Power Variation and Polarization State Evolution in a Two Channel WDM System

Jesman M. Changundega, David Waswa, Lorinda Wu and Andrew W. R. Leitch

Physics Department, Nelson Mandela Metropolitan University, P. O. Box 77000, Port Elizabeth, 6031, South Africa,
Tel: +27 41 5042141; Fax: +27 41 5042573; email: jesmanmoreblessing.changundega@nmmu.ac.za

Abstract — We present experimental results that demonstrate the impact of varying the optical power on the relative angle of the Stokes vectors in a two channel wavelength division multiplexing system. The relative orientation of the output Stokes vectors shows increased evolution with channel power increase as expected. This rotation has a magnitude that is additionally influenced by the initial individual and relative orientation of the Stokes vectors.

Index Terms — nonlinear polarization rotation, cross phase modulation, nonlinear optics.

I. Introduction

With the advent of standard single mode fibre and dispersion management, cross phase modulation (XPM) is the dominant nonlinear effect. In XPM, essentially the high intensity of an optical signal propagating in a fibre causes nonlinear birefringence in the transmission medium through the Kerr effect. This subsequently causes the state of polarization (SOP) of a signal and any copropagating signal to rotate along the fibre length [1]. This phenomenon can seriously impair the performance of a wavelength division multiplexing (WDM) system such as lowering the efficiency of active polarization mode dispersion compensators and of polarization sensitive components [2].

We investigated the relationship between the SOP evolution of the optical transmission signals in a two channel WDM system as channel power increases.

II. Theory

A high power optical wave travelling along an optical fibre induces a nonlinear polarization effect that contributes to the medium's refractive index. The contribution is generally anisotropic thus introducing nonlinear birefringence whose magnitude depends on the intensity and the SOP of the light. For a continuous wave (CW), nonlinear birefringence manifests as a rotation on the SOP along the fibre.

Consider a CW represented by the Stokes vector $\mathbf{s} = (s_1\ s_2\ s_3)$ and travelling along a fibre in the z-direction at time t. The evolution of $\mathbf{s}$ along the fibre may be written in the form [3]

$$\frac{d\mathbf{s}}{dz} = (\mathbf{w} \times \mathbf{s}) \tag{1}$$

where linear and nonlinear birefringence are included in the vector $\mathbf{w} = \mathrm{w} + \mathrm{w}_{NL}$ with $\mathbf{w} = (\Delta\beta, 0, 0)$ and $\mathbf{s} = (0, 0, -2/3\gamma s_3)$

Equation 1 may be written as

$$\frac{ds_1}{dz} = -\frac{2\gamma}{3} s_2 s_3 \qquad \frac{ds_2}{dz} = -(\Delta\beta)s_3 - \frac{2\gamma}{3} s_1 s_3$$
$$\frac{ds_3}{dz} = (\Delta\beta)s_2 \tag{2}$$

In the presence of a second CW whose Stokes vector is $\mathbf{w} = (w_1\ w_2\ w_3)$, interaction between the two waves gives rise to a further rotation of each SOP. The rate of this rotation is governed by [3 - 5]

$$\frac{d\mathbf{w}(z,t)}{dz} = \frac{8}{9}\gamma e^{-\alpha z}\left(\mathbf{s}(z, t - d_{sw} z) \times \mathbf{w}(z,t)\right)$$

and

$$\frac{d\mathbf{s}(z, t - d_{sw} z)}{dz} = \frac{8}{9}\gamma e^{-\alpha z}\left(\mathbf{w}(z,t) \times \mathbf{s}(z, t - d_{sw} z)\right) \tag{3}$$

where α is the absorption coefficient and γ is the nonlinear coefficient. For a chromatic dispersion coefficient of D, $d_{SW} \approx D(\lambda_S - \lambda_W)$ is known as the walk-off parameter. Equation (3) indicates that the two Stokes vectors precess at the same rate about their time- and z-independent average $\mathbf{p} \equiv \frac{1}{2}(|\mathbf{s}| + |\mathbf{w}|)$ [4 - 6]. In addition, attenuation α reduces the SOP rotation along the fibre. From Equation 3, at coordinate z, each Stokes vector has rotated through an angle

$$\Psi(z) = \frac{8}{9}\gamma |\mathbf{P}| L_{eff}(z) \tag{4}$$

where $|\mathbf{p}| = \sqrt{P_S^2 + P_W^2 + 2P_S P_W \cos\theta}$ depends on the initial relative angle θ between the Stokes vectors at z = 0 and the peak powers P_S and P_W for $\mathbf{s}$ and $\mathbf{w}$ respectively. L_{eff} is the effective length of the fibre [3,5,6].

III. Experimental Setup

We copropagated two CWs (1549.3 nm and 1550.1 nm) 100 GHz apart through 24 km of low PMD standard single mode fibre. Various combinations of the initial SOPs were independently controlled using polarization controllers at the input of each signal. The input power for both channels was then varied simultaneously from 3 dBm to 13 dBm. Variation in relative angle of the output Stokes vectors on the Poincaré sphere was calculated. Similar experiments were carried out with power increasing in only one channel to investigate the effect of increasing power within the single channel.

