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Squeezing and amplification in open quantum systems with color centers using the multilevel Janes-Cummings model

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The ability to couple cavity-confined microwave modes to diamond slabs or films containing large numbers of color centers opens up potential new methods for noise reduction, processing, and even generating quantum states of microwaves. The unique feature of various diamond color centers is that they can be prepared in their ground states by illuminating them with light in the optical band. The color centers then become a very low noise (effectively very low temperature) system for processing and manipulating microwaves.
Ensembles of few-level emitters are able to generate nonlinearities for electromagnetic fields. Often, this is done by arranging the level structure and driving to simultaneously induce the electromagnetically induced transparency to eliminate most of the absorption that can accompany nonlinearities due to the decay of the emitter energy levels. For color centers, the lowest lying spin levels, e.g., three levels for nitrogen-vacancy (NV) centers, have very long lifetimes, so this is not a significant issue. Ensembles of emitters will also generate nonlinearities for single modes, but the produced nonlinearities are limited to the maximal ones that can be generated by single emitters. Essentially, for the purpose of generating nonlinearities, having an ensemble effectively increases the coupling rate: if the coupling of each emitter is g_0, then an ensemble with N emitters acts as a single emitter with a coupling rate $g = \sqrt{N} g_0$, which is valid for the off-resonant generation of nonlinearities.
An ensemble of two-level emitters off-resonant with a single mode generates a series of nonlinearities with effective Hamiltonians given by powers of the mode energy operator $a^\dagger a$. The first term in this series generates a frequency shift for the cavity mode proportional to g^2/Δ, where Δ is a detuning between the NV-centers and the cavity mode. Modulating the frequency of a mode induces parametric amplification.
In this study we investigate the optimal modes of operation of a N-level atomic system interacting with the cavity mode to obtain squeezed states and amplification of the electromagnetic cavity mode signal. This is performed in the framework of the Janes-Cummings model for the N-level atomic system within the rotating wave approximation. For this purpose, perturbation theory, namely the Magnus expansion for the evolution operator, up to and including second order of smallness, was used.
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Primary author: OVSIANNIKOV, Roman (NSC «Kharkov Institute of Physics and Technology»)

Co-authors: JACOBS, Kurt (University of Massachusetts at Boston); BONDAR, Denys (Tulane University); Prof. SOTNIKOV, Andrii (National Science Center "Kharkiv Institute of Physics and Technology")

Presenter: OVSIANNIKOV, Roman (NSC «Kharkov Institute of Physics and Technology»)

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