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Full characterisation of the temporal response of complex phase shifted Bragg gratings for OCDMA using frequency resolved optical gating

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Abstract *We report on the use of frequency resolved optical gating based on sampling with an electro-absorption modulator to characterise the phase and intensity of multichip encoded OCDMA pulses generated with fibre Bragg gratings.*

Introduction

Superstructured fibre Bragg gratings (SSFBGs) [1,2] with complex refractive index profiles are currently used as key components for a variety of processing applications in all-optical transmission systems, e.g. for pulse shaping [3], signal regeneration [4] and pulse encoding/decoding in optical code division multiple access (OCDMA) systems [5, 6]. For pulse encoding/decoding applications, the temporal (amplitude or phase) code sequence is formed directly from the spatial modulation of the refractive index of the SSFBG, which can be 'read' by an incoming pulse or code with a suitable wavelength [5]. These codes contain a number of discrete phase shifts and may be bipolar or multi-polar [6].

Conventional measurement techniques, relying for example on electrical or optical sampling, autocorrelation, and/or spectral measurements are largely insufficient to characterise such complex waveforms. Frequency resolved optical gating (FROG) is an established technique for the simultaneous phase and amplitude characterisation of optical waveforms. However, the usual second harmonic generation (SHG) FROG is not suited for the characterisation of such complex waveforms, due to the complexity of the resulting spectrogram [7] and consequently the difficulty in reconstructing full phase and intensity information of the pulses.

In this work, we show for the first time that we can successfully apply an adapted linear technique based on FROG to fully characterise the phase and intensity characteristics of 16 chip multi-level phase encoded pulses generated with SSFBGs. The technique is based on taking a linear spectrogram of the pulses with an electro-absorption modulator (EAM) [8]. This technique provides a simpler spectrogram than SHG FROG and makes a straightforward blind deconvolution possible [9]. Also, being a linear technique, it greatly reduces the power required for the measurement, which can be quite significant when long pulses with low peak powers are considered.

We compare our measured waveform profiles with the intensity profiles measured using a fast sampling oscilloscope, and also with the phase profiles predicted from numerical simulations. There is excellent agreement in both cases.

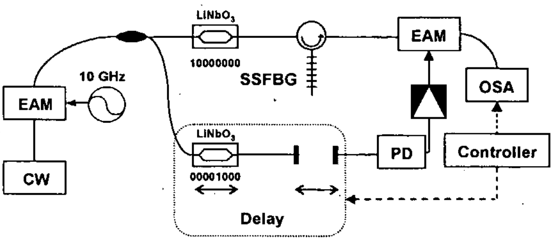

Fig 1. Experimental setup: sampling scheme.

Experiment

a/ Single phase shift grating

In order to validate the suitability of the technique to accurately measure the phase characteristics of pulses with abrupt phase shifts we first characterise pulses reflected from SSFBGs incorporating a single central phase discontinuity of $\pi/2$. The incoming pulse to the SSFBG is generated from a mode-locked fibre laser and has a duration of 2ps and a spectral width of 1.2nm. This enables us to use most of the bandwidth of the SSFBG, and thus create finer phase and intensity features.

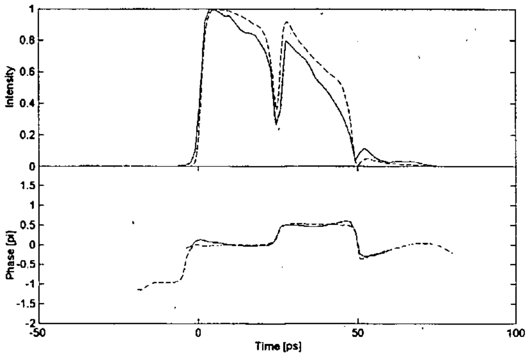

Fig. 2. Retrieved (solid line) and simulated (dashed) intensity and phase of pulses with a $\pi/2$ phase shift.

The EAM-generated sampling window is 50ps long. Note that this does not restrict the temporal resolution of the measurement (Fig.2), because in FROG, both temporal and spectral data are used to determine the pulse shape as opposed to conventional optical sampling where the width of the sampling pulse ultimately defines the temporal resolution [10].

b/ 16 Phase shift grating

The next step is to characterise the code generated from a 16-chip, 4-level phase encoded SSFBG. The chip duration of this code is 25 ps, yielding a total code duration of 400 ps. The experimental setup for this measurement is shown in Fig. 1. Using an EAM, we generated pulses at a repetition rate of 10GHz and a duration of 20ps, which is slightly shorter than the chip duration of the code. The pulses are then split into two parts and sent to two different $LiNbO_3$ intensity modulators, driven by synchronized pattern generators. These gate the repetition rate down to 1.25GHz to ensure that neighbouring encoded pulses do not overlap. The SSFBG-encoded sequence forms the optical input to the sampling EAM. The electrical driving signal to the EAM is formed by the converted 1.25 GHz pulse output from the second $LiNbO_3$ modulator. Use of a fast photodiode ensures that the duration of this sampling window is about 50 ps.

