Effect of Frequency Chirp on the Black and Gray Solitons Propagation in Optical Fiber

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Abstract

The behavior of the first-order black and gray solitons propagated in optical fiber in the presence of frequency chirp is studied analytically and numerically. Results show that phase profile of black solitons changes abruptly by ($\Phi=\pi$) whereas for gray solitons phase profiles change more gradual and smaller than π. Black solitons characterized by the intensity at the dip falls to zero while for gray solitons the dip does not extend all the way to zero. Results indicate that the solitons pulses shift further from the axes of the link path designed as the value of darkness parameter (B) decreases. As a consequence of the frequency chirp the channel capacity performance of an optical communication link is reduced. Numerical study shows a good agreement with the analytical results.

1. Introduction

Solitons communications systems are leading candidates for long –light wave transmission links because they offer the possibility of a dynamic balance between group velocity dispersion (GVD) and nonlinear effect, the two effects that severely limit the performance of nonsoliton systems [1,2].

Dispersion effects have the effect of broadening short pulses as they propagate through the medium.The nonlinear effects in fiber media originates from the fact that the refractive index of the fiber medium depends on the intensity of the light pulse propagating through the fiber .The nonlinear effects have the effect of compression short pulses as they propagate through the fiber [3].

Mathematically speaking solitons are a localized solution of a nonlinear partial differential equations. However, in purely optical terms, optical solitons are solitary wave occurring in an envelope of a light wave and is referred to as envelope solitons. The first "solitary wave" was observed by *John Scott Russell* while observing motion in a canal ,saw a certain kind of wave retained its shape as it advanced, proceeding unchanged for more than a kilometer. Hasegawa and Tappert was first suggested n 973 he possibility of soliton propagation in optical fibers through the interaction between the nonlinear and dispersion effects [4]. However, lack of suitable source of picosecond optical pulses at wavelength >1.3μm delayed their experimental observation until 1980. Mollenauer et al. were able to observe bright solitons propagation in Bell Labs at the first time [5]. As mathematical results continued to appear, researches was experimenting intensively with optical bright solitons.

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looking for ways to use them in long – distance telecommunication system [6,7].Dark solitons are the characteristic steady pulses that propagate in nonlinear ptical iber operating within the normal dispersion regime [8], much as bright solitons when the fiber's dispersion s anomalous. Although dark solitons were discovered in the 1970s,it is only recently that they have been considered for communications and the delay can be attributed to a variety of factors. First, it is relatively difficult to generate and detect black solitons in comparison with as bright solitons. Second, most fibers are designed to have anomalous GVD at the wave-length of minimum loss while dark solitons require normal dispersion. A number of recent studies have shown that dark solitons more resistant to perturbation than their bright counter-parts, including perturbation that are due to loss and to amplified spontaneous emission noise. As a result of this enhanced stability, and of new, simple method that have been proposed for their generation the possibility of using dark solitons in optical communication systems is reexamined [9,10]. Long distance transmission of information using optical fiber is hampered by different types of signal degradation, which are intrinsic to the fiber loss, dispersion, and nonlinearity, frequency chirp or called the phase time dependent. The aim of this paper is to investigate the optical frequency chirp for dark and gray solitons in an optical fiber.

2. Theory

The primary equations to model solitary waves called Korteweg-deVries(KdV) equation and is given by[11]

$$\frac{\partial \eta}{\partial t} + 6\eta\frac{\partial \eta}{\partial x} + \frac{\partial^3 \eta}{\partial x^3} = 0 \quad ......(1)$$

Any bell-shaped function $\eta(x - vt)$ is a solitary wave translating with speed v along distance x in time t.The solitary wave solution of the KdV in the form (1) is

$$\eta = 2a^2 \sec h^2 a(x - 4a^2 t) \;.....(2)$$

where $2a^2$ is the wave amplitude , $4a^2$ is its velocity and t is the time. In this paper we shall restrict ourselves to solitons in optical fibers. The way to describe such envelope soliton propagation by the nonlinear Schrodinger (NLS) equation given by [12].

