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10 Gbit/s based NRZ DWDM systems using polarisation switching in single wavelength channel

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It is experimentally demonstrated that the nonlinear tolerance of 10 Gbit/s/ch NRZ based DWDM systems over 1500 km standard singlemode fibre can be significantly improved through the use of orthogonal polarisation switching between adjacent bits in a single wavelength channel.

Introduction: Owing to the current lull in optical communication business, to reduce costs system providers are searching for modulation formats that are more robust to linear and nonlinear effects and are simple to implement. The NRZ format fulfils the requirement that it is simple to employ, but it possesses a relatively low nonlinear tolerance restricting its reach. A possible method for improving the nonlinear characteristics of NRZ modulation is to implement polarisation switching between orthogonal states of adjacent bits in a single NRZ wavelength channel [1, 2], which we call alternately polarised NRZ (alPNRZ). The orthogonality between adjacent bits efficiently suppresses the power transfer between these bits [3] resulting in an improved nonlinear tolerance and an enhanced maximum transmission length of the system. Furthermore, a standard NRZ receiver can be used for detection of this modulation formation allowing for a cost-effective upgrade.

In this Letter we demonstrate the advantage of alPRNZ with experiments comparing 10 Gbit/s/ch alPNRZ and NRZ based DWDM systems with 50 GHz channel spacing over 1500 km.

Experimental setup: Fig. 1 shows the setup used for our investigations. Standard DFB lasers have been used as the signal light sources with a channel spacing of 50 GHz. All channels are modulated with a single-drive Mach-Zehnder (MZ) modulator driven by a conventional 9.9543 Gbit/s NRZ driver without the use of FEC. After data modulation, the WDM channels are split into two 100 GHz grid signal groups by a 50–100 GHz deinterleaver in order to perform the polarisation switching for even and odd channels separately. In the alPNRZ generator (Fig. 1b) the x- and y-polarisations are separated by a polarisation beam splitter (PBS). The polarisation switching between adjacent bits is realised by a 9.9543 Gbit/s alternating 0-to-π phase modulation of the y-polarisation. The effective length of the fibre between the x- and y-polarisation arms must be identical before they are combined at the polarisation beam combiner (PBC) in order to realise the proper bit stream with polarisation switching. Because of the phase modulation required for alPNRZ modulation, its optical spectrum is broader (Fig. 1c) than the standard NRZ modulation. For the NRZ generation the same setup was used, but the phase modulators were turned off, so that a direct comparison of the two modulation formats could be simply performed. The loop setup consists of 3×100 km SSMF. Dispersion compensation is realised using dispersion compensation fibres (DCF) such that a DC-80 module compensates for 80 km of SSMF. The residual dispersion (D_{RES}) per loop is $D_{RES} = 170$ ps/nm. The optical amplification was performed with EDFAs only. For a smaller number of channels ($N < 5$) optical filters were placed after each EDFA to reduce the impact of ASE noise on the transmission performance. At the receiver side the wavelength channels are demultiplexed first with a 50–100 GHz deinterleaver, and the middle channel is filtered out with a 100 GHz optical bandpass filter. With a tunable dispersion compensator, the D_{RES} of the loop can be tuned and optimised. The signals are detected using a conventional 10 Gbit/s NRZ receiver.

Results and discussion: To compare the performance of NRZ and alPNRZ modulation formats in 10 Gbit/s based transmission, 10 Gbit/s single channel, 3×10 Gbit/s WDM and 7×10 Gbit/s 50 GHz grid DWDM systems have been investigated over five loops (1500 km SSMF).

