Optik 130 (2017) 1–10

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Properties of compact bright pulse in long optical waveguide: Higher-order effects

Chancelor Pokam Nguewawe*, David Yemélé

Laboratory of Mechanics and Modeling of Physics Systems L2MSP, Faculty of Science, University of Dschang, P.O. Box 067, Dschang, Cameroon

ARTICLE INFO

Article history:
Received 27 July 2016
Accepted 30 September 2016

Keywords:
Nonlocal nonlinear Schrödinger equation
Third-order dispersion
Raman term
Higher-order effects
Self-steepening
Compact bright pulse

ABSTRACT

The properties of the compact bright (CB) pulse propagating in the long optical waveguide under the action of third-order dispersion (TOD), time derivative of the pulse envelope and first moment of the nonlinear response function of the waveguide known as the Raman term are investigated. From the dispersionless nonlocal Nonlinear Schrodinger equation (NLS) describing the propagation of light beam in the waveguide with nearly instantaneous nonlinear response and extended either by the TOD or the time derivative of the pulse envelope, the exact analytical expressions of CB pulse are derived. It appears that although the TOD does not affect the pulse amplitude, shape and width, it induces the deviation of the pulse velocity from the group velocity of the wave packet with a magnitude depending of the pulse frequency. Similarly, the presence of the time derivative of the pulse envelope affects the pulse parameters namely the shape, width and constant of propagation and also induces the self-steepening of the CB pulse. As for the Raman term, the result from the perturbation approach shows that the CB pulse experiences a self-frequency shift linearly proportional to the distance of propagation of the pulse. Although some of the obtained results are qualitatively similar to those previously exhibited by the bright soliton, the analytical expressions are quite different. The accuracy of these analytical results is checked trough numerical simulations of the appropriated extended nonlocal NLS equation and the wave spectrum.

1. Introduction

The theory of nonlinear waves with compact support has received these last decades a growing attention due to the fundamental interest of this new concept in one hand and the potential application of the resulting ultra-localized signals in long distance communication in other hand.

In fact, after the pioneering work by Rosenau and Hyman [1] discovering the existence of solitary waves with compact support induces by the nonlinear dispersion, many other researches have been done in order to put forward this new concept. As a main result, it is well-known today that beside to this nonlinear dispersion responsible for the compactness of the nonlinear localized excitations, compact structures may also emerge in a variety of physic contexts with mathematical characterization given via a sub-linear substrate potential or on-site force, a sub-linear convective, a nonlinear diffusion, a nonlocal nonlinearity, to cite just a few. The common mathematical feature of these diverse phenomena being the degeneracy

* Corresponding author.
E-mail addresses: pokam9@yahoo.fr (C.P. Nguewawe), dyemele@yahoo.fr (D. Yemélé).

http://dx.doi.org/10.1016/j.ijleo.2016.09.127

of differential equations describing their properties at certain points and the corresponding failure of the uniqueness theorem at these [2].

This founding stimulated also other researches devoted to physics systems where the properties can be interpreted in terms of the modified nonlinear Schrödinger (NLS) equation [1,3–10], that is, the extended NLS equation with nonlinear and nonlocal dispersion, in order to obtain the envelope bright pulse with compact support (CB pulse) instead of pulse with compact support previously found by Rosenau and Hyman. In this light, the compact dark solitons and other exotic properties and forms of solutions with discontinuous derivatives in the form of peaks and cusps have been unfortunately obtained. Few studies have reported the existence of the CB pulses excepted a serious investigation by Rosenau which has reported the possibility of its existence in the NLS equation extended by the singular nonlinearity particularly difficult to reproduce in a physics context [11]. Recently, by means of powerful methods namely the simplest equation method, the functional variable, sine-cosine function, the tanh function, G'/G-expansion and the first integral methods, which have been constructed to derive exact analytical solutions of nonlinear partial differential equations, Biswas and co-workers [12,13] have derived many solutions of the resonant and generalized resonant NLS equation with time-dependent coefficients and for different types of standard nonlinearity: the well-known Kerr law, the parabolic, power, and dual-power laws. Exact dark and bright solitary waves-type with constant and also time-dependent amplitude were found. In addition a possibility of rational solutions, singular solitary wave and periodic trigonometric solutions were also pointed out. This analysis were also extended to the dense wavelength division multiplexed system [14], in one hand, described by the NLS-type equation with linear spatio-temporal dispersion and with Kerr and parabolic laws for the standard nonlinearity and in other hand by the generalized chiral NLS equation with time-dependent coefficients [15], and some of the above cited solutions were also obtained.

