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Wavelength Conversion of 80 Gbit/s Optical DQPSK using FWM in a Highly Non-linear Fibre

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Abstract: We present, for the first time, wavelength conversion of 80 Gbit/s optical DQPSK. The wavelength conversion is achieved using FWM in a highly non-linear fibre. We demonstrate a conversion power penalty as low as 2.8 dB.

OCIS codes: (060.5060) Phase modulation, (060.4370) Nonlinear optics, fibers.

1. Introduction

Differential quadrature phase shift keying (DQPSK) has recently been proposed as a modulation format for optical communication networks [1]. Benefits of DQPSK include reduced spectral width, improved dispersion tolerance, and reduced required electrical bandwidth compared to binary modulation formats at the same bit rate. Recent experiments have demonstrated transmission over 6500 km [2], system capacity above 4 Tbit/s [3] and very high spectral efficiency [4–6], proving DQPSK as a suitable modulation format for today's optical communication systems. The high spectral efficiency makes DQPSK an attractive modulation format when designing new or upgrading existing optical links in order to maximise the capacity in a given bandwidth.

Large dispersion tolerance is required in reconfigurable optical networks where the fibre path, and thus the accumulated dispersion can vary. DQPSK can increase the reach of such systems. Wavelength conversion is expected to be an essential feature of future all-optical networks. However, conventional wavelength conversion methods—such as those based on cross gain modulation (XGM) in a semiconductor optical amplifier (SOA) or cross-phase modulation (XPM) in SOA interferometric structures [7]—disregard the phase information and thus prevent the conversion of phase modulated signals. Four-wave mixing (FWM) can be utilised to obtain phase-preserving wavelength conversion, as demonstrated in [8] for a 2.5 Gbit/s differential binary phase shift keying (DBPSK) signal using FWM in non-linear fibre, and in [9] for a 10 Gbit/s DBPSK signal using FWM in a SOA.

Here, we present the first demonstration of wavelength conversion of ultra-high bit rate phase modulated signals. Using FWM in a highly non-linear fibre (HNLF), we demonstrate wavelength conversion of 40 Gbit/s DBPSK and 80 Gbit/s DQPSK signals with conversion power penalty less than 2.8 dB.

2. Results and Discussion

As shown in Fig. 1, the 80 Gbit/s DQPSK signal was generated using a phase modulator and a Mach Zehnder (MZ) modulator in series. Continuous wave (CW) light at a wavelength of 1552.0 nm was first modulated by a phase modulator driven by a 40 Gbit/s data signal having an amplitude resulting in a $\pi/2$ phase change. After the phase modulator, a MZ modulator added a π phase shift. The MZ modulator was driven with a peak-to-peak voltage equal to twice the modulator switching voltage V_π, which is a commonly used method of DBPSK signal generation. By disabling the phase modulator, we could generate a 40 Gbit/s DBPSK signal with the same setup. The eye

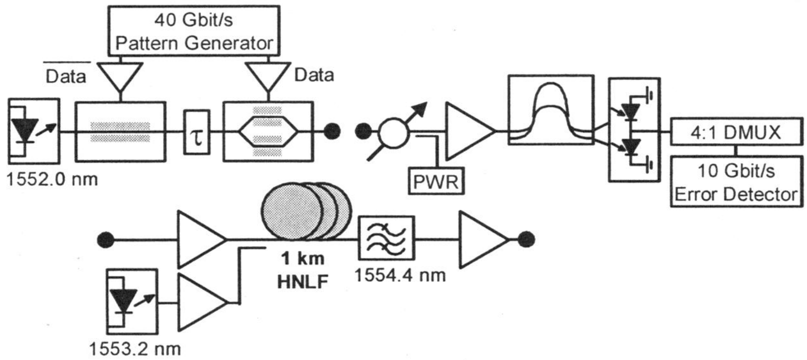

Fig. 1. Experimental setup, showing transmitter, wavelength converter and receiver.

diagram of the generated signal—the same for 40 Gbit/s DBPSK and 80 Gbit/s DQPSK—is shown in Fig. 2(a). At the pre-amplified receiver, the signal was demodulated using a MZ delay interferometer with a $\pm\pi/4$ phase shift in one arm, and received using a 45 GHz balanced photodetector. The sign of this phase shift determined which of the two DQPSK tributaries was demodulated. The delay difference between the two arms of the demodulator was 23.5 ps, optimised for a symbol rate of 43 Gbaud. The eye diagram of the electrical demodulated signal in the back-to-back configuration is shown in Figs. 2(b) and 2(c) for DBPSK and DQPSK, respectively. The inter-symbol interference shown on the back-to-back eye diagram is due to limited bandwidth of the phase modulator (22 GHz), and the $2V_\pi$ driver for the MZ modulator (28 GHz).

A 2^7–1 pseudo-random bit sequence (PRBS) and an inverted 2^7–1 PRBS were used for the MZ modulator and phase modulator, respectively. The two patterns were decorrelated by a relative delay of 48 bits. Pre-coding was not applied to the transmitted data for DQPSK, instead the error detector was programmed with the expected bit pattern. Due to the lack of a programmable 40 Gbit/s error detector, the received signal was electrically demultiplexed to 10 Gbit/s, and the errors counted on a programmable 10 Gbit/s error detector.

