simple and compact fibre circuit has significantly relaxed the severe design constraints for components within practical OTDM systems.

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I.D. Phillips, A.D. Ellis, R.J. Manning, D. Nesset and D.G. Moodie (*Centre for Communications Research, Department of Electrical and Electronic Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom*)

I.Y. Khrushchev, R.V. Penty and I.H. White (*BT Laboratories, Martlesham Heath, Ipswich IP5 3RE, United Kingdom*)

E-mail: I.Khrushchev@bristol.ac.uk

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Polarisation mode dispersion compensation for 6ps, 40Gbit/s pulses using distributed equaliser in LiNbO$_3$

S. Hinz, D. Sandel, M. Yoshida-Dierolf, V. Mirvoda, R. Noé, G. Feise, H. Herrmann, R. Ricken, W. Sohler, H. Suche, F. Wehrmann and R. Wessel

PMD compensation for RZ signals is demonstrated for the first time, using a distributed Ti:LiNbO$_3$ PMD compensator. An electrical detection scheme allows the pulsewidth to be maintained at < 6ps.

Introduction: Polarisation mode dispersion (PMD), especially in installed fibres, broadens optical pulses in a time-variant manner and therefore impedes the development of highest-capacity, long-haul communication systems.

At the receive end, PMD has been optically compensated by equalisers with either one or a few differential group delay (DGD) sections and polarisation transformers [1 – 5] and by distributed equalisers with polarisation transformers embedded in a birefringent waveguide [6, 7], but only for NRZ signals. For RZ signals PMD-induced penalties have been investigated [8]. Here we assess the compensation capability of a distributed LiNbO$_3$ PMD compensator [7] for 6ps RZ pulses at 40Gbit/s data rate.

Experimental setup: A 10GHz modelocked Ti:Er:LiNbO$_3$ waveguide laser (MLL) [9] was used as an optical source (Fig. 1). It emitted a stable train of 5.9ps full width half maximum (FWHM) pulses at $\lambda = 1561$nm with a time-bandwidth product of 0.56. It was externally modulated at 10Gbit/s.

With two delay lines and couplers the signal was optically multiplexed to a data rate of 40Gbit/s. A PMD emulator with two pieces of polarisation-maintaining fibre (PMF), preceded, separated and followed by a total of eight motorised fibre loop devices, simulated a transmission fibre. PMD was equalised in a distributed X-cut, Y-propagation LiNbO$_3$ PMD compensator [7] with ~0.26ps/mm of DGD caused by material and waveguide birefringence. The device was 70mm long and carried 50 sections in which mode conversion in phase and in quadrature was possible by means of voltages applied to appropriately placed comb electrodes. 100 voltages of $\pm \leq 69$V were applied. The fibre-to-fibre insertion loss was 4.4dB, with a variation of ±0.3dB depending on polarisation (when zero voltages were applied). The total compensatory power was 19ps of DGD.

At the receive end the signal was detected in a 40GHz photodiode (u^{2}t Innovative Optoelectronic Components). The electrical signal was amplified and then analysed in two spectral power meters. One was a spectrum analyser tuned to the 40GHz clock line, and the other contained band-limited amplifiers having a 25GHz centre frequency and a 10GHz bandwidth. The signals were read into a PC which worked as a controller. An SHG autocorrelator was used to monitor the received pulsewidth.

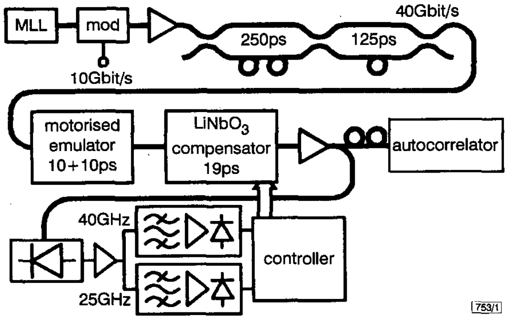

Fig. 1 *Experimental setup*

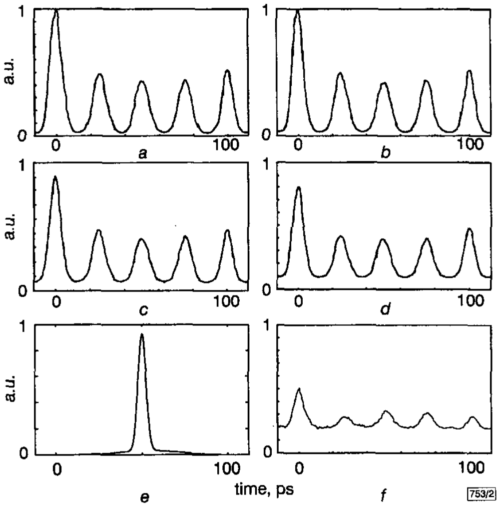

Fig. 2 *Autocorrelation traces*

a Back-to-back, 5.9ps
b With compensator, 5.2ps
c With 10 + 6ps emulator and compensator, 5.4ps
d With 10 + 10ps emulator and compensator, 5.8ps
e Deconvolved pulse with 10 +10ps emulator and compensator, 5.8ps
f Worst case, 10 + 10ps emulator plus compensator

Experimental results: The optical autocorrelator is polarisation-dependent and slow, and for this reason it can only measure at static PMD. The following measurements were therefore repeated several times, and the polarisation was adjusted for the highest intersymbol interference or pedestals due to PMD.

