Spatial multi-mode quantum networks

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Novel quantum communication and computation protocols require an increasing number of entangled modes. Conventionally, the entangled modes are carried by as many single mode beams [1]. In our work we demonstrate experimentally a way to generate, manipulate and detect multi-mode entanglement within a single beam of light. The scheme, shown in Fig. 1, is based on two optical parametric amplifiers (OPA), one producing squeezed field in a Gaussian mode and the other in a flipped mode. Both beams are superimposed within one optical beam using an optical cavity and their relative phase shift is set to $\pi/2$. Using a multi-pixel homodyne detection [2] we show that this scheme can be used to produce spatial multi-mode entangled states. In particular, the electronic outputs of the multi-pixel detectors are recorded using a fast data acquisition system and various gain functions are applied to data in order to show quantum correlations between a set of spatial modes. In this way, the various quantum networks are implemented into the scheme by using a computer code and processing the collected data. Once an optimal gain functions are found, the scheme operates as a real time spatial quantum network. The great advantage of the scheme is that the whole process of switching between the various quantum networks is fully computer controlled.

First, we coded a basic scheme of a spatial 50/50 beamsplitter. In the language of spatial modes this corresponds to entanglement between two distinct parts of an optical beam; the left and the right part of the Gaussian beam in this case. From the quantum imaging point of view, we demonstrated strong quantum correlations within an optical image. Using the EPR criterion we calculated a value of $\varepsilon = 0.86$ witnessing strong quantum correlations between the two spatial modes. Second, we coded into the scheme a more complex quantum network. In this case, we were able to demonstrate multi-mode GHZ states. In particular, 3-mode and 4-mode GHZ states were produced easily satisfying the GHZ inequalities. Moreover, the scheme can lead to production of cluster states. Currently, a rather low quantum efficiency of the multi-pixel detectors does not allow to explore these quantum states. In conclusion, our scheme allows for fully computer controlled entanglement relationships: there is no need for hardware change to switch from one protocol to another.

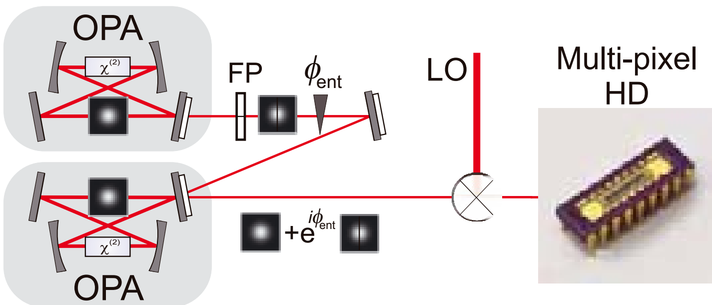

Fig. 1: Overview of the generation and manipulation of entanglement within a single beam of light. FP: flip plate, LO: local oscillator, HD: homodyne detection.

References

[1] M. Yukawa *et al.*, Physical Review A **78**, 012301 (2008)
[2] J.-F. Morizur *et al.*, J. Opt. Soc. Am. A **27**, 130085 (2010)