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Short note

Soliton interactions for optical switching systems with symbolic computation

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ABSTRACT

All optical switches have important significance in photon computation. In this paper, interactions among three solitons are investigated analytically. Optical switches are presented through soliton interactions. The influences of various parameters on their turning on and off functions are analyzed. Results are also useful for the design of all optical logic gates.

1. Introduction

Soliton theory is developed rapidly in recent years, and is widely used in medical imaging, plasma, biomolecular systems, optical communication and nonlinear optics [1–14]. Soliton is a wave that is trapped or confined in a certain location [15–18]. The energy and shape of solitons do not change in the process of propagation. In mathematics, pseudo-particle solutions for some nonlinear wave equations are corresponding to solitons, which have also great value in modern physics and mathematics [19–23].

On the other hand, in modern society, a large number of information are needed to transmit and exchange, while optical fibers are used as a high-speed transmission carrier to satisfy people's demands [24–26]. As a carrier of this kind, optical fibers effectively guarantee the transmission of information, which will encounter the problem of information transformation in the process of propagation. It is necessary to use optical switches to solve it [27,28]. Compared with the general mechanical switch, optical switches can achieve faster switching speed, and interconvert or operate logic on optical transmission lines or optical signals in integrated optical circuits. The optical switch is one of the key components of information systems such as optical computer, optical information processing and optical fiber network [29–31].

In this paper, optical switches will be investigated through soliton interactions, which can be described by the variable coefficient high-order nonlinear Schrödinger (vcHNLS) equation [32],

$$i\frac{\partial u}{\partial x} + \frac{1}{2}\beta_2(x)\frac{\partial^2 u}{\partial t^2} + \sigma(x)|u|^2u + \mathrm{i}\, s(x)\frac{\partial(|u|^2u)}{\partial t} - i\tau_R(x) - i\beta_3(x)\frac{\partial^3 u}{\partial t^3} - i\Gamma u = 0, \tag{1}$$

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where $u(x, t)$ presents the soliton amplitude. x is the propagation distance, and t is the retarded time. $\beta_2(x)$ is the group velocity dispersion effect, $\sigma(x)$ is the nonlinearity, $s(x)$ is the stimulated Raman scattering effect, $\tau_R(x)$ is the self-steepening effect, $\beta_3(x)$ is the third order dispersion effect, and Γ is the attenuation or gain constant. For Eq. (1), soliton amplification and reshaping have been discussed. They have amplified and reshaped the solitons stably in a long distance [32]. However, the optical switches based on soliton interactions have not been reported before.

The structure of this paper will be organized as below. In Section 2, analytic three-soliton solutions for Eq. (1) will be presented. In Section 3, optical switches based on soliton interactions will be demonstrated and discussed. In Section 4, the conclusion will be derived.

2. Analytic soliton solutions for Eq. (1)

Ref. [32] indicated that analytic three-soliton solutions for Eq. (1) can be obtained as,

$$u(x, t) = e^{\Gamma x}\frac{g(x, t)}{f(x, t)} = e^{\Gamma x}\frac{g_1(x, t) + g_3(x, t) + g_5(x, t)}{1 + f_2(x, t) + f_4(x, t) + f_6(x, t)}, \quad (2)$$

with

$$\begin{aligned} g_1(x, t) =& \ e^{\theta_1} + e^{\theta_2} + e^{\theta_3}, \\ g_3(x, t) =& \ e^{2\Gamma x}[\xi_{31}(x)e^{\theta_1+\theta_2+\theta_1^*} + \xi_{32}(x)e^{\theta_1+\theta_2+\theta_2^*} + \xi_{33}(x)e^{\theta_1+\theta_2+\theta_3^*} + \xi_{34}(x)e^{\theta_1+\theta_3+\theta_1^*} + \xi_{35}(x) \\ & \times e^{\theta_1+\theta_3+\theta_2^*} + \xi_{36}(x)e^{\theta_1+\theta_3+\theta_3^*} + \xi_{37}(x)e^{\theta_2+\theta_3+\theta_1^*} + \xi_{38}(x)e^{\theta_2+\theta_3+\theta_2^*} + \xi_{39}(x)e^{\theta_2+\theta_3+\theta_3^*}], \\ g_5(x, t) =& \ e^{4\Gamma x}[\varsigma_{51}(x)e^{\theta_1+\theta_2+\theta_3+\theta_1^*+\theta_2^*} + \varsigma_{52}(x)e^{\theta_1+\theta_2+\theta_3+\theta_1^*+\theta_3^*} + \varsigma_{53}(x)e^{\theta_1+\theta_2+\theta_3+\theta_2^*+\theta_3^*}], \end{aligned}$$

