EURAMET EMN-Q: The European metrology network for quantum technologies

Measurement: Sensors 18 (2021) 100348

Contents lists available at ScienceDirect

Measurement: Sensors

journal homepage: www.sciencedirect.com/journal/measurement-sensors

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ARTICLE INFO

Keywords
Quantum technologies
Quantum metrology
European metrology network

ABSTRACT

The second quantum revolution is underway and the deployment of Quantum Technologies (QT) keeps pace with it. This technological paradigm-switch creates opportunities and challenges for industry, innovation and society. Several large companies, as well as start-ups, have started to develop and engineer quantum devices or begun to integrate them into their products: the commercial success of QT, together with progress in research and development, relies on certification and reliability built upon internationally agreed standards and metrological traceability.

A group of European National Metrology Institutes (NMIs) and Delegated Institutes (DIs) have recently created a European Metrology Network for Quantum Technologies (EMN-Q) under the auspices of EURAMET.

The objective of the EMN-Q is to co-ordinate the activities of the European NMIs and Dis to ensure their efficient support for European competitiveness in quantum technologies. A special focus of the EMN-Q will be to develop new measurement capabilities and dedicated services to serve the rapidly-growing needs of industry and research institutions in this field.

Industry, governmental agencies, academic sectors or any other type of stakeholder are welcome to contact the EMN-Q and discuss their metrology needs. These can relate not only to quantum characteristics of quantum devices, but also to metrology of key enabling technologies, metrology that can improve the supply chain of industrial quantum devices or other industrial needs connected with quantum technologies.

EMN-Q aims to become is to become the central contact point to stakeholders interested in metrology for quantum technologies by:

- contributing to standardisation & certification of quantum technologies;
- promoting the take-up of metrology in the development of these technologies;
- supporting industrial needs in synergy with the technological objectives of the EC Quantum Flagship and national quantum technology programs; and
- promoting the use of quantum measurement techniques where advantageous for "classical" technical areas.

We are in process of structuring and developing the communication services of the EMN-Q. One of the key aspect in this EMN-Q development is the establishment the EMN-Q Strategic Research Agenda (SRA). The SRA will contain the technological roadmaps that are created by the EMN-Q members in consultation with the EMN-Q Stakeholder Community.

In this paper, we will provide a short overview of the EMN-Q organization, and of the SRA and the relative Technological Roadmaps.

1. Rationale

Quantum technologies are one of the major future challenges, but also a major future opportunity, for European industry with respect to innovation and high technology. This can be seen from the currently starting European 1 billion € "Quantum-Flagship" [1] programme triggered by the "Quantum Manifesto" and the related European and national programmes and projects, see e.g. the German "QUTEGA" initiative, the UK Quantum Technologies program (the Quantum-Hub), the European H2020 "Quant-ERA" and the expected follow-on programmes.

Furthermore, quantum technologies and devices have started to have impact in industry, and several large companies have started to develop quantum devices or started to integrate them in their products [2–5]. It will be important for industry to have a contact/reference point for their quantum-related metrological and technological requirements.

Especially at the beginning of the development of new technologies and products, standardisation is one of the key elements for the commercial success of any new technology. The development of globally accepted standards and an anticipatory approach would facilitate the growth of the Quantum Technologies (QT) market worldwide.

National metrology institutes (NMIs) expect in the immediate future large demands from industry, standardisation bodies and governments, which single NMIs will not be able to respond adequately. For this reason, we have created the European Metrology Networks on Quantum Technologies (EMN-Q).

The active coordination of European NMI research activities is fundamental to maintain European competitiveness in the quantum technologies field for future decades, while new big actors appear on the international scene with nearly limitless economic resources.

https://doi.org/10.1016/j.measen.2021.100348

Available online 23 October 2021

This network will react to upcoming challenges

- by coordinating actively the European NMI research activities on quantum technologies,
- by aligning with the objectives of the EC Quantum Technologies Flagship and with the industrial requirements,
- by contributing to standardization & certification of quantum technologies, and
- by promoting take-up of metrology in the development of these technologies, and provide linkage with other technical areas

Strategically, the network will

- ensure the efficient use of the funds available at the European level for these QT research domains,
- limit unnecessary duplication of activities and
- act as the main contact point to stakeholders connected to the domains of QT which are covered by the scope of this EMN.

The network is organising its activities aiming at a certain degree of coherence with the objectives of the EC Quantum Technologies Flagship, and national and intergovernmental programmes, to ensure the consideration of the metrological aspects and thus to ensure the transition of QT research results into QT applications. With this purpose, the General Assembly will establish a direct link of communication with the flagship nominated contact, that has also joined the EMN-Q stakeholder/advisory board.

