CONF-810810--8

LA-UR -81-1946

TITLE: FIBER OPTIC NEUTRON IMAGING SYSTEM: CALIBRATION

AUTHOR(S): R. M. Malone, EG&G/Los Alamos
L. E. Gow, EG&G/Los Alamos
D. R. Thayer, P-14

MASTER

SUBMITTED TO: 25th Annual Technical Symposium
SPIE Technical Programs Committee
San Diego, California

August 24-28, 1981

DISCLAIMER

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

296-27

Fiber Optic Neutron Imaging System: Calibration

Robert M. Malone, Charles E. Gow, and John P. Manning
EG&G, Inc., P. O. Box 809, Los Alamos, New Mexico 87544

Douglas R. Thayer

Los Alamos National Laboratory, P-14, MS-410
P. O. Box 1663, Los Alamos, New Mexico 87545

Abstract

Two neutron imaging experiments using fiber optics have been performed at the Nevada Test Site. In each experiment, an array of scintillator fluor tubes is exposed to neutrons. Light is coupled out through radiation resistant PCS fibers (8-m long) into high-bandwidth, graded index fibers. For image reconstruction to be accurate, common timing differences and transmission variations between fiber optic channels are needed. The calibration system featured a scanning pulsed dye laser, a specially designed fiber optic star coupler, a Tektronix 7912AD transient digitizer, and a DEC PDP 11/34 computing system.

Introduction

A discussion of the first neutron imaging experiment has been presented in several papers.[1-3] This paper describes the calibration system used on the second Space/Time-Resolved EXperiment (STREX). This experiment involves neutron-imaging onto a close-packed array of tubes filled with a fluor material. Each tube corresponds to a resolution element in the image. A single optical fiber is aligned to each fluor tube. Radiation-resistant Plastic Clad Silica (PCS) fiber is used in the severe radiation environment close to the imager. A splice to a high-bandwidth Graded Index (GI) fiber is made in a less demanding radiation environment several meters away. The GI fiber transmits the scintillator emission to a photomultiplier tube (PMT), through an optical interference filter. The PMT signals are then recorded on oscilloscopes. A special calibration system provides accurate inter-channel timing and measures the amplitude variations of the fiber optic channels. More details on the physical layout, preparation, and installation of this experiment is given in a separate paper.[4] Internally generated reports on the first STREX experiment provide more details on fiber handling, fiber optic cable construction, connector terminations, weld splices, calibration laser parameters, photomultiplier tube design, and the computer software used to characterize such a large fiber optic system.[5,6]

Calibration system

A schematic overview of the system is shown in Fig. 1. The calibration light comes from a Molectron nitrogen pumped dye laser system, operating at 30 pps. The laser is triggered in synchronation with a clock driving a step motor used for wavelength scanning. The laser's 3.0-ns pulse is focused through a lens into a Siecor graded index fiber (62.5-um core dia.). The lens has a .25 N.A. for proper coupling of the light. The amount of power the fiber is capable of handling is limited to approximately 1 kW by Raman frequency shifting.

At the other end of the Siecor cable, the calibration light is coupled into the input leg of a star coupler through an ITT connector. The 152 output legs of the star coupler are epoxied into a stainless steel mask, as shown in Fig. 2. The star coupler mask is placed at the bottom of the imager's array of scintillating fluor tubes. The imager, as shown in Fig. 3, consists of an array of silica tubes immersed in a bath of liquid scintillator. Previous papers[2,3] have discussed the requirements of a useful radiation-to-light converter in the situation where the emitted light must be compatible with fiber optic transmission. The calibration light passes through the star coupler into the imager's scintillator tubes and is picked up by radiation resistant PCS fibers. Individual pulses from the scanning dye laser will illuminate all tubes simultaneously. Light transits 30 ft of the low-bandwidth PCS fiber then passes through an ITT connector and into a high-bandwidth graded index Siecor fiber. At the output end of the Siecor fiber, light passes through an 8.5-nm filter centered at 540 nm, then onto a Hamamatsu R928 PMT.

