HASP Student Payload Application for 2012

Payload Title: Single Event Effect Detector			
Payload Class: (check one) ☑ Small ☐ Large	Institution: Montana State University		Submit Date: 12/16/2012

Project Abstract

As part of MSU's research effort into building radiation tolerant computing systems for aerospace applications, a radiation sensor has been developed to provide environmental awareness to the flight computer. This sensor is designed to detect the spatial location of radiation strikes with energy levels that cause single event effects in modern CMOS electronics. These are typically due to trapped protons and heavy ions. Our HASP payload consists of a radiation sensor system in addition to an FPGA-based flight computer that will record strikes throughout the duration of the flight.

Team Name:	Team or Project Website:
MSU Radiation Tolerant Computing (MSU RTC) Group	

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I. Payload Description

An ongoing research project being conducted by MSU's Radiation Tolerant Computing group is the design and development of a radiation-tolerant space flight computer architecture. In space, electrical systems are not afforded the protection of Earth's atmosphere or magnetosphere against interactions with high-energy particles such as heavy ions, protons, electrons, cosmic rays, etc. When impacted by these particles energy may be transferred to sensitive regions of the circuit resulting in deposition of parasitic charge, induction of electrical currents, or physical damage to the constituent crystal lattice structure of the device substrate material. These events may result in the changing of a transistor threshold voltage to the point that it may be impossible to turn the transistor on or off, unanticipated clocking of data through a system, or uncontrolled and undetectable changes in device memory bit values. Radiation tolerance refers to a system's ability to continue operating nominally after such an event with minimal interruption. Radiation tolerance is implemented in many ways. Circuits can be designed using specialized fabrication processes to minimize the radiation cross-section, or the area of the integrated circuit that is susceptible to radiation. These parts are typically more expensive and perform slower than their non-hardened counterparts. Heavy shielding may be used to protect critical systems. This option is non-ideal due to the high cost of putting materials into orbit, and shielding material may add substantial weight to a payload. Another way to protect systems from radiation faults is by incorporating circuitry in triplicate and routing redundant signals to a majority-rules voting sub-circuit. In this way radiation strikes are detected by non-uniform inputs at the voter, and the fault is prevented by only passing the majority signal. The probability of two regions being simultaneously faulted in the same way is low and tolerance is gained through the use of redundant circuitry. In programmable hardware, designs can be implemented using this triple-modulo redundancy (TMR) architecture without the costs of added hardware. Configuration memory "scrubbers" can be used to continually check the FPGA configuration memory against a golden standard and, if found, configuration faults can be rectified by partially reconfiguring the affected circuitry.

The system under development at MSU builds on a traditional TMR/scrubber/partial reconfiguration (PR) architecture with the addition of a custom silicon radiation sensor capable of detecting radiation strikes. The payload proposed herein will continue the testing process associated with the development of any new technology by demonstrating the functionality of the radiation sensor when subjected to ionizing radiation in Earth's upper atmosphere. Previously, this sensor has been flown on a payload designed under the High Altitude Balloon Payload Design Program in collaboration with NASA and the Montana Space Grant Consortium (MSGC). In this flight, the radiation sensor and control electronics logged radiation strikes in an ascent to nearly 100,000 feet MSL. Before termination, the data showed a strong exponential trend in the number of radiation strikes per minute increasing from zero to 20 as the payload passed through the stratosphere (Fig. 1). A similar payload featuring a two-sensor stack-up is proposed for participation in the 2012 HASP flight.

