# HASP Student Payload Application for 2012

Payload Title: High Altitude Radiation Detector (GU-HARD-PL02)

| Payload Class: (check one) | Institution: | Submit Date: |
|---|---|---|
| ☒ Small ☐ Large | Gannon University | 12/16/2011 |

Project Abstract


The Earth’s magnetic field, as well as galactic magnetic fields, deflects cosmic-ray trajectories from a straight line, and primary cosmic rays mostly approach from the west than from the east. This “east-west” asymmetry has been thoroughly investigated in the past at ground level. The goal of the proposed payload is to investigate how the “east-west” angular asymmetry in arrivals of cosmic rays changes with altitude, as the cosmic ray flux transitions from mostly secondary particles near the ground level to mostly primary cosmic rays near balloon-float altitudes. Another goal of this project is to explore the effects of high-altitude environmental factors on nanostructure printed surfaces, particularly, the effects of cosmic ray exposure on nano-scale circuit-components, and relate the integrity of surface patterns to cosmic-ray intensity.

The proposed project will be carried out by five Electrical & Computer Engineering (ECE) undergraduate students and two faculty advisors, one from the ECE department and the other from the Physics department. The proposed payload will be designed for, and operating through, the existing HASP interfaces.


| Team Name: | Team or Project Website: |
|---|---|
| GU-HARD-PL02 | |

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|---|---|---|
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## Payload Description

Background and Objectives

Cosmic rays were first discovered 100 years ago by Victor Hess in 1911. It is now known that primary cosmic rays are largely composed of completely ionized atomic nuclei, mostly protons, traveling near the speed of light. However, 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.

Were it not for Earth's magnetic field, cosmic rays would arrive at the top of the atmosphere isotropically. However, just as the galactic magnetic fields deflect cosmic-ray trajectories from a straight line, so does Earth's magnetic field. 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. The primary goal of this project is to explore how this angular asymmetry changes with altitude, as the cosmic ray flux transitions from mostly secondary particles near the ground level to mostly primary cosmic rays near balloon-float altitudes. The more than 15 hour flight duration provided by the HASP project would allow our payload to make a high-quality, long-exposure measurement at balloon-float altitudes. Additionally, we intend 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.

Dip-pen nanolithography (DPN) is a ground breaking technique in the field of nanotechnology. It has already been implemented successfully in some basic applications, such as pharmaceutical brand protection. If a functioning nano-circuit were to be realized, it would be a revolutionary development in small scale computing. However, using nano-circuitry in the upper atmosphere presents a technical hurdle due to increased susceptibility to radiation, such as cosmic rays, as electronic circuits becomes denser. A significant first step towards overcoming this obstacle would be identifying conductive materials resilient enough to withstand the radiation exposure such as that encountered during the HASP flight.

Another goal of this project is to explore the effects of high-altitude environmental factors on nano-structure printed surfaces. Of particular interest are the effects of cosmic ray exposure on materials and structures that hold potential for nano-scale circuit-components. Toward achieving this goal, we will a) evaluate the effect of near-space conditions on simple DPN-printed surface patterns of various ink compositions and b) evaluate the effect of near-space conditions on DPN-printed surface patterns potentially useful for the development of nano-scale circuit components. After post-flight analysis, we hope to identify one or more materials that can effectively label the surface of high-altitude vehicles such that the pattern can be distinguished after the return of the payload to our facility; to identify one or more electrically conductive materials that can withstand the conditions encountered in the course of a high altitude flight; and relate the integrity of surface patterns to cosmic-ray intensity.

