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An Automated Guarded Bridge System for the Comparison of 10 kΩ Standard Resistors

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***Abstract* - An automated guarded resistance bridge has been specifically developed at the National Institute of Standards and Technology (NIST) for the calibration of high-quality 10 kΩ standard resistors. The system is designed to intercompare up to 30 nominally-equal, four-terminal resistors with a resolution and combined relative standard uncertainty of 0.01 μΩ/Ω and 0.02 μΩ/Ω, respectively. With a few minor modifications, the system is capable of comparing other nominally-equal resistors in the range 100 Ω to 1 MΩ.**

I. INTRODUCTION

NIST establishes and maintains the U. S. representation of the ohm in terms of the quantum Hall effect and disseminates it to other standards laboratories through its measurement service. This service provides measurements of standard resistors with decade nominal values that range from 100 μΩ to 1 TΩ [1]. Many standards laboratories maintain their local ohm unit at 10 kΩ, the middle of the resistance range; and consequently, this resistance level constitutes a significant portion of the resistance measurements workload at NIST. To improve these measurements, NIST has developed an automated guarded system for the comparison of 10 kΩ standard resistors.

This automated system has improved the quality of 10 kΩ calibrations. Automation has eliminated the bias of the operator and errors that result from transcribing data. Measurements can be taken during non-working hours when electrical and mechanical environmental noise is at a minimum. Measurement precision is improved with the taking of more measurements under a controlled and repetitive balancing algorithm. Also, the precise timing of measurement sequences greatly reduces the errors caused by short-term linear drifts of thermal emfs.

II. SYSTEM DESCRIPTION

This automated resistance bridge system was developed to replace the NIST manual system [1] for calibrating high-quality 10 kΩ standard resistors. The goal was to develop an automated system equal or superior in precision and accuracy to the existing system. The main components of this automated system are a self-balancing bridge circuit and a programmable switch.

A. Bridge Circuit

The measurement system is based on the Warshawsky bridge [2] which adds fan resistors at the branch points of the bridge to eliminate first-order errors caused by lead resistances. A schematic diagram of this bridge is shown in Fig. 1 without

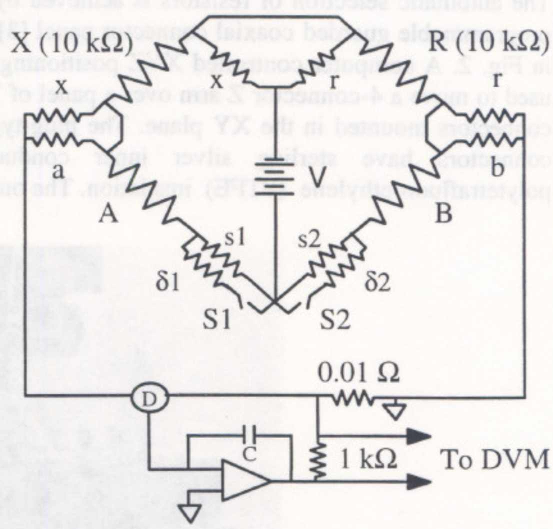

Fig. 1. Automated 10 kΩ guarded resistance bridge.

its active guard network. The guard network is essentially a mirror image of the main bridge, and its function is to maintain the proper potentials at the shields of the branch point terminations in order to suppress errors caused by leakage currents. The main bridge circuit consists of ratio arms A and B, dummy resistor R, the unknown resistor X, and fan resistors a, b, r, and x. Resistors are compared using

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the substitution technique, where the working standards and unknown resistors are indirectly compared by substitution in the X-arm of the bridge circuit. This technique tends to cancel errors resulting from non-linearity, leakage currents, and lead and contact resistances.

B. Self-balancing Circuit

The bridge is designed to be self-balancing using a novel feedback network shown in Fig. 1. The isolated output of the electronic detector, D, is connected to an operational amplifier integrator which provides a feedback current to a 0.01 Ω resistor. The voltage drop across this resistor drives the detector to a null condition. The feedback current is monitored by a digital voltmeter (DVM) connected across a 1 kΩ resistor. The sensitivity of the feedback system is determined by introducing known offsets in ratio arms A or B via switches S1 and S2. These switches connect paralleling resistors δ1 and δ2 across resistors s1 and s2, which change the A/B ratio by +10 μΩ/Ω or -1 μΩ/Ω, respectively. Changes in the feedback current can be equated to changes in resistance as different resistors are switched into the X-arm of the bridge. The measurement range of the feedback circuit is ±100 μΩ/Ω.

C. Programmable Switch

The automatic selection of resistors is achieved by a unique programmable guarded coaxial connector panel [3] as shown in Fig. 2. A computer controlled XYZ positioning system is used to move a 4-connector Z arm over a panel of 72 coaxial connectors mounted in the XY plane. The plug-type coaxial connectors have sterling silver inner conductors and polytetrafluoroethylene (PTFE) insulation. The outer shields of the connectors are electrically isolated from one another to allow the shields to be driven by the guard network. The resistance repeatability of the plug-socket connections, including resistance variations from the 12 m of AWG 12 connecting cable, is (10 ± 4) μΩ. Variations of thermoelectric potentials of the plug-socket connections over a 10-minute measurement period is typically less than 10 nV.

D. Computer Control

A personal computer (PC) controls the measurement system using BASIC language with multiple subroutines to handle the data taking and data processing. The programmable switch is interfaced to the PC via a standard RS-232 serial port. All other operations including DVM measurements, temperature measurements, polarity switching, and offset switching are controlled by an IEEE-488 interface board. A second DVM and commercial scanner are used to monitor the temperatures of the resistors using calibrated thermistor probes.

