Investigating Depolarization of the Probe in a Two Channel Wavelength-Division Multiplexed System

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Abstract-In this research, experiments have been carried out to investigate the depolarization of a probe signal when the pump signal's optical power is changed and when the length of the fibre link is altered. These investigations were done on a two channel wavelength-division multiplexed (WDM) system. Single mode fibre was used with a length varying between 1.7 km and 24.5 km. The optical power of the pump was within the range 17 dBm to 25 dBm while the probe input power was fixed at - 2.5 dBm. Results show an oscillatory variation of the probe depolarization which decreases as the channel spacing is increased.

Index Terms—Cross phase modulation, PMD, Nonlinearity, Depolarization, Pump-probe system, Channel spacing

I. INTRODUCTION

Optical polarization mode dispersion compensators (OPMDCs) are used to reduce polarization-mode dispersion (PMD) impairments in optical communication systems. Most OPMDCs consist of a polarization controller, a differential group delay element, a PMD monitor and a control feedback loop. Often, the feedback control signal utilizes the degree of polarization (DOP) of the output signal to determine the optimum coupling condition between the fibre link and the compensator [1. 2].

As the signal propagates along an optical fibre, PMD randomizes its state of polarization (SOP). In the presence of a co-propagating highly intense pump, a combination of the Kerr nonlinearities and PMD leads to depolarization of the probe. This depolarization reduces the efficiency of an OPMDC [3 – 5].

In this study, a two-channel WDM system with an erbium doped fibre amplifier (EDFA) was used. We experimentally investigated the influence of pump wavelength, channel spacing, fibre length, pump optical power and probe wavelength on the probe DOP.

II. THEORY

Consider a WDM system with two channels, a pump signal at frequency ω_p and a probe signal at frequency ω_s. For a pump optical power much higher than that of the probe, the nonlinear effects of the probe may be neglected while maintaining those of the pump. The pump modulates the phases of both signals through the nonlinear effects, self-phase modulation and cross-phase modulation. Taking the probe as stationery, the coupled nonlinear Schrodinger equations (NLSE) can be written as

$$\frac{\partial |\mathbf{A_p}\rangle}{\partial \mathbf{z}} \div \boldsymbol{\delta} \frac{\partial |\mathbf{A_p}\rangle}{\partial \tau} = \boldsymbol{i}\gamma_e \boldsymbol{P_p} |\mathbf{A_p}\rangle \quad (1)$$

$$\frac{\partial |\mathbf{A_s}\rangle}{\partial \mathbf{z}} + \frac{\boldsymbol{i}}{2}\Omega \mathbf{b} \bullet \boldsymbol{\sigma} |\mathbf{A_s}\rangle = \frac{\boldsymbol{i}\gamma_e}{2} \boldsymbol{P_p}(3 + \hat{\mathbf{p}} \bullet \boldsymbol{\sigma}) |\mathbf{A_s}\rangle \quad (2)$$

where $\Omega = \omega_p - \omega_s$ is the pump-probe frequency difference, and $|A_p\rangle$ and $|A_s\rangle$ are the Jones vectors of the pump and the probe respectively. $P_p = \langle A_p | A_p \rangle$ is the pump power and $\boldsymbol{\sigma}$ is the Pauli spin vector. Intrachannel PMD effects are included in $\boldsymbol{\delta}$.

In equation (2), the Stokes vector of the pump is given by

$$\hat{\mathbf{p}} = \langle A_p | \boldsymbol{\sigma} | A_p \rangle \, p_p \quad (3)$$

The effective nonlinear parameter is γ_e and includes averaging over rapid variations of the pump SOP [4, 5]. In equation (2), the randomly varying vector ***b*** accounts for residual birefringence and the same equation shows that the probe SOP changes randomly, at a rate determined by $\Omega\boldsymbol{b}$. In the absence of the pump, linear birefringence changes the probe's SOP randomly. When PMD is absent, the Kerr nonlinearities cause the probe's phase to shift and induce nonlinear polarization rotation of the probe. A combination of PMD and the Kerr effect causes the probe to become depolarized [4].

III. EXPERIMENTAL SETUP

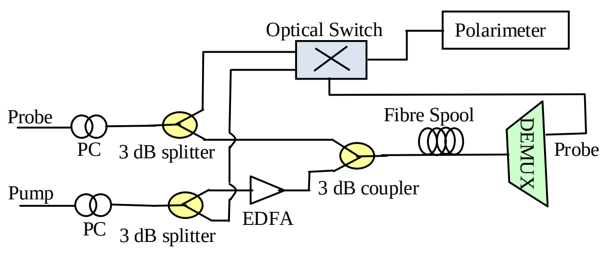

Fig. 1. Experimental setup: A two-channel WDM system (PC = polarization controller)

