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Quantum Electro-optic Control

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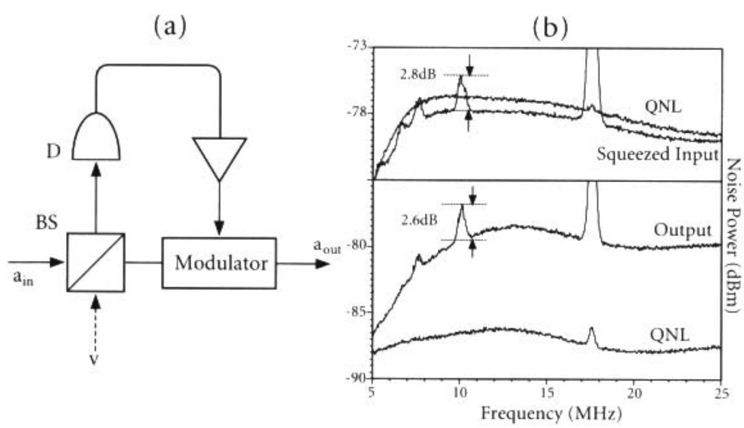
The quantum optical uncertainty principle places restrictions on the accuracy with which the intensity and phase of light can be determined.[1] This in turn places quantum limits on the applications of light in high sensitivity measurements, communications, and information storage. These limits can be avoided under certain circumstances. For example, squeezed light gives improved measurement sensitivity for one observable, say, intensity with the penalty that the other observable, here phase, is less sensitive. Similarly, a quantum non-demolition (QND) device can enable a non-destructive measurement of one observable to be made at the expense of reduced information about the other.

We have recently demonstrated a new tool in the manipulation and control of light at the quantum limit,[2] whose simplicity and efficiency make it attractive for applications. The device is an electro-optic feedforward loop (see Fig. 1a). Splitting an input beam (a) at a beam splitter (BS) introduces quantum vacuum noise (v) onto the reflected and transmitted beams, which reduces the signal-to-noise of any information carried by the input beam. However, by detecting the reflected beam and feeding it forward, with a particular positive gain, the quantum noise can be exactly cancelled on the transmitted beam (a_{out}). In this simple form, the feedforward loop acts as a noiseless signal amplifier. The size of the signals on the output are increased by the feedforward gain without reducing signal-to-noise. This is a major improvement over linear optical amplifiers (such as laser amplifiers), which must reduce signal-to-noise for quantum limited signals.

The versatility of the feedforward loop and squeezed light can both be increased by combining them. We have shown that very fragile information carried on squeezed light can be made robust to losses by amplifying it with the feedforward loop[2] (see Fig. 1b). Also, if the output of the feedforward loop is mixed with a squeezed light source, an efficient and practical type of QND measurement can be made.[3] Although our demonstrations have been of noiseless amplification of intensity signals, the principle can also be applied to phase signals.

A phenomenon of much fundamental interest is quantum teleportation.[4, 5] Quantum limited information of *both* observables is "teleported" via a direct classical channel and an indirect quantum channel. The feedforward loop can achieve teleportation by using an intensity squeezed input for a and a low intensity phase squeezed beam for v. The sender beam, which is to be teleported, is mixed with the reflected beam and the intensity and phase fluctuations are measured. Both observables are then fed-forward to the transmitted beam where, remarkably, the choice of the correct gain results in the reconstruction—in both observables—of the sender beam.



Ralph Figure 1. (a) Schematic of feedforward loop. (b) Low noise amplification of squeezed light. The upper trace shows the noise spectrum of the squeezed input beam, carrying a small signal, and the quantum noise limit (QNL). The lower trace shows the output beam has been significantly amplified relative to the QNL, but there has been very little loss of signal-to-noise.

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SIGNAL PROCESSING

Control of Broad-area Optical Devices: Patterns to Order

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Nonlinear physical systems can have multiple output states compatible with a single input state. This enables them to be used to store, process, and transmit information. Applications typically require the selection of a particular desired state out of this multiplicity, for example, the Gaussian mode in a laser. Often the desired state is, or becomes, unstable—as when a laser passes from single- to multi-mode operation. In 1998, several experiments[1–3] have shown how Fourier-space filtering can persuade optical systems to produce otherwise unstable patterns. Persuade, rather than force, because with appropriate design, the system self-organizes in such a way that little or no energy is lost in the filter.[4] This is exciting because optical systems could, in principle, be similarly persuaded to display unstable states representing images or information rather than simple patterns.

The 1998 control experiments concern optical systems that display spontaneous patterns, such as stripes,