HASP Student Payload Application for 2019

<table>
<tr><td colspan="3">Payload Title:
Silicon Photomultiplier Array for Capturing Energy Radiation (SPACER)</td></tr>
<tr><td colspan="3">Institution: Louisiana State University</td></tr>
<tr><td colspan="2">Payload Class (Enter SMALL, or LARGE): LARGE</td><td>Submit Date: December 15, 2018</td></tr>
<tr><td colspan="3">Project Abstract: Storm systems can produce highly energetic gamma ray emissions of energies up to 10s of MeVs. These terrestrial gamma-ray flashes (TGFs) have been observed by satellite and ground based detectors. We propose a gamma ray detector suitable for observing these TGFs from the balloon altitudes closer to the suspected source locations above storm systems at high altitudes. The goal of the detector is to be able detect emission of gamma rays from a TGF at lateral distances of 10s of km with a ms time resolution. This detector will be capable of measuring gamma ray count rates on millisecond time bin intervals from 8 bismuth germanate (BGO) scintillators using silicon photomultipliers. The proposed detector would be flown as a large payload aboard the High Altitude Student Payload (HASP) platform. Payload mass 12.42 g. Payload will have dimensions of 7.5”x 14” x 9”. Required current supply is 1.23 A. The payload will require a RS-232 connection with a data downlink rate 156 Bps and capability to send commands though uplink in form of a single byte. The team will be led by Blaine Irle, advised Dana Browne, and consist of undergraduate and graduate students at Louisiana State University.</td></tr>
<tr><td colspan="2">Team Name:
GRD HASP Development Team</td><td>Team or Project Website:
N/A</td></tr>
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1.1 Project Background

Silicon Photomultiplier Array for Capturing Energy Radiation (SPACER) is a continuation of a payload originally designed for Correlation of Terrestrial gamma-ray flashes, Electric Fields, and Lightning strikes (COTEL). The gamma-ray detector's purpose was to detect gamma-rays created inside thunderstorms by employing a bismuth germinate (BGO) crystal and silicon photomultipliers (SiPMs). Figure 1 shows the final set-up of the COTEL gamma-ray detector as of summer 2018. Graduate and undergraduate students worked on the payload during the summer, which resulted in one test flight.

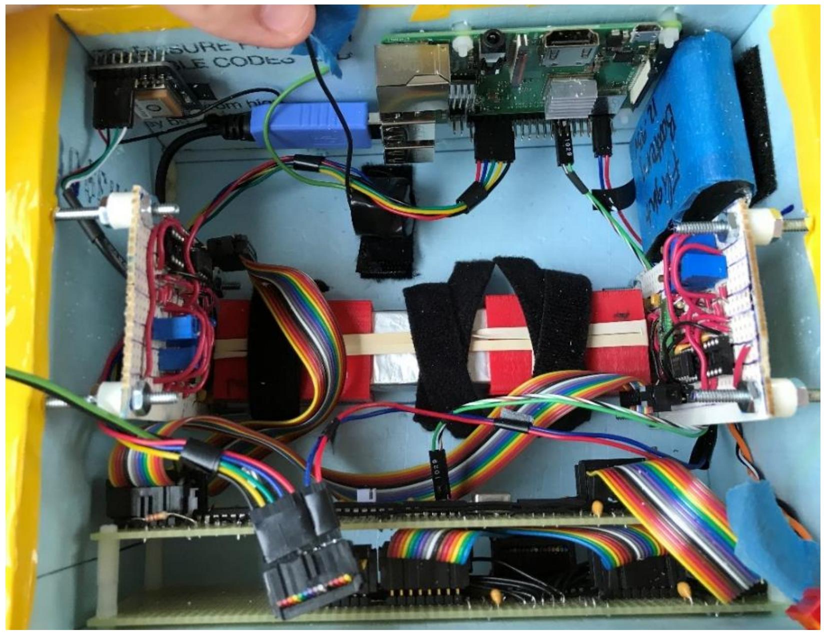

Figure 1: Shown is the final layout of the payload in summer 2018. Many connectors are not linked as they obscured the rest of the set-up. The BGO crystal is in the center of the payload, and the end caps containing the SiPMs are the red plastic caps on the crystal's ends.

The payload successfully detected cosmic rays during lab testing. The flight resulted in no detections. Upon analysis, it was found the mechanical interface between the SiPMs and the crystal was poor. Lab testing and post-flight analysis also revealed a difference in the elapsed time according to the GPS and MHz oscillator. The Raspberry Pi's OS prioritized internal operations over reading the data counters resulting in overflowing counters and the risk of lost counts.

Solutions to these design flaws are being explored. One solution to the prioritization error is implementing and prioritizing interrupts on the Pi. Alternatively, other OS and microcontroller options such as the Arduino Mega can be considered. A Pi was initially chosen because it provides large memory and speed. Research is currently being done to find a way to implement Arduinos, which have less memory and are slower at creating SD files.

1.2 Science Background

Terrestrial Gamma-ray Flashes (TGFs) were first observed by the Burst and Transient Source Experiment (BATSE) aboard the Compton Gamma Ray observatory in 1994 [*Fishman et al., 1994*]. BATSE's intended observation target was gamma-ray bursts. BATSE observed gamma-rays coming from Earth and correlated them with regions of storm activity. Since these initial observations, additional observations have been made by various space based instruments including the RHESSI, AGILE, Gamma-ray Burst Monitor, and Fermi Large Area Telescope;

ground based experiments, such as TETRA and Aragats Space Environment Center; and one aircraft born experiment, Airborne Detector for Energetic Lightning Emissions.

Atmospheric attenuation is expected to significantly decrease photon flux as distance from the source increases. Because of this, it is suspected only a portion of the most luminous events have been observed. Detected gamma-rays have had energies up to the order of 100 MeV. At energies in excess of 10 MeV, the gamma-ray flux is several orders of magnitude below those at lower energies. For a reference of expectant energies of concern, Figure 2 shows the summed spectra of 130 events observed by AGILE. The timescale of these events is on the order of submilliseconds, which is similar to the observed time scale of electrical disturbances and optical emissions associated with lightning strikes [*Dwyer et al., 2012*].

