Chirped Gaussian Pulse Propagation Along Anomalous Dispersive Optical Fiber in the Presence of Interference

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Abstract **– Basic task of all telecommunication systems is that a signal propagation from transmiter to receiver is as good as possible. There are many factors, in optical telecommunication systems, which disable such transmission. Dispersion is one of them. Optical fiber can work under normal or anomalous dispersive regime, but anomalous dispersive regime is better for signal propagation. It is the reason why we study linear chirped Gaussian signal propagation along such fiber. Influence of coherent interference on transmission quality is also studied in this paper. That influence is shown by pulse shape at the reciver, i.e. at the end of optical fiber. Nonlinear Schrödinger equation is solved to get pulse shape along optical fiber. Interference can appear anywhere along the fiber and therefore we determined to what extent appearing place of interference affects signal propagation and transmission quality.**

Keywords **- Chirped Gaussian signal, Interference, Dispersive optical fiber, Nonlinear Schrödinger equation.**

I. Introduction

Intermodal dispersion results from refractive index and mode propagation constant frequency dependence and it leads to pulse deformity, i.e. pulse broadening when pulse propagates along optical fiber [1]. Dispersion coefficient β_2 is a parameter that shows magnitude of dispersion. It defines dispersive regime of optical fiber, too. If $\beta_2>0$, then optical fiber works under normal dispersive regime. On the contrary, when $\beta_2<0$ then we can say that optical fiber is exposed to anomalous dispersion [1,2]. It is optimal that optical fiber works under anomalous dispersive regime because dispersive influence can be reduced and soliton transmission can be realised under determinate conditions in such optical fiber. When optical fiber is linear, pulse broadening is the same in cases when absolute value of dispersive coefficients β_2 are equal [3]. Because of that it does not matter if linear optical fiber work under normal or anomalous dispersive regime.

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Interference is one kind of disturbance that appears in optical telecommunication system and it is the cosequence of crosstalking, reflection, etc... [2,4,5]. It can be coherent or noncoherent, i.e. it can be of the same or different frequency in relation to a useful signal and it can appear anywhere along the optical fiber. Coherent interference is more important because it cannot be eliminated by optical filtering in reciver. It is the reason why such a kind of interference is discussed in the paper [6,7].

There are many ways to resolve signal transmission problems discussed above. They can be solved numerically or analytically. Great mathematical knowledge is needed for analytical solving and it is simpler to solve problem numerically using some programs.

II. Propagation Shrödinger Equation

Pulse propagation along nonlinear-dispersive optical fiber can be described by equation [1]:

$$\frac{\partial A}{\partial z}+\beta_1\frac{\partial A}{\partial t}+\frac{i}{2}\beta_2\frac{\partial^2 A}{\partial t^2}+\frac{\alpha}{2}A=i\gamma\left|A\right|^2 A \tag{1}$$

where $A(z, t)$ is slowly varying amplitude of pulse, α is optical losses, $\beta_1=\left.\frac{\partial\beta}{\partial\omega}\right|_{\omega=\omega_0}=\frac{1}{v_g}, \beta_2=\left.\frac{\partial^2\beta}{\partial\omega^2}\right|_{\omega=\omega_0}$, β is mode-propagation constant, v_g is group velocity and γ is nonlinearity coefficient that is defined as:

$$\gamma=2\pi n_2/\left(\lambda A_{eff}\right) \tag{2}$$

n_2 is nonlinear index coefficient, λ is wavelength of signal and A_{eff} is effective core area. If we introduce the following normalization:

$$\tau=\frac{T}{T_0}=\frac{t-\beta_1 z}{T_0},\ U=\frac{A}{\sqrt{P_0}} \tag{3}$$

where T_0 is half-width, i.e. time when signal power declines to $1/e$ of its top value, P_0 is peak power of useful signal and if we introduce the following changes [1]:

$$L_D=\frac{T_0^2}{\left|\beta_2\right|},\ L_{NL}=\left(\gamma P_0\right)^{-1} \tag{4}$$

where L_D is dispersive length and L_{NL} is nonlinear length, then Eq. (1) becomes:

$$\frac{\partial U}{\partial z} = -i\frac{\operatorname{sgn}(\beta_2)}{2L_D}\frac{\partial^2 U}{\partial \tau^2} + \frac{i}{L_{NL}}|U|^2 U \qquad (5)$$

Optical losses are neglected in Eq. (5), i.e. α=0, because they are very small for λ=1.55 μm [1]. Equation (5) is well-known as nonlinear Schrödinger equation. There are many methods, numerical or analytical, for its solving. Symmetrical split-step Fourier method is used in this paper for solving Schrödinger equation because of the fact that it is very fast and very accurate method [1].

