行政院國家科學委員會專題研究計畫成果報告

預先啾頻與偏極多工在光固子通訊系統之研究
Pre-Chirping and Polarization-Division Multiplexing in Soliton Transmission System

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一、中文摘要

本計畫研究發現在色散管理的光固子通訊系統中，使用預先啾頻與波型重整的方法可穩定波型的變化並且減低其Gordon-Haus效應與色散波。在偏極多工系統下，必須考慮多個光固子的交互作用，才能決定最佳的傳輸距離。

關鍵詞：色散管理，預先啾頻，波型重整，偏極多工。

Abstract

The pre-chirping and pre-shaping method is proposed to reduce the timing jitter and the dispersive wave in a strongly dispersion managed soliton transmission system. We have found that the pre-chirping and pre-shaping method can stabilize the variation of pulse shape due to the perturbation of the dispersion compensation fiber and the timing jitter can be greatly reduced. The maximum transmission distance limited by the interaction of solitons can not be inferred by the collision distance of two solitons in a PDM system, and the interactions of more solitons must be considered.

Keywords: dispersion managed soliton transmission, pre-chirping, pre-shaping, Polarization-Division Multiplexing

二、緣由與目的

For a long distance optical soliton communication system, the soliton is periodically amplified by the optical amplifiers that introduce the amplified spontaneous emission (ASE) noise to the soliton. The noise leads to the timing jitter and is known as the Gordon-Haus effect[1]. The dispersion management techniques using the dispersion compensation fibers (DCFs) are suggested to reduce the ASE noise-induced timing jitter[2-3]. Suzuki *et al.* have experimentally investigated the dispersion compensated soliton transmission system and found that there was an optimum dispersion compensation rate for the system[3]. However, DCF introduces the positive frequency chirp to the soliton periodically and the soliton pulse shape undergoes significant variations. The total frequency chirp in the soliton can be detrimental because it superimposes on the self-phase modulation (SPM)-induced chirp, the group-velocity dispersion (GVD)-induced chirp and the DCF-induced chirp. The DCF-induced chirp disturbs the exact balance between the GVD and SPM effect necessary for the soliton[4]. This local mismatch between the linear and nonlinear effects creates the dispersive wave[5].

The interaction of solitons is an important limitation of the bitrate-distance product in a soliton transmission system. The experiments demonstrated that the interaction between orthogonally polarized solitons is weaker than that of parallelly polarized solitons [6, 7]. Therefore, a way to reduce the soliton interactions and increase transmission capacity is to make the adjacent soliton orthogonally polarized, which is called the polarization-division multiplexing (PDM) technique [6-11]. Moreover, whenever two orthogoally polarized solitons at the input of a fiber transmission link may maintain a high degree of polarization throughout the whole link, even though the presence of random variations of fiber birefringence and polarization dispersion [6]. In fact, it is considered that the typical length scale where the birefringence and polarization dispersion fluctuations occur is much shorter that soliton period, so that the fluctuating local birefringence vector may be averaged over all polarization states [12, 13]. The soliton interaction in a PDM system has been analyzed by the perturbation method [8-10]. In recent experimental and theoretical works, it has been found that the interaction between PDM solitons is also notably reduced by sliding-frequency filter (SFF) [7, 10].

In a parallelly polarized soliton transmission system, the distance of soliton coalescence which is based on the interaction between two solitons is a good indication of the maximum transmission distance since two soliton interaction is stronger than more than two soliton interactions which have longer coalescence distance [14]. So far, for a PDM soliton transmission system, only two soliton interactions have been analyzed theoretically [8-10], where the maximum transmission distance of a PDM soliton system is considered by the coalescence distance of two solitons.

