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FIBER OPTICS AND MICROPROCESSORS:
A CONTROL-SYSTEM SOLUTION FOR THE
LASER FUSION ENVIRONMENT*

by

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ABSTRACT

The use of fiber optics and microprocessors in a distributed computer control system for a 100-kJ CO₂ laser fusion facility is described. Gas-laser control systems must operate in an environment in which megavolt Marx circuits generate megampere discharges in the laser amplifiers, with attendant high electromagnetic fields. By linking the distributed controls with fiber optics we minimize the adverse effect of these fields on the hard-wired controls and gain the additional advantage of ground isolation. Our fiber-optic subsystems and interfaces include low-error-rate digital communication links between computers; nanosecond timing and trigger links; fiber-optic parameter monitors with dc-to-10 MHz bandwidths; binary fiber-optic power control for valves, motors, and contactors; and binary fiber-optic status interfaces to monitor the system response to control outputs.

INTRODUCTION: THE LASER FUSION ENVIRONMENT

Antares, a CO₂ laser system designed for a power output between 100 and 200 TW, about 10 times higher than that of any other present laser system, is being built for inertial confinement fusion research at the Los Alamos Scientific Laboratory. A cross section of the laser facility, with the cylindrical laser amplifiers and pulse power supplies in the Laser Hall, is shown in Fig 1. These power supplies pump the preionized CO₂:N₂ gas mixture, by direct discharge through the gas, to high inversion levels. An initial low-power laser pulse, generated by an oscillator and subsequently split into 72 beams, then passes through the pumped gas mixture in the power amplifiers, extracts the stored light energy, and directs this energy through evacuated beam tubes to the target chamber in the thick-walled Target Building.

Most of the laser control equipment is located in the Laser Hall near the pulse power supplies and the power amplifiers. The power supplies, power cables, and power amplifiers are the major sources of electromagnetic interference (EMI). The pulse power supplies are 1.2-MV Marx circuits that discharge into the power amplifiers with a total peak current of 5 MA. The level of magnetic and electric fields at various places in the facility, resulting from this discharge, range from 20 to 1200 A/m and from 10 to 500 V/m, respectively. Some control equipment penetrates the pulse power supply tanks or the power-amplifier shells and is exposed to even higher fields: up to 50 kA/m and 1.8 MV/m. This interference is broad-band, with peaks at 83 kHz, 140 kHz, and 1.5 MHz; the result of pulsed discharges. In addition, the pumping discharge causes parasitic currents and displacement currents of 1 kA to flow in the power supply tanks and in the ground mesh embedded in the Laser Hall floor. The large size of the facility, coupled with the high-frequency/high-level EMI, precludes the use of a single-point grounding system. We are, therefore, building a distributed grounding system, which requires the use of fiber optics between the separate distributed control elements. Fiber optics are also required to prevent conducted interference and ground loops from penetrating the shielded enclosures containing the control elements.

DISTRIBUTED CONTROL

In our control system the control elements are microprocessors, located throughout the facility, which can be programmed to concentrate data and to perform low-level control functions (Fig. 2). This use of microprocessors eliminates the need to run thousands of control input and output fiber-optic channels to the main control room. The microcomputers operate as slaves in an assigned task hierarchy. An HP-3000 minicomputer, the control-system master computer, communicates over serial asynchronous ASCII fiber-optic channels to the several hundred microcomputers, which are programmed to handle ASCII communication and one or a few real-time tasks. When the master wants a task executed, e.g., vacuum pump sequencing, it can send a command over the fiber-optic communication link to a microcomputer which will then interact with the laser system through many parallel fiber-optic links. This method of control works well in a distributed ground environment with fiber-optic interfaces which eliminate all or most of the conductive connections passing through the microcomputer shielding enclosure. Where wires must be used for control, the microcomputer can be located near the control point to minimize the wire length and thus the exposure to the EMI.

FIBER-OPTIC INTERFACING

Interfacing with fiber optics provides several advantages in a large project with thousands of interface points and data channels ranging from simple limit switch indications to megahertz analog data. First, most control inputs and outputs can be simply wired with two twisted leads, with no attention to shielding or grounding; all the noise picked up by this wiring can be rejected by the fiber-optic interface and by the nonconductive fiber-optic connection to the computer. Second, powerful microcomputers can be used safely to unload the main computer by distributing the control tasks. The microcomputers can be isolated from the noise by good shielding that is not compromised by fiber-optic inputs and outputs. Third, the interface with fiber-optic cabling is clean, which enhances control-system integrity. Control subsystems can thus be tested separately, without fear that performance will be degraded due to new noise-conductive paths when the subsystems are integrated into the overall control system. This independence of subsystems allows better balancing of the work load during assembly, checkout, and integration. Fourth, a modular system is created by combining fiber optics and microprocessors; several general-purpose fiber-optic interfaces can be constructed, with the differentiation between input or output characteristics being a function of microcomputer programming, not a function of a particular hardware set.

An example of fiber-optic interfacing is shown schematically in Fig. 3. The microcomputer is executing a task which calls for control of the pressure in a tank. The desired pressure level is a parameter that can be transmitted to the microcomputer from the supervisory computer via the fiber-optic communication link. The microprocessor controls the tank filling valve through parallel input/output ports. The fiber-optic binary transmitter converts the output logic signals to light, which are routed through the shielding by fiber-optic cables in a waveguide beyond cutoff. The light signals activate circuits on the fiber-optic control panel to apply power to the solenoid valve. Status switches for each valve position then relay the valve actuation information back to the microcomputer. The binary status panel converts the status information to light signals that are conducted through the waveguide into the microcomputer, where the fiber-optic binary receiver converts the status to logic signals and passes the data to the microprocessor. The status panel has a built-in capability for testing the integrity of the status data. Thus, the microcomputer can both initiate an action and check its successful completion.

