Experiments of PMD Compensation Using Electrical Feedback Signals for a 10Gbit/s System*

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Abstract Electrical power, changing with differential group delay (DGD) and detected from an optical communication link, can be used as feedback signals of compensating for PMD. Theoretical calculations and curves are given representing the change of electrical power with DGD. Experimental results confirming the theoretical calculations are presented for voltage V changing with DGD. A setup is built for experiments of PMD compensations. Several factors affecting the feedback signals are proposed and methods are given to make the fluctuations less. Results of PMD compensation prototype for a 10 Gb/s pseudo random sequence are shown through eye patterns. These results are also shown by receiver sensitivity improvements after compensation. Receiver sensitivity under 3 different bit error rates are measured using BER measuring equipment. Comparisons of results using different fibers are made, confirming the effectiveness of compensation.

Keywords Optical fiber communications; Polarization mode dispersion; Polarization control; Differential group delay; Electrical feedback signals

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0 Introduction

Polarization Mode Dispersion (PMD) causes pulse broadening because of the difference in speed between two polarized modes in optical fiber communication systems. It limits upgrading of bit rates and span of relay distances. Solving PMD problem is the key to realizing optical long-haul transmission systems and becomes one of the most important considerations. The difficulty of dealing with PMD lies in its random changes in differential group delay (DGD) between the principal states of polarization (PSP) and the change in PSP itself with time and wavelength[1,2].

So far one of the most effective ways of handling polarization mode dispersion is to perform dynamic compensation for it. Several schemes are presented for this purpose[3,4]. The important factors affecting the results of compensation are feedback signals from optical fibre lines with PMD, algorithm of control, and compensation elements. Using feedback signals changing with PMD, one would design an algorithm of controlling compensation elements to maximize the feedback signals, which corresponds to the minimum of PMD in actual optical fibre lines, thus decreasing the effects of PMD. But the difficulty of designing an algorithm of control is the constant fluctuations in detected voltage as a feedback signal, thus causing the well known 'sub-maximum'. Followings are some of the means for solving some of the problems of compensation for PMD.

1 Theoretical calculations and experimental measurements of feedback signals

Researches[5,6] have shown that as the differential group delay (DGD) increases, the electrical power spectrum density p within a certain frequency range increases correspondingly. p is also related to an optical power split radio γ between principal states of polarization (PSPs) in a fibre. A well known formula has been given as follows

$$p(\omega_e, \Delta\tau, \gamma) \propto 1 - 4\gamma(1-\gamma)\sin^2\frac{\omega_e\Delta\tau}{2} \qquad (1)$$

Where $\Delta\tau$ indicates DGD, γ is the power splitting ratio between two PSPs, and ω_e is the central angular frequency of electrical signal. $p(\omega_e, \Delta\tau)$ represents the relationship between the power spectrum density at frequency ω_e and γ as well as $\Delta\tau$. The relationship is clearly illustrated in Fig. 1.

Within integral limits $\omega_e - \Delta\omega$, and $\omega_e + \Delta\omega$, the electrical power can be written as[7]

$$P(\Delta\tau, \gamma) = \frac{R^2}{4T_0}\int_{\omega_e-\Delta\omega}^{\omega_e+\Delta\omega}\frac{\sin^2(\omega T_0/2)}{(\omega T_0/2)^2}\cdot \left[1 - 4\gamma(1-\gamma)\sin^2\frac{\omega\Delta\tau}{2}\right]\mathrm{d}\omega \qquad (2)$$

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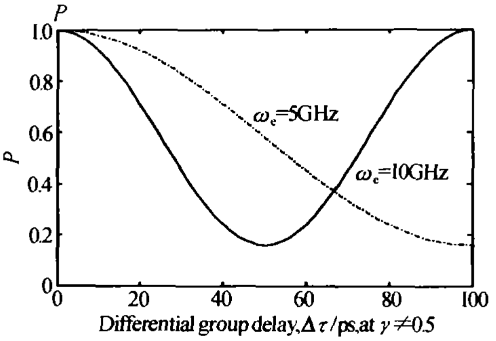

Fig. 1 Theoritical calculation of p with ω_e, γ and $\Delta\tau$

where $\Delta\omega$ is the frequency range, within which the electrical power is extracted as feedback signals. ω_e and $2\Delta\omega$ corresponds to the central angular frequency, as shown in fig. 1, and bandwidth of a radio amplifier used in a feedback signal extracting scheme, respectively. T_0 is time slot of a bit and R the responsiveness of a photodiode. The results of the integral are well explained[7].

Fig. 2 gives experimentally the change of electrical power with differential group delay, which ranges from 0 to 120 ps. The time change in picosecond is controlled electronically. It matches closely with theoretical calculation of fig. 1 for ω_e = 5 GHz. Fig. 3 shows another experimental result using a differential group delay line, with a time delay ranging from −40 to 60 ps. The detected signal is amplified to a level of Volts. It also shows how voltage changes with differential group delay. The signal acts as a feedback signal of compensation for PMD. The results shown in Fig. 3 are averaged data of 3 measurements.

