行政院國家科學委員會專題研究計畫成果報告

不同色散補償光固子通訊系統之研究

The study of different dispersion compensated soliton communication systems

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一、中文摘要

本計劃研究色散補償的光固子通信系統。首先分別探討正負色散光纖等長的色散管理系統、負色散傳輸光纖連接短長度高正色散補償光纖的色散補償系統、及稠密的色散補償系統。研究這三系統的傳輸特性，包括光固子入射能量、入射光脈衝寬度、及光濾波器之適當頻寬，並探討高階色散在色散週期性變化系統中產生的色散波對系統之影響。本計劃的另一目的在研究使用色散補償的光固子通信系統中，其脈衝寬度隨光纖色散週期性變化而劇烈改變，在不同位置進行色散補償，可有效降低訊號誤碼率，計算系統容許的最大信號率和傳輸距離。

關鍵詞：色散補償，光固子，能量強化

Abstract

Three dispersion compensated soliton transmission systems are investigated, including the dispersion map using equal lengths of two different fibers, the anomalous dispersion transmission fiber with dispersion compensation by a short length of highly normal dispersion fiber, and the densely period dispersion-managed system. For the same net anomalous dispersion, the characteristics of three systems are different. We will optimize the input energy of soliton, the input pulse width, and the bandwidth of optical filter. The dispersion managed soliton transmission using unsymmetrical dispersion map in the lumped amplifier system is also investigated. It is shown that the initial fiber length of dispersion map must be shorter than that of the symmetric map in order to attain the chirp-free pulse at the beginning of dispersion management unit cell. By properly adjusting the initial fiber length of dispersion map, the dispersion wave is reduced and the allowed transmission distance can be greatly increased.

Keywords: Dispersion compensation, soliton, energy enhancement

二、緣由與目的

The dispersion management has become an important technique for optical soliton transmission because of its many merits such as increasing the signal-to-noise ratio due to the energy enhancement of pulse power, decreasing Gordon-Haus timing jitter due to the low path-averaged dispersion of soliton system, and suppressing the phase-matching four-wave-mixing processes in the wavelength-division-multiplexing systems [1-3]. In these dispersion managed systems, the dispersion map contains equal-length segments of both normal and anomalous dispersion fibers, in which the average dispersion is very low and is anomalous. The energy enhancement factor depends delicately on the fiber loss and the location of the lumped amplifiers in the optical fiber transmission line [4,5]. To decrease the dispersive wave and suppress the alternate compressing and broadening of the pulse, the unit cell of dispersion map is symmetric in the lossless fiber systems [6]. The prechirping of the input solitons can reduce the dispersive wave created by the local mismatch between linear and nonlinear effects [7]. In the mostly standard fiber compensated by a shorter dispersion compensation fiber, a maximum transmission is demonstrated by reduction of interaction through optimum amplifier positioning [8]. The well designed dispersion map can propagate 3 ps dispersion-managed soliton pulse in the mostly normal dispersion-shifted fiber compensated by a much shorter single-mode fiber [9]. In this project, with equal-length segments of both normal and anomalous dispersion fibers, we examine the unit cell of dispersion map in the soliton transmission system and have found that the initial fiber length of dispersion map in the periodic lumped amplifier system should be shorter than that in the lossless fiber system. Adjusting the initial fiber length of dispersion map, the dispersion wave is reduced and the transmission distance is increased.

三、結果與討論

The propagation of soliton pulse in a lossy single-mode fiber can be described by the modified nonlinear Schrödinger equation

$$i\frac{\hat{o}\,U}{\hat{o}\,z}-\frac{1}{2}\,{}_{2}\frac{\hat{o}^{\,2}U}{\hat{o}\,\mathit{2}^{2}}-i\frac{1}{6}\,{}_{3}\frac{\hat{o}^{\,3}U}{\hat{o}\,\mathit{2}^{3}}+n_{2}\ {}_{o}|U|^{2}U-C_{r}U\frac{\hat{o}}{\hat{o}\,\mathit{2}}|U|^{2}=-\frac{i}{2}\sim U$$