The individual scintillating fluor tubes approximate short, step index optical fibers. The Suprasil silica tube has an index of 1.46 and the liquid fluor has an index of 1.50. This combination leads to light guiding with numerical aperture of 0.34 under the volume

296-27

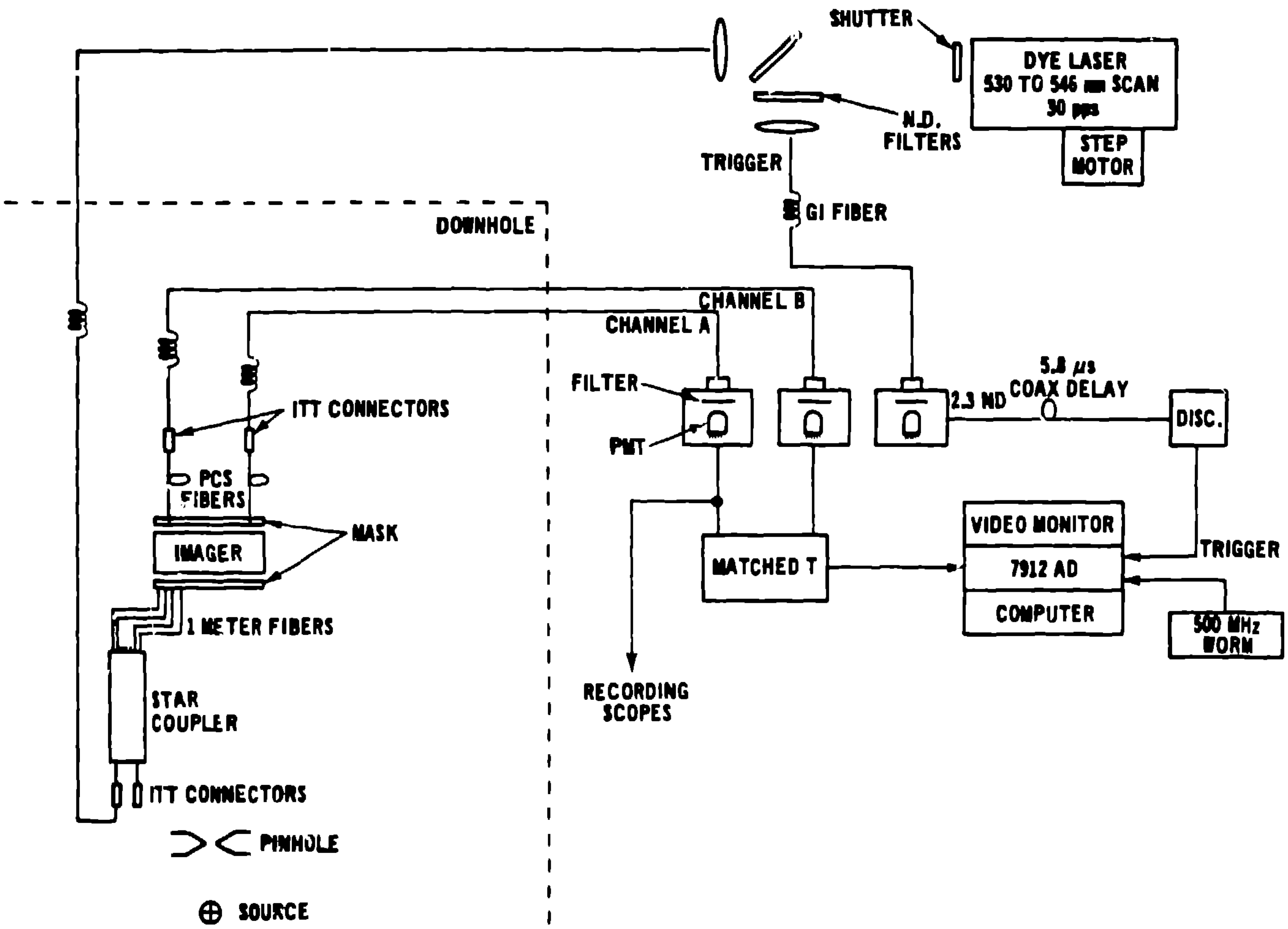

Figure 1. Amplitude and common timing calibration system.

