OMEGA EP
System Operations Manual
Volume VII–System Description

Chapter 3: Laser Amplifiers

Chapter 3
Laser Amplifiers

3.0 INTRODUCTION

The disk amplifiers and their associated power conditioning units are the basic building blocks of the laser, providing the necessary gain and resulting infrared energy. This chapter describes the booster and main 40-cm disk amplifiers that are located in the Laser Bay on the second floor of the OMEGA EP Laser System facility, as well as the 15-cm disk amplifiers on the first floor in the Laser Sources Bay. The amplifiers use xenon-flash-lamp–pumped, Brewster's-angle, Nd-doped glass disks[1] to provide high and relatively uniform gain across their aperture while avoiding thermal gradients transverse to the laser propagation direction. The basic staging of the 40-cm main and booster amplifiers is similar to that of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL).[2] This approach allows the OMEGA EP system to use a modern multipass design and to benefit from experience gained on the Beamlet and NIF lasers. A plan view of such an amplifier is shown in Fig. 3.1.

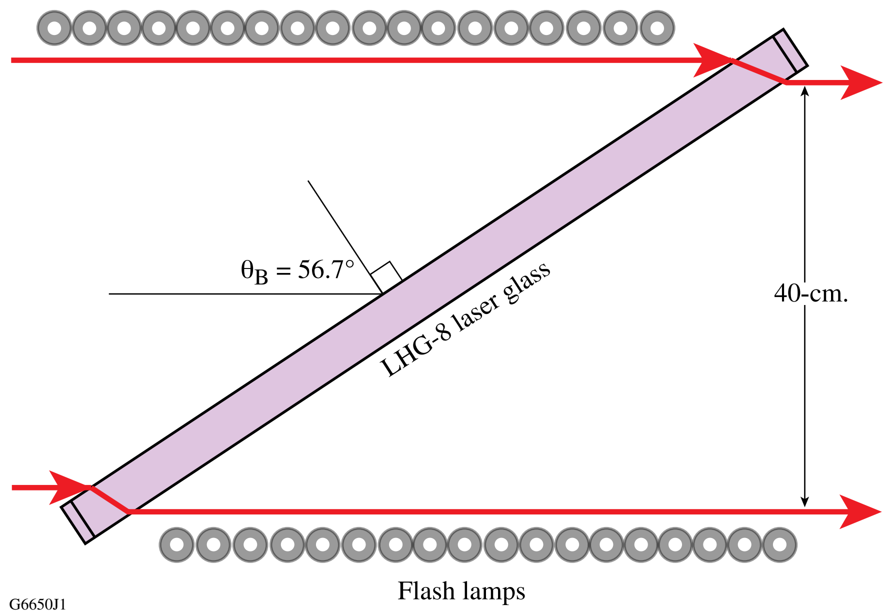


Figure 3.1
Plan view of a Brewster-angled disk amplifier

The OMEGA EP amplifiers differ from those of the NIF in three ways. First, OMEGA EP uses a more modular mechanical-design approach than the highly integrated line-replaceable-unit (LRU) concept[3] used in the NIF, reducing the dependence on expensive robotic handling equipment. Second, the OMEGA EP amplifiers use water-cooled flash lamps[4] to improve the thermal recovery rate. This necessitates single-segment amplifiers (SSA's) rather than the multisegment amplifiers that are used to improve bank-to-disk transfer efficiency in the NIF. The decrease in energy efficiency is traded off against the ability to take at least one shot every 2 hours. The higher shot rate enhances the effectiveness of the OMEGA EP scientific program. Third, OMEGA-like power conditioning (see Volume VII, Chap. 4: Power Conditioning, S-AD-M-008) is used to drive the amplifier flash lamps, taking advantage of the commonality with existing OMEGA parts, procurements, and training.

Beamlines 1 and 2 can operate in either short-pulse (1 to 100 ps) or long-pulse (1 to 10 ns) mode. These beamlines have identical configurations and are 3 m apart. OMEGA EP amplifiers are not compatible with pulses less than 1 ns so they drive the requirement that short pulses are stretched prior to amplification. Beamlines 3 and 4 operate only in long-pulse mode; therefore, their configurations are identical and are similarly displaced from each other. All four beamlines, in long-pulse mode, can be frequency converted from 1053 nm to 551 nm or 351 nm.

The system architecture and design details of the main and booster amplifiers are described in the following sections.

3.1 Main and Booster 40-cm Disk Amplifiers

3.1.1 System Architecture

The multipass laser-system architecture used for the NIF was chosen for OMEGA EP and offers several advantages over the conventional master oscillator/power amplifier (MOPA) configuration used in the OMEGA system. These advantages include higher extraction efficiency at fixed amplifier output fluence, physical compactness, lower temporal-pulse distortions at the output fluences envisioned,[5] reduced total B-integral (ΣB), and reduced cost. B-integral is a measure of the phase retardation accumulated as a beam propagates through a medium possessing a nonlinear index of refraction. This phase retardation can cause self-focusing of optical noise in the beam, creating intensity modulations that can result in severe damage to a laser system by exceeding the damage fluence of the laser glass. Reduced ΣB is particularly important in the chirped-pulse amplification (CPA) mode because ΣB can limit the ultimate degree of compression that can be achieved in the output pulse.[6–8]

As the beam moves through the main and booster amplifier sections, B-integral accumulates and intensity modulations form on the wave front. Spatial filters separating the main and booster amplifier sections decrease the intensity modulations and essentially reset the wavefront distortion to an acceptable level by removing the spatial components that do not focus through the pinhole of the spatial filter. The estimated cumulative B-integral for a beam having an energy of 3.1 kJ and a pulse width of 1.13 ns within the IR portion of the beamline is shown in Fig. 3.2.

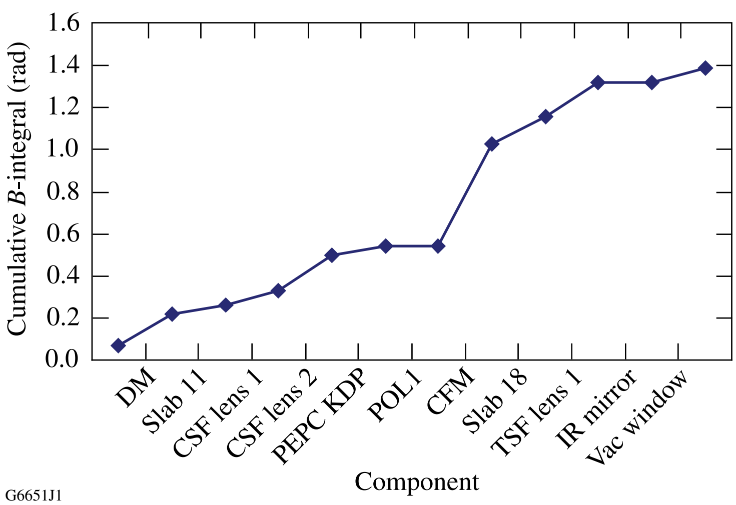


Figure 3.2
Cumulative B-integral for the last pass of the laser pulse

A main amplifier consisting of 11 SSA's and a booster amplifier consisting of 7 SSA's were chosen for each of the four beamlines in order to produce sufficient energy to meet the program's science requirements. Moreover, it is a configuration that could be practically constructed with other beamline components within the physical constraints of the facility. A 13-main, 5-booster configuration of amplifier segments was considered an acceptable alternative configuration based on optical and energy performance. The two systems were compared in the "13-5 versus 11-7" analysis.[9] The 11-7 system is preferred because of the lower *B*-integral and reduced wavefront degradation in four-pass operation. (The four-pass operation is described later in this section.)

Figure 3.3 shows the main component staging from the pulse injection at the injection mirror in the transport spatial filter (TSF) vessel to the diagnostic beamsplitter (DBS) at the exit of the TSF. Each beamline is "folded" into two levels with the center of the beams spaced 1.5 m apart. The upper level includes a 7-disk booster amplifier (BA), the TSF, and a fold mirror. The lower amplifier level forms a cavity between the cavity end mirror (CEM) and the deformable mirror (DM). This cavity includes an 11-disk main amplifier, a cavity spatial filter (CSF), a plasma-electrode Pockels cell (PEPC),[1,2] and two polarizers, POL1 and POL2. POL2 (also known as the short-pulse polarizer, SP-POL) is only used for short-pulse operation and is not required for Beamlines 3 and 4. Its function is further described in Chap. 5: Optomechanical System, S-AD-M-009.

The horizontally polarized, 5.86-cm spatially square pulse from Laser Sources is delivered via periscope to the injection table located under the pinhole vessel of the TSF where it is steered to the injection mirror located near the pinhole of the TSF. The pulse exits the south TSF lens, where it has expanded to its full size of ~36 cm, becomes collimated, and enters the booster amplifier. The cavity fold mirror (CFM) reflects the pulse onto POL1, through the PEPC, POL2, the cavity spatial filter (CSF),

