Performance of IM-DD optical system in the presence interference at input of the fiber

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In this paper, the signal propagation along the fiber, in either absence or presence of the crosstalk interference appearing at input of the fiber, for both dispersive regime cases, is considered. The optical signal, which appears at transmitter output, has the envelope in super-Gaussian form. The crossltalk appears at the transmitter output. The pulse shape at the receiver input is determined using Schrödinger equation. The noise sources are the photodetector and resistance in the receiver. The bit error probability of intensity modulation and direct detection (IM-DD) system in the presence of the crosstalk, quantum and thermal noise is determined.

1. INTRODUCTION

When we talk 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 follow shape of pulse along the fiber. Values of same parameters of optical fiber define which effects, nonlinear or dispersive, will be bigger. In this paper we mostly consider equal influence of both effects on pulse shape and also the case when exist self influence of dispersive effects. The main effect of dispersive effect of optical fiber is broadening an optical pulse as it propagates 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].

In the field of fiber communications, IM-DD techniques are popular and have been used widely for high bit-rate data transmission. This is because IM-DD technique is simple and it enables lower cost for system implementation than any other technique. Recently, optical amplifiers have proven successful in supporting long-haul communications. With optical amplifiers used in IM-DD systems, bit-rate length product becomes greater than ever before.

The following noises appear in the receiver: the photodiode quantum noise, photodiode working resistance thermal noise and amplifier resistance thermal noise.

Crosstalk are very often present in optical telecommunication systems and there influences can be very great. Every device on transmission path can be generating crosstalk. The crosstalk appears at the transmitter output or along the fiber. Crosstalk can be coherent and noncoherent and coherent crosstalk is more important because optical filtering in receiver cannot eliminate it. In the push to develop even more powerful optical telecommunication networks, interferometric noise, which is the result of data crosstalk interference, has frequently been cited as the key performance-limiting factor.

The pulse shape at the receiver input is determined by solving the nonlinear Schrödinger equation, when the influence of nonlinear and dispersive effects is balanced. The starting point, for solving the propagation equation is the useful signal's electrical field envelope and the total field envelope (useful signal and crosstalk) where the crosstalk appears.

In this paper, the bit error probability of IM-DD systems, in the presence of interferometric, thermal noise and quantum noise is determined. The bit error probability as a function of SNR (signal-to-noise ratio) for different SIR (signal-to-interference ratio) values was used as the system performance rate. The system was analyzed for the two following cases:(1) signal propagated along the linear-dispersive fiber and (2) signal propagated along the nonlinear-dispersive fiber .

2. PULSE PROPAGATION ALONG THE NONLINEAR THE DISPERSIVE 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 coefficient 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.

It is useful to observe eq. (1) in normalized form and then we can use following normalized parameters:

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

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_D is the dispersion length i.e.

$$L_D = \frac{T_0^2}{|\beta_2|} \tag{3}$$

Than for $\alpha=0$, eq. (1) takes normalized form:

$$i\frac{\partial U}{\partial \zeta} = \mathrm{sgn}(\beta_2)\frac{1}{2}\frac{\partial^2 U}{\partial \tau^2} - N^2|U|^2 U \tag{4}$$

where $sgn(\beta_2)$ takes values +1 or –1 in dependence of dispersive regime (β_2>0-normal dispersion regime, β_2<0-anomalous dispersion regime). The eq. (5) is known as Nonlinear Shrödinger equation (NSE).

The parameter N is defined as

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

and it represents nondimensional combination of the pulse and fiber parameters. Dispersion dominates for $N<<1$, while SPM dominates for $N>>1$. In eq. (5) parameter L_{NL} is the nonlinear length and it is defined as

$$L_{NL} = \frac{1}{\gamma P_0} \tag{6}$$

Also, in this paper we shall consider the effect of GVD on pulse propagation in linear dispersive medium by setting N=0 (i.e. γ=0) and α=0 in eq. (1):

$$i\frac{\partial A}{\partial z} = \frac{1}{2}\beta_2\frac{\partial^2 A}{\partial T^2} \tag{7}$$

