Final Publishable JRP Summary for IND06 MIQC
Metrology for Industrial Quantum Communication technologies

Overview

The focus of this project was the development of techniques and facilities for traceable characterisation of single-photon components of QKD systems, in particular single-photon sources and detectors operating in the 1550 nm telecom band.

Need for the project

Quantum Key Distribution (QKD) is essentially the generation of secret random cryptographic keys between two parties that communicate over an open quantum channel. These keys are vital for realising secure communication between the parties. QKD has supported the development of quantum information science, and is likely to be a disruptive technology in information management industry. With its strong long-term security perspective, QKD will be an important building block for dependably secure communication networks.

QKD technology can address the need for improved data security in, for example, banking, commerce, government, and the transmission of personal data, e.g. medical records. The lack of validation and standardisation remains a barrier to a wider market take-up of this technology, in which Europe is currently a world-leader, and addressing this falls within the remit of national measurement institutes (NMIs). Currently, the only initiative for the standardisation of QKD is the Industry Specification Group on QKD of the European Telecommunication Standards Institute (ETSI ISG-QKD).

The main challenge is the identification of the physical system parameters critical to quantum communication (QC) and the development of appropriate metrics and measurement techniques for their quantification. These differ from, but are complementary to, the ones of classical communication.

Characterisation of classical (i.e. non-quantum) communication parameters is a well-established metrological activity. In the context of quantum communication, further development of these “classical” measurement techniques is necessary to cover parameter ranges beyond the interests of classical communication. This project was aimed at combining expertise and resources from European NMIs to provide the measurement framework needed for characterising QKD systems. Characterisation of key parameters is required throughout the quantum communication process, that is: the characterisation of the photon sources that act as emitters; the optical fibre that provides the quantum communication channel; and the single-photon detectors that act as receivers. This requires existing facilities and standards to be developed to operate at relevant telecom wavelengths (around 1.5 µm) and at the very low power regime of single photons. This is extremely technically challenging, as no measurement standards currently exist for photon counting telecom detectors and many of the parameters and required uncertainties have yet to be defined within a QKD framework.

Scientific and technical objectives

The overall aim of the project was to develop metrological techniques, standards and methods for the development of new industrial quantum communication technologies focused on three areas: emitters, channels and receivers. The technical objectives of the project were the traceable characterisation of:

Emitters

1. Traceable characterisation of photon sources with unknown quantum states, including measurement of the mean number of photons per pulse, reconstruction of the probability of emitting a certain number of photons per pulse, and quantum tomography of the quantum states;
2. Realisation of optimised single-photon sources as a reference for the quantum source;

Report Status: PU Public

EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Channels

3. Traceable characterisation of quantum channels for optical fibre based communication systems; including de-coherence quantification, and quantum process tomography related to the propagation of states inside optical fibres

Receivers

4. Traceable characterisation of commercial single-photon detectors, including detection efficiency, timing jitter, dead-time, after-pulsing, dark counts and saturation. Identification and standardisation of the definitions specific to quantum detection at single-photon level;
5. Determination of the properties of photon-number-resolving detectors capable of observing more than one photon in a pulse.

Results

This project developed a series of measurements that are sensitive enough to characterise the properties of the individual particles of light, as well as the single-photon detectors which QKD systems use, and laid the foundations for a European measurement infrastructure able to validate the performance of QKD systems, and technologies that use and manipulate single photons. The project results enable the development of new hardware for manipulating single and few photons, required for next-generation communication systems and quantum networks.

The project defined the range of measurements required to characterise and validate the performance of the optical components of QKD systems. Specifications based on the outputs of this project enabled systems to be evaluated and standard measures to be defined, thus helping to shape a validation and certification process for wider implementation of this technology.

The project developed measurements for characterising properties of the optical components of the QKD emitter and receiver, as well as of quantum channels and of quantum random number generators: essential parts of a QKD system.

Traceable characterisation of photon sources with unknown quantum states produced by emitter *(this addresses objectives 1 and 2)*

The following developments have been realised within this project:

Reliable methods for measuring mean photon number traceably to cryogenic radiometry (the SI);

The project extended some of the calibration techniques developed mainly in the visible to telecom wavelengths (where difficulties arise from the lower detection efficiencies and higher dark counts of the single-photon detectors).

