

Impact of polarization dependent loss in the presence of polarization mode dispersion on the optical network

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Abstract—We investigate the behaviour and impact of polarization dependent loss (PDL) in the presence of polarization mode dispersion (PMD) in an optical network. PDL and PMD degrade the optical transmitted signal and therefore limit the system performance. Besides measuring PMD by the Jones matrix eigenanalysis (JME) method, we also determined it from the fast Fourier transform (FFT) of the PDL data and the results are compared. Long term PDL measurements are conducted which show that PDL changes significantly with wavelength and varies only slightly with time.

Index terms – polarization dependent loss, polarization mode dispersion

I. INTRODUCTION

The increase in bit rate, 10 Gb/s and above, results in increasing influence of polarization effects on the bit error rate (BER) [1]. The main polarization effects are polarization dependent loss (PDL) and polarization mode dispersion (PMD). PDL is defined as the maximum change in the optical power transmitted through an optical component over all possible states of polarization (SOPs) [2]. PMD is defined as the relative time delay between the fast and slow principal states of polarization (PSPs) in optical fibres [3]. The combined PDL and PMD cause large power fluctuations, degrade the optical signal to noise ratio (OSNR) and consequently increase the bit error rate (BER) [4]. Researchers have up until recently, focused on the effect of PDL [5] and PMD [6] separately. Since both PDL and PMD are present in optical links, they should be addressed jointly.

The impact of PDL on a PMD link [7, 8] has been investigated. In this paper we show how the presence of PMD causes PDL to vary with wavelength, resulting in increased signal impairments. We take advantage of the wavelength-dependent PDL to deduce PMD information through the fast Fourier transform (FFT) method.

PMD has been found to be statistical and irreproducible with time [9]. This is attributed to the variation of external perturbations such as temperature, wind and other vibrations induced in aerial and buried fibres. This statistical behaviour impact the telecommunication network as it leads to signal distortions. Since some factors affecting PMD also affect PDL [10] and PMD also influence PDL [11] [12], it is

therefore necessary to monitor PDL over time to observe the statistical behaviour of PDL. We present in this paper PDL measurement over a 4 hour period on a laboratory spool and deployed buried single mode cable.

II. MEASUREMENT METHODS

In order to address the impact of PDL and PMD on an optical network, accurate measurement techniques should be implemented [13]. In our experimental set up the frequency domain JME method is used to measure PMD and PDL over a wavelength range of 1520 to 1570 nm. This method incorporates a tuneable laser source, polarization controller and polarization analyzer [13, 14]. The PDL and PMD of a system are obtained by launching three states of polarization (SOPs) at the input and the corresponding output SOPs analyzed.

III. RESULTS AND DISCUSSION

The influence of PMD in a PDL link was investigated by maintaining a constant PDL but varying the PMD. In Fig. 1, the spectrum of a PDL element (in this case a 1×2 splitter) with a PDL magnitude of 0.2 dB is shown. Maintaining the magnitude of the PDL element constant, PMD is introduced in increment of 2.21, 3.15, and 5.45 ps. The PMD was increased by adding in a polarization maintaining fibre (PMF) of a specific length. It can be seen from Fig. 1 (a-d) that the frequency of PDL fluctuations depends on the magnitude of the PMD introduced. The highest fluctuation rate of PDL is observed for highest value of PMD (5.45 ps).

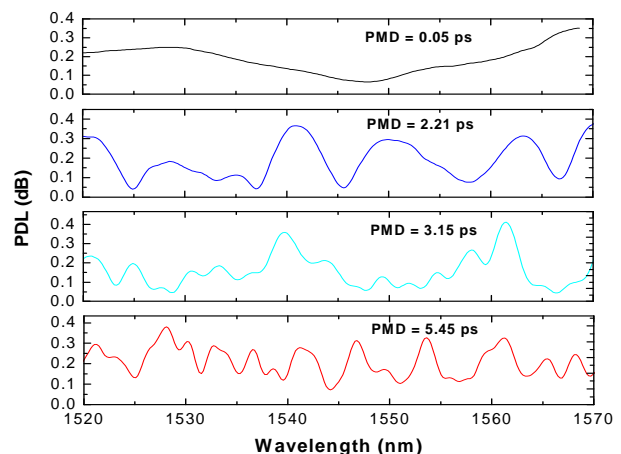


Fig. 1: The PDL spectrum in the order of increasing magnitude of PMD from 0.06 ps to 5.45 ps, for a 0.2 dB PDL element (1×2 splitter).

