Nonlinear compression of solitary waves in asymmetric twin-core fibers

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We demonstrate a different pulse compression technique based on exact solutions to the nonlinear Schrödinger-type equation interacting with a source, variable dispersion, variable Kerr nonlinearity, and variable gain or loss. We show that this model is appropriate for the pulse propagation in asymmetric twin-core fibers. The chirped pulses are compressed due to the nonlinearity as well as dispersion management as also due to the space dependence of the gain coefficient. We also obtain singular solitary wave solutions, pertaining to extreme increase of the amplitude due to self-focusing.

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In recent years, the study of nonlinear fiber optics has attracted much attention and has played an important role toward the development of several technologies [1]. Among them, the development of optical solitons is considered to be one of the ten hottest technologies of the 21st century [2]. In the case of exact soliton pulse propagation, the pulse evolution is governed by nonlinear Schrödinger equation (NLSE). In realistic systems this equation is suitably modified to take into account loss or gain or other medium effects. In recent times, much effort has been devoted to optical pulse compression techniques because of their practical utility. Most of these techniques rely on chirping obtained either by self-phase modulation in the normal dispersion regime or by combining phase modulation with amplification [3,4]. Soliton effects can also be utilized for compression where the problem of residual pedestals can be reduced through appropriate control of intensity, which affects the nonlinearity. However, this procedure has the drawback of waste of energy [5]. Adiabatic soliton compression, through the decrease of dispersion along the length of the fiber, provides a better pulse quality [6], albeit in a less rapid manner. Interested readers are referred to Johnson et al. [7] and Fisher et al. [8] for more information about pulse compressors. Exact solutions have played crucial roles in demonstrating the above pulse compression techniques. The fact that NLSE or modifications of the same is known to possess soliton solutions has come in handy in studying the mechanism of pulse compression in the above models. All the aforementioned methods for pulse compression are restricted to pulse propagation through single core fibers. Although it is easier to fabricate twin-core fibers with some built-in asymmetry, the nonlinear pulse propagation in these types of couplers has not received much attention in the literature. The existence of the solitary wave solutions in twin-core fibers (TCFs) has been reported in Refs. [9,10]. Soliton solutions, when the nonlinearity for one component can be neglected, has been studied perturbatively [11]. In this context, the relevant equation is NLSE driven by a source, originating from the coupling term. Soliton bound states in the TCFs have also been reported [12].

In this paper we delineate the nonlinear pulse compression based on exact solitary wave solutions of NLSE interacting with a source, that is appropriate for the pulse propagation in asymmetric TCF. Apart from using the exact solutions of NLSE with a source, recently obtained by two of the present authors [13], we take recourse to the recent work of Kruglov et al. [14] in the context of NLSE with variable dispersion, variable Kerr nonlinearity, and variable gain or loss.

We first outline below the origin of NLSE with a source, for pulse propagation through asymmetric TCF, with dissipation [11]. The equations for the envelopes of the pulses that propagate through the TCF are

\[ i\partial_t \psi_1 + \partial_z \psi_1 + 2|\psi_1|^2 \psi_1 + ig \psi_1 + \Gamma \alpha_{12} \psi_2 \times \exp[-i(\delta - \omega \tau)] = 0, \]

\[ i(\partial_t \psi_2 - \beta_1 \partial_z \psi_2) + \beta_2 \partial_z \psi_2 + 2|\psi_2|^2 \psi_2 + \frac{\alpha_{21}}{\Gamma} \psi_1 \exp[i(\delta - \omega \tau)] = 0. \]

Here \( \psi_1 \) and \( \psi_2 \) are the field envelopes. The coordinates \( z \) and \( \tau \) in Eqs. (1) and (2) are written in appropriate units [15]. In writing Eqs. (1) and (2), we have considered constancy of the distributed coefficients. In any real soliton transmission system there exists dissipation due to fiber losses. This has been incorporated in Eq. (1), by adding an \( ig \psi_1 \) term. As the second core is a passive one, it is not essential to consider the losses. Since the fibers are not identical, the coupling is not symmetric, i.e., \( \alpha_{12} \neq \alpha_{21} \). \( \Gamma = \gamma_1 / \gamma_2 \) is the ratio of the nonlinearity strengths in the two fibers, where [16,17]

\[ \gamma = \frac{n_2 v_0}{c A_1^{\text{eff}}}. \]

\( A_1^{\text{eff}} \) is the effective core area, \( n_2 \) is the Kerr coefficient, \( c \) is the speed of light, and \( v_0 \) is the carrier frequency in each fiber. Under the assumption that the interaction term in Eq. (1) is much larger than the interaction term in Eq. (2), the last term in Eq. (2) can be dropped. This implies that Eq. (2) is decoupled from Eq. (1); \( \psi_2 \) only enters as a driving term in Eq. (1), while there is no back action. We further assume that