FIBER OPTIC SENSING
IN A HIGH EXPLOSIVES ENVIRONMENT

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DISCLAIMER

Abstract :

Fiber optic technology is having a dramatic impact on the high explosives instrumentation field.

This paper presents results in applying fiber optic technology to high explosives experiments, including: detonation light arrival time, shock wave analysis, control lines, and pressure sensing.

In the correct experimental configuration, coaxial and fiber optic cable can provide excellent signals, but the fiber optic cable's characteristics under high explosive shock environments provide superior signal definition. Enhanced frequency response and cost effectiveness provide an excellent basis for future optical sensor development.

Experiments were conducted comparing the signal response of several shock wave time-of-arrival methods i.e., fabricated mechanical switches, piezoelectric pin configurations, and a plastic fiber optic sensor system. The fiber optic signals were better defined and had a faster response. Fiber optic sensors with two different configurations were used as detonation light sensors. The sensors were oriented in a perpendicular and normal configuration with respect to the plane of detonation and multiple non-time-coincident signals were lensed together into a common instrument fiber.

Sensors that are currently being developed or utilized include detonation velocity indicators, nonreactive shock wave time-of-arrival devices in passive and active configurations, planar shock wave sensors, fragment position locators, and high and low free-field blast pressure sensors.

Fiber optic technology is currently having a significant impact on the high explosives instrumentation field. Many applications are being researched by different facilities for general and specific applications. The intent of this report is to share results in developing and evaluating fiber optic systems for high explosives. The results reported here present data from several fiber optic sensor development activities conducted at Sandia National Laboratories' special explosives experimentation facility. The fiber optic applications being pursued include the following:

* shock wave analysis,
* detonation light sensing,
* shock velocity sensing,
* control lines,
* fireset fiducials, and
* pressure sensing.

Conventional techniques of measuring high explosive shock waves in the 1-5 millimeters/microsecond range include: high-speed photography, mechanical switches interfaced with fast responce circuitry (30-50 nanoseconds rise time), piezoelectric crystals coupled to electrical connections (40-50 nanoseconds rise time), and quartz crystal pressure transducers (1-2 microseconds rise time). An effort is underway to replace these devices with fiber optic sensors.

Signals were analyzed on the following instrumentation: LeCroy 9400 Digitizers, Hewlett Packard 50111 Digitizer, Photodyne Model 1500-XP Optical Analyzer (2 nanosecond rise time photodetection circuit), and an experimental photodetector system whose primary component is the Hewlett Packard Model 4207 phototransistor (Figure 1). The protoype circuit was developed to enable signal acqusition for less cost, i.e., $50 for the experimental circuit compared to $1500 for the Model 1500-XP.