where τ = (t- $_1$z)/T$_0$ and $_1$ is the reciprocal group velocity, $_2$ and $_3$ represent the second-order and third-order dispersions of the fiber, respectively, U is the slowly varying amplitude, n$_2$ is the Kerr coefficient, C$_r$ is the slope of Raman gain profile, and α is the attenuation coefficient of the fiber. For the numerical simulation, the coefficients in (1) are taken as $_3$ = 0.14 ps^3/km, n$_2$ = 2.6× 10^{-20} m^2/w, C$_r$ = 3.8×10^{-16}(ps · m)/W, α = 0.22 dB/km, and $_2$ are –0.5 ps^2/km and 0.4 ps^2/km for the anomalous and normal dispersion fiber, respectively. The path-averaged dispersion $\ddot{\overline{\ }}_2$ is -0.05 ps^2/km. More energy is required for forming a quasi-stable soliton in the dispersion-managed link compared to those required for soliton in a uniform fiber with the same path-averaged dispersion[10].

We consider a system using the unsymmetrical dispersion map as shown in Fig. 1, where the initial fiber length of $\ddot{\ }_1$ dispersion fiber is A, A + B is equal to L the length of $\ddot{\ }_2$ dispersion fiber, and the amplifiers are at the beginning of unit cells. The dispersion map is symmetrical when A is equal to B. We numerically simulate the quasi-soliton propagation of the unsymmetrical dispersion map in the lumped amplifier systems. We have found that, because of the exponential decay of the pulse power due to the fiber loss, the initial fiber length must be shorter than that of the symmetric map and the frequency chirping can be nearly zero at each end of dispersion period. The allowed transmission distance for the lumped amplifier system using unsymmetrical dispersion map is longer than that using symmetrical dispersion map.

First, we simulate the symmetric dispersion map case(A = B = 18 km) using the following parameters: the initial pulse width (full width at half maximum) is 5 ps and the amplifier spacing is 72 km. The optimum enhancement factor is F = 1.75 for the amplifier system and is smaller than it would be for the lossless fiber[4]. Then using the F = 1.75, we adjust A the initial fiber length of dispersion map and examine the influence of different A on the soliton dispersion-managed system. Fig. 2 shows the pulsewidth fluctuation of the quasi-soliton pulse versus transmission distance at the beginning of every dispersion management unit cell for the different A's; the solid, star, square, and dashed lines are for A = 18, 14, 10, and 8 km, respectively. When the dispersion map is symmetric, A is 18 km. We have found that the pulsewidth variation is nearly minimum as A is equal to 10 km. Because of the exponential decay of pulse power, the different initial lengths of dispersion map have a strong impact on the Kerr nonlinearity which influences the chirping of the quasi-soliton pulse. A study of the pulse chirping in the dispersion management shows that the key to quasi-stable propagation lies in the behavior of the chirping. The frequency chirping must be eliminated completely at each end of dispersion map period. Fig. 3 shows the chirping of pulse at the beginning of dispersion management unit cell for the different A's; the solid, square, and dashed lines are for A = 18, 10, and 8 km, respectively. It can be seen that the chirping of the A = 10 case is nearly zero at the central regime of the pulse, and the chirps of A = 18 and A = 8 cases are negative and positive, respectively. Thus the residual chirping causes the increasing of pulsewidth fluctuation.

Within each period of the dispersion map the pulse shapes undergo large changes, alternately compressing and broadening as the sign of the dispersion is reversed. During the transient stage, the pulse adjusts itself by shedding some of its energy into dispersion waves which degrade the performance of dispersion management systems. Fig. 4 shows the pulse power of the quasi-soliton pulse versus transmission distance at the beginning of every dispersion management unit cell for the different A's; the solid, star, square, and dashed lines are for A = 18, 14, 10, and 8 km, respectively. For the A = 10 km, the pulse power maintains well and the dispersion wave is nearly minimum. The results are consistent when compared with Fig. 3. Thus to minimumize the generation of dispersion radiation, it is important to achieve the chirp-free pulse at the beginning of dispersion map cycles. In the meantime, we optimize the initial chirping of input pulses for the symmetric dispersion map A = 18 km and find the optimum prechirping c = 0.2. For the A = 10 km case, the optimum prechirping and enhancement factor are c = 0 and F = 1.75, respectively. Fig. 4 also shows the pulse power versus transmission distance for the symmetric map with c = 0.2 by triangle line. The dispersive wave is smaller than that of the non-prechirping of A =18 km case but larger than that of the A = 10 km case.

