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10-4-90 JS(1)

UCRL-ID-104836

Twelve Signals Multiplexed with the LLNL Optical Streak Camera

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August 28, 1990

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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Twelve Signals Multiplexed with the LLNL Optical Streak Camera*

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1.0 INTRODUCTION

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At our Nova laser facility, the temporal history of incident and reflected laser energy is recorded on LLNL optical streak cameras. Currently, six cameras are used to record the incident 1.06- μm , incident 0.35- μm , and reflected 0.35- μm power of each of the ten Nova beams. Each camera records seven multiplexed signals: typically one signal from each of five beam lines, a fiducial pulse, and a time mark generator signal. The optical signals are transported to the camera through optical fibers. The output end of each fiber is placed in the slit plane of the camera. The light exiting the fiber is focused to the streak camera photocathode by the streak camera relay lens.

One camera can record a signal from each of the ten Nova beams plus a fiducial and time mark generator signal if the number of multiplexed channels can be increased from seven to twelve. This would allow one camera to record the same data that currently requires two cameras. At a savings of \$150K per camera/CCD system, this represents a savings of \$450K. Additionally, camera/CCD maintenance and operation complexity would be cut in half and three streak cameras would be freed for use in other experiments.

Recent laboratory measurements suggest that the number of multiplexed signals per camera can indeed be increased from seven to twelve without noticeably increasing the crosstalk between signal channels. In this memorandum, we describe recent work in which seven and twelve signals were multiplexed to one streak camera. We describe the effect focusing has on the crosstalk between channels and the effect wavelength has on focusing. We conclude the memorandum with suggestions concerning the implementation of a twelve channel system.

2.0 EXPERIMENTAL SETUP

For this work, we used a standard LLNL optical streak camera. It has an S1 photocathode and an adjustable input slit. The slit is imaged to the photocathode by a 1:1 relay lens. The f/1.3 lens has a focal length of 88 mm. The camera focus voltage is selected in the standard manner. (This makes the temporal dispersion nearly independent of the width of the photocathode strip that is illuminated.) The microchannel plate (MCP) image intensifier tube (IIT) is set at a gain of 2000. This low gain is chosen to enhance the visibility of crosstalk between channels. All data are recorded with one of the new lens-coupled CCD systems.

Input into the camera is over a set of Sincor 144 optical fibers. These are the 100/140 graded index fibers generally used with the Nova fiducial system. They have a numerical aperture of 0.29. The output end of each fiber is located at the slit of the streak camera. Measurements were taken in both static and dynamic modes. The incident light for the static (unswept) images comes from a microscope light filtered with the appropriate bandpass filter. Dynamic (swept) images are made with frequency-doubled Nd:YAG laser pulses passing through a 0.53- μm bandpass filter. In both cases, the light was incident on the end of the fiber.

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For this work, two separate fiber interfaces were used to couple light signals into the streak camera. Our initial work was done with a linear array of seven fibers positioned at the camera slit. Each fiber is about six inches long and is connected to a long fiber (five to thirty feet) with a SMA-style connector. Fiber spacing at the slit is 2.33 mm center-to-center. The second interface has twelve fibers spaced 1.18 mm apart. Each fiber in this array is about two feet long. Our system has micrometer adjustments that allow the fiber arrays to be moved to selected positions along the axis of the streak camera.

3.0 SINGLE FIBER FOCUSING

Figure 1 shows spatial lineouts of streak camera images containing seven multiplexed signals. Each lineout is for a different position of the fiber array along the streak camera axis. Each lineout is from an image formed in the static mode with low intensity 0.53- μ m light. Let us focus our attention on the lineout profiles of the individual fibers.

The minimum image width occurs when the image of the fiber end is in focus at the photocathode. The shape is nearly Gaussian. Fiber positions further from the lens result in defocused images with larger FWHM and more amplitude in the wings. Fiber positions closer to the lens cause the lineout shape to form a flat top and very sharp sides.

The variation in lineout shape offers an opportunity to improve signal-to-noise ratio in some streak camera applications. When the temporal lineout of a spatially narrow Gaussian pulse is analyzed, it is difficult to take a lineout along the peak of the data. To get around this problem, the signal is usually averaged in the spatial dimension. Averaging into the adjacent background region can add noise to the resulting analysis. By moving the fiber closer to the lens, the spatial profile of the image can be changed from an approximately triangular shape to a more rectangular shape. This allows a factor of two increase in the signal content of the image at the same peak signal intensity. With the sharper sides of the rectangular profile, a wider image without wider wings is possible. This allows an additional increase in the signal content of the trace.

The single-fiber spatial profile described above is true for the central 6 mm of the tube. At off-axis positions, the profile retains the sharp cutoff at the edges, but the top takes on a tilt due to vignetting by the relay lens.

