The Influence of Spectral Truncation on the Shape of Short Optical Pulses

Xin Yang, Periklis Petropoulos

Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, United Kingdom

Email: xy1v07@orc.soton.ac.uk

Abstract: *This paper studies the influence of spectral truncation on the shape of short optical pulses. As an application example, the case of third-order (m=3) transform-limited super-Gaussian pulses is considered through both simulations and experiments. This work can be used to optimize pulse shaping procedures in the frequency domain.*

1 Introduction

The exact shape of short optical pulses is often of significant importance in optical processing applications and several filtering technologies have been developed to achieve precise shaping of optical pulses [1-3]. However, the spectra of the optimal pulse shapes for such applications often extend to infinity, and it is desirable to be able to restrict the spectral bandwidth of signals by truncating the spectra without significantly distorting the pulses.

This work investigates the compromise introduced on the shape of short optical pulses by the introduction of spectral truncation. As an application example, we investigate the generation of third-order (m=3) transform-limited super-Gaussian (TLSG) pulses with a full width at half-maximum (FWHM) of 15ps, as shown in Figure 1. Such pulses can be generated in principle by appropriate spectral filtering of short pulses at the output of mode-locked lasers. In the sections that follow, the influence of spectral truncation on the shape of TLSG pulses is investigated through both simulations and experiments.

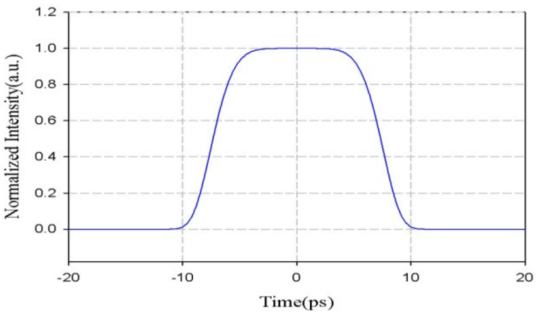

Figure 1 *Pulse shapes of the TLSG waveforms (m=3)*

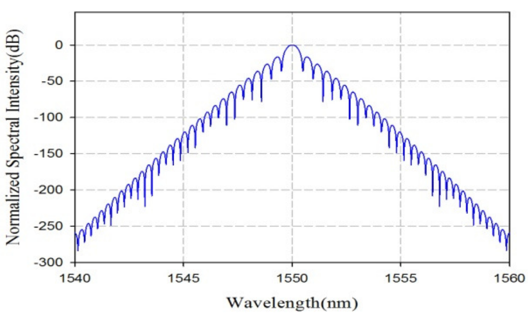

Figure 2 *Optical spectrum of the TLSG pulses (m=3)*

2 Simulations Investigating the Spectral Truncation

As shown in Figure 2, the spectrum of the TLSG pulses of Figure 1 consists of an infinite number of sidelobes, which however decrease in spectral density as we move further from the central wavelength of the pulses. The objective of the simulations presented below was to determine the minimum tolerable bandwidth before the distortion on the pulses becomes too large. The criterion used to determine the level of distortion of the pulse shapes was the misfit factor with respect to the original pulse shape (Figure 1). (The definition of the misfit factor can be found in [4].)

Pairs of sidelobes are truncated one by one in the simulations, allowing a direct comparison between cases that have undergone various levels of spectral filtering.

Alongside the misfit factor, the fraction of power that is truncated and the bandwidth of the truncated spectrum are also calculated in the simulations. The values of all these three quantities are recorded in Table 1.

***Table 1** Values of quantities calculated in the simulations*

Number of Sidelobe Pairs Preserved	Misfit Factor	Bandwidth(nm)	Fraction of Truncated Power
0*	0.393	1	2.7×10^{-3}
1	0.1087	1.95	2.521×10^{-3}
2	3.207×10^{-2}	2.84	2.422×10^{-4}
3	1.005×10^{-2}	3.68	2.54×10^{-5}
4	3.291×10^{-3}	4.48	2.78×10^{-6}

** '0' means there is only the central peak preserved on the spectrum after truncation.*

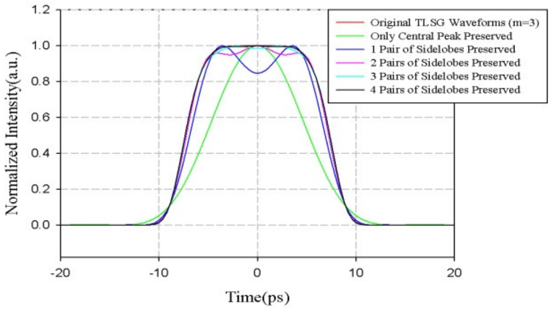

***Figure 3** Pulse shape of the original TLSG pulse and pulse shapes corresponding to the spectra with different number of pairs of sidelobes preserved*

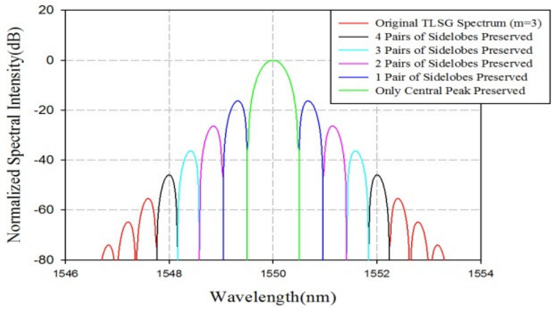

***Figure 4** Original TLSG pulse spectrum and pulse spectra with different number of pairs of sidelobes preserved*

Table 1, Figure 3 and Figure 4 present the results of the simulations. Figure 3 and Figure *4* give a direct representation of the calculated pulse shapes and spectra respectively. The role of the spectral sidelobes in shaping the TLSG is evident in Figure 3, where it is shown that the shape obtained by maintaining only the central spectral peak, which is the most prominent feature of the optical spectrum, differs substantially from the target waveform. In contrast, four pairs of sidelobes are sufficient to give rise to a waveform with no observable difference relative to the original TLSG. (Note that the plot of the waveform corresponding to four pairs of sidelobes (black line) almost overlaps with the one of the original TLSG pulse (red line)). The very low misfit factor obtained for this case is also commensurate with this observation, which can be easily understood by considering the small amount of energy existing in the truncated sidelobes (see last column in Table 1).

