

# Pulsed Power System for the Orion High Power Laser

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This paper describes the design and testing of the pulsed power system for the Orion Laser, which will be used for high temperature and density plasma physics research. The system supplies 8 MJ of energy to laser amplifiers and Faraday rotators. It consists of 17 capacitor bank modules, each with up to sixteen 150  $\mu\text{F}$  charge storage capacitors, 25 kV power supply and controls. The energy is delivered by spark-gap switches to give a pre-pulse to ionise the flashlamps and a main pulse of 490  $\mu\text{s}$ . The system delivers 5 shots a day with less than 0.2% variation in charge voltage.

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## 1. Orion laser

The Orion laser is being built at Atomic Weapons Establishment (AWE) for plasma physics experiments up to 10 million deg C and 3 times solid density [1]. It has twelve beams each delivering 500 J to a microscopic target. Ten are long pulse beams of 0.1 to 5 ns and two are Petawatt ( $10^{15}$  W) beams of 0.5 to 20 ps. The laser has a pulse power system (PPS) to supply the large aperture (100 to 200 mm diameter) final sections with energy to pump neodymium glass amplifiers and current to drive Faraday rotators. The long pulse beams pass 4 times through four 200 mm amplifiers. The Petawatt beams pass twice through a 100 mm rotator and amplifier, once through a 150 mm amplifier and rotator, and once through three 200 mm amplifiers. The small signal gain (SSG) per single amplifier pass is 2.2, 3.5 and 10 for the 200 mm, 150 mm and 100 mm amplifiers, respectively. Each amplifier has 8 Xenon filled flashlamps of 1.2 m by 25 mm diameter arranged in series pairs. The pump energy required is about 160 kJ per amplifier. Multi-pass amplifier configurations are efficient but require a very stable PPS with fine adjustment. For  $N$  passes through  $M$  amplifiers of power gain  $G$  it can be shown that to achieve a balance between laser beams of  $B$  the PPS voltage stability must be better than  $B/(2NM \ln G)$ . Hence for the long pulse beams the PPS stability must be better than 0.2% to achieve the required 5% beam balance.

## 2. Pulsed power system

The PPS consists of 17 capacitor bank modules (CBMs) organised as shown in Table to supply the 12 beams and a test laboratory for measuring amplifier SSG.

Each CBM is an autonomous unit containing up to 16 main charge storage capacitors, a 25 kV charging power

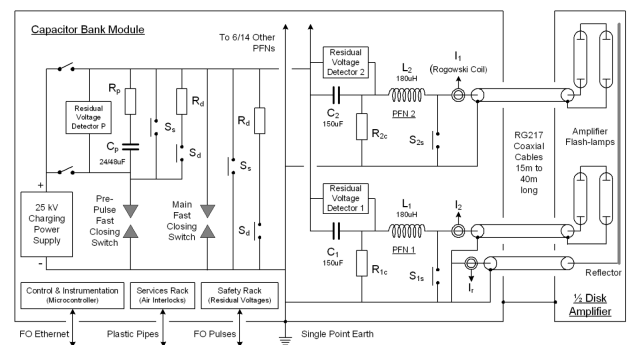


Fig. 1. Scheme showing main components of amplifier CBM.

supply, fast closing switches, safety circuits, instrumentation and controls. The design of the CBMs for amplifiers shown in Fig. 1 is more interesting than for rotators. A pre-pulse of 900 J is generated to ionise the flashlamps before the main pulse which allows the main pulse energy to be set over a wide range. This is also expected to improve efficiency, stability and flashlamp life. The main charge is held in 150  $\mu\text{F}$  metal film capacitors ( $C_1, C_2, \dots$ ) which are charged in 55 s to the required voltage  $V_m$ . The pre-pulse is generated by firing a pre-pulse switch which discharges some of the main charge into the pre-pulse capacitor  $C_p$ . This is charged to a voltage  $V_p = 25000 - V_m$  to keep the pre-pulse energy constant.

## 3. CBM design and component tests

The CBMs were designed to minimise electromagnetic interference. The power supplies and control electronics are well shielded at the bottom of the CBM. Internal and external connections are made by fibre optic (FO) cables or plastic air pipes wherever possible. The power supplies to pulsed circuits are disconnected prior to firing a pulse. There is a single earth point for each CBM and the amplifiers or rotators connected to it. The current flow

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through alternate pulse forming inductors is reversed to minimise the external magnetic field. EMC tests were performed during the design to ensure there was no interference between the pre and main pulses or between adjacent CBMs.

