Relaxation of a Coherent Quantum System During Premeasurement Entanglement

Personnel

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Recent experiments on superconducting loops have demonstrated coherent superpositions between macroscopic quantum states. In the experiment of the superconducting persistent-current qubit, a dc SQUID measures the magnetic flux generated by the persistent currents of the macroscopic quantum states. Due to the inductive interaction between the qubit and the SQUID, the SQUID has various back effects on the qubit. For instance, the relaxation and dephasing of the qubit are limited by the noise from the environment of the dc SQUID. Here, we calculated the noise transmitted to the qubit from the environment of SQUID and analyzed its effect on qubit dynamics within the spin-boson formalism. The results can be applied to optimizing the measurement circuit for the best signal-to-noise ratio. We also studied the intrinsic limitation of the SQUID measurement scheme and developed new method to improve the measurement efficiency.

During measurement, a bias current Ib is ramped through the SQUID; and the switching current, where the SQUID switches to finite voltage state, is measured. Due to quantum fluctuation and thermal activation, the SQUID switches before the critical current and has a finite distribution. The average switching current shifts with the effective critical current and reflects the probability of the two-qubit states. In this ramping process, as the qubit and the SQUID become entangled, the noise from the environment of the SQUID affects the qubit via their inductive interaction. We calculated the noise in the Caldeira-Leggett formalism where dissipation process is described as the generalized susceptibility of an effective circuit. The method we developed can be applied to other interacting systems to study the noise problems.

The qubit dynamics is described within a master equation approach when the interaction with the environment is weak. From this approach the relaxation and decoherence of the qubit, also called the transversal relaxation and the longitudinal relaxation rates, are described by the spectrum density of the environment. As the inductive interaction induces a σ_z interaction between the qubit and SQUID environment, the qubit Hamiltonian H_0 has non-commuting σ_x component with the σ_z interaction, a transversal interaction that flips the qubit and eventually relaxes it and the qubit eigen-basis is created. This transversal interaction depends on both the tunneling between the two localized qubit states and the inductance coupling quadratically. With the renormalized spectrum density, the qubit is damped strongly by the SQUID environment. This effect prevents the measurement of the coherent oscillation between the macroscopic states with the current experimental setup.

Our study also suggests that by engineering the measurement circuit, we can optimize the spectrum density seen by the qubit and minimize the relaxation of the qubit due to various environmental fluctuations. Within the theoretical framework, various designs can be analyzed and compared.

We also studied the built-in limitation of the flux detection scheme by the dc SQUID. Our conclusion is that the direct detection of the flux of the qubit is not an efficient way of resolving the qubit states. This inefficiency is due to the fact that the flux induced in the qubit by the persistent currents is small compared to the quantum broadening of the SQUID loop. To improve the measurement, we developed a new scheme that can resolve the qubit state in one single shot of the measurement by applying an entanglement technique before detecting the flux of the qubit.