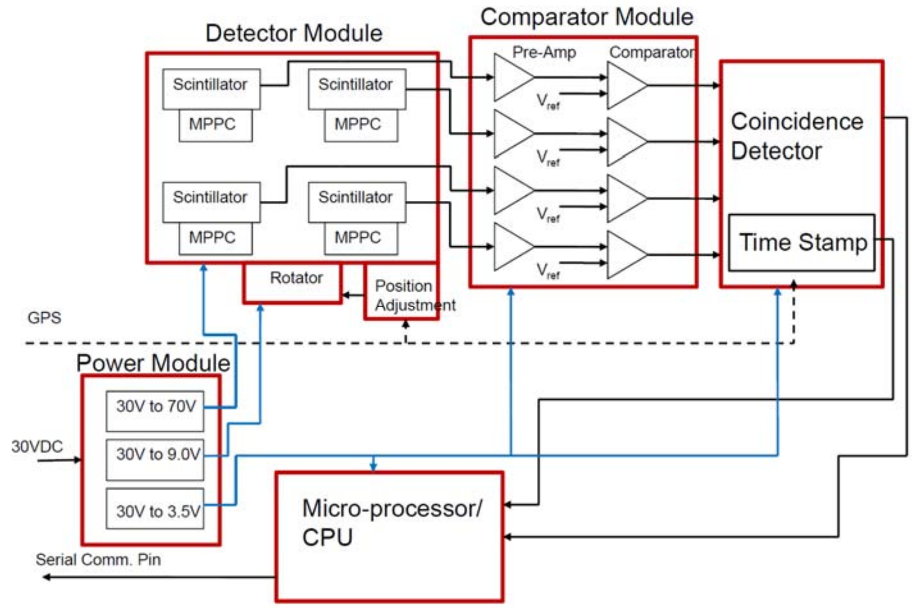


Figure 1. Overall functional block diagram for cosmic ray measurement

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 because it is lightweight, easy to shape, and provides excellent thermal insulation. Additionally, we will include resistive heating elements to maintain proper operating temperatures for electronics. We will investigate other housing materials if testing reveals that Styrofoam cannot withstand the 10 g horizontal and 5 g vertical shocks, as required in the "Call for Payloads." Individual payload components are described in more detail in the following sections.

**Detector Module** – The detector module primarily consists of scintillator material, multi-pixel photon counters (MPPCs), and a rotator with position adjustment. The proposed scintillator layout is shown in Figure 2 and Figure 3 in the Drawings section. Because the MPPC 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 MPPC per event. The scintillator will be covered with a reflective surface (such as aluminum foil or white paper) to reflect stray photons back into the detector, increasing the light output at the MPPC. The whole detector element (MPPC + scintillator) will be wrapped to avoid external sources of light. The MPPC 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 MPPC that has been chosen by the team is made to operate in a low-pressure environment. Typically a photomultiplier tube requires ~1 kV to operate correctly. These, however, have the common problem with arcing. 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 electric compass (e-compass) and GPS that is available from the HASP system. A small light-weight motor such, as Futaba S9405 Servo Coreless High-Torque BB motor, will be selected for this purpose. The motor rotation distance will be determined by the "Position Adjustment" module shown in the figure. The operation of the Position Adjustment module will be based on an electronic compass in combination with GPS coordinates supplied from the HASP system. The GPS data from HASP will be used mainly as a timestamp device.

The electronic compass will output serial data related to the payload/scintillators orientation, and the master microcontroller 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 MPPC units will output a voltage that is proportional to the number of detected photons. If necessary, this signal will be amplified to an appropriate level 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 preamplifiers and four comparators with a reference voltage, $V_{ref}$. The four preamplifiers will be placed before the comparators in case the signal from the MPPC requires amplification before being supplied to the comparators.

**Coincidence Detector**–The coincidence detector monitors whether a signal above $V_{ref}$ is observed from at least two MPPC modules within 1 to 10 $\mu$s. When this condition is met, the MPPC 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. If available, we plan to use two commands from the ground command through the discrete command interface. These signals will either turn our detector array power on or off. We will also need to receive commands from the serial port to ultimately control 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 the EDAC power supply that is provided. From a preliminary study, an off-the-shelf DC power converter (that will be tentatively selected) would help supply a steady 5 Vdc to the rest of the components that the EDAC could not supply. A converter would allow an input range from 8 to 48 Volts and output an output voltage of anywhere from 2 to 80 volts. This particular converter is small in size (10cm x 4.6cm x 2cm) and can accommodate our needs for all electronic modules in the payload. If necessary as the subsystem design may call for, one or more voltage divider(s) will be utilized.

**Nano-materials Subsystem** - The nano-materials subsystem will contain an array of nano-scale test patterns printed onto a silicon dioxide substrate. The individual patterns will be composed of assorted materials in varying arrangements. Structures of particular interest are shown in Figure 4.

This subsystem will not be interfaced with the balloon control system or any other part of the payload. Instead, experimental results will be analyzed after the payload is returned to Gannon University. The DPN fabrication unit that will be used in construction will also be essential for examining the structural integrity of each pattern post-flight. The results of this experiment will be somewhat subjective. Analysis will be a description of each component pattern, as well as a description of any changes undergone during the flight. Any noteworthy behavior will be elaborated upon.

The mechanical requirements are fairly simple. The substrate will be mounted onto a secondary plate with an adhesive, as shown in Figure 5. This plate with then be attached to the payload, taking advantage of its small size to fit securely in a convenient location.