TABLE

List of CBM types.

Type	Load supplied by one CBM	Number required for beams or Lab.		
		Long pulse	Petawatt	SSG Lab
200	4 or 3 × 200 mm aperture disk amps.	10	2	
150/100	150 mm disk amp. + 100 mm disk amp.		2	
150FAR	2 × 150 mm Faraday rotators		1	
100FAR	2 × 100 mm Faraday rotators		1	
SSG	Any one of above			1

Personnel safety is ensured by independent hardwired systems. The Orion safety interlock system provides two air signals to the CBM to enable the opening of the dumps switches ( $S_d$ ) and shorting switches ( $S_s, S_{1s}, S_{2s}$ ) by the controls prior to charging. There is also a residual voltage detection system which gives an indication to personnel outside the PPS room of the charge status. This is derived from passive detectors fitted to every charge storage capacitor which generate a flashing FO signal when the voltage is above 100 V. The indication outside is latched red when one or more capacitors are charged and yellow when all are charged for testing the integrity of the system. The CBM layout is also made so all the pulse power and safety components can be inspected at a safe distance in front of the CBM.

The pulse currents are measured using Rogowski coils and the waveforms stored for post-shot fault diagnosis such as identifying broken flashlamps [2]. The latter is an expected event which the CBMs are designed to withstand. The worst case broken flashlamp has been modelled as a short-circuit fault to confirm that the integral  $i^2t$  and voltage reversal does not damage critical components. The possibility of a direct short circuit of a charged capacitor has also been considered. The selected capacitor type has been shorted circuit tested by the French Atomic Energy Commission (CEA) for Laser Megajoule (LMJ) [3].

The requirement for high reliability led to extensive testing of critical components early in the design. A pre-production CBM was fitted with a set of 1  $\mu$ F 40 kV capacitors made in the same cases as the 150  $\mu$ F 25 kV capacitors. This was used to verify the insulation to 40 kV during both charging and discharge of the CBM. The fast closing switches were also tested early because a very high charge transfer is required with no “pre-fires” or “miss-

-fires”. The no pre-fire requirement is achieved by setting the self-breakdown voltage to 40 kV and the no miss-fire requirement is achieved by setting the triggering voltage to over 100 kV. The switch has for reliability only two graphite electrodes (i.e. no trigger electrode). It has been used in other applications at 400 kA but for Orion the nominal current is set at 80 kA for long life. The CBM type 200 has two switches for the main pulse and one for the pre-pulse. The trigger is provided by a 120 kV solid-state Marx generator.

#### 4. CBM performance

The performance of the CBMs was modelled using PSpice during design using the Markiewicz flashlamp model [4] and is close to the performance measured during factory tests as shown in Fig. 2. These show efficient

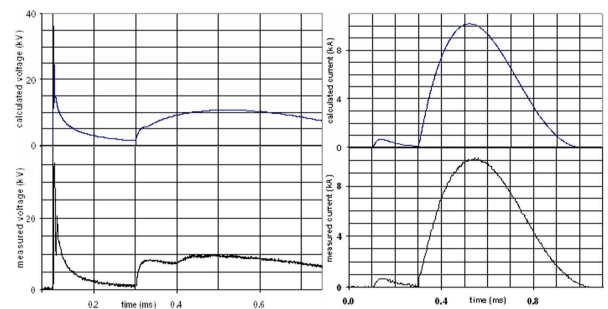


Fig. 2. Performance of amplifier CBM at 24 kV by modelling at the top and measurement at the bottom showing the flashlamp voltage (kV) on the left and current (kA) on the right plotted against time (ms) with the pre-pulse triggered at 0.1 ms and main pulse at 0.3 ms.

performance with no transient over voltage at the start of the main pulse showing the flashlamp pairs are fully ionised by the 900 J pre-pulse. The timing jitter and charge voltage stability measured over 30 pulses were 1  $\mu$ s and 0.1% which meets the required specification.

A pre-production CBM is being subjected to an 8000 shot accelerated life test and the production CBMs are being manufactured at the Thales GERAC facility adjacent to LMJ near Bordeaux.

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