High performance, 64-chip, 160 Gchip/s fiber grating based OCDMA receiver incorporating a nonlinear optical loop mirror

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Abstract: We demonstrate a grating based 64-chip, 160 Gchip/s OCDMA system incorporating a NOLM within the receiver to enhance the code recognition signature. Error-free, penalty-free operation is obtained with complete recovery of the original input pulse shape in a range of transmission experiments.

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1. Introduction

Optical pattern generation and recognition are likely to prove important functions in future high-capacity optical networks. These functions are required for example within transmitters and receivers for Optical Code Division Multiple Access (OCDMA) systems and for header recognition in ultra-fast OTDM packet switched networks [1,2].

Superstructured fibre Bragg grating (SSFBG) technology represents an attractive means to produce compact, and potentially low-cost components for a wide range of pulse processing applications, including pulse pattern generation and recognition [3,4]. For example we recently demonstrated the suitability of SSFBGs for generating, recognizing and recoding 64-bit long, 160 Gbit/s, phase-encoded optical pulse sequences [5]. In all of our SSFBG based optical pattern recognition experiments to date we have relied upon the principle of simple matched filtering which is based upon purely linear optical effects. However one can envisage incorporating additional nonlinear components within SSFBG based processing schemes to either improve the performance, or to extend the functionality, of this technical approach.

In this paper we present the first results in this direction and demonstrate enhanced code recognition quality by incorporating a nonlinear optical loop mirror (NOLM) in a 64-chip, 160Gchip/s OCDMA code:decode system. The nonlinear response of the NOLM significantly enhances the pattern recognition contrast achievable with matched filtering alone. This provides a considerable improvement in the overall system response and allows for error-free, penalty-free performance relative to direct back-to-back measurements on the input laser source itself.

2. Experimental set up and results

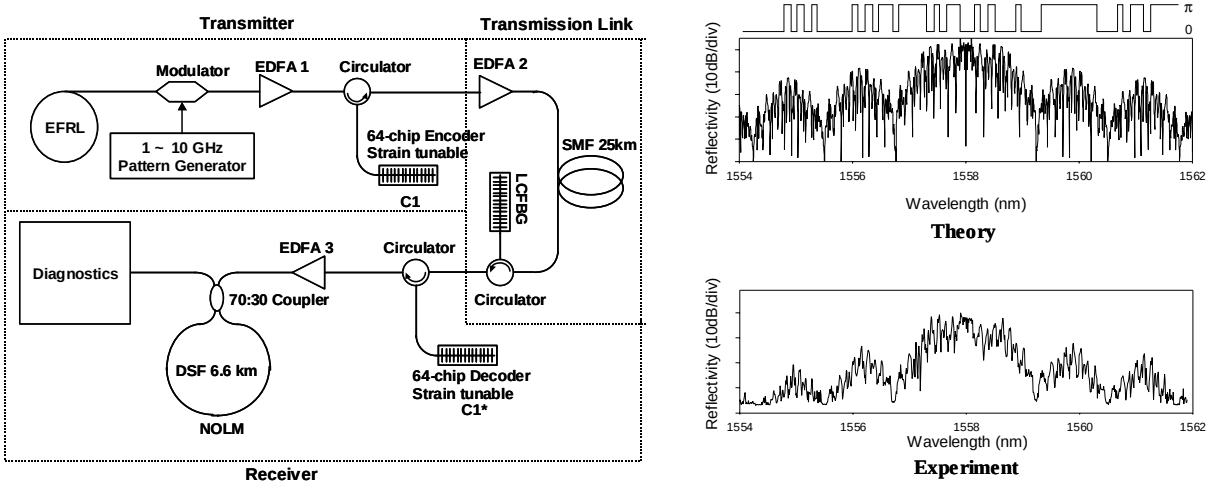


Fig. 1: Experimental set up and spectral profile of SSFBGs for a 64-bit bipolar phase shift keyed Gold sequence code.

Our experimental set up is shown in Fig.1 and comprises a 2.5ps, 10GHz, regeneratively mode locked erbium fiber ring laser (EFRL) with an external 10GHz 'pulse selector' modulator to allow us to vary the final pulse repetition rate in the range 1 to 10 GHz. The short pulses were then launched onto an encoding SSFBG (C1) containing 64-chip bipolar Gold sequence coding information. The particular gratings are more fully described in Ref.[5]. The resulting code sequence is defined by the impulse response of the grating and follows the actual refractive index superstructure profile written into the grating. The chip duration was 6.4ps, and chip rate 160 Gchip/s. The coded data pulse, which had a total duration of ~400ps, was then either fed directly to the associated matched decode grating filter, or transmitted over a 25km standard fiber transmission line whose dispersion was compensated with a chirped fiber Bragg grating. The resulting signal was then fed onto the decode grating (C1*). The pulses reflected from the decode grating represent the correlation function of the incoming coded sequences with the decode grating's impulse response function. When the code and decode gratings are matched then the decode output exhibits a short, chip length long autocorrelation spike on a relatively low-level broad pedestal (see Fig.2(b), and Fig.3(a)) which can be used to provide code recognition as previously reported [5].