Furthermore, leading stakeholders (such as companies working on quantum technologies, standardization bodies, research centers and academia) have shown their strong interest on the European Metrology Network on Quantum Technologies (EMN-Q), and they have sent letters (from more than 150 organizations) enthusiastically supporting the creation of the EMN-Q. They will be continuously informed by the EMN-Q, and it is expected that they will contribute to the preparation of the EMN-Q Strategic Research Agenda and of the EMN-Q Research and Technology Roadmaps aligned to their metrological needs.

Once the EMN-Q will be fully established assuming its role of well identified contact point for the metrology for quantum technologies, it is expected that further European companies, organizations and universities interested in the practical deployment of these technologies will join the EMN-Q Stakeholders Advisory Board.

The network will mainly focus on the research and innovation domains of the Quantum Flagship that have impact on metrology or present specific metrological needs to be addressed, i.e. quantum sensing & metrology, quantum communication and quantum simulation.

The contribution of the network to standardisation & certification bodies within the QT area will be essential to ensure the quality of products and European/worldwide acceptance of European products.

This EMN will be sustainable by the commitment of the partners, and by the fact, that quantum clocks, quantum photonics and quantum electronics are major strategic goals in all participating NMIs.

2. Outputs

The most important outputs from the network will be

- active coordination of the European NMI research activities on Quantum Technologies, ensuring an efficient use of the funds available at the National and European level, thus promoting smart specialisation of present and future EMN members;
- strategic research agenda for short, middle and long term This will be achieved by developing research and technology roadmaps for the next decades focussed on the four mission-driven research and innovation domains the Quantum Flagship is structured around, namely Quantum Communication, Quantum Computation, Quantum Simulation, Quantum Sensing&Metrology.
- new measurement capabilities and dedicated services in the field of Quantum Technologies serving the fast-growing needs of industry, standardization bodies and research institutions;
- alignment of these activities with industrial requirements by knowledge transfer and a portfolio of dedicated services;
- major contributions to standardisation & certification bodies in the area of Quantum Technologies;

EMN-Q will enable efficient provision to the stakeholders of:

- Measurement guidelines and best-practice measurement guides for QT
- Measurement expertise to support the activities of Standardization & Certification bodies on QT
- Scientific collaboration, and workshops and training materials, on Metrology for QT

These outputs, as said, are driven by the industrial requirements, thus there is a substantial complete alignment with the EC Quantum Technologies Flagship strategies.

Although some of the above stated outputs could be in principle obtained also by joint projects, it is rather clear that long-term coordination and sustainability could not be achieved.

Without this network and the commitments of the partners, the partners probably would start national programmes leading to massive duplication on the work throughout Europe, because of the strong needs for each country to become an active player in this very promising and future-oriented fields of quantum technologies.

3. Impact

This EMN aims for the support of companies, institutions and academia in the field of Quantum Technologies.

There is now a critical mass of companies developing quantum technologies ranging from quantum communications (IDQ, Toshiba, Huawei, KETS QuantumSecurity, InfiniQuant, …), via quantum sensors (Bosch, ppqSense, MuQuans), quantum frequency standards (Thales Alenia Space, Leonardo Finmeccanica, T4Science, Menlo Systems) and electrical quantum standards (Supracon AG, Magnicon GmbH, esz AG), to photon detectors and quantum imaging systems (MPD, Single Quantum, Aurea Technology, Picoquant, Laser Components).

Furthermore, there are already big companies, such as e.g. BT, KPN, Orange, Airbus, Leoanrdo …, in quantum communications, that are keen to translate R&D into products and services. It is fundamental that dedicated metrological techniques are developed to provide test and validation services to support the market uptake of these novel technologies. The proposed network, by co-ordinating the development of such expertise, as well as written standards, will directly impact companies developing, or selling products based on, quantum technologies (as confirmed by the letters of support from stakeholders).

This future-oriented field, which is extraordinarily interesting and fast-developing, has already delivered significant innovation. The impact of quantum technologies at the European level and thus naturally also of the metrology network supporting these technologies is clearly stated by the European Commission [1]): “Our ability to manipulate quantum effects in customised systems and materials is now paving the way for a second quantum revolution, which takes quantum theory to its technological consequences. It should lead to devices with far superior performance and capabilities for sensing, measuring and imaging; for communication, simulation and computing. Quantum technologies ultimately are expected to open new opportunities to address grand challenges in such fields as energy, health, security and the environment. Some are already starting to be commercially exploited. Others may still require years of careful research and development. Yet others we cannot even imagine today. The future markets for quantum technologies are going to be at least as significant as current ICT markets. For example,

already in 2020, Quantum Communication could serve a market sized over €1 billion, with a steep estimated growth rate of 20% per year. Near-term technologies could be available within 5 years, notably for sensing, metrology, imaging and communication. Otherwise the anticipated time frame is 10–15 years and beyond."

