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THE ELECTRONICS OF THE TARGET DIAGNOSTICS SYSTEM FOR THE SHIVA LASER FUSION FACILITY

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July 26, 1978

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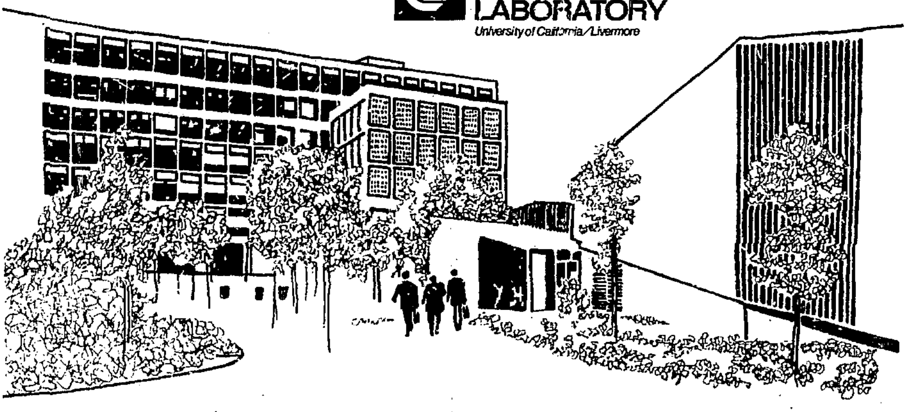

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ABSTRACT

We describe the organizing philosophy and components of a target diagnostics data acquisition system designed and implemented at the Lawrence Livermore Laboratory (LLL) Shiva Laser Fusion Facility. Several features of the system are unique: a central trigger distribution system, fiber optic communications, and fiber optics for the timing, trigger, and control and monitoring links. The system also uses CAMAC instrumentation, transient digitizers, oscilloscopes, and LLL-designed modules and packages, as well as single-point grounding of each diagnostic installation. Distributed instrumentation packages provide instrumentation flexibility and analog-to-digital conversion as close to each diagnostic sensor as practical.

INTRODUCTION

Shiva, the world's highest energy laser fusion facility,[1] will enable LLL scientists to explore inertial confinement fusion by using tiny fuel pellets filled with a mixture of deuterium and tritium gas as targets for laser beams. The Shiva Target Diagnostics Data Acquisition System retrieves sensor data to provide information on both the byproducts of the nuclear reaction and the efficiency of the burning. Figure 1 is a photograph of the entire laser system in model form. Figure 2 shows six of Shiva's 20 arms mounted on one of its laser spaceframes. Figure 3 shows the target chamber.

SYSTEM PHILOSOPHY

The overall design philosophy for the Shiva data acquisition system evolved from similar systems that were successfully installed at the Janus, Cyclops, and Argus target-irradiation facilities.[2] These systems provided valuable experience in grounding, cabling, experiment isolation, data transmission, and system triggering that led to the design of the Shiva acquisition system. (See Fig. 4 for a block diagram of the entire system.)

Fiber optics was used extensively to transmit signals between instrumentation packages while preventing ground currents, common-mode voltages, and other unwanted electrical interaction between units. Each instrumentation package or system is single-point grounded.

A considerable improvement over previous installations was made in the timing and triggering of this system. In the Janus, Cyclops, and Argus systems, instrumentation and control and monitoring functions were kept totally separate to reduce electrical noise interaction. Communication between functions was achieved by means of pulse transformers, optical isolators, or, in a few cases, fiber optic links. For Shiva, however, the instrumentation would use distributed, separate, stand-alone equipment racks located close to the sensors to be interrogated (STRIPES). Fiber optics could also be used to integrate the control and monitoring, trigger, and instrumentation functions throughout the system, while providing total electrical isolation of each system as well. A central diagnostics area would be designated where the system technicians would interact with the entire data acquisition system. This area would include the CAMAC[3] mother crate, teletype interface, minicomputer, and a few conventional oscilloscopes (STARS).

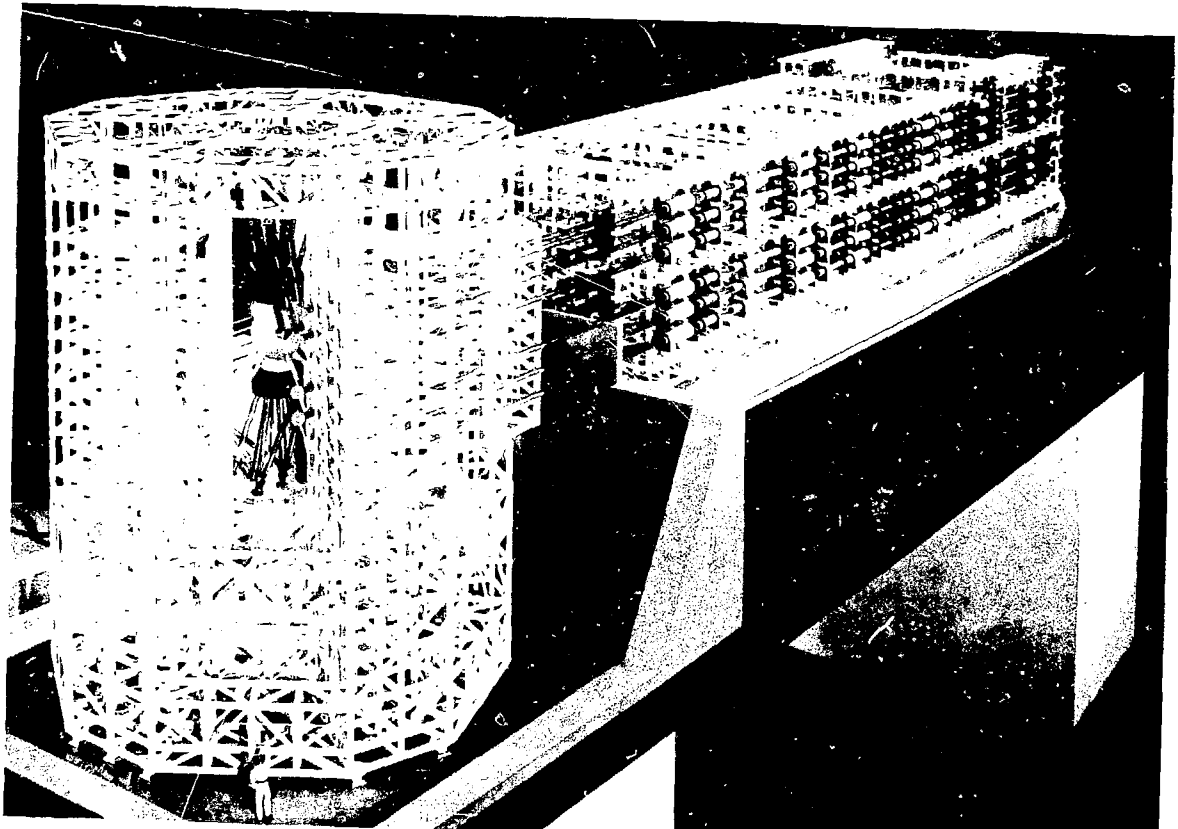

FIG. 1. Model of the Shiva laser.

