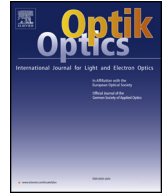




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Original research article

# Optical solitons in birefringent fibers for Lakshmanan–Porsezian–Daniel model using $\exp(-\phi(\xi))$ -expansion method

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## ABSTRACT

This paper studies optical solitons in birefringent fibers by the aid of exp-function approach. The model that is analyzed is Lakshmanan–Porsezian–Daniel equation which is first written in two-component form for vector solitons. The integrability criteria are also presented in the paper.

## 1. Introduction

The theory of optical solitons has drastically advanced the telecommunications industry with captivating technological marvel. There has been several improvements from mathematical and technological perspectives that advanced this industry with cutting edge technology. With a plethora of mathematical models that has near-perfected the dynamics of soliton science in optical fibers and metamaterials, there is still a lot to explore. This paper studies soliton dynamics with Lakshmanan–Porsezian–Daniel (LPD) model in birefringent fibers with differential group delay. The model equations are obtained from LPD equation that is visible in polarization-preserving fibers. The effect of four-wave mixing (4WM) is not included to keep the model simple. The vector coupled LPD equation describing birefringence is integrated, in this paper, by the aid of  $\exp(-\phi(\xi))$ -expansion scheme. It must be noted that there are several forms of integration algorithms that are utilized to retrieve soliton solutions and carry out analytical studies in nonlinear fiber optics [1–15]. Here, in order to integrate the governing model, phase-matching condition is implemented. The details of the mathematical principles are first enumerated followed by the derivation and classification of soliton solutions.

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## 2. Governing model

The dimensionless form of LPD model, with Kerr law nonlinearity, that has been studied in the past is given in the form [2–10,13–15]:

$$iq_\tau + aq_{xx} + bq_{x\tau} + c|q|^2q = \sigma q_{xxxx} + \alpha(q_x)^2q^* + \beta|q_x|^2q + \gamma|q|^2q_{xx} + \lambda q^2q_{xx}^* + \delta|q|^4q \tag{1}$$

In (1), the real-valued coefficients  $a$  and  $b$  represent group velocity dispersion and spatio-temporal dispersion respectively. Then,  $c$  is the coefficient of Kerr law nonlinearity and  $\sigma$  is the fourth order dispersion while  $\delta$  accounts for two-photon absorption. The remaining terms are from other forms of dispersive phenomenon [2–10,13–15]. Soliton formation is the outcome of a delicate balance that sustains between dispersive and nonlinear effects.

For birefringent fibers, the model therefore splits into two components leading to the coupled vector form of LPD. After neglecting the effects of 4WM, this coupled system is [1]:

$$\begin{aligned} & iq_\tau + a_1q_{xx} + b_1q_{x\tau} + (c_1|q|^2 + d_1|r|^2)q \\ & = \sigma_1q_{xxxx} + (\alpha_1q_x^2 + \beta_1r_x^2)q^* + (\gamma_1|q_x|^2 + \delta_1|r_x|^2)q \\ & + (\lambda_1|q|^2 + \theta_1|r|^2)q_{xx} + (\xi_1q^2 + \eta_1r^2)q_{xx}^* + (f_1|q|^4 + g_1|q|^2|r|^2 + h_1|r|^4)q \end{aligned} \tag{2}$$

$$\begin{aligned} & ir_\tau + a_2r_{xx} + b_2r_{x\tau} + (c_2|r|^2 + d_2|q|^2)r \\ & = \sigma_2r_{xxxx} + (\alpha_2r_x^2 + \beta_2q_x^2)r^* + (\gamma_2|r_x|^2 + \delta_2|q_x|^2)r \\ & + (\lambda_2|r|^2 + \theta_2|q|^2)r_{xx} + (\xi_2r^2 + \eta_2q^2)r_{xx}^* + (f_2|r|^4 + g_2|r|^2|q|^2 + h_2|q|^4)r \end{aligned} \tag{3}$$

Here, in (2) and (3),  $c_j$  and  $f_j$  ( $j = 1, 2$ ) represent coefficients of self-phase modulation while the coefficients of  $d_j$ ,  $g_j$  and  $h_j$  are accounted for cross-phase modulation.

## 3. Mathematical analysis

This section will be first a revisitation of the proposed analytical scheme followed by its applicability to the LPD model with birefringence. The details are penned down in the following two subsections.

### 3.1. Proposed analytical technique

Let us take a look at the following general nonlinear evolution equation (NLEE)

$$P(u, D_\tau u, D_x u, D_\tau^2 u, D_{x\tau} u, D_x^2 u, \dots) = 0, \tag{4}$$

where  $u = u(x, \tau)$  is an unknown function and  $P$  is a polynomial in  $u$  and its partial derivatives, in which the nonlinear terms and its highest order derivatives are taken into consideration. The traveling wave solution can be recovered with the wave transformation that reads:

$$u(x, \tau) = U(\xi), \quad \xi = k(x - v\tau).$$

After implementing this wave transformation, the NLEE is converted into a nonlinear ordinary differential equation (ODE) given as:

$$S(U, U', U'', \dots) = 0, \tag{5}$$

where  $'$  denotes the derivative with respect to  $\xi$ .

Based on  $\exp(-\phi(\xi))$ -expansion method, the solution can be casted as:

$$U(\xi) = \sum_{n=0}^N a_n (\exp(-\Phi(\xi)))^n, \tag{6}$$

where  $a_n$  are unknown constants that are to be determined and  $\Phi(\xi)$  governs the auxiliary ODE given by:

$$\Phi'(\xi) = \exp(-\Phi(\xi)) + \mu \exp(\Phi(\xi)) + \lambda. \tag{7}$$

The auxiliary Eq. (7) lists the general family of solutions as:

**Case 1.** (Hyperbolic function solutions) If  $\lambda^2 - 4\mu > 0$  and  $\mu \neq 0$ , then

$$\Phi_1(\xi) = \ln \left( \frac{-\sqrt{\lambda^2 - 4\mu} \tanh\left(\frac{\sqrt{\lambda^2 - 4\mu}}{2}(\xi + C)\right) - \lambda}{2\mu} \right). \tag{8}$$

**Case 2.** (Trigonometric function solutions) However, if  $\lambda^2 - 4\mu < 0$  and  $\mu \neq 0$ ,

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