S-AA-M-12

OMEGA
System Operations Manual
Volume I–System Description

Chapter 4: Power Conditioning

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Chapter 4
Power Conditioning

4.0 INTRODUCTION

The power-conditioning subsystem converts utility ac electrical power (from LLE's 750-kVA substation) into the high-voltage, high-current electrical pulses used to fire the flash lamps that supply optical pump energy to the laser amplifiers. To create these pulses, large capacitors are charged to high voltage (7–14 kV) and then discharged through a pulse-forming network (PFN) made up of the capacitor, an inductor, circuit resistance, and a flash-lamp brick.

The number of flash lamps used in each amplifier is dependent upon the type of amplifier. Each PFN is connected to one, five, or two flash lamps, depending on whether it feeds a 15-cm, 20-cm, or rod amplifier, respectively. An assembly consisting of the PFN's, a charger, and the control circuitry needed to power one laser amplifier is referred to as a Power Conditioning Unit (PCU). This complete unit requires only command instructions from the power conditioning Executive (PCE) computer, ac input power, and a trigger signal. The charging power supply, accurate to ≤0.1%, in each PCU allows adjustment of the energy output of each amplifier. This level of control is required for balancing the power of the laser system. The types and quantities of PCUs are summarized in Table 4.0-1.

Table 4.0-1
PCU Summary

PCU Type	Application	Quantity	PFN's/PCU	Flash lamps per PFN	Maximum Voltage (kV)	Maximum Energy Capacity per PCU (kJ)
Rod w/o PILC			6	2	7.5	78
	LARA's*	4				
	Driver 64	1				
	Stage D	60				
Rod w/PILC			6	2	7.5	78
	Stage A	3				
	Stage B	15				
	Stage C	15				
15-cm SSA	Stage E	60	12	1	15	284
20-cm SSA	Stage F	60	16	5	15	378
Totals		218	7268	6696		47,297

*Large-aperture regenerative amplifiers:
- main driver
- SSD driver
- backlighter driver
- timing fiducial

In addition to the main discharge circuitry, many PCU's have preionization and lamp check (PILC) circuits. This circuitry provides a lower energy pulse that is fired 250 μs early to ionize the gas in the lamp in preparation for the large main-bank current pulse that will follow. This "preionization" provides a near-full-bore discharge that reduces the production of ultraviolet (UV) radiation, which is detrimental to amplifier lifetime. In addition, the acoustic shock from the electrical discharge is reduced when preionization is used. The PILC discharge may also be used alone to check for lamp failures. The PCU has circuitry to monitor each lamp during this PILC discharge and detect any that do not conduct current; faulty lamps are replaced prior to the next shot.

Because of the high voltages present in the power-conditioning subsystem, safety was a major concern during design. The PCU's are computer controlled for normal operation, but for safety there are a number of "hard-wired" interlocks that do not rely on computers for activation. For instance, each of the enclosures is interlocked and the capacitor is immediately discharged when/if the interlock is violated. The computer control functions are provided by a local microprocessor that monitors the interlocks and the status of various voltages and currents. This PCU control module (PCM) is based on the Neuron® Chip from Echelon Corporation. The module contains LON (local operating network) interface circuits, a trigger input receiver, a logic power supply, and fiber-optic transceivers for communication with the PCU. The PCM is housed in a steel enclosure with an eight-character alphanumeric display to indicate the status of the PCU. For more complete information about the power-conditioning control system refer to Sec. 4.3.

At typical operating voltages, the power-conditioning system will store 34 MJ of electrical energy. The system is capable of storing 47.3 MJ at full rated voltages. The extra capability will accommodate future needs as amplifiers (and other components) degrade and require more pump energy to obtain the nominal stage gains.

Power Conditioning Units

The OMEGA power-conditioning system consists of 120 disk amplifier [also referred to as single-segment amplifier (SSA)] PCU's and 98 rod amplifier PCU's. There are two types of disk amplifiers and, hence, two styles of disk PCU's. The difference is the number of individual flash-lamp circuits (PFN's) required. The 20-cm SSA PCU requires 16 PFN's, while the 15-cm SSA PCU requires only 12 PFN's. Other than the number of PFN's the units are identical. These PCU's will store a maximum of 378 kJ (20 cm) or 284 kJ (15cm) at 15 kV .

There are two styles of PCU's for the rod amplifiers. One type powers the stage-D and the laser driver amplifiers. These are re-used OMEGA PCU's with modern controls and new components. A new single-head charging power supply with ≤0.1% accuracy replaces the 12-head chargers formerly used in the OMEGA units. These PCU's do not have PILC circuits and can store a maximum of 78 kJ at 7.5 kV. The second type of rod PCU is used for the A, B, and C stages of rod amplifiers. These are totally new units and are more similar to the SSA PCU in operation.

The performance of the power-conditioning system is outlined in Table 4.0-2.

System Configuration

The power-conditioning equipment is located in capacitor bays 1–4 below the laser bay. Figure 4.0-1 shows the capacitor bay layout and the space allocated for the PCU's. Each PCU is located as close to the laser bay location of its respective amplifier as possible. This keeps cable lengths to a minimum.

Table 4.0-2
PFN Specifications

	Disk Amps	Rod Amps
Pulse width (μs)	550	475
Linear resistance (mΩ)	120	100
Inductance (μH)	160	55
Capacitance (μF)	210	460
Charging voltage (kV)	14.1	7.3
Stored energy/PFN (kJ)	20.9	12.3
Total energy (MJ)	35.1	7.1
TOTAL ENERGY (MJ)	42.2	

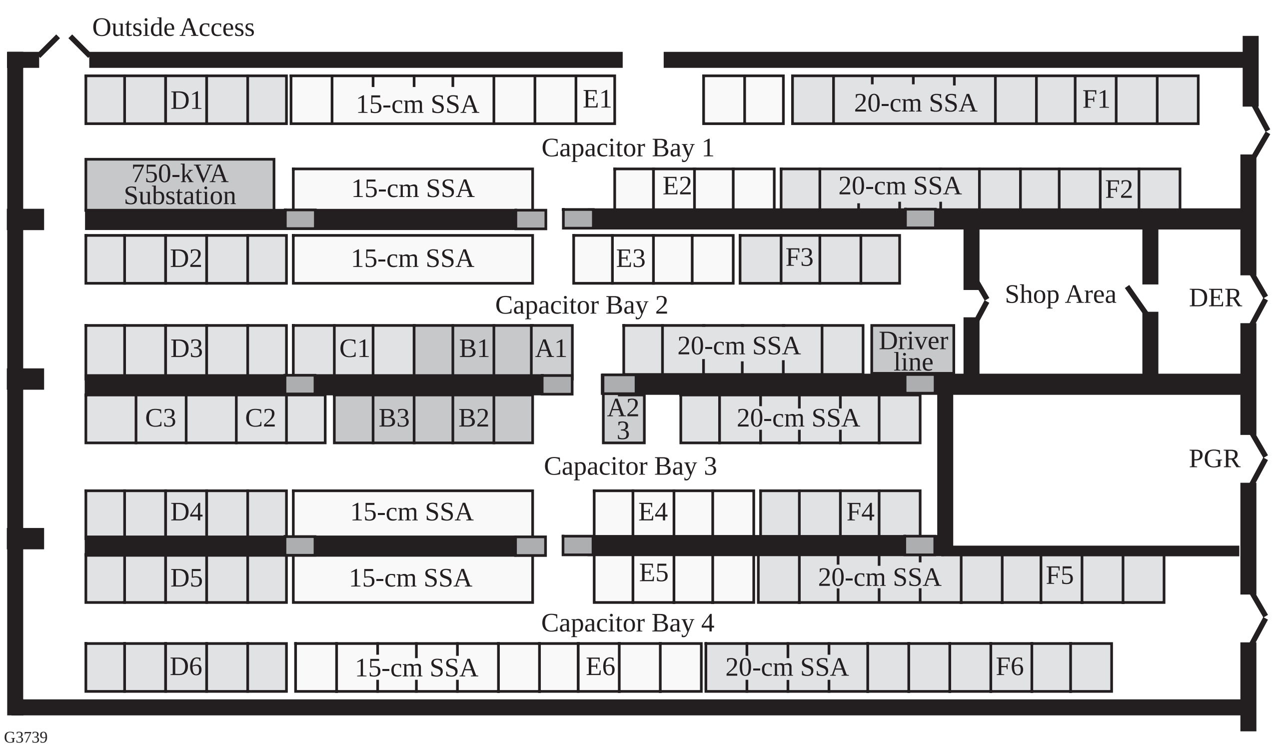

Fig. 4.0-1
PCU configuration in capacitor bays.

System Grounding

The upgraded OMEGA laser system employs the single-point, tree-type ground system for the power-conditioning equipment (shown in Figs. 4.0-2 and 4.0-3). The single-point tree system connects the power-conditioning equipment to ground while allowing fault current to return directly to its source, rather than through alternate, parallel, or serial loops, which might include other control or monitor circuits or act as an antenna for radio frequency (RF) noise. Each branch of the ground system remains independent throughout its extremities. Isolation is maintained between all power conditioning and the other grounding circuits in the facility back to the building ground.

This method insures that the PCU enclosure and the amplifier itself, both of which risk being accidentally connected to high voltage, cannot present a hazard to personnel by floating to dangerous potentials. It also serves as a safe chassis ground to conduct the high peak current that might flow during a short-circuit condition imposed on the high-voltage source.

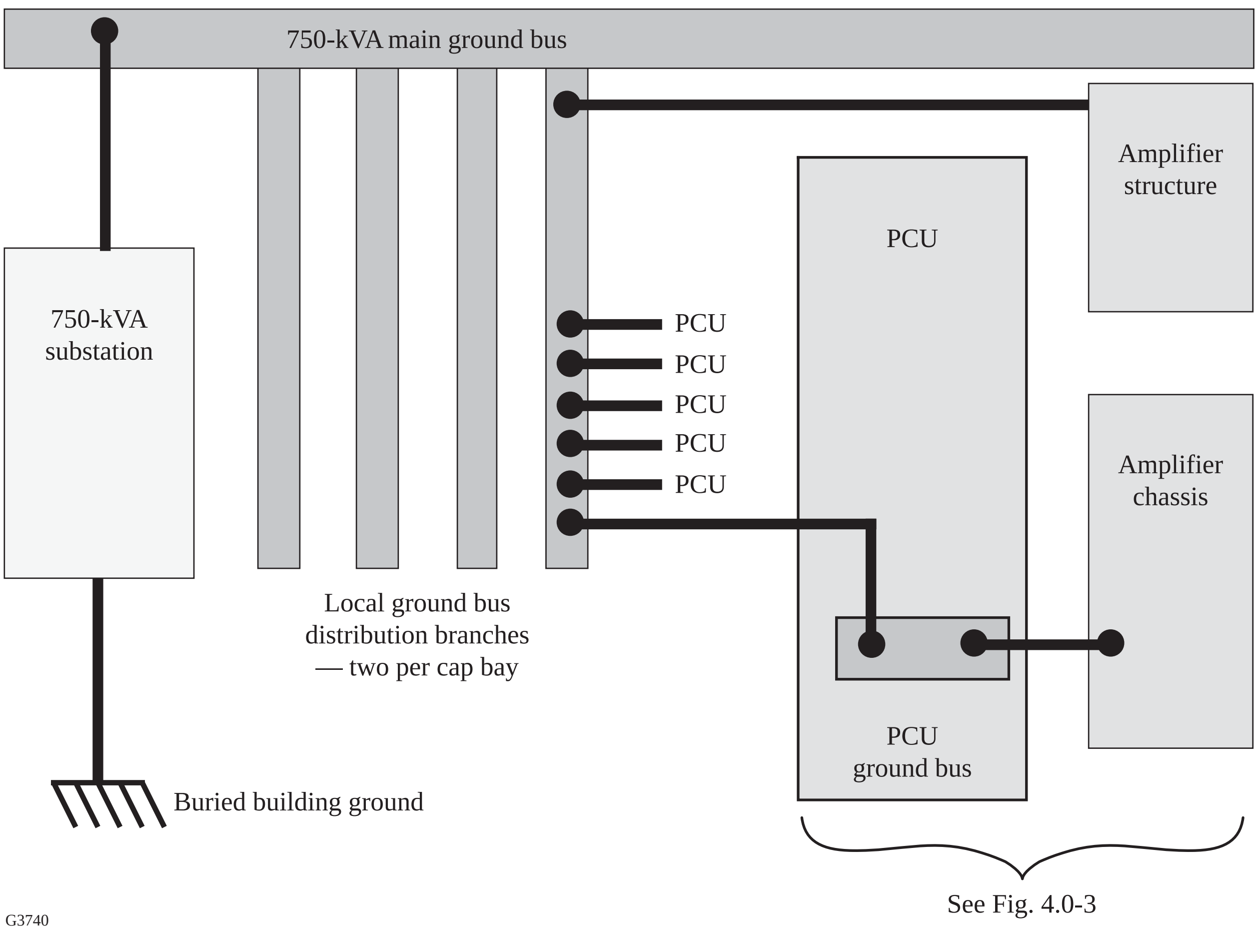

Fig. 4.0-2
OMEGA Power Conditioning System grounding plan.

