The Correlation of Polarization Dependent Loss and Differential Attenuation Slope

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Abstract: The relationship between polarization dependent loss (PDL) and differential attenuation slope (DAS) is investigated in a PMD emulator and field fiber. A model is proposed and system impact issues are discussed.

1 Introduction

Differential group delay (DGD) is a time delay at a discrete frequency between the fastest and slowest modes of an optical signal. This randomly varying delay causes optical pulses to broaden and hence bit errors. Polarization mode dispersion (PMD) is the mean of DGD over all frequencies. Polarization dependent loss (PDL) is normally ignored when dealing with PMD. However, PDL interacting with PMD causes the fast and slow modes to become non-orthogonal\cite{[1]}. This non-orthogonality is related to the imaginary part of the principal state of polarization (PSP) vector or differential attenuation slope (DAS). In this summary we investigate the relation between PDL and DAS.

2 Theory

The complex PSP vector can be described as $\vec{W} = \vec{\Omega} + i \vec{\eta}$ in Stokes Space\cite{[2]}. The DGD is the real part of the PSP vector magnitude $\Delta \tau = \text{Re} \sqrt{\vec{W} \cdot \vec{W}}$. A new quantity called differential attenuation slope (DAS) is defined, as the imaginary part of the PSP vector magnitude $\Delta \eta = \text{Im} \sqrt{\vec{W} \cdot \vec{W}}$. This is what we will correlate to PDL. PDL is simply defined as $10 \log_{10}(P_{\text{max}}/P_{\text{min}})$ over all polarization states, where $P$ is the optical power.

3 Experiment and Model

Figure 1a shows a PDL vs. DAS intensity scatter plot of a 52 km (46 km buried and 6 km aerial) field fiber. Measurements were taken every 2 minutes for 1000 minutes. A commercial test set implementing the Poincaré sphere\cite{[3, 4]} and Jones matrix methods was used to collect all experimental data. The test set collected data every 0.03 nm between 1525 and 1610 nm. The field fiber has a mean PMD of 1.21 ps and a mean PDL of 1.18 dB. Figure 1b shows a numerical model of the field fiber. The model\cite{[2]} consisted of 40 birefringent fiber sections randomly coupled with mean PMD and PDL values matching the field fiber. 10000 realizations were performed. General agreement is obtained with the field fiber.

Figure 2a shows a PDL vs. DAS intensity scatter plot of a PMD emulator. The emulator consisted of 7 polarization maintaining fiber sections randomly spliced together. The emulator was placed in an oven and the temperature was varied to change the PSP vector. Measurements were taken every 2 minutes for 500 minutes. The emulator has a mean PMD of 0.869 ps and a mean PDL of 1.21 dB. Figure 2b shows an identical numerical model as used previously, but with mean PMD and PDL values matching the emulator. The model does not agree well with the emulator which could be due to the fact that one does not use the
true emulator make-up in the model. Irrespective, the emulator over-estimates the proper amount of DAS. This shows that standard PMD emulators are not the ideal way to investigate PDL and DAS.

Figure 3 shows a simulation of the width of the Gaussian DAS function changing with varying amounts of PMD and PDL. The width of the DAS distribution is found to increase linearly with PMD (if plotted on a linear scale).

4 Discussion and Conclusion

Correlations between DAS and PDL were investigated experimentally. A numerical model was implemented that reasonably agreed with the experimental findings. The experimental correlations show the DAS slightly biasing toward negative values. The DAS bias was found to increase as the mean PMD increased when verified with other measurements. From the highly mode coupled model we would expect the DAS to be symmetric about 0. This could be an artifact of the test set.

DAS has been observed in all field fiber cables we have measured. DAS is usually neglected in commercial PMD test sets. Optical pulses in systems with DAS will undergo different attenuations at different frequencies across the pulse. Pulse degradation will occur. DAS must be considered in PMD compensation schemes. The PDL induced non-orthogonality between fast and slow modes means that conventional PMD compensation techniques, like PSP transmission, will not be as effective as compared with zero PDL.

Fig. 1. Field Fiber (a) with mean PMD=1.21 ps and mean PDL=1.18 dB. Numerical Simulation (b) of Field Fiber with 40 fiber sections and 10000 realizations.

References
Fig. 2. PMD emulator (a) (7 PM fiber sections) with mean PMD=0.869 ps and mean PDL=1.21 dB. Numerical Simulation (b) of PMD emulator with 40 fiber sections and 10000 realizations.

Fig. 3. The width of DAS vs. PMD for varying amount of PDL. The width of the DAS distribution increases linearly with PMD.