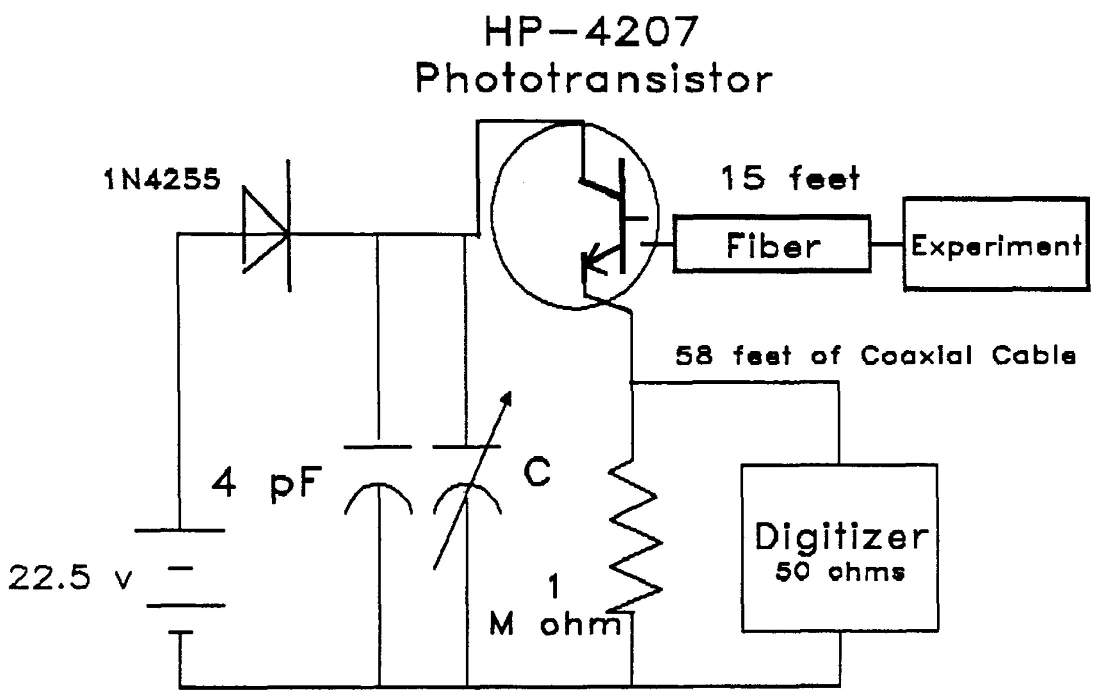


Figure 1. Experimental photodetection circuit

A comparison of performance of the Photodyne detector and the experimental photodetection circuit to a detonation wave generated by a Reynolds Corporation RP-1 detonator is shown in Figure 2. The RP-1 contains 640 milligrams of PETN and RDX explosives and generates a 8.3 millimeters/microsecond detonation wave. Two fifteen foot .030 (in.) solid plastic fiber optic cables were positioned axially with a .100 inch standoff with respect to the detonator output. The Photodyne detector was at a sensitivity level of 1000 millivolts/microwatt, and both systems were driving an impedance of 50 ohms at the digitizers. Resulting waveforms illustrate the experimental photodetection circuit's ability to respond to the light pulse. The experimental circuit has a comparable pulse shape with larger amplitude.

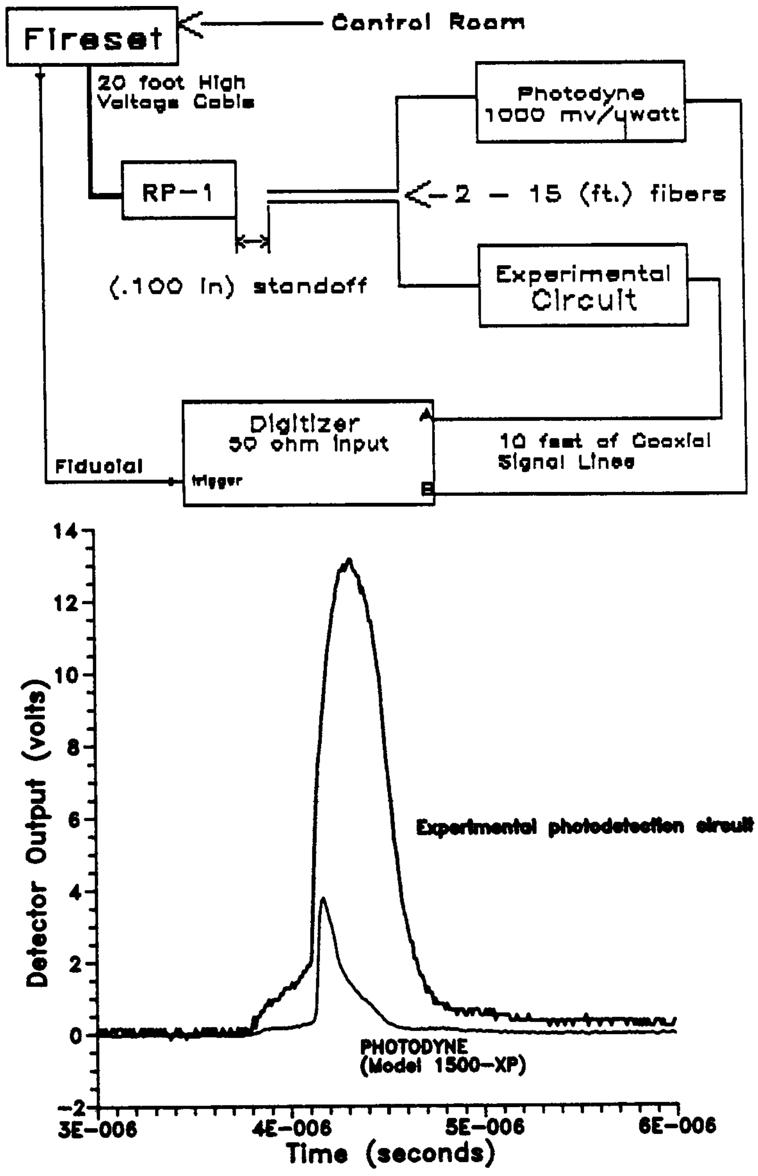
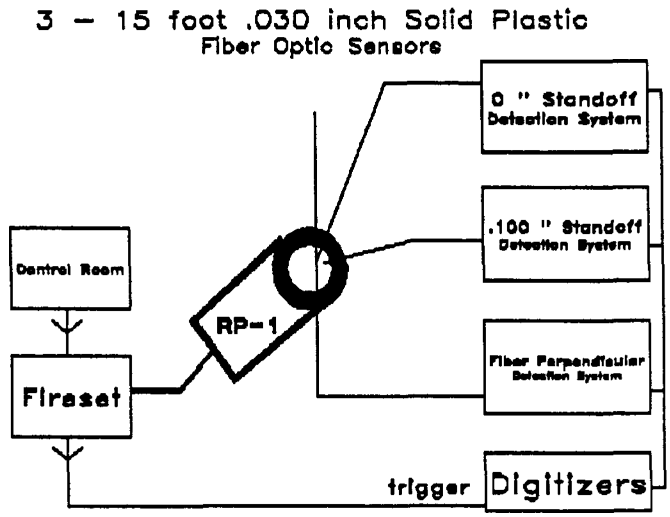


