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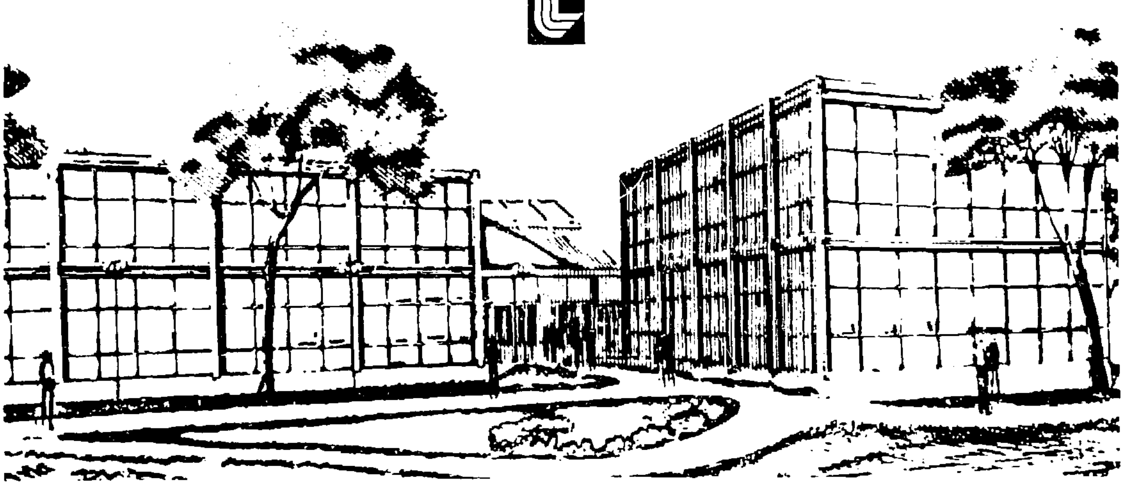

AUTOMATIC ALIGNMENT SYSTEM FOR THE TWENTY BEAM SHIVA FUSION LASER*

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INTRODUCTION

Shiva is a large neodymium glass laser system at the Lawrence Livermore Laboratory that will provide short light pulses of very high energy for irradiation of laser fusion targets. Target experiments performed on Shiva are expected to achieve sufficient heating and compression of the target to cause significant burning of its thermonuclear fuel.

A pulse from a single laser oscillator is split into 20 pulses which are amplified by 20 separate amplifier chains. Fig. 1 is a model of the system with the laser in the foreground and the target room structure in the background. Capacitor banks are located in the basement below the four story tall laser support structure. Productive operation of this facility depends on rapid and accurate alignment of the 20 pulses from the oscillator to the target. The inaccessibility of many components and the numerous adjustments rule out manual alignment except for the initial set up of the system. For this large laser, reliable automatic alignment systems are required.

OSCILLATOR/PREAMP ALIGNMENT

The laser pulse originates in a neodymium YAG oscillator. It is directed by a series of mirrors, two of which are mounted in motor driven gimbals,

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through several glass rod preamplifiers. There are many other components in the pulse line which expand and collimate the pulse, remove high frequency spatial modulation from it, and isolate the high gain rod amplifiers from each other until the moment the pulse arrives. The layout of these components and the path followed by the pulse are shown in Fig. 2.

Near the end of this path, the pulse passes through the oscillator alignment sensor shown in Fig. 3. This sensor is rigidly mounted to the table and serves as the alignment reference for both pointing and centering the pulse. Lenses within the sensor image the pulse in a plane slightly ahead of the sensor onto the centering detector. They bring the pulse to a focus on the pointing detector. Both detectors are lateral effect silicon photodiodes whose outputs indicate the precise position at which the pulse strikes the diode surface.

The four signals from each of the two detectors are integrated and digitized in the integrator unit below the sensor. Then, the digitized signals are transmitted to a nearby microprocessor which calculates the present position and direction of the pulse and compares them with the desired position and direction. The error signals resulting from this comparison are displayed on the control panel, and are used by the microprocessor to compute corrective commands to the motor driven gimbals. As the motors respond, the pulsed beam is brought into alignment.

A CW YAG oscillator is used for alignment through the rest of the system because of the low signal level of the unamplified pulse and the low repetition rate at which the amplifiers can be fired. The CW beam has its own beam expander, motor driven gimbals, and other components through which it passes before combining with the pulse path just ahead of the alignment sensor. (See Fig. 2.) The oscillator alignment system must direct the CW beam along exactly the same path as the pulse so that when the rest of the system is aligned with the CW source, it will also be aligned for the pulse. A third oscillator, which is part of a system for synchronizing the arrival of the twenty pulses at the target, is also aligned by the oscillator alignment system.

CHAIN INPUT POINTING

From the end of the preamp tables, the beam is directed up, is split into two beams, then into four and finally into 20 beams, each of which enters a separate chain of amplifiers. To propagate successfully through the long amplifier chain, each beam must enter at just the right angle. To automatically ensure that this requirement is met, each beam is aligned by the chain input pointing system.