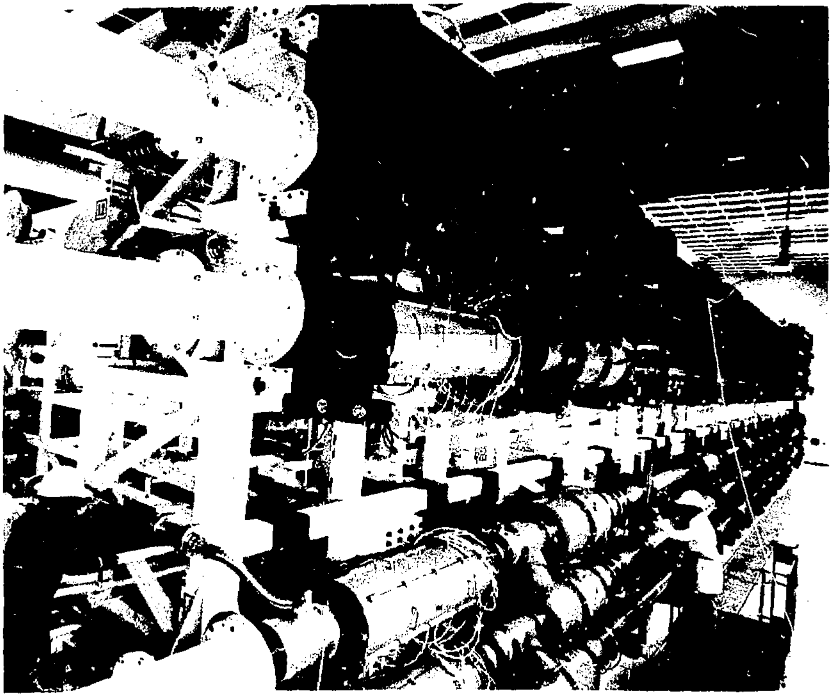

FIG. 2. Shiva laser spaceframe.

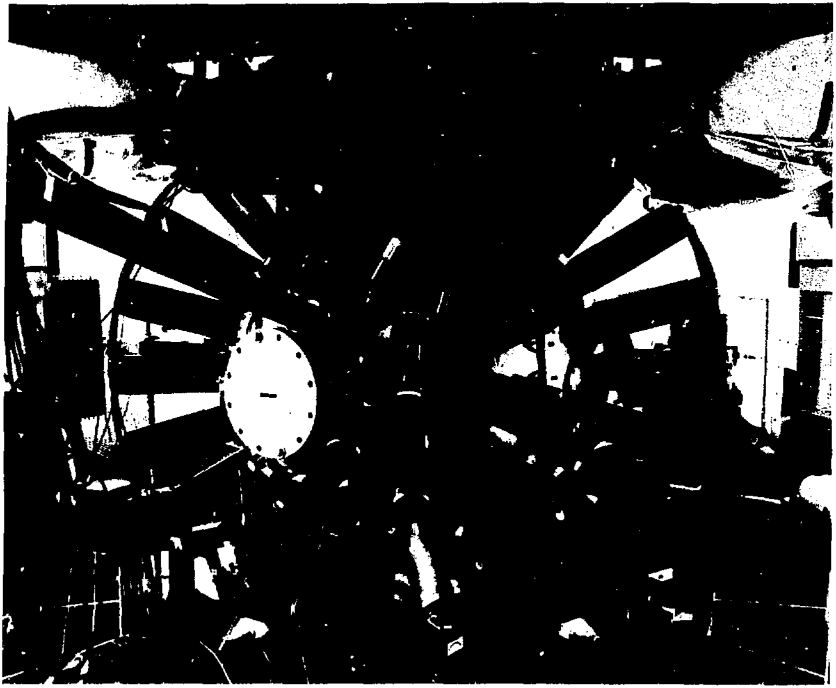

FIG. 3. Shiva target chamber.

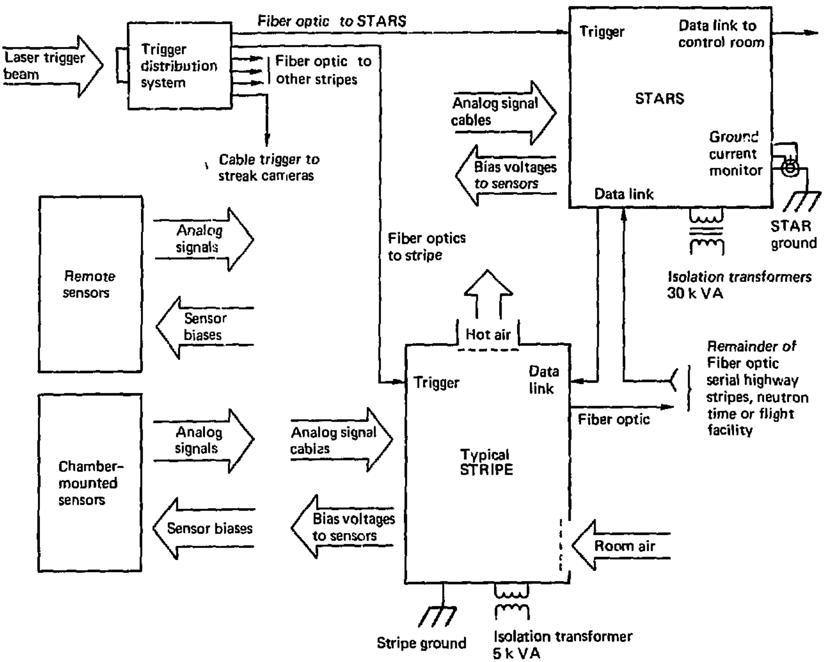

FIG. 4. Block diagram of Shiva target acquisition system.

SHIVA TARGET ACQUISITION REMOTE SYSTEM (STARS)

The STARS is the remote location (i.e., remote from the Shiva control room) where the system diagnostics technicians prepare for target shots, using the teletype to configure the system. In the future, a major portion of this interaction will be extended to the main control room in the console section designated "Target Diagnostics." The STARS is located at the northeast corner of the Shiva target room at the first-floor level (Figs. 5-7). It contains a tandem LSI-11 minicomputer, the CAMAC mother crate, transient digitizers, dual floppy disk, and teletype. It also contains conventional oscilloscopes, power supplies, shutter control chassis, power line monitor, and ground-fault detector (see Fig. 8 for a block diagram).

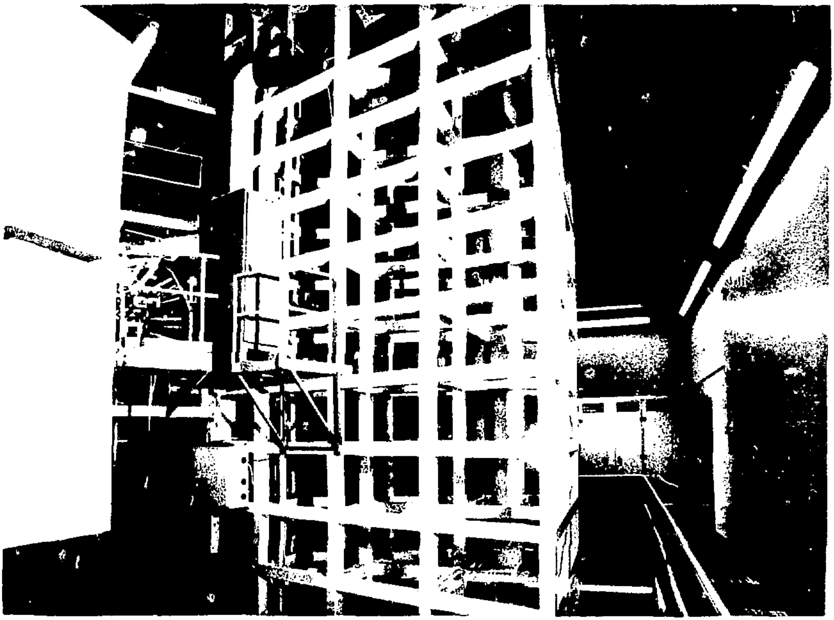

FIG. 5. Target room showing STARS and one STRIPE.