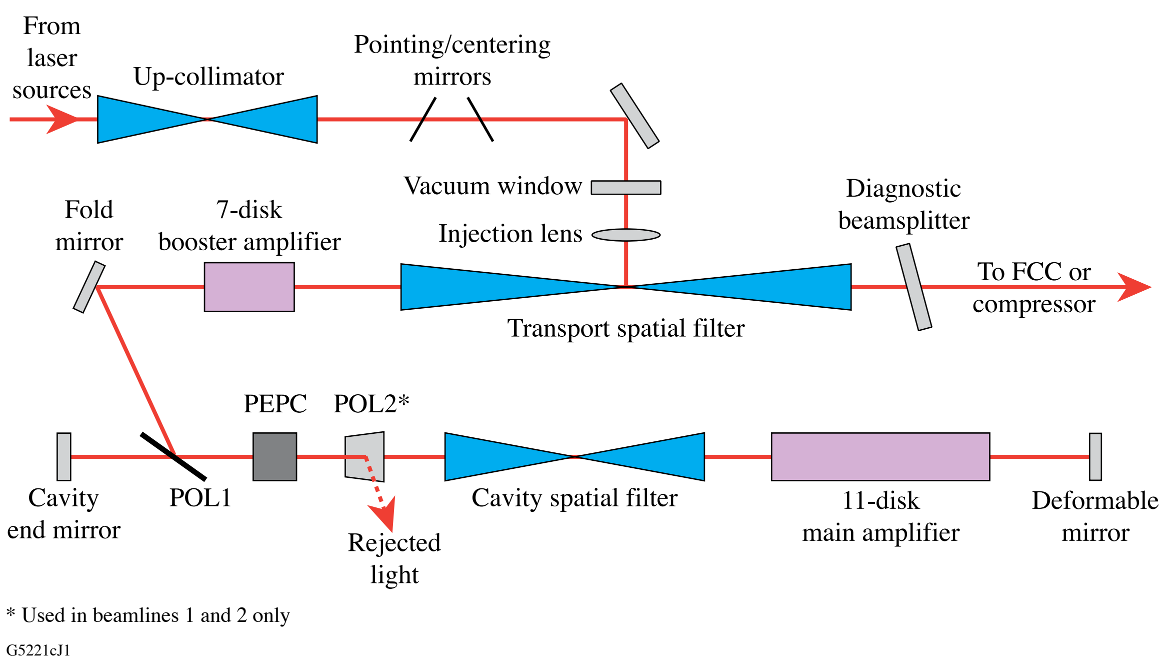


Figure 3.3
Optical components for the injection and amplification portions of an OMEGA EP beamline.

into the main amplifier (MA), and onto the deformable mirror (DM). This constitutes one pass of the system. When the system is operated in two-pass mode, the return pass follows the reverse route, passes through the main and booster amplifiers, and exits the TSF toward the pulse compressor chamber (in short-pulse mode) or the frequency conversion crystals (in long-pulse mode).

When additional energy on target (EOT) is required, the injected pulse may be trapped in the cavity by pulsing the PEPC after the pulse has exited the PEPC on its first pass. After reflecting off the DM, the pulse re-enters the PEPC where its polarization state is rotated from *s* to *p* on POL1 as the PEPC switch pulse occurs. In this polarization, the pulse travels through POL1; reflects off the cavity end mirror (CEM); returns through the PEPC, where it is again rotated back to *s* polarization; travels through the main amplifier; and reflects off the DM. This constitutes the third pass. By this time, the PEPC switch pulse has cycled off, and the return pulse from the DM passes through the PEPC, reflects off POL1, travels up to the CFM, through the booster amp and TSF, and out of the beamline. This completes the fourth pass.

Beamlines 3 and 4 may also operate in two- or four-pass mode, depending upon the EOT requirements.

3.1.2 Amplifier Naming Convention

The naming convention for the amplifiers in the four beamlines is shown schematically in Table 3.1 The convention begins with the last pass of the pulse as it reflects off the deformable mirror. Thus, the main amplifier is named north to south and the booster amplifier from south to north. Since there are 11 SSA's in the main amplifier, it is necessary to use letters and numbers for the 10th and 11th amplifiers, as shown in Fig. 3.4. Figure 3.5 shows the south-to-north naming convention for the booster amplifier.

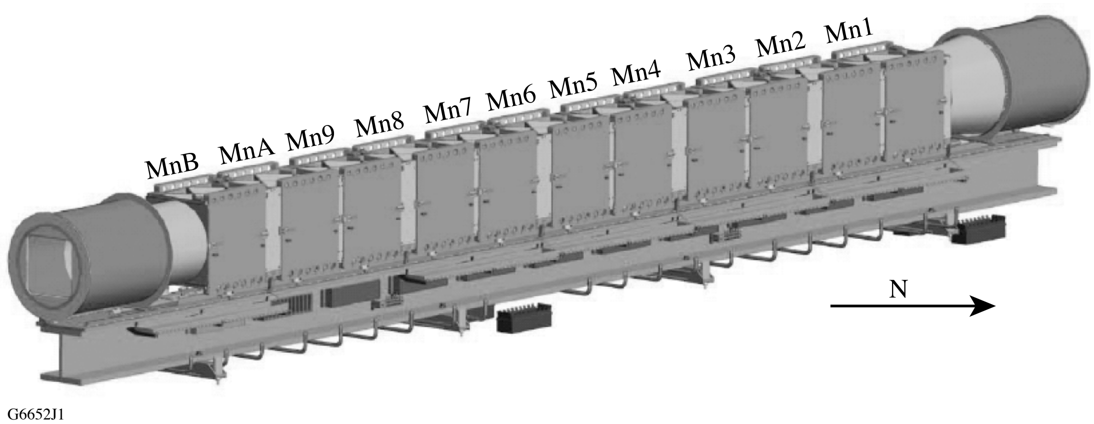


Figure 3.4
Main amplifier naming nomenclature. The letter "n" in the nomenclature refers to the beamline.

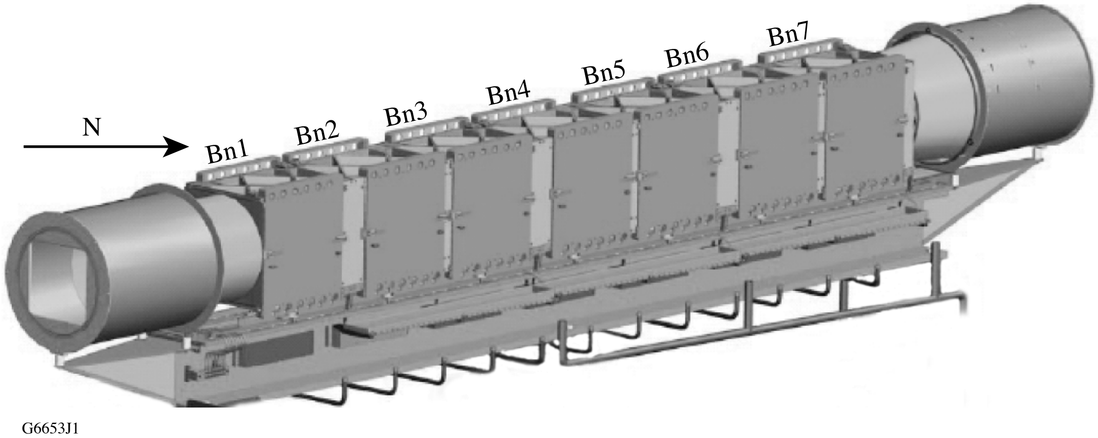


Figure 3.5
Booster amplifier naming nomenclature. The letter "n" in the nomenclature refers to the beamline. Note the number follows the rule of counting disks starting at the DM.

Table 3.1: Seventy-two 40-cm single-segment amplifiers (SSA's) with the 11-7 (main-booster) amplifier system configuration in four beamlines with naming convention are illustrated.

	Booster → / Direction of beam from the deformable mirror to target on the last pass / Main Cavity ←											
Beamline 1	Booster	B11	B12	B13	B14	B15	B16	B17				
	Main Cavity	M1B	M1A	M19	M18	M17	M16	M15	M14	M13	M12	M11
Beamline 2	Booster	B21	B22	B23	B24	B25	B26	B27				
	Main Cavity	M2B	M2A	M29	M28	M27	M26	M25	M24	M23	M22	M21
Beamline 3	Booster	B31	B32	B33	B34	B35	B36	B37				
	Main Cavity	M3B	M3A	M39	M38	M37	M36	M35	M34	M33	M32	M31
Beamline 4	Booster	B41	B42	B43	B44	B45	B46	B47				
	Main Cavity	M4B	M4A	M49	M48	M47	M46	M45	M44	M43	M42	M41

3.1.3 Short- and Long-Pulse Capabilities

In short-pulse operation, the pulse compressor in the grating compression chamber (GCC) compresses the stretched pulse delivered from Laser Sources (see Chap. 2: Laser Sources, S-AD-M-006 and Chap. 5: Optomechanical System, S-AD-M-009) to a width of between 1 to 100 ps. In long-pulse mode (1 to 10 ns), the output pulse is directed to the frequency conversion crystals (FCC) where the IR energy (1ω) is converted to the UV (3ω). Chapter 5: Optomechanical System, S-AD-M-009 describes the pulse transport through the beamline as well as the pulse compressors and frequency-conversion process.

Beamlines 1 and 2 can support either short- or long-pulse operation and their beams may be directed to either the OMEGA or OMEGA EP target chambers. Beamlines 3 and 4 are configured only for long-pulse mode and may be directed to the OMEGA EP target chamber only as 3ω beams.

3.1.3.1 Short-Pulse Injection Requirements

In the short-pulse mode, laser sources provides up to 300 ps/nm of stretch to reduce the fluence in the beamline amplifiers. The cavity amplifier may operate in a two-pass or four-pass configuration. The two-pass mode of operation has three advantages:

1. A wider overall gain bandwidth is achieved because approximately two orders of magnitude of gain are shifted from the relatively narrow-bandwidth Nd:glass to the broadband amplifiers in the front end.

2. Improved beam quality (and therefore focusability) is obtained because the beam makes fewer passes through large optics (notably the 11 cavity disks and the PEPC). This is particularly important for achieving high on-target intensities.

3. It is possible to implement the simple scheme of Ref. 10 to protect the laser from target retroreflections.

The two-pass configuration, however, requires about 12.3 J of raw energy [pre-apodization, (Ref. 11, Table 3.2)] to get 2.6 kJ of energy on target. This high level of energy from a pulse leaving laser sources presents a risk of damaging optics such as the injection mirrors in laser sources and the spatial transport filter. The four-pass configuration requires much lower injection energy,[9] only 0.545 J, as shown in Table 3.2. Short-pulse beams have more than 6 nm of bandwidth associated with them to support gain narrowing in the amplifiers and pulse compression in the grating compressor chamber.

3.1.3.2 Long-Pulse Injection Requirements

In long-pulse (1 to 10 ns) operation, lower input energy is required because the beam passes through the main amplifier section four times[*] and through the booster amplifier section twice. The laser sources requirements are shown in Table 3.2 for two different square pulse widths and compared to the input energy required for short-pulse operations. The bandwidth of the long pulse is typically ±0.3 A at 1053 nm. The spectrum is frequency modulated at 3 GHz with a bandwidth of 0.5 A to suppress stimulated Brillouin scattering (SBS) that could otherwise threaten large optics such as the focus lenses (CDR OMEGA EP SBS Suppression with failsafe system and long pulse pre-amplifier, T-SS-M-003). Various spatial and temporal profiles are available from the pulse-shaping system.

