

Title: Metrology for advanced photonics

Abstract

Photonic integrated circuits (PICs) and fibre optic sensing systems using standard and specialty fibres are becoming increasingly prevalent in the industrial world due to their compactness and ability to sense numerous physical quantities in various environments, either at a single location or in a remote and distributed way. Augmented reality and autonomous vehicles are also hot topics, for which advanced photonics sensors are paramount. Nevertheless, these photonic devices lack metrological characterisation. Moreover, for standard devices already traceable, there is a demand from industry for broader spectral characterisation and the availability of new artefacts. Proposals addressing this SRT should develop metrology for advanced photonics to support this growing global market.

Keywords

Fibre optical sensors, augmented reality glasses, metrology for photonic integrated circuits, specialty fibres metrology.

Background to the Metrological Challenges

The global photonics market was valued at more than 650 billion euros in 2021, and it is expected to grow 7.5 % per year between 2022 and 2027. PICs technology is increasingly applied in high-tech areas such as sensors, data communication, biomedical applications and space industry. A metrological characterisation of quantities such as chromatic dispersion, insertion and propagation losses, modal distribution, group delay or group index dispersion is required for better specifications of these devices and future improvements. In the particular case of integrated optics used in sensing, two limiting factors arise: fabrication variability and thermal dependency, both of which can significantly degrade nominal performance of on-chip system. Therefore, there is a need to develop more resilient building blocks and develop integrated microspectrometers with embedded auxiliary calibration elements.

Fibre optic sensing systems are becoming increasingly prevalent in industrial set ups due to their ability to sense numerous physical quantities accurately, in real time and in different environments. But sensing equipment is very often presented as a black box, which brings significant challenges in measurements. For this reason, specific calibration methods must be developed, which establish a clear link between the measured quantity and the physical effect used in the sensor.

Internet traffic is growing steadily, leading to a need for increased bandwidth and channel capacity. To address this issue recently proposed multiplexing technologies and fibres have attracted great interest. However, these new fibres require the improvement of the characterisation and calibration capacities in their geometry, position of the cores, insertion losses, inter-core crosstalk, birefringent effects, intra and intermodal dispersion, higher-order coupling, and nonlinear effects. Parallel to these improvements, it is necessary to improve calibration artefacts that meet the new needs. The Polarization Mode Dispersion (PMD) is a stochastic quantity that from the point of view of calibration does not present a simple calibration. Until now, PMD analysis methods and analyser equipment's have been developed that are highly specific to a given technique, and for this reason it is difficult to apply them to any PMD analysis equipment. The development of multipurpose calibration artefacts is a challenge that must be addressed.

Improved spectral calibration systems for fibre optic detectors over a wide spectral and power range have gained much interest in recent years, mainly due to the tremendous evolution in fibre optic telecommunications and fibre optic sensors. For this reason, the calibration of the responsivity of detectors and power meters for fibre optics must be improved. In recent years, the development of fibre optic power meters has grown, especially for applications in the spectral regions from 500 nm to 1100 nm (for plastic fibre applications) and in the region from 1600 nm to 2000 nm (for sensors applications). Regardless of these regions, but with greater

emphasis on them, it is necessary to improve standards and calibration techniques with respect to primary radiometers (cryogenic radiometers or predictable quantum efficiency detectors). As an example, the increasing demand from the photonic industry for calibration of Optical Time-Domain Reflectometers (OTDRs) at 1650 nm confirms the need to extend the current traceable spectral domain.

Augmented reality is a hot topic in many fields such as military, industrial manufacturing and maintenance, healthcare, classrooms for education and entertainment. However, the state-of-the-art of the manufacture and quality control of augmented reality products lack accurate metrology tools; therefore, there is a need to develop new metrology, including gratings characterisation. The development of finite element simulations and simulations exploiting the artificial intelligence algorithms will allow validating the characterisation measurements and is required for new solutions for materials and geometry of photonic devices and components.

Improved procedures for the calibration of the attenuation scale of multimode for OTDRs and improved procedures and standards for calibration of PMD analysers are required by standards developing organisations, e.g., IEC TC86/WG4, SC 86B and SC86C to complete current normative documents.

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 the development of metrology capability in advanced photonics.

The specific objectives are to:

1. Establish metrology for: i) PICs, in particular for quantities such as insertion and propagation losses, dispersion, spectral transmission, modal distribution and polarisation properties in the waveguides; ii) distributed / point sensors with complete traceable specifications (target quantities should include temperature, strain and vibration), and iii) specialty fibres (target quantities should include insertion losses, core position and cross-talk).
2. Extend the traceable characterisation of standard fibre optics components, passive or active, to a spectral domain covering the wavelengths from 500 nm to 2000 nm. This should apply to detectors, power meters, attenuators, circulators, and couplers as well as, for the particular region around 1650 nm, to OTDRs.
3. Develop metrology for the manufacturing and quality control of Augmented Reality (AR) photonic components. This should include: i) the characterisation of different diffraction gratings, at different orientations to provide <10 pm accuracy and <0.1 mm data point density for grating pitch uniformity characterisations and pitch range from 300 to 500 nm; ii) the development of calibration artefacts to improve traceability of multimode OTDR and of PMD analyser; and iii) the development of resilient building blocks and integrated microspectrometers with embedded auxiliary calibration elements, to evaluate and compensate the fabrication variability and the thermal dependency.
4. Validate the metrological developments from Objectives 1 to 3 by ad-hoc finite element simulations and artificial intelligence approaches. Additionally, to optimise the design of artefacts and integrated circuits, using the outputs of the simulations.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the EMN Quantum, measurement supply chain (accredited laboratories, instrument manufacturers), standards developing organisations (e.g. IEC TC 86/WG4, IEC SC 86B and IEC SC 86C), and end users.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMPIR project 14IND13 PhotInd, and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

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,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the photonics sector.

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 the Partnership 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.