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

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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 medium through the Kerr effect. This subsequently causes the state of polarization (SOP) of a propagating in a fibre causes 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.

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 $s = (s_1, s_2, s_3)$ and travelling along a fibre in the z-direction at time t. The evolution of $s$ along the fibre may be written in the form [3]

$$\frac{ds}{dz} = (w \times s)$$

where linear and nonlinear birefringence are included in the vector $w = w + w_{NL}$, with $w = (\Delta \beta, 0, 0)$ and $s = (0, 0, -2/3 \gamma s_3)$. Equation 1 may be written as

$$\frac{ds_1}{dz} = \frac{2\gamma}{3}s_3s_3$$

$$\frac{ds_2}{dz} = -(\Delta \beta)s_1 - \frac{2\gamma}{3}s_1s_3$$

$$\frac{ds_3}{dz} = 0$$

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

$$\frac{dw(z,t)}{dz} = \frac{8}{9} \gamma e^{-\alpha z} (s(t-d_mz) \times w(z,t))$$

and

$$\frac{ds(z,t-d_mz)}{dz} = \frac{8}{9} \gamma e^{-\alpha z} (w(z,t) \times s(t-d_mz))$$

where $\alpha$ is the absorption coefficient and $\gamma$ is the nonlinear coefficient. For a chromatic dispersion coefficient of $D$, $d_{SW} = D(\lambda - \lambda_w)$ 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 $p = \frac{1}{2}(|s| + |w|)$ [4 - 6]. In addition, attenuation $\alpha$ reduces the SOP rotation along the fibre. From Equation 3, at coordinate z, each Stokes vector has rotated through an angle

$$\psi(z) = \frac{s}{9} \gamma p \tau_{eff}(z)$$

where $|p| = \sqrt{p_S^2 + p_W^2 + 2p_S p_W \cos \theta}$ depends on the initial relative angle $\theta$ between the Stokes vectors at $z = 0$ and the peak powers $P_S$ and $P_W$ for $s$ and $w$ 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° 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 s3 for the L±45 polarization state due to the high value of s2. 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].

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References


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