Payload Description

Background and Objectives

Gannon University's High Altitude Radiation Detection (HARD) payload #3, GU-HARD-PL03, will be a revision of payload GU-HARD-PL02, which, as one of the HASP 2012 payloads, was designed to detect the arrival rates and distribution of cosmic rays. Problems with in-flight data collection indicate that the payload must be redesigned with more robust operation of all subsystems, particularly the cosmic ray detection components. Our previous payload failed to observe the "east-west" asymmetry in cosmic ray arrival rates, possibly due to a malfunction of the comparator or coincidence subsystems (for more details, see [1]).

First discovered in 1911, primary cosmic rays are largely composed of completely ionized atomic nuclei, mostly protons, traveling near the speed of light. There are still many unanswered questions regarding their origin and propagation history. One of the major obstacles to studying cosmic rays arises from the magnetic fields in the galaxy, which bends the trajectory of these charged particles and randomizes their arrival direction at the Earth. When these particles encounter Earth's atmosphere, they interact, causing cascades of secondary particles. Earth's magnetic field further deflects cosmic-ray trajectories and, since primary cosmic rays are positively charged, it is expected that more cosmic rays will approach from the west than from the east. This "east-west" asymmetry has been thoroughly investigated at ground level and even observed in the atmospheric neutrino flux. Also, it is known that the cosmic ray flux transitions from mostly secondary particles near the ground level to mostly primary cosmic rays near balloon-float altitudes. As such, it is anticipated that the angular asymmetry of arrival rates of cosmic rays would change with altitude.

The primary goal of this project is to explore how this angular asymmetry changes with altitude. The target balloon-float altitudes of 130,000 ft and more than 10 hour flight duration at balloon-float altitudes would allow our payload to make a high-quality, long-exposure measurement. Additionally, this project intends to study how the intensity of cosmic rays changes with altitude, similar to the measurement made by the 2007 West Virginia University team. However, instead of simply measuring the intensity of vertically incident cosmic rays, our project will measure cosmic ray intensity from multiple arrival directions, providing a more complete picture of the high-altitude radiation environment caused by cosmic rays.

Based on the design experiences and lessons learned from GU-HARD-PL02 for HASP 2012, GU-HARD-PL03 for HASP 2013 aims to produce more accurate measurement data in all intended on-board experiments as well as more robust operation of all subsystems of the payload.

Brief Overview of the Proposed Payload

A block-diagram level overview of the proposed payload can be found in Figure 1. The payload will be enclosed in a Styrofoam frame, which is lightweight, easy to shape, and provides excellent thermal insulation, with an outer layer of aluminum for rigidity and strength. Both the thermal and mechanical performance of this design was proven in GU-HARD-PL02 during the required thermal and vacuum testing and in-flight. Key payload components are further described below in more detail.

