Artificial atoms make microwave photons countable

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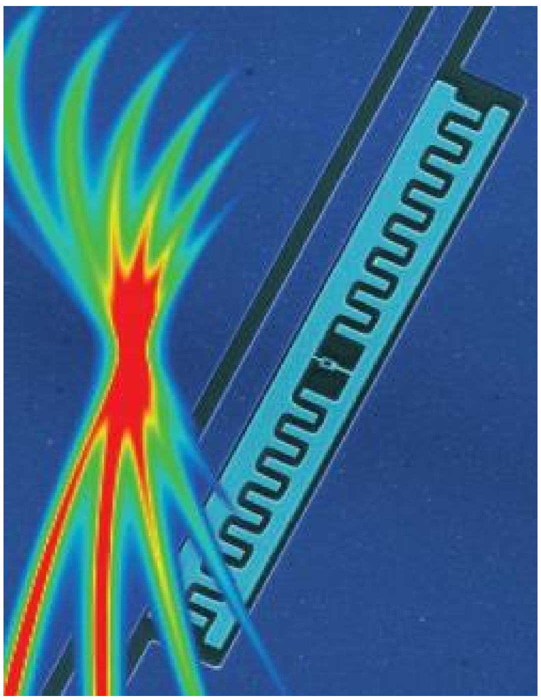

Scanning electron micrograph of an artificial atom (light blue) inside of a transmission line cavity (dark blue). The "atom," composed of over a billion atoms of aluminum, gives a distinct signal for each possible photon number in the cavity. The theoretical prediction (color plot) was verified by these experiments. Credit: Schuster / Yale

Using artificial atoms on a chip, Yale physicists have taken the next step toward quantum computing by demonstrating that the particle nature of microwave photons can now be detected, according to a report spotlighted in the February 1 issue of the journal *Nature*.

Quantum theories are often considered to apply best to processes that happen on the smallest scale of atoms and molecules. By making artificial atoms larger — to a size that is nearly visible — and using microwaves as the source of energy, the collaborative research from the laboratory of Professor Robert Schoelkopf and the theory group of Professor Steven Girvin in the departments of Applied Physics and Physics at Yale created an electronic circuit that stores and measures individual microwave photons. In the process, they bring quantum mechanics to a larger scale and hope to employ it to build new kinds of quantum machines.

"The radiation from a microwave oven or cell phone does not seem to have much in common with light, but like its visible counterpart, microwaves are made of individual photons," said Schoelkopf. "A single microwave photon is quite large, extending over one centimeter in length, and yet has one hundred thousand times less energy than even a visible photon. Unlike a camera, which absorbs the light it detects, our measurement preserves the photons for later use."

"Advances in quantum computing are among the goals of the recently launched Yale Institute of Nanoscience and Quantum Engineering (YINQE), of which Girvin and Schoelkopf are core members," said Paul Fleury, Dean of Yale Engineering and Director of YINQE. "Such manipulation of single microwave photons is an important step towards realizing a quantum computer, which could exponentially speed up computations of difficult problems in cryptography, quantum physics and chemistry."

"Much like the children's game 'telephone,' current solid state quantum computing schemes can only make nearest-neighbor interactions. This forces distant quantum bits (qubits) to communicate by passing through many intermediates causing errors," said lead author David Schuster, a graduate student who completed this work as part of his thesis in January 2007. "Single microwave photons can be used as mobile carriers of quantum information allowing distant qubits to communicate directly, avoiding these problems."

The measurements they made represent the next step in circuit quantum electrodynamics, a field introduced by the same groups at Yale in 2004 to study quantum optics with microwaves using integrated circuits. According to Girvin, the detector they designed works "as if we made an antenna on an atom." Their results demonstrate that microwaves are particles because the system gives a response representing a discrete number of interactions of the microwave with the atom.

In addition to circuits, microwaves interact with a variety of physical systems, including atomic spins, molecules, and even nuclei. Single microwave photons can act as a bridge between these naturally occurring quantum systems and fabricated electrical circuits, resulting in a hybrid processor of quantum information. The next phase of the work, according to the authors, is to connect up multiple "atoms", using the photons to transfer the information between them.

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