A serious attempt have been made very recently by Pokam et al. [16] who pointed out that CB pulse may emerge from an homogeneous NLS equation without singularity, that is, from the NLS equation with a linear dispersion replaced by a simple form of the nonlinear term resulting either from the nonlocal nonlinearity of the response function of the nonlinear kerr media or from the non-instantaneous response function in an optical fiber, and particularly in the limit of zero linear dispersion. This interesting result possesses some features: the width which is independent on the pulse amplitude while its nonlinear phase is an arbitrary function conferring to these compact signals the capacity to carry information of different types.

However, Due to the fact that, the second moment of the nonlinear response function responsible for this new pulse become important only for ultrashort pulses, the CB pulse may then experiences other effects related to this type of pulse namely the third-order dispersion, the time derivative of the pulse envelope and the first moment of the nonlinear response function of the waveguide which has been demonstrated to be particularly important for ultrashort pulse and should be included in modeling pulse evolution of such short pulses in optical fibers. In fact, in the context of bright solitons, it has been shown that these higher order effects may lead to some important phenomena namely the pulse self-frequency shift, the pulse self-steepening [17,18], the pulse decay for higher-order soliton [19–22], and the delay of the soliton peak resulting respectively from the Raman term, time derivative of the pulse envelope and third-order dispersion [23]. At this stage or research, *an interesting question is whether the above higher-order terms may influence the properties of the CB pulse*. The answer to this question constitutes the main objective of this work.

The paper is organized as follows: in Section 2, we derive the NLS-type equation governing the propagation of light beam in the nonlinear waveguide which takes into account the TOD, the Raman term and the time derivative of the pulse envelope term. In Section 3, after a brief review on the derivation of the CB pulse, we use the perturbation approach to investigate the influence of the Raman term on the properties of the CB pulse. In Section 4, we turn our attention on the influence of the TOD on these properties while in Section 5 we search for the effect of the time derivative of the envelope pulse on this CB pulse. Finally, the concluding remarks are devoted to Section 6.

2. Propagation of optical pulse: governing equation

We consider a light pulse propagating inside a nonlinear fiber optic. Like all electromagnetic phenomena, this optical pulse is governed by the Maxwell's equations. Guided by the geometry of the fiber associated to the direction of propagation of the signal inside the fiber, the electrical field associated to this signal can be written in the form

$$E(\vec{r},t) = \left\{F(x,y)A(z,t)e^{i(\beta_0 z-\omega_0 t)} + c.c.\right\}\vec{u} \tag{1}$$

where variables x, y and z are respectively the transverse spatial and the axial coordinates of the fiber, $\vec{u}$ is the direction of polarisation. Similarly, $c.\,c$. stands for the complex conjugation and $F(x, y)$ is the modal distribution whose expression is well-known namely in the particular case of the single mode fiber [24]. The function $A(z, t)$ is the slowly varying pulse envelope and the parameters β_0 and ω_0 are respectively the propagation constant and the frequency of the carrier wave and are related through the expression $\beta_0 = n_0\omega_0/c$ in which $n_0 = n(\omega_0)$ is the linear part of the nonlinear refractive index of the fiber and c the velocity of light in vacuum. In fact, in the nonlinear optic fiber, the refractive index is intensity dependent and satisfies to the relation:

$$n(\omega,|E|^2) = n(\omega) + n_2|E|^2 \tag{2}$$