APPLICATION NOTE

Pulse Burst Generation

Abstract

The creation and control of arbitrarily shaped optical waveforms is quickly gaining interest in all-optical signal processing applications. The WaveShaper 4000 Multiport Optical Processor provides a convenient and flexible platform to access a range of arbitrarily shaped pulses at high bit-rates. In this application note, we discuss how the phase and the amplitude response of a WaveShaper can be adapted to filter out specified pulse bursts out of a single input pulse through a technique referred to as Fourier domain pulse shaping.

1. Fourier-domain Pulse Shaping

Based on the principle of Fourier-domain pulse shaping (Figure 1), an extensive range of waveforms can be filtered out of a short optical pulse. To fully control an optical signal, access to both the phase and the amplitude of the signal is required. The WaveShaper family of Programmable Optical Processors provide a simple way to implement this capability.

The Fourier transform of the desired temporal waveform is calculated: A'(f), as well as the Fourier transform of the available input pulse. A single, complex function relates the two to each other: A'(f)=F(f)E'(f). The desired filter function is thus directly calculated as F(f)=A'(f)/E'(f). The spectral phase and amplitude response of the filter F(f) are calculated and mapped into the correspond vertical and horizontal phase profiles of the pixels on the LCoS array.

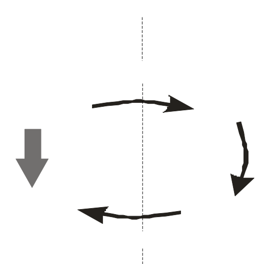

Figure 1: Schematic representation of Fourier-domain pulse shaping.

2. WaveShaper Operation

The WaveShaper family is based on Liquid Crystal on Silicon (LCoS) Technology [1,2] which uses a two-dimensional array of phase modulating pixels as shown in Figure 2.

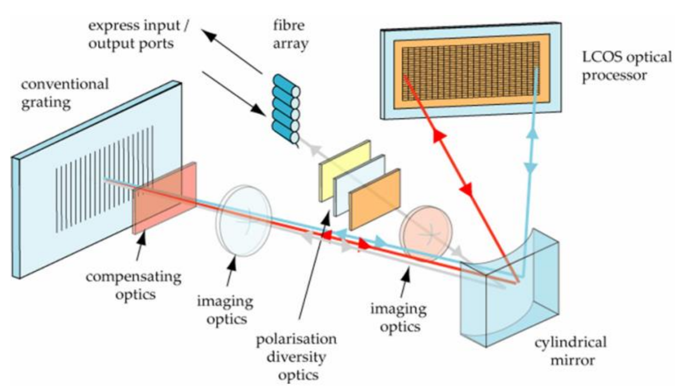

Figure 2: Schematic layout of the WaveShaper 4000S.

The optical signal overlaps a large number of pixels (typically 400) in one dimension ("vertical"), whilst in the other dimension ("horizontal"), the spectrum is spatially dispersed, so that wavelengths can be processed individually. Specially calculated phase front images (modulo 2π) are then applied to this spatially dispersed signal via the LCoS which modulates the phase front of the signal through the voltage dependent retardation of each pixel. Within the limits of the available optical bandwidth of the input pulse, any temporal pulse shape can be obtained through spectral phase and intensity filtering. Note however that the LCoS array is a phase-only modulator. The amplitude modulation is obtained by steering part of the light to dump locations within the device, through advanced phase modulation of the phase front.

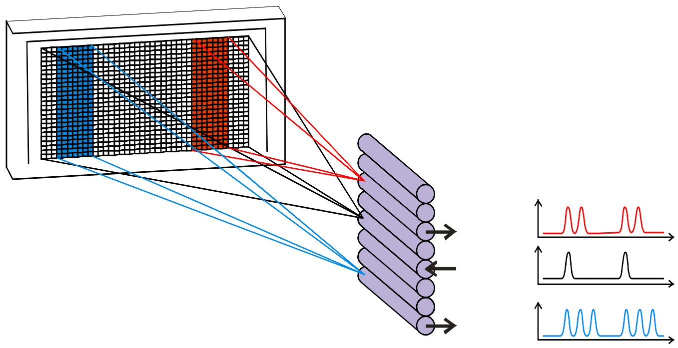

Figure 3: Schematic overview of how different parts of the LCoS can act on different parts of the spectrum. The blue part is programmed to re-shape a short input pulse into a pulse burst with three pulses, and send this specific wavelength range to 'Output 2'whereas the red part is programmed to reshape a short input pulse into a burst of 2 pulses that are being sent to 'Output 1'.

