LOADING EFFECTS IN RESISTANCE SCALING

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Abstract

Power loading effects in dc resistance references are not well understood even for the most commonly used high precision standards. This paper will examine loading effects and their contribution to the uncertainty of recent NIST comparisons of the quantum Hall effect and calculable capacitor.

Introduction

A load coefficient indicates the relative change in resistance as a function of power for steady-state measurement conditions [1]. This effect is seen even in high-quality references operating at 10 mW or less, and is especially difficult to quantify, since the resistance element can set up complex temperature gradients inside a sealed case of a resistance reference. Load coefficients of most reference resistors in the range of 1 Ω to 1 MΩ are not well known.

To minimize the uncertainty caused by loading effects in traditional, non-cryogenic scaling measurements, Hamon devices can be used with equal power levels in the series and parallel configurations. However, the measurement times and duty cycles must be the same to approximate exact cancellation of the loading effect. Hamon device scaling results have been compared with cryogenic current comparator (CCC) ratio measurements at NIST and the techniques are generally in good agreement [2].

In addition to measurements of loading effects in precise resistance scaling, this paper will describe some measurements using a special prototype resistor. The resistor is constructed with a copper resistance element, which has a large temperature coefficient to allow direct measurement of loading effects.

6453.2 Ω transfer standards

Low power QHR measurements are in contrast to the higher power scaling measurements based on Hamon devices. Between 1983 and 1992, four 6453.2 Ω Evanohm wire-wound references were used to transfer values from the NIST QHR experiment to the 1 Ω reference bank. Potentiometric measurements [3], in which the current through the QHR device was typically 25 μA, were used to assign QHR values to the 6453.2 Ω transfer standards. Scaling to 100 Ω was done using a Hamon device consisting of eight 800 Ω series-parallel resistors with a 53.2 Ω series-connected resistor. A relative loading correction of approximately 9×10^{-9} was determined for the 6453.2 Ω transfer standards at 10 mW, based on Hamon measurements and an average measurement time of 20 minutes. Throughout the transfer, the silicone-fluid filled 6453.2 Ω transfer standards were contained in regulated air-temperature enclosures at 27.4 °C. The relative temperature coefficients range from -0.2×10^{-6} / °C to -0.4×10^{-6} / °C at this temperature.

In 1995, the loading effect was re-evaluated in two of the 6453.2 Ω transfer standard resistors. The resistors had been continuously maintained at 27.4 °C. Each was run at 10 mW power for at least four hours, followed by a series of CCC measurements at low power to determine the rate of resistance change with temperature. These measurements agreed with the earlier determination, although the CCC measurements could only be made at low power. The results showed that both the resistance and the temperature measured inside the resistor case relaxed at about the same slow, relatively linear rate after the load was reduced, and only about 30 % of the observed change occurred in the first hour of the CCC measurement.

100 Ω reference bank

A CCC comparison to the 100 Ω level is presently used at NIST to relate the U. S. legal ohm to the QHR standard. Since 1992, two CCC systems have been used to scale from the QHR directly to 100 Ω at device currents of 20 to 60 μA. CCC measurements are routinely made at NIST between the 1 Ω and 100 Ω levels and between the 100 Ω level and other levels including 1000 Ω, 6453.2 Ω, and 12 906.4 Ω. The measurements typically take 30 minutes to determine a resistance ratio.

In 1994 NIST initiated measurements using a bank of five 100 Ω references that were selected for stability and low

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temperature coefficients. The average relative first-order temperature coefficient of resistance of this bank is -1×10^{-8} / °C, and systematic tests have helped to check that the average load coefficient of this bank of resistors is similarly very small. CCC ratio measurements at the 10:1 ratio used in scaling between 1000 Ω and 100 Ω references have been repeated frequently at two power levels (2.6 mW and 10 mW) to determine the effect of loading in the 100 Ω references at 10 mW, but any effect appears to be about at the level of measurement resolution.

A series of measurements was done in early 1995 to determine relative loading effects in the 100 Ω reference bank and in three Hamon devices which can be configured as 100 Ω references. In these measurements each standard was measured at two different power levels using the CCC. The eight 100 Ω references were measured against the same 12 906.4 Ω reference, and on the next day all eight were measured against the same 1 Ω standard, and so on, with suitable measurement averaging to eliminate drift. For each of the eight 100 Ω references two values of the 12 906.4 Ω to 1 Ω ratio were calculated. Loading of the 100 Ω references is about 0.1 mW in the measurements against 1 Ω, and 6 mW in the ratios against 12 906.4 Ω. The 1 Ω standard was an unsealed Evanohm resistor believed to have negligible load coefficient at 10 mW.

The values of this total ratio were nearly independent of the intermediate 100 Ω standard for the five 100 Ω references that make up the bank. Differences of 1×10^{-8} to 2×10^{-8} from the mean were seen for the ratios based on the Hamon devices. This indicates that some loading is present at 6 mW. This effect has not been seen in scaling comparisons [2], probably because the Hamon devices had been used with equal power levels in the series and parallel configurations. The short duration of the CCC measurements indicates that the loading effect is significant after only 30 minutes.

1000 Ω to 100 Ω scaling

The 1000 Ω to 100 Ω scaling step was done using two Hamon devices in the 1988 determination [4]. A study was made in 1995 of possible loading effects in one of these Hamon devices, which consists of ten 1000 Ω resistors. The individual 1000 Ω resistors were measured at 1 mW against the two 100 Ω bank resistors with the lowest temperature coefficients. A small change in the resistance ratio is seen in the first 5 to 10 minutes of these measurements. Using the same power per resistance section, the 100 Ω parallel configuration of the Hamon device was measured at 10 mW against a 1000 Ω resistor. The result can be compared to the average value of the resistance of the ten sections by making some intermediate measurements. These ratio values were the same to within 3×10^{-9}, and agree more closely if the first 5 minutes of each of the ten sectional measurements are deleted.

Copper resistor

Measurements are being conducted to measure the loading effect on the resistance of a specially-made copper resistor. The case construction and the physical dimensions of the element of the approximately 140 Ω resistor are similar to 6453.2 Ω and 10 kΩ sealed resistance references made of Evanohm. Resistance and inner case temperature have been measured in sequences where the power level alternates between 10 mW and 0.1 mW. Both quantities appear to respond quickly to the applied power, with a time constant of about 10 minutes.

Measurements have also been made with the copper resistor inside one of the regulated air-temperature enclosures at 27.4 °C. We have noted that the 6453.2 Ω transfer standards in the 27.4 °C enclosures appear to respond to loading differently than similar standards in an oil bath. A more complex loading effect appears to occur in the enclosures, and the load coefficient may be larger than that observed in oil.

Conclusions

Ongoing tests are helping to quantify loading effects, which are a source of uncertainty in precision scaling measurements. Systematic uncertainties related to loading appear to be significant in NIST comparisons of the QHR and calculable capacitor. New measurement results and uncertainties will be determined and presented.

References

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