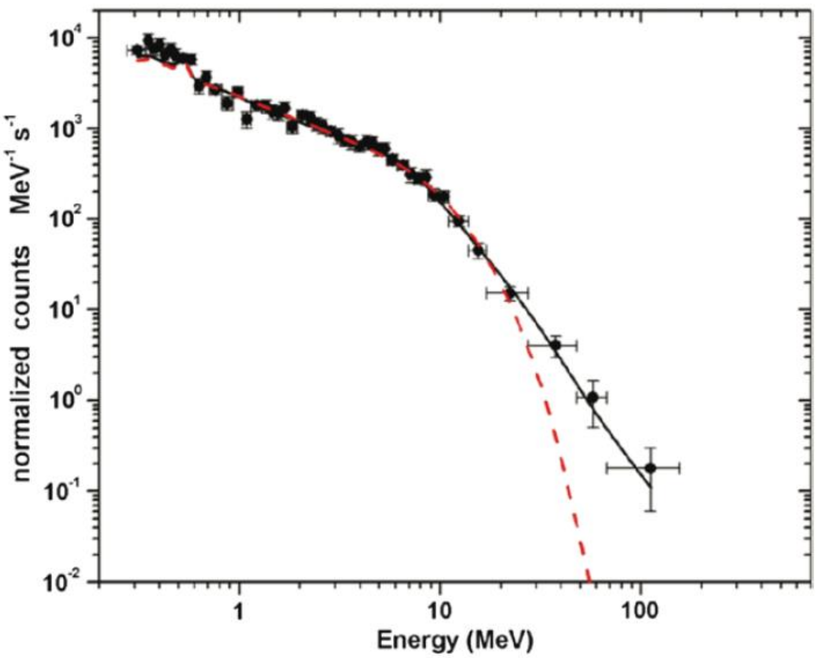

Figure 2: Shown is the summed spectrum of 130 AGILE TGFs from Tavani et al. Phys. Rev. Lett. 106, 018501, (2011).

SPACER will consist of BGO crystals and SiPMs. BGO crystals have a photon yield ~8-10 photons/KeV with emission spectrum peaking at 480 nm. This has good overlap with the photon detection efficiency the proposed SiPM, which peaks at ~450 nm [Jackson et al., 2014].

A SiPM is an integrated circuit that mimics the functionality of a traditional photomultiplier tube (PMT). It is an array of arrays of small photodiodes with a small resistor. When a photon is absorbed in the diode a current is produced that rapidly is quenched by the resistor, which allows the diode to return to its initial state. Each individual photodiode only has an on or off state, but proportional information about the total amount of light absorbed can be obtained by combining several diodes in a large array and combining their output. SiPMs use a much lower voltage (~30V) compared to the many 100s of volts necessary to operate a PMT.

1.3 Science Objectives

1.3.1 Detector Volume

Monte Carlo simulations of a TGF interacting with a single BGO crystal of dimensions 2.5 x 2.5 x 30 cm is shown in in Figure 3 below.

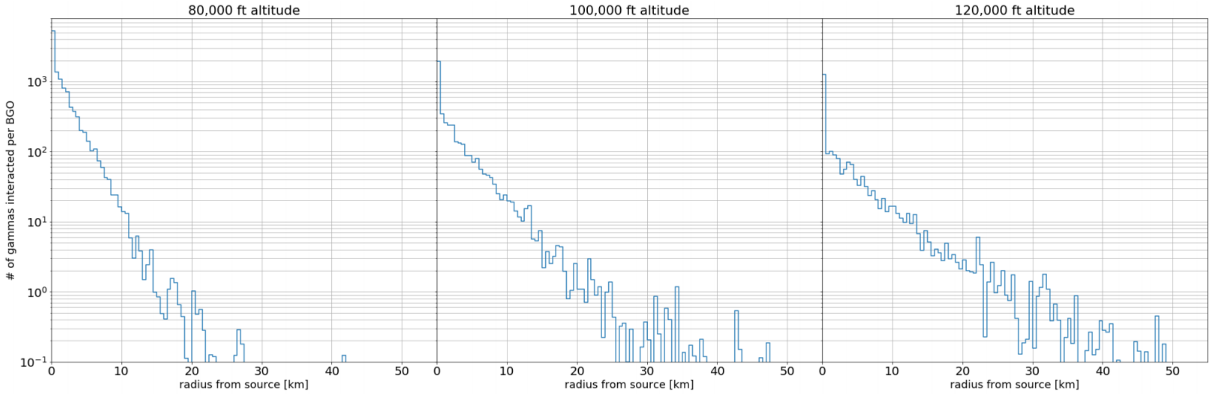

Figure 3: Shown is the estimated number of photons in a single BGO detector from an assumed TGF initiated at 10 km altitude.

The total number of photons collected is expected to scale with the number of crystals. Therefore, to allow for a reasonable number of photons to be detected in excess of the background at a distance of 10 km, eight BGO crystals will be used.

1.3.2 Time Scale

The time scale of these events is on the order of ~1 ms. Therefore, the instrument should be capable of measuring count rates in time bins <1ms. This will be accomplished by dedicated data recorders reading the counters every 1ms.

1.3.3 Cosmic Ray, Gamma-ray Discrimination

High energy charged particles from cosmic rays, primarily muons, are present in the atmosphere and their flux increases with altitude. This flux reaches a peak at ~15 km. Above this altitude, the flux decreases but remains significant. At expected flight altitudes, this cosmic ray flux is above surface muon flux. Therefore, the instrument must be able to distinguish between gamma rays and these charged particles. These particles will be at large energies (>1 GeV) and therefore may be treated as minimum ionizing particles (MIPs). Based on the minimum ionization energy of BGO and dimensions of the scintillator available, it is expected a MIP will deposit >22 MeV of energy.

Since the height of the signal peak is proportional to energy deposited, it is possible to distinguish between higher energy MIPs and low energy gamma-rays. This will be accomplished by use of comparator circuit.