Therefore PMD in a PDL environment will lead to high wavelength-dependent PDL which leads to an increase in signal fluctuations.

Because of the wavelength dependence of PDL due to PMD, a fast Fourier transform (FFT) can be applied to the PDL data, from which the PMD information can be inferred.

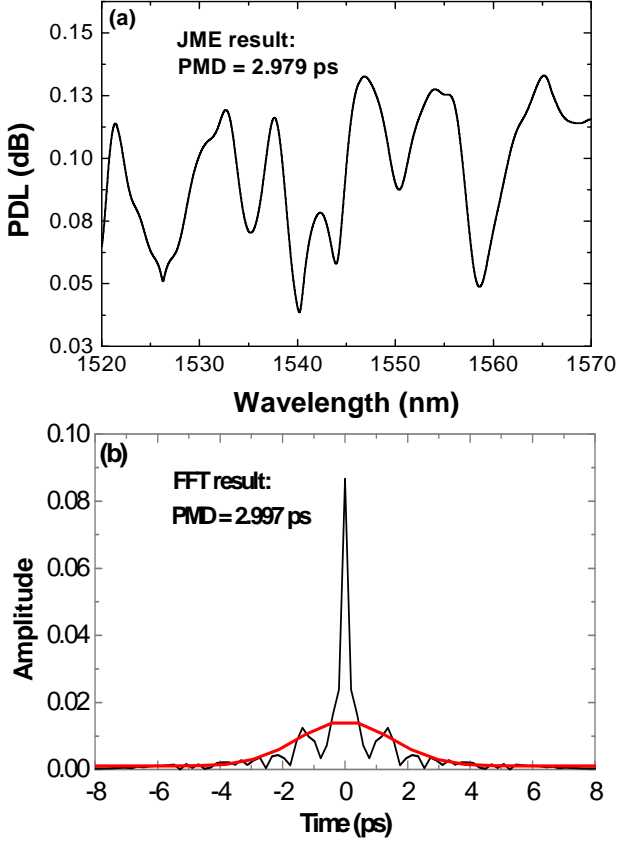


Fig. 2: (a) PDL versus wavelength and (b) its FFT of the concatenation of a PMD and a PDL element.

The JME gave a PMD of 2.979 ps while the FFT gave a PMD of 2.997 ps, which is a difference of 0.6 % within experimental error. The FFT method is based on the fact that a PDL element in a PMD environment becomes a statistical quantity that varies with wavelength. In deployed optical fibres variations in birefringence and mode coupling distributions also contribute to PDLs' statistical nature, increasing the signal impairment.

The two methods are further compared using other optical devices. Results are shown in Table 1. As expected, the PMD results from the JME and FFT methods compared very well. Therefore, we can conclude that this technique is an alternative method for determining PMD from PDL, which confirms the impacts of both PMD and PDL in an optical network. The standard deviation for the PMD obtained using the FFT method is higher than that of the PMD obtained using the JME method. The satellite peaks are the ones that contain PMD information, while the central peak carries no information related to the PMD.

Table 1: PMD values obtained from the JME and the FFT of the PDL data

Device	PMD from JME (ps)	PMD from FFT (ps)
50:50 1x2 splitter	0.050 ± 0.005	0.062 ± 0.020
Isolator	0.135 ± 0.002	0.137 ± 0.080
Attenuator	1.113 ± 0.011	1.126 ± 0.180
Single mode fibre1	2.979 ± 0.021	2.997 ± 0.233
Single mode fibre2	7.008 ± 0.341	7.142 ± 0.642

We performed simulation using VPI Transmission Maker modeling software to illustrate the impact of both PDL and PMD through visualizing the eye diagrams. The eye diagram is a superposition of pseudo-random patterns consisting of zeros and ones of the transmitted bits. An open eye indicates undistorted signal while a closed eye shows highly distorted transmitted signal. This is represented in Fig. 3.