We performed detailed BER measurements on the matched filtered pulse forms shown in Fig.2(b) and 3(a) at a data rate of both 1.25 and 2.5 Gbit/s (see Fig.4). These measurements showed that high quality error-free performance could be obtained. However, a power penalty was found to be associated with the process. At a data rate of 1.25 Gbit/s this power-penalty was ~1.5dB. The power-penalty increased to 4.5 dB at 2.5 Gbit/s for which the 800ps long correlation pulses have significant overlap in the pulse tails. The increased power-penalty at 2.5 Gbit/s results from amplitude noise associated with coherent interference between the adjacent '1' data bits. (The correlation pulse tails do not overlap at a data rate of 1.25 Gbit/s.)

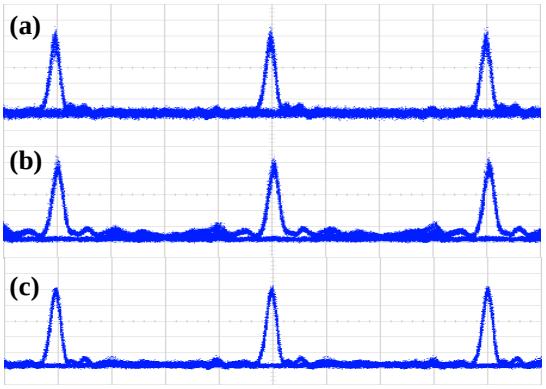


Fig. 2. Eye diagrams of (a) the input 2.5ps pulses, (b) the pulses after matched filtering and (c) the matched filtered pulses after nonlinear switching by the NOLM. The data rate is 2.5 Gbit/s.

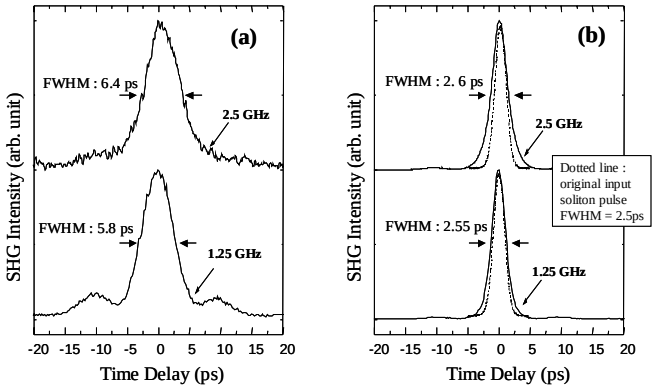


Fig.3. SHG Autocorrelation traces of the central auto-correlation spike associated with pattern recognition (a) after matched filtering, (b) after subsequent nonlinear switching by the NOLM.

In order to reduce the observed power penalty we amplified the decoded code-correlation pulse forms (up to a maximum average power of 15dBm) and fed them into the input of the NOLM [6]. The NOLM incorporated a 70:30 coupler, and contained 6.6km of dispersion shifted fiber, with a dispersion D=1.18ps/ nm/km at the system operating wavelength of 1558nm. The resulting nonlinearly switched waveform was then characterized as previously, and BER measurements were performed. The improved pattern recognition contrast is clearly evident by comparing Figs 2(b) and (c), and Figs.3(a) and (b). The low level pedestal obtained with simple matched filtering is almost entirely eliminated by passage through the nonlinear loop mirror. From Fig.3(b) it is also seen that the shape and duration of the output pulses were restored to values close to the original input laser pulses due to high-order soliton effects within the NOLM [7]. The benefits of the pedestal rejection from a system perspective are shown in Fig.4. The previously observed power penalties associated with matched filtering are entirely eliminated even in the presence of considerable autocorrelation tail overlap at the bit-rate of 2.5 Gbit/s. This is significant from a single-channel data rate perspective since it allows for higher data rates than possible with simple matched filtering alone. We have also performed experiments at bit-rates as high as 10Gbit/s. At this data rate a given bit-slot receives contributions from as many as 16 neighboring '1' data bits resulting in significant interference noise. The eye diagrams shown in Fig. 5(a) illustrate the great performance improvements that can be obtained by nonlinear processing of the signal. After simple matched filtering alone the eye is completely closed, however after nonlinear processing a clear, open eye is restored. The performance benefits were confirmed by detailed BER measurements as shown in Fig.5(b), where error-free performance with a power penalty of ~2dB is observed. Note that it was impossible to make meaningful BER measurements without the use of the NOLM due to the high noise level.

