The Influence of Number of Interference on Signal Propagation Along Nonlinear-Dispersive Optical Fiber

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Abstract - **The influence of nonlinear and dispersive effects of optical fiber on the optical telecommunication systems for high data rate and for long distance is considered in this paper. This influence and influence of interference on signal propagation are determined using Schrödinger equation. Shapes of pulses along the fiber in cases when one and two interference are on the start of fiber and when their total powers are equal are compared in this paper. We show shapes of pulses along spliced optical fiber that work in different dispersive regime.**

Keywords – **Optical fiber, Schrödinger equation, interference, nonlinear and dispersive effects.**

I. INTRODUCTION

When we tolk about optical telecommunication system for high data and long distance, we need consider influence of nonlinear and dispersive effects. We best can see those influences if we folow shape of pulse along the fiber. Values of some parameters of optical fiber define which effects, nonlinear or dispersive, will be biger. In this paper we mostly consider equal influence of both effects on pulse shape, except in second part of spliced fiber, where it is bigger influence of nonlinear effects.

The main effect of dispersive effect of optical fiber is broaden an optical pulse as it propagetes through the fiber. Size of these effects depends from values of GVD (group-velocity dispersion) parameter β_2. GVD parameter can be positive or negative disregarding the light wavelength, which is below or above the zero-dispersion wavelength λ_D of fiber. Intensity dependence of the refractive index in nonlinear media occurs trough SPM(self-phase modulation), a phenomenon that leads to spectral broadening of optical pulses. Size of nonlinear effect depends from values of parameter γ [1,4,5].

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Crosstalks are very often present in optical telecommunication systems and their influences can be very great. Every device on transmission path can be generating crosstalk. Crosstalk can be coherent and noncoherent and coherent crosstalk is more important because it can not be eliminated by optical filtering in receiver.

The pulse shape along the optical fiber is determined by solving Schrödinger equation. Schrödinger equation considers into self influences of nonlinear and dispersive effects of optical fiber. There are many methods for solving Schrödinger equation but pseudospectral method (split-step Fourrier method) is used in this paper because it is faster than other methods [1].

II. SHAPE OF PULSE ALONG NONLINEAR-DISPERSIVE OPTICAL FIBER

Propagation short pulse, which width is between 10 fs and 10 ps, along the nonlinear-dispersive optical fiber can be described by Schrödinger equation. It is [1]:

$$\frac{\partial A}{\partial z} = -\frac{1}{2}\alpha A - \frac{i}{2}\beta_2\frac{\partial^2 A}{\partial T^2} + i\gamma|A|^2 A \tag{1}$$

where A is slowly varying amplitude of pulse envelope and $T = t - z/v_g$, v_g is group velocity, $\gamma = n_2\omega_0/(cA_{eff})$ is coeficient nonlinearity, A_{eff} is effective core area, GVD parameter is $\beta_2 = \partial^2\beta/\partial\omega^2\big|_{\omega=\omega_0}$, n_2 is nonlinear-index refractive coefficient.

In cases when there isn't power loss during transmission of optical signals inside the fiber i.e. α=0 and when we use normalized parameters

$$\tau = \frac{T}{T_0} = \frac{t-\beta_1 z}{T_0}, U = \frac{A}{\sqrt{P_0}} \tag{2}$$

where P_0 is peak power of optical pulse, T_0 is the half width, then equation Eq. (1) become

$$\frac{\partial U}{\partial z} = -i\frac{\operatorname{sgn}(\beta_2)}{2L_D}\frac{\partial^2 U}{\partial \tau^2} + \frac{i}{L_{NL}}|U|^2 U \tag{3}$$

where L_D is dispersion length, L_{NL} is nonlinear length i.e.

$$L_D = \frac{T_0^2}{|\beta_2|},\; L_{NL} = \frac{1}{\gamma P_0} \tag{4}$$

In cases when nonlinear and dispersive effects are balanced (equal) then

$$\frac{L_D}{L_{NL}} = \frac{\gamma P_0 T_0^2}{|\beta_2|} \approx 1 \tag{5}$$

In equation Eq.(3) the term $sgn(\beta_2)$ takes values +1 in the normal dispersion regime and value –1 in the anomalous dispersion regime.