The input pointing system consists of a pointing sensor and a motor driven gimbal at the beginning of each chain and a microprocessor that calculates pointing error signals from sensor data. When a chain is put into the automatic alignment mode, the microprocessor sends appropriate commands to the pointing gimbal and the beam is accurately pointed into the chain. A visual display shows the operator the alignment errors and other information related to the operation of this subsystem.

SPATIAL FILTER PINHOLE ALIGNMENT

Each beam now propagates through its chain of amplifiers to the output end of the laser system. In passing through the chains, the beam encounters not only amplifiers but also isolation components and spatial filters. A motor driven manipulator is mounted on each spatial filter for positioning a small pinhole in the beam to remove intensity modulations. There are 100 spatial filter pinholes in the Shiva laser system, five in each of the 20 amplifier chains.

Before each firing of the laser, the pinholes must be accurately positioned so the beams pass through them. To do this, each pinhole in turn is moved along one of its transverse axes until it intercepts the beam. The reduction in signal is detected by a sensor at the output end of the chain, and the pinhole position at the point of interception is automatically recorded. The pinhole is then moved in the opposite direction until it again intercepts the beam. From these two positions, a computer calculates the mid-point and moves the pinhole to it. When these steps have been repeated for the other transverse axis, the pinhole is centered on the beam.

The pinhole must also be placed in the right focus position along the beam axis. At the position of best focus, the pinhole can travel further before it begins to attenuate the beam than it can at any other focus position. Data collected at several positions is used to calculate the location of best focus and the pinhole is moved to it.

It is also possible to see an image of the pinhole using a TV camera looking back through the amplifier chain. A stepper motor driven mechanism inserts a weak lens at the front of the chain as shown in Fig. 4. This increases the size of the beam at the pinhole, so that a silhouette of the pinhole is displayed on the TV monitor. From such a display the operator can verify that the pinholes have not been damaged by a previous shot.

OUTPUT POINTING, FOCUSING, AND CENTERING SYSTEM

The beams emerging from the laser pass through ports in the wall of the laser bay and enter the target room where each beam must be centered on the focusing lens of the target chamber and pointed and focused on the target. This is accomplished by the output pointing, focusing, and centering or PFC system. For each 20 centimeter diameter beam, this system consists of a PFC sensor, two motor driven mirror gimbals, and a three axis motor driven positioner for the focusing lens. All of these components, along with the target chamber and related hardware, are mounted on a seven story tall steel support frame. The arrangement of alignment components for a representative beam is shown in Fig. 5.

Centering on the Focusing Lens

The lens positioner also serves as a mount for a retro-reflecting screen called a centering screen, which is inserted into the beam immediately ahead of the lens when the system is in the centering mode as illustrated in Fig. 5. This causes the light, which would have entered the focusing lens, to be reflected back toward the output pointing gimbal. A fraction of this light is transmitted by the output pointing mirror and collected in the PFC sensor. The optics in the PFC sensor image the plane of the centering screen onto a lateral effect photodiode. Since the sensor has been previously aligned to look directly at the center of the focusing lens, any offset of the beam on the centering screen generates an error signal. From this signal, the PFC microprocessor calculates the appropriate motor commands for the two gimbals to remove the centering error.

The PFC sensor also contains a television camera that sees an image of the centering screen plane so the operator can monitor the performance of the system.

Pointing at the Surrogate Target

For pointing the beams at the target, the centering screens are retracted and a spherical surrogate target is centered in the target chamber. As illustrated in Fig. 6, the incoming beam is reflected from the surrogate target back through the focusing lens and the output pointing mirror and into the PFC sensor. Because the sensor is imaging the plane formerly occupied by the centering screen, any offset of the reflected beam as it passes through that plane will generate an error signal from the sensor. There will be no offset in this plane and no error signal, only when the incident beam is focused onto the target with its central ray perpendicular to the surface. This is the case shown by the dashed line in Fig. 6. Operation of the system in the pointing mode can also be monitored and verified on the operator's TV screen.

Focusing on the Surrogate Target

Moving the focusing lens toward or away from the surrogate target causes the diameter of the reflected beam in the centering screen plane to vary. The smallest diameter is obtained when the incoming beam is focused toward a point halfway between the center and the front surface of the surrogate. To achieve this condition the operator remotely drives the focusing lens along the beam axis until the smallest spot is seen on his television monitor. Each beam is now aligned in a well defined way with respect to the surrogate target. For each fusion target, the experimenter specifies what alignment changes he desires and the position of each lens is adjusted accordingly.

Target Viewing

The PFC sensor has the additional capability of looking at the target with its TV camera by using different lenses. Lenses are chosen by rotating a lens turret located in front of the vidicon. By removing the target, the target viewing mode can also be used to examine the quality of the focused beam.