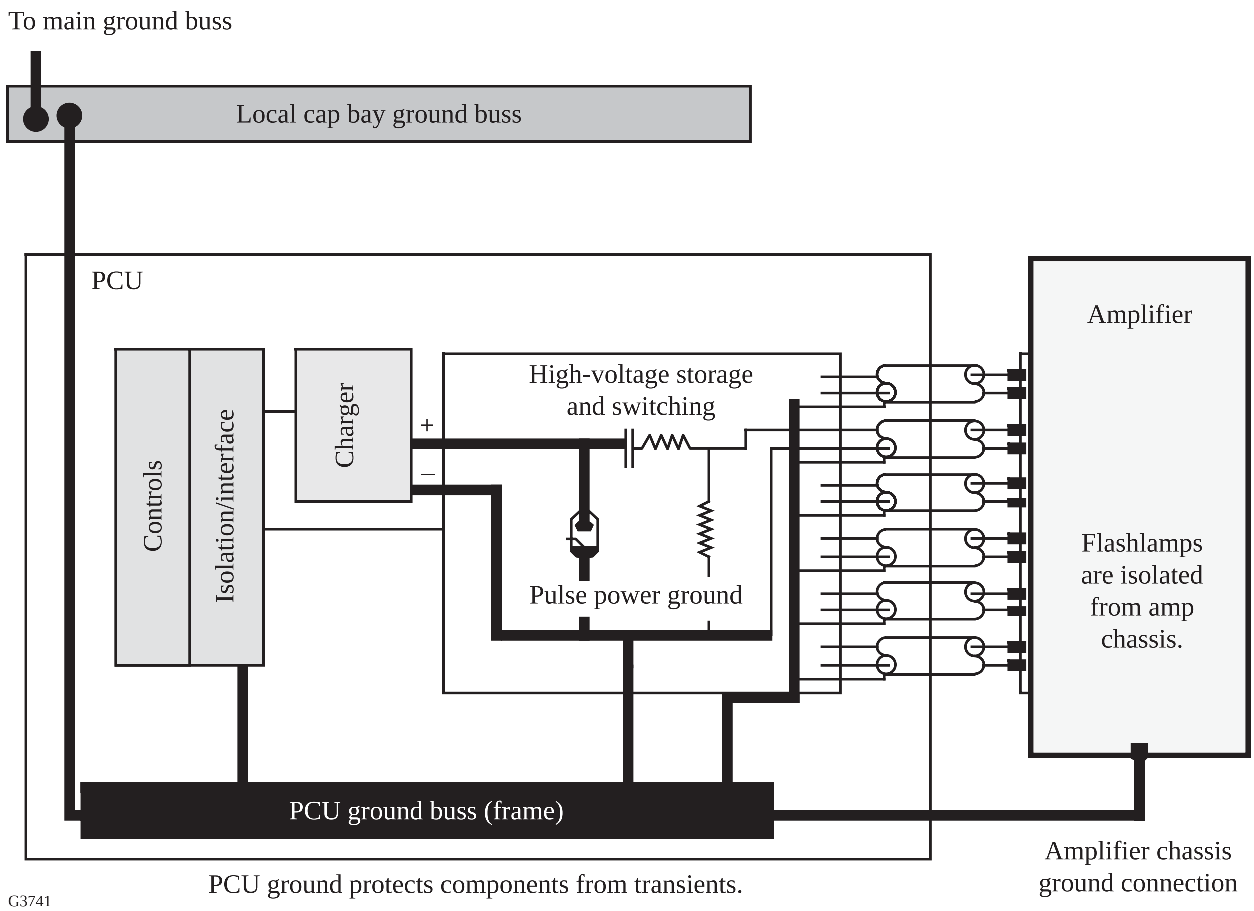

Fig. 4.0-3
PCU Ground Connection Schematic.

4.1 DISK AMPLIFIER SYSTEM

The power conditioning equipment for the 120 disk amplifiers is the bulk of the OMEGA laser power conditioning subsystem. It consists of 120 PCU's, one for each disk amplifier, with each PCU enclosed in an isolated steel enclosure. Each of the 60 20-cm amplifiers has a total of 80 flash lamps, mounted in five-lamp "bricks." Each brick is driven by a single PFN; therefore, each 20-cm PCU has a total of 16 identical PFN's. Each of the 60 15-cm disk amplifiers has 12 (302-cm) flash lamps, each driven by a single PFN. These PFN's are identical to those driving the five-lamp bricks in the 20-cm amplifier. Each of the 15-cm amplifier PCU's has 12 identical PFN's. Figure 4.1-1 is a photograph showing 40 PCU's located in Cap Bay 1. Each PCU has the following subsystems:

- Pulse-forming networks (PFN's)
- Capacitor charging supply
- Pre-ionization and lamp check circuit (PILC's)
- PFN and PILC discharge switches and trigger systems
- Safety and dump networks
- Voltage and current diagnostics
- Enclosure, control panel, and utility interface
- Control circuits that interface to the LLE PCU control module (PCM).

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Fig. 4.1-1
The 120 disk amplifiers are powered with a new 39-MJ system.

PCU Block Diagram

The purpose of the PCU is to provide the correct current amplitude and pulse shape to drive the individual flash-lamp bricks. The PFN's are the central elements and are shown individually in the center of Fig. 4.1-2, the block diagram of the PCU.

The PILC circuits, and the high-power switching circuits that control the timing and to some extent the performance of the main discharge circuits are critical to the performance of PFN's. The remaining elements of the PCU, while important, do not have a direct part in the production of the flash-lamp current pulses.

The charge circuits, dump circuits, and threshold detection circuits control the voltage stored in the capacitors. Feeding them are the main bank and PILC capacitor charging power supplies. The trigger circuits fire the main and PILC ignitrons. Incoming ac power (from the 750kV A) is distributed to the various elements of the PCU as well as to dc power supplies.

The PFN output current travels via shielded, twisted pair cables (6 AWG) to the flash-lamp bricks in the amplifier. Each of the cables, as well as the ground fault current return, is monitored by a current sensor to ensure each PFN is performing above a minimum acceptable threshold. Other voltage monitors are part of individual subsystems and are not explicitly shown in Fig. 4.1-2.

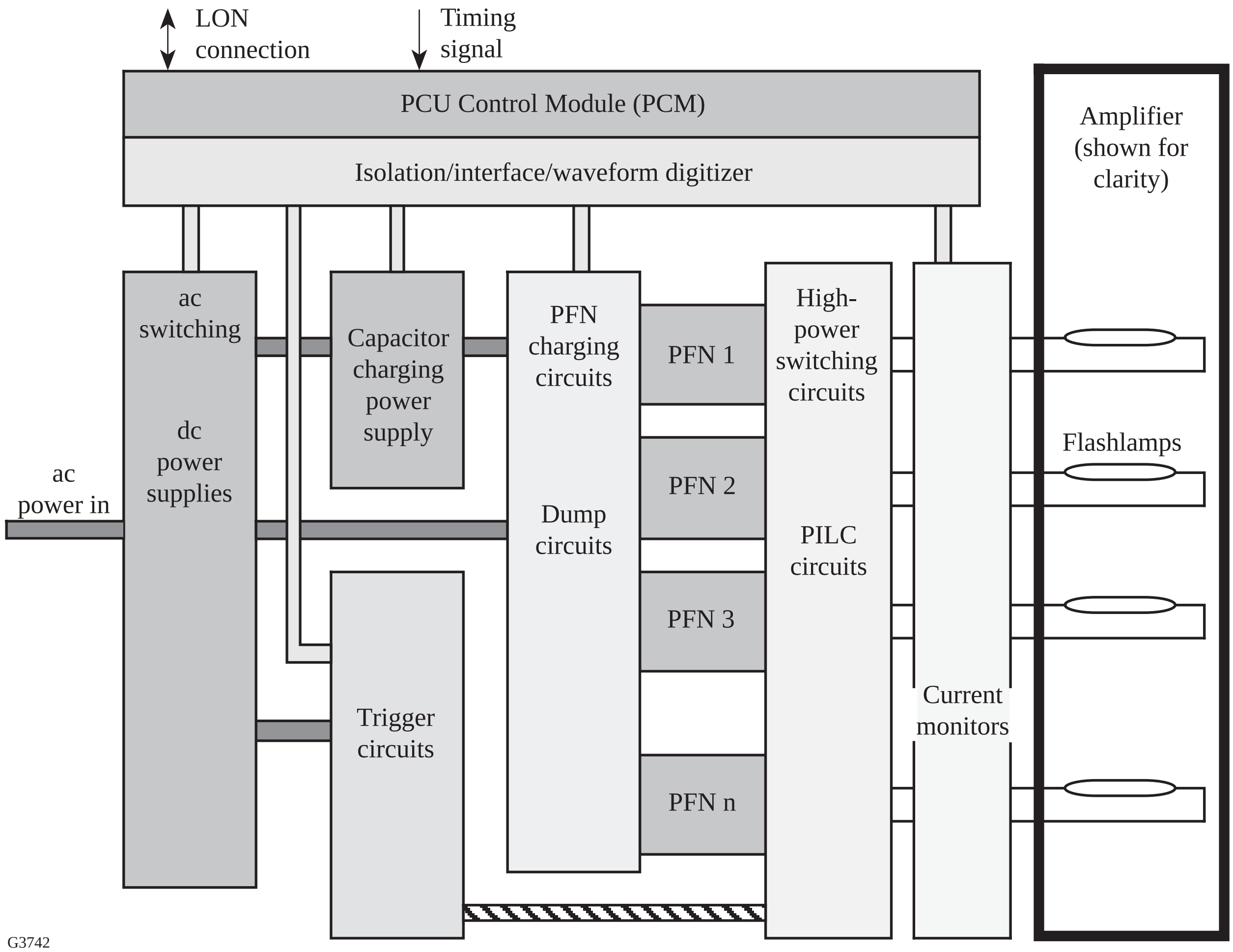


Fig. 4.1-2
PCU block diagram.

A ground block in the PCU forms a single dc reference point, facilitating the safety of the system and allowing the complex interactions of the separate subsystems to be broken down into simpler, logical subsets.

Pulse-Forming Network

The PFN that powers a single flash-lamp brick is a critically damped circuit made up of a single capacitor and inductor. The values for the PFN components used in the disk amplifier PCU are shown in Table 4.1-1 and the PFN energy levels are shown in Table 4.1-2. The calculated flash-lamp current waveform is shown in Fig. 4.1-3.

The SSA PCU electrical schematic is shown in Fig. 4.1-4. In this simplified figure only the primary circuit elements are indicated; stray inductance and capacitance are not shown and all stray resistance's are lumped into R_s, the total circuit series resistance. The main capacitor, C_{PFN}, is a single 210-μF capacitor and is charged during the shot sequence by a power supply common to all the PFN's in the PCU through the 1.5-kΩ charging resistor. The PILC current is delivered when the single "size A" PILC ignitron, IG-PILC, closes; the amplitude and waveshape of the PILC pulse are tailored by the

PILC capacitance of 6.3 μF and the series resistance of 12 Ω, in conjunction with the remaining circuit elements. (The PILC capacitance and resistance represent the value associated with just one of the PFN's.)

The main pulse is initiated when the main ignitron, IG-MAIN, closes nominally 200 μs after the PILC circuit. (The delay is selectable and controlled by the PCM.) Current from the capacitor flows through the single 160-μH inductor, the stray resistance of the circuit, and the flash lamps. It is sensed by a current monitor I_i in the return leg.