[*]The laser system may also be operated in two-pass configuration in long-pulse mode for lower EOT applications.

Table 3.2: Laser Sources raw energy required (pre-apodization).

	Amplifier passes	Energy on target (kJ)	Pulse Width	Sources energy (J)
Long pulse	4	4.1	2 ns	0.575
Long pulse	4	5.0	10 ns	4.3
Short pulse	2	0.4	>1 ps, < 1 ns	1.5
Short pulse	2	1.0	>1 ps, < 1 ns	3.9
Short pulse	2	2.6	>1 ps, < 1 ns	12.3
Short pulse	4	0.4	>1 ps, < 1 ns	0.070
Short pulse	4	1.0	>1 ps, < 1 ns	0.175
Short pulse	4	2.6	>1 ps, < 1 ns	0.545

3.1.4 Beam Size and Shape

The shape of the beam is square to match the aperture of the amplifiers. The transverse beam cross section is close to being a "flattop" on the final cavity-amplifier pass, at the booster amplifier, and at the frequency-conversion crystals in order to maximize the aperture fill factor[12] and frequency-conversion efficiency, and to minimize the risk of damage due to excessive amplitude modulation. The beam fits within the 40-cm-sq clear aperture of the amplifiers and the PEPC, with allowances made for alignment tolerances and the lateral beam shift accumulated on each pass through the amplifier due to the angular multiplexing of the disks.

The ideal beam is a square with steep edges and a perfectly flat spatial profile with an area of 1260 cm^2 (35.5 × 35.5 cm square). The actual beam edges are apodized over an ~1.3-cm region from full intensity to zero (see Fig. 3.6). This minimizes diffraction of the beam upon propagation away from an image plane and minimizes pinhole loading. The beam intensity is zero outside a 36.9-cm square[13] and has a half-intensity width of 35.6 cm. The corners of the beam are rounded to minimize diffraction. The radius of the corners is ~3.0 cm at the zero-intensity level and ~2.65 cm at the half-intensity level.

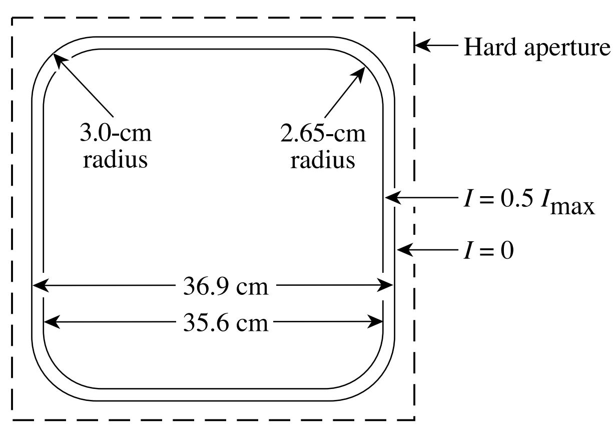


Figure 3.6
40-cm amplifier beam profile, showing contours of intensity $I = 0$ and half the maximum intensity I_{max}.

Amplified spontaneous emission depumping in the amplifier produces a gain coefficient that rolls off toward the edges of the disk. Figure 3.7 illustrates the effect.

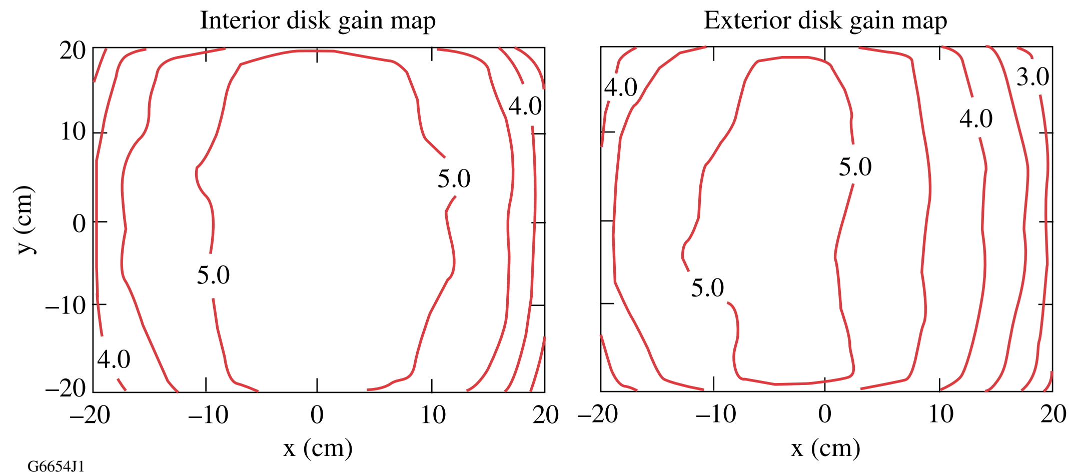


Figure 3.7
Interior and exterior disk gain maps at 13.6 kV. Contours are percent-gain/cm of thickness for LHG8 laser glass.

A nominal gain of ~5%/cm is achieved at the center of the disk, while the edges of the disk produce only ~3% to 4% cm. The roll-off is magnified when the disks are used in the multipass configuration. Figure 3.8 shows the normalized gain after being raised to the 58th power, which is the equivalent of the pulse transversing 58 laser disks as it does in four-pass operation.

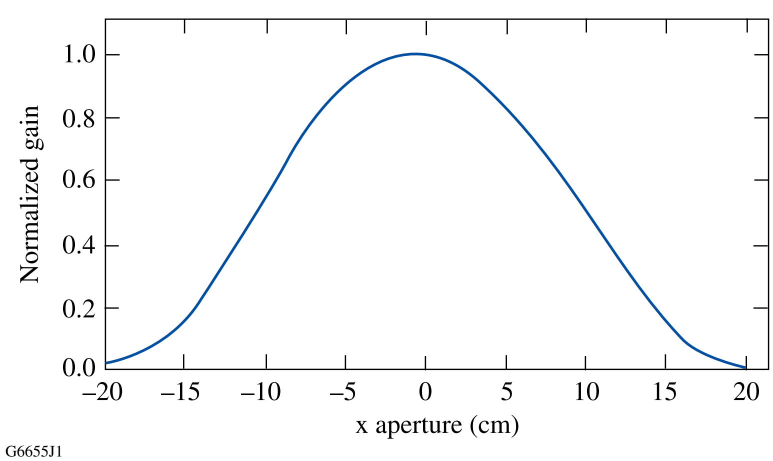


Figure 3.8
A simple approximation of the interior disk horizontal gain line taken to the 58th power.

To compensate for the nonlinear gain profile, the injected pulse must be apodized. Figures 3.9 and 3.10 show the calculated injection beam shape for two- and four-pass operations.

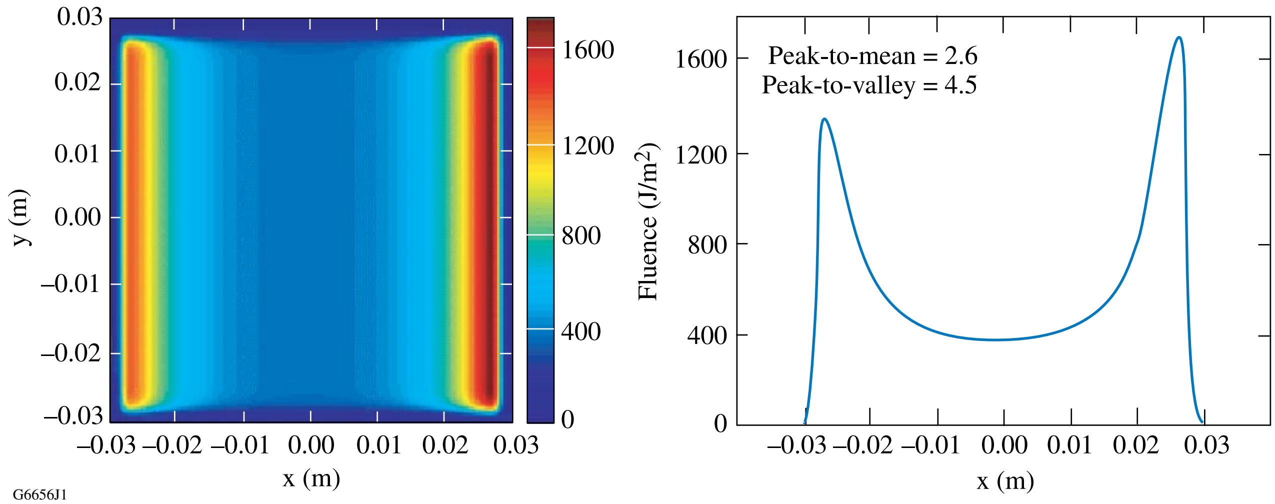


Figure 3.9
Nominal injection beam shape for two-pass mode of operation.

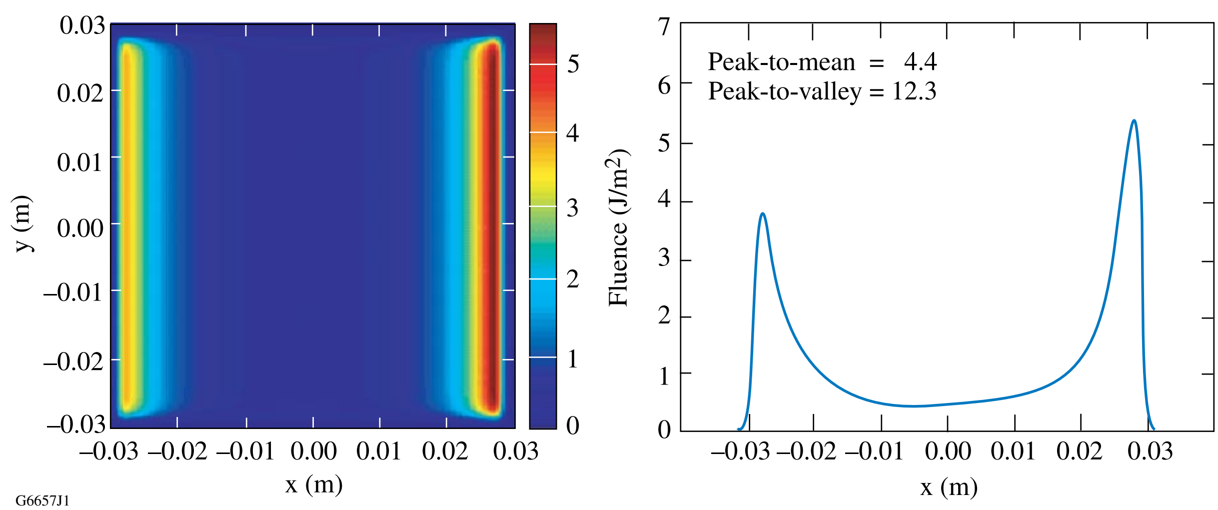


Figure 3.10
Nominal injection beam shape four-pass mode of operation.