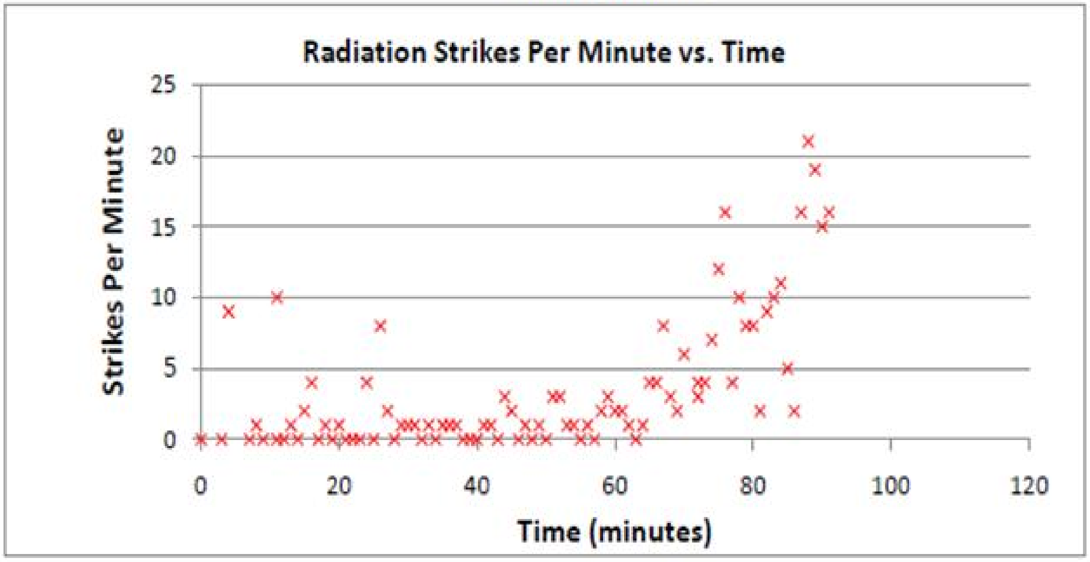

Figure 1: Detected radiation strikes using custom silicon radiation sensor on BOREALIS balloon flight payload. At time 60-minutes the payload was at approximately 70,000-ft. MSL. (http://www.coe.montana.edu/ee/lameres/project_summer11_payload_design.htm)

I. a. Scientific Objectives

The objective of our mission is to measure the performance of our custom single event effect sensor in a high-altitude environment. The strike rate profile generated by the radiation sensor will allow performance comparison with data acquired by independent payload systems on separate flights with similar flight profiles. These data will allow relative sensor sensitivity comparisons and provide feedback regarding the performance of the custom design. By also feeding the radiation sensor outputs into the fault repair and recovery system on the FPGA several performance parameters can be validated. Each sensor in the two-sensor stack provides the spatial location for a radiation strike. This information can be used to extract a radiation trajectory estimate. Radiation trajectory information can be compared with the corresponding location of an observed FPGA fault, should it occur, and the accuracy of the trajectory estimate can be assessed. With this flight it is anticipated that the radiation-tolerant computer system will demonstrate real-time fault detection and recovery and correlate said faults to observed radiation strike data.

I. b. High-level review of payload systems

The payload system will be a circuit card assembly (CCA) stack consisting of the following:

- Power conversion and distribution CCA
- Payload experiment CCA (optional)
- FPGA system control CCA
- Lower radiation sensor CCA

- Upper radiation sensor CCA

The power conversion CCA, or "board", will accept as input the 30-V power supply voltage provided by the HASP system and down-convert it to the required payload voltages. The required voltages are those that power the FPGA system, the radiation sensors and any peripherals included (if any) on the payload experiment board.

The payload experiment board is incorporated as part of a re-usable stack architecture in which the radiation-tolerant FPGA system can interface with project-specific circuitry on the experiment board. As the FPGA system will have adequate data storage and communication capabilities for the HASP flight the experiment board might not be used. If used, the experiment board would likely be a simple HASP interface that passes the RS-232 signals to the FPGA board.