10 Gbit/s single channel and 3×10 Gbit/s DWDM transmission: To determine the optimum residual dispersion for the disper-

sion map used in the experiments, the D_{RES} is varied with a step size of 50 ps/nm. For equal powers per channel ($P_{IN} = 5$ dBm/ch) we find an optimum for the alPNRZ modulation of $D_{RES} = 500$ ps/nm (Fig. 2a). For both single channel and DWDM alPNRZ measurements, a similar D_{RES} dependence is evident. This is because single channel nonlinear effects (SPM, SPM-GVD) are the dominant system limitations for these power per channel and channel spacing values. Using alPNRZ, the impact of single-channel nonlinearities is efficiently suppressed and its performance is much better than that of NRZ. At the optimum $D_{RES} = 500$ ps/nm, we further investigated the power per channel tolerance (Fig. 2b). alPNRZ performance is much better than that of NRZ and is limited due to single-channel effects for up to 7 dBm/ch. For $P_{IN} > 8$ dBm/ch in the 3×10 Gbit/s WDM case, multichannel effects (XPM) become dominant.
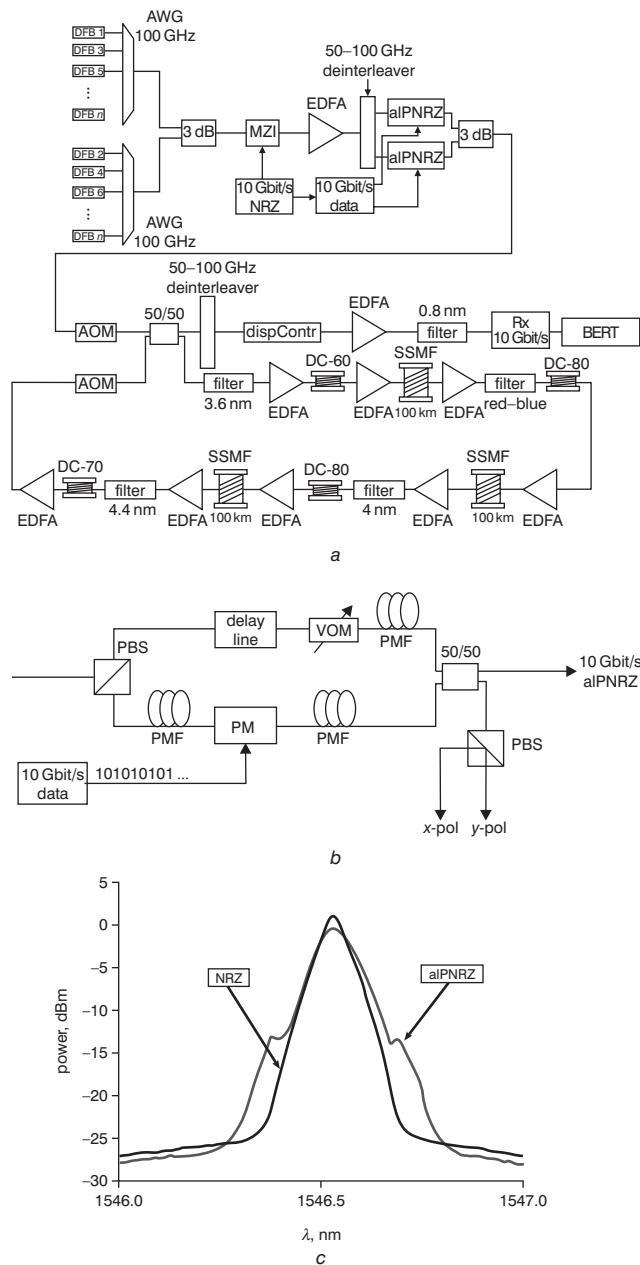

Fig. 1 *Investigated system setup*

a Loop configuration *b* 10 Gbit/s alPNRZ generator
c 10 Gbit/s NRZ and alPNRZ signal spectra ($P_{IN} = 5$ dBm/ch)

The performance of all the experiments presented here was suboptimal due to coherent crosstalk inherent in the alPRNZ generator. This is due to the instability of the polarisation in the two arms of the generator, which could be eliminated with an integrated device. If the polarisations are not truly orthogonal, then coherent crosstalk results. However, this crosstalk should affect the two modulation formats equally. Hence, although the performance is not optimal, a comparison between the two

