Conf-780917-1

MASTER

PREPRINT UCRL-81197

Lawrence Livermore Laboratory

FIBER OPTICS IN SHIVA

John Severyn and John Parker

June 1, 1978

This paper was prepared for the WESCON 78 meeting in Los Angeles, California on September 12-14, 1978.

FIBER OPTICS IN SHIVA*

John Severyn and John Parker
University of California Lawrence Livermore Laboratory
P. O. Box 808, Livermore, California 94550

ABSTRACT

"SHIVA is a twenty arm laser which is controlled with a network of fifty computers, interconnected with digital fiber optic links. Three different fiber optic systems employed on the Shiva laser will be described. Two of the systems are for digital communications, one at 9600 baud and the other at 1 megabaud. The third system uses fiber optics to distribute diagnostic triggers with subnanosecond jitter."

INTRODUCTION

Shiva is a twenty-chain Nd glass laser system to be used for nuclear fusion experiments. Control of the system is performed by a network of mini-computers: approximately fifty LSI-11's serve as first level processors performing elementary control and data acquisition functions, four PDP 11/34's serve as intermediate level processors for supervision of data acquisition and control, performance monitoring, and limited data analysis, and a PDP 11/70 which controls common network peripherals, provides data storage and retrieval, and realizes system integration. Communication between the intermediate processors and the front-end processors (FEP) is handled by the software package "Shivanet" which was developed at LLL for control applications.

Because of the large number of laser amplifiers, Pockel cells, and other high voltage, high current devices in the system, there exists an extremely

*Research performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48.

hostile noise environment through which information must be transmitted. Since the integrity of this information is of utmost importance, communications systems utilizing fiber optics were developed, recognizing the inherent advantages in noise immunity, isolation, safety, and security. Fiber optic cables do not radiate, spark, short circuit, or act as antennae; ground loop problems are eliminated, information transfer capacity is greatly increased; and, in the case of many computer systems, expensive hardware and software used for error checking and correction can be eliminated where errors normally tend to occur (causing wasted time in retransmission) due to noise pickup.

We will describe three separate fiber optic systems. The first two are digital communication systems, one operating at speeds up to 5 megabaud using CAMAC hardware and the other at EIA-RS232 speeds of 9600 baud or 19.2 kilobaud. There is some hardware commonality between these two digital systems. The third system is a low jitter diagnostic triggering system using pulsed laser diodes at low repitition rates ($\sim$ 10 Hz). Its purpose is to provide common timing triggers to diagnose laser and target experiments that require subnanosecond delay repeatability.

Optical Transmitter

This unit consists of driver circuitry and a mechanical mount for one of two types of transmitting diodes. A large area surface emitter is heat sinked to the transmitter case for use with bundle fiber cables. This allows the use of an inexpensive diode at 880 nm wavelength for distances of up to 150 meters. For distances exceeding 150 meters a pigtailed high radiance surface or edge emitting diode is used with single fiber cables. The pigtailed LED is terminated in a bulkhead splice optical connector (AMP 530570-1).

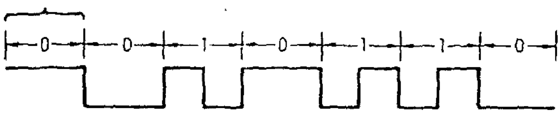
Optical Receiver

The receiver is mounted with an aluminum enclosure to minimize noise coupling from nearby electronics. It utilizes an RCA C30815 hybrid pin diode/transimpedance amplifier at the optical input connector. A pair of transistors provide gain and a low impedance output to a voltage comparator, which outputs TTL levels. The receiver utilizes AC coupling between stages, circumventing all offset and temperature drift problems associated with high gain amplifiers.

CAMAC LINK

The first optical link design is mounted in a single wide (17 mm wide) CAMAC[1] module and designed to operate over the CAMAC bit serial highway. Standard commercial CAMAC modules[2] provide synchronous serial data ports, normally used with twisted wire pairs at TTL levels. The TTL level serial bit stream is converted to an optical equivalent by the transmitter, and back to TTL levels by the receiver. The CAMAC system uses bi-phase encoded data which produces a symmetric waveform with 50% duty cycle Since bandwidth down to DC is not required by this encoding scheme, AC coupling within the receiver is allowable.

