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Generation of bright-dark soliton trains with a central wide dip in optical fibers

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ABSTRACT

The nonlinear propagation dynamics of the dark soliton pulse with hyperbolic tangent profile in the anomalous dispersion regime of an optical fiber is investigated numerically. The corresponding temporal evolutions are provided for different integral or non-integral soliton order and loss perturbations. The results show that, irrespective of the integral or non-integral soliton order, with increase of distance, the width of the dark soliton broadens and more and more bright and dark pulses appear symmetrically on the two sides of the central black soliton. Correspondingly, bright-dark soliton trains with a central wide black soliton can gradually form. The higher the soliton order, the more the bright-dark pulses at the same distance. With increase of distance, the peak values of the bright pulses exhibit oscillation behavior. The loss perturbation only influences the evolutions slightly, which means that the generated soliton trains can resist loss perturbations to some extent. Moreover, this work provides us an alternative approach to generate bright-dark soliton trains by using the dark soliton pulse propagating in the anomalous dispersion regime of the passive optical fiber besides directly using the fiber laser.

1. Introduction

Up to now, people have already found more and more singular optical solitons such as dissipative solitons [1,2], rogue wave solitons [3], chaotic solitons [4], the wave-breaking-free pulses [5], soliton bound states with multiple poles [6], anomalous vortex beams [7], breathers and localized solitons on constant backgrounds [8], conventional solitons in fiber laser [9], and etc. However, it is well known that the fiber optical solitons typically include the hyperbolic-secant typed bright solitons and hyperbolic-tangent typed dark ones. The former has been applied in optical soliton communication systems. While the latter is of special and continuing interests because it is numerically proved to be more robust in adapting to various perturbations such as fiber loss, amplifiers caused time jitters, and intrapulse Raman scattering and can be potentially applied in future optical communication system [10,11]. Many previous reports have investigated the nonlinear propagation properties of input pulses which deviate from the bright solitons in terms of their initial soliton orders (may manifesting as the initial pulse widths or peak powers) [12,13], initial shapes [13,14], initial phases [15–23]. For the case of the initial soliton order deviation, previous reports revealed that the pulse may adjust itself and evolve asymptotically into a standard soliton [12]. The pulse has to experience very long asymptotic evolution distance before the final soliton formation. However, the initial

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soliton order must be larger than 0.5 in order to form solitons eventually. For the case of the initial shape deviation, taking the Gaussian and super-Gaussian optical pulses for example, our recent work indicated that, both their pulse shapes and spectra exhibit interesting damped oscillation behavior with decreasing oscillation amplitude for very long distance [14], which is quite similar to the long-distance asymptotic evolution behavior just mentioned above. While the initial phase deviation means initial frequency chirp or initial phase modulation imposed on the input hyperbolic-secant pulse. Extensive studies discovered that the initial linear frequency chirp or the initial second-order phase modulation is not only detrimental to the soliton formation but also causes energy loss due to the dispersion wave shedding away from the main pulse [16–23]. Accordingly, in practice, the initial phase modulation is generally thought to be minimized as much as possible. However, it should be noted that, not all of the initial phase modulation is detrimental to the shape preserving propagation or breather evolution and causes energy loss. For example, our recent study indicated interestingly that the initial first-order phase modulation or initial constant frequency chirp can make the soliton pulse shift towards the pulse leading or trailing edges along a straight line with the pulse shape profile and its breather evolution behavior unchanged [15]. As for the hyperbolic-tangent typed dark soliton, the fundamental soliton can always form even for the case of the non-integral soltion order provided the soliton order is larger than one [10].

On the other hand, it is familiar to us that, the bright and dark soliton respectively exist in the anomalous and normal dispersion regime of the optical fiber. When the bright soliton propagates in the normal dispersion regime, it will experience optical wave breaking [24,25]. Naturally, one may ask one interesting question—how about the evolution dynamics of the hyperbolic-tangent typed dark soliton propagating in the anomalous dispersion regime of the optical fiber? And whether it can still evolve into corresponding central black soliton surrounded by gray soliton pairs or collapses and turns into other new types of pulse profiles remains unknown. To make these things clear, we numerically study the nonlinear evolutions of the hyperbolic-tangent dark soliton pulses in the anomalous dispersion regime of the single-mode optical fiber in detail.

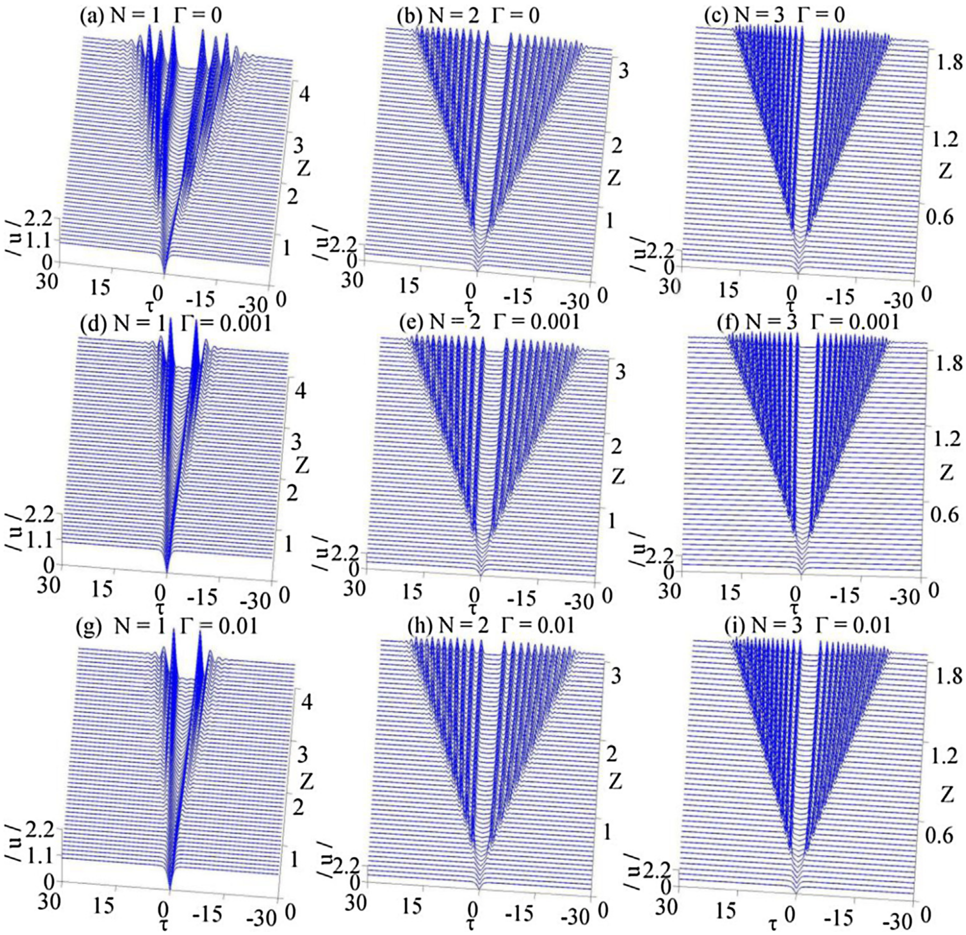

Fig. 1. Three dimensional temporal shape evolutions of the hyperbolic-tangent pulses for different N and Γ.