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Sandia National Laboratories

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subject: Streak camera meeting summary

Streak cameras are important for high-speed data acquisition in single event experiments, where the total recorded information (I) is shared between the number of measurements (M) and the number of samples (S).

$$I = M \times S \tag{1}$$

Figure 1 illustrates how information is shared in different data acquisition systems. Digitizers record many samples ($\gg 10^4$) for a small number (4–8) of discrete sensor measurements. Sensor arrays (CCDs, etc.) store a few samples, often one, of many measurements ($> 10^6$). Streak cameras operate in the intermediate state, recording a moderate number (100–1000) of measurements with a moderate number (100–1000) of samples. This capability is crucial in many time-resolved diagnostics, particularly spectroscopy and spatially-resolved velocimetry.

Virtually all streak cameras rely on an image conversion tube, where incoming photons are converted to electrons and swept across a phosphor screen. However, industry applications for vacuum tubes have largely vanished and it is unclear how much longer streak tubes will continue to be manufactured. Sandia hosted a meeting on August 26–27 to discuss the current and future state of streak cameras. Topics of this meeting included: streak camera use at the national laboratories; current streak camera production; new tube developments and alternative technologies; and future planning. Each topic is summarized in the following sections.

1. Streak camera use at the national laboratories

Representatives from Sandia, Los Alamos, and Lawrence Livermore National Laboratories summarized the use of streak cameras in pulsed power (Z), plate impact (JASPER, Ancho Canyon, etc.), and explosive (HEAF, etc.) experiments. Streak camera use in laser shock experiments was discussed by representatives from OMEGA and NIF. Across these different facilities, streak camera use falls into three characteristic time domains: 1–10 ns (laser shock experiments), 10–100 ns (pulsed power experiments), 100–1000 ns (gun and explosive experiments).

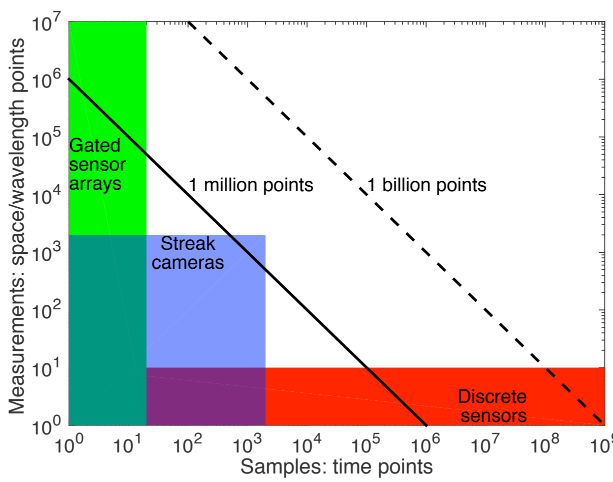

Figure 1: Information acquired in a single-event experiment. Lines indicate states of fixed total information.

Streak cameras are used for a variety of time-resolved diagnostics. Streaked visible spectroscopy (with limited ultraviolet and infrared coverage) was mentioned by every laboratory representative; emission spectroscopy (also known as pyrometry) is the most common example, but reflectance (Sandia and Livermore), absorption (Omega), and Raman (Los Alamos) spectroscopy were also of interest. Streaked x-ray measurements and line VISAR (ORVIS) measurements are important at the various laser facilities (NIF, OMEGA, and Trident); streak cameras also monitor drive beams at these facilities.

Most streak cameras used in laser experiments are ROSS systems, either purchased from Sydor Instruments or built as prototypes at OMEGA. A substantial inventory of EG&G (now National Security Technologies) streak cameras are in operation at Lawrence Livermore's gun and explosive facilities. Sandia and Los Alamos have an eclectic mix of streak cameras from Optronis, Hamamatsu, and various other companies.

2. Current streak camera production

There are currently three manufacturers of streak tubes in the world: Hamamatsu (Japan), Photonis (France), and Photek (U.K.). Hamamatsu's product line is entirely self-contained: their streak tubes are not for sale. The other two companies sell their tubes to other companies but do not make streak cameras themselves.

Several commercial streak camera vendors gave presentations at the meeting.

- Axis Photonique is a Canadian company that builds streak cameras using Photonis tubes. None of the users at the meeting had any experience with AXIS; several of their cameras are said to be in use at AWE and CEA. Axis sells a self-contained spectroscopy system incorporating the spectrometer, streak tube, CCD, control electronics, and computer into a single unit.

- Hamamatsu is a Japanese company with a long history of streak camera manufacture, and their cameras can be found all over the national laboratories. These cameras are entirely built in-house, including the streak tube. Hamamatsu has a U.S. distributor, but most of its production and service take place in Japan.

- Optronis is a German company that builds streak cameras using Photonis and Photek tubes. The cameras are distributed by Specialised Imaging, a British company with an established U.S. distributor. Optronis offers a capable, low cost ($100 K) streak camera.

- Sydor Instruments is a U.S. company using Photonis and Photek tubes. Their product line, the ROSS camera, is the result of a technology transfer from LLE. Significant effort has been put into characterization (distortion, etc.), modeling, and automation of their cameras.

