Conditional Dynamics of a Dual-Rail Qubit with Asymmetric Erasure Rates

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Dual-rail erasure qubits offer a promising route toward higher error correction thresholds by converting dominant energy relaxation errors into detectable erasure errors. Existing implementations typically assume that the erasure rates of the two logical modes are equal, or that any asymmetry is effectively suppressed by averaging or by dynamical decoupling. In this work we develop a detailed microscopic model for erasure errors in transmon-based dual-rail qubits and study the conditional dynamics of the qubit subspace upon post-selection against erasure events. We show that the erasure asymmetry $\delta\Gamma$ introduces an additional dephasing channel in the conditional dynamics. For single trajectories the coherence decays on a timescale set by $1/\delta\Gamma$, typically faster than in the symmetric limit. We further show that T_1 experiments have a reduced sensitivity to the $\delta\Gamma$ induced channel whereas T_2 experiments retain the single trajectory behaviour. We argue that this distinction explains an apparent contradiction in recent experimental data and poses a significant challenge in the calibration of DR qubit based systems. To mitigate the erasure asymmetry dephasing channel in T_2 experiments, the standard approach is to apply CPMG dynamical decoupling sequences. We show that even in the limit of purely static noise, the number of pulses required grows with the magnitude of the erasure asymmetry. Since long CPMG sequences are difficult to integrate into QEC circuits and themselves introduce additional dephasing, as an alternative, we propose a passive mitigation strategy based on modulating the energy splitting of the two-level system bath responsible for the asymmetry, which suppresses $\delta\Gamma$ and recovers the $T_2 = 2T_1$ limit without requiring active pulse sequences on the qubit.