In this White Paper, we describe the use of a WaveShaper 4000S Multiport Optical Processor with a dispersion-bandwidth product of about 40 ps, meaning that light can be delayed or advanced – relatively to the input pulse – by about 20 ps, before half of the signal amplitude is lost due to horizontal beam steering effects [3]. (Note that the newer WaveShaper 4000S provides approximately twice the dispersion-bandwidth product of about 80ps.) +/-20ps of delay control is sufficient for accurate waveform control over the full bit period of 40 GHz pulse trains.

By applying appropriate phase profiles in both horizontal and vertical axes of the LCoS array, spectral amplitude and phase can be controlled independently across the entire pass band of the device (1527 nm-1567 nm). Combining this with the switching capability of the 4000S, leads to the combination of programmable Fourier-domain pulse shaping with output port selection.

In practise, the spectral phase $P(f)=\arg(F(f))$ and attenuation profile $I(f)=|F(f)|^2$ are calculated for each of the desired output waveforms and these are then loaded into the WaveShaper using the User Configured Filter (UCF) capability of the WaveShaper software. The WaveShaper software then automatically converts the filter responses to horizontal and vertical phase modulation profiles respectively. The horizontal phase modulation directly translates to the spectral phase of the signal, whilst the vertical phase modulation controls the attenuation imposed on each wavelength and also determines to which output port the light at the specified wavelengths is sent. Figure 3 gives a schematic representation of how different parts of the LCoS can be selected to act on different wavelengths (the primary function of the wavelength selective switch). In this case however, the different spectral slices are programmed in such a way that on top of the port selection, there is also pulse shaping.

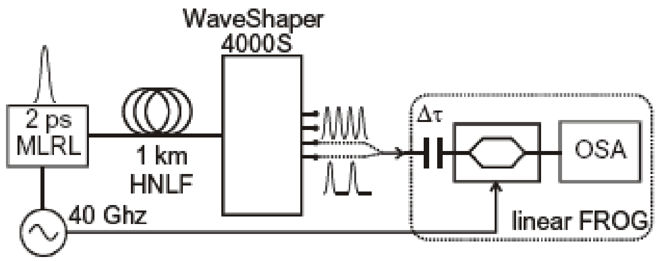

Figure 4: Experimental layout. MLRL = mode-locked ring laser; HNLF = highly nonlinear fiber; OSA = optical spectrum analyzer; FROG = frequency resolved optical gating.

3. Experimental Demonstration of Pulse Shaping

Figure 4 shows a WaveShaper programmed to create two different pulse bursts from a broadband (supercontinuum) optical signal and direct them to two separate output ports of the device. To obtain the supercontinuum source, a 40 GHz train of high-powered optical pulses of 2 ps duration was propagated through ~1 km of dispersion-shifted highly nonlinear fiber (HNLF). The resulting spectrally-broadened pulse was then sent to the input port of the WaveShaper which was programmed to carve spectral slices out of this continuum, introduce independent spectral phase and amplitude modulation to each of these slices, and finally to send them to different output ports. [4]

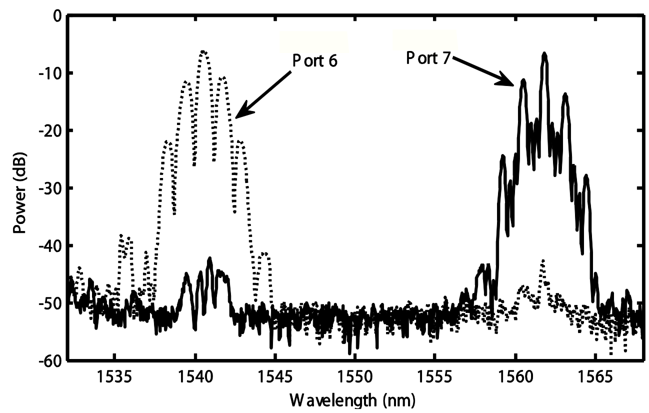

Figure 5: Spectral intensity response measured on two different output ports of the WaveShaper 4000S respectively the profiles of a 2-pulse burst at 1541 nm and a 4-pulse burst at 1562 nm.

