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Chirped Solitons in Generalized Resonant Dispersive Nonlinear Schrödinger's equation

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Abstract

The paper studies the solitons of the generalized resonanat dispersive nonlinear schödinger equation(GRD-NLSE) with power law nonlinearity. Subject to the enhanced and protracted chirped solitons, the model is studied with dispersion of self phase and self steepening coefficients.The results thus obtained shows that bright,dark and singular solitons depends on the intensity of the propagating pulse.

1 Introduction

Optical soliton has attracted the attention of researchers due to their capability of propagation without dispersing over long distance; *i.e.*, they do not change their shape over long distance. They are important subject in optical

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fibers communication due to this property.
In the past few decades optical solitons has attracted the attention of researchers due to their capability of propagation without scattering over long distances.
Optical solitons has become the promising field of research in nonlinear optics, this area of research has led to immense progress with a view to their extensive applications. It is acknowledged that the dynamics of the nonlinear optical solitons and madelung fluids are modeled by the generalized resonant dispersive nonlinear schödinger equation(GRD-NLSE) Commonly a particular resonant term must be considered during the study of chirped solitons in hall current effects in the field of quantum mechanics [1-6]. It must be observed that the equation that governs the propagation of solitons pulse in the nonlinear medium is well-posed only when the extra spatio-temporal dispersion (STD) is assumed [7-30]. It must be observed that the equation that governs the soliton transmission in nonlinear medium is well-posed in the case when the additional spatio-temporal dispersion (STD) is considered. A few such topics are polarization preserving fibers, dispersion flattened fibers,brag gratings, optical switching,magneto optic wave guides, integrability perturbation. Recently several efficient and strong techniques have been used to secure exact bright, dark and singular soliton solutions of NLSE model with power, dual power and kerr nonlinear effects [30-45]. In this work we will apply a different method to obtain a set of solitons solutions for GRD-NLSE with power law non linearity [1]. The soliton solutions comprises of bright, dark and singular solitons with non linear chirping for model under discussion.

$$i(|\Upsilon|^{n-1}\Upsilon)_t + \alpha(|\Upsilon|^{n-1}\Upsilon)_{xx} + \beta(|\Upsilon|^n)\Upsilon + \gamma\frac{(|\Upsilon|^n)_{xx}}{|\Upsilon|}\Upsilon = 0 \tag{1.1}$$

For above model, $\Upsilon(x,t)$ indicates the profile of the wave that propagates and it represents the complex valued function. The parameter α and β used in Eq.(1.1) indicates the coefficients of group velocity dispersion(GVD) and power law nonlinearity while parameter γ symbolize the coefficient of resonant term that arises in the subject of madelung fluids. While n suggests the generalized evolution and the GVD When $n = 1$ the above model reduces to regular form of NLSE, thus parameter n preserves the evolution and GVD on a summarized manner. The solitons while propagating for long distances the GVD and evolution gets changed and modified, that's why it is compulsory to judge NLSE wherever the evolution and GVD are adjusted to sustain the dynamics of propagation of solitons closer to genuineness. Thus Eq.(1.1) is the proposed model.

2 Substance of Solitons

For the substance of chirp optical solitons, we assume the complex function in the form,

$$\Upsilon(x,t) = g(s)e^{i[\chi(s)-\Omega t]}, \tag{2.2}$$

where the real valued functions are given by g and χ of the coordinates $s = \chi - ut$ named as traveling waves. The associated chirp in given by result $\delta\Upsilon(t,x) = \frac{\partial}{\partial x}[\chi(s) - \Omega t] = -\acute{\chi}(s)$. The Substitution of Eq.(2.2) into Eq.(1.1), yields the real and imaginary parts after simplification. We discover the pair of joined equations in g and χ.

$$\begin{aligned} ug^n\acute{\chi} + \Omega g^n + \alpha n(n-1)g^{n-2}g'^2 + \alpha n g^{n-1}g'' - \alpha g^n\chi'^2 + \beta g^{n+1} \\ + \gamma n g'' g^{n-1} + \gamma n(n-1)g^{n-2}g'^2 = 0 \end{aligned} \tag{2.3}$$

and

$$-nug^{n-1}g^{'} + \alpha n g^{n-1}\chi^{'}g^{'} + \alpha g^n\chi^{''} + ng^{n-1}g^{'}\chi' = 0 \tag{2.4}$$