Parameter that defines working regime of optical fiber is:

$$N^2 = \gamma P_0 L_D = \gamma P_0 T_0^2 / |\beta_2| = L_D / L_{NL} \qquad (6)$$

When N^2<<1 then dispersive effects dominate optical fiber. In case when $N^2 \approx 1$ then dispersive and nonlinear effects establish balance among themselves [1].

III. Chirped Gaussian Pulse Propagation along Optical Fiber In the Presence of Interference

Chirped Gaussian pulse is very often found as useful signal in optical telecommunication systems [1,6,8]:

$$U(0,\tau) = a\exp(-(1+iC_1)\tau^2/2)$$
$$s(0,\tau) = U(0,\tau)\cos\omega_r\tau \qquad (7)$$

where value of parameter a depends on transmited information (1 or 0), C_1 is chirp of useful signal and $\omega_r = \omega T_0$ is normalized frequency.

Coherent interference is of the same frequency as useful signal and there is time and phase shift in relation to useful signal. Interference at the place of appearance is:

$$s_i(z_i,\tau) = U_i(z_i,\tau)\cos(\omega_r\tau + \varphi),$$
$$U_i(z_i,\tau) = a_i \exp(-(1+iC_2)(\tau-b)^2/2) \qquad (8)$$

where b i φ are time and phase shift, respectively. z_i is place along optical fiber where interference appears, C_2 is chirp of interference and value of parameter a_i depends on magnitude of interference. Interference can be chirped although useful signal is not linearly chirped and it depends on the kind of interference [7]. Envelope and phase of resulting signal at the place of interference appearance are [6]:

$$U_r(z_i,\tau) = \sqrt{U^2(z_i,\tau) + 2U(z_i,\tau)U_i(z_i,\tau)\cos\varphi + U_i^2(z_i,\tau)} \qquad (9)$$

$$\psi(z_i,\tau) = arctg\,\frac{U_i(z_i,\tau)\sin\varphi}{U(z_i,\tau)+U_i(z_i,\tau)\cos\varphi} \qquad (10)$$

All time shapes of signals both along and at the end of optical fiber, that are showed in following figures, are gained by solving Schrödinger equation (5) by symmetrical split-step Fourier method [1,9,10,11] whereby initial conditions are modificated, at the place of interference appearance. The following values of parameters are used in all cases: T_0=4 ps, A_{eff} =80 μm^2, λ=1.55 μm, , n_2=32·10^{-16} cm^2/W and β_2=-19 ps^2/km.

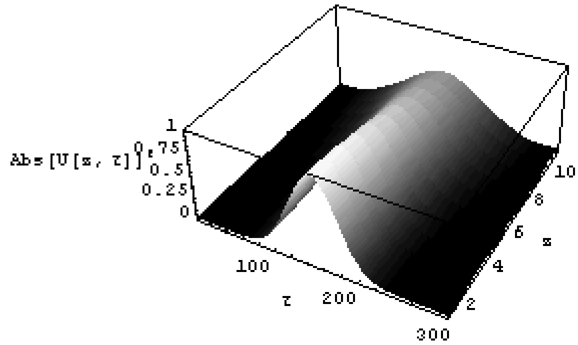


Fig. 1. Nonchirped Gaussian signal propagation along dispersive optical fiber (N^2<<1)

