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A New Gated X-Ray Detector for the Orion Laser Facility

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ABSTRACT

Gated X-Ray Detectors (GXD) are considered the work-horse target diagnostic of the laser based inertial confinement fusion (ICF) program. Recently, Los Alamos National Laboratory (LANL) has constructed three new GXDs for the Orion laser facility at the Atomic Weapons Establishment (AWE) in the United Kingdom. What sets these three new instruments apart from the what has previously been constructed for the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) is: improvements in detector head microwave transmission lines, solid state embedded hard drive and updated control software, and lighter air box design and other incremental mechanical improvements. In this paper we will present the latest GXD design enhancements and sample calibration data taken on the Trident laser facility at Los Alamos National Laboratory using the newly constructed instruments.

Keywords: Plasma Physics, Inertial Confinement Fusion, Laser, Gated X-Ray Detector, Orion, Trident, Kentech, Micro Channel Plate, High Speed Framing, Spectral Instruments, x-ray, MCP, FOFP, CCD, GXD, ICF, LANL, LLNL, AWE

1. INTRODUCTION

In June 2010 the AWE in the United Kingdom contracted the Diagnostic and Systems Engineering (DSE) team in the Plasma Physics Group at Los Alamos National Laboratory (LANL) to build three Gated X-Ray Detectors (GXD) for use on the Orion laser facility.[1] Three GXD units were delivered to the Orion Laser Facility in July 2012.

The GXDs that were built were a next generation design based on the existing design that the DSE team had built in 2005 for use on the NIF.[2] The completed Orion GXDs are shown in Figure 1.

The Orion GXDs function fundamentally like their predecessors:[2] a high voltage (HV) pulser drives a fast gate pulse across a set of Micro Channel Plate (MCP)[34] strips. The gate pulsers are timed so that the gate pulses are propagating across the MCP strips coincidentally with the x-rays generated in the ICF target arriving at the MCP strips. The Orion GXDs are designed for electrical gate pulses as fast as 250 ps which generate 80 ps optical gate pulses. A CCD camera is proximity focused to the phosphor output of the MCP image intensifier (MCPii) to record the images generated by the x-rays. Imaging in two spatial dimensions is provided by a nose cone attached to the front of the instrument which holds an imager such as a pinhole array. The instrument is modular so that any imager or spectrometer designed to work with the instrument can be accommodated.

The Orion GXD is designed around a Kentech gate pulser which drives nominally 1500 V pulses across four MCP strips on a single substrate. A SI-1000 CCD camera built by Spectral Instruments records the image output by the MCPii phosphor. A embedded computer stack based on an Advantech PC/104+ embedded computer and running custom software developed by VI Control Systems provides communication and control to all internal components and external infrastructure. A block diagram of the system is shown in Figure 2. The components reside in an air box which resides in vacuum in a Ten Inch Manipulator (TIM) on the Orion target chamber.

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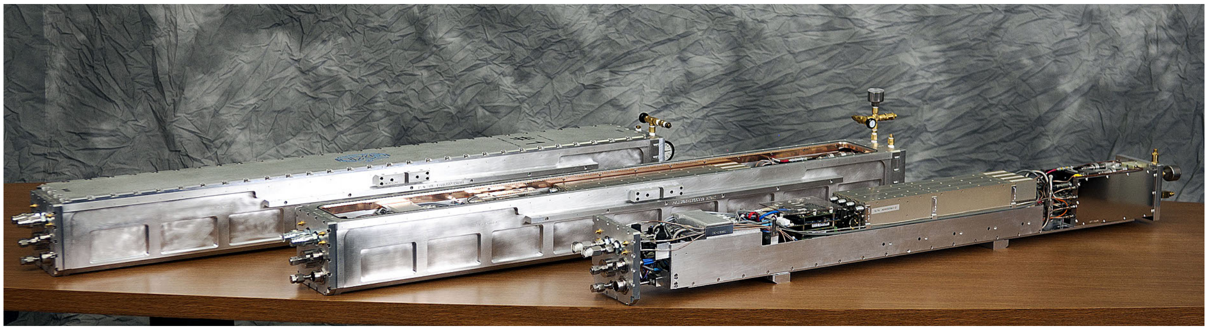

Figure 1. The GXDs constructed for the Orion Laser facility. From left to right: GXD in air box with lid on, GXD in air box with lid off, GXD electronics removed from air box. The MCPii head is to the right and the rear cover is to the left.