**Thermal unit –** A thermal unit is being designed by the Gannon team to ensure that the temperature of all components will remain within operational limits. Ceramic heaters are being considered because they can be designed to fit into the payload. The ceramic heaters will then be integrated into a microprocessor which would then control the amount of heat that is being produced by the heaters. A thermocouple will also be integrated with this unit which will help the microprocessor maintain the temperature that the team has determined.

## 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. There are five ECE student team members and two faculty members involved. Four of the students are concentrating in electrical and electronics engineering, and one concentrating in computer engineering.

| Student | Position | Concentration | e-mail (& phone) |
| --- | --- | --- | --- |
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Team Member's Primary Responsibilities

- **Frantz** – Design and implementation of the power module, radiation detector module, comparator module, and coincidence detector module, and appropriate interface units to other modules
- **Wright** – Design and implementation of the thermal plan and rotator module and its interface to the detector module and position adjustment module
- **Grasinger** - Design and implementation of the micro-processor module and interface for the cosmic ray experiment, as well as the position adjustment module, and communication interface to the HASP.
- **Veneri** – Implementation of the radiation detection module as well as physical interface units to all modules as applicable
- **McGuire** - Design, fabrication, and analysis of the nanofabrication experiment, and implementation of physical interface units to payload modules as applicable; to coordinate team efforts as team leader and participate in monthly teleconferences as well as submission of monthly progress reports
- **Drs. Lee and Conklin** – to provide necessary technical advice and supervision of overall project activities as well as securing funding for project activities, including student traveling for system integration and launch as applicable

Project Management

The team will begin their work in January, 2012 as soon as the spring 2012 semester begins. Student members include three seniors and two sophomores in the ECE department. The seniors are enrolled in their senior design courses for AY 2011-12. The sophomores 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 (1/10/2012 – 3/1/2012): student members complete design of individual system modules and unit testing.
  **Deliverables**: Test plan for unit and integration tests

- Module integration (3/2/2012 – 4/15/2012): 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 testing at CSBF (4/18/2012 – 5/13/2012): 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

- Preliminary thermal testing (late May 2012): conduct thermal and vacuum testing (a test facility to be determined at a later time)

- Submit Final FLOP: July 27, 2012

- Payload integration (7/30/12-8/3/2012): team members on site for integration (at least 2 team members (anticipated) to participate

- HASP launch (9/3/2012): at least 1 team member on site (anticipated) to participate

**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. If we receive payload position 1, 2, or 5, we will use the available extra discrete commands to power the detector module on and off.

Technical Specifications

**I. Mechanical Specifications:**

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

| Component | Weight (kg) |
|---|---|
| Power converters | 0.5 |
| Detector module | 0.050 |
| Comparator module | 0.15 |
| Coincidence module | 0.15 |
| Micro-processor/CPU | 0.15 |
| Rotator | 0.055 |
| Frame/Mounting hardware | 0.75 |
| Nano-materials subsystem | 0.10 |
| **Total Weight (kg)** | 1.9 |

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 6 ~ Figure 9). 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." Additional power may be required for heating elements to maintain payload temperature, but will not exceed the maximum allotted.

| Component | Current (mA) | Voltage (V) | Power (W) |
|---|---|---|---|
| Power converters | 65 | ~6-9 | 0.6 |
| Detector module | 10 | 70 | 0.7 |
| Comparator module | 160 | 22 | 3.5 |
| Coincidence module | 65 | ~6-9 | 0.6 |
| Micro-processor/CPU | 65 | ~6-9 | 0.6 |
| Rotator | 250 | ~5 | 1.3 |
| **Total Power** | --- | --- | **7.3** |

B. Power system wiring diagram will be supplied upon completion of the payload design

## III. Downlink Telemetry Specifications:

A. Serial data downlink format: Packetized

B. Approximate serial downlink rate (in bits per second): 1200 bps

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.

**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 |

D. Number of analog channels being used: 1 channel for temperature monitoring

E. Number of discrete lines being used: 2 lines to power on and off the payload

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: Approximately 3-5 commands per hour during the first couple of hours of flight to ensure payload's operation.

D. A table of all of the commands for uplink will be provided upon completion of the payload design. All commands will be two bytes in hexadecimal, as required in the Interface Manual.

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

Integration and Flight Operation Plan

**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. The nanofabrication system will be vacuum tested at Gannon University to ensure that atmospheric pressures encountered will not have any unforeseen impact on DPN fabricated materials and/or the surrounding payload.

