METROLOGY

Advanced Metrology

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Context of the research activity	The Thematic Grant includes ten 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. Topic 1: Quantum correlations fingerprint of microwave signals for illumination protocols beating classical limits - Quantum Radar Topic 2: Ultra-high Precision Absolute Earth Gravity Measurements Topic 3: Design and characterization of a measurement system for Scattering Parameters at cryogenic temperatures for the characterization of microwave quantum devices Topic 4: Realization of the SI mass unit through the Planck constant (Planckilogram) Topic 5: Quantum Volt Topic 6: Transportable Yb Optical Clock Topic 7: Quantum metrology Topic 8: Measurement of dynamic magnetic properties in 3D printed magnetic materials for energy applications Topic 9: Ultrasound mediated neuromodulation: a metrologic approach Topic 10: Measurement of microplastics in environmental samples through advanced and standard optical microscopy techniques

	Topic 1: Quantum correlations fingerprint of microwave signals for illumination protocols beating classical limits - Quantum Radar Quantum illumination based on entangled radiation sources is capable of exponentially reducing the probability error in the detection of a target

compared to the case of traditional sources, precisely in the limit of low signal to noise ratio (SNR = 0.01). An ideal quantum source generates entangled states such as "two-mode squeezed vacuum states", which can be produced by adjusting the parameters of a quantum limited amplifier (either optical or exploiting the Josephson effect in the microwave regime). By appropriately manipulating signal generation and measurement, the candidate will develop and characterize experimental setups for robust quantum-enhanced detection in the microwave regime.
The research activity will be located in the Quantum Circuits for Metrology Laboratory, where the candidate will treat signals composed by single-photon microwave radiation in a cryogenic environment, exploiting state-of-the-art techniques revealing their quantum fingerprints.

Topic 2: Ultra-high Precision Absolute Earth Gravity Measurements
The value of the local acceleration due to gravity and its variations with time is of interest in a wide field of physical sciences and is measured by ballistic and quantum absolute gravimeters, traceable to the units of length and time. INRiM developed a transportable ballistic rise-and-fall absolute gravimeter (IMGC-02), which is the current Italian primary standard, but is overperforming for the uncertainty levels (around 10-5) required by calibration laboratories, thus a new transportable and more suitable absolute gravimeter has to be developed. The PhD activity will be mainly focused on such task. The PhD candidate will be also involved in in-situ measurements, comparisons and relevant activities aimed at realizing a reference network for absolute gravity and at establishing the International Height Reference System/Frame (IHRS/IHRF) in the Italian area. Such a task is part of a research project of relevant national interest funded by MUR.

Topic 3: Design and characterization of a measurement system for Scattering Parameters at cryogenic temperatures for the characterization of microwave quantum devices
Quantum microwave devices (QMD) play a key role in different fields, e.g.: quantum computation and communication, radio-astronomy and biomedical imaging. New stringent demands are set on, e.g.: signal generation and detection, insertion loss and spectral characteristics of components. Microwave (MW) calibration capabilities exist at room temperature, but they are of limited use in cryogenics due to the major changes the components undergo. Even if QMDs should enable dramatically better accuracy, cryogenic MW measurements still lack in traceability.
The PhD activity consists of the design and setup of a SI-traceable Scattering parameters measurement system for the characterization of QMDs in the context of multi-year European projects. It will be installed in a cryostat capable of reaching temperatures of 10 mK or lower. The first applications will be in the characterization of Josephson Traveling Wave Parametric Amplifiers (JTWPA) and Quantum Power Sensors (QPS).

Topic 4: Realization of the SI mass unit through the Planck constant (Planckilogram)
The objective of the research is to realize a novel and competitive electrostatic balance to address one of the most exciting challenges of modern metrology. The instrument will be realized from scratch and will need a number of skilled people to work on it for a period of at least two years. The most critical aspects are: the design of the delicate flexible structure able to sense piconewton forces; the design of the electrodes structure and the set-up the measurement chain with microvolt accuracy; the FEM modelling of the elastic hinges and the electrostatic fields; the software for the management of the whole instrumentation and for the data analysis. The PhD student will