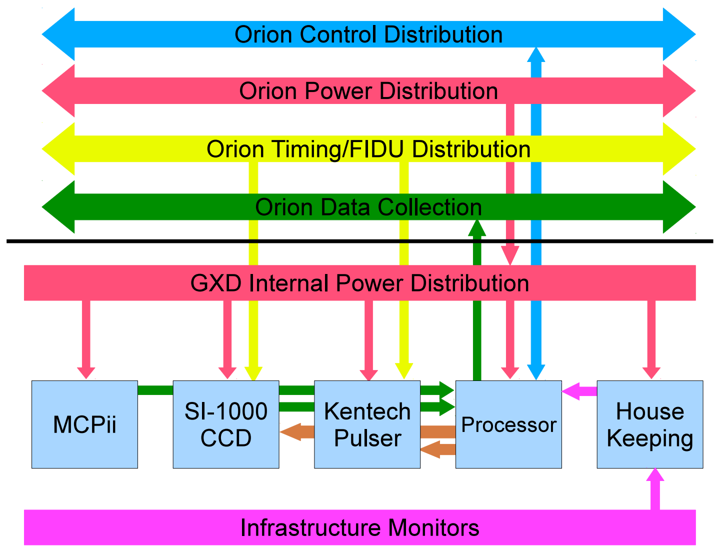

Figure 2. Functional block diagram of the Orion GXDs. The heavy black line represents the rear cover of the GXD. Each arrow crossing the line represents a physical penetration in the cover. The Orion control distribution and data collection are on the same penetration but are shown separately here for clarity.

The GXDs are interfaced to TIM standard triggers, network connections, cooling water, and 24 V power. They are easily installable in any of the Orion TIMs. All of the components are mounted on a water cooled strong back which is inserted into the air box. This strongback is sometimes referred to as the "cooling plane"

The remainder of this paper describes the design improvements of the Orion GXD over the 2005 NIF design.

2. ELECTRICAL IMPROVEMENTS

2.1 Microwave Striplines

The two core components of a GXD are the MCP and the high voltage gate pulser which drives the gate signal across the strips on the plate. The gate pulse combined with a DC bias voltage generated in the Kentech pulser provides the electron gain which in turn provides the optical gain in the MCPii. On the input side the gate pulser is coupled to the MCP strips via microwave striplines etched into a flexible printed circuit board (PCB) which is integrated into the head frame. On the output side a similar PCB is used to couple the gate signal from the output of the MCP strip to a monitor circuit. Figure 3 shows this arrangement. Key features to note in Figure 3 are that trace direction changes are very angulated and that the SMA connector landing at the ferrite involves cutting the board and making a blind solder joint. The new design has two key improvements over the 2005 design. The first is that there is a "via" in the PCB at the SMA connector landing. This allows the SMA

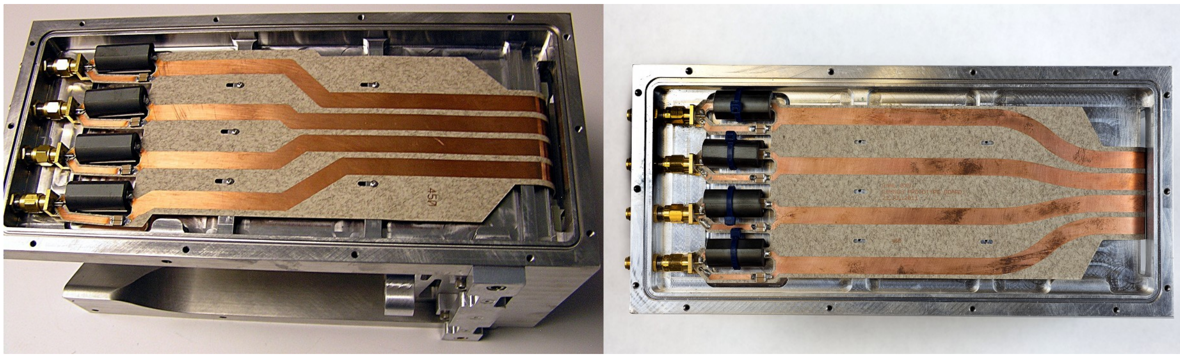

Figure 3. The microwave stripline PCB is integrated into the head frame. The gate pulses are coupled onto the board via the SMA connectors and impedance transformers on the left of the head frame. The MCPii is on the right. The old style striplines are shown in the left image and the striplines of the Orion GXD are on the right.

connector to be attached to the PCB without cutting the board or making a blind solder joint. This gives the connector landing robustness and it will be less likely to fail or degrade performance due to bad or intermittent solder joints. Figure 4 shows a close up view of the improvements of the solder joint.