Figure 2. Photodyne versus Experimental Circuit

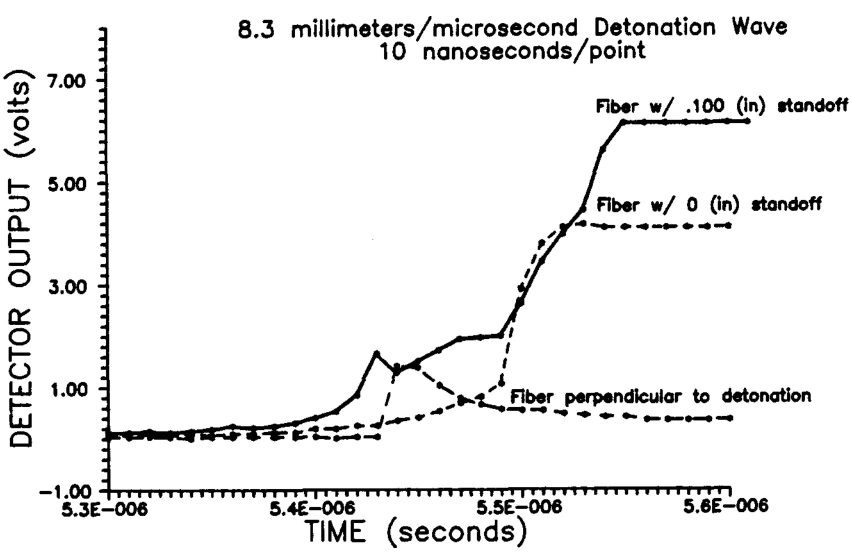
Three other sensor placement configurations were evaluated, utilizing the prototype circuit and 15 feet of plastic fiber optic cable. Placement of the sensors included a 0 and .100 inch standoff position axially and one sensor placed perpendicular to the detonation wave (Figure 3).

Figure 3. Experiment Diagram RP-1 Analysis



The resulting waveforms (Figure 4) illustrate the fiber's response to a detonation wave as a function of sensor location and orientation. The sensor with a .100 inch standoff provides the most amplitude but the perpendicular oriented sensor produced the best rise time. Sensors at 0 and .100 (in.) standoff followed the light thru the output pellet before the detonation front reached the foremost portion of the pellet. This phenomenom is due to the porosity of the explosive material and the ability of the light to leak through. Results have shown that the density and powder porosity do effect signal definition and rise time. High explosives, pyrotechnics, and powders have different detonation wave light characteristics. The capacitors in the experimental photodetection circuit are to allow for long duration light pulses and still maintain a fast rise time. Each experiment was evaluated for the optimum detection system for that particular explosive and application.

Figure 4. Fiber Optic Sensor Placement Comparison Waveforms



The "Shocksensor," a foil switch that uses a capacitive discharge circuit and a passive sensor system, was evaluated for high-velocity, shock wave arrival time. The Shocksensor, originally developed by Bob Benjamin of the Los Alamos National Laboratory, is manufactured by Vitric Technologies of Dundee, MI. The sensor is a 120-micron microshell that is pressurized with argon gas to 5 atmospheres and is optically coupled to a 100-micron silica fiber. The measured shock wave was produced by a commercial plastic explosive known as C-6 Detasheet and was oriented perpendicular to a .125 inch brass plate. A sample response waveform of the Shocksensor is shown in Figure 5. The optical signal was coupled to the experimental photodetection circuit and provided an excellent record with a rise time of 30 nanoseconds.

A conical shaped charge is an explosive assembly that forms a high velocity penetration jet. The shaped charge used for the experiment was the Jet Research Center's Y-1041, which has a metal casing surrounding the PETN explosive and jet liner material. A Shocksensor was mounted at the forefront of the charge to indicate the arrival time of the detonation wave as related to the fireset fiducial. Experiment results (Figure 6) clearly show the shaped charge's function time with respect to the fireset's fiducial. The Shocksensor demonstrated excellent shock wave sensing characteristics. A Shocksensor currently costs ~$60 for a standard sensor with connector, whereas solid plastic fiber optic cable only costs a few cents per several feet.

