A GUARDED TRANSFER STANDARD FOR HIGH RESISTANCE MEASUREMENTS

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Abstract

An improved design for a guarded transfer standard in the resistance range 1 MΩ to 100 GΩ is described. Existing transfer standards and limitations are reviewed. Interchangeable guard networks are used in the improved transfer standards to ensure complete guarding during all phases of the measurement process thus reducing errors caused by leakages to ground.

Introduction

NIST-built transfer standards or Hamon boxes [1] have been used at NIST for many years to scale from one decade of resistance to another [2]. Most of the NIST-built transfer standards use internal guard networks to reduce leakage errors caused by leakage currents flowing from the standard resistors to ground. A NIST-built guarded Wheatstone bridge and guarded active-arm bridge [3] can take full advantage of the guard networks associated with the transfer standards.

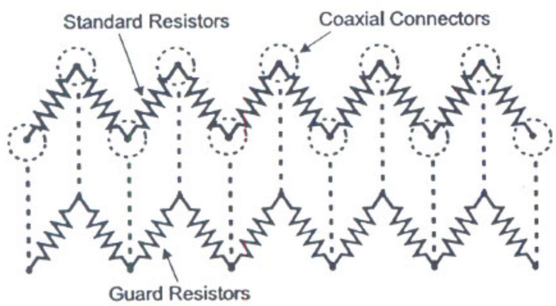

Figure 1. Guarded transfer standard. Coaxial terminations of each resistor are driven at a guard potential.

The circuit for a typical high resistance transfer standard is shown in Figure 1. Ten resistors of the same nominal value are permanently connected in series. Paralleling fixtures can be used to connect the resistors in parallel or series-parallel configurations [2] generating 100:1 and 10:1 ratios for scaling to different resistance levels. An internal guard network is shown to drive the coaxial shield of each resistor junction at a guard potential nominally equal to the potential of the standard resistor at that point.

Unfortunately, the fixed choice of some of the guard resistors has made scaling using the internal guard circuits not possible when comparing two transfer standards that have guard resistor networks of different nominal values. These differing guard networks can make it impossible to balance the bridge due to excessive leakage currents between the guard and the high input of the bridge null detector.

The proposed design is to construct interchangeable external guard modules so several values of guard networks can be selected for different ratios of measurement. The external guard network will drive the shields of the coaxial connectors used in the series, parallel, and series-parallel configurations to interconnect the ten resistors that constitute the guarded transfer standard. This will allow accurate potentials to be generated by the guard circuit for series, parallel, and series-parallel modes of operation.

NIST High Resistance Transfer Standards

Presently NIST has seven transfer standards used in the high resistance laboratory covering the range 10 kΩ to 10 GΩ. Five of the seven standards are internally guarded and the remaining two can be externally guarded at the terminations. The nominal value of the internal guard resistors makes it impossible to take full advantage of the internal guarding for all scaling measurements. Table 1 shows the standard resistors along with the values of their guard circuits. All of the internally guarded transfer standards except for J/895 were built in the late 1960's at NIST.

Transfer standards J/6, J/7, and J/895 have a standard-to-guard ratio of 1:1 and transfer standards J/8 and J/9 have a standard-to-guard ratio of 100:1. The choices of guard resistors were dictated by several reasons that made it difficult to build all of the transfer standards with the same nominal-to-guard ratio. For example, in the case of J/6, if guard resistors were 1/100 the value of the standard resistors like in J/8, this would form a guard resistance of 100 Ω when J/6 would be in the parallel configuration. A 100 Ω guard

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resistance would draw excessive current at test voltages above 5 V, overloading the current capacity of the bridge and causing self heating of the transfer standard. J/9 was constructed using guard resistors 1/100 the value of the standard resistors to maintain accurate guard potentials throughout the transfer standard. 1 GΩ guard resistors able to match guard potentials within 1% of standard potentials may not have been readily available when J/8 and J/9 were built.

Serial Number	Standard Series Value	Guard Series Value	Ratio (Standard to Guard)
J/6	1 MΩ	1 MΩ	1:1
J/7	10 MΩ	10 MΩ	1:1
J/8	100 MΩ	1 MΩ	100:1
J/895	100 MΩ	100 MΩ	1:1
J/9	1 GΩ	10 MΩ	100:1
C/10	10 GΩ	none	N/A
BS10	10 GΩ	none	N/A

Table 1. NIST High Resistance Transfer Standards and Internal Guard Resistors Series Values.

Guard Circuit Theory

The guard resistors are used to increase the effective resistance

$$R_{eff} = V_S/I_{eff} \quad (1)$$

of the insulation between the standard and guard resistors. I_{eff} is the current flowing from V_S to a ground potential. Figure 2 shows a current I_{ins} flowing through the insulator

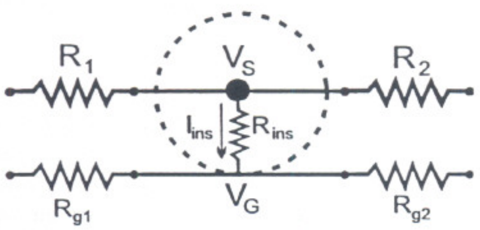

Figure 2. Guard resistor circuit. Standard and guard resistors are separated by an insulator of resistance R_{ins}.

R_{ins} that separates the standard and guard resistors. The insulator current I_{ins} is defined as

$$I_{ins} = (V_S - V_G)/R_{ins} \quad (2)$$

where V_S and V_G. are the standard and guard potentials.

By substituting the insulator current in eq. 2 into the effective current of eq. 1, it can be shown that

$$R_{eff} = R_{ins} * V_S / (V_S - V_G) \quad (3).$$

Assuming the guard resistors can match V_G within 1% of V_S, the guarding will increase the effective resistance of the insulator by 100 times the actual resistance of the insulator.

Improvements to Transfer Standards

Due to the different standard-to-guard ratios of transfer standards, it is not always possible to measure two standards using the internal guard networks. In this situation, an external guard is place across one of the transfer standards test lead terminations, leaving the internal transfer standard resistor junctions unguarded. The interchangeable external guard networks will provide complete guarding, eliminating the problem of not being able to take full advantage of the internal guard networks for all decade comparisons. An external guard network can also be attached in parallel to the internal guard network thus increasing the standard-to-guard ratio. A transfer standard like J/895 could have a 1:1 and 1:100 standard-to-guard ratio permitting fully guarded comparisons with the remaining transfer standards.

Conclusion

By building external guard networks for transfer standards on modules, complete guarding can be used to reduce leakages to ground for many bridge ratios, allowing the comparison of transfer standards that are fully guarded at all resistor terminations. The external guard networks can be used by themselves or in parallel with an internal guard network. Two transfer standards at the 10 GΩ and 100 GΩ decade levels are being constructed at NIST using these guard network configurations.

References

[1] B. V. Hamon, "A 1-100 Ω Build-up Resistor for Calibration of Standard Resistors," J. Sci. Instr., vol. 31, pp. 450-453, Dec. 1954.

[2] 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. 30-33.

[3] D. G. Jarrett, "Automated Guarded Bridge for Calibration of Multimegohm Standard Resistors from 10 MΩ to 1 TΩ," IEEE Trans. on Instrum. and Meas., Vol.46, No. 2, pp.325-328, April 1997.