行政院國家科學委員會專題研究計畫成果報告

光固子光纖通訊系統中色散圖單元與偵測窗最佳化之研究

Study of the Optimal Design Dispersion Map Unit Cell and Signal Detection Window in Soliton Transmission System

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一、中文摘要

我們提出兩種新的方法，以改善光纖通訊系統的傳輸品質。一是在波長多工系統中利用色散斜率補償。在色散補償光纖的不同位置上，寫上不同中心波長的光纖光柵來完全地補償各頻道的色散。二是在光固子通訊系統中利用可調寬度的偵測窗，改善傳輸品質。其最佳的偵測窗寬度取決於 Gordon-Haus 效應、色散波、波形與脈衝寬度。

關鍵詞：光固子、光纖通訊、色散斜率補償、光纖光柵、偵測窗

Abstract

We studied two new schemes to improve the performance of optical communication systems. First, dispersion slope compensator is proposed for the wavelength division multiplexing transmission system. The accumulated dispersion of signals in different channels can be in-line fully compensated by writing fiber Bragg gratings at different positions of a dispersion compensation fiber. Second, a soliton transmission system detected by integration and dump method in the case of adjustable detection window width is studied. We found that the optimal detection window width depends on Gordon-Haus effect, energy fluctuation and pulsewidth.

Keywords: soliton, optical communication, dispersion slope compensator, fiber Bragg gratings, detection window

二、緣由與目的

The wavelength division multiplexing (WDM) soliton transmission has become very attractive for high speed and high capacity optical communication systems. The WDM soliton transmission system is limited by the timing jitters caused by the soliton interactions, the amplifier spontaneous emission (ASE) noise (Gordon-Haus effect), and the unsymmetrical collisions between different channels [1, 2]. By using the dispersion compensation fibers (DCFs) [3, 4] or chirped fiber Bragg gratings (FBG) [5], the dispersion compensation techniques are suggested to compensate for the group-velocity dispersion and improve the system performance. Since the wavelength dependence of the dispersion in the fiber, the signals of different channels suffer different dispersions, a single bare DCF cannot compensate for the dispersions of all channels in an optical WDM transmission system. To overcome this problem, a dispersion slope compensator-A (DSC-A) as shown in Fig. 1(a) was proposed, which first divided the WDM signal channels into different paths by the optical fiber coupler and each channel was selected by an optical bandpass filter placed on each path and then were recombined by the optical fiber coupler following the individual DCFs. In the DSC, some fractional energy of the signal of a channel appears in the neighboring paths because of the incomplete filtering process due to the finite spectral side-level of the optical bandpass filter. This fractional pulse propagates in different path from the principal pulse. After the DSC the fractional pulses lead or lag behind the principal pulses and become the dispersive waves. Such dispersive waves are accumulated along the transmission distance and degrade the transmssion system. We propose a new scheme of DSC-B as shown in Fig. 1(b). The major merits of our scheme are that the accumulated dispersions of different channels can be in-line compensated, i.e., there are no division and combining loss, and the total length of DCFs can be greatly reduced. We will show that the dispersive waves are serious when the Fabry-Perot filters (FPF) are used. The fiber Bragg grating can be properly designed to have a rectangular-like spectrum profile to avoid imcomplete filtering. Therefore, by proper design, the allowed transmission distance by using the DSC-B is larger than those by using the FPF or Butterworth filter (BWF) in the DSC-A.

On the other hand, in optical soliton transmission system the performances were evaluated by considering the noise-induced timing jitter [2], the fluctuation of soliton amplitude [6, 7], and the fluctuation of soliton energy. The most commonly used method of measuring the system performance in an optical transmission system is the decision circuit method of measuring Q factor [8]. The Q factor can be calculated by sampling the signal's amplitude at bit centrum [6], or by integrating its energy over a bit duration [9]. The latter method is usually called the integration and dump method. When the sampling method is used, the response time of an electronic sampling circuit has to be much shorter than the soliton pulsewidth. When the integration and dump method is used, the integration duration can be realized by an electroabsorption modulator with a gate width of about 40-50 ps [10] which is usually larger than the soliton pulsewidth. Therefore, the estimation of system performance by the Q factor obtained by the integration and dump method is more suitable and realistic. The integration of soliton energy over a bit duration is not an optimal design because soliton energy lies within a duration much smaller than a bit duration. When the integration duration is less than a bit duration, a fraction of noise energy can be excluded without the expense of signal energy. On the other hand, with too small an integration duration, the system performance may suffer from the noise-induced timing jitter.

