The Influence of the Crosstalk Interference to Signal Propagation Along the Nonlinear Fiber

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Abstract-**In this paper, the signal propagation along the fiber, in the absence of the crosstalk signal interference and its presence at the transmitter output, for both dispersive regime cases, is considered. The pulse shape at the receiver input is determined using Schrödinger equation.**

Keywords-**crosstalk interference, nonlinear and dispersive fiber**

I. INTRODUCTION

The noises which appear in the receiver are: the photo diode quantum noise, photo diode working resistance thermal noise and amplifier resistance thermal noise. Also, the data crosstalk interference is one of the performance-limiting factor.

The pulse shape at the receiver input in the presence of crosstalk, thermal noise and quantum noise is determined by solving the system of nonlinear Schrödinger equations, when the influence of nonlinear and dispersive effects is balanced. The crosstalk appears at the transmitter output and it can be at the same wave length, or at the some other. The starting point, for solving the propagation equations is the useful signal's electrical field envelope and total field envelope (useful signal and crosstalk) where the crosstalk appears. The obtained results can be used for IM-DD systems design.

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II. THE SOLUTION OF THE SYSTEM OF NONLINEAR SHRÖDINGER EQUATIONS

The propagation equations are nonlinear partial differential equations. To solve this equations we can use many numerical methods. They can be separated into two broad categories known as the finite difference methods and the pseudo spectral methods. Generaly speaking, pseudo spectral methods are faster by an order of magnitude, or more to achieve the same accuracy.

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Because of that, we can use the split-step Fourrier method from the category of pseudo spectral methods to solve the pulse-propagation problem in nonlinear-dispersive media.

Mathematical description of the propagation of optical pulses required solving the propagation equations in dispersive and nonlinear medium. To begin with, we observed the system of propagation equations [1]:

$$\begin{aligned}&\frac{\partial A_1(t,z)}{\partial z}+\frac{1}{v_{g1}}\frac{\partial A_1}{\partial t}+\frac{i}{2}\beta_{21}\frac{\partial^2 A_1(t,z)}{\partial t^2}+\frac{\alpha_1}{2}A_1(t,z)=\\&=i\gamma_1\left(\left|A_1(t,z)\right|^2+2\left|A_2(t,z)\right|^2\right)A_1\\&\frac{\partial A_2(t,z)}{\partial z}+\frac{1}{v_{g2}}\frac{\partial A_2}{\partial t}+\frac{i}{2}\beta_{22}\frac{\partial^2 A_2(t,z)}{\partial t^2}+\frac{\alpha_2}{2}A_2(t,z)=\\&=i\gamma_2\left(\left|A_2(t,z)\right|^2+2\left|A_1(t,z)\right|^2\right)A_2\end{aligned}\tag{1}$$

satisfying slowly varying pulse function $A(z,t)$ in the presence of group-velocity dispersion (GVD) and self-phase modulation (SPM) having β_i and γ_i are given as

$$\beta_i=\frac{\partial^n\beta}{\partial\omega^n},\ i=1,2\tag{2}$$

$$\gamma_i=\frac{n_2\omega_i}{cA_{eff}}=\frac{2\pi n_2}{\lambda_i A_{eff}}\tag{3}$$

β is the phase constant, γ is the nonlinear coefficient, n_2 is the nonlinear-index reflective coefficient, v_{g2} and v_{g2} are the group-velocity, A_{eff} is the effective core area and $\beta_{2\mathrm{i}}$ and γ_i are governed by the effects of GVD and SPM, respectively.