The traces on the PCB in the 2005 design have very angulated and abrupt changes in direction. It has been suggested that these angles could be leading to electrical cross talk between the boards. The boards for the Orion GXD were redesigned to have graceful direction transitions in an attempt to reduce electrical cross talk between strips due to electric field bunching at the sharp edges of the direction transitions. Figure 5 shows a cross talk measurement using the new stripline design. For this measurement strip one* was driven by the gate pulser and the gate inputs to the other strips were terminated in 50 Ω. The output of each strip on the output side of the head frame was monitored on an individual scope channel. The data is the integrated cross talk along the entire signal path from the input on the head frame to the output on the head frame. The data shown here is for strips one and two since they are closest in proximity and have the largest cross talk. The data indicates that the electrical cross talk between strips is essentially identical between the 2005 and new stripline design. This indicates that the cross talk is not dominated by transmission line geometry. Additionally, the peak cross talk coupling amplitude is on the order of -60 dB. It is also interesting to note that the peak frequency component of the signals coupled into the passive lines has shifted higher by approximately an order of magnitude. Further study is required to determine what the source of the cross talk is and what its consequences are †.

The third impact that the the new stripline design has is to provide better impedance matching between the MCP strips and the printed circuit boards. In addition to the path of the length of the stripline, the width of the strip line and the board material have a large impact on the impedance of the transmission line. For this design generation, a computer script was written which optimized the width and board material based on estimating the impedance of the MCP strip as a function of the plates open area ratio (OAR). Figure 6 shows time domain reflectometer (TDR) traces of strip one on both a GXD head built with 2005 style boards and the Orion GXD head. The abscissa is shown as time instead of distance due to differences in propagation velocities in the various materials along the signal path. The most critical interface is where the output of the MCP strip meets the microwave stripline on the output PCB. This is because the gain of the MCP is very non linear[34] and any perturbations in the bias voltage due to a reflection back on to the strip at this interface could cause large errors in the image. Figure 7 shows the first time derivative of the impedance. This emphasizes where the impedance miss matches are located. It can be seen from the data in the figure that the output miss match is reduced in the new stripline design.

*When assembled the striplines are oriented vertically in the head frame. Strip one is on top and the others are numbered in ascending order.

†Robin Benedetti at Lawrence Livermore National Laboratory has studied the cross talk problem. The results of this study were not available to this author at the time of publication

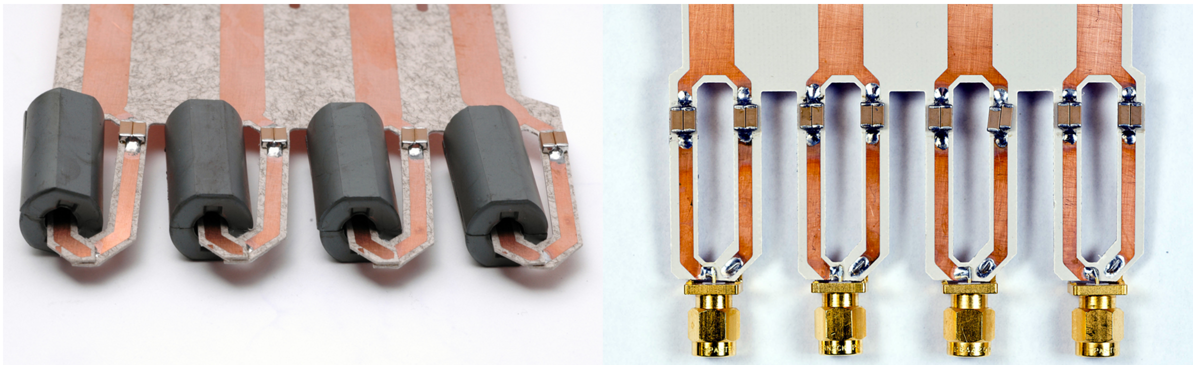

Figure 4. Close up showing the improved solder joints on the stripline PCB. The 2005 design style joints are on the left and the new style joints are on the right. The ferrites for the impedance transformers are employed in the new design but are not shown in this figure.

