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Classical and Quantum Stochastic Resonance

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Abstract

The process whereby external or internal noise operates on a nonlinear multistable system modulated by a weak (generally periodic) force in order to facilitate switching events among threshold states has been termed *Stochastic Resonance* (SR). Previous activity is reviewed together with recent developments relating to quantum features of SR. Some potential applications and an outlook for future developments are elucidated.

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Users of modern communication devices have nothing nice to say about annoying hiss. However, in certain circumstances an extra dose of noise can in fact help rather than hinder the detection of weak signals. There is now even a name for the phenomenon: "Stochastic Resonance" (SR). It is presently creating a buzz in fields such as physics, chemistry, biomedical sciences and engineering [1,2]. Historically, the term SR has been coined by Benzi, Sutera and Vulpiani in 1981 [1]. They observed that in a bistable overdamped dynamics, that is subject to thermal noise and a weak periodic signal, the noisy bistable output mimics a synchronization with the coherent input. This feature occurs whenever the time scale for thermal barrier crossing becomes comparable with the period of the weak perturbation.

The SR-effect is rooted in three basic ingredients: Namely

(i) a source of background noise,

(ii) a generally weak coherent input, and

(iii) a characteristic, sensory threshold (or barrier) that the system typically has to overcome in order to perform its useful task.

Given these three characteristic ingredients, it is clear that the SR-phenomenon is generic, and that it holds universal applications that extend from the physics sciences into the field of biomedicine (such as the firing in a neuron). The modern age of SR has been ushered in by a key experiment in a bistable ring laser in 1988, see in [1], which in turn invigorated the theoretical practitioners to develop state-of-the-art theories that are able to elucidate the multifaceted nonlinear features of the intrinsically nonstationary SR-effect [1–3].

Recently, the question has arisen wheter SR manifests itself also on a quantum scale. Because quantum noise persists even at absolute zero temperature the transport of quantum information should be aided by quantum fluctuations as well. Indeed, quantum mechanics provides the nonlinear system with an additional channel to overcome a threshold. This additional channel is quantum tunneling, i.e., a particle can "tunnel" through a barrier without even going over it. As a matter of fact, we report that the classical SR-effect can be assisted by quantum tunneling contributions already at finite temperatures. The various regimes where quantum effects influence SR are depicted in figure 1. Depending on the species that governs transport (electrons, protons, molecules, ...) this characteristic temperature scale can well be at, or be even far above, room temperatures. In particular, for strongly damped systems, these quantum corrections can enhance the classical SR-effect up to two orders of magnitude [4].

Qualitative new features occur in the deep quantum cold, where tunneling in presence of dissipation and the action of periodic time dependent perturbations mutally influence each other. A series of novel nonlinear quantum stochastic resonance phenomena occur in this deep quantum regime. Of particular interest is the effect of driving-induced quantum coherences in damped quantum systems, or the phenomenon of a characteristic suppression of (nonlinear) higher harmonic responses [5]. The latter phenomenon can, for example, be used to "clean" the quantum output distortion, that is caused in quantum mechanical nonlinearly processed information. The combined application of both, time-dependent perturbations and quantum dissipation then yields novel possibilities to influence quantum processes, such as the strong laser light induced manipulation of electron transfer processes, to control reactant-product yields in chemical reactions, or to regulate tunneling of atoms and/or molecules that are deposited on surfaces, to name only a few.

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