Politecnico di Torino

ELECTRICAL, ELECTRONICS AND COMMUNICATIONS ENGINEERING

INRIM - Advanced Metrology for Electrical, Electronics and Communications Engineering

Funded By	I.N.RI.M. - ISTITUTO NAZIONALE DI RICERCA METROLOGICA [P.iva/CF:09261710017]

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Context of the research activity	The Thematic Grant includes 10 research Topics (listed below), with a specific title and proponent Supervisor/s. The applicants have the possibility to identify the specific topic they are interested in. 1: Design and breadboarding of the payload for a demonstration space mission for a novel accelerometer concept 2: Design and characterization of a Scattering Parameters measurement system at cryogenic temperatures for the characterization of microwave quantum devices 3: Quantum electrical impedance metrology and applications 4: Additive Manufacturing for energy-efficient applications in electrical engineering 5: Artificial intelligence combined to in silico modelling to support disease diagnosis 6: Unconventional computing with neuromorphic nanowire networks 7: Micro and nano photonic devices for quantum technologies 8: Fiber-based quantum key distribution in the frame of the European Quantum Communication Infrastructure 9: Combined optical, x-ray and neutron interferometry with split-crystal technology 10: Josephson-based quantum digitizer for time-varying waveform metrology enabling traceable electrical power, power quality and synchronized phasors measurements

Topic 1: Design and breadboarding of the payload for a demonstration space mission for a novel accelerometer concept

The objective of the activity is the realization of a demonstrator breadboard of a novel accelerometer for space applications with interferometric reading. The main objectives of the activity are:

1) realization of a miniaturized interferometer with picometer sensitivity possibly based on integrated optics.

2) realization of a mass/spring assembly with very low resonant frequency (0.01 Hz) able to stand the launch stresses.

3) realization of the subassembly, realization of the breadboard, validation and testing.

The candidate will participate in at least two of the previous activities.

Topic 2: Design and characterization of a Scattering Parameters measurement system at cryogenic temperatures for the characterization of microwave quantum devices

Quantum microwave devices play a central role in different fields, from fundamental physics to the deployment of quantum technologies. They find application, for instance, in quantum computation and communication, radio-astronomy, biomedical imaging, and radio detection and ranging.

Driven by the worldwide Quantum Technologies initiatives that require the ultimate precision in signal generation and detection, an increasing number of companies develop miniaturised and tailored microwave components and control electronics specifically for cryogenic temperatures. Many applications set new stringent demands on, e.g., insertion loss, footprint, and spectral characteristics of components. Microwave calibration capabilities exist at room temperature, but they are practically useless for novel applications since the components undergo major changes as they are cooled from room temperature to temperatures of 4 K and below. Presently, no microwave traceability exists at such temperatures, even though the availability of quantum devices should in principle enable and utilize dramatically better accuracy than can be achieved at room temperature.

The proposed activity consists of the design and setup of a Scattering Parameters measurement system for the characterization of quantum microwave devices [1, 2]. The system will be installed in a cryogenic environment capable of reaching temperatures of approximately 10 mK or lower. The work will take place in the context of multi-year research projects in collaboration with prestigious European institutes. The first foreseen applications, in perspective, are in the characterization of Josephson Traveling Wave Parametric Amplifiers (JTWPA) and Quantum Power Sensors (QPS). With this measurement system, in the framework of the European EMPIR “SuperQuant” project, we intend to give traceability to the SI for the measurement of Scattering Parameters and microwave power in a cryogenic environment.

The candidate will join the INRIM Superconductive Quantum Electronics research group and will collaborate in the realization of the measurement setup, in its characterization and data analysis, also through the writing of proper software.