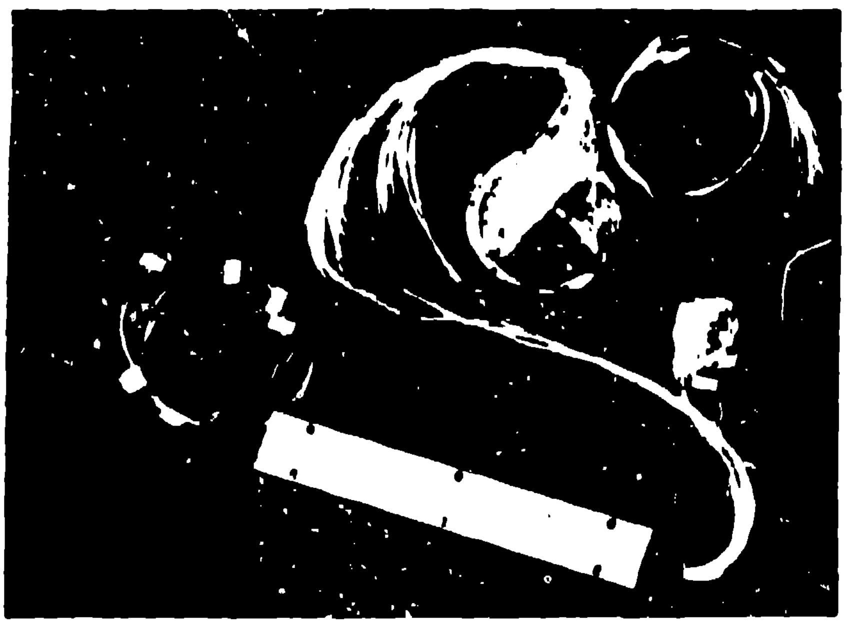

Figure 2. Star coupler.

Figure 3. Neutron imager.

excitation by neutrons. Thus the light from the fluor tubes overfills the numerical aperture of the PCS fibers, which overfills the numerical aperature of the high-bandwidth graded index fibers.

In the calibration system, the numerical aperture of the fluor tubes is not filled. The near-field pattern of light as it exits the tube shows definite modal structure. The PCS fiber, with a 125-um diameter, will average out some of this modal structure. By allowing a rough grind on the bottom mask containing the star coupler fibers, the light entering into the fluor tubes will be lightly diffusing. If too much diffusing occurred, cross talk of the light between fluor tubes would be a problem. Proper mode filling in the calibration system is necessary to make accurate common timing measurements on the fibers.

The calibration system is configured to measure the relative transit time of channel A compared to channel B (the reference channel). Signals from two detectors are combined in a matched T and displayed on a Tektronix 7912AD transient digitizer. Because of the large amount of light in the calibration system, no signal averaging is needed (as was the case in the first STREX experiment). The laser is scanned from 530 to 545 nm because of differences in the filter's spectral bandpass. A stepping motor under remote control scans the laser wavelength through the filter's bandpass. A gate on the trigger detector allows every twelfth pulse to trigger the 7912AD. The 7912AD collects data from 64 pulses, each shifted by .24 nm in wavelength. The total wavelength scan of 15.36 nm takes 12.80 s to complete.

The 7912AD is under program control with the analysis of pulse amplitudes, pulse time differences, and computation done in the computer. The linearity of the 7912AD time axis is calibrated with a 500-MHz sine wave. The computer-averaged display of the pulses from two channels is shown in Fig. 4. The 7912AD requires that the two pulses have a peak ratio between 0.1 and 1.1 for proper digitization. The time differences between the front slopes of the two pulses at a number of different amplitudes (35-65%) were computed and averaged to arrive at DELTA T. The two displayed pulses have FWHM of about 3.5 ns. For highest time resolution, the 7912AD is run at 2 ns/division. The pulse separation will be adjusted from 8 to 12 ns by use of delay coax on the PMTs. If pulses are spaced closer than about 8 ns, a time distortion occurs when the trace does not return to the baseline between pulses. At least half of the back slope of the second displayed pulse needs to be displayed for the FWHM calculation. From previous results on STREX I, averaged over all channels and all conditions, the time stability of the fibers, plus our measuring system, was ±60 ps. FWHM needs to be monitored during data collection. Variations in FWHM show variations in system bandwidth, trigger instability into the 7912AD, or problems with the laser system.

