NUMERICAL STUDY OF THE PROPAGATION OF TWO CHIRPED VECTOR SOLITONS IN BIREFRINGENT OPTICAL FIBERS WITH VARIABLE COEFFICIENTS

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RÉSUMÉ: In this work, we study numerically the propagation of two chirped optical vector solitons in birefringent optical fibers with variable coefficients using the compact split step Padé scheme (CSSPS). In the case of one managed chirped vector soliton, a negative chirp makes the vector soliton broadening, while; a positive chirp leads to a vector soliton compression. The effect of the chirp on the vector soliton temporal width of an amplification system ($\sigma > 0$) is greater than that in a loss system ($\sigma < 0$). The evolution of two managed chirped vector solitons is submitted not only to the effect of the chirp, but also to the interaction between the adjacent vector solitons. In all the cases, the energy of each managed chirped vector soliton is conserved.

MOTS-CLÉS: vector solitons, chirped solitons, birefringent optical fibers, compact split step Padé scheme, coupled higher-order nonlinear Schrodinger equations with variable coefficients, temporal waveform.

1. Introduction

It is known that the fundamental optical soliton propagates undistorted in the anomalous dispersion region of fibers due to the exact balance between the nonlinear (self phase modulation SPM) and dispersive (group velocity dispersion GVD) effects [1,2,3]. The balance between group-velocity dispersion and nonlinear self phase modulation can be described by the nonlinear Schrödinger NLS equation [1,2,3].

Due to the birefringence in optical fibers, the fundamental mode of a single-mode fiber splits into two orthogonal polarization modes. The two orthogonal polarization modes can be coupled together through the Kerr effect. The propagation of solitons in birefringent optical fibers can be modeled by a system of coupled nonlinear Schrödinger (CNLS) equations [1,2,4,6,8] which has been the subject of huge of theoretical and experimental investigations during recent years. A solution to the CNLS equations has been found to be the 'Vector Soliton' [1,2,4,6,8] which have a lot of nonlinear dynamics because of their multicomponent structure [4], and their potential applications in fiber-optic-based communication systems [9].

Usually, the propagation of managed vector solitons in birefringent optical fibers is governed by the coupled NLS equations [1,2,4,6,8] with variable coefficients. In general, the coupled NLS equations [1,2,4,6,8] with variable coefficients are not integrable except in some particular cases. As a result, to study the propagation of managed vector solitons, we need to use numerical methods. In this paper, we use the compact split step Padé scheme (CSSPS) [5] which is more efficient, more rapid and well adapted for higher order time derivatives such as third order dispersion or Kerr dispersion.

2. Equations model

The coupled nonlinear Schrödinger (CNLS) equations [8] with variable coefficients, describing the propagation of managed optical vector solitons in birefringent optical fibers, can be written under the following vectorial form:

$$\frac{\partial}{\partial Z}\begin{pmatrix} u \\ v \end{pmatrix} + \delta \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \frac{\partial}{\partial T}\begin{pmatrix} u \\ v \end{pmatrix} - \left(\frac{i}{2} D(Z) \frac{\partial^2}{\partial T^2} + \Gamma(Z) \right) \begin{pmatrix} u \\ v \end{pmatrix} \\ = iR(Z) \begin{pmatrix} |u|^2 + \quad |v|^2 & 0 \\ 0 & |u|^2 + |v|^2 \end{pmatrix} \tag{1}$$

Where *u(Z,T)* and *v(Z,T)* are the slowly varying amplitudes, *Z* and *T* are normalized distance and time, the functions *Γ(Z)*, *D(Z)*, and *R(Z)* are respectively, the linear and nonlinear gain (or loss), the group velocity dispersion (GVD), and the self-phase modulation (SPM). *δ* is the difference of the group velocities for the two polarization components and *β* is the cross-phase modulation (XPM) coefficient (For linearly birefringent fibers, *β=2/3*).
The parameters *D(Z)*, *R(Z)*, and *Γ(Z)* are given by the following expressions[7]:

- the varying GVD parameter

$$D(Z) = exp(\pm Z) R(Z) / D_0 \tag{2}$$

- the nonlinear parameter

$$R(Z) = R_0 + R_1 \, sin(gZ) \tag{3}$$

- and the gain or loss distributed parameter

$$\Gamma(Z) = \pm\!/_2 \tag{4}$$

Where D_0 is the parameter related to the initial peak power, *σ* is the parameter described gain or loss, and R_0, R_1, *g* are the parameters described Kerr nonlinearity. For our study, we take the parameters $D_0=1$, $R_0=0$, $R_1=1$ and $g=1$ [7].

3. Numerical model

In order to do our numerical simulations, we choose the following initial conditions with linear chirp:

$$u(0,T) = cos\alpha \; exp\left(-\frac{iCT^2}{2} \right) / cosh(T) \tag{5}$$

$$v(0,T) = sin\alpha \; exp\left(-\frac{iCT^2}{2} \right) / cosh(T) \tag{6}$$

Where *C* is the linear chirp parameter and the angle *α* determines the relative strengths of the partial pulses in each of the two polarizations. It represents the angle of the polarization of the soliton with respect to the polarization axis of the fiber.