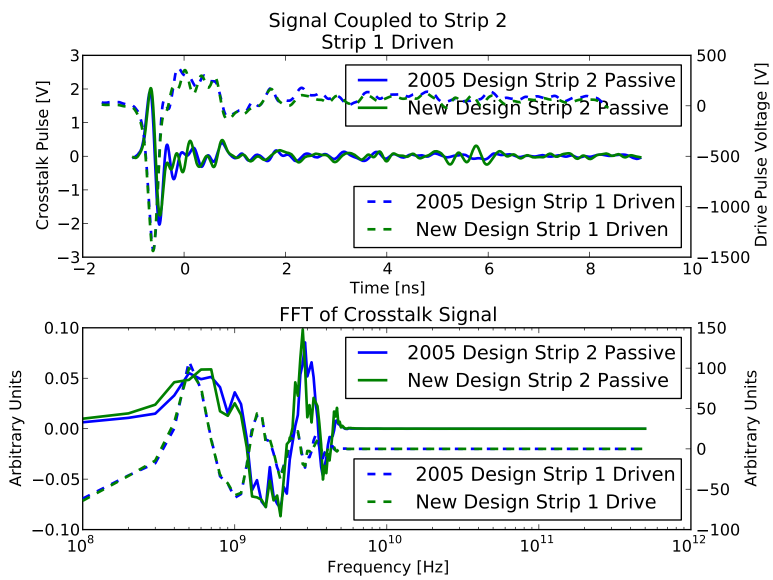

Figure 5. Electrical cross talk between strip one driven by the Kentech pulser and strip two which is not driven. There is no appreciable difference between the 2005 and the new design.

2.2 PC/104 Stack

The embedded computer in the Orion GXD is built around an Advantech PCM-3362 PC/104+ embedded computer running Windows XP Pro. Figure 8 illustrates the stack configuration. The PC/104+ stack is designed to be a centralized communication and control center inside the air box. The only communication that the Orion GXD has to the external control and data acquisition network infrastructure is via the 1000base-SX Gigabit optical ethernet switch. The MPL MAGBES-12+SFP-1X is an addition to the PC/104 stack not found in previous GXD generations. It is a network switch that is independent of the PC/104+ and communicates with the CPU via CAT5e cable connected to the PC/104+ on board ethernet controller. The MPL switch also allows the Orion GXD to be configured with a CAT5e connection to the external network. Additionally it can be configured to use optical protocols other than 1000base-SX.

The other main improvement to the stack is the addition of the Kingston Technology solid state hard disk (SSD). In previous GXD designs, the embedded computer was run with a “disk on chip” arrangement which required downloading the operating system from an external source to the embedded computer each time it was booted. The DSE team found this process to be very unreliable and slow. In the current design, the entire instrument including the embedded computer is a stand alone system and does not require any external

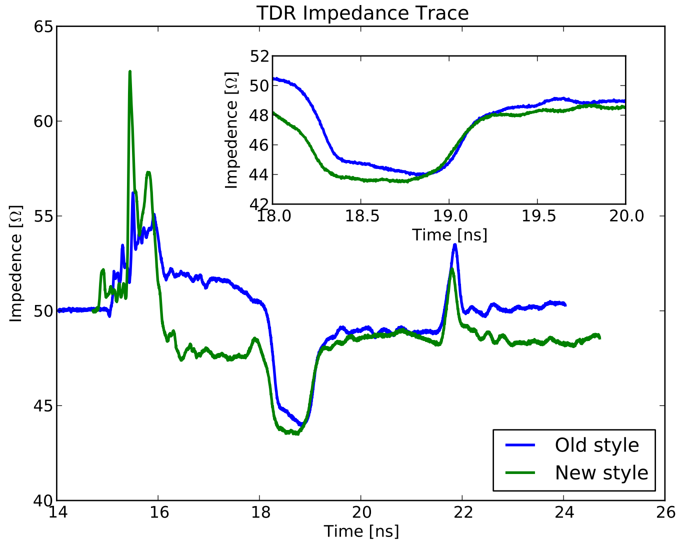

Figure 6. A comparison of the TDR impedance measurements of a 2005 style microwave stripline design and a new style design. The peaks around 15 ns are due to the impedance transformer. The rising edge at 19 ns is the MCP strip output interface and the peak at 22 ns is the DC blocking capacitor and impedance trim resistor network at the output interface of the monitor board. The time axis datum is arbitrary and the axis is only useful for making relative comparisons between designs.

infrastructure to run. In this configuration, the instrument boots quickly and reliably. The SSD is a 2.5" SATA type and is mounted in a location that makes it easily removable and replaceable. The location of the SSD is shown in Figure 10.

