First and second order PMD statistical properties of installed fiber

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Abstract

We present for the first time, long term statistical characteristics of second order PMD over installed fiber and investigate the correlation between first and second order PMD. We show that the wavelength-averaged SOPMD increases linearly with the wavelength-averaged DGD.

Introduction

The difficulty in compensating polarization mode dispersion (PMD) is largely because of its statistical nature. Therefore, it is essential to understand the statistical characteristics of first and second order PMD for high bit rate transmission systems. As PMD varies with temperature, stress, and other extrinsic perturbations, the statistical description is essential to predicting outage probabilities. Second order PMD (SOPMD) is more detrimental to bit rates of 40Gb/s and higher, hence it is important to be able to determine the magnitude of SOPMD given a known first order PMD (FOPMD). So far only simulations and experiments using high order PMD emulators and high PMD spooled fibers have been used to analyze the statistical characteristics of PMD and the components of SOPMD vectors [1-2]. These reports [1-2] show good agreement between the statistical first and second order PMD and the theoretical probability density functions. However, the statistical dependence between FOPMD and SOPMD vectors over installed fibers has yet to be investigated and verified.

Using the customary definition of the PMD vector [3] in Stokes space,

$$\vec{\Omega}(\omega) = \Delta\tau\,\vec{q} \tag{1}$$

where the PMD vector $\vec{\Omega}(\omega)$ has length $\Delta\tau$ equal to the differential group delay (DGD), and $\vec{q}$ is a Stokes vector pointing in the direction of the fast principal state of polarization (PSP).

Differentiating the PMD vector with respect to frequency gives two components of SOPMD $\vec{\Omega}_\omega = \Delta\tau_\omega\,\vec{q} + \Delta\tau\,\vec{q}_\omega$, where the first term is known to cause polarization-dependent pulse compression and broadening, while the second term causes depolarization.

The probability densities for the magnitude of FOPMD $\left|\vec{\Omega}(\omega)\right|$ and SOPMD $\left|\vec{\Omega}_\omega\right|$ as derived in [3] are the familiar Maxwellian probability density function

$$p_{\Delta\tau} = \left(8/\pi^2\tau\right)\left(2x/\tau\right)^2 \exp\left\{-\left(2x/\tau\right)^2/\pi\right\} \tag{2}$$

and

$$p_{\left|\vec{\Omega}_\omega\right|} = \left(32x/\pi\tau^4\right)\tanh\left(4x/\tau^2\right)Sech\left(4x/\tau^2\right), \text{ respectively.} \tag{3}$$

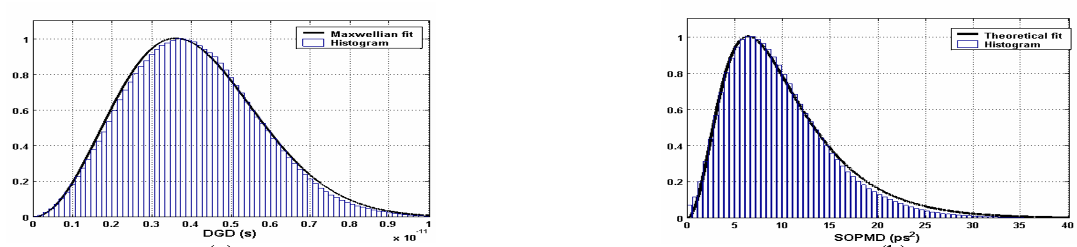
The primary objective of this paper is to verify the theoretical statistical properties of SOPMD against the statistical properties of installed fibers and conclude if the probability density of $\left|\vec{\Omega}_\omega\right|$ agrees with the theoretical prediction [4]. Also, in contrast to previous studies that focussed on the correlation between the parallel and orthogonal components of the SOPMD vector with respect to the magnitude of the PMD vector, we investigated the correlation between the magnitude of the SOPMD vector and wavelength-averaged differential group delay ($\langle DGD \rangle_\lambda$), because this relationship allows estimation of the system impairments due to SOPMD from knowledge of the FOPMD.

Measurement setup

A commercial femtosecond PMD test unit was used to measure the first and second order PMD of a four span amplified system over installed buried standard single mode fiber. Each span length was about 67km and looped back to our lab for amplification before launching into the next span. The test unit utilized a wavelength dependent Poincare sphere Analysis (PSA). The PSA determines the principal states of polarization and the DGD from the measured output Stokes vectors as a function of frequency, for the three linear input states of polarization.

Results

The FOPMD and SOPMD were measured repeatedly every two minutes over a spectral range of 70nm for 90 days continuously. The total distance of the 4 spans was about 268 km. We first generated contour maps of the measured DGD and dispersion vector velocity (DVV) as functions of wavelength and time (not shown), where DVV is defined as the magnitude of the SOPMD $\left|\vec{\Omega}_{\omega}\right|$. We studied the contour maps for events such as loss of signal or any unexplained events before analyzing the data. Fig. 1 shows plots of the measured probability densities of $\left|\vec{\Omega}(\omega)\right|$ and $\left|\vec{\Omega}_{\omega}\right|$ derived from the 90 days of data and the theoretical densities. Fig. 1 shows that the theoretical densities described in Eq. 2 and Eq. 3 have a good agreement with the statistical sample of PMD data collected over a 90 day period. DGD occurrences greater than three times the mean DGD in the tail of the PMD distribution were measured. Similarly, we measured DVV values greater than six times the mean in the tail of the SOPMD. The DGD and DVV averaged over wavelength and time were found to be 4.06ps and 9.65ps^2, respectively.



(a) (b)

Fig. 1 Probability densities of the magnitude of (a) first-order PMD $\left|\vec{\Omega}(\omega)\right|$, (b) second-order PMD $\left|\vec{\Omega}_{\omega}\right|$

Fig. 2 shows that the wavelength averaged DGD scales linearly with the magnitude of the SOPMD. Thus, compared to the theory described in [3], which states that the RMS of the second-order magnitude is $1/\sqrt{3}$ the value of the mean square of the first-order magnitude, our measurement yields an estimated ratio of $\sqrt{4.5}$ using $(\langle DGD \rangle_\lambda)^2 / (DVV_\lambda)$. However, when we used the time-averaged DGD and DVV (not shown), we obtained an estimated ratio of $\sqrt{3.7}$.

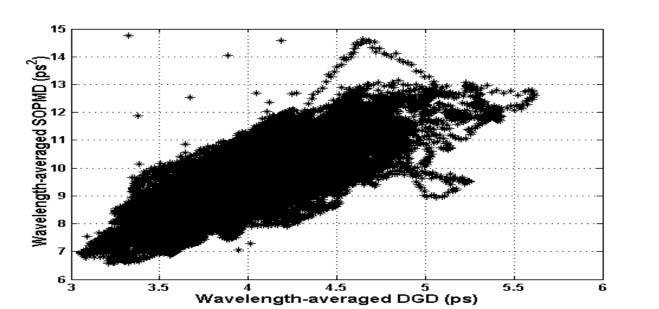


Fig. 2 Correlation plot of the wavelength-averaged SOPMD and DGD

Conclusion

We verified the theoretical prediction of second order PMD against experimental field data collected over 90 days after proving that the first order PMD statistics follows the proven Maxwellian probability density function. We measured a ratio of $\sqrt{3.7}$ using the time-averaged DGD and DVV. This is important for estimating the system impairments due to second order PMD using only knowledge of the mean DGD.

References

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