Intensity correlations of thermal light

Noise reduction measurements and new ghost imaging protocols

T. Iskhakov¹, A. Allevi², D.A. Kalashnikov³, V.G. Sala⁴, M. Takeuchi⁵, M. Bondani⁶, and M. Chekhova¹,⁷
¹ Max-Planck-Institute for the Science of light, G.-Scharowsky Str. 1/Bau 24, 91058 Erlangen, Germany
² Dipartimento di Fisica e Matematica, Università degli Studi dell’Insubria and C.N.I.S.M., via Valleggio 11, 22100 Como, Italy
³ Data Storage Institute, Agency for Science Technology and Research, 117608 Singapore
⁴ Laboratoire Kastler Brossel, École Normale Supérieure, Université Pierre et Marie Curie-Paris 6 et CNRS, UPMC Case 74, 4 place Jussieu, 75005 Paris, France
⁵ Department of Arts and Sciences, Graduate School of Science, the University of Tokyo, 3-8-1 Komaba, Meguro-ku, 184-8795 Tokyo, Japan
⁶ Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche and C.N.I.S.M., via Valleggio 11, 22100 Como, Italy
⁷ M.V. Lomonosov Moscow State University, Vorobievy Gory 1, Moscow 119991, Russia

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Abstract. We demonstrate measurement of normalized Glauber’s intensity correlation functions of different orders using an array photodetector. As the light source, we use a laser beam scattered by a rotating ground-glass disc, which has statistics close to that of thermal light. We compare the measurements of the normalized correlation functions to that of the difference-intensity variance and show that they are in a certain sense complementary. The independence of the variance measurement on the number of temporal modes has been demonstrated for the first time. Different versions of high-order ghost imaging are also realized and characterized quantitatively.

1 Introduction

The formalism of normally ordered correlation functions was introduced by Roy Glauber in 1963 [1] and since then has been widely used for the characterization of classical and nonclassical states of light [2]. Interestingly, the first measurement of such correlation functions had been performed earlier than the theoretical base was introduced, namely, in the famous work by Hanbury Brown and Twiss [3]. Indeed, a Hanbury Brown – Twiss (HBT) interferometer measures Glauber’s correlation functions (GCFs). There are two basic configurations of the HBT interferometer. The most commonly used one involves a beamsplitter and two detectors in its output arms, and a coincidence circuit (or a photocurrent correlator), to which the signals from

*e-mail: drquantum@hotmail.com
the detectors are sent [3]. Another configuration, used in the HBT stellar interferometer [4], involves no beamsplitter but instead, two spatially separated photodetectors. This configuration can be very useful if one considers the measurement of GCFs of orders higher than two, as a large number of beamsplitters can be avoided in this case. However, there still remains the problem of using many detectors. For this, a good solution are multi-pixel or array photodetectors, in which each pixel can be considered as a single detector. At present, the most advanced array detectors are CCD cameras and their more sensitive analogues, ICCDs and EMCCDs. If particularly high quantum efficiency or particularly low noise are not required, even a commercial digital photographic camera can be used for the measurement of GCFs [5].

Most useful are not just GCFs but GCFs normalized to the products of the mean intensities measured by the detectors [2]. Similarly to photocount probability distributions, normalized GCFs are an instrument for studying the statistics of light. An important advantage of normalized GCFs compared to photocount statistics is that they are not sensitive to losses [2]. In terms of normalized GCFs, one can formulate observable signs of nonclassicality [6,7]. For instance, the nonclassical effect of anti-bunching, in which the second-order normalized GCF is less than the unity, is widely used to indicate a single emitter. In the original experiment on observing anti-bunching [8], emission from a single atom was studied; nowadays, similar measurements are performed with single quantum dots, trapped ions, and other microscopic emitters. Measurements involving GCFs are not sensitive to phase distortions. This is why, for instance, the HBT stellar interferometer [4] outperforms the Michelson one.

Besides the GCF measurement, classical and nonclassical intensity correlations can be studied by measuring another parameter, the variance of the intensity difference for two beams. In the quantum optics of bright beams, this is the main measurement tool. Remarkably, the features retrieved by this measurement are in a sense complementary to those provided by the GCF measurement.

Intensity correlations are at the basis of the technique of ghost imaging (GI) [9]. One of the important advantages of GI over other imaging methods is that it is robust against atmospheric distortions [10], a direct consequence of the fact that it relies on the intensity, rather than field, correlations. Although initially GI was considered as a purely nonclassical technique, later it was demonstrated with classical light [11]. At present, most GI experiments use pseudo-thermal sources to provide intensity correlations [12,13].

There are several schemes of GI. In the most commonly used ones, the image is restored by calculating normalized GCFs or GCFs with the background subtracted. Without normalization or background subtraction, GI has low signal-to-noise ratio, which, in addition, scales as the inverse resolution parameter (number of details in the image) [14–16]. GI based on normalized GCFs or on correlation functions of intensity fluctuations provide signal-to-noise ratio scaling as the inverse square root of the resolution parameter. The same behavior is typical for the GI with twin-beam light provided that the mean photon number is adjusted according to the resolution [16,17]. Recently there were attempts to increase signal-to-noise ratio by passing to higher-order GI, i.e., GI based on the measurement of GCFs of orders higher than two [18]. However, it was shown theoretically [14,15] that in this case, too, optimal conditions of the experiment depend on the required resolution. Namely, the resolution determines the optimal order of intensity measured by each detector. This theoretical conclusion has not yet been experimentally confirmed. Finally, in recent works [16,19] it was suggested to use for GI the variance of the intensity difference as an alternative to GCFs. The resulting signal-to-noise ratio also scales as the inverse square root of the resolution.

Thus, normalized GCFs of different orders represent an important tool in quantum and statistical optics. At the same time, a somehow complementary information is