1.3.4 Compensation of Signal Gain Due to Temperature

BGO crystal photon yield is a function of temperature. Since the temperature of the instrument is expected to change over the course of flight, it is desired to adjust the voltage thresholds of comparators to compensate for the varying photon yield.

1.4 Principle of Operations

The payload consists of gamma-ray detectors, two data collection controllers, a diagnostics controller, a GPS and memory board, environmental sensors, and a power regulation subsystem. A diagram showing the connections of the individual systems and their interfaces are shown in section 4.1. In normal operation, incident radiation will trigger a pulse of light within the gamma-ray detector. The pulses are counted and recorded by the data collection controllers. A diagnostic computer collects the temperature and voltage applied to each detector; this information is recorded for further analysis. Additionally, ambient temperature, temperatures of critical systems, pressure, GPS location, and a timestamp are also recorded. A copy of the data is stored on onboard memory and sent down the HASP serial interface.

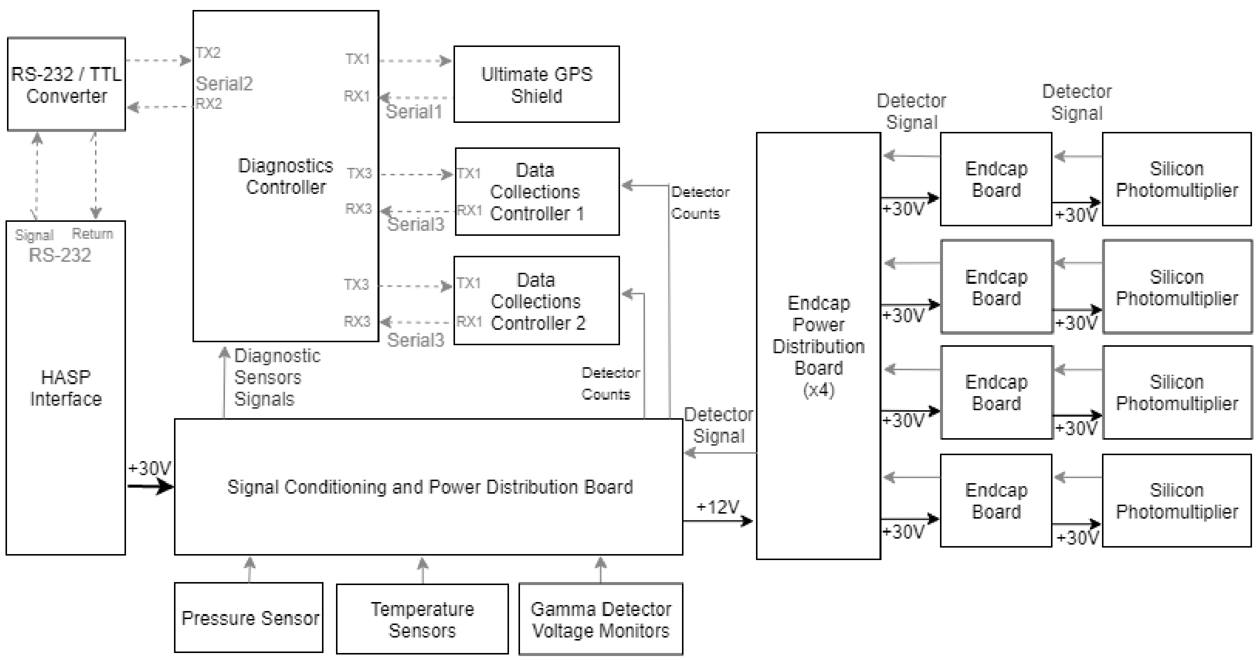

Figure 4: System diagram showing major components of SPACER experiment

1.4.1 Gamma Detector

SPACER contains eight BGO crystals with two SiPMs on each crystal, for a total of 16 SiPM detectors. Each SiPM will be attached to an endcap PCB and secured via an endcap. Power will be provided by an external cable that attaches to the endcap PCB. The amplified signal pulse will be transmitted through an SMA cable to the coincidence detectors and counters. A schematic of this can be found in Figure 4. The count of each SiPM will be read out to the Diagnostic Controllers in a round-robin fashion. Details of the endcap board circuit, the coincidence detectors, and counters are presented in sections 4.2.1.

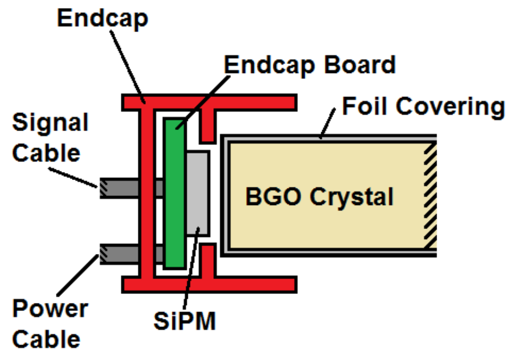

Figure 5: Shown is a rough schematic of the interface between a BGO crystal, SiPM and its PCB, an endcap, and power and signal cables. This set-up will be identical for each end of a crystal.

1.4.2 Data Collection Controllers

The gamma-ray detector will be read out by two data collection controllers. For this operation, we have selected two Arduino Megas to read and clear the counters. These controllers serve as an intermediate interface between the high-speed circuits of the gamma-ray detectors and the low speed operations of the diagnostic controller.

1.4.3 Diagnostic Controller

Communication with HASP will be handled by an Arduino Mega designated as the Diagnostic Controller. The Diagnostic Controller will read the various temperature probes, pressure sensor, and voltage monitors utilized in the experiment, compile the environmental and experimental data with onboard GPS data into a singular data format, and transmit this data packet once every second. It will also coordinate the readout of the data collection controllers to prevent collisions between the controllers.

1.4.4 Environmental Sensors and Voltage Monitors

The yield and efficiency of the gamma-ray detectors is affected by temperature fluctuations. In order to account for these variations, temperature probes will used to record the temperature of the BGO crystal. One probe will be used per crystal. Additional probes will be used to measure the temperature of critical systems to help identify any potential errors during integration or flight operations.

