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Efficient scheme for implementing the Deutsch-Jozsa algorithm in cavity QED

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Abstract. A scheme is proposed for implementing a two-qubit quantum logic gate and realizing the Deutsch-Jozsa algorithm in cavity QED. In the scheme a three-level atom interacts with highly detuned cavity modes. The gate is not affected by the atomic decay rates because of the metastable lower levels are involved in the gate operations. The Deutsch-Jozsa algorithm is easily realized with current experimental techniques.

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Key words: cavity QED, quantum logic gate, Deutsch-Jozsa algorithm

1 Introduction

In the last decade, people have paid much attention to physical realization of quantum computer owing to that it can offer an enormously acceleration compared to the classical one, such as quantum search [1] and Shor factoring [2]. As we all know that a quantum computing network is made up of a series of one-qubit rotation and two-qubit gates [3]. Considering a simple example of quantum algorithm-the Deutsch-Jozsa algorithm, which combines quantum parallelism with quantum interference. Also, two-qubit gate is an important step in it. It aims to distinguish function $f(x)$ between constant and balanced on 2^n inputs [4,5]. The value of function $f(x)$ is 0 or 1 for each input. If $f(x)$ is the constant, for all the inputs, the function values will be constant. But the values of the balanced function are equal to 0 for half of all the inputs while 1 for the other half. So far, there are many proposals for realizing the Deutsch-Jozsa algorithm theoretically and experimentally in the NMR system [6,7], ion trap [8], homonuclear multispin systems [9] and cavity QED [10,11].

Cavity QED is regarded as an ideal system to realize quantum information processing [10-17]. Lately, Zheng *et al.* [10]. have proposed a scheme for implementing the

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Deutsch-Jozsa algorithm. Following this, Yang *et al.* [12] have come up with a scheme to implement the Deutsch-Jozsa algorithm in cavity QED by using Schrodinger cat states, the atomic spontaneous emission can be minimized and it doesn't need the Hadamard gates because of the use of Schrodinger cat states. Ma *et al.* [13] also have proposed an idea to realize the Deutsch-Jozsa algorithm which uses superconducting quantum interference devices. Recently , Vallone *et al.* [14] describe an experimental scheme of the Deutsch-Jozsa algorithm with a six-qubit cluster states in their scheme, and the basis of the original measurement model allowing the algorithm implementation is its biggest characteristics. In our work, we propose a way to implement two-qubit quantum gates and the Deutsch-Jozsa algorithm in cavity QED system, in which a three-level atom interacts with highly detuned cavity modes. And the gate error induced by atomic spontaneous emission is minimized during the gate operation. The required experimental techniques are easy obtainable. Therefore our scheme might be experimentally realizable by using present available techniques. Meanwhile, the experimental achievement of the Deutsch-Jozsa algorithm would give birth to more important role in quantum computation.

The paper is organized as follows. In Section 2, we propose a scheme to realize a two qubit C-NOT gate. In Section 3 is devoted to describe how to implement the Deutsch-Jozsa algorithm in detail. Discussion and conclusion are given in Section 4.

2 Two qubit C-NOT gate

Here we consider a three-level Λ-type atomic system, as shown in Fig. 1. The atom levels are devoted by $|g\rangle$, $|l\rangle$, and $|e\rangle$.

The cavity modes having the annihilation operators $\hat{a}$, $\hat{b}$ interact with the atomic transitions $|g\rangle$ to $|e\rangle$, $|l\rangle$ to $|e\rangle$, respectively. And the cavity-field mode frequencies and the corresponding atomic transition frequencies are w_1, w_2 and w_{eg}, w_{el}, respectively. The

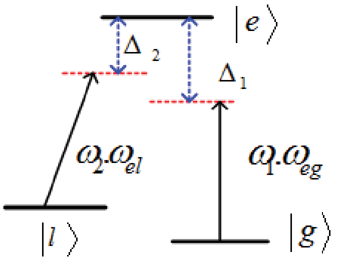

Figure 1: Schematic drawing of a three-lever atomic system in -type configuration. Here, ω_1, ω_2 are frequencies of the cavity-field mode. The parameters Δ_1 and Δ_2 are corresponding detuning of cavity-field mode from the respective atomic transition, respectively.