Streak tubes and cameras are export controlled devices. Export licenses typically do not permit defense applications or weapons research. This requirement has been a problem for similar equipment (photomultiplier tubes) used in Nevada. Export control issues presumably applies to all streak camera vendors—which are foreign-built, use a foreign-built tube, or both—but has been particularly acute for Hamamatsu.

National Security Technologies (formerly EG&G) has traditionally maintained two camera production capabilities. Until 2012, the Livermore office (LO) manufactured streak tubes and complete camera systems; tube production is not currently in operation, but repair and support for existing EG&G cameras is still available. The LO cameras have a larger photocathode and are more sensitive than most commercial systems. The Los Alamos office has built a number of streak cameras based on commercial tubes; these systems were primarily deployed in Nevada and are not widely used elsewhere.

3. New developments and alternative technologies

Several new developments were mentioned during the meeting.

- Hamamatsu has an infrared streak camera that operates at 1000–1650 nm wavelengths. Unfortunately, the camera is probably not sensitive enough for single-event measurements (as stated by the vendor).
- Axis has an ultrafast framing camera that might be useful in some streak applications. Rastering a small image along an inward spiral, it might be possible to record 100–200 samples (10 ns exposure) at 20 ns intervals.
- Sydor commissioned a new streak tube (ST-DS) from Photek, broadening their supplier base.
- Pulse dilation imagers, which are being developed at General Atomics, are an interesting variation of streak camera technology. These imagers aren't currently used in a streak mode, but might configured for ultrashort measurements in the future.

Solid-state cameras are a recurring topic amongst streak camera users, and several presentations discussed current efforts in this area.

- Livermore had a collaboration with MIT Lincoln Laboratory to develop a CMOS imager with sub-nanosecond exposure time. Some interesting progress was made in this area, but the system architecture may be not be well suited for streak applications
- Sandia has an ongoing project to develop solid-state cameras using switched-capacitor-array ASICs. Several multi-frame prototypes have been built and newer designs are under development/fabrication. Streak versions of the camera have not been produced, but several conceptual approaches to doing so were identified.
- National Security Technologies has produced several solid-state cameras. Generally these cameras have exposure/inter-frame times in the realm of 100 ns with 8–10 frames. They are also working on a system for visible and infrared spectroscopy using avalanche diode arrays.
- Specialised Imaging sells a commercial framing camera that acquires 180 frames with exposure times down to 100 ns. Their engineers believe that the camera could easily be modified to record thousands of 20 ns exposures.

Funding is an issue in each case: many are former LDRD/SDRD projects that have little or no dedicated support at this time.

Several alternative technologies were discussed at the end of the meeting.

- Cordin Scientific Imaging has developed a rotating mirror camera with sub-nanosecond time resolution using a multi-CCD readout. The technique eliminates the photon-electron-photon conversions used in streak tubes, maintaining purely optical signals up to acquisition. A major challenge is synchronization: rotating mirror cameras typically trigger the event of interest instead of accepting an external trigger. Cordin believes the problem can be solved, but a working prototype with external trigger does not currently exist.
- National Security Technologies has a current SDRD project to develop a solid-state beam deflector. If successful, this approach is conceptually similar enough to existing streak cameras that much of the support technology (micro-channel plates, etc.) could be utilized.
- Sandia has a LDRD project to build infrared conversion arrays, which could be used as a "photonic" streak camera. Visible (or x-ray) measurements are mapped into a set of infrared signals that can be efficiently multiplexed onto a small number of digitizers. This approach could expand the total information content from millions to billions of points (Figure 1).

It may be some time before the viability of these new approaches can be fully determined.

4. Future planning

No decisive plans were made at this meeting, but there is a shared concern about the future. Streak cameras require tubes, and there is no domestic supplier. One or more the following actions is needed in the short term (1–5 years).

- Dedicate operational EG&G tubes to applications that truly require them.
- Replace streak camera measurements with alternative diagnostics (such as multiplexed Photonic Doppler Velocimetry) wherever possible.
- Begin stockpiling commercial streak tubes before production becomes a problem.
- Resume tube production at National Security Technologies.

Most of these actions require significant coordination with National Security Technologies. For example, there was interest in a "camera exchange program" where working EG&G systems could be traded for a more appropriate camera or alternate diagnostic.

Service and repair is another area of concern. Most commercial cameras are shipped internationally for repair, causing considerable experiment delays. Preserving some level of domestic service over the next 10 years is essential.

Several streak-camera alternatives were discussed at this meeting, and sporadic efforts have been reported in the open literature. Various technical goals and challenges must be considered.

- Matching the time resolution of streak tubes will be difficult, particularly in the sub-nanosecond regime. Most alternative technologies are best suited to the time scales of impact, explosive, and some pulsed power experiments. Laser shock experiments will probably depend on streak cameras for some time.
- Streak cameras have optical gain within the tube and (optional) micro-channel plate; spatial separation provided by the camera allows the use of high-efficiency phosphors and slow readout systems. Lacking these features, alternative technologies may have limited sensitivity. Characterizing the response of existing streak camera systems (including the tube, phosphor, micro-channel plate, and readout) with a known irradiance would be helpful in assessing the sensitivity requirements needed by alternative systems.
- Expanded wavelength coverage, especially in the infrared, is highly desirable.

Strategic, sustained investments are needed to promote the transition from tube-based cameras to alternative technologies over the next 5–15 years.

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