Data cell = 1 bit period



Logic 1 = transition within data cell

Logic 0 = no transition within cell

When configured for 2 MHz bandwidth, the receiver has a sensitivity of -55 dbm for a S/N ratio of one. Since the link is essentially a two level pulse amplitude modulated system, an approximation of the error rate is:[3]

$$P_e = \frac{1}{\sqrt{2\pi}} \int_{S/N}^{\infty} e^{-t^2/2}\, dt = \mathrm{erfc}\ (S/N).$$

S/N (db)	P_e Prob. of Error	Time of Error at 10^6 bps
14	5.4×10^{-9}	185 SEC
15	5.4×10^{-11}	5.1 HRS
16	1.7×10^{-13}	70 DAYS
17	1.1×10^{-16}	279 YR
18	1.2×10^{-20}	10^6 YR
19	1.1×10^{-25}	10^{11} YR

The above table shows that a 17 db S/N ratio should be maintained at the receiver at 10^6 bits per second.

Maximum transmission distance at 1 MHz is based on maintaining at least -38 dbm optical power at the receiver. The single fiber version of the transmitter couples a minimum of -10 dbm (100 μW) at 820 nm into fiber such as Valtec PC-10 (15 db/km attenuation) resulting in a total system loss of 28 db. This provides satisfactory system performance at distances exceeding one kilometer and provides a large power margin for splices using inexpensive plastic connectors (1-2 db/splice).

EIA RS-232 LINK

The second optical link performs the functions of transmission and reception of signals over a pair of fiber optic cables and the I/O of serial data to a local device in EIA format. System requirements included fiber cable transmission length of up to 150 m and baud rates up to 9600, although the design criterium of transmission at 19.2 KB has been met. With the use of single fiber cables and high radiance LED's, transmission over distances greater than 1 km is easily realized. As illustrated in Figure 1, fiber optic links are used between the central control area and each of the alignment control subsystems, in addition to sending timing signals over long distances between subsystems.

The optical transmitter and receiver used in this design were identical to that of the first; however, FSK encoding was used providing increased signal integrity and the necessary modulation for the AC coupled receiver.

The hostile noise environment in which the system was to be operated warranted a coding scheme that would provide a realization of system error-rate requirements. If only additive noise is considered, phase-shift keying (PSK) can be shown to be optimum.[4] However, PSK requires phase synchronization with the carrier, a problem compounded by the distance over which transmission must occur. Although this could be accomplished by either transmitting a pilot carrier superimposed on the data stream to synchronize the receiver local oscillator or by using a PLL to lock on the data stream at the receiver to drive the phase difference to zero, it was decided to use a frequency-shift keying (FSK) scheme instead. Synchronous detection is thus easily accomplished and the decoding circuitry is minimized.

Operation

Serial data (EIA) from a local device is first converted to TTL at the FSK Encoder-Decoder board. A local oscillator is then gated with the data