$$i\frac{\partial u}{\partial z} - \mathrm{sgn}(\beta_2)\frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + N^2|u|^2 u = 0 \quad ....(3)$$

where u is the complex amplitude of the pulse, z represents the distance along direction of propagation, τ is the time, and N is the soliton order. The second term is originated from the group velocity dispersion (β_2) and the third is due to the nonlinear (kerr) effect.The group velocity dispersion β_2 is given by

$$\beta_2 = \frac{\partial^2 \beta}{\partial \omega^2}|\omega_0 \quad ....(4)$$

where ω_0 is the carrier frequency, and β is wave number.

For N=1,and $\beta_2 > 0$ (normal dispersion regime) equation (2) can be written as

$$j\frac{\partial u(z,\tau)}{\partial z} - \frac{1}{2}\frac{\partial^2 u(z,\tau)}{\partial \tau^2} + |u|^2 u(z,\tau) = 0 \quad ....(5)$$

and the solution to NLS equation are referred to as "dark solitons", which designates the depth of the modulation Analytically NLS equation is solved by Inverse Scattering Method (ISM) which works only in certain cases (solitons in lossless optical fiber only) [13].

The general form of the solution of equation 2 can be expressed as[14] :

$u(z,\tau)=$

$$A_0\left[B^2-\sec h(A_0{}^2\tau)\right]^{1/2}\exp\left[\begin{matrix} i\phi(\tau') \\ +i(A_0/B)^2 z\end{matrix}\right]$$

..............(6)

and the phase is given by:

$$\phi(\tau')=\sin^{-1}\left[B\tanh(\tau')/(1-B^2\sec h^2\tau')^{1/2}\right]$$

...............(7)

The parameter A_0 governs the background level and the parameter B governs the depth of the dip (blackness parameter). For $|B|=1$

$|u(0,\tau)|=A_0\tanh(A_0\tau)$ ....(8)

and the simplest form of the first-order dark soliton solutions evolve for arbitrary distance along the fiber can be written as

$|u(z,\tau)|=A_0\tanh(A_0\tau)\exp(-iz/2)$

.................(9)

The dark soliton obtained for $|B|=1$ is then referred as the black soliton. Dark solitons with $|B|<1$ are sometimes called gray solitons to emphasize this feature. The parameter B governs the blackness of such *gray solitons.*

The most numerical modeling approach to solving NLS equations numerically are spectral techniques (efficient, uses FFT) or finite-difference techniques, or Wavelet transform technique [15].In this paper, equation (5) is solved numerically by using Split Step Fourier Method described by Al-Dabagh [16] ,and the initial condition used is :

$u(0,\tau)=(A\tanh B\tau)\exp[i\phi(\tau)]$ ....(10)

3. Results

Using Matlab program to represent equation (7) for different values of B at the beginning of the optical fiber (z=0) and are plotted in figure (1).Figure (1) shows that phase profile of black solitons ($|B|=1$) changes abruptly by π.while for gray solitons the phase change is such that the phase changes become more gradual and smaller for smaller values of $|B|$ .i.e.,dark solitons are chirped.Using the same Matlab environment o epresent equation (6) for different values of B at the beginning of the optical fiber are plotted in figure (2). Figure (2) shows that the intensity at the dip falls to zero for black solitons but for gray solitons the dip not extend all the way to zero. This figure describes a family of first -order solitons whose width increase inversely with B. Analytically, Figure (3) shows the propagation of black and grays solitons for15km distance. As the distance increase he pulse shift more from the axes of the optical fiber for smaller value of B. Numericall results are plotted in figure(4). The used parameters n he rogramming are the increment $\Delta t=0.05, \Delta z=0.1$ to investigate frequency chirp or the phase time dependent. Figure(4)shows the intensity profile for gray solitons inside the optical inside the optical inside the optical fiber at z=0,and z=15km for the darkness parameter 0.5,0.8 respectively. This figure indicates that gray solitons pulses with small value of B shift further from the axes of the link path designed, and much more than black solitons which are illustrated in figure(5).A comparison between From figure (4a) and figure(5b) shows that the gray soliton pulses have large width compared to black solitons. Numerical study shows a good agreement with the analytical results.

