in polarization control is found to occur for a non-zero control field detuning from resonance. For a probe detuning of 1.1 GHz, the system behaves as a half-waveplate as demonstrated by the large transmission through the crossed polarizer. In similar experiments we find that we can coherently induce the system to behave as a quarter-waveplate or as an optically-active material. Theoretical simulations based on our model are found to be in good qualitative agreement with our experimental observations.

We also find that such polarization control can occur in various other energy level schemes, such as a lambda system. Potential applications of this coherent polarization control are optical switching, achieving controllable birefringence in wavelength regimes where waveplates are not available, and phase matching of nonlinear optical processes.

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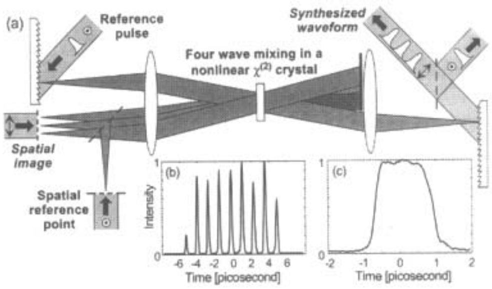
Signal Processing

Instantaneous Processing of Ultrafast Waveforms By Wave Mixing Spectrally Decomposed Waves

Dan Marom, Dmitriy Panasenko, Rostislav Rokitski, Pang-Chen Sun and Yeshaiahu Fainman

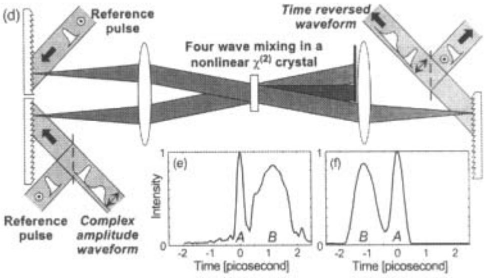
Ultrafast phenomena in the natural sciences can be excited, manipulated and observed with tailored ultrashort optical pulses. These ultrafast waveforms are synthesized and processed in the temporal frequency domain by spatially dispersing the frequency components in a spectral processing device (SPD) and performing operations on the spectrally decomposed wave[1] (SDW). Waveform synthesis by SDW filtering has been demonstrated with prefabricated masks, spatial light modulators and holograms. These filters are limited in their adaptability rate—a new filter can be implemented only as fast as the modulator response time or recording time of a new hologram—typically well over a microsecond.

To fulfill our goal of real-time SDW processing, we utilize a nonlinear wave mixing process based on four-wave mixing via cascaded second-order nonlinearities (CSN) in a $\chi^{(2)}$ medium performed inside the SPD (Figure 1a). The CSN arrangement consists of a frequency-up conversion process followed by a frequency-down conversion process satisfying the type-II non-collinear phase matching condition.[2] In the ultrafast waveform synthesis experiments,[3] the SDW of a featureless ultrashort femtosecond pulse interacts with two spatial information modulated waves carried by quasi-monochromatic light. The four-wave mixing process produces a SDW that is the product of three waveforms—the spatial Fourier transforms of the two spatial information carrying waves and the SDW (i.e., temporal Fourier transform) of a femtosecond laser pulse. The spatial-temporal information exchange results in a synthesized waveform that is a time-scaled version of the spatial image, performed on a single shot basis with femtosecond-rate response time due to the fast nonlinearity.



Marom Figure 1. (a) Experimental setup of the real-time spatial-temporal wave-mixing processor. Generated ultrafast waveforms: **(b)** pulse packet from a spatial sequence of point sources and **(c)** square pulse from a slit.

We performed several experiments to demonstrate various synthesized waveforms. A spatial sequence of point sources, generated by a cylindrical lenslet array, was converted to an ultrafast pulse packet (Figure 1b). Modulating the individual point sources in the spatial domain resulted in an analogously modulated ultrafast waveform, with no evidence of crosstalk between the pulses. This functionality may be desired for an ultrahigh bandwidth optical communication application. When an adjustable slit was placed in the spatial channel, the ultrafast waveform resembled a square pulse (Figure 1c). The duration of the square pulse was adjusted in real time by varying the width of the slit. The synthesized waveforms were generated with a high conversion efficiency of 16%.



Marom Figure 1. (d) Experimental setup of the real-time temporal waveform processor. Time reversal of complex amplitude waveforms: **(e)** input signal: transform limited pulse followed by a positively chirped pulse and **(f)** time reversed signal: positively chirped pulse emerging first.

More recently we extended the wave-mixing approach to instantaneous time domain processing of ultrafast waveforms.[4] Three ultrafast waveforms are introduced into the SPD, giving rise to a fourth SDW by the wave mixing process (Figure 1d). The resultant ultrafast waveform depends on the configuration of the SPD, as it is possible to control the effective processing by changing the directions of the spatial dispersion, enabling new signal processing functionality. We demonstrated time reversal of ultrafast waveforms with our processor by both phase conjugation and spectral information inversion—the latter achieving true time reversal of complex amplitude ultrafast waveforms. The input complex amplitude ultrafast waveform consisted of a transform limited pulse followed by a positively chirped pulse (Figure 1e). After true time reversal, the two pulses exchanged their location while the positively chirped pulse remained positively chirped (Figure 1f).