Pressure information is acquired from an isolated parameter monitor. The output of a pressure transducer is wired a short distance to the monitor circuit, where the analog information is converted to frequency data by a voltage-to-frequency converter and then to a pulse-modulated light signal by a light-emitting diode (LED). A fiber-optic cable transmits the information through the microcomputer shield to a receiver circuit, which converts the data back to logic signals. The pressure information is recovered from the frequency information by using the microprocessor programmable timer. A local display/control panel is used with some systems. The display can be a graphic representation, with either some or all the status and parameter information displayed.

The interface hardware with its parallel input and output boards is shown in Fig. 4. The control and status panels can be mounted in junction boxes, exposed to the EMI, and are simply wired into the control system by means of terminal barrier blocks. By using these fiber-optic interfaces, we eliminate all the noise-carrying signal wires which would otherwise enter the shielded microcomputer enclosure.

FIBER-OPTIC INTERFACES

General

We will now describe the general-purpose fiber-optic interfaces that have been developed for the Antares laser control system. The common characteristics are high reliability, cost effectiveness, and noncritical assembly. High reliability is the result of design goals that fit the sometimes wide variation in electro-optic components and that incorporate, where possible, built-in performance tests or indicators. Cost effectiveness is achieved with the use of low-cost fiber-optic connectors, fibers, electro-optic components, and a minimal assembly effort. Non-critical assembly is obtained by using pigtailed devices and splices rather than device connectors, for better control of critical fiber-to-device connections.

Digital Communication Interface

The digital communication interface has been designed for low-error digital asynchronous communication over a fiber length of 100 m. Digital bit rates of up to 2 MHz can be accommodated. The measured bit error rate is less than one in 10^{10} bits. The fiber-optic transceiver schematic is shown in Fig. 5. The transmitter consists of a pigtailed 670-nm LED driven by a standard peripheral power driver circuit. The driver circuit switches ~ 50 mA to drive the LED at an output level of $\sim 36 \mu\text{W}$. The LED is connected to a rugged silica fiber cable with a plastic splice connection. The variation in this connection is less than $0.5 \mu\text{W}$.

over many matings when a 400- μm plastic fiber is used for the pig-tail and a 200- μm fiber is used in the cable. The silica fiber cable provides a fairly low attenuation of ~ 50 dB/km at 670-nm. An added advantage of using visible light is easy monitoring of system operation by eye.

The receiver is a PIN diode-amplifier integrated circuit coupled to a comparator. The typical light power input to this circuit exceeds $0.5\mu\text{W}$. The diode amplifier is wired in a single-ended transimpedance connection to provide high responsivity, high speed, and dynamically stable operation. The comparator converts the tens-of-millivolts output of the amplifier to a logic signal while rejecting the amplifier noise and thermal drift.

Binary Control Interface

The binary control interface consists of a pair of printed wiring boards that provide 18 parallel output channels (Fig. 6). The transmitter board connects directly to a parallel digital output port of the microcomputer and converts the logic outputs to light signals. The transmitter consists of a peripheral power driver and a long-life incandescent bulb mounted in a plastic fiber-optic device connector. The control signals are slow, 200 Hz, and an expensive LED, therefore, is not required. The incandescent black-body radiation is effectively transmitted over distances of 30 m by the fiber cable.

Two kinds of control receiver circuits are being used. The simplest is a PIN diode in the photovoltaic mode connected to the input of a slow comparator. Because of its slow response, the comparator is insensitive to the EMI produced during laser operation. The comparator drives a relay with contacts wired to a terminal barrier strip which becomes the interface point for ac or dc control circuits.

The other control circuit is a fiber-optic-operated solid state relay (SSR) that can switch 8-A, 220-V loads. It is a conventional SSR circuit, triggered by the light from a fiber-optic input rather than by a low-level electrical input. The trigger circuit is powered from the line-load circuit and has a sensitivity of $\sim 1\mu\text{W}$. Back-to-back silicon controlled rectifiers (SCR) are used for the switch because of their high transient immunity. By adding snubber networks across the SCRs, this circuit can be made totally immune to transients.

Binary Status Interfaces

The binary status interfaces are used to acquire slow on-off information from limit switches, status switches, thermal switches, and rotation monitors.

The status switches are wired to a terminal barrier strip on the status-transmitter panel (Fig. 7). A switch closure lights an incandescent bulb mounted in a plastic fiber-optic device connector. The slow response of the bulb rejects the EMI from the operating laser. The light signal is carried through the microcomputer shield by fiber-optic cable. The fiber output is converted to logic signals by a receiver consisting of a photodiode on the input of a slow comparator.

The binary status panel has a built-in test function: Two fiber-optic control relays are wired so that they can either short all status inputs or disconnect the lamp power supply to test all the input channels; by using this circuit the microcomputer can test the integrity of the interface from transmitter through fiber cable, receiver, and input port.

Timing and Trigger Interfaces

These interfaces are used to transmit timing reference pulses to controllers that must sequence the firing of the laser. They are also used to trigger the pulser-power supplies. The transmitters in the main control room consist of an injection laser diode driven by an LC pulse-forming network. The circuit provides a 50-ns pulse with a few nanoseconds rise. The receivers are back-biased PIN diodes coupled to video amplifiers. The amplified output drives high-speed comparators for logic timing outputs. For triggering, the amplifier output drives a commercial solid-state trigger generator which provides a fast-rising output of several hundred volts. The jitter of these timing and triggering interfaces is less than 5 ns.