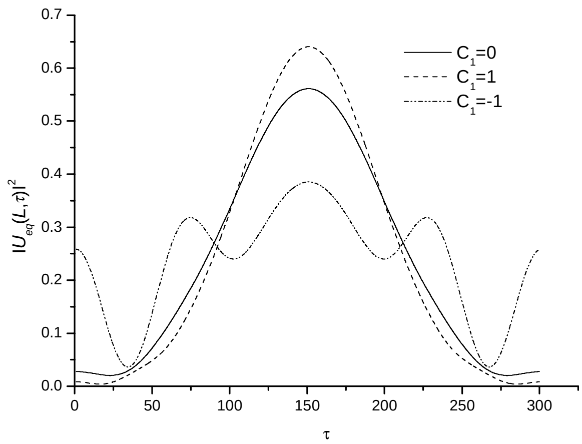
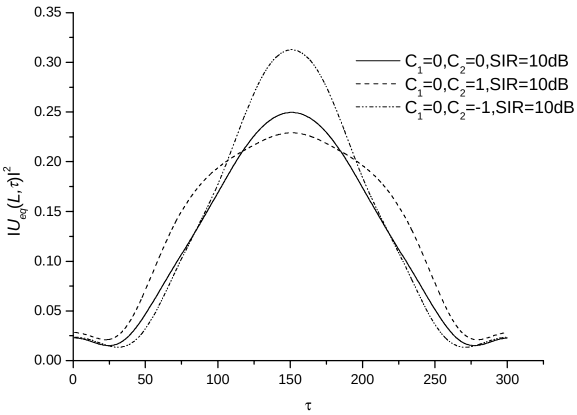
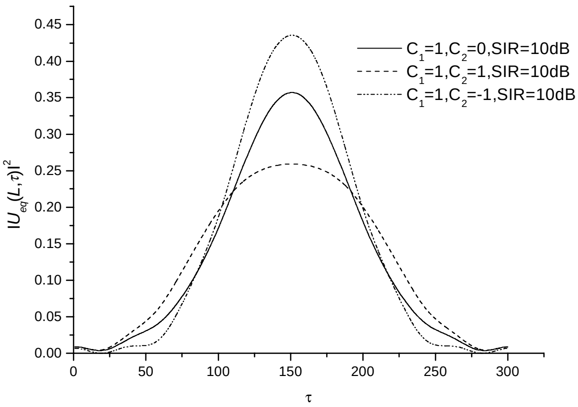


Fig. 2. Useful signal shape at the end of optical fiber in the absence of interference

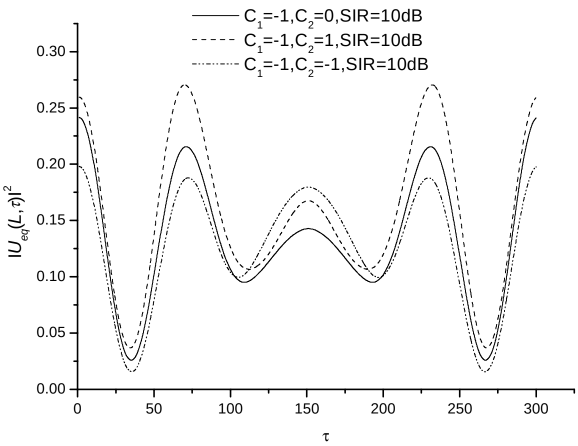
Nonchirped signal propagation along dispersive optical fiber is displayed in Fig. 1 and it shows to what extent dispersion affects signal expansion. We can see that this dispersion influence is quite great and it is proved in Fig. 2 that shows signal shapes at the reciever for both chirped and nonchirped useful signal. It is known that if optical fiber and signal have such parameters that $\beta_2 C_1$<0 is valid, then signal narrows until determined length of optical fiber and after that signal starts



a)

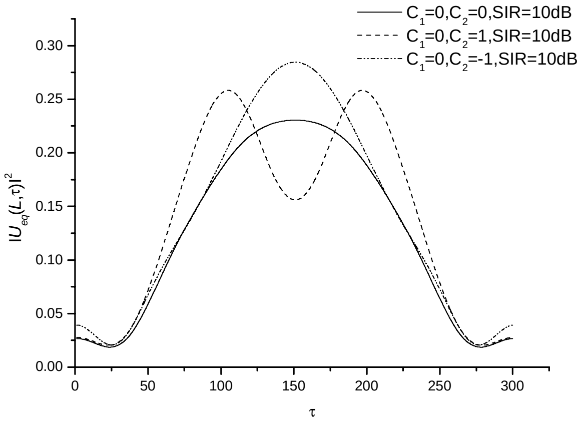


b)