Table 4.1-1
SSA PFN Specifications

PFN capacitor	210 μF ±5%
PFN inductor	160 μH ±5%
PFN max charge voltage	14.8 kV
PFN peak current	7,885 A
Pulse width	550 μs
PFN Max Energy (110%)	23 kJ
Max PFN circuit impedance	120 mΩ

Table 4.1-2
SSA PFN Energy Levels

% Energy	Joules/PFN	PFN Volts
10	2088	4459
20	4176	6308
30	6264	7124
40	8352	8919
50	10,440	9,971
60	12,528	10,923
70	14,616	11,798
80	16,704	12,613
90	18,792	13,378
100	20,880	14,102
110	22,968	14,790

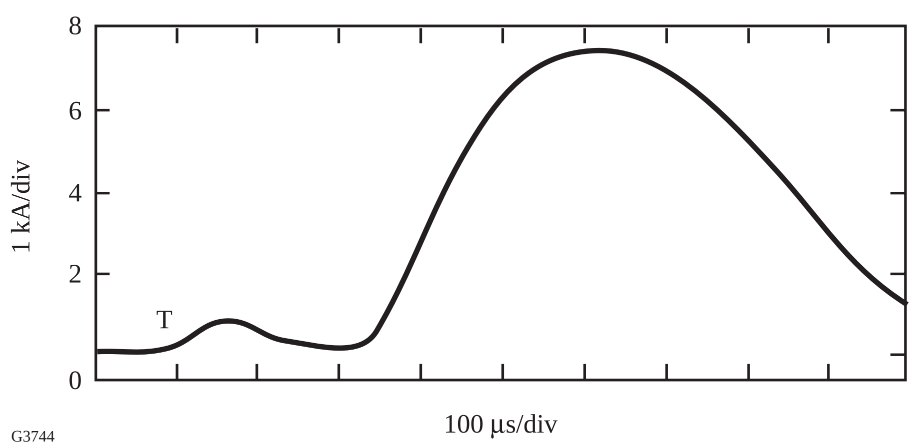
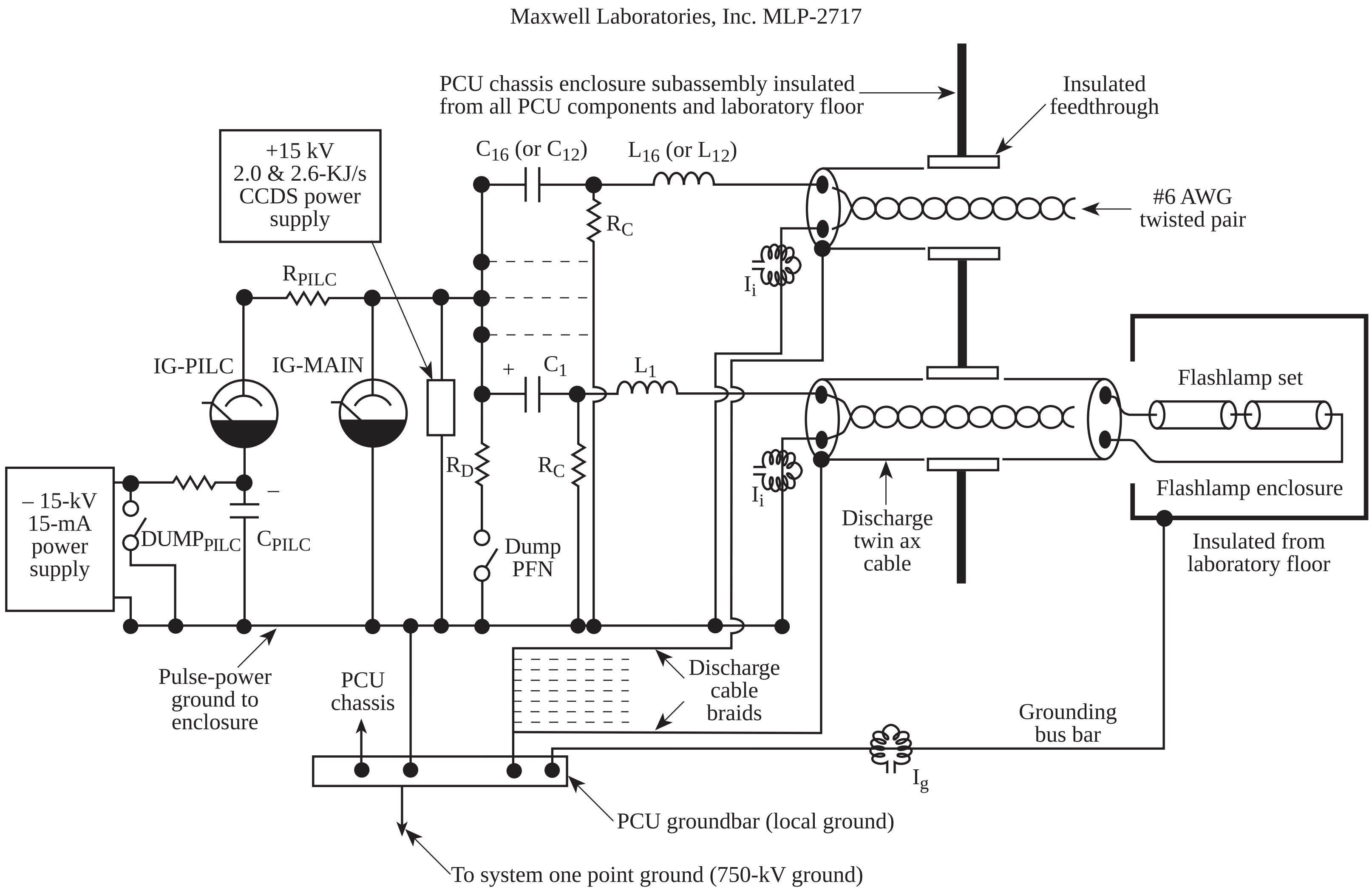


Fig. 4.1-3
Flashlamp Current Waveform with PILC. PFN voltage = 14,160.



C_{PILC}: 100 μF (or 78 μF)
C_1, C_{16}: 210 μF (15 kV)
L_1, L_{16}: 160 μH, 8 kA nominal
R_C: Charging resistors
IG-M: main discharge ignitron (size D)

IG-P: PILC ignitron (size A)
R_{PILC}: PILC circuit-damping resistor
I_i: lamp current monitor
R_D: main dump resistor

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Fig. 4.1-4
Electrical schematic of the SSA PCU components showing the single-point grounding scheme.

PFN Capacitor

The capacitors in the disk power conditioning are of a hybrid metalized design having four layers of standard dielectric paper and one layer of metalized paper in a dual bushing can, as shown in Fig. 4.1-5. The metalized paper layer gives extended lifetime due to its fault clearing ability. The units have a specified minimum lifetime of 30,000 shots and are rated for 20% reversal. The normal operating peak current is 7.83 kA; normal charge time is 180 s. Normal hold time at volt is 20 s and will not exceed 60 s maximum.

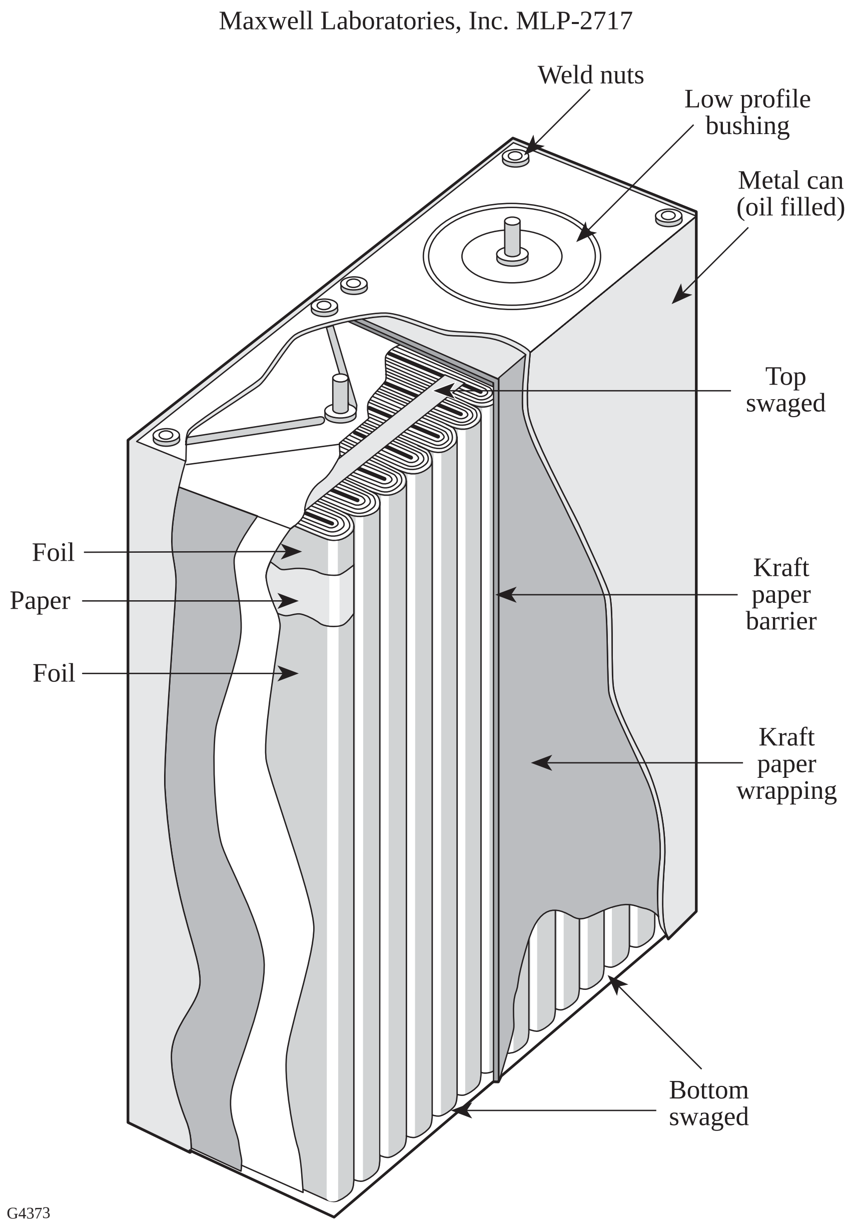


Fig. 4.1-5
Cutaway view of PCU energy storage capacitor.

