Open quantum system approach to ring laser gyros including correlations

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Abstract: Motivated by GINGERINO's femto-rad/s noise floor, we present a quantum model of a ring-laser gyroscope—from light generation to Sagnac-frequency readout—that incorporates correlations between counter-propagating beams.

A recent work demonstrates that the experimental noise floor of the large-frame ring-laser gyroscope GINGERINO lies in the femto-rad/s range for an integration time of about 2.3 days [1,2]. This result is obtained from the Allan deviation evaluated in a differential measurement scheme.

The counter-propagating beams interfere outside the cavity through a balanced beam splitter, and the Sagnac frequency is estimated from the beat note of the optical signals at the two output ports (*Fig.1*).

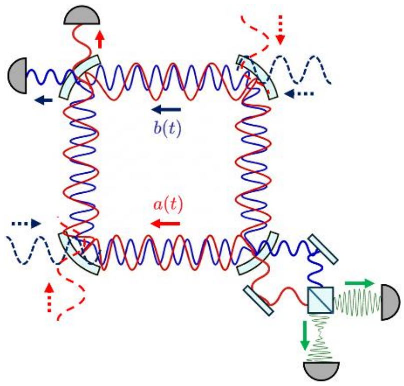

Fig. 1 Scheme of a ring laser including incoming external noises and readout setup.

Then, by analogy with common-mode rejection, the noise is evaluated by computing the Allan deviation of the difference between the frequency data from the two ports. In the $10^{-1}s - 10^{5}s$ integration-time range, the resulting Allan deviation is roughly one order of magnitude below the noise-level limit predicted by a formula commonly used in the literature [3]. However, that formula relies on an independent-beams model and therefore does not account for correlations between the counter-propagating modes, which naturally arise from interactions with the active medium and from backscattering.

Motivated by these recent results, we have developed a model for a ring-laser gyroscope starting from first principles and based on open-quantum-system theory. The model describes the gyroscope as a leaky optical cavity sustaining two modes coupled to a common environment of many inverted two-level atoms. Additional Caldeira–Leggett thermal baths are included to account for backscattering from the corner mirrors.

In this framework we derive exact quantum Langevin equations; the resulting mean-value dynamics agree with standard ring-laser theory, including partial mode synchronization and the lock-in region. Once the intra-cavity dynamics is fully characterized, input–output theory allows us to derive the intensity of the fields measured outside the cavity. Incorporating the actual measurement scheme used in GINGERINO, we obtain a new formula for the expected uncertainty on the beat frequency, which reproduces the standard $1/\sqrt{T}$ - scaling in the limit of uncorrelated beams.

References

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