

Simulations of a pulse compression in planar waveguide

M. PIETRZYK

Institute of Fundamental Technological Research, Polish Academy of Sciences, ul. Świętokrzyska 21, 00-049 Warszawa, Poland.

A numerical study of the properties of Gaussian chirped pulses propagating in planar waveguide under the combined effect of positive Kerr-type nonlinearity, diffraction and anomalous or normal dispersion, is presented. It is demonstrated how the relative strength of dispersion and diffraction, the strength of nonlinearity and the initial spatial and temporal pulse chirps affect the maximal compression factor. We first estimate the values of the relative strength of dispersion and diffraction and the strength of nonlinearity for which the pulse collapse can occur using the method of moments. More precise conditions are obtained by means of the numerical simulations based on the (2+1)-dimensional Nonlinear Schrödinger Equation.

The propagation of a light pulse in planar waveguides with positive, instantaneous Kerr-type nonlinearity can be described by the (2+1)-dimensional NLS equation

$$i \frac{\partial}{\partial \zeta} U - \frac{1}{2} \sigma \frac{\partial^2}{\partial r^2} U + \frac{1}{2} \frac{\partial^2}{\partial \xi^2} U + N^2 |U|^2 U = 0 \quad (1)$$

where $\sigma > 0$ corresponds to the normal dispersion and $\sigma < 0$ corresponds to the anomalous dispersion.

As the initial condition we take the Gaussian chirped pulse given by

$$U(\xi, \tau, \zeta = 0) = e^{-\xi^2(1+iC_\xi)/2} e^{-\tau^2(1+iC_\tau)/2} \quad (2)$$

where C_ξ (C_τ) is the spatial (temporal) pulse chirp (the focusing spatial chirp $C_\xi < 0$ and the focusing temporal chirp corresponds to $\text{sgn}(-\sigma C_\tau) < 0$).

It is known that some solutions of the two- or three-dimensional NSE can develop into a singularity of the electric field when the initial pulse power exceeds a certain critical value [1]. This phenomenon, known as pulse collapse, can occur simultaneously in space and time for a pulse propagating in planar waveguides with the anomalous group velocity dispersion (GVD) [1], [2]. Our task is to determine the values of the parameters σ and N^2 for which the pulse collapse can occur. For this purpose the so-called method of moments [3] could be used. However, it gives only an estimation of the sufficient conditions of the pulse collapse, whereas the latter can occur, in fact, at earlier times or at the shorter propagation distance [4], [5]. More precise conditions can be obtained by means of the numerical simulations.