- 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 Kapton 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

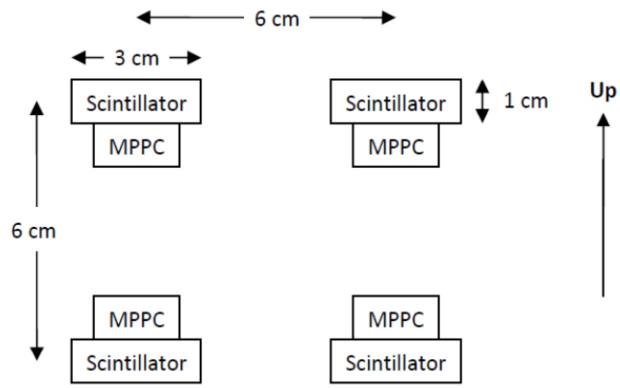


Figure 2. Detector Module - scintillator layout

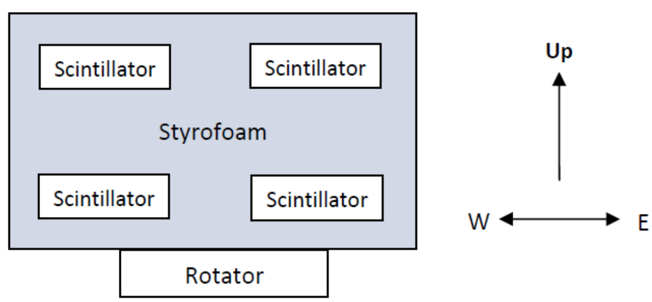


Figure 3. Detector Module with a rotator for position adjustment

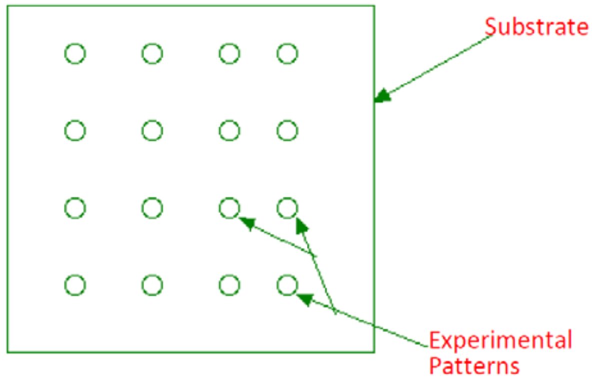


Figure 4. Schematic diagram of nano-pattern array (4 x 4 as an example)

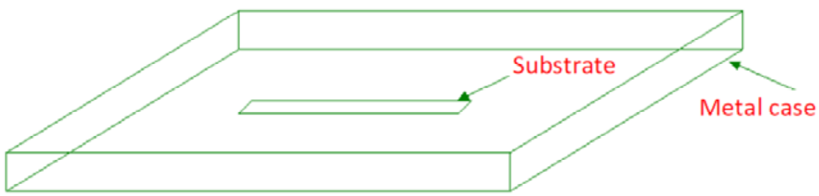


Figure 5. Schematic diagram of housing for substrate (overall size: approximately 3 x 4 x 1 cm)

