Optik 123 (2012) 228–234

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Tuneable polarization mode dispersion emulator: Fixed polarization maintaining fibre sections and rotatable polarization orientations

Vitalis Musara*, Winston T. Ireeta, Samuel K. Fosuhene, Lorinda Wu, Andrew W.R. Leitch

Department of Physics, P. O. Box 77000, Nelson Mandela Metropolitan University, Port Elizabeth, 6031, South Africa

ARTICLE INFO

Article history:
Received 1 July 2010
Accepted 17 November 2010

Keywords:
Polarization mode dispersion
PMD statistics
Reproducibility
Stability

ABSTRACT

We design a polarization mode dispersion (PMD) emulator capable of adjusting first-order (FO-) and second-order (SO-) PMD statistics, making it capable to mimick differerent fibre links or fibre plants. The emulator can adjust PMD statistics by controlling mode coupling angles between polarization maintaining fibres (PMFs) of fixed length using its seven rotatable electro-optic polarization rotators which act as half waveplates (HWPs). The stability and repeatability of the emulator under a stable laboratory environment makes PMD statistics reproducible. The control mechanism of the emulator is in real-time.

1. Introduction

Polarization mode dispersion (PMD) has become a major concern in long haul ultra-high speed, transmission bit rates greater than 10 Gb/s, optical network systems. In this paper, PMD will be addressed for first-order (FO-) and second-order (SO-) only, although it extends to other higher orders (third order and above). PMD is defined to first-order as the relative disparity in arrival time between the two polarization modes, pointing along the unit Stokes vector [1]. To second-order, PMD is defined as the variation of the FO-PMD and principal states of polarization (PSPs) with optical frequency [2]. The stochastic nature of PMD has made it an on going complex puzzle yet to be solved [3]. The best approach to understanding the PMD phenomenon is through novel emulation.

The need to understand and compensate for PMD has led the research community to develop interest in PMD emulation. PMD emulators exhibiting FO-PMD only [4–6], SO-PMD and other higher-order PMD [7–9] and both FO-PMD and SO-PMD [10–16] have been designed and implemented. The demerit with each of these emulators is that they only mimick a specific fibre plant or fibre link. To address the former, Yan et al. [17] in 2003 designed a high speed, stable and repeatable PMD emulator with tuneable statistics through the use of birefringent crystals and polarization switches. The emulator is applicable in imitating PMD exhibited by different fibre links and fibre plants. Though the emulator is novel, it is costly. Some of the earlier above mentioned emulators try to ensure FO-PMD statistics approaches the Maxwellian distribution [18,19] and SO-PMD approaches the distribution first proposed by Foschini et al. [20]. FO-PMD follows the Maxwellian distribution and SO-PMD follows the distribution proposed by Foschini et al. [20] only under ideal conditions, infinite random mode coupling.

In this paper, by simply using polarization maintaining fibres (PMFs) and half waveplates (HWPs) we build an alternative PMD emulator of similar characteristics to that of Yan et al. [17]. Due to the environmental sensitivity of PMFs as portrayed by Hauer et al. [14] and Yan et al. [17], the emulator presented in this paper was controlled under a stable laboratory environment to achieve the desired outcome. The HWPs are remotely controlled using a computer programme to do away with control errors. Though the PMF sections are fixed, the HWPs adjustments enable changes in the first-order and second-order PMD in accordance to the concatenation rule [21].

2. PMD emulator design and operation

This section focuses on the principle operation of the emulator and its components. The discussion will make it easier for one to rebuild a similar type of emulator. The emulator design is shown as a schematic diagram and then as a photograph (Fig. 1). Of the eight HWPs shown in Fig. 1(b), only seven were used due to a high loss from one of the HWPs. In order to get a mean FO-PMD equal to 13.3 ps and stochastic PMD spectra, PMFs of different FO-PMD magnitudes were randomly distributed as shown in Fig. 1(a). The PMFs and HWPs are interconnected using single mode fibre (SMF) patchcords with negligible PMD (Fig. 1(b)). Each PMF section has SO-PMD of approximately 0.31 ps^2. The loop diameter of each PMF

* Corresponding author. Tel.: +27 41 504 2141; fax: +27 41 504 2573.
E-mail address: vitalismusara@gmail.com (V. Musara).

