DAMOP17-2017-020024

Abstract for an Invited Paper
for the DAMOP17 Meeting of
the American Physical Society

Arbitrary Dicke-State Control of Symmetric Rydberg Ensembles

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We study the production of arbitrary superpositions of Dicke states via optimal control. We show that N atomic hyperfine qubits, interacting symmetrically via the Rydberg blockade, are well described by the Jaynes-Cummings Model (JCM), familiar in cavity QED. In this isomorphism, the presence or absence of a collective Rydberg excitation plays the role of the two-level system and the number of symmetric excitations of the hyperfine qubits plays the role of the bosonic excitations of the JCM. This system is fully controllable through the addition of phase-modulated microwaves that drive transitions between the Rydberg-dressed states. In the weak dressing regime, this results in a single-axis twisting Hamiltonian, plus time-dependent rotations of the collective spin. For strong dressing we control the entire Jaynes-Cummings ladder. Using optimal control, we design microwave waveforms that can generate arbitrary states in the symmetric subspace. This includes cat states, Dicke states, and spin squeezed states. With currently feasible parameters, it is possible to generate arbitrary symmetric states of _10 hyperfine qubits in ˜1 microsec, assuming a fast microwave phase switching time. The same control can be achieved with a "dressed-ground control" scheme, which reduces the demands for fast phase switching at the expense of increased total control time. More generally, we can achieve control on larger ensembles of qubits by designing waveforms that are bandwidth limited within the coherence time of the system. We use this to study general questions of the "quantum speed limit" and information content in a waveform that is needed to generate arbitrary quantum states.