

Consultative Committee for Photometry and Radiometry (CCPR)
24th Meeting (19 - 20 September 2019)

Questionnaire on activities in radiometry and photometry

Reply from: Czech Metrology Institute

Delegate: Marek Šmíd

1. Summarize the progress in your laboratory in realizing top-level standards of:
 - (a) broad-band radiometric quantities:

Study of Long-term Spectral Responsivity Stability of Predictable Quantum Detectors (PQEDs)

The spectral responsivity values of several PQEDs, used to evaluate their EQE, have been measured using two independent state of the art cryogenic radiometer facilities in the Czech Metrology Institute (CMI) and the Physikalisch-Technische Bundesanstalt (PTB) with the highest accuracy currently available. (Porrovecchio G., Smid M., Werner L., Johannsen U., Linke U.). The study has been going on over a period of more than eight years: starting from about one year after the photodiode manufacturing in 2011 to the current date; where the core part of results has been accomplished in the years 2016-2019. The measurements were performed on a set of laser lines covering the visible spectral range: 476nm, 532 nm, 647 nm, 760nm, 800 nm and 850 nm. All PQEDs were room temperature operated.

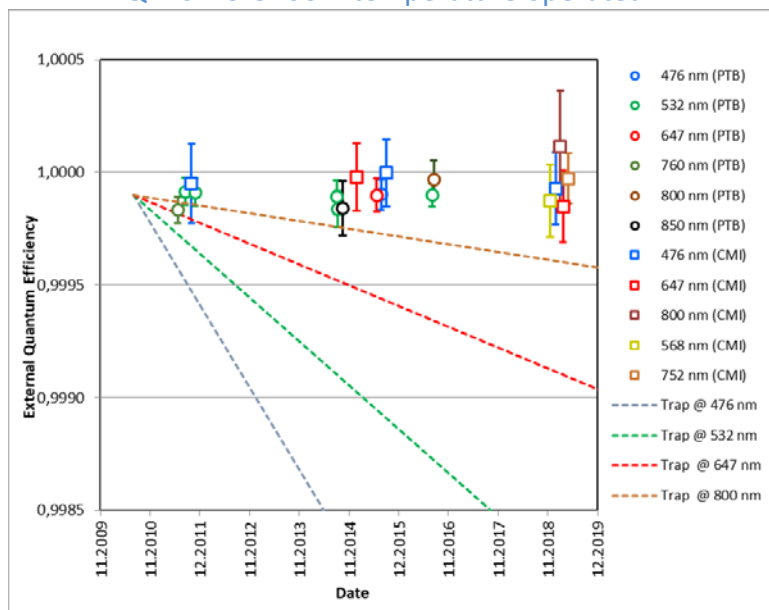


Fig. 1 Results of CMI and PTB PQEDs long term stability study

The data collected by for a period of time of over 8 years either don't show any noticeable temporal degradation within the stated measurement uncertainties. As shown in figure 1

the PQED outperform the traditional trap detectors (TDs) in terms of EQE temporal stability over all visible spectral range, most remarkably at shorter wavelengths where the TD exhibit the largest temporal drift: about 370 ppm/year.

Cryogenic Bolometer as a Novel CMI Primary Absolute Standard Detector for Optical Power Measurements for Fibre Optics and Photonics

