Measuring everything there is to know about an ultrashort laser pulse

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We describe two simple new devices for completely characterizing—in space and time—even complex or focused ultrashort pulses.

Measuring the temporal intensity and phase of ultrashort laser pulses, especially those directly out of the laser, is becoming routine. But many applications involve much more interesting light pulses, such as white-light filaments generated in the atmosphere or the light transmitted by living tissue. The ability to measure these potentially very complex light pulses could lead to important new technologies and serve as a research tool not only for physics and engineering but also for chemistry, biology, and medicine.

These applications make substantial demands on pulse measurement techniques. Rather than measuring smooth, intense, short laser pulses, which are simple in space and time, they will need to be able to characterize, more generally, light pulses, which are likely to be weak or complicated (or both). Additionally, the techniques should be straightforward, and hence less prone to error. Here we present two such methods. Both of these techniques are linear-optical methods that involve interfering the complicated, unknown pulse with a simple reference pulse and measuring the resulting interference pattern. Both have colorful acronyms.

One of the techniques is called SEA TADPOLE (spatially encoded arrangement for temporal analysis by dispersing a pair of light E-fields). In SEA TADPOLE, the unknown and reference pulses cross at an angle and are spectrally resolved. We use optical fibers to introduce the beams into the device to make it insensitive to alignment (see Figure 1). SEA TADPOLE is the first practical method for measuring shaped pulses.

It is also important to be able to measure pulses at a focus because this is where the pulses are almost always used. And because common lens aberrations result in serious spatiotemporal distortions, measuring a focused pulse requires high spatial and spectral resolution. Fortunately, SEA TADPOLE also solves this problem. To measure a focused pulse with SEA TADPOLE, we use a fiber whose mode size is smaller than the focused spot size. Then one measures $E(t)$ at many positions within the focus, yielding $E(x,y,z,t)$. To characterize smaller foci (with spot sizes $<5\mu m$), one uses near-field scanning optical microscopy (NSOM) fiber probes. Figure 2 shows the results of a SEA TADPOLE measurement of a focused pulse that reveals some interesting structure due to aberrations that were present in the focusing lens.

SEA TADPOLE requires scanning and is thus necessarily a multishot technique. But a laser that emits only one pulse per day requires a single-shot method. This, too, we have recently developed and named STRIPED FISH (spatially and temporally resolved intensity and phase evaluation device: full information from a single hologram). The setup for STRIPED FISH requires only two optical components (see Figure 3). The unknown and reference pulses pass through a rotated low-dispersion 2D diffraction grating, generating a tilted 2D array of holograms. A tilted bandpass filter

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Figure 2. The measured (top) and simulated (bottom) spatiotemporal electric field of a focused pulse with significant chromatic aberration. Each box shows the intensity versus x and t at a given distance from the geometric focus (z). The color in the plots is the pulse’s color.

Figure 3. (left) STRIPED FISH experimental setup. (right) Ideal STRIPED FISH trace. The color in the plot represents the pulse’s color.

spectrally separates the beam pairs so that each hologram contains a single, unique frequency (see Figure 3). A single camera frame records all of the holograms, from which the complete spatiotemporal field of the unknown pulse can be reconstructed (see Figure 4). STRIPED FISH is capable of measuring even very complex pulses in space and time.

These new complementary techniques should solve most spatiotemporal light-pulse measurement problems. Their simplicity and robustness should make them powerful tools in any ultrafast optical lab. In the future, using NSOM fibers with smaller apertures, we hope to use SEA TADPOLE to improve the resolution and image quality in multiphoton microscopy. Using STRIPED FISH we hope to be able to characterize the complete spatiotemporal electric field of interesting pulses, such as white-light filaments, or the output of low-repetition-rate high-power lasers.

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Rick Trebino is the coinventor of FROG and the inventor of GRENOUILLE and a host of other techniques for measuring ultrashort laser pulses. He has received wide recognition for this work, including SPIE’s prestigious Edgerton Prize for developments in ultrafast measurement technology.

Pablo Gabolde recently graduated from Rick Trebino’s group, where he did the work described here.

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References


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