The FPGA system control board is the primary payload system. This board will feature two FPGA chips: one primary FPGA that controls payload operation, and a secondary FPGA responsible for interpreting data from the radiation sensors, scrubbing the configuration memory of the primary FPGA, and performing partial reconfiguration on faulted regions. Additionally, the secondary FPGA is responsible for configuring the primary during system start-up. The FPGA system will include non-volatile memory for local data storage and RS-232 communications support for interfacing with the HASP

I. c. Statement of principle of operation

The system will be designed for autonomous data logging operation for the duration of the flight. At power-on, the FPGAs will perform an initialization sequence and begin monitoring the radiation sensors for strikes. Simultaneously, a configuration SRAM scrubbing circuit will continually check the FPGA for faulted partially reconfigurable tiles. As radiation strikes are detected, the location of the strike, the cumulative number of strikes, and a timestamp will be transmitted to the HASP telemetry system as well as stored locally. For each detected strike, the SRAM scrubber will check the FPGA areas that were most likely affected, and indicate whether a fault was induced. In this way, the number of faults versus the number of detected strikes can be studied. It is also conceivable that the FPGA may be faulted by radiation from incidence angles large enough to bypass the radiation sensors. As they occur, these FPGA faults and locations will be passed to the telemetry system for downlink as well as stored locally. During the initial phase of the flight it is anticipated that few or no strikes will occur. In the absence of observed faults or strikes, the system will periodically transmit status updates including the cumulative number strikes and faults detected. This allows the health of the payload to be monitored in the absence of radiation events.

I. d. Thermal Control Plan

As the payload will be operated in extreme temperature environments over the course of a flight, considerations for cooling or heating the payload are critical to mission success. The most sensitive components to heating and cooling cycles will be the system FPGAs. Although it is immediately unknown whether these chips will require cooling, it is expected that the chips will generate enough heat to maintain an operating temperature within device specifications. A thermoelectric cooler may be included in the design to enable heating or cooling, but its necessity is currently not known. Drawing on experience from previous balloon flights, the payload's outer enclosure will be of a light, reflective color to help prevent radiative heating. A layer of insulation may be added to the enclosure to help keep the system warm in very cold temperatures.

II. Team Management and Structure

The MSU RTC team supporting this project will consist of five students and two faculty advisors. Of the students, four are electrical engineering graduate students and one is a mechanical engineering graduate student. Two of the students will be primary team members, and the remaining three will act as secondary support members as they will be graduating in spring 2012. The faculty advisors carry expertise regarding the custom radiation sensor interface and operation as well as detailed knowledge of the FPGA system architecture. The organization chart of Fig. 2 shows this team hierarchy graphically. Table 1 provides the names and contact information for the team members.

