Fast State of Polarization Changes in Aerial Fiber Under Different Climatic Conditions

David S. Waddy, *Student Member, IEEE*, Ping Lu, Liang Chen, *Member, IEEE*, and Xiaoyi Bao, *Member, IEEE*

***Abstract*—The state of polarization (SOP) is measured in aerial fiber during winter and summer. Correlations are made between the SOP changing and the current weather to search for the reason of the fastest SOP fluctuations. The fastest SOP changes are found to be faster then 10 ms, which is limited by the resolution of the measurements.**

***Index Terms*—Meteorology, optical communications, optical fiber cables, optical fiber polarization.**

I. Introduction

POLARIZATION mode dispersion (PMD) is a major limitation on higher speed fiber communications systems (10 Gb/s and higher). PMD broadens an optical pulse causing extra bit-error-rate (BER) degradation. One of the major problems with dynamic PMD compensation is the time scale over which the polarization changes occur. Generally, one expects PMD to change slowly on buried [1] and submarine [2] fiber, because the fiber strain stays relatively constant, and the temperature changes slowly as a result of being underground. On the other hand, the aerial fiber is expected to have faster PMD changes, because the fiber is exposed directly to a dynamic environment and undergoes greater strain and temperature fluctuations [3], [4]. This letter expands on the work done in [4] by investigating extreme weather fluctuations. As PMD changes, it results in output state of polarization (SOP) changes, hence SOP sets an upper limit on how fast the PMD is changing.

In this letter, summer and winter aerial fiber SOP measurements are correlated with weather data to search for the mechanism of fast PMD changes as a function of time. The distribution of 50% decorrelated SOP time is shown.

II. Experiment

A block diagram of the experimental configuration is shown in Fig. 1. A continuous wave beam of light is launched at a wavelength of 1550 nm and power of 0 dBm from an Agilent 8164A tunable laser, which then passes through the fiber under test (FUT). In this experiment, the FUT is a 34-km length of SMF-28 aerial-loose tube-fiber cable located at Woodstock in New Brunswick, Canada. Two separate fibers in the cable were tested (Fiber I and Fiber II). The FUT travels aerially from the local central office (CO1) to the far central office (CO2), where a patch panel is located. The fiber is then looped back through the same cable. As laser light travels through the FUT, it undergoes changes in its relative SOP. These changes are detected by the Agilent polarimeter. Patch fibers in the COs are securely taped down to measure only SOP changes on the FUT. Temperature fluctutations inside the CO were very small over the 10-min measurement period and not within the experiment's resolution. The polarimeter outputs the Stokes vector [three Stokes parameters and the degree of polarization (DOP)] as analog signals. These signals are converted to discrete digital values. A computer code collects Stokes parameters for a 10-min interval at a resolution of 10 ms. After the field experiment is completed, an autocorrelation $[R(t)]$ is performed on the collected Stokes vectors. The computer code is designed to find the fastest SOP changes by recording when the autocorrelation function first drops below the 0.5 mark $[t_{1/2}]$ on the $R(t)$ as a function of time curve (see [4] and [5] for details). It is conceivable that with a static compensator, the worst PMD fluctuation occurs with the SOP decorrelated to timescale $t_{1/2}$.

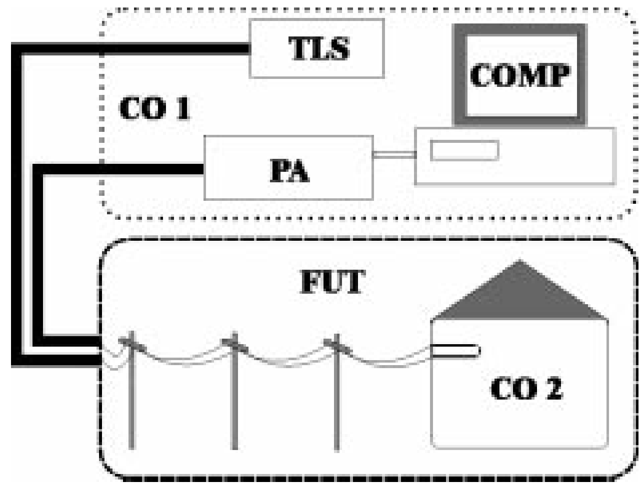

Fig. 1. Experimental setup of field fiber PMD measurement. CO1: Central office 1. TLS: Tunable laser source. PA: Polarization analyzer. COMP: Experiment control computer. FUT: Fiber under test. CO2: Central office 2.

