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Population transfer in a nitrogen-vacancy spin qutrit via shortcuts to adiabaticity with simplified drivings

R.-Y. Yan, Z.-B. Feng[1)]

School of Science, Xuchang University, 461000 Xuchang, China

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Electron spin of nitrogen-vacancy (NV) center in diamond holds many distinct advantages. Acting as a significant building block towards information science and technology, coherent population transfer has attracted increasing attention in recent years [1–4].

Rapidly implementing quantum operation of interest and accurately manipulating quantum system are highly desirable. A set of techniques named as shortcuts to adiabaticity (STA) has been put forward [5–7], capable of performing the adiabatic-like robust operation but in a shorter time. By means of the STA of superadiabatic transitionless driving (SATD), Zhou et al. experimentally reported an accelerated population transfer in a spin qutrit of NV center [8]. However, the SATD-corrected Rabi pulses had the complex time profiles, which could be adverse to precisely adjust control variables. Thereby, choosing simple and feasible pulses plays a key role in the subject of STA for obtaining fast and robust operations.

The ground state of electron spin of NV center is a triplet, which are denoted as $|m_0\rangle$, $|m_{-1}\rangle$, and $|m_1\rangle$. A spin-orbit excited state is labeled as $|A_2\rangle$. Then $|m_{-1}\rangle$, $|A_2\rangle$, and $|m_1\rangle$ constitute a three-state system (qutrit). $|m_{-1}\rangle$ and $|m_1\rangle$ are encoded into qubit states, while $|A_2\rangle$ acts as an auxiliary state. An optical driving is applied to the qutrit, leading to a coupling between $|m_{-1}\rangle$ and $|A_2\rangle$ with a Rabi rate Ω_p. Meanwhile, the coupling between $|m_1\rangle$ and $|A_2\rangle$ can be realized using another driving, and the Rabi rate of which is Ω_s. At two-photon resonance, we get a Λ-configuration interaction of the qutrit with external drivings. We design Rabi pulses within the framework of invariant-based STA.

First, we address a population transfer from an initial state $|m_{-1}\rangle$ to a target state $|m_1\rangle$ by setting $\Omega_{p,s}$ as the sine and cosine functions of time $t \in [0, t_f]$. Numerically, the time dependencies of $\Omega_{p,s}$ are demonstrated in Fig. 1a, in which we have $t_f = 10\,\text{ns}$. Based on the designed Rabi pulses Ω_p (Ω_s) having the commonly utilized sine (cosine) waveform, we achieve the prescribed population transfer, see Fig. 1b. Secondly, it is necessary to consider the reversed transfer from $|m_1\rangle$ to $|m_{-1}\rangle$ by adjusting the Rabi pulses Ω_p and Ω_s. Correspondingly, $\Omega_{p,s}$ versus time $t \in [0, 15\,\text{ns}]$ are plotted in Fig. 1c. Based on the designed Rabi couplings, the coherent population transfer from $|m_1\rangle$ to $|m_{-1}\rangle$ of interest can be realized well, see Fig. 1d.

Our strategy may have the following advantages. (i) The Rabi drivings in our scheme have the sine and cosine waveforms, which are easily generated in experiment. Compared with the SATD-based counterpart [8], the simplified pulses are beneficial to reduce the control deviation error. (ii) The drivings under consideration satisfy the condition of two-photon resonance. Compared with the drivings in the large-detuning regime, the resonant drivings can induce faster population transfer. (iii) Based on the Rabi drivings as the sine and cosine functions of time, the bidirectional state transfer in a convenient way is highly desirable to quantum state engineering.

In summary, an efficient strategy is developed for rapidly implementing population transfer within a spin qutrit of NV center in diamond via STA with simplified drivings. We perform population transfer and its reversed operation by designing the time-dependent Rabi pulses with sine and cosine waveforms. Compared with the STAD-corrected pulses, the pulses adopted in our protocol are more accessible technically. The present scheme could offer an optimized avenue towards the STA-based quantum control of spin qutrit experimentally.

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[1)]e-mail: zbfeng010@163.com

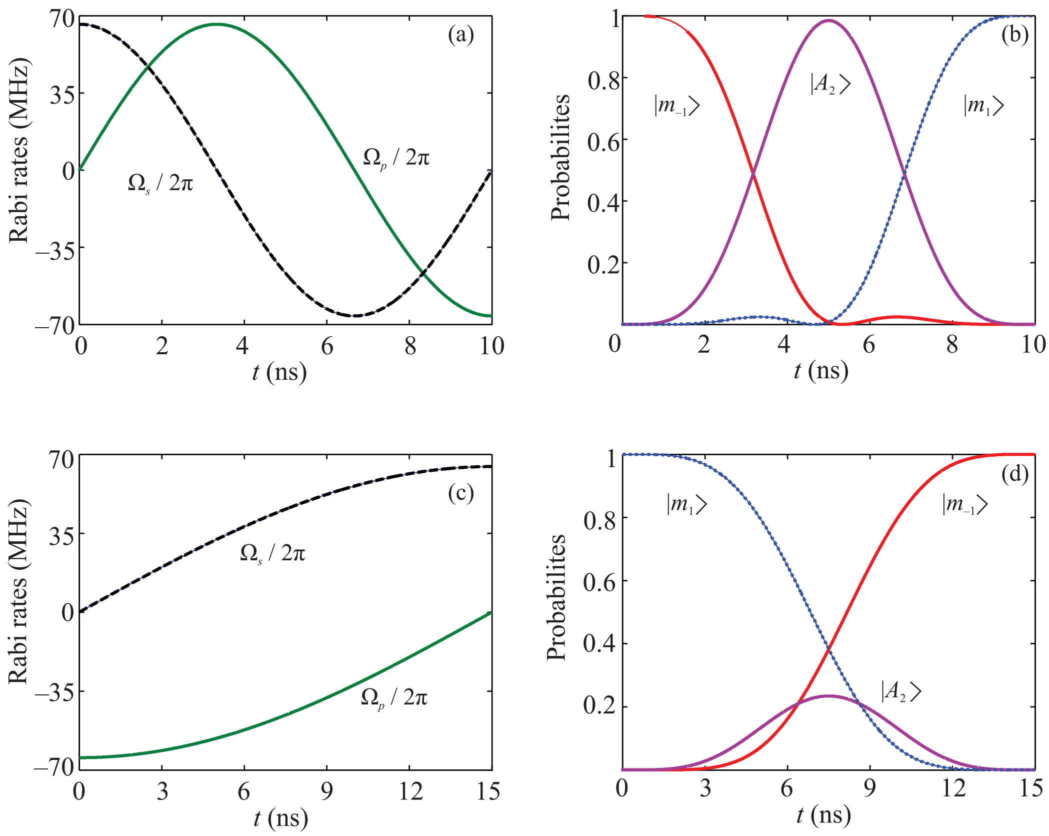

Fig. 1. (Color online) (a) – Rabi pulses $\Omega_{p,s}/2\pi$ with sine and cosine waveforms versus time t. (b) – The time evolution of the probabilities occupied by $|m_{-1}\rangle$ (red solid line), $|A_2\rangle$ (purple solid line), and $|m_1\rangle$ (blue dotted line). (c) – Rabi pulses $\Omega_{p,s}$ for performing a reversed state transfer from $|m_1\rangle$ to $|m_{-1}\rangle$. (d) – Coherent population transfer from $|m_1\rangle$ to $|m_{-1}\rangle$ versus time t

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