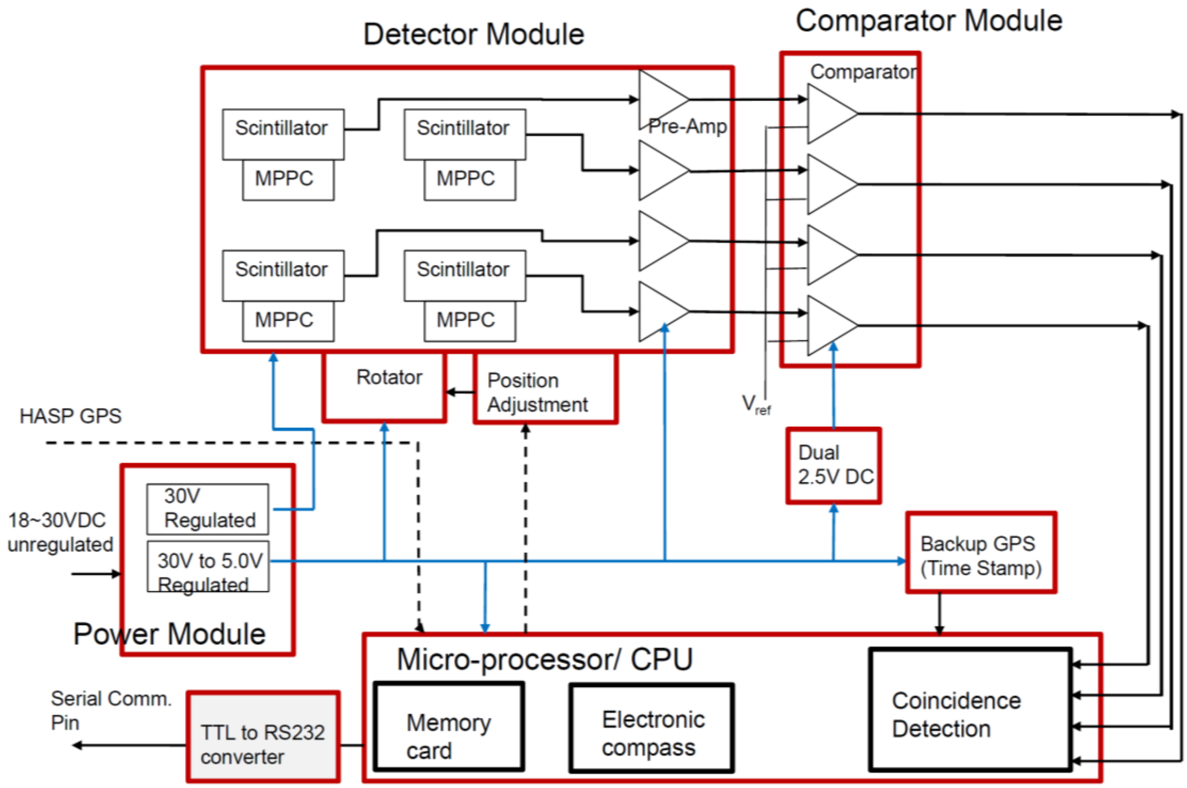

Figure 1. Overall functional block diagram for cosmic ray measurement

Detector Module – The detector module primarily consists of scintillator material, silicon photomultipliers (SiPMs), preamplifiers, and a rotator with position adjustment. The proposed scintillator layout is shown in Figure 2 and Figure 3 in the Drawings section. Because the SiPM has such a small active area, the size of the scintillation material was chosen to ensure that approximately 5 primary photons would be incident on the SiPM per event. The scintillator will be covered with a reflective surface (white Teflon) to reflect stray photons back into the detector, increasing the light output at the SiPM. The whole detector element (SiPM + scintillator) will be wrapped to block external sources of light. The SiPM will be coupled to the scintillator using an optical epoxy. Cosmic-ray arrival direction can be determined based on which photon counters detect light. The preamplifiers have a voltage gain of about 40 dB so that the weak, short-duration (of nano-second range) signal from the SIPM can be amplified to a signal amplitude of about -0.7 V (i.e., a negative pulse).

The SiPM that has been chosen by the team can operate in a low-pressure environment without potting, unlike typical photomultiplier tubes that require ~1 kV to operate. Dielectric breakdown, or "arcing," is a common problem with these high voltage devices. However, the silicon photomultipliers that will be used in our payload operate at ~30 V which will help to prevent any arcing at float altitude.

Rotator Module and Position Adjustment – In order to maintain an east-west orientation, a rotator will be used in combination with an electronic compass (e-compass) and an internal GPS as well as an external GPS that is available from the HASP system. A small light-weight servo has been selected for this purpose. The motor rotation distance will be determined by the "Position Adjustment" module shown in Figure 1. The operation of the Position Adjustment module will be based on an electronic compass in combination with GPS coordinates. The GPS data from HASP will also be used as a timestamp device.

The electronic compass will output serial data related to the payload/scintillators orientation, and the master microcontroller/CPU of the payload will process the electronic compass's output. When necessary, the microcontroller will send a signal to the Rotator Module to adjust the position of the scintillators.

Comparator Module – Each of the SiPM units in the Detector Module will output a voltage that is proportional to the number of detected photons. As necessary, this signal will be amplified to an appropriate level (about -0.7 V) and then compared with a specific threshold via a comparator (e.g., Analog Devices AD96687). This threshold will be adjustable via an external command. As shown in Figure 1, the comparator module consists of four comparators with a reference voltage, V_{ref}. The four preamplifiers in the Detector Module will provide negative pulses as cosmic arrivals are detected by the SiPMs.

Coincidence Detector – The coincidence detector monitors whether a signal above V_{ref} is observed from at least two Comparator modules within 1 to 10 μs. When this condition is met, the corresponding SiPM modules that contributed to the coincidence are identified and stored for later analysis. The timestamp will also be recorded. From this information, it will be possible to reconstruct the angle of the incident cosmic ray and the event rate. A microprocessor will be used to provide the necessary functionality and signal processing.