2.3 Control Software

The Orion GXD control software was significantly updated to integrate properly into the Orion facility. The original NIF system required an external rack mounted computer to send and receive controls and status to a PC/104+ computer inside the GXD that did not have much intelligence built inside it other than being able to pass commands/status to/from the IO boards built into it. For Orion, all GXD control functionality was programmed into the single PC/104+ computer inside the GXD running Windows XP. The PC/104+ computer can either be accessed by logging into the PC/104+ via Windows Remote Desktop and directly running the LabView interface or can be controlled remotely via OPC commands. The OPC commands are a wrapper around the LabView code and are completely independent. The GXDs will interface to the Orion facility using OPC to control instruments from a central command/control computer system but will use Windows Remote Desktop for troubleshooting and detailed control and calibration of the GXD instrument. The control software on the PC/104+ was custom developed by VI Control Systems using LabView.

3. MECHANICAL IMPROVEMENTS

3.1 Air Box and Lid

The Orion GXD air box is nominally 60 inches long including the end covers and weighs 42 pounds (19 kg). The air box lid weighs 12 pounds (6 kg). This length makes the Orion GXD compatible with the Diagnostic Instrument Manipulator (DIM) at the NIF and the Ten Inch Manipulator (TIM) at Orion and the Trident laser at LANL. The Orion GXD will also fit in the TIM at omega. However, with a nose cone installed it will not fit in the Omega TIM with the target chamber vacuum valve closed. Additionally there is an Omega TIM operational weight limit of 90 pounds (40 kg) which the current instrument exceeds. The weight of the air box was reduced by 13 pounds (6 kg) and the weight of the lid was reduced by five pounds (2 1/4 kg) over the 2005 design. The

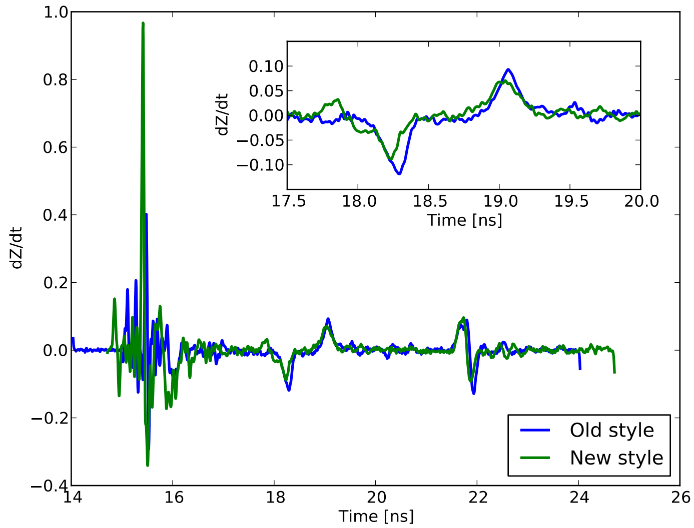

Figure 7. The first time derivative of the impedance trace emphasizes the locations of miss matches. The features are the same as described in Figure 6. The inset magnifies the MCPii output interface at the monitor board. It can be seen that there is less of a miss match in the new design. The output interface is at 19 ns.