CMI has developed a fibre coupled cryogenic bolometer aiming to establish a novel primary absolute standard detector for measurements of optical and photonics fibres with the target measurement uncertainty better than 0,2 % (*Marek Šmíd, Geiland Porrovecchio, Malcolm G. White, Nathan A. Tomlin, Igor Vayshenker, Christopher S. Yung, John H. Lehman, SPIE Proceedings Volume 10683*). The system uses a lithographically grown chip with carbon nanotube forest grown on a flat Si substrate built by NIST (*N A Tomlin, M White, I Vayshenker, S I Woods and J H Lehman, Planar electrical-substitution carbon nanotube cryogenic radiometer 2015 Metrologia 52 376*). The chip comprises integrated electrical heaters and a TES-based temperature sensor. The CMI mechanically cooled ultra-low vibration cryostat facility allows fast cool-down process and possibility to tune the operational temperature of the absorber between 3K to 6 K according the optimal TES sensitivity. CMI developed controlling software for running the system, performing the optical power measurements using the static substitution method and the DUT calibration process. Two independent optical channels have been implemented: one for 850 nm and one common for telecom spectral ranges. To switch between the cryogenic radiometer optical channel and DUT optical channel CMI utilises spectrally calibrated MEMS-based switch with high stability of operation (developed by METAS). The first experiments comparing the fibre coupled cryogenic radiometer calibration of CMI reference FO radiometer with its current calibration data (based on CMI CR working on visible and transfer to IR using a RT pyro-detectors) show agreement at the level of 0,5 % (within the current CMI scale stated uncertainty 0, 7%). Further characterisation of optical losses of input optical fibres and their temperature dependence is going on.

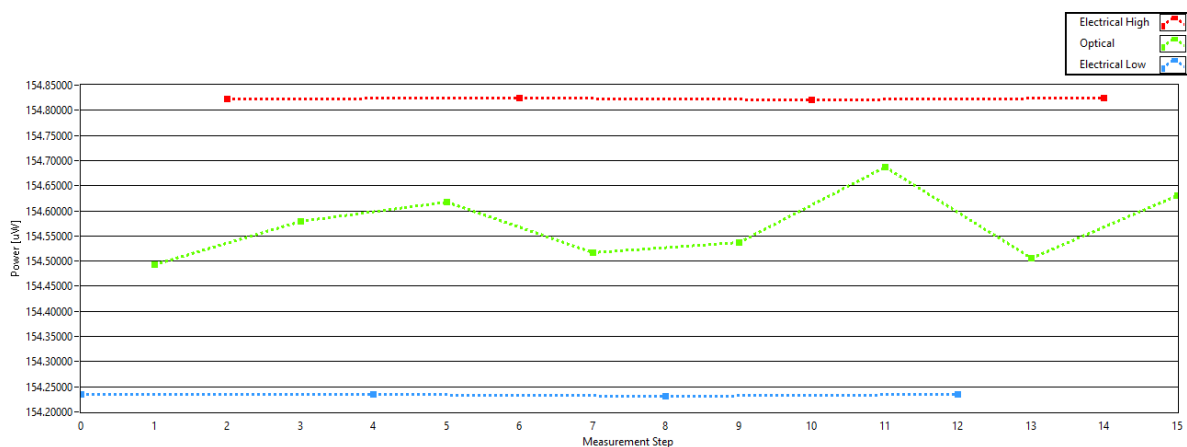


Fig. 2 Optical power measurement performed with the fibre coupled bolometer in CMI using static substitution method

Low Photon Flux Transfer Standard detector for Absolute Calibration of Free Beam Photon Counters (LOFD)

New transfer standard detector to provide direct traceability for absolute calibration of photon counters in visible and near infrared spectral ranges (Si-range) has been developed in CMI (G. Porrovecchio and M. Šmíd: Traceable Analog Detector for Quantum Radiometry, 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018)). It consists of commercially available silicon detector in conjunction with custom-made low noise switched integrator based electronics that provides a current to voltage conversion of $10E12$ with just 1 second of integration time. Its broad dynamic range spans from classical radiant flux levels of $10e-6$ W (allowing its direct calibration using currently established classical standard radiometers) down to the $30E-15$ W. The lowest power level measured was 30 fW with less than 2% noise.

The LOFD has been used in a bilateral comparison with the low photon flux scale realized using the fully independent double attenuation technique in PTB at power levels lower than 100 fW. The deviation values between the two techniques are reported in figure 2 and are compatible with the expected uncertainties. (G. Porrovecchio, .. Metrologia 53 1115–1122)

