TRULY ENDLESS POLARIZATION CONTROL WITH I&Q MODE CONVERTERS IN X-CUT, Y-PROPAGATION LITHIUM NIOBATE

David Sandel, Reinhold Noé
Univ. Paderborn, EIM-E, Warburger Str. 100, D-33098 Paderborn, Germany
sandel@ont.upb.de, noe@upb.de

Abstract *A calibrated polarization transformer, controlled by just 2 parameters, permits endless polarization control even under worst case conditions. Several such systems can be cascaded on one chip for PMD compensation.*

Introduction

No system or subsystem with polarization control, such as a PMD compensator, seems to be selling, or to ever have been sold, in significant quantities. One reason for this can be put (almost correctly) in simple words: The Poincaré sphere surface, where polarizations are represented, can not be parametrized in angle coordinates without forming poles. When one passes a pole the longitude angle changes instantaneously. This is practically difficult, and problems of this type are inherent to all polarization control systems, for example:

(i) The azimuth angle of a waveplate with variable retardation $\le \pi$ and circular input polarization must be changed by 90° (equivalent to π on the Poincaré sphere) when the output polarization passes the orthogonal circular polarization [1].

(ii) Let the desired output polarization of a rotatable quarter-, half-, quarterwave plate arrangement [2] first be elliptical with azimuth angle α, then become circular, then elliptical with azimuth angle $\alpha + 45°$, while the input polarization is always circular. Just when passing circular output polarization the last quarterwave plate has to flip by 45° (equivalent to $\pi/2$ on the Poincaré sphere), and one of the other plates must also flip.

Whether they are called resets or not, such situations lead to tracking speed problems in a certain region of the Poincaré sphere even if the devices are ideal. They inherently complicate any polarization control – but are neglected in almost all reports.

One can guarantee endless (unlimited) polarization tracking if one just adds more and more retarders. But many are required in practice, and this leads to speed (and cost, space, and loss) problems. The only truly endless, yet speedy solutions possible feature calibrated retarders. Even if these are somewhat nonideal the system should be able to track polarization changes in all directions on the Poincaré sphere surface, and this is possible with one suitable extra degree-of-freedom [1]. Experiments of this kind have been published but the retarders were either four magnetic fiber squeezers [3] (can not be used outside lab) or X-cut, Z-propagation $LiNbO_3$ waveplates [1]. The latter suffer from DC drift and will not stay calibrated stably enough for longtime operation.

Polarization transformer

A rotatable waveplate or Soleil-Babinet compensator (SBC) with a retardation of $\le \pi$ can endlessly convert circular into any other polarization [1]. We have realized this principle with in-phase and quadrature TE-TM mode converters [4] (Soleil-Babinet analogs, SBAs) in X-cut, Y-propagation $LiNbO_3$ [5] (Fig. 1). Such devices can be configured as high-performance, “distributed” PMD compensators which replace many discrete polarization transformers and differential group delay sections. While a halfwave SBC converts circular polarization into its orthogonal with selectable phase shift the same is true for TE and TM waves in an SBA. Each mode converter section in the ~90mm long device is ~1.3mm long. Only 6 sections were used, 4 of which were sufficient for a halfwave SBA operation (full mode conversion).

At the optical frequency where the comb electrode period equals the TE-TM beat length (22µm @ 1550nm) a section is described by the Jones matrix

$$\begin{bmatrix} \cos\varphi/2 & je^{j\psi}\sin\varphi/2 \\ je^{-j\psi}\sin\varphi/2 & \cos\varphi/2 \end{bmatrix},$$

where $\varphi \propto \sqrt{V_1^2 + V_2^2}$ is the (mode conversion) retardation and $\psi = \arg(V_1 + jV_2)$ an orientation angle.

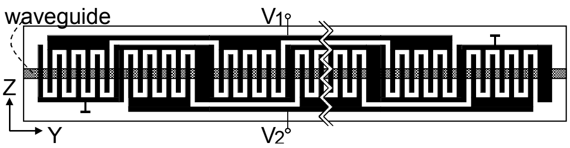

Fig. 1: Elementary in-phase and quadrature mode converter (one section) in X-cut, Y-propagation $LiNbO_3$

Results

The SBAs can be accurately calibrated and have no bias voltages which suffer from DC drift. The voltages V_1, V_2 of the various sections are chosen individually, which yields individual retardations φ and orientation angles ψ. Driving the sections with different orientation angles allows to compensate for local variations of the beat length caused by waveguide nonuniformity, and this driving mode was implemented [6]. Together the sections form a single retarder which depends only on total retardation and total orientation as parameters.

