Protecting the $\sqrt{\text{SWAP}}$ operation from general and residual errors by continuous dynamical decoupling

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In order to to take advantage of the benefits of reliable quantum information processing, we depend on the development of efficient ways to avoid or recover from the errors that, induced by environmental interaction, occur in the state of our quantum system. Accordingly, several strategies to protect quantum information, particularly during the operation of a quantum gate, have been designed, including quantum error correcting codes, fault-tolerant quantum computing, decoherence-free subspaces, etc. One of the most effective methods to protect the state of a quantum system from decoherence is called dynamical decoupling (DD). The DD approach is based on applying a sequence of external control pulses to the quantum system to be protected, in order to suppress the errors arising from its coupling with the environment. In other words, one introduces an additional Hamiltonian, called the control Hamiltonian, that acts on the Hilbert space of the system, averaging out the effects of the environmental perturbations.

Alternatively, instead of control pulses, it is also possible to apply continuous external fields to decouple the system from the environmental interactions. This scheme, known as continuous dynamical decoupling (CDD), has attracted a lot of attention in recent years [1–4]. The CDD procedure is more experimentally friendly than pulsed procedures and it also sets a natural stage for the implementation of two-qubit quantum gates [5].

In this work, we consider CDD of a two-qubit system going through a $\sqrt{\text{SWAP}}$ operation while interacting with a bosonic environment. We obtain a simple control prescription which allows us to prove the effectiveness of our method in a realistic decoherence model. The effect of the environment is simulated by two different quantum channels – amplitude damping and dephasing – simultaneously and independently coupled to the qubits with different coupling strengths. We also study the effects of residual errors when the CDD protection is supplied just against the predominant error source, i.e., the one with the strongest coupling. In the present context, we consider the residual error as arising from the amplitude damping channel, while the qubits are dynamically decoupled from dephasing. We adopt the concurrence and the fidelity as the figures of merit of the CDD procedure. We show that the adopted CDD scheme provides nearly full protection against environmental effects when both error mechanisms are present and, for a residual amplitude-damping environment, a super-ohmic spectral density of states is more destructive than an ohmic one. Furthermore, in the absence of the CDD, we see that, in the case of a common environment for the qubits, both entanglement and fidelity decay more slowly than in the case of independent environments.

Protection of $\sqrt{\text{SWAP}}$ operation has a particular importance since, together with local measurements, it is sufficient for universal quantum computation.

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