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Numerical simulation and comparison for computing dark and bright soliton in the optical fiber

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Abstract: An analytic perturbation solution to the nonlinear Schrodinger equation with loss Gamma for both normal and anomalous dispersion is developed. Clear results are obtained through third order in the perturbation Gamma. The fallout show that the dark pulse spreads with less speed than the bright. Comparisons are made with a zeroth-order perturbation theory and with numerical simulations.

Introduction

Dark solitons denotes to the solutions of Eq.

$$\frac{i\partial U}{\partial \xi} = \mathrm{sgn}(\beta_2)\frac{1}{2}\frac{\partial^2 U}{\partial \tau^2} - N^2 e^{-\alpha z}|U|^2 U$$

with $\mathrm{sgn}\beta_2=1$ and occur in the normal-GVD region of fibers. They were discovered in 1973 and have drawn considerable attention since then [1–11]. The intensity profile connected with such solitons exhibits a dip in a uniform background, hence the name *dark* soliton The NLS equation describing dark solitons is obtained given by

$$\frac{i\partial U}{\partial \xi} = \frac{1}{2}\frac{\partial^2 U}{\partial \tau^2} - |u|^2 u = 0 \tag{1}$$

Similar to the case of bright solitons, the inverse scattering method has been used to find dark-soliton solutions of Eq. (1) by imposing the boundary condition that $|u(\xi,\tau)|$ tends toward a constant nonzero value for large values of $|\tau|$. Dark solitons can also be obtained by assuming a solution of the form $u(\xi,\tau)| = V(\tau)exp[i\phi(\xi,\tau)]$ then solving the normal differential equations satisfied by V and ϕ.

Simulation and Result

The main difference compared with the case of bright solitons[8-11] is that $V(\tau)$ becomes a constant (rather than being zero) as $|\tau|\to\infty$. The general solution can be written as

$$|u(\xi,\tau)| = V(\tau) = \eta\{1 - B^2 \ \mathrm{sech}^2[\eta B(\tau-\tau_s]\}^{1/2} \tag{2}$$

with the phase given by

$$\phi(\xi,\tau) = \frac{1}{2}\eta 2(3\text{-}B2)\xi + \eta\sqrt{1-B^2}\,\tau + \tan^{-1}\left(\frac{B\tan h(\eta\beta\tau)}{\sqrt{1-B^2}}\right) \tag{3}$$

The parameters η and τ_s represent the soliton amplitude and the dip location, respectively. Similar to the bright-soliton case, τ_s can be chosen to be zero without loss of generality. In contrast with the bright-soliton case, the dark soliton has a new factor B. Physically, B governs the deepness of the dip ($B \leq 1$). For $|B|=1$, the intensity at the dip center falls to zero. For additional values of B, the dip does not go to zero. Dark solitons for which $|B|<1$, are called *gray* solitons to stress this feature; the parameter B directs the blackness of such gray solitons. The $|B|=1$, case implies a *black* soliton.For a given value of η, Eq. (2) illustrates a family of dark solitons whose thickness increases inversely with B.

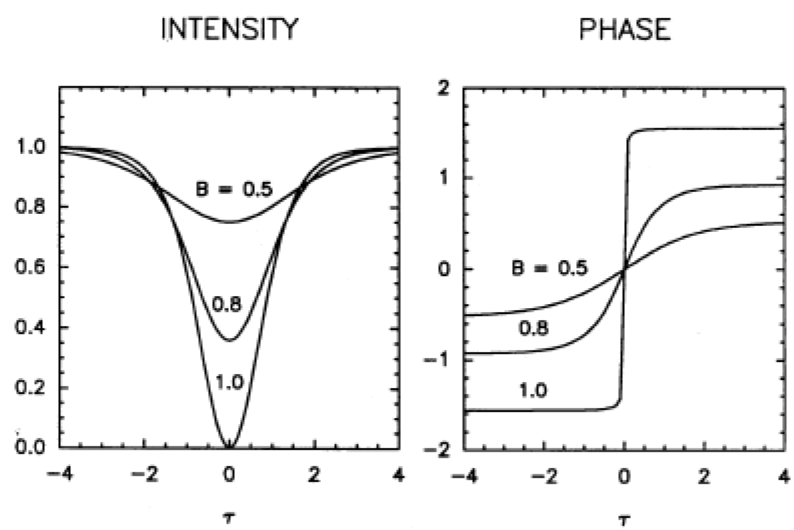

Figure 1 Intensity and phase profiles of dark solitons for several values of the blackness parameter B [12]

