Dispersion Compensation Module as a Polarization Hinge

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Abstract *We study polarization rotations by a Dispersion Compensation Module responding to quasi-periodic room temperature oscillations. The rotations seems to have a functional temperature dependence on short time scales interupted by rather abrupt shifts occuring, on average, every month.*

Introduction

Dispersion Compensation Modules (DCM) have been shown to act as polarization rotators in response to temperature fluctuations [1]. Such rotations, when occurring in field offices, in combination with extremely slow polarization dynamics of buried fibers result in Non-Maxwellian temporal statistics for Polarization Mode Dispersion (PMD) [2]. Based on these results, several recent theoretical papers have proposed a novel way of looking at PMD – related outages [3-5]. Lacking real-world data, each of these papers model a DCM as a polarization hinge, which uniformly covers the Poincare Sphere over time.

In this paper, we report results of a long-term study of polarization rotation caused by a DCM subjected to small daily temperature fluctuations of the type expected in large telecommunication offices. For nine months we simultaneously measured frequency dependent polarization transfer matrices and the temperature of the fiber, placed in room with a conventional temperature regulator – benign conditions similar to that of a field office. The polarization rotation we observed has different characteristics on short and long timescales. We find that on small timescales of about five to ten temperature peaks (usually 0.6 - 1°C each) the DCM had a practically linear response, rotating input polarization by any number between 0 and 180 degrees depending on optical frequency and time. However, on longer time scales an additional random component is added to the rotation which does not seem to be related to observed temperature changes. At random times either the angle or the direction of rotation or both could drift significantly in a relatively abrupt fashion. By performing autocorrelation analysis we determined an average time between these shifts to be about 30 days.

Experimental Setup

Light from a tunable laser source passed through a polarization controller, and then was fed into a DCM under test, which was followed by a polarimeter. For each optical frequency, three different state of polarizations (SOP) A, B, and C, were sequentially launched into the device and the output polarization was recorded. Polarization states A, B and C were arranged to make a great circle on the Poincare sphere. Thus, our setup is capable to determine fiber Muller matrices $T(\omega,t)$ up to unknown but fixed rotation, which relates a frame of reference of the polarimeter with that of the polarization controller. Then polarization rotation as a function of time can be also expressed as a rotation matrix $R(\omega,t) = T(\omega,t)T^{-1}(\omega,t_0 = 0)$. We represent matrix $R(\omega,t)$ by its axis of rotation $\vec{z}$ and an angle of rotation φ. These two quantities allow us to compute output SOP for *any* input SOP and, therefore, completely characterize the DCM.

DCM modules were places on a bench in our lab. The mean temperature in the room was 21.5°C with a standard deviation of 0.3°C. Between one and four temperature cycles were made daily, and four times during our nine-months measurement period the temperature dropped sharply by 6-7 degrees.

Results

Fig. 1 and 2 provides an illustrative sample of our data in the time range between days 60 and 75. During this time the axis of rotation $\vec{z}$ did not change much and was contained to an arc about 45 degrees in length on the Poincare sphere (Fig. 1). The angle of rotation φ of the matrix $R(\omega,t)$ (thick line) on the other hand underwent two typical transformations:

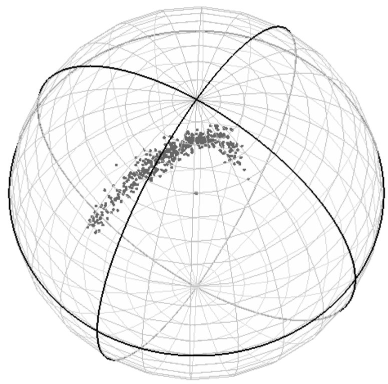

Figure 1. Direction of rotaion z.

first, between days 62.3 and 68.6, and second, after 68.6. To elucidate these we plot a following linear function of the fiber temperature on the same plot (thin line): $F(time) = -110 \times Temp(time) + 3035$.