III. THE INFLUENCE OF COHERENT CROSSTALK ON OPTICAL PULSE SHAPE

Equation Eq.(3) is Schrödinger equation which described propagation along the optical fiber. There are many methods for its solving but we use split-step Fourrier method because its fast [1,2].

We consider propagation optical signal whose envelope has Gaussian form [3,7]

$$U(0,\tau) = a\exp\left(-\tau^2/2\right) \tag{6}$$

where values of parameter are depended from transmitting information (1 or 0).

Coherent optical crosstalk signal is optical signal having Gaussian shaped envelope, too.

$$U_i(z_i,\tau) = a_i\exp\left(-(\tau-b)^2/2\right) \tag{7}$$

where b representing time shift of interfered signal to useful signal and z_i is distance along the fiber where crosstalk is occurred.

Useful signal is

$$s(0,\tau) = U(0,\tau)\cos(\omega_r\tau) \tag{8}$$

and coherent crosstalk signal is

$$s_i(z_i,\tau) = U_i(z_i,\tau)\cos(\omega_r\tau+\varphi) \tag{9}$$

where $\omega_r = \omega_0 T_0$ is normalized frequency, φ is phase shift of interfered signal to useful signal.

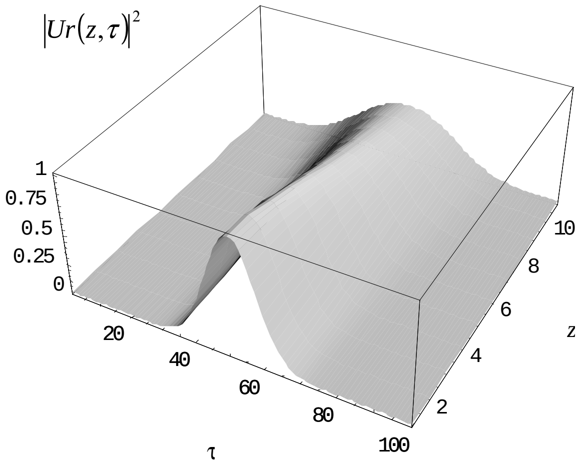
Resulting signal envelope and resulting signal phase at the place where interfered signal is occurred i.e. on distance z_i are obtained as [3,6]

$$U_r(z_i,\tau) = \sqrt{U^2(z_i,\tau) + 2U(z_i,\tau)U_i(z_i,\tau)\cos\varphi + U_i^2(z_i,\tau)} \tag{10}$$

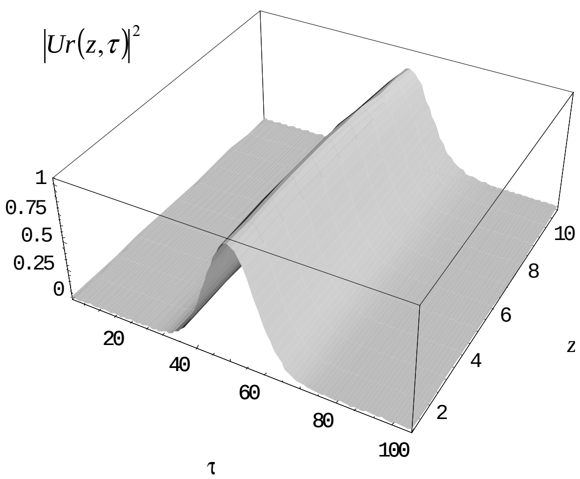
$$\psi(z_i,\tau) = arctg\frac{U_i(z_i,\tau)\sin\varphi}{U(z_i,\tau)+U_i(z_i,\tau)\cos\varphi} \tag{11}$$

Many different cases are considered in this paper and below parameters are used in each case of them [1]. λ=1550 nm, T_{FHWM}=1,665 ps i.e. T_0=1 ps, A_{eff}=80 μm^2, D=±1 ps/km·nm (D≤1), n_2=2,24·10^{-20} m^2/W^2, P_0=1W, $\beta_2 = -\lambda D^2/(2\pi c)$ and these parameters make possible equal influence of nonlinear and dispersive effects.

