Mimicking an Amplitude Damping Channel for Laguerre Gaussian Modes

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Abstract: An amplitude damping channel for Laguerre-Gaussian (LG) modes is presented. Experimentally the action of the channel on LG modes is in good agreement with that predicted theoretically.

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1. Introduction

It has recently been shown that the time evolution of the entanglement of a qubit pair caused by a quantum channel acting on one of the qubits can be determined for any initial state by probing only the entanglement evolution of the maximally entangled state[1]. This is most beneficial in experimentally characterizing the entanglement dynamics of unknown channels.

We have designed an experimental realization of an amplitude damping channel which can be implemented to verify the evolution of entanglement proposed in Ref. [1]. Our approach is an extension of a previously reported orbital angular momentum (OAM) sorting device[2]. In Ref. [2] a Mach-Zehnder interferometer with a Dove prism in each arm is used to sort OAM states (or LG modes) according to their parity. We have extended this concept to implement an amplitude damping channel for LG modes.

2. Theoretical Background

The interferometer, in Fig. 1, induces a phase shift in the incoming beam so that constructive interference occurs in either output paths A or B. The relative phase shift, Δ , is proportional to both the OAM of the incoming light and the relative angle, θ, between the two Dove prisms and is given by: $\Delta = 2l$ [2]. A phase mask, such as an SLM or spiral phase plate, which decreases the OAM by 1ħ is inserted into path B.

When a mode with l=0 enters the interferometer, there is no relative phase shift resulting in the mode existing in path A. However, a mode with l=1 experiences a relative phase shift, $\Delta = 2$, and therefore exits in a superposition of paths A and B. Subsequently, the l=1 mode in path B is reduced by 1ħ. The overall action of the channel, on a general superposition of modes, l=0 and l=1, can be viewed as the action on a single photon and is denoted as

$$|l=0\rangle^{A} + \ |l=1\rangle^{A} \rightarrow \ |l=0\rangle^{A} + \ \left(\sqrt{1-p}\,|l=1\rangle^{A} + \sqrt{p}\,|l=0\rangle^{B}\right), \tag{1}$$

which mimics the well-known quantum amplitude damping channel. $\sqrt{1-p} = \cos$ and $\sqrt{p} = \sin$, where is the relative angle between the two Dove prisms.

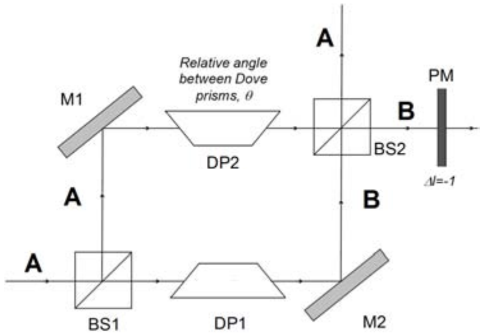

Fig. 1. Schematic of the LG mode amplitude damping channel. (BS: beam-splitter, M: mirror, DP: Dove prism, PM: phase mask).

3. Experimental Results

When the relative angle, , between the two Dove prisms is 90°, the interferometer 'sorts' the incoming beam into even (path A) and odd (path B) ports[2].

The theoretical prediction of our amplitude damping channel for single photons, given by Eq. 1, is verified by means of classical light carrying OAM. The evolution of the classical electric field in the interferometer can be described similarly to Eq. 1. Therefore, by measuring the power in each path which is proportional to the square of the electric field, the same behaviour in measuring the probabilities of single photons is obtained. The two exiting paths of the interferometer are monitored for various angles between the two Dove prisms, . The optical setup is tested classically for an initial mode of l=0 and l=1. The results for an initial mode of l=1 are depicted in Fig. 2 (a), for path A, and (b), for path B.

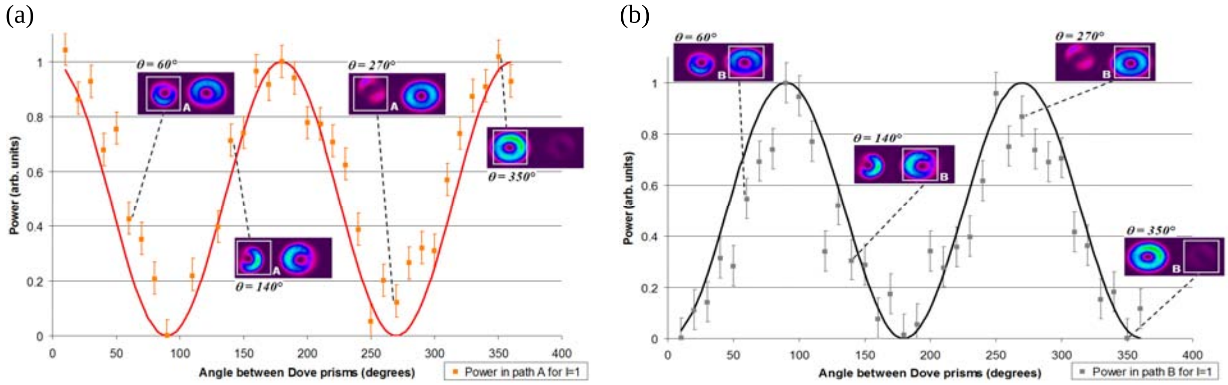

Fig. 2. Plot of the measured power in path A ((a); orange points) and path B ((b); grey points) for various values of .

The power in each path is recorded for various values of . The measured power in path A (Fig. 2 (a)) follows the trend of the theoretical result, $P_A \sim \cos^2$, denoted by the red curve. It is also evident that there is good agreement between the measured power in path B (Fig. 2 (b)) and the theoretical result, $P_B \sim \sin^2$, denoted by the black curve in Fig. 2 (b).

4. References

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