Optik 164 (2018) 380–384

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Optical solitons having weak non-local nonlinearity by two integration schemes

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ARTICLE INFO

Article history:
Received 4 February 2018
Accepted 9 March 2018

OCIS:
060.2310
060.4510
060.5530
190.3270
190.4370

Keywords:
Solitons
Parabolic law nonlinearity
Weak nonlocal nonlinearity

ABSTRACT

This paper employs a couple of integration schemes to obtain soliton solutions in parabolic law medium with weak non-local nonlinearity. These are dark, singular and bright-singular combo solitons.

1. Introduction

The growing dynamics of optical soliton molecules has become an engineering marvel in the field of telecommunications technology. There is always a pressing need for the extraction of soliton solutions to the governing model that is studied in this context. The most visible model is the nonlinear Schrödinger's equation that is studied in varous form of optical waveguides with a variety of non-Kerr law nonlinearities. There is a gradual and growing interest to venture into the wide range ofnonlinearities that permit soliton solutions to the NLSE. This paper studies the soliton solution extraction procedure for NLSE that carries parabolic law nonlinearity and also comes with weak non-local nonlinearity [1–10]. Two integration schemes are employed to retrieve soliton solutions that will be of great value to the soliton community. These integration

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https://doi.org/10.1016/j.ijleo.2018.03.026
0030-4026/

schemes are Kudryashov's method and the exp $\left\{-\phi(\eta)\right\}$-expansion method. These are dark and singular solitons as well as bright-singular combo solitons. The derivation technicalities are detailed in subsequent sections.

1.1. Governing model

The dimensionless form of our model equation that describes the dynamics of soliton molecule propagation through an optical fiber having parabolic law nonlinearity with a weakly nonlocal nonlinearity component is given by [4,8–10]

$$iq_t + \rho q_{xx} + \left(b_1|q|^2 + b_2 \ |q|^4\right) q + b_3 \left(|q|^2\right)_{xx} q = 0, \tag{1}$$

In this equation, the first term on the left side is the temporal evolution while the coefficient of ρ is the group-velocity dispersion (GVD) and $i = \sqrt{-1}$. The two nonlinear terms are the coefficients of b_1 and b_2 respectively that are from cubic and quintic nonlinear forms respectively. These two terms bind together for the cumulative nonlinear effect that stem from these two effects. The third nonlinear effect accounts for the coefficient of b_3 that is from weak non-local nonlinearity [1–10]. The sustainability of stable soliton propagation for the model given by (1) is the outcome of a delicate balance that exists between GVD and nonlinearities. This model will now be analyzed mathematically in the subsequent sections by the aid of two integration schemes.

2. Mathematical analysis

To solve Eq. (1), we look for a solution in the form

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

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

$$\eta = x + 2\rho\kappa t, \tag{3}$$

and the phase component is defined as

$$\Phi(x, t) = -\kappa x + \omega t + \theta_0. \tag{4}$$

By inserting (2) in (1), we obtain

$$\rho P'' - (\omega + \rho\kappa^2)P + b_1P^3 + b_2P^5 + 2b_3 \left\{P\left(P'\right)^2 + P^2P''\right\} = 0. \tag{5}$$

Balancing P^5 with P^2P'' in Eq. (5), then we get $N = 1$.

2.1. Application of modified Kudryashov's method

According to the modified Kudryashov method, Eq. (5) has the solution in the form

$$P(\eta) = c_0 + c_1Q(\eta), \tag{6}$$

where c_0 and c_1 are unknown constants and

$$Q(\eta) = \frac{1}{1 + KA^{\eta}}, \tag{7}$$

and $Q(\eta)$ satisfies ODE

$$Q'(\eta) = Q(\eta)(Q(\eta) - 1)\ln A, \tag{8}$$

where K and A are nonzero constants with $A > 0$ and $A \neq 1$.

Substituting (6) along with Eq. (8) into Eq. (5), and collecting the coefficients of $Q(\eta)$ to zero, we obtain a set of over-determined algebraic equations and by solving it, we find the following results:

$$c_0 = \mp\frac{1}{2}\sqrt{-\frac{6b_3}{b_2}}\ln A, \qquad c_1 = \pm\sqrt{-\frac{6b_3}{b_2}}\ln A, \qquad \rho = \frac{3b_3\left(b_1 - 2b_3\ln^2 A\right)}{b_2}, \tag{9}$$

$$\omega = \frac{3b_3\left(-2b_1\ln^2 A + 3b_3\ln^4 A - 4\kappa^2 b_1 + 8b_3\kappa^2\ln^2 A\right)}{4b_2}. \tag{10}$$