A pressure sensor is included as a redundancy check for data validity during the ascent and descent phases of flight operations. Additionally, the voltage applied to the SiPM detectors will be monitored using a voltage monitor. The voltage monitor consists of a voltage divider network and an external ADC utilizing I2C interface to communicate.

1.4.5 Power Subsystem

Power for SPACER will be provided by HASP. The raw battery voltage supplied by HASP will be regulated to +12V using a MHB75-24S12 DC-DC Converter. Component specific voltages are regulated further from this 12V regulator, as shown below in Figure 5. An AS431H shunt regulator provides +5V for the environmental sensors and their associated signal conditioning circuits. An LT3461A provides a steady +30V for the gamma-ray detectors. The voltage supplied by this regulator is recorded through voltage monitors. Each Arduino Mega and the GPS Board has an onboard power regulation system that powers its own circuitry.

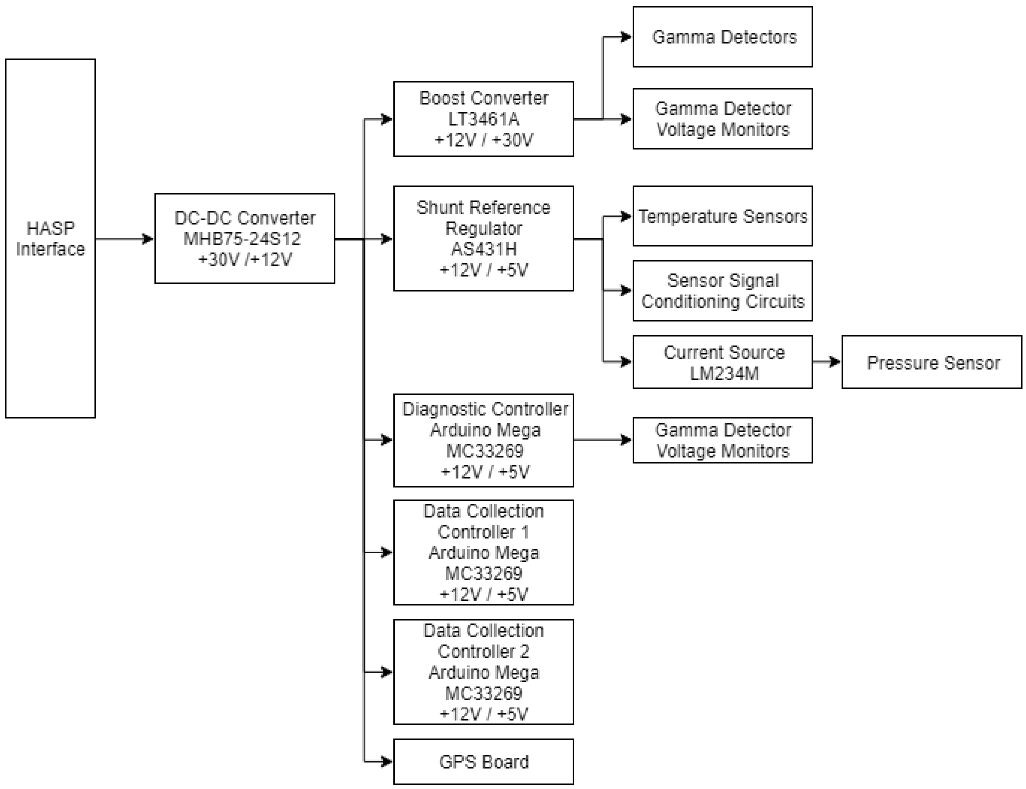

Figure 6: Shown is a schematic of voltage regulation for the various parts of SPACE.

1.5 Payload Structure and Thermal Control

SPACER's structure will consist of four aluminum payload walls as well as an aluminum top and bottom plate. The inside of the payload walls and plates will be coated with a black epoxy to reduce light from flight computers' LEDs reflecting off the walls and affecting count rates. The payload plates will be bolted to a structural skeleton (also aluminum); the bottom plate will also be bolted to the HASP mounting plate through the use of 6 #12 machine screw bolts with secured with a spring type lock washer and nylon insert locking nut. SPACER interior will consist of three vertical layers or "floors".

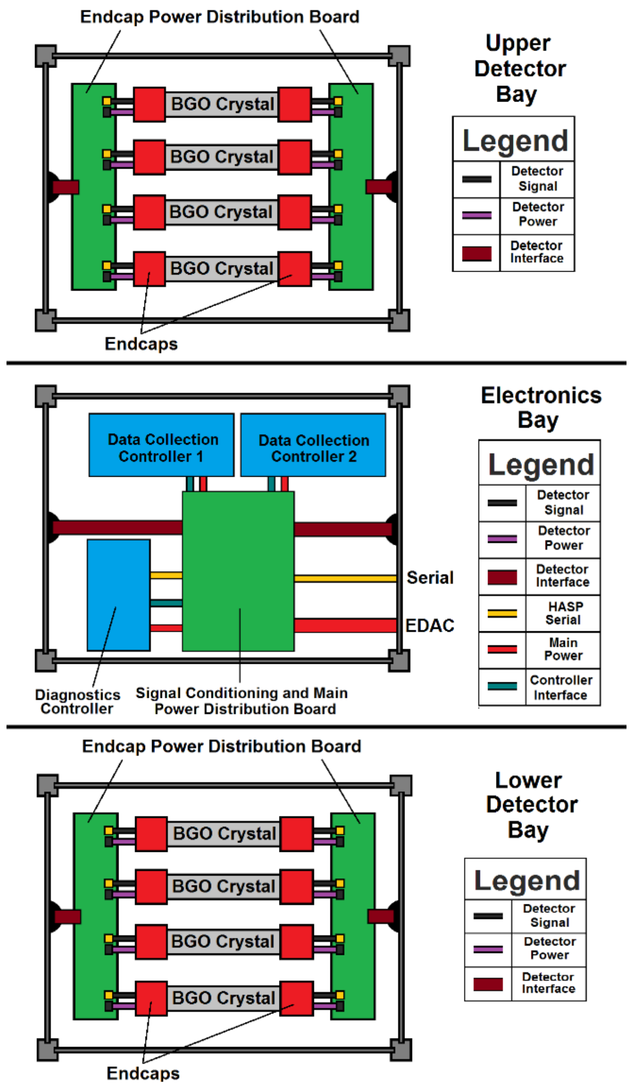

Figure 7: Internal layout out of SPACER enclosure.