ALIGNMENT CONTROLS

The alignment systems guide twenty beams, generated from a single oscillator output through twenty separate amplifier chains and recombine them in a precisely defined way at the target. The complete alignment sequence involves approximately 600 separate motorized adjustments and can only be carried out efficiently with carefully designed controls. Similar requirements for other Shiva subsystems have led to development of a facility wide network of control computers which includes alignment controls. Shiva control is divided into four major functional blocks which operate in parallel with a minimum of interaction. These blocks are power conditioning, alignment, beam diagnostics, and fusion target diagnostics. In the control room, each functional block has its own control console and minicomputer which operate at the second (or middle) level of the three-level digital control network shown in Fig. 7.

At the first (or lowest) level in the network, microprocessors or front-end processors (FEP's) dedicated to each alignment subsystem provide for local monitoring and manual control of all sensors, gimbals, and drives and for manually enabled, closed-loop control of that subsystem. The FEP's are located in close proximity to the hardware they control and are interfaced to the operator through local control panels such as the one in Fig. 8. From this particular control panel, a technician can monitor and control all operations of the oscillator alignment subsystem. The functions of the alignment FEP's are summarized in Table I.

Table I. Functions of alignment-control, first-level or front-end processors (FEP's)

- Local monitoring and control of one chain at a time.
- Manual enabling of 20-chain, closed-loop alignment.
- Correction of nonlinear detector characteristics.
- Calculation of cross coupling between pointing and centering.
- Built-in self-testing and calibration.
- Interfacing with the second-level, alignment-control processor.

At the second (or middle) level, the alignment system minicomputer provides centralized, coordinated control of all alignment activities. Second level control functions are listed in Table II.

Table II. Functions of alignment-control, second-level processor

- Control of all alignment subsystems from the control room.
- Automatic sequencing.
- Continuous monitoring and display of performance and real-time identification of failure.
- Display of residual errors and gimbal positions in meaningful units.
- Recording and storage of residual-error and gimbal-position data.

  (Subsequent summaries will identify trends resulting from alignment drift or changes in alignment-system performance.)
- Computational support for manual-alignment tasks.
- Manual intervention and control.
- Provision of flexibility needed for adding necessary automatic alignment tasks.
- Interfacing with the third-level, integrated control computer and the alignment-system, first-level processors.

At the third (or top) level of the network, a larger minicomputer and an overall facility-control console will be employed to integrate the operations of all four second level control subsystems. All the minicomputers and microprocessors in the three level control network are from the same family of upward-instruction, set-compatible machines. This allows considerable flexibility in maintaining control capability, since the third level processor, for example, can be substituted for any 2nd level processor in case of failure.

SUMMARY AND ACKNOWLEDGEMENTS

This paper describes the design and operation of the Shiva automatic alignment system, a major electro-optic system, whose successful operation is

the culmination of many persons' efforts. The authors acknowledge the important contributions of R. Boyd, R. Cody, R. Duffus, R. Gant, T. Gilmartin, J. Greenwood, B. Kowalskie, G. McCray, J. Parker, G. Snyder, M. Summers, G. Suski, P. VanArsdall, and J. Wintemute at Lawrence Livermore and H. Ellis, J. Grime, R. Kroeger, B. Liddle, and J. Meiron at Aerojet.