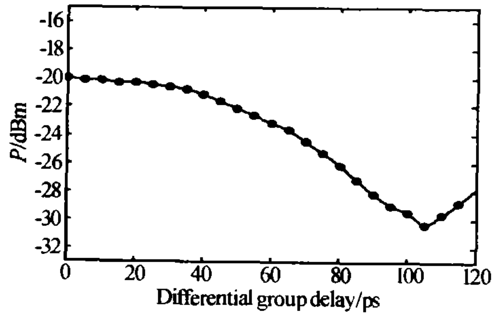

Fig. 2 Changes of electrical power with DGD

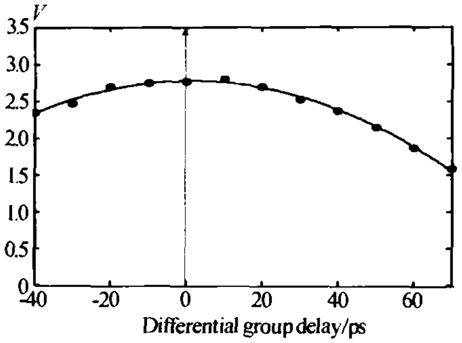

Fig. 3 Detected voltage as feedback signal with DGD

There is a fluctuation in voltage as a differential group delay line moves, because the device introduces a change in insert loss. Other changes may also give fluctuations in feedback signals. It is this fluctuation that makes it quite difficult for an algorithm to find a maximum voltage corresponding to a minimum differential group delay, instead of sub-maximum voltage.

2 Set-up for experiments of compensation for PMD

The scheme uses voltages as feedback signals and it consists of 4 parts. The light emiting system gives light pulses modulated by a LiNbO$_3$ modulator, sending 10 Gb/s pesudo random sequences, with an output power of 1.4 dBm. The light is amplified by an EDFA and sent to an emulator which simulates PMD variations, with 2 sections of optical delay elements providing about 16 to 60 ps of differential group delay and providing changes of principal states of polarization.

The compensation part consists of 2 elements, a polarization controller and an optical differential group delay line, as shown in the Fig. 4. The former matches the principal states of polarization of the emulator with a DGD line and the latter compensates for changes in DGD introduced by the emulator. The last part of the whole system is feedback control signal extracting circuits, which are made up of a photodiode, an amplifier, a bandpass filter, a detector, and a control algorithm. The voltage from the detector changes with DGD, which is the combination of the emulator and the optical delay line.

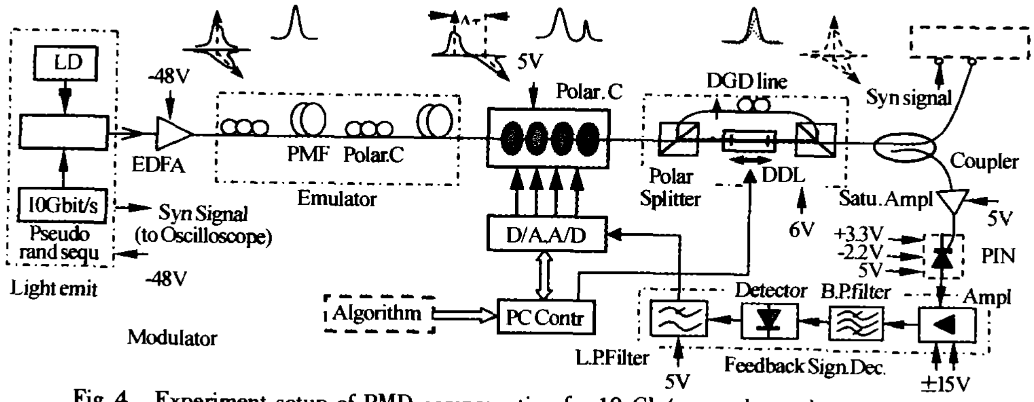

Fig. 4 Experiment setup of PMD compensation for 10 Gb/s pseudo random sequences

Under a certain ranger of DGD, the voltage decreases as the total DGD increases, shown in Fig. 3. That is the main machemism of compensation for PMD. To get known what contributes to the fluctuations of feedback signals, several factors are investigated. These are electrical power stability, optical dependence loses of optical couplers, polarization controller, insert loss change of optical delay line, algorithm of control, etc. Sub-maximum problem arises when light power is not stable even as the DGD keeps constant. If the photodiode detects a change in light and the voltage changes are caused not by DGD but other reasons, the control algorithm does not know what is happening. The algorithm will be made confused of whether the change in feedback voltage is caused by DGD. To overcome all these changes caused by other factors than DGD, a saturate amplifier may be inserted before the photodiode. With it the voltage will change with DGD monolithically.

3 Experimental results

With measures taken as stated above and a proper algorithm of control, some of the results of compensation for PMD are observed. An eye pattern is one of the ways showing the effects of PMD compensation. Therefore, some eye patterns are given as follows with and without compensation. Fig. 5 shows the results of compensation for PMD with the system stated above. Fig. 5 (a) is set by adjusting the polarization controller within the emulator. The eye pattern opening becomes wider after the compensation system starts to work.