The first floor of the payload will be the base plate and will contain four BGO crystals bolted down to the plate on either side with 3-D printed endcaps. These endcaps will have a slot with a locking mechanism to attach the SiPM PCBs on each end of a crystal. Insulating foam will be put in-between and around crystals to reduce heat fluctuations in crystal temperature as well as to reduce mechanical stress during flight and ensure electrical components are not shorted. The second floor will consist of an aluminum plate and will be identical to the first floor with four BGO crystals, endcaps, SiPMs, and insulating foam.

The third floor of the payload will contain PCBs for the readout electronics of each SiPM as well as the three flight computers and any additional electronics. Data collection computers will be mounted on the Port and Starboard sides of the plate. Each will be responsible for recording the counts of four BGO crystals below it. The third, diagnostic computer will be mounted at the center of the plate.

The top plate of the SPACE enclosure will have mounting EDAC and RS-232 ports for connection of HASP cables to the payload. With the interior side of the ports connected to the power distribution board.

1.6 Flight Computer and Data Logging

SPACER will have three onboard flight computers, all Arduino Megas: two data collectors and one diagnostic controller. Each Mega will have its own datalogging shield for recording data.

The first two Arduino Megas are Data Megas and will be responsible for recording and storing experimental data from a scintillator network consisting of four BGO crystals. SiPM counts will be recorded with 32-bit counters, one for each SiPM. A megahertz oscillator will have its own 32-bit counter that will be read by the Data Megas during each cycle to determine the bin width of the data. The Data Megas will continuously read these counters and will write the counts, as well as update one-second sums of the counts, to a buffer on the Arduino EEPROM. The Arduino EEPROM has a size of 4kB and will be divided into eight 512-byte buffers. Once a buffer is full, it will be written to the payload's SD card. Counts will be simultaneously recorded in another buffer.

The third Arduino Mega is the Diagnostic Mega. It will have an attached GPS shield that will send one-second pulses to the Data Arduinos. Upon receiving this pulse, the Data Arduinos will send their one-second count sums to the Diagnostic Mega. The Diagnostic Mega records these sums to its onboard memory with a timestamp. A record of this interaction will then be made in the data record of the Data Megas and their one-second sums will reset to zero. Diagnostic data will be collected every five seconds and will include scintillator temperatures, SiPM voltages, ambient pressure, ambient temperature, and GPS time data. The collected diagnostic data, along with the one-second count sums, will then be sent using the HASP telemetry downlink.

2. Project Management

2.1 Team Structure

SPACER will be constructed by a student team. Table 1 outlines the team's structure and team members' contact information. There will be a project lead, electrical lead, mechanical lead, physics lead, and computer science lead.

Blaine Irle, a physics undergraduate, will be the project lead. As the project lead, Mr. Irle will be responsible for general team management as well as submitting monthly reports and attending HASP teleconferences. In addition, Mr. Irle will be responsible for procurement of any additional hardware necessary for SPACER's flight. Mr. Irle will also assist with any scientific calculations for the scintillators and in completion of the flight computer design and software.

Josh Collins will be the electrical lead for the team and will be responsible for the electrical design of SPACER. This includes designing and ordering any PCBs that need to be made. Robert Sack will be the lead on payload fabrication and mechanical design.

As designers of previous versions of SPACER, graduate students Aaron Ryan and Emma Western will assist the team in developing the newest iteration of SPACER. Mr. Ryan will be the physics lead and will therefore perform needed scientific calculations. Ms. Western will be the computer science lead and will design the software.

Dr. Dana Browne will be the faculty supervisor for SPACER, and will provide advice and guidance as needed. Additional assistance will be provided by the Louisiana State University

Scientific Ballooning Team to help payload development if needed. Blaine Irle and Josh Collins will lead SPACER's HASP integration.

Project Role	Name & Title	Address	Contact
Faculty Sponsor	Dr. Dana Browne Principal Investigator	Louisiana State University 202 Nicholson Hall Baton Rouge, LA 70803	browne@phys.lsu.edu 225-578-6843
Project Lead	Blaine Irle Undergraduate	Louisiana State University 202 Nicholson Hall Baton Rouge, LA 70803	birle1@lsu.edu 404-547-3195
Physics	Aaron Ryan Graduate	Louisiana State University 202 Nicholson Hall Baton Rouge, LA 70803	aryan21@lsu.edu 808-783-9096
Electrical	Josh Collins Staff / Graduate	Louisiana State University 202 Nicholson Hall Baton Rouge, LA 70803	jcoll72@lsu.edu 985-287-1093
Mechanical	Robert Sack Undergraduate	Louisiana State University 202 Nicholson Hall Baton Rouge, LA 70803	rsack1@lsu.edu 337-849-0075
Computer Science	Emma Western Graduate	Louisiana State University 202 Nicholson Hall Baton Rouge, LA 70803	eweste3@lsu.edu 715-417-1382

Table 1: Outline of team structure and individual roles as well as contact information

2.2 Schedule and Milestones

Table 2 below displays a preliminary timeline highlighting major milestones and deadlines to be met throughout SPACER's lifetime.