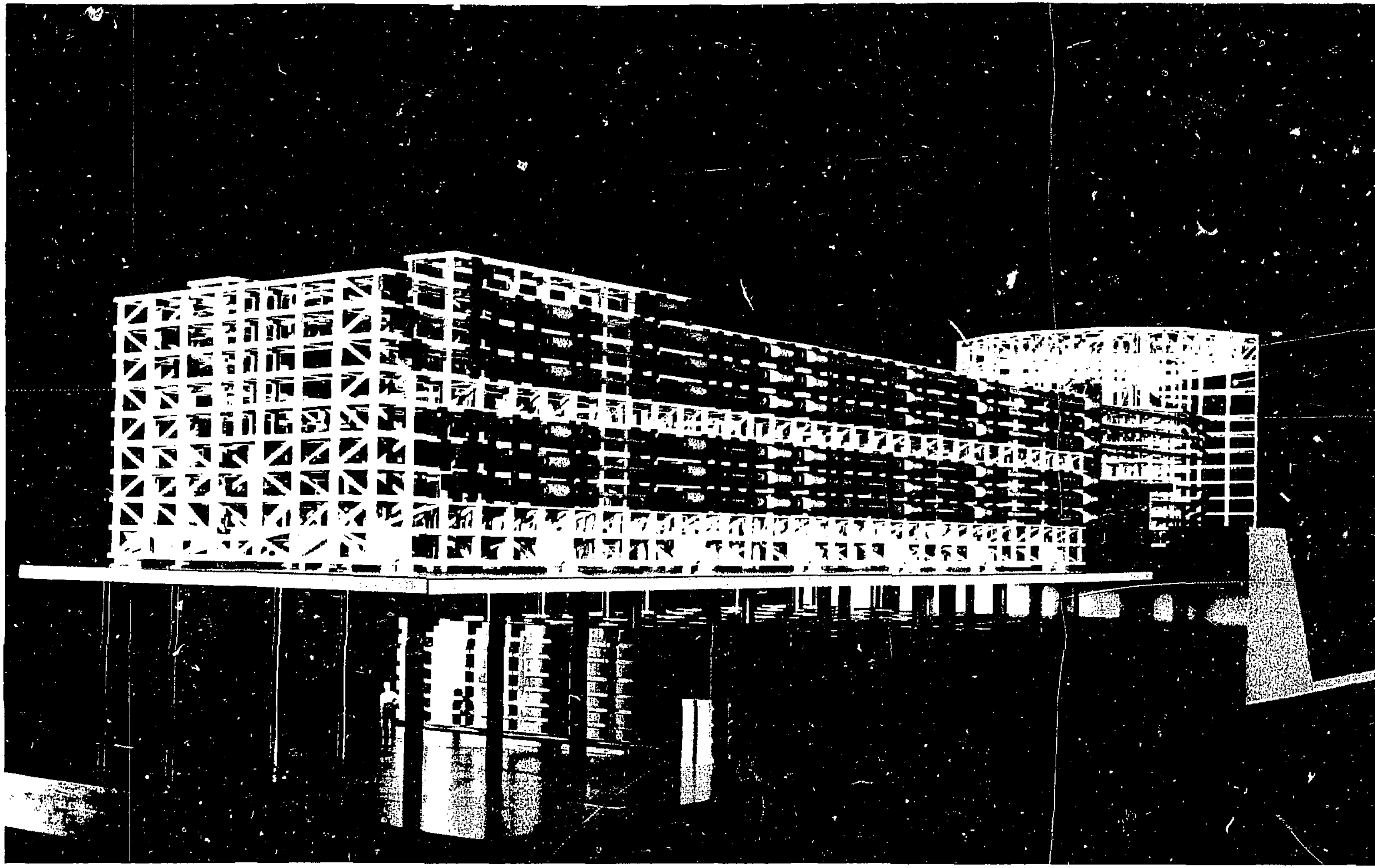


Figure 1. This photograph of a Shiva scale model shows the laser support structure and amplifier chains in the foreground with the capacitor banks in the basement below. The structure for supporting the target chamber and related hardware is in the background. For an indication of scale, notice the workers in the basement at the left and in the laser bay at the wall separating the target and laser bays.

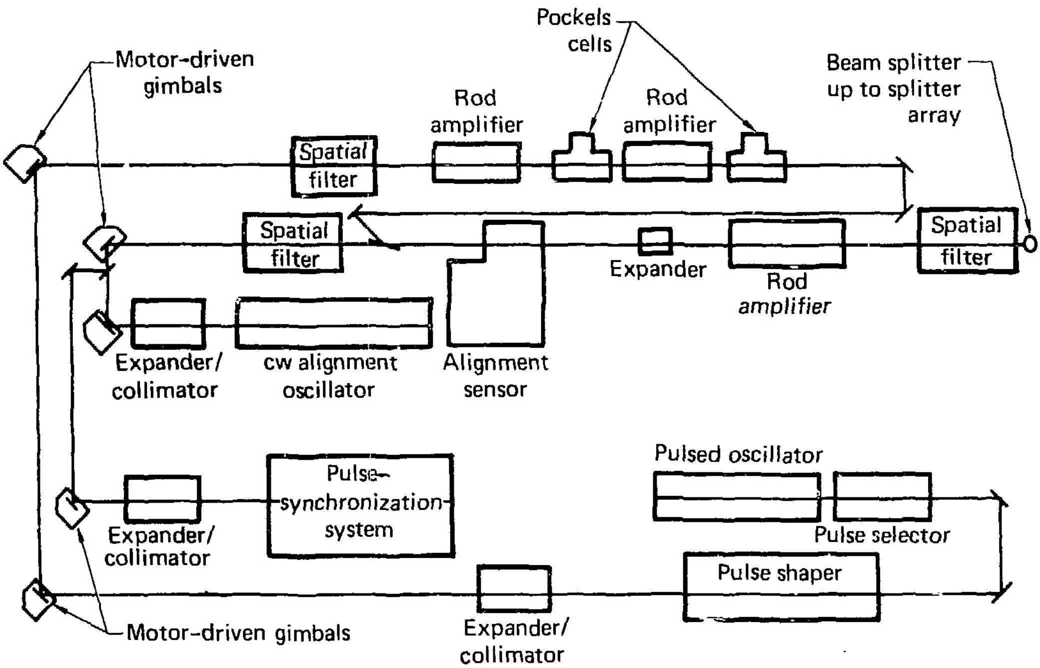


Figure 2. Arrangement of the Shiva oscillator and preamplifier components.

