Compensation for Polarization Mode Dispersion in Multi-Channel System.

David W. Waswa[1], Vitalis Musara[2], Lorinda Wu[2] and Andrew W. R. Leitch[2]
Department of Physics[1], Moi University, P.O Box 1125, Eldoret, 30100, Kenya Tel: +254 053-2063101, +254 722 984 904 Fax: +254 053 43047/2063257
Department of Physics[2], Nelson Mandela Metropolitan University, P.O Box 77000, Port Elizabeth, 6031, South Africa Tel: +27 41 504 2141, Fax: +27 41 504 2573
E-mail contact: dwaswa2000@yahoo.com or david.waswa@mu.ac.ke

Abstract— Intensity induced random varying birefringence leads to nonlinear polarization mode dispersion (PMD) in addition to linear PMD. In this article we investigate the effect of nonlinear PMD on a sideband channels with respect to centre wavelength. It is shown that if three or more channels are launched in the fibre such that the two sideband signals are aligned along the fast and the slow axis respectively, the nonlinear PMD due to change in power of the centre wavelength will affect the two signals differently. The effect will depend on how the State of polarization (SOP) of the centre wavelength are oriented with respect to the fibre axis. Generally we noticed that the sideband signals are little affect with nonlinear PMD if the centre wavelength power is coupled equally into the fibre axes. It was also shown that the nonlinear and linear PMD can be compensated for the effective PMD for each channel by tracking the SOPs of the sideband signals and applying the feedforward technique. The worst channel signal Degree of polarization (DOP) improved by more than 100%.

Index Terms — Nonlinear PMD, Linear PMD, compensation and Multichannel

I. INTRODUCTION

As bit rates per channel increases up to 40 Gb/s or beyond and the transmission distance increases, the linear polarization mode dispersion (PMD) and nonlinearities are gradually becoming a major factor limiting the performance of optical transmission system. In order to cancel fibre PMD in multi-channel system, several optical and electrical PMD compensation (PMDC) techniques have been proposed [1]. In a Subcarrier-Multiplexing, electrical equalization is not effective as it is based on cancelling intersymbol interference and therefore does not recover a PMD-faded RF tone. Optical PMD compensation using RF signal power as feedback control signal is not effective because it is affected by nonlinearities [2, 3]. The feedforward PMDCs have shown advantages over feedback PMDCs. It is the purpose of this paper to demonstrate a DOP based PMD compensator using feedforward double sideband (DSB) method. We also show that nonlinear polarization rotation due to change in input power of the sidebands can also be cancelled PMDC.

II. THEORETICAL BACKGROUND

The evolution of a polarized field of a continous wave signal in a birefringent fibre, in the presence of the mode coupling can be expressed as follows [4]

$$\partial_z\psi = -i\omega\beta\sigma_\theta\psi$$

$$-i\omega\alpha\frac{1}{2}\left(\langle\sigma_3\rangle_\psi\sigma_3+\left(1-\left\langle\sigma_{\theta+\frac{\Pi}{2}}\right\rangle_\psi\sigma_{\theta+\frac{\Pi}{2}}-\langle\sigma_\theta\rangle_\psi\sigma_\theta\right)\right)\psi \quad (1)$$

Ψ represents the complex transverse electric fields at the position z. The first term accounts for linear birefringence with β being the birefringence, ω is the optical frequency and σ_θ is the birefringence axis in the θ direction. The second term accounts for nonlinear birefringence with $\alpha=\frac{n_2P}{3cA_{eff}}$ and $\langle\sigma_3\rangle_\psi=\frac{|E_1|^2-|E_2|^2}{|E_1|^2+|E_2|^2}$. P is the total light power, A_{eff} is the effective mode area, c is the speed of light and n_2 is the nonlinear refractive index.

If we assume that the birefringence is very small, like in a spool. The equation (1) changes to

$$\partial_z\psi = -i\omega\beta\sigma_\theta\psi+\alpha\langle\sigma_3\rangle_\psi\sigma_3)\psi \quad (2)$$

Since β<<α, the output polarization are power dependent. When β is small, the nonlinear birefringence causes the SOPs to slowly rotate along the σ_3 axis. As the birefringence strength tends to zero, the length scale over which the field remains correlated along a fixed set of axes increases. We expect that the SOPs will be preserved over this length scale, but because of the increasing nonlinear birefringence the beat length is reduced and the SOPs are randomly scattered along the S_3 axis, hence the signal is depolarized.

