A Novel Dynamical Polarization Mode Dispersion Emulator

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Abstract

A novel polarization mode dispersion (PMD) emulator is presented which accurately follows the dynamics of PMD in field optical fiber. A modification on a dynamic mode coupling wave-plate model is presented to model the emulator. It is found that the emulator and model can accurately describe the dynamical behaviour of the state of polarization (SOP) and thus PMD in a fiber.

I. Emulator

POLARIZATION mode dispersion is of great interest because of its noticeable pulse broadening effect on systems of 10 Gb/s and higher. Field fiber is tested for PMD to determine how it degrades system performance. This is a time consuming and expensive process. Optical systems designers must take PMD into account when designing next generation systems.

Emulation of PMD allows one to recreate the behaviour of an optical field fiber in the laboratory. Many groups have demonstrated PMD Emulators [1–3,5,7]. These emulators rely on randomly varying the Polarization state of light launched into PM fiber sections or birefringent crystals. The emulator we present takes this one step further, from others work, by randomly varying the birefringence of each fiber squeezer in a biased manner to track the dynamics of PMD in time and allows for different cable types to be emulated. A Gaussian probability density function (PDF) (previously presented in [8]) is used to create the biased changes. A new fiber squeezer model is derived to accurately model the birefringence changes of the emulator.

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<th>Polarimeter</th>
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Figure 1 shows a block diagram of the PMD emulator. The PMD emulator consists of five polarization controllers. Each of which has four fiber squeezers. Randomly spliced polarization-maintaining fiber (PMF) sections are placed after each controller to allow changing differential group-delay via varying the birefringence induced by each fiber squeezer. The PMF sections are of different lengths to reduce the periodicity of the emulator. The polarization controllers are made up of piezoelectric fiber squeezers [6] orientated at fixed angles (0°, 45°, -45°, 0°) to squeeze the fiber, thus inducing birefringence. The polarization controllers are constructed in such a way that when certain voltages are applied the SOP is modified to an arbitrary point on the Poincaré sphere. The max and min applied voltages on each fiber squeezer are calibrated to provide a 0 and 2π rotation of the SOP on the Poincaré sphere, respectively. A Gaussian PDF was used to determine how to change the birefringence for each of the 20 fiber squeezers. It is described by the following conditional transition probability with periodic boundary condition \( \tau_j = \text{mod}(\tau_j, \tau_{2\pi}) \); \( \tau_{2\pi} \) is the magnitude of DGD that corresponds to making a 2π rotation on the Poincaré sphere:

\[
P[\tau_j(t_0 + \tilde{t}) | \tau_j(t_0)] = \frac{1}{\sigma \sqrt{\pi}} e^{-\frac{[\tau_j(t_0 + \tilde{t}) - \tau_j(t_0)]^2}{\sigma^2}}
\]

The width of the Gaussian PDF is \( \sigma \). To account for a time evolution step of \( \tilde{t} \) we allow each of the birefringence \( \tau_j \) to update with every realization. This is the key difference of this emulator from a classical PMD emulator which randomly varies each polarization controller to cover the whole Poincaré sphere. The dynamical PMD emulator will cover the whole sphere if given enough time. It is important to cover the whole sphere to fully understand the system impact.

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Figure 2 shows real Stokes vector data collected from an aerial fiber. This is the effect the emulator is trying to recreate. The Stokes vectors do not cover the whole sphere when changing, instead they stay correlated and favour areas of the Poincaré sphere as a “Random Walk” [8] is performed.

To model the PMD emulator we modify the fiber wave-plate model [4] where we assume a fiber can be described by a randomly coupled concatenation of PMF sections. A classical PMD emulator uses polarization controllers with rotating mechanical fiber wave-plates to change the mode-coupling angle between the PMF sections. Our polarization controllers use squeezers to change the birefringence. We assume that our polarization controller is made up of four PMF sections at constant specific coupling angles. The angles correspond to the physical makeup of the polarization controller. The polarization controller has a small amount of PDL and PMD. This is negligible when compared to the PDL and PMD of the PMF sections. For a polarization controller squeezer to change the SOP it squeezes the fiber and changes the birefringence. This can be modelled by just changing the birefringence value of the PMF section corresponding to that of the squeezer. This is equivalent to changing the length of the PMF section. A single PMF section scales linearly with DGD.

II. Results

The model and experiment of the emulator both generate Stokes vector data. To process this data the angle between the Stokes vectors; having fixed separation time of value \(t\), are used:

\[
\gamma(t_0, t) = \arccos\left(\vec{S}_{t_0} \cdot \vec{S}_{t_0+t}\right).
\]

Where \(\vec{S}_{t_0}\) corresponds to a normalized Stokes vector at time \(t_0\) and \(\vec{S}_{t_0+t}\) refers to the same at time \(t_0 + t\) from the experimental SOP data.

Figure 3 shows the output of the emulator. It randomly fills the Poincaré sphere because a very large Gaussian width (\(\sigma = 1.00\)) was chosen. Figure 4 shows the “Random Walk” in action. The Gaussian width was chosen to be (\(\sigma = 0.01\)).
This represents how a real field fiber transverses the Poincaré sphere.

Figure 5a shows a fit of the emulator and the model. The SOP is very correlated, this approximates a buried fiber. We believe the small mis-alignment is due to the model not describing the PMF sections correctly and stability errors in the polarization controllers. Figure 5b shows the same thing, but with the SOP more de-correlated. This correlation level corresponds to a high PMD aerial fiber. 

Figure 6a shows the emulator fit to an aerial field fiber. An exact match is not expected due to the emulator and field fiber having different PMD values of ∼6.44 ps and 7.20 ps, respectively. One can see that the general dynamics are followed. Figure 6b shows the DGD distribution of the emulator as compared to a Maxwellian PDF of the same mean DGD (6.44 ps). The DGD data was collected at 1550 nm using the Jones-Matrix method. It has been shown [3] that a 12 section emulator is needed to properly reproduce a Maxwellian PDF. The 5 sections used in this emulator produces a biased (to lower DGD values) Maxwellian

III. Conclusions

A PMD emulator that tracks the PMD dynamics of an aerial field fiber is demonstrated for the first time. Reasonable agreement with tracking of SOP and PMD is obtained by both the emulator and a model. If the number of sections were increased we believe much better agreement would be observed.

ACKNOWLEDGEMENTS

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REFERENCES