Figure 5. SHOCKSENSOR Waveform
Microballon pressurized to 5 atmospheres of Argon Gas
C-6 Detasheet Detonation Wave at 6.6 millimeters/microsecond
10 Nanoseconds/point

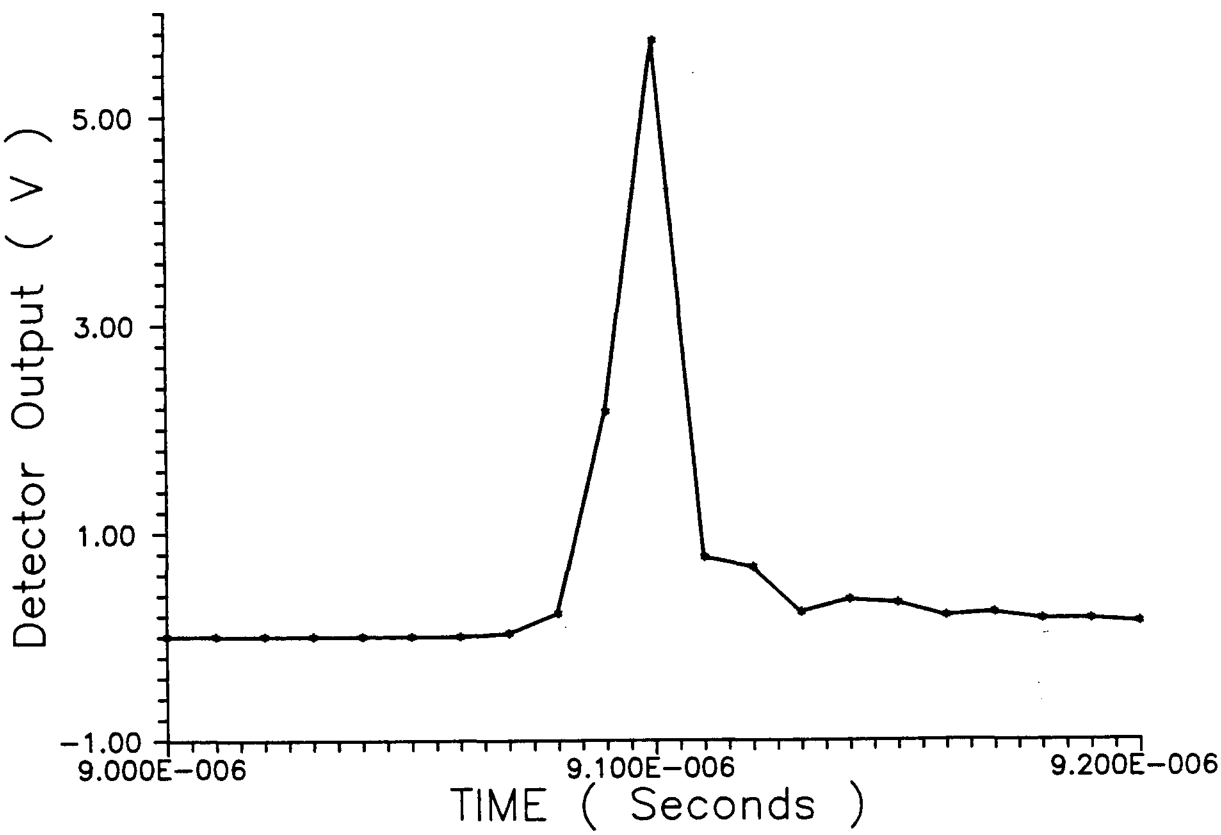
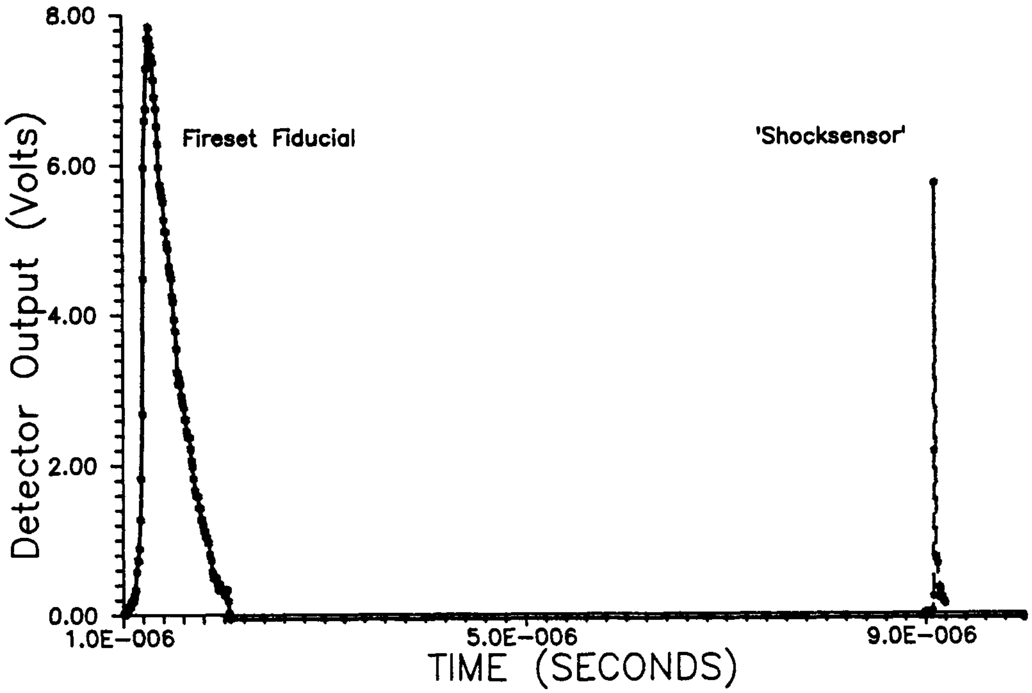