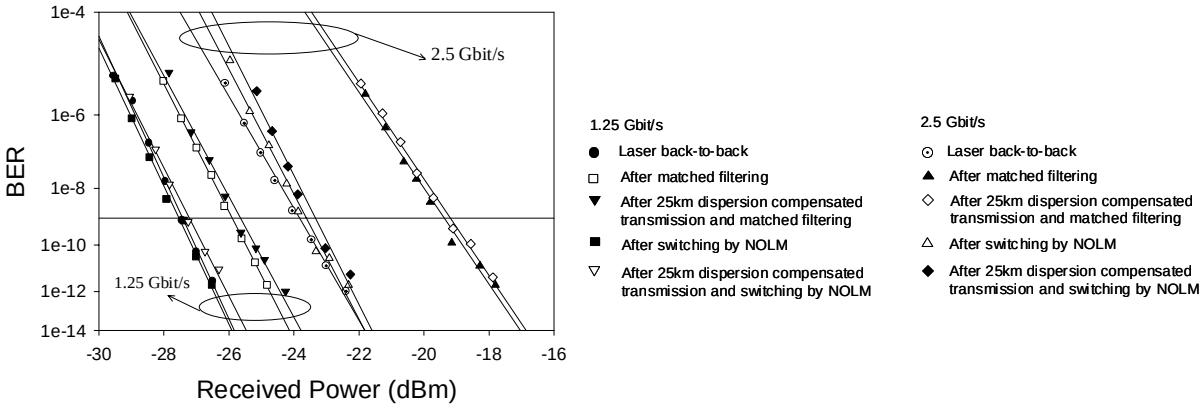


Fig. 4. BER versus received power for 1.25Gbit/s and 2.5Gbit/s system.

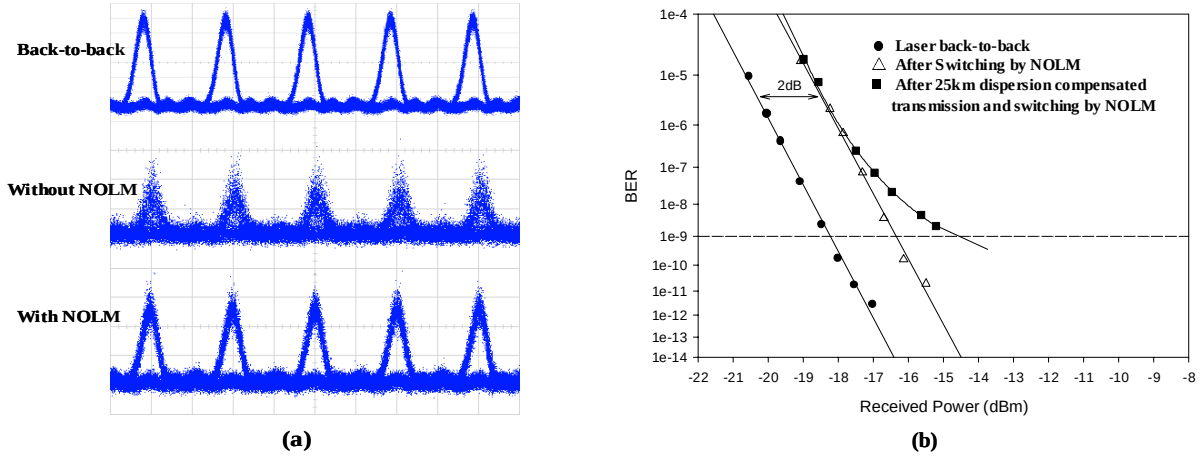


Fig.5. For 10 Gbit/s operation, (a) eye diagrams (b) BER versus received power.

3. Conclusion

We have experimentally demonstrated the benefits to be obtained from incorporating a nonlinear element within SSFBGs based OCDMA and associated all-optical processing schemes. Error-free, penalty-free operation of a 64-chip, 160 Gchip/s OCDMA transmitter/receiver is reliably obtained through the addition of a simple nonlinear optical switch. In our experiments we used a fiber based NOLM however semiconductor based nonlinear devices should offer similar system benefits. The improved performance that we have observed offers the possibility of closer bit-spacings than previously considered viable for coherent, direct-sequence OCDMA systems. Moreover the approach should give equivalent system benefits when used in OCDMA systems operating under multi-user operation. We consider the above experiments to represent just one example of the sorts of optical processing function that will be enabled by the combination of SSFBG technology and nonlinear optical devices.

4. References

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