Long-range transfer of hole spin qubits with shortcut-to-adiabaticity methods

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Quantum state transfer is crucial for modular quantum computing, where communication between different quantum processing units is achieved using quantum buses [1]. The success of these communications relies on their speed, high-fidelity, and noise robustness. In semiconductor spin qubits, linear arrays of quantum dots are used as communication lines, with tunneling between sites serving as the driving parameter. However, the presence of spin-orbit coupling (SOC) in hole spin qubits can negatively impact transfer fidelity by causing spin-flip processes and loss of quantum information. On the other hand, SOC can also be leveraged to allow for one-qubit gates to be performed during particle transfer between distant sites.

In this study, we analyze different state transfer protocols, including CTAP, a linear ramp, and a driving protocol based on shortcuts to adiabaticity (STA) [2]. We investigate how these protocols are affected by 1/f charge noise [3, 4] on the detuning and tunneling rate between dots (see Figure 1). We also explore how the total number of dots impacts the final spin of the transferred particle. By tuning the ratio between spin-conserving and spin-flip tunneling, we can control the one-qubit gate performed during the transfer. Additionally, we extend our study to quantum state distribution [5], where two entangled particles are distributed across distant sites of a linear quantum dot array (see Figure 2). Thanks to SOC, we can adjust the total transfer time to tune the final spin projection [6].

Overall, our work contributes to the development of efficient and robust quantum state transfer protocols, which are essential for the successful implementation of modular quantum computing.

References

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Figures

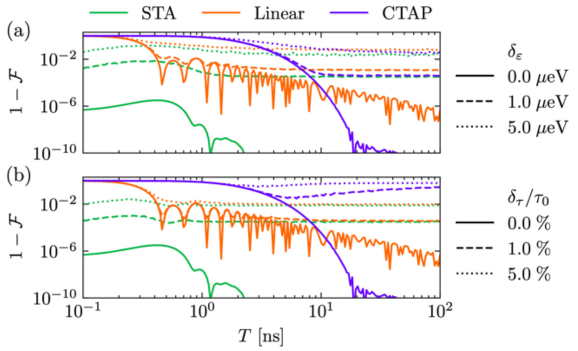

Figure 1: Infidelity of a state transfer versus to total protocol time, for different driving pulses (STA, Linear, CTAP). The transfer in performed under a 1/f noise model in the detuning between dots (a) and in the tunnelling rates (b).

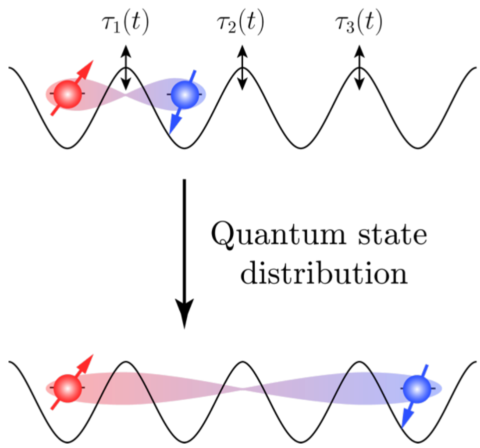

Figure 2: Quantum state distribution of two entangled spin qubits in a quantum bus.