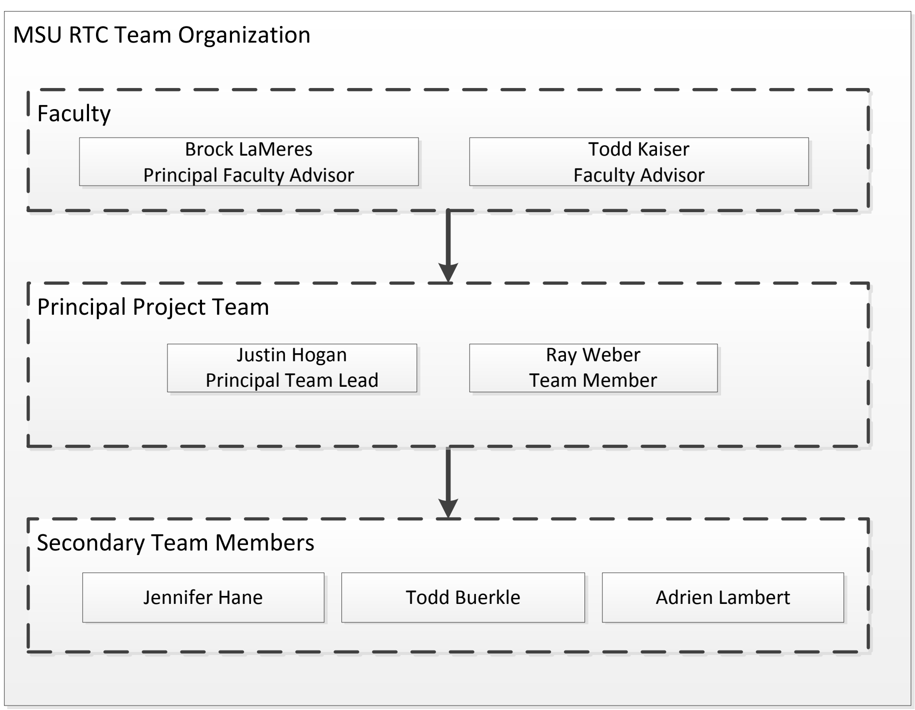

Figure 2: Team Organization Chart

Name	Team Role	E-mail	Phone
Dr. Brock LaMeres	Principal Faculty Advisor	lameres@ece.montana.edu	(406) 994-5987
Dr. Todd Kaiser	Faculty Advisor	tjkaiser@ee.montana.edu	(406) 994-7276
Justin Hogan	Principal Team Lead	justin.hogan@msu.montana.edu	(505) 977-3844
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Jennifer Hane	Team Member	jennifer.hane@msu.montana.edu	
Todd Buerkle	Team Member	toddbuerkle@gmail.com	
Adrien Lambert	Team Member	adrien.lambert@msu.montana.edu	

Table 1: Team Contact Information

II. a. Team Effort Organization

The payload design and development work will be predominantly carried out by Justin Hogan and Ray Weber. Both PhD candidates, these students have experience working with the FPGA systems and the radiation sensors and will be with the team for the duration of the project. Justin Hogan will be responsible for the design of the FPGA board, experiment board, and power conversion board as well as maintaining awareness of the overall project requirements including interface specifications, physical system constraints, project deadlines, etc. Ray Weber will assist with porting the existing FPGA system design to the new hardware platform, maintain a working knowledge of all payload systems, and help with interface testing and system firmware development as necessary.

Jennifer Hane has extensive working knowledge of the radiation-tolerant FPGA system architecture and will serve as a consultant as the current FPGA design is ported to the new HASP payload hardware. Jennifer will be instrumental in conveying knowledge regarding the reconfigurable architecture, including the configuration SRAM scrubbing logic, the partial reconfiguration processes, TMR system design and other aspects of the FPGA board design. Jennifer has been involved with previous MSU HASP payloads, so she is also able to provide relevant design input based on her experience.

Todd Buerkle designed and has intimate knowledge of the radiation sensor board. He manufactured the generation of sensors that will be in the payload using MSU's in-house micro-fabrication facilities. His research involves testing the radiation sensors and amplification circuitry in an ion beam at a cyclotron and the work he performs in that capacity is directly supportive of our sensor requirements for the HASP payload.

Adrien Lambert will be available to help with the mechanical design aspects of payload development. This includes maintaining system drawings, consulting on payload mounting considerations to ensure a robust design, and assisting with vibration and thermal testing as necessary. Adrien has previous ballooning experience as he worked with the MSU team that flew the radiation sensors as part of the previously mentioned MSGC program.

II. b. Project Timeline

The following milestones are crucial to having a payload ready for thermal/vacuum testing in May 2012, payload integration on July 30, 2012, and flight as early as August 31, 2012:

- Power conversion, experiment, and FPGA CCA requirements review – January 13
- Power conversion, experiment, and FPGA CCA design review – February 17
- Power conversion, experiment, and FPGA CCA testing – March 1
- Complete CCA stack testing – March 15
- Mounting and enclosure system complete – April 1
- Radiation-tolerant FPGA architecture hardware port – April 15
- System Firmware complete – April 15
- Thermal/Vac – May 1 (TBD)
- Follow-on testing – May – July 30
- Student payload integration – July 30-August 3
- Flight prep and operations – August 26 – August 31

II. c. Team Operations at CSBF

Team operations at CSBF will include two student team members and one faculty advisor at most.

