

SUMMARY OF RECENT AC QHR MEASUREMENTS AT THE NATIONAL PHYSICAL LABORATORY

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Abstract

A summary of recent AC quantum Hall resistance (QHR) measurements for realising the farad from the ohm using a quadrature bridge is presented. Measurements made on 1 nF standard capacitors using the 'AC QHR' route are compared with those using the normal 'DC QHR' ($\equiv R_H$) route. Although the former involves fewer intermediate bridge measurements, offering the possibility of lower uncertainties, the relative frequency dependence $(R_H(f) - R_H)/R_H$ despite having a small value of $0.118 \pm 0.005 (\mu\Omega/\Omega)/\text{kHz}$, will require calibration for each device. The effects of current and temperature dependencies of R_H on the frequency dependence are also discussed.

Introduction

One of the main benefits of establishing the AC standard of resistance based on the quantum Hall effect is that the farad can be realised via the ohm using a quadrature bridge [1]. This type of measurement would, apart from eliminating several measurement steps required using the DC QHR route (with 1σ uncertainty of $\pm 46 \times 10^{-9}$ [2]), also lead to the possibility of improved accuracy and reduced uncertainties [3]. However, once established to sufficient accuracy the AC QHR route may have a significant impact on impedance standards in general, by eliminating the need to maintain the calculable capacitor, providing a phase-angle standard and making the construction of measurement systems in emerging national metrology institutions relatively straightforward. However, before these benefits can be fully realised, several very significant questions remain to be answered. Prime among these is an understanding of the frequency dependence of R_H up to a few kHz. Additionally, constraints imposed by the reproducibility of samples suitable for AC measurements and their magnetic field, temperature and current dependencies, all require resolution [4,5].

In the first part of the paper we present measurements with a quadrature bridge operating at 1.233 kHz which is used to relate the values of two 10 nF capacitors to a 12.906 k Ω quadrifilar resistor and a QHR sample operated on the $i=2$ plateau at a temperature of 0.45 K. These results are compared with measurements using the traditional DC QHR route. However, the main problem with such quadrature bridge measurements is that operating at 1.233 kHz means that the frequency dependence of the QHR and the 10 nF transfer standards must be known to a few parts in 10^8 since the latter are compared with 1 nF standards at 1.592 kHz. In our measurements the QHR frequency dependence is determined, to sufficient accuracy by calibration with a quadrifilar resistor with a known calculated frequency dependence. This could be considered as unacceptable if a 'true' realisation of the farad from the ohm is the ultimate objective. In the second part of the paper, frequency, current and temperature dependencies of the QHR are discussed. Comparisons are made with recent measurements by Delahaye *et al.* [5] where it is claimed that better current distribution at the source-drain terminals can lead to reduced frequency dependence of the QHR. A possible mechanism for this *change* of frequency dependence is thought to be due to reduced power dissipation in the device, leading to device temperatures being closer to the operational bath temperature of 1.2 K.

Quadrature Bridge Measurements

The circuit diagram for the quadrature bridge and the schematic diagram of the AC and DC QHR traceability routes for obtaining the value of the 1 nF capacitors (QC1 and QC2) can be found in [1]. A comparison of the measurement results using the AC and DC QHR routes is shown in Fig. 1. The