The other way of evaluating the effects of compensation is to measure the receiving sensitivity under the condition of fixed bit error rate, by using an error rate measuring equipment. The measurement gives the power penalty before and after compensation. Measurement shows that the system compensates most of the degradation caused by PMD . Under a fixed BER of 10^{-7}, 10^{-8} and 10^{-9}, the measured receiving sensitivity of back to back test is −20.3 dB, −19.93 dB, −19.59 dB. When an emulator is inserted, corresponding values are −19.31 dB, −19.15 dB, −18.51 dB, respectively, showing a channel penalty as 0.99 dB, 0.78 dB and 1.08 dB, accordingly. With PMD compensation system working, the receiving sensitivity of compensation is −20.06 dB, −19.78 dB, −19.48 dB, with a recovery of 0.75 dB, 0.63 dB and 0.97 dB and a channel penalty being only 0.24 dB, 0.15 dB, and 0.11 dB. The effectiveness of compensation is obvious. Data of channel penalty or the differences between the receiving sensitivity are compared with and without compensation. With the penalty getting larger, the compensated recovery is getting better, as well. When the penalty is 0.89 dB, the system recovers to 0.11 dB.

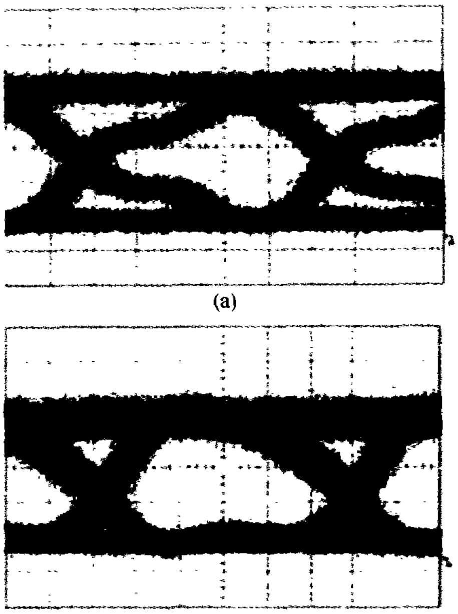
(a)
(b)

Fig. 5 Eye patterns with and without compensation

Fig. 6 shows the procedure of adjustment when the algorithm works. Fig. 6 (a) is the initial state when a polarization controller in the emulator is rotated. Fig. 6(b) shows the diagram is getting better and (c) the final results after compensation.

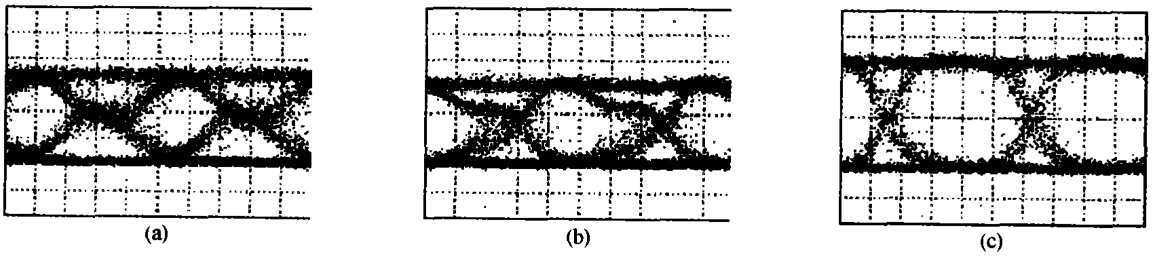
(a) (b) (c)

Fig. 6 Procedure of compensation for PMD

4 Conclusions

Using electrical power as a feedback signal for PMD compensation shows effectiveness in recovering receiver sensitivity and reducing channel penalty. Eye patterns also give a wider opening when PMD compensation is effectuated. To have a fast compensation, one should consider the response time of an optical delay line. The delay line used in the experiment is not fast enough. When a large DGD is needed of the delay line, it takes longer time to move the delay line to a proper position, which is sometimes not allowable. For a polarization controller, a range of phase changes should be large enough to avoid an instantaneous change of state of polarization of output optical signals.

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用电功率反馈控制信号实现 10Gbit/s 系统的 PMD 补偿实验

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摘　要　光纤通信线路检测到的电功率随差分群延迟变化,可以作为 PMD 补偿的反馈控制信号.给出了这一变化关系的理论计算和曲线并通过实验验证这一关系,确定电压信号与 DGD 的变化关系.建立了一套完整的实验系统,并考虑了影响反馈电压信号的多种因素以及减小这些影响的措施.眼图给出的实验结果说明了补偿的效果,还利用误码测试仪测量了补偿前后的接收灵敏度的改变以定量说明补偿的效果,最后比较了不同情况下的补偿结果.

关键词　光纤通信;偏振模色散;偏振控制;差分群延迟;反馈控制信号

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