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Unitary Transformations in a Large Hilbert Space

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Quantum systems with Hilbert space dimension greater than two (qudits) provide an alternative to qubits as carriers of quantum information, and may prove advantageous for quantum information tasks if good laboratory tools for qudit manipulation and readout can be developed. We have implemented a protocol for arbitrary unitary transformations in the 16 dimensional hyperfine ground manifold of Cesium 133 atoms, using phase modulated rf and microwave magnetic fields to drive the atomic evolution. Our phase modulation waveforms are designed numerically using a variant of the highly efficient GRAPE algorithm. The fidelity of the resulting transformations is verified experimentally through randomized benchmarking, which indicates an average fidelity better than 97% across a sample of random unitaries.