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

Grzegorz Chimczak

1Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland

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 \( \pi \) 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 \( t_{\pi} \) to perform operation \( |10\rangle \rightarrow |01\rangle \).

Since the first stage is ultra-short, this protocol is almost as fast as state mapping performed in \( \Lambda \)-type systems [2]. Moreover the fidelity is almost as high as in \( \Lambda \)-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.

---

*chimczak@kielich.amu.edu.pl*