4.0 SEVEN MULTIPLEXED SIGNALS

Figure 2 shows three-dimensional representations of streak camera data in which the signals are coupled to the camera with the seven-element fiber array. The image intensity is plotted as a function of the spatial position in the output image. X is the spatial direction of the camera and Y is the temporal direction. These images were formed in the static mode. The left column of images were formed with 0.53- μ m light and the right column of images with 1.06- μ m light. The position of the fiber ends were moved along the camera axis several millimeters either side of best focus. The origin of the Z axis is arbitrarily chosen as that point which gives the best focus for 0.53- μ m light.

4.0 SEVEN MULTIPLEXED SIGNALS (cont'd)

At best focus, the image peaks are very narrow and well-defined. For positions further from the lens, the peaks remain sharp while their bases broaden and the valleys between the peaks begin to fill. When the fiber is moved closer to the lens, the output image broadens, but the pulse sides become very sharp. The 1.06- μm data show similar characteristics. The position of best focus for 1.06- μm light is about 3 mm further from the lens than for 0.53- μm light.

Figure 1 shows spatial lineouts through the 0.53- μm images shown in Figure 2. The peak-to-valley ratio of the focused image is 1000 for peak 4. The excellent channel separation observed here suggested that we should have reasonable success with twelve multiplexed channels.

5.0 TWELVE MULTIPLEXED SIGNALS

Figure 3 shows a contour plot and a spatial lineout of an image containing twelve multiplexed signals. The fibers are spaced an average of 1.18 mm center-to-center. The image was formed in the static mode with 0.53- μm light. The lineout shows the peak-to-valley ratio between peaks 2 and 3 to be 400. Uneven spacing between the fibers at the slit causes the variation in spacing between the peaks in the lineout.

Figure 4 shows the contour plot and spatial lineout of an image that was formed in the dynamic mode. It, too, contains twelve multiplexed signals. This image was formed with a 50 ps FWHM pulse of 0.53- μm laser light. The peak-to-valley ratio between peaks 2 and 3 is 175. This is a pessimistic value because the peaks have reached saturation. Indeed, nearly all the signal peaks in Figure 4 have reached the saturation limit of the IIT. This tends to compress the signal peaks and results in a poorer peak-to-valley ratio than when operating the camera in its linear range.

6.0 CROSSTALK

The relationship between channel width and crosstalk can be calculated from a point spread function (PSF). The width of a signal channel is the spatial extent of the image over which one input signal is averaged. The crosstalk is the ratio of the signal in the channel centered at the peak of the PSF divided into the signal in the adjacent channel. The peak-to-valley ratios measured for lineouts in Figures 1-4 give an indication of the crosstalk that exists between adjacent channels of information. For a Gaussian distribution, the crosstalk is approximately one-half of the reciprocal of the peak-to-valley ratio.

Figure 5A shows the lineout in the spatial direction through the peak of the PSF of a single fiber illuminated with 0.53- μm light. The image of the fiber at the streak tube photocathode is at "best focus" (Figure 1C). Figure 5B shows the calculated crosstalk between channels as a function of channel width. (Conversion between input spatial distance and an output CCD pixel is 50 μm /pixel.) Wider channels have lower crosstalk. However, for channel widths greater than 20 CCD pixels, crosstalk is weakly dependent on channel width. The seven and twelve fiber systems have spacings between signal peaks of 46 and 23 CCD pixels, respectively. This corresponds to crosstalk values of -34 and -30 dB, respectively.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Twelve or more multiplexed signals can be recorded on a single LLNL optical streak camera. The penalty for increasing the number of channels from seven to twelve is a slight increase in crosstalk between signal channels. The rejection ratio of the twelve channel system is about 1000 (30 dB) compared to 2500 (34 dB) for the seven channel system.

Optimum fiber position depends on the wavelength of the light being imaged. The axial position of each fiber must be selected based on the wavelength of the signal it is to carry. For the lens on our camera, the output end of fibers carrying 0.53- μm light should be 3 mm closer to the lens than fibers carrying 1.06 μm light. The optimum position for fibers carrying 0.35 μm light needs to be determined. The fiber-array holder should be designed to allow each fiber to be positioned for the signal wavelength it is to carry.

The lineouts in Figures 4 and 5 show that our twelve-fiber array uses only 280 CCD pixels in the spatial direction. The CCD has 384 pixels in the spatial direction and it images only the central 29 mm of the 40mm IIT. Crosstalk between channels of the twelve-fiber array can be reduced slightly by increasing the center-to-center spacing from 1.18 mm to 1.5 mm. This increases the number of CCD pixels per signal channel from 23 to 30. If the crosstalk associated with 23 pixels per channel is satisfactory, then the number of channels can be increased from twelve to fifteen.

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