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# DESIGN AND COMMISSIONING OF THE ASU CXLS MACHINE PROTECTION SYSTEM*

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*Abstract*

To protect against fault conditions in the high-power RF transport and accelerating structures of the ASU Compact X-Ray Light Source (CXLS), the Machine Protection System (MPS) extinguishes the 6.5 MW RF energy sources within approximately 50 ns of the fault event. In addition, each fault is localized and reported remotely via USB for operational and maintenance purposes. This paper outlines the requirements, design and performance of the MPS applied on CXLS.

## OVERVIEW

The purpose of the Machine Protection System (MPS) is to prevent damage to the high-power radio-frequency (HPRF) source and/or its various transmission and load components when a fault or arc occurs in the system. Fig. 1 shows a notional block diagram of the Compact X-Ray Light Source (CXLS) RF system, including the MPS.

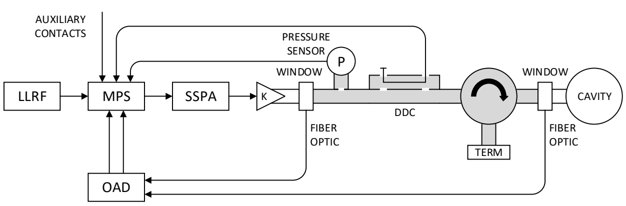


Figure 1: CXLS RF system block diagram.

Modulated 9.3 GHz RF pulses are generated by the Low-Level RF (LLRF) subsystem and are applied to the MPS. Under operating conditions the pulse is first amplified by a solid-state power amplifier (SSPA) and then by a Klystron (K). RF windows are employed to segregate the klystron and cavity vacuum regions from the RF waveguide, which is pressurized with $SF_6$.

The MPS senses fault conditions through a variety of sensors. A pressure sensor sends an alarm to the MPS when WG pressure falls below a prescribed level. Reverse RF power is sampled with a dual-directional coupler (DDC) and sent to the MPS. Light generated by arc flash at the WG windows is detected in the Optical Arc Detector (OAD) and then applied to the MPS. A number of auxiliary contact channels are provided for integration with other protection subsystems. When any of these faults are detected, the MPS interrupts the RF signal applied to the SSPA, extinguishing the klystron HPRF output.

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## SIGNAL CONDITIONING

The front-end signal conditioning of the MPS analog signals is depicted in Fig. 2. The reverse RF power envelope is extracted in a fast diode detector, then passed to a threshold comparator channel. The OAD provides analog channels proportional to optical power. Four fast Schmitt trigger channels, with individually programmable thresholds, convert these four signals to binaries for event detection. Each channel has input overvoltage diode protection. The threshold circuits have nonvolatile memory to hold system thresholds over power interruptions.

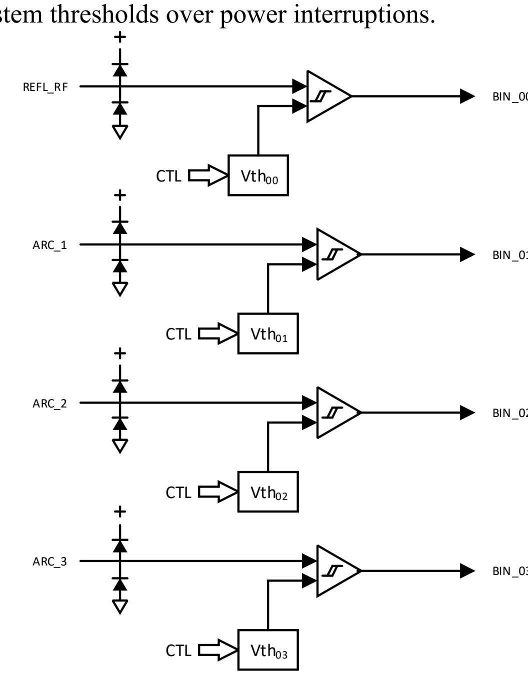


Figure 2: Analog signal processing.

