Extending the low-frequency limit of qubit noise spectroscopy beyond the inverse dephasing time

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Engineering noise-aware control pulses is a powerful strategy to reach the gate fidelities necessary to operate fault-tolerant quantum computers. Such tailored pulses require the detailed knowledge of the noise in the qubit host environment, and demand an accurate, full bandwidth characterization of the noise spectrum. Established dynamical-decoupling-based noise spectroscopy protocols [1] have the drawback that the lowest detectable frequency is bounded by the inverse of the T_2 coherence time. Moreover, the coarse resolution in the low frequency region fails to provide detailed knowledge of the noise. These limitations become more severe in most solid-state quantum systems, where $1/f$ noise dominates.

Here, we show a novel spectroscopy method that circumvents these limitations by employing non-π pulses to reconstruct the low-frequency part of the noise spectrum. We design control sequences that generate a frequency sampling equation with an extra modulation term, which allows moving the sampling regime to lower frequency regions. By employing a Bayesian reconstruction algorithm, the basic properties of the low frequency spectrum can be estimated.

We apply this spectroscopy method to ^{31}P qubits in silicon, which are excellent candidates for a large-scale quantum computer, due to their long coherence times [2], high gate fidelities [3], and the compatibility with classical semiconductor fabrication process. Our noise spectroscopy method is verified by successfully picking up noise that is artificially introduced through our gate electrodes. The information gained from this new method will help us design noise-aware quantum gates that further improve the gate fidelities beyond the fault-tolerance thresholds.

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