EMRP Call 2012 – Open Excellence, Industry and SI Broader Scope

Selected Research Topic number: **SRT-x03**
Version: 1.0

Title: Measurement and control of single-photon microwave radiation on chip

Abstract

Currently the metrology is lacking for the measurement and control of novel microwave detection methods (at the single-photon level) and for the improvement of the performance of cryo-electronic quantum devices. A major task for this is the development of ultra-sensitive on-chip detectors and spectrum analysers for microwave radiation, based on, e.g., the sensitivity of single-electron devices to single photons. Single-photon detectors are needed for quantum information processing and communication in the framework of circuit quantum electrodynamics. Cryo-electronic components are also used in a wide range of applications including radiation detectors for cosmic background, terahertz imaging for homeland security, and brain research.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Industry & Fundamental Metrology on pages 9, 10, 11 and 32.

Keywords

Microwave radiation, single photonics, ultrasensitive on-chip photon detector, quantum nanocircuits, spectrum analysers, cryogenic setups.

Background to the Metrological Challenges

Quantum cryodevices, such as the Josephson voltage standard and quantum Hall resistance standard, have been widely used in electrical metrology for decades. However, single-electron current sources based on nanosize cryo-components are currently poised to take their place in the realisation of the ampere, and over the past decade research has led to the development of quantum information processing and communication using quantum bits (qubits) based on superconducting nanodevices and other cryo-electronic components.

So why is the cryogenic environment so important? The simple answer is: because low temperature means low noise. Unfortunately, cryo-electronic components cannot always be completely isolated and control by room-temperature electronics is required. Furthermore, under certain conditions, a severe deterioration of the device performance also results from photon exchange between devices operating on the same chip (and therefore not in thermal equilibrium), when in vicinity of each other. To counteract this researchers have spent a significant time trying to suppress photon propagation by designing and installing signal line filters, thermalisation elements, and radiation shields in their cryostats. However, recent research has indicated that the required level of noise elimination for many applications of quantum nanocircuits has been underestimated. Moreover, the residual photon density has been found to vary substantially between different experimental systems.

Two major factors that have hampered the detection and elimination of the problems caused by photon propagation is that there is no simple way to characterise the noise intensity at the single-photon level at the location of the quantum circuit and no method for independent real-time detection of single microwave photons. Therefore, the development of spectrometric single-photon detectors and their implementation in ultra-low-noise cryogenic environments is critical for providing high-fidelity quantum nanocircuits.

Several experiments with quantum nanoelectronic components have recently demonstrated the importance of radiation shielding. Using novel schemes of radiation shielding, significant improvements in the relaxation time of quantum bits and in the Q value of superconducting resonators used in quantum information processing have been achieved, a low density of quasiparticles of 0.033 μm^{-3} has been detected in superconducting aluminium, and a stability time exceeding 10 hours has been achieved in a SINIS single-electron trap. These recent results stress the importance of microwave noise protection for quantum nano- and cryo-electronics, but they are just the first step towards the characterisation of local radiation levels and the determination of the efficiency of noise protection methods.

Scientific and Technological 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 JRP-Protocol.

The JRP shall focus on the development of novel microwave detection methods on the single-photon level and on the improvement of the performance of cryo-electronic quantum devices. A major task is the development of ultra-sensitive on-chip detectors and spectrum analysers for microwave radiation, based on, e.g., the sensitivity of single-electron devices to single photons.

The specific objectives are

1. To develop ultra-sensitive on-chip superconductor - normal metal devices for the detection and spectral analysis of single microwave photons in the frequency range 10 GHz – 300 GHz.
2. To calibrate the developed photon spectrometers using cryogenic emitters of single microwave photons in the frequency range 10 GHz – 300 GHz.
3. To develop and verify methods to improve the fidelity of cryo-electronic quantum nano-devices by decreasing the noise level much below 1 $pV/Hz^{1/2}$ at frequencies above 10 GHz, simultaneously allowing increased bandwidth up to about 10 GHz for control signals from room temperature to the cryo-electronic device.
4. To demonstrate the improved fidelity in a SINIS-SET and a superconducting aluminium device.

Proposers shall give priority to work that enables new metrological methods and techniques in the future through excellent science. The project need not address metrology directly.

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

The total eligible cost of any proposal received for this SRT is expected to be around the 1.8 M€ guideline for proposals in this call. The available budget for integral Research Excellence Grants is 84 months of effort.

Potential Impact

The project should be designed to bring together the best scientists in Europe and beyond whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes. Significant non-NMI/DI and international participation in the projects is expected and proposers should make full use of the larger budget for Research Excellence Grants available for this SRT.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology and includes 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 Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.