## EVENT CAPTURE

Figure 3 shows a collapsed schematic of the event capture and control section of the MPS. Along with the previous four binary signals, an additional twelve auxiliary inputs are serviced, each with a Schmitt trigger gate to minimize chatter and signal uncertainty. These inputs are pulled up in the MPS, so that a contact closure to ground indicates an alarm condition. One auxiliary channel services the waveguide pressure switch; others can be used as tie-ins to external systems, such as personnel interlocks. All sixteen channels then pass through invert/noninvert gates, selectable as needed. The state of these channels is reported as the “INPUT STATE” of each.

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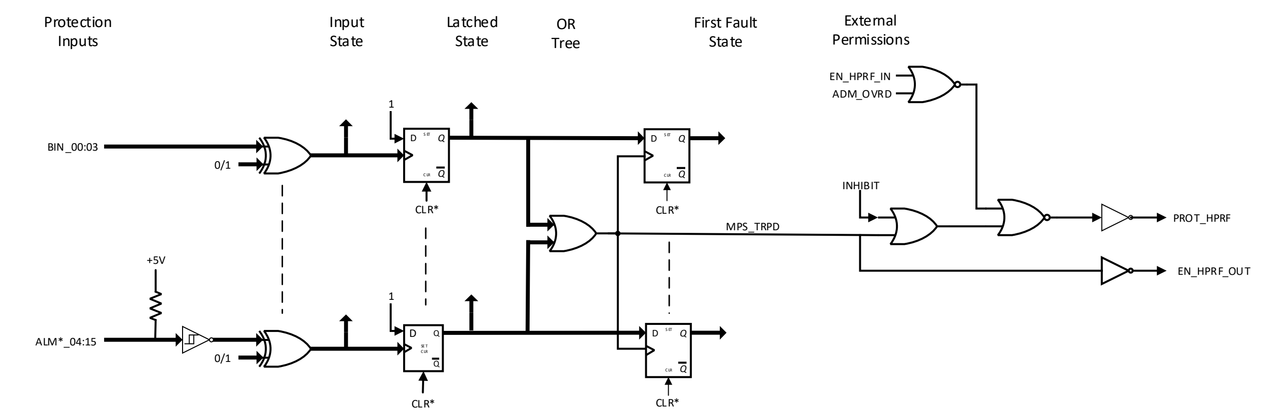

Figure 3: MPS event capture circuitry.

The first register layer consists of D flip-flops, with the data inputs pulled high. Clearing this register resets the flip-flops, ready to detect faults. A fault condition on any input is latched by a falling edge at the corresponding first register clock input. The register output is reported as the "LATCHED STATE".

An OR tree combines the sixteen outputs of the first register layer, creating a clock input for the second layer. The first fault detected is thereby sampled by the associated flip-flop in the second register, indicating the channel which first tripped. This register output is reported as "FIRST FAULT STATE".

## SUPERVISORY LOGIC AND CONTROL

As shown in Fig. 3, the output of the event OR tree is passed to combinatorial elements that manage the behavior of the MPS. Three external permissions are applied. In operation, the CXLS utilizes two HPRF sources, each with its own MPS. Each system is cross-connected through hardwiring of the EN_HPRF control lines, so that an event in one system also inhibits its sibling unit. The EN_HPRF_OUT line echoes the state of an MPS to its sibling's EN_HPRF_IN line, enabling the RF protection function to cascade to the sibling unit. Each system can be run independently, for instance for maintenance, by exercising the "ADM_OVRD" administrative override control.

The external permissions are ORed with an external "INHIBIT" control, which acts as a final safety point to inhibit the RF path until the system is ready for operation. The resultant of this logic network is "PROT_HPRF", which in the high state extinguishes the RF signal into the SSPA.

## RF PROCESSING

The "PROT_HPRF" signal controls a PIN diode switch, which passes/inhibits the RF signal to the SSPA accordingly. This switch has a specified switching time of 25 ns, and isolation of 55 dB at 9.3 GHz.

## IMPLEMENTATION AND TEST

The MPS is built in a 19 inch EIA chassis; see Fig. 4. The Signal Conditioning and Event Capture circuit is realized as a custom-designed PCA. The fast RF detector is a semi-custom module acquired from X-Microwave, utilizing an Analog Devices ADL6010 RFIC.