The PMD of the FUT is recorded with an EXFO PMD test set, which uses the interferometric method. The mean DGD (C-band PMD) is found to be 7.49, 7.20, and 9.97 ps, respectively, on fiber I summer, fiber I winter, and fiber II winter, respectively.

III. Results and Discussion

The experiment is set to run on Fiber I over six days from August 2 to 8, 2000 (summer). We returned and duplicated the experiment in December 2000–January 2001 (winter). This allowed us to have a contrast of the extremes of a temperate North American climate.

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The authors are with the Department of Physics, University of Ottawa, ON K1N 6N5, Canada (e-mail: dwaddy@science.uottawa.ca).

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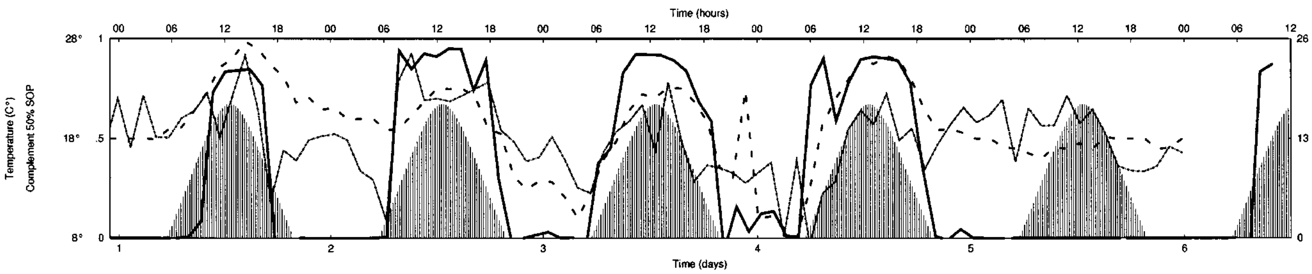

Fig. 2. Normalized complement 50% SOP autocorrelation function (dark line, a larger value corresponds to a faster changes), normalized sun altitude (parabolas), normalized temperature (dotted line), and normalized wind speed (dashed–dotted line) as a function of time in the summer.

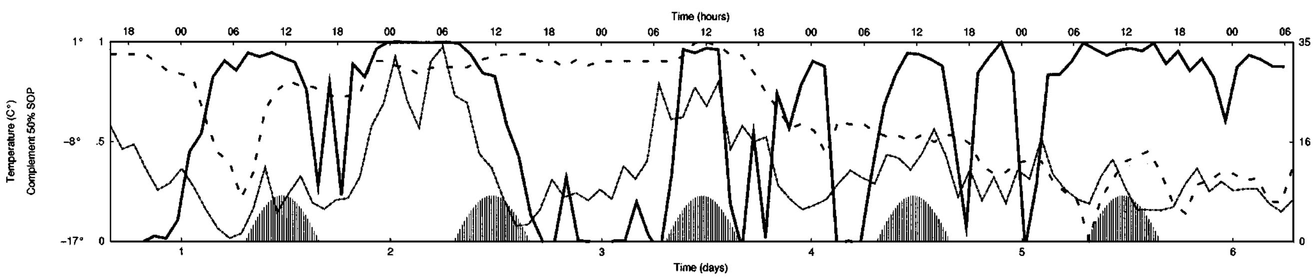

Fig. 3. Normalized complement 50% SOP autocorrelation function (dark line, a larger value corresponds to a faster changes), normalized sun altitude (parabolas), normalized temperature (dotted line), and normalized wind speed (dashed–dotted line) as a function of time in the winter.

