NEW DESIGNS FOR HIGH-RESISTANCE STANDARD RESISTORS

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Abstract

Discussed are recent efforts undertaken at the National Institute of Standards and Technology (NIST) to create a new set of high-resistance standards (specifically in the 10 MΩ to 100 MΩ range) using newer, more stable film-type resistors. The history of film-type resistors in high-resistance standards is briefly reviewed. Also examined are the improvements made upon similar resistance standard implementations done by the Instituto Nacional de Tecnología Industrial (INTI) in Argentina. The new NIST standards use a guarded, highly resistive backbone to reduce leakage currents. Promising results, including reduced settling time and improved stability, are presented.

Introduction and Challenges

Contemporary designs for high-resistance standards in the 10 MΩ to 100 MΩ range at NIST have reached a plateau in precision. This is largely due to the wire-wound resistors used in most of the older standards. Wire-wound resistors have been used due to their low temperature coefficients of resistance (TCRs) and negligible voltage coefficients of resistance (VCRs). These characteristics lend themselves well to resistance standards. But as efforts have been made in recent years to increase the resolution of calibrations at the 10 MΩ level and above, settling time has become a significant problem. The many close windings of the wire-wound resistors give them a distinctly capacitive property, which introduces an RC time constant into the system [1]. Measurements of resistance standards containing wire-wound resistors often take from 90 s to 120 s to reach a state where their fluctuations drop within a 2 μΩ/Ω range (deemed a steady state). This settling time now serves as a barrier to the higher accuracies that can be obtained by a high-resistance cryogenic current comparator (HR-CCC) bridge in the range 1 MΩ to 1 GΩ [2].

Traditionally, film type resistors have not been used in resistance standards except at the 1 GΩ level and above, where wire-wound resistors are not available. Film-type resistors are known to have instabilities, such as relatively high drift rates, TCRs, and VCRs. Also, if such a film-type resistor is not hermetically sealed, moisture damage can occur. Moisture can create current leakage on the surface of the insulating substrate (reducing resistance) or be absorbed by the insulation (increasing resistance) [3]. In recent years, film-type resistors have become significantly more viable. New developments in resistive films have made film-type resistors commercially available that have low TCRs and are quite stable [4].

INTI, a collaborator with NIST, recently produced a set of high resistance standards in the 10 MΩ to 1 GΩ range using commercial film-type resistors. These resistor elements are physically small (19 mm length), stable (± 0.01 % tolerance), and have a low TCR (< 2 μΩ/Ω/°C). The INTI standards showed good long-term stability and negligible settling times. Unfortunately, they also showed significant VCRs, 0.2 μΩ/Ω/V for the 100 MΩ standard resistor [4].

Research at INTI demonstrated that ten of these commercial film-type resistor elements could be used to form a standard resistor with characteristics suitable for use with a HR-CCC. It was decided to build upon this work by designing and constructing guarded standard resistors using the film-type resistor elements used by INTI. In the NIST version, the resistor junctions are guarded and may be tapped allowing some of the standards to be configured as guarded Hamon transfer standards. High resistance standards constructed at NIST use guard circuitry to reduce leakage current, hermetic seals to reduce humidity effects, and mounting techniques to counteract some of the instabilities inherent in film-type resistors [3]. It was determined that, with improved selection, matching, and modeling of both the standard and guard resistors that film-type standard resistors with lower Type A standard uncertainties and negligible settling times compared to those of the wire-wound resistors could be fabricated.

Methodology and Design

A new version of the traditional guard circuit was designed and implemented for this new set of high-resistance standards. The resistors were mounted in a "resistive backbone" made out of FR4 insulation,

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a common insulation used in printed circuit boards. The resistive backbone was constructed so alternating planes of metal and insulation formed a guarded structure as shown in Figure 1. FR4 was chosen for its high insulation resistance (R_{ins}) which was measured at NIST to be on the order of 1 PΩ. By the formula

$$I'_{ins} = (V_S - V_G) / R_{ins} \qquad (1)$$

this would result in a very small leakage current (I'_{ins}) provided that the standard voltage (V_S) and guard voltage (V_G) were well matched.

Special care was taken to insure that this condition was met. The resistors of both networks were carefully measured. The resistors were then sorted into groups of ten so as to minimize the standard deviation of each group. A script program was written to quickly compare different pairing methods in an attempt to simulate ideal symmetry. Several different algorithms were attempted. The best results came from matching the group of guard resistors with the smallest standard deviation to the group of standard resistors with the smallest standard deviation. Remaining groups were matched the same way. The ordering within the groups was randomized. The average projected leakage current was calculated to be ~$3 * 10^{-19}$ A. If the model is accurate, this small leakage current translates to a few electrons per second, a negligible error for a 100 MΩ standard resistor.

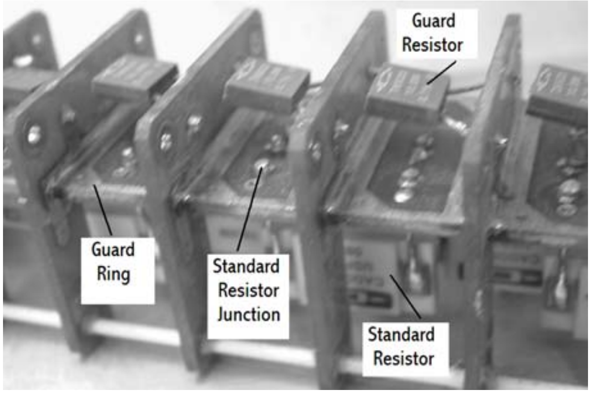

Fig.1. FR4 resistive backbone in which the standard (white) and guard (black) resistors were mounted. The backbone is constructed of alternating sections of FR4 separated by metal guard planes. The standard resistors are connected to nodes in the center of the small circuit boards and surrounded by guard rings. The guard resistors are attached to each side of the larger boards, driving the guard potentials of each guard ring. Fiberglass rods were added to the larger boards to provided added rigidity to the backbone structure.

Results

Preliminary comparisons with NIST's HR-CCC and Dual Source Bridge (DSB) have yielded promising results. Both measurement systems show the new standards as having no measurable settling time. This result could allow measurements to be made significantly faster in the future. Additionally, the new standards are very stable, drifting less than 20 μΩ/Ω/yr over a four-month period. The standard deviations of the measured values of the devices when calibrated with the DSB are around half those of comparable wire-wound standards. Finally, early measurements at different voltages show a change of approximately 2 μΩ/Ω when calibrated at 10 V and 100 V. The factor of ten reduction in voltage coefficient to 0.02 μΩ/Ω/V is attributed to the guarded backbone structure.

Summary

The techniques implemented in this generation of NIST high-resistances standards at 100 MΩ have been effective in eliminating settling times and increasing stability. The guarded backbone structure has been designed and resistance elements carefully selected to suppress leakage currents. Initial testing of the new standard resistor has demonstrated improved performance over earlier NIST designs. Voltage coefficients, temperature coefficients, and drift rates will be more thoroughly determined once the resistor standards have aged six to twelve months. The guarding and construction techniques reported here will be applied to future high-resistance standards in the 1 GΩ to 100 TΩ ranges.

References

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