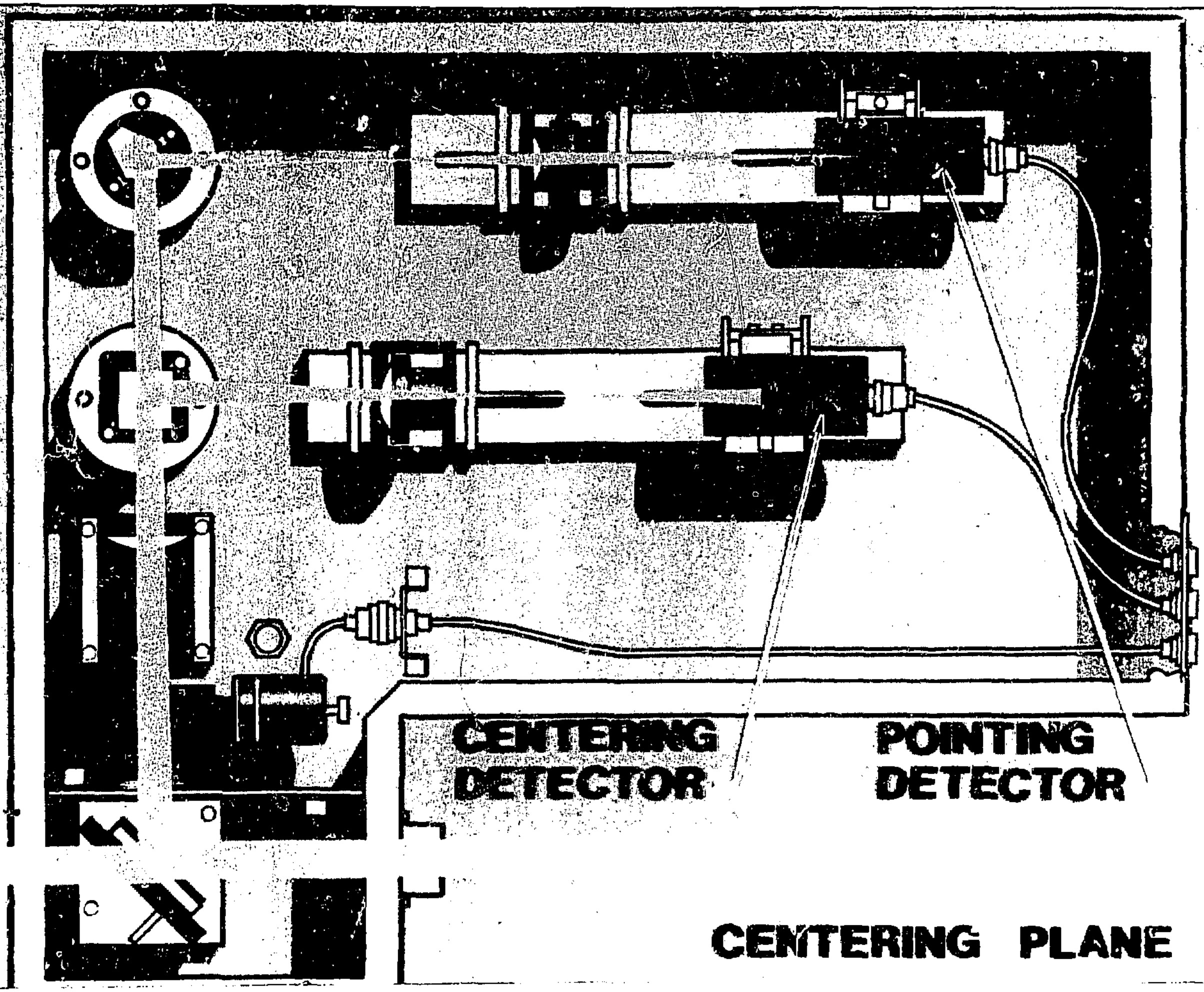


Figure 3. Shiva oscillator alignment sensor.

