Field measurements of state of polarization and PMD from a tier-1 carrier

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Abstract: Field measurements of the state of polarization in buried and aerial transmission fiber are presented and analyzed. State of polarization changes measured under field conditions are compared to the state of polarization changes generated by commercially available polarization scramblers for the purpose of laboratory evaluation.

OCIS Codes: (260.5430) Polarization; (120.5410) Polarimetry; (060.2310) Fiber optics

1. Introduction

The temporal variation of the state of polarization (SOP) in optical fibers is of particular interest because of its effect on polarization mode dispersion (PMD) compensators and other polarization dependent devices, especially in the presence of polarization dependent loss (PDL). Recently the dynamic variation of SOP in optical transmission systems under various conditions has been measured and attempts have been made to model the dynamics of PMD using this SOP data [1-4].

In the laboratory evaluation process of devices, SOP dynamics need to be emulated in system test beds. For a carrier, this ensures that equipment certifications are reliable and mirror real world impairments in a multitude of deployments. Thus, understanding the temporal nature of SOP changes in transmission systems, at time scales relevant to polarization tracking or polarization-sensitive devices, is essential. In this paper, we discuss the measurement of SOP changes on an 110 km buried fiber and a 220 km length of aerial fiber over intervals on the order of ms. We then compare these SOP changes to those generated by a commercial polarization scrambler. Key to this comparison is a method for simply describing SOP excursions using Rayleigh distributions [2].

This paper will address only the SOP changes. The temporal evolution of PMD will be discussed in detail during the presentation. For this work we measure the temporal evolution of the magnitude of the differential group delay (DGD) and second-order PMD for buried fiber adjacent to railroad tracks [1].

2. Measurement Characterization

Two sites are described in this paper. Site A is a 110 km route of three spans (36.6 km, 36.5 km, 37.3 km) of fiber manufactured in 1994. The fiber is direct-buried adjacent to railroad tracks. Site B is a 220 km aerial fiber-optic-ground (FOG) wire. The fiber is contained inside the ground wire of a 160 kV transmission line. PDL measurements were performed on each fiber by launching polarization-scrambled monochromatic light into each fiber and monitoring the output with a polarimeter. Measurements were made over ~5 minutes (to provided significant coverage of all input polarization states). The PDL measured for all fibers was less than 0.5 dB. PMD of each fiber was measured using the interferometric method. The mean PMD was found from averaging 5 measurements. We assume that the line equipment (such as EDFAs, DCMs, mux/demux optics) contributed a PMD of ~3 ps.

The instantaneous changes in the polarization state after propagation were measured on each fiber route by launching light with a fixed polarization and detecting the output with a commercial Stokes polarimeter. The rate of change of the SOP was calculated from the measured time series of SOP data. The times series can be broken into many data sets of equal duration (1 ms in our example). Within each of these samples, the excursion on the

Poincaré sphere was calculated from the initial position to all other positions for each sample interval, and the maximum excursion angle from each time bin was found. Performing this calculation on the entire data set allows us to construct a histogram of the maximum SOP excursions in Poincare′ space over the entire time series [2].

The polarimeter internally logs data at a rather low rate, but has analog output ports that provide Stokes parameter values {S1, S2, S3, S0} at a 4 kHz update rate. We used A/D boards, a laptop computer, and a data acquisition program to gather this data for extended periods. To present this large amount of data, we partioned the time series into bins of 1 ms. We then formed histograms plotting number of occurences for each maximum excursion (figure 1). For the buried fiber at Site A 110km link (3 spans with two midspan EDFAs, with 25 ps PMD over 110 km) we acquired 9 hours of data at 4 kHz.