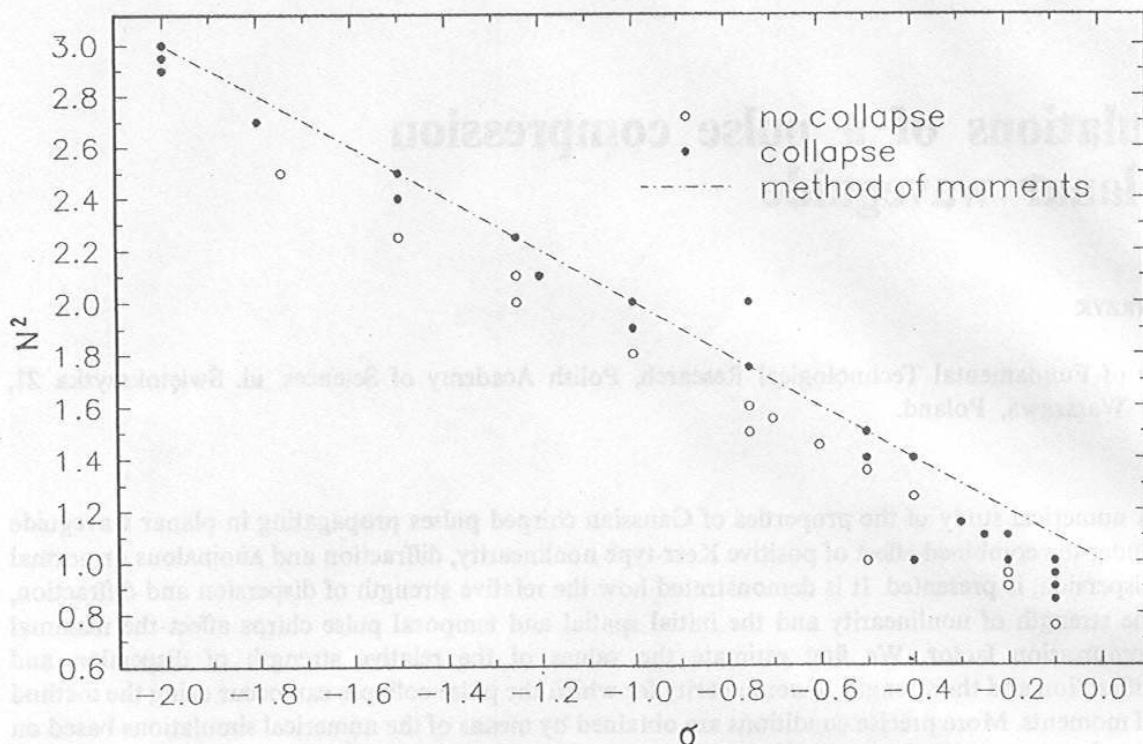


Fig. 1. Comparison of the sufficient conditions for pulse collapse predicted by the method of moments (straight line) and numerical calculations (filled circle points denote pulse collapse and empty circle points indicate no collapse)

The pulse collapse conditions obtained by means of the method of moments in the particular case of flat phase front, $C_\xi = C_\tau = 0$, for the Gaussian input pulse given by Eq. (2), are plotted in Fig. 1 by the straight line $N^2 = 1 - \sigma$, where $\sigma < 0$. Above results are compared with those obtained by numerical simulations by means of Split Step Spectral Methods. The boundary line between two kinds of points corresponding to the cases when, respectively, the pulse collapse occurs or does not occur is parallel to the straight line predicted by the method of moments. However, it lies below the latter for about 10%, except the small values of σ : ($\sigma > -0.2$).

A simultaneous space-time collapse, which can occur in planar waveguides under the combined effect of positive nonlinearity, diffraction and anomalous dispersion may be useful for pulse compression [6]. On the other side, the interplay of normal dispersion and positive nonlinearity in planar waveguide causes quite different behaviour of the pulse. It slows the self-focusing and causes splitting of the pulse [7], [8], however, spatial-temporal coupling can lead to a pulse compression [9], [10].

It is demonstrated by means of numerical calculations [11] that in the regime of both anomalous and normal dispersion the increase of the nonlinearity and the decrease of the dispersion $|\sigma|$ cause the increase of the maximal compression factor

$c_{\max} = \frac{\tau_0}{w_{\tau \min}(\zeta_m)}$. In Figure 2, the results of numerical simulations of the influence of the initial spatial, $C_\xi = C$, and two cases of temporal $C_\tau = S \cdot C$, $S = \pm 1$, chirps on

