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Optical solitons with differential group delay for coupled Fokas–Lenells equation by extended trial function scheme

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ABSTRACT

This paper retrieves optical soliton solutions to the Fokas–Lenells equation in birefringent fibers by the application of extended trial function method. The algorithm reveals bright and singular soliton solutions to the model along with several other solutions whose limiting case for the modulus of ellipticity yields soliton solutions.
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1. Introduction

The phenomena of birefringence in optical fibers is a natural occurrence in fiber optic transmission technology across inter-continental distances. Manufacturing imperfections and other defects of fibers lead to differential group delay that eventually accumulates into birefringence. Therefore, this is an unwanted and at the same time an unavoidable feature that needs to be addressed professionally. The equation that models this dynamics stems from Fokas–Lenells equation (FLE) that is applicable to a polarization-preserving fiber. This paper will secure soliton solutions to vector-coupled FLE by the aid of extended trial function method. This is one of the very many integration algorithms that have been fruitfully applied to fluid dynamics, liquid crystals, DWDM systems, magneto-optic waveguides and various other situations [1–10]. This paper will detail the derivation of soliton solutions in a birefringent fiber, with this integration scheme, in subsequent sections.

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1.1. Governing equation

The dimensionless form of coupled FLE with spatio-temporal dispersion (STD) is given by [5,8–10]:

$$iq_t + a_1 q_{xx} + b_1 q_{xt} + \left(c_1|q|^2 + d_1|r|^2\right)(\rho_1 q + i\lambda_1 q_x) + qr^*(\gamma_1 r + i\eta_1 r_x) = 0, \quad (1)$$

$$ir_t + a_2 r_{xx} + b_2 r_{xt} + \left(c_2|r|^2 + d_2|q|^2\right)(\rho_2 r + i\lambda_2 r_x) + rq^*(\gamma_2 q + i\eta_2 q_x) = 0, \quad (2)$$

In (1) and (2), the first term in both of these equations represents the temporal evolution of the pulses in birefringent fibers and $q(x, t)$ and $r(x, t)$ are complex valued functions that represents the soliton profiles for the two components in birefringent fibers. For l = 1, 2, a_l represents the group-velocity dispersion (GVD) and b_l are the STD terms along the two components.

1.2. Mathematical analysis

In order to solve this coupled system, a general hypothesis of the solution structure is adopted:

$$q(x, t) = P_1[\zeta(x, t)]\exp[i\phi_1(x, t)], \quad (3)$$

$$r(x, t) = P_2[\zeta(x, t)]\exp[i\phi_2(x, t)], \quad (4)$$

where $P_l(\zeta)$ for l = 1, 2 represents the amplitude component of the soliton and

$$\zeta = x - vt, \quad (5)$$

and the phase component ϕ_l is defined as

$$\phi_l = -\kappa_l x + \omega_l t + \theta_l, \quad (6)$$

for l = 1, 2. Here, v is the velocity of the soliton, κ_l are the frequencies of the solitons in each of the two components while ω_l are the soliton wave numbers and θ_l are the phase constants. Substituting (3)–(6) into (1) and (2) and then decomposing into real and imaginary parts give

$$(a_l - b_l v)P_l'' - \left(\omega_l + a_l\kappa_l^2 - b_l\kappa_l\omega_l\right)P_l + \left(\gamma_l + \kappa_{\bar{l}}\eta_l + d_l\kappa_l\lambda_l + d_l\rho_l\right)P_l P_{\bar{l}}^2 + (c_l\kappa_l\lambda_l + c_l\rho_l)P_l^3 = 0, \quad (7)$$

and

$$(b_l v\kappa_l - v - 2a_l\kappa_l + b_l\omega_l)P_l' + d_l\lambda_l P_{\bar{l}}^2 P_l' + \eta_l P_l P_{\bar{l}} P_{\bar{l}}' + c_l\lambda_l P_l^2 P_l' = 0. \quad (8)$$

Using the balancing principle implies

$$P_{\bar{l}} = P_l, \quad (9)$$

and then we have

$$(a_l - b_l v)P_l'' - \left(\omega_l + a_l\kappa_l^2 - b_l\kappa_l\omega_l\right)P_l + \left(\gamma_l + \kappa_{\bar{l}}\eta_l + (c_l + d_l)(\kappa_l\lambda_l + \rho_l)\right)P_l^3 = 0, \quad (10)$$

and

$$(b_l v\kappa_l - v - 2a_l\kappa_l + b_l\omega_l)P_l' + (\lambda_l(c_l + d_l) + \eta_l)P_l^2 P_l' = 0. \quad (11)$$

Next, setting the coefficients of the linearly independent functions, in (11), to zero is possible to procure the speed of the soliton

$$v = \frac{2a_l\kappa_l - b_l\omega_l}{b_l\kappa_l - 1}, \quad (12)$$

provided that

$$b_l\kappa_l \neq 1, \quad (13)$$

and the constraint conditions

$$\lambda_l(c_l + d_l) + \eta_l = 0. \quad (14)$$

Eq. (10) will now be analyzed further along, in the subsequent section, in order to retrieve bright, dark and singular soliton solutions, and other solutions to the coupled FLE under the conditions $\kappa_{\bar{l}} = \kappa_l$.

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