have ten resistors of the same nominal value which are permanently connected in series. Paralleling fixtures are used to connect the resistors in parallel or series-parallel configurations allowing 1:100 and 1:10 ratios for scaling to higher resistance levels. The guard circuit maintains approximately the same potential as the main circuit at each junction, thus suppressing leakage currents from flowing through the insulation to ground [3].

Thirty-four 10 TΩ elements were measured and ten were selected for the main circuit based on their corrections and settling times. The selected elements had corrections ranging from 40 000 μΩ/Ω to 60 000 μΩ/Ω and reasonable settling times on the order of five RC time constants or 300 s. Twenty-four 100 GΩ elements were measured for the guard circuit and ten were chosen to minimize the leakage current. This minimization was done by calculating the voltage potential at each node for both the main and guard circuits using different combinations of the main and guard resistors. The leakage current at each node was calculated from the potential difference between the main and the guard circuits using 1 PΩ as the nominal resistance of the glass-to-metal seals that separate the two networks. The calculated leakage currents ranged from 10 aA to 100 aA for the resistor ordering selected to build the device.

III. CONSTRUCTION OF THE HAMON DEVICE

Glass-to-metal seals were used to hermetically seal the resistor elements and as junction nodes for the main and guard resistors. The resistances of the seals were initially measured to be about 10^{14} Ω. After cleaning with acetone and ethyl alcohol and heat-drying the seals, the resistances of the seals were increased to 10^{15} Ω to 10^{16} Ω. The seals were soldered to a printed circuit board (PCB) which allows the main and guard resistor elements to be hermetically sealed in one container. The device uses the PCB in the structure as a guarded top plate for the enclosure. Gold plated pins and sockets are used to connect the main and guard junction points on the guarded top plate PCB to coaxial terminations or paralleling fixtures for measurements in the series, parallel, or series-parallel modes.

Metal shields were designed to protect the ambient side of the glass-to-metal seals from contamination by dust, fingerprints, and other substances that may reduce the

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[1] Quantum Measurement Division, Gaithersburg, MD. NIST is part of the U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology; not subject to copyright in the United States.

insulation between the main and guard circuits. The shields also provide radio frequency screening for the main circuit by extending the guard circuit around the gold pins, paralleling fixtures, and coaxial adapters. A removable metal lid has also been fabricated to extend the Faraday cage of the enclosure around the paralleling fixtures and coaxial adapters.

IV. RESULTS

Measurements of the 100 TΩ transfer standard have shown that the settling time is reduced compared to the 100 TΩ transfer standards built at NIST a decade ago. Before hermetically sealing the device, it had an average correction from nominal of 67 000 μΩ/Ω when measured 1800 s after the 500 V was applied. These measurements showed that the transfer standard reached a steady state in approximately 700 s, which was 1/5 of the 3600 s the decade-old transfer standards would take to reach a steady state. Figure 1 shows a sequence of four bridge balances using a 3600 s soak time.

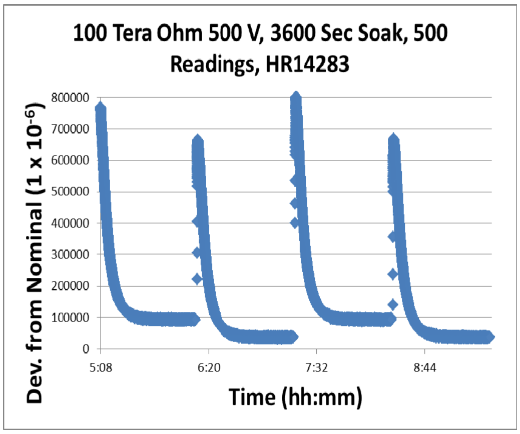

Fig. 1. Settling times for the 100 TΩ transfer standard with a 3600 s soak time. Four measurements of alternating polarity are shown.

Testing of the individual elements showed that if more than two elements were measured during a set of measurements then there would be too much charge built up from the increased capacitances of coaxial connectors and coaxial connectors attached to the eleven glass-to-metal seals. Elements remained stable once connected into the Hamon network and measurement results were similar to those made on the elements before building the transfer standard. To reduce the capacitances and RC time constant, connections were only made to two of the ten resistors during a set of measurements. The measurements of individual resistors were used to calculate the series, parallel, and series-parallel resistances. Figure 2 shows the calculated and measured resistances for the parallel, series-parallel, and series configurations. To evaluate the RC time constant of the transfer standard in series mode, a set of measurements using a 3600 s soak time was used which confirmed that the device reached a steady state after 1800 s. An RC time constant of ≈400 s was determined from these measurements. This indicates a capacitance of 4 pF, which is nominally the capacitance of the glass-to-metal seals, as measured with a capacitance bridge.

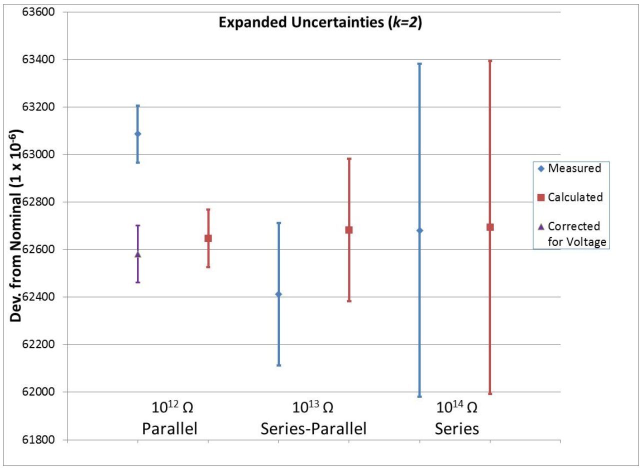

Fig. 2: Calculated and the measured resistance for the parallel (10^{12} Ω), series-parallel (10^{13} Ω), and series (10^{14} Ω) measurements. A correction for the test voltage was applied to the parallel (10^{12} Ω) measurement, improving the agreement with the calculated resistance. Error bars are the expanded uncertainties ($k = 2$) for each decade of resistance.

V. CONCLUSION

A 100 TΩ guarded Hamon transfer standard with a time constant of 400 s was built and measured. First results demonstrate agreement between the three modes of operation within the expanded uncertainties ($k = 2$) and with values calculated from the measurement of the ten sections of the transfer standard. Settling time is reduced by 80 % as compared to previous devices. Testing of this device will continue and the stability will be determined depending upon the temperature coefficient, change in correction over time, and repeated transfers from parallel to series-parallel and series configurations.

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