The results reported in this paper were carried out using the setup shown in Fig. 1. A linearly polarized probe of input optical power - 2.5 dBm and a similarly polarized pump at input power 25 dBm, both in the form of continuous waves, were co-propagated in 1.7 km of low

PMD single mode fibre (SMF). With the probe at a wavelength of 1551.32 nm, the pump wavelength was varied over the range 1549.94 – 1552.72 nm while monitoring the DOP of the probe (Fig. 2). The part of this spectrum within 50 GHz of the probe wavelength i.e. 1550.92 – 1550.74 nm, was excluded since the demultiplexer had a 50 GHz channel spacing. Similar analysis was done with the probe at wavelengths 1551.72 nm and 1552.93 nm (Fig. 2). Thereafter, the pump optical power was varied through the EDFA gain over the range 17 - 25 dBm (Fig 3.). Fixing the pump power at 25 dBm, the probe DOP was also measured for SMF of lengths 3.2 km and 24.5 km (Fig 3).

IV. RESULTS AND DISCUSSION

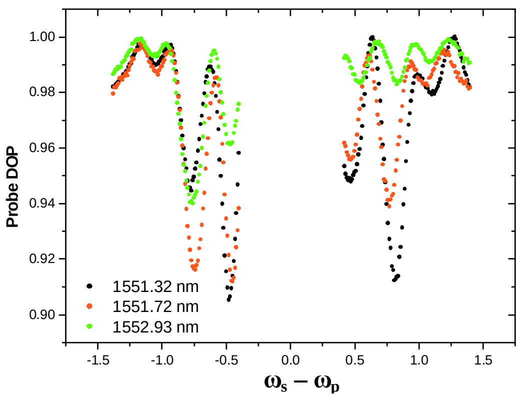

Fig. 2. Variation of probe DOP over the pump spectrum for the probe at 1551.32 nm, 1551.72 nm and 1552.92 nm

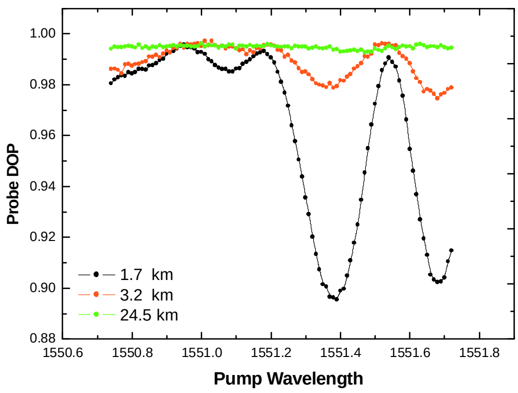

Fig. 3. Probe DOP degradation for fibre lengths 1.7 km, 3.2 km and 24.5 km

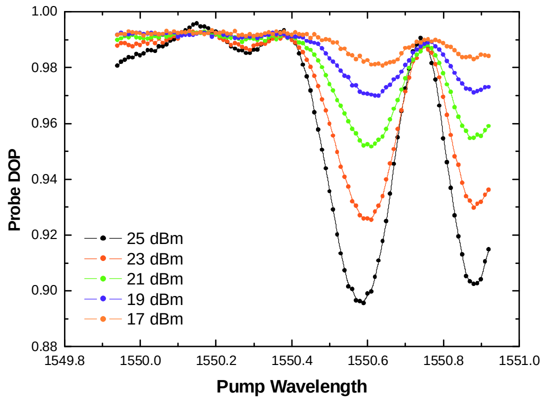

Fig. 4. Effect of varying the input pump power (through EDFA gain

As evident in Fig. 2, the DOP of the probe varies in an oscillatory fashion and the DOP degradation reduces when the channels become far spaced. The dependence of probe depolarization on the channel spacing is supported by equation (2). The decrease in depolarization is expected as described in previous research [2]. The oscillatory pattern, followed by the probe's DOP is however, yet to be explained. It appears to be a property of the pump-probe configuration since changing the probe wavelength retains the trend. Notable, is the fact that when the probe wavelength is increased to 1552.92 nm, the depolarization is generally reduced over the whole spectrum. This is probably because the EDFA gain profile at these wavelengths is decreasing.

As the length of the fibre link increases (Fig. 3), probe depolarization dies away. This may be explained by the reduced pump power after attenuation during propagation. Degradation of the probe DOP is greater for the higher values of pump power depicted (Fig. 4). From equation (2) the nonlinear polarization rotation increases with pump power and this supports the DOP variation observed in Fig. 3 and Fig. 4. CONCLUSIONS

Probe depolarization does not appear to vary monotonically as the channel spacing between the pump and the probe is increased. As reported in other work, the depolarization dies away for wider channel spacing. Probe depolarization is highly linked to the length of the fibre In agreement with theory and previous studies, depolarization decreases as the pump power reduces.

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