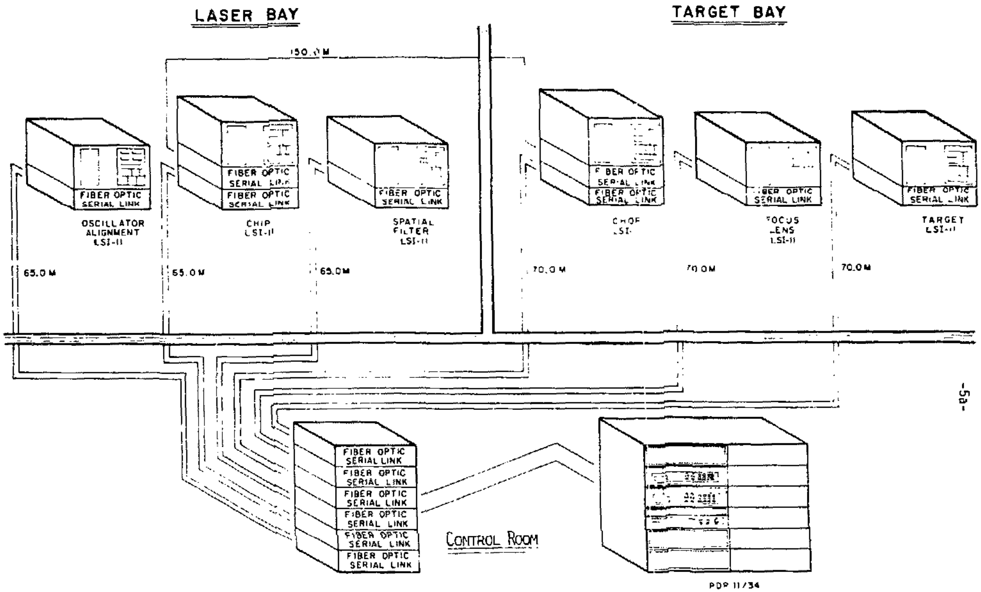


FIGURE 1. EIA LINK ARCHITECTURE

producing a 1.23 MHz square-wave for a "1" state or a 308 KHz signal for a "0" state. It should be noted that this scheme is not only baud-rate independent, but also follows the criterium that the lowest carrier frequency be at least ten times the maximum baud-rate (19.2 KB) for reliable digital information transmission.

The LED in the transmitter is then switched at one of the aforementioned data-dependent frequencies.

At the opposite end of the fiber optic cable, a receiver unit converts the modulated low-light level signal to TTL levels, after which it is sent to the local FSK Encoder-Decoder.

Signal processing is by means of a threshold-crossing detector, a digital equivalent of the zero-crossing detector popular in analog FM. A block diagram of the circuit is shown in Figure 2. The dual-edge detector is a convenient method of effectively doubling the signal frequency so that conversion time is halved. With a local 615 KHz signal being similarly processed, each threshold crossing is counted and a decision made on the carry bits of the counters. An input signal of 1.23 MHz (1 state), for example, will obviously have twice as many threshold crossings as one of 615 KHz; consequently, counter B will reach its terminal count first and the output will be reset.

Subsequently, the result is converted from TTL to EIA format for input to the local device.

System Analysis

An analysis of the Fiber Optic Serial Link must include a characterization of receiver performance, end-coupling effects, fiber cable losses, coding scheme and data error rate.

THRESHOLD CROSSING DETECTOR

FSK ENCODER-DECODER

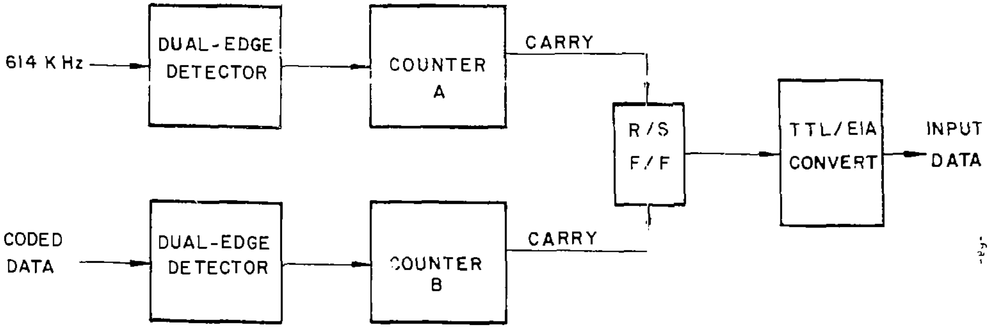


FIGURE 2.
THRESHOLD CROSSING DETECTOR FSK ENCODER DECODER

Photodetector performance can be described in terms of noise-equivalent-power (NEP) which should be minimized so that the lowest possible level of radiant flux can be detected. The RCA C30815 photodetector has a maximum NEP of $6(10^{-12})W/\sqrt{Hz}$. Since a 10K bias resistor is used external to the module, the internal load resistor is 14K and the junction capacitance is $\sim$ 3 pF, the value of incident flux that gives a signal equal to the noise signal is

$$N = [6(10^{-12})W/\sqrt{Hz}]\ [(1.55)(10^{3})\sqrt{Hz}]$$
$$= 9.3 \text{ nW.}$$

Measurements to determine the flux corresponding to a unity S/N ratio yielded values on the order of 5-10 nW.

