Large Tunable Optical Delays via Self-Phase Modulation and Dispersion

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Abstract: We demonstrate continuously tunable delays and advancements of 3.5-ps pulses over a total range of more than 1200 pulsewidths in optical fiber using a combination of nonlinear spectral broadening and filtering.

OCIS codes: (060.4370) Nonlinear optics, fibers; (230.1150) All-optical devices.

Communication networks require components that have the capability of buffering or delaying information. In ultra-high speed communications, where information is encoded in pulses, optical/electronic conversion of information is a bottleneck for increasing the data transmission rate. Thus, it is desirable to have all-optical components for buffering and delaying signal pulses.

One approach for demonstrating tunable all-optical delays, which has attracted significant interest, is the use of slow light based on laser-induced resonances to reduce the group velocity [1]. However, the maximum relative delay, that is, the total delay divided by the input pulse duration, that has been generated using slow-light schemes has been limited to approximately a few pulsewidths. An alternative approach involves wavelength conversion, where the central wavelength of the pulse is shifted, and then sent into a medium with large group-velocity dispersion (GVD) [2-5], and large all-optical delays based on this technique were recently demonstrated [6-8]. Sharping, et al., [6] used four-wave mixing (FWM) for wavelength conversion and achieved 80 pulsewidths of delay. In this scheme, the wavelength and bandwidth of the signal pulse were preserved after the delay system, which allows for a much larger range of delays while maintaining the signal pulse information.

In this paper, we present a novel wavelength conversion and dispersion technique for all-optical delays, which offers a significant reduction in complexity. For wavelength conversion, we use the Mamyshev regenerator [9], which involves spectral broadening via self-phase modulation (SPM), and wavelength filtering. Using this delay scheme, we demonstrate tunable delays of more than 4.2 ns for a 3.5-ps input pulse, which corresponds to 1200 pulsewidths of delay. Our system substantially increases the range of achievable delays, while maintaining the original wavelength and bandwidth of the pulses and represents a significant step in the development of optical signal processing devices.

The pulse-delay generator consists of three stages: wavelength conversion, dispersive delay, and wavelength reconversion. The wavelength conversion, based on the Mamyshev regenerator, is performed in two steps. First, the pulse is sent through a length of highly nonlinear fiber (HNLF) where the pulse undergoes SPM. The broadened spectrum is then sent through an optical bandpass filter, where the desired wavelength window is selected. After the wavelength conversion stage, the pulse is sent through a dispersive fiber, where the delay is generated. The amount of delay (advancement) induced is proportional to the product of the GVD of the dispersive fiber and the wavelength shift. After the dispersive fiber, the pulse is sent through another length of HNLF where the spectrum is again broadened and filtered at the original wavelength to achieve wavelength reconversion so that the output pulse wavelength is the same as the input pulse wavelength.

In Fig. 1(a), we show the measured signal delay/advancement through the system as the band-pass filter of the Mamyshev regenerator is tuned. Each of the different traces shown represents a 1-nm change in the filter center wavelength before the dispersive-delay fiber. The total tuning range of the delay line is 4.2 ns. Figure 1(b) shows temporal pulse delay/advancement as a function of the center wavelength of the tunable bandpass filter, and as expected we observe a linear dependence.

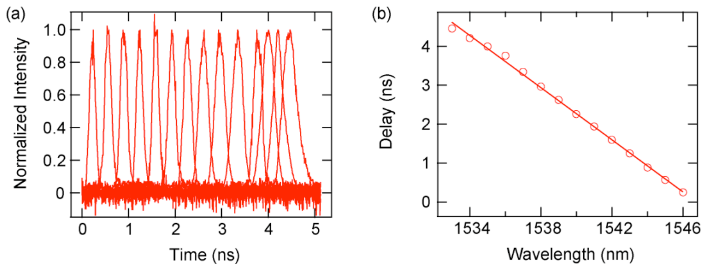

Fig. 1. Experimental results of pulse-delay generator. (a) Normalized oscilloscope traces of the pulses through the system for various wavelength settings of the tunable bandpass filter. (b) Delay as a function of the center wavelength of the tunable bandpass filter.

Pulse broadening does occur due to the dispersion of the DCM, and the output pulse duration from the delay generator is approximately 350 ps. However, this broadening can be minimized by optimizing the bandwidth of the tunable bandpass filter before the DCM. The DCM used in the experiment has a GVD of -342 ps/nm. Thus, assuming a transform-limited Gaussian pulse, a pulse with a bandwidth of 0.1 nm, which corresponds to a 34-ps pulse, will have minimal broadening through the DCM. Due to the minimum broadening that occurs, this selection of the bandwidth allows for data rates greater than 10 Gb/s. Any additional broadening can be post-compensated by adding an appropriate span of standard communication fiber after the pulse-delay generator.

We have demonstrated a novel tunable all-optical delay scheme based on wavelength conversion, dispersion, and reconversion. We show that the temporal position of a 3.5 ps pulse can be tuned continuously over 4 ns, which corresponds to a fractional delay of 1200. An advantage of using the Mamyshev-regenerator configuration for the wavelength conversion is that the scheme helps reduce noise that arises in data transmission. In addition, since it is possible to choose the appropriate bandwidth for the optical bandpass filter at the output, the scheme allows for the same signal wavelength and bandwidth before and after the delay line. The simplicity of the setup and the use of "off-the-shelf" components allow for easy integration into communication systems and other applications.

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