Figure 5 shows an example of the spectral power transmission profiles generated by the WaveShaper 4000S at 1541 nm and 1562 nm, measured at different output ports with an optical spectrum analyser (OSA). The profile at 1541 nm is a burst of two pulses with a separation of 6.25 ps, while the profile at 1562 nm is a burst of four pulses also with a separation of 6.25 ps. As the input pulse train has a 40 GHz repetition rate, application of this second pulse burst sequence results in a continuous 160 GHz pulse train. Note also that we achieved 35 dB suppression of cross-talk between the different output ports of the WaveShaper 4000S.

The ultrafast pulse trains were characterized with a sensitive, linear frequency-resolved optical gating (FROG) technique which provided sub-picosecond temporal resolution. Figure 6 shows two series of intensity profiles of various pulse trains at the two different wavelengths. Note that the small ~20 % variation in peak intensity between the pulses in the bursts was due to the fact that the pulse-shaping profiles imposed onto the optical continuum were calculated assuming an ideal impulse response for the input waveform, whereas experimentally the continuum was spectrally not perfectly flat. Better uniformity of the peak intensities of the individual pulses in the burst should be possible with complete characterization of the input wave in both phase and amplitude.

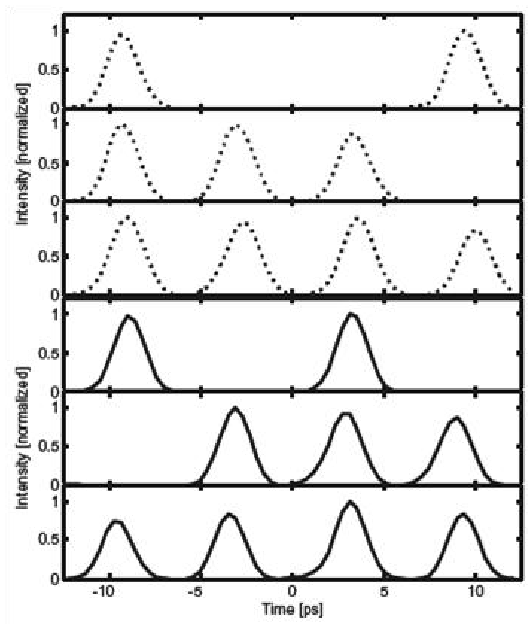

Figure 6: Measured temporal intensity profiles of various pulse bursts around a carrier wavelength of 1562 nm, sent to output port 1 (top three) of the WaveShaper 4000S and around 1541 nm sent to output port 2 (lower three).

4. Summary

The WaveShaper family of Programmable Optical Processors have the unique ability to provide highly accurate pulse shaping based on Fourier-domain Optical Pulse Shaping. Combining this with the ability to selectively process different parts of the spectrum and switch the processed signals to different output ports provides an extremely powerful tool for nonlinear optical signal processing applications. This provides a very quick and simple way of creating synchronized pulse sources at different wavelengths. Such accurate pulse shaping can have interesting applications in a range of nonlinear optical signal processing and pulse control.

5. Acknowledgement

This work was carried out by the Centre for Ultrahigh Bandwidth Devices for Optical Systems (CUDOS) at the University of Sydney as part of an ARC Linkage Project Grant with Finisar Australia.

6. References

[1] G. Baxter et al., "Highly programmable Wavelength Selective Switch based on Liquid Crystal on Silicon switching elements" in Proc. OFC/NFOEC 2006, OTuF2 (2006).

[2] S. Frisken et al., "High performance 'Drop and Continue' functionality in a Wavelength Selective Switch" in OFC/NFOEC 2006, postdeadline paper (2006).

[3] M. Roelens et al., "Dispersion trimming in a reconfigurable wavelength selective switch" Journal of Lightwave Technology, Vol. 26 (1), 2008.

[4] M. Roelens et al., "Multi-wavelength synchronous pulse burst generation with a wavelength selective switch" Optics Express, Vol. 16, Issue 14, pp. 10152-10157.

FINISAR®

1389 Moffett Park Drive
Sunnyvale, CA 94089
Tel.: +1-408-548-1000
Fax: +1-408-541-6138
waveshaper@finisar.com
http://www.finisar.com/optical-instrumentation