Micro-processor/CPU – This is the main microprocessor module that will be used for the interpretation and storage of data from the coincidence detector. On our proposed payload, this microprocessor will be the only component to have direct access to memory units. Most processors will have enough on-board memory for necessary operations in the proposed payload.

The microprocessor will also be in charge of interpreting commands from the operator and the memory dump when the device is on the ground. We will need to receive commands from the serial port to adjust the comparator's reference voltage if necessary. Necessary precautions shall be given to the microprocessor for extremely high altitude and high shock resistance as well as protection from undesired radiation.

Power Module - Several power converters are needed for all devices in the payload to perform properly. This power module will be designed to provide at least three different voltage ranges as indicated in Figure 1. Most of the components will draw their power from a 30V-to-5V DC-to-DC converter which is connected to the EDAC power supply from the HASP. As we learned from GU-HARD-PL02, an off-the-shelf DC power converter will supply a steady 30 Vdc to the SiPM amplifiers, since the output of these components is very sensitive to changes in the bias voltage and the HASP power rails can change during flight.. A dual 2.5V DC-to-DC converter is also used to operate the comparator. If necessary as the subsystem design may call for, one or more voltage divider(s) and/or additional DC-DC converters will be utilized.

Thermal unit – Not explicitly shown in Figure 1 (and not used in GU-HARD-PL02), a thermal unit (for both heating and cooling) was designed by the Gannon team to ensure that the temperature of all components would remain within operational limits. This unit could be utilized if determined to be necessary during the design of GU-HARD-PL03.

Team Structure, Members, and Management

Team Structure

The design and implementation of this payload is a topic of undergraduate research in the department of Electrical and Computer Engineering (ECE), Gannon University, located in Erie, Pennsylvania. It is currently anticipated that there are seven ECE student team members and three faculty members involved. Five of the student members are concentrating in electrical and electronics engineering, and two concentrating in computer engineering.

Student	Position	Concentration	e-mail (& phone)
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Project Management

The team will begin their work in January, 2013 as soon as the spring 2013 semester begins. Student members include three juniors and four sophomores in the ECE department. All student members will participate in the project as part of their extracurricular research activities.

Our tentative timeline and milestones are as follows:

- Requirement analysis and initial functional decomposition: done as part of this application preparation

- Design of payload modules (1/10/2013 – 3/1/2013): student members complete design of individual system modules and unit testing.
  Deliverables: Test plan for unit and integration tests

- Module integration (3/2/2013 – 4/15/2013): student team members complete integration of all modules into a payload, complete FMEA, and integration testing.
  Deliverables: Payload Specification and Integration Plan (PSIP)

- Preparation for on-site integration at CSBF (4/18/2013 – 5/13/2013): complete any necessary revision/refinement of the modules and payload; assemble the payload onto the HASP plate; travel arrangement for student members
  Deliverables: a complete payload prototype, ready to go

- Submit Final FLOP: July 2013

- Payload integration (7/30/13-8/3/2013, to be confirmed): team members on site for integration (at least 3 team student members are anticipated to participate)

- HASP launch (9/3/2013): at least 1 team member on site (anticipated) to participate if necessary

For project funding, an arrangement has been made with the Pennsylvania Space Grant Consortium for financial support for parts/materials and student traveling as appropriate; there are additional funds available for this project from faculty advisors' research funds.

Payload Specifications

Desired Payload Location and Orientation

Our payload will have the capability of rotating to maintain proper orientation; therefore any of the "small payload" locations will be acceptable.

Technical Specifications

I. Mechanical Specifications:

A. Preliminary weight budget: Total payload weight will be less than 3 kg, as shown below:

Module name	Status	Mass (g)	Uncertainty (g)	Comments
Detector Module	Measured	220	±5	Measured 2 of 4, multiplied by 2
Rotator	Measured	61	±1	
GPS unit	Measured	170	-10	May remove some headers to decrease mass
Microprocessor and SD memory	Measured	40	±1	
Frame - styrofoam	Measured	138	±2	
Frame – aluminum + hardware	Calculated	607	±100	Calculated based on two 0.5 cm plates at bottom (overestimate) + estimate of hardware
Power circuit and comparator	Estimated	40	±10	Estimate based on existing circuit boards of similar size
Battery	Estimated	150	±50	Estimate based on existing 9.6V 8-cell batter pack (may be

Module name	Status	Mass (g)	Uncertainty (g)	Comments
				necessary to provide negative voltage to comparator)
Wiring/misc	Estimated	50	±20	Probably an overestimate
TOTAL		1476	±200	

B. Mechanical drawing detailing the major components of the proposed payload and how the payload is attached to the payload mounting plate is shown in the Drawings section below (Figure 2 ~ Figure 6). Final payload height will be 30 cm.