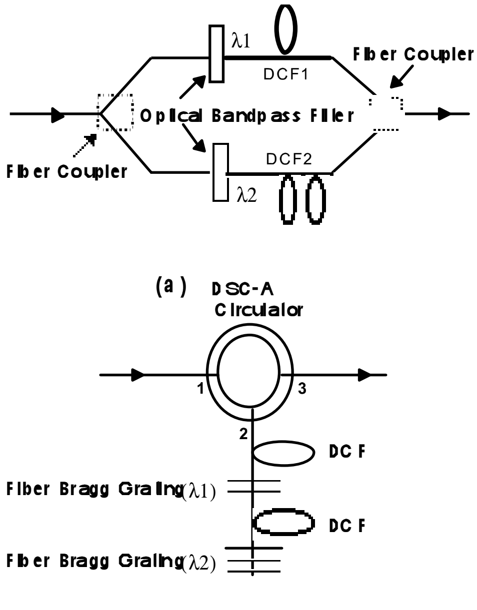
三、結果與討論

The incident soliton pulse with linear frequency chirp is assumed to be of the form $U(z=0, \tau) = \eta_0 \operatorname{sech}(\tau) \exp(-iC_0\tau^2/2)$, where η_0 is the initial pulse amplitude and C_0 =0.5 represents the pre-chirping parameter. The initial pulsewidth of signal $\tau_{FWHM} = 1.763\tau$ =12.5 ps, the bit rate is 20 Gbit/s for the single channel, the average powers are -0.01087 dBm and 0.6632 dBm for λ_1 and λ_2, respectively. We simulate the soliton transmission by using the FPF and the BWF in the DSC-A, and by using the FBG in the DSC-B. We use the 512 pseudo-random bits for the simulations. With the different DSCs, Figs.2(a) and 2(b) show the Q-value versus propagation distance for λ_1 and λ_2, respectively. A 10^{-9} bit-error rate corresponds to Q=6. For a 10^{-9} bit-error rate, the allowed transmission distances are 630 km and 10080 km by using the FPF and the BWF in the DSC-A, respectively. By using the DSC-B, the allowed transmission distance is well beyond 10080 km. If the extra division and combining losses in DSC-A are considered, the performance of DSC-B is much better than DSC-A.

Now we consider a soliton system of 10-Gb/s bit rate and its bit duration $T_d = 100$ ps . The soliton pulsewidth T_s(FWHM) and the transmission distance L_t are varied. We take the carrier wavelength $\lambda = 1.55\,\mu$m, the second-order fiber dispersion $\beta_2 = -0.25\,\text{ps}^2/\text{km}$, the third-order fiber dispersion $\beta_3 = 0.14\,\text{ps}^3/\text{km}$, the Kerr coefficient $n_2 = 2.7\times10^{-20}\text{m}^2/\text{W}$, the effective fiber area $A_{eff} = 50\,\mu\text{m}^2$, and the fiber loss $\alpha = 0.2$ dB/km. The soliton is amplified every 50 km and the spontaneous emission factor n_{sp} of an optical amplifier is assumed to be 1.2. An in-line Fabry-Perot filter is inserted after every amplifier to reduce the amplified spontaneous emission (ASE) noise and noise-induced timing jitter, where the filter bandwidth is optimized. Before the receiver's sampling circuit, a second-order Butterworth electric filter with a narrower bandwidth $\Delta\nu_f$ is used to further reduce noise. The accumulated ASE noise is detrimental for optical amplified long links [6], and the shot noise and thermal noise in the receiver are negligible. The integration duration for calculating the bit energy is T_d and the duration centrum coincides the bit centrum.