4. Conclusion

1- Gray soliton has large width and requires larger background intensity than a black soliton of the same width.

2- Gray soliton pulses suffer from frequency chirp more than black soliton pulses.

3- As a consequence of the frequency chirp effect, the channel capacity

Performance of an optical communication link is reduced.

4-The time–dependent phase or frequency chirp of black solitons repre -sents the major difference between bright and black solitons, whereas the phase of bright solitons remains constant across the entire pulse.

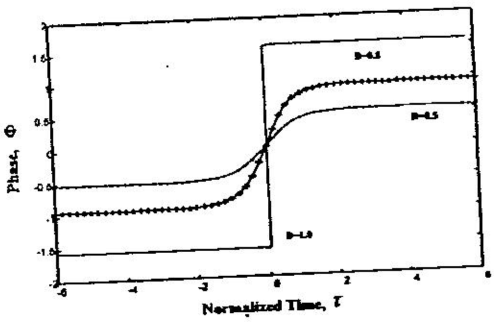


Figure (1): Phase Profile of first-order black and gray solitons at z=0

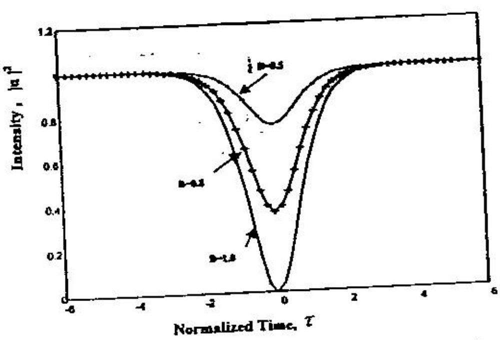


Figure (2): Intensity Profile of first-order dark soliton for several values of the blackness parameter B at z=0km.

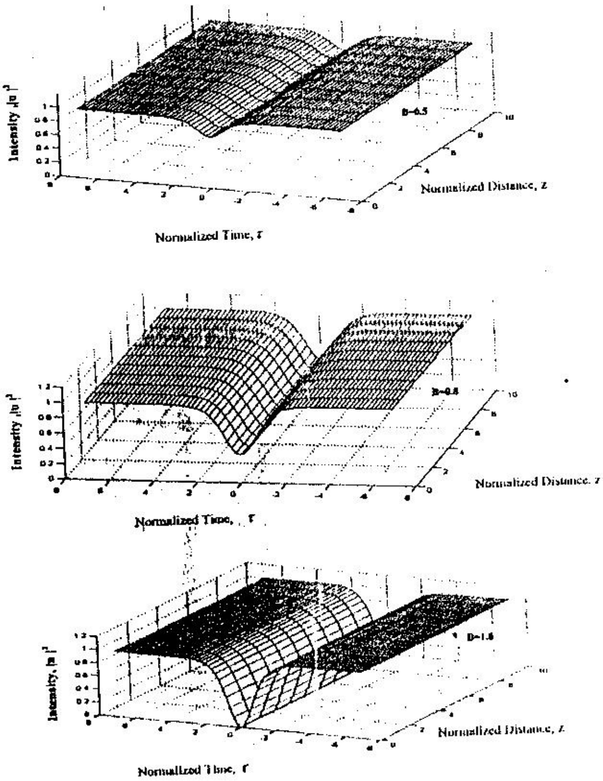


Figure (3): Intensity Profile of black solitons (B=1) and gray solitons(B=0.5,0.8) 15km optical fiber length.