The equations (1) are sufficiently exact for the description of the picosecond pulses and can be used in many practical cases. It is better observe equations (1) in normalized form and then we can use next normalized parameters

$$\tau=\frac{t-\beta_{1i}z}{T_0}\ ,\ \zeta=\frac{z}{L_{Di}}\ ,\ U=\frac{A}{\sqrt{P_0}}\tag{4}$$

where T_0 is the half width (at 1/e-intensity point) of pulse, P_0 is the peak power of the incident pulse and L_{Di} is the dispersion length, i.e.

$$L_{Di} = \frac{T_0^2}{|\beta_{2i}|} \tag{5}$$

Then for α=0, equations (1) take form:

$$\frac{\partial U_1}{\partial \zeta} + \frac{i}{2}\frac{\partial^2 U_1}{\partial \tau^2} = iN^2\left(|U_1|^2 + 2|U_2|^2\right)U_1$$

$$\frac{\partial U_2}{\partial \zeta} + \mathrm{sgn}(\beta_{2i})\frac{L_D}{L_W}\frac{\partial U_2}{\partial \tau} + \frac{i}{2}\frac{\beta_{22}}{\beta_{21}}\frac{\partial^2 U_2}{\partial \tau^2} = \tag{6}$$

$$= iN^2\frac{\omega_2}{\omega_1}\left(|U_2|^2 + 2|U_1|^2\right)U_2$$

where $\mathrm{sgn}(\beta_{2i})$ takes values +1 or -1 in dependence of dispersive regime ($\beta_{2i} > 0$-normal dispersion regime, $\beta_{2i} < 0$-anomalous dispersion regime). The equation (6) is known as Nonlinear Shrödinger equation (NSE).

The parameter N is defined as

$$N^2 = \frac{\gamma P_0 T_0^2}{|\beta_{2i}|} = \frac{L_{Di}}{L_{NLi}} \tag{7}$$

and it represents non dimensional combination of pulse and fiber parameters. The effect of the dispersion dominates for N<<1, while SPM dominates for N>>1. In equation (7) parameter $L_{NL\,i}$ is the nonlinear length and it is defined as

$$L_{NLi} = \frac{1}{\gamma_i P_0} \tag{8}$$

III. THE INFLUENCE OF THE INTERFERENCE ON THE PULSE PROPAGATION ALONG THE FIBER

In this paper we consider the input pulse which envelope have Gaussian form, i.e.

$$A(0,\tau) = a\exp\left(-\tau^2/2\right) \tag{9}$$

where the value of the parameter a depend on sent information (1 or 0). The interference signal which appear in the transmitter has also the envelope in Gaussian form. Because its nature , the signal interference which appears at the same place along the fiber together with the useful signal can walk along the useful signal, i.e. it can be time shifted in respect to the useful signal. Also, it can be phase shifted The useful signal at the input of an optical system can be defined as:

$$s(0,\tau) = U(0,\tau)\cos\omega_1\tau \tag{10}$$

where ω_1 is frequency.

The signal interference is defined as:

$$s_1(\zeta_i,\tau) = U(\zeta_i,\tau)\cos(\omega_1\tau + \varphi) \tag{11}$$

$$U(\zeta_i,\tau) = a_1\exp\left(-(\tau - b)^2/2\right) \tag{12}$$

where b represent time shifting of the signal interference in relation to the useful signal. ζ_i is the distance where the interference signal appears, φ represent phase shifting of the interference signal in respect to the useful signal. The total signal envelope at the place the interference signal appears is determined as

$$U_r(\zeta_i,\tau) = \sqrt{U^2(\zeta_i,\tau) + 2U(\zeta_i,\tau)U_i(\zeta_i,\tau)\cos\varphi + U_i^2(\zeta_i,\tau)} \tag{13}$$

The total signal phase at the place the interference signal appears is determined as

$$\psi_i(\zeta_i,\tau) = arctg\frac{U_i(\zeta_i,\tau)\sin\varphi}{U(\zeta_i,\tau) + U_i(\zeta_i,\tau)\sin\varphi} \tag{14}$$

This envelope and phase are then used for solving the system of Nonlinear Shrõdinger equations (NSE).