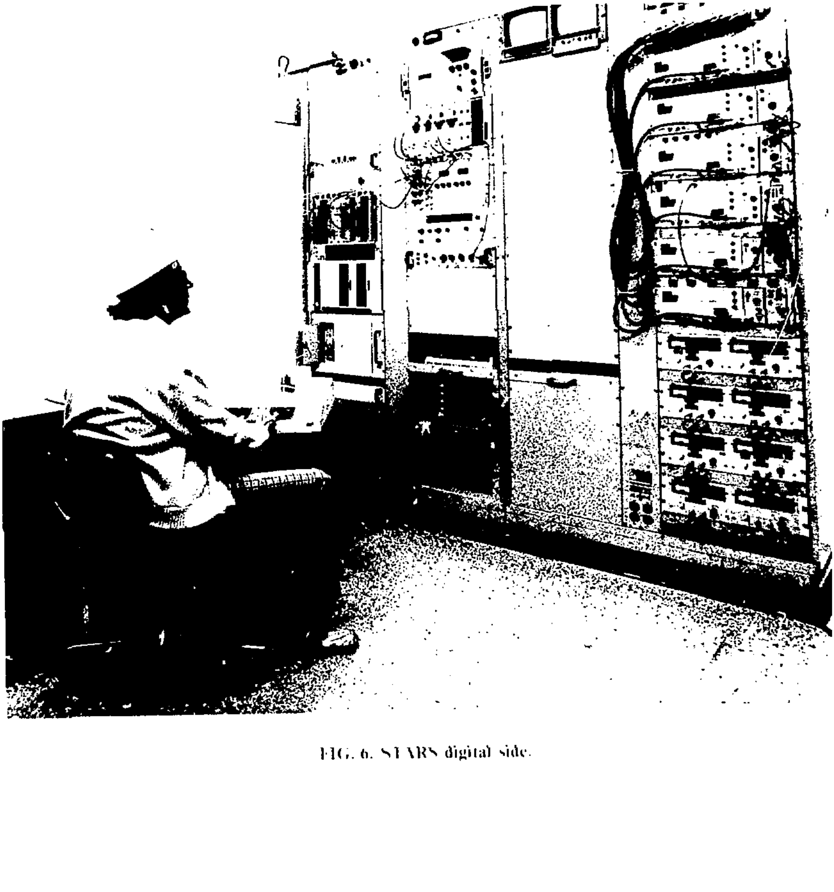

FIG. 6. STARS digital side.

FIG. 7. STARS oscilloscope side.

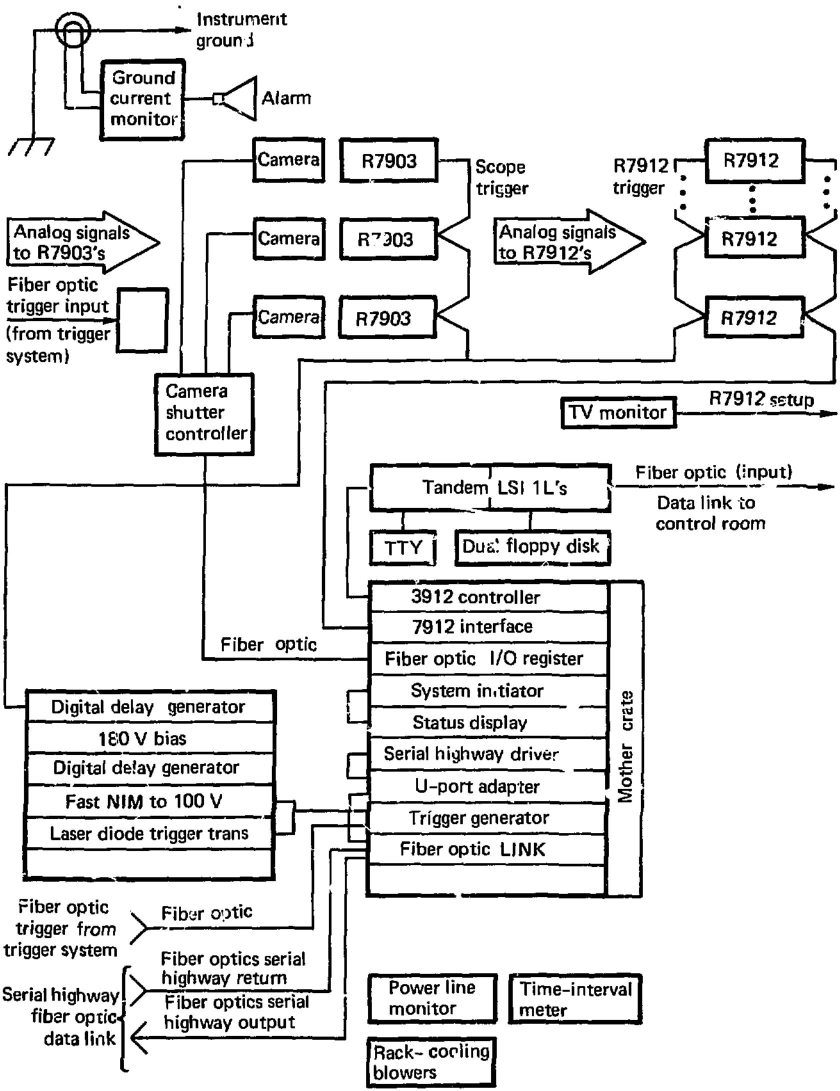

FIG. 8. Block diagram of STARS area.

SHIVA TARGET ROOM INSTRUMENTATION PACKAGE (STRIPES)

The STRIPES are secured to the target chamber spaceframe with insulated hardware. On the spaceframe, the STRIPES are close to the instrumented sensors shortening analog-signal cable lengths. The ac input power for each STRIPE is obtained from a 5-kVA isolation transformer mounted within a ventilated steel enclosure (Fig. 9). This isolation transformer package is mounted on the spaceframe adjacent to the STRIPE it powers. A short cable from the spaceframe to the transformer enclosure case provides the single-point ground for each STRIPE. The power cable from the isolation transformer package to the STRIPE extends this ground to the instrumentation package.