The eye diagrams corresponding to combination of PDL values (0 and 3 dB) and PMD values (0 and 1.5 ps) were generated through a simulated link. The largest eye opening,

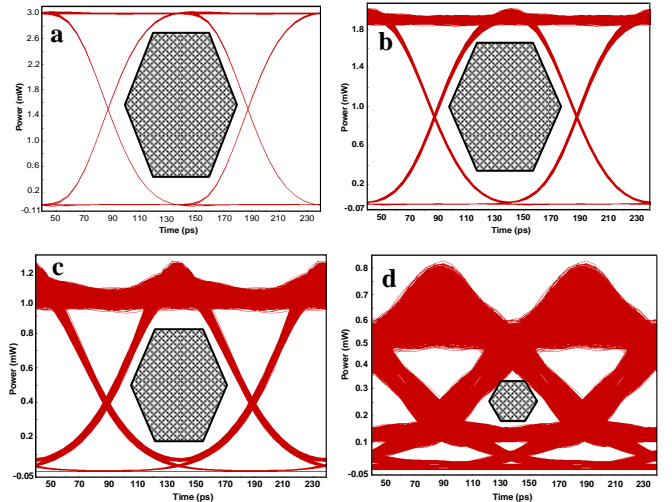
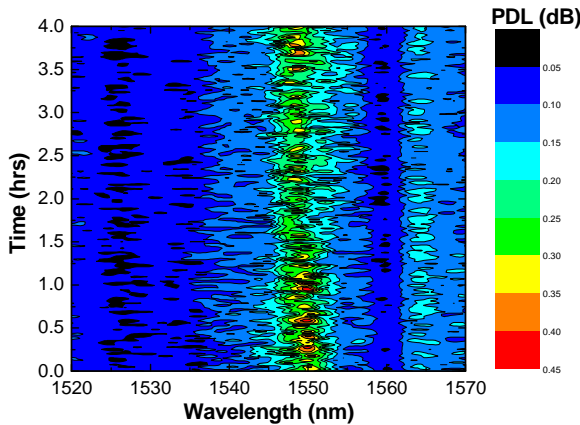


Fig. 3: A simulation of eye diagrams for optical transmission network with (a) no PMD and PDL (b) PDL of 3 dB and 0 ps PMD (c) PDL of 0 dB and 1.5 ps PMD, and (d) PDL of 3 dB and 1.5 ps PMD.

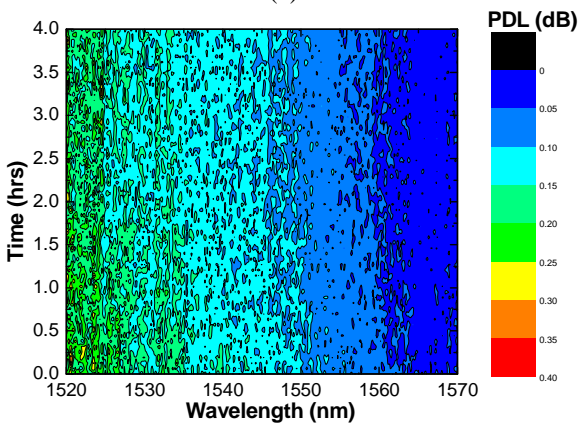
represented by the shaded part, are observed when the effects of PMD and PDL are set to zero (Fig. 3 a). When 3 dB PDL is added, the upper section of the eye is distorted and the shaded region is reduced (Fig. 3 b). The addition of 1.5 ps PMD (PDL = 0 dB) leads to a highly distorted eye as represented by Fig. 3 c and the shaded region is reduced. Both the presence of PMD and PDL lead to the complete closure of the eye as represented by Fig. 3 d. This would indicate a very high bit error rate (BER). It can be seen that the combined effect of PDL and PMD results in a much higher signal distortion than each individually.

PDL is usually measured over a range of wavelengths at a given time. Since the factors affecting PDL can also vary with time, it is therefore necessary to monitor PDL per given wavelength as time changes. We performed four hour PDL measurements on a 24.74 km fibre spool and a 28.8 km buried fibre. Figure 4 (a) and (b) show the contour maps of the measured PDL respectively. Both figures show PDL changing slightly with time and significantly with wavelength.

In Fig. 4 (a) the small changes of PDL (step size 0.05 dB) with wavelength is attributed to the changing birefringence within sections of the single mode fibre. This birefringence splits the polarization modes that travel along the fiber which result in increased signal distortions.



(a)



(b)

Fig. 4: Contour plots of PDL as a function of time and wavelength for (a) fibre spool and (b) buried cable.

The change of PDL with time is very minimal. This could be attributed to the lack of external perturbations such as temperature which can induce birefringence and mode coupling. In addition, the JME method is highly sensitive to any disturbances (movements, vibrations etc.). We therefore believe small disturbance on the fibre during measurements also contributed to the slight PDL changes.

The same reasoning can be applied to Fig. 4 (b). PDL remained constant with time while changing with wavelength. This is due to the fact that buried fibres are in a stable environment. Therefore further long term PDL studies needs to be conducted for PDL measurements in buried cables. This stable environment means that the four hour period is insufficient to fully monitor the PDL evolution of the fibre due to slow temperature changes.