When β > α and σ_θ is fixed or minimally vary to the first order, from (1) the terms $\langle\sigma_3\rangle_\psi\sigma_3$ and $\left\langle\sigma_{\theta+\frac{\Pi}{2}}\right\rangle_\psi\sigma_{\theta+\frac{\Pi}{2}}$ cancel each other. Thus (1) can be expressed as follows

$$\partial_z\psi = -i\omega\beta\sigma_\theta\psi+i\omega\frac{\alpha}{2}\langle\sigma_\theta\rangle_\psi\sigma_\theta = -i\omega\left(\beta-\alpha\frac{1}{2}\langle\sigma_\theta\rangle_\psi\right)\sigma_\theta\psi \quad (3)$$

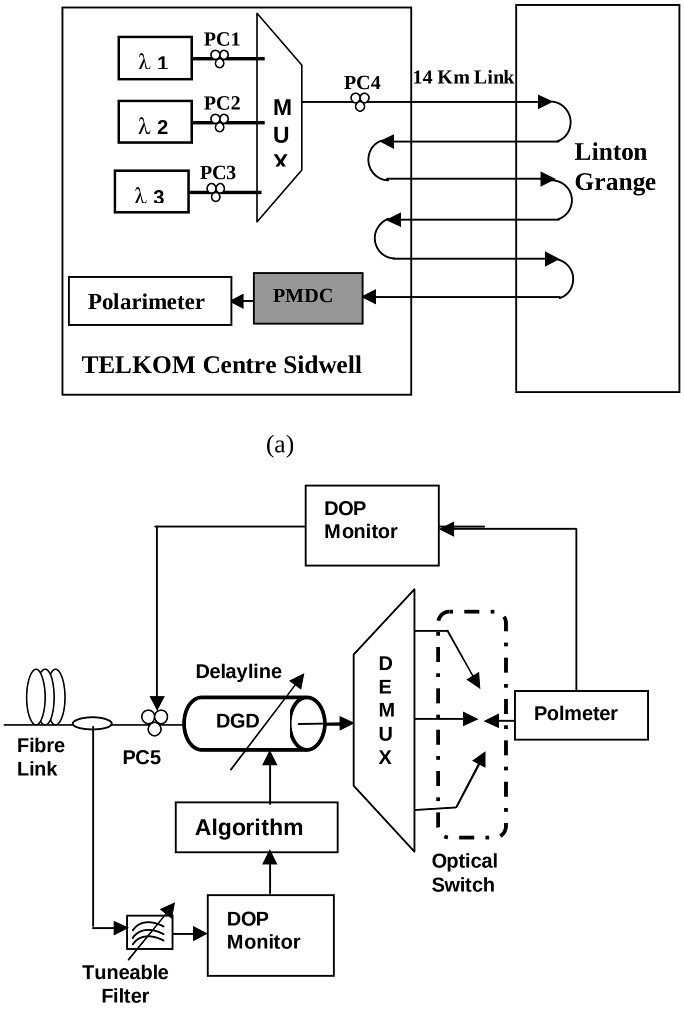
Where $\beta_{eff} = \beta - \frac{\alpha}{2}\left\langle \sigma_{\theta} \right\rangle_{\psi}$ is the effective birefringence.

We find that if the linear birefringence vector is constant then the effective birefringence magnitude changes depending on the intensity and the polarization state of the input light. Therefore the signal can be depolarized and repolarized as power changes. The slow rotation due to the nonlinear birefringence therefore causes a rotation of the input polarization vector around the linear birefringence axis, σ_θ. From (3) we do also observe that at a critical input power, the nonlinear birefringence cancels the existing linear birefringence.

Nonlinear birefringence couples to higher order PMD and decreases the effective birefringence faster than when there is no higher order PMD. This is due intensity-dependent ellipticity.

