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TITLE A FIBER OPTIC ANALOG AND TIMING MONITORING SYSTEM FOR THE ANTARES LASER FUSION PROGRAM

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A fiber optic analog and timing monitoring system for the Antares laser fusion program*

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Abstract

The development and use of two optical fiber systems for the Antares 40 kJ CO_2 laser is described. In the Antares power amplifier, electron guns produce a discharge-sustaining 8 kA beam of 500 kV electrons. Eight 300 kJ, 3 μs Marx pulsers provide a direct electrical pumping discharge through the laser gas. The electro-optic systems developed allow the measurement of pulsed analog waveforms and trigger timing information within the laser and power systems by a computer based control and data acquisition network.

Each fiber optic system consists of a signal powered transmitter, a fiber optic cable, and an optical receiver that interfaces through a CAMAC module to the data acquisition network. The data channels are capable of operating with 1.2 MV of common mode voltage in the electromagnetic interference environment, 500 kV/m and 50 kA/m, produced by the Marx pulsers.

The analog transmitters send 10 MHz bandwidth information to CAMAC waveform digitizers in the data acquisition system. About 200 data channels monitor voltage and current in the pulsers and current density in the laser power amplifiers. The laser transmitters send 2 ns resolution timing information from each stage of the Marx trigger amplification and the Marx output to CAMAC time-to-digital converters. These 120 channels of information are processed to provide prefire diagnostics for the energy storage systems.

Introduction

Antares is the fourth CO_2 laser system developed at Los Alamos to support laser fusion research. The Antares power amplifier module, the largest built so far, is designed to deliver 20 kJ of infrared light energy in a one nanosecond pulse. The power amplifier requires 1.2 MJ of electrical energy which comes from five Marx power supplies. The laser timing, the Marx triggering, the currents and voltages produced by the Marx, and the distribution of current in the power amplifier anodes are all critical parameters of the laser operation. Each power amplifier module has 157 data channels associated with these critical parameters. To record and analyze this data and provide the complex control functions a computer based data and control system was developed.

The short-pulse high-current electrical pumping discharges produce high levels of broad band electromagnetic interference that disrupts the operation of electronics systems and computers. The design of the Antares control system applies fiber optics for all measurement and control channels, thus allowing complete isolation between the EMI shielded control and data computers and the laser system. Two high speed monitoring links, the analog monitor and the timing monitor, were developed for the Antares system. Two hundred and fifty of these fiber optic data channels have been built, installed, and operated in the laser system. The control system, with about half of the 53 computer systems operating, has had no noise-induced data or control errors in hundreds of operations on the power amplifier. This paper will describe the design, development, and operation of these fiber optic monitors.

Analog monitor

The analog monitor is used to transmit analog voltage waveforms from transducers in the Marx power supplies and power amplifier to the computer data acquisition system. In each Marx power supply the 600 kV output voltage, the 250 kA output current, and the 280 kV trigger voltage are monitored. In the power amplifier an array of 76 sensors, mounted on the anodes, measures the distribution of 1 MA of anode current.

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The fibers connected to the transmitters on the anode must withstand 1.2 MV peak anode voltage during laser operation. These fibers must also be resistant to the 500 kV x-rays and electrons generated by the power amplifier electron gun. Since the 150 analog transmitters must be sealed in the laser gas in the amplifier shells, reliability and ruggedness are design requirements. The use of temporary floating power sources, such as batteries, are impractical. However, the signal is sufficiently large to power the transmitter directly. All of these monitor channels must faithfully transmit waveforms with rise times less than 50 ns and with amplitude accuracy better than 5%.

Optical fiber selection

Samples of commercially available optical fibers were subjected to a dose of about 30 k-rads to determine which fiber's optical attenuation properties were affected the least by the electron gun radiation. The same test also exposed the fibers to dry, oxygen-free laser gas in a laser power amplifier prototype. As part of the Marx power supply voltage and current monitoring system, the fibers are immersed in transformer oil. A series of tests were conducted to analyze the effects of transformer oil on fiber optic cables. In addition to the above conditions, the fiber optic cable must be sufficiently rugged to withstand installation by construction crews. The fiber selected for Antares was plastic clad silica DuPont PIFAX S-120 type 30. The core material in the type 30 fiber is pure synthetic silica, which is resistant to radiation damage. The cable materials in S-120 show resistance to transformer oil. DuPont PIFAX S-120 cables have aramid members that provide the required strength properties. A large numerical aperture and core diameter simplify problems in coupling to emitters and detectors.