IV. THE ANALYSIS OF THE OBTAINED RESULTS

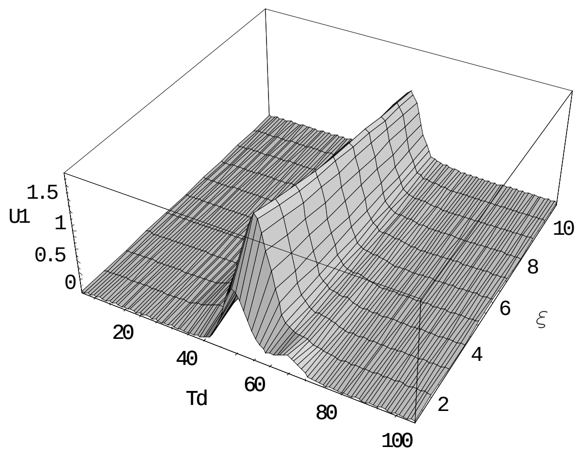

Fig.1. The envelope of pulse with interference at the same wave length and amplitude ratio is 0.5

As we saw, the crosstalk interference which appears at the transmitter output can be at the same wave length, or at the some other. We will show three different cases: when the crosstalk interference is at the same wave length, is at some other wave length and when exist both of them together. The ratio of ω_1 and ω_2 is 1.2 in all cases.

At the Figures 1. and 4. we show the case when the crosstalk interference is at the same wave length, but for two different amplitude of interference. At Fig. 1 the ratio of signal and interference amplitude is 0.5, and at Fig. 4. it is 1.

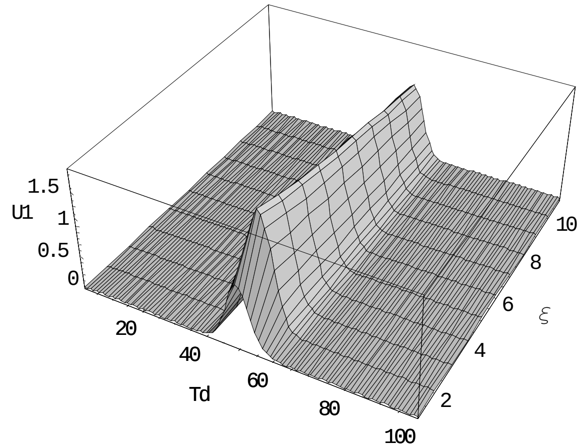

Fig.2. The envelope of pulse with interference at the other wave length and amplitude ratio is 0.5

At Fig 2. and 5. the interference is at the other wave length, for amplitude of signal and interference ratio 0.5 and 1, respectively, and at Fig 3. and 6. exist the crosstalk interference at both of wave lenghts for the same amplitude of signal and interference ratio.

We can see that the influence of the crosstalk interference is greater when the crosstalk interference is at the same wave length then in the other case.

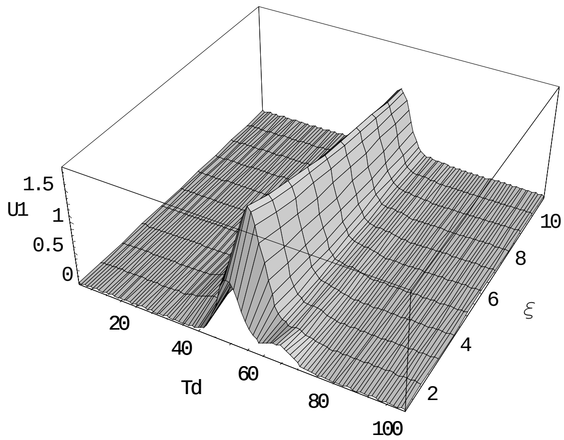

Fig.3. The envelope of pulse with interference at both of wave lenghts and amplitude ratio is 0.5