Figure 6

Y-1041 Shaped Charge
Optical Detection of Case Expansion
Theoretical Expansion Velocity 8.3 millimeters/microsecond
10 nanoseconds/point



Shock wave arrival and shaped charge jet penetration time are in fractions of nanoseconds of each other but must be optically detected with different methods due to the fiber's behavior under extreme shock conditions. An ongoing research program is the fiber optic detection of a conical shaped charge jet at a target material with fireset timing correlation. Figure 7 shows the result of a Y-1041 jet penetrating a fiber positioned 30 inches away. Light amplitude is dependent on the jet tip temperature and penetration angle at the fiber. Initial amplitude values are less than desired for long optical data transmission but different experiment configurations and triboilluminescence enhancement of the fiber detection surface area is currently being evaluated for possible signal increases. Experimental results have proven promising for future developmental systems.

Research is underway to evaluate the possibility of a fiber optic conical shaped charge jet position locator (Figure 8). The theoretical assembly would optically provide the jet penetration point at a target material within 1/4-inch accuracy. Previous experiments involving shaped charges demostrated that the light amplitude of the jet is sufficient for prototype hardware and system analysis. Experiments attempted involved a 60-foot plastic fiber optic cable configured in a weave covering a total of 1 inch with no separation between fibers and a detection system on each end of the fiber. The signal with the first light arrival and also the time difference between the two pulses divided by the optical delay of the fiber (1.5 nanoseconds/foot) result in the relative position of jet penetration as a function of digitizer resolution and fiber length.

Figure 7
Resulting Waveform of Y-1041 Conical Shaped Charge
Penetrating a .030 (in) Solid Plastic Fiber
Optic Cable at a distance of 30 (in)
10 nanoseconds/point