When the quasi-soliton is periodically amplified by the optical amplifiers, every amplifier introduces amplified spontaneous emission(ASE) noise to the pulse. Since the soliton interaction depends on the separation of the solitons, the ASE noise-induced timing jitter influences the soliton interaction and vice versa. The ASE noise power per unit frequency generated by an amplifier is $P_a = n_{sp}(G-1)h\neg$, where n_{sp} = 1.2 is the spontaneous emission factor, $G = \exp(\sim L_a)$ is the gain of the amplifier, and $h\neg$ is the photon energy. Fig. 5 shows the standard deviation of the timing jitters of the solitons versus transmission distance in the dispersion management transmission systems of the different A's, which is caused by the combination of the soliton interactions and ASE noise-induced timing jitters for the 1024 pseudorandom bits (512 ONE's and 512 ZERO's). The bit rates are 40 Gbits/s. The 5 nm inline optical filter is used to stabilize the pulse after the amplifier and the input pulse peak power is 13.8 mW. A 10^{-9} bit-error rate corresponds to the jitter 1.36 ps. The allowed transmission distances with 10^{-9} bit-error rate for the 18, 8, and 10 km of A are 5800, 6700, and 7500 km, respectively. For the c = 0.2 and A = 18 km case, the transmission distance can reach 6600 km.

In conclusion, we have found that the soliton dispersion management system with equal-length segments of both normal and anomalous dispersion fibers needs a shorter initial fiber length in the dispersion map to attain the chirp-free pulse at the beginning of dispersion map. By properly adjusting the initial fiber length of dispersion map, the dispersion wave is reduced and the allowed transmission distance can be greatly increased.

四、計畫成果自評

This project has been performed thoroughly. The results are outstanding in the respects of unsymmetrical map of dispersion managed soliton transmission system. The initial fiber length of dispersion map must be shorter than that of the symmetric map in order to attain the chirp-free pulse at the beginning of dispersion management unit cell.

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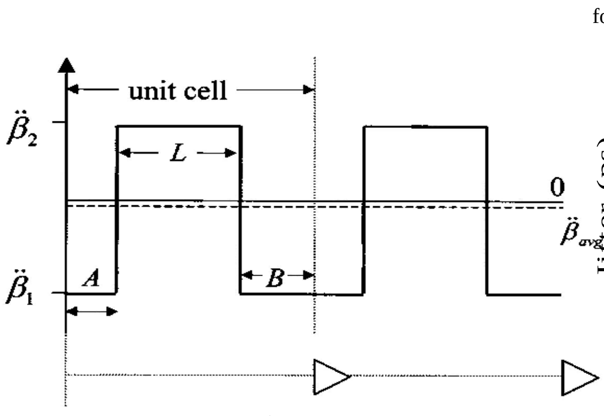

Fig. 1 The schematic diagram of a dispersion management unit cell and the arrangements of the amplifier locations. The dispersion map consists of alternate normal and anomalous dispersion fiber with length L and A + B, respectively.

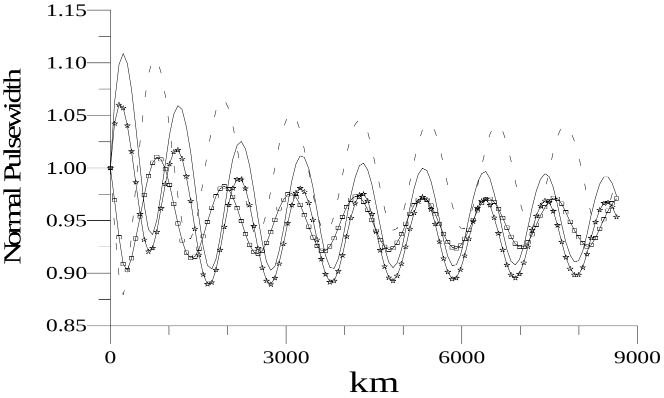

Fig. 2 The pulsewidth variations of the quasi-soliton versus transmission distance at the beginning of every dispersion management unit cell. The solid, star, square, and dashed lines are for A = 18, 14, 10, and 8 km, respectively.