Apodization filters are inserted into the beamline in Laser Sources. The apodizer is overfilled by the input beam and “contours” the edges of the beam, making it square to match the aperture of the amplifiers. The goal is to produce a 40th-order super-Gaussian pulse shape. Secondly, it proportionally filters out the energy in the center of the pulse to compensate for the amplifier gain variation with the goal of producing a flat wavefront entering the pulse compressor or the FCC’s. A significant portion of the energy produced in Laser Sources is lost in the process. The resulting pulse shape is frequently referred to as a “half-pipe.” An example** of the input pulse post-apodization is shown in Fig. 3.11. The wavefront budget for Laser Sources has been determined and is documented in “Wavefront Budget, S-AC-X-004.” Excess wavefront errors can be compensated for by the deformable mirror in the cavity.

Gain narrowing of the Laser Sources input pulse by the amplification process significantly changes the spectral shape and width of the laser pulse. The output-pulse spectral shape changes from a high-order super-Gaussian to that of the gain spectrum of the LHG-8 laser glass. As shown in Fig. 3.12,

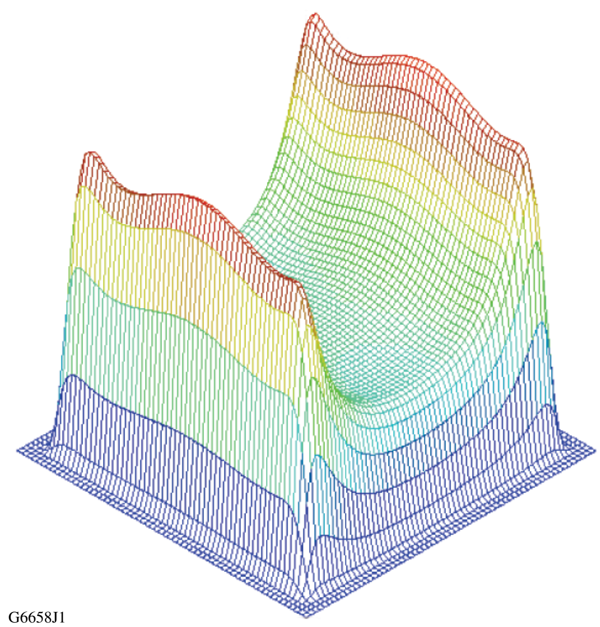


Figure 3.11
The spatial shape of the amplifier input required to achieve a spatially flat output pulse in two-pass configuration.

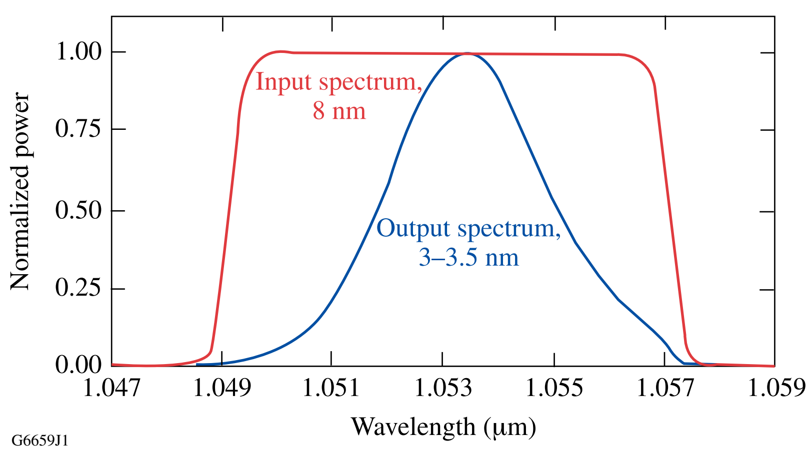


Figure 3.12
An example of gain narrowing caused by the gain profile of the LHG-8 laser glass. The 8-nm input pulse is narrowed to approximately 3–3.5 nm.

**MIRO modeling simulation by L. J. Waxer.

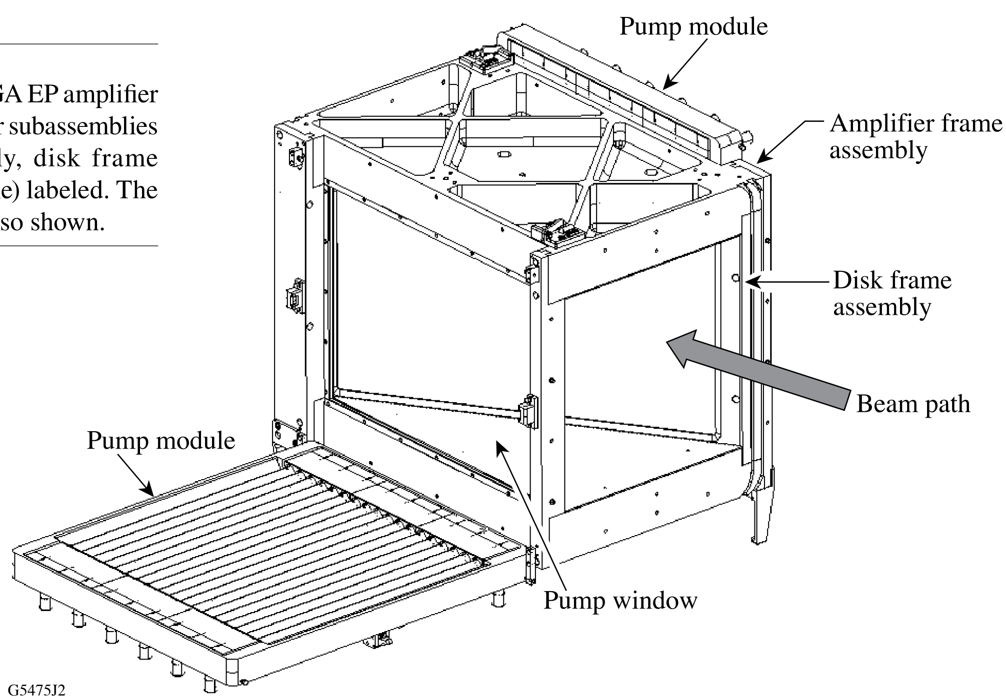
an 8-nm input pulse is narrowed approximately 3 nm to 3.5 nm by the gain profile of the laser glass. Thus, the bandwidth induced by chirping the pulse in Laser Sources is reduced by the gain profile of the amplifiers. This means that at the nominal 300-ps/nm stretch ratio used for short-pulse operation, an input pulse having a temporal duration of 2.4-ns will be reduced to ~1 ns. Thus, gain narrowing in short-pulse operation must be carefully managed to prevent inadvertent reduction of the pulse width that could damage the downstream optics.

3.2 SINGLE-SEGMENT AMPLIFIER ARCHITECTURE

The two major classes of amplifier architecture are the single-segment amplifier (SSA)[14] and the multisegment amplifier (MSA).[15] The MSA seeks to maximize pumping efficiency by eliminating the reflector placed behind the flash-lamp array in the SSA and using the rear side of the array to pump another disk. This is done because the flash lamps are operated in the regime where they are optically opaque, so that a substantial fraction of the reflected light in an SSA is absorbed by the lamp plasma rather than reaching the disk, resulting in a loss of efficiency. SSA's operate with storage efficiencies (defined as the ratio of the stored energy in the laser glass to the energy initially stored in the capacitor bank) of the order of 1%–2%,[16] while MSA-architecture amplifiers can deliver storage efficiencies of the order of 3%–4%.[17]

The MSA architecture is used on the NIF in order to reduce the overall cost of the capacitor bank. The dense packing and cleanliness requirements of the NIF lend themselves to robotic handling equipment and the LRU concept.[3] The OMEGA EP amplifiers use SSA architecture to avoid the expense of robotic handling equipment. Additional power conditioning is required to compensate for the lower storage efficiency of the SSA's, but this is not a significant concern in a four-beam system. A schematic of one OMEGA EP amplifier module is shown in Fig. 3.13. These modules are mounted together on an I-beam support structure, as shown in Figs. 3.14 and 3.15, to form a main cavity amplifier. The elevated booster amplifier support structure is shown in Fig. 3.16.

Figure 3.13
Isometric view of an OMEGA EP amplifier module with the three major subassemblies (amplifier frame assembly, disk frame assembly, and pump module) labeled. The path of the laser beam is also shown.