Analog Pulse Waveform Interfaces

These interfaces transmit analog amplitude-modulated information over distances of up to 40 m.² The bandwidth is 1 kHz to 10 MHz with a 40-dB dynamic range. The completely isolated transmitter is an LED driven by the measured signal through a current transformer. The receiver is an integrated photodiode amplifier which is usually coupled to a transient recorder. This system has been operated with 600-kV common-mode voltage on the transmitter. The circuit exhibits nonlinearity around the zero signal level, but, when used for pulse measurement, it exhibits a linearity deviating less than a few percent from norm.

Low-Speed Analog Interfaces

These interfaces, shown schematically in Fig. 8, transmit analog information in serial digital form. The voltage or current from a transducer is wired into the instrumentation amplifier where the voltage is scaled for the voltage-to-frequency converter. The frequency output drives a pigtailed LED which is coupled to a

silica fiber up to 100 m long. The fiber-optic receiver, located near the microprocessor, is wired to a programmable timer where the voltage information is recovered. Voltage scaling by the microcomputer then yields the transducer input information. The system has a bandwidth of 500 Hz and a 60-dB dynamic range.

CONCLUSIONS

Fiber Optics will be applied in control systems operating in adverse EMI environments. The isolation provided by fiber optics will simplify equipment grounding and shielding by eliminating ground loops and conducted interference. Further, fiber-optic interfaces are cost-effective if available electro-optical components, cables, and the design concepts presented herein, are used.

Distributed computer systems and fiber optics are complementary technologies. The optical interfaces allow true isolation of powerful, but EMI-sensitive, microcomputers from the environment. Control tasks can be assigned to the protected microcomputers generating a control system with high integrity.

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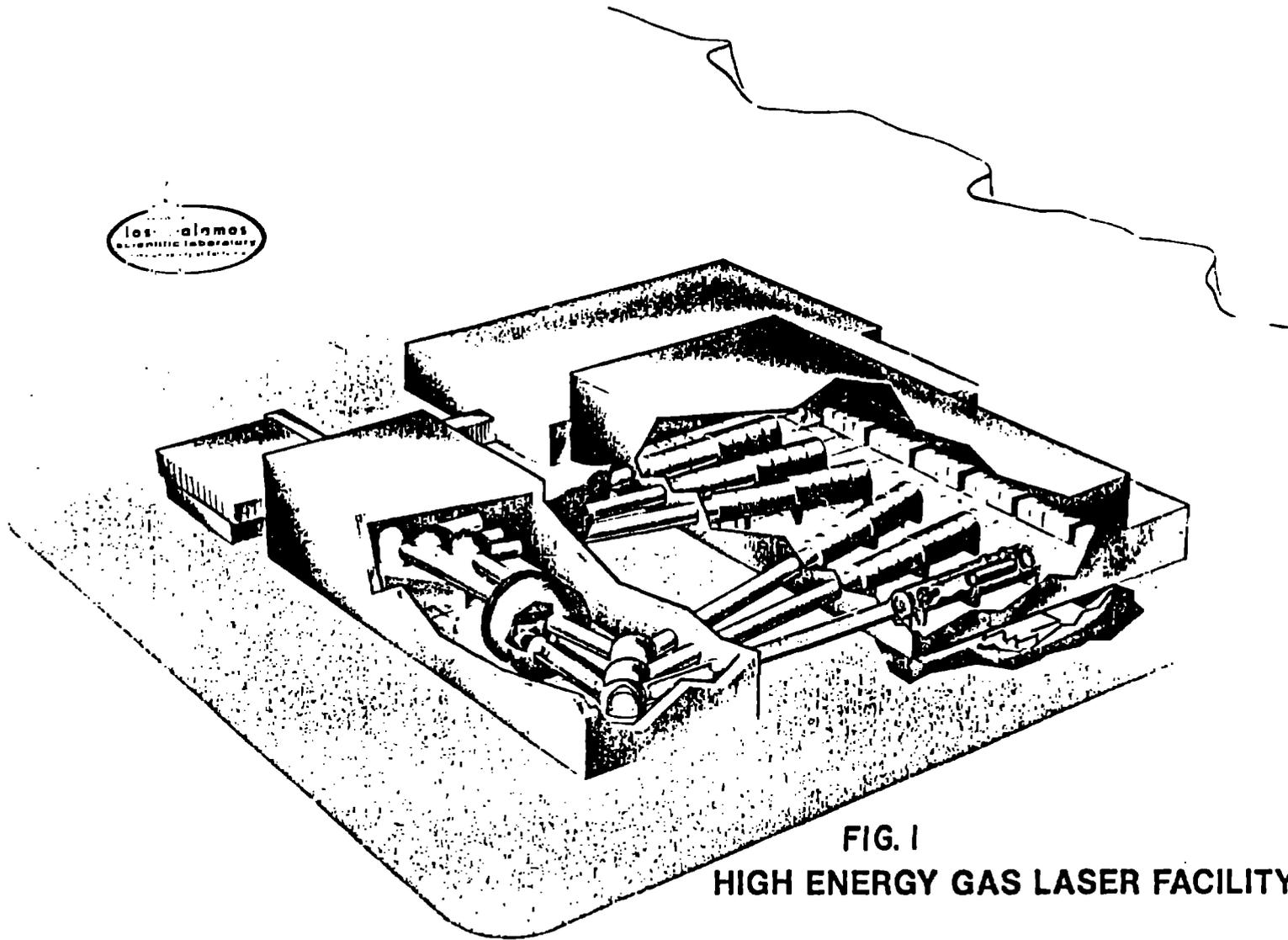


