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Parity-Protected Josephson Qubits

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Abstract:

We have developed two novel types of protected qubits that decouple logical states from the environment by encoding them in a parity of a large number. The first type, the so-called charge-pairing qubit, represents a chain of two Josephson elements characterized by the π periodicity of the phase dependence of their Josephson energy $E_J cos(2\varphi)$ (the so-called Josephson rhombi [1]). The second type, the flux-pairing qubit, consists of a 4π periodic Josephson element (a Cooper pair box with the e charge on the central island) shunted by a superinductor [2]. The lowest-energy quantum states of the charge-pairing qubit are encoded in the parity of Cooper pairs on a superconducting island flanked by the Josephson rhombi. The flux-pairing qubit encodes its quantum states in the parity of magnetic flux quanta inside a superconducting loop. The design of these devices enforces, respectively, charge- and flux-pairing, prohibits the mixing of lowest-energy quantum states, and protects the qubits from both the decay and dephasing. We have studied the low-energy excitations in each of these qubits by microwave spectroscopy; the observed spectra are in agreement with theoretical expectations. We will present experimental evidence for the decay protection which resulted in the energy relaxation time T_1 up to 100 μs and the quality factors $\omega_{01}T_1 > 10^6$, a 100 fold improvement vs. the unprotected state of each of these qubits [3]. We will also present our preliminary data on the dephasing protection in these qubits, and discuss the possibility of fault-tolerant operations with these qubits.

[1] S. Gladchenko, D. Olaya, E. Dupont-Ferrier, B. Douçot, L.B. Ioffe, and M.E. Gershenson. Superconducting Nanocircuits for Topologically Protected Qubits. *Nature Physics* **5**, 48-53 (2009).

[2] M.T. Bell, I.A. Sadovskyy, L.B. Ioffe, A.Yu. Kitaev, and M.E. Gershenson. Quantum Superinductor with Tunable Non-Linearity. *Phys. Rev. Lett.* **109,** 137003 (2012).

[3] M.T. Bell, J. Paramanandam, L.B. Ioffe, and M.E. Gershenson. Protected Josephson Rhombus Chains. *Phys. Rev. Lett.* **112,** 167001 (2014).