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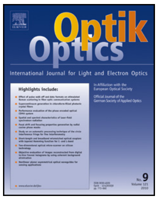

Long-term nonlinear propagation and damped oscillation behaviors of Gaussian and super-Gaussian pulses in optical fibers

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The long-term nonlinear propagation of Gaussian and super-Gaussian optical pulses in the anomalous dispersion regions of optical fibers are investigated numerically in terms of the pulse shapes and spectra evolution. The results show that, both the pulse shapes and spectra exhibit interesting damped oscillation behavior with decreasing oscillation amplitude for very long distance. In particular, the spectra profiles exhibit interesting arrow shaped evolution. Variations of the pulse widths, maximal normalized amplitudes, and maximal spectral amplitudes with the propagation distance, are also presented. We find that, for the higher-order super-Gaussian pulses, their pulse widths and maximal normalized amplitudes have larger values of oscillation periods and initial oscillation amplitudes. However, the higher-order super-Gaussian pulses have larger values of average pulse widths but smaller values of average maximal normalized amplitudes. In frequency domain, the higher-order super-Gaussian pulses have larger values of average maximal spectral amplitudes.

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1. Introductions

It has been demonstrated that in the anomalous dispersion and positive Kerr nonlinearity regimes, optical fibers can support hyperbolic-secant shaped fundamental and higher-order bright optical solitons. The former is of special significance for the reason that it can all along maintain its pulse width as well as shape and spectral profiles during propagation. Accordingly, it founds important applications in soliton optical communication systems. While the latter exhibits interesting breather behavior with its width as well as shape and spectral profiles varying and recovering periodically. Practically, however, a natural question is, as Agrawal [1] asked, what happens if the initial input pulse does not correspond to an optical soliton. Typically, for example, the actual input pulse may not be exactly matched to an optical soliton in terms of its shape, pulse width, initial phase, or peak power. Such questions involve mathematically the initial value problems of nonlinear Schrödinger equation and physically the soliton stability or soliton perturbation.

Previous report has revealed analytically, experimentally, and numerically that [1–3], when the soliton order number (which is closely related to the pulse width and the peak power) of the input pulse is not an integer which is required by an soliton, the pulse will adjust itself and evolve asymptotically into a standard soliton. During this evolution process, the pulse will disperse away parts of the pulse energy which is referred to as the continuum radiation or the dispersive wave. The interference between the dispersive wave and the asymptotic soliton will cause spectral oscillations or spectral modulations

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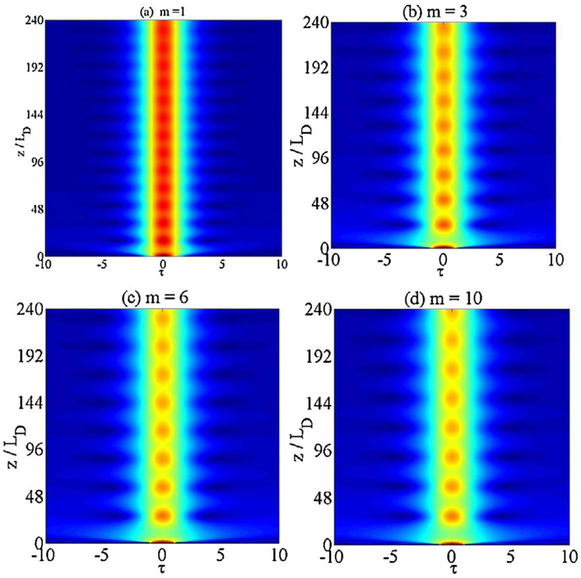

Fig. 1. The contour maps of shape evolutions of Gaussian and super-Gaussian pulses for different parameters *m*.

[3]. The pulse will experience long-time asymptotic evolution before the final soliton formation. Of course, the initial soliton order must be larger than 0.5, otherwise, no soliton can be formed eventually. In addition, the effect of the initial frequency chirp or the initial phase modulation on the soliton formation has also been investigated extensively [4–11]. However, to our best knowledge, when the pulses are of the Gaussian or super-Gaussian shapes, previous reports have studied the optical wave breaking in the normal dispersion regime [12,13]. While in the anomalous dispersion regime, previous study mostly limited to the cased of the short distance numerical evolution and coarse qualitative description [1]. All in all, the long-term nonlinear propagation and detailed evolution properties of these pulses still remain incomplete. Thus, the purpose of this work is to numerically study the long-term nonlinear propagation properties of the initial Gaussian or super Gaussian optical pulses with different degrees of edge sharpness in the single-mode optical fiber in detail.

2. Calculations and discussions

The familiar standard nonlinear propagation equation in the anomalous dispersion regime is of the following form [1]

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

where U, τ, $\xi = z/L_D$, and $N = \sqrt{\gamma P_0 T_0^2/|\beta_2|}$ are respectively normalized envelope of the optical field, normalized time, normalized propagation distance, and soliton order number. And β_2, γ, P_0, T_0, z, and L_D, are the second-order group velocity dispersion (GVD) coefficient, cubic nonlinear coefficient, incident optical power, pulse width, propagating distance, and the dispersion length, respectively.

We assume that the initial optical pulse is of the following super-Gaussian form

$$U(0,\tau) = \exp\left(-\tau^{2m}/2\right) \tag{2}$$

where m is the order number which reflects the degree of edge sharpness. When $m = 1$, Eq. (2) corresponds to the Gaussian pulse. According to Eqs. (1) and (2), we can numerically calculate the nonlinear evolution of the Gaussian or super-Gaussian pulse by utilizing the split-step Fourier method. During calculation, we set the common parameter $N = 1$.

Fig. 1 shows the contour maps of shape evolutions of Gaussian and super-Gaussian pulses for different parameters m. Clearly, the pulse amplitudes and widths exhibit interesting oscillation behavior for very long normalized propagation. But the oscillation amplitudes and periods are different depending on different values of parameter m. One can see this characteristic more clearly from Fig. 2 where the variations of maximal normalized amplitudes and pulse widths with propagation distance for different parameters m are shown. Their damped oscillation characteristics are very obvious. But their decay rates will reduce as increase of the propagation distance, which means that the distances required to evolve to soliton pulses cannot be short but extremely long instead. Moreover, for higher-order super-Gaussian pulses, their pulse widths and maximal normalized amplitudes have larger values of oscillation periods and initial oscillation amplitudes. However, higher-order super-Gaussian pulses have larger values of average pulse widths but smaller values of average maximal normalized amplitudes.

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