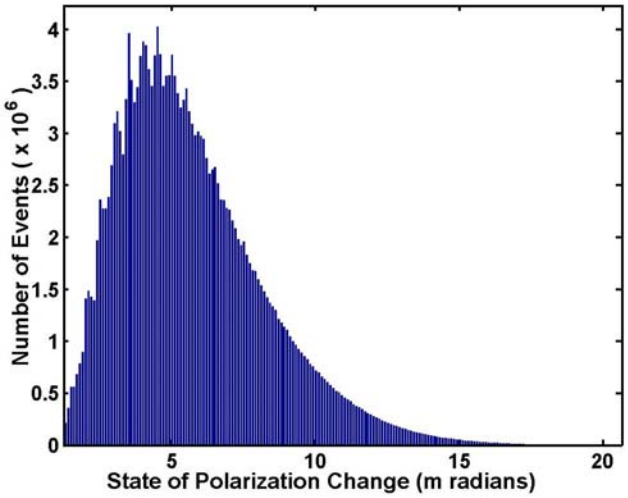

Fig. 1. Histogram from Site A measurements (110 km buried fiber) using a 1 ms sampling interval.

Using the same polarimeter, SOP variations arising from a commercial polarization scrambler were measured at 4kHz with the scrambler set at various scan rate settings [2]. The histograms of filtered data from the fiber plant measurements of both the buried fiber and the aerial fiber as well as multiple scan-rate SOP distributions of the polarization scrambler are shown in Figures 2a and 2b, respectively. The data shown from the polarization scramblers do not include a few rare occurences of very large SOP changes. These tails are an erroneous artifact of measuring Stokes parameters from the 4 kHz ouput port. The artifact manifests itself as occasional “hold” voltages at the port, and are removed during the data analysis by removing intervals where two or more Stokes parameters became constant.

3. Results

Figures 2 show log-log plots of the occurrence of maximum excursions in fiber. Also plotted as smoother lines are the Rayleigh fits to the data from the commercial polarization scrambler [2]. From Figure 2a, the plot shows that the SOP changes in this buried fiber could be emulated using a scan rate of 4 on the commercial scrambler. The scrambler does not generate the exact SOP changes at the same occurence frequency as in the fiber. However, when devising laboratory tests, reproducing the occurrence frequency of the largest SOP excursions is often of most interest. Thus, while not an exact replica of the SOP dynamics, this scan rate provides a reasonable representation of the field conditions and can be considered a conservative test because it effectively encompasses the largest maximum SOP excursions. Figure 2b shows that for the aerial fiber, a scan rate of 5 would cover most of the SOP variations, but a scan rate of 6 would cover the full extent of SOP variations measured in this fiber. Also on the aerial fiber, we observed a strong 60 Hz tone along with harmonics of 120 Hz and 180 Hz in the Stokes parameters. The effect of the tone was to add circular trajectories on the Poincare′ sphere on the order of the 60 Hz period. We do not believe these large excursions will create a problem for polarization tracking devices. A more detailed description will be discussed in the presentation. We have found variation in the SOP dynamics of commercial scramblers, so the scan rate values noted here should not be taken as absolute values, but rather as a demonstration of emulation possibilites.

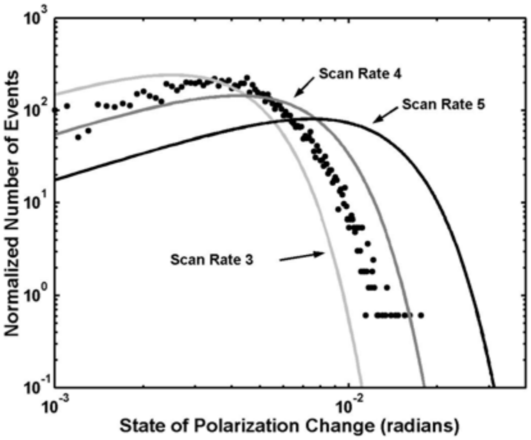

Fig. 2a. Measured occurrences of SOP changes over 1 ms intervals measurements on buried fiber.