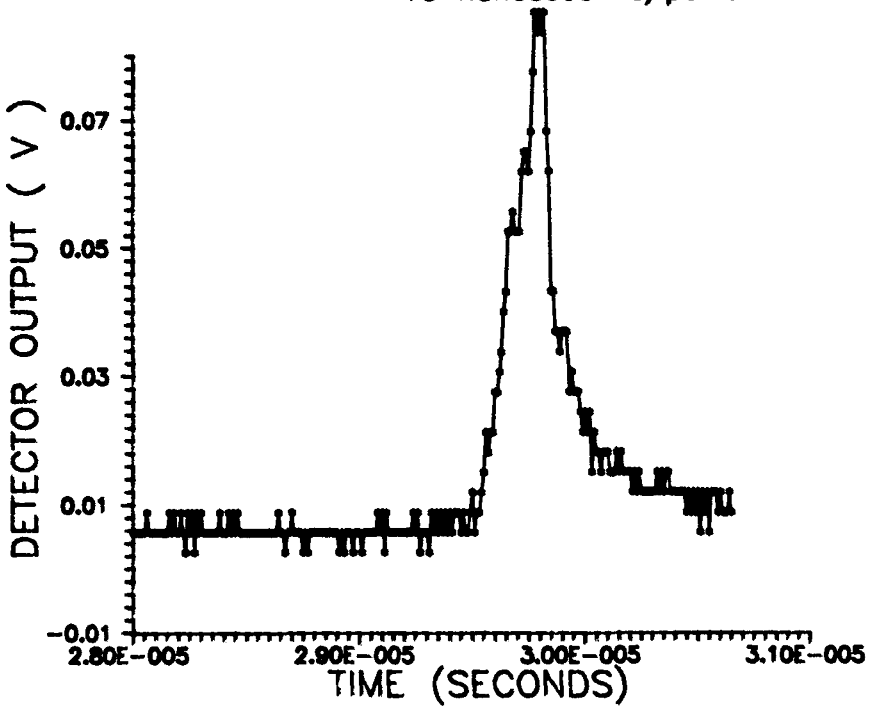


Figure 8
Fiber Optic
Conical Shaped Charge Jet Locator

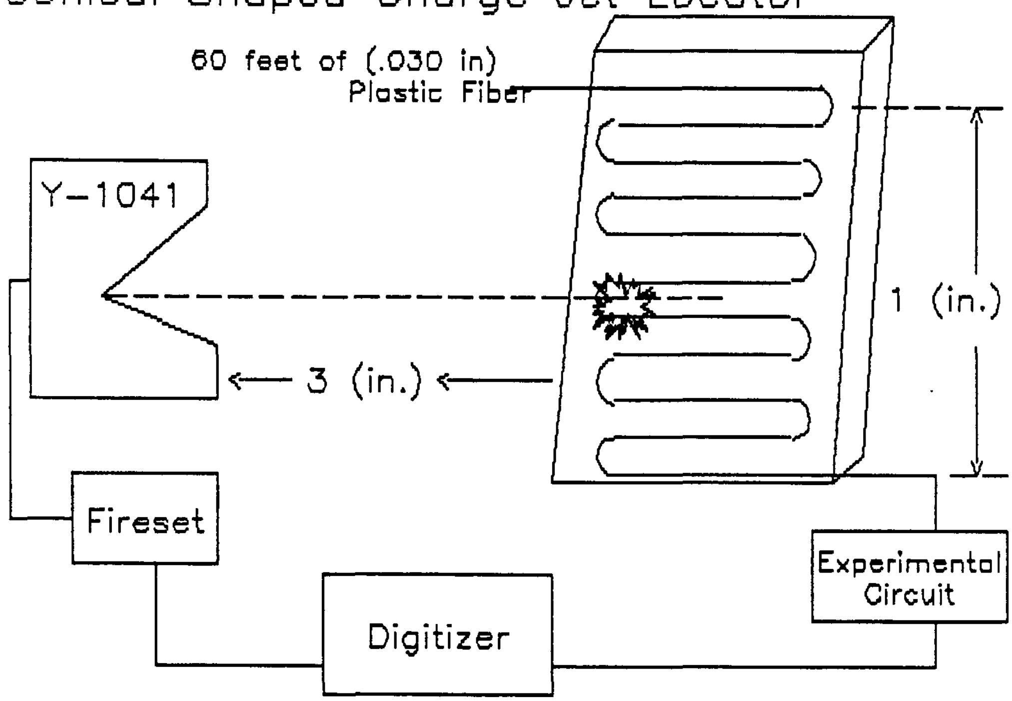
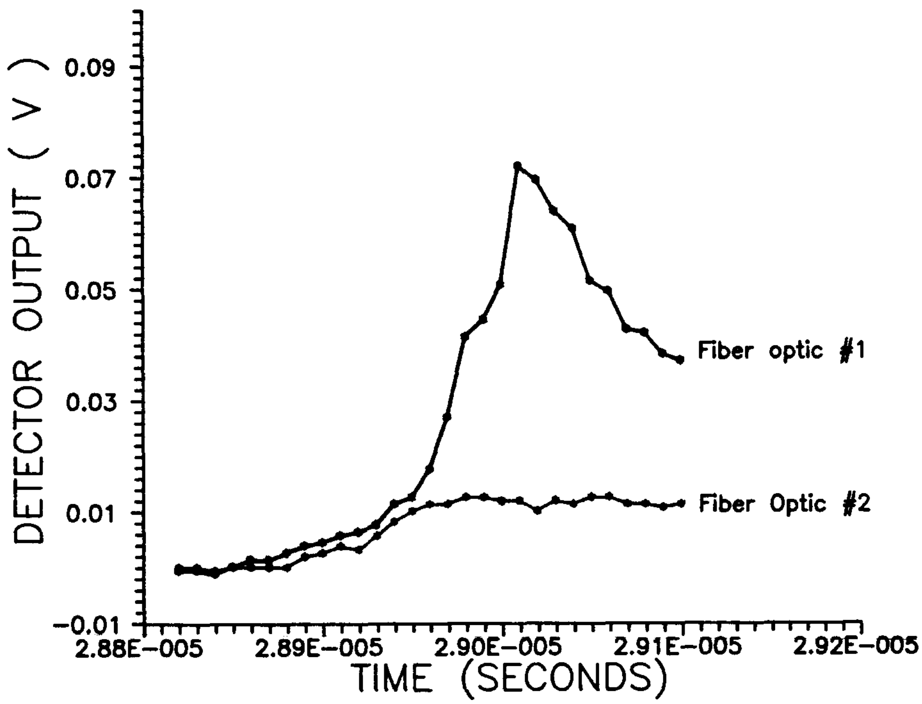