The project has also developed techniques for characterising single-photon sources based on: (i) a calibrated attenuator and photon counting; (ii) statistical reconstruction; (iii) (anti-)correlation measurements. These techniques are now available for characterising the (pseudo-)single-photon-sources of QKD systems.

These techniques have been tested using attenuated pulsed laser sources (i), as well as a low-noise heralded single-photon source on based spontaneous parametric down-conversion [1].

Photon-number-resolving detector

PTB and INRIM collaborated on a novel kind of photon-number-resolving (PNR) detector, capable of measuring more than one photon in a pulse, using a space-multiplexed system of four non-PNR commercial InGaAs - single-photon avalanche diode (SPAD) detectors with field programmable gate array (FPGA) - based intelligent control. This PNR detector was used to reconstruct the optical mode occupation numbers of a light field [4]. Furthermore, it inspired the development of an innovative characterisation technique using entangled light [5]. This solution has attracted the attention of a single-photon detector manufacturer. A full characterisation of the PNR detector is now available.

Tuneable Fabry-Perot resonator

NPL developed a high resolution, high transmission fibre-coupled single-photon spectrometer based on a Fabry-Perot cavity, which uses a nanowire single-photon detector to measure spectral linewidth. The instrument's unique combination of free spectral range and resolution makes it suitable for spectral analysis of pulsed sources across the 1.3 μm -1.5 μm wavelength range.

Optimised single-photon source as a reference for quantum sources

A novel technique has been implemented at PTB for measuring traceably the detection efficiency of superconducting nanowire single-photon detectors (SNSPDs) against a classical radiation detector (InGaAs diode calibrated against the cryogenic radiometer at 1.55 µm) without using a calibrated attenuator or relying on the linearity of the classical detector over several orders of magnitude. The technique exploits the fact that the spectral radiant intensity of synchrotron radiation from electron storage rings is directly proportional to the stored electron beam current.

Traceable characterisation of quantum channels for optical fibre based communication systems *(this addresses objective 3)*

The following developments have been realised within this project:

Single-photon polarimeter

INRIM and KRISS developed a single-photon polarimeter for reconstructing the evolution of the polarisation state of a single photon propagating in an optical fibre. The system is highly configurable and can also be used at light levels other than single-photons. In particular, it has been used in the project when measuring polarisation noise at conventional light levels on a real fibre link.

Although single photon detection provides unmatched sensitivity, only a few realisations of Optical Time Domain Reflectometers (OTDRs) based on single-photon detectors were known at the start of the project. An OTDR system operating at single photon level was developed by INRIM in collaboration with KRISS, PoliMi and IDQ, and used to investigate back-scattering in fibre.

Components required to build a quantum random number generator

In parallel, two ‘open system’ quantum random number generators (QRNGs) have been constructed by IDQ and NPL: one uses a 50/50 beam-splitter while the other uses a matrix of detector elements. The parameters to measure and the techniques to measure these parameters have been determined and developed. A model describing the QRNG has been developed by IDQ that allows the estimation the quality of the raw bit stream as a function of the parameters of the QRNG components.

Traceable characterisation of single-photon detectors in receiver *(this addresses objectives 4 and 5)*

The following developments have been realised within this project:

Reliable methods for characterising detectors traceably to cryogenic radiometry (the SI)

The project established a comprehensive traceable characterisation of detector parameters and properties for commercial single photon detectors, like InGasAs/InP SPADs as well as SNSPDs and extrinsic PNR detectors. Parameters are detection efficiency, dead-time, jitter, after-pulse and dark count probability, and the presence of back-flashes. PTB realised precise measurement setups to traceably characterise dead-time and jitter of InGaAs SPADs using attenuated laser pulses. In this context the jitter of SNSPDs has been measured traceably using synchrotron pulses from the Metrology Light Source (MLS).