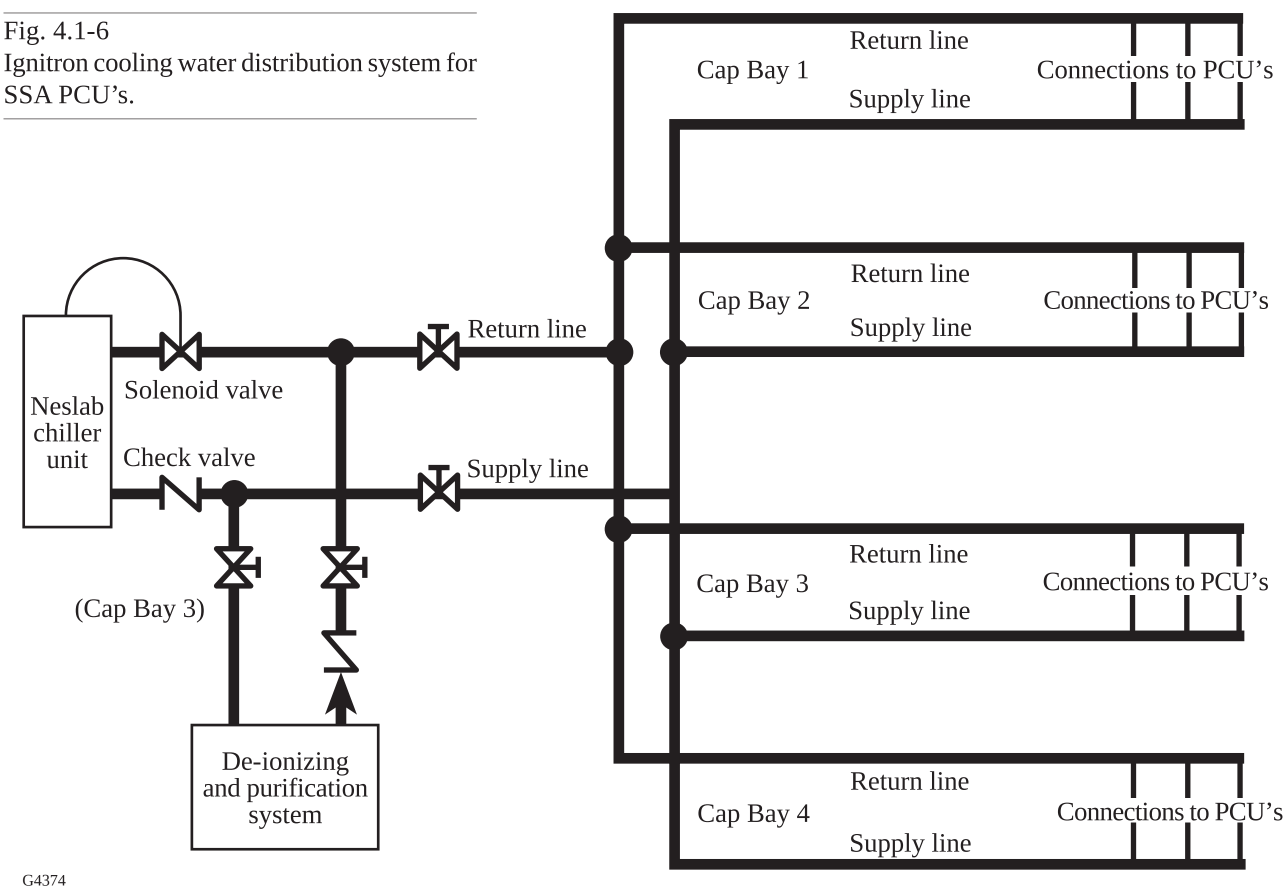
Ignitrons

The PFN capacitors in each PCU are switched simultaneously by firing a single main ignitron. This main ignitron provides simultaneous main discharge current for all flash-lamp bricks connected to that PCU. The main ignitron is a Richardson NL-8900R. This unit is approximately 5.5 in. in diameter by 9.5 in. tall, and weighs 24 lbs. The ignitron has a mercury pool cathode and a baffled steel anode. It operates at ≤15 kV and can hold off ≥25 kV, with a peak discharge current for a 2-ms-wide damped discharge pulse of 300 kA. This peak discharge current rating is more than a factor of 2 higher than the peak discharge current that is encountered during a main bank discharge at 14.1 kV in the LLE application.

The cathode of this unit is water cooled by circulating de-ionized water through a water jacket. A dedicated, closed-loop, system in the capacitor bays provides chilled, de-ionized water (see Fig. 4.1-6). A flow of approximately 6 GPH is adequate and is controlled by a valve on the Rotameter at the PCU front panel. This water temperature is controlled to 21°C. Connections to the distribution system are made with quick disconnect fittings at the PCU front panel (see Fig. 4.1-7).

The anode of the ignitron is heated with a 50 W resistive heater. The 6 V ac power for this heater is supplied by a 208 V/6 V step-down transformer that has a secondary high-voltage isolation in excess of 30 KV. This heater keeps the anode in the range of 35°–40°C. This temperature differential across the tube helps to clear any condensed Mercury vapors from the anode or the insulating glass between it and the cathode. This, in turn, helps prevent unexpected high-voltage breakdown (prefire) of the tube. For reliable operation, the PCU must be powered for at least an hour to preheat the anode.

Fig. 4.1-6
Ignitron cooling water distribution system for SSA PCU's.



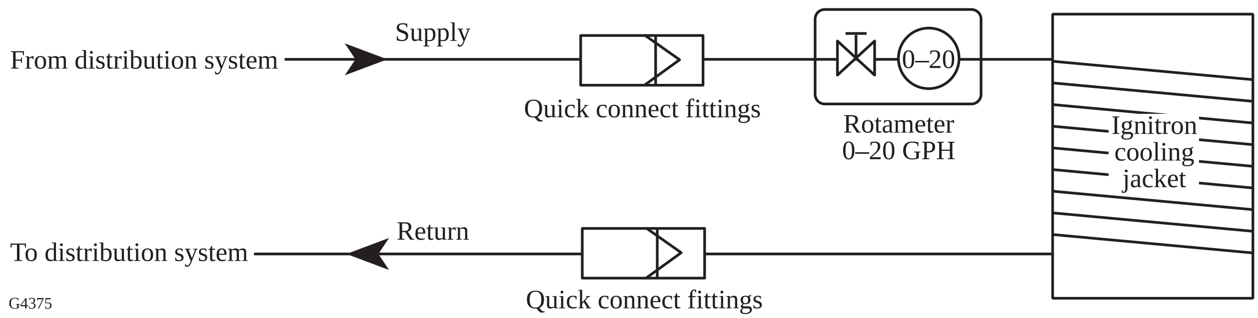


Fig. 4.1-7
Ignitron cooling water connections in the SSA PCU.

The PILC ignitron is a size-A National Electronics NL-7703. It has an overall envelope of 2.2-in. diameter by 7 in. long and is rated for 50 kV at 100 kA. This ignitron utilizes anode heating similar to the main ignitron described above, but does not have cathode cooling. Both ignitrons are triggered by solid-state trigger generators.

Capacitor Charging Power Supplies

The capacitor charging power supply used in the SSA units is a constant current supply utilizing a high-frequency (40-kHz) series resonant switching power converter topology. It is packaged in a standard 19 in. wide × 8.75 in. tall × 21 in. deep rack-mount chassis and weighs about 55 lbs., with a standard input of four-wire, 208-V ac, 3Ø with a ground. The output charges the PFN capacitors to 15 kV at a constant current with an average charge rate of 2.6 kJ/s for the 20-cm amplifier units, and 2.0 kJ/s for the 15-cm PCU's. Output voltage regulation is maintained to better than 0.1% peak-peak or ±0.05% for load rep rates up to 2 kHz. The power-supply efficiency is ≥92% with a power factor of >0.9. The power supply is immune to output short circuits that could occur as the result of a PFN breakdown or ignitron prefire. The output section also has voltage reversal protection circuitry incorporated to assure no damage to the supply in the event of voltage reversal from normal or fault conditions.

PCU Configuration

The limited space in the OMEGA capacitor bays led to a compact design for the PCU enclosures with overall dimensions not exceeding 5 ft wide × 5 ft deep × 7.5 ft high. The enclosure and all of its principal components are shown in Fig. 4.1-8. It is a steel frame structure with a safety interlocked door. The PCU is designed such that all components and subsystems are easily accessible without sacrificing system performance or personnel safety. Any of the major high-voltage components in the PCU (PFN capacitors, ignitrons, trigger circuits, control chassis, power supply, etc.) can be replaced within 30 min. The enclosure is designed to meet the LLE single-point grounding specifications and philosophy, and it is insulated from the floor via stand-offs providing ≥30-kV isolation. There is a flame-sprayed zinc PCU central ground bar located at the bottom of the enclosure, which is connected directly to the 750-kVA ground buss. The PFN capacitors are supported on fire-proof plywood shelves and are grounded back to the single-point ground bar mentioned above. In the event that a capacitor must be pulled, the segmented busswork and the inductor must first be removed.

The PFN discharge cables are connected to their respective capacitors in the PCU through the top lid of the enclosure. The main and PILC charging power supplies for the controller, the controller-to-PCU interface chassis, and chassis for other PCU auxiliary equipment are mounted on a 19-in. rack within, and insulated from, the PCU enclosure. All chassis are tied directly to the PCU ground bar. All connections between chassis and the central PCU high-voltage components maintain the single-point grounding for system safety. The controller-to-PCU interface has optical isolation on all inputs and outputs.

Safety Features

High-voltage relays provide for the discharge of any stored energy within the PFN's when conditions warrant such action. The relay is connected in a fail-safe mode: it must be powered open to allow charging, and when it is de-energized, a resistive load is connected across the capacitors to bleed off any stored energy. The load insures that the capacitor voltage is below 100 V in less than 10 s when dumping from 14 kV. The circuit also prevents buildup of any charge on the capacitor when in the de-energized mode.

There is an automatic safing system in place in each PCU that resistively shorts the main bank to ground when the front enclosure door is opened. This is by way of a spring-loaded arm that is pressing against the door when it is closed. As the door is opened, this arm is allowed to slide forward until a ground contact on its far end contacts the PFN high-voltage buss. Once this has happened, each PFN capacitor is shorted to ground through its own 1.5-kΩ charging resistor (R_C in Fig. 4.1-4).

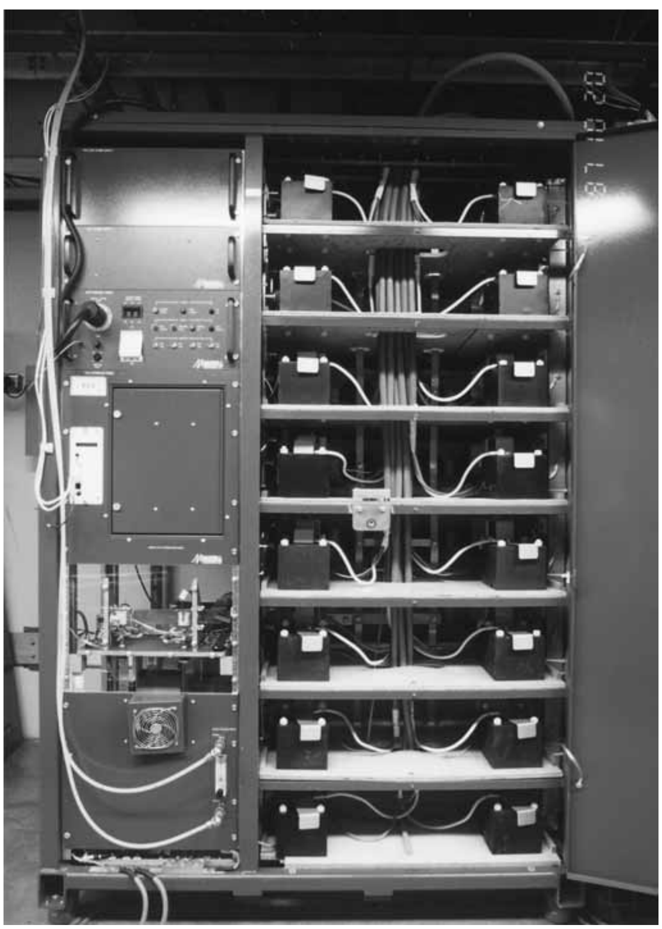


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Fig. 4.1-8
Power conditioning unit enclosure showing layout of major high voltage components.

Dump sticks are provided as a supplement to the automatic safing system to ensure that the capacitors are discharged prior to servicing. It is a soft (resistive) dump that when touched to a terminal can bring a charged capacitor at 14 kV down to below 100 V in 2 s. The dump stick also allows for a hard ground to be applied after the soft dump.

4.2 ROD POWER CONDITIONING

The rod power conditioning, providing about 7 MJ of electrical energy for the 98 rod amplifiers, consists of two slightly different styles. The 60 stage-D amplifiers and the LARA's and the 64-mm amplifier in the drivers, are powered by original OMEGA power-conditioning units that have been updated with modern controls and new components. These are all non-PILC'd PCU's. The fiducial LARA and 90-mm rod amplifiers in stages A, B, and C are powered by completely new units that operate more similarly to the SSA PCU's with PILC. All rod PCU's have single-head charging power supplies with ≤0.1% accuracy. Figure 4.2-1 is a photograph showing the components of the units for stages A, B, and C; Fig. 4.2-2 shows the stage-D unit.

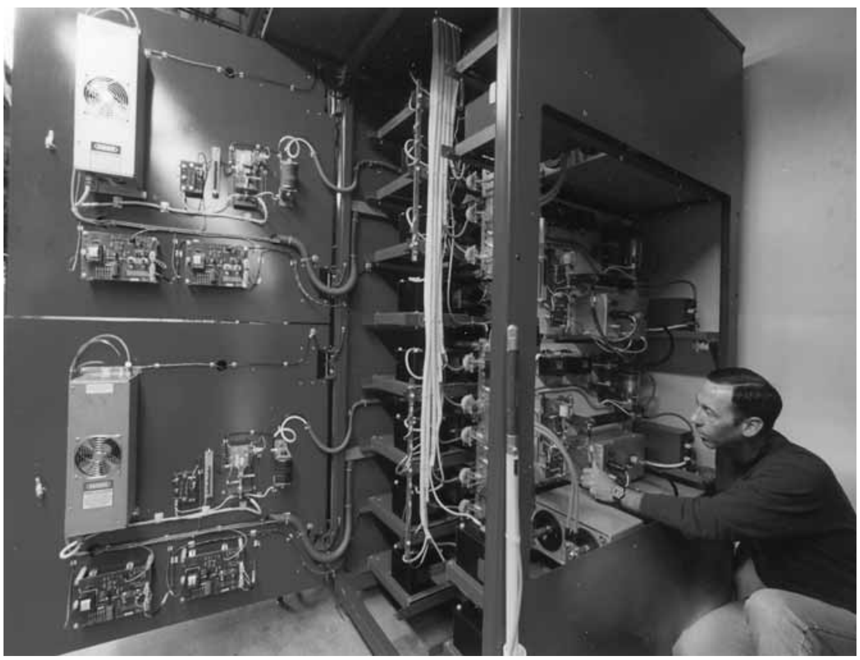

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Fig. 4.2-1
Stage A, B, and C power conditioning unit showing the layout of major components.