C. No components are used that would be potentially hazardous to HASP or the ground crew before or after launch.

II. Power Specifications:

A. Preliminary Power Budget:

The power budget outlined below easily fits within the 15 W (0.5 Amps @ 30 VDC) limit for the small payload class as outlined in the "Call for Payloads."

Module name	Current (mA)	Voltage (V)	Power (W)
Detector Module	29.0	5.0	0.145
GPS unit	67	7.2	0.482
Microprocessor , rotator, e-Compass, and SD memory	88 (w/o servo operating) 130 (w/ servo operating)	7.2	0.936 (w/ servo operating)
Comparator (2 dual OP-AMP board)	8.1	+/- 2.5 (dual power)	0.040
Power circuit (resistor-based voltage divider)	100	29.0	2.9
TOTAL			4.503

B. Power system wiring diagram is shown in Figure 7.

III. Downlink Telemetry Specifications:

A. Serial data downlink format: Packetized

B. Approximate serial downlink rate (in bits per second):

Average bit rate: 2 bps (~19 bytes*8 bits per 2 min.)

C. Serial data format will follow the HASP guidelines shown below. This data will be used to monitor payload health and operation during the flight.

For the header of the data packet, the HASP guidelines shown below are used. For the Data Field (i.e., after the Checksum Field), the following info will be collected every two minutes.

Table 3: Suggested Student Payload Data Format

Byte	Bits	Description
1	0-7	Record Type Indicator
2-5	0-31	Timestamp (seconds since January 1, 1970)
6-9	0-31	Timestamp (nanoseconds past the last second)
10-11	0-15	Record Size
12	0-7	Least significant 8 bits of the record checksum
13-n		Data

Table 4. Data Fields

Data field	# bytes	Comments
Counts of coincidences	3 bytes	To count an estimated hits of up to 2^19
e-compass angle in degrees	2 bytes	To count 0~360 degrees
Temperature (inside)	2 bytes	-50 ~ +125 degrees (9~12 bit precision)

Total: 7 bytes

D. Number of analog channels being used: None

E. Number of discrete lines being used: N/A

F. No on-board transmitters will be used as all connections among electronic modules are expected to be by direct wiring.

IV. Uplink Commanding Specifications:

A. Command uplink capability required: Yes

B. If so, will commands be uplinked in regular intervals: No

C. How many commands do you expect to uplink during the flight:

Around 3-5 commands per hour during the first couple of hours of flight to ensure payload's operation. 1 or 2 commands per hour during the rest of the flight (in case of abnormal situation) – no commands to be sent if the payload downlink data indicate normal operation.

D. A table of tentative commands for uplink are shown below.

All commands will be two bytes in hexadecimal, as required in the Interface Manual.

Command	Description	Hexadecimal Value
Reboot	Reboot the Microprocessor	0x00 0x00
Auto-rotation OFF	Turn off auto-rotation	0x00 0xF0
Auto-rotation ON	Turn on auto-rotation	0x00 0x0F
Rotate X	Rotate the rotator by X degrees	0xFX 0xXX [see notes]
Change V_{ref}	Change reference voltage to	0xDY 0xYY [see notes]

	comparitor	

[Notes] "XXX" represents an integral number in hexadecimal format for degrees ranging from 10 to 350 degrees that is initially represented by 12 binary bits (i.e., 9 bits for degrees and 3 leading 0's). "YYY" represents and integral number in hexadecimal format for millivolts ranging from 0 to 4096 mV.

E. No on-board receivers are used as all connections among electronic modules are expected to be by direct wiring.

<u>Integration and Flight Operation Plan</u>

I. Steps for Integration with HASP

The payload will not be sealed until integration is successfully completed. All unit and integration tests for payload components will be successfully completed before shipping the payload to the launch site.