III. EXPERIMENTAL

To demonstrate the principle of operation the system shown schematically in Fig. 1 is used.



(a)

(b)

Fig. 1: (a) A compensator inserted in the transmission link
(b) Block diagram of the compensator. PC- Polarization Controller.

Fig.1 (a) shows the compensator connected to the transmission link. The three WDM sources used were operating at 1551.72 nm (Upper Sideband (USB): λ_1), 1552.12 nm (Centre wavelength: λ_2) and 1552.52 nm (Lower Sideband (LSB): λ_3) respectively. Their respective input powers were 3 dBm, 13 dBm and 3 dBm. This represented a symmetrical optical spectrum where the power falls off from the centre wavelength, and the intention is to compensate for all wavelengths within the spectrum. The polarization controllers PC1 and PC3 aligned the SOPs of USB and LSB anti-parallel to each other, while polarization controller PC2, was aligned to SOPs of the λ_C 90° with respect to the slow axis in the Stokes space (This was to create the worst scenario). The PC4 was used to maximize the power into the fibre. With the help of the demultiplexer and optical switch, the DOP and SOPs for each channel were measured using a single polarimeter. The experiments were carried out on six looped buried fibres installed between two exchange stations in Port Elizabeth, South Africa, with a total transmission distance of 84 km. The average first- and second-order PMD is 19 ps and 54 ps^2 respectively, measured over a wavelength range of 50 nm.

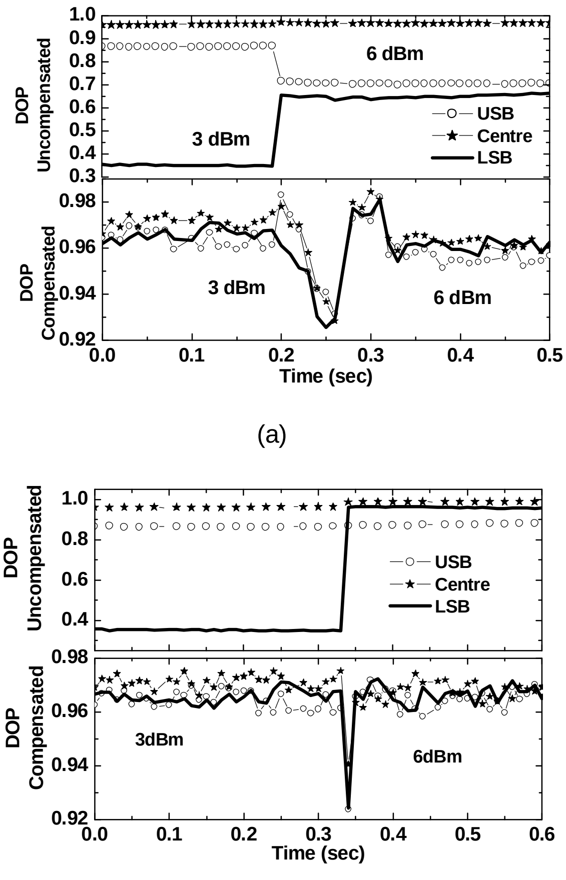
The schematic diagram shown in Fig.1 (b) was used to demonstrate the operation of the compensator. To commence the PMD compensation process, the SOPs were scrambled at the input. By tapping off a small part of the signal at the link output and filtering out the LSB and USB signals the minimum DOP for each subcarrier was determined within one polarization scrambling period, which was then used to monitor the instantaneous DGD of the link. When the minimum DOP of either LSB or USB was below the threshold value (0.95), the DGD was inferred from the lookup table and used to preset the value of the tuneable delayline. The lookup table was generated whereby the DGD to monitoring signal was defined by function F given below [4],

$$F = 4 - (DOP_{max,\,USB} + DOP_{max,\,LSB} + DOP_{min,\,USB} + DOP_{min,\,LSB}).$$

The output signal from the delayline was demultiplexed and by making use of the optical switch the DOPs of the three channels were measured using a single polarimeter. Part of the LSB and USB output minimum DOP was tapped and used as feedback signal to the polarization controller, PC5. The settings of the PC5 were dithered to increase the minimum DOP measured. The polarization controller PC5 and variable delayline were automatically set to track this threshold operating point as it drifted in time with changing PMD.

