Room-Temperature Photon-Number-Resolved Detection Using A Two-Mode Squeezer

Elisha S. Matekole[1], Deepti Vaidyanathan[2], Kenji W. Arai[3], Ryan T. Glasser[4], Hwang Lee[1], Jonathan P. Dowling[1]
[1]*Hearne Institute for Theoretical Physics and Department of Physics and Astronomy, Louisiana State , Baton Rouge, Louisiana 70803, USA.*
[2]*Baton Rouge Magnet High School, Louisiana 70806, USA.*
[3]*Reed College, Portland, Oregon 97202-8199, USA.*
[4]*Department of Physics and Engineering Physics, Tulane University, New Orleans, LA 70118, USA.*
Email: esiddi1@lsu.edu

Abstract:We study the average intensity-intensity correlations signal at the output of a two-mode squeezing device with $|N\rangle \otimes |\alpha\rangle$ as the two input modes. We show that the input photon-number can be resolved from the average intensity-intensity correlations. In particular, we show jumps in the average intensity-intensity correlations signal as a function of input photon-number N. Therefore, we propose that such a device may be deployed as photon-number-resolving detector at room temperature with high efficiency.
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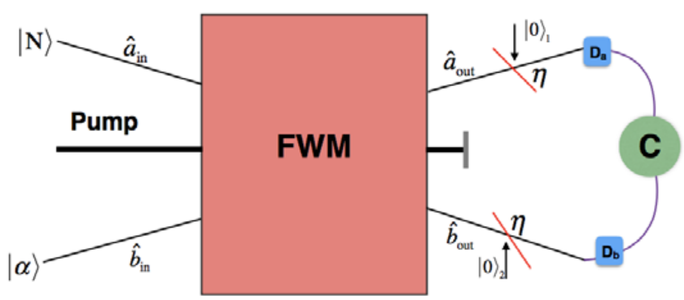
Photon-number-resolving detectors (PNRD) are crucial to the field of quantum optics, and quantum information processing. PNRD can be useful in two major classes of application: Single-shot measurement of photon number, and ensemble measurements for photon number statistics. Single-shot photon number measurement is useful in the field of linear optical quantum computing, quantum repeaters, entanglement swapping, and conditional state preparation [1-5].

Ensemble measurement based PNRD can be used in quantum interferometry for measuring photon statistics, characterization of quantum light sources, and improvement in sensitivity and resolution [6-10]. For example, a true single-photon source is important for quantum key distribution. The ultimate security of the key can be compromised if the source emits more than one photon in the same quantum bit state. Hence, a photon-number resolving detector that can characterize the single-photon source accurately is vital for the success of quantum key distribution [11-12]. Also, the reconstruction of photon-statistics of unknown light sources by ensemble measurements can be used to determine the nature of the light source (classical or non-classical), and detection of weak thermal light, and coherent light.

We propose a scheme to resolve photon number at room temperature without using photon-number-resolving detectors, and calculate the output signal. We use a two-mode squeezing device, such as an optical parametric amplifier (OPA), or a four-wave mixer

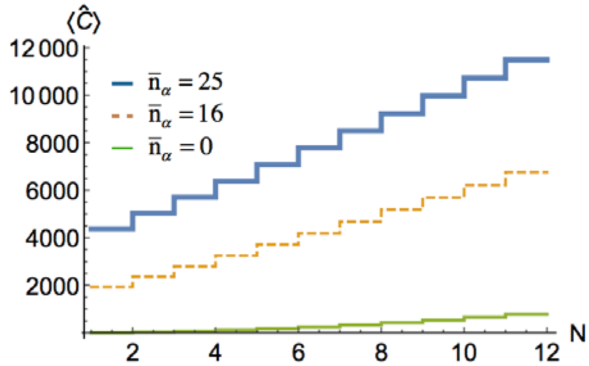


(FWM), in a spatially non degenerate configuration.

