

Managing weights and probing the phases of Schmidt modes of squeezed vacuum light

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Abstract

We present a development of ideas about quantum optical gates for non-classical squeezed light, which are based on sum-frequency generation (SFG) process. We worked out a theoretical description of sum-frequency generation process with seeding by squeezed light in terms of Schmidt modes which allows to clarify known results and also opens new prospects for managing spectral and temporal properties of the input squeezed light. In the case when several modes of squeezed light are involved in SFG, new possibilities, such as switching the weights and probing the relative phases of these Schmidt modes are found.

Squeezed states of non-classical light become the subject of numerous modern researches and find many applications in various fields of science due to their unique and important properties. For instance, decreased variance of one field quadrature of squeezed vacuum light is utilized in overcoming a standard quantum limit of measurements. Furthermore, it is a bright squeezed vacuum in which a large number of photons are entangled and correlated, what is very attractive to researchers in the field of quantum information.

To fully utilize all possibilities provided by squeezed light, one has to be able to control its spectral, temporal and spatial properties [1]. Unfortunately, the use of conventional methods and usual optical devices leads to the loss of the unique properties of such states due to introduced noise and losses. Therefore, for many applications fully quantum-optical methods are strongly required, which preserve useful properties of squeezed light and provide the possibility to tailor their features.

An example of such method is a quantum pulse gate (QPG) scheme, suggested in [1], [2] and [3]. Quantum pulse gate is based on nonlinear sum-frequency generation (SFG) process seeded by squeezed vacuum light, and allows to perform the selection of temporal modes of squeezed vacuum. This possibility is provided by special regime of SFG process, in which signal mode is determined only by pump spectrum profile. If pump spectrum matches single mode of squeezed vacuum seed, photons in this mode may be completely converted into sum-frequency mode. At the same time the matched mode is blocked in the output signal.

In this work we focus on further development of the quantum pulse gate scheme. Starting with complete theoretical description of SFG process in terms of Schmidt modes in frequency domain, we perform the generalization of QPG to a so-called quantum optical gate. Suggested theoretical model allows to calculate the influence of quantum optical gate on spectral and temporal properties of the squeezed vacuum seed. For instance, if pump spectrum matches single mode of squeezed vacuum seed, in case of full conversion into sum-frequency mode, the latter is in a squeezed vacuum state. In other words, such scheme converts any selected Schmidt mode into a well-defined mode centered at sum-frequency. For partial conversion both matched mode and sum-frequency mode are found in squeezed state, but with lower degree of squeezing. In addition we consider the case when several modes of the squeezed seed are involved in SFG conversion. The main result of the work is a description of case of multimode matching. Derived equations of transformation of Schmidt operators shed light on new integrals of motion and give full picture of the dynamics of matched Schmidt modes. New possibilities, such as switching the weights and probing the relative phases of the Schmidt modes are demonstrated. The relative phases of the Schmidt modes involved in SFG are shown to influence dramatically on the spectral and temporal output signal as well as are found to determine the variances of the field quadratures of the converted modes.

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