[1] L. Ranzani, L. Spietz, Z. Popovic, J. Aumentado: Two-port microwave calibration at millikelvin temperatures. Rev. Sci. Instr., 84, 034704 (2013); http://dx.doi.org/10.1063/1.4794910

[2] J.-H. Yeh, S. M. Anlage: In situ broadband cryogenic calibration for two-port superconducting microwave resonators. Rev. Sci. Instr., 84, 034706 (2013); https://doi.org/10.1063/1.4797461

Topic 3: Quantum electrical impedance metrology and applications

The International System of units (SI) defines all the units in terms of fundamental constants of Nature. The electromagnetic units are linked to the electron charge e and the Planck constant h. Quantum electrical impedance metrology aims to realize the impedance units (ohm, henry and farad) with quantum experiments with graphene devices.
The PhD proposal is associated to an INRIM long-term development project of quantum national standards of electrical quantities.The project involves the fabrication of quantum devices, the implementation of ultra-low temperature and high magnetic field facilities for their exploitation, the design and realisation of electronics which allows the characterisation of the devices and the calibration of artifact impedance standards with accuracies in the part per million to part per billion range. The precision measurements allowed by the infrastructure will be applied to perform traceable characterisations of novel materials and devices, in particular new Dirac-like materials for quantum devices, and graphene-based supercapacitors for energy storage in electromobility.
The project is linked to the following funded projects, running at the present time:
1. European project 20FUN03 COMET "Two dimensional lattices of covalent- and metal-organic frameworks for the Quantum Hall resistance standard". The INRIM activity focuses on the electrical characterisation of quantum devices with Electrical Resistance Tomography and noise spectroscopy. https://comet.imdea.eu/
2. European project EMPHASIS "Efficient materials and processes for high-energy supercapacitors for smart textiles and electromobility applications"
3. National project PRIN CAPSTAN "Quantum Electrical National Capacitance Standard" https://www.inrim.it/it/ricerca/progetti/capstan
4. INRIM Project Next Generation Metrology "New metrology and sensors for electrotechnical applications"

Topic 4: Additive Manufacturing for energy-efficient applications in electrical engineering Worldwide there is a tremendous demand for more efficient and cleaner devices to reduce energy and natural resource consumption and gas emissions. Over 20% of the final energy consumption in Europe is in the form of electricity. Electrical energy undergoes multiple stages of conversion and transformation, all of which involve soft-magnetic materials (SMM) in the form of cores of electrical machines and magnetic components in power electronics.
The quest for energy-efficient motors will be here based on recyclable amorphous metals, thereby increasing the availability of alloys with unique magnetic and mechanical properties. The research focuses on developing new metallic materials for additive manufacturing (3D printing) using selective laser melting (SLM) technology. In particular, Fe-based soft magnetic amorphous metals for electrical devices will be designed.
The main objective is to evaluate the magnetic behaviour of magnetic materials of different nature, structures and dimensions in search of the lowest intrinsic coercivity, highest magnetic permeability, and highest magnetic saturation, which will maximize the energy efficiency (nano- and mesoscale design level).
This objective will be achieved by alloy development, casting technologies and microstructure characterization at several length scales. The electrical and magnetic properties of powders, ribbons, bulk metallic glasses samples, and additive manufactured complex elements will be investigated.
In particular, the candidate will develop testing methods to measure magnetic materials' DC and AC electromagnetic properties. In addition, the candidate will be closely in contact with the project partners through short-term stays in