The results of the complement of the 50% SOP decorrelation are plotted as a function of experimental time. The normalized complement of 50% SOP decorrelation is defined as

$$1 - \frac{t_{1/2}}{(t_{\max} - t_{\min})} \tag{1}$$

where $t_{\max} - t_{\min}$ is the length of time over which the autocorrelation is performed, and $t_{1/2}$ is the point in time where $R(t)$ first drops below 0.5.

Weather data is then obtained from a nearby Houlton, Maine, USA weather station. Wind speed, temperature, sun altitude, and complement 50% SOP decorrelation are all normalized and plotted together as a function of time. The altitude of the sun is normalized to 90° (directly overhead) and took into account the time of year and latitude. This gives some insight into when day/night occurs and is a general estimate of solar intensity. Precipitation data is not used as it would be difficult to quantify in this experiment.

Fig. 2 shows Fiber I in the summer. The maximum sustained wind speed is 26 km/h. The min/max temperatures are 8 °C / 28 °C, respectively. There is a large temperature gradient seen in most 24-h periods that varies from day to night. A clear correlation between daylight and fast SOP changes can be seen. Day five shows no fast SOP changes, because the temperature varied only from 18 °C to 19 °C from day to night. Fast changes occur when winds are of higher speeds, but temperature gradients are the dominant factor. In general, during the day the sun causes heating on the fiber and the wind causes strain, while the nights are relatively calm.

Fig. 3 shows the same fiber (Fiber I) in the winter. The maximum sustained wind speed is 35 km/h. The min/max temperatures are -17 °C / 1 °C , respectively. Once again, a clear correlation between day and night can be seen with the fastest SOP changes occurring during the day. The fastest SOP changes on this plot are observed during the night and morning of the second day. The temperature is stable around freezing, but winds of ~35 km/h are observed and gusts of up to 67 km/h. A small amount of precipitation is observed in the form of snow and freezing rain. It is possible that the cable could have become coated and stiff, and thus subjected to high stress. A large temperature gradient can be observed starting at sunset on the second day. It is plausible that this causes the fast SOP changes occurring a short time afterwards. The daytime of the fifth day has consistent fast changes over a long period, which once again looks to be mostly caused by a temperature gradient. Temperature gradients cause the majority of the fastest SOP changes. Very cold temperatures also have fast SOP changes, but there is also always small temperature gradients.

The winter weather causes the fastest changes in our experiments. Winter is the more likely season to have extreme storms, but thunder storms also have high winds, so it would be expected that fast SOP changes would also occur in the summer.

IV. Histograms

A histogram of 50% SOP decorrelation times can be observed in Fig. 4. This plot is made up of 342 10-min datasets collected every 20 min over six days in the summer on Fiber I. The fastest change is found to be 13.62 s. Most of the fast changes are distributed around 65 s. The large bar at the 600-s mark corresponds to the maximum interval of the measurement. Slower changes are not of interest because of their ease of compensation.

Fig. 5 shows the same fiber (Fiber I) in the winter. Data is collected continually in 10-min intervals, so there is 798 points for approximately the same time period. This plot is similar to the previous except that there is a large peak at the beginning.

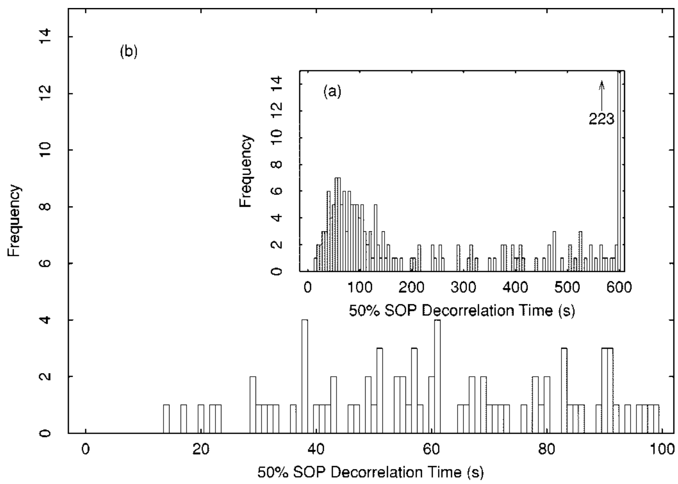

Fig. 4. (a) Histogram of 388 Fiber I 50% SOP decorrelations (frequency as a function of time) during the summer. Bandwidth is 5 s. (b) The first 100 s of part (a). Bandwidth is 1 s.

