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Symplectic FDTD Algorithm for Semiclassical Quantum Electromagnetic Model

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The manipulation of quantum states of atoms/artificial atoms using electromagnetic waves is the foundation of quantum computing, quantum communication, and quantum precision measurements. Propagation of electromagnetic waves satisfies the classical Maxwell equations while motion of quantum states satisfies the Schrödinger equation or the optical Bloch equation. Firstly, we established a semiclassical quantum electromagnetic model suitable for simulating the interaction between electromagnetic waves and atoms/artificial atoms. We also derived the corresponding Hamiltonian of the quantum electromagnetic system and proved that the coupled system still retains a symplectic structure. Secondly, using the high-order-accuracy symplectic FDTD algorithm, we discretized the multiscale and multiphysics system and developed the temporal symplectic operators and spatial subgridding techniques. Finally, we applied the numerical model to solve typical quantum electromagnetic problems, including quantum state manipulation, Rydberg atom detection, and spontaneous emission of quantum dots. In long-time simulations, the symplectic FDTD algorithm showed significant numerical stability and accuracy compared to traditional FDTD method. In future, we will study the interactions of multiple atoms/artificial atoms in complex electromagnetic environments for more practical applications.

References

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