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160GBIT/S, 64-BIT ALL-OPTICAL CODE GENERATION AND RECOGNITION USING SUPERSTRUCTURED FIBRE BRAGG GRATINGS

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Abstract: We demonstrate high contrast, optical code generation and recognition of 160 GBit/s, 64-bit bipolar Gold sequence codes using superstructured Bragg gratings. This represents a nearly ten-fold increase in code length relative to previous works.

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.

Superstructured fibre Bragg grating (SSFBG) technology represents an attractive means to produce components for a wide range of pulse shaping and matched filtering functions including pulse generation and recognition. We have already demonstrated the suitability of SSFBGs for generating, and recognising, both unipolar (amplitude-encoded) and bipolar (phase-encoded) 8-chip, OCDMA code sequences at chip rates as high as 160 Gchip/s and data rates as high as 10 Gbit/s /1/. SSFBGs are extremely attractive for such applications offering major advantages in terms of compactness, complexity, ease of manufacture and cost relative to alternative approaches such as the use of Planar Lightwave Circuits (PLCs) /2/, and arrays of discrete fibre delay lines /3/ or arrays of fibre Bragg gratings (FBGs) /4/. However, to date all experiments reported with SSFBGs have used short code sequences (up to 8 bits only /1,5/) and it has not been demonstrated whether the approach can be scaled to encompass the longer code sequences required for any significant practical application. In this paper we address this important issue and report the fabrication and performance of SSFBGs for the generation and recognition of 64-bit bipolar Gold sequence codes.

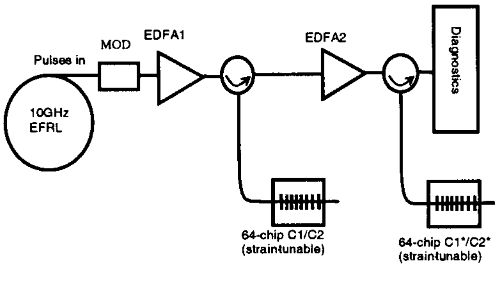

Fig. 1: Experimental set up

Experimental set up

Our experimental set up is shown in Fig.1 and comprises a 2ps, 10-GHz, 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 2.5 to 0.5 GHz. The short pulses were then launched onto either one of two coding SSFBGs (C1 or C2) containing bipolar code information relating to two different 64-bit Gold sequences (see Fig.2). The resulting code sequence generated, as defined by the impulse response of the grating, was then reflected from a decoding grating matched to one of the code sequences, and the resulting pulseform measured using either a fast diode/scope (~20 GHz bandwidth), or an autocorrelator (with <100fs resolution).

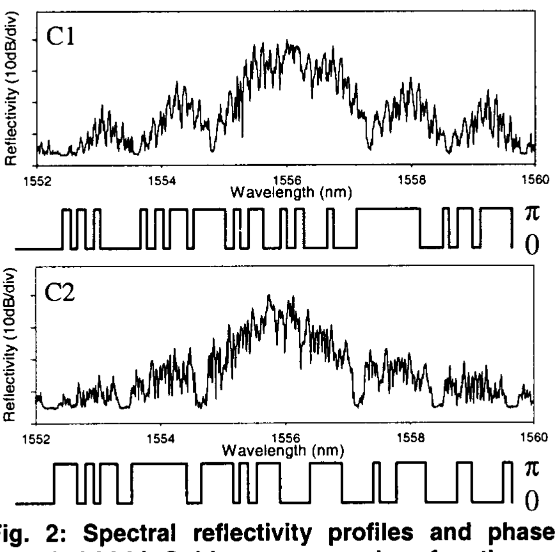

Fig. 2: Spectral reflectivity profiles and phase encoded 64-bit Gold sequence codes of gratings C1 and C2