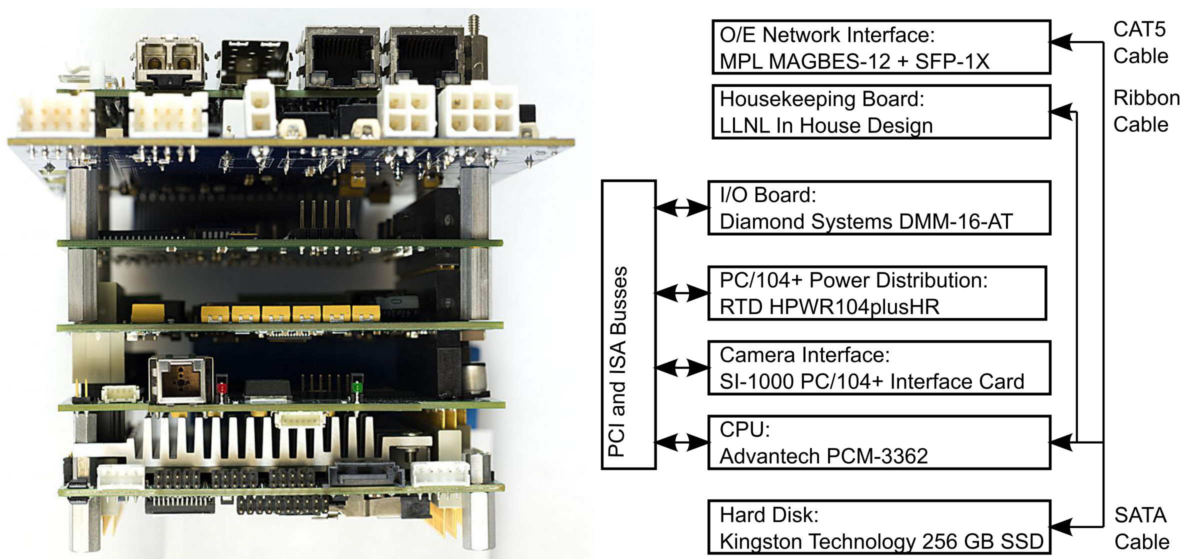

Figure 8. The Orion GXD PC/104+ embedded computer stack. Descriptions of the components and a block diagram of the internconnections are shown on the right. The blocks in the diagram are vertically aligned with the corresponding board in the photograph.

total weight reduction was comprised totally of the weight reduction in the air box and lid and was reduced from 139 pounds (63 kg) to 121 pounds (55 kg).

The front cover has been updated to include the NIF standard nose cone kinematic mounts. The rear cover has been outfitted to include five SMA connectors. Three of the connectors are for the Kentech pulser trigger, the SI-1000 CCD trigger and the pulsed phosphor trigger. There are two SMA ports for monitoring the pulser comb signal and the Photo Conductive Diamond (PCD) signal, which provides an x-ray based timing fiducial. This allows the possibility of monitoring these signals on separate channels. The Orion GXDs as they currently

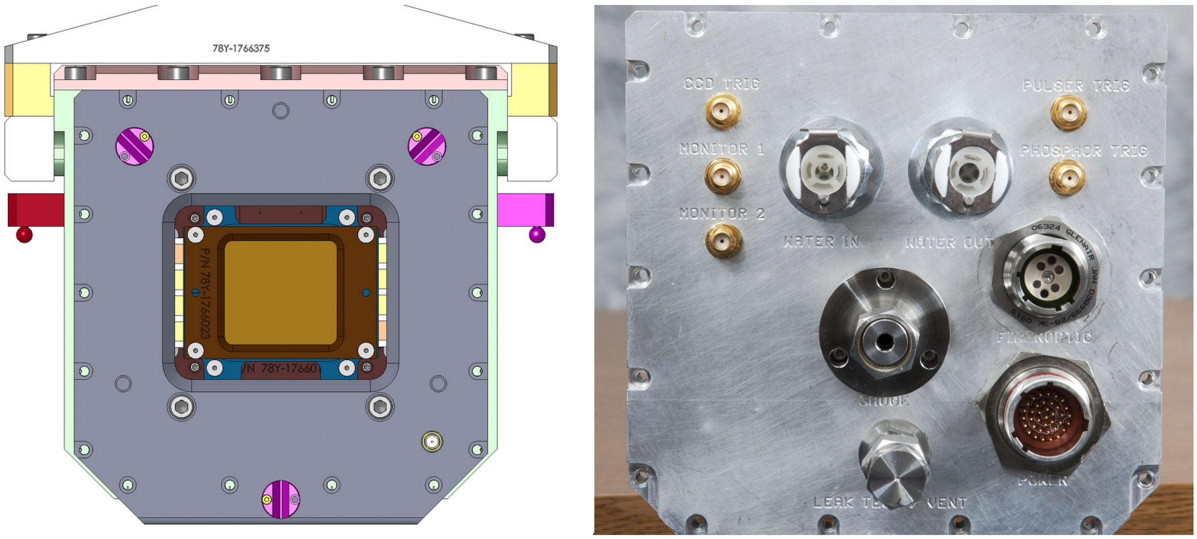

Figure 9. The front and rear covers of the Orion GXD. The front cover showing the NIF standard kinematic mounts is on the left and the rear cover is on the right. A photograph of the front cover was not available. The kinematic nose cone mounts are shown in purple in the model.