Heralded single-photon source

A low-noise heralded single-photon source was developed based on spontaneous parametric down-conversion [1]. The novelty of the latter “low-noise” source - a joint effort by INRIM and PoliMi - is its ability to almost nullify the presence of background counts in the heralded channel without temporal post-selection, achieving the best performance reported to date in terms of single-photon emission. This source has also been used to perform a test on the foundations of quantum mechanics [2] and has inspired a proof-of-principle demonstration of a novel QKD protocol based on interaction-free measurement [3]. This source is made of standard commercial components and can be easily developed as a commercial prototype.

Calibrated attenuator

A calibrated attenuator was constructed and characterised to simplify detector characterisation, and eventually applied to SPADs. The device was designed and realised to determine the quantum efficiency with an uncertainty of less than 3%. Metrosert constructed a polarization-independent transmission trap configuration based on two InGaAs photodiodes. MIKES used the trap to construct a fibre-coupled device which provides an attenuation of 10^5 at 1.55 µm, an important step for determining the detection efficiency of single-photon detectors at this wavelength. CMI built the read-out electronics able to measure incident power on the front photodiode at the 5 pW level with a noise level < 0.5% using an integration time of 20 s. The attenuation was measured by NPL and the device was used to determine the mean photon number from a source, comprising a pulsed laser and the calibrated InGaAs photodiode attenuator.

Measurement of back-flash from a commercial SPAD

The single-photon OTDR was used to investigate back-flashes from a commercial single photon detector. Back-flashes present a potential security problem for practical QKD systems and conventional OTDRs do not have enough sensitivity to observe the presence of back-flashes. OTDR operating at single-photon level were able to observe active or passive optical phenomena at such a low light level. The OTDR operating at single photon level is ready to become an industrial prototype.

Actual and potential impact

The outputs from this project contributed to the necessary metrological foundations for the standardisation of the QKD. The direct impact is to provide assurance to end users of the conformance to standards of QKD components thereby promoting market uptake of the technology and ultimately revolutionising data security in ICT. Successful deployment of QKD will also kick start the quantum industry – there are already related areas of research which are being pursued by academia to take QKD to the next phase – such as quantum repeaters and quantum memories.

The impact was ensured by the presence in the consortium of influential manufacturers, standardisation bodies and researchers from all over Europe and outside Europe. The key European QKD manufacturers, namely IDQ and Toshiba Research Europe Laboratories, were actively involved in this project through the ETSI industry-specification group (ISG) on QKD. In fact, the frequent contact with the ETSI-ISG on QKD ensured the work was aligned with industrial requirements.

Dissemination

A website - http://projects.npl.co.uk/MIQC/, linked from http://www.miqc.org - has been established to disseminate the results of the project. On the website, a best practice guide outlining the measurement procedures to be followed and a review article on metrology of single-photon sources and detectors were made freely available. The website is referenced in the Wikipedia page on QKD - http://en.wikipedia.org/wiki/Quantum_key_distribution

Peer-reviewed papers have been published in high-impact journals and presentations were made at international conferences and at high-level international metrology business meetings. A paper by the of ETSI QKD-ISG , entitled 'Worldwide Standardization Activity for Quantum Key Distribution' has been accepted for presentation at the IEEE GLOBECOM 2014 in December 2014, one of the two flagship conferences for IEEE Communications Society.

A lecture "Metrology for Quantum Communication Technologies" was presented at the International School of Physics "Enrico Fermi" - Metrology and Physical Constants, in July 2012 at Varenna in Italy. This was published in 2013 in an edited book compilation of the lectures. Two on-demand web lectures discussing basic aspects of QKD were created and hosted by *Agorà Scienza* at http://www.activeresearch.eu/. The lectures went 'live' in March 2014 and 69 participants were registered as of August 2014. The topics covered were *'Introduction to QKD', 'Practical QKD', 'Security of the QKD', and 'Metrology for QKD'.*

At the highest level of primary measurement standards, the NMI members of the consortium have ensured that the telecom wavelength region will be covered in pilot comparisons in the single-photon regime to be organised by the Consultative Committee for Photometry and Radiometry (CCPR) of the International Committee for Weights and Measures (CIPM).