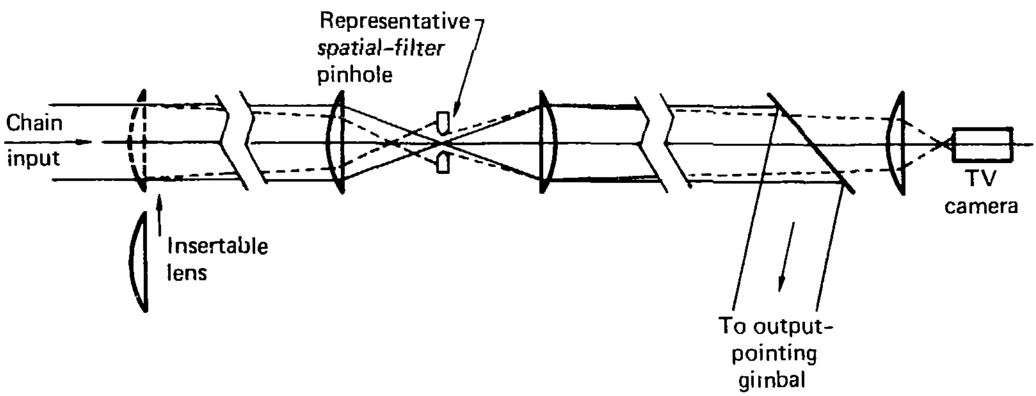
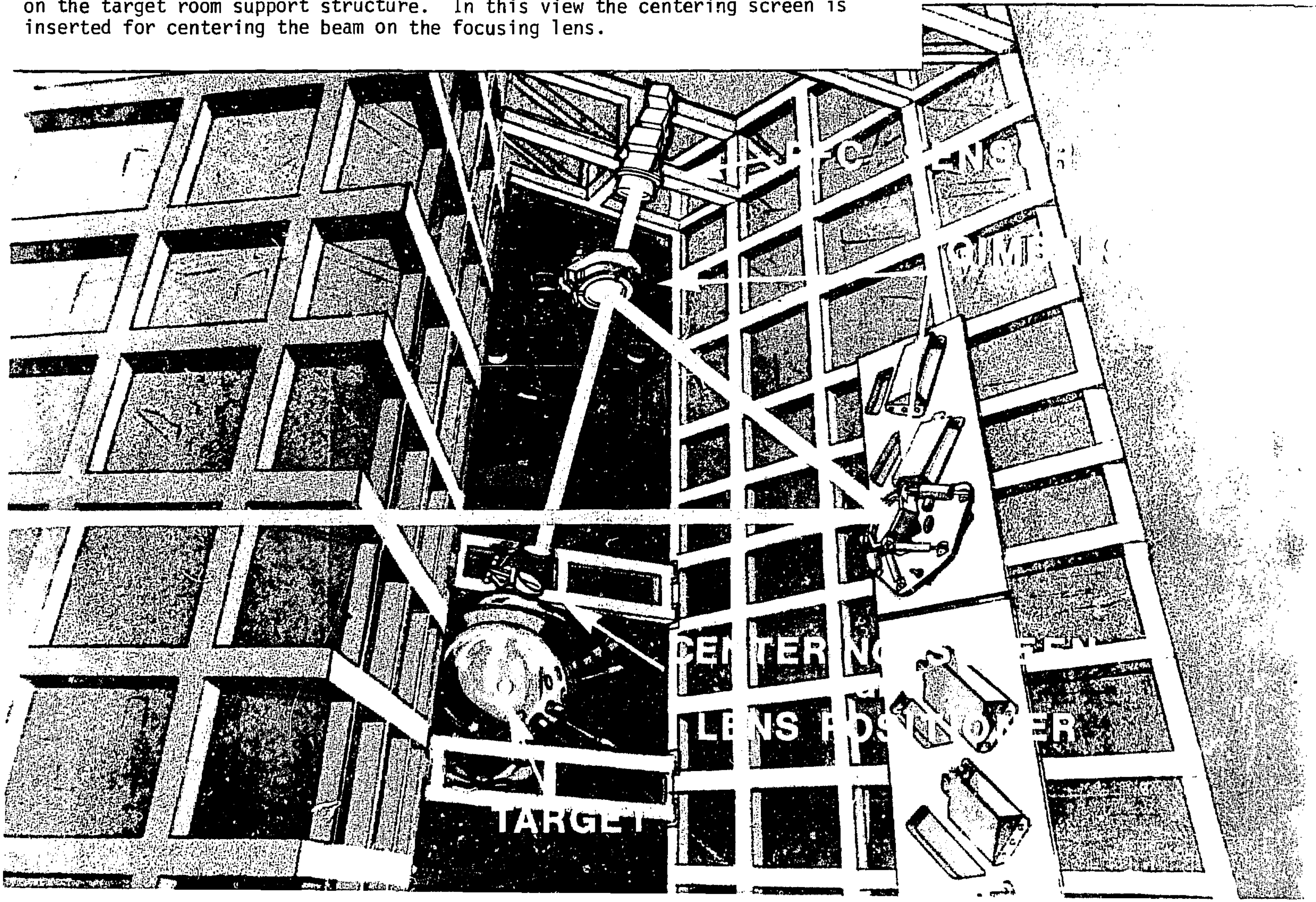


Figure 4. Back illumination of spatial filter pinholes for viewing from the output of a laser amplifier chain.

Figure 5. Arrangement of the output pointing, focusing, and centering components on the target room support structure. In this view the centering screen is inserted for centering the beam on the focusing lens.