Each STRIPE is unique in that it can be outfitted with instrumentation aimed at a particular type of data recording. Currently three STRIPES are secured to the spaceframe (Figs. 10-12). One is primarily dedicated to time-integrated experiments, another to calorimetry data, and the third to high-speed transient digitizers. A shift in experimental emphasis can be quickly accommodated by either changing CAMAC or NIMS modules (or both) within a STRIPE or by substituting a properly outfitted STRIPE. Additional grounds in the sensor, cabling, and STRIPE are prevented by the use of insulating mounting hardware. The sensor ground is obtained via the signal or bias cable at the front panel of the module or chassis mounted in the STRIPE. A cooling system mounted at the basement-floor level draws heated air from the STRIPE chimney and discharges it beneath the basement subfloor, where it dissipates into the target room clean air system. All other connections to the STRIPES are via fiber optic cables, which are discussed in *Timing and Trigger System* and *CAMAC*.

FIG. 9. Isolation transformers ("birdhouses").

GROUNDING

Previous data acquisition systems used single-point grounds to minimize low-frequency ground currents in system cabling. This required that each experimental package or instrumented sensor be isolated from any additional ground path. At LLL we developed electrically isolated vacuum feedthrough connectors to service sensors within the laser target chamber vacuum vessel.[4] We paid particular attention to chamber flange interfaces, where electrically insulated mating or mounting surfaces are required. Remote sensors, such as those mounted on pedestals, are also carefully insulated from their mechanical support structures. The single-point earth ground for the STARS is obtained by running a 4/0 welding cable through a hole drilled in the target room east wall. This cable connects to one of the Shiva building peripheral ground rods and provides a single, low-impedance

FIG. 10. STRIPES / I time-integrated data.

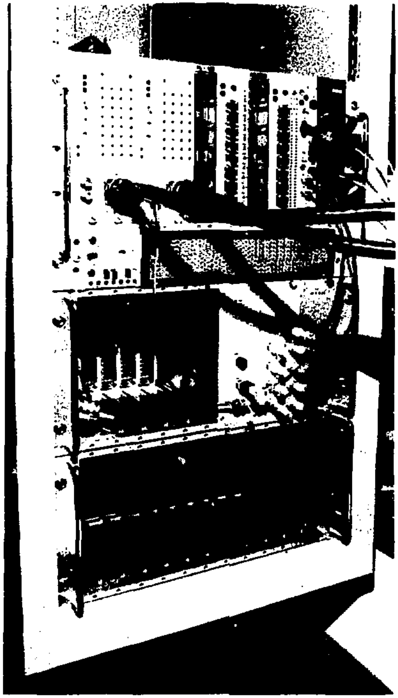

FIG. 11. STRIPES / II, calorimeter data, I/O registers.

ground path for STARS: a ground-current detector monitors the current in this ground cable. If an additional ground occurs from any point connecting the STARS to the building, an alarm sounds. Additional grounds are immediately removed to prevent the build-up of .nore ground paths, which become increasingly difficult to uncover.* The ground circuit is shown in Fig. 3.

*Experience has justified these precautions, particularly where interaction between various experiments is concerned. Experimentalists at all LLL irradiation facilities have cooperated in maintaining single-point grounds. No experiment that has a "ground problem" is connected to the instrumentation system until the problem is corrected.

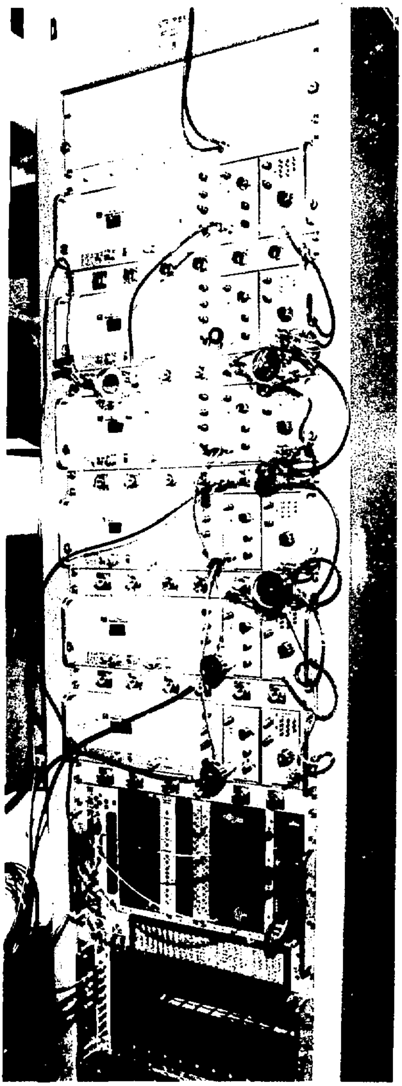

FIG. 12. STRIPES / III, transient digitizers.

TIMING AND TRIGGER SYSTEM

The Shiva Target Diagnostic System must collect data for each laser or target shot. Proper operation cannot be assured unless the data acquisition system is accurately synchronized with the operation of the laser. Two major subsystems, one "slow," the other "fast," control this timing (Fig. 13). The slow trigger system encompasses all preshot times up to 10 μs before "zero" time (when the main laser beams reach the target). The slow system provides jitter of ± 1 μs; its time reference is derived from the power-conditioning processor (LSI-11) that controls the laser operation. The fast trigger system provides low-jitter (50 ps) triggers to target room devices for 200 ns before zero time. This system derives its basic time reference from the Shiva oscillator table.

SLOW TRIGGER SYSTEM

The slow trigger system (Fig. 14) derives its basic timing from the power conditioning LSI-11 via the power conditioning 50-V "Q" Bus. (See Fig. 11.) This is actually a redundant or dual bus system (Bus A and Bus B). Within the bus interface, two output cards are "wire"- *or* -gated together to form the output signals to the initiator transmitter. The initiator transmitter frequency encodes the timing-bit pattern and transmits it to the system initiator (LEA 77-1305) over a fiber optic cable. The system initiator decodes the FM optical data and presents the data to the dual LSI-11 via the CAMAC dataway. The dual LSI-11 then sends programmed timing commands to the target diagnostics via the CAMAC serial highway. [Also note that the System Initiator also provides direct triggers (front panel BNC connectors) to allow direct use of these signals without relying on the target diagnostics LSI-11 as a controller.]

INITIATOR TRANSMITTER (LEA-1332)

The bit pattern presented to the initiator transmitter is negative true logic with only one bit "low" at a time. Only the eight least significant bits are utilized. The chassis encodes the bits into the following frequencies:

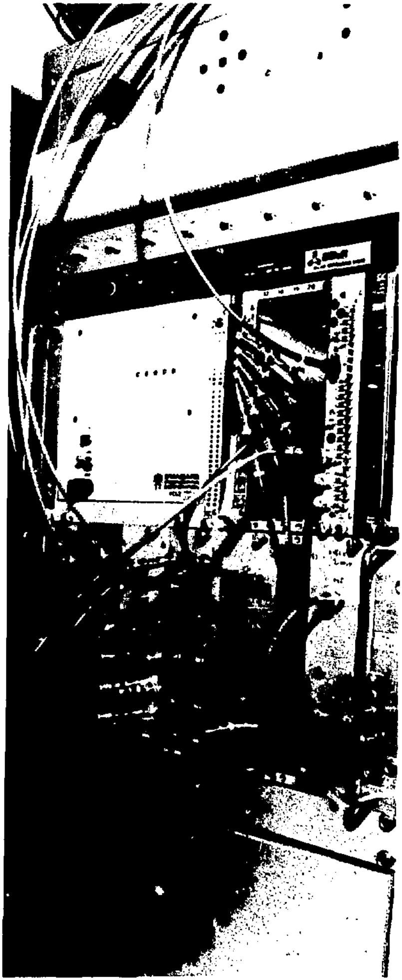

FIG. 13. Central timing and trigger electronics.

