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Saturation of the nonlinear refractive index for optical solitons in two-core fibers

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ABSTRACT

This article studies the dynamics of optical solitons in two-core fibers with saturation of the nonlinear refractive index describe by dual power law. The decoupled model is considered with group velocity dispersion, linear coupling coefficients and spatio-temporal dispersion. As the result bright, dark and two forms if singular optical 1-solitons are extracted using ansatz approach. Additionally, the constraint conditions for the existence of these solutions are also listed.

1. Introduction

In two-core fibers the pulse propagation is distinct from continuous wave propagation. The coupled mode equations has been solved for the extensive study of pulse propagation, in a conventional two-core fibers. In this study a structure dependent parameter, namely the coupling coefficient, is used for the characterization of the light coupling between the two cores. The dynamics of the soliton pulses in the two cores are imperative to be addressed from mathematical perspectives. For trans-continental and trans-oceanic information transfer, optical solitons are used [1–16].

The extraction of exact 1-soliton solutions for the governing model is the motivation of this paper. The model under our discussion is the coupled nonlinear Schrödinger's equation (NLSE). For the solution of the model there are a number of integration tools. Some famous techniques include homotopy analysis method, Kudryashov's method, variational principle, traveling waves, simplest equation method, extended tanh method, tanh-expansion scheme and many more [17–31]. The paper in hand will address one such integration mechanism. Thus for the retrieval of bright, dark and singular solitons for the coupled NLSE, we have an approach which is known as ansatz approach.

The remaining article is characterized as follows, in Section 3 the dual-power law nonlinearity has been discussed. Furthermore, for the decoupled NLSEs, the three kinds of soliton solutions have been discussed for two-core fibers. And at the end the conclusion has been drawn in last Section 4.

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2. The model

Let us now introduce $\bar{j} = 3 - j$ for $j = 1, 2$, for the model of decoupled NLSE [30,31] and read as:

$$i\left(\frac{\partial \psi_j}{\partial t} + a_j \frac{\partial \psi_{\bar{j}}}{\partial x}\right) + b_j \frac{\partial^2 \psi_j}{\partial x^2} + c_j \frac{\partial^2 \psi_j}{\partial x \partial t} + d_j F(|\psi_j|^2)\psi_j + k_j \psi_{\bar{j}} = 0. \quad (1)$$

where ψ_j for $j = 1, 2$ are the field envelopes, while x is the propagation co-ordinate and $1/a_j$ are group velocity mismatch, b_j are group velocity dispersions, c_j represent spatio-temporal dispersion and k_j are linear coupling coefficients. It may also be noted that d_1, d_2 are defined by $2\pi n_2/\vartheta A_{eff}$, where n_2, ϑ and A_{eff} are nonlinear refractive index, the wavelength and effective mode area of each wavelength, respectively. These details are already known [32,33].

The functional F represents the nonlinearity type. The dual-power law nonlinearity is being studied in this article. The functional F is real-valued algebraic function where it is necessary to have smoothness of the complex function $F(|\psi_j|^2)\psi_j : C \to C$ for $j = 1, 2$. Treating the complex plane C as a two-dimensional linear space R^2, the function $F(|\psi_j|^2)\psi_j$ is k times continuously differentiable, so that

$$F(|\psi_j|^2)\psi_j \in \bigcup_{m,n=1}^{\infty} C^k\left((-n, n) \times (-m, m); R^2\right) \quad (2)$$

In order to study this coupled system are being split into

$$\psi_j(x, t) = P_j(x, t)e^{i\phi} \quad (3)$$

Here, $P_j(x, t)$, for $j = 1, 2$ and $\bar{j} = 3 - j$ are the amplitude components of the wave profiles, while ϕ is the phase component of the profiles where

$$\phi = -kx + \omega t + \theta. \quad (4)$$

The parameters k, ω and θ are the wave number, frequency and the phase constant, respectively. Substitute Eqs. (3) and (4) into Eq. (1) and decomposed into real and imaginary parts. The real part equations for the two components are

$$-\omega P_j + k a_j P_{\bar{j}} + b_j\left(\frac{\partial^2 P_j}{\partial x^2} - k^2 P_j\right) + c_j\left(k\omega P_j + \frac{\partial^2 P_j}{\partial x \partial t}\right) + d_j F(P_j^2)P_j + k_j P_{\bar{j}} = 0. \quad (5)$$

The imaginary part equation for the two components lead to the velocity of the solitons as

$$v = \frac{a_j + \omega c_j - 2kb_j}{1 - c_j k} \quad (6)$$

where $j = 1, 2$. If v is the velocity and g is the functional form of the wave profile, then the wave profile can be written as $g(x - vt)$. A constraint relation between the soliton parameters can be obtained by equating the above two velocities with each other. Thus we find the relation as below:

$$\omega = \frac{(2kb_j - a_j)(1 - kc_{\bar{j}}) - (2kb_{\bar{j}} - a_{\bar{j}})(1 - kc_j)}{c_j - c_{\bar{j}}} \quad (7)$$

where $j = 1, 2$ and $\bar{j} = 3 - j$. This relation holds for dual-power laws of nonlinearity as well as for bright, dark and singular solitons of this law. The real part equations given by (5) will now be analyzed separately in the following two sections, based on the type of nonlinearity.

3. Dual-power law nonlinearity

For Dual-power law nonlinearity, $F(\psi) = \psi^m + v\psi^{2m}$ so Eq. (1) take the form

$$i\left(\frac{\partial \psi_j}{\partial t} + a_j \frac{\partial \psi_{\bar{j}}}{\partial x}\right) + b_j \frac{\partial^2 \psi_j}{\partial x^2} + c_j \frac{\partial^2 \psi_j}{\partial x \partial t} + d_j\left(|\psi_j|^{2m} + v_1|\psi_j|^{4m}\right)\psi_j + k_j \psi_{\bar{j}} = 0. \quad (8)$$

where $j = 1, 2$ and $\bar{j} = 3 - j$. Hence, the real part equations for the components are

$$-\omega P_j + k a_j P_{\bar{j}} + b_j\left(\frac{\partial^2 P_j}{\partial x^2} - k^2 P_j\right) + c_j\left(k\omega P_j + \frac{\partial^2 P_j}{\partial x \partial t}\right) + d_j\left(P_j^{2m} + v_j P_j^{4m}\right)P_j + k_1 P_{\bar{j}} = 0. \quad (9)$$

where $j = 1, 2$ and $\bar{j} = 3 - j$. The real part Eq. (9) is being analyzed on the type of solitons that are considered. The study is, thus, divided into the following four subsections.

3.1. Bright solitons

For constructing the bright solitons of above equations, the ansatz hypothesis is of the form

$$P_j(x, t) = A_j \ \text{sech}^{p_j}\xi \qquad \text{and} \qquad \xi = B(x - vt). \quad (10)$$