Experimental Research on Obtaining DGD from the Degree of Polarization Ellipsoids*

Duan Gaoyan[1,2], Zhang Xiaoguang[1,2], Yu Li[1,2], Zhang Ru[1,2], Yang Bojun[1,2]

1 *Department of Physics, School of Science, Beijing University of Posts & Telecommunications, Beijing* 100876

2 *Key Laboratory of Optical Communication & Lightwave Technologies, Ministry of Education, Beijing University of Posts & Telecommunications, Beijing* 100876

Abstract By using the degrees of polarization (DOP) ellipsoid method, the values of differential group delay (DGD) and the direction of the principal sterte of polarization (PSP) were obtained from limited sampling data in the experiment, which provided the most key factors of the feed-forward compensation scheme. Moreover, the values of DGD obtained from the experiment were accordant with that of the theoretical values when the DGDs were less than 30 ps. Results indicated that DGD and the orientation of PSP could be obtained by using the DOP ellipsoid method in the experiments.

Keywords Optical fiber communication; Polarization mode dispersion; Feed-forward; Degree of polarization ellipsoid; Differential group delay

CLCN TN929.11 **Document Code** A

0 Introduction

Polarization mode dispersion (PMD) compensation has become a hot topic in recent years[1~3]. Most PMD compensation experiments adopted the feedback scheme. However, the feedback technique must adjust excessive control parameters continually, which may trap the controlling algorithm in local sub-maxima. It may expend too long response time and it is also difficult to compensate the high-order PMD totally. Recently, a feed-forward control scheme was, proposed[4]. Moreover, a kind of theoretic model that can compensate the first- and the second-order PMD completely was presented[5]. The feed-forward scheme can avoid this kind of undesirable situations. According to the principles of the feed-forward scheme, PMD information in the fiber link is obtained in advance, and then the feed-forward control algorithm can quickly adjust parameters of a compensator into the desired states. So, the key of the feed-forward scheme is to get PMD information in the fibre link in advance.

In this paper, an experiment was set up to obtain the degree of polarization (DOP) ellipsoids. In terms of the relation between the ellipsoid and PMD information, differential group delay (DGD) and the orientation of the principal state of polarization (PSP) were obtained from ellipsoids, which offered an important factor for the feed-forward PMD compensation.

1 The relation between DOP ellipsoids and DGD

DOP ellipsoids obtained by using a polarization scrambler can determine DGD[6]. The polarization scrambler placed at the fiber input generates the random input states of polarization (SOPs) uniformly distributed over the whole Poincaré sphere. If there is no PMD in the transmission fiber link, the Stokes parameters of the output signals would satisfy the relation $s_0^2=s_1^2+s_2^2+s_3^2$, and DOP=1. All the output SOPs form a perfect sphere in Stokes space with unity radius. For the first-order PMD in the fiber link, the Stokes parameters satisfy the relation $s_0^2>s_1^2+s_2^2+s_3^2$, and DOP<1, with the exception that the input SOP is aligned with one of the PSPs (in this point DOP=1). All the output SOPs form an ellipsoid. These indicate that there is certain relation between DGD and DOP ellipsoids.

If the input signal is regarded as the Gauss shape pulse

$R(\tau)=\exp\left(-\tau^2(\Delta\omega/2)^2\right)$, where $\Delta\omega=1/T_0$ and T_0 is the original pulse width. From the DOP ellipsoid formula[6]

$$\bar{s}_1^2+\frac{\bar{s}_2^2+\bar{s}_3^2}{R^2(\tau)}=1 \tag{1}$$

the relation between the DGD and the axes of the ellipsoid is obtained[7]

*Supported by Corporate Building Project of Beijing Educational Committee (XK100130537) and the National Natural Science Foundation of China (No. 60578043 and No. 60577046)

Tel: 010-62281490 Email: miss_yaner@sohu.com

Received date: 2005-07-12

$$|\tau|=\frac{2}{\Delta\omega}\sqrt{\ln\frac{1}{r_3}} \tag{2}$$

where r_3 represents the shortest axis of an ellipsoid.