0030-4026/$ – see front matter
doi:10.1016/j.ijleo.2010.11.035

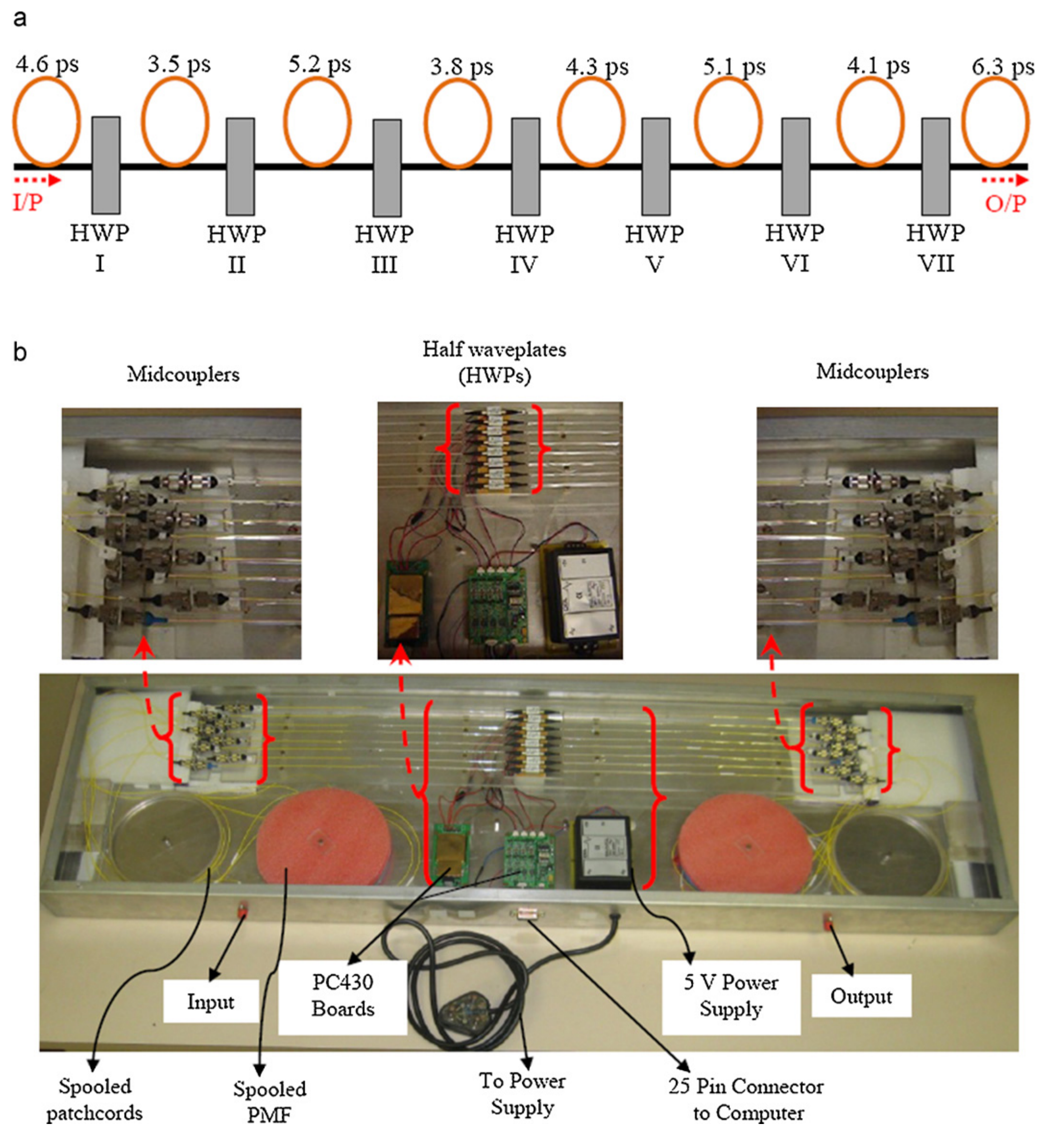

Fig. 1. The (a) Schematic and (b) photographic layout of the emulator. The orange circles in (a) denote the PMF sections. The yellow fibres appearing in the photograph are single mode patchcords used to connect the HWPs and the PMFs. The FO-PMD values of each PMF section are provided. I/P stands for input and O/P for output.

sections was $\geq$ 13.5 cm to minimise the introduction of PDL. PDL makes the principal states of polarization (PSPs) experience abrupt changes and become nonorthogonal [22,23].

Each HWP tunes between 0 to 180° by supplying voltages between 0 – 4 V from the computer through the PC430 board (refer to Fig. 1(b)). Voltage above 4 V will damage the HWPs. Before assembling the emulator each HWP had the 0 to 180° range experimentally determined using two arbitrary PMFs (see Fig. 2, for HWP II), though they are from the same manufacturer. This is required since the alignment axes of PMF sections might vary after the introduction of the SMF patchcords and also due to imperfections in the manufacturing of the HWPs. The SMF patchcords enable easy flexible attachment and removal of the PMF section(s) to the HWP via mounted midcouplers.

Calibrations of HWPs between 0 and 180° were performed by monitoring FO-PMD, SO-PMD and DOP (min, max and mean) as the voltage to the HWP was varied between 0 to 3.8 V in steps of 0.2 V. The maximum applied voltage was set at 3.8 V as a safety measure to reduce the possibility of voltage overshoot. The C+L broadband light source (after polarization scrambling) was