Title: Waveform metrology based on spectrally pure Josephson voltages

Abstract

The application of the Josephson effect, as the basis of a DC voltage standard, started 30 years ago and over the last years much work has been done to obtain AC quantum voltage standards based on the same effect. Established techniques that consider AC and DC as separate disciplines are not aligned with the needs of dynamic measurements and provide no measure of waveform parameters. Waveform metrology has the potential to demonstrate the true limits of spectral purity of arbitrary wave form generation as well as traceability of the amplitude to the SI volt Proposals against this SRT should extend the applications of AC voltage quantum devices with high levels of accuracy.

Keywords

AC quantum standards, quantum electrical metrology, Josephson Arbitrary Waveform Synthesizer (JAWS), SI traceability, AC voltage, digital measurement, waveform metrology

Background to the Metrological Challenges

To meet the evolving requirements in AC voltage metrology much effort has been devoted to the development of quantum voltage standards based on the Josephson effect. Quantum based measurement standards are much more relevant to digital electrical metrology than established analogue techniques and quantum effects play a fundamental role in the redefinition of the SI electrical units, allowing their direct realisation.

Currently, two different types of AC quantum standards are being developed. The Josephson Arbitrary Waveform Synthesizer (JAWS) generates spectrally pure output voltages from high-speed pulses applied to Josephson junctions while the Programmable Josephson Voltage Standard (PJVS) uses segments of programmable Josephson junctions to staircase waveforms. Both types are providing practical AC voltage quantum standards. However, applications using the PJVS are limited in frequency (DC to a few kHz) due to steps in the waveform. JAWS is suitable for a wide frequency range from DC to MHz but it is usually limited to an amplitude below 100 mV (for which an uncertainty of about 100 nV/V has been verified). Recently, with improvements in the synthesizers, amplitudes larger than 1 V have been reached that demonstrate proof-of-concept and contribute to the development of a real-time measurement system. Good progress has also been achieved in the development of digital sampling methods and towards a practical AC quantum voltmeter. However, both the Josephson synthesizer and the quantum voltmeter are difficult to operate and show technical and operational limitations when used in practice.

Established AC voltage and current standards based on thermal converters relate AC and DC values by the heat dissipated in a resistive element, but they only provide root mean square (rms) values and require about one hour measurement time to achieve the best uncertainties (100 nV/V). With digital techniques measurement time can drop down to one minute. Therefore, their use is increasing in NMIs and in industry, even though digital instrumentation requires traceability for measurements with amplitude and phase information.

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 AC-voltages to the SI volt for dynamic measurements in the DC to 1 MHz range, up to levels of 1 kV.

The specific objectives are

1. To develop a quantum-based real-time measurement system for the DC to 1 MHz range, utilising the Josephson effect representation of the SI volt;
2. To develop a robust and user-friendly quantum system as a practical realisation for providing direct traceability of the redefined base unit ‘volt’ to end users, either national measurement laboratories or next tier of users in the calibration and test sectors;
3. To evaluate digital signal processing techniques with respect to their contribution to the measurement uncertainty and to validate measurement methods for AC voltage calibration based on spectrally pure Josephson-AC-voltage references. The target uncertainty is 10 nV/V-level for frequencies up to kHz and better than 10 µV/V for frequencies up to 1 MHz;
4. To scale quantum waveforms up to 1 kV. The target uncertainties must be in the range of 5 µV/V for 1 kV / 50 Hz and 25 µV/V for 120 V / 100 kHz for the fundamental tone.
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), standards developing organisations (ISO, CEN) and end users.

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 iMERA-Plus, EMRP and EMPIR projects JOSY, Q-WAVE and ACQ PRO, respectively 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 measurement 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.