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Stochastic resonance for modulated gain in a single-mode laser

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Abstract

Stochastic resonance (SR) induced by the signal modulation is investigated, by introducing the signal-modulated gain into a single-mode laser system. Using the linear approximation method, we detailedly calculate the signal-to-noise ratio (SNR) of a gain-noise model of the single-mode laser, taking the cross-correlation between the quantum noise and pump noise into account. We find that, SR appears in the dependence of the SNR on the intensities of the quantum and the pump noises when the correlation coefficient between both the noises is negative; moreover, when the cross-correlation between the two noises is strongly negative, SR exhibits a resonance and a suppression versus the gain coefficient, meanwhile, the single-peaked SR and multi-peaked SR occur in the behaviors of the SNR as functions of the loss coefficient and the deterministic steady-state intensity.

Keywords: Stochastic resonance; Signal-modulated gain; Quantum noise; Pump noise; Signal-to-noise ratio

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1. Introduction

The phenomenon of stochastic resonance (SR) was originally discovered in 1981 by Benzi et al. [1] and Nicolis et al. [2]. Since then, it has been enthusiastically investigated in many scientific fields [3–10], and Gammaitoni et al. [11] comprehensively summarized the achievements. Recently, there are considerable developments in the process of exploring the essence of SR. Comparing to the traditional concept of SR, the new progresses in theories and experiments lie in the following three aspects. First, the restriction of the three essential ingredients at the very outset of SR (nonlinear systems, noises, and periodic signals), was broken because SR was observed without external signals or in linear systems [12,13]. Second, conventional SR was confined to the single peaked, i.e., there was only one resonant peak in SR. The multi-peaked SR, namely, stochastic multiresonance, was detected firstly by Vilar and Ruby [14] in 1997 and becomes a focus nowadays. Finally, the dependence of signal-to-noise ratio (SNR) upon the noise intensity was generally used to describe the characteristic of SR [11]. In 1989, Presilla et al. [15,16] firstly observed SR characterized by the dependence of the SNR on the noise correlation time, even on other parameters of stochastic systems [17]. Further it can be characterized as the synchronization mechanism [18].

In optical systems, SR has also attracted wide interests. In 1988, McNamara et al. firstly observed that the output SNR in a ring laser exhibited a maximum versus the input noise intensity, i.e., stochastic resonance [4]. Soon after, Vemuri et al. studied a bistable ring laser by means of numerical simulations, and they also found a bell-shaped behavior in the dependence of SNR upon the noise intensity [19]. Grohs et al. observed SR again by virtue of an optically bistable behavior in 1994, which was achieved by the thermally induced absorption nonlinear characteristic of CdS crystals [20]. Then, Bartussek and Henggi analytically studied SR both in a symmetric optical bistable case and in an asymmetric optical bistable case, then drew a comparison between the two cases [21].

For modern communication devices, it is a rather difficult problem to get rid of various background noises. We think SR can supply a new way to solve this problem, whereas there are few reports concerned the idea up to now. Our aim here is to explore this problem with an analytic study. In this paper, introducing the signal-modulated gain into a single-mode laser, we investigated SR induced by the signal modulated pump current. In order to prevent distortions of the modulated signal, the laser is required to operate in the linear region in the process of signal modulations. Hence, using the linear approximation method, we calculated the laser intensity power spectrum and the SNR in a gain-noise model driven by the cross-correlated quantum and pump noises. With the expression of the SNR, we analyzed the dependences of SNR upon the intensities of the quantum and the pump noises, the gain coefficient, the loss coefficient, and the deterministic steady-state intensity.

The rest content of this paper is organized as follows. Our model is given in Section 2; the analytic expression of the SNR is obtained in Section 3; Section 4 is discussions and conclusions.