Multi-frequency control and measurement of a spin-7/2 system encoded in a transmon qudit

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Qudits hold great promise for efficient quantum computation and the simulation of high-dimensional quantum systems [1]. Utilizing a local Hilbert space of dimension d > 2 is known to speed up certain quantum algorithms relative to their qubit counterparts given efficient local qudit control and measurement. However, the direct realization of high-dimensional rotations and projectors has proved challenging, with most experiments relying on decompositions of SU(d) operations into series of rotations between two-level subspaces of adjacent states and projective readout of a small number of states [2]. In this talk I will discuss recent experiments [3] which employed simultaneous multi-frequency drives to generate rotations and projections in an effective spin-7/2 system by mapping it onto the energy eigenstates of a superconducting circuit. We implement single-shot readout of the 8 states using a multi-tone dispersive readout ($F_{\text{assignment}}$ = 88.3%) and exploit the strong nonlinearity in a high-EJ/EC transmon to simultaneously address each transition and realize a spin displacement operator. By combining the displacement operator with a virtual SNAP gate, we realize arbitrary single-qudit unitary operations in O(d) physical pulses and extract spin displacement gate fidelities ranging from 0.997 to 0.989 for virtual spins of size j = 1 to j = 7/2. These native qudit operations could be combined with entangling operations to explore qudit-based error correction or simulations of lattice gauge theories with qudits. Our multi-frequency approach to qudit control and measurement can be readily extended to other physical platforms that realize a multi-level system coupled to a cavity and can become a building block for efficient qudit-based quantum computation and simulation.

[1] Wang et al. Frontiers in Physics 8, 479 (2020)
[2] Bianchetti et al. Physical Review Letters 105, 223601 (2010)
[3] Champion et al. arXiv:2405.15857 (2024)