Analog transmitter design

A circuit was developed (Fig. 1) that is powered by the signal and is totally contained in an aluminum EMI shielding housing (Fig. 2). The transmitter circuit contains transient input protection for impulses up to 20 kW. Signal current through the light emitting diode (LED) is set by a precision film resistor at 200 ma for an input of 100 volts. The transmitter LED couples an optical signal greater than 80 μW into the 200 μm diameter optical fiber core. Rise time is less than 20 ns. A survey of LEDs that are commercially available produced a wide range of linearity data (Fig. 3). The linearity error of the 4689 LED was not worse than 4%.

In addition to the shielding provided by the transmitter housing, the use of ground planes on printed circuit boards, and keeping signal leads as short as possible were important aspects of the design. Interference tests conducted in 100 kA/m magnetic fields and 1.5 MV/m electric fields showed no measurable interference.

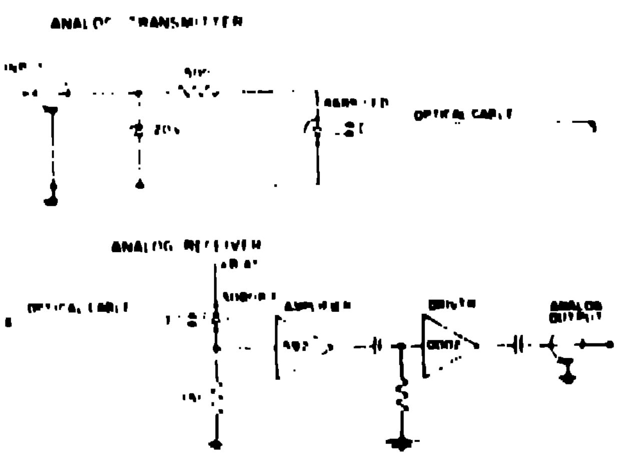

Figure 1. Simplified schematic of analog monitor.

Figure 2. Analog monitor in EMI shield.

Analog receiver design

The optical signal arriving at the receiver must be coupled to a photodetector from the optical fiber with minimum signal loss, and allow re-connecting without loss of system calibration. To achieve these goals, good alignment and proximity of the fiber to the detector surface are required. The solution was a special detector, the RCA C-30808F, with the active area positioned close to the device window.

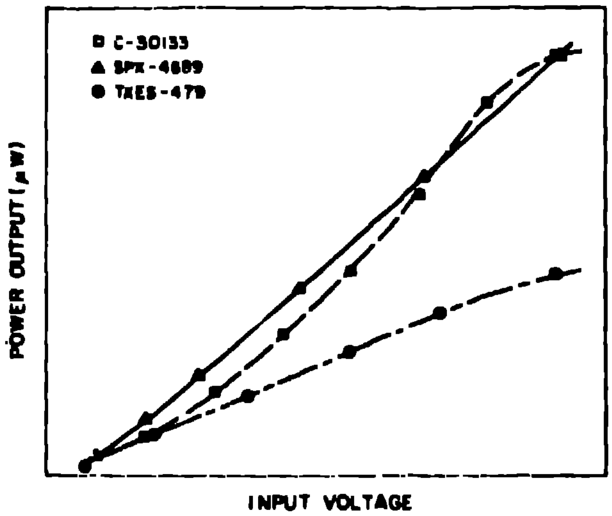

Figure 3. Linearity comparison of LEDs for analog transmitter.

Except for the fresnel reflection, all light emitted from the fiber end is collected by the detector active surface. The detector is operated in the photocurrent mode for the required linearity and bandwidth. Voltage amplification is provided by an integrated circuit video amplifier. The output amplitude is controlled by varying the amplifier gain (Fig. 1). A signal-to-noise ratio of 40 dB is required for the complete receiver. The receiver noise is dominated by the 592 amplifier input noise, typically 12 μV. The amplifier gain required is about 200 for a receiver input of 40 μW and an output of 0.6 volts. The output noise voltage is about 3 mV, giving a signal-to-noise ratio of 46 dB. The receiver must be able to drive a meter of 50 ohm cable. This is accomplished with a standard current driver amplifier. For convenience the receivers were packaged with four channels on a printed circuit card.

Timing monitor

The timing monitor is used to transmit timing information from ten Marx power supplies to the computer data system. Each Marx trigger, the five trigger amplifier stages, and the output of the Marx generator use timing monitor channels to detect and locate prefires and to measure system performance. Timing monitors are also used to detect cable faults in the 24 coaxial cables connecting the Marx power supplies to the power amplifier. The prefire detection and location function requires a system resolution of 2 ns.

The characteristics of the trigger signals are different, ranging in current from 10 to 1000 A and in pulse width from 50 ns to 5 μs. As in the analog monitoring system, each timing monitor transmitter must be a self-contained unit which is powered directly by the signal. Many of the timing monitor transmitters are located inside the Marx power supplies where they are subjected to kilovolt electrical transients, electric fields of 2-MV/m, and magnetic fields of 100 kA/m at 140 kHz. The timing system must provide reliable timing information in the presence of these interfering transients and fields.