FIG. 1
HIGH ENERGY GAS LASER FACILITY

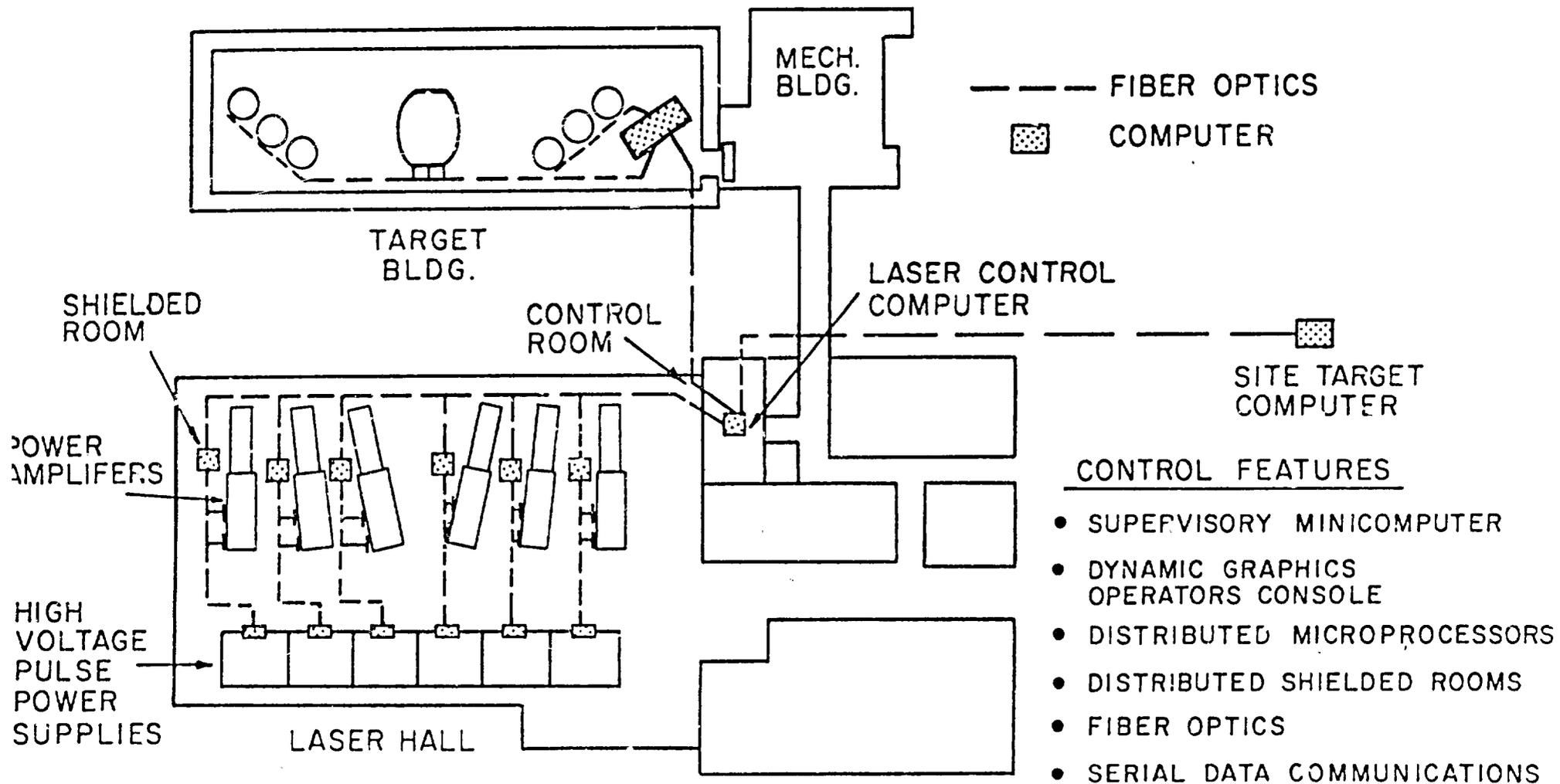


FIG. 2