Fig. 2*a* shows the back-to-back autocorrelation trace. Only the centre and one half are shown because the other (mirrored) half is not accessible due to a limited scanning range. At delay multiples of the 25ps bit period the autocorrelation signal exhibits peaks. Owing to the PRBS modulation these are half as high as the peak at zero delay. The FWHM is 8.3ps, and this corresponds to a deconvolved 5.9ps pulsewidth.

As a next step the PMD compensator was inserted. The controller maximised the 25 and 40GHz power levels. The autocorrelation trace reveals a slightly narrower pulse with a deconvolved 5.2ps width (Fig. 2*b*). Similar pulse peaking has already been found in NRZ experiments [3, 6, 8]. Then the emulator was inserted with 10 + 6ps of DGD in the PMF pieces. The deconvolved pulsewidth was now 5.4ps but the autocorrelation pedestal (3% back-to-back) increased to 7.5% (Fig. 2*c*). With 10 + 10ps of DGD in the emulator the deconvolved pulsewidth was 5.8ps and the pedestal 12% (Fig. 2*d*). However, the autocorrelation function exaggerates the true pedestal, as may be seen from a fitted calculation result assuming the superposition of two Gaussian pulses (Fig. 2*e*). There is very little intersymbol interference. For comparison we give also an autocorrelation trace for the emulator plus compensator with the control signals minimised rather than maximised. In this case the original pulses essentially disappear due to PMD (Fig. 2*f*).

A dynamic measurement was made with the 10 + 6ps emulator and the compensator. Starting from an initial standstill the motorised fibre polarisation transformers were made to turn successively faster.

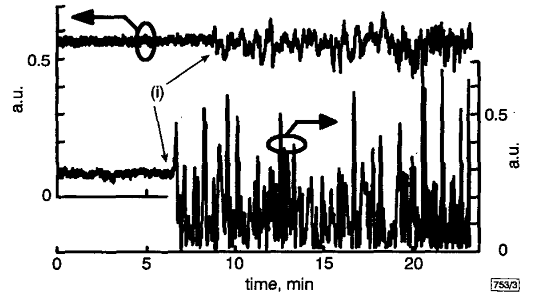

Fig. 3 *Recorded spectral power*

Top trace: control on
Bottom trace: control off
(i) eight fibre coils in emulator start turning

Fig. 3 (upper trace) shows an aggregate control signal obtained by linearly combining the 40 and 25GHz power level signals. Part of the signal variations can be attributed to polarisation dependence (~1dB) of the components following the compensator. For a comparison the measurement was repeated when the control was off. Large signal fluctuations occurred as expected when the fibre coils started to turn (Fig. 3, lower trace). The experiment shows that optical PMD compensation with a simple, purely electrical PMD detection scheme is also possible for RZ signals.

Conclusions: For the first time to our knowledge, the PMD of RZ signals has been compensated. A distributed LiNbO$_3$ PMD compensator was used to equalise 6ps, 40Gbit/s pulses distorted by 10 + 10ps of DGD, using a 10GHz modelocked Ti:Er:LiNbO$_3$ waveguide laser.

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S. Hinz, D. Sandel, M. Yoshida-Dierolf, V. Mirvoda and R. Noé (*Optical Communications and High-Frequency Engineering, University of Paderborn, Warburger Strasse 100, 33098 Paderborn, Germany*)

G. Feise, H. Herrmann, R. Ricken, W. Sohler, H. Suche, F. Wehrmann and R. Wessel (*Applied Physics, University of Paderborn, Warburger Strasse 100, 33098 Paderborn, Germany*)

R. Noé: Corresponding author

E-mail: noe@uni-paderborn.de

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Spectral encoding and decoding of 10Gbit/s femtosecond pulses using high resolution arrayed-waveguide grating

H. Tsuda, H. Takenouchi, T. Ishii, K. Okamoto,
T. Goh, K. Sato, A. Hirano, T. Kurokawa and
C. Amano

A 10Gbit/s, 810fs, return-to-zero signal is spectrally encoded, transmitted over a 40km dispersion shifted fibre, and decoded using a photonic spectral encoder and decoder pair that uses high resolution arrayed-waveguide gratings and phase filters. A 255bit binary phase code with the maximum length sequence is used for spectral coding.

Introduction: A combination of optical code division multiplexing (OCDM) with time division multiplexing (TDM) and wavelength division multiplexing (WDM) improves the signal spectrum efficiency and flexibility of fibre optic communication systems. A photonic encoder/decoder pair is one of the key components of such an optical CDM system. Studies have been made on encoding and decoding optical pulses through the use of diffraction grating pairs [1, 2] and optical transversal filters [3]. These diffraction grating systems, however, do not have sufficient spectral resolution for high signal spectrum efficiency, while optical transversal filters are not easy to use with WDM systems. In this Letter we describe a photonic spectral encoder and decoder pair [4] that uses high-resolution arrayed-waveguide gratings (AWGs).

Configuration and operating principle of spectral encoder/decoder: We used a reflection-type AWG, which is polarisation insensitive, and a spatial phase filter on the spectral plane, as shown in Fig. 1. This configuration can also be used for other photonic signal processing operations, including dispersion compensation and