Non-PILC'd Rod PCU

The non-PILC'd PCU enclosures contain two complete PCU's, each of which has six PFN's. A single PFN powers two flash lamps in series and has two capacitors and one inductor per PFN. The General Electric capacitors used in these units are from the original OMEGA power conditioning and are of the standard paper dielectric variety. These original capacitors are of a robust design, with a predicted lifetime of over 1,000,000 shots. Although new ignitrons have been installed, they are the same type (NL7703) as used in the original OMEGA power conditioning. The PFN specifications are listed in Table 4.2-1, and Fig. 4.2-3 is a block diagram of the stage-D PCU. A flash-lamp current

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Fig. 4.2-2
Stage D power conditioning unit.

Table 4.2-1
Stage-D PFN Specifications

PFN capacitor	460 μF ±5%
PFN inductor	55 μH ±5%
PFN max charge voltage	7.5 kV
PFN normal charge voltage	7.3 kV
PFN normal peak current	7.83 kA
Pulse width	475 μS
PFN max energy (7.5 kV)	12.94 kJ
Max PFN circuit resistance	100 mΩ

waveform for 7.3 kV is shown in Fig.4.2-4. Note the absence of the PILC waveform that precedes the main pulse in a disk PCU. The basic operation of the rod units is similar to that explained for the disk amplifier PCU's.

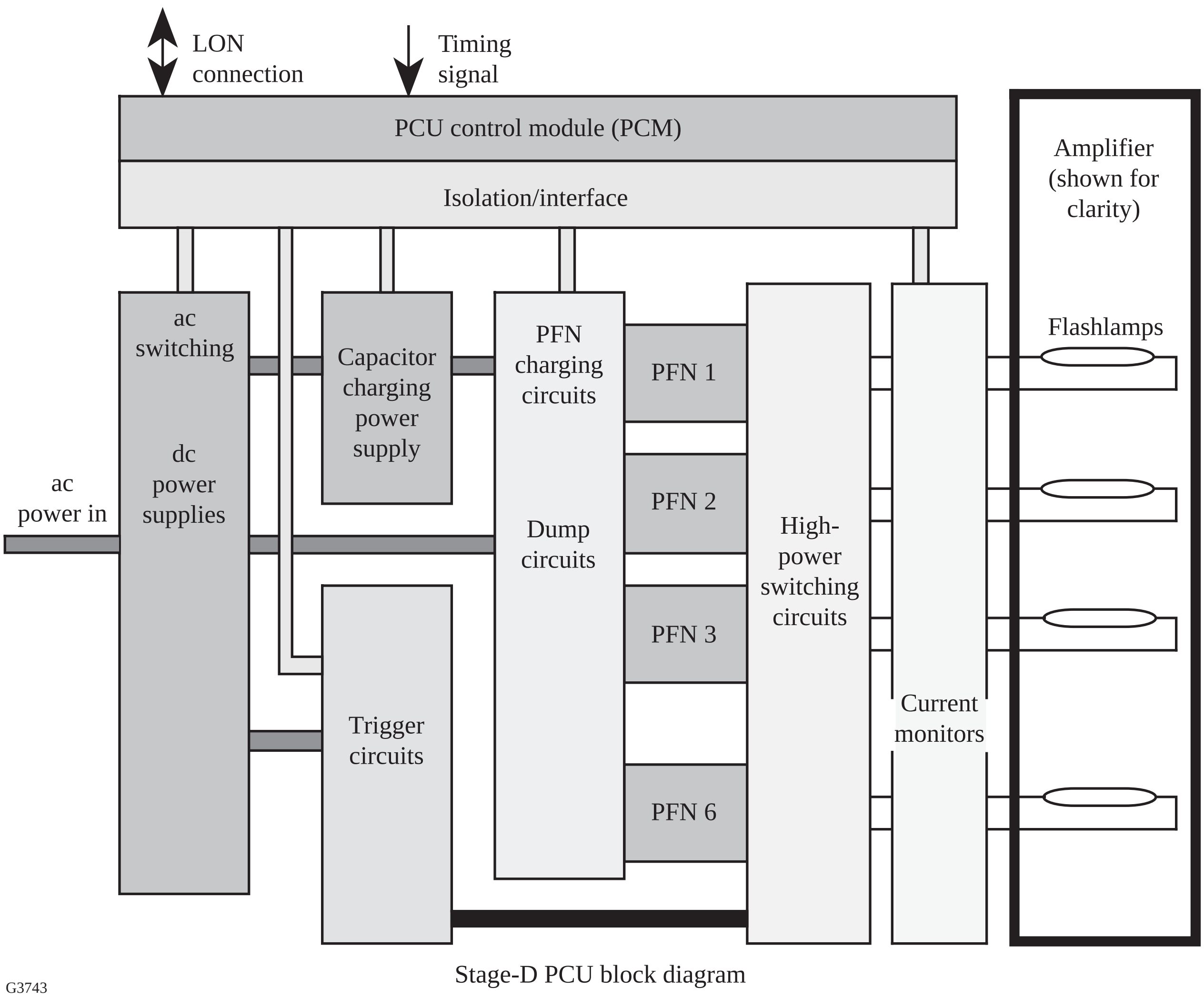


Fig. 4.2-3
Block diagram of stage-D power conditioning unit.

PILC'd Rod PCU

The PILC'd rod PCU enclosures are similar to the non-PILC'd units, each containing two complete PCU's, each of which has six PFN's. A single PFN powers two flash lamps in series and has one capacitor and one inductor per PFN. The capacitors used in these units are of a metalized dielectric design. The PFN specifications are listed in Table 4.2-2. The block diagram is very similar to Fig. 4.2-3, the block diagram of the non-PILC'd PCU, except the PILC circuit is grouped into the block with the high-power switching. A flash-lamp current waveform for 7.3 kV is shown in Fig. 4.2-5. Note the presence of the PILC waveform. The basic operation of the PILC'd rod units is similar to that explained for the disk amplifier PCU's.

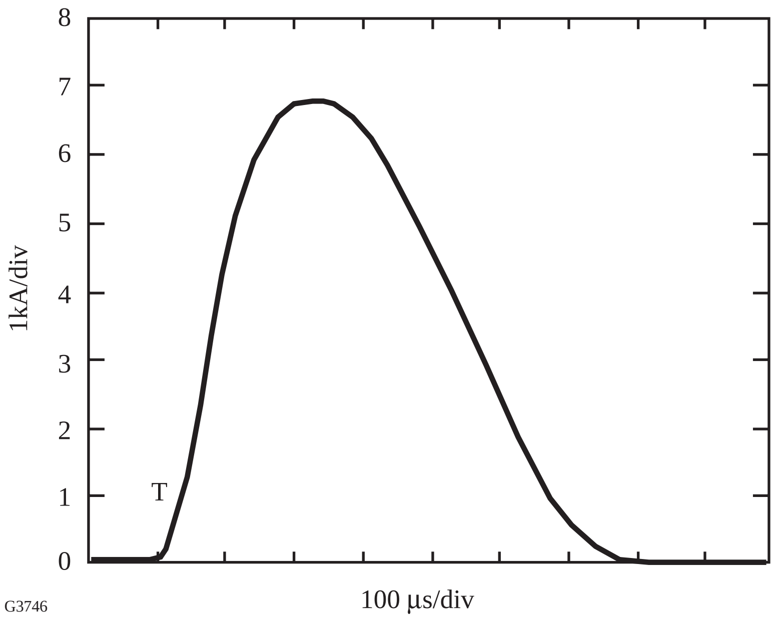


Fig. 4.2-4
Flash-lamp current for stage-D power conditioning unit. PFN voltage = 7.3 kV.

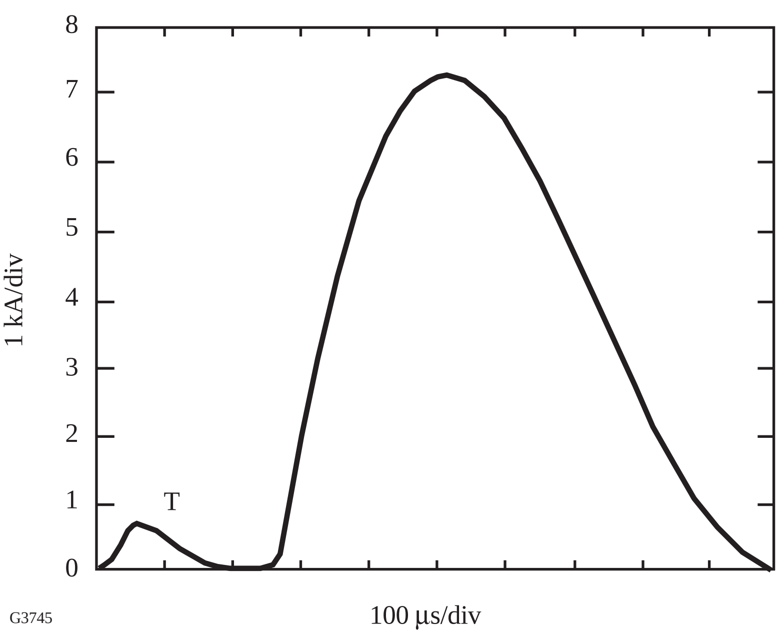


Fig. 4.2-5
Stage A, B, and C (Note PILC waveform.)

Table 4.2-2
Stage-ABC PFN Specifications

PFN capacitor	460 μF ±5%
PFN inductor	55 μH ±5%
PFN max charge voltage	7.5 kV
PFN normal charge voltage	7.3 kV
PFN normal peak current	7.83 kA
Pulse width	475 μS
PFN max energy (7.5 kV)	12.94 kJ
Max PFN circuit resistance	100 mΩ

4.3 POWER CONDITIONING CONTROLS

The primary function of the executive level control system for power conditioning is to integrate the operation of the 218 PCU's into the operations of the overall OMEGA system. In fact, the Power Conditioning Executive (PCE) software provides the signals that sequence the entire OMEGA system shot sequence. The PCE and the PCM's provide control and sequencing functions that complement the basic hardware interlocks that are described in Sec. 3.6 and Chap. 10. Auxilliary computer programs allow the control room operator to monitor the 29 Amplifier Facilities Controllers (AFC's) and the 95 sensors and controls in the two cooling systems that serve the laser amplifiers.

Cart-mounted computer systems called power conditioning test units (PCTU's) are also provided for subsystem maintenance. These allow all of the functions of a single PCU to be exercised.

Overall Configuration

Figure 4.3-1 is a block diagram of the power conditioning computer controls. The PCE software system runs on a SUN workstation referred to as *pawpaw* in the control room and communicates with the system database and the other executive processes via the OMEGA Ethernet. The *pawpaw* system unit has a hardware interface that provides three fiber-optic signal connections to the Master Timing Generator (which is located in the Driver Electronics Room). The workstation is also connected to the PCU computer controls via eight LON's. Figure 4.3-2 details the connections.