ANTARES CONTROL SYSTEM GEOGRAPHY

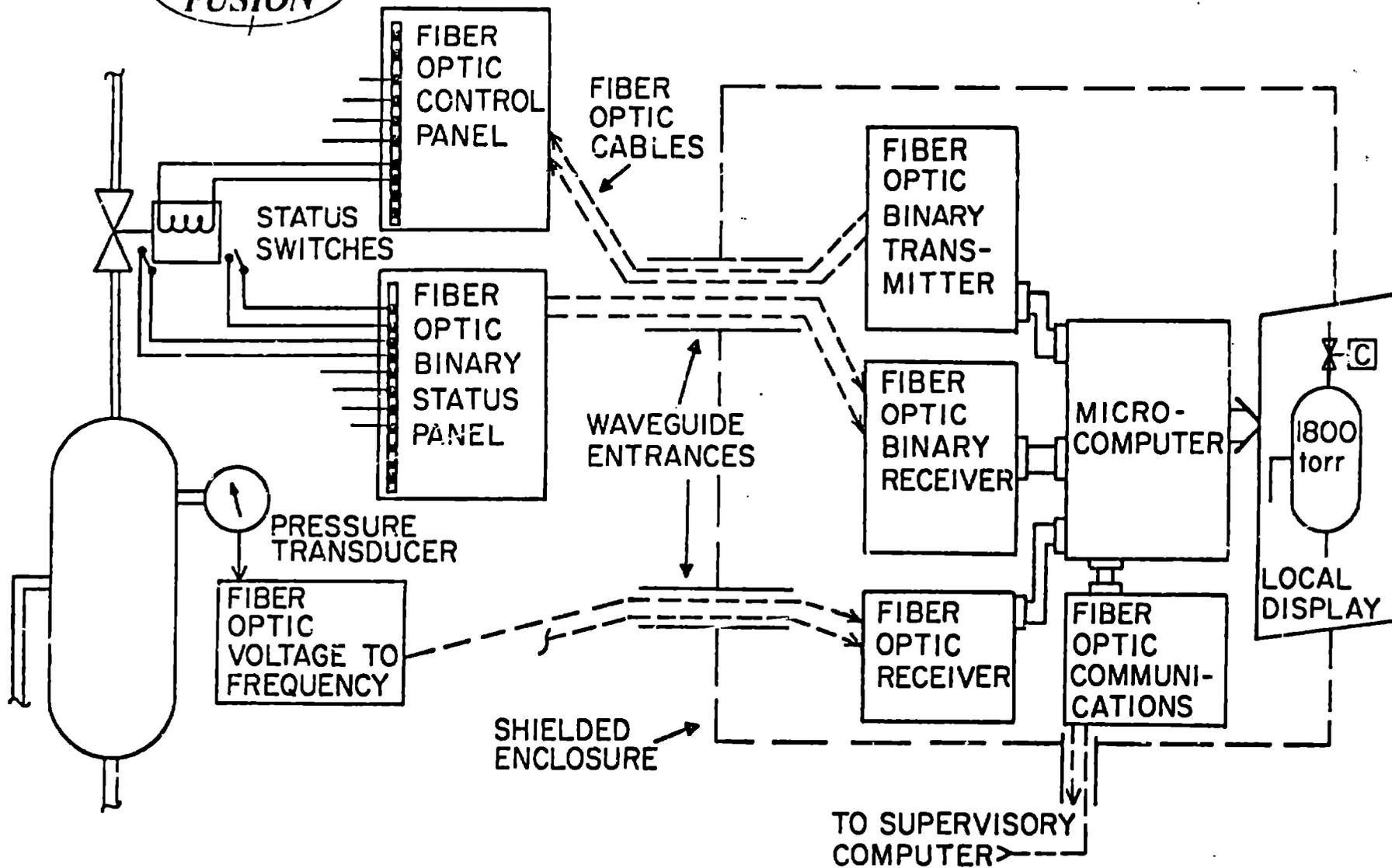
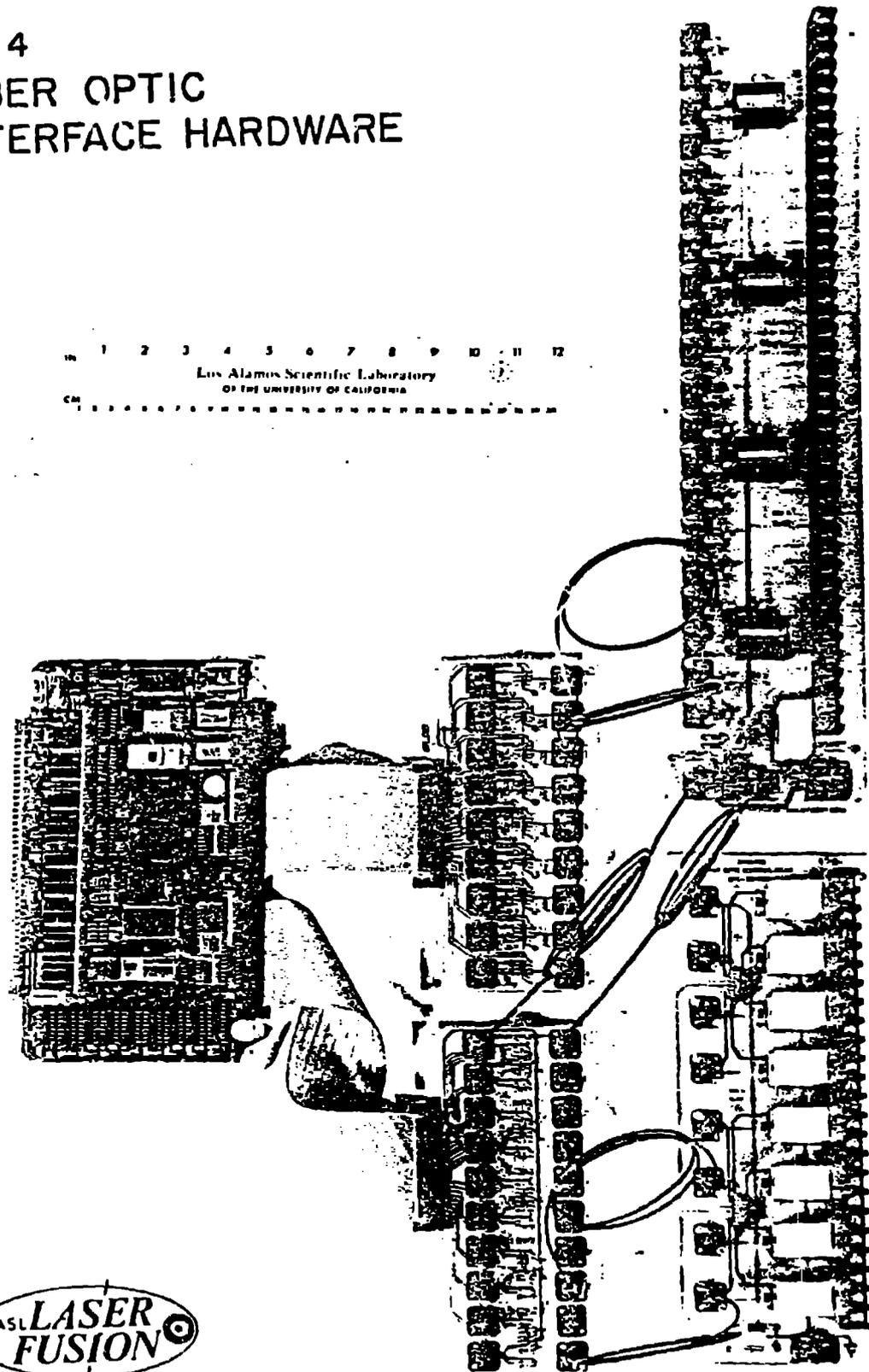