Objectives	have the opportunity to contribute to the realization of the instrument, from the design to its completion, bringing his or her expertise in one or more of the above-mentioned fields. He or she will author the papers, will participate in conferences and will visit other institutes involved in similar research. Topic 5: Quantum Volt In science and technology accuracy in many measurements derives from electrical standards. The central role of the electrical quantities is also motivated by the high accuracy of quantum devices based on fundamental constants of physics. The doctorate is aimed at forming a highly qualified scientist in primary quantum metrology, targeted to a research career in National Metrological Institutes, as well as to manage a secondary calibration laboratory or a metrological lab in industry. To mention some of the scientific objectives: 1) engineering He-free Josephson standards with advanced cryogenic temperature controls; 2) realization of an optical driven Josephson standard; 3) study of high speed biasing techniques and dedicated analog to digital conversion solutions. The student will be involved in all experimental activities of the Josephson laboratory, partly on leave in laboratories of a foreign Institute. Topic 6: Transportable Yb Optical Clock Optical lattice clocks are among the most promising candidates for the redefinition of the SI unit of time: the second. For many years, INRIM has been developing optical lattice clocks based on either Yb and Sr atoms, with accuracy approaching the E-18 range. The BIPM roadmap toward the redefinition of the second indicates that a significant number of clocks comparisons with E-18 accuracy must be performed before proceeding toward a new definition of the second. Nowadays the only means that has demonstrated such capability is the coherent fiber link, however this technique allows to compare clocks in a range of thousand km, leaving open the quest for intercontinental comparisons. Transportable optical clocks, capable of E-18 accuracy, are a strong candidate for carrying remote intercontinental comparisons at the highest accuracy level, traveling from a laboratory to another and acting as a flywheel clock. The objective of this PhD is to design the overall architecture of a transportable Yb optical lattice clock. Particular focus will be on the following topics: 1) overall design of the Yb OLC; 2) development of an ultra-low noise transportable clock laser; 3) development of a transportable multicolour reference cavity for frequency stabilization of all required laser sources; 4) testing of developed systems on existing Yb clock. Topic 7: Quantum metrology The quantum optics research sector of INRIM is working for 25 years on the study of the properties of quantum optical states and their application to quantum technologies, such as quantum communication and, in particular, quantum metrology-imaging & sensing as well as the creation of metrology for quantum technologies, fields whose birth it substantially contributed to. The group also addresses the study of foundations of quantum mechanics, in particular quantum measurement. This Ph.D will be devoted to developing new measurement tools exploiting specific properties of quantum (optical) states, such as entanglement based measurements, weak, protective, genetic measurements etc. The objectives of this PhD are:

1) Feasibility study on the quantum-optical implementation of quantum metrology schemes;
2) Realization of a bright and stable source of high-purity polarization-entangled photon pairs;
3) Realization of the weak-interaction-based measurement protocols;
4) Analysis and comparison, from the metrological perspective, of the experimental results obtained.

Topic 8: Measurement of dynamic magnetic properties in 3D printed magnetic materials for energy applications
Within the framework of the AM2softmag project, novel magnetic materials for power applications are going to be prepared by means of 3D printing, with the aim of obtaining cheap to fabricate and lightweight components for electrical motors. However, their magnetic properties must be comparable with those of the materials currently in use, to prevent a reduction of efficiency and an increase in energy consumption. At present, these novel magnetic materials lack adequate magnetic characterisation and measurement methods directly aiming at finite, complex products are currently missing or underdeveloped. Metrological tools are required and must be developed to provide suitable measurement and characterisation techniques for these materials, and to support the emerging needs of the revolution of the electrification of the transports.
The objectives of this PhD are:
1) To characterise novel 3D printed magnetic materials with simple shapes and compare their properties with those of conventional materials used in power applications, providing feedback to their developers and manufacturers.
2) To develop novel metrological tools to characterise the magnetic properties of 3D printed products with complex shapes, and relate them to those measured with standard techniques on objects having a simple shape.