used in the calibration process. Fig. 2 shows the calibration results when HWP II interconnected two arbitrary PMF sections. The max, min and mean DOP cycle upwards and downwards as the HWP voltage varies (Fig. 2(a)). A complete peak to peak cycle indicates the 0 to 180° range; when the max DOP is at its minimum, the angle between the two FO-PMD vectors provided by the two arbitrary PMF sections is 90°. The 1.48 V to 2.14 V range was selected as the operating range and a voltage of 1.87 V indicates 90°. At an applied voltage of 2.14 V the FO-PMD was maximum ($\sim$ 6.3 ps) and minimum ($\sim$ 1.6 ps) at 1.48 V (Fig. 2(b)), which corresponds to 0° and 180° respectively. The voltage giving maximum SO-PMD corresponds to 90° (refer to concatenation equations below), in this case it coincided with the expected voltage 1.87 V.

Considering two PMF sections coupled together, the mean FO-PMD ($\boldsymbol{\tau}_{mean}$) and SO-PMD (τ_{ω_mean}) depend on the coupling angle. This can be mathematically proved using the concatenation equations [21]:

$$\boldsymbol{\tau}_{mean} = \boldsymbol{\tau}_2 + \mathbf{R}_2\boldsymbol{\tau}_1 \tag{1}$$

$$\boldsymbol{\tau}_{\omega\_mean} = \boldsymbol{\tau}_{\omega\_2} + \mathbf{R}_2\boldsymbol{\tau}_{\omega\_1} + \boldsymbol{\tau}_2 \times \boldsymbol{\tau}_{mean} \tag{2}$$

where $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$ are the FO-PMD vectors of section 1 and section 2 respectively, $\mathbf{R}_2$ is the rotational matrix of section 2, $\boldsymbol{\tau}_{\omega\_1}$ and $\boldsymbol{\tau}_{\omega\_2}$ are the SO-PMD vectors for section 1 and section 2 respec-