III. Payload Specifications

III. a. Mechanical

III. a. i. Anticipated Use of HASP Resources

The weight of the payload will be minimized through the use of plastic or polymer materials for the system enclosure and lightweight aluminum standoffs for circuit board stack reinforcement. The populated radiation sensor boards have a weight of 86 grams each. The only remaining CCA that may exceed this weight is the power conversion board. However, by using lightweight board-mount DC-DC converters for power conversion the chances of the power board exceeding the weight of the sensor board can be minimized. If a worst-case scenario in which all circuit card assemblies weigh as much as the radiation sensor assemblies is considered this yields a circuit board stack weight of approximately 0.5-kg. The balance of the payload weight includes the mounting hardware, enclosure, and insulation. It is not expected that the total of these weights will come close to the remaining 2.5-kg. Uncertainties in this statement include the absolute enclosure weight, exact weights of the circuit components for each of the CCAs, particularly the power conversion elements, and miscellaneous mounting hardware.

It is anticipated that the payload will make use of the entire mounting plate footprint area, but easily remain within the specified ~6-in. by ~6-in. constraints. The payload electronics are limited in footprint size by the dimensions of the circuit board stack which is 4-in. by 4-in. The stack will be centered in the mounting area. The area around the stack will be used for affixing a protective enclosure through which the power and communication signals will be passed to the payload.

Again, the payload footprint will be 4-in. by 4-in. with an enclosure occupying the remainder of the available mounting area. A conservative estimate of the maximum height of the circuit board stack is 5-in. which is significantly less than the ~12-in. allowed for small payloads. The enclosure will add to this height, but the overall payload size will easily remain within specifications.

The only orientation requirement for this payload is that it be mounted on the HASP structure such that the radiation sensors are facing upward (toward the balloon). There are no specific locations on the fixture that would be more or less advantageous for this payload, so there is flexibility in where it is placed. There is a request for a single discrete signal in the electrical subsection below. Payload positions 1, 2, and 5 would accommodate this request. However, this is not a stringent requirement and this payload can yield to others with more strict needs for extra discretes in which case payload positions 3,4,6,7 and 8 would be fine.

III. b. Electrical

The power consumption for the payload will be determined by three main system components: the efficiency of the power conversion process, the speed of operation of the FPGA system and the radiation strike rate. At this stage it is difficult to estimate the power draw of our payload because significant design efforts are still underway. As power requirements become clearer, options exist for minimizing power consumption by choosing lower speed-grade FPGA components. The maximum power draw from the HASP system is 15-W (0.5-A @ 30-V). Currents in excess of the maxima allowed by the individual chips would likely be required to surpass the allowable HASP power consumption. It is expected that damage to the payload would occur before the power circuit fuse was blown. Regardless, careful monitoring of the maximum currents and power consumption will be performed throughout the design and integration processes.

Downlink telemetry will be used to transmit the most mission critical data at regular intervals, and queried data packets as requested through serial uplink commands. The mission critical data will include radiation strike count and sensor locations, observed FPGA fault numbers and locations, associated timestamps, and the most recently received uplink command. The data transmission occurs at a baseline interval to provide a pulse, of sorts, when no radiation strikes are observed to show that the payload is working. Beyond that, rate will be event-driven with transmission occurring upon the detection of a radiation strike or FPGA fault. The transmission rate will be throttled such that the 1200 baud rate is not exceeded. Local buffering of data can be used to handle excessive downlink transmission requirements.

The use of uplink serial telemetry will be for the purpose of querying system status. Receipt of this command will trigger transmission of a status packet containing current system state information. Additionally, as recommended in the HASP Student Payload Interface Manual, the most recent command received by the payload will be echoed in the downlink telemetry stream. It is anticipated that this command will be sent early in the flight to ensure proper system operation from the start and on an as-needed basis throughout the flight if anomalies are observed in the payload.

There is no presently anticipated use of the analog downlink resources.

In addition to the power-on and power-off discrete signals, a single discrete signal for power-on reset of the FPGA system is requested.

III. c. Procedural

As part of payload design, test procedures will be developed to ensure reliability of the serial communications interface. It is feasible to emulate the HASP Mini-SIP communication system and exercise the payload interface signals using an 8-N-1, 1200 baud RS-232 connection. All uplink system commands can be sent to the payload and the payload response can be evaluated. Additionally, the power provided to the payload during bench testing can be varied to simulate the initial ~32-V and final ~28-V power supply voltage fluctuations. These test procedures will naturally flow into a set of integration procedures for use during HASP system integration. It is anticipated that as part of the integration process the system will be powered by the HASP power system, correctly complete the power-on initialization steps, receive all anticipated uplinked serial commands from the HASP control system and demonstrate data acquisition capability by transmitting a simulated data value or stream through the downlink telemetry system.

