Quantum microwaves in a strong coupling circuit QED regime

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Abstract

Transport of elementary charge carriers across a circuit usually does not couple to the electromagnetic modes embedded in the circuit. We consider here a dc voltage biased Josephson junction in series with a microwave resonator. In this very simple quantum electrodynamics open system, the effective coupling constant that replaces the fine structure constant of QED is the ratio between the resonator characteristic impedance , which can be engineered, and the relevant resistance quantum RQ= h/4e2 ˜6.5 kOhms. At large coupling constant, the transfer of a single Cooper pair across the Josephson junction strongly couples to the circuit mode. This regime corresponds to the dynamical Coulomb blockade of Cooper pair tunneling [1].

We show that, in the strong coupling regime, the transfer of a single Cooper pair only occurs when its energy $2eV$ can be transformed in *1,2,..n* photonic excitations in the resonator. We also identify a recently predicted regime for which the presence of a single photon blocks the creation of a second one, which forces the resonator to emit a single photon in the external circuit before another Cooper pair can pass and re-excite it: Cooper pair transfer and photon emission are locked.

Using a two-mode resonator circuit with different frequencies, we demonstrate a regime in which the transfer of a single Cooper pair simultaneously excites a single photonic excitation in each mode. We find that the quantum state of the resonator violates a Cauchy inequality, which demonstrates its non-classical character [2].

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