Wavelength conversion was realised using FWM in a 1 km HNLF—supplied by OFS Fitel Denmark—with a non-linear coefficient $\gamma = 10.9\ W^{-1}km^{-1}$. The signal was fed into the HNLF along with a pump at a wavelength of 1553.2 nm. At the fibre input, the power of the data and pump was 14 and 17 dBm, respectively. Fig. 3 shows the optical power spectrum of the signal at the input and output of the HNLF, and it is seen that FWM products were

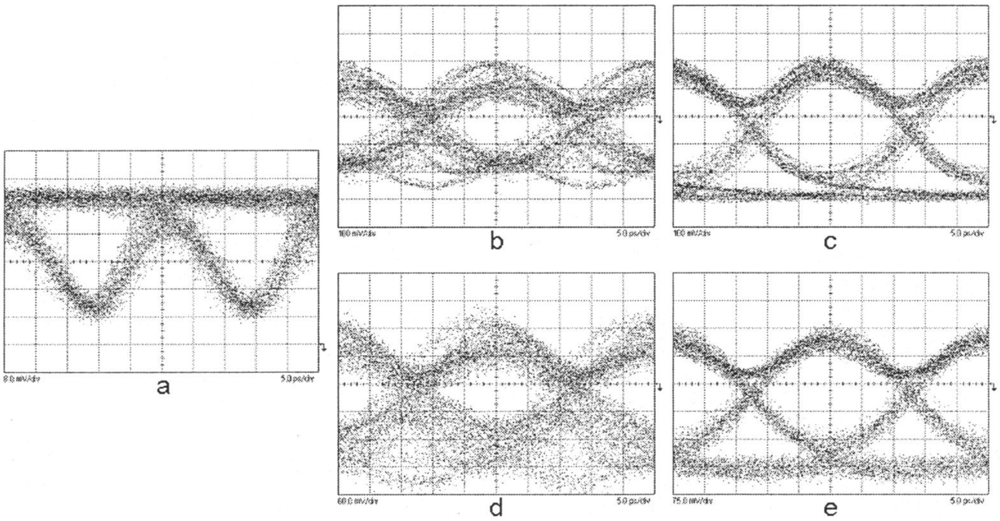

Fig. 2. Eye diagrams of signals at various points in the system. The generated signal shown in (a) is identical for both 40 Gbit/s NRZ-DBPSK and 80 Gbit/s DQPSK. Please see text for details.

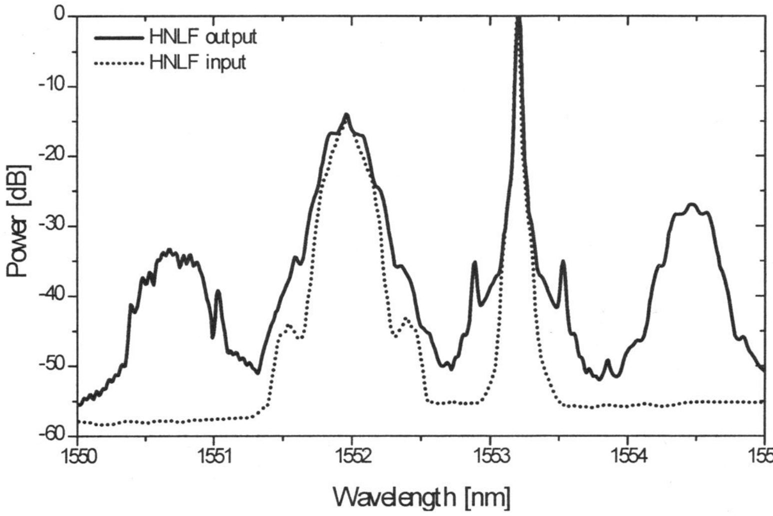

Fig. 3. Optical power spectrum at the input and output of the HNLF, illustrating the generation of the FWM products at 1550.8 and 1554.4 nm.

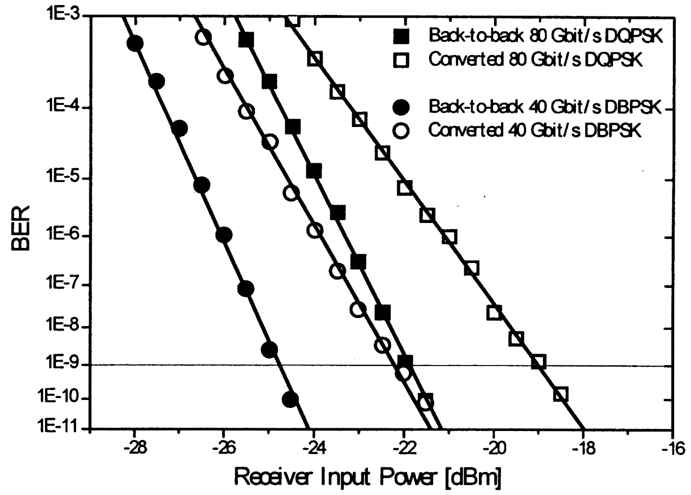

Fig. 4. Measured BER vs. receiver input power for 80 Gbit/s DQPSK (one of the two tributaries are shown) and 40 Gbit/s DBPSK before and after wavelength conversion.

generated at wavelengths of 1550.8 and 1554.4 nm. An optical band-pass filter was used to suppress all signals expect the converted signal at 1554.4 nm. The conversion efficiency, defined as the ratio between the power of the converted signal and the power of the original signal at the output of the HNLF, was –12.4 dB.

