Circuit QED: Recent Results in Quantum Optics with Superconducting Circuits

Robert Schoelkopf

Departments of Applied Physics and Physics, Yale University, New Haven CT, USA

Circuit QED[1] is an approach for studying quantum optics in a superconducting integrated circuit. By combining a one-dimensional transmission-line cavity that stores microwave photons and a superconducting qubit that plays the role of an artificial atom, one can easily enter the strong coupling limit of cavity QED. In recent experiments, we attain couplings that are several percent of the qubit or cavity frequency, and in fact approach the maximal fine-structure limit for a electric-dipole interaction of light and matter, giving rise to a remarkable vacuum Rabi splitting of several hundred linewidths. We will present studies of the nonlinear response of this system, which shows two novel effects: 1) each vacuum Rabi peak develops a supersplitting, which can be understood in a simple picture as the saturation of a new two-level system consisting of photon-qubit superpositions, and 2) the emergence of additional peaks, corresponding to multi-photon transitions up the Jaynes-Cummings ladder, and constituting a simple demonstration of the $\sqrt{n}$ nonlinearity in this system. Experiments show striking agreement with analytical and numerical predictions confirming the Jaynes-Cummings Hamiltonian description of the system. The coherent coupling of qubits to microwave photons that are guided around a chip by wires raises many possibilities for quantum information and communication. I will also review experiments demonstrating the generation of single 5 GHz photons on demand, and the communication of quantum information between qubits using photons in a cavity as an intermediary.

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[1] R.J. Schoelkopf and S.M. Girvin, "Wiring up quantum systems", Nature 451, 664 (2008).