At the Quantum 2014 conference a session was devoted to the project and a presentation made on a public demonstration of a characterised QKD system.

Intermediate impact:

Standards

In Europe, the ETSI ISG-QKD is the only known standardisation initiative for QKD systems [http://www.etsi.org/index.php/technologies-clusters/technologies/quantum-key-distribution]. It is recognized that one of the building blocks necessary to achieve QKD systems standardisation is that of traceable measurements at the single-photon level. For this reason, three NMIs who participated in this project are members of ISG-QKD: INRIM, NPL, and PTB. Through these NMIs, the consortium maintained frequent contact with the ISG-QKD to ensure that work within the project was aligned with industrial requirements and also that the project's experience and expertise on single-photon measurements was made available to support the work of the ISG.

Project members of the ISG contributed to reviewing the published ETSI document "GS QKD 003: Quantum Key Distribution (QKD); Components and Internal Interfaces" (before the project start), and to the drafting of current ETSI documents i) "DGS/QKD-0011_OptCompChar: Quantum Key Distribution (QKD) Component characterisation: characterising optical components for QKD systems" (NPL is the rapporteur, INRIM contributed writing some sections and reviewing the document, PTB reviewed the document) and ii) "DGS/QKD-0010_ISTrojan: Quantum Key Distribution (QKD) Implementation security: protection against Trojan horse attacks in one-way QKD systems" (NPL, PTB and INRIM reviewed the document). The drafting of DGS/QKD-0011 is being led by one of the consortium members.

This work advances the development of standards which will be used for validating and certifying QKD systems, thereby supporting European QKD manufacturers and the need for secure data transfer.

Industrial and other user communities

The project provided important metrological expertise to support a real-world public demonstration of well-characterised QKD over a single field-installed lit fibre. This demonstration was performed by Toshiba Research Europe Limited (a QKD system developer), BT Group plc (the UK's largest network provider), ADVA Optical Networking SE (a provider of data encrypters to network providers), and the project partner NPL. It demonstrated to key users and providers of secure communications that QKD and QKD-secured data can be transmitted over a single fibre and does not need dedicated and expensive dark fibre to be used for the quantum channel in a QKD link. This work makes QKD a more attractive commercial proposition, and will accelerate its commercial deployment. In addition, a number of companies used the new measurement capabilities developed in the project to better understand their QKD instrumentation and components:

- A European company used a facility developed in the project to characterise the relative spectral response of its single-photon detectors. This is of general value for the use of these detectors in a broad range of single-photon applications, and will advance their market take-up.
- The back-flash from a commercial single-photon detector operating at telecom wavelengths was measured for the manufacturer. Back-flash from a QKD detector can provide a side-channel which can be exploited by a quantum hacker. Knowledge of the back-flash, and its characteristics, enables appropriate counter-measures to be implemented when this detector is used in QKD systems.
- Measurement of the detection probability of commercial single-photon detectors has been performed for a European company as a test of the performance of an internal component.

Long-term impact:

Quantum cryptography has great potential to become the key technology for securing confidentiality and privacy of communication in the future ICT world and thus to become the driver for the success of a series of services in the fields of e-government, e-commerce, e-health, transmission of biometric data, intelligent transport systems, and in many other areas.

Standardisation is one of the key elements for the success of such an initiative: a European lead in developing globally accepted standards and an anticipatory approach would facilitate market take-up, both in Europe and abroad. This project has developed traceable measurement techniques for the quantum optical components of QKD systems, and participated in the review and drafting of ETSI pre-standard documents. This will enable Europe to continue to drive the standardisation process, and achieve the goal of implementing a validation and certification process for QKD systems, ultimately revolutionising data security in ICT. The project has also demonstrated to the industrial and user community that the necessary metrological foundations for the standardisation of QKD are being developed, thereby providing confidence for the continued development and deployment of this technology.

The measurement techniques and devices developed in this project will also serve the needs of other developing quantum photonics technologies that rely on the production, manipulation and detection of single photons. Here European industry has a prominent position. This project has therefore made a significant contribution to the foundations of a robust quantum industry that will provide a step change in the telecoms industry and future-proof data management that will impact on us all.