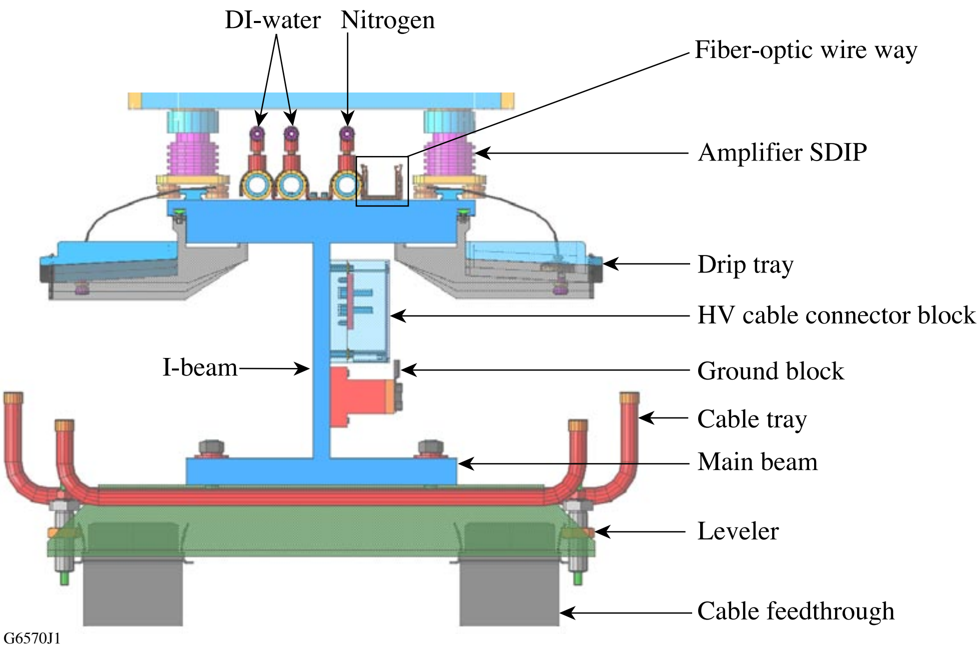


Figure 3.14
The I-beam amplifier support: main cavity structure—end view.

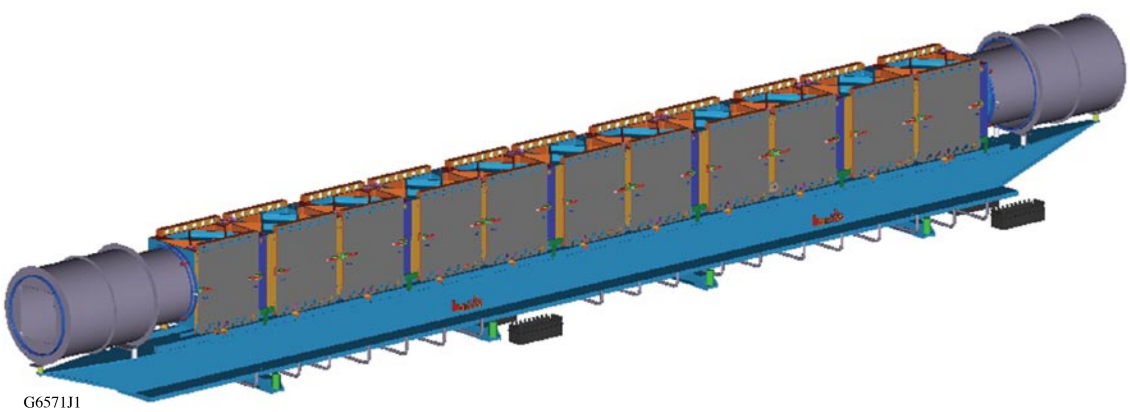


Figure 3.15
Main cavity (11-disk) amplifier with added beam tubes and I-beam support structure. Each module contains one disk.

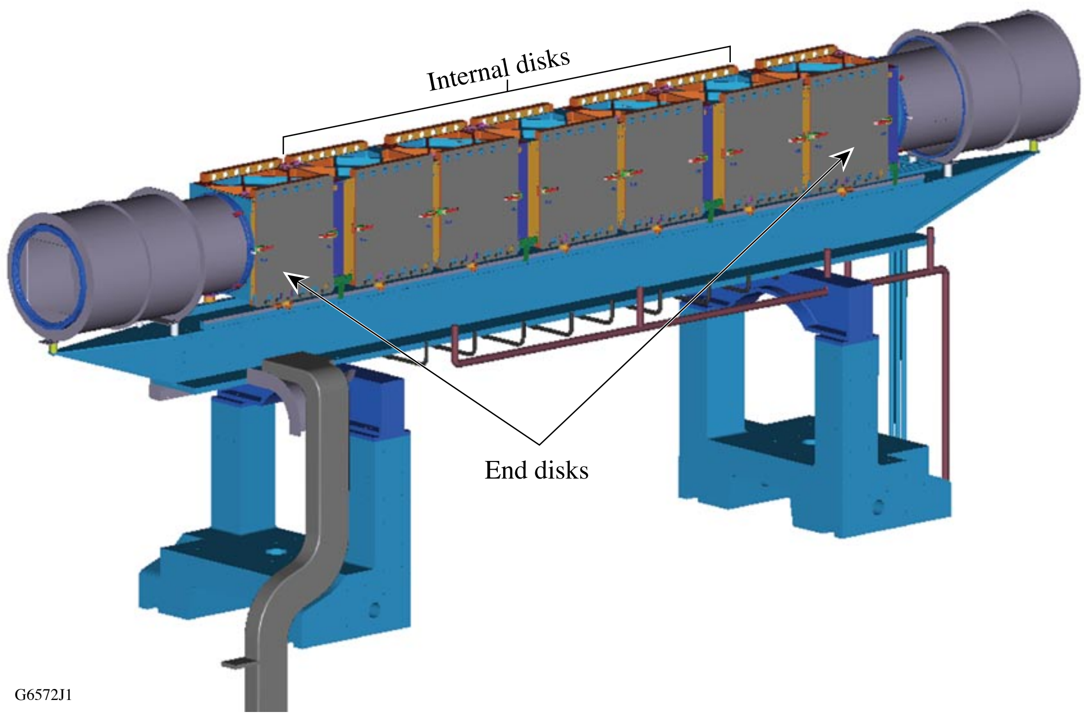


Figure 3.16
Booster (7-disk) amplifier with support structure with added beam tubes.

The LLE-engineered SSA architecture provides additional benefits. The first benefit is that the flash lamps are water cooled since ultraclose packing of interior flash lamps is not required. This eliminates "post-shot thermal soak," a phenomenon whereby heat from the hot flash lamps radiatively transfers to the laser disks for several minutes after the shot, causing increased thermal loading. Water cooling the lamps returns them to ambient temperature in seconds and provides a thermal sink for heat radiated by the disks, which require more than an hour to cool (Ref. 18). Another benefit of the SSA architecture is the separation of the beamlines into individual entities that are three meters apart. This results in considerable equipment space for other components in the laser system, particularly in the focal region of the transport spatial filter where beam injection, alignment sensor packages, and laser diagnostics are located.

Internal disks of the main-cavity and booster amplifiers are pumped by flash lamps from their respective amplifier modules and from adjacent amplifier modules, thereby creating a symmetric roll-off gain profile in the horizontal direction across the aperture. In the case of an amplifier module at the end of the amplifier, the spatial symmetry of the pump is lost, resulting in a gain reduction in the laser glass that lies closest to the exit aperture of the amplifier. The main-cavity and booster amplifiers thus use an odd number of amplifier modules to ensure that both edges of the beam experience this lower gain relative to the center of the beam aperture.

3.2.1 Amplifier Requirements and Specifications

Since the OMEGA EP Laser System is based on the NIF laser system architecture, the baseline amplifier gain and wavefront requirements are the same as those of the NIF. The amplifier performance requirements and the simplified wavefront requirements are based on Secs. 1.1 and 1.2 of the Amplab[19] report, respectively, and are summarized in Table 3.3. More details can be found in the Laser Amplifier Technical Requirements Document S-AC-R-016; MTW, Glass Amplification CDR A-AJ-M-060; and 40-cm Single Segment Amplifier FDR A-AJ-M-059.

Table 3.3: Summary of amplifier performance requirements for OMEGA EP.

Average gain coefficient	5%/cm
Gain uniformity, peak-to-average ratio	<1.05
Prompt-induced wavefront distortion	<2.7 waves, peak-to-valley
Slab thermal distortion for a multipassed chain	<2.2 waves, peak-to-valley
Both the prompt-induced distortion and the slab thermal distortion will be of sufficiently low order as to be largely correctable with the deformable mirror system.	
Shot-cycle time	<2 h

3.2.2 Amplifier Module Configuration

The features of the OMEGA EP amplifier modules are similar to those of the OMEGA SSA's[16] with one notable difference. Each OMEGA disk-amplifier module contains four laser disks, whereas an OMEGA EP amplifier module contains a single disk. This achieves maximum modularity of amplifiers to achieve an economy of scale for procurement. Each amplifier module consists of three major assemblies: the amplifier frame assembly, the disk frame assembly, and the pump module, as shown in Fig. 3.13.

High fluences in the laser disk and pump cavity amplifier components require a high level of cleanliness. The amplifiers operate in a class-1000 laser bay. They are assembled in a class-100 clean room with pump cavity components assembled in a class-10 laminar flow bench. These cleanliness levels drive materials selection, coating requirements, and design techniques. All components that are exposed to flash-lamp light are made of passivated stainless steel, silver-plated stainless steel, silver-plated aluminum, or Alcoa Everbrite.[20] Plastics are not exposed to direct or indirect flash-lamp light because of their tendency to photodegrade and carbonize, contaminating surrounding areas. The contamination propensity was further minimized with careful design by avoiding, where practical, commonly employed design features such as threaded fasteners and sliding contacts.

3.2.3 Amplifier Frame Assembly

The amplifier frame assembly forms the structural backbone to which the other assemblies attach. Its components are aluminum plated with electroless (autocatalytic chemical reduction) nickel. Figure 3.17 shows orthogonal views of the amplifier frame assembly.

This structure provides the necessary torsional stiffness between the horizontal upper and lower plates of the assembly. This stiffness is important for the flash-lamp pump windows that mount in the two large rectangular openings of the amplifier frame assembly. The two larger vertical members and the tongue-and-groove interface (Fig. 3.17) between the horizontal and vertical components prevent excessive out-of-plane deflections that could lead to a structural failure of the pump window.

