Theoretical Description of Motional Averaging in a Superconducting Qubit

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In a superconducting qubit, the energy splitting of the two quantum states can be controlled accurately with e.g. magnetic flux or voltage. In addition, the energy splitting can be measured with a weak excitation field i.e. by using spectroscopy. Motivated by these we study the absorption spectrum of a superconducting qubit, whose energy splitting is randomly jumping between the discrete values $\hbar(\omega_0 \pm \delta)$. We derive the absorption spectrum by solving the master equation and averaging over the Markovian stochastic fluctuations of the energy splitting. The spectrum is studied as a function of the average jumping rate Ω, which, together with the amplitude δ, characterizes the jumping process. When the jumping rate is small with respect to the amplitude ($\Omega \ll \delta$), the qubit absorbs energy at frequencies $\omega_0 \pm \delta$. In the opposite limit ($\Omega \gg \delta$), the absorption occurs only at the average frequency ω_0. This phenomenon is known as motional averaging in NMR, but, to our knowledge, it has not been studied before in a single artificial atom. We have studied the effect by making numerical simulations based on quantum trajectories. We show that the motional averaging phenomenon can be observed in a parameter range that is experimentally realizable in a circuit QED system consisting of a superconducting transmon qubit and a superconducting quarter-wave length coplanar waveguide.