Furthermore, we now acquire an ansatz to solve equation in (2.3) and (2.4). This ansatz dependent on the amplitude of the and is given by,

$$\acute{\chi} = pg^{2n} + q. \tag{2.5}$$

Consequently, the resultant chirp transforms into $\delta\Upsilon(t,x) = -(pg^{2n} + q)$, where p and q represent chirp parameters which are non-linear and constant in nature, in particular. This shows that the chirp related to propagating pluses depends on intensity, (*i.e.,* $\delta\Upsilon(t,x) = -(pg^{2n}+q)$, where $I = |q|^2 = g^2$) and together include the contribution of linear and nonlinear terms.

Morever, by substituting the ansatz Eq.(2.5) into Eq.(2.4) gives the relation for p and q in the following forms. The relation for the nonlinear chirp parameter p is given by

$$p = -\frac{2n\alpha}{n(\alpha+1)} \tag{2.6}$$

The above relation of chirp constraint q strongly vary on the self steeping, GVD, and spatio-temporal nonlinear spreading effects and while the relation for constant chirp parameter q is given by

$$q = \frac{nu}{n(\alpha + 1)} \tag{2.7}$$

The above relation of constant chirp parameter q depends on the spatio-temporal, GVD, self steeping and nonlinear scattering effects. Hence the difference of above parameters permits efficient command of the breadth of chirp using Eq.(2.5)-(2.7) in Eq.(2.3), one obtains.

$$g^{''} + \alpha_1 g^{4n+1} + \alpha_2 g^{2n+1} + \alpha_3 g + \alpha_4 g^2 + \alpha_5 g^{-1} g'^2 = 0 \tag{2.8}$$

Eq.(2.8) is an elliptic equation which describes the growth of the wave amplitude in a nano optical fiber. This phenomena is ruled by the modified kind of the GRD-NLSE, given in Eq.(1.1). We want to evaluate the above equation analytically for $\alpha_i \neq 0$ with $(i = 1, 2, ..., 8)$ to obtain bright, dark and singular soliton solutions for the nonlinear chirping model given in section 1 where,

$$\alpha_1 = -\frac{\alpha p^2}{n(\alpha + \gamma)}, \quad \alpha_2 = \frac{p(u - 2q\alpha)}{n(\alpha + \gamma)}, \quad \alpha_3 = (n - 1)$$
$$\alpha_4 = \frac{uq + \Omega - \alpha p^2 q^2}{n(\alpha + \gamma)}, \quad \alpha_5 = \frac{\beta}{n(\alpha + \gamma)} \tag{2.9}$$

More newly, we derived families of chirped soliton like solutions for a higher-order GRD-NLSE having inter model dispersion, self-steepening and self-frequency shift.

3 Chirped Solitons

This section describe the exact solitons solution of the model defined in Eq.(1.1). The exact solution is presented in the existence of physical parameters as done in the earlier studies. Our solutions will give the results in the form of nonlinear pluses that depends on the pulses force intensity.

3.1 Bright Solitons

In this section we will present major types of chirped soliton solutions. We came across two kinds of bright solutions with definite parametric settings.

The obtained solutions is in explicit form and associated chirping are certain below.

Case-I: Let us consider the bright solitons are given in the following form.

$$g(\xi) = \frac{M}{[1 + T\cosh(\mu\xi)]^{1/2n}} \tag{3.10}$$

where μ, M and T are defined by the following values.

$$\mu = \left[-\frac{4\alpha_3 n^2}{1+\alpha_5} \right]^{1/2} \tag{3.11}$$

$$M = \left[-\frac{2\alpha_3}{\alpha_2}\left(\frac{1+n+\alpha_5}{1+\alpha_5}\right)\right]^{1/2n} \tag{3.12}$$

and,

$$T = \left[\frac{\alpha_2^2(1+\alpha_5)(1+2n+\alpha_5) - 4\alpha_1\alpha_3^2(1+n+\alpha_5)^2}{\alpha_2^2(1+\alpha_5)(1+2n+\alpha_5)}\right]^{1/2}. \tag{3.13}$$

For the assistance of bright soliton it is necessary to have $\alpha_2(1+\alpha_5) < 0$, where n is an even integer from Eq.(3.12). But, if n is an odd integer of Eq.(3.12) then it is necessary to have $\alpha_2(1+\alpha_5) < 0$. In this case the soliton will be pointing downwards

$$\Upsilon(x,t) = \frac{M}{[1 + T\cosh(\mu\xi)]^{1/2n}} e^{i[\chi(s) - \Omega t]}. \tag{3.14}$$

and its frequented chirping is given by the following relation

$$\delta\Upsilon(x,t) = -\left(\frac{pM^{2n}}{1 + T\cosh(\mu\xi)} + q\right). \tag{3.15}$$

where μ, M and T are already given in equations (3.11)-(3.13).