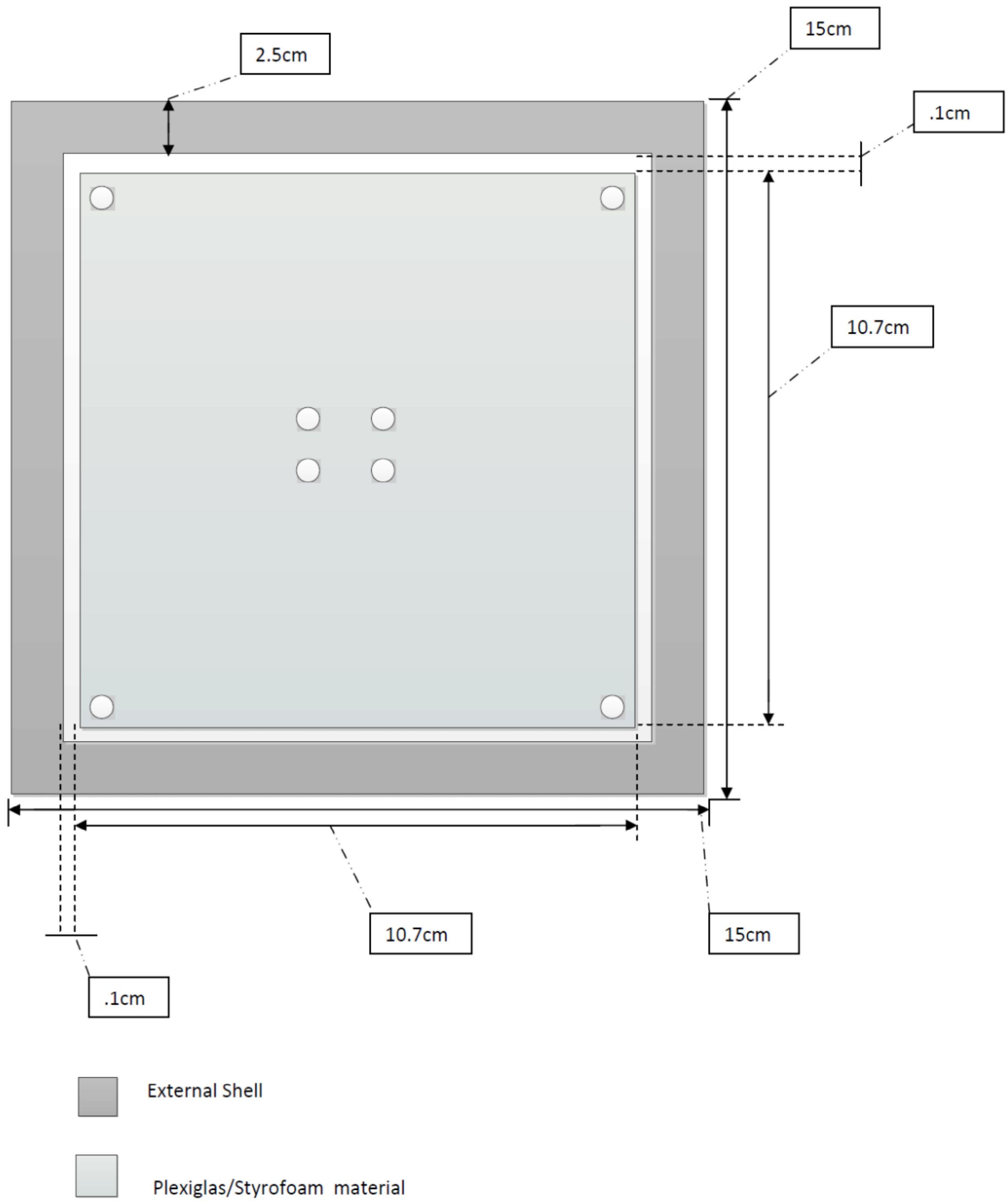


Figure 6. Top view of the proposed payload