- Connect the EDAC 516 connector to the payload.
- Connect the DB9 Serial Connector to the payload.
- Test power on and off of the payload through the Discrete Command Interface, i.e., EDAC516 pins F and H (a power-on/off LED indicator will be included inside the payload for this testing purpose).
- Test serial communication to control the comparators (and others - to be determined - as applicable) through DB9 pins 2 and 3 (an LED indicator will be included inside the payload for this testing purpose)
- Ensure proper operation of Detector Module by collecting cosmic-ray events for ~5 minutes to ensure the rate is consistent with previous measurements.
- Seal the payload with Rocket tape. It is now flight ready!

II. Flight Operation Procedures

A. During climb-out: The payload must be turned on and operational during the climb-out to monitor cosmic-ray intensity and arrival direction as a function of altitude.

B. Flight Configuration Setup: Commands will be sent 1) to adjust the reference voltage of the comparator and 2) to check coincidence rates from the file that the HASP puts on the ground through its communication link.

C. Failure Response: Proper operation of the payload will be verified from the coincidence rates. For failure of the payload operation, power off and on commands will be sent to the payload to reset the payload components. More detailed potential failure mode shall be analyzed through our Failure Mode and Effect Analysis (FMEA) as part of our design process.

D. Termination: The payload should be powered off prior to the termination of HASP. Once the system is on the ground, the payload will be recovered. The HASP's online data file will be reviewed for retrieval of data. Once the payload returns to Gannon University, we will retrieve data stored in the memory on the payload for post-processing and analysis.