Data bit	Frequency	Time
7	5 MHz	~500 μs
6	2.5 MHz	~7 ms
5	1.25 MHz	Spare
4	0.625 MHz	~2 s
3	312 kHz	Spare
2	156 kHz	~120 s
1	78 kHz	Spare
0	39 kHz	Link alive (reset)

An internal multiplexor selects either "on line" (power conditioning LSI-11) or "local" pushbutton input, according to the appropriate front panel switches. The data actually used by the FM encoder are displayed by light-emitting diodes (LED's) on the front panel. The FM-encoded data are then converted to an optical equivalent by the transmitter half of a serial fiber optic link (LEA 76-1318). A hardwired equivalent is also available for direct connection using cable with BNC connectors.

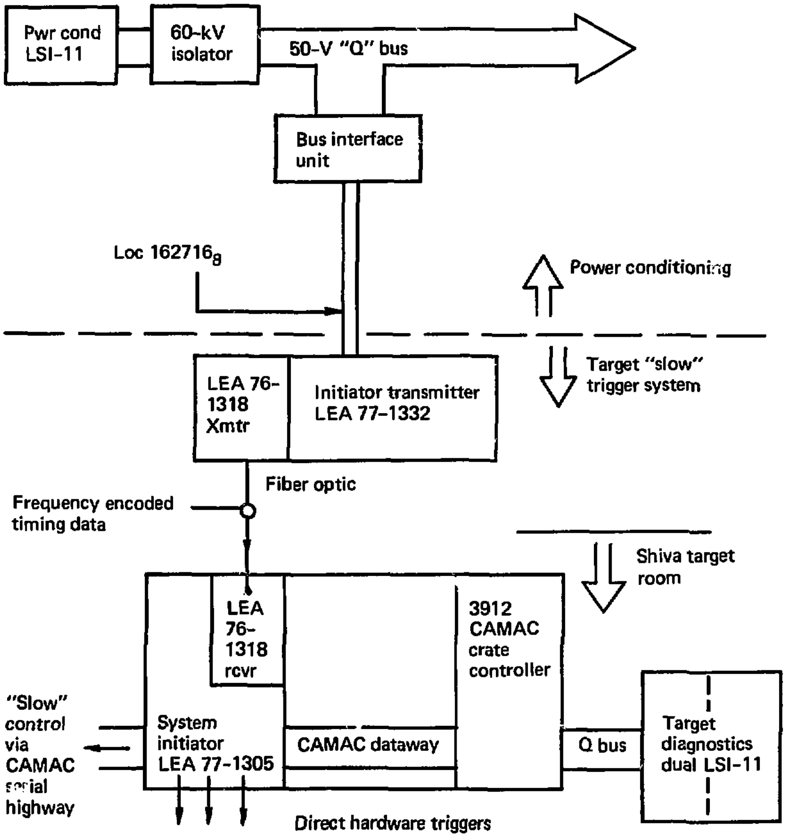

FIG. 14. Slow trigger system.

FAST TRIGGER SYSTEM

The trigger system in the Shiva target room is designed to provide stable timing triggers to various devices, including the STARS and STRIPES systems. Therefore, in addition to providing fast risetime triggers, the trigger system must not violate the single-point ground constraints (Fig. 15). The trigger input must not ground the instrumentation systems a second time and, perhaps 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 Shiver oscillator pulse via a beam path that parallels the main laser beam paths but does not traverse the pulse-shaping, path-length-equalization, and multiple beam-splitting optics required for the 20 main laser beams. Consequently, the trigger beam arrives in the target room more than 200 ns before the main beams, allowing time for level discrimination and fanout before it triggers the instrumentation systems.

The trigger beam enters an enclosed box in the target room through a beam tube located above beam No. 12. Within the box are a 400-mm (16-in.)-focal-length Fresnel lens, a beam splitter, and two PIN photodiodes (Fig. 16). The trigger PIN photodiode (MRD-500) provides the main timing signal. The position-sensing photodiode (PIN-SC/25) provides x-y position error information to

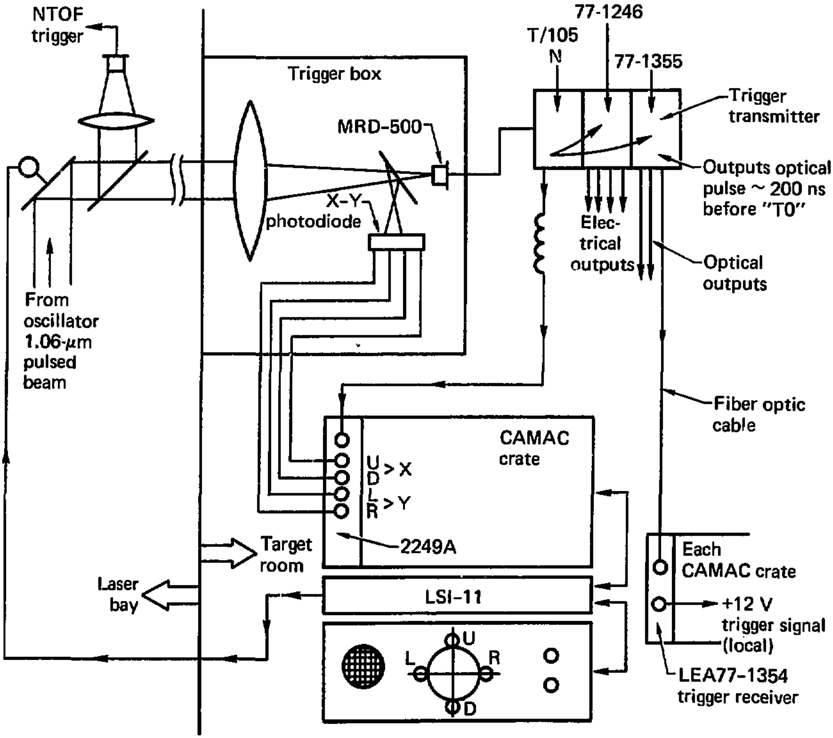

FIG. 15. Fast trigger system.

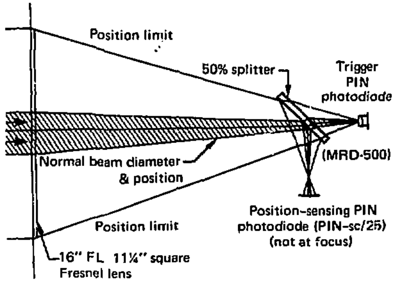

FIG. 16. Trigger box components.

allow a closed-top control system to center the beam on the Fresnel lens.

FAST TRIGGER SIGNAL FLOW

The trigger photodiode (MRD-500) signal is amplitude-discriminated by an EG&G T-105/N fast discriminator and then distributed in one or both of two formats, a fast-rise electrical or a fast optical pulse. The electrical pulse is used primarily for streak-camera triggers, where adjustable optical delay in a trigger line is cumbersome. An LLL-designed module (LEA 77-1246) provides eight 100-V output triggers from the T-105/N output. Another LLL-designed module (LEA 77-1355, Fig. 17) provides eight optical triggers to fiber optics cable for distribution to all other target diagnostics. The optical output is generated by laser diodes at a wavelength of 850 nm, which is compatible with low loss over many types of fiber optics cable. The optical cable is terminated in a CAMAC module (LEA 77-1354) that converts the optical pulse to an electrical equivalent, which is then used within each isolated instrumentation rack.