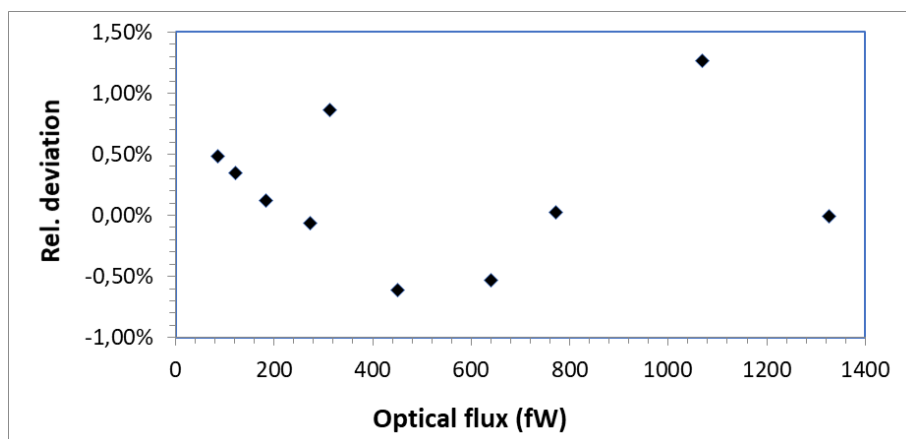


Fig. 3 Relative deviation between the LOFD scale and the double attenuation technique (PTB)

Low Photon Flux Fibre Coupled Transfer Standard detector for Calibration of Photon Counters Working in Telecom Spectral Range (LOFIR)

To cover the NIR spectral range the LOFIR detection system has been developed; it comprises a dual-stage thermally-cooled InGasAs photodiode in conjunction with a highly sensitive low noise SIA custom made electronics. The photodiode with circular sensitive area of 3 mm diameter was selected based upon the optimal trade-off between noise, and its minimum sensitive area required to achieve underfilled configuration for both free beam and fibre coupled set up. The LOFIR is equipped with a fibre coupler, designed in National Physical Laboratory (NPL), to keep the tip of the fibre at a minimum distance from the photodiode housing window. The LOFIR photodiode's responsivity has been calibrated in CMI in the spectral range from 1200 nm to 1650 nm with a relative standard uncertainty of about 0.4%.

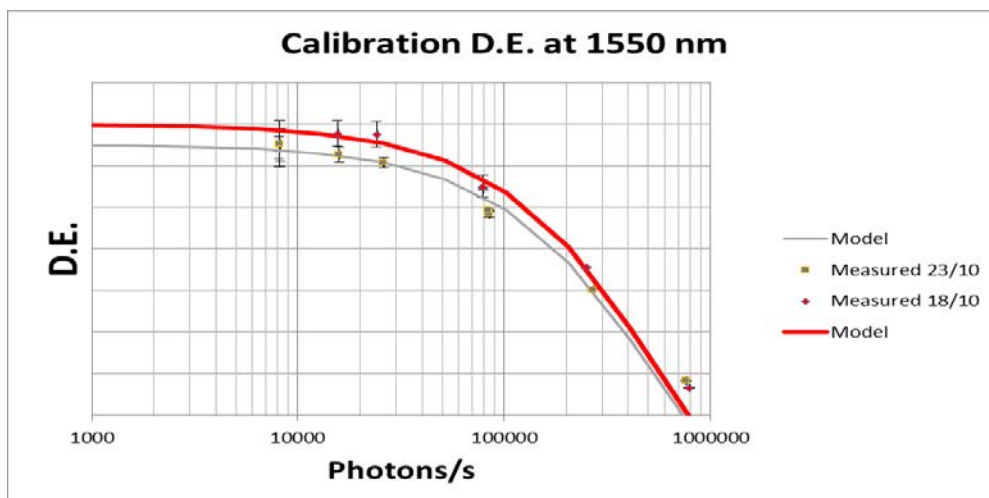


Fig. 4 Detection efficiency of free running single photon detectors for telecom measured with the LOFIR

During a measurement campaign performed in INRIM to calibrate the detection efficiency of fibre coupled single photon detectors the LOFIR measured down to 88 fW of optical power with a relative noise of 1.2% and a total relative standard uncertainty of 2 %. LOFIR will be a valuable tool for low photon flux calibrations, such as required for calibrating quantum key distribution hardware.