2 The experimental setup

Since the equation (2) shows the relation between DOP ellipsoids and the DGD, it is to be expected that DOP ellipsoids can be determined from the output SOPs in order to get DGD. An experiment was designed for obtaining ellipsoids as shown in Fig. 1. A gain-switch distributed feed-back laser was driven externally with a 10Gb/s microwave source for non return-to-zero (NRZ) format generation. A variable time-delay ranging from −40 ps to −70 ps was used as an emulator to generate the DGD. An optical band-pass filter with

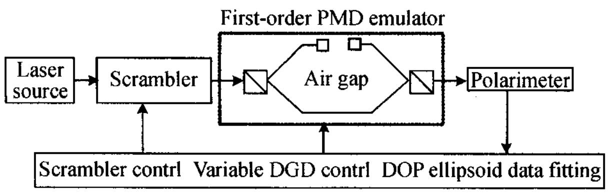

Fig. 1 10Gb/s NRZ experimental system for obtaining DOP ellipsoids

3 dB band - width of 0. 8 nm was used to suppress amplified spontaneous emission (ASE) noise from the erbium-doped fiber amplifier (EDFA). The central wavelength was 1563. 16nm. An in-line polarimeter with analog bandwidth of 700 kHz was used to measure the Stokes parameters S_0, S_1, S_2, and S_3 instantaneously

3 An algorithm for processing sampling data

The output SOPs spread all over an ellipsoid. It was found that it would require at least thousands of SOP sampling data to form an apparent ellipsoid in the experiment. Fig. 2 shows the 8000 sampling points of the output SOPs with different DGD values. However, the more output sampling data are, the longer the time consumed for the PMD compensation. Table 1 shows the time spent for sampling and processing of 8000 data. However, the feed-forward scheme required compensation quickly. It is expected to obtain ellipsoids with sufficient accuracy and with less sampling data.

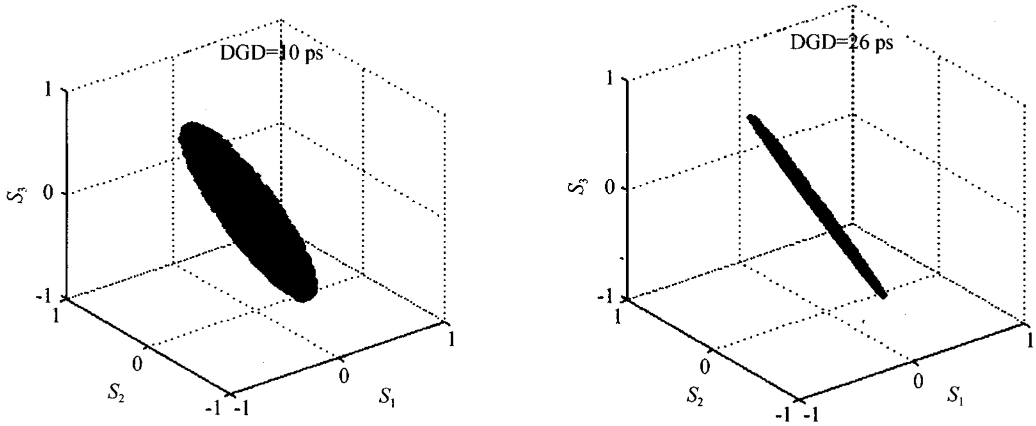

Fig. 2 8000 sampling points of output SOPs with different DGD values

Particle swarm optimization (PSO) algorithm[7] is adopted to settle the problem. An ellipsoid is described with 6 parameters $r_1, r_2, r_3, \alpha, \beta, \gamma$, three radii and three orientation angles as depicted in Fig. 3, A standard ellipsoid equation

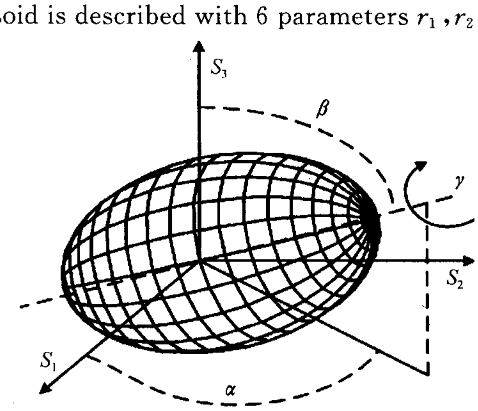

Fig. 3 The orientation of DOP ellipsoids in Stokes space

$$\frac{S'''_1}{r_1^2}+\frac{S'''_2}{r_2^2}+\frac{S'''_3}{r_3^2}=1 \tag{3}$$

is expressed in the principal axis coordinate system $S'''_1-S'''_2-S'''_3$ by three rotations $-\alpha, -\beta, -\gamma$. Thus the problem of obtaining ellipsoids can be described as a problem of finding the minimum of the following function by adjusting 6 parameters $r_1, r_2, r_3, \alpha, \beta, \gamma$.

