RESISTANCE MEASUREMENT ASSURANCE PROGRAM AT NIST

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Abstract
The National Institute of Standards and Technology (NIST) offers resistance Measurement Assurance Program (MAP) transfers at the 1 Ω and 10 kΩ levels, to provide a method of assessing and maintaining the quality of a customer's measurement process. The NIST resistance MAP calibration service is described, including the measurement procedures for participating in the program. A discussion of the data analysis follows, along with an explanation of the estimate of the uncertainty of the MAP transfer. Presentation of past resistance MAP data is also included.

Introduction
At the National Institute of Standards and Technology (NIST), the U. S. representation of the ohm is based on the quantum Hall effect. It is maintained and disseminated at nominal decade values in the range between $10^4$ Ω and $10^{12}$ Ω to provide a calibration service for standard resistors. In addition to this regular calibration service, NIST offers a Measurement Assurance Program (MAP) at 1 Ω and 10 kΩ since they represent the two primary levels at which most standards laboratories maintain their unit of resistance. Measurements at these two selected levels also provide a test of the laboratory's ability to scale or make ratio measurements linking these levels. In the past, MAPs at other resistance levels have been offered, but have not been frequently requested by customers. In the future, a high-resistance MAP will be offered to help address the special problems at levels above 1 MΩ. Participation in a resistance MAP is advisable for a standards laboratory that supports resistance measurements at or near state-of-the-art in uncertainty, and whose measurement process is being continuously monitored by check standards during the intervals between MAP transfers.

The main advantages for a laboratory's participation in a resistance MAP are 1) NIST provides the transfer standards; consequently, the new correction assignments of the customer laboratory's...
the transfer standards to nominal temperature (23.00 °C or 25.00 °C) and standard atmosphere (101.325 kPa) or have NIST make the corrections.

After the MAP package is returned to NIST, the transfer standards are measured three times a week for at least four weeks. Subsequently, all the data are analyzed by NIST and a Report of Calibration is issued, indicating the difference between the unit of resistance at either the 1 Ω or 10 kΩ level maintained at the customer laboratory and the U. S. legal ohm, as maintained at NIST in terms of the quantum Hall effect.

**Data Analysis**

Standard resistors usually display a linear drift over a short time period. Therefore, using the least-squares method\(^6\), a straight line is fit to the corrections from nominal of the “before” and “after” measurements taken by NIST on the transfer standards, after being corrected for temperature and pressure. The slopes and intercepts of the fitted lines are used to predict the values of the transfer standards on the dates of their measurements by the customer. Straight lines are also fit to the data taken by the customer. The estimate of the difference between the unit of resistance as maintained by the customer laboratory and the U. S. ohm representation as maintained by NIST is determined by subtracting each NIST predicted value from each customer predicted value for each transfer standard for each date upon which the customer's measurements were made. Thus, for each resistor an average difference, \( \Delta R \), can be determined. The average over all resistors, \( \Delta R_{\text{mean}} \), represents the estimate of the difference between the units.

If this estimated value is greater in magnitude than the combined standard uncertainty of the MAP transfer, then NIST recommends adjusting the assigned mean value of the customer's reference standards such that

\[
\Omega_{\text{LAB}} - \Omega = 0
\]  

where \( \Omega_{\text{LAB}} \) the laboratory's unit of resistance at the particular level (either 1 Ω or 10 kΩ), and \( \Omega \) is the U.S. ohm representation. (The symbol \( \Omega \) is italicized to denote a physical quantity.)

The combined standard uncertainty of the estimate of the difference consists of the combination of the Type A and Type B uncertainties resulting from random and systematic effects of the measurement process\(^7\), where Type A uncertainties are those that can be evaluated by statistical methods based on observed data, and Type B uncertainties are those that cannot. The expanded uncertainty can be expressed by the following equation:

\[
U = 2 \left( s_{\text{LAB}}^2 + s_{\text{NIST}}^2 + t_{\text{transfer}}^2 + \sum u_B^2 \right)^{1/2}.
\]

The standard deviation of the customer data (\( s_{\text{LAB}} \)) is an estimate of the effect of random error resulting from the customer laboratory measurements, and is determined by the following equation:

\[
s_{\text{LAB}}^2 = \left( \frac{1}{MN} \right) \sum_{j=1}^{M} \sum_{i=1}^{N} s_{ij,\text{LAB}}^2,
\]
resistor, and \( \bar{x}_{\text{NIST}} \) is the mean date of all the NIST measurements on the \( j^{th} \) resistor. Although the values of \( s_{\text{NIST}} \) are determined from actual measurement dates at the customer laboratory and not from measurement dates at NIST, the measurement dates used in the calculations are inside the range of NIST measurement dates and using the form of Eq. (4) is applicable.

The standard deviation of the \( \Delta R \) measurements serves as an estimate of the variability of the transfer standards (\( s_{\text{transfer}} \)). The value of \( s_{\text{transfer}} \) can be calculated by the equation:

\[
s_{\text{transfer}}^2 = \frac{1}{M(M-1)} \sum_{j=1}^{M} (\Delta R_j - \bar{\Delta R})^2 ,
\]

where

\[
\Delta R_j = \frac{1}{N} \sum_{i=1}^{N} \left( R_{ij(\text{pred})_\text{LAB}} - R_{ij(\text{pred})_\text{NIST}} \right)
\]

and represents the mean difference of the \( j^{th} \) resistor for the \( i^{th} \) measurement, \( R_{ij(\text{pred})_\text{LAB}} \) is the NIST predicted value of the \( j^{th} \) resistor for the \( i^{th} \) measurement at the customer laboratory, and

\[
\bar{\Delta R} = \frac{1}{M} \sum_{j=1}^{M} \Delta R_j .
\]

Notice that any shifts in mean or variability resulting from transportation effects are reflected in the above analysis.

To provide coverage for \( s_{\text{transfer}} \), which has a low degree of freedom, it is multiplied by \( t' \), which is defined as

\[
t' = \frac{t_{97.5}}{2} \]

where \( t_{97.5} \) is a percent point of the Student t distribution. The value of \( t_{97.5} \) depends on the number of transfer standards (\( M \)), and can be obtained from Table 1. This value is divided by two to simplify the expression of Eq. (2).
Conclusion

Standards laboratories that do not have a quantized Hall resistance measurement system and are required to support resistance measurements at an uncertainty of ±0.2 × 10^{-6} or better should consider participating in a NIST resistance MAP. To be effective, the laboratory should adopt a system of monitoring its measurement process using check standards during the intervals between MAP transfers. The main advantages of a laboratory’s participation in a resistance MAP are that the laboratory does not have to ship its standard resistors to NIST for calibration, and the laboratory has a better assessment of its measurement uncertainty. Also, the results of a MAP can provide information for the laboratory to improve its precision and accuracy in this measurement area. The main disadvantages of a MAP transfer are that it is more time consuming and costly than routine NIST calibrations of standard resistors.

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References


Fig. 2a. Laboratory standard deviations for 76 MAPs at 1 \( \Omega \).

Fig. 2b. Laboratory standard deviations for 34 MAPs at 10 k\( \Omega \).
Fig. 4a. Transfer standard deviations for 76 MAPs at 1 Ω.

Fig. 4b. Transfer standard deviations for 34 MAPs at 10 kΩ.
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