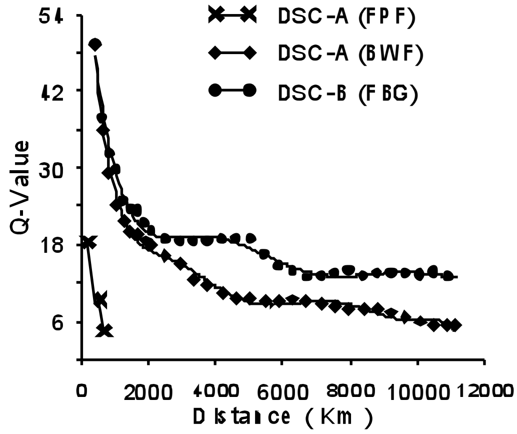
For the integration and dump method, the optimal T_d relates to soliton pulsewidth.We optimize T_d along the transmission distances and the results are shown in Fig. 3(a), where the corresponding system performance Q are also shown. One can see that the optimal T_d increases with pulsewidth. A larger pulsewidth requires a wider integration duration in order to reduce the degradation of Q that is due to noise-induced timing jitter and soliton energy fluctuation. Figure 3(b) shows Q versus T_d for $L_t = 10000$km and $T_s = 10$ps, 15 ps, and 20 ps. One can see that the optimal T_d for the maximum Q factor increases with initial soliton pulsewidth. The optimal $T_d = 32$ps, 44 ps, and 52 ps for $T_s = 10$ps, 15 ps, and 20 ps, respectively.

For the considered cases, the optimal T_d's are about three times of the initial pulsewidths. Again, from the results shown in Fig. 3(b), the Q measured by sampling method are smaller than the maximum Q measured by the integration and dump method. With the integration and dump method, the maximum Q is higher for shorter initial pulsewidth because the signal-to-noise ratio is higher for the soliton of shorter pulsewidth.

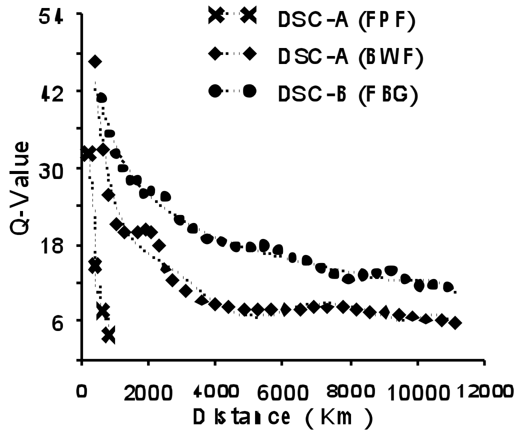


(b) DSC-B

Fig. 1 (a) The dispersion slope compensator-A(DSC-A), used by Suzuki et al. (b) The dispersion slope compensator-B(DSC-B), a new scheme of the dispersion slope compensator.



(a)



(b)

Fig. 2 The Q-value of (a) λ_1- and (b) λ_2-channels in the WDM transmission system with dispersion slope compensation versus propagation distance by using the different DSCs. The DSC-A(FPF), DSC-A(BWF) and DSC-B(FBG) indicate the DSC-A with FPF, BWF and DSC-B with FBG, respectively.

Fig. 3 (a) Optimal integration duration T_d and the corresponding Q factor for different transmission distances for the case of 10-ps soliton. (b) Q factor versus integration duration T_d for 10-Gbit/s bit rate and 10000-km transmission distance. The cases of the soliton pulsewidth T_s=10 ps, 15 ps, and 20 ps are shown.

四、計畫成果自評

We have shown the slope compensator is an effective element for slope dispersion compensation in dispersion map management and the performance of the integration and dump method is better than the sampling method optical soliton transmission system. These methods can be fully implemented to improve the system performance. We expect to further study the adjustable detection window method used in the dispersion map management.

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