(b) spectral radiometric quantities:

Robot-based spectro-goniophotometer for BRDF measurements

The automated robot based spectro-goniophotometer for measurements of BRDF of complex materials was developed and its operation launched in CMI in 2016. Flexible system allows us to operate it both in monochromatic illumination- broadband detection and broadband illumination spectrally resolved detection modes. Its development and successful validations run through the EMRP project xDReflect. Recent works focussed on BRDF measurements of dark and gonio-chromatic samples, with close collaboration with MSL, New Zealand, as well as development of standard measurements methods for characterising of sparkle effect (in cooperation with IO-CSIC, Spain). These works are currently going on within the framework of EMPIR project Its results feed the work of CIE TC2-85 and CIE JTC 12.

Automated OPO laser-based system for spectral characterisation of radiometers

In 2018 CMI implemented and started operating the new 1 kHz repetition rate 1 ns pulsed laser system. In conjunction with pulsed wave meter this system offers excellent metrological parameters for spectral characterisation of broadband/filtered radiometers as well as spectroradiometers in terms of characterisation of their wavelength scale, optical bandwidth and internal straylight. System operates in the spectral range from 210 nm to 2500 nm.

- (c) photometric quantities :

PQED as a direct standard photometer for LED-based sources

As a part of EMRP project NEWSTAR SIB57 CMI in collaboration with PTB and Aalto characterised room temperature PQED for operating as a direct primary photometer (*Katharina Salfner, et al., Metrologia, 55 (2018)*). Further works in this direction have been going on within current EMPIR project PhotoLED 15SIB07, where this potential has been validated via comparison study using standard LED sources LISA.

2. What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

The Design and Development of Tuneable and Portable Radiation Source (TuPS) for in-situ Spectrometer Characterisation

The Tuneable Portable Source (TuPS) was developed as an instrument to be used for determining the slit function and centre wavelength of a Dobson Spectrophotometer. These works running within the EMRP project ENV59 ATMOZ were based on experience received from CMI lab based characterisation works (*Köhler et al, Atmos. Meas. Tech., 11, 1989–1999, (2018)*).

TuPS was characterized at CMI for bandwidth and the central wavelength accuracy all over the spectral range of interest. Wavelength scale calibration and the investigation of FWHM bandwidth of emitted radiation was performed using the fibre coupled CMI tuneable laser facility – 1kHz ns pulsed OPO in combination with the CMI reference wave meter and they were proved to be better than 0.5 nm and 0.02 nm in respect. Additionally, the long term (one year) temporal stability of both key parameters has been measured over an interval of two years to be better than 0.02 nm. (*Smid M., et. al., The design and development of tuneable and portable radiation source for in-situ spectrometer characterization, Proceedings of the 29th CIE Session Washington D.C.*). The TuPS is designed such that only minor modification of its optical system extends/shifts its spectral range towards visible and near-infrared spectral region and thus it is possible to expand its application for spectral characterisation of spectrometers in different spectral regions.

3. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.

Emerging technology of cost efficient mini- and micro-spectrometers is gradually replacing traditional radiometric measurements systems in many industrial oriented applications. Although the traditional high accuracy calibration methods are as well applicable for characterization of these systems, they are often not efficient enough for our industrial partners. Therefore, we see the space for discussing harmonization of calibration methods of these systems within CCPR in future.

4. What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

N/A

5. What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

CMI backs the strategical priorities listed in CCPR strategy document. From our point of view following areas seem to have highest priority, taking it for highest expected stakeholders request in near future:

- Metrology support for quantum photonics
- Metrology of visual appearance and optical properties of material in general
- Efficient calibration methods/instruments for in-field calibrations of (spectro)-radiometers for industries, meteorology, etc...
- Metrology support for evaluation of non-visual effect of optical radiation
- Development of novel LED- based standard sources for photometry

6. Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

Our international research collaboration is currently concentrated in cooperation with mostly European partners within the ongoing EMPIR projects. Besides that, CMI currently as well collaborates intensively with NMIs from other RMOs on particular joint projects, with NIST, US and MSL, New Zealand.

7. Have you got any other information to place before the CCPR in advance of its next meeting?

non

8. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2016)?

2019

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