One optical trigger also terminates in the master CAMAC crate and provides the last computer interrupt to signal the Digital Data Acquisition System to acquire shot data.

POSITION-SENSING PHOTODIODE

A second photodiode with four x-y outputs is also mounted in the trigger box. The four x-y outputs are separately integrated by a Lecroy 2249A CAMAC charge-integrating analog-to-digital converter. This CAMAC module is mounted in a CAMAC crate in an adjacent rack, complete with a crate controller (KS 3911A), and LSI-11 microcomputer and an x-y visible display.

The LSI-11 provides computation and control capability to allow true beam-position calculation. After acquiring the digitized data from the 2249A, the LSI-11 calculates the following values:

$$V_{\text{error}} = \left(\frac{U - D}{\Sigma}\right) * K$$

$$H_{\text{error}} = \left(\frac{L - R}{\Sigma}\right) * K$$

where V_{error} and H_{error} are vertical and horizontal beam-position errors. Position detector integrated outputs are U, D, L, and R.

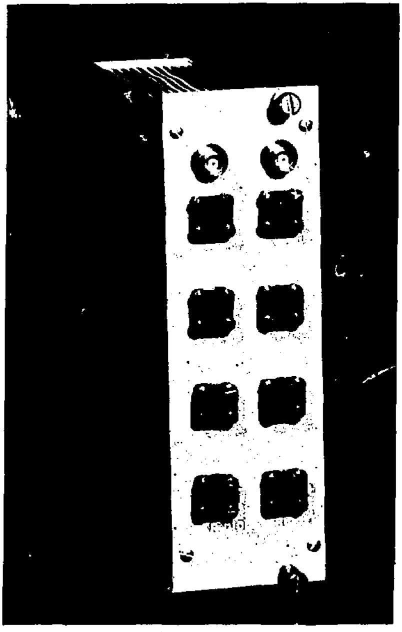

FIG. 17. Laser diode trigger transmitter.

$\Sigma = U + D + L + R$

K = Proportionality constant to scale error.

The results of these calculations are available in two formats. First, the numerical values ^{V}error and ^{H}error are available for closed-loop control of stepping motors of the last trigger-beam pointing mirror. Secondly, the magnitude of ^{V}error and ^{H}error are compared to values manually preset in a *CAMAC manual switch register. Overflow of the* 2249 analog-to-digital converter is also checked. The result of these comparisons is displayed on a local panel—the Bullsi display.

BULLSI DISPLAY

The Bullsi display panel provides status information on manual beam positioning and intensity control. An array of LED's visual indicates the approximate beam position on the *x-y* photodiode. Intensity overrange and underrange conditions are *displayed to allow rough manual adjustment with* neutral-density filters.

CAMAC

Since CAMAC was introduced to the Janus target-irradiation facility in September 1974, use of this standard has increased each succeeding facility. Shiva, therefore, represents our most extensive use of CAMAC for target diagnostics instrumentation. We have developed several CAMAC modules unique to the instrumentation of fusion experiments. A summary of these modules appears in Table 1.

FIBER OPTIC LINK (LEA 76-1318)

The fiber optic link[5] contains an optical transmitter and receiver and provides interface between the CAMAC crate which powers it, and the fiber optic serial highway (Fig. 18). At least one crate in every STRIPES package contains this module.

TABLE 1. CAMAC module summary.

Module name	LEA No.	Fig. No.	Module width	Purpose
Fiber optics link	76–1318	18	Single	Provides serial fiber optic communications between crates
System initiation	77–1305	19	Triple	Provides timing signal to the data acquisition system
Fiber optic input-output register	77–1308	20	Double	Interfaces electromechanical devices to the CAMAC dataway
Fiber optics trigger generator	77–1354	21	Single	Provides fast risetime trigger for R–7912's, etc
Programmable sensor charge integrator	77–1260	22	Double	Bipolar integrator with programmable gain, analog to digital included, 4 channels.
Programmable-gain amplifier	77–1260	23	Triple	Gain of 1, 10, 100, or 1000 programmable, bipolar 16 channels ±10 V output.

FIG. 18. Fiber optic link.

SYSTEM INITIATOR (LEA 77-1305)

The system initiator module (Fig. 19) receives the frequency-encoded timing signals from the initiator transmitter (see *Special Packages*) and interfaces them to the CAMAC dataway. This module also determines the function that the data acquisition system is performing under the software control of TACAI.[6]

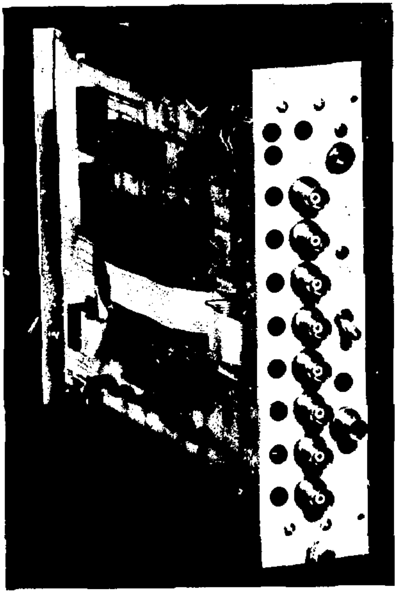

FIG. 19. System initiator.

FIBER OPTIC I/O REGISTER (LEA 77-1308)

The fiber optic I/O register module (Fig. 20) was designed to interface with a wide variety of electromechanical devices. In the current Shiva system, this module is responsible for opening the camera shutters in the STARS area; it can also be interfaced through inexpensive plastic fiber optic cable to the 15 shutter-control boxes mounted on the target chamber spaceframe. Each module has four LED outputs and four phototransistor inputs. This module also permits the interconnection of the electrically clean environment of the STARS or STRIPES to electrically noisy control and monitor areas. (See *Special Packages, Camera Shutter/Spaceframe Shutter Box*.)

FIBER OPTIC TRIGGER GENERATOR (LEA 77-1354)

This trigger generator module (Fig. 21) receives signals from the central trigger system via fiber optics and converts them to an electrical pulse for driving oscilloscopes, transient digitizers, and other instrumentation modules. This module also defines zero time for the data acquisition software from the module resident in the serial system "mother" crate. The module will also provide an output trigger signal under software control. This is useful for dry run and baseline functions.

PROGRAMMABLE SENSITIVITY CHARGE INTEGRATOR (LEA 77-1260)

The charge integrator module (Fig. 22) contains four bipolar charge integrators. The sensitivity of each integrator is independently and digitally programmable in eight steps from ± 150 pC to $\pm 5 \times 10^5$ pC full-scale (150, 500, 1500, etc., 500,000). Resolution is 13 bits (12 bits plus sign). Data are latched in data registers until a READ command is received. The sensitivity setting of each channel is contained in a status register and is displayed by front panel LED's. Individual bias connectors at the rear panel permit the biasing of sensors using the signal cable (± 200 V maximum). When used with photomultipliers, each bias connector (BNC) must be terminated using a 50-Ω terminator.

