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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 singlenode 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 alPNRZ 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 (1500 km SSMF). 50 GHz grid DWDM systems have been investigated over five loops (module compensates for 80 km of SSMF. The residual dispersion consists of 3

modulation formats could be simply performed. The loop setup consists of 3

nm. The 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 compensating fibres (DCF) such that a DC-80 module compensates for 80 km of SSMF. The residual dispersion (DRES) per loop is DRES=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 DRES 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 dispersion map used in the experiments, the DRES 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 DRES=500 ps/nm (Fig. 2a). For both single channel and DWDM alPNRZ measurements, a similar DRES 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 can be efficiently suppressed and its performance is much better than that of NRZ. At the optimum DRES=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.

The performance of all the experiments presented here was suboptimal due to coherent crosstalk inherent in the alPNRZ 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 \(D_{\text{RES}}\) (\(P_{\text{IN}} = 5\) dBm/ch)  b BER against \(P_{\text{IN}}\)

- NRZ
- 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 \(D_{\text{RES}} = 500\) ps/nm is found to be optimal for the alPNRZ case. At this \(D_{\text{RES}}\), 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 \(P_{\text{IN}}\)

References