The experimental results were compared with the results produced at the lab when the emulators were used.

IV. RESULTS



(a)

(b)

Fig. 2: Investigating stability of the compensator with fluctuating power in the sideband signals. (a) Compensating for PMD with varying power of the USB. (b) Compensating for PMD with varying power of the LSB.

Fig. 2(a) and (b) show the compensated and uncompensated DOP of the LSB and USB changes as a function of time when input power in either of the two sidebands exhibit a sudden change power from 3 dBm to 6 dBm. In this case we investigated the stability of the compensator with changing input power of the sideband signals. In Fig. 2(a) for the uncompensated case, when the input power of the LSB signal increased, its DOP reduced and for USB signal whose input power was kept constant had its DOP increased. While in Fig. 2(b) an increase in an input power of the USB signal led to increase in its DOP but the LSB signal was less affected. In the process of the input power of either LSB or USB changing, we report that the compensator was successfully able to track the SOPs and compensate for the distorted signals in less than a second. This is evident from Fig. 2, where the compensated DOP of the three wavelengths was sustained above the threshold DOP, while before compensation the DOP for the worst channel was as low as 0.35. We therefore conclude that our compensator is able to compensate for the nonlinear PMD and is stable with change of signal power.

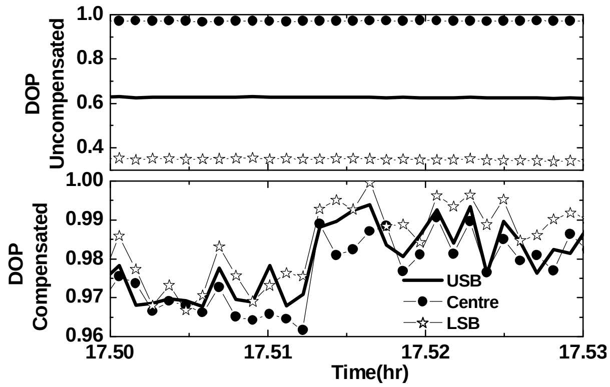


Fig. 3: Compensating for PMD in the buried fibre at Telkom station for USB, centre wavelength and LSB having fixed powers of 3 dBm, 13 dBm and 3 dBm respectively.

In Fig. 3, we investigate the stability of the compensator over time. The compensator was connected to the link for 23 hrs, and we observe that in comparison with uncompensated signals, the DOP measured for all the channels after compensation was well above the threshold value (0.95).

It is worth mentioning that we could not display all the data over the whole time period because of many data points. We randomly chose on the time range displayed in Fig. 3; it has nothing significant since in the whole time period range the DOP was above 0.95.

V. CONCLUSION

We have demonstrated that the nonlinear PMD affects the sidebands differently and both the nonlinear and the linear PMD in multichannel system can be compensated by tracking the SOPs of the sideband channels

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BIOGRAPHY

David Waswa, received his B.Sc and M.Sc. degrees in physics from Physics department, Moi University, Kenya in 1993 and 1999 respectively. He got his doctorate Physics from Physics department, Nelson Mandela Metropolitan University, South Africa in 2009. He is lecturer at Moi University. His research interest are: Measurement and compensation of PMD and nonlinear distortion in the optical . He is a member of OSA and SPIE

Vitalis Musara got his doctorate Physics from Physics department, Nelson Mandela Metropolitan University, South Africa in 2010. He is currently with the Optical Fibre Research Unit at the Nelson Mandela Metropolitan University. Her research interests include polarization effects in optical fibre.

Lorinda Wu obtained her Ph.D in physics at University of Port Elizabeth in 2002. She is currently with the Optical Fibre Research Unit at the Nelson Mandela Metropolitan University. Her research interests include semiconductor characterization and polarization effects in optical fibre

Andrew Leitch is a professor of Physics. He obtained his doctorate in physics at the University of Port Elizabeth in 1984. He is currently the Dean of Faculty of Science. His research interests include semiconductor crystal growth and characterization of signal in optical fibre.