$$F(r_1, r_2, r_3, \alpha, \beta, \gamma)=\mathop{\mathrm{MIN}}_{(r_1, r_2, r_3, \alpha, \beta, \gamma)}\left\{\sum_{n=1}^{N}\left|\frac{S'''_{1n}}{r_1^2}+\frac{S'''_{2n}}{r_2^2}+\frac{S'''_{3n}}{r_3^2}-1\right|\right\} \tag{4}$$

where N is the number of sampling SOP data. As long as the function in the parenthesis is close enough to zero, the corresponding $r_1, r_2, r_3, \alpha, \beta, \gamma$ are the right parameters that determined the DOP ellipsoid.

Only 100 sampling data was collected in the experiment. PSO algorithm searches and gathers these sampling data to obtain DOP ellipsoids. The Table 1 compared the time spent for obtaining ellipsoids from 100 sampling data with that from 8000 sampling points. Results indicated that the searching algorithm is effective.

Table. 1

DGD/ps	Sampling points	Spent time/s	$\alpha/(°)$
10	8000	3.0750	—
	100	1.278	58.289
26	8000	3.014	—
	100	1.249	57.650

4 Results and discussion

DOP ellipsoids are obtained from selected 100 sampling data. As shown in Fig. 4, the unequal DGDs accompanied DOP ellipsoids with different shapes. An ellipsoid is formed when the DGD is 1 0 ps. And a needle - like spheroid comes into being

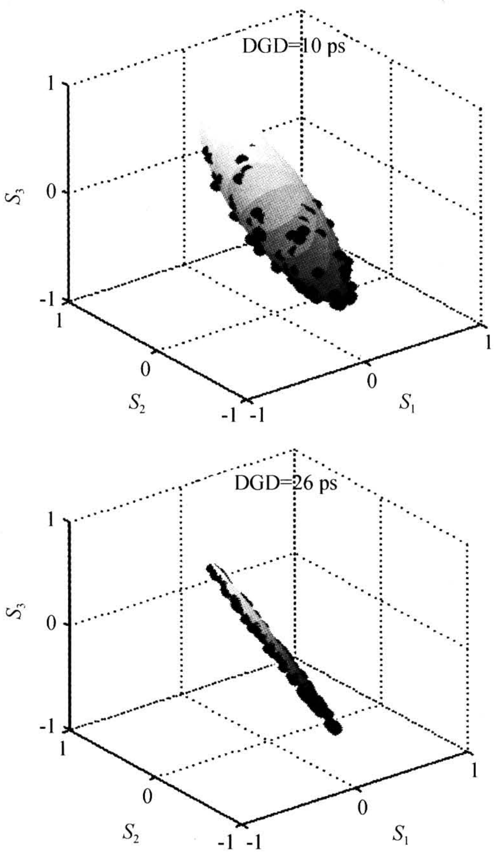

Fig. 4 Sampling points (black dots) from the experiment and the DOP ellipsoids (curve line) obtained by using PSO algorithm

with DGD equal to 2 6 ps. The figure also shows that the orientations of both the ellipsoids are invariable for different DGDs. The direction of the changeless gradient is the direction of the PSP.

The Table. 1 gived the direction of PSP, α. PSP is not given from 8000 sampling data because the calculation would spend much more time by itself. It was not fit for the PMD compensation. While PSO was applied, the values of α and DOP ellipsoids were obtained at the same time. And the values of α with the different DGDs were identical.

DGD values were gotten with the equation (2). In Fig. 5, the solid curve was the theoretical results and the dotted curve was the experimental results. When DGD was small, the measured DGD values accorded with the DGDs of the variable delay line. However, the deviation appears when the values of DGD were larger than 10 ps. And the maximal gap was 3 ps, which was derived from the approximate disposal of the equation (2). And the imprecise instruments and incorrect operation might also lead to the error.

