A 4-channel WDM/OCDMA system incorporating 255-chip, 320 Gchip/s quaternary phase coding and decoding gratings

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Abstract: We report four channel WDM/OCDMA experiments using superstructured fiber Bragg gratings for coding and decoding. The codes are four times longer (255 chips) and have twice the chip rate (320 Gchip/s) of any previously reported direct sequence OCDMA demonstration. As far as we are aware this is also the first experimental demonstration of quaternary phase coding in OCDMA.
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1. Introduction

Optical Code Division Multiple Access (OCDMA) is an area of emerging research interest and which promises a variety of potential advantages in network applications relative to more conventional WDM/OTDM and associated optical access techniques. Direct Sequence (DS-) OCDMA in which data bits are coded and decoded directly within the time domain represents an attractive OCDMA system approach, however the best technical means to perform the necessary coding and decoding functions is still an open issue [1]. Recently, Superstructured Fiber Bragg Grating (SSFBG) technology has emerged as an attractive and highly flexible route to produce high performance, and potentially low-cost, code generation and recognition components. To date we have reported single-wavelength, one or two-user experiments using gratings with bipolar codes up to 63 chips in length and with chip rates as high as 160 Gchip/s [2].

In this paper we experimentally demonstrate: (1) the use of quaternary phase coding in OCDMA for the first time and (2), that the approach is scaleable to longer codes (255 chips) and higher chip rates (320 Gchip/s) than previously shown. Furthermore, we demonstrate that the wavelength selectivity of gratings means that this coding/decoding approach is inherently compatible with WDM, and that multi-user systems can simultaneously support different coding schemes, repetition rates and wavelength channels.

2. Experimental set up and results

Our experimental setup is shown in Fig. 1. Pulses from a 2.5ps, 10GHz, regeneratively mode locked erbium fiber ring laser (EFRL) operating at 1552.5nm were first split using a coupler into two separate fibers. The first of these outputs was modulated to provide a pseudorandom data sequence of 2.5ps pulses at 1.25 Gbit/s. The second output was first amplified and then fed to the control port of a dual-wavelength NOLM operating as a wavelength converter (WC). The NOLM configuration allowed us to modulate the output of a continuous-wave DFB laser operating at 1556.5nm using 1552.5nm control pulses. By appropriately setting the loss and polarisation of light within the WC we were able to generate a 10 GHz train of high-quality, 3.5ps pulses at 1556.5nm.

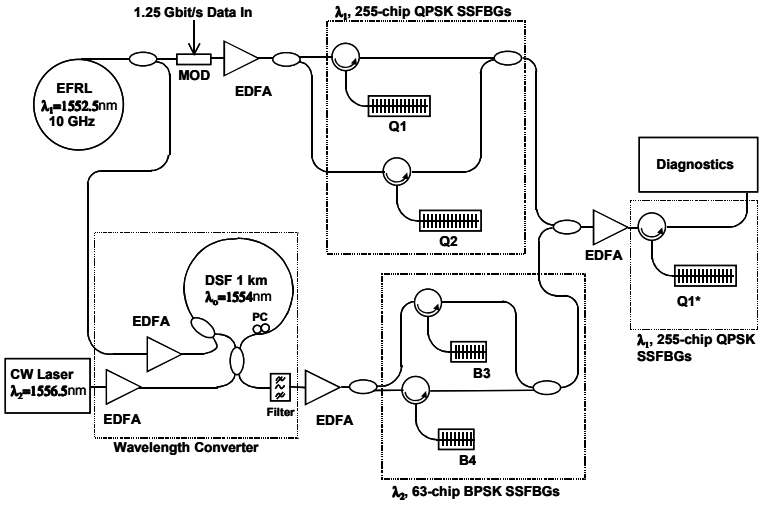
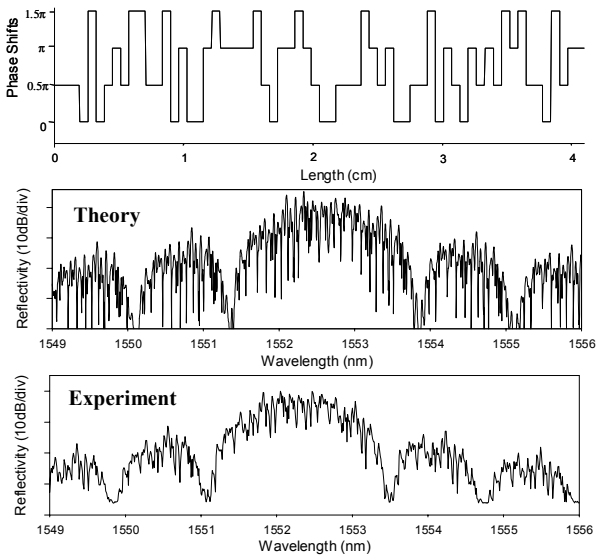


