EMPIR Call 2015 – Health, SI, Normative and Research Potential

Selected Research Topic number: **SRT-s04**
Version: 1.0

Title: Quantum realisation of the SI Ampere

Abstract

This SRT describes the development required for the practical realisation of the future SI ampere. After the envisaged redefinition based on the fixed elementary charge, e, single-electron current sources will become the most direct realisation of the new ampere. Two EMRP projects, T1.J1.3 REUNIAM and SIB07 Qu-Ampere, have demonstrated the potential of candidate technologies to reach the required accuracy (< 1 part in 10^7), but the pump accuracy achieved so far has been limited by the NMIs' metrological capabilities. Proposals against this SRT should aim to improve small-current measurement capabilities across NMIs and to test the universality of single-electron current quantisation in preparation for the planned SI redefinition in 2018.

Keywords

SI base units, ampere definition, ampere realisation, quantum current standard, single-electron tunnelling (SET) device, cryogenic current comparator (CCC), universality test, quantum metrological triangle, electron pump, error counting

Background to the Metrological Challenges

Today, the SI units are under heavy scrutiny. The move to eliminate the need for physical artefacts from the definition will lead to the redefinition of four base units, the kilogram, mole, kelvin, and ampere, based on exact fixed values of physical constants. The new ampere will be based on an exact value of the elementary charge *e* [1]. Under the current definition, the difficulty of ampere realisation has forced the electrical calibration chains to be decoupled from the SI definition. They are currently based on the conventional units using the agreed values of the Josephson constant K_{J-90} and von Klitzing constant R_{K-90}. The proposed redefinition is expected to simplify the *mise en pratique* (practical realisations) of electrical units [2] and will maintain the direct traceability to the SI units.

Under the new definition, the realisation of the ampere becomes simple, at least in concept. One needs to generate an electric current by transferring exactly *n* electrons (*n*: an integer) per cycle at a frequency *f*. Since each electron has an electric charge exactly *e*, the current, by definition, becomes quantised at $I = nef$. *f* can be determined with high accuracy (uncertainty < 1 part in 10^{10} can be routinely established) so that the uncertainty in the ampere realisation in practice solely depends on the uncertainty in *n*.

Single-electron pumps work on exactly this principle, and are naturally the most ideal candidates for the practical realisation of the new ampere. However, in order to use single-electron pumps for the ampere realisation, greater confidence needs to be established in their accuracy and robustness in operation and handling. The accuracy and universality of the current quantisation needs to be demonstrated at the 1 part in 10^7 level, or better.

There are two main types of single-electron-based current sources that are potentially suitable for the realisation of the new ampere. One is the tunable-barrier pump based on semiconductors and the other is the hybrid turnstile pump based on superconductor-metallic tunnel junctions. None of these devices has demonstrated pumping accuracy of 1 part in 10^7, although for some devices the theoretically predicted accuracy reaches 1 part in 10^8. This is likely due to the limitation in measurement accuracy.

The verification of single-electron current source accuracy by current measurement requires a high-accuracy system traceable to the Josephson voltage standard and quantum-Hall resistance standard. The cryogenic current comparator (CCC) through a comparison to a reference current source (traceable to the quantum Hall resistance standard and the Josephson voltage standard), and the ultra-stable low noise current amplifier (ULCA) are expected to provide accuracy at the 1 part in 10^7 level.

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 JRP-Protocol.

The JRP shall focus on the development of nano-ampere single-electron-based current sources

The specific objectives are

1. To develop single-electron-based current sources reaching a current level of ~1 nA with an uncertainty at or below 1 part in 10^7. This will require parallelisation of pumps, or development of pumps which are able to operate at higher frequencies.
2. To test the universality, robustness and reproducibility of single-electron-based current sources which will be used for the practical realisation of the new SI ampere. The difference in current quantisation values between devices of the same or different material/structure needs to be tested with resolutions at or better than 1 part in 10^7.
3. To implement high-accuracy current measurement capability across NMIs, suitable for the test of various types of single-electron devices. This includes the development of wider-range (100 nA – 10 mA) reference quantised current sources directly realised by Josephson Voltage standards and quantum Hall resistance standards.
4. To develop guidelines for testing the accuracy of single-electron-based current standards. This may include electron-transfer error counting or quantitative assessment of “plateau flatness”.
5. To facilitate the take up of the technology and measurement infrastructure developed by the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers) and end users (industries where small current measurements at pico-ampere and femto-ampere levels are required).

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 iMERA-Plus project T1.J1.3 REUNIAM and EMRP project SIB07 Qu-Ampere 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 21 % of the total EU Contribution to the project. Any deviation from this must be justified.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

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 measurements 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.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] Draft 9th SI Brochure, Section 2.4.4 p14 (2013).
[2] Mise en pratique for the ampere and other electric units in the International System of Units (SI), CCEM/09-05, Note to the reader and Point 4, (2009).