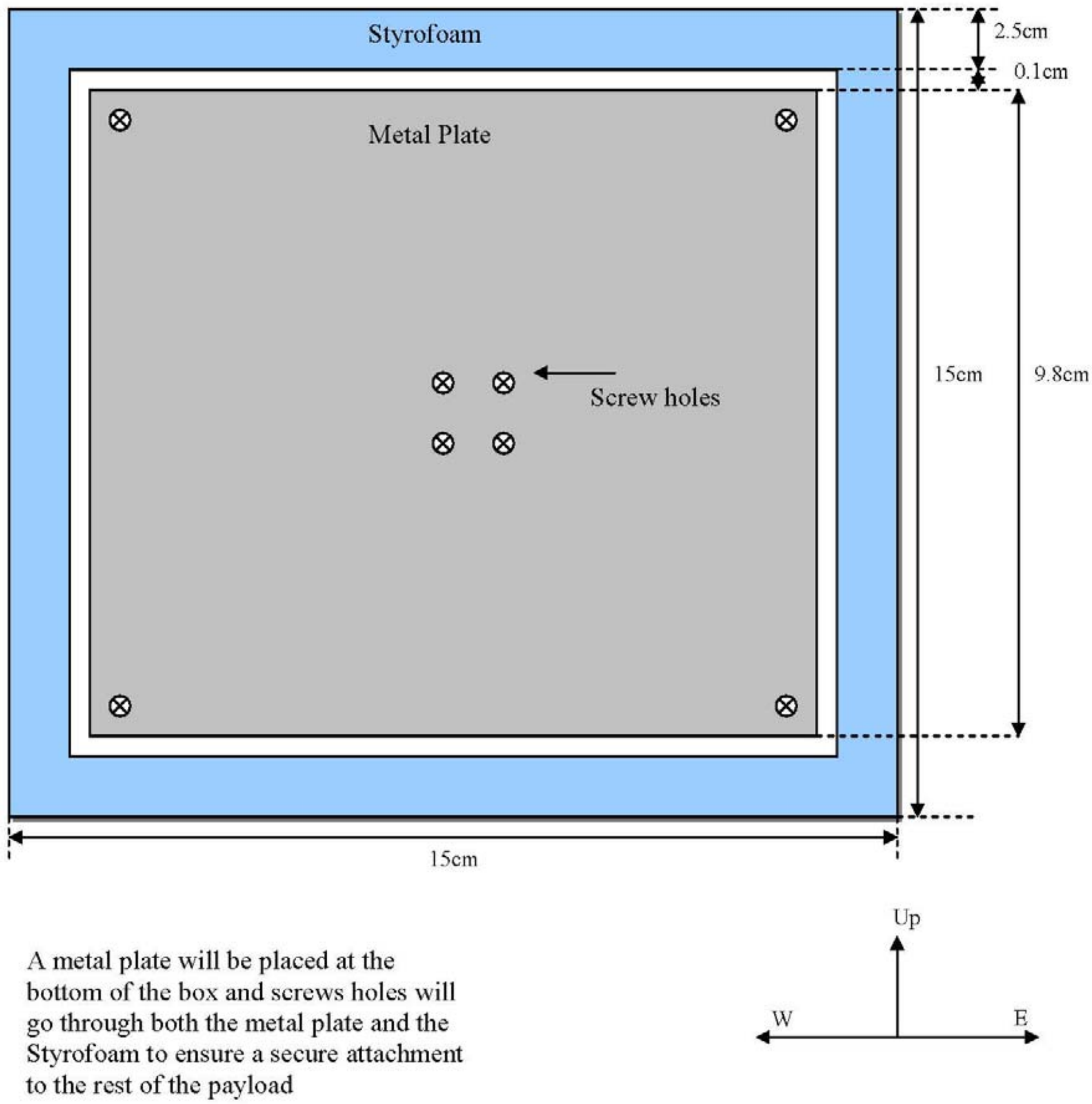


Figure 7. Top view (empty payload)

