Traceable calibration of single-photon detectors and accurate determination of fibre-coupling loss

Anders Brusch[1*], L. C. C. P. Filho[1], J. B. Christensen[1]

[1]*Danish Fundamental Metrology, Kogle Allé 5, 2970 Hørsholm, Denmark*

**ab@dfm.dk*

Abstract: Optimal performance of photon-based quantum systems, such as single photon quantum computing and quantum key distribution, requires a detailed understanding of the different subsystems. Of particular interest is knowing the quantum efficiency of the single-photon or lowpower detectors that are used in these systems.
Performing accurate calibrations in the relevant pico- to femtowatt regimes is challenging due to the large attenuation required when referencing the microwatt power level that is realized in typical traceable power calibration.

We present Hyperion, a commercial prototype of a single-photon calibration device, developed at the Danish National Metrology Institute (DFM). This device, which was initially conceptualized and demonstrated in the EMPIR projects QaDET and METISQ, provides a fibre-coupled and power-stabilized output in the single-photon power regime traceable to DFMs primary scale of optical power. The device is based on a series of fibre attenuation stages that are configured to allow accurate system calibration at the few % level. Its performance has been validated through internal comparison of three similar devices at the nanowatt level, and it has also been used as a calibrated source to characterize heterodyne detectors" [1]. We will present recent internal test results as well as the results of a comparison performed at a European NMI.

A recurring problem when measuring optical powers in fibre-coupled systems is to determine the coupling loss in the fibre-to-fibre interface. For calibrations with fibre coupled components such as the Hyperion, the uncertainty in fibre coupling can be the dominant factor. We present a novel method to characterize the coupling loss with an uncertainty that can reach the few permille level. This level of uncertainty is below that which is typically achieved with active core alignment of optical fibres.
The method can be used in many scenarios where accurate knowledge of losses is important [2].

Acknowledgements
The project is supported by funds from Danish Agency for Higher Education and Science.

References

[1] L.C.C.P. Filho, J. B. Christensen, A Brusch, M Lassen. "Quantifying Effective Heterodyne Detection Efficiency with SI-Traceable Standards". arXiv:2602.20301

[2] L.C.C.P. Filho, A Brusch. Method for estimating the fibre-to-fibre coupling loss and the free space coupling efficiency. Manuscript in preparation