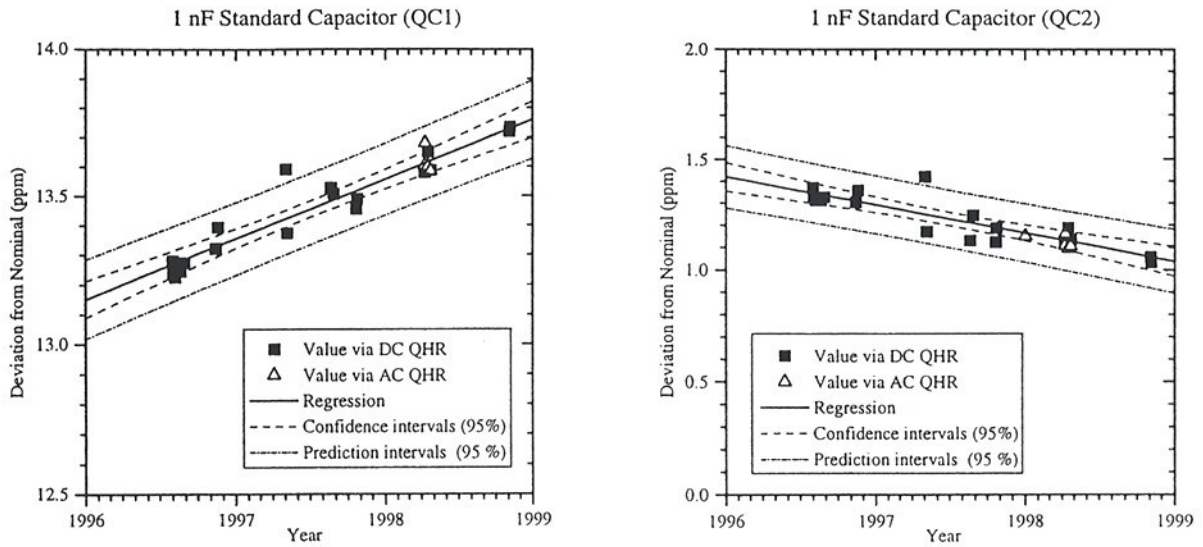


Fig. 1. Comparison of the AC and DC QHR traceability measurements for QC1 and QC2 [1].

agreement between the two chains of measurements is found to be within a few parts in 10^8 for both QC1 and QC2. As mentioned earlier there are two main problems in these measurements, the frequency dependence of the QHR and that of the 10 nF transfer standards from 1.233 kHz to 1.592 kHz. However, the former dependence can be corrected using the quadrifilar frequency dependence [6], and the latter is determined by applying a measured correction term which is proportional to ω^2 . This work is now being extended in a European SMT project to develop an automated modular bridge system for calibration of capacitance standards based on the AC QHR.

Frequency and Temperature Dependence of the QHR

The four terminal-pair frequency dependence measurements of the QHR normally show an ω^2 behaviour [7,8]. This is thought to be mostly due to the self-capacitance, C_s , of the device being transformed into an effective inductance $C_s[R_H(i)]^2$, leading to an enhanced 'cable correction'. The Delahaye double-series connections eliminate effects due to not only the device self-capacitance but also those from contact impedances [9]. However, in the double-series (or higher) connections the QHR shows a frequency dependence proportional to ω [8,10]. This is shown in Fig. 2 (left graph)

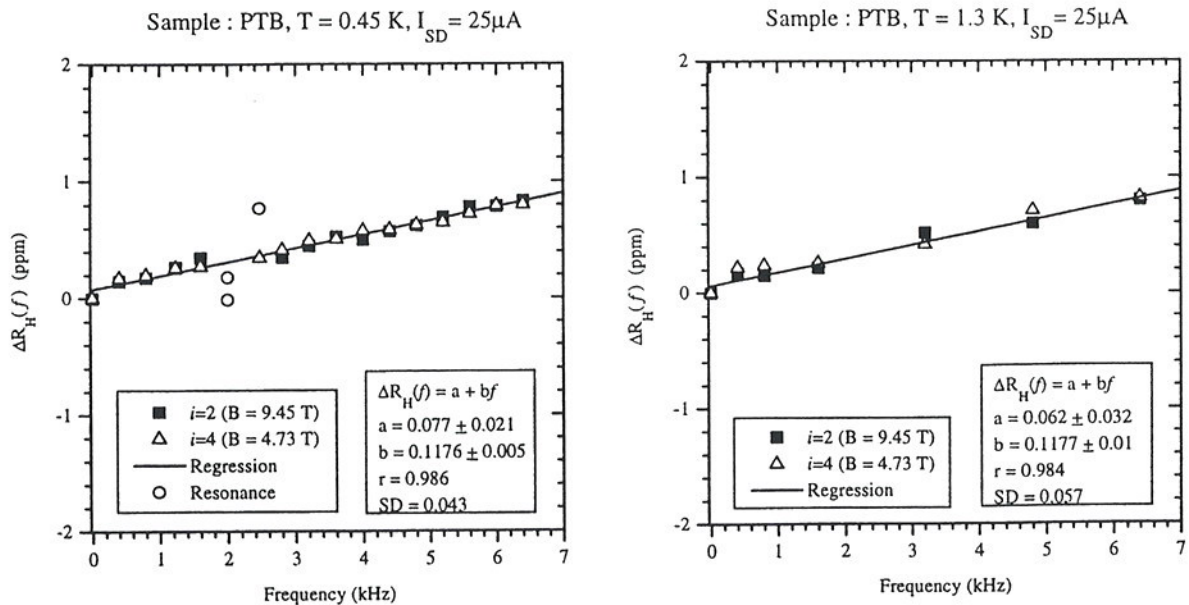


Fig. 2. Double-series measurements of the $i = 2$ and 4 plateaux up to 6.4 kHz and at 0.45 and 1.3 K.

where R_H for $i=2$ and 4 at $25\text{ }\mu\text{A}$ and 0.45 K in a PTB device is compared with quadrifilar resistors in a 1:-1 bridge [11]. In this particular sample the magnitude of the linear frequency dependence for both plateaux is found to be almost identical to $0.118\pm0.005\text{ ppm/kHz}$, having applied both quadrifilar frequency dependence and cable corrections. Additional measurements have confirmed very good repeatability of this value, including when the bridge had been moved to another location and reassembled. Further work is needed to determine the nature of this dependence in other samples and to confirm whether it is an artefact of the measurement bridge or an intrinsic property of the device. Several other combinations of connections have been reported by Chua *et. al.* [8].