Fig. 4 presents the receiver sensitivity measurements, showing the measured bit error rate (BER) as a function of the receiver input power. We measured a receiver sensitivity of –21.8 dBm for 80 Gbit/s DQPSK in the back-to-back case. After conversion we measured a receiver sensitivity of –19.0 dBm, corresponding to a conversion power penalty of 2.8 dB. For 40 Gbit/s DBPSK, we found a wavelength conversion power penalty of 2.6 dB. It is interesting to note that the multiple symbol levels of DQPSK do not lead to significant extra wavelength conversion penalty compared to DBPSK. The electrical demodulated signals after conversion are shown in Figs. 2(d) and 2(e) for DBPSK and DQPSK, respectively. It is seen that the waveform is very well preserved after wavelength conversion, and that the main degradation is noise due to reduced optical signal-to-noise ratio.

3. Conclusion

Using FWM in a HNLF, we have for the first time demonstrated wavelength conversion of an 80 Gbit/s DQPSK signal. The conversion penalty is found to be 2.8 dB, which is only 0.2 dB more that the conversion penalty for 40 Gbit/s DBPSK.

4. References

[1]. R. A. Griffin, R. I. Johnstone, R. G. Walker, J. Hall, S. D. Wadsworth, K. Berry, A. C. Carter, M. J. Wale, P. A. Jerram, and N. J. Parsons. 10 Gb/s optical differential quadrature phase shift key (DQPSK) transmission using GaAs/AlGaAs integration, in *Technical Digest Optical Fiber Communication Conference, OFC'02*, Anaheim, California, U.S.A., Paper FD6, March 2002.

[2] T. Tokle, C. R. Davidson, M. Nissov, J.-X. Cai, D. G. Foursa, and A. Pilipetskii. 6500 km transmission of RZ-DQPSK WDM signals, *Electronics Letters*, vol. 40, no. 7, pp. 444–445, April 2004.

[3] N. Yoshikane and I. Morita. 1.14 b/s/Hz spectrally-efficient 50×85.4 Gb/s transmission over 300 km using copolarized CS-RZ DQPSK signals, in *Technical Digest Optical Fiber Communication Conference, OFC'04*, Los Angeles, California, U.S.A., Paper PDP38, February 2004.

[4] T. Tokle, C. R. Davidson, M. Nissov, J.-X. Cai, D. G. Foursa, and A. Pilipetskii. Transmission of RZ-DQPSK over 6500 km with 0.66 bit/s/Hz spectral efficiency, in *IEEE/LEOS 2004 Workshop on Advanced Modulation Formats*, San Francisco, California, U.S.A, pp. 3–4, Paper ThA2, July 2004.

[5] P. S. Cho, G. Harston, C. J. Kerr, A. S. Greenblatt, A. Kaplan, Y. Achiam, G. Levy-Yurista, M. Margalit, Y. Gross, and J. B. Khurgin. Investigation of 2 b/s/Hz 40 Gb/s DWDM transmission over 4×100 km SMF-28 fiber using RZ-DQPSK and polarization multiplexing, *IEEE Photonics Technology Letters*, vol. 16, no. 2, pp. 656–658, February 2004.

[6] Y. Zhu, K. Cordina, N. Jolley, R. Feced, H. Kee, R. Rickard, and A. Hadjifotiou. 1.6 bit/s/Hz orthogonally polarized CSRZ - DQPSK transmission of 8x40 Gbit/s over 320 km NDSF, in *Technical Digest Optical Fiber Communication Conference, OFC'04*, Los Angeles, California, U.S.A, Paper TuF1, February 2004.

[7] K. E. Stubkjær. Semiconductor optical amplifier-based all-optical gates for high-speed optical processing, *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 6, no. 6, pp. 1428–1435, November 2000.

[8] N. Chi, J. Zhang, P.V. Holm-Nielsen, C. Peucheret, and P. Jeppesen. Transmission and transparent wavelength conversion of an optically labeled signal using ASK/DPSK orthogonal modulation, *IEEE Photonics Technology Letters*, vol. 15, no. 5, pp. 760–762, May 2003

[9] J. Wang and J. M. Kahn. Conventional DPSK versus symmetrical DPSK: Comparison of dispersion tolerances, *IEEE Photonics Technology Letters*, vol. 16, no. 6, pp. 1585–1587, June 2004.