Timing transmitter design

The most important design consideration for the signal-powered timing transmitter is selection of the emitter. A galluim arsenide single heterojunction injection laser diode was selected for large signal output and fast response. The optical power launched into a 200 μm core fiber from the laser diode is typically 20 mW. The nanosecond optical risetime from the laser provides the required timing system resolution.

Current pulses that are wider than 200 ns will cause degradation or failure of injection laser diodes. A differentiating circuit was developed which effectively shortens 5 μs trigger pulses to 100 ns, (Fig. 4). High power signals are clamped by diodes capable of absorbing kilowatts. The monitor transmitter circuits are housed in an egg-shaped EMI shield with rounded corners to prevent field enhancement in high-voltage applications (Fig. 5).

Timing receiver design

The main criteria in the receiver design are high timing accuracy and the electrical interface to the TDCs. High timing accuracy circuits require fast signal slew rates and small noise amplitudes. Since the laser diode transmitters produce large signals that are very fast, signal amplification at the receiver is not required. A fast photodetector, followed by a comparator, provides the required timing resolution (Fig. 4). Again the C-30808E PIN photodetector was chosen for wide bandwidth and low depletion voltage. The optical detector output is about a tenth of a volt or 300 ohms. Noise at the comparator input is small, thereby ensuring excellent receiver timing resolution. A voltage comparator converts the signal into a logic format and an output gate drives the TDC signal inputs.

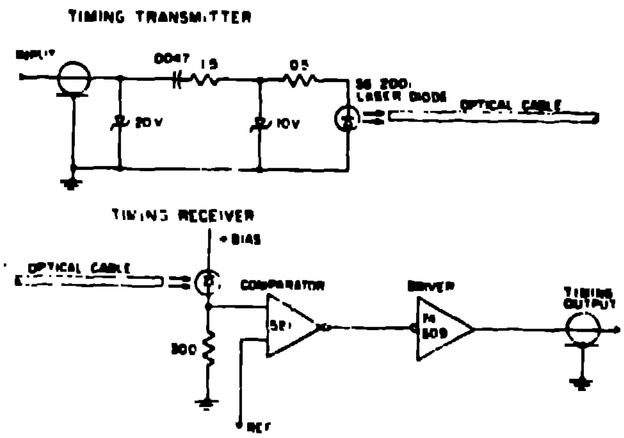

Figure 4. Simplified schematic of timing monitor.

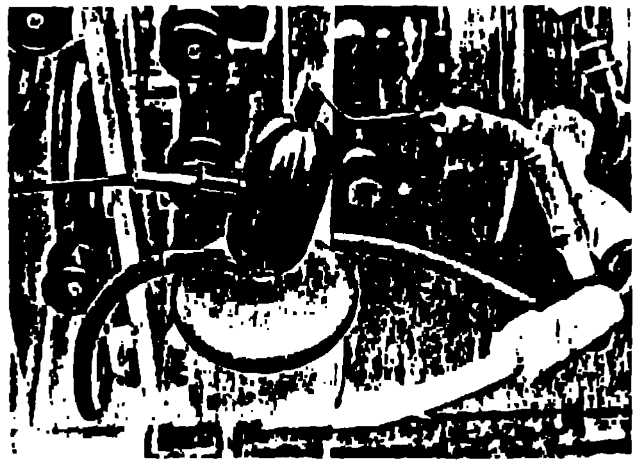

Figure 5. Timing transmitter installed in trigger amplifier.

Prefire detection system

Prefires in the laser Marx generators are detected by a computer process running during the Marx charge cycle. When a prefire occurs, the prefire current operates a fiber optic timing monitor. The outputs of all timing monitors are "OR"ed into the start input and separately connected to each stop input of the CAMAC time-to-digital converter (TDC).

The TDC measures the time interval between the start and stop input, recording the relative operating time of each trigger amplifier stage. TDC operation causes a look at me (LAM) signal that is detected by the computer monitor. If the LAM signal occurs before the laser is fired, the prefire monitor process halts laser charging and firing and compares the TDC records to determine which trigger amplifier prefired. The gaps in the prefired system are purged, the system is recharged, and the charge and fire process is automatically continued. Multiple prefires will abort the laser firing. After each firing, the system operator can request the timing records to evaluate trigger system variations.

Conclusion

A fiber optic analog monitor was developed that transmits wide bandwidth waveform data in the presence of radiation, severe EMI, and high common mode voltages. The signal powered fiber optic timing monitor described allows reliable prefire detection and automatic control response to prefires in laser power systems. Installation of hundreds of channels of these monitors have demonstrated a practical method of computer data acquisition in adverse environments.

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