Drawings

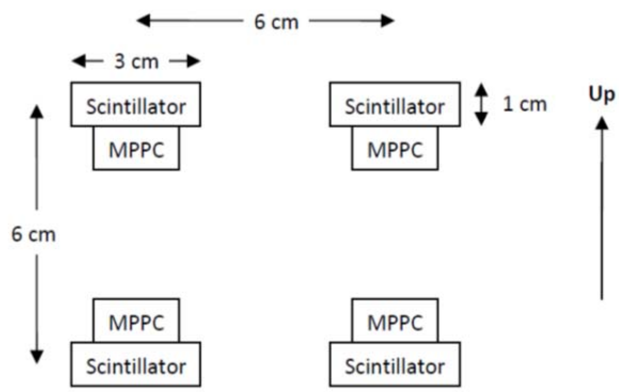

Figure 2. Detector Module - scintillator layout

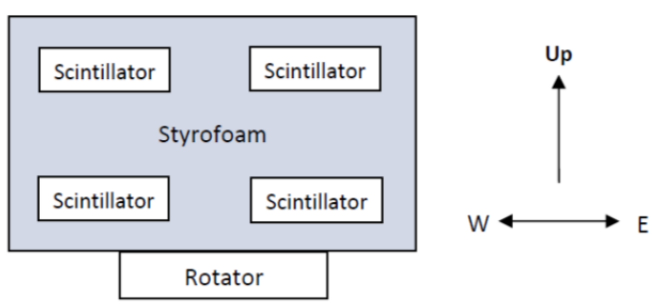

Figure 3. Detector Module with a rotator for position adjustment

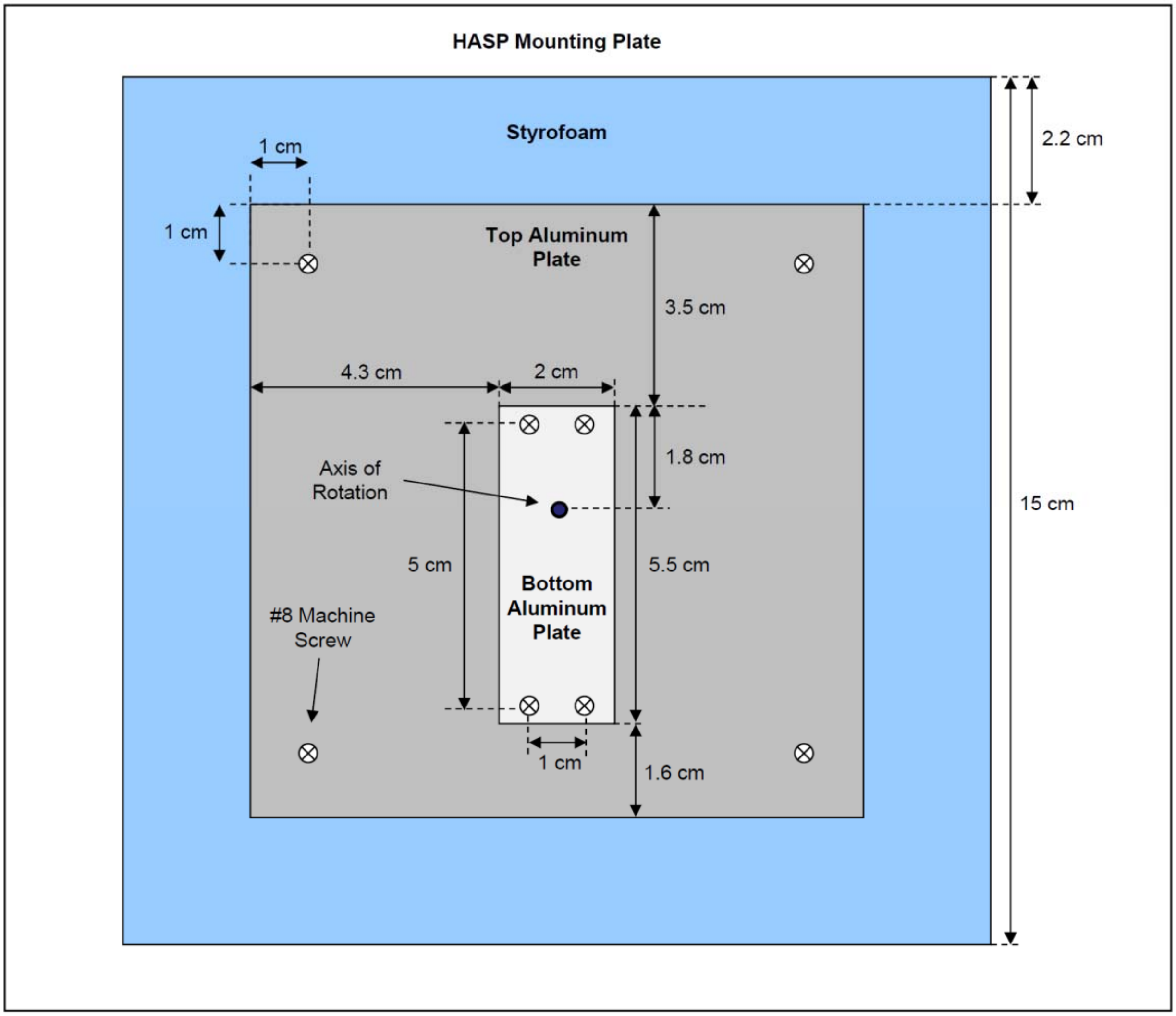

Figure 4. Top view (empty payload)

