A CCC resistance bridge for the range 10 kΩ to 1 GΩ

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Abstract

This paper describes a new resistance bridge to provide improved traceability for resistance measurements at NPL in the range 10 kΩ to 1 GΩ. The provision of ratio measurements by a cryogenic current comparator (CCC) rather than the traditional method using Hamon ratio devices should improve the uncertainties for values up to 1 GΩ by an order of magnitude.

Introduction

Since the adoption in 1990 of the internationally agreed value for the von Klitzing constant, $R_{K\text{-}90} = 25\,812{\cdot}807\ \Omega$, all resistance calibrations carried out at NPL have been traceable to the quantized Hall resistance (QHR) primary standard [1]. In practice this is achieved via 100 Ω working standards, which are measured directly against the QHR and subsequently used as the reference for all routine calibration work. The determination of 100 Ω can be achieved with an uncertainty of better than 1×10^{-8}. The challenge is then to maintain low uncertainties as the values of these 100 Ω standards are propagated up and down the decades (down to 100 μΩ and up to 100 TΩ).

The range 1 Ω to 10 kΩ has been covered by an automated CCC bridge in routine use for several years [2]. Another recently developed CCC bridge now covers values down to 100 μΩ at currents of up to 100 A [3]. Above 10 kΩ, NPL currently still uses the traditional techniques of substitution measurements combined with series-parallel networks to obtain ratios. The aim of this paper is to describe the progress towards a third CCC system to bring greater resolution and accuracy to measurements in the range 10 kΩ to 1 GΩ.

A CCC for small currents

The big advantage of CCC bridges is the inherent ratio accuracy of the CCC device (ratio errors can be demonstrated to be smaller than 1×10^{-9}). The problem for high resistance measurements is that the currents involved become very small, requiring a CCC with high sensitivity and low noise. (An alternative method of realising resistance ratios using two arrays of Josephson junction voltage standards was investigated but discarded due to the 10 V limit available from present arrays.)

The ampere-turns imbalance between 2 windings of a CCC is sensed using a superconducting quantum interference device (SQUID) detector. Present NPL CCC designs rely on RF SQUID sensors, but modern DC SQUID systems offer a factor of approximately 100 lower noise. This noise combined with a typical CCC sensitivity and a winding of 10 000 turns gives a current sensitivity of 10^{-14} A for a 1 Hz bandwidth. For a 1 GΩ measurement at 100 V, this corresponds to a noise level of <0.1 ppm in the same bandwidth.

Recent experiments measuring the quantized currents from surface acoustic wave (SETSAW) devices [4], where the aim is to measure a current of 1 nA to an accuracy of 1 ppm, have demonstrated that this resolution can be achieved in a working CCC.

Bridge Design

Figure 1 shows a proposed bridge design using such a CCC to make ratio measurements of 4-terminal standards. The bridge is energised from a single current source, and the SQUID detector is kept nulled by a servo loop using an FET as a voltage controlled resistor to balance the current division between the two sides of the bridge. Resistors R_s form a combining network to ensure that no current flows in the potential leads of the standards R_x and R_y.