A principal state-of-polarization (PSP), say TE, is fed into the polarization transformer. The device was initially operated as a rotating halfwave SBA, and the output polarization (near TM) was recorded with a polarimeter. After proper amplitude adjustment of the sinusoidal voltages the output polarization stayed within a circle having a radius of just 0.05 rad on the Poincaré sphere. Fig. 2 shows output polarizations when the SBA retardation was varied from 0 to almost π for various SBA orientations. They converge fairly well in one point which is essential for endless polarization tracking. According to our experience such a good accuracy was not achievable with electrooptic waveplates in X-cut, Z-propagation $LiNbO_3$ from two vendors.

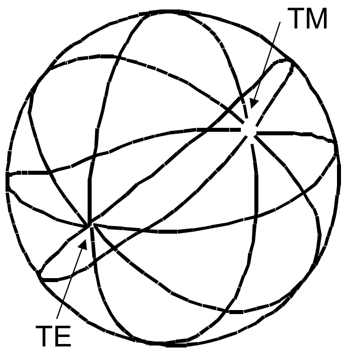

Fig. 2: Poincaré sphere meridians generated by SBA where the retardation varies from 0 (uncritical “pole”, ”TE”) to almost π (critical “pole”, ”TM”) with various orientations. Coordinate system rotation is arbitrary.

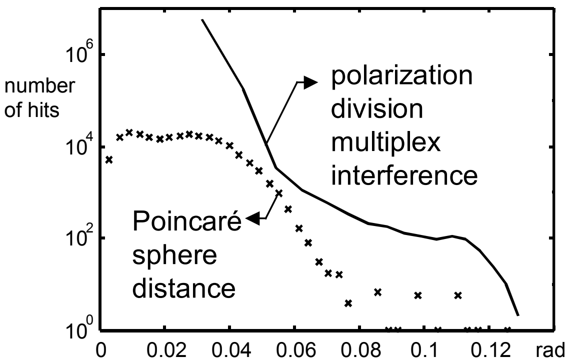

Fig. 3: Misalignment angle distributions during worst case polarization tracking with a polarimeter (x), and during random polarization tracking using a polarization division multiplex interference signal (—).

Next a moving target polarization, which the polarization controller has to track, was defined by software. Only the distance (on the Poincaré sphere) between the actual polarization, measured by a slow polarimeter, and the target ws used in the control algorithm. Virtually all possible polarization states and trajectories were investigated but extreme care was taken to scrutinize the behavior at and near the “pole” of TM polarization. In 30 most critical great circle trajectories across the poles the worst displacement from the wanted trajectory was <0.125 rad (Fig. 3). Most measurements had deviations <0.04 rad. The tracking speed was 0.012 rad/iteration.

In order to get rid of the slow polarimeter a polarization division multiplex signal was set up, and the interchannel interference was monitored as an polarization error signal [7]. Fig. 3 (—) shows the misalignment angle distributions obtained while random polarization variations are being tracked. These were generated by motorized endlessly rotating fiber coils. The tracking speed was ~1.3 rad/s or 0.002 rad/iteration (1 iteration = 1.5ms). The slower permissible tracking per iteration (compared to the previous case) is believed to be due to a non-rectangular electrooptic step response of the device. It is caused by a higher conductivity of the buffer layer compared to the $LiNbO_3$. Nevertheless the worst case misalignment was <0.13 rad.

Discussion

The electrooptic step response may be electrically equalized.

Cutting the time per iteration down to <50 µs should be possible.

A straightforward approach for PMD compensation is to specify, say, 4 “discrete” polarization transformers at 0, $L/4$, $L/2$ and $3L/4$ where L is the chip length. Such a PMD compensator needs ≤48 voltages but just 8 control variables, and is 4 times more powerful than a PMD compensator featuring one commercial X-cut, Z-propagation $LiNbO_3$ device, which requires up to 16 control variables for its 8 waveplates.

Conclusions

A truly endless polarization control system has been realized. It features a calibrated X-cut, Y-prop. $LiNbO_3$ polarization transformer with a DC drift susceptibility smaller than in Z-prop. devices. Under all circumstances the polarization tracking error was <0.13 rad on the Poincaré sphere. The extension of this control scheme for a fast integrated PMD compensation is feasible.

Acknowledgements

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