Low power, high-contrast, ultrafast O-CDMA nonlinear waveform discrimination at 10 GHz

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

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1. Introduction

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. In many O-CDMA approaches, input ultrashort pulses are time-spread during the encoding process into lower intensity noise-like signals [1-6]. In the receiver, data corresponding to a desired user is properly decoded back to the original pulse-like signals, while improperly decoded signals remain low-intensity noise-like temporally broadened waveforms. However, even for improperly decoded signals, the total time spread may be limited to tens of picoseconds, which is less than the data period for systems at ~40 Gb/s and below. Therefore, since both properly and improperly decoded signals have similar energy they will both appear nearly identical to an electronic receiver band-limited to the data rate. Consequently a nonlinear optical intensity discriminator plays a critical role in separating desired data from O-CDMA 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), approximately two orders of magnitude lower than previous discriminators based on nonlinear fiber optics [3-5]. This is very important for scaling of O-CDMA systems to significant numbers of simultaneous users.

2. Experiment and Results

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 is coupled to a 7.5 GHz bandwidth photoreceiver, designed for 10 Gb/s Ethernet, operating at the second harmonic wavelength of 0.77 μm.

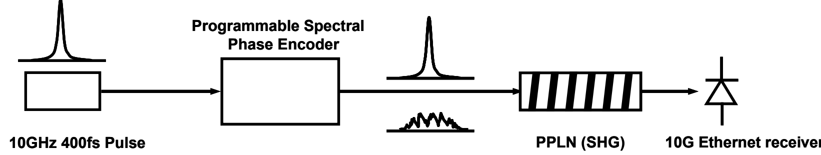

Fig. 1 Experimental apparatus.

The advantage of a nonlinear pulse discriminator is dramatically demonstrated in Fig. 2. First, we used a 1.5-μm photo-detector with a 12.4 GHz measurement system bandwidth to detect the pulse shaper output prior to entering the PPLN waveguide. Fig. 2 (a) shows the non-averaged real time traces of both uncoded (all zero phases) and length-31 M-sequence (MS) coded (0 or π phase shift) signals as seen on a sampling scope. Other than the 0.8

dB amplitude difference due to coding loss, there is no noticeable difference between the signals. **This clearly illustrates the main issue in O-CDMA with ultrashort pulses: uncoded, coded, and decoded waveforms have fundamentally the same energy, which means they produce the same output from an electronic detector band-limited to the data rate, even though they can show strong differences in temporal structure and peak intensity on an ultrafast time scale (which is much faster than the electronic processing bandwidth).**

Fig. 2(b) shows the output of the nonlinear PPLN waveguide as measured by the 7.5 GHz photoreceiver and 12.4 GHz sampling scope for both uncoded and coded waveforms. Clear pulse eyes ensuring excellent contrast ratio are observed. Second harmonic power contrast ratios of up to 20.1 dB were observed when coding with a length-31 M-sequence code and 0.9 mW in the PPLN waveguide. The second harmonic power was -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. Thus, contrast enhancements up to nearly 20 dB are achieved through nonlinear processing!

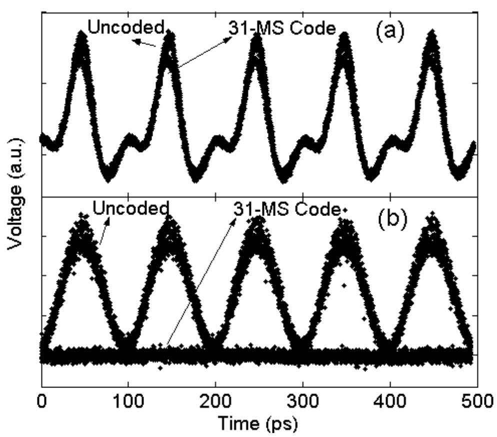

Fig. 2 Linear detector output (a) and nonlinear receiver output (b) for uncoded and 31-MS coded waveforms at 10GHz. The waveforms are clearly distinct after nonlinear processing but almost indistinguishable using a 12.4 GHz linear receiver.

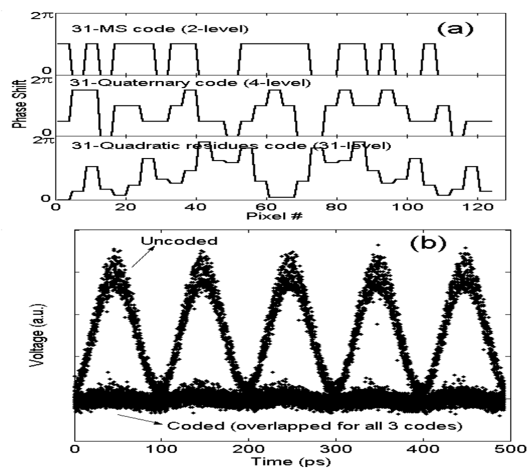

Fig. 3 Multi-level phase codes (a) and corresponding nonlinear receiver output (b). All three coded signals are strongly suppressed by the nonlinear processing.

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. In addition to a binary MS code, a 4-level quaternary code [8] and a 31-level quadratic residue code [9], as shown in Fig. 3(a), have been applied to the liquid crystal modulator. All of these codes show similar nonlinear output (PPLN) contrast ratio, as seen in Fig. 3(b) where all three traces are overlapped. In this way, our programmable pulse shaper enables us to select arbitrary phase codes which can be used to optimize their cross-correlation properties and minimize multi-access interference in future multi-user O-CDMA demonstrations.

In summary, 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 and clear pulse eyes are 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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