Creating arbitrary coherent superposition in multi-level systems using optimal control theory

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Efficient control of population transfer in multi-level systems has been an ultimate goal in a variety of research areas including laser atomic and molecular spectroscopy, photochemistry, biology and quantum information processing. The development of robust population transfer schemes, such as stimulated Raman adiabatic passage (STIRAP) and chirped-pulse adiabatic passage, provide new opportunities of quantum control and even creating a new state of matter, such as Bose-Einstein condensate.

In this work we consider the creation of quantum superposition states in the multi-level systems using the optimal control theory. Using the Krotov method including a reference field into the cost functional we design optimal field for different excitation conditions, resonant and off-resonant. Minimum population transfer to the intermediate levels is achieved via a functional constraint which depends on the state of the system at each time instant. For various conditions, convergence feature and frequency spectrum of the optimal fields are analyzed. We demonstrate that the frequency profile of the optimized fields has a major contribution from the resonant frequencies of the quantum system, independently from the choice of carrier frequency of the initial guess field. We also examine the strategies that incorporate the evolution of carrier frequency into the optimal control technique leading to the final target goal. We also develop a control method allowing to incorporate some restrictions from quantum control setups which can facilitate future experimental studies.