EMPIR Call 2018 – Health, SI Broader Scope, Normative and Research Potential

Selected Research Topic number: **SRT-s05**
Version: 1.0

Title: Graphene impedance quantum standard

Abstract

The complexity and cost of operating quantum standards has up to now prevented their widespread use, especially for the quantum Hall effect (QHE) standards of resistance and impedance that require high magnetic fields, and temperatures much lower than Josephson voltage standards. Also, at present, the graphene standards can be used to provide direct traceability only for DC (direct current) quantities. Recent progress with the quantum Hall effect (QHE) in graphene has made it realistic to develop a robust, simple-to-operate and economical practical realisation of electrical impedance units (ohm, farad, and henry) in the revised SI. Proposals in response to this SRT, in addition to further advancing the fabrication technology for graphene and its use for reliable traceability of impedance units, should develop primary AC (alternating current) quantum impedance standards based on automated impedance bridges in a user-friendly, cryogen-free, and compact environment.

Keywords

Graphene, Quantum Hall Effect (QHE), quantum impedance standard, SI, quantum resistance.

Background to the Metrological Challenges

At present, traceability of almost all electrical calibrations is based on the quantum standards of voltage (Josephson Effect) and resistance (Quantum Hall Effect, QHE), and their importance will grow with the anticipated revision of the SI in 2019. However, the complexity and cost of operating quantum standards has up to now prevented their widespread use, especially for the QHE standards of resistance and impedance that require high magnetic fields, and temperatures much lower than Josephson voltage standards.

Development of graphene-based primary resistance standards has been a success story of European metrology research during recent years but the fabrication technology of graphene devices is not mature yet. The problem of reliable fabrication of uniform graphene films has been tackled in several worldwide research efforts, but the indispensable long-term stability, without need for re-adjusting a key property of the graphene device before each use, has not been achieved up to now.

During the last years, intense research has started and much of the progress has resulted from work in previous EMRP projects such as SIB51 GraphOhm “Quantum resistance metrology based on graphene” and SIB53 AIM QuTE “Automated impedance metrology extending the quantum toolbox for electricity”.

For primary traceability of capacitance or inductance to a quantum standard, a special impedance bridge is needed. The state-of-the-art in that field was set in SIB53 AIM QuTE where novel digital impedance bridges were developed but the design and construction of such a system is still a challenge. There is a need to develop new bridges by combining the achievements reached in AIM QuTE with measurement uncertainties required for a primary realisation of impedance units, removing the need for cumbersome traceability chains via complex bridges which are available only in few NMIs.

Regarding the AC-Quantised Hall Effect (AC-QHE) in graphene, promising first results were achieved in the EMRP project GraphOhm. They indicated the great potential of graphene also for AC metrology, since the AC-quantum Hall plateaus were found to be much flatter than for GaAs quantum Hall devices. Those experiments used devices specifically designed for DC applications. Devices adapted for AC have yet to be fabricated and tested. Additional optimisation steps specific for AC applications (e.g. avoidance or systematic removal of parasitic conductive material) must be also addressed.

Finally, when graphene instead of GaAs is used as the material of the quantum Hall standard, a much more user-friendly and economical quantum resistance/impedance standard can be constructed, working at temperatures provided by a cryogen-free refrigerator, and in a magnetic field produced by a compact solenoid, or even by a permanent magnet. Such a quantum standard could be used in small NMIs but also in other measurement laboratories. This would be a starting point for a longer-term and larger-scale approach to strengthening the European capabilities in the metrologically important field of DC resistance and AC impedance.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the development of a graphene-based quantum standard of resistance and impedance units at DC and AC.

The specific objectives are

1. To optimise and to tailor graphene material and graphene devices in order to improve the understanding of the graphene AC quantised Hall effect (AC-QHE), as the basis for traceability of impedance units to the QHE at temperatures of 4 K or higher in as low as possible magnetic fields of at most 6 T.
2. To advance digital bridges for the capacitance range from 10 pF to 10 nF at frequencies up to 100 kHz, and to develop an impedance bridge working with spectrally pure Josephson voltages up to 50 kHz in the entire complex plane.
3. To combine graphene devices with a Josephson impedance bridge (with a target uncertainty below 0.01 µΩ/Ω), and with a full digital bridge for simplified operation, (with an uncertainty target in the 0.1 µΩ/Ω range), in order to trace capacitance to the QHE.
4. To develop and investigate a cryo-cooler system hosting the superconducting Josephson device and the graphene device, both operating at AC and serving as the core element of a quantum resistance and impedance standard in the revised SI.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. graphene manufacturers), standards developing organisations and end users (e.g. NMIs and calibration centres as well as the Graphene Flagship of the European Commission).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

In particular, proposers should outline the achievements of the EMRP projects SIB51 GraphOhm and SIB53 AIMQuTE and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the electrical metrology community and the graphene industry sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.