and

$$\begin{aligned} f_2(x, t) =& \ e^{2\Gamma x}[\zeta_{21}(x)e^{\theta_1+\theta_1^*} + \zeta_{22}(x)e^{\theta_2+\theta_1^*} + \zeta_{23}(x)e^{\theta_1+\theta_2^*} + \zeta_{24}(x)e^{\theta_2+\theta_2^*} + \zeta_{25}(x)e^{\theta_1+\theta_3^*} \\ & + \zeta_{26}(x)e^{\theta_2+\theta_3^*} + \zeta_{27}(x)e^{\theta_3+\theta_1^*} + \zeta_{28}(x)e^{\theta_3+\theta_2^*} + \zeta_{29}(x)e^{\theta_3+\theta_3^*}], \\ f_4(x, t) =& \ e^{4\Gamma x}[\eta_{41}(x)e^{\theta_1+\theta_2+\theta_1^*+\theta_2^*} + \eta_{42}(x)e^{\theta_1+\theta_2+\theta_1^*+\theta_3^*} + \eta_{43}(x)e^{\theta_1+\theta_2+\theta_2^*+\theta_3^*} + \eta_{44}(x)e^{\theta_1+\theta_3+\theta_1^*+\theta_2^*} \\ & + \eta_{45}(x)e^{\theta_1+\theta_3+\theta_1^*+\theta_3^*} + \eta_{46}(x)e^{\theta_1+\theta_3+\theta_2^*+\theta_3^*} + \eta_{47}(x)e^{\theta_2+\theta_3+\theta_1^*+\theta_2^*} + \eta_{48}(x)e^{\theta_2+\theta_3+\theta_1^*+\theta_3^*} \\ & + \eta_{49}(x)e^{\theta_2+\theta_3+\theta_2^*+\theta_3^*}], \\ f_6(x, t) =& \ \psi_{61}(x)e^{6\Gamma x+\theta_1+\theta_2+\theta_3+\theta_1^*+\theta_2^*+\theta_3^*}. \end{aligned}$$

In those conditions,

$$\theta_j = a_j(x) + b_j t + k_j = [a_{j1}(x) + \mathrm{i}a_{j2}(x)] + (b_{j1} + \mathrm{i}b_{j2})t + (k_{j1} + \mathrm{i}k_{j2}), \quad (j = 1, 2, 3)$$

$$\xi_{36}(x) = \frac{A_{32}^2\sigma(x)}{4b_{31}^2A_{22}^2\beta_2(x)}, \quad \xi_{37}(x) = \frac{A_{33}^2\sigma(x)}{4A_{11}^2A_{12}^2\beta_2(x)}, \quad \xi_{38}(x) = \frac{A_{33}^2\sigma(x)}{4b_{31}^2A_{13}^2\beta_2(x)}, \quad \xi_{39}(x) = \frac{A_{33}^2\sigma(x)}{4b_{21}^2A_{23}^2\beta_2(x)},$$

with

$$A_{11} = b_1^* + b_2, A_{21} = b_1 + b_2^*, A_{31} = b_1 - b_2, A_{41} = b_1^* - b_2^*, A_{12} = b_1^* + b_3, A_{22} = b_1 + b_3^*,$$

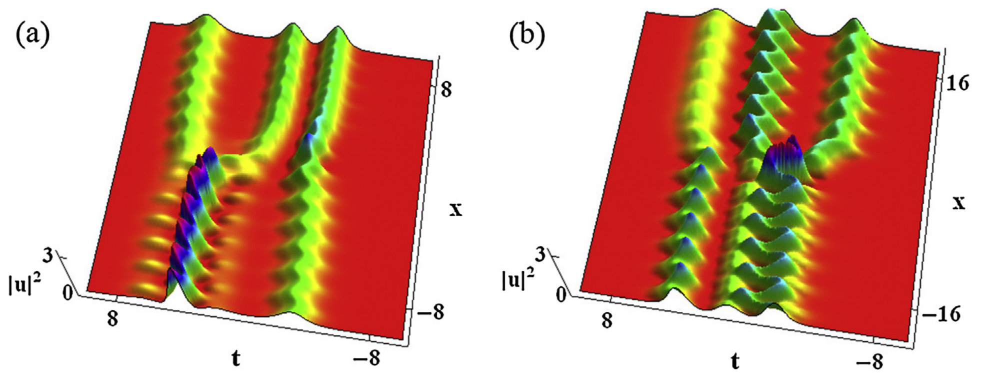

Fig. 1. All optical switches based on the interactions among three solitons. The parameters are $b_{11} = 0.8$, $b_{21} = 0.9$, $b_{31} = 1$, $k_{11} = 1$, $k_{12} = 2$, $k_{21} = 2$, $k_{22} = 3$, $k_{31} = 3$, $k_{32} = 3$, $\sigma(x) = e^{-0.1x^2}$ and $\Gamma = -0.001$ with (a): $b_{12} = -0.84$, $b_{22} = 0.27$, $b_{32} = 0.1$, $\beta_3(x) = sin(-4x)$; (b): $b_{12} = 0.58$, $b_{22} = -0.1$, $b_{32} = -0.74$, $\beta_3(x) = sin(2x)$.