The high-voltage power conditioning for the flashlamps in each laser amplifier is provided by a single power conditioning unit. The high-voltage discharge cables and an amplifier chassis ground cable are the only connections between the PCU in the capacitor bays and the amplifiers, which are mounted on structures in the laser bay. The laser bay amplifier structures hold one (Stage A), five (Stages B and C), or ten (Stages D, E, and F) amplifiers each. Fluid support and configuration interlocks are handled on a structure basis by the structure cabling and the AFC's. Hardware logic in the AFC accepts signals from sensors on the amplifiers and the structure and combines them to determine the readiness of each amplifier (see Sec. 3.6 for details.). This status is signaled to the amplifier's PCU as an "Amplifier OK" signal carried on a dedicated fiber-optic cable. The PCU/PCM will not initiate charging if this signal is not present. After charging has started, loss of the signal will cause the charge to be dumped. This signal is a constantly occurring pulse train (~5 Hz) if the AFC senses all fluid flows and interlocks to be okay. If any are sensed as not okay, the pulse train stops. The PCU will only read

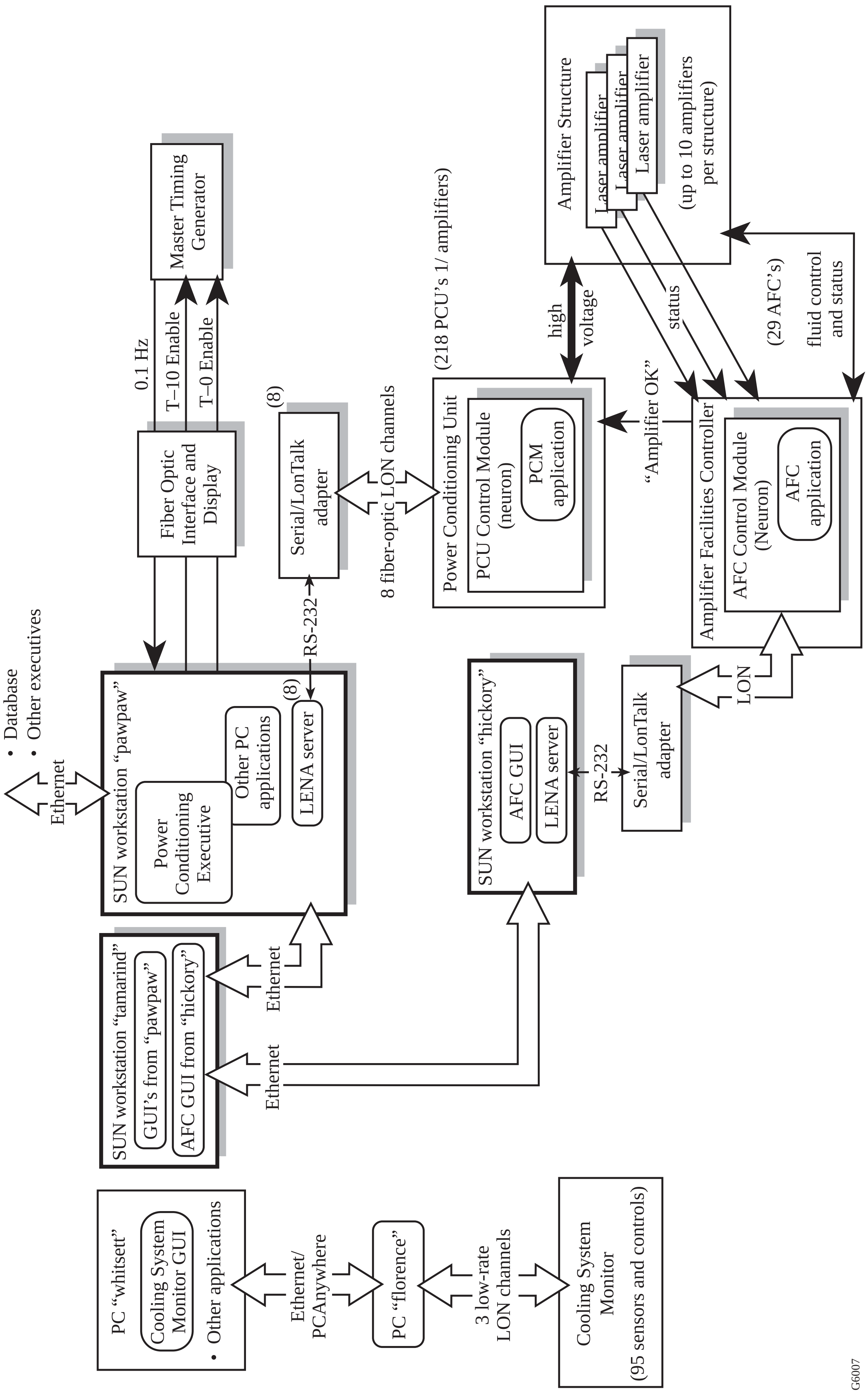


Fig. 4.3-1
The power conditioning control configuration features a control workstation that integrates master timing and more than 300 low-level devices.

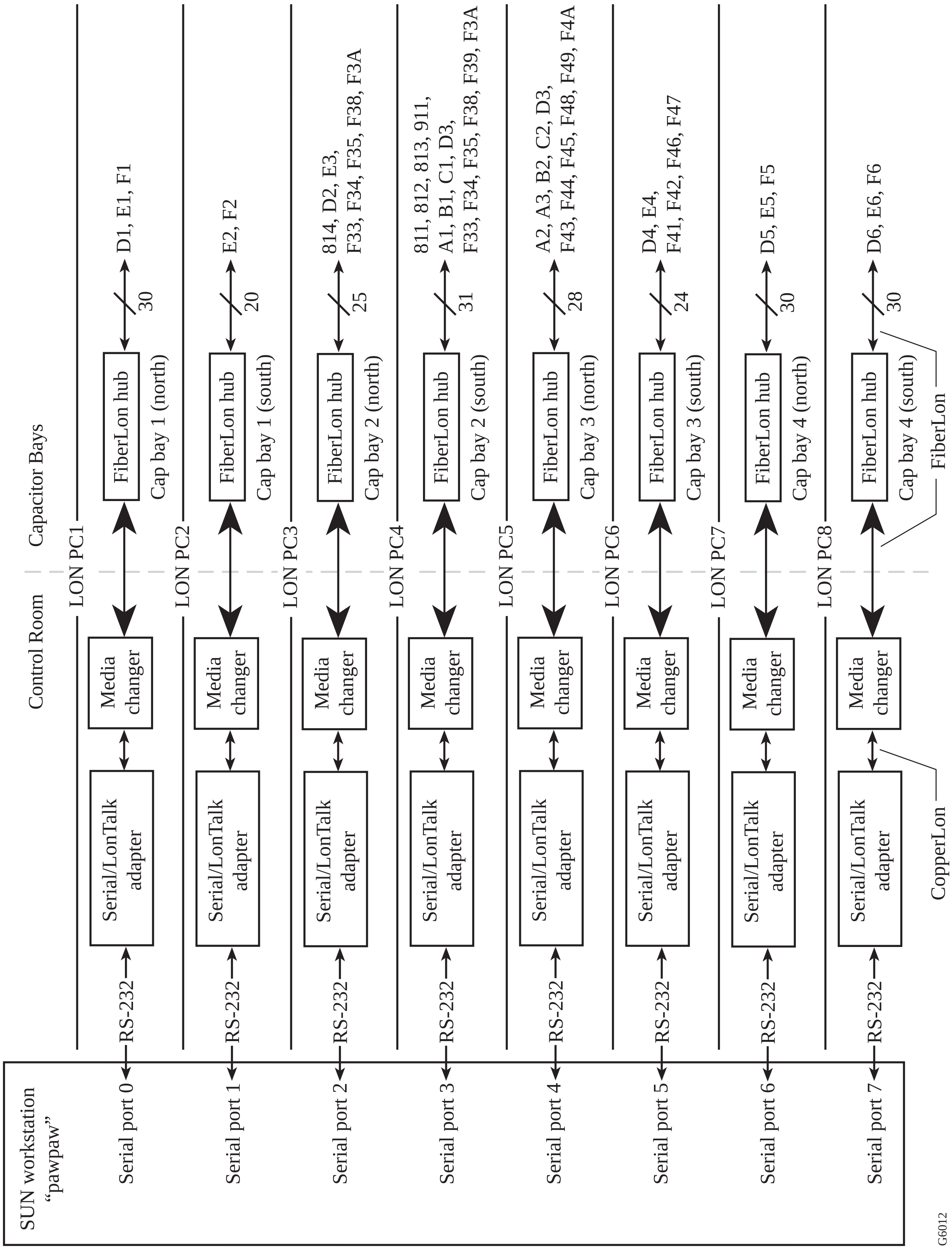


Figure 4.3-2
The PCM's in the Capacitor Bays are interfaced to the SUN workstation "pawpaw" via eight LON channels (PC1–PC8). Each channel includes a serial LonTalk adaptor (SLTA), a media changer that converts between copper and optical fiber, and fiber-optic distribution equipment that connects to the PCM's.

this signal as “okay” if the pulse train continues. If either no light or constant (DC) light is received, the PCU will treat this as “AFC NOT okay” and not allow charging or, if already charging, “dump” to a safe state.

The identifications assigned to the power conditioning control elements and their addresses on the LON’s are based on the stage, cluster, beamline (amplifier) nomenclature that is used throughout the system. These conventions are summarized in Table 4.3-2.

Table 4.3-2
Amplifier and PCU Control Module Designations
(218 total)

STAGE	CLUSTER	BEAM	NOMENCLATURE
Subnet		Node	
8	1	1	Main LARA
8	1	2	SSD LARA
8	1	3	Backlighter LARA
8	1	4	Timing Fiducial LARA
9	1	1	Driver 64 mm Rod
A	1	1	Stage A, Leg 1
A	2	1	Stage A, Leg 2
A	3	1	Stage A, Leg 3
B	1	1	Stage B, Leg 11
	to	to	
	3	5	Stage B, Leg 35
C	1	1	Stage C, Leg 11
	to	to	
	3	5	Stage C, Leg 35
D	1	1	Stage D, Beam 11
	to	to	
	6	0*	Stage D, Beam 60
E	1	1	Stage E, Beam 11
	to	to	
	6	0*	Stage E, Beam 60
F	1	1	Stage F, Beam 11
	to	to	
	6	0*	Stage F, Beam 60

*The LON node for beam “0” items will be hex A, decimal 10.

PCU Controls

The basic functional parts of the PCU's were introduced in the earlier sections of this chapter. The control elements are shown in greater detail in the block diagram Fig. 4.3-3.

The PCM, shown on the left, consists of a mother board designed specifically for use in PCU's and a standard Neuron daughter board housed in a dedicated panel mount enclosure. Figure 4.3-4

