Paper

Ultra-short optical pulses having initial chirp

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Abstract — Arbitrary shape optical pulses in nonlinear guides are discussed. The Nonlinear Schrödinger Equation for complex initial conditions is solved numerically using Split-Step Fourier Method and some selected results for solitons are presented. The computations confirm physical expectations of an influence of the chirp magnitude on pulse propagation in nonlinear guide.

Keywords — solitons, optical fibers.

Introduction

Propagation of ultra-short optical pulses in lossless guides is analysed using Nonlinear Schrödinger Equation (NLSE)

$$j\frac{\partial A}{\partial z} - \frac{1}{2}\beta_2\frac{\partial^2 A}{\partial T^2} + \gamma|A|^2 A = 0, \tag{1}$$

where A represents the envelope function, γ – nonlinearity, β_2 – dispersion of the fiber, z and T are, respectively, the spatial and time co-ordinates [1].

This equation is valid when duration of the pulse is greater than 100 fs and it can be solved analytically using the Inverse Scattering Method [2], if the input pulse is of hyperbolic secant shape. Otherwise, numerical methods should be used.

Then, fundamental solution is a secant hyperbolic function, what means that the pulse does not change its shape during propagation. So, it is stable, called soliton.

The soliton occurs due to mutual compensation of the dispersion and the nonlinearity of the fiber. So, if any initial chirp exists, the compensation is not full and the pulse is distorted.

The chirp phenomenon can be taken into consideration in the NLSE assuming complex initial condition of the form

$$u(0,\tau) = N\sec h(\tau)\exp\left\{\frac{-jC\tau^2}{2}\right\}, \tag{2}$$

where C represents the magnitude of the chirp.

To include Eq. (2) in NLSE one of numerical methods must be applied: Split-Step Fourier Method (SSFM) or Beam Propagation Method (BPM).

Method description

Split-Step Fourier Method has physical grounds. The idea is based on separate consideration of consequences of nonlinearity and dispersion on the pulse propagation in a short segment of the guide.

It can be represented schematically when Eq. (1) is expressed in the operator form [3–5]

$$\frac{\partial A}{\partial z} = (D+N)A. \tag{3}$$

Here D and N is the dispersion and nonlinearity operator, respectively.

After some calculations, the optical field can be expressed as follows

$$A(z+h,T) = \exp(hD)\exp(hN)A(z,T), \tag{4}$$

where h denotes the length of the step.

Results

Making use of the formulas above, computations were carried out for soliton of the first order when $\beta_2 = -1.6\ \frac{\text{ps}^2}{\text{km}}$ and $\gamma = 1.6\ \text{W}^{-1}\ \text{km}^{-1}$ for selected values of C and initial duration of the initial pulse $T_{in} = 1.5$ ps.

The dispersion and nonlinearity parameters have been chosen so, that the effective fibre core section would be $A_{eff} = 80\ \mu\text{m}^2$, and the threshold power of the pulse $P_{th} = 443$ mW.

As, it is seen the initial chirp throws out of balance the dispersion and nonlinearity, which determine a formation of the soliton in optical fibre. The positive chirp narrows the pulse at the beginning of the propagation (Fig. 1).

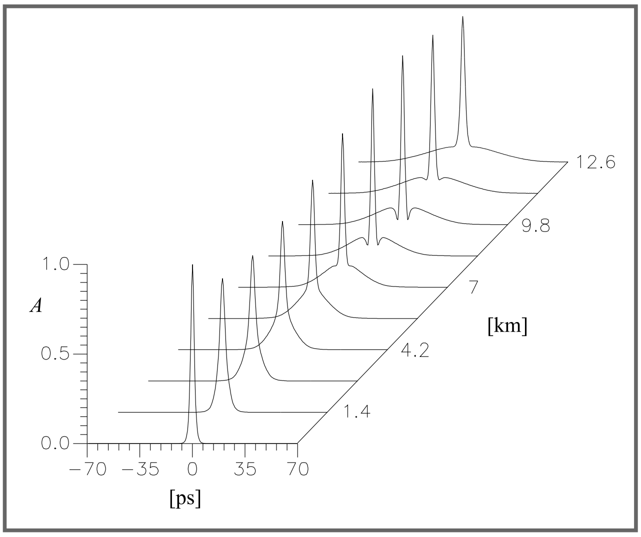

Fig. 1. Evolution of the fundamental soliton when $C = 0.5$

This is an effect of the predominance of the phase modulation over the dispersion. The negative chirp increases the predominance of the dispersion effect (Fig. 2).

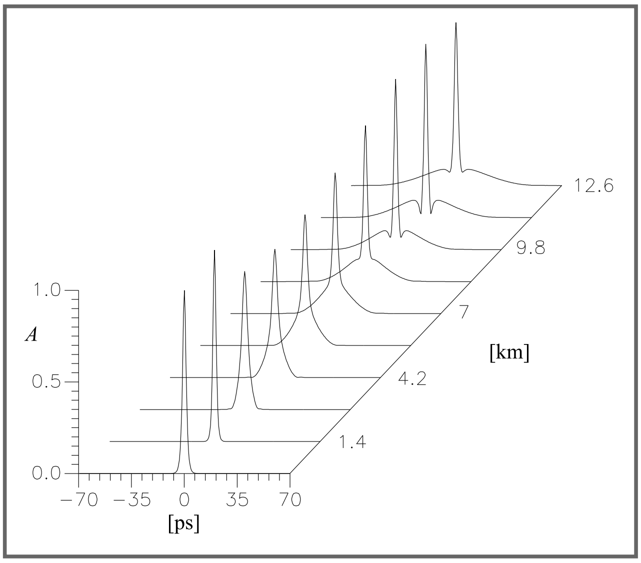

Fig. 2. Evolution of the fundamental soliton when $C = -0.5$

Conclusion

The numerical results are physically substantiated. They confirm proper selection of the method.
Generally, initial chirp is undesirable phenomenon especially positive one, besides that, negative effects of it are more observable in a case of long distances.
Prepared software can serve the analysis of the propagation of the pulses not only of hyperbolic secant shape.

References

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