At a temperature of 1.3 K the corresponding frequency dependence for $i=2$ and 4 plateaux is shown in Fig. 2 (right graph). Also shown in the graph is the regression fit to the measured results, which indicates that within the experimental uncertainty the frequency dependence of R_H for the two temperatures is about the same. This appears to contradict the mechanism suggested by Delahaye *et al.* [5], which is purported to be responsible for the decrease in the frequency dependence observed in a similar PTB sample. However, it may be too soon to be certain of the exact mechanism responsible for the above observations and further work is needed on different samples to resolve these remaining problems.

Current Dependence of the QHR

The current dependence for the $i=2$ plateau at $10\text{ }\mu\text{A}$, $25\text{ }\mu\text{A}$ and $50\text{ }\mu\text{A}$ for 0.4 kHz , 1.6 kHz , 3.2 kHz and 6.4 kHz is shown in Fig. 3. The plateau flatness near 9.5 T for $25\text{ }\mu\text{A}$ and $50\text{ }\mu\text{A}$ is found to be within $\pm 2 \times 10^{-8}$, whereas at $10\text{ }\mu\text{A}$ the results are less clear due to the reduced signal to noise

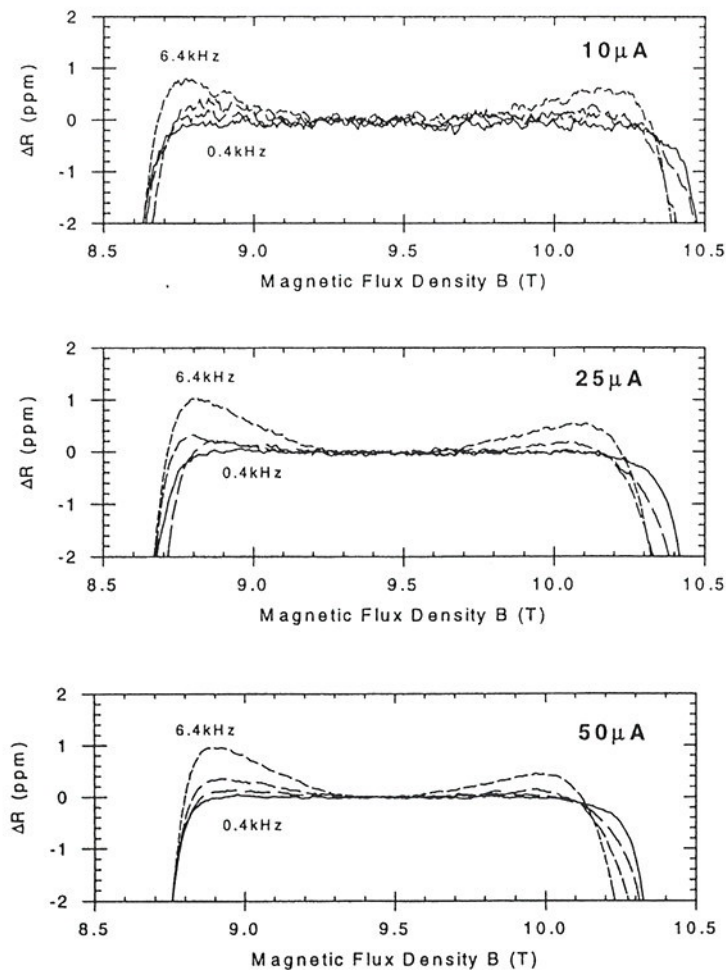


Fig. 3. Current dependence of the $i=2$ plateau at 0.45 K .

ratio. It is also interesting to note that the width of the flat region of the plateaux at $25\mu\text{A}$ and $50\mu\text{A}$ reduces from approximately 0.5 T to 0.2 T, as the frequency is increased, whereas the edges of the plateaux remain similar.

Conclusions

Preliminary results show that the farad could be realised via the ohm using the QHR and a quadrature bridge, with a possible increase in accuracy compared with the traditional DC QHR route. Measurements of the current and temperature dependence of the QHR and their influence on frequency dependence were found to be negligible in this device. However, further work is needed to determine the frequency dependence of both the transfer standards and the QHR if a true traceability from the ohm to the farad is to be realised.

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