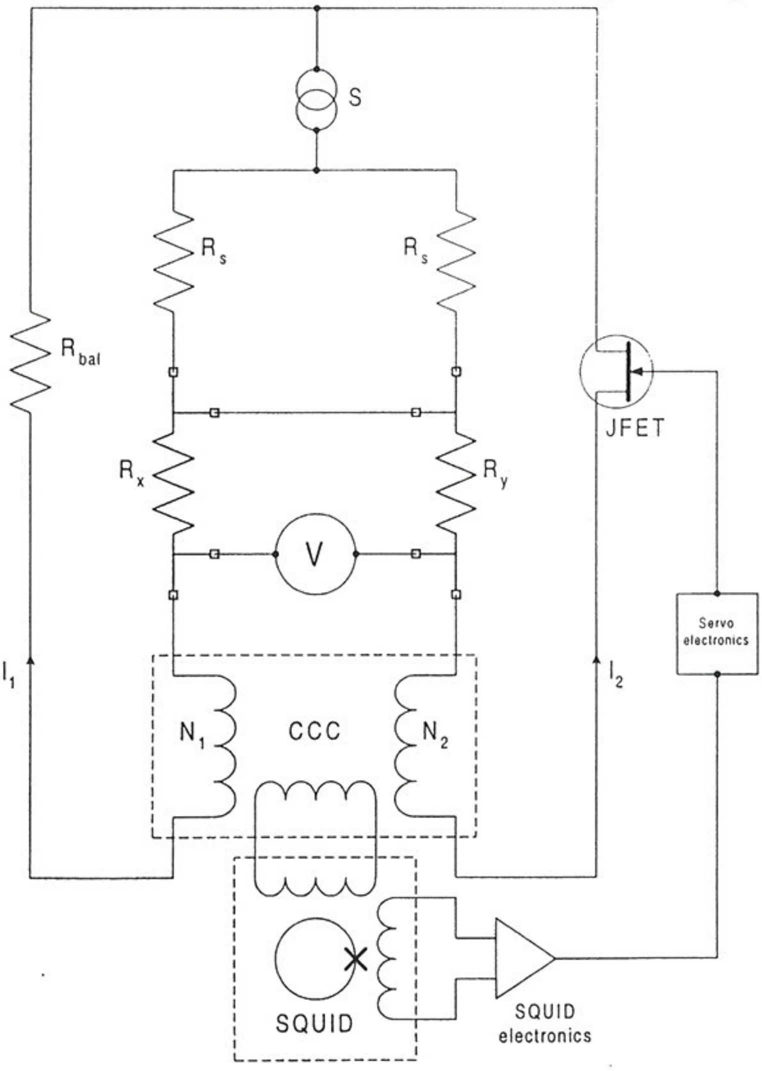

Figure 1

With the SQUID servo ensuring that the currents in the two resistors under test are locked to the turns ratio of the CCC windings, any deviation of the standards from that ratio can be measured with a voltage detector.

A complete measurement consists of a sequence of current reversals to eliminate offsets such as thermal emfs, and this introduces a complication in that the gain of the servo loop using the FET changes with the current and indeed changes sign as the current is reversed. This obviously has to be cancelled out if the feedback is to remain stable, and this can be achieved by including a 4 quadrant analogue multiplier in the loop, with an appropriate control voltage that follows the current reversals.

Results

A prototype, including servo electronics and a low noise current source with 100 V compliance was built to demonstrate this bridge principle. A less sensitive CCC that currently forms part of a bridge designed for 1 Ω to 10 kΩ measurements was used. Trial measurements were performed using 10 kΩ and 100 kΩ standards and some results from these tests are presented below. Figure 2 show the output from the voltage detector with the SQUID servo in operation. After 5 current reversals, a 100 MΩ resistor was connected in parallel with the 10 kΩ standard to produce a known change of about 100 ppm and thus calibrate the voltage detector readings. Figure 3 shows an enlarged section (with reversal differences subtracted) to show the noise level. The results of this measurement agreed to within 0.5 ppm with the ratio obtained via the traditional method using series-parallel boxes. Experiments at higher values were prevented by lack of a CCC sensitivity.

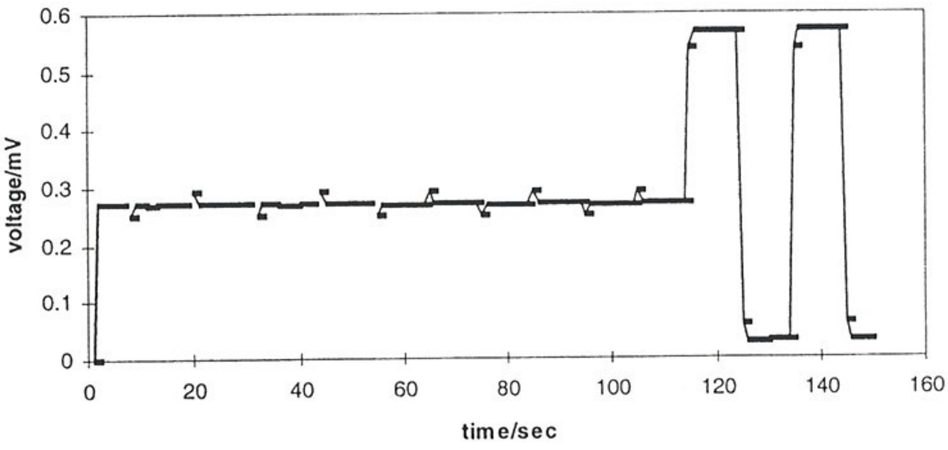

Figure 2

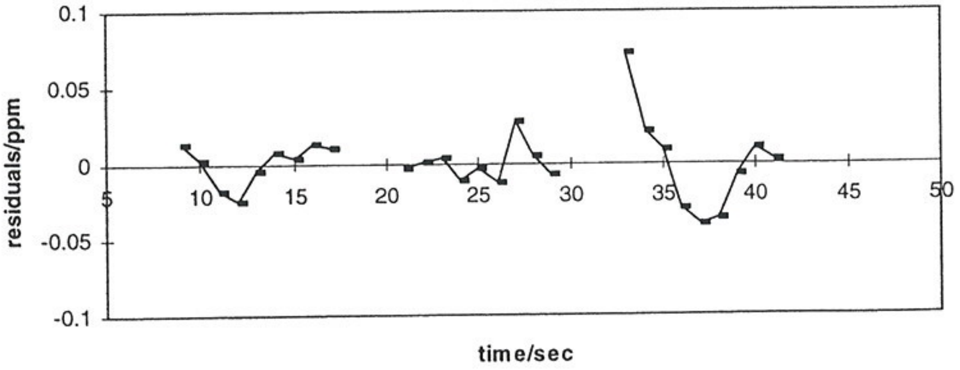

Figure 3