Now the figure can be separated into three regions in time. Starting from the beginning of the plot at *t=60* till about *t=62.3* the angle of rotation is almost perfectly matches the function *F(time)*. In fact, this match extends to the smaller time values beyond the left boundary till *t=54*. Between the time values 62.3 and 68.6 *F(time)* gradually deviates from the angle. Around day 68 a slightly different function would be a better fit: $F_1(time) = -110 \times Temp(time) + 3013$.

Such small shifts are rather common and occur on average every five to days. In this particular example we see a gradual shift only in the value of the angle, whereas the axis of rotation did not change significantly. A reverse situation, when either only the axis $\vec{z}$ drifts or both quantities changes seem to be somewhat less frequent.

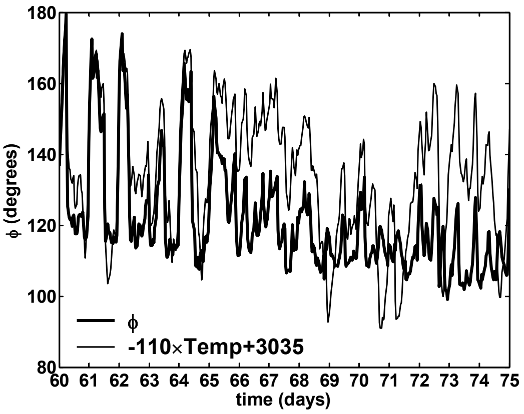

Figure 2. Angle of rotation φ (thick line) and function of temperature F (thin line)

Finally, for times greater than 68.6 a more significant transformation happened. There were phase slips between the angle φ and *F(time)* each time there was vertical rapid shift in temperature (0.1-0.2°C in one hour). It seems that the angle φ could not follow such changes, and the phase between the temperature and the angle are reversed after each shift. Note that peaks in the value of the angle occurring around t=69, 70.7, 71.3, 72.8 and 74.7 are out of phase with the function *F(time)*. This new dependence on the temperature continued for some time till the day 95. We find that such bigger abrupt events happen roughly every month.

To quantify the occurrence frequency of these transformations we compute the time autocovariance functions of both the angle and the direction of the rotations. The resulting curves averaged in optical frequency are plotted in Fig.3 for the angle (thick) and the directions (thin). The ripples on the curves indicate partial diurnal repeatability of the data.

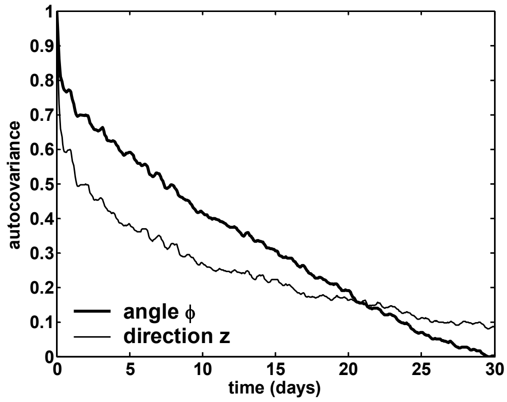

Figure 3. Frequency averaged autocovariance of angle φ (thick line) and direction of rotaion z (thin line).

Because this repeatability is not exact, both curves show a fast decay during the first day. Interesting feature is very slow, almost linear decay of the autocovariance functions with time. This linearity indicates on relatively sudden changes in the data occurring almost periodically. Thus we conclude DCM rotations are coherent with the temperature for about a month.

Conclusions

We report long-term study of polarization rotations by a commercially available DCM responding to small temperature variations in a temperature controlled environments. We find an almost functional dependence of the parameters of the DCM rotation matrix with the temperature on week-long time scale. This dependence gets corrupted by sudden events occurring monthly. Despite strong daily polarization rotations, output SOP does not seem to uniformly cover the Poincare sphere even after nine months of observations. Thus we feel that recent theoretical predictions of PMD-related outages based on the hinge model should be modified to encompass more realistic hinge behaviour.

References

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