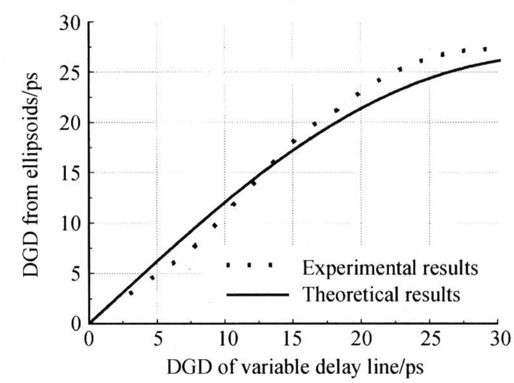

Fig. 5 DGDs obtained from the ellipsoid in the experiment versus DGDs of the variable time-delay

In addition, the two curves are parallelled with the same trend, which meant that the DGDs obtained from the experiment were correct. However, the curves deflected along the same direction when the DGD value is larger than 30 ps. It meant the model of DOP ellipsoids is likely to be not fit for the large DGDs.

5 Conclusion

DOP ellipsoids are gotten from limited sampling data in the experiment. From the ellipsoids, it obtain the direction of PSP and the DGDs which have the good linear relation with the DGD values of the theoretical values. DOP ellipsoid method is effective on obtaining DGD and PSP when DGD is less than 30 ps.

References

1 Zhang Xiaoguang, Yu Li, Zheng Yuan, *et al*. An experiment of adaptive polarization mode dispersion compensation for optical communication systems. *Acta Photonica Sinica*, 2003, **32**(12): 1474～1478

2 Zhou Guangtao, Zhang Xiaoguang, Shen Yu, *et al*. The first-order PMD adaptive compensation experiment in 10 Gb/s optical communication system. *Acta Photonica Sinica*, 2004, **33**(4): 448～451

3 Shen Yu, Zhou Yaping, Zhou Guangtao, *et al*. An adaptive algorithm for dynamic polarization mode dispersion compensation and its realization. *Acta Photonica Sinica*, 2004, **33**(11): 1351～ 1355

4 Chou P C, Fini J M, Haus H A. Demonstration of a feed-forward PMD compensation technique. *IEEE Photon Technol Lett*, 2002, **14**(2): 161～163

5 Phua P B, Haus H A. Deterministic approach to first- and second-order PMD compensation. *IEEE Photon Technol Lett*, 2002, **14**(9): 1270～1272

6 Zheng Y, Zhang X G, Chen L, *et al*. Analysis of degree of polarization ellipsoid as feedback signal for polarization mode dispersion compensation in NRZ, RZ and CSRZ systems. *Opt Commun*, 2004, **234**(1-6): 107～117

7 Sylla P M. Richardson C J K, Wanleeuwen M, *et al*. DOP ellipsoids for systems with frequency-dependent principal states. *IEEE Photon Technol Lett*, 2001, **13**(12): 1310～1312

前馈PMD补偿实验中从偏振度椭球获得差分群时延的研究

段高燕[1,2] 张晓光[1,2] 于 丽[1,2] 张 茹[1,2] 杨伯君[1,2]

(1 北京邮电大学理学院,北京 100876)

(2 北京邮电大学光通信与光波技术教育部重点实验室,北京 100876)

收稿日期:2005-07-12

摘 要 运用偏振度(DOP)椭球法从实验的有限样点数据中获得了差分群时延和偏振主态方向,这为前馈补偿实验提供了最关键的技术因素.在实验中获得了偏振主态方向和DGD,而且当DGD较小时,从实验所获得的DGD值与理论模拟的变化趋势基本一致.结果表明当DGD较小时,可以用偏振度椭球法从实验上得到正确的DGD和偏振主态方向.

关键词 光纤通信;偏振模色散;前馈;偏振度椭球;差分群时延

Duan Gaoyan was born on August 27, 1976 in Shandong, China. Now she is pursuing her Ph. D. degree in the school of science of Beijing University of Posts and Telecommunications. Her main research focuses on the study of polarization mode dispersion in high-speed optical fiber communications.