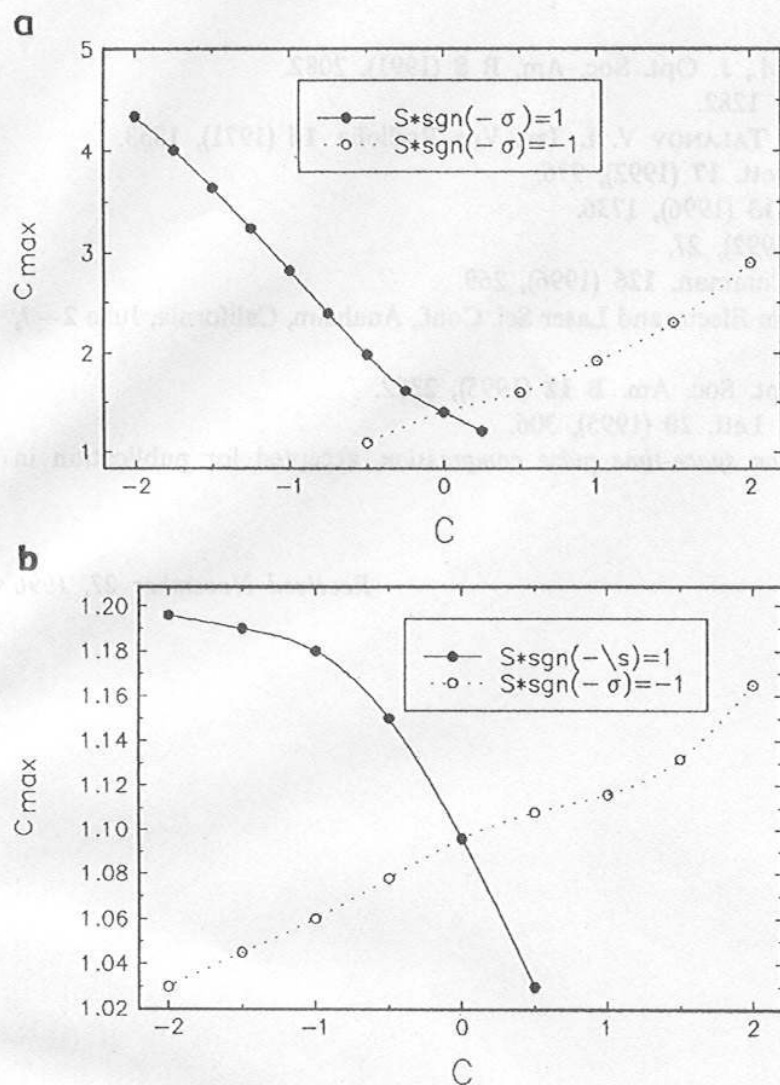


Fig. 2. Maximal compression factor, for two cases of an anomalous (a) and normal dispersion regime (b) as a function of the initial spatial, $C_x = C$, and temporal, $C_t = SC$, $S = \pm 1$, pulse chirps. For a — $\sigma = -0.5$, $N^2 = 1.0$, and for b — $\sigma = 0.1$, $N^2 = 2.0$

maximal compression factor are presented. In the case of both anomalous and normal GVD the increase of the focusing temporal and spatial chirps of the initial pulse (i.e., if $C < 0$ and $-\text{sgn}(\sigma)S = 1$) lead to the increase of the maximal compression factor. However, in the case of the anomalous GVD maximal compression factor grows with chirp fast. Namely, the $c_{\max}$ for a chirped initial pulse with $C = -2$ is three times larger than that for an initial pulse with flat phase front ($C = 0$), see Fig. 2a. On the contrary, for the normal GVD the increase of the $c_{\max}$ is rather slow, and a saturation of the maximal compression factor occurs for the initial chirps below -2 (see Fig. 2b).

Moreover, the increase of the focusing temporal chirp in the case of the defocusing spatial chirp leads to the increase of $c_{\max}$ whereas the defocusing temporal chirp always leads to the decrease of $c_{\max}$ even in the case of the focusing spatial chirp. It may be concluded, therefore, that the temporal chirp has larger effect on the maximal pulse compression factor than the spatial chirp.

References

- [1] DESAIX M., ANDERSON D., LISAK M., J. Opt. Soc. Am. B 8 (1991), 2082.
- [2] SILBERGER Y., Opt. Lett. 15 (1990), 1282.
- [3] VLASOV S. N., PETRISHCHEV V. A., TALANOV V. I., Izv. Vuz Radiofiz. 14 (1971), 1353.
- [4] MANASSAH J. T., GROSS B., Opt. Lett. 17 (1992), 976.
- [5] NASALSKI W., J. Opt. Soc. Am. B 13 (1996), 1736.
- [6] TURISYN S. K., Phys. Rev. A 47 (1992), 27.
- [7] GROSS B., MANASSAH J. T., Opt. Commun. 126 (1996), 269.
- [8] BURAK D., BINDER R., Proc. Quantum Electr. and Laser Sci. Conf., Anaheim, California, June 2–7, 1996, QPD12–1.
- [9] RYAN A. T., AGRAWAL G. P., J. Opt. Soc. Am. B 12 (1995), 2382.
- [10] RYAN A. T., AGRAWAL G. P., Opt. Lett. 20 (1995), 306.
- [11] PIETRZYK M. E., *Numerical study on space-time pulse compression*, accepted for publication in Optical & Quantum Electron.

Received November 27, 1996