

# Ten Times More Data for Shock-Physics Experiments

**F**OR years, scientists conducting shock-physics experiments were limited to measuring sudden velocity increases at only a few discrete points on a target's surface. For example, as recently as a year ago, the high costs and complexity of setup forced researchers at the National Nuclear Security Administration (NNSA) laboratories to collect velocity data at only a dozen or so points on a moving surface as part of stockpile stewardship experiments. These scientists then used extrapolation, assumptions, and models to determine what was occurring in regions of the experimental target not observed directly.

Today, scientists are routinely recording 96 channels of optical velocity data at a fraction of the former cost to acquire data from just a few channels. This new technology, for which its developers earned an R&D 100 Award, is called multiplexed photonic Doppler velocimetry (MPDV).

The MPDV system was designed and developed by a team from NNSA's National Security Technologies (NSTec), LLC, the managing and operating contractor for the Nevada National Security Site and its related facilities, including operations in Los Alamos and Nevada. Senior scientist Ed Daykin led the development team together with Livermore physicist Ted Strand. The project began under NSTec's Site Directed Research and Development Program, and final development was conducted under the Shock Wave Related Diagnostic Development Project, which addresses the diagnostic needs of the NNSA nuclear design laboratories (Lawrence Livermore, Los Alamos, and Sandia national laboratories) in the area of shock physics.

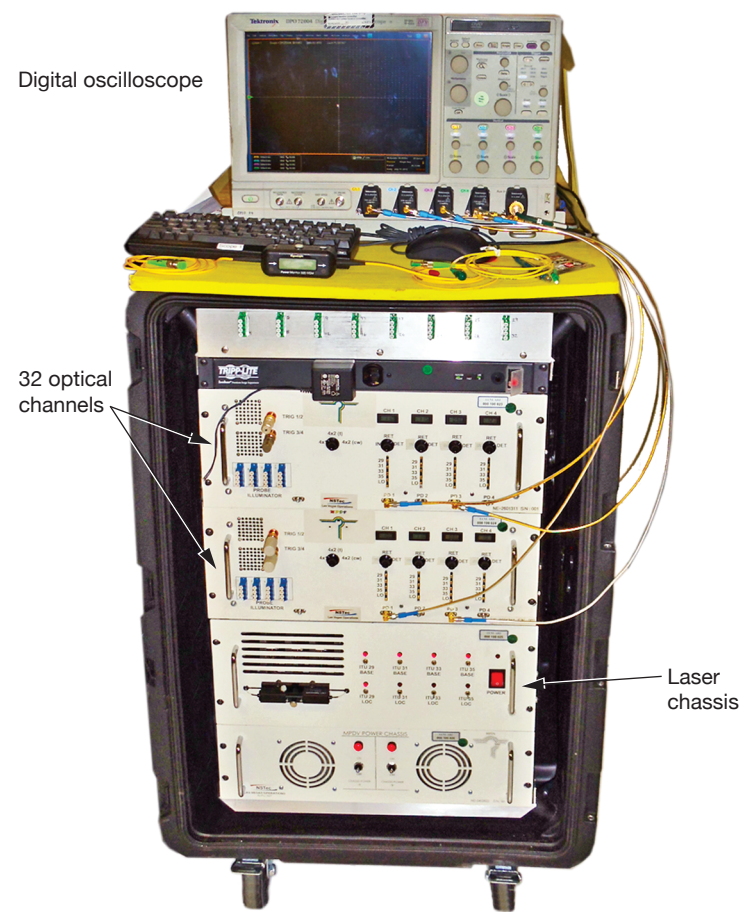
## Beat Frequency a Matter of Subtraction

MPDV is an optical velocimeter, a group of noncontact diagnostics that measure the velocities of explosively driven metal surfaces in single-shot shock-physics experiments. These surfaces may be driven to kilometer-per-second velocities in less than a billionth of a second. MPDV is a significant improvement over photonic Doppler velocimetry (PDV), which was pioneered by Strand. He searched in the early 2000s for an optical-based technique that was easier to deploy and more cost-effective than two other instruments: the Fabry-Perot velocimeter, developed at Livermore, and the commercially available VISAR (velocity interferometer system for any reflector).

