NIST COMPARISON OF RESISTANCES BASED ON THE CALCULABLE CAPACITOR AND THE QUANTUM HALL EFFECT

J. Q. Shields, R. F. Dziuba, R. E. Elmquist, and L. H. Lee
National Institute of Standards and Technology*
Gaithersburg, MD 20899-0001

Abstract

The latest NIST results comparing the quantized Hall resistance based on the value $R_{K\text{-}90} = 25\ 812.807\ \Omega$ with the realization of the ohm in SI units obtained by direct calculable-capacitor measurements will be reported.

Introduction

Since January 1, 1990, the U.S. representation of the ohm has been based on the quantum Hall effect in which a resistance is related to the ratio of fundamental constants h/e^2 [1]. The quantized Hall resistance, R_H, is defined as the quotient of the Hall voltage V_H of the i^{th} plateau to the current I in the Hall device and is given by

$$R_H(i) = V_H(i)/I = R_K/i\ ,$$

where the von Klitzing constant R_K is believed to be equal to h/e^2, and where i is an integer of the quantum Hall state. The value of the U. S. representation of the ohm is consistent with the conventional value of the von Klitzing constant, i. e.,

$$R_{K\text{-}90} = 25\ 812.807\ \Omega\ ,$$

exactly, adopted internationally for use in representing the ohm beginning January 1, 1990 [2]. This conventional value is believed to be consistent with the SI Ω to within 0.005 Ω which is the value assigned to be the combined standard uncertainty, corresponding to a relative uncertainty of 0.2 ppm.

The last reported realization of the ohm using the NIST calculable capacitor was presented at CPEM '88 [3]. At that time, the NIST representation of the ohm was based on the mean resistance of five Thomas-type wire-wound resistors maintained in a 25 °C oil bath. The time-dependence of the NIST representation of the ohm was determined using the quantum Hall effect and was also reported at CPEM '88. Combining the results of these NIST ohm-realization and quantized Hall resistance measurements, the NIST value for the von Klitzing constant was reported to be

$$R_K = 25\ 812.807\ 23\ (61)\ \Omega\ ,$$

in good agreement with the 1990 internationally adopted value [4].

Measurements

Comparison of the quantized Hall resistance based on $R_{K\text{-}90}$ with the NIST realization of the ohm in SI units is accomplished via a transportable 1000 Ω resistor, hand carried between two laboratories. A block diagram indicating these two measurement sequences is shown in Fig. 1.

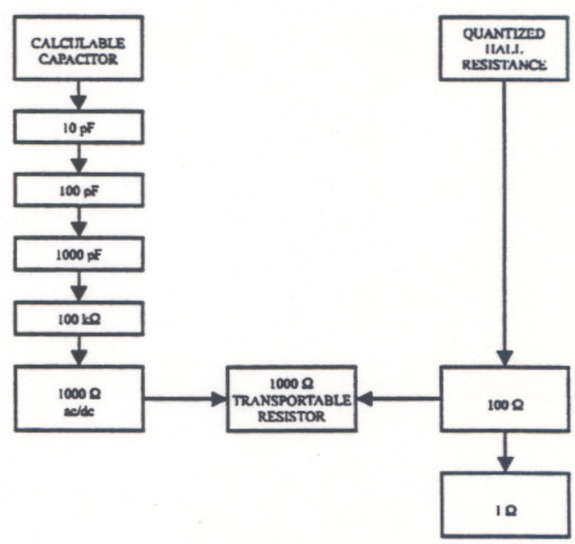

Fig. 1. Comparison of SI ohm and R_H.

*Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology; not subject to copyright in the United States.

The measurement systems used to assign a value in SI units to the transportable resistor using a 0.5 pF calculable cross capacitor are essentially the same as reported earlier [3]. However, improvements in reducing random effects have provided the stability necessary for more accurately evaluating systematic effects.

Several improvements in the quantized Hall resistance apparatus and measurement systems have also occurred at NIST since CPEM '88. A new high-field superconducting magnet and ^{3}He system have been installed near the primary resistance calibration laboratory. The magnet is designed to provide a field in excess of 14.5 T at 4.2 K and 16.0 T at 2 K. The cryosorb-pumped ^{3}He insert provides a sample temperature below 0.3 K with a hold time approaching 24 hours. Cryogenic current comparator (CCC) resistance bridges are now being used to link the R_H steps of $i = 2$ and $i = 4$ to the transportable 1000 Ω resistor or to the 1 Ω reference bank [5]. This scaling is accomplished via an intermediate reference bank of 100 Ω resistors. With the use of CCC bridges, the uncertainties associated with resistance scaling are significantly reduced as contrasted to Hamon-type scaling.

Although the 1 Ω bank does not define the U. S. representation of the ohm, it is still used to preserve the unit between R_H determinations. Measurements indicate that the time dependence of the mean value of this bank is not exactly linear; consequently, periodic adjustment of its drift is necessary.

Conclusions

Results of this comparison will ensure that the ohm based on the quantum Hall effect is consistent with the SI Ω. It is important that the implementation of the U. S. representation of the ohm be periodically verified by an independent method such as the calculable capacitor experiment. Furthermore, the results of this comparison will provide data for the least-squares adjustment of the fundamental constants in 1995.

References

[1] K. v. Klitzing, G. Dorda, and M. Pepper, "New method for high-accuracy determination of the fine-structure constant based on quantized Hall resistance," *Phys. Rev. Lett.*, vol. 45, pp. 494-497, Aug. 1980.

[2] B. N. Taylor and T. J. Witt, "New international electrical reference standards based on the Josephson and quantum Hall effects," *Metrologia* 26, pp. 47-62, 1989.

[3] J. Q. Shields, R. F. Dziuba, and H. P. Layer, "New realization of the ohm and farad using the NBS calculable capacitor," *IEEE Trans. Instrum. Meas.*, IM-38, pp. 249-251, April 1989.

[4] M. E. Cage, R. F. Dziuba, R. E. Elmquist, B. F. Field, G. R. Jones Jr., P.T. Olsen, W. D. Phillips, J. Q. Shields, R. L. Steiner, B. N. Taylor, and E. R. Williams, "NBS determination of the fine-structure constant and of the quantized Hall resistance and Josephson frequency-to-voltage quotient in SI units," *IEEE Trans. Instrum. Meas.*, IM-38, pp. 284-289, April 1989.

[5] R. F. Dziuba and R. E. Elmquist, "Improvements in resistance scaling at NIST using cryogenic current comparators," *IEEE Trans. Instrum. Meas.*, IM-42, pp. 126-130, April 1993.