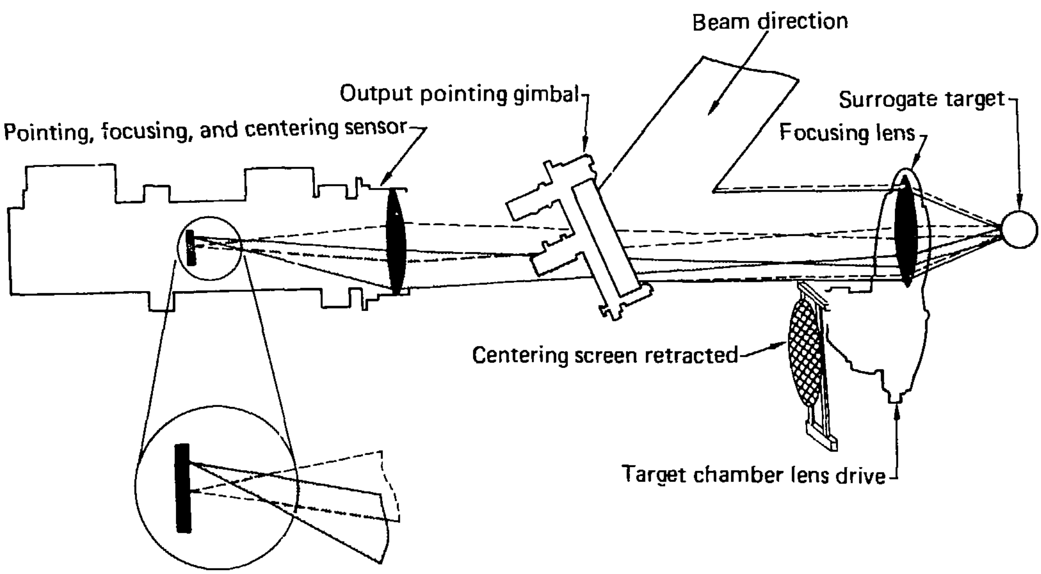


Figure 6. Operation of the output pointing, focusing, and centering sensor in the output pointing mode. The dashed lines show a properly pointed beam. The shaded area shows the path followed by a beam pointed slightly below the center of the target.