FIG. 3

FIBER OPTIC ISOLATION OF CONTROL AND MONITOR FUNCTIONS

FIG. 4
FIBER OPTIC
INTERFACE HARDWARE



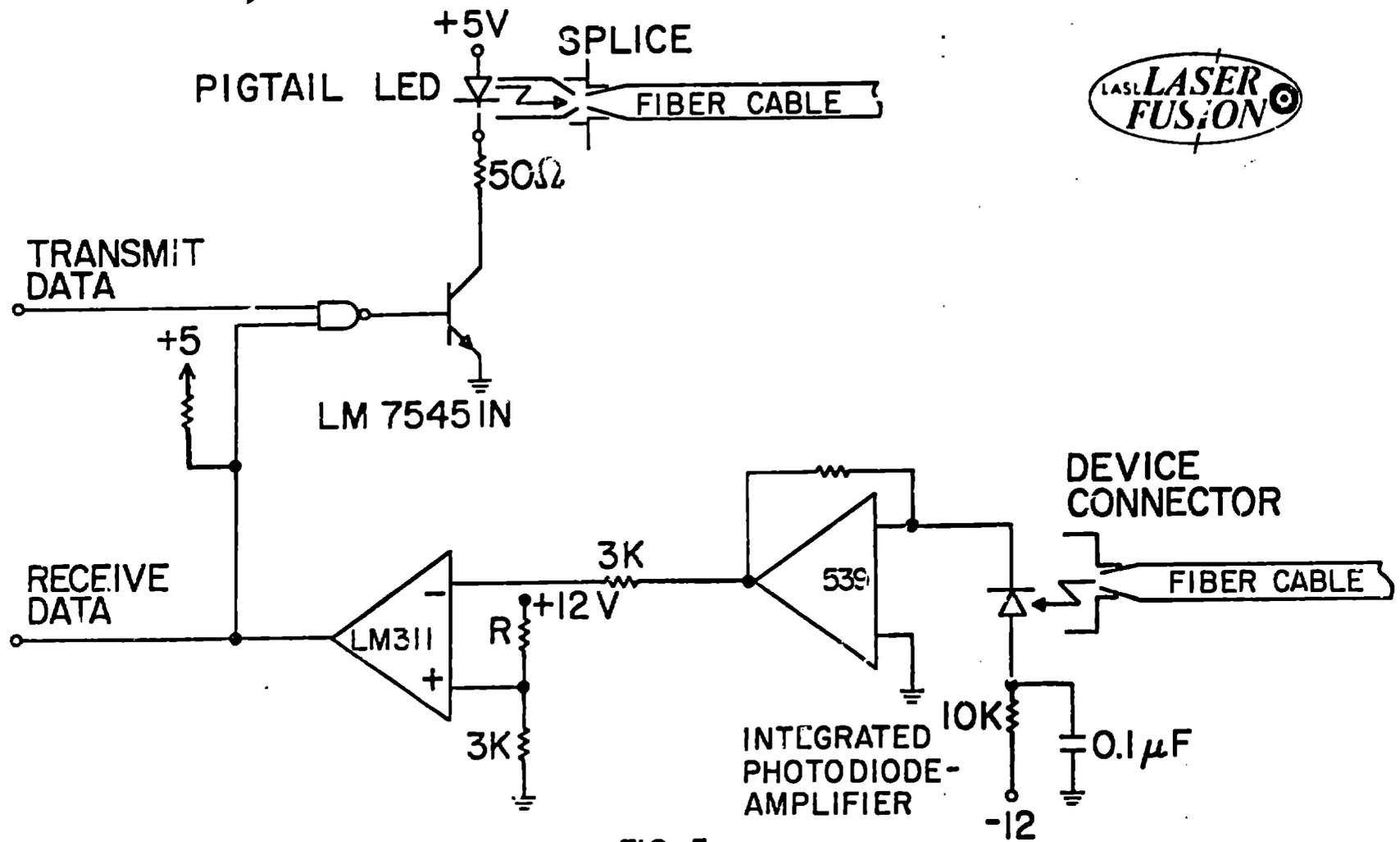


FIG. 5

