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Pheliqs
Quantum Physics & Engineering

Université Grenoble Alpes

GRENOBLE INP UGA

Master thesis Project

Superconducting spin-boson model for an Andreev qubit

Despite spectacular progress over the last 20 years, there seems to be an emerging consensus in the quantum technology community that current qubits are not sufficiently well protected against relaxation and dephasing mechanisms. Therefore, a lot is at stake in designing new types of qubits with inherent protection. A promising route, that is actively explored and that the master project inscribes itself in, is the combination of bosonic and fermionic degrees of freedom.

A Josephson junction formed by a weak link between two superconductors can accommodate localized fermionic states, known as Andreev bound states, whose energy depends on the phase difference between the two superconductors. New types of qubits realized by coupling these Andreev bound states to a bosonic mode of the surrounding electromagnetic environment have been proposed recently. The general idea is to convert two possible occupations of an Andreev bound state into two logical states of the qubit encoded in well-separated regions of the space of superconducting phase differences near 0 and π (modulo 2π), respectively. Such a separation is expected to strongly suppress the relaxation between two qubit states and therefore protects the qubit. However, at the same time it makes it harder to address the qubit. The aim of the master project will be to assess theoretically the best compromise between the desire to reach good protection and the needs for qubit manipulation.

In spite of the complexity of the circuit, a phenomenological model that contains the basic ingredients to describe such qubits involves a quite limited number of degrees of freedom: a spin, which accounts for the Andreev bound state occupation, and an oscillating mode of the environment. Their coupling is provided by the quantum fluctuations of the phase difference across the Josephson junction, which are driven by the displacement of the oscillator. As a first step, we will evaluate the performance of a qubit described by the resulting Hamiltonian and identify observables that allow one to assess the proper functioning of the qubit. Despite the apparent simplicity of the model, we expect that the interplay of various energy scales (Andreev gap, charging and inductive energy) and external control parameters (magnetic flux, electrostatic gate) can result in a broad variety of regimes. Our study will provide a useful guidance for the qualitative effects to be expected in realistic devices.

Analysis of the phenomenological Hamiltonian will rely on standard methods of theoretical condensed matter physics, such as analytical methods based on the Born-Oppenheimer picture of a spin degree of freedom coupled to a quantum oscillator. We will benchmark the results from the emerging physical picture with numerical evaluations based on exact numerical diagonalization.

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The internship will be supervised jointly with Benoit Douçot (LPTHE, Paris). A possible extension for a PhD project will be to explore more complex models needed for a quantitative description of the experiments. The focus will be, e.g., on the role of the quasiparticle continuum and the effect of additional Andreev bound states. The main issue here lies in the precise correspondence between theory and experiments. We will constrain the theoretical models by fitting their spectroscopic predictions with actual experiments performed in the Quantronics group in Saclay.

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