Implementation of the Quantum Fourier Transform on a molecular qudit with full refocusing and state tomography

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Abstract: We implemented the Quantum Fourier Transform on a molecular spin qudit with high fidelity. Precise control over populations and coherences was achieved with a refocusing strategy during gate implementation, mitigating inhomogeneous broadening.

Molecular spin qudits based on lanthanide complexes offer a promising platform for quantum technologies [1]. However, experimental demonstrations of their envisaged capabilities remain scarce [2]. Here, we implement in a ^{173}Yb(trensal) qudit the Quantum Fourier Transform (QFT), a core component of numerous quantum algorithms, storing quantum information in the phases of coherences [3]. QFT provides an ideal benchmark for coherence manipulation and an unprecedented challenge for molecular spin qudits. We address this challenge by embedding a full-refocusing protocol for spin qudits in our algorithm, mitigating inhomogeneous broadening—which otherwise dampens the coherence of the ensemble in a short time $T_2^* < 1$ μs—and enabling a high-fidelity recovery of the state. Complete state tomography demostrates the performance of the algorithm, while simulations provide insight into the physical mechanisms behind inhomogeneous broadening. This result shows the feasibility of quantum logic on molecular spin qudits and highlights their potential for quantum technologies.

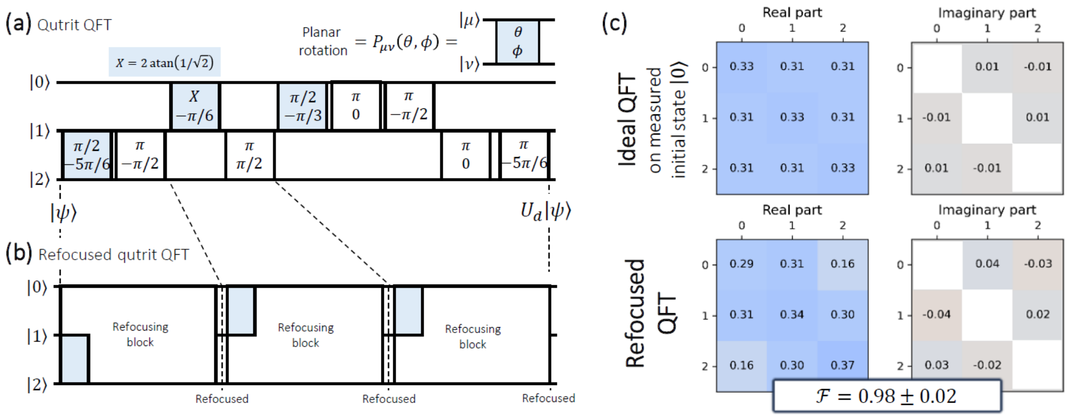

Fig. 1. (a) QFT decomposition in planar rotations. (b) Refocused QFT. (c) Tomography after implementing QFT on state |0⟩.

Our refocusing strategy can be generalized to any quantum gate and qudit dimension, potentially setting the much longer pure dephasing time $T_2 \gg T_2^*$ as the maximum time scale for any implementation, at the cost of a longer pulse sequence. In this regard, we have devised a method to find the shortest possible refocused pulse sequence for any gate, while in parallel we are exploring how T_2 can be enhanced by both changing magnetic dilution and cooling down to very low temperatures. Recent studies in a different molecular complex—VO(TPP), [4]—show an enhancement of T_2 from 40 μs at 1.4 K (temperature of the QFT implementation experiment) up to above 800 μs (above 1 ms using CPMG) by decreasing the concentration of magnetic molecules and cooling down to 30 mK in our new dilution fridge.

References

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