Objectives	consortium research to follow all the processing steps. Topic 5: Artificial intelligence combined to in silico modelling to support disease diagnosis The main goal of the activity is the development of methodologies for the assessment of the trustworthiness, reliability and explainability of image-based artificial intelligence (AI) tools for disease detection. The AI tools will be tested on clinical data, coming from breast cancer screening by mammography, and in particular from large-scale diagnostic imaging databases, made available by cancer screening centers across Europe. The research will be conducted in the framework of the European Project MAIBAI "Developing a Metrological framework for Assessment of Image-Based Artificial Intelligence systems for disease detection", coordinated by INRIM and starting in September 2023. The first objective is the categorization of the clinical data, i.e. x-ray breast images (mammograms), into subsets based on relevant subgroups within the screened population and image acquisition key-factors, affecting image quality and subsequent cancer detection rates. The data will also be split into separate sets for AI tool training, validation (e.g., for hyperparameter selection), uncertainty calibration and testing. The main source of data will be the OPTIMAM Mammography Image Database, developed by one of the partners of the MAIBAI's consortium, the Royal Surrey NHS Foundation. The second objective is the implementation of in silico models to generate synthetic mammograms for supplementing incomplete datasets and provide a ground truth for AI tool benchmarking. The synthetic images will be produced by means of the VICTRE open-source platform, developed by FDA, starting from the creation of high-resolution breast digital phantoms with pathology features. To mimic mammography procedures, compressed versions of the digital phantoms will be generated, simulating realistic tissue deformation by means of biomechanical modelling. Then, the irradiation process will be numerically replicated following the image acquisition pipeline, to reconstruct the radiographic projections of the digital breast phantoms and obtain a wide set of clinically realistic images, with variable anatomical properties and pathology features. To extend the datasets for AI tool benchmarking, synthetic mammograms will also be generated via data augmentation techniques based on generative deep learning models. The third objective is the assessment of the performance of tailored AI tools, by using both clinical and synthetic mammograms. The benchmarking will be carried out on prediction tasks with high clinical relevance, e.g. breast cancer risk estimation, tissue segmentation, abnormality detection and classification/grading. The performance will be tested under various scenarios, including low versus high image quality data, validation for specific patient demographics, presence of machine-based artefacts and noise sources. Finally, the developed and validated methods will be exploited to address the design of a global, standardized and impartial AI assessment framework in disease screening. Topic 6: Unconventional computing with neuromorphic nanowire networks The main objective of the PhD work is the experimental implementation of unconventional computing paradigms and neuromorphic functionalities in multiterminal devices based on memristive nanowire networks. The aim is the development of a hardware computing architectures able to solve a wide range of computing tasks such as pattern recognition and time series prediction with reduced training cost and energy consumption. This includes the nanofabrication of memristive devices based on nanowire networks and

the electrical characterization of these devices in multiterminal configuration, with the aim of investigating the emergent memristive and neuromorphic behavior of the system. Neuromorphic functionalities including short-term/long-term synaptic plasticity and heterosynaptic plasticity effects will be investigated. A hardware-software co-design approach will be explored for implementing computing tasks through the development of tailored algorithms in the framework of reservoir computing. This includes the development of measurement protocols and schemes for the electrical characterization of multiterminal memristive devices, the development and characterization of control circuitry for the experimental implementation of different computing tasks such as pattern recognition and time series prediction and circuit simulations.

Topic 7: Micro and nano photonic devices for quantum technologies
The efficient generation, manipulation and collection of single photons is crucial for the development of quantum information technologies based on photonic devices. Recently, the fast development of research fields such as integrated photonics and optical metasurfaces has offered novel tools to engineer the radiative properties of light sources and enhance light matter interaction to manipulate light at the micro and nanoscale.
The research activity proposed is focused on the design, fabrication and characterization of photonic devices for the management of single photons. In detail, the scattering properties of micro and nano structured thin films will be investigated in order to couple far field radiation to guided modes and manipulate light on photonic integrated devices. Moreover, photonic devices will be designed and investigated to control the emissive properties of light sources in terms of radiative decay time, spectral emission and directivity.

Topic 8: Fiber-based quantum key distribution in the frame of the European Quantum Communication Infrastructure
In 2019, the European Commission launched the European Quantum Communication Infrastrcuture (EUROQCI), a large initiative aimed at deploying quantum communication links and services in all 27 member states within the next decade. This effort is mandatory to provide Europe with strategic secure communication technologies. The Quantum Metrology and Nanotechnology division at INRIM has a role in this challenge and, among other research lines, is investigating the realization of fiber-based quantum communication networks on local to regional scales. Specifically, INRIM addresses the role that ultrastable laser sources, coherent transfer of optical phase over fiber and precise synchronization of network remote nodes can play in real-world quantum key distribution (QKD) deployments. These technologies were originally developed in the context of optical clocks, and an example of their application to quantum communication was given in 2022 with their exploitation in the recently-proposed family of QKD protocols known as twin-field quantum key distribution [C. Clivati et al., Nat Comm. 13, 157 (2022)]. These protocols are based on the coherent production of phase-encoded single-photon states at remote location, their transfer along conventional optical fibers and interference, at a third intermediate node, for extracting the key information.
The proposed activity builds on previously achieved results to demonstrate a real key exchange on regional scale testbeds. This requires the realization of highly coherent laser-based photon sources, advanced interferometric schemes for the detection and cancellation of environmental noise affecting the optical paths and phase-manipulation of single photons. Then, suitable encoding-decoding protocols will be investigated and tested. The activity will then explore novel experimental approaches, based for instance on