4. Numerical results and discussions

Now, we are going to examine the evolution of the managed optical vector soliton under the effect of the chirp *C* when $\alpha=45^0$ (the two polarization components have same strength) in the following two cases.

4. 1. First case: Evolution of one chirped managed optical vector soliton

Starting with the simple case, we will examine the evolution of one managed vector soliton under the effect of the chirp in the case where the two polarization components have the same strength. From the following figures, we can see that the temporal width (*FWHM*) of the two components of an unchirped vector soliton performs a slight oscillation with the increase of propagation distance (Figure 1). A negative chirp makes the soliton broadening (figure 2), while; a positive chirp leads to a soliton compression (Figure 3).

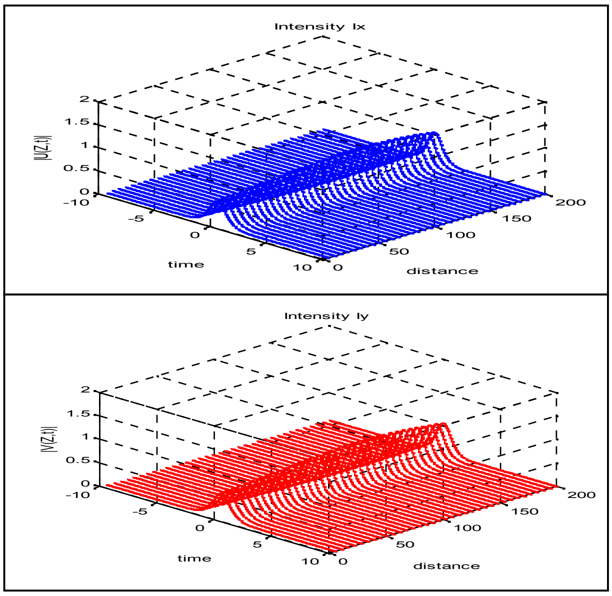

Figure 1 : Evolution of the two components of unchirped vector soliton in birefringent optical fiber with the parameters α=45^0, C=0, and σ=0.025

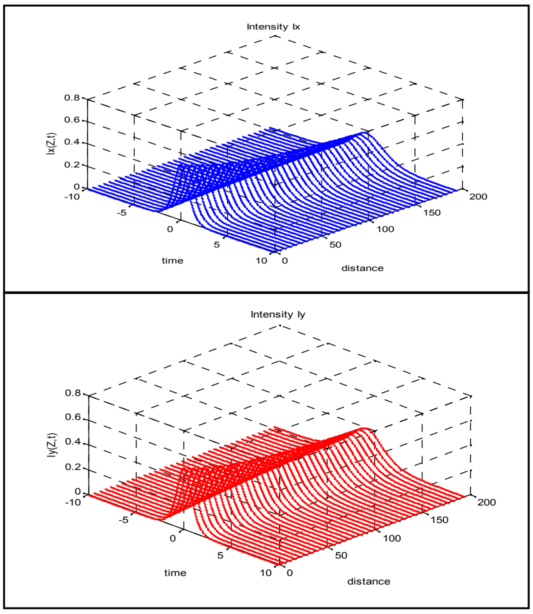

Figure 2 : Evolution of the two components of chirped vector soliton in birefringent optical fiber with the parameters α=45^0, C=-0.2, and σ=0.025

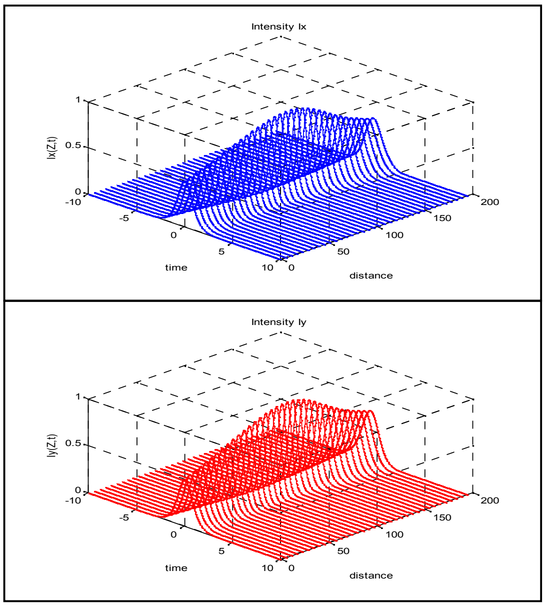

Figure 3 : Evolution of the two components of chirped vector soliton in birefringent optical fiber with the parameters α=45^0, C=0.1, and σ=0.05

4. 2. Second case: Evolution of two chirped managed optical vector soliton

In this case, the evolution of two chirped managed optical vector solitons is submitted not only to the effect of the chirp, but also to the interaction between the adjacent vector solitons. As for the vector soliton width *W*, the space between two vector solitons *d*, and the chirp *C*, the results are shown in the figures bellow.

