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Using Quasiparticle Poisoning To Detect Photons

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According to a proposal, a phenomenon associated with excitation of quasiparticles in certain superconducting quantum devices would be exploited as a means of detecting photons with exquisite sensitivity. The phenomenon could also be exploited to perform medium-resolution spectroscopy. The proposal was inspired by the observation that Coulomb blockade devices upon which some quantum logic gates are based are extremely sensitive to quasiparticles excited above the superconducting gaps in their leads. The presence of quasiparticles in the leads can be easily detected via the charge states. If quasiparticles could be generated in the leads by absorption of photons, then the devices could be used as very sensitive detectors of electromagnetic radiation over the spectral range from x-rays to submillimeter waves.

The devices in question are single-Cooper-pair boxes (SCBs), which are mesoscopic superconducting devices developed for quantum computing. An SCB consists of a small superconducting island connected to a reservoir via a small tunnel junction and connected to a voltage source through a gate capacitor. An SCB is an artificial two-level quantum system, the Hamiltonian of which can be controlled by the gate voltage. One measures the expected value of the charge of the eigenvectors of this quantum system by use of a radio-frequency single-electron transistor. A plot of this expected value of charge as a function of gate voltage resembles a staircase that, in the ideal case, consists of steps of height $\epsilon$ (where $\epsilon$ is the charge of one electron).

Experiments have shown that depending on the parameters of the device, quasiparticles in the form of "broken" Cooper pairs present in the reservoir can tunnel to the island, giving rise to steps of 1 $\epsilon$. This effect is sometimes called "poisoning." Simulations have shown that an extremely small average number of quasiparticles can generate a 1-$\epsilon$ periodic signal.

In a device according to the proposal, this poisoning would be turned to advantage. Depending on the wavelength, an antenna or other component would be used to couple radiation into the reservoir, wherein the absorption of photons would break Cooper pairs, thereby creating quasiparticles that, in turn, would tunnel to the island, creating a 1-$\epsilon$ signal. On the basis of conservative estimates of device parameters derived from experimental data and computational simulations that fit the data, it has been estimated that the noise equivalent power of a device according to the proposal could be as low as $6 \times 10^{-22}$ W/Hz$^{1/2}$. It has also been estimated that the spectroscopic resolution (photon energy $\Delta$ increment of photon energy) of such a device in visible light would exceed 100.

This work was done by Pierre Echternach and Peter Day of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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