PROGRAMMABLE GAIN AMPLIFIER (LEA 77-1317)

The programmable gain amplifier (Fig. 23) provides 16 channels of bipolar amplification at

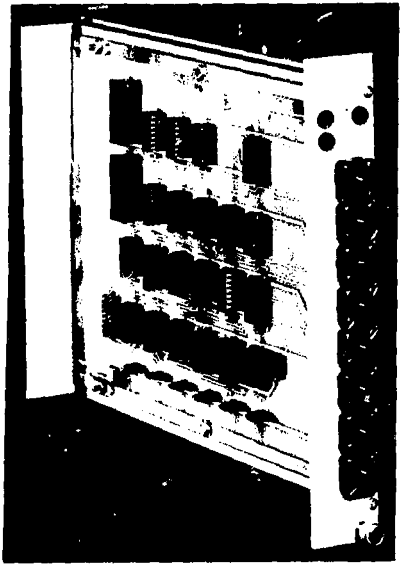

FIG. 20. Fiber optic I/O register.

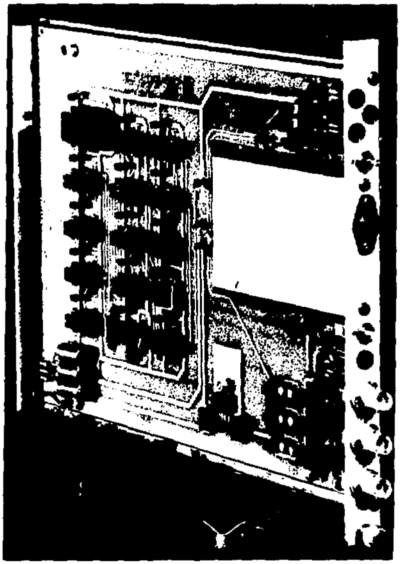

FIG. 21. Fiber optic trigger generator.

digitally programmable gains of 1, 10, 100, or 1000. Each of the 16 channels can be independently programmed, and the module contains a status register from which the gain settings can be verified. In addition, the gain setting of each channel is indicated on front panel LED's. The module, which has a 3-dB upper cut-off frequency of 0.84 Hz, is intended to be used as a part of the calorimeter instrumentation system. That system consists of the gain amplifier module, a Calorimeter Digitizer, a Power Fanout Box, Gain of 1000 Preamplifier and associated cabling. (The power fanout box and gain of 1000 preamplifier are discussed under *Special Packages*.)

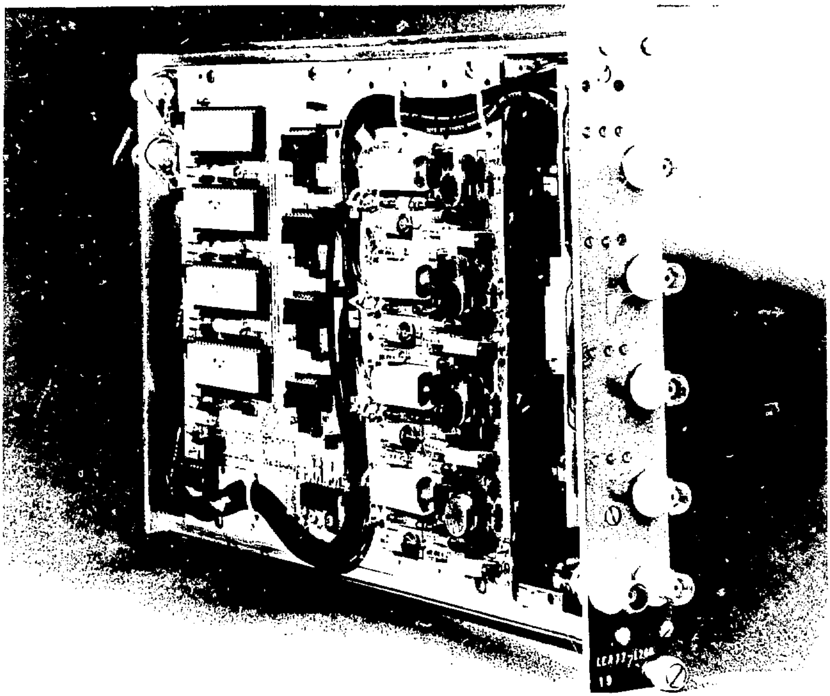

FIG. 22. Programmable sensitivity charge integrator.

FIG. 23. Programmable gain amplifier.

GAIN OF 1000 PREAMPLIFIER POWER FANOUT (LEA 77-1358)

The Gain of 1000 Preamplifier Power Fanout Chassis (Fig. 24) provides the interface between the Programmable Gain Amplifier CAMAC module (LEA 77-1317) and the Gain of 1000 Preamplifiers (LEA 77-1265). The entire calorimeter diagnostics system is shown in Fig. 25. This chassis provides a means of centrally collecting the signals from 16 calorimeter channels. A single multiconductor cable connects the 16 preamplifier calorimeter signals to the CAMAC module. The dc power to operate each preamplifier and the output signal of each preamplifier is combined on individual multiconductor shielded cables. The Power Fanout box is mounted at a central location as close as practical to the 16 programmable modules it is servicing. Ferrite cores in the dc power leads help prevent the occurrence of interfering ground currents between channels.

GAIN OF 1000 PREAMPLIFIER (LEA 77-1265)

The Gain of 1000 Preamplifier (Fig. 26) amplifies the μV output signal level of the calorimeter module to mV levels before it is sent to the power fanout box. This maintains a high signal-to-noise ratio at the Programmable Gain Amplifier CAMAC module input. The preamplifier mounts directly on the hermetic target chamber feedthrough connector and is isolated from it by means of a special busing. The design was optimized for low-level (μV) inputs and has a 3 dB upper cutoff frequency of 0.84 Hz. Small ferrite beads on all power and signal leads help provide immunity to radio frequency interference. (The diode junctions in the integrated circuit chip can rectify rf interference, causing dc offsets.)

The preamplifier is cigar-shaped; several can be mounted side-by-side. (The box calorimeter requires 26 preamplified channels.)

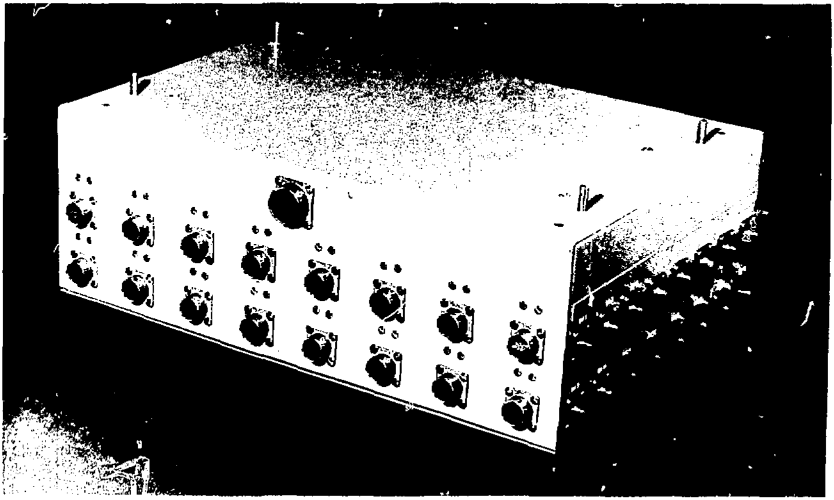

FIG. 24. Gain of 1000 preamplifier power fanout.