Coupling from a large surface area transmitter LED was analyzed by using a length of fiber cable sufficiently short that its attenuation was negligible. Since the power output of the LED was known for a given drive current, the measured output of the cable gave a good approximation to the input coupling loss. Taking into account the responsivity of the power meter, the input coupling loss was found to be

$$\text{Input Loss (dB)} = \left| 10 \log \frac{23.3(10^{-6})}{22.5(10^{-3})} \right|$$
$$= 29.8 \text{ dB}$$

This is a typical value for bundle fiber cables and low radiance LED's. Input loss for high radiance LED's and single fiber cables is significantly lower at the expense of increased transmitter cost ($\sim$ 10X).

For a cable length of 70 m (typical in the present system), the attenuation is

$$\text{Cable Loss (dB)} = (.06\ \text{dB/m})(70\ \text{m}) = 4.2\ \text{dB}.$$

Finally, considering that there is, at most, a 3 dB loss in coupling from fiber cable to the photodetector, the flux incident on the receiver for an LED average power of 22.5 (10^{-3})W is

$$S_R = [\text{LED OUTPUT}]\ 10^{(\text{total loss in dB}/10)}$$
$$= [22.5(10^{-3})]\ 10^{-3.7} = 4.5\ \mu\text{W}.$$

The signal-to-noise ratio, based on the given NEP, is then

$$S/N(\text{dB}) = 10 \log \frac{4.5(10^{-6})}{9.3(10^{-9})} = 26.8\ \text{dB}.$$

As mentioned previously, for reliable FSK transmission, the carrier is generally taken to be at least ten times the data rate. Although the system design reflects this premise and, indeed, this design may be used between any EIA format devices, the total system response is effectively band-limited by the "integrating time" of the serial interface UART. Since the UART clock frequency is 153.6 KHz @ 9.6 KB and data sampling occurs after a minimum of 7.5 clock cycles, the system bandwidth is effectively 20.5 KHz.

Assuming, then, a two-level pulse amplitude modulated signal, the probability of error may be, as before, approximated by,

$$P_e\ (S/N) = \text{erfc}\ (S/N).$$

An "error free" link is consequently realized for a $S/N \sim 15$ corresponding to an error rate e(t) of 10.4 days.

Comparison with the actual system S/N of 26.8 dB indicates an apparent wide margin of reliable system operation. It should be noted that performance is gradually degraded as transmitter diode output decreases with extended life and, in fact, can be considerably reduced by such seemingly harmless acts as numerous removal and re-connection of fiber optic cable connections.

TARGET DIAGNOSTICS TRIGGER SYSTEM

Target diagnostics typically consist of inputs from 100-200 sensors that provide electrical and optical data during the target implosion. Proper operation cannot be assured unless the data acquisition system is accurately synchronized with the operation of the laser. Two major subsystems control this timing. The first will be called the "Slow" Trigger System and encompasses all pre-shot times up through zero time. Zero time is defined as the instant the main laser beams hit the target. The "Slow" Trigger System provides jitter of $< 1\ \mu s$ and is derived from the power conditioning processor (LSI-11) that controls the laser operation. The second trigger system provides low jitter (< 1 ns) triggers to target room devices during the time interval of minus 250 nS through zero time. This is the "Fast" Trigger System and derives its basic time reference from the Shiva Oscillator and Switchout (see Figure 3). The oscillator is the source of the optical "seed" pulse (50 pS to 3 nS width) that is amplified by the twenty arm laser.