III. CONCLUSIONS

The presence of PMD in a PDL environment results in PDL being wavelength dependent. The greater the PMD magnitude the more wavelength dependence PDL becomes. This PDL wavelength dependence due to PDL-PMD interaction allows one to calculate PMD from the PDL data through the FFT method. A good agreement was found between the JME and FFT methods. Simulations show that PDL-PMD interactions increased signal distortions and consequently high bit error rates. PDL varies significantly more with wavelength than with time for a laboratory fibre spool and deployed buried fibre. This is because PDL variations with wavelength are due to birefringence and mode coupling changes along the length of the fibre.

The PDL change with time is small due to limited temperature changes that cannot excite significant birefringence changes. Therefore longer time PDL measurements are to be conducted in future. These results indicate the importance of fully addressing the impacts of PMD and PDL which will assist in devising appropriate measures for their active emulation and compensation.

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REFERENCES

- [1] N. Gisin and B. Huttner, "Combined effects of polarization mode dispersion and polarization dependent losses in optical fibres," *Optics Communications*, vol. 142, pp. 119-125, 1997.
- [2] R. M. Craig, S. L. Gilbert and P. D. Hale, "High-resolution, nonmechanical approach to polarization-dependent transmission measurements", *Journal of Lightwave Technology*, vol. 16, no. 7, pp. 1285-1294, 1998.
- [3] N. Gisin, J. P. von der Weid and J. P. Pellaux, "Polarization mode dispersion of short and long single mode fibres", *Journal of Lightwave Technology*, vol. 9, no. 7, pp. 821-827, 1991
- [4] A. Sivasubramanian, and V. C. Ravichandran, "Pulse narrowing in optical fibre with polarization mode dispersion and polarization-dependent loss for different input states of polarization", *Optical Engineering*, vol. 46, no. 2, pp. 025010-1-025010-5, 2007.
- [5] A. El Amari, N. Gisin, Beat Perny, H. Zbinden, and Christian W. Zimmer, "Statistical Prediction and Experimental Verification of Concatenations of Fiber Optic Components with Polarization Dependent Loss", *Journal of Lightwave Technology*, vol. 16, no. 3, pp. 332-339, 1998.
- [6] C. D. Poole and R. E. Wagner, "Phenomenological Approach to Polarization Dispersion in Long Single-Mode fibres", *Electronics Letters*, vol. 22, no. 19, pp.1029-1030, 1986.
- [7] A. E. Willner, S. M. Reza Motaghian Nezam, L. Yan, Z. Pan and M. C. Hauer, "Monitoring and Control of Polarization-Related Impairments in Optical Fiber

- Systems”, *Journal of Lightwave Technology*, vol. 22, no. 1, pp. 106-125, 2004.
- [8] N. Y. Kim, D. L. Lee, H. Yoon, J. Park and N. Park, “Limitation of PMD Compensation Due to Polarization-Dependent Loss in High-Speed Optical Transmission Links”, *IEEE Photonics Technology Letters*, vol. 14, no. 1, pp. 104-106, 2002.
- [9] N. Gisin and J. P. Pellaux, “Polarization mode dispersion: Time versus frequency domains”, *Optics Communications*, vol. 89, pp. 316-323, 1992.
- [10] P. Lu, L. Chen and X. Bao, “Statistical Distribution of Polarization-Dependent Loss in the Presence of Polarization-Mode Dispersion in Single-Mode Fibers”, *IEEE Photonics Technology Letters*, vol. 13, no. 5, pp. 451-453, 2001.
- [11] S. Yang, L. Chen and X. Bao, “ Wavelength dependence study on the transmission characteristics of the concatenated polarization dependent loss and polarization mode dispersion elements”, *Optical Engineering*, vol. 44, no. 11, pp. (115006) 1-5, 2005.
- [12] B. Huttner, C. Geiser and N. Gisin, “Polarization-Induced Distortions in Optical Fiber Networks with Polarization-Mode Dispersion and Polarization-Dependent Losses”, *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 6, no. 2, pp. 317-329, 2000.
- [13] D. Derickson (editor), “Fibre Optic Test Measurement”, Prentice Hall, 1998.
- [14] B. L. Heffner, “Automated measurement of polarization mode dispersion using Jones matrix eigenanalysis,” *IEEE Photonics Technology Letters*, vol. 4, no. 9, pp. 1066-1068, 1992.

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