Date of 2019	Milestone
January	Train undergraduate team members. Acquire needed hardware electronics. Test SiPMs and new flight computer.
February	Develop and modify existing flight software. Finalize design of back-end detector electronics. Develop mechanical structure of payload. Finish fabrication of front-end detector electronics.
March – April	Complete payload flight software. Finalize mechanical and electrical interfaces. Finalize mechanical design. Fabricate back-end electronics.
April – May	Fabricate mechanical structure. Full assembly and testing of detector electronics and flight software. Begin developing flight operations plan.
April 15th	Submit NASA On-site Security Clearance Document
April 24th	Complete Preliminary PSIP Document
April 26th	Submit Preliminary PSIP Document
May – June	Fabrication of final payload. Prepare payload for July integration at CSBF
June 19th	Complete Rough Draft of FLOP Document
June 26th	Complete Final Draft of PSIP Document
July 15th – 19th	Payload Integration at CSBF
July 17th	Complete Final Draft of FLOP Document
July 19th	Submit Final Draft of FLOP Document
July	Fix payload issues discovered during integration
September 2nd	Launch
September	Parse, extract, and analyze payload flight data. Begin development of payload scientific report.
October – November	Complete post-flight data analysis. Continue work on final scientific report.
November 20th	Complete rough draft of final science report
December 6th	Submit final flight/science report

Table 2: Milestones and deadlines to be met by the team.

2.3 Integration Plan

It is expected that two or three team members will attend HASP flight integration at CSBF. One or two team members will attend flight operations in Fort Sumner. To ensure SPACER is prepared for integration and flight, a timeline of important dates and team milestones is shown in Table 2.

3. Payload Specifications

3.1 Power and Weight Budget

The weight requirements for the SPACER payload is shown below in Table 3.

Component	Mass per unit (g)	Component Quantity	Total Mass for all units (g)
BGO Crystal	1160	8	9280
Arduino Mega	35	3	105
Wires/Cabling	95 ± 10	1	95 ± 10
Signal Conditioning and Detector Circuits	130 ± 20	8	1040 ± 160
Structure (7.5 x 14 x 9 in. box) and Frame	500 ± 200		500 ± 200
Aluminum Wall	200 ± 50	6	1200 ± 300
Internal Structure (Endcaps, wire harnesses, etc.)	200 ± 100	1	200 ± 100
Total			12,420 ± 770

Table 3: Preliminary Weight Budget

Expected maximum current draws for each component were used to estimate an upper limit of the total current draw. Total current draw is shown below in table 4.

Component	Current Draw per unit (mA)	Component Quantity	Total Current Draw for all units (mA)
SiPM	< 1	16	< 1
Signal Conditioning Circuit	60 ± 20	8	480 ± 60
Arduino Mega	250 ± 50	3	750 ± 150
Total			1239 ± 217

Table 4: Preliminary Power Budget

3.2 Telemetry and Command Rates

The Arduino Mega cannot communicate using RS232 protocol, and as a result will be connected to the HASP gondola using a TTL to RS232 converter. The Arduino TTL serial library can be set to 4800 baud to match HASP. The default Arduino serial communication settings match with HASP as well (8 data bits, no parity, 1 stop bit, and no flow control).

Downlink bandwith will be required for diagnostic system information including: SiPM voltages, crystal temperatures, ambient temperature, ambient pressure, GPS timestamp, and total count number from each SiPM. The bitrate of the payload downlink will be 156 Bps and sent over a 4800 baud connection. The current data downlink format is displayed in Table 5. The finalized data rate and packet structure may be subject to change as the payload is developed. These changes, if made, will be outlined in future documentation.

The downlinked diagnostic information may be used to implement a discrete command to change the configuration of the payload. If a SiPM is reporting faulty data commands may be used to turn its voltage regulator off and end data collection. A command may also be implemented to adjust voltage regulator output level in order to account for temperature fluctuations. Additional commands may be used to adjust the thresholds of the detectors, as these may change during flight. If data collection is not going at all as expected, a command to cycle the payload's power may be implemented.

Byte	Name	Purpose
1	Header	Indicate start of packet
2-3	Timestamp	GPS time of data record creation
4-5	Scintillator 1 Temperature	ADC value of temp. sensor in contact with scintillator crystal
6-7	Scintillator 2 Temperature	ADC value of temp. sensor in contact with scintillator crystal
8-9	Scintillator 3 Temperature	ADC value of temp. sensor in contact with scintillator crystal
10-11	Scintillator 4 Temperature	ADC value of temp. sensor in contact with scintillator crystal
12-13	Scintillator 5 Temperature	ADC value of temp. sensor in contact with scintillator crystal
14-15	Scintillator 6 Temperature	ADC value of temp. sensor in contact with scintillator crystal
1-6-17	Scintillator 7 Temperature	ADC value of temp. sensor in contact with scintillator crystal
18-19	Scintillator 8 Temperature	ADC value of temp. sensor in contact with scintillator crystal
20-21	SiPM 1 Voltage	ADC of voltage supplied to SiPM
22-23	SiPM 2 Voltage	ADC of voltage supplied to SiPM
24-25	SiPM 3 Voltage	ADC of voltage supplied to SiPM
26-27	SiPM 4 Voltage	ADC of voltage supplied to SiPM
28-29	SiPM 5 Voltage	ADC of voltage supplied to SiPM
30-31	SiPM 6 Voltage	ADC of voltage supplied to SiPM
32-33	SiPM 7 Voltage	ADC of voltage supplied to SiPM
34-35	SiPM 8 Voltage	ADC of voltage supplied to SiPM
36-37	SiPM 9 Voltage	ADC of voltage supplied to SiPM
38-39	SiPM 10 Voltage	ADC of voltage supplied to SiPM
40-41	SiPM 11 Voltage	ADC of voltage supplied to SiPM
41-42	SiPM 12 Voltage	ADC of voltage supplied to SiPM
43-44	SiPM 13 Voltage	ADC of voltage supplied to SiPM
45-46	SiPM 14 Voltage	ADC of voltage supplied to SiPM
47-48	SiPM 15 Voltage	ADC of voltage supplied to SiPM
49-50	SiPM 16 Voltage	ADC of voltage supplied to SiPM
51-54	SiPM 1 Count avg.	SiPM counts/sec
55-58	SiPM 2 Count avg.	SiPM counts/sec

