Linear and Low-Power Nonlinear Processing for Optical Code Division Multiplexing (O-CDMA), Short Pulse Transmission, and Measurement

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Abstract: This talk discusses examples of our work on linear optical signal processing using pulse shapers (O-CDMA encoding and dispersion compensation) and low power nonlinear processing using PPLN waveguides (O-CDMA waveform discrimination and ultrashort pulse measurement).

Optical signal processing is essential for lightwave communications systems in which the use of ultrashort pulses is envisioned. This includes both optical time-division multiplexed (OTDM) systems at rates of ~160 Gb/s and higher and optical code-division multiple-access (O-CDMA) systems based on the used of complex optical waveforms. This talk discusses several examples of research involving ultrafast optical signal processing, carried out in the Purdue University Ultrafast Optics and Fiber Communications Laboratory in collaboration with the Fejer group at Stanford.

Optical code-division multiple-access (O-CDMA) systems are receiving increasing attention due to their 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 [1-8]. 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. The CDMA approach is widely applied in cellular radio technology but is still exploratory in optics. In our effort on O-CDMA, optical signal processing is used primarily in two important ways. First, coherent encoding and subsequent decoding of subpicosecond modelocked pulses is achieved using programmable fiber-pigtailed pulse shapers [9] in a spectral phase encoder mode; this is a purely linear form of optical signal processing. Second, nonlinear waveform discrimination in order to differentiate between correctly and incorrectly decoded pulses is achieved via second harmonic generation in periodically-poled lithium niobate waveguide devices. An important point is that our discriminator permits suppression of incorrectly decoded signals by as much as 20 dB at an operating pulse energy as low as 30 fJ per bit [5], approximately two orders of magnitude lower than previous discriminators based on nonlinear fiber optics [1-3]. The ability to operate at low power per user is critical for scaling an O-CDMA system to multiple users. In our laboratory we have demonstrated O-CDMA operation with four simultaneous users at up to 10 Gb/s per user with error rates well below 10^{-9} [4-5]. In addition, we have explored the ability to perform all-optical code translation which may be advantageous in the context of O-CDMA networking [10].

Another aspect of optical signal processing involves dispersion compensation, which can be critical both for high-speed OTDM and for O-CDMA. The most successful and commercialized dispersion compensation (DC) technique is the use of dispersion compensating fiber (DCF) specially designed to have opposite dispersion parameters compared to single mode fiber (SMF), in which most second-order and partial third-order dispersion are compensated. For ultrashort pulses, accumulated residual second- and third-order dispersion in a fiber link can still cause serious distortion even if high quality DCF is used. A technique for fine tuning of higher order dispersion based on synchronous phase modulation of a pre-chirped pulse has been demonstrated in a 380 fs, 70 km transmission experiment [11]. However, this synchronous modulation scheme restricts the transmission format. In our group we have demonstrated a passive, format independent technique capable of fine tuning and completely removing the residual dispersion for a nearly compensated fiber link, which relaxes the required precision in fiber lengths and increases the tolerance to fiber dispersion variations. In this technique pulse shapers function as programmable spectral phase equalizers. Previously, our group has used this approach for complete third-order correction for 500-fs pulse distortion-free transmission over 2.5 km [12] and 10 km [13] SMF/DCF links. Recently, we extended this approach to achieve essentially distortion-free transmission for 470 fs pulses over a 50 km fiber link [14]. Our results demonstrate that the pulse shaping technique can effectively remove both the residual second- and third-order dispersion for femtosecond pulse transmission in excess of 50 km without strict requirements on the DCF length, which covers a distance range of practical interest for local area networks (LAN) and metro area networks (MAN). As an example, we have applied the 50 km fiber transmission results in an O-CDMA system context.

Finally, retuning now to nonlinear optics, we have exploited the extremely high sensitivity of SHG in PPLN waveguide devices to achieve nonlinear optical measurements of ultrashort pulses at extremely low powers. For example, we recently reported that SHG with chirped aperiodically poled lithium niobate (A-PPLN) waveguides enables intensity autocorrelation of 220-fs, 50-MHz pulses at only 52-aJ energy per pulse (only 1.3 nW average power). This corresponds to a nonlinear measurement sensitivity of 3.2×10^{-7} mW^2 [15], a factor of five hundred better than previously reported. We have extended these results to SHG-FROG for complete intensity and phase characterization with a measurement sensitivity of 2.7×10^{-6} mW^2, roughly five orders of magnitude lower than previous SHG-FROG results, and to 10 GHz laser systems where SHG may be attractive for dispersion monitoring applications. An important and interesting aspect of this work is that chirping of the lithium niobate poling period allows tailoring (broadening) of the phase matching curve to match the ultrashort pulse bandwidth, without requiring significant sacrifice of nonlinear optical efficiency or sensitivity.

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