INFLUENCE OF SOLITON INTERACTION ON OPTICAL COMMUNICATION SYSTEMS

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Abstract. In this paper, we used numerical method to investigate the two-soliton interaction in optical fiber communication systems, in the case of in-phase and equal amplitude solitons. With some difference initial separation of two-solitons, separation between neighboring solitons in a digital bit stream, we obtain limit values of bit rate and maximum transmission distances of soliton communication system respectively.

1. Introduction

The existence of fiber solitons is the result of a balance between group velocity dispersion (GVD) and self-phase modulation (SPM) in dispersive nonlinear medium. So soliton pulses can propagate undistorted over long distance and remain unaffected after collision with each other. Thus the soliton communication systems have ultra-high bit rate and extremely long propagate distance. However, soliton light-wave systems were not commercially available, now. Because, they have some limitations, example: soliton interaction, soliton collision, pulse chirp... In this paper, we consider the two-soliton interaction with initial equal-phase and amplitudes. By the Matlap software, we showed the evolutionary process of two solitons with difference initial pulse separation

2. Basic propagation equation

The mathematical description of one fiber soliton is solution of the nonlinear Schrodinger equation (NSE) [1] [2] [3].

$$j\frac{\partial u}{\partial \xi} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = 0, \quad \text{with } u(0,\tau) = \text{sech}(\tau). \tag{1}$$

This equation was solved by inverse scattering method [2] [3]. And with two-soliton, initial condition is: $u(0,\tau) = \text{sech}(\tau - \gamma_0) + r\,\text{sech}\{r(\tau + \gamma_0)\}\exp(j\theta)$. So we have two-soliton solution in fiber with arbitrary initial phase and separation is [4]:

$$u(x,\tau) = \frac{|\alpha|\cosh(a_1 + i\theta_1)e^{i\phi_2} + |\alpha_2|\cosh(a_2 + i\theta_2)e^{i\phi_1}}{\alpha_3\cosh a_1 \cosh a_2 - \alpha_4\left[\cosh(a_1 + a_2) - \cosh(\phi_2 - \phi_1)\right]}, \tag{2}$$

where: $\phi_{1,2} = \left[\frac{(\eta_{1,2}^2 - \xi_{1,2}^2)x}{2} - \tau\xi_{1,2}\right] + (\phi_0)_{1,2}$; $\quad a_{1,2} = \eta_{1,2}(\tau + x\xi_{1,2}) + (a_0)_{1,2}$,

$$|\alpha_{1,2}|e^{i\theta} = \left\{\left[\frac{1}{\eta_{1,2}} - \frac{2\eta}{\Delta\xi^2+\eta^2}\right] \pm \frac{2\Delta\xi}{\Delta\xi^2+\eta^2}\right\} \text{ and } \alpha_3 = \frac{1}{\eta_1\eta_2} \; ; \; \alpha_4 = \frac{2}{\eta^2+\Delta\xi^2}$$

$$\Delta\xi = \xi_2 - \xi_2, \; \eta = \eta_1 - \eta_2$$

$u(x,\tau)$ is the normalized form of two-soliton envelope amplitude

3. The two-soliton interaction with initial equal phases and amplitude

With two-solitons are launched whose amplitudes and phases are equal, we have: $\theta=0$ and $\xi_1=\xi_2=0$. And then substituting into equation (2), it become:

$$q(\tau,x) = Q\left\{\eta_1 \operatorname{sech}\eta_1(\tau+\gamma_0)e^{i\eta_1^2 x/2} + \eta_2 \operatorname{sech}\eta_2(\tau-\gamma_0)e^{i\eta_2^2 x/2}\right\} \tag{3}$$

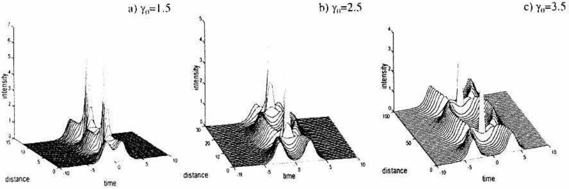
where: $$Q = \frac{\eta_2^2-\eta_1^2}{\eta_1^2+\eta_2^2-\eta_1\eta_2[\tanh a_1 \tanh a_2 - \operatorname{sech} a_1 \operatorname{sech} a_2 \cos\psi]}$$

$$a_{1,2} = \eta_{1,2}(\tau+\gamma_0), \qquad \psi = \frac{(\eta_2^2-\eta_1^2)x}{2}, \quad \eta_{1,2} = 1 + \frac{2\tau_0}{\sinh 2\tau_0} \pm \operatorname{sech}(\tau_0)$$

Where γ_0 is Initial separation,τ is normalized time, x is normalized propagate distance. The two-soliton solution Eq. 3 describes the interaction of two solitons with above initial condition. We investigate the soliton communication systems with parameters in Table1. Because x is normalized with respect to L_D, so each unit of x is 50km. We investigate the two-soliton interaction when the value of initial separation γ_0 varies from 1.5 to 6.5. Thus, from Eq.3, we have evolutionary process of two solitons is shown in Fig. 1. Because bit rate is $B=(\gamma_0 T_0)^{-1}$, so B varies from 15,4 Gb/s to 67 Gb/s.

Table 1

Pulse width	T_0= 5ps
Dispersion parameter	β_2 =-0.5 ps²/km
Dispersion length	L_D= 50 km



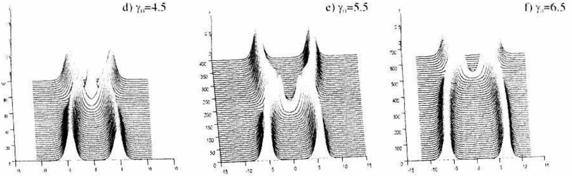


Fig.1. Soliton interaction with initial equal amplitude and phase

Fig.1 displays the evolution pattern showing periodic collapse of a soliton pair for various pulse separation. The periodic collapse of neighboring solitons is undesirable from the system standpoint. One way to avoid the interaction problem is to increase γ_0 such that the collapse distance, Z_M is much larger than the transmission distance L_T. From the results in the Fig 1, we can measure the collapse distance Z_M at each difference pulse separation γ_0 and thus we have table 2.

Table 2

τ_0	1,5	2,5	3,5	4,5	5,5	6,5
B (Gb/s)	67	40	28,6	22,2	18,2	15,4
Z_M (km)	105	460	1750	3850	10500	17250

4. Conclusion

The curve shown in Figure 2 is very useful for us to use as a guideline to choose the optimum pulse separation given a certain transmission distance. Pulse separation has to be minimized in order to achieve high bit rate transmission.

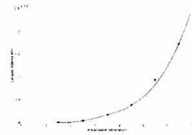


Fig.2. ZM as a function of initial separation.

With initial condition are equal phase and amplitude, the soliton interaction investigated is the strongest. Actually, we can choose the value of initial phase and amplitude to decrease "soliton interaction force" to the minimum. We will investigate this problem in later papers.

References

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