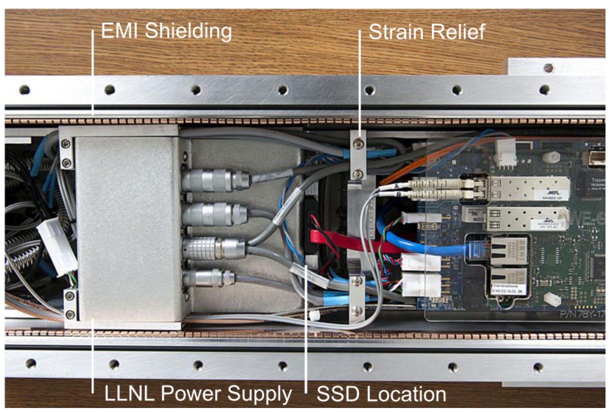

Figure 10. SSD location, EMI shielding, cable strain relief, and LLNL designed power supply.

configured have these signals multiplexed onto a singal monitor port and the other monitor port is unused. The power and network connectors are configured to match the Orion infrastructure, but can be configured with or adapted to connectors for other facilities that the air box design is compatible with. Figure 9 shows the front and rear covers.

3.2 Internal Mechanical Improvements

The major upgrades to the inside of the air box are the addition of electromagnetic interference (EMI) shielding around the rim of the lid, improved cable strain relief and upgrading from a Spectral Instruments designed power supply to a LLNL designed power supply. The EMI shielding is copper finger stock which is mounted completely around the top and end openings in the air box. The Orion GXD design also features engineered cable strain relief and routing which greatly reduces the likelihood of failure of the device due to cables shaking loose during transportation and installation. The SI-1000 power supply was replaced by a LLNL designed power supply which reduced its footprint on the cooling plane which allowed the positions of other components to be optimized on the cooling plane for better space management inside the air box. Figure 10 shows examples the EMI shielding, strain relief, and LLNL power supply.

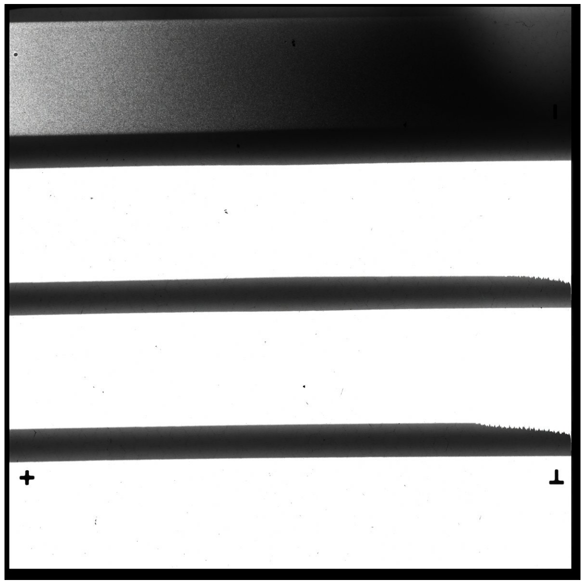

Figure 11. Sample Trident laser data for shot 23121 on Orion GXD #3. Strip one is on the top and time runs from right to left. The x-rays arrived at the MCPii as the gate pulse was propagating across strip one.

4. EXAMPLE CALIBRATION DATA

All three Orion GXDs were tested at the Trident laser at LANL before being shipped to Orion. At the time of the testing, there were no nose cones with imagers available and the GXDs were run in flat field mode. The MCPii was located at 15" from target chamber center (TCC) and filtered with 40 mils of Beryllium. The Trident laser was tuned for a single beam of nominally 200 J with best focus onto a gold disk target. The laser pulse width was 5 ns and the strips on the GXD were timed with 1.5 ns inter frame timing (IFT) for the data shown in Figure 11. The IFT is the delay between the gate pulser outputs for each strip. Figure 11 shows the image acquired with GXD #3 on Trident laser shot 23121. For Trident shot 23121 the Kentech pulsers were configured for 750 ps electrical gate gate width and the DC bias was set to +150 VDC. The wide gate accounts for strips two, three, and four being driven into saturation. The key feature of this data is that strip one can be seen turning on part way across the strip. This indicates that the triggers are timed to make the x-ray arrival at the MCP strips nearly coincident with the gate pulse propagating across the strip. Figure 12 shows the monitor signal associated with the image for Trident shot 23121. Figure 13 shows the image acquired with GXD #1 on Trident laser shot 23132. This image was acquired with 250 ps electrical gate width pulses and a bias of +100 VDC on the strips. It is shown to demonstrate what the strip data looks like when it is not driven into saturation.

5. CONCLUSION

The design of the Orion Gated X-Ray Detectors has been improved over previous GXD designs in several important areas. The new mechanical design of the microwave striplines will reduce the likelihood of a mechanical failure internal to the head frame. The new microwave stripline layout has improved impedance matching which will reduce gate pulse reflections at the critical interface between the MCPii output and the output PCB. The embedded computer stack has been upgraded to allow for more reliable operation without need for an external computer, the hard drive has been design to allow for easy software reconfiguration of the instrument, and the network communication interface has been upgraded for optical communication to external networks. The control software has also been upgraded to allow for direct control of the instrument via LabView or remote control via OPC tags.

