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Random-access quantum memory using chirped pulse phase encoding

We introduce a random access quantum memory protocol using adiabatic fast passage (AFP) chirped pulses to imprint phase shifts onto single quantum excitations stored in an ensemble of spins coupled to a superconducting cavity. These spatially- and spectrally-dependent phase shifts suppress collective emission of the excitations stored in the ensemble and uniquely label them so they can be retrieved on-demand following the application of a precise AFP. In addition to random access, our protocol offers in-built dynamical decoupling (DD) while suppressing emission into the cavity when the ensemble is in the excited state. We experimentally demonstrate the protocol using Bi donor spins in Si coupled to a superconducting resonator, storing up to four weak (~400 photon) microwave pulses before retrieving them, in a different order, up to 2 ms later. With even modest cooperativity (C~0.045), echo emission from the excited ensemble state results in superradiant spin echo emission, reducing the fidelity and lifetime of the memory, and we show that this is mitigated using our protocol. Finally, we explore the independence of the storage modes and implications for scaling the memory and enhancing its efficiency and lifetime.