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Coherent superpositions of states in coupled Hilbert-space using step by step Morris–Shore transformation

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ABSTRACT

Creation of coherent superpositions in quantum systems with N_a states in the lower set and N_b states in the upper set is presented. The solution is drived by using the Morris–Shore transformation, which step by step reduces the fully coupled system to a three-state Λ-like system and a set of decoupled states. It is shown that, for properly timed pulse, robust population transfer from an initial ground state (or superposition of M ground states) to an arbitrary coherent superposition of the ground states can be achieved by coincident pulses and/or STIRAP techniques.

1. Introduction

Coherent population transfer and coherent creation of superposition states attracted a great amount of attention for the control of quantum information processing [1–6]. Potentially several schemes to produce them, based on Stimulated Raman adiabatic passage (STIRAP) [7–10], quantum Householder reflections (QHR) [11] and a train of coincident pulses [12] techniques have been proposed. In Refs. [13–17] coherent superposition of states has been studied in multi-state systems by STIRAP. QHR has been used in Refs. [18,19] to generate an arbitrary superposition in N-pod systems (N ground states all coupled to the same excited state) and two coupled sets of levels. A technique of coherent superposition of ground states in multi-states systems based on coincident pulses was developed in [20,21].

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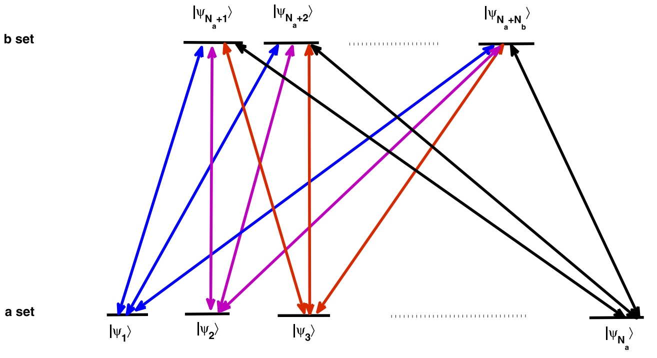

Fig. 1. A multistate system consisting of two coupled sets of levels.

In description of multi-state quantum systems which involve numerous connections (linkages) between quantum states, the resulting dynamics of the time-dependent Schrödinger equation (TDSE) can become correspondingly complicated. The Morris–Shore (MS) transformation [22–24] offers a means of simplifying the description of multi-state systems by defining a unitary constant transformation that present the multi-state system as a set of independent three and/or two excitations and uncoupled dark states. This transformation has been very recently investigated for the pulse propagation in a dressed, degenerate system [25]. According to the original MS transformation [22], two coupled sets of degenerate levels with N_a sublevels of the a level and N_b sublevels of the b level will be $\min\{N_a, N_b\}$ two-state systems and $|N_a - N_b|$ uncoupled dark states.

The application of stimulated Raman adiabatic passage and/or a train of coincident pulses techniques in two coupled sets of levels requires that the original linkage pattern reduced to a three level Λ-like system and uncoupled dark states. That is why we cannot implement STIRAP and/or coincident pulses techniques using one step Morris–Shore transformation in two coupled sets of levels.

In this paper, MS transformation has been used in stepwise manner, in order to reduce two coupled sets of levels to a three level Λ-like system and uncoupled dark states. We show that, using MS transformation in stepwise manner, a train of coincident pulses and STIRAP can be implemented in two coupled sets of levels. Besides for properly timed pulses population can be transferred from an initial state to an arbitrary coherent superposition of the ground states.

This model can therefore be considered as an extension of STIRAP and coincident pulses techniques in N-pod systems [14–17,21] to two coupled sets of levels. It can also be viewed as a solution of the presented models in [19,26], when the pulses are on exact resonant (or near resonant) with a particular transition.

This paper is organized as follows. I define the model in Section 2 and step by step MS transformation is introduced in Section 3. Arbitrary superposition of the ground states by a train of coincident pulses and STIRAP are considered in Sections 4 and 5. In Section 6 I demonstrate some examples of this method in realistic physical situations. The conclusions are summarized in Section 7.

2. The model

We consider a quantum system with N_a states $\{|\psi_m\rangle\}_{m=1}^{N_a}$ in the (lower) a set and N_b states $\{|\psi_{N_a+n}\rangle\}_{n=1}^{N_b}$ in the (upper) b set, as displayed in Fig. 1 [26,19]. Each of the a states $|\psi_m\rangle$ is coupled to each of the b states $|\psi_n\rangle$ by a time dependent resonant pulses $\Omega_{mn}(t)$. The real functions $\Omega_{mn}(t)$ will be assumed to be positive as the population do not depend on their signs. In our method we impose that for a certain value m all pulses $\Omega_{mn}(t)$, $\quad n = 1, 2, \ldots, N_b$ have the same time dependence, however they may have different magnitudes. We shall consider the possibility that there be no zero elements of the Hamiltonian matrix linking any states from the lower set and the states in the upper set. In the