The wider indirect impact of the project, through its advancement of QKD, is expected to be as follows:

Social, economic and political impact. Governments are increasingly converting data, such as medical records, into digital format and increasing the risk of lost or stolen data. The secure transmission of information and the protection of privacy of individuals is important for the data traffic at public institutions, and for strengthening and maintaining the competitiveness of the European economy, as stated in the document published jointly by the European Commission and the High Representative of the Union for Foreign Affairs and Security Policy entitled "Cybersecurity Strategy of the European Union: An Open, Safe and Secure Cyberspace" [EUC]. Global market for QKD is projected to reach $1.0 billion by 2018, driven by the need to secure the transmission of sensitive communications.

Environmental impact. Successful deployment of validated QKD systems will encourage and accelerate the use of network communications and services, such as secure video conferencing and secure data transfer of important documents, thereby reducing our dependence on travel- and paper-based communication.

List of publications

Journal articles:

1. **Quantum and classical characterization of single/few photon detectors**
   M G Mingolla, F Piacentini, A Avella, M Gramegna, L Lolli, I Ruo Berchera, E Taralli, P Traina, M Rajteri, G Brida, I P Degiovanni and M Genovese
   Quantum Matter, Volume 4, p.1-13 (June 2015),

2. **Random Variation of Detector Efficiency: A Secure Countermeasure against Detector Blinding Attacks for Quantum Key Distribution**
   C C Wen Lim, N Walenta, M Legré, N Gisin and H Zbinden
   *IEEE Journal of Selected Topics in Quantum Electronics, **21** (3), pag 6601305 May/June 2015*

3. **Compact two-element transmission trap detector for 1550 nm wavelength**
   A Vaigu, T Kübarsepp, F Manoocheri, M Merimaa, E Ikonen
   Measurement Science and Technology, **26**(5), p. 055901 (March 2015)

4. **Reconstruction of mode structure of faint sources and its applications**
   F Piacentini, E A Goldschmidt, I P Degiovanni, I Ruo Berchera, S V Polyakov, S Kück, G Brida, A Migdall and M Genovese
   Physica Scripta,Volume 2014, Number T163, p. 014024 (December 2014)

5. **Worldwide standardisation activity for quantum key distribution**
   A. Mink, R. Alléaume, T. H. Chapuran, C.J. Chunnilall, I. P. Degiovanni, N. Lutkenhaus, V. Martin, M. Peev, M. Lucamarini, A. Shields, and M. Ward
   IEEE Communications Magazine, Volume: Globecom Workshops (GC Wkshps) 2014, p.656-661 (December 2014)

6. **Metrology for industrial quantum communications: the MIQC project**
   M L Rastello, I P Degiovanni, A G Sinclair, S Kück, C J Chunnilall, G Porrovecchio, M Smid, F Manoocheri, E Ikonen, T Kubarsepp, D Stucki, K S Hong, S K Kim, A Tosi, G Brida, A Meda, F Piacentini, P Traina, A Al Natsheh, J Y Cheung, I Müller, R Klein and A Vaigu
   *Metrologia, **5**1(6), S267–S275 (November 2014)*

7. **Traceable metrology for characterising quantum optical communication devices**
   C J Chunnilall, G Lepert, J J Allerton, C J Hart and A G Sinclair
   *Metrologia, **51**(6), S258–S266 (November 2014)*

8. **Traceable calibration of a fibre-coupled superconducting nano-wire single photon detector using characterised synchrotron radiation**
   I Müller, R Klein and L Werner
   *Metrologia, **51**(6), S329–S335 (November 2014)*

9. **Beating Abbe diffraction limit in confocal microscopy via non-classical photon statistics**
   D Gatto Monticone, K Katamadze, P Traina, E Moreva, J Forneris, I Berchera, P Olivero, IP Degiovanni, G Brida, M Genovese
   Physical Review Letters , Volume 113, p. 143602[5] (September 2014)