Case-II: Let us consider another form of the bright soliton solutions

$$g(\xi) = \frac{m_1}{[1 + m_2\cosh^2(\mu\xi)]^{1/2n}} \tag{3.16}$$

where μ, m_1 and m_2 are defined by the following values

$$\mu = \left[- \frac{\alpha_3 n^2}{1+\alpha_5} \right]^{1/2} \tag{3.17}$$

$$m_1 = \left[- \frac{\alpha_3}{\alpha_2} \left(\frac{(2+m_2)(1+n+\alpha_5)}{1+\alpha_5} \right) \right]^{1/2n} \tag{3.18}$$

and,

$$m_2 = \frac{-[4\alpha_1\alpha_3^2(1+n+\alpha_5)^2 - \alpha_3\alpha_2^2(1+\alpha_5)(1+n+\alpha_5) - n\alpha_3\alpha_2^2(1+\alpha_5)]}{2\alpha_1\alpha_3^2(1+n+\alpha_5)^2} + \frac{\sqrt{[4\alpha_1\alpha_3^2(1+n+\alpha_5)^2 - \alpha_3\alpha_2^2(1+\alpha_5)(1+n+\alpha_5) - n\alpha_3\alpha_2^2(1+\alpha_5)]^2}}{2\alpha_1\alpha_3^2(1+n+\alpha_5)^2} - \frac{\sqrt{4\alpha_1\alpha_3^2(1+n+\alpha_5)^2[4\alpha_1\alpha_3^2(1+n+\alpha_5)^2 - \alpha_3\alpha_2^2(1+\alpha_5)(1+2n+\alpha_5]}}{2\alpha_1\alpha_3^2(1+n+\alpha_5)^2} \tag{3.19}$$

It is essential to have $\alpha_2(1+\alpha_5) > 0$ for the bright soliton to occur if n is chosen as an even number in Eq.(3.18), but if n is taken to be an odd integer then there will be no such no such restrictions , utilizing these results we have existing solitons and the additional family of bright soltion with onlinear chirp of Eq.(1.1) as

$$\Upsilon(x,t) = \frac{m_1}{[1+m_2\cosh^2(\mu\xi)]^{1/2n}} e^{i[\chi(s)-\Omega t]}, \tag{3.20}$$

and its consequent chirping return in the form

$$\delta\Upsilon(t,x) = -\left(\frac{pm_1^{2n}}{1+m_2\cosh^2(\mu\xi)} + q \right). \tag{3.21}$$

where μ, m_1, m_2 and are assumed by the relations(3.17)-(3.19).

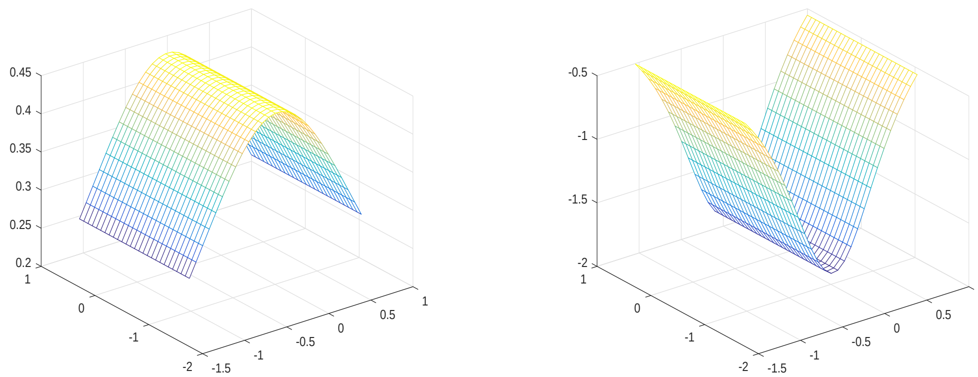

Figure 1: Bright Soliton of Case-I and Case-II

with the different parameters of case-I is, $\mu = 1.4, T = 1.34, q = -1.5, -\frac{\pi}{3} < \xi < \frac{\pi}{3}, M = 2, n = 1, p = 0.5$ and case-II is $\mu = 0.7, p = 1.14, q = -1.3, m_1 = 0.5, m_2 = 2, -\frac{\pi}{3} < \xi < \frac{\pi}{3}$

