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Ultrastrong Coupling of matter and radiation: detection of virtual photons and multiqubit quantum gates

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Ultrastrong coupling (USC) between light and matter has been recently achieved in architectures of solid state artificial atoms coupled to cavities. They may provide new building blocks for quantum state processing, where ultrafast quantum gates can be performed thus meeting the requirements for fault-tolerant quantum computation. However it has been shown [1] that in the USC regime the dynamical Casimir effect (DCE), may pose limits on the fidelity of quantum operations, as for protocols based on quantum Rabi oscillations [1]. These latter are used for processing in strongly coupled (SC) circuit-QED systems where only single excitations are manipulated across the system the cavity working as a quantum bus. In the USC multiphoton generation deteriorates the fidelity of such quantum operations [1] even in absence of decoherence.

To overcome this problem we propose a communication channel based on an adiabatic protocol similar to STIRAP [2]. Ideally the cavity is never populated, operating as a virtual bus, thus it is expected to greatly reduce the impact of DCE. Indeed we show that high fidelity operations can be performed for moderate couplings in the USC regime [3] thus allowing to operate faster than in SC. Moreover properly crafted control exends the high fidelity region to even larger couplings. The protocol is extremely robust agaist DCE, in the absence of decoherence yields almost 100% fidelity for remote population [3] and state trensfer. It is also resilient to decay due to leakage from the cavity, which is the main decoherence mechanism for present USC architectures [3]. In this more realistic scenario it is seen that for larger coupling (entering the deep strong coupling regime) the fidelity decreases due to the interplay between decoherence and DCE.

The communication channel we address being a prototype of family of adiabatic protocols for state transfer and multiqubit gate, our results suggest that adiabatic manipulations, which has been recently proposed for detecting dynamically USC [4], may be a promising tool for quantum state processing in the USC regime.

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