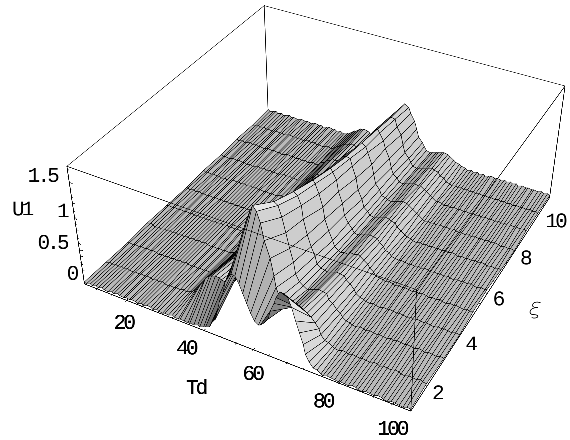

Fig.4. The envelope of pulse with interference at the same wave length and amplitude ratio is 1

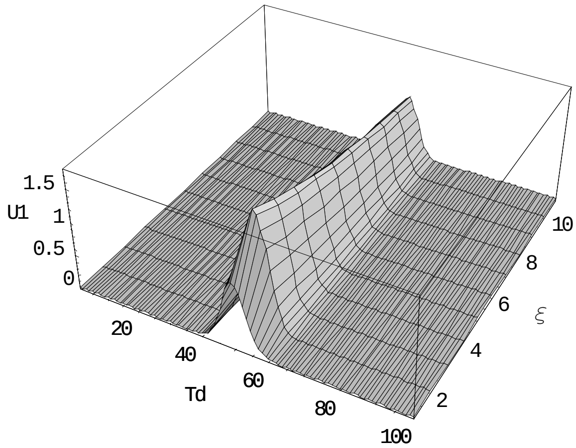

Fig.5. The envelope of pulse with interference at the other wave length and amplitude ratio is 1

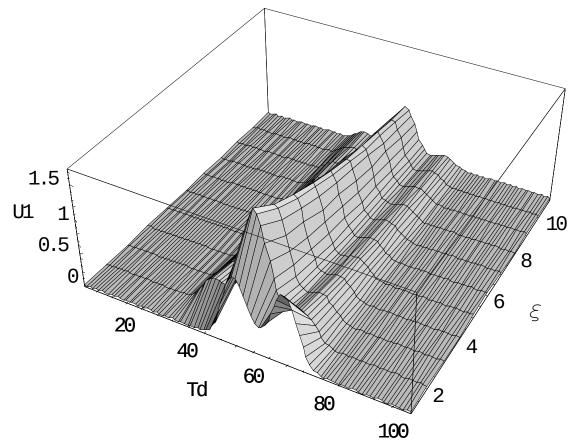

Fig.6. The envelope of pulse with interference at both of wave lenghts and amplitude ratio is 1

V. CONCLUSION

The data crosstalk interference is one of the performance-limiting factor to signal propagation along the nonlinear and dispersive fiber.

In this paper we determined the pulse shape at the receiver input in the presence of crosstalk interference, thermal noise and quantum noise by solving the system of nonlinear Schrödinger equations, when the influence of nonlinear and dispersive effects is balanced. The crosstalk appears at the transmitter output and it can be at the same wave length, or at the some other. We saw that the influence of the crosstalk interference is greater when the crosstalk interference is at the same wave length then in the other case.

The obtained results can be used for IM-DD systems design.

REFERENCES

[1] Govind P. Agrawal, *Nonlinear Fiber Optics,* The Institute of Optics, University of Rochester, New York

[2] Mihajlo Stefanović, Dragana Krstić, Jelena Antonijević, "*Performanse IM/DD optičkog sistema sa nelinearnim karakterstikom vlakna u prisustvu smetnje"*, YU INFO 2002, *Conference Proceedings,* Kopaonik, 11-15. mart 2002.

[3]Wenrui Xue, Guosheng Zhou, Zhonghao Li and Shuqin Guo, "Stable Propagation of Solitons in Strongly Dispersion-Managed Unequal-Lenght Optical Fiber Link with Loss", Journal of Lightwave Tecnology, July 2000, Volum 18, Number 7