CHANNEL NUMBERS	146
	26
DATE	23-SEP-90
TIME	16:24:25
DELTA T	9.19483
PEAK1	.102992
PEAK2	.166214
PEAK RATIO	.619637
FWHM1	3.23619
FWHM2	3.28688
STD DEV R	3.68759E-03
SLOPE	7.25353E-04
STD DEV	2.27761E-03
DATAFILE	14626.1

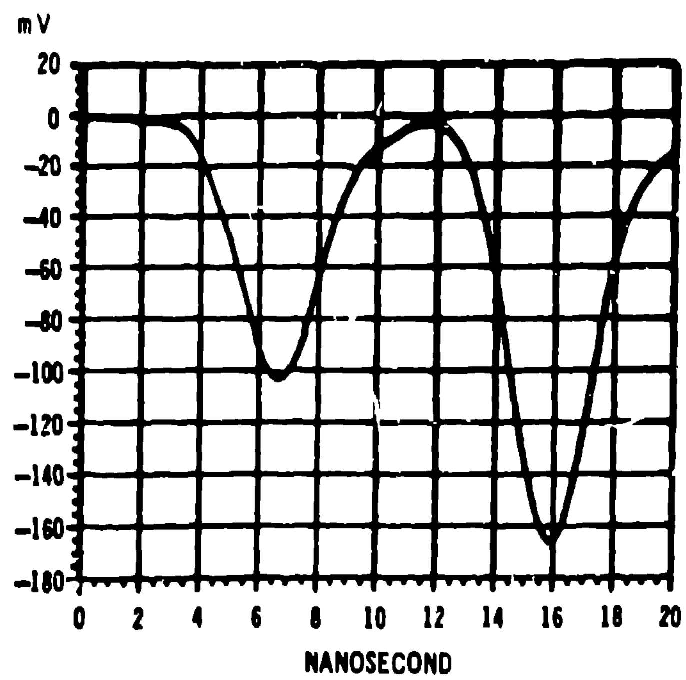

Figure 4. Channel A(146) is compared to reference channel B(26).

Software programs were developed to collect data on a large number of fibers in a short amount of time. In one program, data are collected and computation is done in <100 s. In the second program, data from channel pairs are collected and stored in <80 s. A third program will call up all stored data, do the computations, and print out the results without requiring a computer operator. Using the second program, analyzing 150 fiber channels took 3.5 hrs, with the results printed later using the third program.

Star coupler

A method of providing uniform illumination to the STREX imager is necessary for proper amplitude calibration. In our previous STREX I experiment, the downhole laser fiber was placed about 15 in. from the bottom of the imager and its light passed through a diffusing plate before entering into the fluor tubes. This arrangement resulted in huge light losses and a large variation of light levels exiting the different fluor tubes.

To improve on this arrangement, a star coupler was constructed. This star coupler split light from one input fiber into 210 output fibers. Light mixing inside the star coupler occurs in a close-packed bundle of fused biconical tapered fibers. Fibers were Corning SDF step index fibers with 100-um core, 140-um O.D., and 0.3 N.A. For star coupler #47, the total transmission loss was 3.12 dB. For each output fiber used, the average loss was 26.09 dB with a standard deviation of ±.53 dB. For the two worst case fibers, they deviated by -.69 dB and 2.32 dB from this average loss.