FIBER OPTICS COMMUNICATION INTERFACE SCHEMATIC

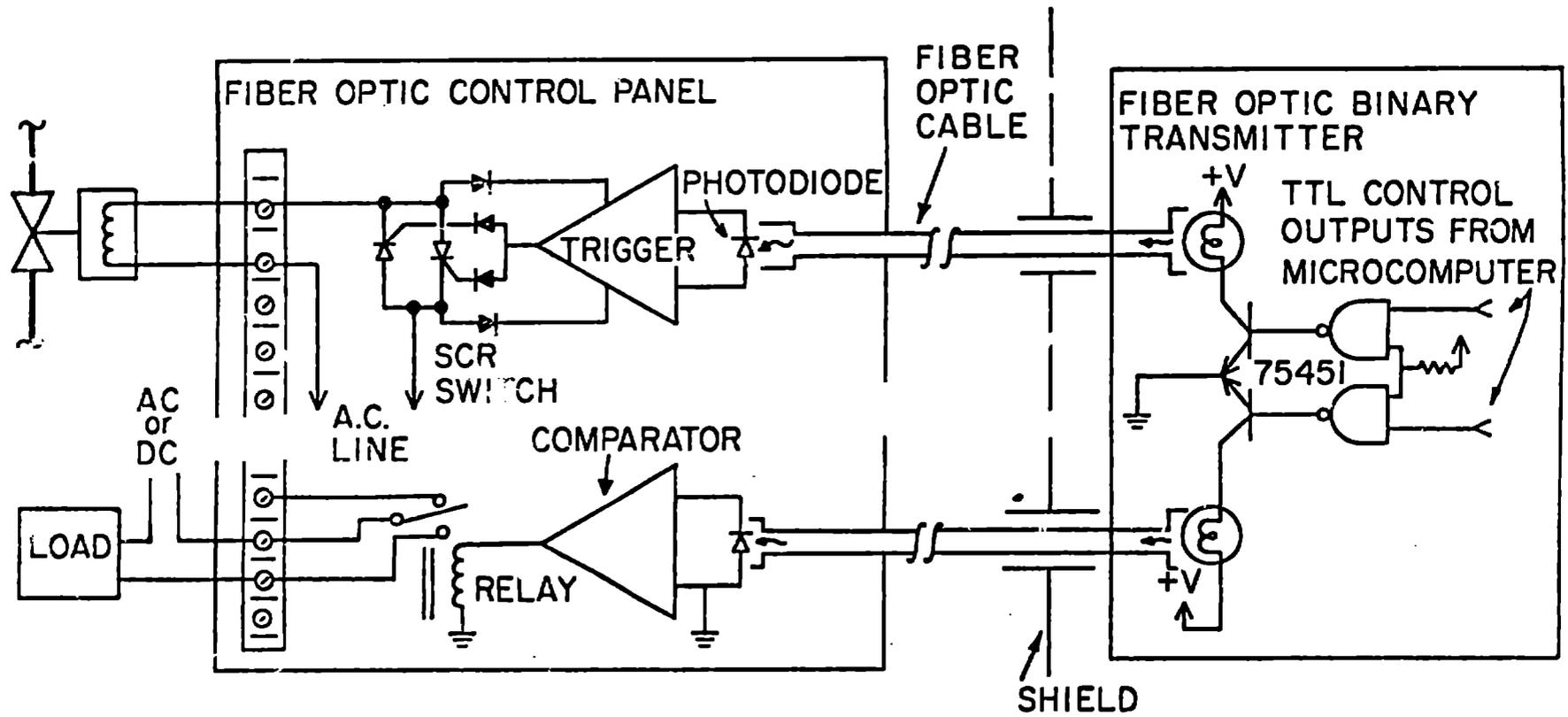


FIG. 6
FIBER OPTIC CONTROL SCHEMATIC



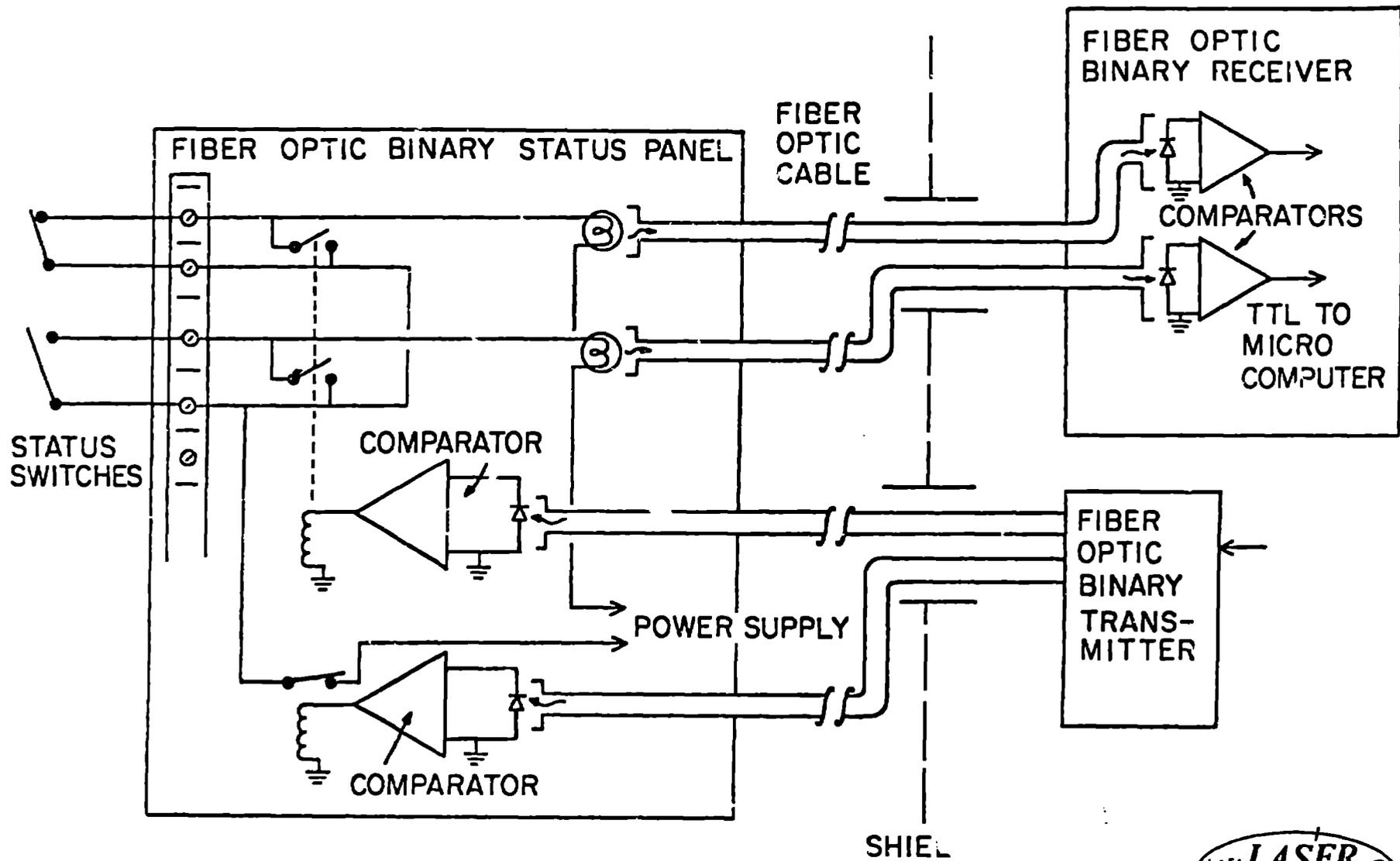


