The Enhanced Performance of the DCC Current Comparator using AccuBridge™ Technology
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Abstract:
The Quantum Hall effect (QHE) or primary resistance standard provides a universal representation of the unit of resistance which depends on the elementary charge e and the Planck constant h. The quantum resistance standard can be reproduced with a relatively low uncertainty using the traditional GaAs silicon sample. If the measurements on a QHE are implemented according to specific technical guidelines at temperatures of 1.2 K or lower in an 8 tesla magnetic field, uncertainties as low as few parts in $10^{-9}$ can be achieved. Quantum Hall resistors (QHRs) have a defined value (RH) of 25,812.807 Ω on step i = 1, with appropriate sub-multiples of this value on other steps. Such resistors are used as representations of the ohm in national laboratories of many countries, where it is common practice to compare these primary resistance standards on a regular basis with a set of thermally stabilized wire resistors.

These Quantum Hall resistance measurements are typically carried out using either resistance ratio bridges equipped with the cryogenic current comparator bridge (CCCB) or the room temperature direct current comparator (DCC) where the performance of each relies on the magnetic flux sensitivity. Binary wound current comparators are used in both which makes them easy to calibrate. Calibrations of wire resistors in terms of the QHE can also be carried out with similarly low uncertainties.

Over the last five years the DCC bridge, which is another application of the same connection technique as the CCCB, provides an effective solution for measuring the QHR with a relative ratio uncertainty below two parts in $10^{-8}$. The DCC ratio bridge itself has been hindered by the inherent ratio error (type A and type B uncertainties) of the direct current comparator due to its magnetic flux sensitivity. By improving on the technologies around the DCC, as described in this paper, both the specific technical guidelines used firstly to verify the GaAs sample and the reduction of the inherent ratio error in the range of 0.01 ppm to 0.005 ppm can be achieved. This presentation offers techniques and examples on the measurement of graphene samples.
Abstract:
The Ultrastable Low-noise Current Amplifier (ULCA) is a user-friendly and superior alternative to existing instruments for small direct currents in the range between about 1 fA and 5 μA. The ULCA is a portable laboratory table-top device, operated at room temperature. Its principle is based on a novel dual-stage transimpedance amplifier (i.e. current-voltage converter) concept. The total transimpedance of 1 GOhm is calibrated with a cryogenic current comparator with an uncertainty < 0.1 μOhm/Ohm traceable to the quantum Hall resistance. The output voltage is measured with a voltmeter calibrated and traced to the Josephson voltage standard. In addition to its electrometer function, the ULCA in combination with a voltage source also can be used as a current generator. Therefore, it represents a new tool for ultra-precise small-current measurement and generation traceable to quantum electrical standards. It outperforms commercial devices and calibration setups used in metrology institutes by up to two orders of magnitude in accuracy. The most special features of the ULCA are the excellent stability of its transimpedance (drift less than 5 μOhm/Ohm per year, short-term fluctuations over one week < 0.1 μOhm/Ohm), its small temperature coefficient (typically about 0.2 μOhm/Ohm per Kelvin), fast settling (difference to final value < 0.1 μA/A after 3 s), and the low input current noise of 2.4 fA/√(Hz). This enables measuring a direct current of 100 pA with a total relative uncertainty of 0.1 μA/A in about 10 h of measurement time. Besides being excellently suited for R&D in ultraprecise small-current metrology (e.g. for research on single-electron pumps) the ULCA is also widely applicable for calibrations, for instance for electrometers, small-current sources, or high-value resistors. Corresponding fields (and specific examples) are electronic industry (ICs), medicine and biotechnology (dosimetry, radiation protection, DNA sequencers) as well as environmental monitoring (concentration measurements of small particles in air or aerosols), and lighting industry (photocurrent measurement). Framed by two patent applications, the technology was transferred from the Physikalisch-Technische Bundesanstalt (PTB) to a German company (Magnicon GmbH, Hamburg), which manufactures and markets the ULCA since 2016 under PTB license.
Abstract:
The traceable measurement of small electric currents is becoming increasingly relevant in a number of sectors. By “small current” we mean currents in the nanoamp range or below, where measurement functionality is not available in standard off-the-shelf multimeters, and specialised instrumentation must be deployed. Examples of measurement areas requiring small current traceability are radiation dosimetry, environmental particulate monitoring, semiconductor characterisation and precision mass spectrometry for gas analysis. Against these burgeoning needs are set a number of challenges. Although progress has been made in NMIs over the last 10-15 years, traceability routes for small currents are still not widely available, and commercial instruments suffer from instabilities which limit the accuracy achievable outside specialised NMIs. With very small signals to measure, obtaining a satisfactory signal-to-noise ratio can require long averaging times, and this in turn requires the correct use of experimental methodology and statistical data analysis to assign a meaningful random uncertainty to the measurement. We will describe innovations in both primary traceability and instrumentation which overcome these problems and bring accurate traceable small current measurements closer to the end user. We will present case studies in the dissemination of small current traceability to radiation dosimetry and environmental particle counting, and will also discuss a new type of primary current standard under development at NPL and other NMIs, which works by moving electrons one at a time.