

Circuit Quantum Electrodynamics with two-dimensional material-based Josephson Junctions

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In the context of hybrid superconductor-semiconductor systems, Josephson junctions based on two-dimensional materials, such as graphene, offer promising opportunities because of their scalability and gate-tunable electronic properties. In this work, we investigate the inductive coupling between a quantum LC resonator and a superconducting loop embedding a short, ballistic, planar Josephson junction, with the graphene-based case as a representative example.

Within a mean-field formalism, we analyze how the properties of the global system depend on the light-matter interaction coupling, the Fermi level of the two-dimensional material, and temperature. Our findings reveal that the current-phase relation can show features indicative of spontaneous time-reversal symmetry breaking [1].

Moreover, we investigate the same system as a possible solid-state implementation of a Dicke-like quantum battery where Andreev bound states naturally act as non-interacting, energetically non-degenerate two-level systems, and the setup allows for both single-photon and two-photon resonant processes. The coupling between the LC-circuit flux and the supercurrent through the junction gives rise to peculiar longitudinal interaction terms that have no counterpart in the conventional Dicke model. These additional couplings can enhance energy storage for a proper range of parameters [2].

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