Title: Coherent quantum phase slips in superconducting nanowires for metrological applications

Abstract

The Coherent Quantum Phase Slips (CQPS), recently observed in superconducting nanowires, is the phenomenon at the core of a completely new class of quantum electronic devices. Being an exact dual to the Josephson Effect, CQPS is expected to have particularly important applications in metrology and quantum information processing.

Keywords

Superconductivity, nanowires, coherent quantum phase slip, charge-flux duality, quantum current standard, quantum sensors, nanotechnology, quantum technology, quantum metrology, qubit.

Background to the Metrological Challenges

Superconducting quantum devices revolutionised accurate measurements and electrical metrology about 50 years ago, when SQUIDs and quantum voltage standards based on the Josephson Effect were invented. Recently discovered Coherent Quantum Phase Slips (CQPS) in superconducting nanowires offer an alternative to Josephson Effect both in quantum information processing and in metrology. CQPS devices made entirely of a superconducting material have several benefits, such as fewer fabrication steps than Josephson Effect devices, robustness to larger electric currents, wide parameter range, and seemingly the lack of undesired two-level fluctuators present in the insulating tunnel barriers of Josephson devices. It is expected that a single CQPS device can produce much higher and potentially more precise quantised current than a single-electron pump, which is presently the most advanced quantum current standard.

Although CQPS has successfully been demonstrated, reliable and reproducible fabrication of superconducting nanowires and circuits suitable for CQPS is a challenging issue that must be resolved before applications can be realised. In addition, understanding physics of CQPS is still largely based on applying theories developed for the dual phenomenon, the Josephson effect. However, better microscopic understanding of highly disordered materials is needed for optimal performance of CQPS applications and particularly for the observation of quantised current steps dual to the voltage Shapiro steps in Josephson Effect. This requires experimental studies of nanobridges and constrictions in disordered materials and developing theoretical approaches and simulations of the devices. An important tool to obtain understanding of CQPS physics is to study quantum phase slips in Josephson junctions. To achieve the CQPS regime in Josephson junctions, a non-dissipative high impedance environment must be implemented.

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 developing technology and prepare the basis for metrology applications of coherent quantum phase slip (CQPS)

The specific objectives are

1. To find suitable materials and to develop fabrication techniques for superconducting nanowires and circuits suitable for CQPS applications. For different applications, the nanowires should be embedded

in various networks of other electrical components, such as high-ohmic thin-film resistors, compact kinetic inductors and microwave resonators.

2. To develop an understanding of the physics of CQPS devices to the level needed in implementation of quantum circuits with unique characteristics. In particular, understanding the role of (possible) quasiparticle tunnelling in superconducting nanowires is necessary to realise the circuits operating exclusively on single Cooper pairs. Phase slips in hybrid structures consisting of Josephson junctions and inductances made of highly disordered materials should also be investigated.
3. To develop charge detectors and other CQPS-based devices for ultrasensitive and small back-action quantum measurements, and to develop qubits and other CQPS-based devices for quantum informatics. CQPS regimes enabling coherent dc transport of single Cooper pairs should be demonstrated.
4. To perform a proof-of-principle demonstration of quantised current steps in the first prototype of an rf-driven CQPS-based quantum current standard.
5. To facilitate the take up of the technology developed in the project by end users in the field of superconductive, micro- and nano-electronics.

Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 40 % of the total EU Contribution to the project.

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,

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.