Quantum operations in ultrastrongly coupled quantum networks

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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. New phenomena related to the highly entangled nature of the eigenstates are displayed. Such architectures may provide new building blocks for quantum state processing, where ultrafast quantum gates could be performed.

Concerning quantum state processing, it has been shown that in the USC regime the dynamical Casimir effect (DCE), may pose limits on the fidelity of standard quantum operations based on quantum Rabi oscillations [3], used for processing in strongly coupled (SC) circuit-QED systems. In the USC multiphoton generation deteriorates the fidelity of such quantum operations [3] even in absence of decoherence. We show that an adiabatic protocol similar to STIRAP [1,2] may overcome this problem [4]. Ideally, the cavity is never populated, operating as a virtual bus, thus it is expected to greatly reduce the impact of DCE. 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 extends the high fidelity region to even larger couplings. The protocol is extremely robust against DCE, in the absence of decoherence yields almost 100% fidelity for remote state transfer and multiqubit entanglement generation. 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. Our results suggest that adiabatic manipulations may be a promising tool for quantum state processing in the USC regime.

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