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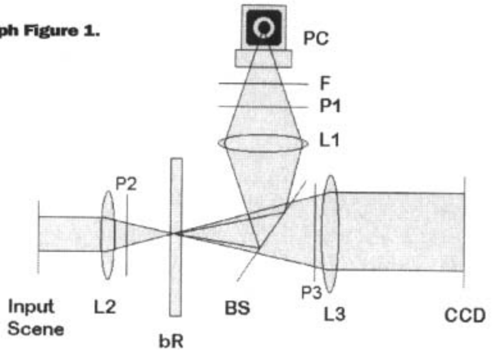
Optical Implementation of the Wavelet Transform By Using a Bacteriorhodopsin Film as an Optically Addressed Spatial Light Modulator

Joby Joseph, D.V.G.L.N. Rao, Francisco J. Aranda, Barry S. DeCristofano, Brian R. Kimball and Masato Nakashima

The Fourier Transform (FT) is a powerful technique commonly used for the analysis and processing of signals. In the FT, sines and cosines are the basis functions used to represent an arbitrary signal. Fourier basis functions have the drawback of being localized only in frequency but not in time or space. In order to overcome the limitations of Fourier analysis with regard to the representation of transient signals, localized in time or space, the windowed FT and more recently the wavelet transform (WT) were introduced. Wavelet analysis represents a signal in terms of a family of functions derived from a single basic function called a wavelet. Signal analysis is accomplished by translating and scaling the wavelet function. While the FT gives global information about a signal, evaluating the WT at various scales and translations yields local frequency information about a signal. Optics with the inherent advantage of speed and ease of parallel processing has been utilized by several researchers[1] for implementation of WT. In the frequency domain, the WT is the product of the FT of a wavelet (wavelet filter) and the FT of a signal. The wavelet filters act as band pass filters, thus the WT in optics amounts to a spatial filtering operation. Since the FT is translation invariant, only scaling operations on the wavelets are required for spatial filtering. Scaling of the wavelets can be accomplished using a combination of lenses or a spatial light modulator. We implemented[2] optically the WT by using a Bacteriorhodopsin (bR) film as an optically addressed spatial light modulator, in which a computer generated wavelet can be imaged on a bR film. The bR film is kept at the FT plane in a 4f imaging system as shown in Figure 1. Dichroism induced by the wavelet filters displayed on the bR film leads to polarization rotation for wavelet selected Fourier components of an input image. The rotated Fourier components are analyzed to extract the wavelet transformed components.

In optical engineering, bR has several intrinsic properties of importance: it is more sensitive to light than inorganic crystals, thus the wavelet processor can be realized with very low light levels resulting in an extremely energy efficient device. The spectrum and kinetic aspects of the bR photocycle can readily be modified by replacing the retinal chromophore with natural and synthetic analogs which can shift the bR spectrum to virtually any color and by genetic mutations attained by biotechnological procedures. The cost of producing and its environmental friendliness make it an attractive material. A crystal like architecture makes bR very stable. Dry films of bR have been stored for several years without degradation and are structurally stable up to a temperature of 140°C. A unique feature of our method is that the WT is obtained in real time. As no interference is involved, vibration isolation and a coherent source are not required. We have thus demonstrated the feasibility of a real time, field deployable, efficient and environmentally friendly optical wavelet image processor.

Joseph Figure 1.



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Solitons

Polarization-locked Temporal Vector Solitons In an Optical Fiber

S.T. Cundiff, B.C. Collings, N.N. Akhmediev, J.M. Soto-Crespo, K. Bergman, and W.H. Knox

Temporal vector solitons have components along both birefringent axes. Despite different phase velocities due to linear birefringence, the relative phase of the components can be locked at $\pi/2$. These fragile polarization-locked vector solitons (PLVS) have been the subject of much theoretical conjecture,[1] but have previously eluded experimental observation.

Polarization preserving solitons occur due to interplay between birefringence and the nonlinear index of refraction (Kerr effect). In order for the nonlinear index of refraction to exactly cancel the linear birefringence, the soliton must have sufficient energy. Hence, polarization locked solitons appear above certain threshold that can be achieved inside the laser cavity. We have studied[2] the polarization evolution of solitons circulating in a mode-locked fiber laser and observed that PLVS form for low amounts of intracavity birefringence.

The experimental setup is shown in Figure 1a. The fiber laser consists of three pieces of single mode fiber fusion spliced together. By changing the angles of the two polarization control paddles, Θ_1 and Θ_2, we can adjust the total cavity retardance (the total birefringence in the cavity) from zero to approximately a full wavelength. To measure the round trip retardance in the laser cavity, we pass the output