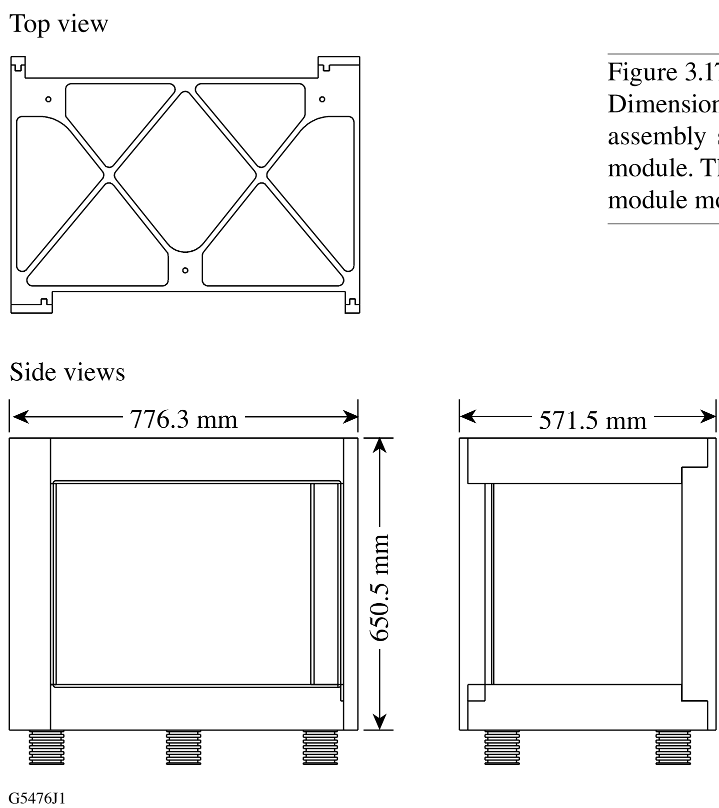


Figure 3.17
Dimensional view of the 40-cm amplifier frame assembly. This assembly serves as the structural backbone of the amplifier module. The disk frame assembly mounts inside and the pump module mounts to the exterior.

3.2.4 Disk Frame Assembly

The disk frame assembly (Fig. 3.18) consists of a disk frame and cover, heat sinks, and marcel springs. (The marcel springs have been omitted from Fig. 3.18 for clarity.) The marcel springs are made from stainless steel, and all remaining components are made from 6061-T6 aluminum. The heat sinks are electroless nickel plated, while the disk frame and cover are silver plated.

The frame assembly provides both optical and mechanical functions. Mechanically, the frame holds the laser disk in a low-stress state and provides a mechanical interface to the amplifier frame. The frame assembly mounts kinematically within the amplifier frame to provide accurate positioning and minimal stress on the disk. This configuration ensures that the disk is not subjected to stress during handling of the amplifier module. The disk frame cover is attached to the disk frame using a spring-loaded pin as shown in the detail view of Fig. 3.18. The resulting contact pressure on the laser disk is chosen to ensure that stress-induced birefringence is minimal at the edge of the clear aperture.

Optically, the disk frame and frame cover shield the cladding glass from excessive thermal loading from flash-lamp light. The heat sinks are in direct contact with the laser glass. An offset aperture mask decreases the pumping of unused laser glass (Fig 3.19), and the net effect is to help reduce prompt and cumulative wavefront errors.[18]

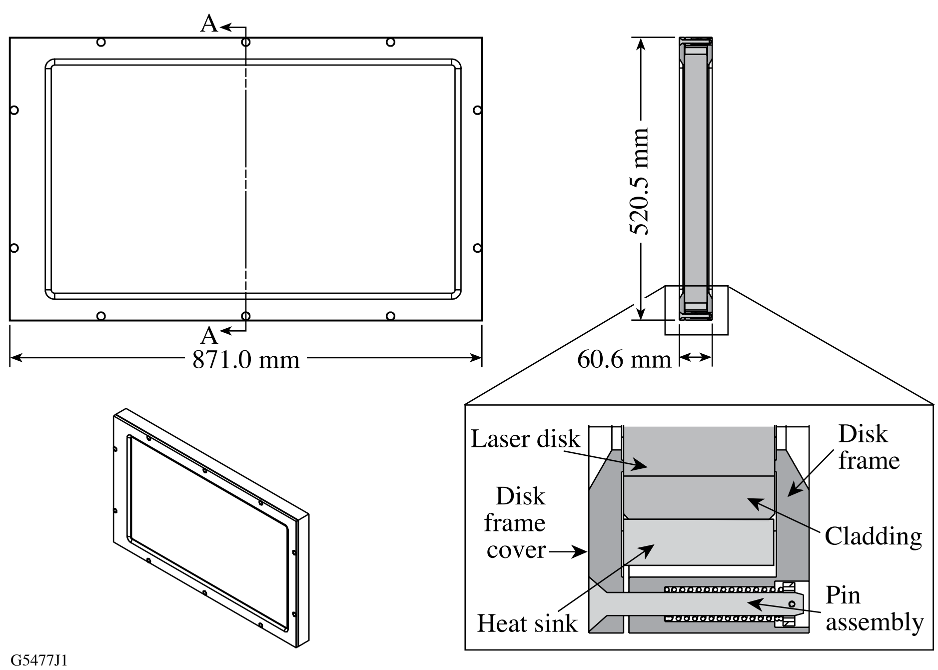


Figure 3.18
Dimensional and sectional views of the disk frame assembly. This assembly serves as a structural backbone of the amplifier module. The disk frame assembly mounts inside and the pump module mounts to the exterior.

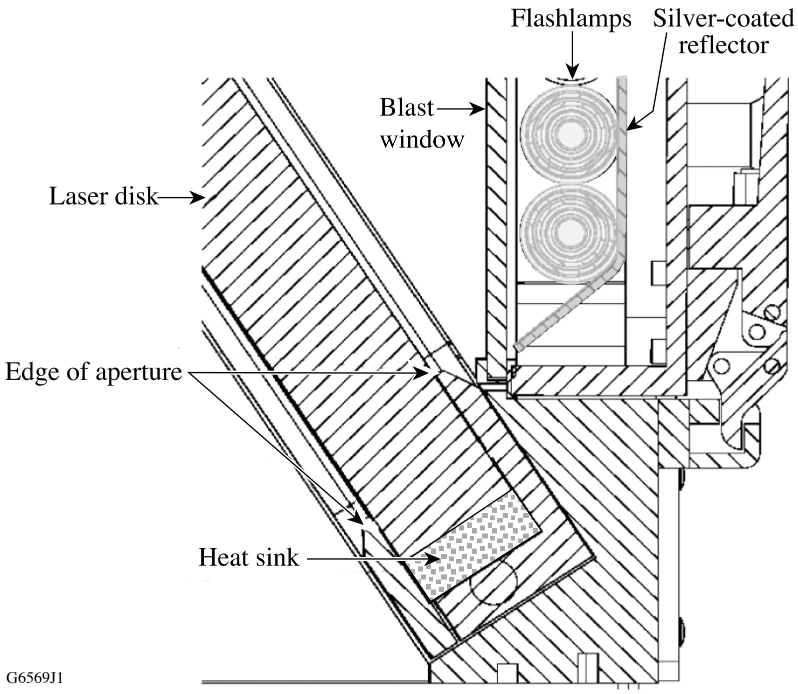


Figure 3.19
The off-set aperture mask eliminates the pumping of unused laser glass and with the heat sink prevent excessive thermal loading from flash-lamp light.

3.2.5 Pump Module

A water-cooled flash-lamp assembly is shown in Fig. 3.20. It consists of a flash lamp, a Pyrex water jacket, and two flash-lamp connector assemblies. The connector assemblies provide the electrical connections to the flash lamp as well as the means for moving cooling water into and out of the assembly. The flash-lamp assembly is insensitive to the direction of coolant flow, and the 18 lamps on each side are plumbed together in series. All wetted components that are exposed to flash-lamp light within the flash-lamp assembly are made of quartz, glass, or stainless steel.

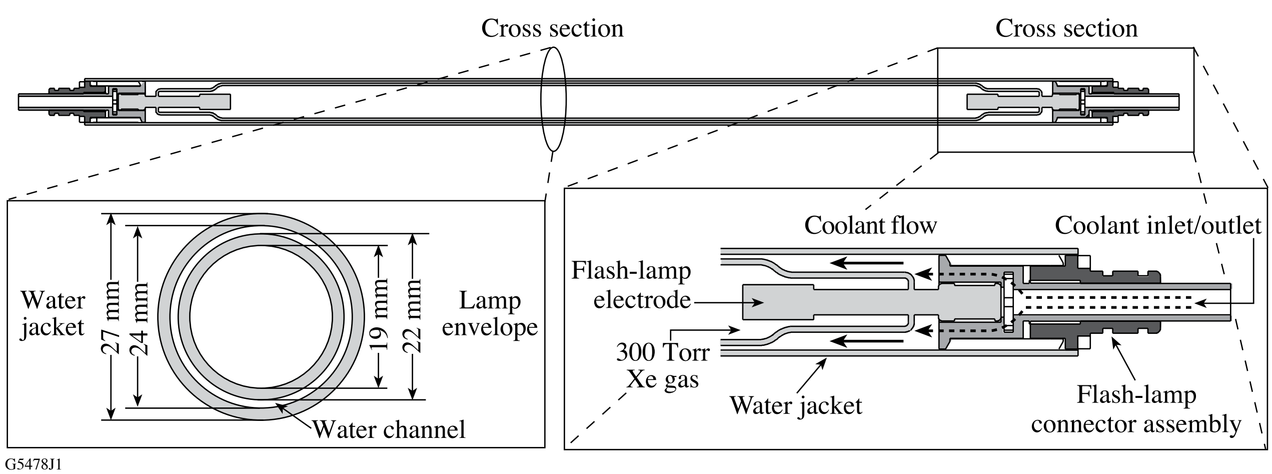


Figure 3.20
Sectional view of a water-cooled flash-lamp assembly.

A pump module fitted with 1.9-cm-bore flash lamps and consisting of three flash-lamp brick assemblies is used to energize one side of the amplifier module. Two pump modules energize each amplifier disk, one on each side. Six flash lamps are grouped together to form a flash-lamp brick assembly. One half of a brick contains three lamps that are connected in series electrically and powered by one pulse-forming network (PFN); 12 PFN's are used for each 40-cm amplifier module.

One side of the pump module is hinged to the frame assembly so that the pump module can swing down from the amplifier frame assembly to provide quick access to the flash-lamp bricks (see Fig. 3.13). In the event of a flash-lamp failure, a brick can be readily replaced, without requiring any tools, prior to the next laser shot.

