Programmable Josephson junction series arrays for coherent sub-sampling measurement of time-varying waveforms

Abstract:

Superconducting programmable Josephson junction series array chips, designed for primary voltage metrology applications ranging from DC to low-frequency AC, are now commercially available. They represent a trade-off between conventional semiconductor technology, which dominates mixed electronic devices, and superconducting electronics, which offer superior accuracy and precision.

Following the resounding success in DC applications, the use of programmable Josephson junction series array chips in alternating current began several years ago, primarily focusing on mains frequencies and not exceeding a few kilohertz. This development led to a complex experiment known as the quantum voltmeter. Although this experiment has not yet fully matched the performance of traditional devices - such as AC/DC voltage transfer standards based on multijunction thermal converters and calorimetric thermal voltage converters - it remains the most promising candidate for linking AC electrical quantities to fundamental constants, as outlined in the new SI.

The research activity will lay the foundations for a new quantum traceability for AC voltage, current and power quantities under sinusoidal and non-sinusoidal regime in response to growing needs and importance of waveform metrology related to time-varying and multi-tone signals.

The expected impact will be:

- Provide the necessary step change from conventional techniques to quantum based measurements for the traceability of stationary AC electrical quantities.
- Establish new traceability chain for linking non-RMS quantities required for power quality (PQ) measurements in the new SI.
- Exploiting the potentially of analog-to-digital conversion technique for the development of a synchronized AC quantum voltmeter for synchrophasor measurements.

Need

Nowadays, the existing metrological chain for AC voltage, current and power relies on AC/DC thermal converters (TVCs), which are reliable, time-consuming, insensible to spectral components and do not provide a direct link to the fundamental constants, as expected in the new quantum SI. Signal digitizing and waveform reconstruction techniques using analog-to-digital converters and machine learning algorithms, are key enabling technologies that, when integrated into the framework of quantum electronics, can meet emerging demands in terms of accuracy and reduced uncertainties in the measurement of time varying AC signals.

Objectives

The goal is to lay the foundation for step change from conventional to quantum methods in the metrology of time-varying waveforms, using coherent subsampling strategy based on programmable Josephson arrays and machine learning.

In particular will include:

- Prepare and improve the AC quantum voltmeter based on a 13–bit binary Josephson junction arrays (JJAs) for AC voltage measurements base on differential sampling up to 1 kHz.
- Extend the bandwidth of the AC quantum voltmeter up to 100 kHz by developing a novel measurement technique using the subsampling strategy and data processing algorithms.
- Develop and prepare the necessary synchronization framework for the generation of electric quantum synchrophasors.
- Implementation of testbed for integration and simultaneously operation of quantum devices in the same cryogenic bath.

Outcomes

- Setup a fully synchronous AC quantum voltmeter for practical measurements of voltage, current and power under sinusoidal, non-sinusoidal waveforms and synchrophasors.
- Reduce cost and time for calibrating and maintaining of AC measurements to the new quantum SI.

Skills and competencies

The ideal candidate should have a solid background on condensed matter physics and engineering.

- Experience in solid state physics, electronic properties of materials - superconductors and semiconductors – from room to cryogenic temperatures, multi-physic modelling and signal theory would be a surplus.
- Basic knowledge of macroscopic quantum effects with particular emphasis on AC-Josephson effect in superconductors and its application in primary voltage metrology.
- Willingness to work in a research laboratory and conduct activities related to the setup of scientific experiments, preparation of measurement protocols and automation of measurement process.
- Strong predisposition to work with programming languages and multithreading environments and have knowledge in C++, Labview/Lavindows/CVI, Matlab, Paython, VHDL, etc.

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