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Signal power amplification of intracellular calcium dynamics with non-Gaussian noises and time delay☆

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ABSTRACT

The effect of non-Gaussian noises on stochastic resonance of intracellular Ca^{2+} concentration in intracellular calcium oscillation(ICO) system with time delay is investigated by means of second-order stochastic Runge–Kutta type algorithm. By simulating the signal power amplification(SPA), the results indicate: there are respectively continuous values and a value of the parameter p(which is used to control the degree of the departure from the non-Gaussian noise and Gaussian noise.) to enhance reverse resonance in the behavior of SPA vs. p in cytosol and calcium store, namely continuous reverse resonance occurs in cytosol and reverse resonance occurs in calcium store. Moreover, SPA monotonically decreases as non-Gaussian noises strengthen, and SPA fast decays to constant as correlation time of non-Gaussian noises increases.

1. Introduction

In many studies on ICO, there are a variety of channels showing calcium-induced calcium release and a variety of models to describe ICO [1–4]. Many interesting phenomena have been found such as stochastic resonance [5,6], reverse resonance [6–8], coherence resonance [7], oscillatory coherence [9], resonant activation [10], bistability solutions with hysteresis [11], calcium puffs [12], various spontaneous Ca^{2+} patterns [13], colored noise-optimized calcium wave [14], stochastic backfiring [15], stability transition [16], and dispersion gap and localized spiral waves [17]. More importantly, Matjaž Perc et al. [18–21] has found that noise and other stochastic effects indeed play a central role [18,19] in system. Recently, calcium wave instability [22,23] has also been studied.

Martin Falcke et al. [15,17,24–29] has intensively studied ICO. For instance, a discrete stochastic model for calcium dynamics in living cells [24], spatial and temporal structures in intracellular Ca^{2+} dynamics caused by fluctuations [25], and key characteristics of Ca^{2+} puffs in deterministic and stochastic frameworks [28]. Additionally, they clearly showed that real ICO is non-Gaussian [29]. As stated in above, stochastic resonance and reverse resonance have been discovered in ICO. Thus, in this paper, we study the effect of non-Gaussian noise on stochastic resonance of ICO. For the role of noise on some stochastic systems, there are also some research [30–35].

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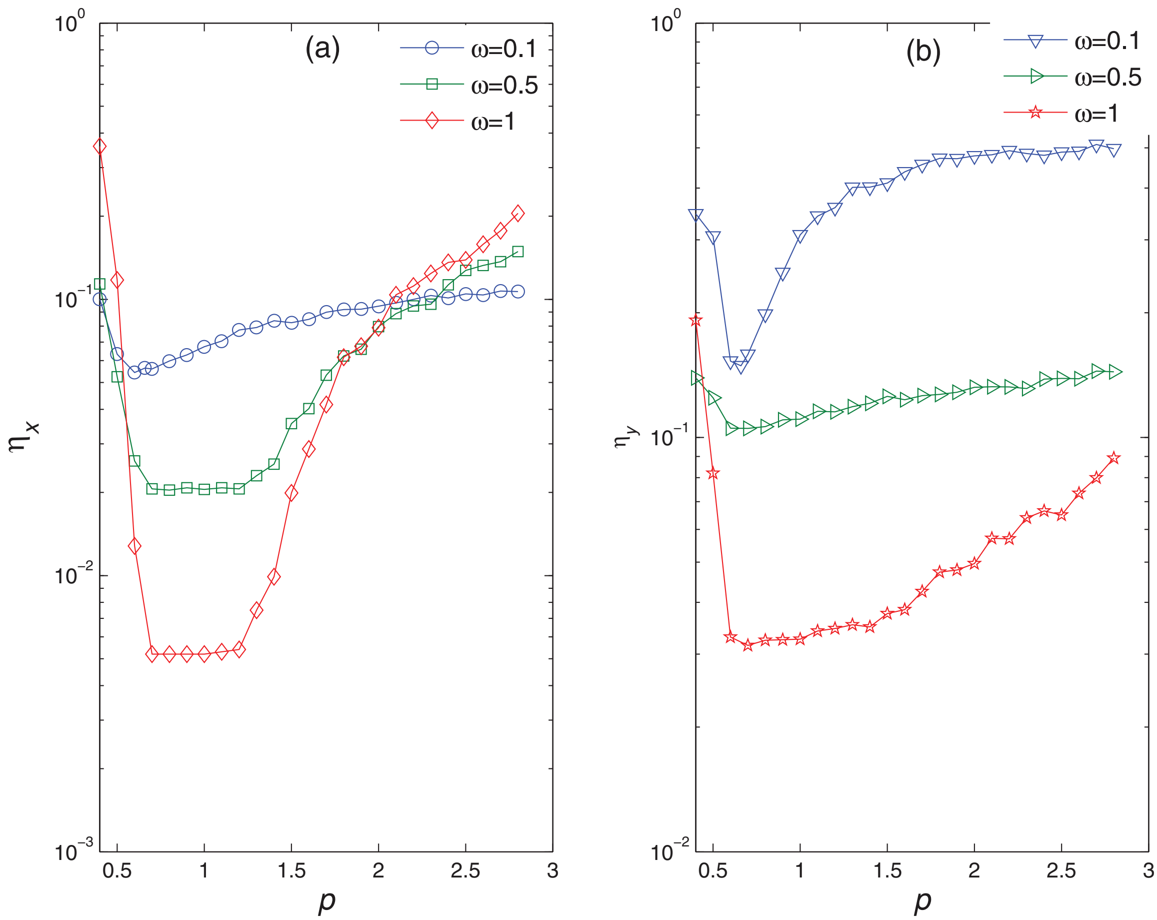

Fig. 1. The SPA η_x(see Fig. 1(a)) and η_y(see Fig. 1(b)) vs. parameter p of non-Gaussian noises.

2. The model for ICO with non-Gaussian noises and time delay

In order to study easily, taking into account same time delay τ in processes of active and passive transport of Ca^{2+} in a real cell. In this paper, x and y denote the concentration of free Ca^{2+} of cytosol and calcium store in a cell, respectively. Based on calcium-induced calcium release, the Langevin equations of ICO system can be read as follows according to our previous results [7,8]:

$$d_t x = A_1(x; x_\tau, y_\tau) + B_1(x; x_\tau, y_\tau)\eta_1(t), \tag{1}$$

$$d_t y = A_2(x, y; x_\tau) + B_2(x, y; x_\tau)\eta_2(t), \tag{2}$$

with

$$A_1(x; x_\tau, y_\tau) = v_0 + v_1\beta_0 - v_2 + v_{3\tau} + k_f y_\tau - kx, \tag{3}$$

$$A_2(x, y; x_\tau) = v_{2\tau} - v_3 - k_f y, \tag{4}$$

$$B_1(x; x_\tau, y_\tau) = \sqrt{v_1^2\beta_0^2 + 2v_1\beta_0\lambda W + W^2}, \tag{5}$$

$$B_2(x, y; x_\tau) = \sqrt{\frac{v_{2\tau} + v_3 + k_f y}{V}}, \tag{6}$$

$$W(x; x_\tau, y_\tau) = \sqrt{\frac{v_0 + v_1\beta_0 + v_2 + v_{3\tau} + k_f y_\tau + kx}{V}}, \tag{7}$$

and

$$v_2 = \frac{V_2 x^2}{x^2 + k_1^2}, v_3 = \frac{V_3 x^4 y^2}{(x^4 + k_2^4)(y^2 + k_3^2)}, \tag{8}$$