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Resonant optical solitons with anti-cubic nonlinearity

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ABSTRACT

This work obtains the integration of the resonant nonlinear Schrödinger's equation, with anti-cubic nonlinearity, in presence of perturbation terms that are considered with full nonlinearity. The csch method, extended tanh–coth method and the modified simple equation method are applied to extract the analytical soliton solution.

1. Introduction

Optical solitons is one of the fastest growing areas of research in photonics sciences [1–20]. There are several results that are revealed on a frequent basis and are visible across various journals. These optical solitons are a true engineering marvel in the field of telecommunications during the 21st century. There are various aspects of these solitons that are studied. One avenue of research is the analysis of a wide form of waveguides such as an optical fiber, crystals, PCF as well as optical metamaterials and metasurfaces. The other avenue of research is the study of solitons with various forms of non-Kerr law nonlinearity. This paper focuses on resonant optical solitons that is considered with anti-cubic (AC) form of nonlinearity. This form of nonlinearity was first reported during 2003 [9]. Later, a variety of results on optical solitons with such nonlinearity has flooded several journals. This paper once again, nevertheless, revisits the problem but with resonant solitons. There are three integration schemes adopted in this paper that addresses the governing model with AC nonlinearity in presence of perturbation terms that appear with full nonlinearity. After a quick introduction to the model, the details are enumerated.

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1.1. Governing model

The governing model for soliton propagation is the nonlinear Schrödinger's equation (NLSE) with AC nonlinearity that is given in the dimensionless form as [6]:

$$iq_t + aq_{xx} + b\frac{|q|_{xx}}{|q|}q + \left(\frac{c_1}{|q|^4} + c_2|q|^2 + c_3|q|^4\right)q \\ = i\alpha q_x + i\lambda\left(|q|^{2m}q\right)_x + i\nu\left(|q|^{2m}\right)_x q + i\delta|q|^{2m}q_x + \sigma\left(\frac{q^*_{xx}}{|q|^2}\right)q^2 \tag{1}$$

where x and t are spatial and temporal variables respectively and $q(x, t)$ is the complex-valued dependent variable. The group velocity dispersion coefficient is a and b is the Bohm potential coefficient for chiral solitons with quantum Hall effect. The nonlinear terms are the coefficients of c_j, for j = 1, 2, 3. The first nonlinear term with c_1 accounts for the AC effect while c_2 and c_3 together constitute the cubic-quintic effects. The first term on the left hand side is the linear evolution term and also $i = \sqrt{-1}$. On the right hand side of (1), α is the inter-modal dispersion, and λ is the self-steepening term for short pulses while ν and δ represents nonlinear dispersion. Finally, σ represents relativistic effect in plasmas. The perturbation terms with λ, ν and δ all appear with full nonlinearity and m is the full nonlinearity parameter.

This model will be studied using three integration schemes. They are csch method, extended tanh–coth method and the modified simple equation that will reveal soliton solutions to the model. The starting hypothesis is the traveling wave ansatz. The details are all jotted in the upcoming sections.

2. Traveling wave hypothesis

The solutions of (1) is assumed to be

$$q(x, t) = u(\xi)e^{i\theta(x,t)} \tag{2}$$

where $\xi = x - \gamma t$ and the phase $\theta(x, t) = -kx + \omega t + \theta_0$, $u(\xi)$ is the amplitude component of the wave and γ is its speed. k is the soliton frequency; ω is its wavenumber and θ_0 is the phase constant. With this definition, Eq. (1) can be decomposed into real and imaginary parts that yields a pair of relations. The real and imaginary parts of Eq. (1) respectively are:

$$(a + b - \sigma)u'' - (a + b - \sigma)k^2 + \omega + k\alpha u - \left[2m(\lambda + \nu) + (\lambda + \delta)\right] ku^{2m+1} + \left(\frac{c_1}{u^4} + c_2u^2 + c_3u^4\right)u = 0 \tag{3}$$

$$\left\{\alpha + \gamma + 2k(a + b - \sigma)\right\} + \left[\delta + 2m\nu + \lambda(2m + 1)\right] u^{2m} = 0 \tag{4}$$

Eq. (4) leads to the speed of the soliton

$$\gamma = 2k(\sigma - a - b) - \alpha \tag{5}$$

along with the constraint condition on the perturbation parameters

$$\delta + 2m\nu + \lambda(2m + 1) = 0 \tag{6}$$

Next, multiplying (3) by u' and integrating once with zero constant gives

$$6(a + b - \sigma)u'^2 - 6(a + b - \sigma)k^2 + \omega + k\alpha u^2 - \frac{6\left[2m(\lambda + \nu) + \lambda + \delta\right]k}{(m + 1)}u^{2(m+1)} - \frac{6c_1}{u^2} + 3c_2u^4 + 2c_3u^6 = 0$$

assume

$$V(\xi) = u^2(\xi) \tag{7}$$

Eq. (7) can be written as:

$$n_1V'^2 - n_3V^{m+2} - 12c_1 - n_2V^2 + 6c_2V^3 + 4c_3V^4 = 0 \tag{8}$$

where

$$n_1 = 3(a + b - \sigma), \quad n_2 = 12(a + b - \sigma)k^2 + \omega + k\alpha, \quad n_3 = \frac{12[2m(\lambda + \nu) + \lambda + \delta]k}{(m + 1)} \tag{9}$$

3. Integration methodologies

In this section we will apply three different methods to solve Eq. (8). These methods are csch method, extended tanh–coth method, and the modified simple equation method.