The coding:decoding gratings were written using our continuous grating writing technique which enables us to write Bragg gratings on a grating plane by grating plane basis and allows the fabrication of gratings with truly complex refractive index profiles /6/. SSFBGs are obtained by modulating the slowly varying phase/amplitude (on the rapidly varying) refractive index profile of an otherwise uniform grating. The impulse response of a weakly reflecting SSFBG (reflectivity <~20%) is given directly by the superstructure modulation profile used to write the grating. In our experiments we chose to use two different 64-bit phase encoded Gold sequences, the phase superstructure profiles of which are shown in Fig.2, along with the measured grating reflectivity profiles for the encoder gratings. The complex, many peaked, reflectivity profiles observed result from the numerous discrete phase jumps within the gratings. The corresponding decode gratings (C1*, C2*) are identical to the encoder gratings other than that their superstructure refractive index profiles are spatially reversed. Gold sequence codes were chosen since they constitute the subset of possible 64-bit codes that minimize the inter-code cross-correlation functions. For a 64-bit pattern there are 65 Gold codes, allowing for example up to 65 individual separately addressable users in an OCDMA system /7/. The total length of each grating is only 4.22cm and each individual chip width is 0.66mm (this corresponds to a temporal code length of 409.6ps and chip length of just 6.4ps).

Experimental Results

The pulse forms resulting from both the C1:C1* and C2:C1* grating coding:decoding processes are shown in Fig.3, and constitute the optical cross-correlations between the corresponding coding:decoding grating pairs. The pulse repetition rate in this instance was 500 MHz ensuring that the correlation functions originating from adjacent pulses within the input pulse stream did not overlap in time (the pulseforms have a full width of twice the code-length). The incident power to the detector was the same in each instance.

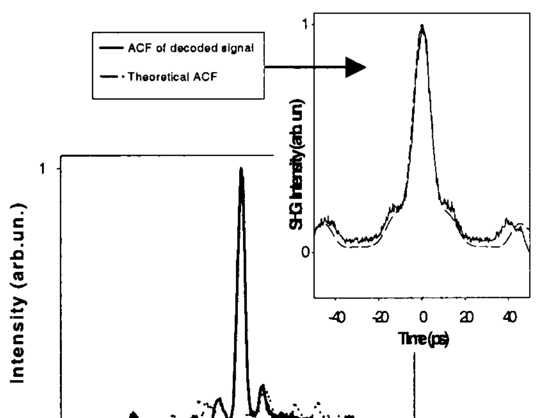

Fig. 3: Optical correlation functions for the cases C1:C1* (solid line), C2:C1* (dotted line). The SHG intensity autocorrelation function of the C1:C1* and is shown inset (note the full range of the ACF measurement in this instance is only 100ps)

The existence of a strong and distinct, correlation peak for the C1:C1* case is observed as expected (a similarly strong single peaked structure was obtained for the C2:C2* case). No such peak is evident in the C2:C1* case as expected from the properties of Gold sequences (neither was a peak observable for the C1:C2* case). The limited bandwidth of our electronic measurement system restricts our estimate of the actual width of the correlation peak. However simple SHG intensity autocorrelation measurements of the pulseforms (see inset Fig.3) show the correlation peak to have the theoretically predicted form and a duration of ~6.5ps, i.e. the approximate chip duration. The existence of such sharp well-defined peaks on the code self-correlation pulses, and the lack of significant peaked structure on the code cross-correlation pulses, confirm that high-quality bit-pattern recognition is possible with SSFBGs with such long code sequences, and highlights the precision of our grating writing process.

Finally, we obtained eye diagrams for the C1:C1*, and C2:C1* cases (see Fig.4). The measurements were made at a repetition rate of 2.5 Gbit/s, corresponding to a period of 400ps, such that the tails of adjacent bits could overlap their nearest neighbours. Open eyes are readily observed for the matched case even in this instance, and only low signal levels are observed for the incorrectly matched code case. This shows that our approach can be implemented within a dense OCDMA system where the codes overlap in time.

Fig. 4: Eye Diagrams: (a) C1:C1*, (b) C2:C1*. The data rate is 2.5Gbit/s

Conclusions

Our experiments demonstrate that SSFBGs can be used to perform all optical code generation and recognition for bit sequences as long as 64-Bits, almost an order of magnitude longer a code length than has previously been demonstrated. Excellent autocorrelation and cross correlation traces with pulse forms and contrast ratios close to theoretical expectations were obtained for 64-bit, bipolar Gold sequence codes.

References

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