Summary

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December 20, 2019

The dissertation describes the work performed in the laboratories of three National Metrology Institutes: at the Istituto Nazionale di Ricerca Metrologica (INRIM), Turin, Italy, and, as a guest researcher, at the National Metrology Institute of Japan (NMIJ), National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan and at the National Institute of Standards and Technology (NIST), Gaithersburg, MD, US. The thesis was carried out in the framework of the resistance and impedance metrology in the current International System of Units, and is focused, in particular, on the realization of the units ohm, farad and henry from the quantum Hall effect and on the measurement techniques used to calibrate resistance and impedance standards.

This dissertation reports my work on three theoretical and experimental methods. The first is a general method to analyze complex measuring circuits that can be applied to the simulation of interconnected networks of quantum Hall effect elements, such as quantum Hall array resistance standards (QHARS). The method is implemented as a Mathematica application, the `QHARSmachine`, which estimates the error of a QHARS as a probability distribution simulated with a Monte Carlo analysis on the basis of the layout of the circuit network and the set of stray resistances of all interconnections. As an example, the `QHARSmachine` is applied to an existing $1\,\mathrm{M\Omega}$ QHARS fabricated by the NMIJ.

The second method is a DC quantum Hall effect Kelvin resistance bridge, designed and implemented to direct calibrate a four-terminal resistance standards operating at room temperature against the quantum Hall effect. The bridge is implemented as a bridge-on-a-chip based on a graphene QHARS, fabricated at NIST. The resulting system is simple and robust, requiring only few leads to connect the room temperature standard resistor and the measuring electronics. Moreover, with this method, only two room temperature electronic instruments of standard accuracy are necessary for the calibration of four-terminal resistance standards operating at room temperature. The calibration accuracy of an artefact standard resistor with nominal value R_{H} is at the level of a few parts in 10^9 (standard uncertainty). The calibration

results are compatible within a few parts in 10^9 with that of the state-of-the-art calibration bridge, the cryogenic current comparator. With respect to a calibration performed with a cryogenic current comparator against a QHR, the quantum Hall Kelvin bridge operates in a single cryogenic environment. The bridge can thus operate in a dry cryocooler, even of small size when graphene is adopted for the quantum Hall effect elements. The usage of QHARS can extend the operation of the quantum Hall Kelvin bridge to resistance standards of arbitrary nominal value.

The third method developed is a four terminal-pair fully-digital impedance bridge operating in a $1:1$ ratio configuration for the direct calibration of an $8\,\mathrm{nF}$ standard capacitor against a quantum Hall resistance standard at $1541\,\mathrm{Hz}$. The evaluated uncertainty is of about 2×10^{-7}. The bridge performance is validated by comparing the $8\,\mathrm{nF}$ capacitance standard calibration performed with the four-terminal-pair fully-digital impedance bridge and that performed with the transformer-based impedance bridges currently employed in the traceability chain of farad at INRIM. The two systems are compatible within a few parts in 10^7. The obtained result is a further proof that digital bridges are mature for primary impedance metrology and, in particular, that the $1:1$ ratio four-terminal-pair fully-digital impedance bridge here presented is suitable for the realization of the farad from an AC quantum Hall resistance standard.