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Optical soliton perturbation with full nonlinearity for Fokas–Lenells equation

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ABSTRACT

The extended trial function approach was successfully applied to determine soliton solutions to Fokas–Lenells equation. Bright, dark and singular soliton solutions are retrieved with the aid of this algorithm. In addition, several other solutions also emerged from this scheme whose limiting case led to optical solitons.

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1. Introduction

Optical soliton dynamics is administered by a plethora of mathematical models. A few of these models frequently visible are the familiar nonlinear Schrödinger's equation, Schrödinger–Hirota equation, Sasa–Satsuma equation, Kundu–Eckhaus equation, Radhakrishnan–Kundu–Lakshmanan equation, Lakshmanan–Porsezian–Daniel model, Chen–Lee–Liu equation, Gerdjikov–Ivanov equation and many others. While these models govern the soliton dynamics in (1 + 1)-dimensions, in higher dimensions, some of the commonly visible models are Manakov model, Thirring model, cascaded systems and others. This paper will study one such model in (1 + 1)-dimensions that has recently gained popularity. It is the Fokas–Lenells equation (FLE) that was first proposed less than a decade ago and ever since it has gained popularity. The method of extended trial function scheme is the integration scheme that will be applied in this paper to extract solitons and other solutions to the equation. This is one of the very many popular methodologies that has been successfully applied to extract soliton solutions

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to a variety of nonlinear evolution equations [1–6]. This paper will now explore the details of extended trial function method applied to FLE.

1.1. Governing equation

The dimensionless form of the Fokas–Lenells equation (FL) in presence of perturbation terms is given by [7–10]

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

In model (1), $q(x, t)$ represents a complex field envelope, and x and t are spatial and temporal variables, respectively. Here, the first term represents the linear evolution of the pulses in nonlinear optical fibres, while the coefficient a_1 is the spatio-temporal dispersion (STD) and a_2 is the group velocity dispersion (GVD). Then the fourth term introduces the cubic nonlinear term, while the fifth term accounts for dispersion. On the right-hand side of (1), the coefficient of α is the inter-modal dispersion (IMD), while λ is the self-steepening perturbation term and finally μ is the nonlinear dispersion (ND) coefficient. The parameter m conforms to full nonlinearity.

1.2. Mathematical analysis

To get start with the integration process of (1), the starting hypothesis is

$$q(x, t) = P(\xi)e^{i\phi(x,t)}, \tag{2}$$

where $P(\xi)$ represents the shape of the pulse and

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

and the phase component is defined as

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

Here, v is the velocity of the soliton, κ is the frequency while ω is the soliton wave number and θ is the phase constant. Inserting (2) along with (3) and (4) into (1) and decomposing into imaginary and real parts, the following pair of equations, respectively gives

$$\left(v + \alpha + 2a_1\kappa - a_2(v\kappa + \omega) - \sigma P^2 + (\lambda + 2m\lambda + 2m\mu)P^{2m}\right) P' = 0, \tag{5}$$

$$(a_1 - a_2 v)P'' - \left(\alpha\kappa + \omega + a_1\kappa^2 - a_2\kappa\omega\right) P + (b + \kappa\sigma)P^3 - \kappa\lambda P^{1+2m} = 0. \tag{6}$$

To carry out the integration of Eqs. (5) and (6) it needs to choose $m = 1$ which means Eq. (1) condenses to:

$$iq_t + a_1 q_{xx} + a_2 q_{xt} + |q|^2 (bq + i\sigma q_x) = i\left\{\alpha q_x + \lambda\left(|q|^2 q\right)_x + \mu\left(|q|^2\right)_x q\right\}, \tag{7}$$

so that Eqs. (5) and (6) simplify to

$$\left(v + \alpha + 2a_1\kappa - a_2(v\kappa + \omega) + (3\lambda + 2\mu - \sigma)P^2\right) P' = 0, \tag{8}$$

$$(a_1 - a_2 v)P'' - \left(\alpha\kappa + \omega + a_1\kappa^2 - a_2\kappa\omega\right) P + (b - \kappa\lambda + \kappa\sigma)P^3 = 0. \tag{9}$$

The imaginary part Eq. (8) now leads to the velocity of the soliton as

$$v = \frac{\alpha + 2a_1\kappa - a_2\omega}{a_2\kappa - 1}, \tag{10}$$

whenever

$$a_2\kappa \neq 1, \tag{11}$$

and the constraint condition

$$3\lambda + 2\mu - \sigma = 0. \tag{12}$$

2. Extended trial function method

This section will apply extended trial function technique [1–6] for acquiring bright, dark and singular soliton solutions to the model (1). To start with the extraction of solutions to (9), the following assumption for the soliton structure is made:

$$P = \sum_{i=0}^{\varsigma} \tau_i \Psi^i, \tag{13}$$

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