III. SYSTEM PERFORMANCE

The automated system was compared with the manual system by measuring the same check standard resistor C1410. Results of these measurements over a three-month period are shown in Fig. 3. The residual standard deviations of the linear least-squares analysis of the data for the manual and automatic systems are 0.008 μΩ/Ω and 0.004 μΩ/Ω, respectively. There appears to be a slight bias of 0.005 μΩ/Ω between the two systems which is under investigation. Fig. 4 is a histogram of 117 differences between the two systems when measuring 17 different resistors over approximately a four-month time interval. The mean of these differences is

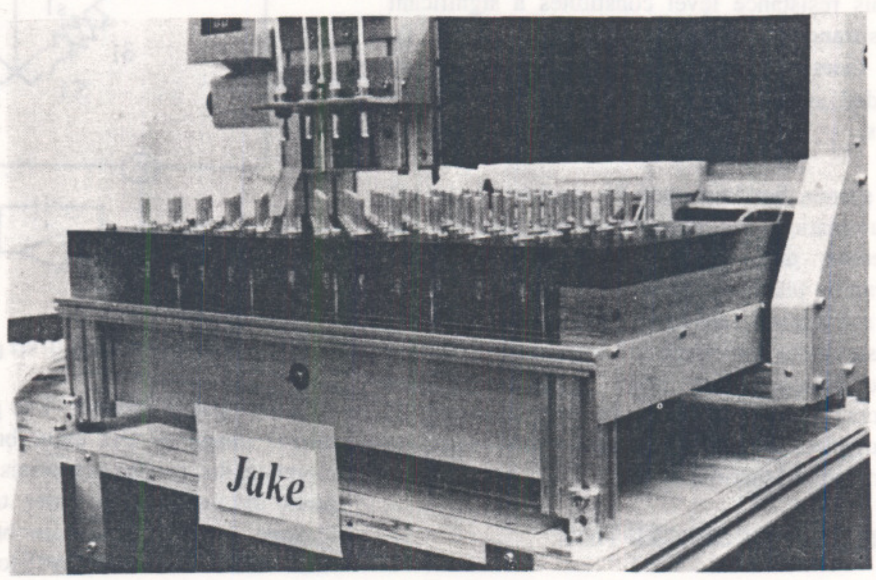

Fig. 2. Photograph of programmable switching system.

(0.002 ± 0.008) $\mu\Omega/\Omega$. The analyses of the data in Fig. 3 and Fig. 4 indicate that the automated system is capable of a resolution of 0.01 $\mu\Omega/\Omega$, and a combined standard uncertainty of 0.02 $\mu\Omega/\Omega$ relative to the manual measurements. It should be noted that the reported expanded uncertainty, using a coverage factor of two, is 0.15 $\mu\Omega/\Omega$ for 10 kΩ standard resistors [1].

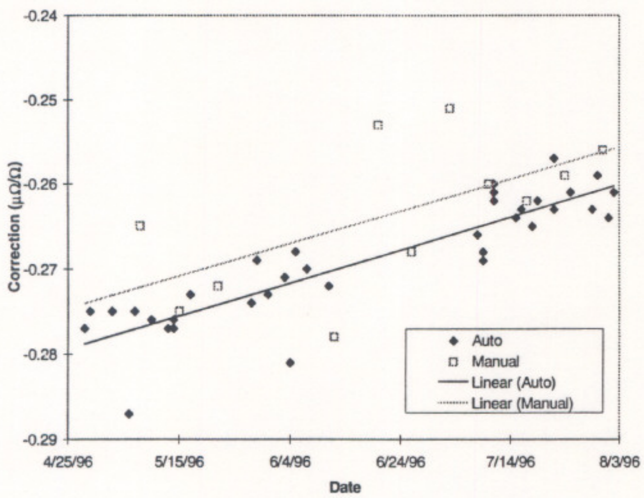

Fig. 3. Corrections from nominal of automatic and manual systems for check standard C1410.

IV. CONCLUSION

This automated system has improved the precision of comparing 10 kΩ standard resistors. It is expected, after a re-evaluation of the uncertainties in the measurement process, an improvement of the uncertainty of these measurements will be demonstrated. Modifying the feedback circuitry, and using the appropriate fan resistances, this system is capable of comparing other nominally-equal resistors in the range from 100 Ω to 1 MΩ.

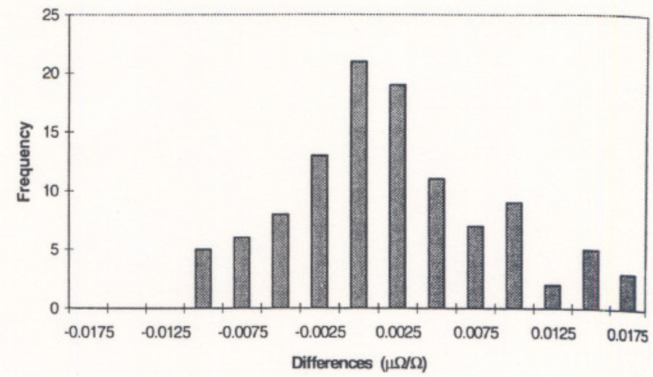

Fig. 4. Histogram of differences between automatic and manual systems of 17 resistors over a four-month period.

V. REFERENCES

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