Protocol for mapping of a V-type atom state onto cavity field state

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We consider state-mapping operations performed in the system composed of an V-type atom (or an atom-like structure like a quantum dot) and a cavity (see Fig. 1). The evolution of this system is governed by the Hamiltonian

$$H = -\Delta\sigma_{22} + (\Omega\sigma_{02} + ga\sigma_{12} + \text{h.c.}).$$

We prove that it is impossible in this quantum system to transfer a qubit encoded in excited states of the atom to the state of the cavity field mode with the fidelity equal to one using a single rectangular laser pulse [1]. The population of the ground atomic level $|2\rangle$, which plays the role of the intermediate state, is always non-zero at the end of the mapping pulse, and thus reduces the fidelity. This situation is illustrated in Fig. 2 for mapping of the state $(|0\rangle_{\text{atom}} + |1\rangle_{\text{atom}})/\sqrt{2} \otimes |0\rangle_{\text{cavity}}$. It is seen in Fig. 2 that this state cannot be perfectly transformed into $(|0\rangle_{\text{cavity}} + |1\rangle_{\text{cavity}})/\sqrt{2} \otimes |0\rangle_{\text{atom}}$ because of non-zero population of the intermediate state $|2\rangle$. This obstacle limits the usefulness of V-type systems in large quantum algorithms, and therefore, we propose a state-mapping protocol, which performs the state-mapping operation almost perfectly.

The main idea is illustrated in Fig. 3. The state-mapping protocol consists of two stages only:

- *The evolution-shift stage*. In the first stage we change the state $|20\rangle = |2\rangle_{\text{atom}} \otimes |0\rangle_{\text{cavity}}$ without changing other states using the intense laser pulse operation. After this ultrashort laser pulse the evolution of the state $|20\rangle$ is in a sense shifted. We choose big enough intensity and the proper phase of the laser field.

- *The π pulse stage*. In the second stage of the protocol we decrease the intensity of the laser field to satisfy the condition $|\Omega| = |g|$ and we keep the laser on for such time t_π to perform operation $|10\rangle \to |01\rangle$.

Since the first stage is ultra-short, this protocol is almost as fast as state mapping performed in Λ-type systems [2]. Moreover the fidelity is almost as high as in Λ-type systems, because it tends to unity with increasing of the intensity of the laser field in the first stage. Hence the state-mapping protocol makes V-type atom-cavity systems useful in large quantum algorithms.

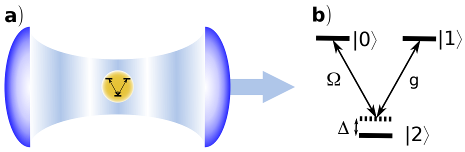

FIG. 1. (a) Schematic representation of the setup. (b) Level scheme of the atom.

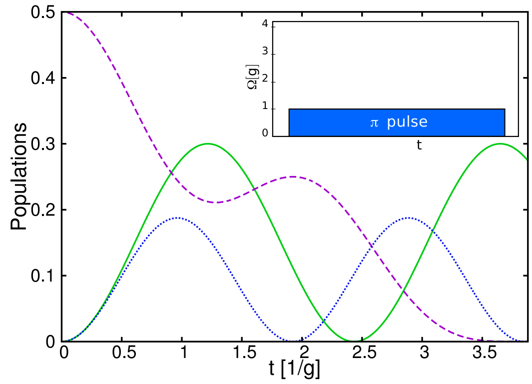

FIG. 2. Populations of the states $|20\rangle$ (solid line), $|21\rangle$ (dotted line) and $|10\rangle$ (dashed line). All these populations should be equal to zero at the end of the mapping pulse.

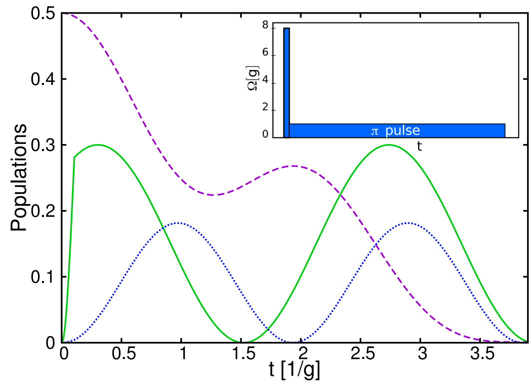

FIG. 3. At the end of the state-mapping protocol all these populations are close to zero, and thus, the fidelity of the state mapping is close to one. Inset: the pulses sequence of the protocol.

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[2] G. Chimczak and R. Tanaś, Phys. Rev. A **77**, 032312 (2008).