The benefits of internal squeezing in cavity-enhanced sensing

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Abstract

Optical cavities allow to increase the sensitivity in quantum metrology, at a price of reduced detection bandwidth. In some detectors, such as gravitational-wave observatories, this limits the access to important physical regimes. We propose to overcome the bandwidth limitation by squeezing the quantum uncertainty directly inside the detector cavity. We investigate, both theoretically and experimentaly, how the fundamental limits on sensitivity and bandwidth can be reduced by this aprroach in the presence of optical loss. We propose a novel approach to expanding the detection bandwidth without affecting the peak sensitivity, and demonstrate its effect in application to gravitational-wave detectors.

The advances in technology bring metrological devices into quantum regime, allowing to reach the shot noise limited sensitivity. For example, optomechanical force-sensing devices are limited by the shot noise from microscopic devices to the kilometer-scale gravitational-wave detectors. One of the conventional ways to further increase the sensitivity is to use resonators for amplifying the interaction with the sensor. Their linewidth, however, reduces the detection bandwidth, and the higher is the sensitivity enhancement, the narrower is the bandwidth. This imposes a standard sensitivity-bandwidth limit on the detector's sensitivity. This limit can be overcome using the non-classical states of light, as stated the quantum Cramer-Rao bound (QCRB) [1]. Recently injection of quadrature squeezed light has become a common tool in the metrological experiments. This approach, however, allows to lower the QCRB equally in a broad band, but doesn't help to increase the detection bandwidth.

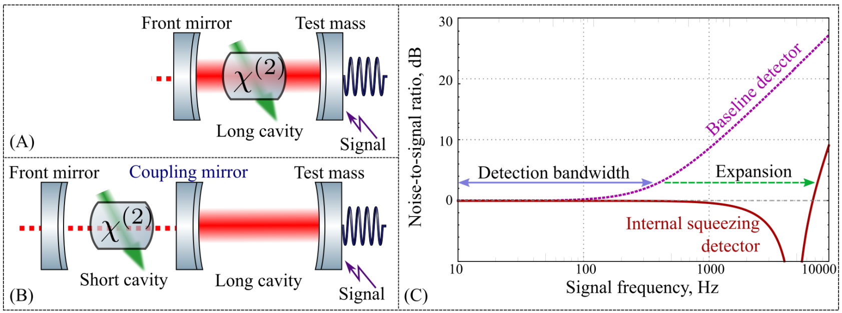

Figure 1: (A) Internal squeezing cavity concept: a nonlinear crystal is placed inside the detector cavity. (B) Auxiliary cavity for nonlinear crystal enables expansion of detection bandwidth. (C) Noise-to-signal ratio of an auxiliary cavity detector (normalized to peak sensitivity): the baseline detector (magenta) is limited by the cavity bandwidth; internal squezing allows to expand the bandwidth by generating internal squeezing (red).

We present an new approach for beating the standard sensitivity-bandwidth limit by generating squeezing directly inside the detector cavity, see Fig.1A. We demonstrate the improvement experimentally [2], and investigate the benefits of the internal squeezing in the presence of external squeezing injection, which allows us to explore the loss-induced limit to the sensitivity. We further propose to use internal squeezing to expand the detection bandwidth. For that the nonlinear crystal can be placed in an additional optical cavity, which creates the coupled-resonance structure, see Fig.1B. We apply this technique to the gravitational-wave detector design, and predict significant bandwidth expansion, see Fig.1C.

In conclusion, we explore how squeezed light generated directly inside the detector cavity can benefit cavity-enhanced devices in different regimes. We anticipate the internal squeezing approach to become a new versitile tool in the toolbox of quantum metrology.

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[2] M. Korobko, L. Kleybolte, S. Ast, H. Miao, Y. Chen, and R. Schnabel, *Beating the Standard Sensitivity-Bandwidth Limit of Cavity-Enhanced Interferometers with Internal Squeezed-Light Generation*, Phys. Rev. Lett. **118**, 143601 (2017).