IV. Results and Discussion

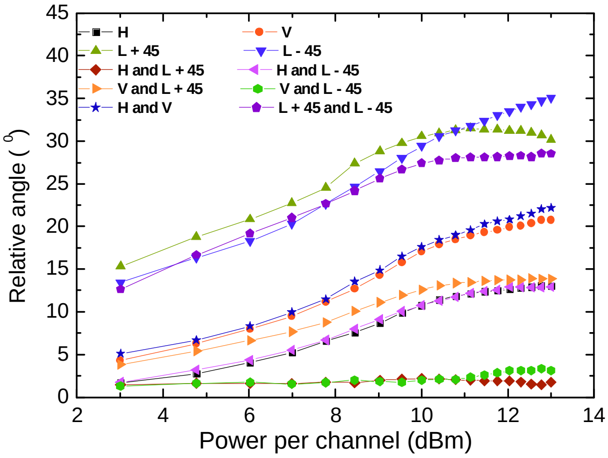

Fig 1. Variation of relative angle between output Stokes vectors with increasing power (Linear orientations: H = horizontal, V = vertical, L±45 = linear polarization inclined at 45 ^{0} to the horizontal)

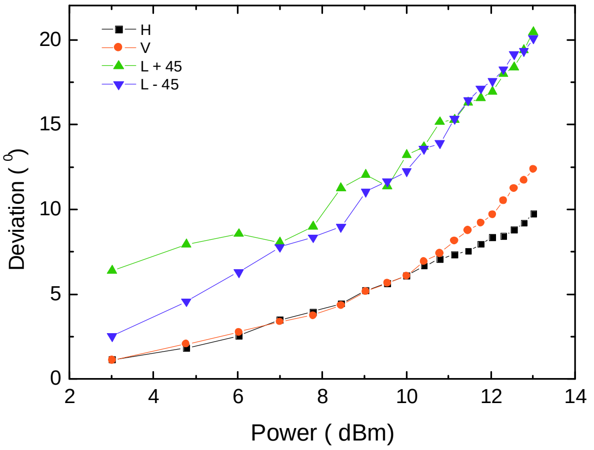

Fig 2. Deviation of a single channel's SOP as power is increased

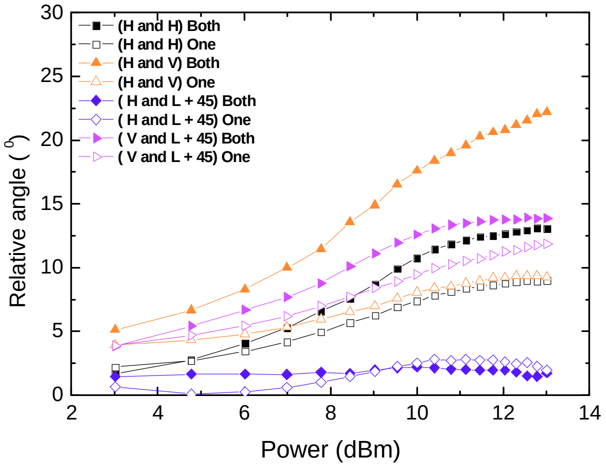

Fig 3. Varying power for either one or both channels

Increasing power in both channels simultaneously, raised the angle between the SOPs of the two channels (Fig 1). The increase is expected from cross phase modulation when Equation (4) is considered. Different combinations of initial SOPs produced different rates of increase in relative angle. Including the L±45 polarization state led to marked change in relative angle (increase or decrease). In such cases, Equation (2) which incorporates self phase modulation predicts a greater negative or positive change in s_3 for the L±45 polarization state due to the high value of s_2. Overall, this leads to either a marked rise or decline of the relative angle between the two propagating signals. This deduction is in agreement with results from experiments in which power was increased in the presence of one channel only (Fig 2) with L±45 polarization state showing marked deviation from its original SOP. In the presence of two channels, raising power in one channel only (Fig 3) lowered relative angle in agreement with Equation (4) since total optical power was now reduced.

V. Conclusions

Results confirm the dependence of the SOP rotation along a fibre on the optical power through linear and nonlinear birefringence. SOP evolution observed agrees well with theory and previous reports [4 – 6].

Acknowledgments

This project is part of the Telkom Centre of Excellence at Nelson Mandela Metropolitan University, supported by Telkom S.A. Ltd, Ingoma Communications Services (Pty) Ltd, Hezeki Contracting (Pty) Ltd, MCT Telecommunications (Pty) Ltd and THRIP.

References

[1] C. Heras, J. M. S. Domingo, J. Pelayo and F. Villuendas, 'Polarization properties of optical spectral components generated by XPM effect,' *J. Lightwave Technol.* **25** (2007) 1313

[2] M. Karlsson and H. Sunnerud, 'Effects of nonlinearities on PMD-induced system impairments,' *J. Lightwave Technol.* **24** (2006) 4127

[3] G. P. Agrawal 'Nonlinear Fiber Optics,' *Academic Press*, (2001) pp. 204 – 223

[4] A. Bononi, A. Vennucci, A. Oriandini, E. Corbel, S. Lanne and S. Bigo, 'Degree of polarization degradation due to cross-phase modulation and its impact on polarization-mode dispersion compensators,' *J. Lightwave Technol.* **21** (2003) 1903

[5] B. C. Collings and L. Boivin, 'Nonlinear polarization evolution induced by cross-phase modulation and its impact on transmission systems,' *IEEE Photon. Technol. Lett.* **12** (2000) 1582

[6] M. R. Phillips and S. L. Woodwind, 'Cross-polarization modulation: Theory and measurement of a two-channel WDM system, *IEEE Photon. Technol. Lett.* **17** (2005) 2086

Jesman M. Changundega holds a B.Sc Physics Hons. degree (1999) and an M.Sc degree in Applied Physics (2006). She is currently a Physics PhD student at NMMU. Her area of research interest is Cross-Polarization Modulation and its implications on PMD compensation