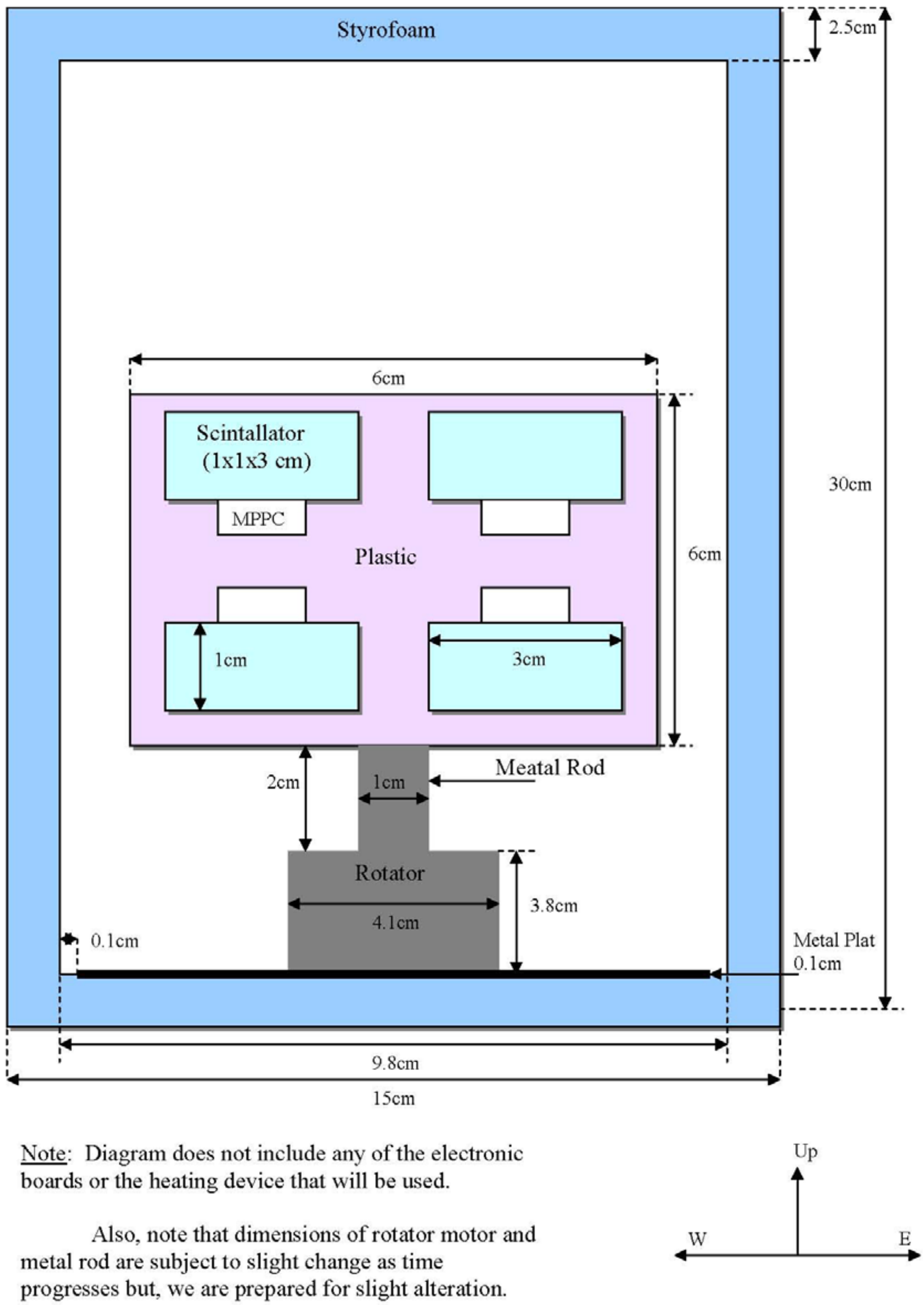


Figure 8. Front cut view of payload

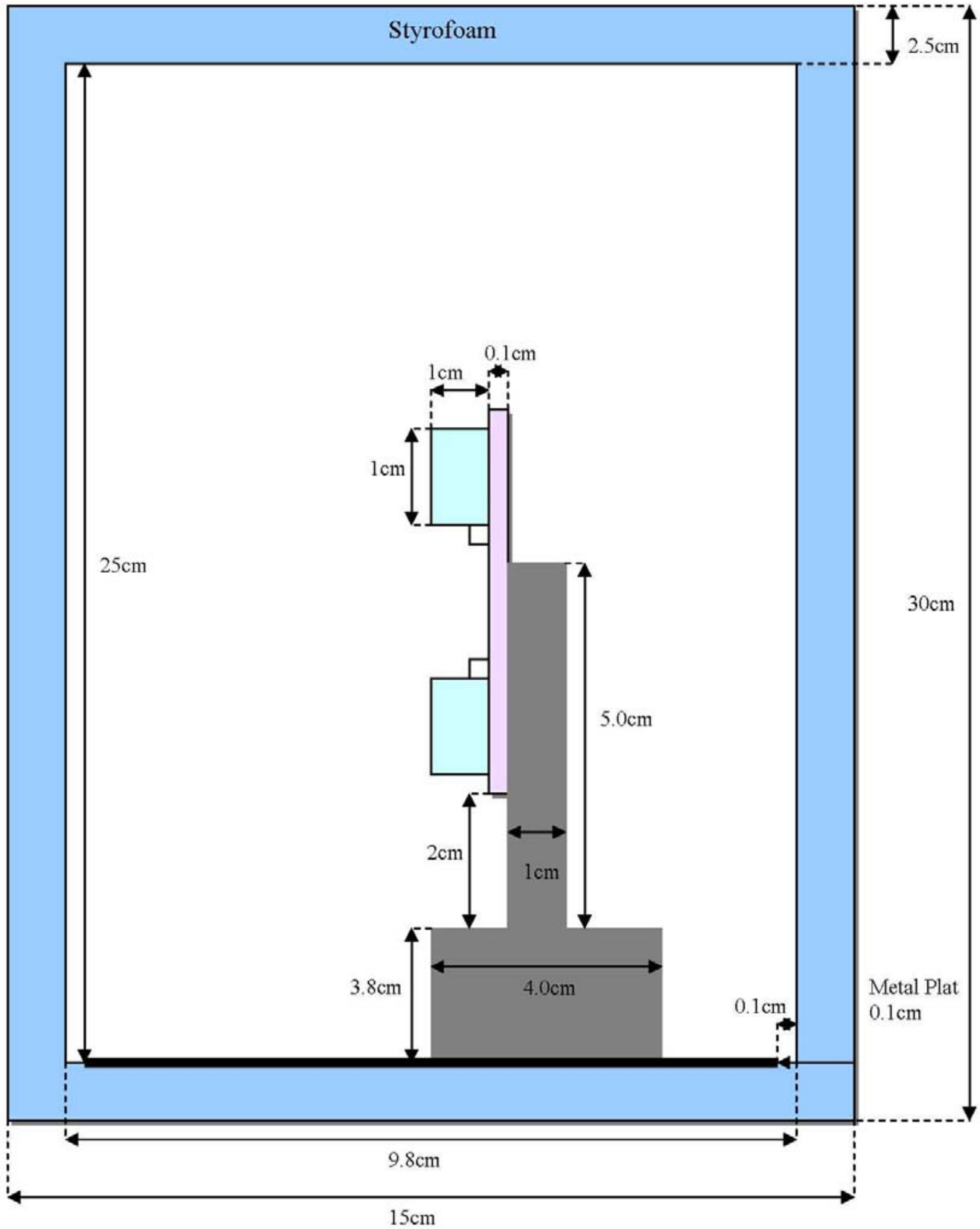


Figure 9. Side cut view of payload