Topic 9: Ultrasound mediated neuromodulation: a metrologic approach
Ultrasounds (US) are mechanical waves with frequency exceeding human audible sound (>20KHz). When used at low intensities, they deliver mechanical energy that can exert transient neuromodulatory effects on nervous structures. To date the optimal parameters and targets to achieve stimulation and inhibition are still not clear. Further understanding of ultrasound excitatory/inhibitory effects is needed in order to provide optimal and tailored therapeutic effects to treat nervous diseases and to exploit ultrasound to recover from focal neurologic deficit or disorder of consciousness in post-traumatic, post-surgical and ischemic conditions. The project will be performed at INRIM in synergistic partnership with Fondazione IRCCS Istituto Neurologico C.Besta in Milan. The study encompasses a mechanistic approach studying different ultrasound sources and parameters applied initially to an ex-vivo, in-vitro brain model developed at the IRCCS Istituto C. Besta. Subsequently a pure in-vivo set-up is envisaged. Safety and side effects of different modalities and intensities of US stimulation preliminarily analyzed will provide the ground for clinical translation.
The objectives of this PhD are:
1) Measure the effects of the application of different US intensities/frequencies on physiological and epileptiform neuronal activities, achieved by analysing changes in evoked potentials and pharmacologically induced epileptiform discharges;
2) Analyze and measure the effects of US-Microbubbles (MBs) induced BBB opening on brain excitability and drug delivery. US will be applied during MBs perfusion while simultaneous electrophysiological recordings in the treated areas are performed.

Topic 10: Measurement of microplastics in environmental samples through advanced and standard optical microscopy techniques

The need for a reliable and standardized method for microplastics quantification and identification in environmental samples is of extreme importance, given the implication of plastics pollution in the ecosystems and in the alimentary chain. The EURAMET project PlasticTrace is running on this topic.

Optical microscopy techniques could play an important role to address some of these issues using more standardized techniques such as optical widefield and phase contrast microscopy, in order to quantify in number and size the microplastics without performing a chemical identification. More advanced techniques like non-linear optical coherent Raman microscopy techniques (i.e. Coherent Anti-Stokes Raman Scattering and Stimulated Raman Scattering) could instead add also a fast chemical identification of the microplastics in samples. An important part of this research field is the data and image processing that have also to be addressed and developed in order to automatically extract the relevant parameters from the acquired images in a reliable and fast way.

The objectives of this PhD thesis are the development of robust measurement methods to quantify and characterize microplastics in environment samples using optical microscopy techniques.

Part of the efforts would be addressed to the development of the software to analyse the collected images and to automate the measurement process. The metrological study of the techniques and the determination of the uncertainty sources and the uncertainty budget of the measurements will also be key objectives.

Topic 1

Data acquisition (transducers, digitalization)

Microwave signals manipulation (waveguides, spectrum analysis, network analysis)

Data processing (FPGA, post-processing)

Topic 2

Master degree in Physics or Engineering.

Skills on mechanical measurements, optical-interferometric systems, measure-ment uncertainty assessment, Finite Element Method (FEM) programs, LabVIEW and C ++ development environment are appreciated, but not mandatory.

Topic 3

Required Skills: microwave design and measurements (active and passive devices, network analysis, spectrum analysis), data acquisition and analysis

Appreciated Skills: Python language programming, cryogenics

Topic 4

The candidate is expected to have one or more of the following competences:

mechanical engineering, to design the delicate flexible structure able to sense piconewton forces;

electrical engineering to design the electrode structure and to set-up the measurement chain with microvolt accuracy;

finite element analysis to model the elastic hinges and the electrostatic fields;

informatics, to manage the whole instrumentation and for data analysis.

Skills and competencies for the development of the activity	Topic 5 Master degree in Physics, or Electronic Engineering or Energy and Nuclear Engineering Basic electronics Familiarity with at least one programming language Interest for laboratory/experimental physics work Topic 6 General knowledge of atomic physics. General knowledge of laser technology. General knowledge of programming and remote management of experimental apparatus. Topic 7 Knowledge of quantum measurement foundation. Knowledge of quantum optics. Expertise on quantum optics equipment and experimental setups. Knowledge of LabView and some data elaboration programs, like Matlab and Mathematica. Topic 8 The candidate must be willing to perform experimental activity, consisting both in developing measurement techniques and tools, and to perform measurements on materials and products. The candidate must feel comfortable into using software tools to analyse data. The candidate must have adequate knowledge of the English language (both written and spoken). Topic 9 Master degree in Electronic Engineering, Biomedical Engineering, Mathematics or Physics; Good understanding of physical principles of medical ultrasound and electrophysiology (incl. electrical activity recording/processing); Solid programming skills (e.g., Matlab, Python); Fluency in English (oral, written); Analytical and critical reasoning, system thinking attitude, international mindset, active learning, team working, adaptability. Topic 10 The candidate should be able to work in a team and to sustain also a good autonomy during the development of the PhD thesis. English language, computer language, statistics skills and ability of developing algorithms will be a key factor. Knowledge of optics and chemistry will be a plus. Ability to gather relevant information through scientific papers will be highly demanded.