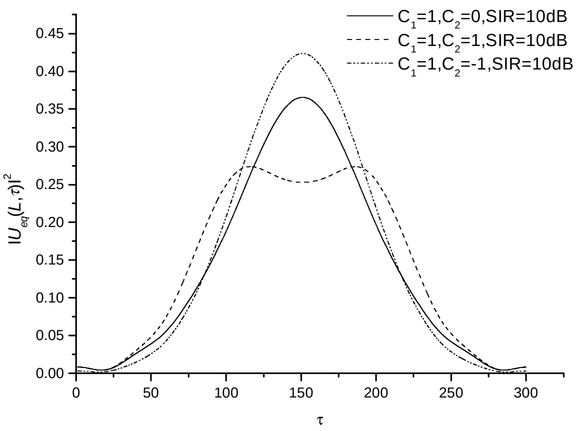


c)

Fig. 3. Signal shapes at the end of optical fiber in the presence of interference (z_i=0.3L)
a) C_1=0 *b*) C_1=1 *c*) C_1=–1



a)



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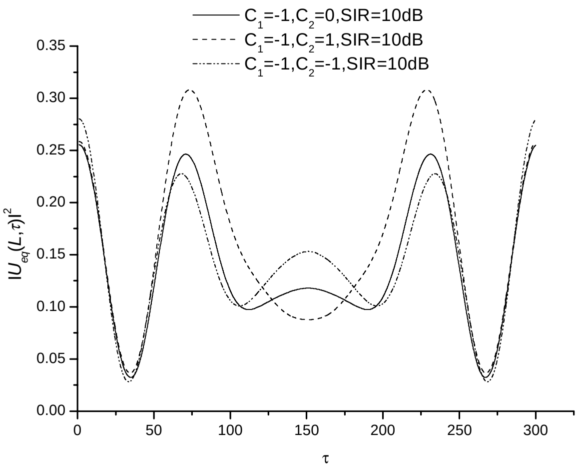

c)

Fig. 4. Signal shapes at the end of optical fiber in the presence of interference (z_i=0.6L)
a) C_1=0 *b*) C_1=1 *c*) C_1=–1

broadening to the end of optical fiber [1]. It is documented in Fig. 2, too. Signal with minimal expansion along optical fiber is signal which has such a chirp that the condition above is realised. Maximal signal deformation is in case when $\beta_2 C_1>0$.

Figs. 3 and 4 show signal shape at the end of optical fiber in the presence of interference along optical fiber. If we look at Eq. (8), we can conclude that time and phase shift are random values and that they can have any values ranging from [-1/(2*B*), 1/(2*B*)], i.e. [0, π] respectively (B – bit rate), but in this paper we have considered the worst case, i.e. b=0 and $\varphi=\pi$. We concluded, comparing Figs. 2, 3 and 4, that maximal deformation, i.e. maximal pulse expansion happens in case of C_1=-1 because of condition $\beta_2 C_1>0$ (β_2=-19 ps^2/km). This appearance is more pointed up in the presence of interference. Then, signal loses its shape and big error can be made at the reciever in detection process in the presence of jiter (Figs. 3*c* and 4*c*). The least pulse deformation, bacause of dispersive effects and presence of interference, happens when C_1=1. Reason for that is signal behaviour which narrows along the first part of optical fiber and expands along the second part of optical fiber [1]. We can see that, under such condition, signal is more immune to place of interference appearance, too. It is interesting that signal broadening is quite less for case C_1=1 and C_2=-1 then when C_1=1 and C_2=1. It can be explained by opposite action of chirps such as opposite action of chirp which is made by dispersion and initial chirp which enable pulse narrowing (Fig. 2).

IV. CONCLUSION

Dispersion is inevitable phenomenon in optical telecommunication systems and because of that its influence on chirped Gaussian signal propagation is considered in this paper. First, we showed that influence of dispersion depends on chirp sign of useful signal and dispersive regime optical fiber works under. Since interference which can be anywhere along the fiber appears as one of the disturnabces in optical telecommunication systems, we considered useful signal immunity to it and its place of appearance. From these results we concluded that the signal with negative initial chirp is the least immune to interference and its appearing place in case when optical fiber works under anomalous dispersive regime. All the problems considered in the paper we resolved by using programming package Mathematica 4.

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