Asymptotic dynamics of the alternate degrees of freedom for a two-mode system: An analytically solvable model*

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The composite systems can be non-uniquely decomposed into parts (subsystems). Not all decompositions (structures) of a composite system are equally physically relevant. In this paper we answer on theoretical ground why it may be so. We consider a pair of mutually un-coupled modes in the phase space representation that are subjected to the independent quantum amplitude damping channels. By investigating asymptotic dynamics of the degrees of freedom, we find that the environment is responsible for the structures non-equivalence. Only one structure is distinguished by both locality of the environmental influence on its subsystems and a classical-like description.

Keywords: amplitude dissipative channel, two-mode state, Kraus representation, alternate degrees of freedom

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1. Introduction

Realistic physical systems are composite, i.e. decomposable into smaller "parts" (subsystems). The set of the "subsystems" (i.e. of the degrees of freedom) of a composite system is not unique.

In classical physics, only one such set of subsystems (e.g. of the constituent particles) is usually considered physically relevant. The alternate decompositions (structures) of the composite system are typically considered non-realistic, a mathematical artifact. However, in the quantum mechanical context, the things may look different.

There is ongoing progress in distinguishing physical relevance of the alternate structures of a composite quantum system both on the foundational as well as on the level of application, cf. e.g. Refs. [1]–[12]. Regarding the foundational issues, the following question is of interest: which degrees of freedom of a composite system are accessible or can provide the above-mentioned classical description?[2,3,5,8,9,11,12] A closely related interpretational question reads: is there physically a fundamental set of the degrees of freedom of a composite system?[2,3,5,10] In the context of physical application, one can differently manipulate the different structures of a composite system, e.g., with the use of "entanglement swapping" for teleportation[1] or by targeting observables of a specific structure in order to avoid decoherence.[7] Quantum entanglement relativity[2–6] and relativity of the more general quantum correlations[9] open new possibilities in manipulating the quantum information hardware.[3,5,11] As a matter of fact, we just start to learn about the physical subtlety and possible usefulness of the concept of "quantum subsystem".

In this paper, we do not tackle the related deep questions. Rather, as a contribution to this new discourse in quantum theory, we stick to a concrete model that can be solved analytically and we provide some interesting observations.

We consider a pair of un-coupled modes in "phase space" representation (as a pair of non-interacting linear harmonic oscillators) independently subjected to the quantum amplitude damping channels.[13–16] We analytically (exactly) solve the Heisenberg equations of motion in the Kraus representation[13–19] and analyze the results obtained for the original as well as for some alternate degrees of freedom. We find that the environment non-equally "sees" the different structures. Particularly, only one structure is distinguished by the locality of the environmental influence on the structure's subsystems that provides a classical-like description of the subsystems.

This paper is arranged as follows. In Section 2 we rederive the solutions to the Heisenberg equations for a pair of modes. Our derivation is specific as it is an exact calculation in the infinite-sum Kraus representation of the amplitude damping dynamics of the two-mode system. In Section 3 we introduce and analyze the alternate degrees of freedom (the alternate structures) for the pair of modes and we obtain the Heisenberg equations of motion for the new degrees of freedom. In Section 4 we emphasize the special characteristics of the original degrees of freedom that do not apply to the alternate degrees of freedom. Section 5 is conclusion.

2. The model

We consider the two uncoupled modes in the respective "phase space" representations,[16] i.e. as a pair of noninteracting linear oscillators, 1 and 2, with the respective frequen-

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