AUTOMATION OF 1 TΩ TO 100 TΩ ULTRA-HIGH RESISTANCE MEASUREMENTS AT NIST

D. G. Jarrett, A. M. Muñiz-Mercado† , and M. E. Kraft
National Institute of Standards and Technology*
Gaithersburg, MD 20899-8171 USA

Abstract

The automation of ultra-high resistance measurements at the National Institute of Standards and Technology (NIST) in the range 1 TΩ to 100 TΩ has been completed with the use of a programmable XY positioning system to facilitate the guarded connection of multiple standard resistors to an automated dual-source bridge. Automated guarded switching that is immune to leakages to ground is critical to the characterization of standard resistors and transfer standards in this range.

Introduction

In recent years, the calibration of standard resistors at NIST in the range 10 MΩ to 100 TΩ has been automated and uncertainties reduced by a factor of 10 [1] due to the implementation of an automated guarded dual source bridge [2] in combination with a low thermal electromotive force guarded scanner [3], which provides automated switching in the range 10 MΩ to 100 GΩ. Standard resistors in the range 1 TΩ to 100 TΩ have been measured by manual connection to the automated bridge in order to reduce leakage and obtain the lowest possible expanded uncertainty ($k = 2$) of 100 μΩ/Ω at 1 TΩ. Internal capacitances of the guarded scanner have made manual connections necessary for measurements at 1 TΩ and above.

For each order of magnitude increase in resistance, the RC time constant increases by an order of magnitude also, requiring the use of longer settling times before accurate measurements can be made. To maintain the same levels of uncertainty with automated connections as with manual connections requires minimizing the shunt capacitances, which are charged each time voltage is applied to the circuit. Shunt capacitances can be minimized by keeping the cable connections as short as possible. Other methods for reducing settling times are the use of guarding and the “source voltage, measure current” technique, both of which are implemented in the guarded dual source bridge [2,4].

XY Positioning System

To solve the automation problem without compromising the measurement system performance, an XY positioning system was developed as shown in Figure 1. The NIST resistance laboratory has several programmable multi-axis positioning systems to automatically make coaxial connections to guarded resistance bridges at the 10 kΩ and 1 MΩ levels of resistance [5, 6]. Other guarded switching systems, which do not use relays, make use of stepper motors to rotate stacks of guarded disks through a series of commutator positions [7].

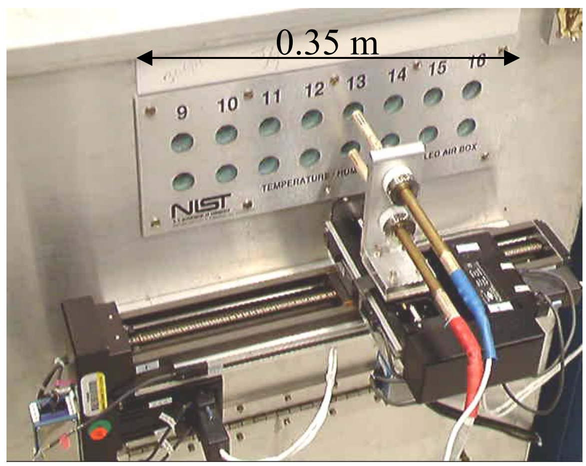

Fig.1. XY positioning system shown mounted on side of environmental test chamber at NIST. The close proximity to the standard resistors inside the test chamber to the dual source bridge keeps test lead lengths to a minimum. The XY positioning system can make guarded two-terminal connections for up to eight standard resistors to a high resistance bridge.

The guarded connectors are silver-plated British Post Office (BPO) type coaxial connectors with polytetrafluoroethylene (PTFE) insulation. These connectors are widely used at NIST and other National Metrology Institutes (NMIs) due to their low variation in thermoelectric voltages (typically 10 nV) and high insulation resistances (> 1 TΩ). In addition to these electrical properties, the low insertion force, plug-type connection makes these connectors well

† Department of Electrical Engineering, University of Puerto Rico, Mayaguez Campus.
* Quantum Electrical Metrology 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.

suited to automation where only push and pull operations are required for making and breaking connections.

The design principles of this XY positioning system for use at 1 TΩ to 100 TΩ are similar to those used in earlier-built multi axis positioning systems for 10 kΩ and 1 MΩ, but there were some issues that made an identical system impractical. At 1 TΩ and above, minimum settling times for standard resistors are 120 s to 300 s. However, settling times may be longer, so shunt capacitances need to be minimized by keeping the coaxial connections as short as possible. The shielded PTFE insulated cables that connect between the standard resistors and the detector have a capacitance of 300 pF/m. The detector current, ΔI, charges the shunt capacitance exponentially and the RC time constant determines the settling time. Minimizing the capacitance between the detector and resistors is necessary for ultra-high resistance measurements in the range 1 TΩ to 100 TΩ.

To keep the cabling of the bridge circuit as short as possible, the two-axis positioning system was mounted on the side of the environmental chamber where the standard resistors are measured, as shown in Figure 1. This required building a much smaller positioning system than used in the 10 kΩ and 1 MΩ measurement systems and added only 0.1 m of cabling to each resistor terminal. Because the positioning system motors would be in close proximity to the standard resistors and bridge, low-noise brushless dc motor assemblies were selected to minimize RF interference. These commercially available motor assemblies have all electronics (servo motor, controller, amplifier, and encoder) enclosed in a single package. The positioning system can be used with any system that makes coaxial connections to devices under test, such as the dual source bridge or teraohmmeter measurement systems.

Evaluation

Initial data sets taken with the XY positioning system have shown no differences from data sets taken manually at 1 TΩ. Data sets comparing the XY positioning system to the guarded scanner [3] at 100 GΩ showed a factor of 10 reduction (from 200 μΩ/Ω to 20 μΩ/Ω) in the differences of bridge ratio readings from predicted resistances, independently verified by guarded transfer standards. The system will be used to evaluate ultra high resistance standards and transfer standards in the range 1 TΩ to 100 TΩ. Results of those measurements will be reported at the conference.

Summary

The implementation of an XY axis positioning system was essential to complete the automation of measurements and calibrations of high value standard resistors in the range 1 TΩ to 100 TΩ. The completion of this critical automation will facilitate the collection of additional data sets needed to characterize and evaluate standard resistors and scaling devices in the range 1 TΩ to 100 TΩ. Large time constants and long settling times in this range and the lack of full automation have limited advances in this range in recent years. The ability to automatically collect large sets of data overnight and on weekends without operator involvement will allow further evaluation of standard resistors and scaling devices in this range, leading to the extension of calibration services and reduction of uncertainties at 1 TΩ and above.

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