IMPROVEMENTS IN RESISTANCE SCALING AT NIST USING CRYOGENIC CURRENT COMPARATORS

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Abstract

Cryogenic current comparators (CCC's) are being used at NIST to verify Hamon-type resistance scaling techniques from the 1-Ω level to the 100-Ω, 1-kΩ, 6453.20-Ω, and 10-kΩ resistance levels. Measurements comparing the 100/1 ratio of a CCC to that of a Hamon transfer standard agree to within 0.01 ppm - the practical limit of accuracy for a Hamon standard. The higher ratio accuracies and higher sensitivities of CCC bridges will make it possible to lower the uncertainties associated with resistance scaling at NIST by a factor of two or more.

Introduction

Since January 1, 1990, the unit of resistance has been based on the quantum Hall effect in which a resistance is related to the von Klitzing constant, h/e^2, divided by an integer of the quantum Hall state [1]. For precision measurements, the integer is usually chosen to be either 2 or 4 resulting in quantized Hall resistances (QHR's) of 12,906.4 Ω or 6,453.20 Ω [2]. These quantized Hall resistances are used to assign values to standard resistors of nominal decade values, directly or indirectly through some scaling process.

Traditionally, this scaling process has been accomplished through the use of series-parallel transfer standards or Hamon boxes [3]. In recent years, the application of cryogenic current comparators has resulted in the development of systems characterized by high accuracies and high sensitivities in the measurement of resistance ratios [4]. This paper describes resistance scaling techniques at NIST using special Hamon transfer standards and the latest CCC resistance bridges featuring isolated ramping current sources.

Resistance Scaling

Hamon Standards Several Hamon transfer standards have been built at NIST using series connected card-type Evanohm resistors sealed in aluminum boxes filled with mineral oil. The Hamon standard, designated HQHA, shown in Fig. 1 is used to scale from the quantized Hall resistance of 6453.20 Ω to the 100-Ω level. It consists of nine series-connected resistors. The first eight resistors have a nominal value of 800 Ω each and the ninth has a value of 53.20 Ω to make the total resistance equal to 6453.20 Ω. The total resistance of HQHA is compared to 6453.20-Ω reference resistors whose values are based on the quantum Hall effect. The eight 800 Ω resistors of HQHA can be connected in a parallel configuration to equal 100 Ω and then compared to the series configuration of a 10 x 10 Ω Hamon standard, H10. The 53.20-Ω section is compared to H10 using an automatic NIST resistance thermometer bridge. The 53.20-Ω measurement is not very critical since it only represents ≈ 0.82% of the total resistance of HQHA. Hamon H10 in its parallel configuration is then compared to the NIST bank of 1-Ω working standards to complete this scaling process.

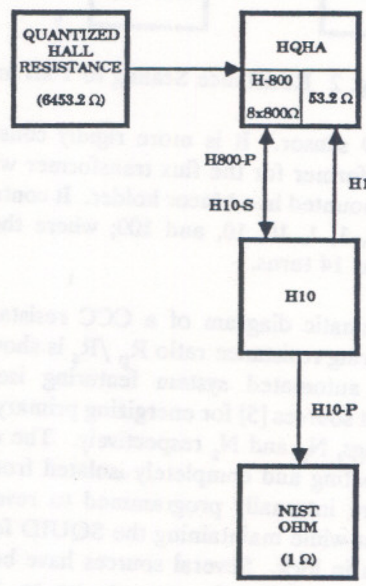

Fig. 1 Resistance Scaling from QHR to 1 Ω.

Figure 2 is a block diagram indicating how the resistance scaling at NIST is extended to the 1-kΩ and 10-kΩ resistance levels using Hamon standards. Hamon H1k, a 10 x 1kΩ transfer standard, is compared in its parallel configuration to the series configuration of Hamon H10. This assigns a value to H1k based on the QHR. Then Hamon H1k can be used in a series-parallel configuration to measure 1-kΩ standard resistors, or it can be connected in a series configuration to measure 10-kΩ standards.