multimode photon pulses production with coherent optical supercontinuum radiation, or the application of the previously-demonstrated technologies to other QKD protocols. These activities are performed in the framework of the Quantum Italian Deployment (QUID project), in collaboration with partner institutions and high-tech companies.

Topic 9: Combined optical, x-ray and neutron interferometry with split-crystal technology
In the framework of the NeqstPi (Neutron Experiments on Quantum States at Pico Scale) project a new experimental setup combining neutron, optical and x-ray interferometry is under development at ILL (Institut Laue-Langevin) in Grenoble, France, as part of an international collaboration between the ILL, INRiM and TU Wien (Atom Institute of Vienna).
Neutron interferometry makes the neutron phase observable, which phase is influenced by any momentum and/or energy change that the beam experiences in its interaction with a sample. This, together with the spin angular momentum of the neutron, makes it a powerful tool to perform fundamental as well as applied research in quantum mechanics and solid-state matter with an unprecedented width of investigable effects.
The single crystals used so far to realize neutron monolithic interferometers have a size that typically limits the length of the neutron path to a few centimetres. To extend this path length (to host bigger and more sensitive experiments) it is necessary a separate crystal interferometer. In turn, this requires new measurement and control technologies (having linear and angular resolution approaching the pm and the nrad levels) to recombine the whole crystal in such a way that the lattice planes are realigned, the geometry of the interferometer is recomposed, and the bulk perfect crystal is restored. Even though x-ray interferometry with split-crystal is well settled, the same with neutrons was only just investigated (https://onlinelibrary.wiley.com/iucr/doi/10.1107/S1600576722006082).
The PhD activity will be mainly of experimental type and shall lead to the development of a test bed able to perform the alignment of two separate crystals operating at a one-metre distance with angular controls with a sensitivity of tens pico-radians. The work will be primarily related to the development of state-of-the-art competencies in high-precision mechanics, optomechanics and optoelectronics, optics and optical interferometry, temperature stabilization and measurement, vibration control, analogue and digital electronics, and data analysis.

Topic 10: Josephson-based quantum digitizer for time-varying waveform metrology enabling traceable electrical power, power quality and synchronized phasors measurements
In the era of clean energy transition, the electrical power system is witnessing a rapid growth of renewable energy sources with unprecedented levels of integration and rapid decarbonisation of the electricity supply chain. For stable operation of smart grids, precise and traceable electrical power measurements, PQ and real-time phasors across the power system, are vital to guarantee stable supply, prevent blackouts, identify the origin and causes of the disturbances, and ensure a fair electricity market.
Up to now, most AC measurements, e.g. voltage, current and power, have been related to the corresponding DC values using thermal converters, where only the RMS value is considered. Sampling system-based analogue-to-digital converters (ADC) have been purposed as alternative standards for electrical power, PQ and phasor measurements, where the traceability is either secured by calibration of all components separately using thermal transfer techniques. Sampling systems provide all the necessary information