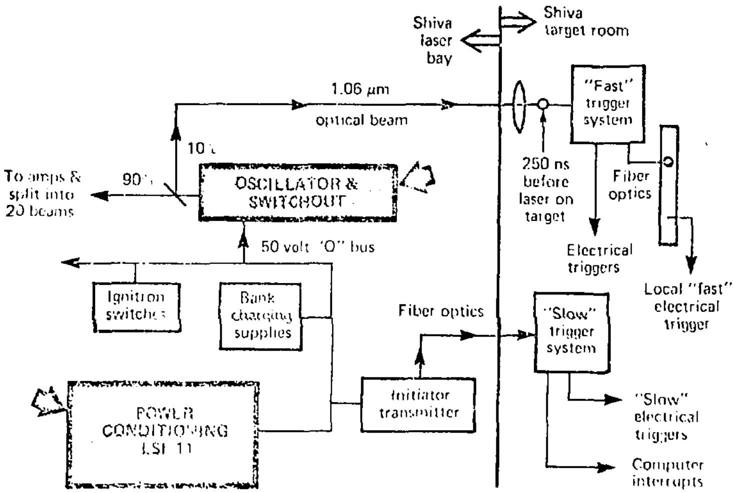


Figure 3. Target Room Timing Sources

"Slow" Trigger Subsystem

The target room "Slow" Triggers are derived from a clock controlled LSI-11 processor that controls the power conditioning components of the laser. An interface, called the Initiator Transmitter, frequency encodes a timing bit pattern and sends an optical equivalent to the target room over fiber optic cable (Figure 4). This allows eight timing bits to be sent over a single fiber. The optical transmitter is identical to the units in the CAMAC and EIA links.

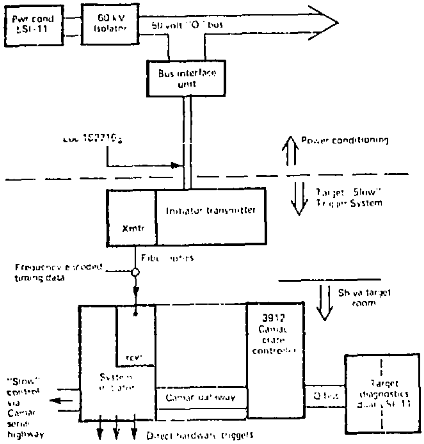


Figure 4. Slow Trigger System

In the target room, another CAMAC module, the System Initiator, decodes the optical timing data into front panel electrical triggers and appropriate interrupt signals to the target diagnostics LSI-11. Frequency discriminators within the System Initiator limit the response time of the system to ~ 6 µS.

"Fast" Trigger System

The Trigger System within the Shiva target room is designed to provide stable timing triggers to various devices, including remote diagnostics packages scattered throughout the target room. The trigger fanout uses pulsed laser diodes at a maximum repetition rate of 10 Hz. In addition to providing fast risetime triggers, the trigger system must not violate the single point ground constraints, and perhaps just as important, it must not provide an electrical path that might cause undesirable coupling between target experiments.

The target room Trigger System receives a small fraction of the Shiva Oscillator Pulse via a beam path that is parallel to the main laser beam paths, but does not traverse the pulse shaping, path equalization, and multiple beam splitting optics required for the twenty main laser beams. Consequently the trigger beam arrives in the target room more than 250 ns before the main beams, allowing time for level discrimination and fanout before triggering the instrumentation systems.

When the trigger beam enters the target room it impinges on two PIN photodiodes (Figure 5). A fast response diode (MRD-500) provides the main timing signal for the distribution system. The position sensing diode (PIN-SC/25) provides x-y position error information to allow closed loop centering control of the trigger beam.

Beam Position Sensing

Beam position is sensed by a lateral-effect PIN photodiode. Its four x-y outputs are separately integrated by a Lecroy 2249A CAMAC charge integrating A/D converter. This module is mounted in a CAMAC crate in an adjacent rack, complete with crate controller, LSI-11 microcomputer and a visible LED x-y display. The LSI-11 provides computation and control capability to allow true beam position calculation, independent of the optical signal intensity. Its software is placed in read-only-memory to allow operation independent of other computers in the network. The position errors are sent back to the laser bay over an EIA optical link, and used to control stepping motors on the two-axis trigger beam turning mirror (Figure 6).

