Non-classicality of Optical Hybrid States in Noisy Quantum Channel

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Some people think that quantum effects such as quantum superposition and quantum entanglement appear only in a physical system of microscopic scale. However, as Schrodinger discussed in the cat paradox, macroscopicity and quantumnes may not be an incompatible concept. In other words, there might exist a physical system of the macroscopic quantum property. Along the line, there have been many researches on deciding the effective size of a macroscopic system with quantum effects.

On the other approach, there exists some progress about the implementation of a macroscopic quantum state. One of the main ideas in this field is to use the toolbox in quantum optics. Using the toolbox one can build the macroscopic superposition state and the microscopic-macroscopic entanglement state, which may be suitable to test Schrodinger's cat paradox. Recently Jeong et al.[1] and Morin et al.[2] could implement the optical hybrid state composed of the polarization of a single photon and coherent state of multiphoton. The optical hybrid state can be used in loophole-free Bell's test and quantum gravity.

In fact, one has to consider the possibility of quantum noise in implementation of a optical hybrid state or investigation of quantumness by the optical hybrid state. A quantum noise can reduce the quantumness of optical hybrid state, which can be checked by the analysis of relation between the maximal Bell violation and the noisy quantum channel. If there is no violation in Bell-CHSH inequality, the optical hybrid state with noise may be considered to lose a macroscopic superposition[3].
In this paper, we examine the maximal Bell violation of optical hybrid state using a depolarizing-like channel and a local phase damping channel. We obtain the range of noise strength to preserve a macroscopic quantumness on the basis of maximal Bell's violation.

To understand Bell-CHSH inequality of optical hybrid state, one has to consider the detector to measure the states of microscopic system and macroscopic system. The detector of microscopic part discriminates the vertical and horizontal polarization. Since the outcome of a detector to macroscopic part is the number of photons, there can be many possibilities.

In our paper, we use the on/off measurement and the parity measurement. As a noisy quantum channel, we consider a depolarizing-like channel and a local phase-damping channel. The depolarizing-like channel changes an optical hybrid state into a product state with certain probability. Since the eigenvalues of product state are generally not a uniform distribution, a depolarizing-like noise is close to the color noise rather than the white noise. Since even in the classical communication, color noise occurs more frequently than white noise, the consideration of a depolarizing-like channel is suitable. And local phase-damping channel eliminates the element corresponding to phase in the partial state of optical hybrid state, with certain probability.

Here we assume that there are two detector observable for the microscopic and the macroscopic part in evaluating Bell-CHSH inequality[3]. If the value of Bell's operator is greater than 2, it means the existence of a non-classical correlation. It is equivalent to the existence of the macroscopic superposition. To understand the effect of a noise channel, we first consider optical hybrid state using a depolarizing-like channel. When a on/off measurement(parity measurement) is used, if noise strength is less than 0.2395(0.2923), the macroscopic superposition is partly preserved. According to the result, parity measurement is more effective to macroscopic superposition of optical hybrid state through a depolarizing-like channel. For a local phase-damping channel, one can see the different behavior according to whether the noise exists in microscopic part or macroscopic part. If the noise strength of microscopic part and macroscopic part are 0.2 and 0.2381 respectively, the optical hybrid state becomes separable. It should be noted that the limit of quantumness depends on the detector.

References

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