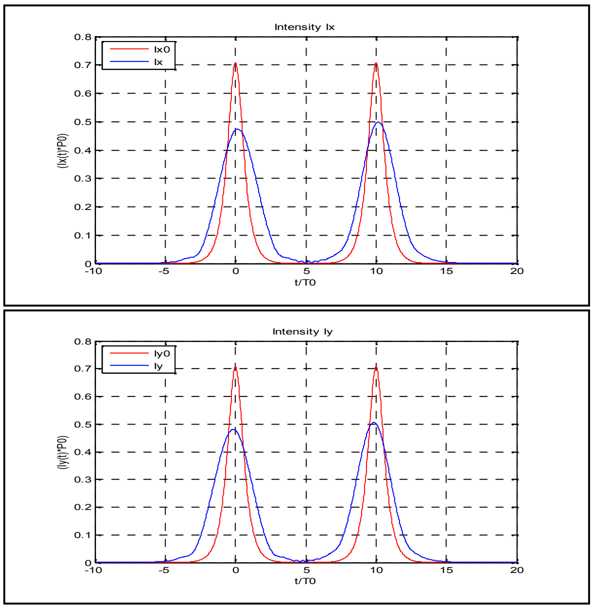

Figure 4 : Evolution of the two components of two chirped vector solitons in birefringent optical fiber with the parameters α=45^0, C=0.2, σ=0.05, W=0.5 and d=10

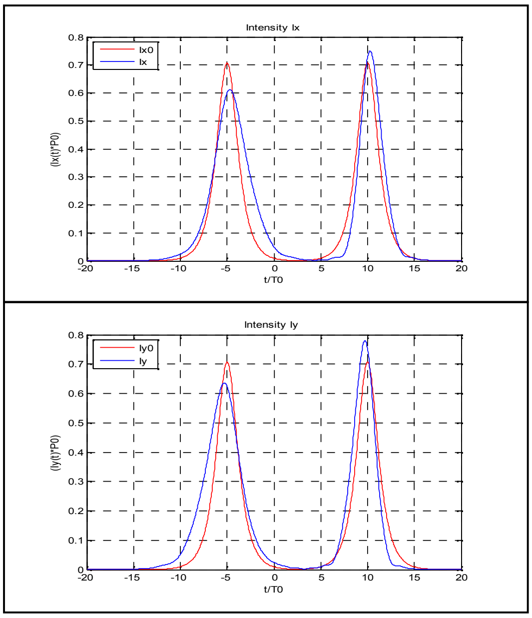

Figure 5 : Evolution of the two components of two chirped vector solitons in birefringent optical fiber with the parameters α=45^0, C=0.2, σ=0.05, W=1 and d=15

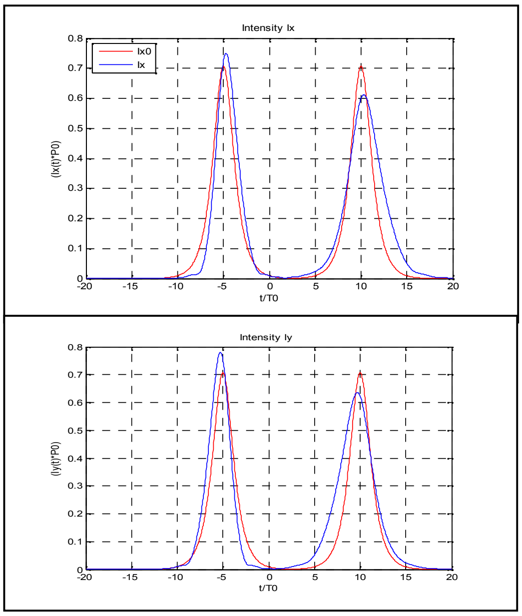

Figure 6 : Evolution of the two components of two chirped vector solitons in birefringent optical fiber with the parameters α=45^0, C=-0.2, σ=0.05, W=1 and d=15

From figure 4, we note a decrease of the amplitude and an increase of the width of the two components of two chirped vector solitons. If we increase the distance between the two vector solitons with a positive chirp, we note in figure 5 a decrease of the amplitude with an increase of the width of the first vector soliton, while the inverse happens for the second one. In figure 6, a negative chirp makes an increase of the amplitude with a decrease of the width of the first vector soliton, while the inverse happens for the second one. In all this cases the energy of each soliton is conserved.

5. Conclusion

The propagation characteristics of two chirped managed optical vector solitons in birefringent optical fibers is studied numerically in this work. The propagation of vector solitons has a rich nonlinear dynamics. A negative chirp makes chirped managed optical vector soliton broadening, while; a positive chirp leads to a chirped managed vector soliton compression. The evolution of two of managed vector solitons is submitted not only to the effect of the chirp, but also to the interaction between the adjacent optical vector solitons.

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