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Optical-microwave quantum state transduction beyond the ideal

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Leading designs for quantum networks require efficient microwave-to-optical signal transduction. One promising platform uses ensembles of atoms (Er3+) coupled to dual microwave-optical cavities [1]. It is projected that these devices can reach practical efficiencies by boosting the coupling between cavities and optical and microwave transitions in atoms. However, increasing these couplings (where the effective transduction rate exceeds cavity losses) simultaneously increases the rates of parasitic processes (e.g. Kerr) which degrade the fidelity of atom-based interfaces. Therefore, building efficient transducers requires an understanding of these additional effects, which have to date not been captured by theoretical models. Here we develop a theoretical framework that characterises rates of transduction and higher-order parasitic processes, and demonstrate their effect on different quantum states of interest.

We model the atom ensemble as three-level systems, with transitions coupled to microwave and visible optical photons, and controlled by a classical pump [2]. Extending the perturbation theory (Schrieffer-Wolff transformation [3]), we identify an effective description of the dynamics to arbitrary order. We go beyond lowest-order perturbations (that govern the transduction rates) to calculate rates of the parasitic processes, and account for the dynamics within the atomic excited states subspace.

We apply this effective model to analyse the fidelity of transduction of different quantum states of interests, like single-photon states, complex coherent states, and Gottesman-Kitaev-Preskil (GKP) states. We demonstrate our effective model for describing these nonlinearities and their impact on the overall transduction fidelity, giving insight into the performance of future microwave-optics transducers.

References

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