Design of a Free-Space, Image-Relay Optical Time Domain Reflectometer to Measure Fiber-Optic Time Delays at Inertial Confinement Fusion-Relevant Wavelengths

T. Filkins and J. Katz

Laboratory for Laser Energetics, University of Rochester

Fiber optics are used extensively at LLE and other research laboratories to transport critical timing and experimental data. In inertial confinement fusion (ICF) experiments, fibers are used to transport light in the UV, visible, and IR ranges. When a fiber is replaced, a change in the optical path length will introduce a change in the absolute timing of the associated diagnostic. To maintain absolute timing, the change in the fiber-optic time delay (FOTD) must be measured. A commercial optical time domain reflectometer (OTDR) can be used, but only to measure the FOTD at telecom wavelengths, typically in the 800-, 1300-, or 1500-nm range; therefore, it would not provide the relevant FOTD. A simple free-space, image-relay OTDR was designed at LLE that can measure the FOTD at the relevant wavelengths to within 2 ps.

The OTDR requires a short-pulse laser source, simple optics and optomechanics, a photodetector, and a fast oscilloscope. For this setup, the OMEGA 60 2ω fiducial and Diagnostic Support and Development Laboratory (DSDL) 3ω laser pulses were used as the laser source to measure the FOTD of an ~16-m-long, large-core Russian graded-index fiber at two wavelengths relevant to ICF experiments (see Fig. 1). The fiber-launched laser light was collimated with a Thorlabs aspheric fiber-coupled collimator. The light was then coupled into the test fiber using a second collimator. The Fresnel reflections off the input and output surfaces of the test fiber were then transported to a large-core step-index collection fiber with a broadband pellicle beam splitter and coupled with a third collimator. The collection fiber was coupled with a fast (less than 100 ps) photodetector that was coupled to a fast-oscilloscope sampling at 40 GSa/s.

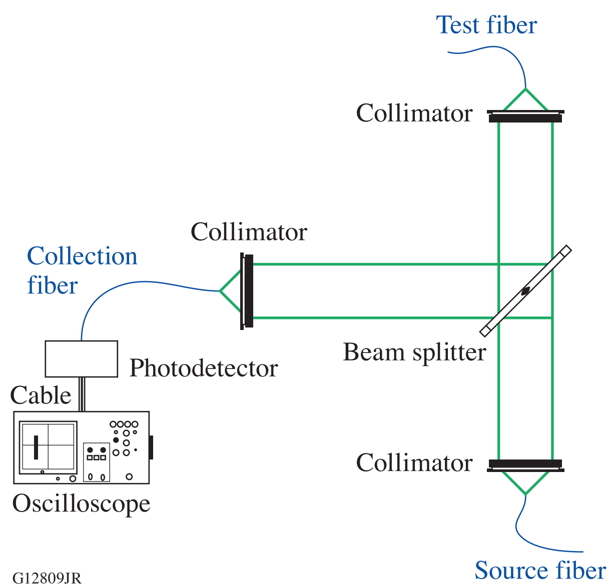

Figure 1
A short-pulse laser with a width of 10 ps from the DSDL or a 2-GHz comb from the OMEGA fiducial is used to measure the FOTD of the test fiber. Two different photodetectors were used to digitize the signals: a Hamamatsu biplanar phototube (R1328U-53) or a Hamamatsu GaAs photodiode (G4176-01). The phototube had better signal-to-noise ratio, which led to smaller uncertainties.

The signals on the oscilloscope (Fig. 2) were fitted with Gaussian functions to determine the centroid of each peak. The distance between corresponding peaks was twice the FOTD. The uncertainty of the fits was found by using methods outlined by Bobroff.[1] With a strong signal-to-noise ratio, and taking advantage of eight simultaneous measurements, the uncertainty of the FOTD was determined to be about 2 ps.

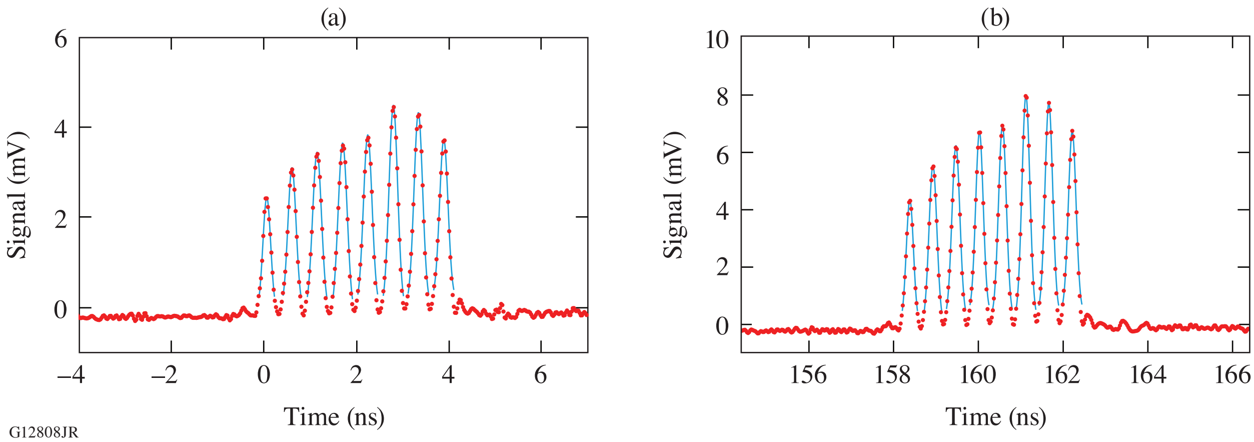

Figure 2
The (a) input surface and (b) output surface reflections were captured on a single trace in one channel and with the same detector, which eliminated any skew that might have been present between channels in the oscilloscope and removed any uncertainty about instrument response variations in the analysis between the two signals.

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1. N. Bobroff, Rev. Sci. Instrum. **57**, 1152 (1986).