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Optics Communications 249 (2005) 43–50
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

Uniformly distributed states of polarization on the Poincarè Sphere using an improved polarization scrambling scheme

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Received 10 October 2004; received in revised form 19 November 2004; accepted 17 December 2004

Abstract

We propose a periodic random polarization scrambling scheme that can generate uniformly distributed output states of polarization (SOPs) on the Poincarè sphere for any arbitrary input polarization state. This approach is compared with previous methods using computer simulations, as well as an experimental measurement consisting of 1000 samples that confirms the uniformity of output SOPs.

Keywords: Polarization; Optics communication; State of polarization; Polarization mode dispersion; Polarization dependent loss

1. Introduction

As optical fiber transmission systems begin to employ higher data rates (>10-Gb/s/channel), the once-disregarded effects of lightwave polarization on a system can cause significant network impairment. In particular, polarization mode dispersion (PMD) and polarization dependent loss (PDL) [1–3], as well as polarization dependent gain (PDG) [3] have received recent attention. In addition, the random nature of polarization effects is also a major problem for polarization-sensitive instrumentation. Scrambling the states of polarization (SOPs) of the signal has been shown to be a valuable technique that can facilitate the compensation or reduction of polarization-related impairments [3–10], or the reduction of measurement uncertainty.

Typically, polarization scrambling schemes are based on high-speed polarization modulators or relatively low-speed polarization controllers, for example, $LiNbO_3$ devices (>1 MHz bandwidth) [11,12] or fiber squeezer-based polarization controllers (up to 100 kHz bandwidth). $LiNbO_3$ polarization modulators have been used

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0030-4018/$ - see front matter
doi:10.1016/j.optcom.2004.12.043

as bit-synchronous polarization scramblers to reduce PDG effects in undersea transmission systems where output SOP of the scrambler is modulated along a great circle on the Poincarè sphere at the bit rate [13]. When high-speed polarization scrambling is not required, sets of polarization controllers are used as scramblers. Scramblers with different scrambling speeds and different output SOP distributions (corresponding to different reduced degrees of polarization (DOPs)) may have different effects on the system performance. Moreover, it is often necessary that output SOP of the scrambler is distributed, preferably uniformly, on the entire Poincarè sphere for the purposes of PMD and/or PDL monitoring and compensation [5–10]. In this paper we concentrate on this type of uniformly distributed polarization scrambling. Specifically, we discuss fiber squeezer-based polarization controllers, which have the advantages of low cost and ultra-low intrinsic PDL (i.e. negligible intrinsic signal degradation).

One common fiber squeezer-based polarization scrambling scheme uses varying control voltages (each following a different waveform) applied to each of the three sections of the polarization controller, known as the three-function approach. Note that a two-section fiber squeezer generally cannot generate polarization scrambling over the entire sphere unless the input polarization state is aligned along specific directions (i.e. input polarization dependent). The three control functions vary in both frequency and peak-to-peak voltage. Although this method does move the output SOP over the Poincarè sphere, it suffers from uncertainty (it is randomly non-repeatable) from measurement to measurement, and it is difficult to uniformly distribute the output SOP over the sphere. To obtain the most efficient PMD and/or PDL monitoring and compensation, it is desired that the output (scrambled) SOPs are uniformly distributed and repeatable.

In this paper, we propose a periodic random polarization scrambling scheme that can generate uniformly distributed output SOPs on the Poincarè sphere for any arbitrary input polarization state using a three-section fiber squeezer-based polarization controller.

2. Uniformly random polarization scrambling

Typical fiber squeezer-based polarization controllers consist of multiple fiber squeezers oriented 45° with respect to each other (Fig. 1(a)). Each fiber squeezer is driven by an applied voltage signal on the fast electronic actuator. Squeezing the optical fiber produces a linear birefringence in the fiber and thus alters the state of polarization of a light signal passing through it. i.e. induces phase retardation. For a given input polarization state, the first section can make the polarization rotate around a fixed axis on the Poincare sphere (named s_1), the second section will rotate around another axis that is perpendicular to the first one (named s_2), as shown in Fig. 1(b). The third section always has the same characteristics as the first section with a little perturbation to facilitate the realization of input polarization independent.

For a three-section fiber squeezer scrambler, the transfer matrices for the three sections are [14,15]

$$\begin{bmatrix} \exp(i\frac{\theta_1}{2}) & 0 \\ 0 & \exp(-i\frac{\theta_1}{2}) \end{bmatrix}, \quad \begin{bmatrix} \cos\frac{\theta_2}{2} & i\sin\frac{\theta_2}{2} \\ i\sin\frac{\theta_2}{2} & \cos\frac{\theta_2}{2} \end{bmatrix}, \text{ and} \quad \begin{bmatrix} \exp(i\frac{\theta_3}{2}) & 0 \\ 0 & \exp(-i\frac{\theta_3}{2}) \end{bmatrix},$$

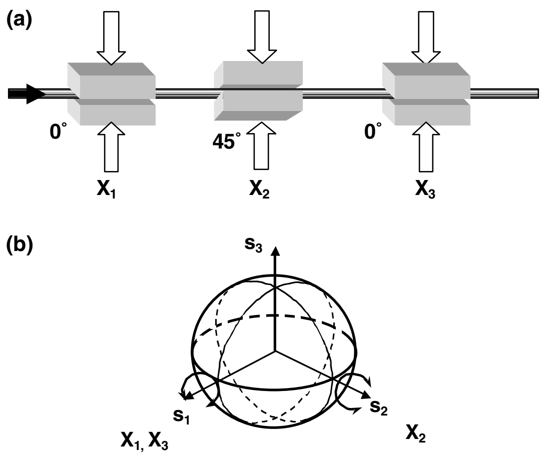

Fig. 1. (a) Configuration of a three-section fiber squeezer polarization controller and (b) the corresponding polarization state traces on the Poincarè sphere as driving voltages vary.