should be reliable. To verify our experimental results, numerical simulations were performed.
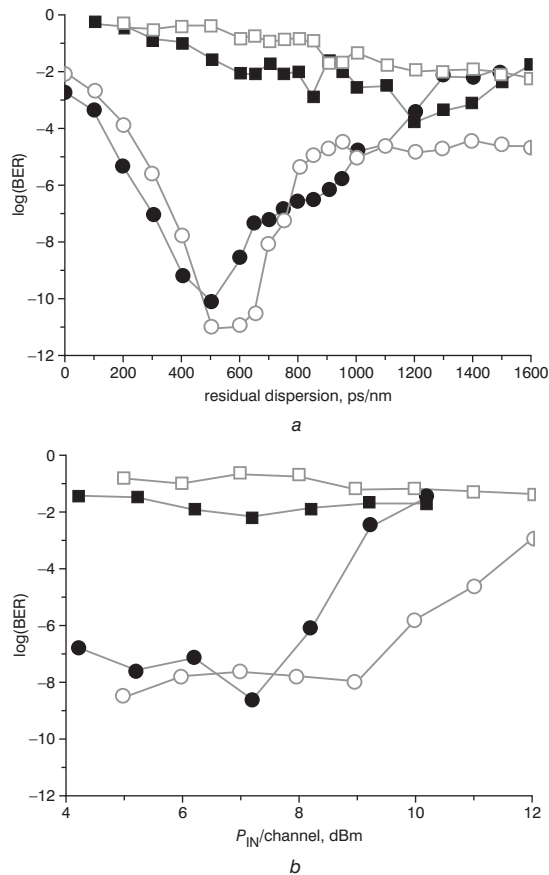

Fig. 2 *Experimental comparison between 3 × 10 Gbit/s DWDM (50 GHz grid) and 1 × 10 Gbit/s transmission over 1500 km SSMF*

a BER against D_{RES} ($P_{IN} = 5$ dBm/ch)   *b* BER against P_{IN}

■— NRZ   □— NRZ
●— alPNRZ   ○— alPNRZ

7 × 10 Gbit/s DWDM transmission: To investigate the feasibility of alPNRZ based 10 Gbit/s/ch DWDM systems, the number of channels was increased to seven. Thereby the optical filters after each EDFA were taken out of the loop. Because of the broader alPNRZ spectrum (Fig. 3a), alPNRZ is more affected by linear crosstalk than NRZ. Again a $D_{RES} = 500$ ps/nm is found to be optimal for the alPNRZ case. At this D_{RES}, the BER dependence on the power per channel was investigated (Fig. 3b). The performance of alPNRZ is dramatically better than that of NRZ modulation. The optimum operating region lies between 3 and 8 dBm/ch. The multichannel limitations prevail for channel powers larger than 8 dBm/ch. The experimental results imply that the use of polarisation switching in 10 Gbit/s/ch DWDM systems may strongly improve the nonlinear tolerance. Thus systems with longer maximum transmission lengths and a reduced number of optical amplifiers could be realised.
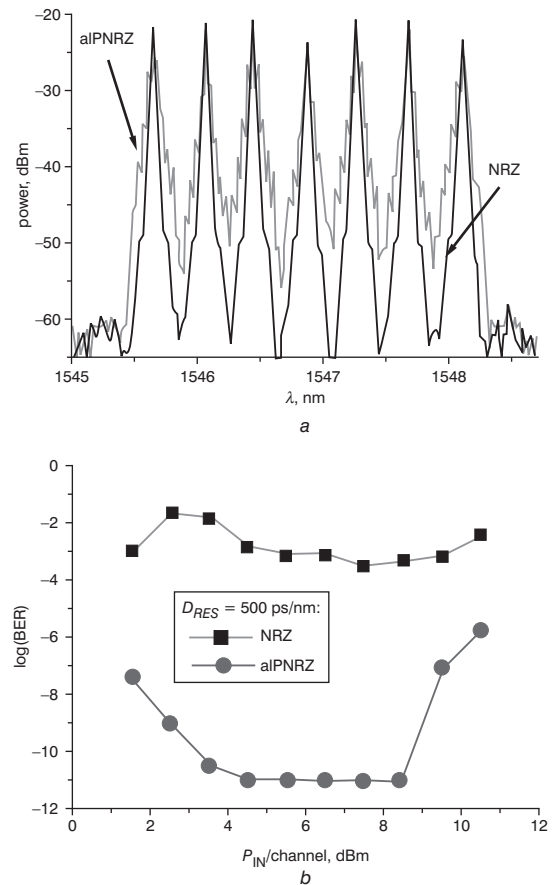

Fig. 3 *7 × 10 Gbit/s WDM transmission (50 GHz grid) over 1500 km SSMF*

a 7 × 10 Gbit/s alPNRZ spectrum   *b* 7 × 10 Gbit/s BER against P_{IN}

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