European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry, Normative and Research Potential

Selected Research Topic number: **SRT-r01**
Version: 1.0

Title: Wideband AC quantum traceability

Abstract

A “practical” traceability route for AC measurements based on thermal converters relating AC values to DC values has been established at NMIs for more than 60 years, however this is limited to RMS (Root Mean Square) values only and requires long measurement times. The new realisation of the ampere based on quantum standards allows direct traceability for AC measurements. New techniques and tools for the digitalisation of the traceability chain for AC electrical quantities have been developed in a series of EMRP and EMPIR projects. However, these must be further improved to establish the link between quantum standards and calibrations with a broader frequency and amplitude range for widespread implementation at NMIs and accredited laboratories.

Keywords
Programmable Josephson voltage standard, AC voltage, thermal transfer standards, power, power quality, quantum traceability, open-source, digitalisation

Background to the Metrological Challenges

By 2030, the European Metrology Network for Quantum Technologies expect that “quantum technologies will be ubiquitous”, but to reach this goal, confidence in the technologies must be increased. This can only be achieved through “validation and certification, based on internationally agreed standards and metrological traceability, implemented by independent experts.” Substantial research has been conducted in the field of AC quantum standards, with a broad distribution of Programmable Josephson Voltage Systems (PJVS) in operation. Research performed in EMPIR projects 14RPT01 ACQ-PRO and 19RPT01 QuantumPower have made these systems accessible to more NMIs and calibration laboratories, but their use in implementation of AC traceability is still only in a very limited frequency range and for specific applications.

Established AC voltage standards, based on thermal converters that relate AC values to DC values, provide traceability for RMS values only and require measurement times of around one hour to achieve their best uncertainties of 100 nV/V. There is an urgent need to support the digitalisation of waveforms with direct traceability to the SI for non-RMS quantities, by providing a robust open-source platform for research, development, and traceability, validated by international comparisons. Whilst techniques based on the Josephson Arbitrary Waveform Synthesizer (JAWS) are in development, they are still limited in voltage range, very complex and very expensive, thus not suitable for industry or calibration laboratories. Digital quantum based sampling techniques, requiring measurement times less than a minute, are used increasingly, both in NMIs and in industry. AC quantum voltmeter uncertainties at 50 nV/V-level for frequencies up to 1 kHz and better than 10 µV/V up to 100 kHz have been demonstrated.

Techniques and requirements for digitalisation of the traceability chain for AC metrology were developed and quantum traceability for electrical power was established by EMPIR projects 17RPT03 DIG-AC and 19RPT01 QuantumPower. The basic components have also been developed in EMRP and EMPIR projects SIB59 Q-WAVE, 14RPT01 ACQ-PRO, 15SIB04 QuADC, and 15RPT04 TracePQM: PJVS systems and control drivers (QPS), sampling software for commercial digitisers (TWM), algorithms for analysing waveforms (QWTB) and understanding of transducers (TracePQM Guide). However, further development is needed to make the connection between quantum standards and practical calibrations within a broader frequency and amplitude range for AC metrology to enable widespread implementation at NMIs and accredited laboratories.

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 enabling the replacement of thermal converter based traceability for AC measurements by increasing the bandwidth of available techniques for providing traceability to Josephson standards.

The specific objectives are

1. To develop techniques and algorithms for calibration of AC voltage sources and measurement instruments at frequencies up to 100 kHz with a target uncertainty better than 10 µV/V by utilising sub-sampling and differential sampling.
2. To expand on the open-source quantum sampling standard based on Josephson voltage standards developed in previous EMRP and EMPIR projects to calibrate digitisers, transducers, and sources in the AC field, extending the bandwidth of validated techniques up to 100 kHz.
3. To develop at least two working implementations of the expanded open-source quantum sampling standard working up to the increased bandwidth and specified voltages based on existing commercial devices.
4. To transfer the expertise in AC Josephson standards to emerging NMIs by expanding on the common platform for quantum accurate waveform analysis developed within EMPIR 19RPT01 QuantumPower and developing a coordinated approach for replacement of AC traceability from thermal transfer techniques to Josephson standards.
5. To facilitate the take up and long-term operation of the capabilities, technology and measurement infrastructure for AC measurements developed in the project, by the measurement supply chain (NMIs/DIs, calibration and testing laboratories), and end users (e.g. industry, instrument manufacturers, regulators). The approach should be discussed within the consortium and with other EURAMET NMIs/DIs, e.g. via EURAMET TC-EM and EMN for Quantum Technologies, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole and the Smart Specialisation concept is promoted such that NMIs with emerging needs can avail of the developed technology.

Joint Research Proposals submitted against this SRT should identify

- the particular metrology needs of stakeholders in the region,
- the research capabilities that should be developed (as clear technical objectives),
- the area for which the capabilities will be built (Green Deal, Digital Transformation, Health, Integrated European Metrology, Industry, Normative or Fundamental Metrology) and in which future main call the developed research capabilities are planned to be employed,
- the impact the developed research capabilities will have on the industrial competitiveness and societal needs of the region,
- how the research capability will be sustained and further developed after the project ends.

Proposers should establish the current state of the art and explain how their proposed research goes beyond this. In particular, proposers should outline the achievements of the EMRP or EMPIR projects SIB59 Q-WAVE, 15RPT04 TracePQM, 14RPT01 ACQ-PRO, 15SIB04 QuADC, 17RPT03 DIG-AC and 19RPT01 QuantumPower and how their proposal will build on those.

The development of the research potential should be to a level that would enable participation in other TPs.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 0.7 M€ and has defined an upper limit of 0.9 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 20 % 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,
- Provide a lasting improvement in the European metrological capability and infrastructure beyond the lifetime of the project,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the industrial sector and the metrology community.

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.