Figure 1 shows the intensity and phase profiles of such dark solitons for a number of values of B. while the phase of bright solitons stays constant across the entire pulse, the phase of dark soliton transforms with a total phase shift of $2\sin^{-1}B$, i.e., dark solitons are chirped. For the black soliton ($|B|=1$), due to chirp the phase changes abruptly by π in the center. The phase amendments becomes more gradual and smaller for smaller values of $|B|$. The time-dependent phase or frequency chirp of dark solitons characterize a major difference between bright and dark solitons. One outcome of this difference is that higher-order dark solitons neither form a bound state nor follow a periodic evolution pattern as in the case of bright solitons. Consider a black soliton whose canonical form is obtained from Eq. (2), choosing $\eta = 1$ and $B=1$, and given by

$$u(\xi,\tau) = \tanh(\tau)\exp(i\xi) \quad (4)$$

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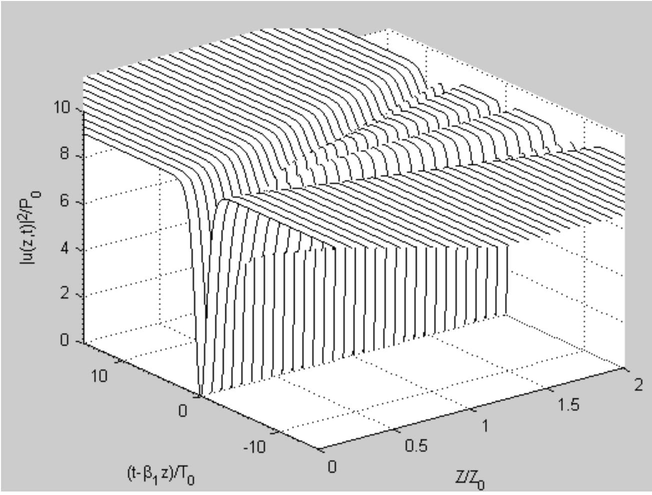

Figure.2 Evolution of a third-order dark soliton showing narrowing of the central dip and creation of two pairs of gray solitons

where the phase jump of π at $\tau = 0$ is included in the amplitude part. Thus, an input pulse with "tanh" amplitude, display an intensity "hole" at the center, would propagate without change in the normal-dispersion region of optical fibers. when the input power exceeds the $N=1$ limit. This can be answered by solving Eq. (1) numerically with an input of the form $u(\xi,\tau) = N tanh(\tau)$

Figure 2 shows the evolution pattern for $N=3$; it should be compared with Figure 3

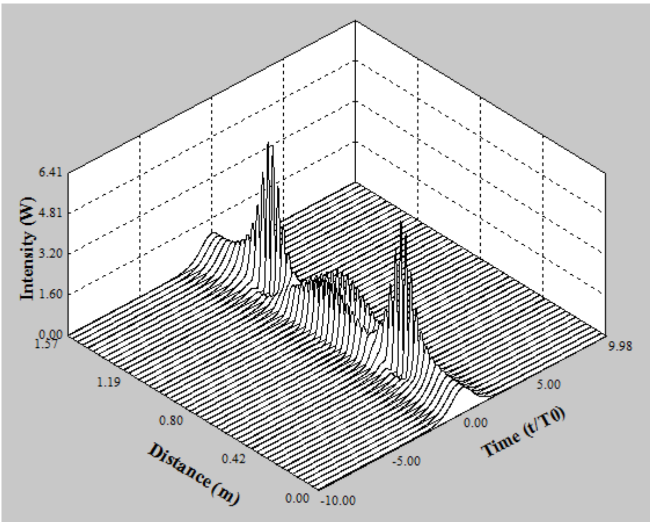

Figure 3 Temporal evolution over one soliton period for the third-order soliton. Note pulse splitting near $z_0=0.5$ and soliton recovery beyond that

where the evolution of a third-order bright soliton is displayed. Two pairs of gray solitons come into view and move away from the central black soliton as the transmission distance increases. At the same time, the width of the black soliton reduces [referene]. This nature can be understood by noting that an input pulse of the form $N\tanh(\tau)$ can form a fundamental black soliton of amplitude $N\tanh(N\tau)$ subject to its width decreases by a factor of N. It discharge part of its energy in the process that comes in the form of gray solitons. These gray solitons move away from the central black soliton since they have different group velocities. The number of pairs of gray solitons is $N=1$, where $N'=N$ for integer values of N or the next integer close to it when N is not an integer. The significant characteristic is that a fundamental dark soliton is always formed for $N>1$.

Conclusion

Dark solitons neither form a bound state nor follow a periodic evolution pattern as in the case of bright solitons. We find that Two pairs of gray solitons come into view and move away from the central black soliton as the transmission distance increases. At the same time, the width of the black soliton reduces while in case of bright soliton it reains its shape after some distance.

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