The laser disks are pumped with flash lamps that have pulse durations of 550 μs and 360 μs for the 15-cm and 40-cm disk amplifiers, respectively. The 15-cm disk amplifier is physically identical to the 15-cm disk amplifier used on the OMEGA Laser System and is described in Ref. 21. Each 40-cm disk SSA has 36 flash lamps. The lamps are 1.9-cm-bore, 300-Torr, xenon-filled flash lamps, each with an arc length of 43 cm. Three lamps are wired in series to create a circuit length of 129 cm. The 15-cm disk amplifier has flash lamps with a length of 132 cm. Other than the arc length, the features of these flash lamps are identical to those of the 15-cm disk amplifier, which is used in OMEGA and the Laser Sources area of OMEGA EP.

In OMEGA EP, the 15-cm disk amplifier is used as the final power amplification stage in Laser Sources area, and its use is described in detail in Volume VII Chapter 2: Laser Sources S-AD-M-008.

The flash lamps are water-cooled, providing a number of advantages over their air-cooled counterparts. These lamps can run at a higher explosion fraction (the operational energy divided by the maximum energy a lamp can survive and not explode). Water-cooled lamps are operated at 26% to 34% of their explosion fraction, whereas air-cooled lamps are normally operated at 20% to 25%. The de-ionized (DI) water that is used to cool the lamps eliminates electrical arcing because of its high resistivity (>15 MΩ-cm). The DI water also provides mechanical support, allowing the use of lower-cost, industry-standard, 1.5-mm thick jackets. Water-cooled flash lamps also increase the transfer of thermal energy out of the amplifier after a shot. Air-cooled lamps, which dissipate thermal energy by radiation, ultimately heat the laser glass after a shot; water-cooling removes this heat without greatly heating the laser glass. Even with water-cooling, the flash can increase the bulk laser glass temperature by approximately 0.65°C. And, because of a mechanism known as amplified spontaneous emission,[22] some light is propagated and amplified laterally through the glass toward the edges where it is absorbed by the cladding glass and can increase the heatsink temperature by approximately 9.8°C. The heatsinks, as previously discussed, are a key part of the disk frame assembly (Fig. 3.18) used to manage the heat generated by the lamps and enable a less than two-hour shot cycle.

Along with the visible light used to pump Nd-doped glass laser, xenon flash lamps produce large amounts of UV light. The solarization of phosphate laser glass when exposed to intense UV light is a problem in high-power laser designs. Cerium-doped quartz (CDQ) flash-lamp envelopes are used to mitigate this effect by absorbing much of the UV radiation from the flash-lamp discharge.

3.3 LASER GLASS

LHG-8 laser glass[23] was chosen for both the 15-cm and 40-cm disk amplifiers as the active medium because it meets the needs of the OMEGA EP project and is a proven low-risk technology used on OMEGA. It is a well characterized, athermal phosphate laser glass that provides a high cross section for stimulated emission, extremely low 1-μm absorption, and a reduced nonlinear index of refraction when compared with the silicate glasses. LHG-8 can be melted in production quantities while maintaining sufficient homogeneity and low-particulate platinum content. (Platinum inclusions[24–26] in phosphate glass can cause fractures when irradiated by high-energy laser pulses.) Additional background information on the glass decision can be found in Refs. 27 and 28.

The disk-cladding technology used for the amplifier disks was developed at LLNL[29] utilizing an epoxy polymer bond to attach copper-doped LHG-8 glass to the disk edges in a stress-free manner. This cladding effectively reduces parasitic oscillations through absorption.

3.4 AMPLIFIER STRUCTURE

The amplifier I-beam structure (Fig. 3.14) provides the spatial foundation of the amplifier within the laser system. The main cavity amplifier structure (Fig. 3.15) and the booster amplifier structure (Fig. 3.16) support 5,000 and 2,300 kg, respectively. The structures have sufficient stiffness to deflect less than 0.25 mm between unloaded and loaded states to maintain acceptable alignment tolerances. Since the amplifiers are optics used in transmission only and do not reflect or focus the beam path, the minimum allowed natural frequency of these structures is reduced from 25 Hz to 2 Hz. Type A36 structural steel was used where possible to meet this requirement. Additionally, the structures are designed in such a manner as to not encumber routine maintenance tasks. This is accomplished by using the open, I-beam structures as described.[30]

The location of the amplifiers within the class-1000 clean room environment of the Laser Bay adds requirements to the surface finish of the structures. The structures must be readily cleaned by wiping, which dictates that the exposed surfaces must have a smooth finish. This was achieved by a combination of surface preparation (sanding) and coating. Epoxy paint was chosen for the amplifier structures as specified in Ref. 31.

A number of requirements were placed on the interface between the amplifier and structure. The amplifier and structure have different grounding paths. The amplifier is grounded through the PCU that powers the amplifier, and ground faults to the structure return to the main power conditioning ground buss. In a fault scenario, an electrical potential can develop between the amplifier and the structure. The interface is thus electrically isolated to prevent a conducting "track path" and an air gap that may be arced. The amplifier structures also provide the supporting platform for the high-voltage discharge cables and the DI-water and nitrogen services to the amplifiers. The grounding and facility safety interlocks are discussed in Volume VII, Chap. 9: Facility and Safety Interlocks, S-AD-M-009. The amplifier discharge cables and the DI-water and nitrogen services attach to the vertical portion of the I-beam. In this configuration, all services are readily accessible from either side of the amplifier. More information on the amplifier structures can be found in the Amplifier Structures, FDR B-DB-M-011.

3.5 Nitrogen Purge Supply

To improve the cavity transfer efficiency of the laser amplifiers, all large metallic surfaces within the pump volume are electroplated with silver. Since silver degrades when exposed to sulfur and ozone, the amplifier cavity is purged with nitrogen to prevent the formation of silver sulfide or silver oxide on the silver-plated surfaces. The amplifiers are connected to the adjacent components in the system with beam tubes. With this configuration, the amplifier cavity is enclosed, but not airtight, and requires a flow rate of the order of 0.1 standard cubic feet per minute per disk to maintain a high-nitrogen environment.

The nitrogen distribution system consists of a main distribution line from a research-grade nitrogen source connected to four distribution lines. All the nitrogen lines are made of copper pipe. A low flow velocity is maintained in the copper pipes, allowing the nitrogen time to thermally adjust to the laser bay ambient temperature prior to delivery to the amplifiers. The nitrogen passes through a Zeolite molecular sieve filter before reaching the amplifiers to remove any additional impurities, such as sulfur. The nitrogen from the amplifiers is also allowed to migrate and fully fill the attached beam tubes.

3.6 De-ionized Water System

LLE has a long history of using water-cooled flash lamps in laser amplifiers.[4,32–35] The two primary benefits of water-cooled flash lamps are thermal management and electrical insulation. The DI water system supplies the 15-cm disk amplifier in the Laser Sources area and the main and booster amplifiers in the Laser Bay. This water system has four parallel loops: distribution, polishing, temperature regulation, and ignitron cooling. The required flow rates through the four loops are shown in Table 3.4.

Table 3.4: Cooling system flow distribution.

Loop	Flow rate (gpm)
Distribution	150
Polishing	30
Temperature regulation	20
Ignitron cooling	20
Total Flow	220

The polishing loop establishes and maintains the overall water quality within the system. The minimum acceptable water quality is electronics grade type E-1, whose attributes are shown in Table 3.5. The polishing loop consists of reverse osmosis, UVA and UVB lamps, de-ionizing resin elements, and filters connected in series.

The temperature of the water supplied to the amplifiers is controlled to ±1ºC. Water flows through a water/water plate heat exchanger. Temperature control is achieved using an active feedback control loop that operates a variable flow control valve. The valve modulates the flow rate on the secondary side of the heat exchanger, leaving the flow of the primary DI water unrestricted.

Table 3.5: Water quality requirements.

Property	Value
Resistivity (MΩ-cm)	>15
Silica (SiO_2) (mg/liter)	<5.0
Particles/ml	<1.0
Particle-size limit (μm)	<0.1
Copper (μg/liter)	<1.0
Zinc (μg/liter)	<0.5
Nickel (μg/liter)	<0.1
Sodium (μg/liter)	<0.5
Potassium (μg/liter)	<2.0
Chloride (μg/liter)	<1.0
Nitrate (μg/liter)	<1.0
Phosphate (μg/liter)	<1.0
Sulfate (μg/liter)	<1.0
Total organic content (μg/liter)	<2.5
Viable bacteria (number/liter)	<1.0
Endotoxin units (EU/ml)	<0.3

The distribution loop within the Laser Bay is comprised of four main distribution loops in parallel, one for each beamline. Within each loop there is parallel distribution to the amplifiers. Two cooling circuits are provided for each amplifier, one for each side. Each circuit supplies water in series to the 18 flash lamps, which are connected in series. Two flow meters allow flow monitoring on the return line on each side of the amplifier. A drip tray catches any leaks. The laser system DI cooling is shut down when the amplifier facilities controller (AFC—described in Sec. 3.7) detects a leak or insufficient flow through a flash lamp brick. Additionally, PCU charging is inhibited if a leak, low flow, or a door fault is detected.

3.7 Amplifier Facilities Controller and Interlocks

The utilities and interlocks required to operate the laser amplifiers are readily divided into four subsystems: power conditioning, cooling, nitrogen, and interlocks. As described in Volume VII, Chap. 4: Power Conditioning S-AD-M-008, the power conditioning system provides the energy for the flash lamps within the amplifiers. The cooling system consists of the closed-loop DI water system. The nitrogen system provides a purge environment within disk cavities and flash-lamp pump modules. Amplifier interlocks are associated directly with amplifier hardware to ensure safe operation.

A primary function of the AFC is to provide the amplifier staff a single status-state indicator for maintenance. Due to the HV hazards that may be present on the amplifiers, an operator must confirm that power conditioning has been placed in a safe state prior to starting any maintenance operation. The AFC provides an indicator for each group of SSA's used to indicate the PCU safe status (Fig. 3.21).