	(e.g. harmonics and phases) which are crucial in the field of power and energy measurements. Additionally, quantum effects play an important role in the redefinition of the SI units e.g. the volt can now be directly realised by the Josephson quantum effect. For this reason, the permanent integration of electrical quantum standards into sampling power standards is therefore necessary step in the new quantum SI. The main objective of the research activity aims to extend and establish a Josephson-based quantum sampler standard for traceable power measurements under sinusoidal and non-sinusoidal waveforms to support the incoming needs related to the power and renewable energy market. The specific objectives of are: 1. To expand on and validate the sampling standard based on a AC programmable Josephson voltage standard (AC-PJVS) developed in the framework of EMPIR projects (TracePQM and QuantumPower) for sinusoidal waveform measurements up to 20 kHz. 2. To develop techniques and algorithms by utilizing the AC-PJVS and sub-sampling or differential sampling strategies for harmonic calibration and synchrophasor measurements. 3. To develop e new measurement protocol for distorted waveforms generation using the AC-PJVS and testing them in practice for the characterization of novel high-precision ADCs architectures, which will be developed in the framework of the EMPIR project True8Digit (2023-2026). The expected impact will be: - provide a step change from thermal transfer techniques to quantum standard in the traceability of AC electrical quantities and for harmonic content and non-RMS quantities required for power and PQ measurements; - lay the foundation for robust quantum traceability for synchronized voltage measurements required for reliable, efficient and power stability of smart grids; - reduce cost and time for calibrations and maintaining the traceability of AC electrical quantities to the quantum SI.

	Topic1: One or more of the following skills are required: electronics design and prototyping and/or mechanical design and modelling and/or programming of microcontrollers, LabVew, Matlab. Topic2: Required Skills: microwave design and measurements (active and passive devices, network analysis, spectrum analysis), data acquisition and analysis. Appreciated Skills: Python language programming, cryogenics Topic3 Degree in physics or engineering. Availability to possible secondments abroad. Topic4 A general background in materials science or electrical engineering is appreciated. Candidates having prior knowledge or experience in characterization of metallic materials are strongly encouraged to apply.. Experience and willingness in experimental activities will be preferred. Full proficiency in English, oral and written, is mandatory. The candidates should be highly motivated to join a dynamic consortium to contribute to the EU Green Deal. Capabilities in team working in a multidisciplinary environment are then recommended. Topic5 To proficiently conduct the research activity, a successful candidate should have: -Master degree in one of the following tracks: Computer Engineering, Electronic Engineering, Biomedical Engineering, Mathematical Engineering or Mathematics; -Competences in data analysis and data preparation, fundamentals of statistics, and skills in machine learning and deep learning models;

Skills and competencies for the development of the activity	-Basic knowledge of machine learning frameworks, e.g. PyTorch, TensorFlow, Dask, RAPIDS AI; -Basic knowledge of numerical modeling and computer programming, possibly also exploiting graphic processing units (GPUs). Topic6 Technical skills and competencies required for the development of the activity includes Python programming for controlling measuring instruments, circuit analysis and simulations through Python and Spice and general knowledge of neural networks and machine learning techniques. General knowledge of nanotechnology and electronic transport properties at the nanoscale are preferred. Soft skills including excellent communication capabilities, problem-solving and ability to work independently as well as in an international team are required. Topic7 The activity proposed requires basic knowledge about: -quantum mechanics and solid state physics. -the main fabrication processes for thin films (CVD, RIE, lithography, ALD etc...) -fundamentals of optics Topic8 The activity is predominantly experimental. Interest in experimental laboratory activity is thus required. Basics in laser physics and optical transmission. Basic knowledge of a programming language for data analysis and control of lab equipment (Python preferred but not strictly required). Basic knowledge of digital electronics and FPGA programming could be useful but is not mandatory. The motivated candidate will have the chance to fill initial background gaps during the activity. Topic9 A master degree in electronic engineering is welcome. Interest in the experimental job, software for applications that require testing, measurement, and control with access to hardware and data insights (LabVIEW) and the capability of setting up a test bed are highly recommended. Topic10 It would be useful if the candidate has familiarity with the following aspects: -Design, modelling and prototyping of electronics boards. -Analog and digital theory circuits. -Mixed signal circuit building blocks and devices: A/D and D/A converter; Low Noise Amplifier; PLL; FPGA, etc. -Electrical network automation and communication systems. -Basic knowledge on superconducting electronics, e.g. to the macroscopic Josephson effect, is welcome but not mandatory. -Basic knowledge on the cryogenic. -Willingness to work in an electronics research laboratory for the preparation of experimental setups compliant with the project specifications. -Strong predisposition in programming languages and multithreading environments for data acquisition and real-time processing