3. THE INFLUENCE OF COHERENT CROSSTALK ON OPTICAL PULSE SHAPE

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

We consider propagation optical signal whose envelope has Super-Gaussian form [3,4,5]

$$A(0,T) = \sqrt{P}\exp\left(-(T/T_0)^{2m}/2\right)$$
$$m = 2 \tag{8}$$

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

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

$$I(0,T)=\sqrt{P_i}\exp\left(-\left((T-b)/T_0\right)^{2m}/2\right)$$
$$m=2 \tag{9}$$

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

$$s(0,T)=A(0,T)\cos(\omega_0 T) \tag{10}$$

and coherent crosstalk signal is

$$s_I(0,T)=I(0,T)\cos(\omega_0 T+\varphi) \tag{11}$$

where ω_0 is optical 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 $z=0$ (input of fiber) are obtained as [3,6]

$$A_r(0,T)=\left(A^2(0,T)+2A(0,T)I(0,T)\cos\varphi+I^2(0,T)\right)^{1/2} \tag{12}$$

$$\psi(0,T)=arctg\frac{I(0,T)\sin\varphi}{A(0,T)+I(0,T)\cos\varphi} \tag{13}$$

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 ($D\leq1$), 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.

For solving eq. (7) split-step Fourier method is not necessary. Equation 7. is readily solved by using Fourier method, so that we have

$$A(z,T)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{A}(0,\omega)\exp\left(\frac{i}{2}\beta_2\omega^2 z-i\omega T\right)d\omega \tag{14}$$

4. The determination of bit probability error

The conditional bit error probability $P_{e/\varphi}$, was determined on the basis of the square of light envelope and variances of the IM-DD receiver noises. The conditional bit error probability is determined using Gaussian approximation [6,7].

We will calculate P_e - the bit error probability for the worse case when $p(\varphi)$ is uniformly distributed [8,9].

$$P_e=\int_{-\pi}^{\pi}P_{e/\varphi}\,p(\varphi)\,d\varphi \tag{15}$$

Figure 1. shows the bit error probability as a function of SNR for propagating along the linear dispersive fiber in the anomalous dispersion-regime in cases when (1)the interference is absent, (2)when interference signal appears at the input of fiber-SIR=20 dB and (3) when the interference signal appears at the input of fiber-SIR=25 .We can see from Fig. 1. that the bit error probability decreases with the increase of SNR in all cases. Also, the bit error probability increses with increase of the power of the interference signal [9].

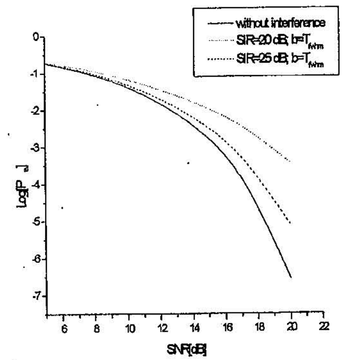

Figure 1 – The bit error probability as a function of SNR_{sr} in the anomalous dispersion-regime,when signal propagated along the linear dispersive optical fiber.

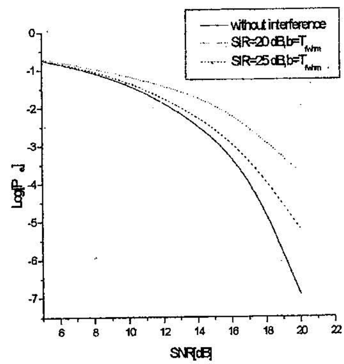

Figure 2 – The bit error probability as a function of SNR_{sr} in the anomalous dispersion-regime, when signal propagated along the nonlinear dispersive optical fiber

Figure 2. show bit error probability in the function of SNR for propagating along the nonlinear dispersive fiber with the same conditions as for Figure 1. The same conclusions, regarding the bit error probability, being valid for Fig. 1. are valid for Fig. 2. too. However, in this case the bit error probability is lower because the influence of GVD and SPM is mutually cancelled.

5. Conclusion

We can see from figures that the influence of crosstalk interference on the pulse shape is greater in normal dispersion-regime than anomalous regime.

Also, we can see that is signal propagating is greater along the nonlinear dispersive fiber because the influence of GVD and SPM is mutually cancelled. The bit probability error decreases with the increase of SNR and SIR for all cases.

Regarding the bit error probability, we can also see that the system performance is better for propagating along the nonlinear dispersive fiber.

6. REFERENCES

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