Entanglement in Quantum Communication: Dispersion Cancellation and Decoherence-Free Subspaces

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Abstract

We discuss several benefits that intelligent use of entanglement brings in quantum communication and quantum cryptography. We present results of theoretical modeling and experimental demonstration of new dispersion cancellation effect that enables us to separate even-order and odd-order spectral dispersion effects in two distinct sub-regions of a single quantum interference pattern. We discuss potential application of this effect for QKD as well as several other benefits of using a decoherence-free subspace concept as a resource for quantum communication.

Summary

We describe our theoretical and experimental results demonstrating new approach to manipulating dispersion in quantum interferometry using spectral properties of optical entanglement. Even-order dispersion cancellation that is based on frequency-anticorrelated entangled photons has been known for many years in quantum optics [1,2]. It has been used in several quantum measurement applications. This effect has been exploited for precise evaluation of a photon transit-time through a material [3] and for enhancing the accuracy of remote clock synchronization. The same effect has also provided superior accuracy in quantum optical coherence tomography [4] by reducing broadening of the coincidence interference pattern for the light passed through layers of dispersive material.

We recently designed new type of a quantum coincidence interferometer that illustrates odd-order and even-order dispersion cancellation effects in one single experiment. This effect is based on manipulation of quantum probability amplitudes of entangled-photon pairs produced in the nonlinear optical process of spontaneous parametric down conversion (SPDC). Selection of specific parameters of our coincidence interferometer enables us to separate the detection of two non-classical dispersion cancellation effects in one experimental setup. The interference pattern in the central section depends only on the even-order dispersion coefficients and it depends only on the odd-order terms for outside peaks. The position of outside peaks is directly proportional to the group velocity delay (first order coefficient). The shape of outside peaks is protected from a regular group velocity dispersion broadening (second-order coefficient cancelling) thus presenting an attractive option for a high-speed quantum communication.

This effect represents a generalization of the even-order quantum dispersion cancellation and opens new venues in quantum measurement and in quantum communication. We believe the possibility of accessing even-order dispersion terms independently from odd-order dispersion terms may find more applications in the field of applied quantum technology and communication. We also discuss the possibility of building a classical apparatus for mimicking this quantum effect within a narrow spectral interval. In many cases such classical counterparts prove to be rather useful for practical deployment in real world communication circuits.

From the standpoint of quantum information processing the dispersion cancellation due to frequency entanglement can be considered as a special type of decoherence-free subspace application. It is particularly useful in case of phase implementations of QKD. We also discuss several other decoherence-free subspace configurations that may improve quality of future quantum communication and quantum cryptography.

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