FIG. 7
 FIBER OPTIC BINARY MONITOR SCHEMATIC



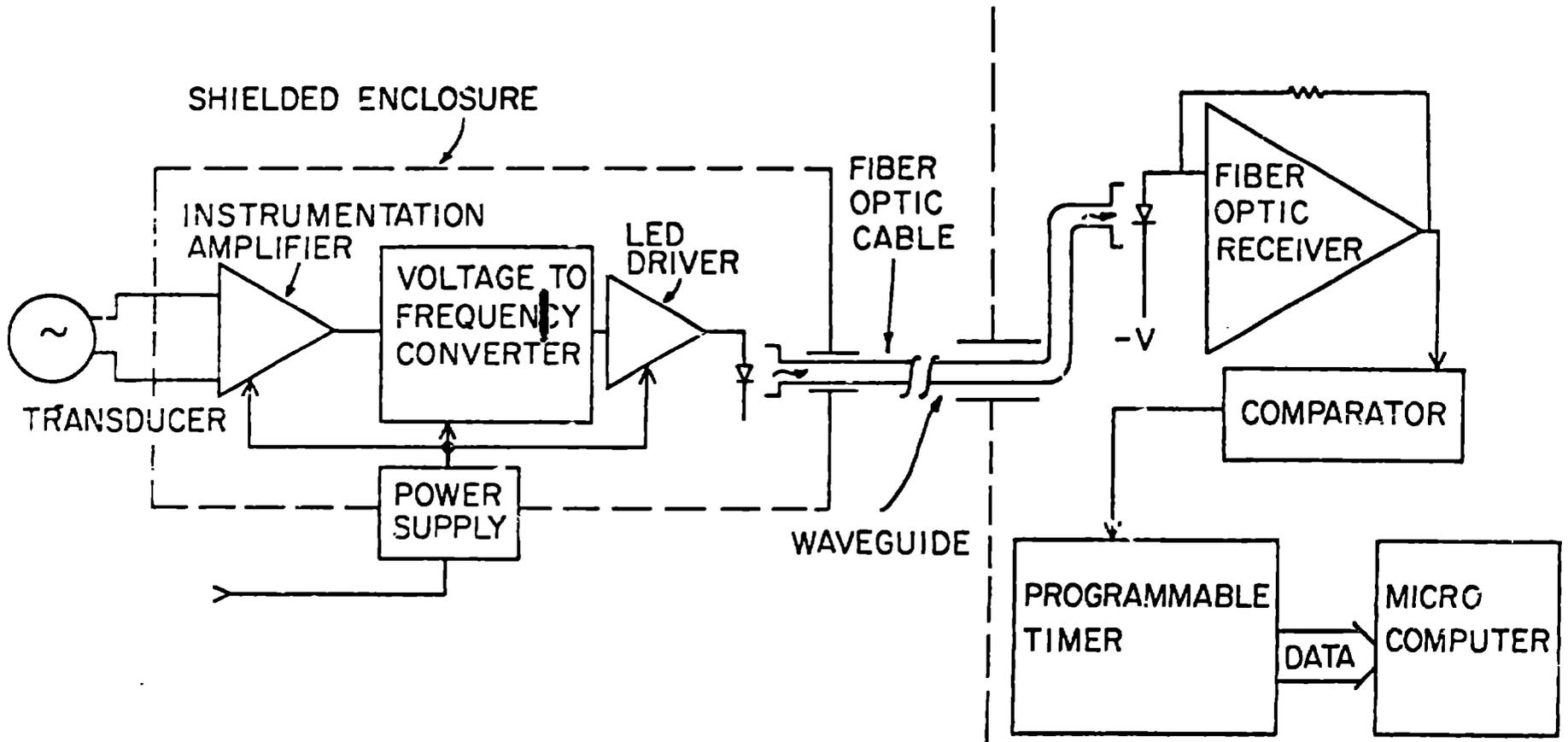


FIG. 8
ISOLATED PARAMETER MONITOR SCHEMATIC