Quantum-Imaging: detecting spatial multimode quantum information

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Laser beams are widely used to send and process quantum information. In our experiments we employ CW beams and squeezed light as the medium to carry modulation which is defined better than the conventional quantum noise or shot noise limit. Normally all the information is contained in one mode. However, it is possible to surpass this limit by using spatial information and thereby linking several optical modes. In our work we demonstrate simple techniques for encoding information in higher order modes, through the modulation of the displacement and tilt of a beam.

Each spatial detector has a special set of eigenmodes, and it is these specific spatial modes of squeezed light that have to be generated. For example the eigenmodes of the simplest detector, the split detector, are the so called flipped modes with a \(\pi\) phase discontinuity across the beam. This was analyzed by in detail by the group in Paris and we demonstrated the improvements in accuracy in experiments at ANU in 2003.\(^1\)[2]

During 2004 we searched for the optimum detection scheme and found that for small displacements all the information about displacement and tilt of a conventional \(TEM_{00}\) beam is in the real and imaginary part of the higher order \(TEM_{01}\) and \(TEM_{10}\) modes. We also found that spatial homodyne detector, that is a homodyne detector with \(TEM_{01}\) local oscillator, is ideally suited for these measurements. That is that the eigenmodes are the Hermite Gaussian \(TEM_{01}\) and \(TEM_{10}\) modes. We found that the Split detector is only 80 % as efficient as the homodyne detector.\(^3\)

We now have the first experimental demonstration that displacement measurements with spatial homodyne detectors are efficient and that we can measure displacements below the quantum noise limit, using squeezed light. Our next aim is to find more efficient ways of generating squeezed light in the \(TEM_{10}\) mode to demonstrate spatial entanglement and to look for practical applications of these new methods. In particular we have joined a European wide team which proposes, as part of the EUsix framework, to investigate enhanced techniques for optical data storage.

Figure 1: Spatial homodyne measurement with and without squeezing. The local oscillator has a \(TEM_{01}\) mode. The phase of the local oscillator is scanned, the measurement cycles from displacement (minimum) to tilt measurement (maximum). The classical measurement, without squeezing, are given by the quantum noise trace (MOD), the displacement \(d_{CL}\) and tilt \(t_{CL}\). The measurements with squeezing, trace (MOD-SQZ) for the quantum noise, \(d_{SQZ}\) and \(t_{SQZ}\), show the improvement. We can measure a displacement below the shot noise, trace (SN)

References