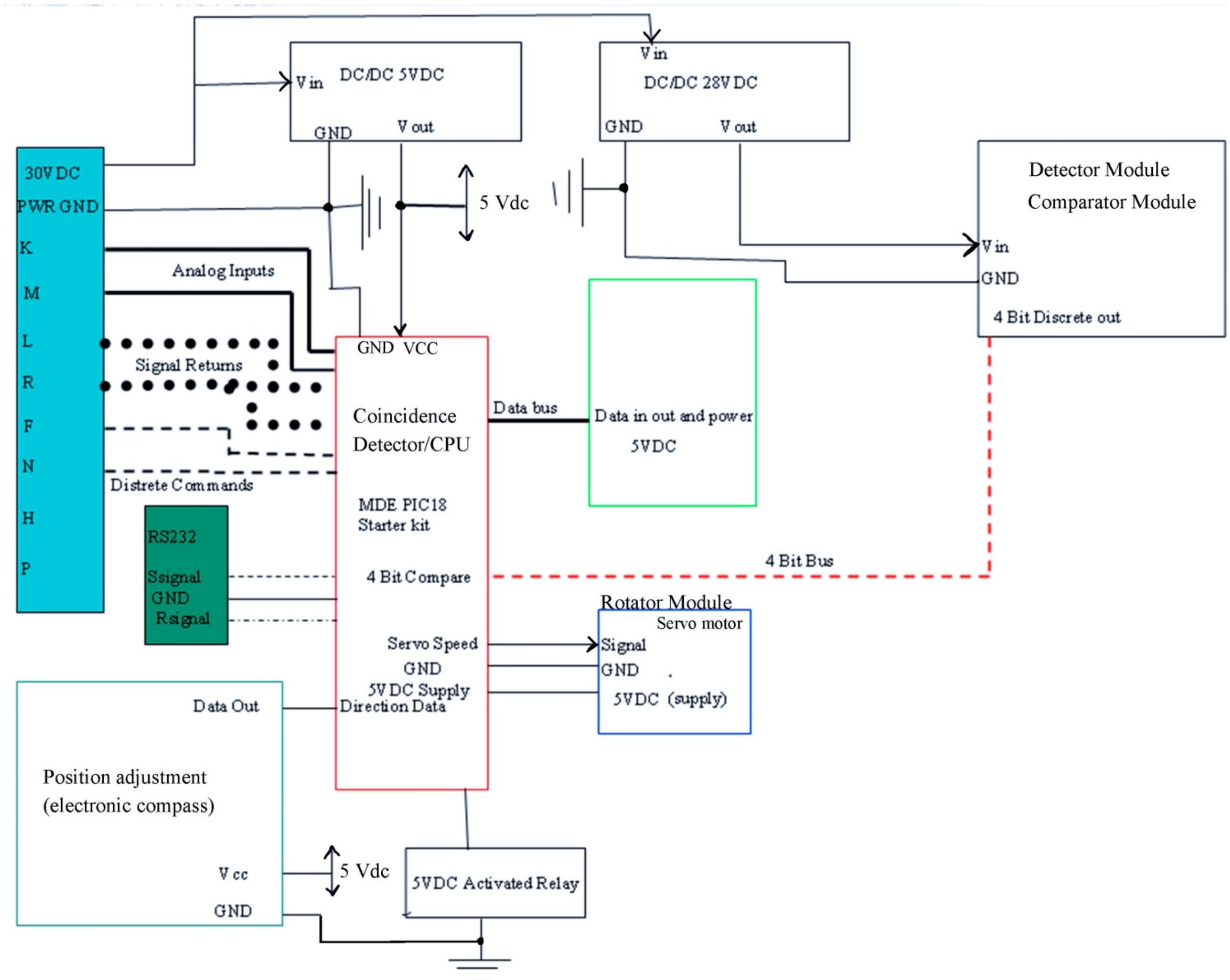


Figure 10. Electrical circuit diagram of the EDAC pins and the primary voltage conversion components