The payload will be designed for hands-off operation from start to finish with system initialization occurring automatically with application of HASP system power. Provisions for uplink commands to perform a system reset will be included as well as a mechanism for querying the status of the system. In general, no complex interactions with the system will be required as the payload will remain in a single mode of operation throughout the entire flight. Team members will be on-hand as needed during preparation for flight to address any last-minute concerns with the payload. The team will also have a representative present with mission control personnel to monitor the status of the payload, the quality of the downlink data, and to request any necessary uplink commands verbally as alluded to in the CFP.

IV. Preliminary Drawings

IV. a. Mounting Plate Modifications

Four holes will be drilled in the mounting plate to align with the mounting holes on the CCAs in the stack. The payload electronics stack will be affixed to the mounting plate using short aluminum or stainless steel, threaded standoffs. A flanged outer enclosure will fit over the top of the CCA stack and will be affixed to the mounting plate using screws. Lateral support for the CCA stack will be provided by structure added to the enclosure as the vertical standoffs are not expected to provide enough strength against lateral loading.

Anticipated modifications to the mounting plate include four CCA mounting holes, and three or four holes along each edge of the mounting area for securing the enclosure.

Again, the location and orientation of this payload on the HASP structure is flexible.

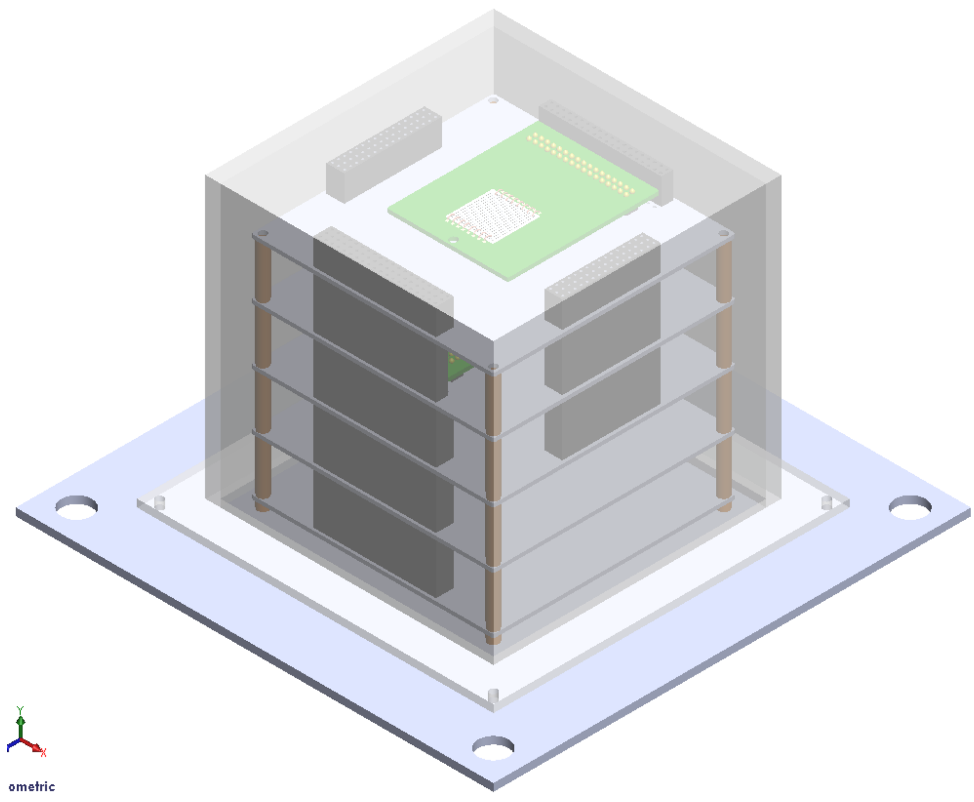

Figure 3: Isometric view of payload electronics stack and enclosure attached to HASP mounting plate.