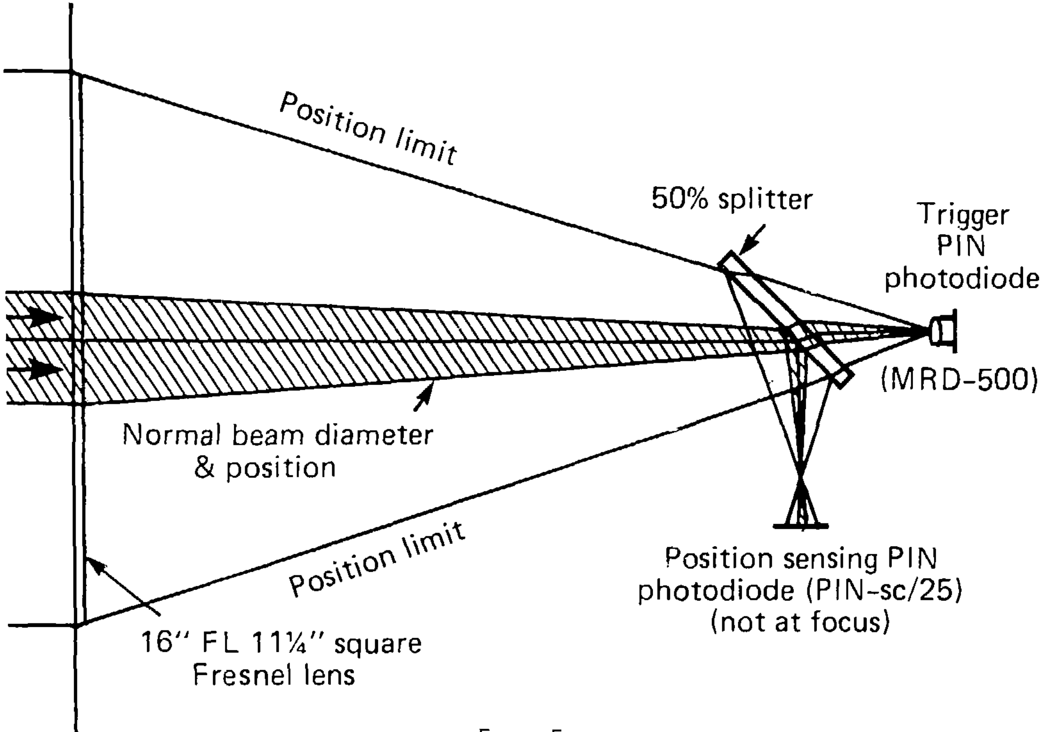


FIGURE 5.
TRIGGER BOX COMPONENTS

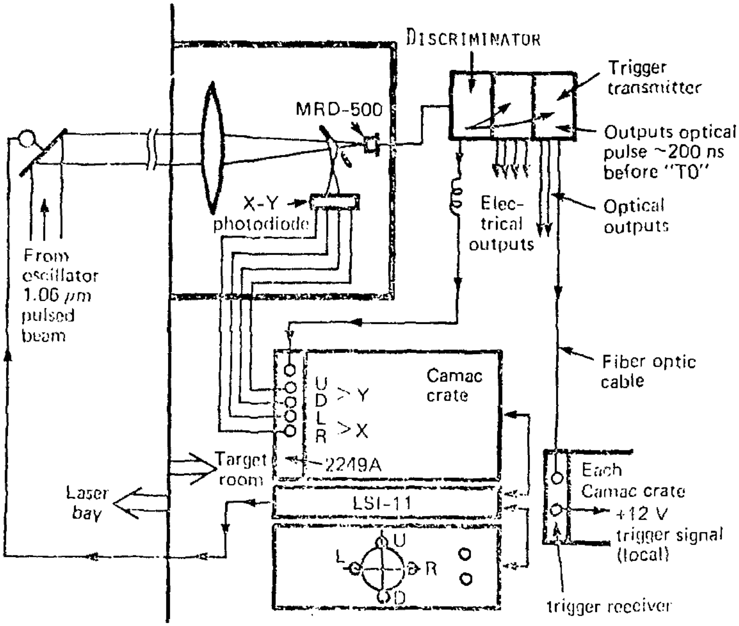


Figure 6. Fast Trigger System

Trigger Transmitter

The trigger photodiode (MRD-500) signal is amplitude discriminated and then distributed in two formats, a fast rise electrical or a fast optical pulse. The electrical pulse is used primarily for streak camera triggers where adjustable delay in an optical cable is cumbersome. The trigger transmitter provides eight optical triggers to fiber optic cables for distribution to all other target diagnostics. This unit emits a 40 ns (FWHM) optical pulse at 850 nm wavelength. The emitters are GaAlAs laser diodes with a size of

630 x 32 μm. The diodes are mounted in commercial headers behind a glass window, 1.4 mm from the tip of a terminated optical fiber or bundle of fibers. The beam divergence of the source is typically 13x26 degrees. When utilized with Galite 3000/19 fiber, a user can expect a 20 mW optical pulse to be launched into the optical cable. Since the receiver requires approximately 1 mW to trigger, a total of 20 db of cable loss may be allowed.

Trigger Receiver

This unit is designed in a single width (17 mm wide) CAMAC module. It accepts an optical input via a fiber optic cable and produces an electrical equivalent + 12 V pulse used for triggering isolated diagnostic equipment. The optical detector is another MRD-500 silicon PIN photodiode with 10% sensitivity points of 0.3 μm and 1.1 μm which closely matches the transmitter wavelength (0.85 μm). A pulsed input of at least 1 mW peak power (at 0.85 μm) is required to exceed the internal fixed discriminator threshold.

Three separate electrical outputs are available:

1. + 12 V from an optical input or CAMAC command
2. + 12 V from an output input
3. + 12 V from a CAMAC command

Normally output #1 will be utilized as it provides the capability of triggering via an optical input or to baseline the system through a CAMAC command. Each of the three outputs is capable of driving a 50 Ω load.