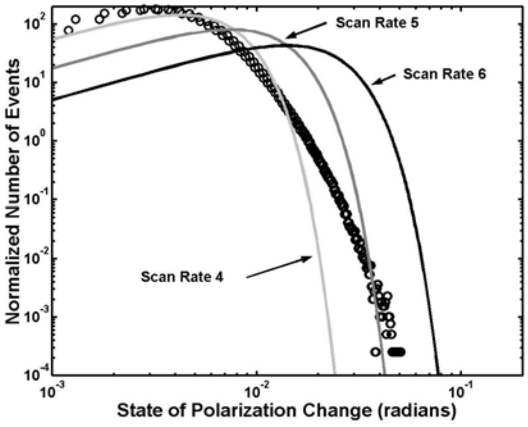

Fig. 2b. SOP changes over 1 ms intervals in aerial fiber.

4. Conclusions

State-of-polarization measurements are straightforward, but methods to quantitatively describe the polarization evolution in fiber and polarization scramblers are lacking. Greater insight into the evolution of polarization in real systems would improve modeling and laboratory testing of fiber optic systems. In addition, this information is necessary to test devices that track polarization, or operate in high PDL environments. With this goal we have analyzed SOP changes on a millisecond time scale, which is an appropriate speed for polarization tracking devices.

Recent work has shown that SOP changes generated by commercial polarization scramblers (measured as the excursion distance on the Poincaré sphere during an appropriate time interval) follow Rayleigh statistics [2]. This is expected since Rayleigh distributions result from the combination of two normally distributed independent random variables. When the degree of polarization is fixed, only two variables are needed to describe trajectories along the Poincaré sphere. Rayleigh distributions are defined by a single parameter, so polarization evolutions that fit this criterion can be described and simulated using a single number derived from measured data.

As expected, the histogram scales with the sampling interval; that is, the magnitude of the maximum excursion doubles if the time interval doubles. Thus the close fit to Rayleigh statistics is not sensitive to changes in the time interval and measurement rate, within reason. Most important is that the interval is not so long (or the measurement rate so slow) that aliasing occurs, or that the interval is not so short (or sampling so fast) that the measured excursions are not comparable to the measurement noise.

Although there has been much work done on SOP variations [3, 4], this paper reports, for the first time, a comparison between field SOP variations and laboratory equipment SOP variations. It also quantifies SOP changes in installed fiber in the form of Rayleigh distributions of angular excursions over a given time interval and provides a reasonable and objective way to represent SOP data. This analysis improves the equipment certification process by allowing carriers' laboratories to emulate the range of real-world SOP variations. This improved understanding is critical because SOP variations affect system outage statistics [5, 6]. More work is underway regarding mixed fiber deployments (buried and aerial). The correlation of SOP variation and soil type is also being performed.

5. References

1. D. L. Peterson, B.C. Ward, K. B. Rochford, Paul J. Leo, and G. Simer, "Polarization mode dispersion compensator field trial and field fiber characterization," *Optics Express* **10** 614 (2002).
2. P. J. Leo, G. R. Gray, G. J. Simer, and K. B. Rochford, "State of polarization changes: classification and measurement", accepted by *J. Lightwave Technol.* For this measurement, an Agilent 11896A polarization scrambler was used, but others may yield similar results.
3. K. Ogaki, M. Nakada, Y. Jagao, "Fluctuation differences in the principal states of polarization in aerial and buried cables", in *Proc. OFC '03, Atlanta, Ga*, MF13 (2003).

4. D. S. Waddy, P. L. Liang Chen and X.Bao, "Fast state of polarization changes in aerial fiber under different climatic conditions", *IEEE Photonics Lett.* **13** 1035 (2001).
5. P. J. Leo, D. L Peterson, and K. B. Rochford, "Estimation of system outage statistics due to polarization mode dispersion," *12th Symp. on Optical Fiber Measurements, Boulder, Colorado* 213 (Sept. 2002).
6. P. J. Leo, D. L. Peterson Jr., S. C. Wang and K. B. Rochford, "Estimation of the frequency and distribution system outage statistics due to polarization mode dispersion", submitted to *J. Lightwave Technol.*