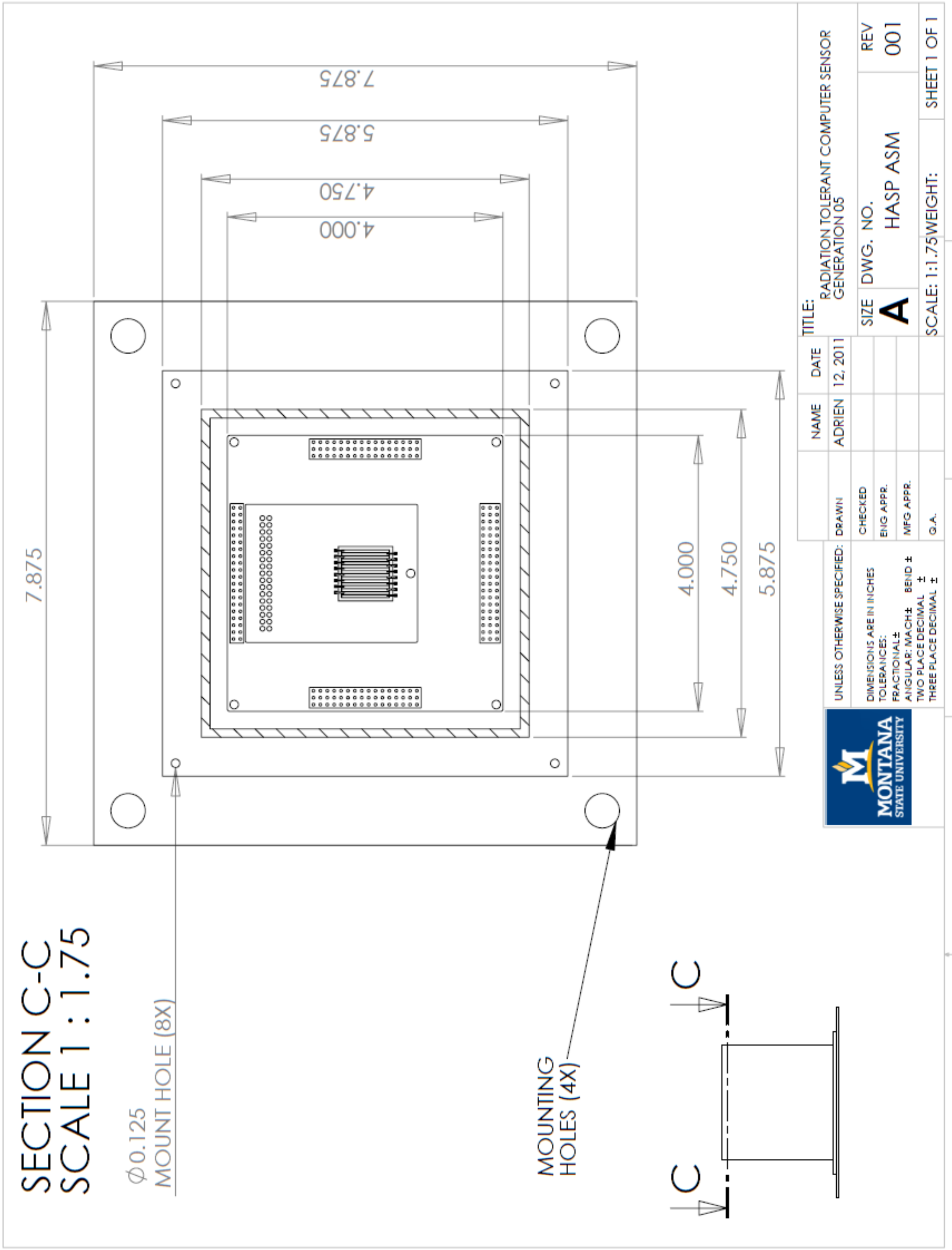

Figure 4: Top view of payload with electronics stack. Dimensions are in inches.

