Scheme for sub-shot-noise transmission measurement using a time multiplexed single-photon source

Agustina G. Magnoni[1,3], Laura T. Knoll[2,1], and Miguel A. Larotonda[1,3]

[1] Laboratorio de Óptica Cuántica, DEILAP, UNIDEF (CITEDEF-CONICET), Buenos Aires, Argentina.
[2] INRIM Istituto Nazionale di Ricerca Metrologica, Turin, Italy.
[3] Departamento de Física, Facultad de Ciencias Exactas y Naturales, UBA, Ciudad de Buenos Aires, Argentina.
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Abstract. A promising result from optical quantum metrology is the ability to achieve sub-shot-noise performance in transmission/absorption measurements. In this work, we simulate results from an experiment that uses a multiplexed single-photon source based on pair generation by continuous spontaneous parametric down conversion (SPDC). Results show that sub-shot-noise performance can be achieved, even without using number-resolving detectors, with improvement factors that range from 1.5 to 2. This technique would allow transmission/absorption measurements with reasonable uncertainty using ultra-low light intensity and minimum disruption of biological or other fragile samples.

Keywords: quantum imaging, single-photon sources, sub-shot-noise

Due to the significantly lower uncertainty in light intensity of quantum beams with respect to their classical counterparts, optical quantum metrology has the potential ability to achieve sub-shot-noise performance in transmission measurements. In this work, we simulate results from an experiment that uses a specific single-photon source based on SPDC and time multiplexing (BinMux-SP) [1,2]. The strategy is to approximate an N-photon perfect Fock state using single-photon generated from the BinMux-SP source as input and performing N repetitions. In a direct measurement scheme, we construct estimators for both number-resolving and threshold detectors.

We compare the performance of the BinMux-SP source with two binary time correcting stages with that of an ideal single photon source and a weak coherent pulse source with Poissonian statistics. Figure 1 shows the improvement factor (the ratio between the mean-squared error (MSE) of the shot-noise limit and the one obtained with each source) as a function of the transmission for number-resolving detectors and threshold detectors (inset). The mean number of photons incident on the sample is set to 1 in all cases. Sub-shot-noise performance can be achieved even without using number-resolving detectors, with improvement factors ranging from 1.5 to 2. In terms of accuracy, the number-resolving detectors are unbiased, as opposed to the threshold detectors.

While the precision may be arbitrarily reduced with increasing repetitions in the number-resolving case, a fundamental limit exists in the threshold case. Nonetheless, the bias is non-trivially reduced to zero for $t = 1$, indicating that an acceptable performance can still be obtained for low absorption samples. Such results encourage the use of multiplexed single-photon sources as suitable input beams for transmission estimation, while achieving a large quantum enhancement. Particularly, this study of the BinMux-SP source takes into account several experimental imperfections and show that multiplexed single-photon sources represent a valid, cost-effective and room-temperature alternative to other single-photon sources.

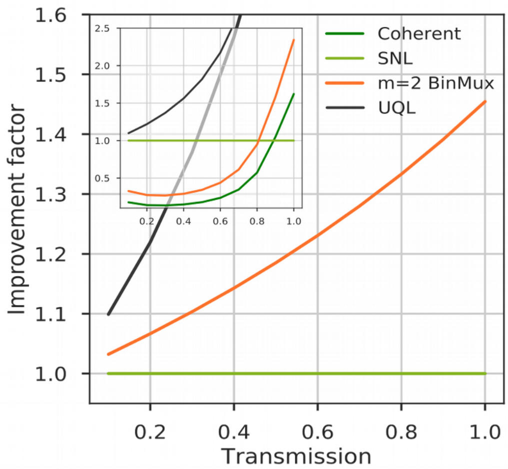

Figure 1 Improvement factor as a function of transmission for number-resolving detection and (inset) threshold detection, 200 repetitions.

References

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