Metrological Uncertainty and International Comparisons in Brillouin Light Scattering and Microwave Photonic Systems

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Abstract—Brillouin Light Scattering enables key functionalities in nonlinear quantum photonics, from precision sensing to low-noise microwave generation. This contribution highlights the importance of rigorous uncertainty evaluation and international comparability. Recent analyses of Brillouin frequency shift measurements using tandem Fabry-Pérot interferometry and phase noise characterization of optoelectronic oscillators are reviewed within a global metrology framework.

Keywords—Measurement Uncertainty; International Comparisons; Uncertainty analysis; Brillouin Light Scattering; Microwave Photonics; Optoelectronic oscillator

I. Introduction

Brillouin and Raman scattering processes play a central role in nonlinear quantum photonics, enabling high-resolution sensing, frequency generation, and ultra-low-noise microwave photonic systems. As these applications increasingly support fundamental measurements and advanced technologies, rigorous uncertainty evaluation and traceability to international standards become critical. This contribution presents a coherent metrological framework for Brillouin Light Scattering (BLS) and optoelectronic systems, drawing on recent results spanning optical spectroscopy, microwave photonics, and global metrology coordination.

II. International Comparison and Uncertainty Analysis

Measurement uncertainties are estimated following the Guide to the Expression of Uncertainty in Measurement (GUM) [1]. There is still a debate regarding the determination of measurement uncertainty [2]. The role of international comparisons in ensuring consistency and equivalence among national metrology institutes is reviewed, highlighting their importance for optical frequency, time, and microwave standards in a global measurement system [3,4]. This context establishes the necessity of harmonized uncertainty budgets for photonic measurements derived from nonlinear light–matter interactions.

III. Application to BLS and Optoelectronics Oscillators

A detailed uncertainty analysis of Brillouin frequency shift measurements using a scanning tandem Fabry-Pérot interferometer is discussed [5]. Key contributions include the impact of interferometer free spectral range calibration, scanning nonlinearity, signal-to-noise ratio, and fitting procedures on the overall measurement uncertainty estimated to be in the range of 0.26% for the expanded relative uncertainty in the measured Brillouin frequency shift. These results are directly relevant to Brillouin spectroscopy, distributed fiber sensing, and phonon-based quantum photonic platforms. Then we address uncertainty evaluation in the phase noise characterization of a 10.52 GHz optoelectronic oscillator, with 2dB on phase noise estimation [6], emphasizing the links between optical sources, Brillouin interactions, and microwave signal purity. The analysis demonstrates how metrological rigor enhances the reliability and comparability of phase noise measurements in photonic oscillators.

IV. Conclusion

Together, these results underline the critical importance of uncertainty quantification and international comparability for Brillouin Light scattering applications and in Optoelectronics, paving the way for robust, traceable, and globally consistent nonlinear quantum photonic technologies.

References

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