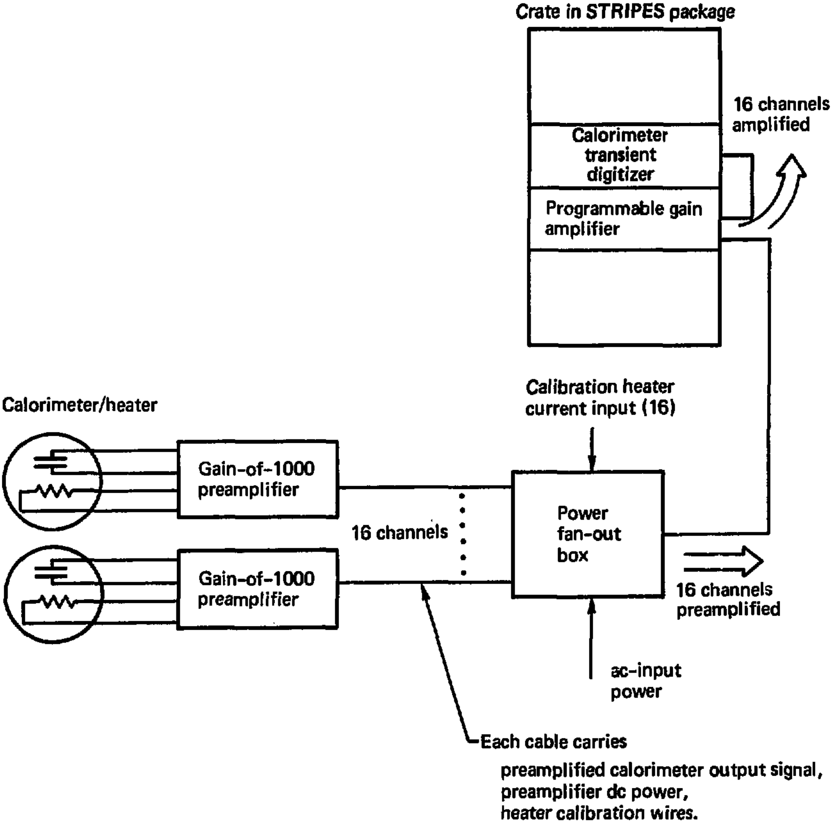

FIG. 25. Calorimeter instrumentation.

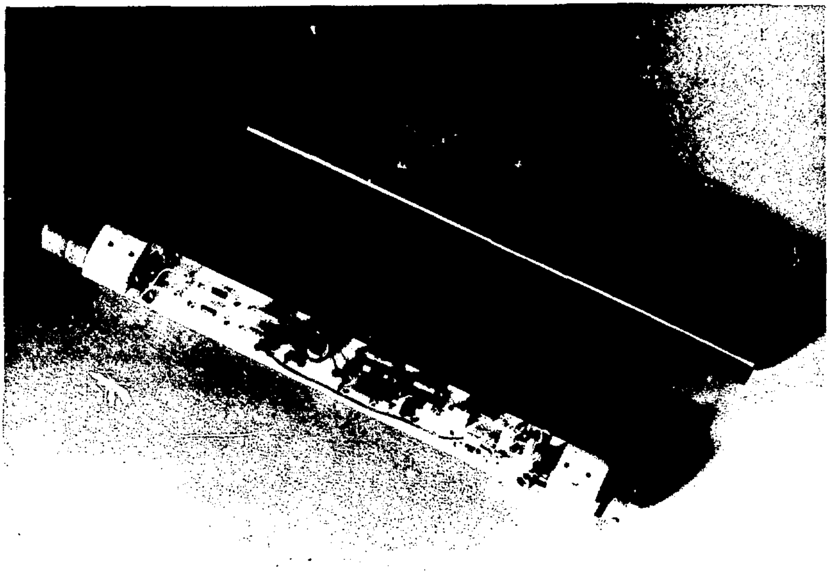

FIG. 26. Gain of 1000 preamplifier.

SHUTTER CONTROL (LEA 77-1370)

The Shutter Control Chassis (Fig. 27) provides an interface between the instrumentation system and control functions that require closures or either ac or dc power. The primary use of this chassis is to open camera shutters of conventional oscilloscope systems. The chassis is interfaced to system timing signals by means of inexpensive fiber optics cable connected to one output of the Fiber Optic I/O Register (LEA 77-1308). The system software provides the proper control functions codes to open the camera shutters at the correct time and for a specific duration keeping graticule intensities uniform from shot to shot.

INITIATOR TRANSMITTER (LEA 77-1332)

The Initiator Transmitter (Fig. 28) has a fiber optics interface to the System Initiator (CAMAC module LEA 77-1305). This chassis provides overall timing information by means of a frequency-modulated optical pulse. At Shiva, this chassis is mounted in the basement in the system interlock racks and a fiber optic cable carries the frequency modulated optical signal to the STARS area, where it is connected to the System Initiator in the mother crate.

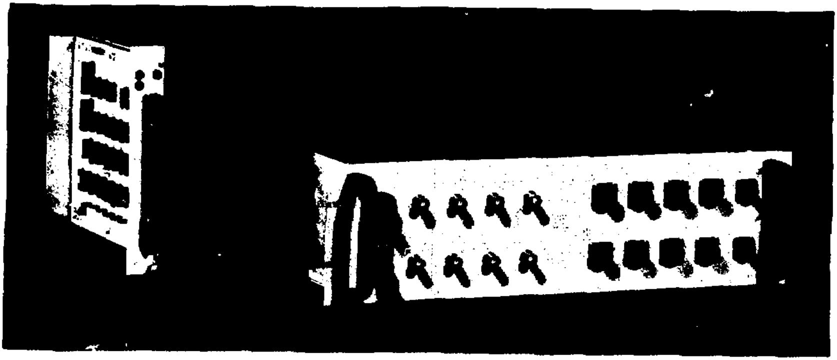

FIG. 27. Shutter control box.

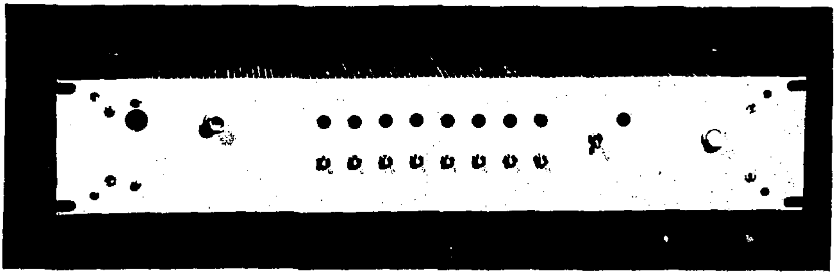

FIG. 28. Initiator transmitter.

SUMMARY

The system described is now totally installed and is operational. Additional CAMAC modules are now being fabricated to increase the number of data channels obtainable. In addition, many of the features now in use at Shiva are now being implemented at the Argus facility. This will greatly enhance the Argus target diagnostics capability.

ACKNOWLEDGMENTS

The software for control of the dual or tandem LSI-11 package was written by J. Greenwood, J. Ozawa and S. Lacy.

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