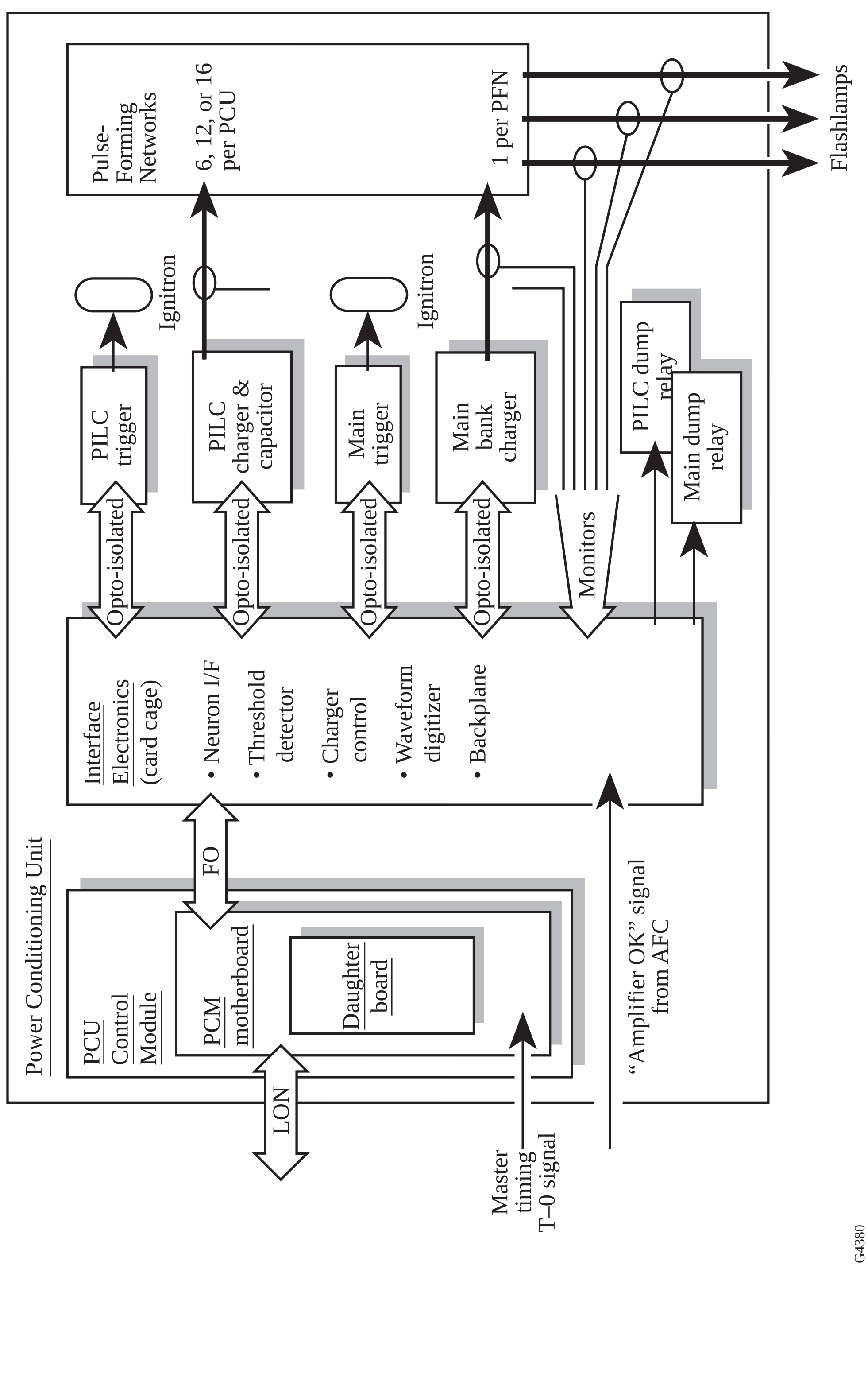
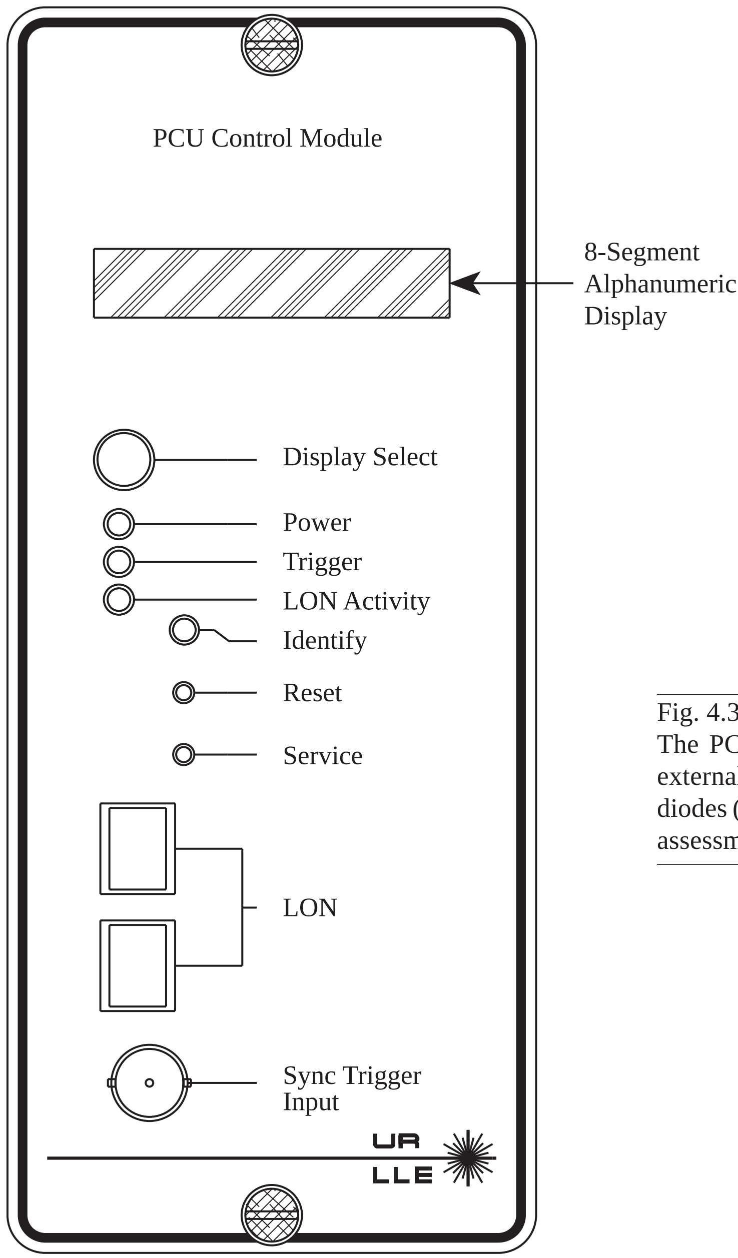


Fig. 4.3-3
The power conditioning unit (PCM) controls include a standard computer unit, modular control and diagnostic circuits, and hardwired dump controls. Fiber optics techniques are applied extensively to isolate digital microcircuits from high voltages and transients.



G4381

Fig. 4.3-4
The PCU control module has front panel connections for external signals. A combination of descrete light-emitting diodes (LED's) and a one-line dot-matrix display allow local assessment of status.

illustrates the front panel of the PCM. The PCM is connected to the executive computer via the LON and receives the T-0 trigger signal from the MTG over a dedicated fiber-optic cable. (This trigger system is discussed further below.) The PCM controls and monitors the rest of the PCU using signals transmitted over internal fiber optic links to and from the interface electronics package (Fig. 4.3-3). The SSA PCU's have the PCM and the interface electronics integrated into a single panel of the PCU enclosure. These items are housed in a separate NEMA enclosure mounted on the front of the rod PCU.

The interface electronics provide control and diagnostic functions appropriate to the type of PCU. These include hardware logic control of the dump relay circuits that incorporates the "Amplifier OK" signal from the AFC, control and monitoring of the charger(s), and monitoring of the currents in each of the discharge cables and in the PCU ground circuit. Both the PCM firmware and the interface electronics incorporate periodic checks of the internal control links and are capable of dumping the charge if a problem is indicated.

All of the PCM messages are decribed in the PCM Messages section. The most important, most frequently encountered mesages are:

- notify_NV = 0 "Successful Event" All PILC bits are good and capacitors are discharged properly. ("Good shot")
- notify_NV = 1 "Link Check Failure" PCM did not receive a Link Check message from the executive before the previous timer expired. PCM automatically goes back to the Online state.
- notify_NV = 4 "At Volt" The PCU has successfully charged and is in the "At Volt" condition.
- notify_NV = 6 "Post Shot Error" Error(s) detected on the last shot. ("Bad shot")
- notify_NV = 7 "Spurious Trigger" A trigger signal was received by the PCM when it was not in the charged and armed "Fire Ready" state. PCU is dumped and not triggered.
- notify_NV = 11 "Dump Relay Fault" The dump relay is in the wrong state. After attempted actuation of the Dump Relay, the position switch indicates that it is not closed. This will appear during system charging when the charge delay for the PCU expires and the unit tries to charge.
- notify_NV = 22 "Mainbank Negative Ramp" Negative voltage slope detected on the Mainbank capacitors during charging. Indicates possible prefire or capacitor failures.
- notify_NV = 36 "Mainbank Undervolt" An under voltage condition measured on the Mainbank while at volt (voltage droop). Indicates possible capacitor or charger failure.
- notify_NV = 49 "At Volt Time-out" The PCU remained in the At-Volt condition too long while waiting for the Fire Ready command. (Current value is 60 seconds.)
- notify_NV = 50 "Trigger Time-out" The PCU remained in the Fire Ready state too long while waiting for the Trigger signal. (Current value is 20 seconds.)

Each PCU has a control power supply on a separate circuit from the charger power supplies. External manual circuit breakers allow these to be engaged independently. The control panels of the rod amplifier and the SSA PCU's are shown, in Figs. 4.3-5 and 4.3-6. Although the layouts and implementations are different, the functions are the same. In addition to the PCM features and the power controls, these include: the socket for connection to the 750 kVA subsystem power source, the connection for the "Amplifier OK" signal, and lights which indicate power is connected, the status of the hardwire fault detection logic and the status of the dump relay.

The electric power used by the PCU for both control and charging is derived from the front panel connection to the bus duct from the 750 kVA power station. This includes the energy that holds the dump relay open to allow the capacitors to be charged. Interruption of the 750 kVA power will cause the relay to close and any energy stored in the PFN capacitors to be discharged into the dump resistors.

G4382

Fig. 4.3-5
The rod amplifier PCU front panel includes the PCM, power circuit breakers, other external connection points, and PCU status indicators.

G4383

Fig. 4.3-6
The disk amplifier PCU front panel includes the PCM, power circuit breakers, other external connection points, and PCU status indicators.

PCU Triggering

While the Laser Drivers subsystem produces a shaped optical pulse suitable for amplification by the laser power amplifiers five times every second, charging the PCU's takes about 2.5 min and the power amplifiers can be fired only once every hour (approximately). When the system is ready for a shot, the PCE is able to coordinate charging of the PCU's so that they all arrive at the desired charge voltages within about 10 s of each other. It is then necessary to synchronize firing of the PCU's with each other and with the laser drivers so that the pumping energy in the laser glass is at its peak at the point in time when a driver pulse propagates through the laser amplifier.

To achieve this, the PCE monitors a 0.1 Hz signal relayed from the Master Timing Generator (MTG). (See Fig. 4.3-1 and Sec. 2.3.) This signal is synchronous with the signals that control the driver pulses and precedes the next actual light pulse by about 5 ms. When all of the PCU's have completed charging, the PCE sends signals to the MTG that cause it to issue a "T-0" trigger synchronized to a subsequent 0.1 Hz pulse. This event is used to sequence the PCU's and other elements of the OMEGA system that operate on the shot.

The T-0 trigger used by the PCU's originates in the Driver Electronics Room (DER) as a optical signal output by the MTG. As is shown in Fig. 4.3-7, the signal is relayed by a fiber optic cable to a main distribution box in Capacitor Bay 2. There, it is converted to an electrical signal, amplified, and reconverted into eight separate optical signals that go to local distribution boxes. These are mounted on the north and south walls of each of the four capacitor bays. In the local boxes, the signal is again

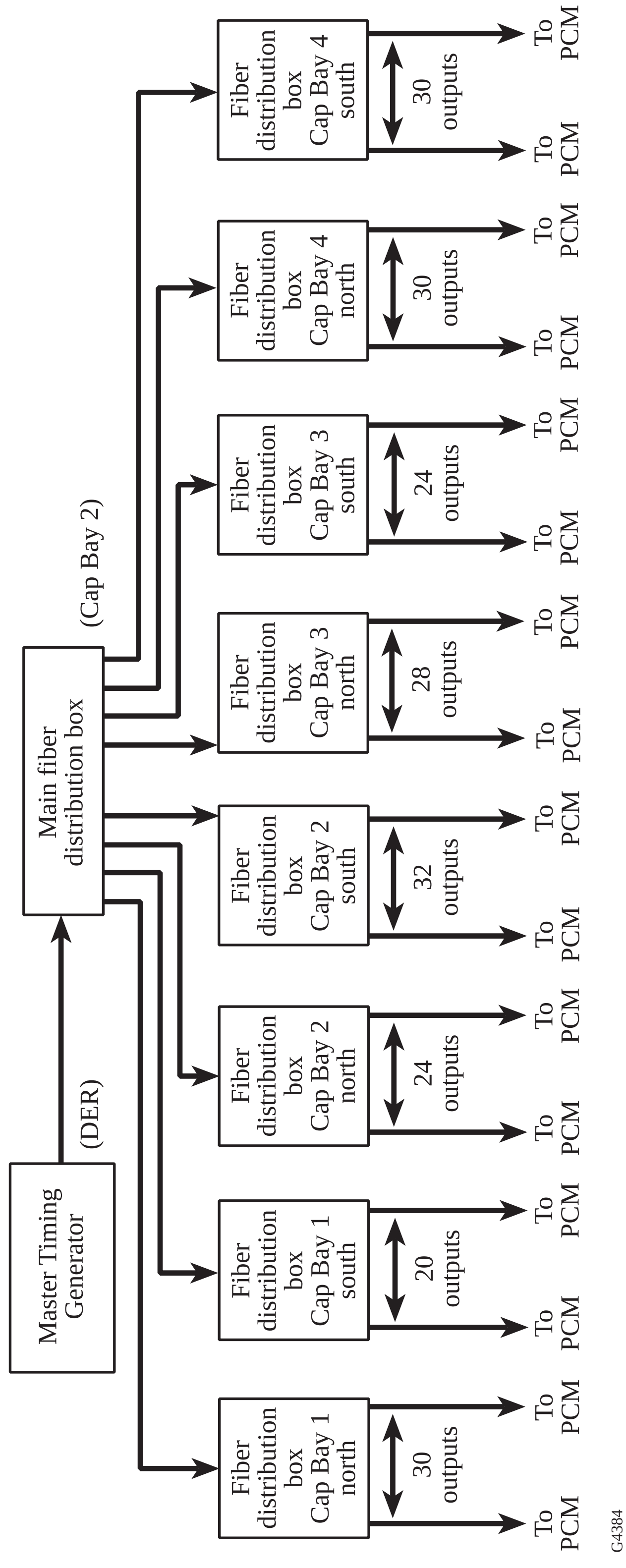


Fig. 4.3-7
Distribution of PCU "T-O" trigger.

converted into an electrical signal that is used to drive fiber optic drivers that provide a dedicated fiber signal to each of the PCU's on that side of the capacitor bay.

