Two-beam SPIDER for dual-pulse single-shot characterization

Doug French¹, Christophe Dorrer², and Igor Jovanovic¹

¹Department of Mechanical and Nuclear Engineering, The Pennsylvania State University
²Laboratory for Laser Energetics, University of Rochester

28 September 2010
Outline

- Motivation and potential applications
- Two-beam SPIDER (TB-SPIDER)
  - Optical layout
  - Experimental validation
- TB-SPIDER for phase amplification experiment
- Conclusions
Simultaneous temporal characterization of multiple pulses can benefit ultrahigh intensity laser experiments

- Pulse characterization/diagnostics in ultrahigh intensity systems

- Multi-beam probing of dynamic processes


http://sciencewise.anu.edu.au/articles/chalcogenide
Multiple pulses can be measured by multiple instruments, but more convenient solutions are desired.

- Large footprint
- Expensive
- Difficult/time-consuming to align

- Smaller footprint
- Less expensive
Candidate techniques for multiplexed temporal characterization

- TREEFROG exists for twin-beam measurement
- Single-shot requires time-space encoding, which can be difficult for distorted beams
- Requires 2D spectrometer

http://www.physics.gatech.edu/gcuo/Tutorial/FROG.html
Candidate techniques for multiplexed temporal characterization (2)

SPIDER

- Only requires 1D spectrometer for traditional implementation
- Vertical multiplexing provides a convenient method for multi-beam measurement

Implementation of TB-SPIDER

S - Stretched beam
R - Replica beams

Type II BBO
0.5 mm thick

Etalon
L ~ 200 µm

τ = 1.92 ps

Spectrometer
0.3 nm resolution

600 g/mm
φ(2) = 1.19 ps/THz

Prism

Mirror

Etalons

B - Bottom beam
T - Top beam

D. French, ICUIL 2010
TB-SPIDER experimental layout
Two-beam SPIDER for dual-pulse single-shot characterization

Doug French 1, Christophe Dorrer 2, and Igor Jovanovic 1

1 School of Nuclear Engineering, Purdue University, 400 Central Drive, West Lafayette, IN 47907, USA
2 Laboratory for Laser Energetics, University of Rochester, 250 East River Rd, Rochester, NY 14623, USA

Low repetition rate high intensity laser systems and their applications are fields of prolific research. However, such systems can exhibit significant shot-to-shot variations and full characterization of the electric field must be performed on a single shot. The two most popular techniques for ultrashort pulse characterization are spectral phase interferometry for direct electric field reconstruction (SPIDER) and frequency-resolved optical gating (FROG). We demonstrate a novel design of the SPIDER technique, two-beam SPIDER (TB-SPIDER) [1], which simultaneously measures the electric field of two pulses, reference and probe, on a single shot, and by calculating the spectral phase difference of the two pulses is able to compensate for systematic shot-to-shot phase variations originating from the laser system.

![Two-beam SPIDER system schematic](image)

Fig. 1. Two-beam SPIDER system schematic, M-mirror, E-etalon, G-grating, P-retroreflector, 2ω-second-harmonic crystal, D1-short-wave pass dichroic mirror, D2-long-wave pass dichroic mirror. The insets show the relative orientation of the vertically multiplexed beams throughout the device, T-top beam, B-bottom beam, S-stretched beam, R-replica beams from the etalon; vbw interferograms for probe and reference beam as they appear on the CCD sensor of the spectrometer (false color is used to indicate intensity).

The TB-SPIDER utilizes two vertically multiplexed beams and passes each of them through conventional SPIDER setup (Fig. 1). Both input beams generate their own stretched and replica pulses that are mixed in a nonlinear crystal. After the crystal, the fundamental and upconverted pairs of pulses are overlapped using dichroic mirrors and sent to a two-dimensional spectrometer. Two interferograms are present in each spectrometer image (Fig. 1), corresponding to the top and bottom input beams, which are used to reconstruct the amplitude and phase as in conventional SPIDER.
TB-SPIDER data acquisition and analysis

- The 2D spectrometer has additional degrees of freedom for alignment

- Ideal image from spectrometer:

- Imaging system in the spectrometer can lead to curved field lines at the extremities of the image:

- Restricting beams to the center region of the entrance slit minimizes curvature

- Independent $\lambda$ calibration for each beam
Experimental validation of TB-SPIDER

- Measure dispersion for 10cm of glass

TB-SPIDER was deployed as a diagnostic for a single-shot phase amplification experiment

**Optical parametric amplification (OPA):**

\[ \omega_3 \rightarrow OPA \rightarrow \omega_3 \]
\[ \omega_1 \rightarrow OPA \rightarrow \omega_1 \]
\[ \omega_2 \rightarrow OPA \rightarrow \omega_2 \]

**Phase-sensitive OPA (PSOPA):**

\[ \omega_3 \rightarrow PSOPA \rightarrow \omega_3 \]
\[ \omega_1 \rightarrow PSOPA \rightarrow \omega_1 \]
\[ \omega_2 \rightarrow PSOPA \rightarrow \omega_2 \]

---

**Diagram:**

- **TB-SPIDER**
- **Ti: Sapph CPA**
- **OPA**
- **PS-OPA**
- **Dichroic Mirror**
- **Mirror**
- **Polarizer**

28 September 2010

D. French, ICUIL 2010
TB-SPIDER was deployed as a diagnostic for a single-shot phase amplification experiment (2)

- The phase-sensitive OPA acts as a *phase* amplifier rather than an energy amplifier
- Ideally: $\Delta \phi_{\text{out}} = G \Delta \phi_{\text{in}}$
- Calculation

Y. Yin, “Phase-Sensitive Temporal Pulse Shaping for Ultrahigh Intensity Lasers,” WP4, Wed. 4:30
TB-SPIDER scaling for characterization of multiple pulses

- Design parameters
  - Acceptance angle of the nonlinear crystal
  - Beam size and overlap

![Two-beam SPIDER system schematic](image)

The TB-SPIDER utilizes two vertically multiplexed beams and passes each of them through conventional SPIDER setup. Both input beams generate their own stretched and replica pulses that are mixed in a nonlinear crystal. After the crystal, the fundamental and upconverted pairs of pulses are overlapped using dichroic mirrors and sent to a two-dimensional spectrometer. Two interferograms are present in each spectrometer image, corresponding to the top and bottom input beams, which are used to reconstruct the amplitude and phase as in conventional SPIDER.
Conclusions

- TB-SPIDER is capable of simultaneously measuring the amplitude and phase of two pulses on a single shot
- TB-SPIDER reduces systematic errors in measurements of the effect of experimental systems on spectral phase

Future work
- Expansion of this technique for more than two beams
- Redesign to make it easier to align reference and probe pulse injection
- Use as standard diagnostic for current/future experiments