The star coupler fibers were installed into a stainless steel mask, which was keyed to the bottom of the imager (Fig. 2). Output fiber legs of the star coupler were cut to 1-m lengths, and the plastic jacket of each fiber end was removed by a solvent. Fibers were epoxied into EG&G ferrules using Epotech 331 epoxy. Epoxy was oven cured at 80°C for 2 hrs then allowed to cool before the grinding operation. Each EG&G ferrule was rough ground on 600 grit paper and inspected through a 200X microscope. Emerson and Cummings 1217 epoxy (non-oven curing) was used to secure ferrules into the mask holes and allowed to cure for a few days. Silicone glue provided strain relief for fibers coming out of the completed star coupler mask. The star coupler and its mask was then placed inside a protective aluminum box and readied for testing by the calibration system.

Calibration results

The star coupler was characterized separately from the STREX experiment by using the 1/8 in. opal glass sandwiched between the star coupler mask and the top mask to the imager. Opal glass provided uniform illumination from the different fiber legs of the star coupler, and simplified alignment. Using one fixed reference fiber, an intensity mapping of the star coupler was made. This was furnished for both inputs #2 and #4 to the star coupler. Each input gave a slightly different intensity mapping across the star coupler mask plate. However, each mapping was consistent to ±5% from run to run. All data taken were normalized and a final average computed. Figure 5 shows the intensity mapping of a star coupler using input #2. Figure 6 shows the relative arrival time of the calibration light pulses to the neutron imager.

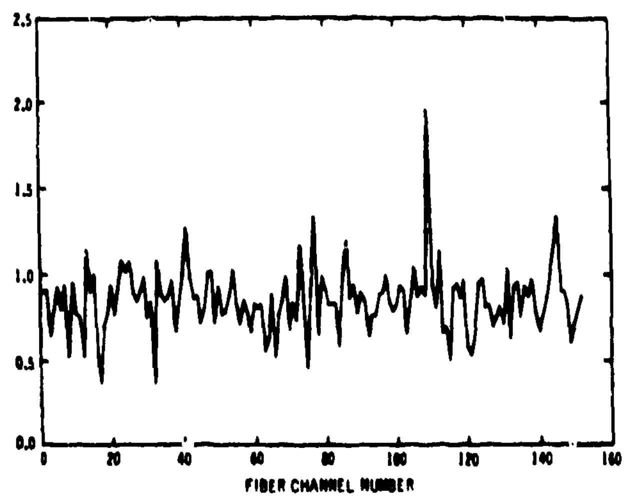

Figure 5. Intensity mapping of of star coupler.

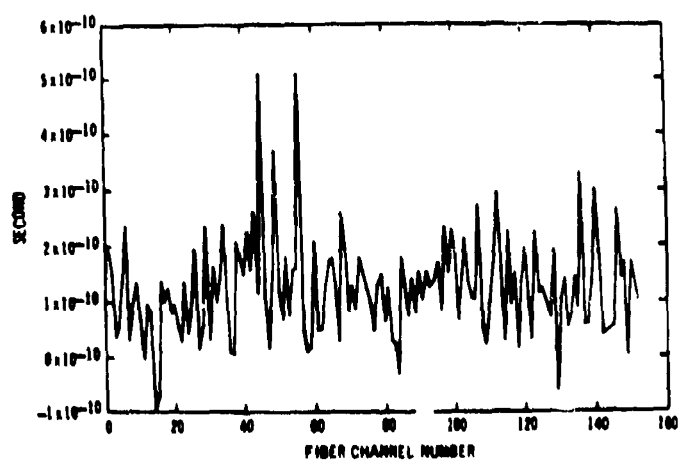

Figure 6 Star coupler common timing.

The imager provided light guiding of the calibration pulses. However, the light at the top of the imager was not uniform. As a consequence, the amplitude calibration of the STREX experiment was performed with 1/8 in. opal glass replacing the imager. After calibration was obtained for all fiber channels, the imager was secured in place. The completed experiment was then monitored for changes only.

Figure 7 shows the relative amplitude of the fiber channels with the opal glass replacing the imager in the system. The lowest amplitudes correspond to some of the multiplexed channels. Excess loss was due to the fiber optic cross couplers and extra Deutsch connectors used. Figure 8 shows the final common timing differences of the fiber optic channels. These results are averages taken over many data runs.