Similar observations apply to the case of three pairs of sidelobes, whereas the result obtained with just two pairs is also quite satisfactory and would be sufficient for most applications. This is of practical significance, since it is normally quite challenging to obtain a filter with sufficient control on its spectral response over a dynamic range that exceeds 30-35 dB.

3 Experimental Results

We tested our numerical observations using the experimental set-up shown in Figure 5. The source used in the experiment was a 10GHz Erbium Glass Oscillator (ERGO) pulsed laser source, generating 2ps Gaussian pulses. The spectral amplitude and phase of the ERGO pulses were changed into the desired spectrum leading to the TLSG pulse using a programmable optical filter (Finisar Wave-Shaper, W/S), the operation of which is based on Liquid Crystal on Silicon (LCoS) technology [5]. The corresponding pulse shapes and spectra were measured by an Optical Sampling Oscilloscope (OSO) and an Optical Spectrum Analyzer (OSA), respectively.

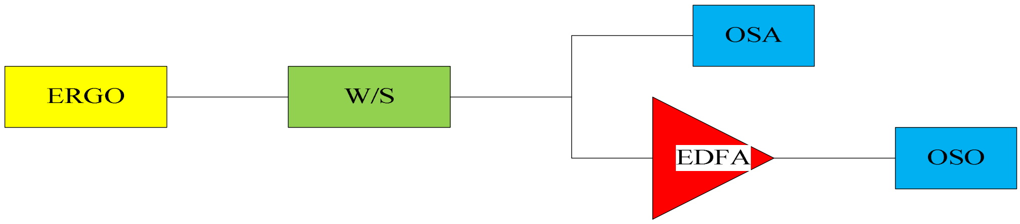

Figure 5 *Experimental setup for the generation of TLSG pulses*

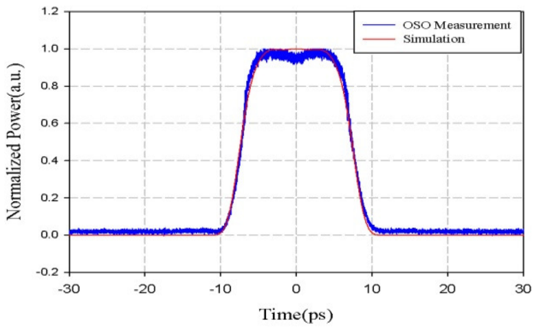

Figure 6 *Generated TLSG pulses (m=3) with only 3 pairs of sidelobes preserved on the spectrum*

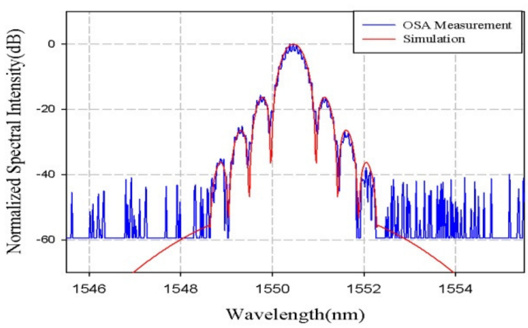

Figure 7 *The spectrum with 3 pairs of sidelobes preserved after shaping the ERGO spectrum*

Figure 6 and Figure 7 show the generated TLSG pulses and their corresponding spectrum with three pairs of sidelobes preserved, respectively. The generated TLSG pulses have a good agreement with the simulations at the pulse edges, while the discrepancy at the top of the pulses is attributed to insufficient filter control over the low intensity spectral components of the filter, i.e., those that correspond to the third pair of spectral sidelobes. The experimental results verify the validity of the observations from the simulations.

4 Conclusions

Pulse shaping based on the spectral manipulation of optical pulses exhibits a certain trade-off between the overall bandwidth of the shaped signal and the quality of the shaping function. This trade-off has been examined in this work both with simulations and experimentally. The generation of 15ps TLSG pulses has been studied and the effect of different amounts of truncation has been assessed. The simulations and experiments described in this work provide a method to reach a compromise between bandwidth and performance, and optimize the pulse shaping procedure.

5 References

[1] Weiner, A.M., *Femtosecond pulse shaping using spatial light modulators.* Review of Scientific Instruments, 2000. **71**(5): p. 1929-1960.

[2] Petropoulos, P., et al., *Rectangular pulse generation based on pulse reshaping using a superstructured fiber Bragg grating.* Journal of Lightwave Technology, 2001. **19**(5): p. 746-752.

[3] Thomas, S., et al., *Fiber-Based Programmable Picosecond Optical Pulse Shaper.* Journal of Lightwave Technology, 2010. **28**(12): p. 1832-1843.

[4] Finot, C., et al., *Parabolic pulse evolution in normally dispersive fiber amplifiers preceding the similariton formation regime.* Optics Express, 2006. **14**(8): p. 3161-3170.

[5] Baxter, G., et al., *Highly programmable Wavelength Selective Switch based on Liquid Crystal on Silicon switching elements.* 2006 Optical Fiber Communication Conference/National Fiber Optic Engineers Conference, Vols 1-6. 2006, Washington: Optical Soc America. 94-96.