Fig. 1. The schematic diagram of a room-temperature number-resolving photon detector. The two-mode inputs to the four-wave mixer (FWM) are *N*-photon Fock states, and a coherent state of light \$$|\alpha\rangle$, $\hat{a}_{in}(\hat{a}_{out})$ and $\hat{b}_{in}(\hat{b}_{out})$ represent the mode operators of input (output) light beams. The average intensity-intensity correlations and the noise in the intensity-intensity correlations are detected at the output. The losses due to imperfect squeezing and the inefficiency of the photon detectors, are modeled by adding fictitious beam splitters each of overall transmissivity η, where the vacuum modes are denoted by $|0\rangle_1$ and $|0\rangle_2$.

The setup used for the proposed scheme is shown in Fig. 1. An unknown *N*-photon state is incident on one port of the FWM and a coherent-light state with average photon number $\overline{n}_\alpha$ is incident on the second port. The average intensity-intensity correlations $\langle\hat{C}\rangle$ and the noise in the intensity-intensity correlations $\Delta\hat{C}$ are measured at the output to detect the input photon number.

The average intensity-intensity correlations and the standard deviation (noise) of the average intensity-intensity correlations as a function of the input photon state are plotted in Fig. 2. From the figure we can see that there is a huge jump in both $\langle\hat{C}\rangle$ and $\Delta\hat{C}$ even when a single photon is incident on the FWM. What is interesting is the amplification of the noise in the intensity-intensity correlations when a single photon is detected. Hence, a large change in $\Delta\hat{C}$ is an indicator of the presence of photon. In Fig. 2. we compare the amplitude of the signal for vacuum and coherent-light input respectively. The steps for the case of nonzero coherent-light input are greatly amplified compared to the vacuum, and hence this provides a boost to the intensity-intensity correlations signal. Thus the purpose of having coherent light as input to the second mode is to amplify the output signal while still displaying the steps as the photon number changes.



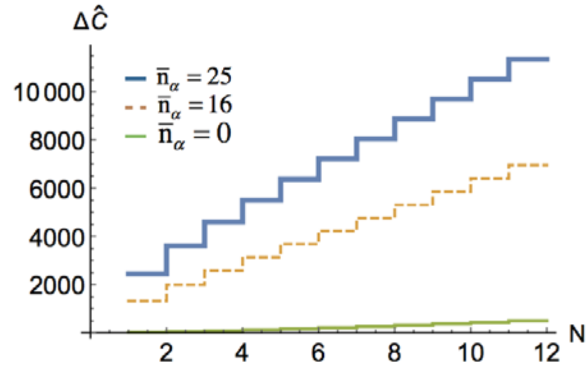


Fig. 2. Above figures show the average intensity-intensity correlations $\langle\hat{C}\rangle$ and the noise $\Delta\hat{C}$ in the intensity-intensity correlations as a function of input photon number N incident on one port of a two-mode squeezing device with $\bar{n}_s = 2$ respectively: Both$\langle\hat{C}\rangle$and $\Delta\hat{C}$ increase in steps as the input photon number changes in increments of one. When a single photon is incident, there is huge jump in $\langle\hat{C}\rangle$ and $\Delta\hat{C}$. $\langle\hat{C}\rangle$ and $\Delta\hat{C}$ for vacuum as input in the second mode shows smaller step sizes than those with coherent-light inputs. Hence the coherent-light state provides a *boost* to the $\langle\hat{C}\rangle$ and $\Delta\hat{C}$ signals. Also this shows that even in the presence of coherent state amplitude fluctuation, we still see the steps in the signal and the noise. Therefore, for a slowly fluctuating coherent state, we expect to observe slowly fluctuating signal while still maintaining the steps, representing the input photon number.

In summary we propose a room-temperature photon-number-resolving detector using a two-mode squeezer. The N-photon number state is fed into a two-mode squeezing device, along with a coherent-light input which amplifies the output signal. The output intensity-intensity correlations signal reports jumps with the changing photon number. Even in the presence of losses, the output signal is strong due to the amplification provided by the coherent light. Hence, we have a high efficiency photon-number-resolving detector. Since the scheme is robust against low detector efficiency, the intensity-intensity correlation measurement can be carried out at room temperature for optical photons.

Additionally since the photon-number states to be counted are boosted (amplified) in the squeezer, dark counts will have negligible. effect, particularly at room temperature. Also, this particular setup is robust against any phase fluctuations due to the presence of Fock states which are insensitive to phase. Hence, phase matching is not required, making our technique easier to implement in the lab.

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