# DF Few Photon Metrology

Activity Report to CCPR WG-SP meeting in 2023

Dong-Hoon Lee (KRISS)

# Terms of Reference

- To discuss the outstanding issues in the field of few photon metrology
- To monitor the advances and demands in the field of few photon metrology
- To monitor and report on needs for SI traceability in the field of few photon metrology

# List of TG Activities

- To discuss the outstanding issues in the field of few photon metrology:
  - Maintain and update the list of technical issues with the DF members
  - If possible, required actions can be initiated, e.g., organizing a comparison, organizing a workshop or a conference session, or forming a group for publication, or cooperating with other international standard organizations
- To monitor the advances and demands in the field of few photon metrology
  - Collecting inputs from members in major conference events (such as SPW)
  - Collecting information from members on the standardization activities in other communities
  - Chair will make a survey to members before reporting to the annual CCPR WG-SP meeting
- To monitor and report on needs for SI traceability in the field of few photon metrology
  - Collecting inputs from members especially working in NMIs
  - Chair will make a survey to members before reporting to the annual CCPR WG-SP meeting

# Member List

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48 experts from
14 countries

*Updated based on the participants list of the TG meeting in Nov 2022

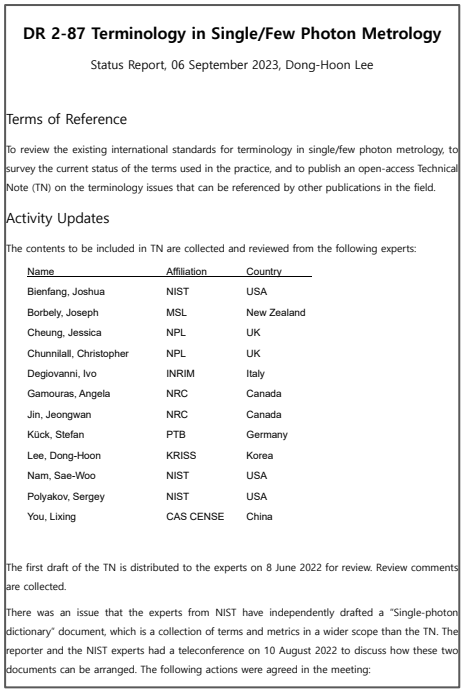
[EXCEL file included]

# Activities since Dec 2021

- CIE Reportership DR 2-87: Created in Aug 2020 with a proposal of a TN publication within one year (by Aug 2021)
  - Revised workplan: Working Draft by April 2022 → Delayed
  - The first draft of TN circulated and reviewed by Oct 2022 → Delayed
- TG meeting: 4th meeting on 04 Nov 2022 in Seoul
  - Face-to-face meeting in SPW 2022
- Member survey: Proposed to conduct before reporting to the annual WG-SP meeting
  - Survey circulated in June 2023
  - 5 responses collected

# Status of CIE DR 2-87

- The first draft of the TN is distributed to the experts on 8 June 2022 for review. Review comments are collected.
- NIST experts prepares an independent publication of “single-photon dictionary.” Cooperation discussed in a teleconference on 10 August 2022 and also in the TG meeting.
- Revision of the TN by considering the comments received and also the NIST dictionary document is delayed by the reporter → Submission of WD by the end of 2023 proposed.
- A special session on terminology will be organized at Quantum 2023 (11 to 15 September in Torino)



**DR 2-87 Terminology in Single/Few Photon Metrology**

Status Report, 06 September 2023, Dong-Hoon Lee

Terms of Reference

To review the existing international standards for terminology in single/few photon metrology, to survey the current status of the terms used in the practice, and to publish an open-access Technical Note (TN) on the terminology issues that can be referenced by other publications in the field.

Activity Updates

The contents to be included in TN are collected and reviewed from the following experts:

| Name | Affiliation | Country |
|---|---|---|
| Bienfang, Joshua | NIST | USA |
| Borbely, Joseph | MSL | New Zealand |
| Cheung, Jessica | NPL | UK |
| Chunnilall, Christopher | NPL | UK |
| Degiovanni, Ivo | INRIM | Italy |
| Gamouras, Angela | NRC | Canada |
| Jin, Jeongwan | NRC | Canada |
| Kück, Stefan | PTB | Germany |
| Lee, Dong-Hoon | KRISS | Korea |
| Nam, Sae-Woo | NIST | USA |
| Polyakov, Sergey | NIST | USA |
| You, Lixing | CAS CENSE | China |

The first draft of the TN is distributed to the experts on 8 June 2022 for review. Review comments are collected.

There was an issue that the experts from NIST have independently drafted a “Single-photon dictionary” document, which is a collection of terms and metrics in a wider scope than the TN. The reporter and the NIST experts had a teleconference on 10 August 2022 to discuss how these two documents can be arranged. The following actions were agreed in the meeting:

[WORD file included]

# TG Meeting on 04 Nov 2022

- 11 members participated in-person
  - New member joined: Tobias Heindel from TU Berlin
- Current TG actions and list of technical issues reviewed.
  - Information on publications from other organizations shared, e.g. QED-C
  - “Best practice” publications for device characterization and data analysis suggested (comparison report?)
  - Terminology for entanglement
  - Effects with fiber connectors under investigation at NIST
- Member survey questions reviewed and revised.
- Change of the TG chair in 2023 proposed.