Fig. 1 shows Gaussian optical pulse propagation without interfered signal (a) β_2>0 anomalous dispersive regime, b) β_2<0 normal dispersive regime) and this shape of pulse is obtained by solving Schrödinger equation Eq.(3). Propagation optical Gaussian signal with crosstalk at the begin of optical fiber is showed in Fig.2. The signal-to-interference ratio is SIR=10.8 dB. Fig.3. shows propagation signal with two interference , which total power is equal power of interfered signal in above (previous) case, at the begin of optical fiber. Propagation optical Gaussian signal along spliced fiber with different values and different sign of parameter β_2 is showed in Fig.4. In second part of spliced optical fiber, dispersion effect is negligible compared nonlinear effect.

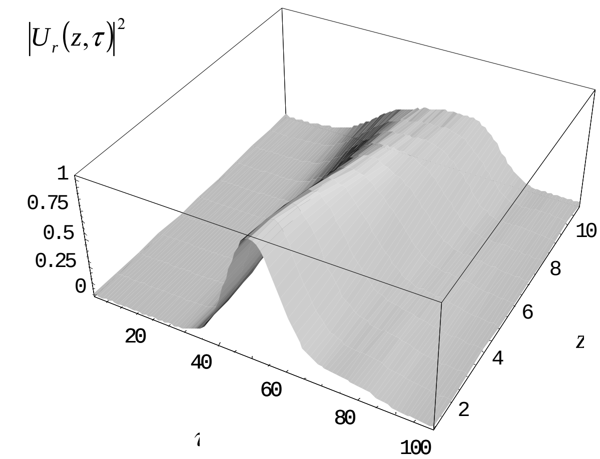


a)

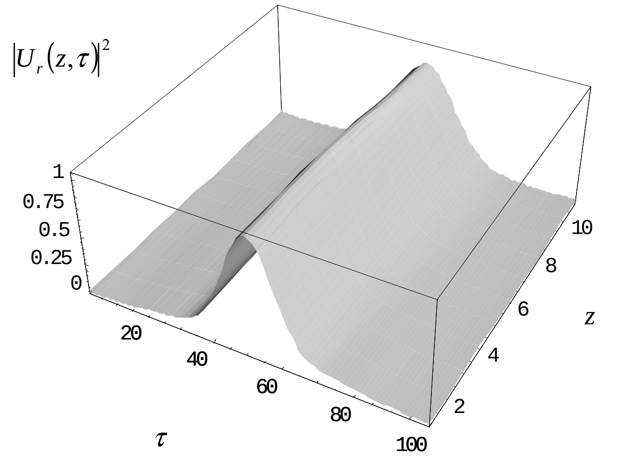


b)

Fig. 1. Gaussian signal along nonlinear-dispersive optical fiber



a)