三、結果與討論

We numerically simulate a single soliton propagation in a strongly dispersion managed transmission system. We use the guiding center soliton, the parameters of input pulse are chosen to be η_o = 1.39, $T_{FWHM} \cong 1.763\ T_o$ =7 ps, the initial soliton separation is 50 ps (20 Gbits/s) , and C_o = 0, i.e., without initial chirp. Fig.1(a) and Fig.1(b) show the chirping parameter at $\tau = 0$ and the pulsewidth of the soliton versus distance, respectively, as the soliton propagates along the fiber in the dispersion compensated system with 100% dispersion compensation rate. In the beginning, DCFs cause the local mismatch between the linear and nonlinear effects, by creating the dispersive wave, the soliton self-adjust its phase and pulse shape gradually to tend to the most stable condition. Thus, the oscillation of the chirping parameter reaches a steady state after 4 Mm transmission. Using this pre-chirping and pre-shaping method, i.e., for obtaining the most stable initial pulse shape and frequency chirp, we simulate a recursive 10 Mm soliton loop and choosing the input parameters of the soliton to be η_o = 1.05, T_{FWHM} =12.376 ps, the initial soliton separation is 50 ps (20 Gbits/s), and C_o = 0.59 for 100% dispersion compensation rate, we obtain the chirping parameter and the pulsewidth of the soliton as shown in Figs.2. Since the most stable initial pulse shape is not the exact sech function, the trifling non-steady oscillation in the beginning are unable to avoid. Comparing Figs.1 and Figs.2, we can see the oscillations of the chirping parameter and the pulsewidth are more stable when the pre-shaping and pre-chirping method is used.

Figs.3 shows the standard deviation of the timing jitters of the solitons in the dispersion compensated transmission system, which is caused by the combination of the soliton interactions and ASE noise-induced timing jitters for the 512 pseudo-random bits. In the Ref.3, Suzuki *et al.* have experimentally investigated the dispersion compensated soliton transmission system with different compensation rates which range from 80% to 100%, the best performance of the system was obtained with 90% dispersion compensation rate. In Fig.3(a), ★ and ◇ represent the timing jitters of solitons at Z=10260 Km versus dispersion compensation rate for input solitons with and without pre-chirping and pre-shaping, respectively. When the solitons are not pre-chirped and pre-shaped, the minimum timing jitter occurs at 90% dispersion compensation rate, which coincides with Suzuki *et al.*'s experiment. When the solitons are pre-chirped and pre-shaped, the minimum timing jitter occurs at 98% dispersion compensation rate, since the dispersive wave caused by the DCF can be reduced by using the pre-chirping and pre-shaping method. Fig.3(b) shows the timing jitters of solitons increase as the propagation distance when the dispersion compensation rates are optimized for the input solitons with and without pre-chirping and pre-shaping.

We have numerically simulated the propagation of the multiple solitons in a parallelly polarized soliton transmission system, the behaviors are similar to those shown in Ref. 14. The two solitons coalesce at about 17 L_D, whereas, the other multiple solitons interact after this coalescence distance. Thus, the interaction between two solitons is the main limitation in a parallelly polarized soliton transmission system. It is seen that in the case of two solitons the standard deviation gradually increases until the collision distance, and in the cases of the larger number of solitons initially the pulses maintain their relative positions, then the standard deviations greatly increase after the distance 50 L_D. The standard deviation of the four solitons is larger than that of the other cases after the distance 59 L_D and is found the maximum at about 75 L_D where the center solitons coalesce. Therefore, the maximum transmission distance can not be inferred by the collision of two solitons in a PDM soliton transmission system.

For a numerical example in terms of real units, we take T_W = 12 ps and β_2 = - 0.382 ps^2/km (D =0.3 ps/km/nm). When sliding-frequency filters are not used, the isolated two adjacent solitons collide at about 13.5 Mm, and in the case of four solitons the two central pulses coalesce at a distance about 9 Mm. When the up-sliding-frequency filters are used, the shortest coalescence distance found in the case of four solitons is about 19.4 Mm.

We have numerically studied the dispersion compensated soliton transmission system and the interactions of multiple solitons in a PDM transmission system. It is shown that pre-chirping and pre-shaping method can effectively reduce the dispersive wave and timing jitter in the dispersion compensated soliton transmission system. The maximum transmission distance limited by the interaction of solitons can not be inferred by the collision distance of two solitons in a PDM system, and the interactions of more solitons must be considered.

四、計畫成果自評

This project has been accomplished thoroughly. The results by using pre-chirping and pre-shaping method in the dispersion compensated soliton transmission system to improve the system performance are successful, and the discovery of the interactions of more solitons must be considered in a PDM system is remarkable. The research papers are published.