10) **Field trial of a quantum secured 10 Gb/s DWDM transmission system over a single installed fiber**
   I Choi, Y R Zhou, J F Dynes, Z Yuan, A Klar, A Sharpe, A Plews, M Lucamarini, C Radig, J Neubert, H

Griesser, M Eiselt, C Chunnilall, G Lepert, A Sinclair, J-P Elbers, A Lord, A Shields
Optics Express **22**(19), 23121-23128 (September 2014) [Open Access]

11) **Metrology of single-photon sources and detectors: a review**
C J Chunnilall, I P Degiovanni, S Kück, I Müller, A G Sinclair
Optical Engineering, **53**(8), 081910[17] (August 2014) [Open Access]

12) **Native NIR-emitting single colour centres in CVD diamond**
D Gatto Monticone, P Traina, E Moreva, J Forneris, P Olivero, I P Degiovanni, F Taccetti, L Giuntini, G Brida, G Amato, M Genovese
New Journal of Physics, **16**(5), 053005[18] (May 2014) [Open Access]

13) **Measurement facility for the evaluation of the backscattering in fibre: realisation of an OTDR operating at single photon level**
F Piacentini, A Meda, P Traina, K Hong, I P Degiovanni, G Brida, M Gramegna, I Ruo Berchera, M Genovese, M L Rastello
International Journal of Quantum Information, **12**, 1461014[8] (March 2014)

14) **Separable Schmidt modes of a nonseparable state**
A Avella, M Gramegna, A Shurupov, G Brida, M Chekhova, M Genovese
Physical Review A, **89**(2), 023808[8] (February 2014)

15) **Practical implementation of a test of event-based corpuscular model as an alternative to quantum mechanics**
S. V. Polyakov, F. Piacentini, P. Traina, I. P. Degiovanni, A. Migdall, G. Brida, M. Genovese
Foundations of Physics, **43**(8), 913-922 (August 2013)

16) **Fast Active Quenching Circuit for Reducing Avalanche Charge and Afterpulsing in InGaAs/InP Single-Photon Avalanche Diode**
F. Acerbi, A. Della Frera, A. Tosi and F. Zappa
IEEE Journal of Quantum Electronics, **49**(7), 563-569 (July 2013)

17) **Mode reconstruction of a light field by multi-photon statistics**
E. A. Goldschmidt, F. Piacentini, I. Ruo Berchera, S. V. Polyakov, S. Peters, S. Kueck, G. Brida, I. P. Degiovanni, A. Migdall and M. Genovese
Physical Review A, **88**(1), 013822[5] (July 2013)

18) **Reply to comment on the 'Experimental test of an event-based corpuscular model modification as an alternative to quantum mechanics'**
G. Brida, I. P. Degiovanni, M. Genovese, A. Migdall, F. Piacentini, S. V. Polyakov, P. Traina
Journal of the Physical Society of Japan, **82**(8), 086001[1] (July 2013)

19) **Review on recent groundbreaking experiments on quantum communication with orthogonal states**
P. Traina, M. Gramegna, A. Avella, A. Cavanna, D. Carpentras, I. P. Degiovanni, G. Brida and M. Genovese
Quantum Matter, **2**(3), 153-166 (June 2013)

20) **Experimental Test of an Event-Based Corpuscular Model Modification as an Alternative to Quantum Mechanics**
G. Brida, I. P. Degiovanni, M. Genovese, A. Migdall, F. Piacentini, S. V. Polyakov and P. Traina
Journal of the Physical Society of Japan, **82**(3), 034004[5] (February 2013)

21) **An extremely low-noise heralded single-photon source: A breakthrough for quantum technologies**
G. Brida, I. P. Degiovanni, M. Genovese, F. Piacentini, P. Traina, A. Della Frera, A. Tosi, A. B. Shehata, C. Scarcella, A. Gulinatti, M. Ghioni, S. V. Polyakov, A. Migdall and A. Giudice
Applied Physics Letters, **101**(22), 221112[4] (November 2012)

