

# Femtosecond direct space-to-time pulse shaping in an integrated-optic configuration

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We demonstrate femtosecond operation of an integrated-optic direct space-to-time pulse shaper for which there is a direct mapping (no Fourier transform) between the spatial position of the masking function and the temporal position in the output waveform. The apparatus is used to generate trains of more than 30 pulses as an ultrafast optical data packet over approximately an 80-ps temporal window. © 2004 Optical Society of America

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Femtosecond pulse shaping<sup>1</sup> has become a frequently used tool in many ultrafast-optics laboratories because of the large range of pulse shapes that can easily be generated with high fidelity by use of that technique. The most commonly utilized configuration is one in which there exists a Fourier-transform relationship between the output temporal profile and the spatial pattern impressed onto the optical spectrum in the apparatus. To achieve any general output pulse shape requires simultaneous control of both spectral amplitude and phase. For applications for which the Fourier-transform relationship is inconvenient or both spectral amplitude and phase control cannot be simultaneously implemented, an alternative geometry, which we call the direct space-to-time (DST) pulse shaper, can be used.<sup>2</sup> This apparatus is particularly well suited to applications in which the desired pulse shape is a pulse packet consisting of a series of discrete pulses separated in time. In this case there is a direct mapping, rather than a Fourier-transform relationship, between the spatial masking elements and the output temporal waveform. The generation of arbitrary millimeter-wave wave forms<sup>3</sup> is an example of one area to which this pulse-shaping technique can be applied.

Although the bulk-optic DST pulse shaper is not significantly more complex to align than the Fourier-transform pulse shaper, an essentially alignment-free, integrated-optic configuration can greatly simplify the implementation of the technique, particularly in the optical communications band near 1550 nm in which integrated-optic devices and techniques are well developed. Although Fourier-transform pulse shaping by use of integrated-optic devices was demonstrated previously,<sup>4,5</sup> our current research is the first demonstration to our knowledge of an integrated-optic DST pulse shaper. In this Letter we demonstrate an integrated-optic implementation of the femtosecond DST pulse shaper based on a modified arrayed waveguide grating (AWG) structure.

The standard AWG structure, shown schematically in Fig. 1(A), is commonly used in optical communications as a wavelength (channel) multiplexer-demultiplexer.<sup>6</sup> The device consists of at least one input guide, an input slab waveguide, an array of

waveguides with a constant length difference between adjacent guides, an output slab, and one or more output waveguides. When the input pulse that is used to excite the AWG is shorter than the delay increment per guide in the waveguide array, the AWG can be used to generate bursts of femtosecond pulses on multiple spatially separated, wavelength-shifted

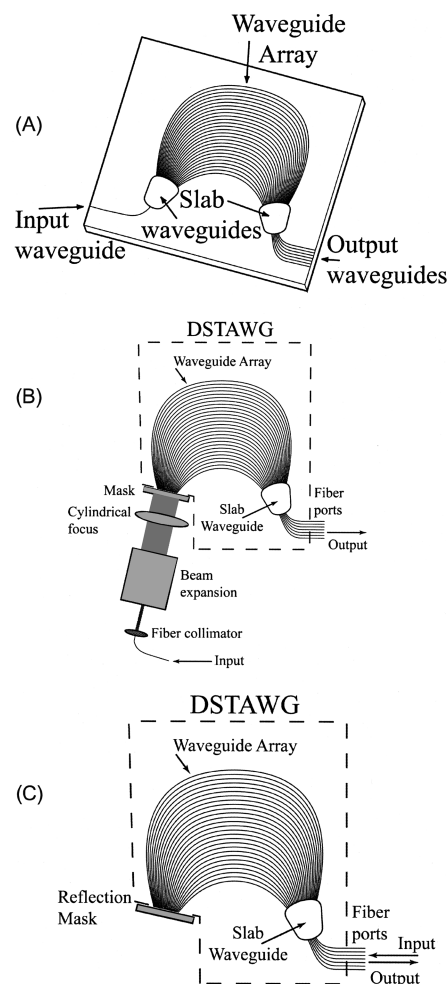


Fig. 1. (A) Standard AWG structure utilized in optical communications, (B) transmission implementation of the DSTAWG, (C) reflection implementation.



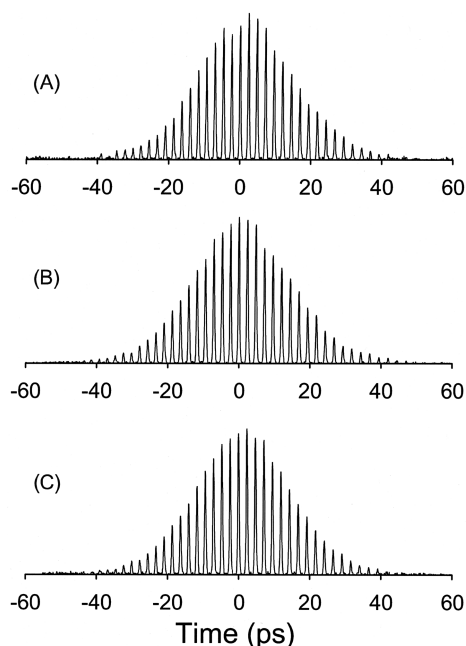


Fig. 3. Temporal intensity profile of output channels (A) 3, (B) 9, and (C) 17 for light input onto channel 10, demonstrating invariant output temporal intensity profiles.

the mask to facilitate demonstration of significantly different pulse patterns. Excellent interpulse extinction is present because the reflection mask is butt coupled to the DSTAWG device with index-matching fluid such that unwanted reflections are essentially eliminated. Figures 2(B) and 2(C) show two additional examples of aperiodic pulse packets intended to simulate a data stream as might be generated when an optoelectronic modulator array is used to control the temporal output pulse sequence programmatically; to clarify the contrast between adjacent pulses, every other guide is utilized to generate the data packet, resulting in a pulse repetition rate that is half that of Fig. 2(A).

Figure 3 shows output temporal profiles obtained from several single-mode guides while the DSTAWG was excited in a central guide (number 10) and the reflection mask was fixed. The DSTAWG has 18 single-mode guides for use as the input-output guides. The output temporal profiles obtained from guides 3, 9, and 17 are displayed in Figs. 3(A), 3(B), and 3(C), respectively, as representatives of the output of the fiber-connected ports. The mask used in this case blocks every other guide, demonstrating a periodic pulse train with twice the pulse spacing of that shown in Fig. 2(A). The invariant temporal profile across the different output guides is identical to the

character noted previously<sup>7,8</sup> in short-pulse excitation of AWGs. The  $\sim 25$ -dB measured fiber-to-fiber insertion loss is dominated by the splitting loss incurred by use of only one of the 18 available fiber ports in addition to the  $\sim 3$ -dB loss that is expected when a broadband excitation source is used.

In summary, we have demonstrated, for the first time to our knowledge, an integrated-optic implementation of a direct space-to-time pulse shaper. This planar light wave circuit configuration not only simplifies alignment and considerably decreases the apparatus's footprint but has the potential to be directly integrated with an optoelectronic modulator array to permit programmable configuration of the output temporal profile. Such an apparatus, with a full high-speed modulator array, could serve as a high-speed parallel electrical-to-ultrafast serial optical conversion apparatus.

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