59-62	SiPM 3 Count avg.	SiPM counts/sec
63-66	SiPM 4 Count avg.	SiPM counts/sec
67-70	SiPM 5 Count avg.	SiPM counts/sec
71-74	SiPM 6 Count avg.	SiPM counts/sec
75-78	SiPM 7 Count avg.	SiPM counts/sec
79-82	SiPM 8 Count avg.	SiPM counts/sec
83-86	SiPM 9 Count avg.	SiPM counts/sec
87-90	SiPM 10 Count avg.	SiPM counts/sec
91-94	SiPM 11 Count avg.	SiPM counts/sec
95-98	SiPM 12 Count avg.	SiPM counts/sec
99-102	SiPM 13 Count avg.	SiPM counts/sec
103-106	SiPM 14 Count avg.	SiPM counts/sec
107-110	SiPM 15 Count avg.	SiPM counts/sec
111-114	SiPM 16 Count avg.	SiPM counts/sec
115-116	Ambient Pressure	ADC value of pressure sensor of payload
117-118	Ambient Temperature	ADC value of temp. sensor of payload
119-120	Time of last pulse	GPS time of last one-second pulse

Table 5: Sample of expected downlinked data packet

Command Byte	Function
00 – 0F	Select SiPM for changing setting high voltage.
10	Turn on high voltage for selected SiPM
11	Turn off high voltage for selected SiPM
12	Increase high voltage of selected SiPM by 0.5V
13	Decreases high voltage of selected SiPM by 0.5V
20	Select Crystal 1 for setting voltage threshold
21	Select Crystal 2 for setting voltage threshold
22	Select Crystal 3 for setting voltage threshold
23	Select Crystal 4 for setting voltage threshold
24	Select Crystal 5 for setting voltage threshold
25	Select Crystal 6 for setting voltage threshold
26	Select Crystal 7 for setting voltage threshold
27	Select Crystal 8 for setting voltage threshold
30 – 4F	Set voltage threshold to predefined value
90	Resend last downlink packet
91	Send last received command
92	Power on Data Collection Controller 1
93	Power off Data Collection Controller 1
94	Power on Data Collection Controller 2
95	Power off Data Collection Controller 2

Table 6: Preliminary lookup table for uplink commands

3.3 Payload Orientation

SPACER has no preference for orientation on the gondola. If there is a location on the gondola where high density material below the payload is at a minimum relative to other locations, SPACER would prefer this location to minimize shielding of gamma-rays originating below the payload.

3.4 Potential Hazards

SPACER has no potential hazards as defined in the NASA Balloon Program Ground Safety Plan. SPACER's SiPMs operate at 30 V and pose the only potential high voltage hazard.

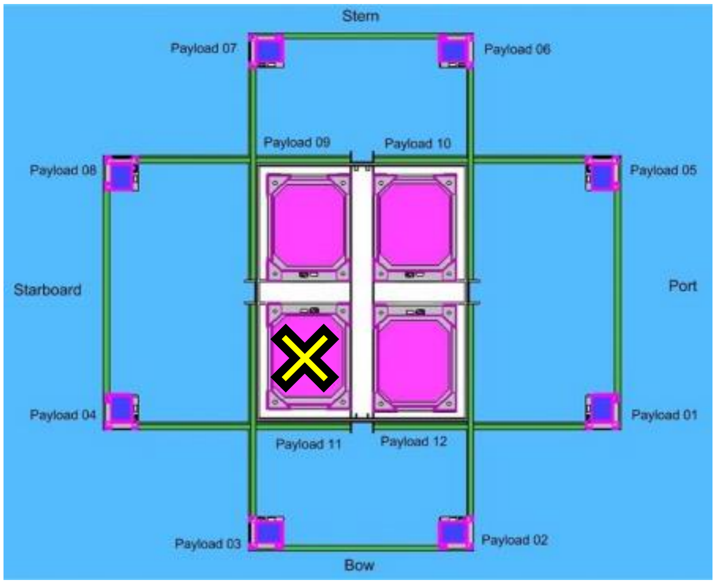

Figure 8: Payload location if location 11 has the least amount of high-density material below it.

