Optik - International Journal for Light and Electron Optics 172 (2018) 150–155

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

New combo and dipole solitons in multiple-core couplers with dual dispersion

Nauman Raza[a,*], Muhammad Rizwan Aslam[a], Asma Rashid Butt[b], Sultan Sial[c]

[a] Department of Mathematics, University of the Punjab, Quaid-e-Azam Campus, Lahore, Pakistan
[b] Department of Mathematics, University of Engineering and Technology, Lahore, Pakistan
[c] Lahore University of Management Sciences, Lahore Cantt, Pakistan

ARTICLE INFO

Keywords:
Combo soliton
Dipole soliton
Optical couplers
Kerr law nonlinearity
Ansatz method

ABSTRACT

This paper is concerned with combo and dipole solitons in nonlinear directional optical couplers using Kerr law media. The governing model is multiple-core couplers with group velocity dispersion (GVD) and spatio-temporal dispersion (STD) described by a nonlinear Schrödinger's equation (NLSE). The Ansatz method is used to construct these combo and dipole solitons. The necessary conditions for the existence of these solitons is also given.

1. Introduction

Nonlinear optical dynamics and the propagation of light pulses is of great current interest. Current applications are in birefringent fibers, optical metamaterials, optical fibers and there are many others. Nonlinear couplers with switching have lots of applications in optical communication networks. The process of switching distributes the light pulse from a main fiber into multiple branched fibers.

There are numerous models for the kinetics of soliton propagation. The most well-known is the nonlinear Schrödinger equation (NLSE). Some references for the large number of applications involving the NLSE for optical solitons are [1–10]. Optical solitons travel over long distances without varying their speed and shape, making them very important in optics. Propagation of optical solitons through various media with perturbations is also worthy discussion [11–17]. In this article, the NLSE is considered with group velocity dispersion (GVD) and spatio-temporal dispersion (STD). Multiple-core nonlinear directional optical couplers using Kerr law of nonlinearity are studied. Another type of nonlinear directional optical coupler is the twin-core coupler. Twin-core couplers having high intensity of wave propagation have already been studied [18].

Dark and bright solitons are also studied using the NLSE in [19–25]. The ansatz technique was introduced by Li et al. [26]. Another form of this method was introduced by Porsezian and Choudhuri [27]. This method gives solitary wave solutions in the form of combo and dipole solitons. In this ansatz method, the product of dark and bright solitons results in a dipole soliton or a dark-in-the-bright soliton [27–30]. Some recently obtained important results using different analytic techniques are also included in the references [31–50].

In this work, we derive some new and general results, such as soliton solutions, rational function like solutions, hyperbolic solutions and periodic solutions for the perturbed NLSE.

* Corresponding author.
E-mail addresses: nauman.math@pu.edu.pk, raza_nauman@yahoo.com (N. Raza).

https://doi.org/10.1016/j.ijleo.2018.06.135
Received 5 June 2018; Received in revised form 27 June 2018; Accepted 27 June 2018
0030-4026/

2. The governing model

The governing model for multiple-core couplers is given as follows [1,2]:

$$iq_t^{(l)} + a_l q_{xx}^{(l)} + b_l q_{xt}^{(l)} + c_l F(|q^l|^2)q^l = k_l[q^{(l-1)} - 2q^{(l)} + q^{(l+1)}], \tag{1}$$

where $1 \le l \le N$. The N coupled NLSE with the ansatz approach is described by Eq. (1). Here, k_l shows the coupling coefficient and $q^{(l)}$ is representing the optical field in the lth core. In addition a_l and b_l are the coefficients of GVD and STD respectively. Also c_l is the coefficient of nonlinearity. The type of nonlinearity will be defined by the function F.

F is a real-valued complex function $F(|q|^2)q : C \mapsto C$, further we consider the complex plane C as a two-dimensional linear space R^2, the function $F(|q|^2)q$ is k times continuously differentiable, so that

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

Now the complex valued function q is taken to be

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

where $P_l(x, t)$ is the amplitude of the soliton, while ϕ represents the phase component which is defined as

$$\phi(x, t) = -\mathrm{kx} + \mathrm{wt} + \theta, \tag{3}$$

where w and k represent the wave number and frequency of the soliton respectively, while θ is the phase constant. Putting Eq. (2) into Eq. (1) and on comparing the real and imaginary parts we have

$$a_l \frac{\partial^2 P_l}{\partial x^2} + b_l \frac{\partial^2 P_l}{\partial x \partial t} + P_l(b_l \mathrm{wk} - w - a_l k^2) + c_l F(P_l^2)P_l - k_l[P_{l-1} - 2P_l + P_{l+1}] = 0 \tag{4}$$

and

$$(1 - b_l k)\frac{\partial P_l}{\partial t}\partial t + (b_l w - 2a_l k)\frac{\partial P_l}{\partial x} = 0, \tag{5}$$

now using the travelling wave transformation

$$P_l(x, t) = U_l(\xi), \quad \xi = B(x - \mathrm{vt}), \tag{6}$$

real part becomes

$$(a_l - b_l v)B^2 \frac{\partial^2 U_l}{\partial \xi^2} + U_l(b_l \mathrm{wk} - w - a_l k^2) + c_l F(U_l^2)U_l - k_l[U_{l-1} - 2U_l + U_{l+1}] = 0, \tag{7}$$

and imaginary part becomes

$$\{-v(1 - b_l k) + b_l w - 2a_l k\}B\frac{\partial U_l}{\partial \xi} = 0. \tag{8}$$

From Eq. (8) we get

$$v = \frac{b_l w - 2a_l k}{1 - b_l k}. \tag{9}$$

This represents the velocity of the soliton given by the above equation which will remain same in any case of the nonlinearity in this problem.

3. Kerr law nonlinearity

In this case, the Kerr law states $F(q) = q$. This kind of nonlinearity appears in deep water waves or nonlinear fiber optics when both the refractive index of light and intensity behave in a similar fashion. For Kerr law Eq. (1) representing the NLSE becomes

$$iq_t^{(l)} + a_l q_{xx}^{(l)} + b_l q_{xt}^{(l)} + c_l(|q^l|^2)q^l = k_l[q^{(l-1)} - 2q^{(l)} + q^{(l+1)}]. \tag{10}$$

And real part Eq. (7) reduces to

$$(a_l - b_l v)B^2 \frac{\partial^2 U_l}{\partial \xi^2} + U_l(b_l \mathrm{wk} - w - a_l k^2) + c_l U_l^3 - k_l[U_{l-1} - 2U_l + U_{l+1}] = 0. \tag{11}$$

3.1. Combo solitons

We suppose that U is in the following form for the combo soliton solution [21] of Eq. (11)

$$U_l(\xi) = i\beta_l + \lambda_l \tanh \eta(\gamma - \mu\xi) + i\rho_l \operatorname{sech} \eta(\gamma - \mu\xi), \tag{12}$$