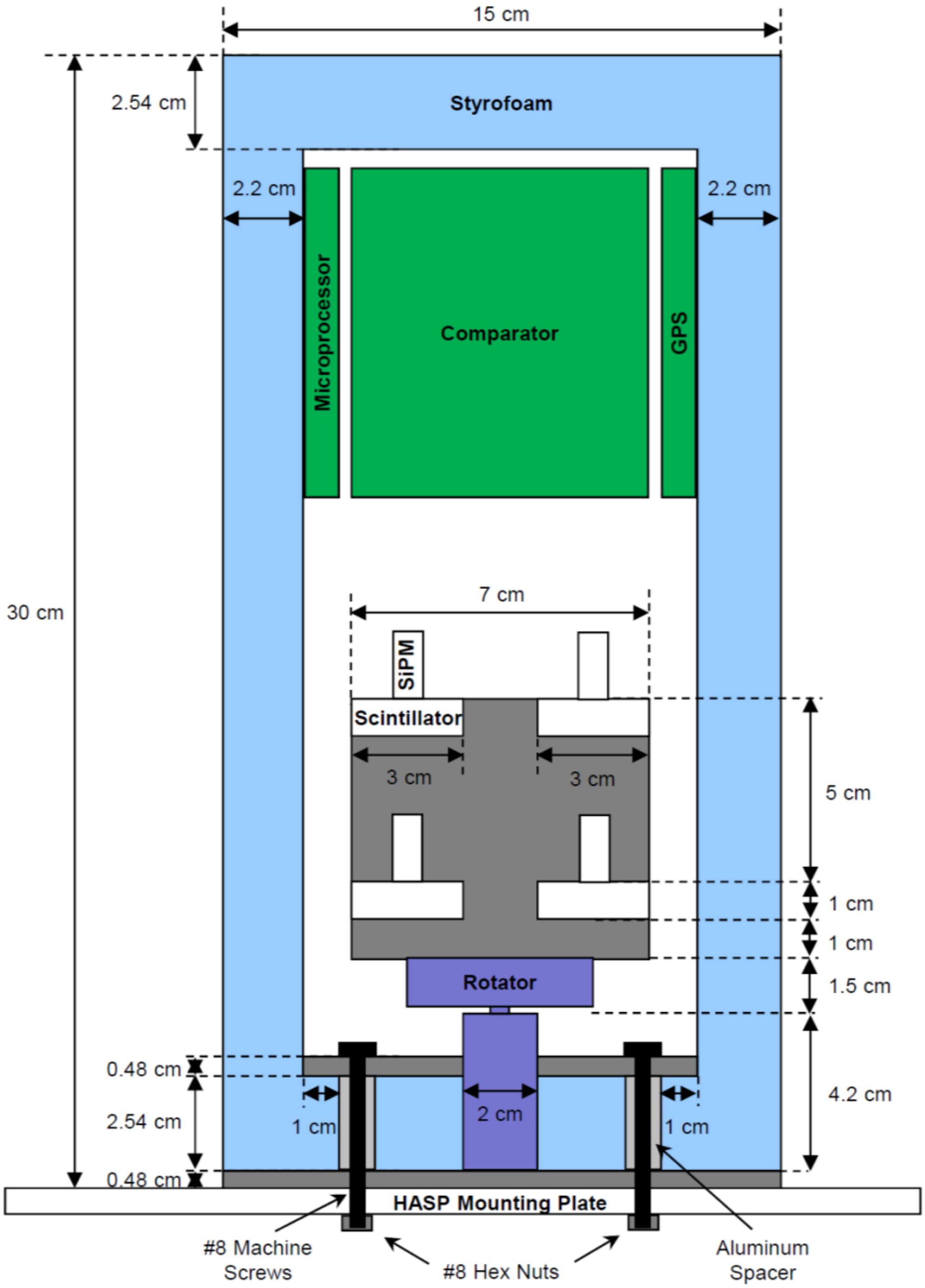

Figure 5. Front cut view of payload

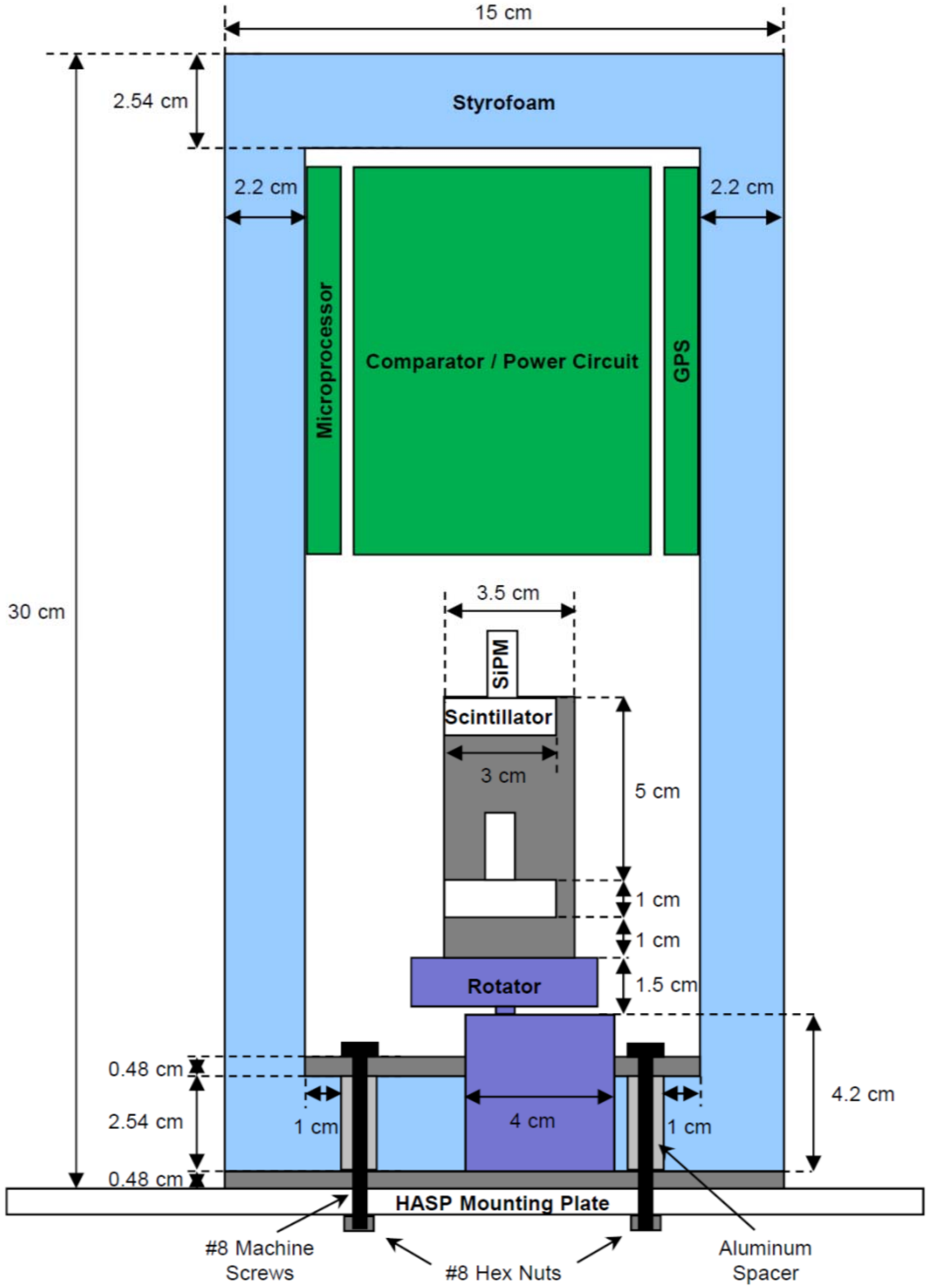

Figure 6. Side cut view of payload

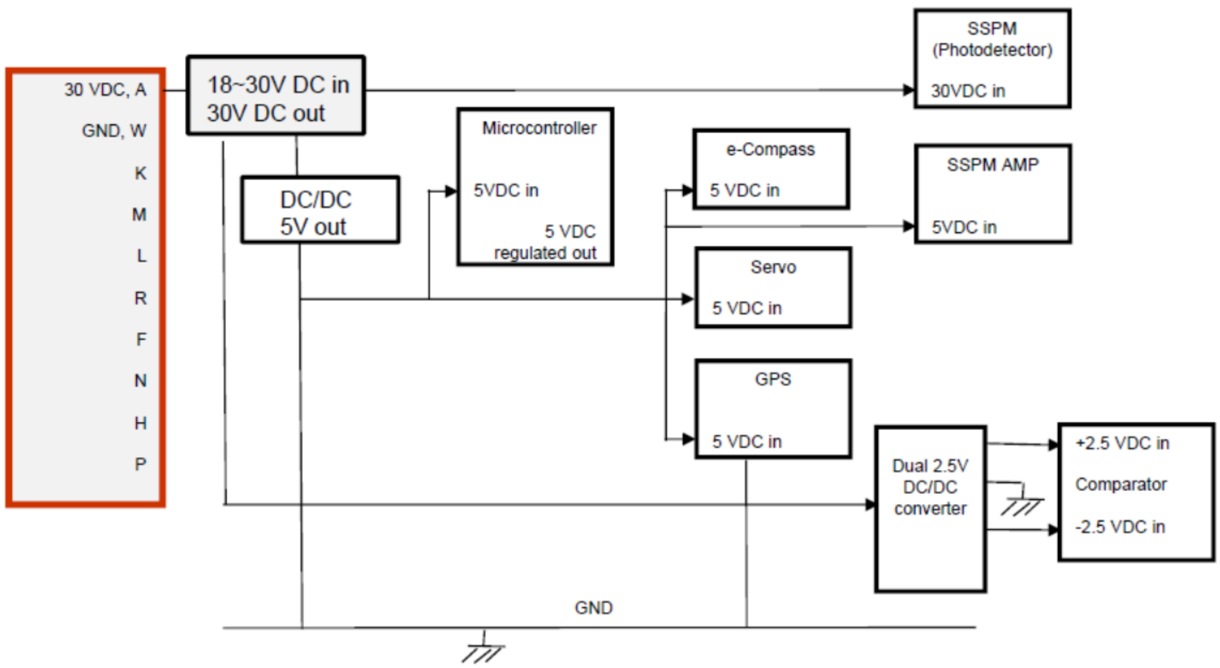

Figure 7. Electrical circuit diagram of the EDAC pins and the primary voltage conversion components

References

[1] Gannon University HARD project team, "High Altitude Radiation Detector (GU-HARD-PL02) Final Project Report," submitted to HASP project office, 12/14/2012.