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Method for a photon number statistics estimation

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Abstract

We report on the theory and experimental verification of a novel approach to the problem of estimating the statistics of photons emitted from an unknown source of light. In particular, we investigate two types of detection systems, based on photon-number resolved single photon detectors and spatial multiplexing with four bucket detectors.

There are many applications of quantum photonics technologies, which require a strictly defined number of photons for their correct working. However, realistic sources of light are imperfect and the number of photons generated by them in a single pulse can be governed by various probability distributions. Precise characterization of a given source is therefore an essential condition for its reliable utilization in practice. Unfortunately, also the detection systems that can be used for this task in realistic situation are imperfect. Due to this fact, the number of photons emitted in a single pulse typically corresponds to the number of clicks registered in a detection system in non-trivial way. In effect, the estimation methods for the probabilities of emitting different number of photons often rely on precise measurement of several quantities and are unstable to the statistical fluctuations. This means that a slight change in the measured values can lead to a dramatic change in the calculated probabilities. Moreover, multipixel detectors, which offer decent photon-number resolution, are usually plagued by significant level of crosstalk, further complicating precise characterization of photon sources [1, 2, 3].

Here we present a novel approach to the problem of estimating the statistics of photons emitted from an unknown source of light by utilizing a detection system based on spatial multiplexing of four on/off single-photon detectors [4]. To this end we derive a set of analytical formulas that can be used to estimate the probabilities of producing up to four photons by the source. We also calculate the error bounds and show that the obtained formulas are relatively stable to the statistical fluctuations. To test it we perform numerical simulations of a spontaneous parametric down-conversion (SPDC) source in realistic situation. Assuming that the relative errors of all the quantities that should be measured in experiment are within 2%, we demonstrate that the expected photon statistic is recreated correctly with errors for the probabilities of emitting one, two and three photons smaller than 3%, 7% and 15% respectively. Furthermore, we show how the relevant parameters of the detection system can be estimated by using a single-mode SPDC source with unknown intensity of the generated light.

The method can be implemented using standard on/off detectors or multipixel ones. The results of our work have several applications including phase estimation utilizing multiphoton interference effects [5] and quantum optical coherence tomography [6]. They may be also used in the analysis of the number of luminescent color centers located in diamonds [7].

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