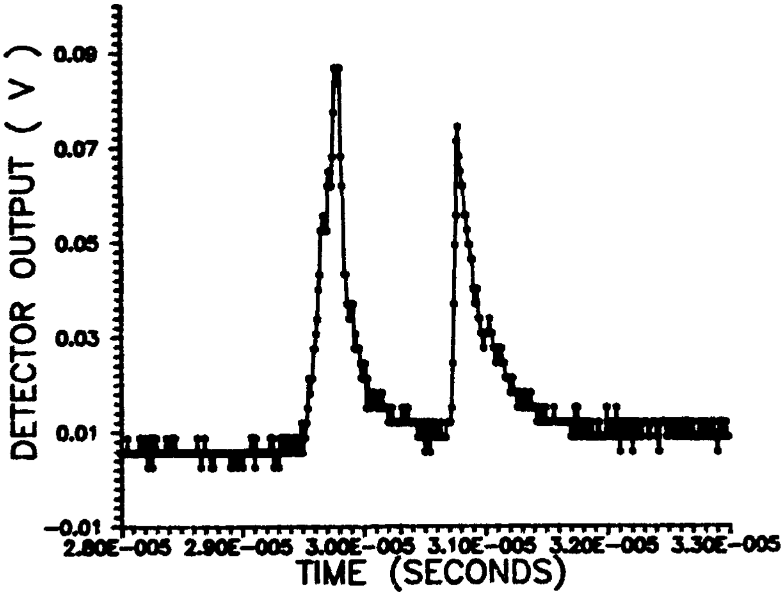
Figure 9 shows the result of a Y-1041 jet penetrating a single fiber array target at 30 inches, with the jet aimed at the center of the array. According to the initial rise of the waveforms, the jet did indeed penetrate the fiber at the array center. One signal is well defined with sufficient amplitude but the second signal requires additional improvement, possibly different experiment configurations, triboilluminescence enhancement of fiber detection area, and/or different fiber optic cables.

Figure 9. Y-1041 Conical Shaped Charge Jet Indicator Experiment
Penetration of a 60 foot .030 (in) Solid Plastic Fiber
Optic Cable at a distance of 30 (in)
10 nanoseconds/point
2 - Experimental Photodetection Circuits as Monitors



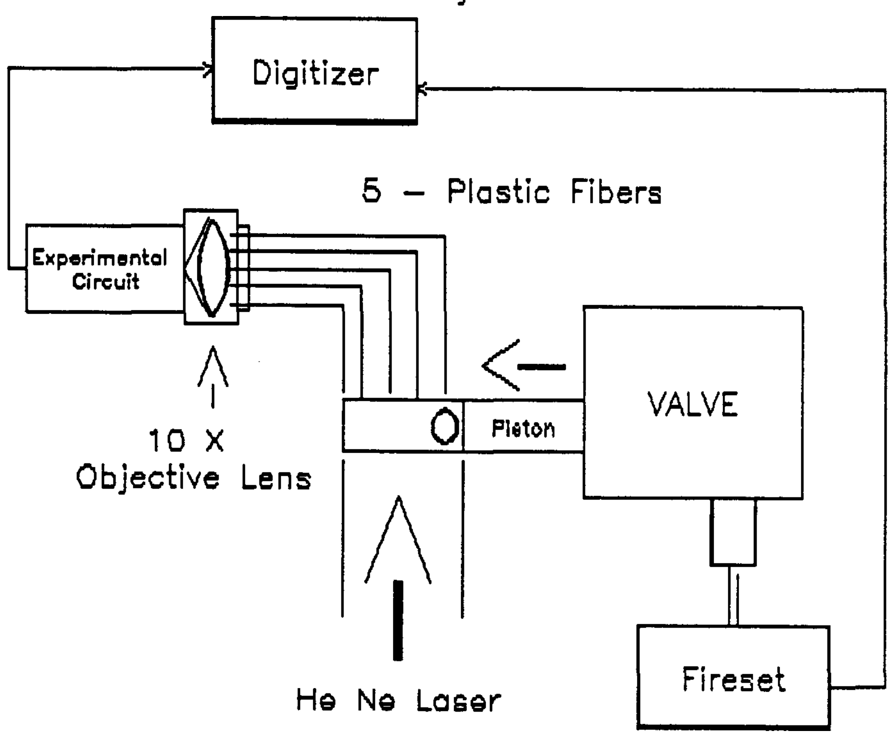
Velocity measurements are a vital function of a high explosives laboratory. A passive fiber optic system was configured and evaluated for shaped charge jet and detonation wave measurements with acceptable success as compared to standard methods. The ends of two 15 foot fibers were positoned a known distance from each other and the other end was optically coupled with lenses to a single photodetection system. A limitation of this configuration was that the discharge time of the detector circuit must be less than the time differential between expected pulses for the given jet velocity, which is determined by sensor placement distances. Figure 10 illustrates the waveform of the previously described experiment configuration. Optical signal definitions are excellent and very comparable with typical foil switch data. Another velocity meaurement technique utilized a 1 milliwatt HeNe laser and fiber optic cable to indicate piston valve velocity (Figure 11).

