European Partnership on Metrology
Call 2022 – Digital Transformation, Health, Integrated European Metrology, Normative and Research Potential

Selected Research Topic number: **SRT-s11**
Version: 1.0

Title: Small electrical current metrology for industrial and scientific applications

Abstract

The magnitudes of small electric currents are a key measurand in diverse disciplines of science, metrology and engineering. These include ionising radiation metrology, aerosol metrology, photometry, radiometry, and resistance metrology among others. Currently, measurements of these currents pose problems at the point-of-use related to the stability and linearity of measuring instruments, obtaining traceable calibrations and uncertainties evaluation. This research focuses on the optimisation and dissemination of new types of primary current standards, calibrated instrumentation and validated methods for the measurement of small electrical currents, as well as on the collaborative research interaction between electrical metrologists and point-of-use practitioners.

Keywords

Electric current, ammeter, single electron pump, traceability, ionisation chamber, aerosol electrometer, photometry.

Background to the Metrological Challenges

The importance of small electric currents for metrology has been steadily growing for some time, driven by different factors including the increased use of radionuclides in medicine and the increasingly stringent environmental legislation. Ubiquitous devices in these fields, such as ionisation chambers and particle counting electrometers, require traceable small current measurements. Although calibration services for currents down to fA levels are already available, standard calibration services offered by NMIs do not always meet the stakeholder needs, i.e. calibrations are usually performed on dedicated current meters or sources at direct current (DC), while stakeholders often use specialised instruments adapted for specific types of measurement. In addition, methods for evaluating instrument behaviour at point-of-use are not well disseminated in the stakeholder community, which can lead to underestimation of the electrical contribution to the measurement uncertainty. At the same time, the availability of high quality, yet reasonably priced commercial calibrators and DC sources in the 1 pA – 1 µA range on the market is limited.

Research results from NMIs electrical metrology departments and the EMPIR 15SIB08 project E-Si-Amp, led to the development of several instruments and techniques able to generate or measure small DC electric currents with relative systematic uncertainties less than a part per million. These include:

(i) The electron pump, a cryogenic device which generates currents in the pA range, with uncertainties in the range 0.1 ppm - 1 ppm, by controlled manipulation of single electrons;

(ii) the programmable quantum current generator (PQCG), a versatile wide-range reference current source (from a few mA down to a few nA) with sub-ppm accuracy;

(iii) The Ultrastable low-noise current amplifier (ULCA), a commercially available, portable, electronic device which can source or measure currents in the fA to µA range with ppm-level accuracy;

(iv) reference current sources adapted from existing standard resistors and voltmeters or using the capacitance-charging method;

(v) methods for robustly evaluating the measurement uncertainty under conditions of high noise and fluctuating background signals.

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However, the newly developed primary standards, such as the electron pump and PQCG, have not yet been applied to practical calibration problems. The electron pump, due to its noiseless property, has the potential to evaluate the stability of ultralow current electrometers (pA and below) with higher resolution than any other type of standard. At higher currents, from nA to mA, the PQCG has demonstrated sub-ppm-level linearity. Also, advanced instruments such as the ULCA are not widely deployed, or even known about, in stakeholder laboratories. Last, methods for robust signal processing and uncertainty expression in the presence of large, fluctuating background signals and various types of offsets are not used in many stakeholder communities.

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 traceable measurement and characterisation of small electrical currents.

The specific objectives are

1. To evaluate the electron pump performance and exploit its ideal linearity over many decades of current, and its low (ideally, zero) noise. To evaluate the stability and linearity of current meters under test at the 0.01 % relative uncertainty level at ultralow currents of 1 pA and below. Other state-of-the-art primary standards with a low uncertainty across a wide range of currents, such as the programmable quantum current generator (PQCG), should also be investigated for currents up to 1 μA.
2. To develop and optimise portable reference current sources and meters for stakeholder applications including: (i) DC sources and meters with background offset current stability better than 1 fA over one month and gain stability better than 10 ppm over 1 year; (ii) Instruments and calibration methods for pA level pulsed-current meters; (iii) Calibrated instruments and validated methods for the characterisation of electrical insulators at high voltages.
3. To deploy the tools developed in objectives (1) and (2) for performance evaluation of small current measuring instruments under actual conditions of use (including e.g. temperature, air flow and EM interference sensitivity). To demonstrate improved measurement accuracies in key application areas, such as ionising radiation metrology, photometry and radiometry, and aerosol metrology. To evaluate the gain and offset stability of instruments under a range of lab conditions, as well as the linearity of instruments over many decades of current, from fA to μA (depending on the application), at uncertainty levels of 0.01 % to 0.001 %.
4. To develop standardised measurement protocols and statistical methods for signals measurement in the presence of large fluctuating offsets, where a stationary mean cannot be assumed.
5. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (EURAMET TC-EM, metrologists in other application areas, accredited laboratories), standards developing organisations (CCEM) and end users (instrument manufacturers, electrical devices manufacturers, point-of-use practitioners).

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 both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships 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 and end users.

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 EMPIR 15SIB08 project E-Si-Amp and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.6 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated 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,
- Develop an integrated self-sustaining European metrology infrastructure,
- 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 the Partnership 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.