High-Contrast Nonlinear Waveform Discrimination at 10GHz in an Ultrafast O-CDMA Testbed

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Abstract

We demonstrate ultrafast O-CDMA nonlinear waveform discrimination at 10 GHz with less than 1 mW coupled in a nonlinear PPLN waveguide and greater than 20dB contrast ratio between coded and uncoded waveforms.

Summary

Optical code-division multiple-access (O-CDMA) is receiving increasing attention due to its potential for enhanced information security, simplified and decentralized network control, improved spectral efficiency, and increased flexibility in the granularity of bandwidth that can be provisioned. In O-CDMA, different users whose signals may be overlapped both in time and frequency share a common communications medium; multiple-access is achieved by assigning different, minimally interfering code sequences to different CDMA transmitters. In many O-CDMA approaches, input ultrashort pulses are time-spread during the encoding process into lower intensity noise-like signals [1-5]. In the receiver, data corresponding to a desired user is separated from multi-access interference via a matched filtering (decoding) operation, in which properly decoded signals are converted back to the original pulse-like signals, while improperly decoded signals remain low-intensity noise-like temporally broad waveforms. Since the energy in properly and improperly decoded signals is similar, and since the temporal duration of even improperly decoded signals is on the order of the bit period or below, both properly and improperly decoded signals will appear identical to an electronic receiver band-limited to the data rate. Consequently a nonlinear optical intensity discriminator plays a critical role in separating properly decoded short pulses from improperly decoded multi-access interference. In this paper we demonstrate 10 GHz operation of a highly-efficient, nonlinear optical intensity discrimination technology based on second harmonic generation (SHG) in a periodically-poled lithium niobate (PPLN) waveguide. Our discriminator demonstrates a suppression of greater than 20 dB at an operating pulse energy of less than 0.1 pJ (average power less than 1 mW), <u>approximately two orders of magnitude lower than previous discriminators</u> based on nonlinear fiber optics [3-5].

Previously, an optical fiber nonlinear intensity discriminator, based on the filtering of decoded pulses spectrally broadened through the Kerr nonlinearity, was reported with a suppression ratio in excess of 30 dB, but required a high pulse energy of ~25 pJ and was demonstrated at only 30 MHz [3]. Recently, a holey fiber technology has been used in a similar scheme to reduce the fiber length to less than 10 meters in ~1 GHz experiments; however, this technique still required high pulse energy (~100 pJ) [4]. A nonlinear fiber loop mirror discriminator has also been reported, but it required similarly high energy [2]. In previous work we demonstrated that SHG nonlinearity could provide a much lower operating energy than Kerr effect nonlinearities in fibers. These experiments demonstrated high suppression (~20 dB) nonlinear discriminator operation using PPLN waveguides at 0.25 pJ per pulse, but were tested at only 40 MHz [6]. In the present work we demonstrate operation of PPLN waveguide nonlinear discriminators much higher (10 GHz) speed while simultaneously further reducing the energy per pulse by 2.5 times!

Fig. 1 shows a schematic diagram of our experimental apparatus. An actively mode-locked fiber laser followed by a dispersion decreasing fiber soliton compressor producing nearly transform-limited ~0.4 ps pulses at ~10 GHz centered near 1542 nm is used as the pulse source. These ultrashort pulses are input into a fiber coupled Fourier Transform pulse shaper [7] which incorporates a 128 element liquid crystal modulator array to spectrally phase code the spectrum of the source laser. The fiber-to-fiber insertion loss of the pulse shaper is less than 5 dB. The output of the pulse shaper is connected to a fiber pigtailed PPLN waveguide chip to perform the nonlinear discrimination function, and the output of the PPLN was coupled to a 7.5 GHz bandwidth photoreceiver, designed for 10 Gb/s Ethernet, operating at the second harmonic wavelength of 0.77 μm.

The advantage of a nonlinear pulse discriminator is dramatically demonstrated in Fig. 2. Here, we used a 1.5 μm photo-detector with 12.5 GHz measurement system bandwidth to detect the pulse shaper output prior to entering the PPLN waveguide. Fig. 2 shows the temporal profile of both uncoded (short pulse) and coded (temporally broadened) signals, using a length 31 M-sequence code as seen on a sampling scope. Other than the 0.8 dB amplitude difference due to coding loss in the pulse shaper, there is no noticeable difference between the signals. This clearly illustrates the main issue in O-CDMA with ultrashort pulses: all coded waveforms have fundamentally the same energy, which means they produce the same output from a relatively slow electronic detector, even though they can show strong differences in temporal structure and peak intensity on an ultrafast time scale.

Fig. 3 shows the output of the nonlinear PPLN waveguide as measured by the 7.5 GHz photoreceiver and sampling scope for both uncoded (dotted) and coded (solid) waveforms. Contrast ratios up to 20.1 dB were observed when coding with a length 31 M-sequence code with 0.9 mW in the PPLN waveguide. The second harmonic power is -8.4 dBm, exceeding the receiver sensitivity by 5.5 dB, yielding the excellent signal-to-noise ratio seen in the figure. Contrast ratios of up to 13.6 dB and 17.2 dB were observed for shorter M-sequence code lengths of 7 and 15 respectively. The liquid crystal modulator array utilized to spectrally code the input short pulses provides flexibility and ease of use in switching to different spectral codes. As we will discuss in the talk, all members of a large code family can be investigated in a short period of time to explore the output contrast across the code family.

In summary, here we have demonstrated ultrafast O-CDMA waveform discrimination at 10 GHz using a PPLN waveguide nonlinear element. A contrast ratio of greater than 20 dB is observed for less than 1 mW of fundamental power in the waveguide. Excellent signal-to-noise is observed at the system receiver demonstrating the practicability of nonlinear waveform discrimination in a system environment.

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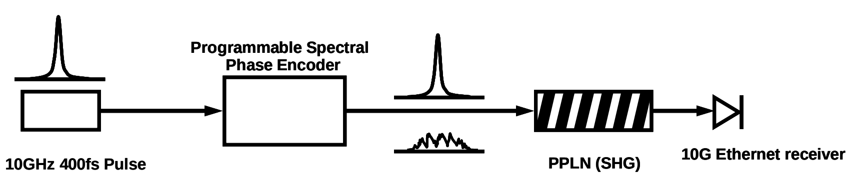

Fig. 1 Experimental apparatus.

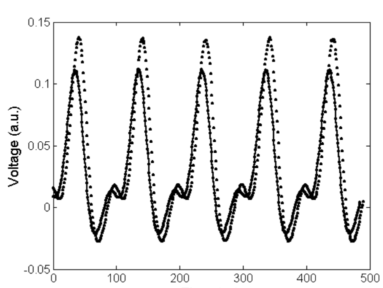

Fig. 2 Linear detector output for uncoded (dotted) and coded (solid) waveforms. Minimal 0.8dB contrast is due to coding loss in the pulse shaper.

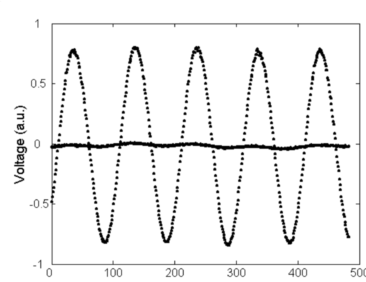

Fig. 3 Nonlinear receiver output at 0.9mW average power in the PPLN for uncoded (dotted) and coded (solid) waveforms. 20.1 dB contrast after nonlinear discrimination.