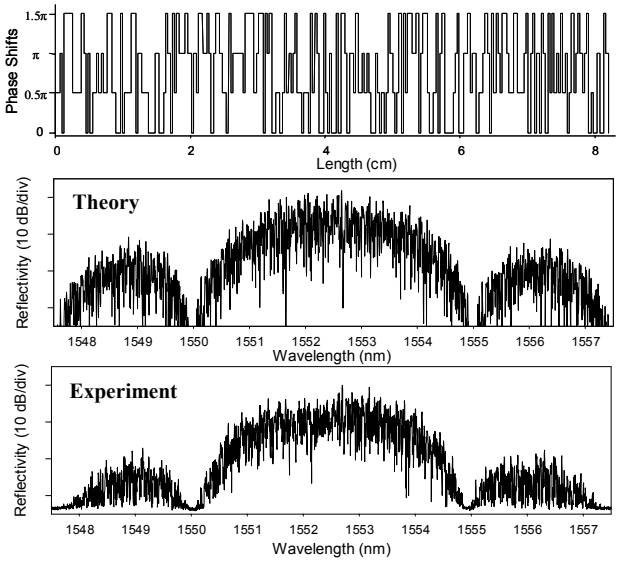
Fig. 1: Experimental setup - QPSK: Quaternary phase shift keying, BPSK: Bipolar phase shift keying.

The individual pulse streams at the two wavelengths were then reflected off of one of four coding gratings to generate four separate coded data channels. The 1.25 Gbit/s 1552.5nm channels were encoded with either one of two 'orthogonal' 255-chip, 320 Gchip/s, quadrature codes sequences (Q1, Q2). Experimental and theoretical plots of the reflectivity spectrum of grating Q1, along with the associated phase-modulation profile of the code sequence are shown in Fig. 2(b). The codes used are members of the Family $\mathscr{A}$ sequences known from Mobile communications. Quaternary coding is known to provide codes with more desirable cross-correlation characteristics than can be achieved with lower level coding [3] (e.g. unipolar and bipolar previously demonstrated with SSFBGs). These SSFBGs provide the longest code sequences, and highest chip rates yet reported for DS-OCDMA, moreover we believe that these are the first gratings to be reported that incorporate quaternary phase coding. The quality of the gratings is self-evident by comparing the experimental and theoretical reflectivity spectra of both 63-chip and 255-chip quaternary phase coding gratings in Figs. 2(a) and (b). It is worth noting that all of the gratings used in these experiments were written using a single, uniform pitch phase mask. The 10 GHz channels at 1556.5nm were encoded with either one of two 63-chip, 160 Gchip/s, bipolar codes sequences (B3, B4) corresponding to two 'orthogonal' Gold code-sequences. The characteristics of these particular gratings have been reported previously [2].



2 (a): 63-chip QPSK SSFBG

Fig. 2(a): Phase modulation profile, and spectral reflectivity profiles (theory and experiment) of a 63-chip, 160 Gchip/s quadrature sequence SSFBG. The grating has a peak reflectivity at ~20% and is 4.22cm long.



2 (b): 255-chip QPSK SSFBG (Q1)

Fig. 2(b): Phase modulation profile, and spectral reflectivity profiles (theory and experiment) for a 255-chip, 320 Gchip/s quadrature sequences SSFBG. The grating has a peak reflectivity of ~25% and is 8.44cm long.

All four channels were combined into a single fibre and the resulting signal fed onto an appropriate decode grating matched to the particular channel we wished to decode. For convenience, we denote the individual matched filters to the individual codes using the notation Q1*, Q2*: (255-chip quadrature SSFBGs) and B3*, B4*: (63-chip bipolar SSFBGs), where Q1* is the matched decoder to grating Q1. Note that the inherent wavelength selectivity of the grating can be used both to provide wavelength channel selection as well as the decoding function for 'in-band' signals, eliminating the requirement for additional wavelength channel filtering elements [4].

In Fig. 3(a) we show an oscilloscope trace of the coded Q1 channel recorded just after reflection from grating Q1. Although the individual features of the coded sequence are too short to be resolved (each chip has a length of 3.2ps and the detection system ~20ps resolution) it is clear that the coding grating spreads the incident 2.5ps pulse over a time period of ~800ps as expected. In Fig. 3(b) we plot the decoded response of grating Q1* to grating code Q1 denoted Q1:Q1* and where it is seen that a short chip length pulse on a very low-level pedestal background is obtained providing a very high-quality pattern recognition signal. In Fig. 3(b) we also plot the response Q2:Q1* (i.e. incorrect code matching). No discernible recognition signature is observed as expected for two 'orthogonal' Family $\mathscr{A}$ codes. Similarly high quality recognition signals were obtained for the other combinations of code grating pairs.

