AUTOMATED GUARDED BRIDGE FOR CALIBRATION OF MULTIMEGOHM STANDARD RESISTORS

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Abstract

The implementation of an automated guarded bridge for calibrating multimegohm standard resistors is described. A guarded Wheatstone bridge has been assembled with programmable dc calibrators in two of the arms allowing multiple ratios and test voltages to be remotely selected. Preliminary measurements are reported along with the balancing algorithm.

Introduction

Calibration of standard resistors from 10 MΩ to 1 TΩ at NIST are done manually on a guarded Wheatstone bridge or by using a semiautomated procedure with a teraohmmeter [1]. Both measurement systems require a degree of manual operation and have constraints that limit their flexibility. Neither system sufficiently covers the entire range of 10 MΩ to 1 TΩ with the lowest possible uncertainty. A single automated and robust system is being developed at NIST to replace the two aging systems, eliminate operator error, reduce uncertainties, and expand calibration services to resistances above 1 TΩ.

The method of using dc calibrators in two of the arms [2] is the approach selected to accomplish this task. The low impedance of the calibrators reduces errors caused by leakage currents. Guarding of the high side of the detector is also done to reduce leakages at that point. A graphical user interface (GUI) [3] has been written to provide flexibility to the measurement system and improved control of the instrumentation. Initial data indicate that the completed bridge should be able to calibrate multimegohm standard resistors at uncertainties of at least a factor of two below those presently assigned to calibrations of multimegohm resistors at NIST.

Guarded Multimegohm Bridge

For a Wheatstone bridge [4], the equation at time of balance is

$$R_1/R_2 = R_X/R_D \qquad (1)$$

where R_1 and R_2 are the ratio arms of the bridge and R_X and R_D are unknown and dummy resistors as shown in Figure 1. The detector D and voltage source V complete the traditional Wheatstone bridge.

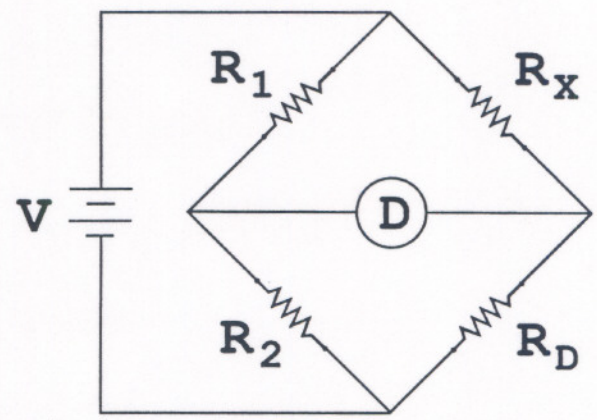

Fig. 1. Conventional Wheatstone Bridge.

In the automated multimegohm bridge, resistances R_1 and R_2 are replaced with programmable voltage sources V_1 and V_2 set to voltages E_1 and E_2 respectively yielding the following equation

$$E_1/E_2 = R_X/R_D \qquad (2)$$

at time of balance. The bridge voltage supplied by source V shown in Figure 1 now is generated by V_1 and V_2. Substituting programmable voltage sources for the main ratio arm and adding a guard resistor network to the bridge yields the circuit shown in Figure 2 where r_X and r_D are guard resistors.

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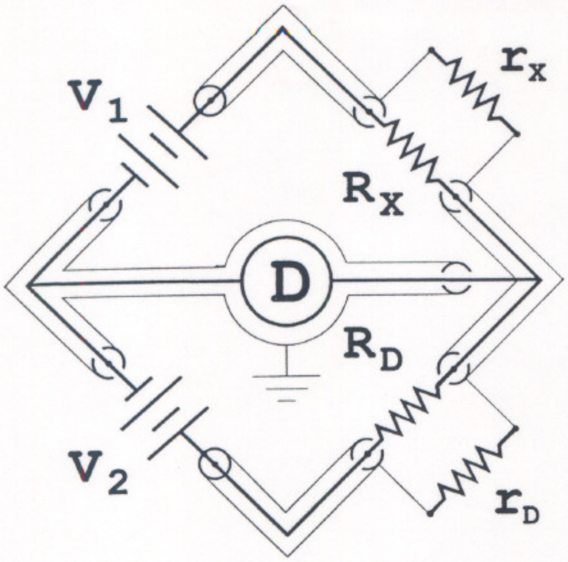

Fig. 2. Guarded Multimegohm Bridge.

Balancing Procedure

An electrometer with a resolution of ±3 fA in the current mode is used as the detector to measure the difference in the currents, ΔI, flowing through R_X and R_D. Initially the voltage sources are set to E_{1Est} and E_2, the nominal ratio of R_X/R_D. The current ΔI is measured by the detector. The estimated output E_{1Est}' of source V_1, required to drive the bridge to a null, is calculated using the following equation

$$E_{1Est}' = [\, \Delta I + E_2 / R_D]\, R_X \qquad (3)$$

where R_D and R_X are nominal resistances. The source V_1 is then set to the voltage E_{1Est}' which reduces ΔI to a lower value $\Delta I'$ bringing the bridge closer to a null. A linear fit is then applied to determine the exact setting of V_1 required to reach a null based on the two iterations of E_{1Est} and ΔI as shown in Equation 4 below

$$E_1 = [\, \Delta I \cdot E_{1Est}' - \Delta I' \cdot E_{1Est}] / [\Delta I - \Delta I']. \qquad (4)$$

The unknown R_X can then be solved for by substituting E_1, E_2, and R_D into Equation 2.

A GUI has been written that makes selection of voltage ranges and bridge ratio automatic. Balancing and computations are also controlled by the GUI along with the electrometer and calibrators.

The GUI allows the operator to easily select test parameters such as nominal resistances, test voltages, and bridge ratios. The event driven control structure of the GUI allows the software to respond immediately to changing parameters and handle errors without complex error handling routines. Changes in bridge parameters can be made without the risk of creating overload conditions such as a test voltage out of the calibrator range or applying voltages that could damage bridge components.

Other features of the GUI are multiple control options, linking to databases, plotting of data, and a user friendly interface.

Results

Using the substitution method, agreement between the automated multimegohm system and the two existing measurement systems used at NIST has been well within uncertainties presently assigned by NIST to standard resistors from 10 MΩ to 1 TΩ [1]. An extensive comparison of the systems will be reported at the conference along with uncertainty analysis for the automated multimegohm system.

Acknowledgements

I would like to thank Ronald Dziuba for his guidance and insight while I worked on this project and as I continue to work in the resistance laboratory. I also want to thank Randolph Elmquist for his encouragement and help with high resistance measurements.

References

[1] R. F. Dziuba., P.A. Boynton, R. E. Elmquist, D. G. Jarrett, T. P. Moore, and J. D. Neal,"NIST Measurement Services for DC Standard Resistors," National Institute of Standards and Technology Technical Note 1298, 1992, pp. 5, 20-22, 27-28, 47.

[2] L. C. A. Henderson, "A New Technnique for the Automated Measurement of High Valued Resistors," Journal Physics, Electronics, Scientific Instruments, vol. 20, pp.492-495, Sept. 1987.

[3] R. P. Nelson, Running Visual Basic for Windows. Redmond, Washington 98052-6399: Microsoft Press, pp. xiii-xvi, 1993.

[4] F. K. Harris, Electrical Measurements. New York: John Wiley & Sons, Inc., 1952, pp.258.