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六、圖表

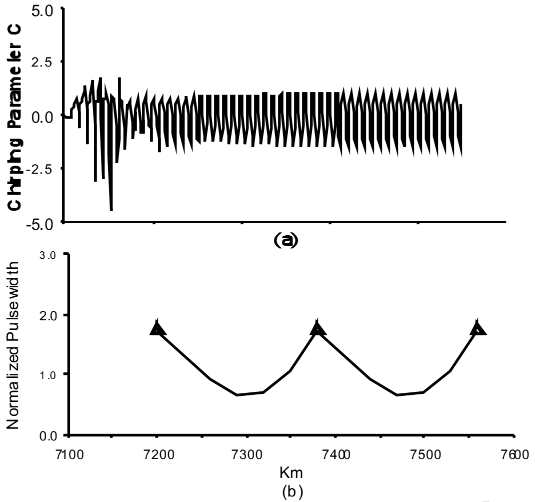

Fig 1: **(a)** The chirping parameter C at $\tau = 0$ and **(b)** the normalized pulsewidth of the soliton in dispersion compensated soliton transmission system.

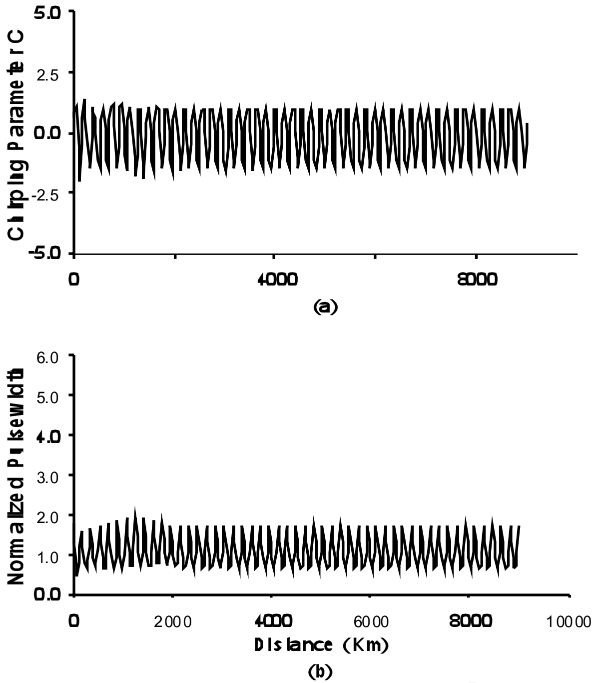

Fig 2: **(a)** The chirping parameter C at $\tau = 0$ and **(b)** the normalized pulsewidth of the soliton in dispersion compensated soliton transmission system by using the pre-chirping and pre-shaping method.

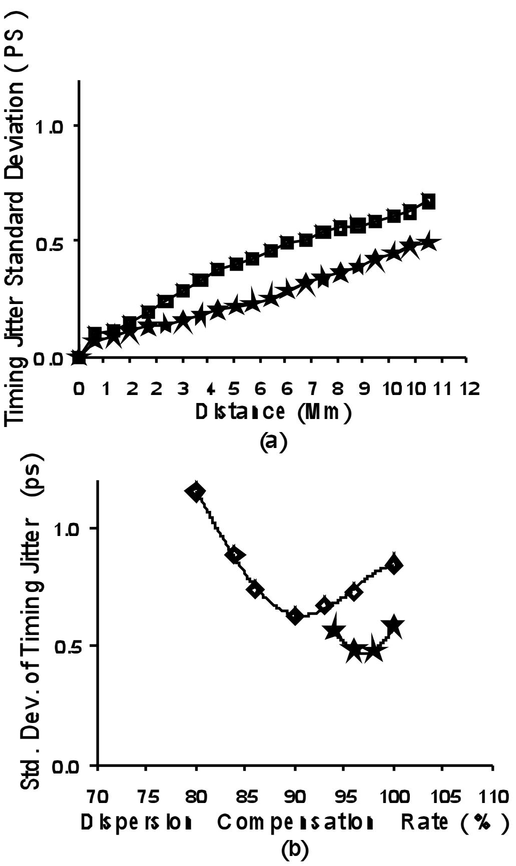

Fig.3: The standard deviation of the timing jitters of solitons **(a)** at $z = 10260$ km for different dispersion compensation rates and **(b)** in dispersion compensated transmission system for the optimum dispersion compensation rate. ★ and ◇ represent the timing jitters of solitons for the input solitons with and without pre-chirping and pre-shaping, respectively.