3.2 Dark Solitons

The dark soliton solutions are also very interesting due to their stable nature under the effects of material losses. In order to justify the constraint conditions two types of dark soliton solutions of Eq.(1.1) are given as,
Let us consider the dark soliton solutions in the following form.

$$g(\xi) = [n_1(1 \pm \tanh(\mu\xi))]^{1/2n} \tag{3.22}$$

where μ and n_1 are defined by the following values

$$\mu = \left[-\frac{\alpha_3 n^2}{1 + \alpha_5} \right]^{\frac{1}{2}} \tag{3.23}$$

and,

$$n_1 = -\frac{\alpha_3}{\alpha_2}\left(\frac{1 + n + \alpha_5}{1 + \alpha_5}\right) \tag{3.24}$$

provided that to certify the wave parameter μ to be real, So the chirped dark soliton solution of Eq.(1.1) takes the form:

$$\Upsilon(x, t) = [n_1(1 \pm \tanh(\mu\xi))]^{1/2n} e^{i[\chi(s) - \Omega t]} \tag{3.25}$$

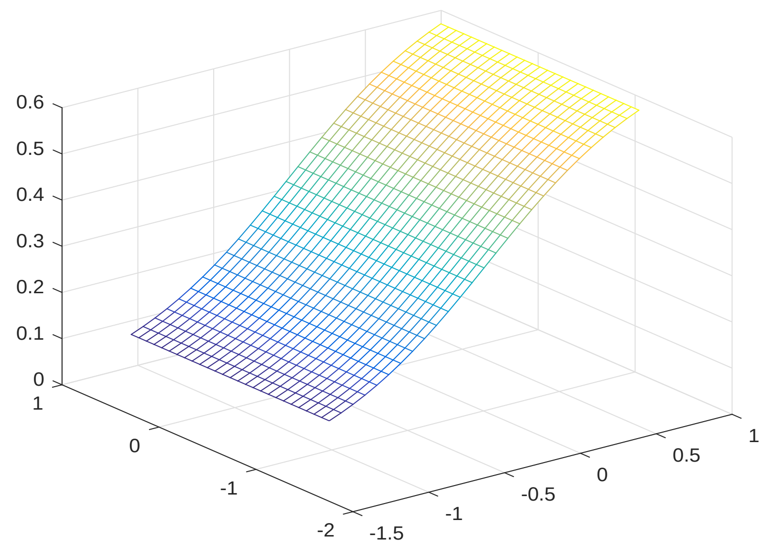

Figure 2: Dark Soliton
with the, $\mu = 1.3, n_1 = 2, p = 0.2, q = 1.5, n = 1, -\frac{\pi}{3} < \xi < \frac{\pi}{3}$.

While associated chirping is given by,

$$\delta\Upsilon(t, x) = -n_1 p(1 \pm \tanh(\mu\xi) - q \tag{3.26}$$

Where μ and n_1 are assumed by the relations (3.23) and (3.24).

3.3 Singular Solitons

We came across two kinds of singular solutions under definite constraints conditions. These solutions in explicit form and associated chirping are given under.

Case-I: Consider the first type of singular soliton solution of the form.

$$g(\xi) = [F(1 \pm \coth(\mu\xi))]^{1/2n}, \tag{3.27}$$

Where μ and F are defined by the following values

$$\mu = \left[-\frac{\alpha_3 n^2}{1 + \alpha_5} \right]^{1/2} \tag{3.28}$$

and,

$$F = -\frac{\alpha_3}{\alpha_2}\left(\frac{1+n+\alpha_5}{1+\alpha_5}\right) \tag{3.29}$$

provided μ to be real thus we have chirped singular soliton solution for Eq.(1.1)

$$\Upsilon(x,t) = [F(1 \pm \coth(\mu\xi))]^{1/2n} e^{i[\chi(s)-\Omega t]} \tag{3.30}$$

to consequent chirping set by

$$\delta\Upsilon(t,x) = -pF(1 \pm \coth(\mu\xi)) - q \tag{3.31}$$

While μ and F are illustrated by Eq. (3.28) and Eq.(3.29).

