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Decoherence induced by the environment for dimerized anisotropic XY spin chain

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Abstract. The Loschmidt echo of single qubit coupling to the environment for dimerized anisotropic XY spin chain in transverse field have been analyzed. We have obtained analytical expression for the Loschmidt echo. By numerically computing the Loschmidt echo, we find that the decay of coherence will be enhanced with the increasing of the staggered parameter.

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Key words: dimerized anisotropic XY spin chain, decoherence, Loschmidt echo

1 Introduction

Decoherence is considered to be the main obstacle in quantum information processing [1]. The uncontrolled interactions of the system with the environment will result in a suppession of cohrence or loss of entanglement within system, namely, so called local decoherence or nonlocal decoherence [2, 3]. In study of decoherence, the environment is usually modelled as a collection of harmonic oscillators or spin-1/2 particles. In recent years, the study of spin-bath environment has been attracted special attentions [4-7]. For instance, it is found that quantum phase transitions in the spin-bath environment enhance the decay of coherence of single qubit interacting homogeneously with .all spins in the environment [8]. This phenomenon has also been observed in the experiment [9]. The decay of coherence is characterized by the Loschmidt echo (LE) which first appears in the context of quantum chaos. The properties of the Loschmidt echo have been extensively investgated in various spin-bath environments such as XY spin chain [8, 10], XY spin chain with three-site interaction [11], many-body system with two XY spin chain [12], time-dependent spin chain [13], etc. These reseaches reveal some connections between

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the enhanced decoherence of the Loschmidt echo and quantum phase transitions. In the other hand, one has studied the properties of entanglement of two quabits coupling to the spin-bath environment in vicinity of quantum phase transition points [14].

In this paper, we investigate decoherence induced by the environment for dimerized anisotropic XY spin chain. The statistical properties of the dimerized XY spin chain have been extensively studied such as spin-Peierls transition [15, 16], correlation function [17]. Here we compute the Loschmidt echo of single qubit coupling to the dimerized anisotropic XY spin chain and analyze the properties of LE. We find that the decay of coherence will be enhanced with the increasing of the staggered parameter.

2 The Model

Let us study the decoherence of a spin-1/2 particle coupling to the environment formed by a chain of N spin-1/2 particles. We consider the qubit interacts equally all the spins in the chain and neglect the self-Hamiltonian of the system. The Hamiltonian of the total system is given by

$$H = H_B + H_{SB} \tag{1a}$$

$$H_B = -\sum_{k=1}^{N}\left\{\frac{1}{2}[1+(-1)^k\delta](S_k^x S_{k+1}^x - S_k^y S_{k+1}^y)+\lambda S_k^z\right\} \tag{1b}$$

$$H_{SB} = -g|1><1|\oplus\sum_{k=1}^{N} S_k^z \tag{1c}$$

where periodic boubdary conditions are imposed, i.e. $S_{k+N}^a = S_k^a(\alpha = x, y, z)$, δ is referred to as staggered parameter, S_k^a are the Pauli operators for the kth site of the chain, λ and g are coupling parameters, two eigenstates of Pauli operator. S^z for the qubit are represented by $|1>$ and $|0>$). It is noted that the envirinment (to see Eq. (1b)) is described by the dimerized anisotropic XY spin chain in transverse magnetic field. If the parameter $\delta = 0$, then the envirinment will be degenerated to the anisotropic XY spin chain in which quantum phase transition was in detail investiged in ref. [18]. In the following study, we set $0 < \delta < 1$. As noted later, the decoherence of the qubit is dependent of the evolution of the environment with different effective Hamitonian

$$H^{(a)} = H_B - ag|1><1|\otimes\sum_{k=1}^{N} S_k^z \tag{2}$$

where $a = 0, 1$. In the following, we diagonalize the Hamitonian $H^{(a)}$. Making Jordan-Wigner transformation