CCC Resistance Bridges At NIST two CCC's are in use for scaling from the 1-Ω level to the 100-Ω, 1-kΩ, 6453.20-Ω, and 10-kΩ resistance levels. The first CCC was constructed in 1985 and is an overlapped-tube type with a commercial rf SQUID sensor. It contains 12 windings of 1, 1, 1, 1, 2, 4, 8, 16, 17, 32, 32, and 64; where, the unit winding contains 32 turns. Ratios available with this CCC include 1/1, 10/1, 100/1 and 64.532/1. The second CCC was constructed in 1990 and is also an overlapped-tube type ; however, it uses a dc

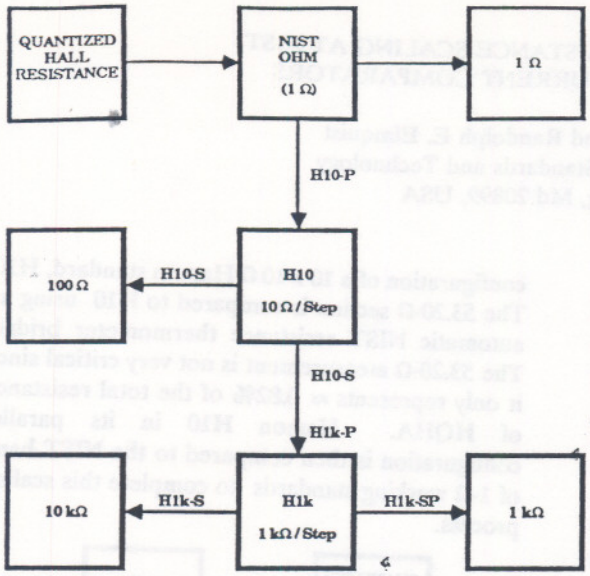

Fig. 2 Resistance Scaling to 1 kΩ and 10 kΩ.

SQUID sensor. It is more rigidly constructed with a quartz former for the flux transformer winding and the CCC mounted in a Macor holder. It contains 7 windings of 1, 1, 1, 1, 10, 10, and 100; where the unit winding contains 14 turns.

A schematic diagram of a CCC resistance bridge for measuring resistance ratio R_p / R_s is shown in Fig. 3. It is an automated system featuring isolated ramping current sources [5] for energizing primary and secondary windings, N_p and N_s respectively. The current sources are floating and completely isolated from one another, and are internally programmed to reverse the output current while maintaining the SQUID feedback control system in lock. Several sources have been constructed to provide full-scale currents up to 100 mA. The SQUID provides ampere-turn balance by controlling the secondary current source using an isolated SQUID

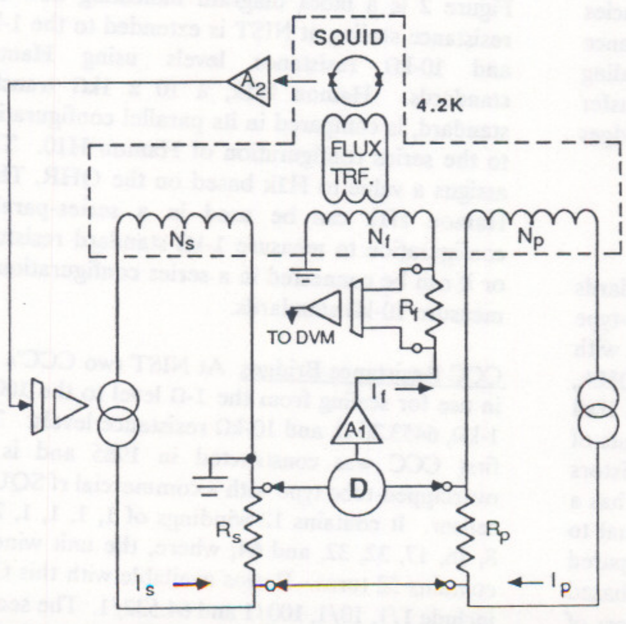

Fig. 3 CCC Resistance Bridge.

output. The isolated output of detector D is amplified by A_1 which provides a current through feedback winding N_f to drive the detector to a null condition. The feedback current I_f is monitored by measuring the voltage drop across R_f with a digital voltmeter (DVM) optically isolated from the feedback circuit.

Measurements

The uncertainty of the resistance scaling measurements based on the conventional Hamon transfer standards is estimated to be ≈ 0.01 to 0.02 ppm (1σ). Measurements comparing the 100/1 ratio of a CCC to the 100 Ω/1 Ω ratio of Hamon standard H10 agree to within 0.01 ppm. Measurements comparing the 10/1 ratio of a CCC to a resistance ratio of 1 kΩ/100 Ω are underway. Results of these measurements will be presented at the conference along with resistance ratio measurements of 10 kΩ/1 kΩ and the QHR of 6453.20 Ω to 100 Ω.

Conclusion

The CCC resistance bridges have significant advantages of higher ratio accuracies and lower noise over resistance scaling techniques using Hamon transfer standards. These factors will help to reduce by a factor of two or more the uncertainties in the resistance scaling process at NIST.

References

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