Simulating Markovian quantum decoherence processes through an all-optical setup

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Abstract. We investigate through both theory and experiment quantum decoherence processes. By considering a qubit under the effect of Markovian channels, we analytically obtain expressions for the l1-norm of coherence and for the corresponding maximal coherence measure. In particular, we examine under which conditions such quantum coherence quantifiers exhibit the eternal freezing phenomenon. We implement an all-optical setup with an intense laser to perform the experimental simulation of the quantum channels, where the qubit was encoded in polarization degree of freedom and the environment was encoded in the propagation path.

Keywords: Decoherence, Open Quantum systems, Optical circuits, Polarization modes.

Recent developments in the field of quantum coherence have led to arenewed interest in quantifying coherence for general states from a quantum information perspective, focusing on the understanding and quantitative characterization of coherence as an operational resource [1-3]. By definition, quantum coherenceis a basis-dependent quantity; thus, local unitary transformations can alter quantum coherence in a given quantum state. There is an increasing concern about the notion of basis-free coherence [4,5]. In particular, it is established that quantum coherence minimized over unitary transformations is closely related to entanglement [6] and quantum discord [7], as well as, the equivalence between maximal quantum coherence and purity [4]. The interaction between a quantum system and its environment may result in the degradation and eventual disappearance of the quantum coherence. In this regards, one of the important phenomena observed is the freezing of coherence, namely the time invariance of a quantum system that evolves under noisy dynamics without external control [8–13]. In this work, we examine, in particular, the initial conditions required for different types of Markovian quantum channels for which it is possible to obtain freezing of both quantum coherence and maximum quantum coherence measures. Our theoretical results are then experimentally simulated through linear optical circuits in an all-optical setup. Linear optical circuits with an intense laser beam have been shown to be an excellent test bed for quantum simulations. Indeed, a laser beam can be described as a classical electromagnetic field or as a coherent state with a macroscopic number of photons and simple setups are suitable to perform useful simulationsof single-photon experiments. For instance, the emergence of topological phases int he evolution of a pair of entangled qubits [14, 15], environment induced entanglement [16] and conditional operations that emulate quantum gates [17, 18] were investigated in this approach. In this work, we performed the simulation of simulation of quantum coherence in the phase damping (PD), phase flip(PF), bit flip (BF), bit-phase flip (BPF) and amplitude damping (AD) channels. The results are in very good agreement with the theoretically predicted. Then, linear optical circuits associated to intense laser beams can constitute an excellent bed test for the evolution of quantum properties in quantum channels.

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