The mechanical design has also been improved. The air box and lid have been lightened by a combined weight of 18 pounds (8 kg). EMI shielding has been added. Engineered cable management has reduced the risk

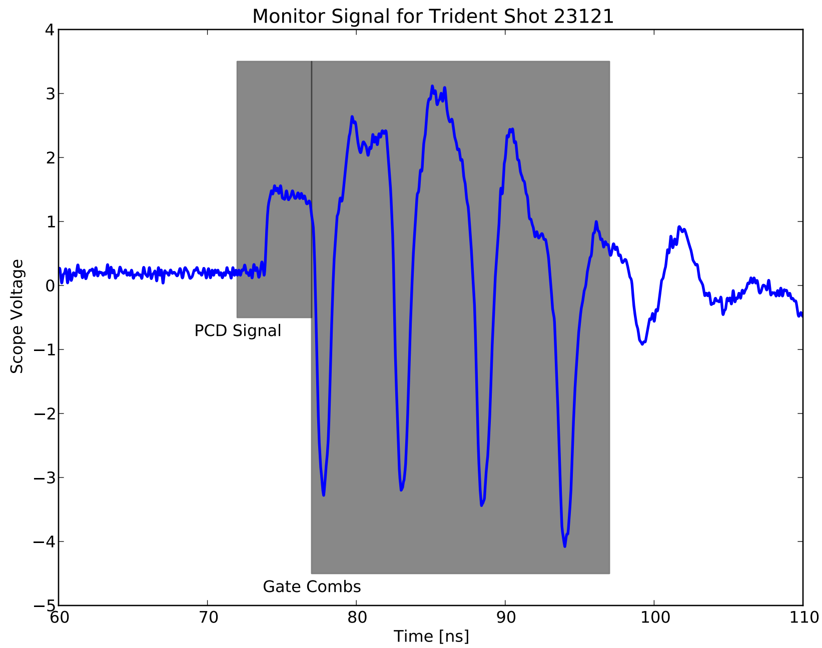

Figure 12. Monitor signals associated with Trident shot 23121 on GXD #3.

of failure due to cables failing during transportation and installation.

All three instruments have been tested on the Trident laser at LANL. The have been exercised to a point that indicates that all three instruments function. However, detailed commissioning and calibration work is still required at Orion.

ACKNOWLEDGMENTS

The Orion GXD project was complex and spanned two years. The authors would like to thank the following teams and individuals for their contributions to the success of the Orion GXD project. The Trident laser team led by Randy Johnson at LANL and the Orion laser team lead by Kevin Oades and Simon Daykin at (AWE) were indispensable in brining the instruments to life at actual ICF laser facilities. Chris Bentley and his team at the AWE Manson X-Ray source provided unparalleled support and service while the instruments were being checked out and prepared for fielding on Orion. Finally thanks to technical photographer Joseph Cowan for providing the excellent photographs presented in this paper.

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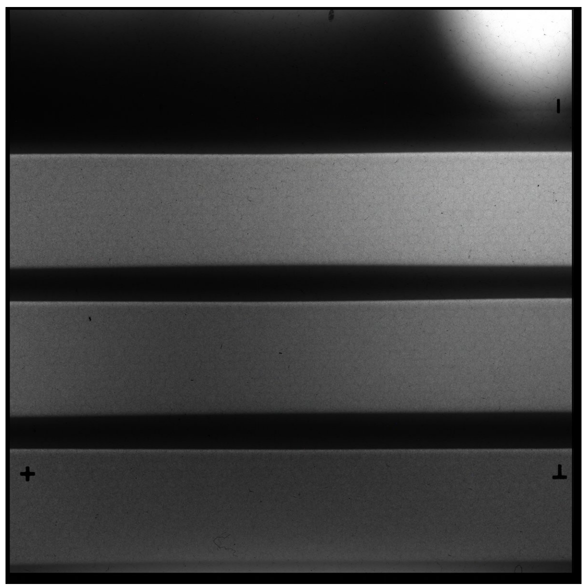

Figure 13. Sample Trident laser data for GXD #1. Strip one is on the top and time runs from right to left. The x-rays arrived at the MCPii after the gate pulse had propagated across strip one. The bright spot in the upper right corner is due to a light leak around the filtering in front of the MCPii.