22) **Ancilla-Assisted Calibration of a Measuring Apparatus**
G. Brida, L. Ciavarella, I. P. Degiovanni, M. Genovese, A. Migdall, M. G. Mingolla, M. G. A. Paris, F. Piacentini and S. V. Polyakov
Physical Review Letters, **108**(25), 253601[5] (June 2012)

23) **Experimental realization of counterfactual quantum cryptography**
G. Brida, A. Cavanna, I.P. Degiovanni, M. Genovese and P. Traina
Laser Physics Letters, **9**(3), 247-252 (March 2012) [Free to download]

Conference papers (not peer-reviewed):

1) SPIE Photonics Europe, Brussels, 2014:
High performing SPS based on native NIR-emitting single colour centers in diamond
P. Traina, D. Gatto Monticone, E. Moreva, J. Forneris, M. Levi, G. Brida, I. P. Degiovanni, G. Amato, L. Boarino, P. Olivero, M. Genovese
Proc. SPIE [9136], 913624 (May 2014)

2) SPIE Security & Defense, Dresden, 2013:
Towards a high-speed quantum random number generator
Damien Stucki, Samuel Burri, Edoardo Charbon, Christopher Chunnilall, Alessio Meneghetti, Francesco Regazzoni
Proc. SPIE, [8899] 88990R[6] (October 2013)

3) SPIE Optics & Photonics 2013:
Some recent progresses in quantum tomography realised at INRIM
F. Piacentini, E.A. Goldschmidt, M.G. Mingolla, I.P. Degiovanni, M. Gramegna, I. Ruo Berchera, S. V. Polyakov, S. Peters, S. Kück, E. Taralli, L. Lolli, M. Rajteri, M.G.A. Paris, A. Migdall, G. Brida, M. Genovese
Proc. SPIE, [8875], 88750G (2013)

4) SPIE Optics & Optoelectronics 2013:
An extremely low-noise heralded single-photon source without temporal post-selection
F. Piacentini, P. Traina, A. Della Frera, A. Tosi, C. Scarcella, A. Ruggeri, A. Gulinatti, M. Ghioni, S. V. Polyakov, A. Migdall, A. Giudice, G. Brida, I. P. Degiovanni, M. Genovese
Proc. SPIE, [8873], 87730S (2013)

5) SPIE Security and Defense 2012:
Report on proof-of-principle implementations of novel QKD schemes performed at INRIM
A Avella, G Brida, D Carpentras, A Cavanna, I P Degiovanni, M Genovese, M Gramegna and P Traina
Proc. SPIE, [8542], 8542-65 (2012)

Book chapter:

1) **Metrology for Quantum Communication technologies**
M L Rastello
Proceedings of the International School of Physics "Enrico Fermi", [185], 243-271 (2013)
Editors: E. Bava, M. Kühne, A.M. Rossi
ISBN: 978-1-61499-325-4 (print) **|** 978-1-61499-326-1 (online)

Good Practice Guide:

1) Characterisation of optical components of weak-coherent-pulse Quantum Key Distribution systems
C Chunnilall, I P Degiovanni, S Kuck, A G Sinclair
http://projects.npl.co.uk/MIQC/training.html

JRP start date and duration:	01 September 2011, 36 months
JRP-Coordinator: Maria Luisa Rastello, dr, INRIM Tel: +39 011 39 19 219 E-mail: m.rastello@inrim.it JRP website address: : www.miqc.org	
JRP-Partners: JRP-Partner 1 INRIM, Italy JRP-Partner 2 Aalto, Finland JRP-Partner 3 CMI, Czech Republic JRP-Partner 4 Metrosert, Estonia JRP-Partner 5 NPL, United Kingdom	JRP-Partner 6 PTB, Germany JRP-Partner 7 AIT, Austria JRP-Partner 8 IDQ, Switzerland JRP-Partner 9 KRISS, Republic of Korea JRP-Partner 10 MIKES, Finland
REG-Researcher (associated Home Organisation):	Damien Stucki, Switzerland IDQ, Switzerland
REG-Researcher (associated Home Organisation):	Alberto Tosi, Italy PoliMi, Italy
REG-Researcher (associated Home Organisation):	Anas Al Natsheh, Finland UOULU, Finland

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union