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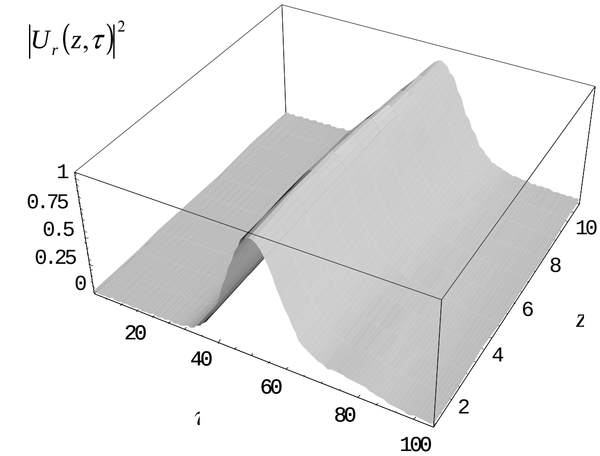
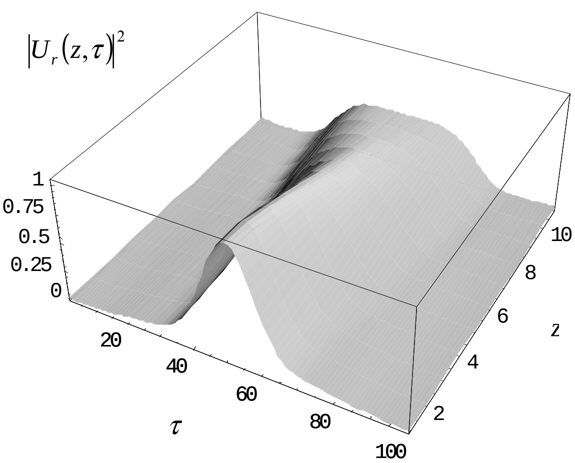


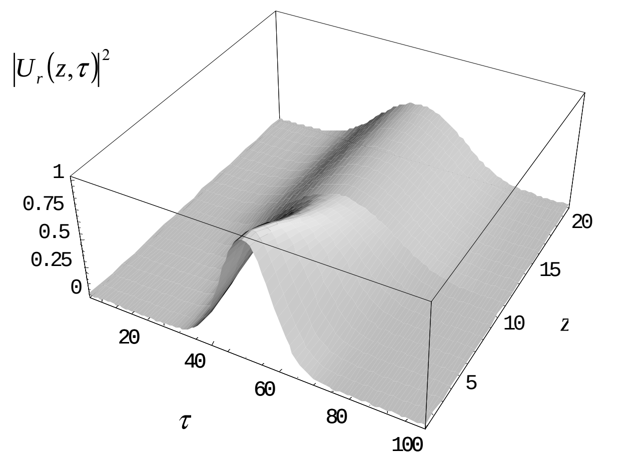
b)

Fig. 2. Gaussian signal in the presence of interfered signal at the begin of optical fiber.

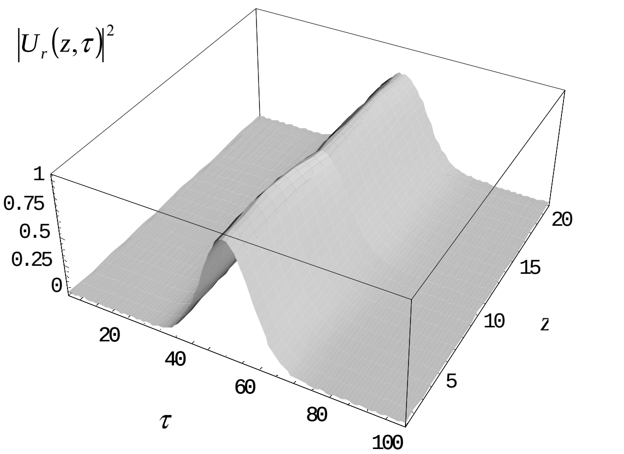


a)

Fig. 3. Gaussian signal in the presence of two interfered signal at the begin of optical fiber.



a) first part of spliced fiber-β_2>0, secand par of spliced fiber-β_2<0



b) first part of spliced fiber-β_2<0, secand par of spliced fiber-β_2>0

Fig.4. Gaussian signal along spliced optical fiber

V. CONCLUSION

Main contribution of this paper is to show influence of the coherent crosstalk on propagation of optical signal along the optical fiber. Influence coherent crosstalk is very important because it can not be eliminated by filtering of signal in reciever. We can see, from Figures 1-4, that change of shape of optical fiber along optical fiber is greater in case normal-dispersion regime than anomalous regime. This paper shows how spliced fiber affects on shape pulse, too.

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