Case-II: Now consider another singular soliton solution of the form :

$$g(\xi) = \frac{B}{[1 + C\sinh(\mu\xi)]^{1/2n}} \tag{3.32}$$

Where μ, B and C are defined by the following values.

$$\mu = \left[-\frac{4n^2\alpha_3}{1+\alpha_5}\right]^{1/2} \tag{3.33}$$

$$B = \left[-\frac{2\alpha_3}{\alpha_2}\left(\frac{1+n+\alpha_5}{1+\alpha_5}\right)\right]^{1/2n} \tag{3.34}$$

and,

$$C = \left[-\frac{\alpha_3\alpha_2^2(1+\alpha_5)(1+2n+\alpha_5) - 4\alpha_1\alpha_3^2(1+n+\alpha_5)^2}{\alpha_3\alpha_2^2(1+\alpha_5)(1+2n+\alpha_5)}\right]^{1/2} \tag{3.35}$$

Based on above results, Singular soliton solution of Eq.(1.1) is given by:

$$\Upsilon(x,t) = \frac{B}{[1 + C\sinh(\mu\xi)]^{1/2n}} e^{i[\chi(s)-\Omega t]} \tag{3.36}$$

where the consequent chirping can be written as:

$$\delta\Upsilon(t,x) = -\left(\frac{PB^{2n}}{1 + C\,\sinh(\mu\xi)} + q\right) \tag{3.37}$$

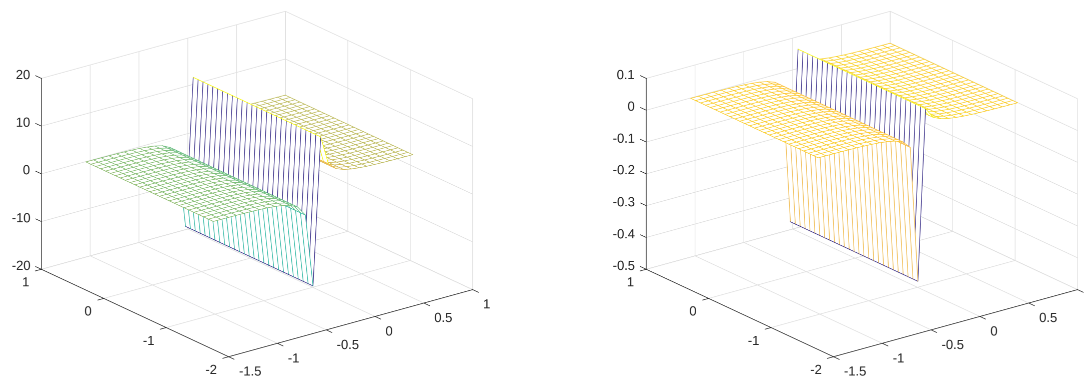

Figure 3: Singular Soliton with Case-I and Case-II

Where μ, B, C and are given by the relations (3.33)-(3.35).

with the different parameters of case-I is, $\mu = 2.3, F = 7.4, p = -2, q = -1.2, n = 3, -\frac{\pi}{3} < \xi < \frac{\pi}{3}$ and case-II is $\mu = 4.5, p = 1.5, B = 12.93, C = 1.5, -\frac{\pi}{3} < \xi < \frac{\pi}{3}, n = 3, q = 1.5.$

4 Conclusion

We have inspected the enhanced nonlinear schrödinger equation with power law nonlinearity in the existance of generalized resonant dispersive nonlinear terms. We have assumed a different ansatz to extract associated nonlinear chirping with soliton pulses that propagates. A class of exact soliton solutions which possess non trivial phase chirping that alters as a function of intensity has obtained. Solutions enlists bright, dark and singular type solutions of localized nature. Similarly the nonlinear chirping associated with every soliton solution is also determined.
Conditions for the propagation of chirped pulses to exist are also extracted. The results thus obtained are of prime importance particular for soliton-particularly applications of nano optical fiber systems. Therefor nonlinear chirped solitons of bright,dark and singular type are extracted. The analogous corresponding integrability criterion also noted as constraint condition that arises from analysis. This work enlighten the way for future research and provides a lot of encouragement and inspiration for the students in the field of chirped solitons.

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