Supervisory control and status readback is exercised over a USB-2 interface. Internal to the MPS, digital I/O is accomplished with a National Instruments type USB-6509 device.

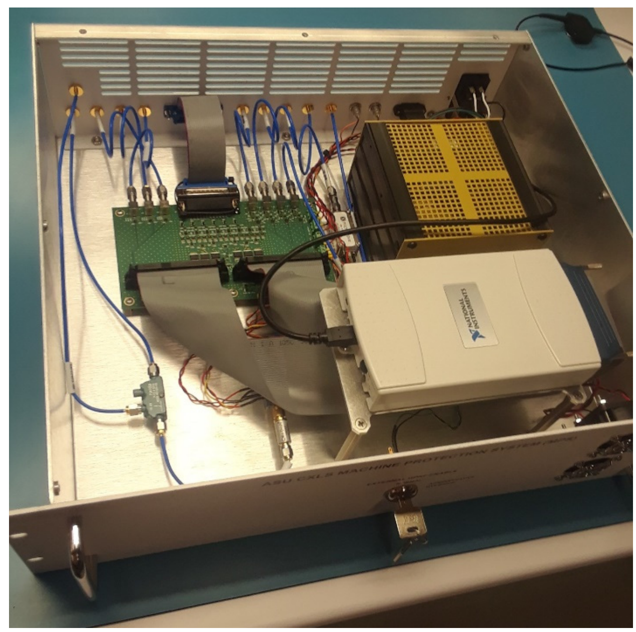
Figure 4: MPS chassis interior.

Figure 5 shows a test setup, wherein a simulated reverse RF power pulse is applied to the MPS. In Fig. 6, the upper trace is the envelope of a typical 1 µs RF pulse. A copy of the RF pulse is also applied to simulate a reflection in the waveguide. The lower trace shows how the RF pulse is truncated by the MPS within about 50 ns. Assuming a 6.5 MW source, with allowance of an additional 20 ns of response time due to cable delays and stored RF energy in the system, the MPS limits the energy available to an arc event to less than 500 mJ.

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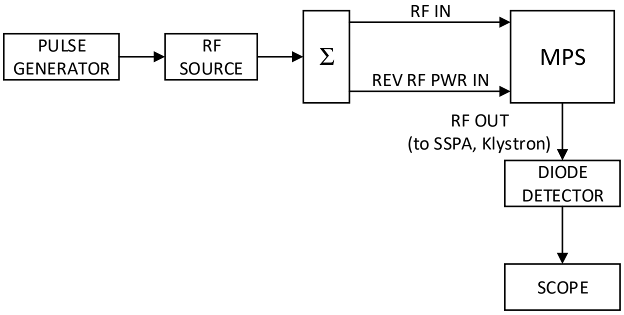


Figure 5: MPS test setup.

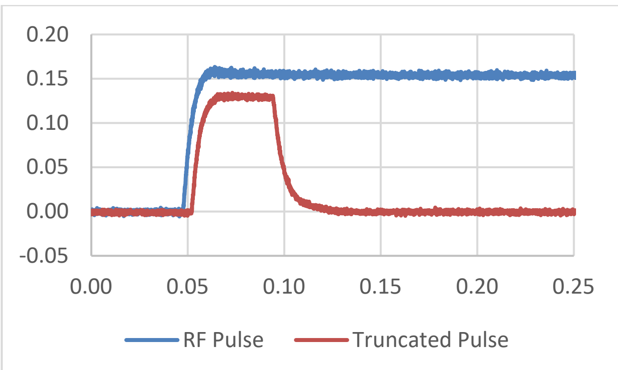


Figure 6: MPS performance.

## CONCLUSION

The MPS on CXLS at ASU successfully interrupts the RF energy source(s) to protect the HPRF equipment from multiple fault scenarios. It also captures, identifies and reports the source to the machine controls. In the event of an arc in the HPRF transport system, the MPS limits the arc energy to 500 mJ.