State-dependent photon blockade via quantum-reservoir engineering

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The progress in realizing macroscopic quantum states in a variety of systems (in particular, involving superconducting devices [1]) makes many recently purely academic problems very relevant for experimental research. Some such problems are related to the interaction of photons in a cavity with non-standard reservoirs (e.g., reservoirs with entanglement).

An arbitrary initial state of an optical or microwave field in a lossy driven nonlinear cavity can be changed into a partially incoherent superposition of only the vacuum and the single-photon states. This effect is known as single-photon blockade [2, 3] or as optical state truncation by nonlinear scissors [4]. PB was observed in a number of experiments (for a review see [5]). Recently, the occurrence of two-photon blockades was also predicted, where the transmission of more than two photons can be effectively blocked by single- and two-photon states [6]. This approach can be further generalized for multiphoton blockades [6–8].

Photon blockades, and analogous phonon blockades [9], are usually analyzed for a Kerr-type nonlinear cavity parametrically driven by a single-photon process assuming single-photon loss mechanisms. Here we study photon blockade engineering via a nonlinear reservoir [10], i.e., a quantum reservoir, where only two-photon absorption is allowed. Namely, we analyze a lossy nonlinear cavity parametrically driven by a two-photon process and allowing two-photon loss mechanisms, as described by the master equation derived for a two-photon absorbing reservoir. Such master equation for engineering dissipative channels were analyzed in different contexts in, e.g., Refs. [11–14]

The nonlinear cavity engineering can be realized by a linear cavity with a tunable two-level system via the Jaynes-Cummings interaction in the dispersive limit. We show that by tuning properly the frequencies of the driving field and the two-level system, the steady state of the cavity field can be the single-photon Fock state or a partially incoherent superposition of several Fock states with photon numbers, e.g., (0,2), (1,3), (0,1,2), or (0,2,4). At the right (now fixed) frequencies, we observe that an arbitrary initial coherent or incoherent superposition of Fock states with an even (odd) number of photons is changed into a partially incoherent superposition of a few Fock states of the same photon-number parity. We find analytically approximate formulas for these two kinds of solutions for several differently tuned systems.

A general solution for an arbitrary initial state is a weighted mixture of the above two solutions with even and odd photon numbers, where the weights are given by the probabilities of measuring the even and odd numbers of photons of the initial cavity field, respectively. This can be interpreted as two separate evolution-dissipation channels for even and odd-number states.

Thus, in contrast to the standard predictions of photon blockade, we prove that the steady state of the cavity field, in the engineered photon blockade, can depend on its initial state. To make our results more explicit, we analyze photon blockades for some initial infinite-dimensional quantum and classical states via the Wigner and photon-number distributions.

We hope that our proposal [10] of state-dependent photon blockade via a two-photon absorbing reservoir is another convincing example demonstrating how to harness quantum-reservoir engineering for quantum technology.

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