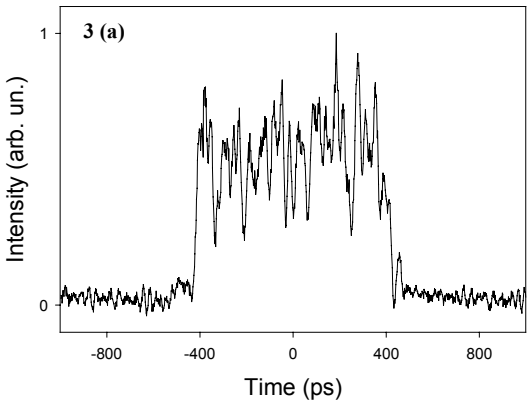


Fig. 3(a): Oscilloscope trace of encoded waveform after reflection from SSFBG Q1 for 2.5ps soliton input pulses. The detection bandwidth was ~25 GHz.

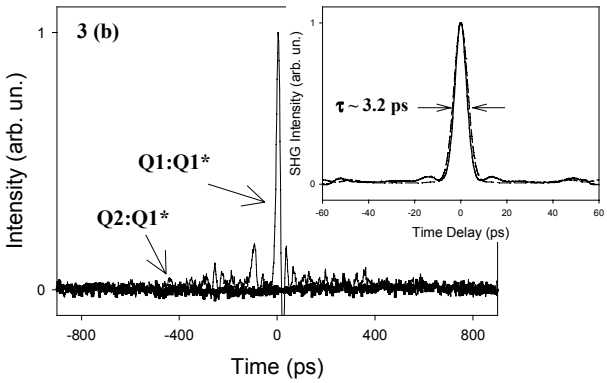


Fig. 3(b): Pulseforms obtained after matched filtering for the grating combinations Q1:Q1* (thin line) and Q2:Q1*(thick line). The detection bandwidth was ~25 GHz.
Inset: Theoretical (dashed line) and experimental (solid line) SHG intensity autocorrelation traces for the Q1:Q1* process. Note that the low level pedestal indicates a high quality code recognition signature. The correctly decoded pulsewidth was ~3.2 ps.

In Fig.4 we plot BER measurements made on the individual 255-chip Q1 channel in the presence of various combinations of interfering channels. A number of features are apparent. Firstly, there is no power penalty observed when additional channels at a second wavelength (1556.5nm) are added, even when these channels operate with different coding schemes and repetition rates. The ~4dB power penalty observed when comparing the BER cases corresponding to the channel combinations Q1+Q2+B3+B4:Q1* with Q1+B3+B4:Q1* results primarily from the increased average power due to the addition of the second 'in band' channel (Q2), although a contribution from coherent interference noise between the code sequences also arises since the codes are generated from seed pulses from the same source. Note that the individual pattern recognition signatures each have a total length of 1.6ns. At a data rate of 1.25 Gbit/s the tails of adjacent recognition signatures overlap. This provides an additional element of interference noise which contributes the major part of the ~4 dB power penalty measured when comparing Q1:Q1* relative to the back-to-back measurement.

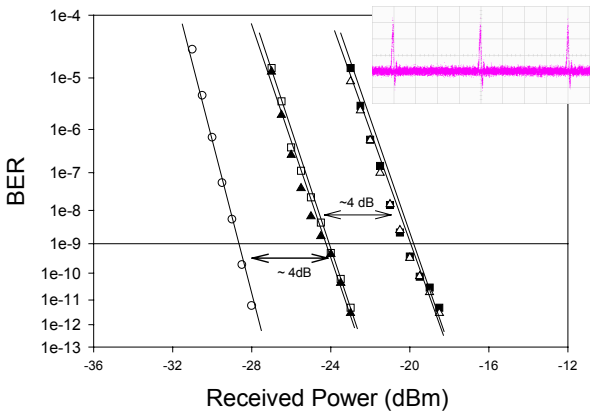


Fig. 4: BER curves for various combinations of interfering channels measured against received power:
Laser back-to-back (open circles),
Q1:Q1* (closed triangles),
Q1+Q2:Q1* (open triangles)
Q1+B3+B4:Q1* (open squares),
Q1+Q2+B3+B4:Q1* (closed squares) and for which the corresponding eye diagram at 1.25 Gbit/s is shown inset.

3. Conclusions

In conclusion, we have experimentally demonstrated that the SSFBGs coding/decoding approach can be extended to far longer codes-sequences and chip-rates than hitherto thought possible. We have also demonstrated the viability of quaternary phase coding and demonstrated an elementary four-channel, multi-transmission format WDM/OCDMA system. These results further demonstrate that the SSFBG approach provides an extremely powerful and flexible way of performing many of the elementary optical processing functions required within both OCDMA and packet-switched networks.

4. References

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