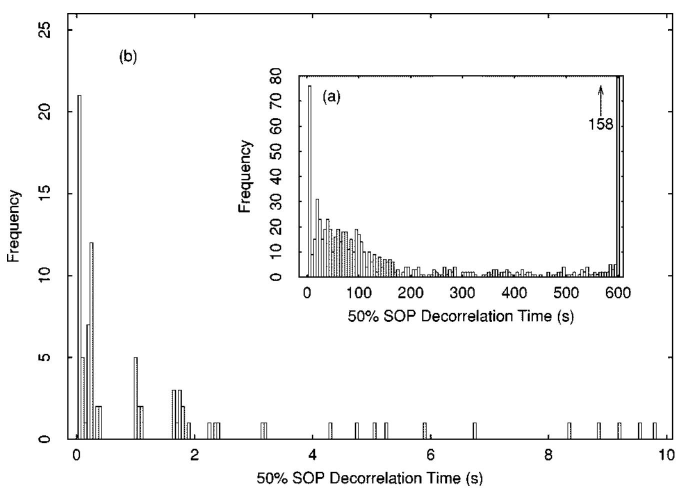

Fig. 5. (a) Histogram of 798 Fiber I 50% SOP decorrelations (frequency as a function of time) during the winter. Bandwidth is 5 s. (b) The first 10 s of part (a). Bandwidth is 0.1 s.

A closer inspection of (b) shows that the majority of the fastest 50% SOP changes occurred at 30–60 ms. These fastest changes are at the edge of the experiments resolution of 10 ms.

Fiber II has ten days of data collection during the month of January 2001. The winter data seen in Fig. 6 can be compared to fiber I's winter data. Fiber II also has a large peak at less than 1 s. In fact, all the data values are 30 or 40 ms. This indicates a completely separate event (extreme weather) and tends to agree with what is observed in fiber I for the winter.

V. Conclusion

A general picture of SOP changes in aerial fibers is presented, showing typical values of SOP varying with time of day. The fastest 50% SOP decorrelation time over a six-day period is 30 ms and is observed 25 times in the winter experiment. It is observed that most of the fast SOP fluctuations occur during the daytime and the slower changes occur during the night. Buried fiber show typical SOP fluctuations on the order of minutes; our result on aerial fiber, shows much faster SOP fluctuations. SOP data collection needs to be performed on the order of milliseconds to get an accurate view of the fastest SOP changes in fibers.

Fast SOP fluctuations can be said to occur with large temperature gradients and extreme weather events (storms), thus the coming of fast SOP events can be predicted from weather forecasts.

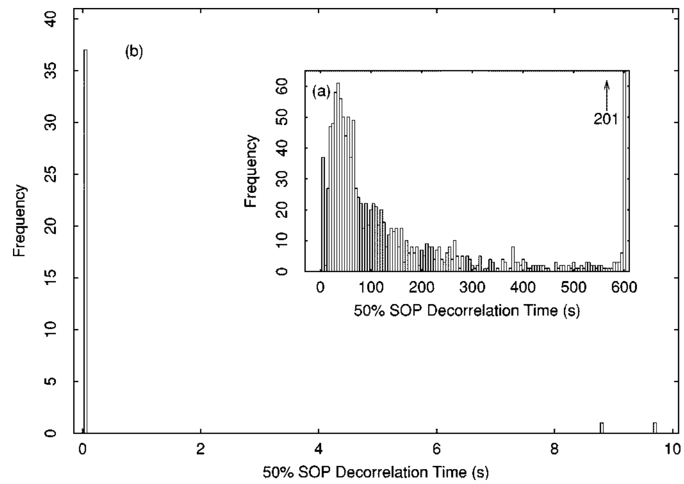

Fig. 6. (a) Histogram of 1340 Fiber II 50% SOP decorrelations (frequency as a function of time) during the winter. Bandwidth is 5 s. (b) The first 10 s of part (a). Bandwidth is 0.1 s.

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