Deterministic GKP state generation in programmable photonic cavities

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Abstract

Bosonic quantum error correction (QEC) encodes quantum information in harmonic oscillators, offering a reduced hardware overhead. Gottesman–Kitaev–Preskill (GKP) states are promising resources for bosonic QEC, as they enable correction of small displacements and photon loss. However, their generation remains challenging, with current experiments limited to low photon numbers.

In this work, we propose a deterministic protocol to generate large-photon-number GKP states with high fidelities using a programmable photonic circuit composed of squeezing, displacement, and Kerr non-linearity gates. We benchmark the performance of our protocol under realistic experimental imperfections, such as imperfect control of the Kerr non-linearity and photon loss, identifying the former as the dominant limitation under current experimental conditions. Finally, we evaluate the performance of the generated GKP code under photon loss by calculating the near-optimal channel fidelity.

Our results provide a route towards scalable generation of GKP states.

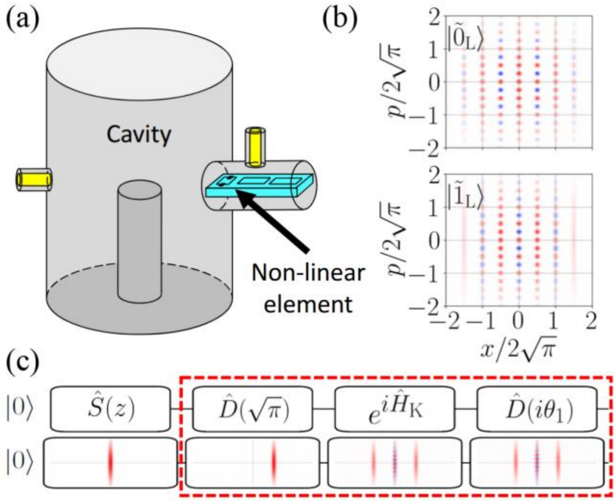

Figure 1:
(a) Sketch of a possible experimental setup for the implementation of our protocol in superconducting circuits platforms. The scheme depicts a 3D microwave cavity coupled to a non-linear element (such as a SQUID or a SNAIL) providing a tunable Kerr non-linearity. (b) Wigner quasi-probability distribution of the approximate GKP states. (c) Scheme of the first cycle of the proposed protocol. Initially, a squeezing $\hat{S}(r)$ with $r \in R$ is applied to the vacuum state. Each cycle of the protocol (inside the red, dashed box) consists of a displacement, a Kerr non-linearity and another displacement (small corrections). The bottom panels represent the Wigner distributions in optical phase space after the action of each gate.