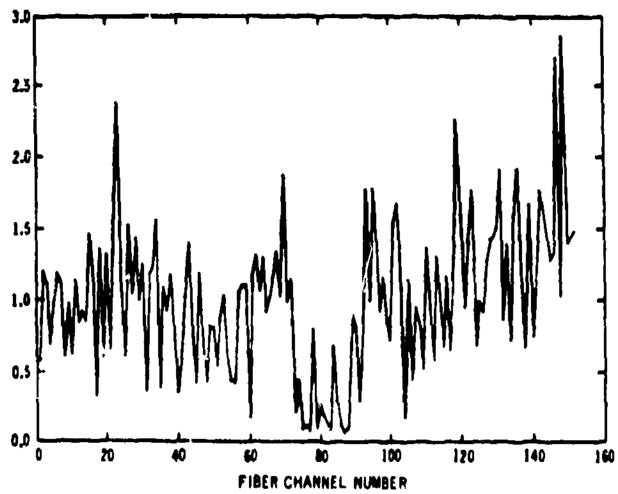

Figure 7. Relative amplitude of fiber channels without images in system.

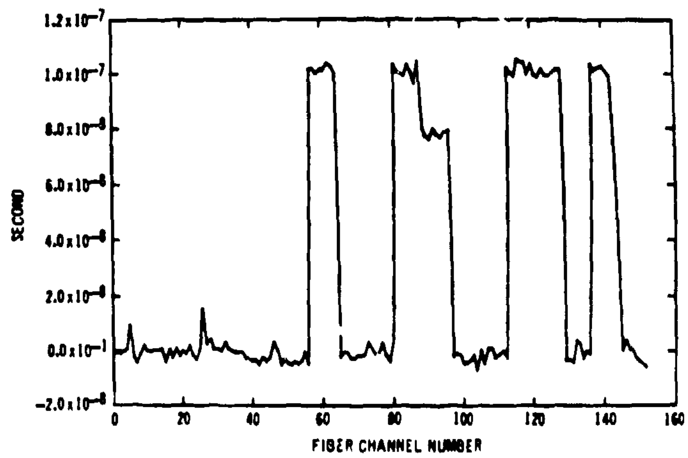

Figure 8. Common timing of fiber channels.

Conclusion

A successful neutron imaging experiment was fielded at the Nevada Test Site. The accuracy of the common timing of the fiber optic channels was better than ±80 psec. The amplitude throughputs of the fiber channels were characterized to an accuracy of ±7%. Many improvements were made in the computer software allowing each fiber channel to be completely characterized in less than 2 minutes.

The star coupler performed very well, providing enough light to drive the recording oscilloscopes. We were thus able to obtain an optical plus electrical common timing of all channels. On future experiments, we would like to perform the optical plus electrical amplitude calibration as well. Other types of star couplers (i.e. 3x8 fibers) have been characterized by our group and fielded successfully. Results on these star couplers will be published later.

References

1. Lyons, P.B., et al., "Fiber Optic Applications in Nuclear Testing," Electro Optics/Laser 79 Conference, Anaheim, California (October 1979).
2. Lyons, P.B., L.D. Looney, S. Lutz, and M.A. Nelson, "Fiber Optic Applications in Plasma Diagnostics," Los Alamos Conference on Optics, SPIE Vol. 190, pp.383-395 (1979).
3. Lyons, P.B., et al., "Applications of Optical Fibers in Nuclear Text Diagnostics," Proceedings of Defense Nuclear Agency (DNA) Meeting, Washington, D.C. (March 1980).
4. Thayer, D.R., et al, "Preparation, Installation, and Calibration of a 152 Fiber Imaging Experiment at the Nevada Test Site," Fiber Optics in Adverse Environments, SPIE Vol. 296 (1981).
5. Malone, R.M., "Golden Egg Fiber Optic Technology," EG&G 1183-5120 Report prepared for Los Alamos National Laboratory under DOE Contract No. DE-AC08-76NV01183 (February 1981).
6. Manning, J.P., and C.E. Gow, "Golden Egg Calibration Report," EG&G 1183-5121 Report prepared for Los Alamos National Laboratory under DOE Contract No. DE-AC08-76NV01183 (March 1981).