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Optical soliton perturbation with Fokas–Lenells equation using three exotic and efficient integration schemes

Anjan Biswas[a,b,c], Hadi Rezazadeh[d], Mohammad Mirzazadeh[e], Mostafa Eslami[f], Mehmet Ekici[g], Qin Zhou[h,*], Seithuti P. Moshokoa[c], Milivoj Belic[i]

[a] Department of Physics, Chemistry and Mathematics, Alabama A&M University, Normal, AL 35762, USA
[b] Department of Mathematics and Statistics, College of Science, Al-Imam Mohammad Ibn Saud Islamic University, Riyadh 13318, Saudi Arabia
[c] Department of Mathematics and Statistics, Tshwane University of Technology, Pretoria 0008, South Africa
[d] Faculty of Modern Technologies Engineering, Amol University of Special Modern Technologies, Amol 49767-46168, Iran
[e] Department of Engineering Sciences, Faculty of Technology and Engineering, East of Guilan, University of Guilan, P.C. 44891-63157, Rudsar-Vajargah, Iran
[f] Department of Mathematics, Faculty of Mathematical Sciences, University of Mazandaran, Babolsar 13534-47416, Iran
[g] Department of Mathematics, Faculty of Science and Arts, Bozok University, 66100 Yozgat, Turkey
[h] School of Electronics and Information Engineering, Wuhan Donghu University, Wuhan 430212, People's Republic of China
[i] Science Program, Texas A&M University at Qatar, PO Box 23874, Doha, Qatar

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ABSTRACT

The soliton dynamics in optical fibers with Fokas–Lenells equation is illustrated in this paper. Bright, dark and singular soliton solutions are retrieved along with few forms of combo-soliton solutions that also naturally emerged from the three integration schemes applied to the model. The existence criteria of these solitons are also presented.

1. Introduction

Optical solitons have meticulously sculpted pulse transmission technology, through a variety of waveguides, over the past few decades. There are several mathematical models that describe this engineering marvel at a superlative level [1–10]. One of the models that govern this dynamics first appeared about a decade ago. This is the Fokas–Lenells (FL) equation [7,9,10]. This model has gained quite a bit of familiarity in the fiber-optic community since its first appearance. There are several forms of soliton solutions that have been retrieved for this model in the past. However, none of these works

* Corresponding author.
E-mail address: qinzhou@whu.edu.cn (Q. Zhou).

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have considered the effects of perturbation terms that appear from natural causes in soliton transmission dynamics. This current paper addresses FL equation that is studied with a few perturbative effects included. Three exotic and efficient integration schemes are applied to retrieve soliton solutions to the model. They are bright, dark and singular solitons as well as complexitons and combo-solitons. The existence criteria of these solitons are also presented. The details are all visible in the upcoming sections.

1.1. Governing model

The perturbed FL equation to be studied in this paper is [7,9,10]:

$$iq_t + a_1 q_{xx} + a_2 q_{xt} + (bq + i\sigma q_x)|q|^2 = i\left[\alpha q_x + \lambda\left(|q|^2 q\right)_x + \mu\left(|q|^2\right)_x q\right]. \tag{1}$$

This is the model that was lately proposed to describe the soliton dynamics accurately in various waveguides [7,9,10]. The two independent variables are x and t and they correspond to spatial and temporal variables respectively. The dependent variable $q(x, t)$ is a complex valued function that represents the soliton profile. In (1), a_1 and a_2 are the coefficients of group velocity dispersion and spatio-temporal dispersion respectively. Also b is the coefficient of Kerr law nonlinearity and σ represents the nonlinear dispersion. Then, from the right hand side of (1), Next, from the right hand side, we have the inter-modal dispersion is the coefficient of α, while λ and μ are the self-steepening and nonlinear dipersion terms respectively.

2. Mathematical analysis

In order to solve the model, the following hypothesis is framed:

$$q(x, t) = U(\eta)e^{i\Phi(x,t)} \tag{2}$$

where $U(\eta)$ represents the shape of the pulse and

$$\eta = x - vt, \tag{3}$$

and the phase component is defined as

$$\Phi(x, t) = -\kappa x + \omega t + \theta_0. \tag{4}$$

Substituting (2) into Eq. (1) and decomposing into real and imaginary parts, give

$$(a_1 - va_2)U'' + (b + \sigma\kappa - \lambda\kappa)U^3 - (\omega + a_1\kappa^2 - \kappa\omega a_2 + \alpha\kappa)U = 0, \tag{5}$$

and

$$(v - a_2(\kappa v + \omega) + \alpha + 2a_1\kappa)U' + (3\lambda + 2\mu - \sigma)U^2U' = 0. \tag{6}$$

From (6), setting the coefficients of the linearly independent functions to zero gives the speed of the soliton as:

$$v = \frac{a_2\omega - \alpha - 2a_1\kappa}{1 - a_2\kappa}, \tag{7}$$

and the constraint condition

$$\sigma = 3\lambda + 2\theta, \tag{8}$$

with the constraint

$$a_2\kappa \neq 1. \tag{9}$$

By applying Eq. (7) in Eq. (5), we get

$$\left\{a_1\beta - (a_2\omega - \alpha - 2a_1\kappa)a_2\right\}U'' + \beta MU^3 - \beta(\omega + a_1\kappa^2 - \kappa\omega a_2 + \alpha\kappa)U = 0, \tag{10}$$

where

$$\beta = 1 - a_2\kappa, \quad M = b + \sigma\kappa - \lambda\kappa. \tag{11}$$

2.1. Modified Kudryashov's method

According to the modified Kudryashov method [1,4,8], we get from Eq. (10) the expression for

$$U(\eta) = c_0 + c_1 Q(\eta), \tag{12}$$

where c_0 and c_1 are constants to be determined, such that

$$Q(\eta) = \frac{1}{1 + KA^\eta}, \tag{13}$$