International Conference on Quantum Energy 2025 hosted by Dipartimento di Fisica e Astronomia Galileo Galilei an event by ICQE

Contribution ID: **96** Type: **Poster presentation**

Enhanced phase sensitivity in DSU(1,1) interferometer via photon recycling

In the SU(1,1) interferometer, proposed by Yurke [Physical Review A, 33(6), 4033], beam splitters are replaced by nonlinear elements like optical parametric amplifiers (OPA) to achieve the sensitivity up to the Heisenberg limit. Non-Gaussian operations, like photon addition or subtraction, can further improve its phase sensitivity and robustness against photon loss but at a high implementation cost. To address this issue, Wei Ye et al. [Optics Express 31(25), 41850] introduced the displacement-assisted SU(1,1) (DSU(1,1)) interferometer, using a displacement operator with displacement strength $|\gamma|$.

In this work, we propose a novel method to improve the phase sensitivity of the DSU(1,1) interferometer through photon recycling. We begin with this interferometer having a vacuum state at port "a" and a squeezed vacuum state (with squeezing parameter r) at port "b". We consider a phase shift ϕ, experienced in the arm "b". This setup is modified by re-injecting the output mode "a" into the input mode after a phase shift θ, and photon loss is characterized by $\sqrt{}$(1-T), where T is the transmission coefficient of a fictitious beam splitter.

We determined the phase sensitivity of the PR-DSU(1,1) interferometer, denoted as $\Delta\phi^{PR}$ under two detection schemes: single-intensity detection (SID) and homodyne detection (HD). To provide the fundamental theoretical limit of phase sensitivity, we computed the quantum Cramér-Rao bound (QCRB), denoted as $\Delta\phi^{PR}_{QCRB}$. To compare the performances of PR-DSU(1,1) interferometer with the conventional DSU(1,1) interferometer, we defined two enhancement factors $\Sigma = \Delta\phi^{Conv.}/\Delta\phi^{PR}$ and $\Xi = \Delta\phi^{Conv.}_{QCRB}/\Delta\phi^{PR}_{QCRB}$. Additionally, for each detection scheme, we evaluated the improvement in the phase sensitivity and QCRB of the PR-DSU(1,1) interferometer relative to the SNL using $\Gamma = \Delta\phi_{SNL}/\Delta\phi^{PR}$ and $\Lambda = \Delta\phi_{SNL}/\Delta\phi^{PR}_{QCRB}$, respectively.

Our results demonstrate that both Σ and Ξ can exceed unity, indicating that the PR-DSU(1,1) interferometer can achieve improved phase sensitivity and a lower QCRB compared to the conventional DSU(1,1) configuration. We further analyzed Γ as a function of the phase shifts ϕ and θ, for various values of T, g, $|\gamma|$, and r, under both SID and HD detection schemes. The values of Γ exceeding unity indicate that our scheme can achieve phase sensitivity beyond the SNL. Moreover, it increases with increase in T, g, $|\gamma|$, and r. Comparing the phase sensitivity of the PR-DSU(1,1) interferometer under both SID and HD schemes, we observe that the HD scheme outperforms the SID scheme. Similarly, we plotted Λ as a function of r for different values of g and observed that Λ exceeds unity and increases monotonically with both g and r. Further, by plotting Λ as a function of T for various $|\gamma|$, we observed significant enhancement due to photon recycling, especially in the presence of LDO, provided the proper choice of g, r, and photon loss in the feedback arm is chosen.

Therefore, our findings show that this modified scheme has phase sensitivity and QCRB beyond the SNL as well as beyond those in the case of a conventional DSU(1,1) interferometer, offering a novel approach to increase phase sensitivity via photon recycling.

Theme

Theme 2. Quantum effects in energy processes and materials

Author: Mr KUMAR, Taj (Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, India)

Co-authors: Mr KUMAR, Anand (Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, India); Mr PANDEY, Aviral Kumar (Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, India); MISHRA, Devendra Kumar (Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, India)

Presenter: MISHRA, Devendra Kumar (Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, India)

Track Classification: Theme 1. Energy advantage and cost of quantum technology