[PDF file included]

# Member Survey Results

1. What are the most remarkable achievements in the field of single/few photon metrology for the last 3 years? Please list up to 3 publications. (1/3)

- Justus Christinck et al., *Bright single-photon emission from a GeV center in diamond under a microfabricated solid immersion lens at room temperature*, Journal of Applied Physics 133(19), 193102-1-193102-13 (2023); https://doi.org/10.1063/5.0150208
- Stefan Kück et al., *Single-photon sources for quantum radiometry: a brief review about the current state-of-the-art*, Applied Physics B 128(28), 1-8 (2022); https://doi.org/10.1007/s00340-021-07734-2

# Member Survey Results

1. What are the most remarkable achievements in the field of single/few photon metrology for the last 3 years? Please list up to 3 publications. (2/3)

- Chenglong You et al., *Scalable multiphoton quantum metrology with neither pre- nor post-selected measurements*, Applied Physics Reviews 8, 041406 (2021)
- M. Pompili et al., *Realization of a multinode quantum network of remote solid-state qubits*, Science 372(6539), 259-264 (2021)
- Hristina Georgieva et al., *Absolute calibration of a single-photon avalanche detector using a bright triggered single-photon source based on an InGaAs quantum dot*, Opt. Express 29, 23500-23507 (2021)
- Hristina Georgieva et al., *Detection of ultra-weak laser pulses by free-running single-photon detectors: Modeling dead time and dark counts effects,* Applied Physics Letters 118(17), 1-6 (2021); https://doi.org/10.1063/5.0046014

# Member Survey Results

1. What are the most remarkable achievements in the field of single/few photon metrology for the last 3 years? Please list up to 3 publications. (3/3)

- P. Hu et al., *Detecting single infrared photons toward optimal system detection efficiency*, Optics Express 28(24), 36884 (2020)
- D. V. Reddy et al., *Superconducting nanowire single-photon detectors with 98% system detection efficiency at 1550 nm*, Optica 7(12), 1649-1653 (2020) **x2**
- B. Korzh et al., *Demonstration of sub-3 ps temporal resolution with a superconducting nanowire single-photon detector*, Nature Photonics 14, 250-255 (2020)
- T. Gerrits et al., *Calibration of free-space and fiber-coupled single-photon detectors*, Metrologia 57, 015002 (2020)

# Member Survey Results

2. What are the major conference events in which your group is participating in the field of single/few photon metrology for the last 3 years? Please list up to 3 events?

- Single Photon Workshop (SPW) 2022
- NEWRAD 2021 and 2023 (upcoming)
- QED-C Workshop
- The CU Boulder/NIST <Q|School
- European Quantum Technologies Conference 2023 (upcoming)

# Member Survey Results

3. What are the major standardization activities in which your group is participating in the field of single/few photon metrology for the last 3 years? (1/2)

- Review of the NIST single-photon dictionary
- Participation in CIE terminology document
- QED-C Single-Photon Measurement Infrastructure for Quantum Applications Workshop
- IEC 61788-22-3 Superconducting (nano)strip photon detector – Dark count rate, released in Aug. 2022
- Participation to the pilot study of CCPR WG-SP TG11 (SPAD detection efficiency at 850 nm) **x3**
- Participation in the CEN-CENELEC Focus Group on Quantum Technologies (FGQT) writing the "Standardization Roadmap on Quantum Technologies"

# Member Survey Results

3. What are the major standardization activities in which your group is participating in the field of single/few photon metrology for the last 3 years? (2/2)

- Training of academic and industrial scientists in single photon metrology in the The CU Boulder/NIST <Q|School: Introduction to Single Photonics and Quantum Radiometry Short Course: Sources, Detectors and Measurements, https://www.colorado.edu/initiative/cubit/single-photonics-and-quantum-radiometry-short-course
- Development of the primary standard for optical fiber power meters and fiber-coupled single photon detectors based on the absolute radiometer [NIST-NRC cooperation]

# Member Survey Results

4. [For NMI members] What are the urgent needs for SI traceability in the field of single/few photon metrology? (1/2)

- Accurate $g^{(2)}$ measurement using photon number resolving single-photon detectors [NRC]
- On-chip device characterization [NRC]
- Low-light optical power measurements of quantum sources [NRC, KRISS]
- Performance test of sources and detectors in the “commercial” QKD systems on request of the government authority [KRISS]
- Calibration service: in 2023, we performed calibration of two single photon detectors at 1550 nm for a commercial company [NIST]

# Member Survey Results

4. [For NMI members] What are the urgent needs for SI traceability in the field of single/few photon metrology? (2/2)

- High precision connectors and high accuracy splice and connector characterization so that the losses due to these can be included in calibrations of efficiency and uncertainty analysis [NIST]
- Continuous wavelength coverage of efficiency calibration at the lowest uncertainty [NIST]
- Primary standard at the few photon level, either based on electrical substitution or photon momentum, rather than via electrical substitution at the $10^{-3}$–$10^{-4}$ W level followed by attenuation down through 12–18 orders of magnitude [NIST]
- For single-photon metrology: no need with respect to traceability to the SI, issues are mainly technological [PTB]
- For quantum metrology based on entangled photons: definition of terms, protocols and important measurands required [PTB]