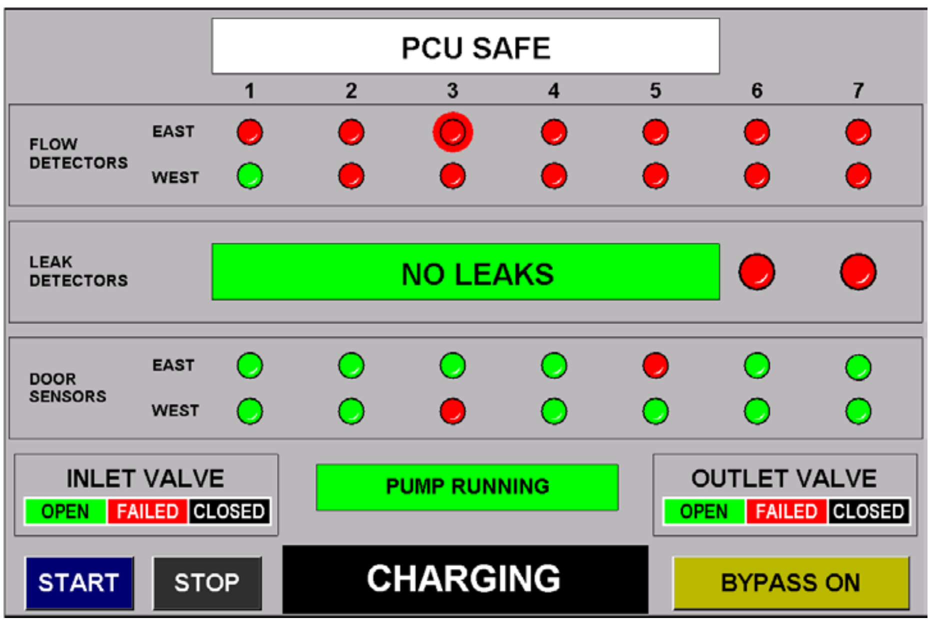


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Figure 3.21
OMEGA EP AFC quick panel view GUI for a booster amplifier with seven SSA's. There are eight GUI's for the four main and four booster amplifiers in the beamline and an additional GUI for laser sources. System status of the amplifier facilities is shown. This includes location and nature of faults, such as cooling water flow, leaks, and door interlocks. A larger red light (flow detector: east, 3) indicates the first, latched fault.

To prevent unsafe operation, the AFC provides fail-safe monitoring of the critical services of cooling water flow, interlock sensors, and leak detectors to each of the OMEGA EP main and booster laser amplifiers and the laser sources glass amplifier. It provides status information about the readiness of the amplifiers for shot operations and acts as an interface between the laser amplifier, laser sources, power conditioning, pump supervisor, local operator, and remote monitor systems (Fig. 3.22).

The pump supervisor is incorporated into the laser system's building facilities that interface with the GE-Fanuc programmable logic controller (PLC) equipment. Software programmed into the facility's PLC monitors the flow rates, pressure, temperature, resistivity, and other parameters of the de-ionized water system.

The AFC and its laser amplifier structure interface via fiber optics to avoid damaging on-shot energies coupling into the AFC. There is one AFC for each amplifier and its associated power conditioning units (PCU). The AFC provides information locally to the amplifier laser technician (ALT). The remote monitor allows maintenance personnel to view the real-time operational status of each AFC and pump supervisor and automatically logs information remotely on shot.

There are nine AFC's. The Laser Sources AFC is located in the Laser Sources area. The other eight AFC enclosures are located in the Laser Bay. There is one AFC for each amplifier or two for each of the four beamlines. Each AFC is located near the main that it supports. More detail can be found in the Amplifier Facilities Controller Requirements Definition, A-AK-R-001; the Amplifier Facilities Controller, CDR C-AR-M-001; and the Amplifier Facilities Controller, FDR C-AR-M-002.

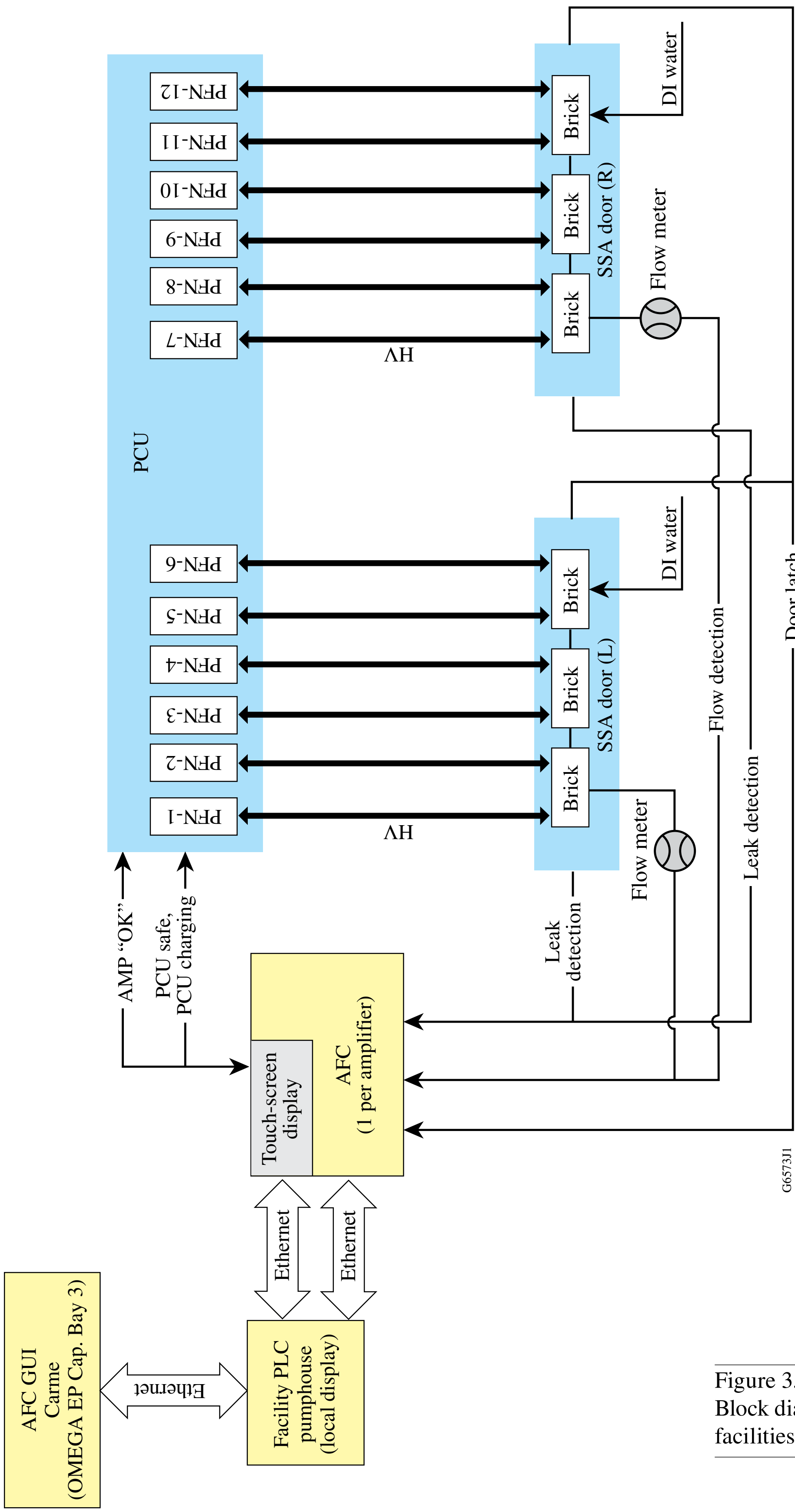

Figure 3.22
Block diagram of the OMEGA EP amplifier facilities controller.

3.8 AMPLIFIER SUPPORT FACILITIES

The OMEGA EP Laser System facility has dedicated support areas for the construction and maintenance of laser amplifiers: the optics assembly area (OAA) and the flash-lamp test facility (FTF). The cluster of OAA rooms is located adjacent to the Laser Bay and south of the Control Room. The FTF is located on the first floor of the building, in the south end of Capacitor Bay 3, North. Rooms within the OAA contain metal ultrasonics cleaning, glass ultrasonics cleaning, and optical assembly operations. The OAA is a class-100 clean room facility.

Flash lamps are inspected and the bricks are built in the OAA. All lamps are bar coded, and statistics on operational usage are kept in a relational database. Lamps are inspected for conformity to dimensional and cosmetic specifications. When the lamp bricks are constructed, they are tested for infant mortality in the flash-lamp tester in the FTF. This test stand consists of a single circuit that can be fired at a repetition rate of six times per minute. The flash-lamp database tracks all flash lamps within the laser system and contains both manufacturing and shot data. The shot data contains the entire history of each flash lamp including receipt, assembly, installation, location, and number of shots. The shot history is automatically updated after each shot.

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Appendix A

Glossary of Acronyms

AFC	Amplifier facility controller
ALT	Amplifier laser technician
BA	Booster amplifier
CDQ	Cerium-doped quartz
CDR	Conceptual Design Review
CEM	Cavity end mirror
CPA	Chirped-pulse amplification
CSF	Cavity spatial filter
DBS	Diagnostic beamsplitter
DI	De-ionized
DM	Deformable mirror
EOT	Energy on target
FCC	Frequency conversion crystals
FDR	Final Design Review
FTF	Flash-lamp test facility
GCC	Grating compression chamber
GUI	Graphical User Interface
IR	Infrared
LLNL	Lawrence Livermore National Laboratory
LRU	Line replaceable unit
MA	Main amplifier
MOPA	Master oscillator/power amplifier
MSA	Multisegment amplifier
Nd	Neodymium
NIF	National Ignition Facility
OAA	Optics assembly area
PCU	Power conditioning unit
PEPC	Plasma-electrode Pockels cell
PFN	Pulse-forming networks
POL1	Polarizer in lower main amplifier cavity, positioned first between CEM and PEPC in MA cavity
POL2	Second polarizer used for short-pulse operation, positioned between PEPC and CSF in MA cavity (also referred to as SP-POL)
ΣB	Total *B*-integral
SBS	Stimulated Brillouin scattering
SDIP	Structure device interface package
SP-POL	Short-pulse polarizer between PEPC and CSF in MA
SSA	Single-segment amplifier
TSF	Transport spatial filter
UV	Ultraviolet