Figure 10. Y-1041 Conical Shaped Charge Jet Velocity Measurement
Penetrating 2 - .030 (in) Solid Plastic Fiber
Optic Cables at a distance of .175 (in)
10 nanoseconds/point
Resulting Velocity = 5.3 millimeters/microsecond



Individual fibers were coupled to an objective lense, which was in turn coupled to an experimental detection system. The valve had low-density foam with a .030 inch hole and was mounted to the end of the piston. As the piston moved in the direction indicated, the laser resulted in light pulses representing the velocity.

Figure 11. Active Fiber Optic
Valve Velocity
Measurement System

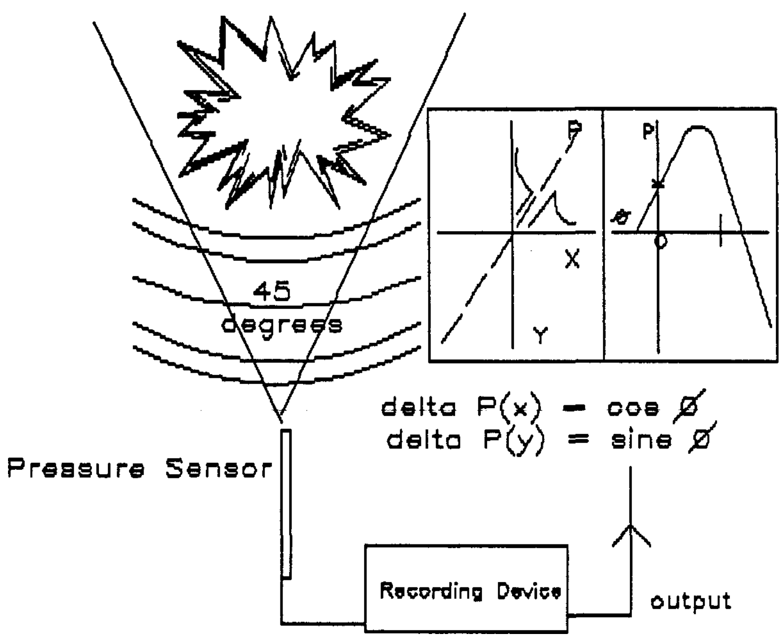


Fireset monitoring is a vital part of any explosive experiment. A program is underway to replace electronic fireset fiducials with fiber optics. The operational characteristics of one prototype production unit is currently being evaluated. Initial results are favorable. Further development and evaluation is underway. Production units should be available within the next year.

Conventional laboratories use short distances of coaxial cable for instrumentation lines with sufficient success, but with fiber optic signals, a solid optical path from the experiment to the recording devices is desirable. Fiber optics enable complete isolation from the arming and firing equipment as well as independent monitoring methods. Several types and sizes of fiber optic cables are being evaluated at the present time for optimum sensor signal transmission.

Free-blast, air pressure measurements are typically done with quartz crystal gauges. A developmental contract, with Geo-Centers Inc., Boston, MA., is in effect for a fiber optic planar pressure transducer. The sensor will incorporate two dimensional crystal stress analysis for representation of vertical pressure amplitude and horizontal location within 45 degrees (Figure 12). Prototype sensors will be experimentally compared against typical methods.

Figure 12. Fiber Optic Planar Pressure Gauge



Fiber optics is a new area of technology providing a wide range of applications and solutions. Explosive experimentation will benefit from the effort of the many different agencies in the fiber optic research field. A concentrated effort to share results must be established, thus benefitting the future development of other optical systems.

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