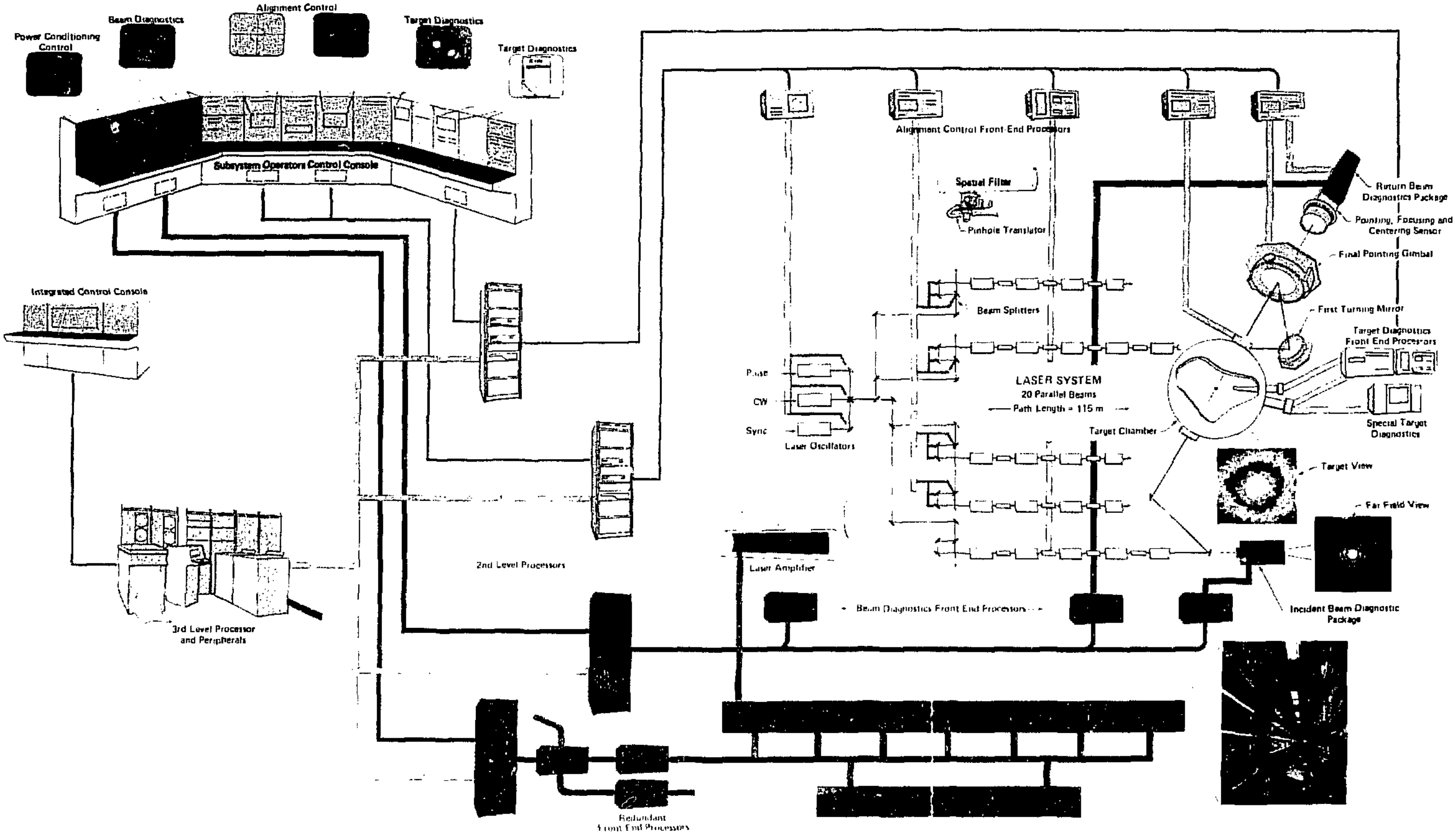


Figure 7. The Shiva digital control network. Each of the 4 major laser sections (power conditioning, alignment, beam diagnostics, and target diagnostics) is interfaced to sets of first-level or front-end microprocessors. These are in turn connected to a second-level minicomputer associated with each laser section. A top level computer connected to the 4 minicomputers will provide overall integrated control.

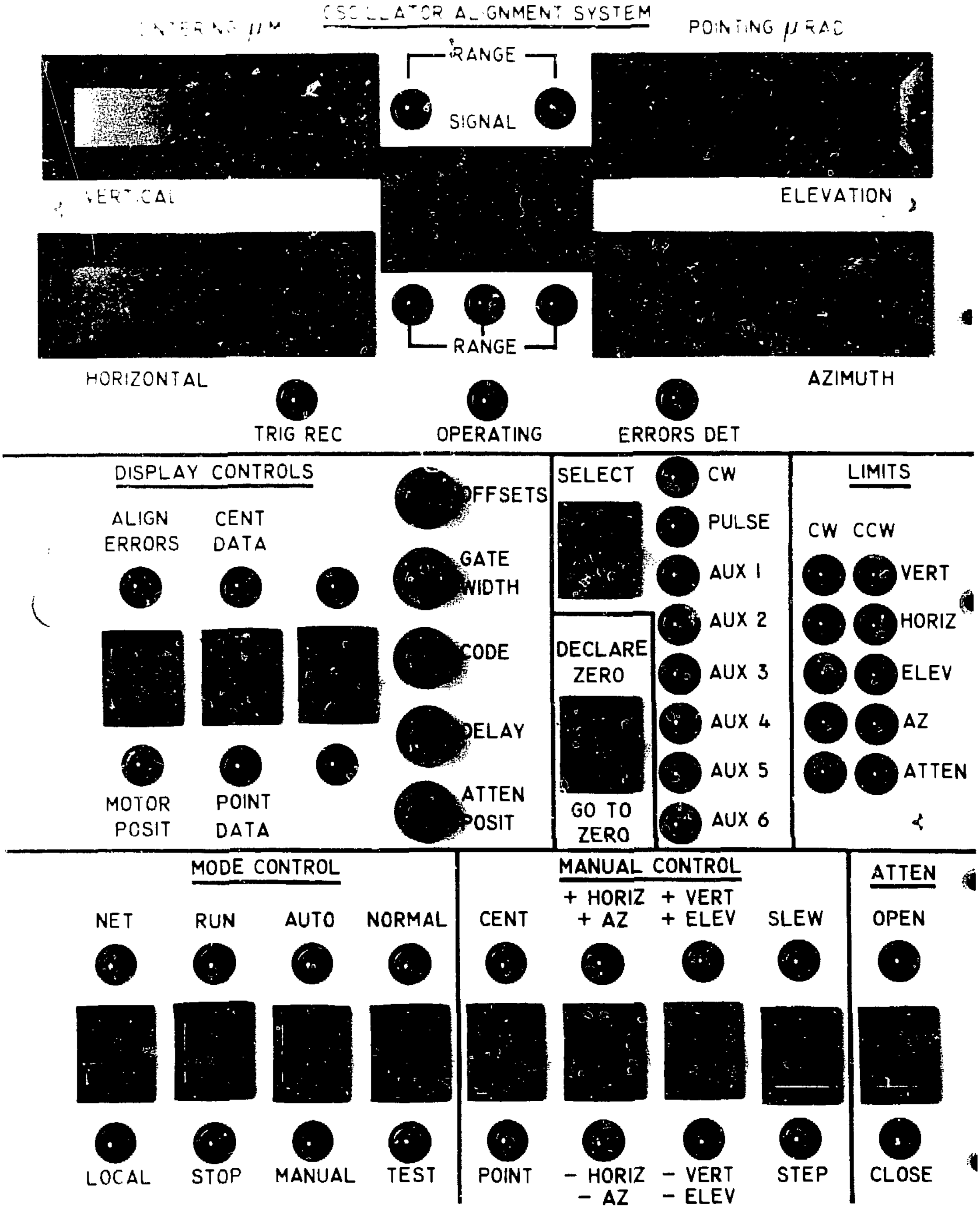


Figure 8. The local control panel for the oscillator alignment system. This panel is typical of the operator interface provided at the front-end processor level of the three level control network.