At the PCU, the fiber that carries the trigger signal is connected to the front of the PCM. The PCM converts the light pulse to an electrical signal that starts PILC and main trigger delay timers on the Neuron chip. These timers are set by the software/firmware to values that achieve the desired synchronization of peak amplifier gain and laser pulse arrival. (The values displayed by the software are 200 ns "counts".) If the PCM logic is in the correct state when the timers expire, the appropriate ignitron trigger signals are issued to the PCU interface electronics.

Operating States

With the PCU correctly assembled and its enclosure closed, the only way to operate the unit is to communicate via the LON connection with the PCM firmware stored in the programmable read-only memory on the neuron daughter board. This communication will normally be with the PCE but, under the correct maintenance circumstances, a single PCU may be operated by a Power Conditioning Test Unit (PCTU). The PCTU is a personal computer with special software allowing it to interact with *pawpaw* to control one PCU. The PCTU is capable of issuing the set-up, charge, and fire enable command sequence described below and monitoring the PCU/PCM responses. The PCTU can also issue a command that will cause the PCM to trigger the ignitron(s) in lieu of the signal from the Master Timing Generator.

The PCM code includes a state engine that accepts or rejects commands and responds to other inputs based on a sequence of events. The unit will not respond to any commands unless it is correctly connected and in current communication with an executive (the PCE or the PCTU). Initially, the only acceptable command is to go to the ONLINE state. When the code is in the ONLINE state, it will accept set-up commands, respond to requests for data, and can be commanded to the charge or OFFLINE states. In the ONLINE state, a command to charge the capacitors is accepted only if all of the PCU hardware checks and interlocks are good. In the CHARGE state, charging is monitored by time and voltage trajectory limits, and "ABORT" is the only acceptable command. Once the commanded voltage is reached, the PCM is in the CHARGE COMPLETE state. Time and voltage limits are enforced and the only acceptable commands are FIRE ENABLE and "ABORT." When FIRE ENABLE is accepted, the PCM is in the FIRE READY state and time and voltage limits are also enforced. When the trigger signal is received, the PCM will delay by pre-programmed intervals and activate the PILC and main trigger circuits as required. The PCM then checks the electronics that monitor the discharge and sends a signal indicating shot success or problems to the executive via the LON. Additional post-shot data will also be available to the executive.

Receipt of the ABORT command or any violations of the hardware checks, the command sequence, or the voltage or the state time limits will cause the PCM to abort. This involves closing the dump relay, signaling the executive computer and returning to the ONLINE state. An abort by one PCU has no direct affect on any other PCU.

Operating Sequence Interactions

During the normal OMEGA shot cycle, the operators generate a table that specifies which PCU's to charge and to what voltages. This list, referred to as the "power conditioning template," is used by the PCE to command all of the required PCM's through the state sequence to produce an integrated system shot.

The command sequence is summarized in Table 4.3-3 and begins with "prepare" action (generally referred to as the "download"). This is an extended series of interactions that ends with the active PCU's checked and ready to charge to the specified voltages. As part of this process, the PCE provides each PCM with a time increment called the "charge delay."

Table 4.3-3
PCE/PCM Shot Cycle Interactions

PCE		PCM	COMMENT
			start of download
Online	⇒		• heads in template only
Linkcheck	⇒		• is periodic after download
Read thresholds	⇒		• PCE checks versus template
	⇐	Response: values	
Set thresholds	⇒		• only if change required
Read trigger delays	⇒		• PCE checks versus template
	⇐	Response: values	
Set delays	⇒		
Read trigger delays	⇒		• PCE double checks
	⇐	Response: values	
Read timeouts	⇒		• linkcheck
	⇐	Response: values	• at volt • trigger wait • trigger test
Set timeouts	⇒		
Set charge voltages	⇒		• PCM checks values
Read PCM info	⇒		• PCE check of Stg, Cl, Beam, PCU type validates PCM & LON
	⇐	Response: values	
Read charge time	⇒		• PCE uses max. for AT Volt counter
	⇐	Response: values	
Set charge delay	⇒		• PCM delays charging from charge command
Read faults	⇒		
	⇐	Response: values	***end of download***
			(system may hold here indefinitely)
			beginning of charge state
Charge	⇒		• PCM checks latched faults • PCM zeros post shot fields
	⇐	Notify: Charging (3)	• delay timer has expired
• Read bank volts	⇒		• PCE polls these data periodically throughout charging
• Read notify	⇐	Response: values	
• Read state			
	⇐	Notify: At volt (4)	***Charge state ends*** (when all have reported system synchronizes with driver)
Fire enable	⇒	(PCM will fire when trigger arrives)	***Beginning of fire state***
			(system is triggered)
			beginning of post shot state
	⇐	Notify: good/bad shot (0)/(6)	
	⇐	Notify: waveform in Memory (5)	

When the charge command is given, each PCM counts off its charge delay before activating its charger. As a result, all of the active PCU's arrive at their specified voltages within about 10 sec of each other. When all of the amplifier stages are included, the charging process takes about 2 min, 30 sec. During that time, the PCE checks on the status of each PCM and displays the results to the operators. The PCM's also send the messages listed in this section to the PCE when they detect a problem or complete the charge process.

When all of the PCU's are "at volt," the PCE initiates the trigger synchronization process described in the preceding section. Shortly after the T minus 20 sec mark, the PCM's are authorized to trigger the ignitrons in response to the trigger signal from the fiber-optic system (Fire Enable). After it has triggered, aborted itself, or been commanded to abort by the PCE, the PCM assembles its post-shot reports and transmits them to the PCE. The PCM then transitions to the ONLINE state and is logically ready for another charge cycle.

PCM Messages

For safety, the PCM firmware monitors the status of the PCU and the sequence of commands that it receives from the PCE. The PCM may unilaterally dump the PCU on the basis of its own internal state and the information that it gathers from the PCU. Messages are sent back to the PCE to indicate the status of the PCM/PCU. These are categorized as either "command result" responses or asynchronous messages ("aysnchs").

Command Results

The PCM will issue a reply to any cmd_NV that it receives. The available responses are listed in Table 4.3-4. These take the form of a Command Result Network Variable that can have a value from 0 to 10.

Asynchronous Messages

The PCM can also issue asynchronous messages to notify the PCE of events that are not the immediate result of a command from the PCE. These take the form of Notify Network Variables (notify_NV) that can have a value from 0 to 50. The available responses are listed in Table 4.3-5.

Table 4.3-4
PCM Command Result Responses

cmd_result _NV	Name	Description
0	Command Successful	Command was successfully executed
1	Command Acknowledged	Command accepted and being is being executed (An ansych follows.)
2	Command Failed Error	General error
3	Unknown Command Error	Invalid command for this device
4	Wrong State Error	PCM is in an Invalid State for this command. Such as: received a charge command while in the Offline state.
5	Out Of Range Error	Data value received is out of range for this adjustment
6	PILC Volts Too Low Error	The received PILC voltage setting is too low to break down the flashlamps (out of preset range).
7	Non PILC PCU Error	PILC voltage specified to a PCU that does not have PILC capabilities.
8	Existing Fault Error	A pre-existing fault prevents this command, Such as: trying to charge with an interlock open.
9	Trigger Failure Error	Trigger Test Command failed (for diagnostic use only).
10	Waveform Already Downloaded	The waveform is already in the Neuron RAM.

Table 4.3-5—PCM Asynchronous Notifies
Part A—General

notify_NV	Name	Description
0	Successful Event	All PILC bits are good and capacitors are discharged properly. (“Good shot”)
1	Link Check Failure	PCM did not receive a Link Check message from the executive before the previous timer expired. PCM automatically goes back to the Online state.
2	Remote Mode Enabled	Informs the PCE that it is back in control. This is only issued after the PCTU has relinquished control of a PCM.
3	Charging	The PCU is being charged.
4	At Volt	The PCU has successfully charged and is in the “At Volt” condition.
5	Waveform Download Complete	The digitizer data has been downloaded and is in Neuron memory.
6	Post Shot Error	Error(s) detected on the last shot. (“Bad shot”)
7	Spurious Trigger	An trigger signal was received by the PCM when it was not in the charged and armed “Fire Ready” state. PCU is dumped and not triggered.
8	Fiber Interface Failure	Self test has detected that the PCM cannot communicate with the PCU interface circuits. The PCM automatically aborts and returns to the Online State if this occurs while charging

Table 4.3-5—PCM Asynchronous Notifies
Part B—Errors encountered at start of charging
(These will cause the PCM to abort.)

notify_NV	Name	Description
9	PILC Loopback Error	The PILC analog circuits have failed a loopback test prior to enabling the power supply. This indicates problems in the PCU's interface circuitry.
10	Mainbank Loopback Error	The Mainbank analog circuits have failed a loopback test prior to enabling the power supply. This indicates problems in the PCU's interface circuitry.
11	Dump Relay Fault	The dump relay is in the wrong state. After attempted actuation of the Dump Relay, the position switch indicates that is not closed.
12	PILC Charger High Voltage Enable Failure	The PILC charger didn't enable
13	Mainbank Charger High Voltage Enable Failure	The Mainbank charger didn't enable

Table 4.3-5—PCM Asynchronous Notifies
Part C—Errors encountered during charging
(These will cause the PCM to abort and dump the charge in the PCU.)

notify_NV	Name	Description
14	PCU Interlock Fault	The PCU enclosure interlock series circuit is open.
15	PILC Charger Fault	A fault has been detected from the PILC charger.
16	Mainbank Charger Fault	A fault has been detected from the Mainbank charger.
17	PILC Ramp Too Slow	The voltage on the PILC capacitor is increasing too slowly.
18	Mainbank Ramp Too Slow	The voltage on the Mainbank capacitors is increasing too slowly.
19	PILC Ramp Too Fast	The voltage on the PILC capacitor is increasing too fast.
20	Mainbank Ramp Too Fast	The voltage on the Mainbank capacitors is increasing too fast.
21	PILC Negative Ramp	Negative voltage slope detected on the PILC capacitor, indicates possible prefire or other problems.
22	Mainbank Negative Ramp	Negative voltage slope detected on the Mainbank capacitors, indicates possible prefire or other problems.
23	PILC Early End Of Charge	PILC charger has indicated End Of Charge before set voltage reached.
24	Mainbank Early End Of Charge	Mainbank charger has indicated End Of Charge before set voltage reached.
25	PILC Late End Of Charge	PILC charger voltage is at set point and EOC has not been received.
26	Mainbank Late End Of Charge	Mainbank charger voltage is at set point and EOC has not been received.
27	PILC Overvolt	An over voltage condition was measured on the PILC cap during charge or while at volt.
28	Mainbank Overvolt	An over voltage condition was measured on the Mainbank during charge or while at volt.
29	PILC Undervolt	An under voltage condition measured on the PILC cap while at volt (voltage droop).
30	Mainbank Undervolt	An under voltage condition measured on the Mainbank while at volt (voltage droop).
31	Prefire Fault	Detected the “prefire” bit set.
32	Ground Fault	Detected the “ground fault” bit set.
33	Charge Time-out	The PCU is taking too long to charge. .
48	AFC Amplifier OK Fault	AFC contact for PCU AFC interlock is open.
Note: NV values 34–47 were reserved for other AFC errors. As of Firmware Rev 4.00, these are no longer to be used by the PCM.		

Table 4.3-5—PCM Asynchronous Notifies
Part D—Errors encountered after reaching At Volt
(These will cause the PCM to abort and dump the charge in the PCU.)

Notify_NV	Name	Description
49	At Volt Time-out	The PCU remained in the At-Volt condition too long while waiting for the Fire Ready command. (Current value is 60 seconds.)
50	Trigger Time-out	The PCU remained in the Fire Ready state too long while waiting for the Trigger signal. (Current value is 20 seconds.)