Dynamical and antidynamical Casimir effects via controlled artificial atoms

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Circuit quantum electrodynamics (circuit QED) offers unprecedented possibilities to manipulate in situ the properties of mesoscopic systems composed of superconducting artificial atoms interacting with the electromagnetic field inside the waveguide resonator on a chip [1]. This solid-state architecture thus allows for the experimental study of some of the most fundamental physical processes, such as the light-matter interaction at the level of a few photons. One example is the implementation of the dynamical, and antidynamical, Casimir effect and associated phenomena using actively controlled artificial atoms, which may serve both as the source and as the detector of modulation-induced radiation [2]. The broad term dynamical Casimir effect (DCE) refers to the generation from vacuum of excitations of some field (electromagnetic, in the majority of cases) due to time dependent boundary conditions, such as changes in the geometry or material properties of the system [3]. The antidynamical Casimir effect (ADCE) instead is a term coined to designate the coherent annihilation of excitations due to resonant external perturbation of system parameters, allowing for extraction of quantum work from nonvacuum states of some field [4]. Here we consider the dissipative single-qubit circuit QED architecture in which the atomic transition frequency undergoes a weak external time modulation. For sinusoidal modulation with linearly varying frequency we derive effective Hamiltonians that resemble the Landau-Zener problem of finite duration associated with a two or multilevel systems. The corresponding off-diagonal coupling coefficients originate either from the rotating or the counter-rotating terms in the Rabi Hamiltonian, depending on the values of the modulation frequency. We demonstrate that under this condition photon generation from vacuum via effective Landau-Zener transitions could be implemented with the current technology on the time scales of a few microseconds[4]. Unlike the harmonic dynamical Casimir effect implementations, our proposal does not require precise knowledge of the resonant modulation frequency to accomplish meaningful photon generation. Photon generation is not the only phenomenon induced by parametric modulations in circuit QED. Recently indeed it was shown that the counter-rotating terms can also be employed to annihilate excitations of the electromagnetic field from nonvacuum initial states (ADCE) [5]. We here demonstrate, analytically and numerically, that the ADCE rate can be increased of, at least, one order of magnitude, by replacing the qubit by an artificial three-level atom (qutrit) in a properly chosen configuration [6].

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