The spectrograms are formed by spectrally resolving the crosscorrelation between the grating encoded pulses and the sampling window generated by the EAM, with an optical spectrum analyser (OSA), as a function of the delay. By adjusting the pattern on the modulator in the delay arm of the setup, and using a 220ps optical delay stage, four consecutive 200ps scans are stitched together to obtain the full 800ps spectrogram.

The measured and reconstructed spectrograms for the 16-chip, 400ps long pulses are shown in Fig. 3. The retrieved pulse intensity and phase profiles are shown in Fig. 4, where the theoretical prediction for the phase in the case of an idealised grating is superposed, showing an excellent agreement between the two.

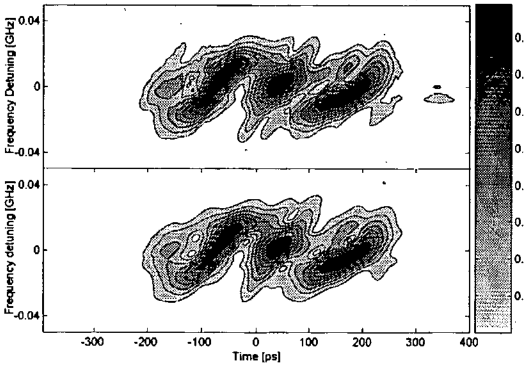

Fig 3. Measured (top) and reconstructed (bottom) spectrogram of a 16 chip phase encoded pulse. The rms retrieval error is 0.01 (128x128 grid).

For comparison, the intensity profile measured with an electrical sampling oscilloscope is given in Fig. 5. Taking into account the ringing effects of the 20GHz photodiode, there is again good agreement. Note that in contrast to the case of the single phase shift pulses, for the multichip encoded pulses, the input pulses are now only slightly shorter than the chip duration of the grating, which makes the phase and intensity features less abrupt. In this case, more information is stored in the temporal domain of the spectrogram (horizontal axis). We obtained equally good agreement from SSFBGs with different phase codes.

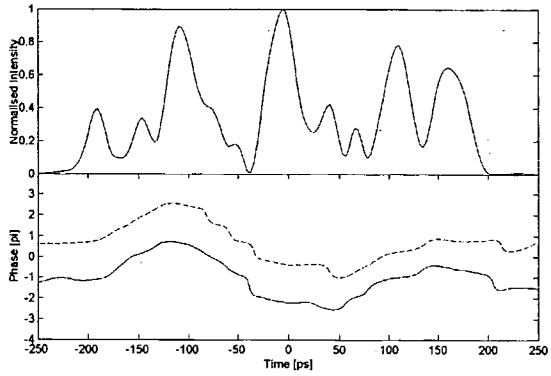

Fig. 4. Retrieved intensity and phase (solid line), and simulated phase (dashed line) of a 16 chip phase encoded pulse.

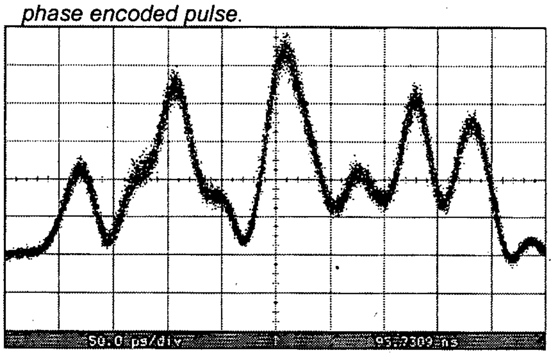

Fig. 5. Intensity of 16 chip phase encoded pulses measured with an electrical sampling oscilloscope and a 20GHz photodiode.

Conclusion

We have directly measured the pulse intensity and phase of both single phase shift and multichip encoded pulses generated with SSFBGs. The excellent agreement with simulations and independent intensity measurements confirms the validity of the measurements. With this, we also confirm directly the accurate phase encoding capability of specifically designed SSFBGs. Our experiments demonstrate that this FROG technique based on sampling with an EAM is a practical and accurate tool to assess the temporal properties of fibre Bragg grating-generated waveforms.

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