The EMN-Q activities will cover a relevant part of the whole quantum technologies considered in the Flagship, namely the R&D domains:

- Quantum Sensing & Metrology
- Quantum Communication
- Quantum Computing

In particular, regarding Quantum Sensing & Metrology, electrical quantum metrology is well established at NMIs and first commercial products are entering the market, e.g. various DC and AC-voltage standards based on the Josephson effect. Quantum standards for resistance and impedance metrology have experienced a boost with the use of graphene and can be expected to lead to commercial products in the next years, and topological insulators offer exciting new possibilities in this field. Quantum coherence and other fundamental phenomena in novel quantum devices based on, e.g., superconducting nanostructures or semiconducting quantum dots will have important applications in electrical metrology and sensing, and metrology will be an important enabler for applications of new quantum technologies in other fields.

Regarding quantum communication (cryptography), the Network responds to the needs addressed in the Directive 2002/58/EC of the European Parliament [6] concerning the processing of personal data and the protection of privacy in the electronic communications sector (Directive on privacy and electronic communications), and the General Data Protection Regulation (GDPR), which has been binding since May 2018 [7]. Progress in quantum computing and crypto-analysis will render some forms of current encryption insecure. Quantum cryptography, in which Europe has a long and well established tradition, will be used to secure future communications. It is clear, that the European citizen should have greater confidence in Quantum Cryptography if systems have been tested and certified by independent bodies.

Concerning quantum frequency standards, the EMN directly supports the establishment of novel ways for quantum standards and their transfer and as expressed in the EMRP outline document [8, pp. 11, 33], the CCTF-Recommendation 6 to the CIPM from the 17th CCTF meeting in 2006 [9], CCTF-Recommendation 5 to the CIPM from the 19th CCTF meeting in 2012 [10] and resolution 9 of the 23rd General Conference on Weights and Measures (CGPM) [11].

The activities of the Network will contribute by coordinate cutting edge research activities in the context of all these R&D quantum technologies domains, as well as coordinate the development of the necessary metrological infrastructure for the characterisation of the quantum devices and for their certification. Furthermore, the Network measurement expertise will coordinate fundamental contributions to the standardisation process of these devices.

The Intermediate Report of the Quantum Flagship states: "Developing Europe's capabilities in Quantum Technologies will help create a lucrative knowledge-based industry, leading to long-term economic, scientific and societal benefits." ([12] page1). "Key to the initiative's added value is its pan-European dimension. This would allow an optimal integration of the diverse expertise of academic and industry partners across Europe, …, integrate national and European metrological and standardisation institutes in developing quantum based standards, and, …, align existing Member States strategies and activities ensuring that funding is spent in the most efficient way at all levels, regional, national and international." ([12] page 2]); This is exactly what the proposed Network aims to be and to do. This is also enforced where it is written that "The Flagship should work closely with existing standardisation institutes (such as the metrology institutes organised in EURAMET) and the European committees for standardisation (e.g. CEN-CENELEC and ETSI) to drive standardisation of quantum technologies." ([12] page 24]). Even more explicitly the "Quantum Technologies Flagship Final Report" by High-Level Steering Committee states that: "The national metrology institutes, organised in EURAMET, already have strong expertise in QT and should be encouraged to put a focus on next generation QT in sensing and metrology" [13].

Acknowledgments

This paper is based on the activities carried on in the project 19NET02 Quantum. 19NET02 Quantum has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

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Ivo Pietro Degiovanni[1,*]
INRIM -Istituto Nazionale di Ricerca Metrologica- (Quantum Metrology and Nanotechnology Division), Torino, Italy

Marco Gramegna[1]
INRIM -Istituto Nazionale di Ricerca Metrologica- (Quantum Metrology and Nanotechnology Division), Torino, Italy
E-mail address: m.gramegna@inrim.it.

Sébastien Bize[1]
LNE-SYRTE - Systèmes de Référence Temps, Observatoire de Paris-Université PSL, CNRS, Sorbonne Université, Paris, France
E-mail address: sebastien.bize@obspm.fr.

Hansjörg Scherer[1]
PTB - Physikalisch-Technische Bundesanstalt - (Department 2.6 "Electrical Quantum Metrology"), Braunschweig, Germany
E-mail address: hansjoerg.scherer@ptb.de.

Christopher Chunnilall[1]
NPL -National Physical Laboratory- (Quantum Metrology Institute), Teddington, Middlesex, UK
E-mail address: christopher.chunnilall@npl.co.uk.

[*] Corresponding author.
E-mail address: i.degiovanni@inrim.it (I.P. Degiovanni).

[1] EMN-Q –EURAMET European Metrology Network for Quantum Technologies.