It might be noted that although fiber optic cable provides excellent electrical isolation, the user must be aware of its delay characteristics.

Most optical glasses have an index of refraction of approximately 1.5 ($n = 1.5$). This means a light ray that passes through the fiber exactly on axis, travels at $3 \times 10^8/n$ meters/second. Since this system uses multimode optical fiber, most light rays make multiple reflections off the fiber interior surface. This means that the velocity of propagation on most optical cables is nearer to 1.5×10^8 meters per second.

Since the main laser beam velocity through air is the speed of light and the optical trigger cable propagates the trigger pulse at approximately one-half the speed of light, care must be taken to insure sufficient pre-shot triggering time for each experimental package. The Trigger Transmitter outputs an optical pulse ≈ 200 ns before the main beams hit the target; therefore an optical pulse will exit a 30 meter cable at the same instant the target is hit by the main beams. At the present time this distance is sufficient to reach all points within the target room.

We have described just three systems using fiber optics within the Shiva Laser Fusion Facility. Practical fiber optic applications have allowed the computer based alignment, control and diagnostic systems to operate in a hostile electrical noise environment, achieving system isolation and integrity not possible with metallic wire communications.

REFERENCES

1. CAMAC Standards Manual(s) IEEE Std(s) 583-1975, 596-1976, 595-1976, 683-1976, IEEE New York, N.Y.

2. Instruction Manual, Model 3932 U-Port Adapter, Kinetic Systems Corp, Lockport, Ill.

3. Principles of Data Communication, Lucky, Salz and Weldon, Pgs. 55, 56. McGraw-Hill 1968.

4. Schwartz, M., Information Transmission, Modulation and Noise, McGraw-Hill, 1970.