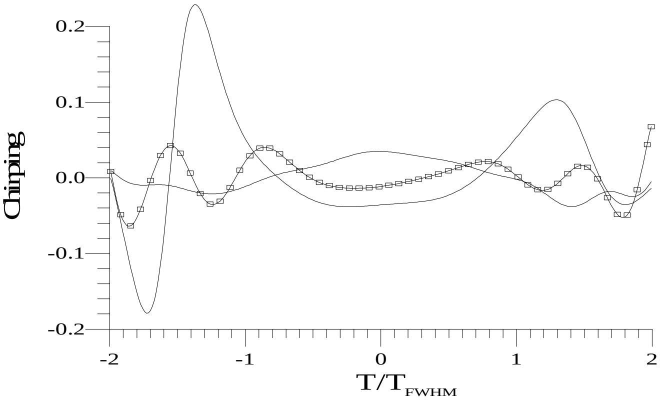

Fig. 3 The chirping of pulse at the beginning of dispersion management unit cell. The solid, square, and dashed lines are for A = 18, 10, and 8 km, respectively.

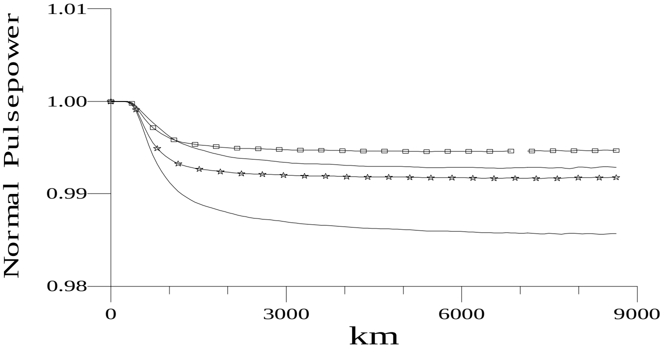

Fig. 4 The pulse power of the quasi-soliton pulse versus transmission distance at the beginning of every dispersion management unit cell. The solid, star, square, and dashed lines are for A = 18, 14, 10, and 8 km, respectively.

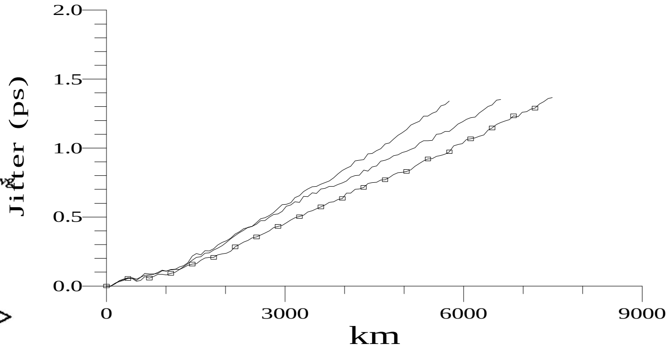

Fig. 5 The standard deviation of the timing jitters of the

quasi-solitons versus transmission distance in the dispersion management transmission systems of the different A's. The solid, square, and dashed lines are for A = 18, 10, and 8 km, respectively.

附件：封面格式

行政院國家科學委員會補助專題研究計畫成果報告

不同色散補償光固子通訊系統之研究

計畫類別：☑個別型計畫　□整合型計畫
計畫編號：NSC90－2215－E－009－081－
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計畫主持人：祁甡教授

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- □出席國際學術會議心得報告及發表之論文各一份
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執行單位：交通大學光電工程研究所

中　華　民　國　91 年　10 月　23 日