PDV is based on determining the "beat frequency," the difference in frequency between two waves, in this case, the

difference in frequencies between a reference laser and the Doppler-shifted light reflected from a moving surface. Over the years, PDV became a standard diagnostic tool available to Livermore researchers. (See *S&TR*, July/August 2004, pp. 23–25.)

Strand explains that although highly reliable, PDV cannot economically provide the many dozens of simultaneous



A compact multiplexed photonic Doppler velocimetry (MPDV) system includes a 20-gigahertz digital oscilloscope for recording data, 32 optical channels for simultaneously measuring 32 discrete surface velocities, and a chassis for powering the lasers that are used to determine the beat frequency—a combination of the Doppler-shifted light from one laser and the reference light from another laser.

measurements needed to improve physical understanding and experimental accuracy in some stockpile stewardship experiments. In particular, Los Alamos and Lawrence Livermore scientists performing hydrodynamics experiments requested a more portable and cost-effective diagnostic system that could record more than 100 points of optical velocimetry data. Hydrodynamics experiments monitor the movement of a curved imploding surface inside a domelike configuration. In these experiments, the detonation of high explosives sends a shock wave through the test material, causing a liquidlike flow. Liquid behavior is described by hydrodynamic equations, so the experiments are often called hydrotests. (See the related article beginning on p. 16.)

### More Information at Reduced Cost

In response to the experimenters' requests, the MPDV development team increased the data-recording capacity of PDV by nearly an order of magnitude and reduced the cost per data channel fivefold. Built entirely from commercially available components, MPDV incorporates frequency- and time-division multiplexing to provide increased channel count, simultaneously measuring up to 32 discrete surface velocities onto a single digitizer. Frequency-division multiplexing sends signals in several distinct frequency ranges at a given time. Time-division multiplexing involves sequencing groups of data from individual input streams, one after the other, in such a way that they can be associated with the appropriate receiver. The equipment is designed to be set up and operated by one person per 32-channel system. While traditional PDV cannot discern between forward- and backward-traveling surface motion, MPDV measures the direction of travel.

MPDV uses a fiber-optic interferometer that measures the beat frequency resulting from a combination of the Doppler-shifted light from one laser and the reference light from another laser—an approach referred to as the heterodyne method. The Doppler-shifted light from four different probes is combined with four different reference light frequencies and applied to a photodetector. This process is accomplished within a fiber-coupled system that leverages commercially available telecommunications hardware. The beat frequency is recorded onto a high-bandwidth (20-gigahertz) digitizing oscilloscope and is then analyzed to determine velocity versus time at any of the surface locations that were monitored.

With MPDV, scientists can make hundreds of velocity measurements between 0.001 to 30 kilometers per second that



Livermore MPDV codeveloper Ted Strand.

are both economical and logistically feasible. The portable MPDV system requires no special laser safety requirements.

Proof-of-concept experiments were conducted in early 2011. The technology was first demonstrated at Los Alamos in August and September of that year. MPDV was then fielded on two multimillion-dollar experiments in October and December at Lawrence Livermore and Los Alamos, respectively. On March 7, 2012, a record 96 channels were demonstrated using three MPDV units.

By providing scientists with much more high-quality data, MPDV improves the ability to predict shock and material conditions and allows detailed comparisons between computational and experimental results. In this way, the technology helps ensure the safety and security of the nation's nuclear stockpile.

The new capability has potential applications to pulsed-power experiments as well as low-velocity commercial applications such as noncontact measurements of vibration. The team plans to continue development with an eye on increasing channel count, improving cost-effectiveness, and enhancing measurement capabilities.

—Arnie Heller

**Key Words:** fiber-optic interferometer, hydrodynamics test, multiplexed photonic Doppler velocimetry (MPDV), R&D 100 Award, shock physics.

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