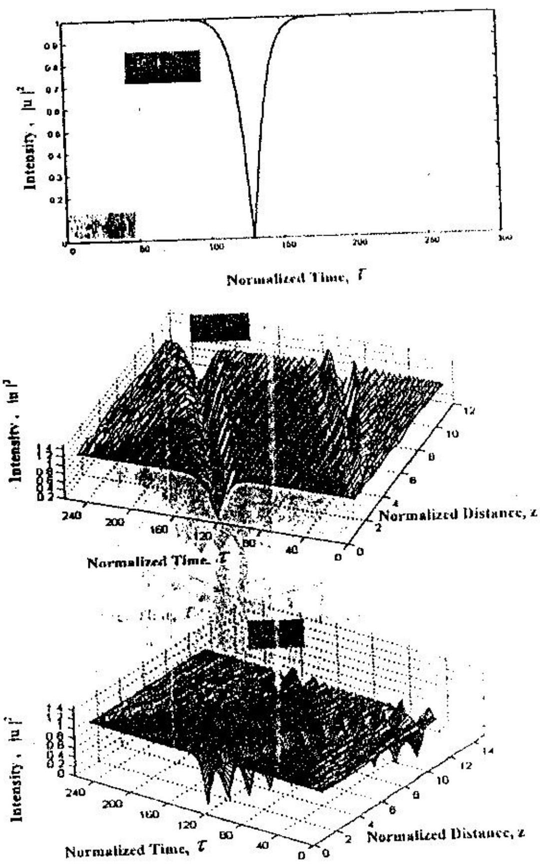
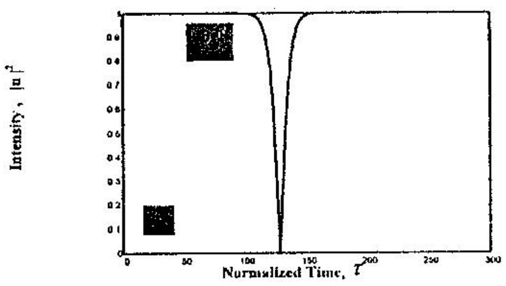


Figure (4): Intensity Profile of gray solitons at (B=0.5,0.8) inside optical fiber at z=0,15km.



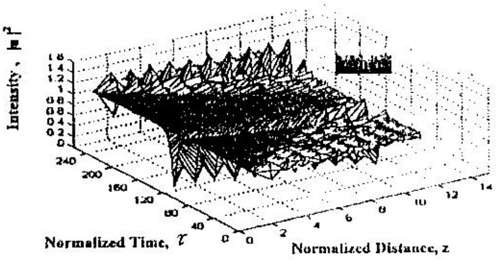


Figure (5): Numerically Intensity Profile of black solitons (B=1) inside optical fiber at z=0,z=15km.

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تأثير عدم أستقرارية التردد على انتشار السوليتونات السوداء والرمادية في الليف البصري

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الخلاصة:

أجريت دراسة خواص السوليتونات السوداء والرمادية الأحادية المرتبة المنتشرة في ليف بصري بتأثير عدم أستقرارية التردد باستخدام إحدى طرق التحليل الرياضية والعددية .أظهرت نتائج الدراسة الرياضية أن تغير طور السوليتونات الرمادية مع الزمن يكون تدريجي وأقل من السوليتونات السوداء التي يتغير طورها بشكل فجائي (π-Φ) أي أن السوليتونات الرمادية والسوداء تعاني من عدم أستقرارية التردد(Frequency Chirp).وتبين أيضا من خلال الدراسة أن شدة نبضة السوليتون الرمادية لاتصل إلى الصفر مقارنة بالسوليتونات السوداء . كذلك تنحرف النبضات بشكل كبير عن محور المسار المصمم كلما قلت قيمة B . أن نتائج تأثير عدم أستقرارية التردد يؤدي إلى أن يقل معدل الإرسال في منظومة الاتصالات البصرية. أما نتائج الدراسة التحليل العددية فأظهرت توافق مع نتائج الدراسة التحليل الرياضية.