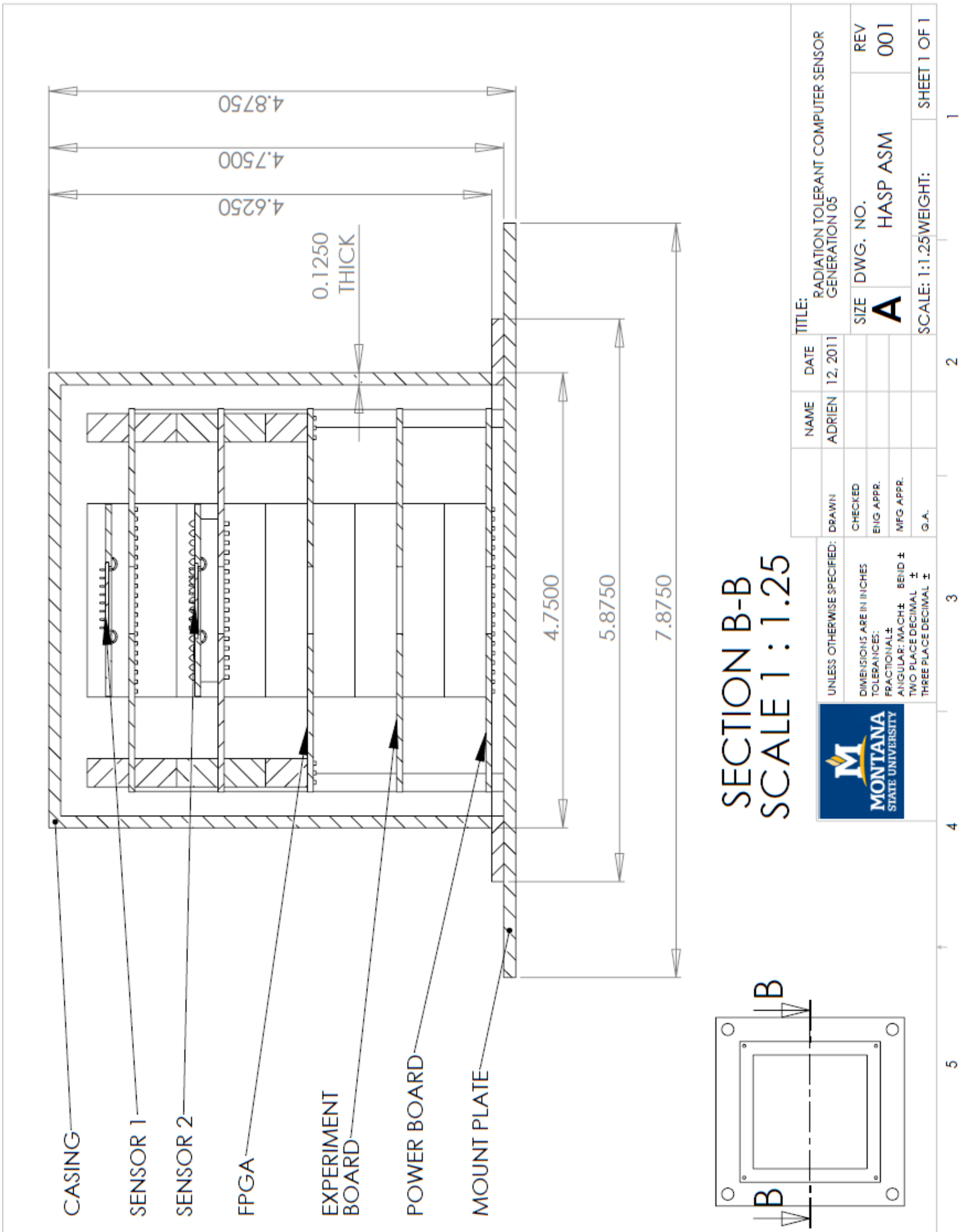

Figure 5: Side view of payload electronics stack. Dimensions are in inches.