4.0 Preliminary Drawings

4.1 System Diagram

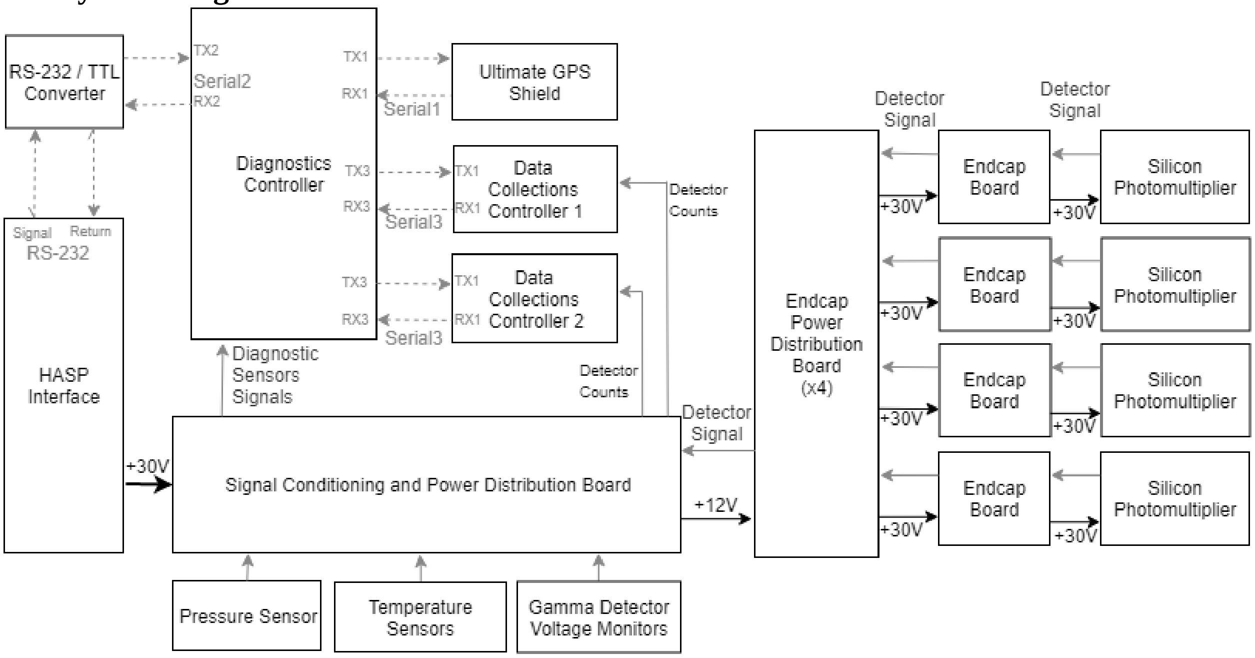

Figure 9: Functional block diagram of SPACER detector system

4.2.1 Endcap Board Schematic

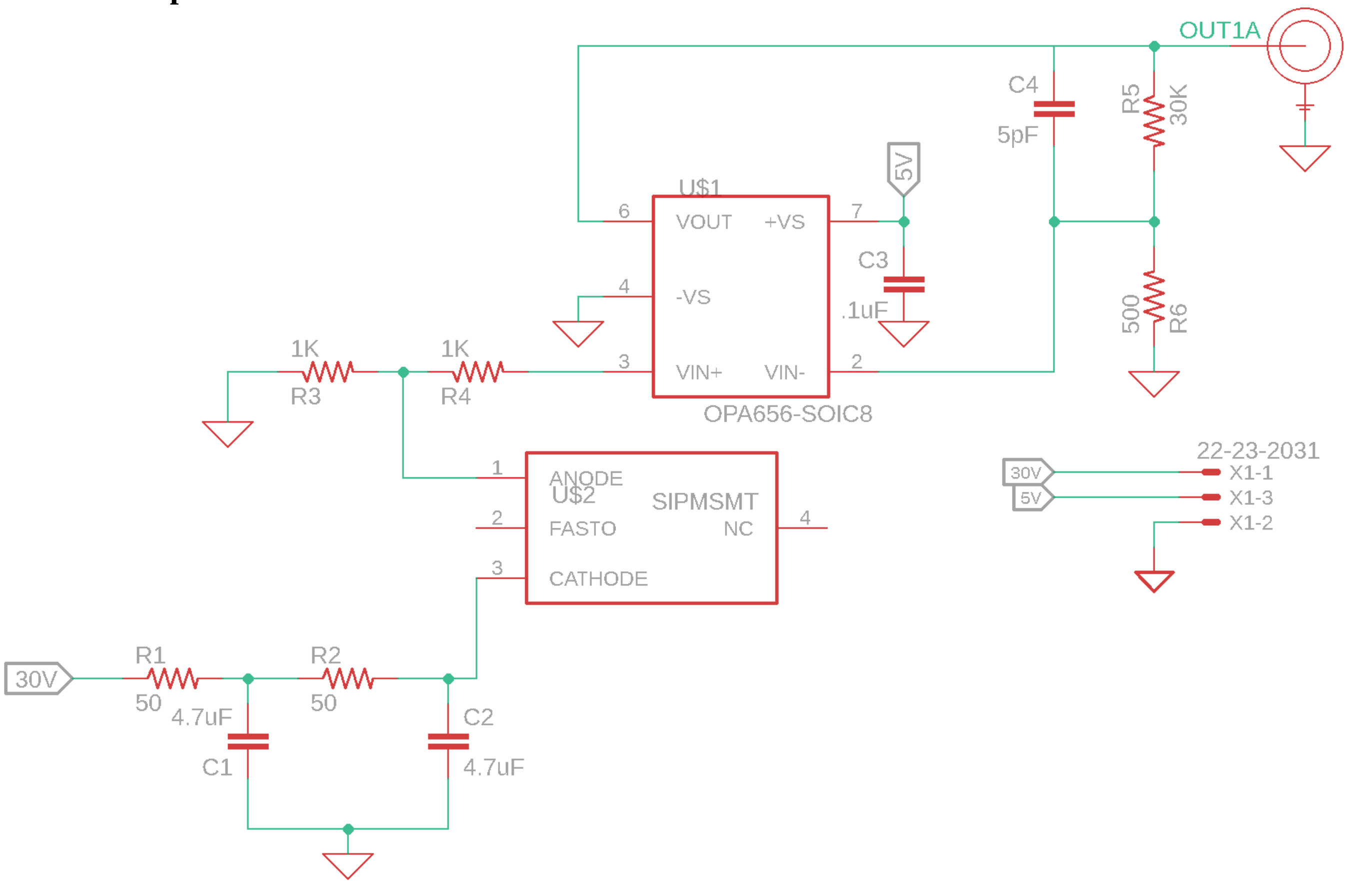

Figure 9: Schematic of endboard circuit

4.3 Mechanical Design and Dimensions

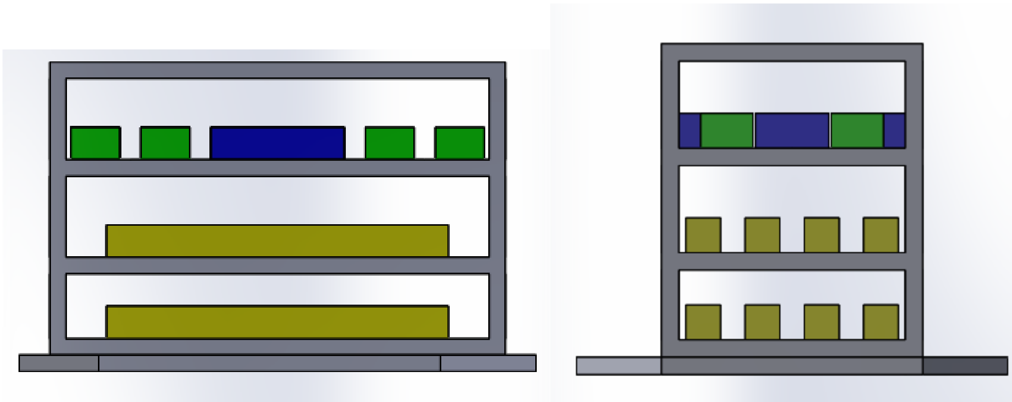

Figure 10: Side views of SPACE payload attached to mounting plate without aluminum walls or insulating foam. Dimensions: (7.5in x 14in x 9in)

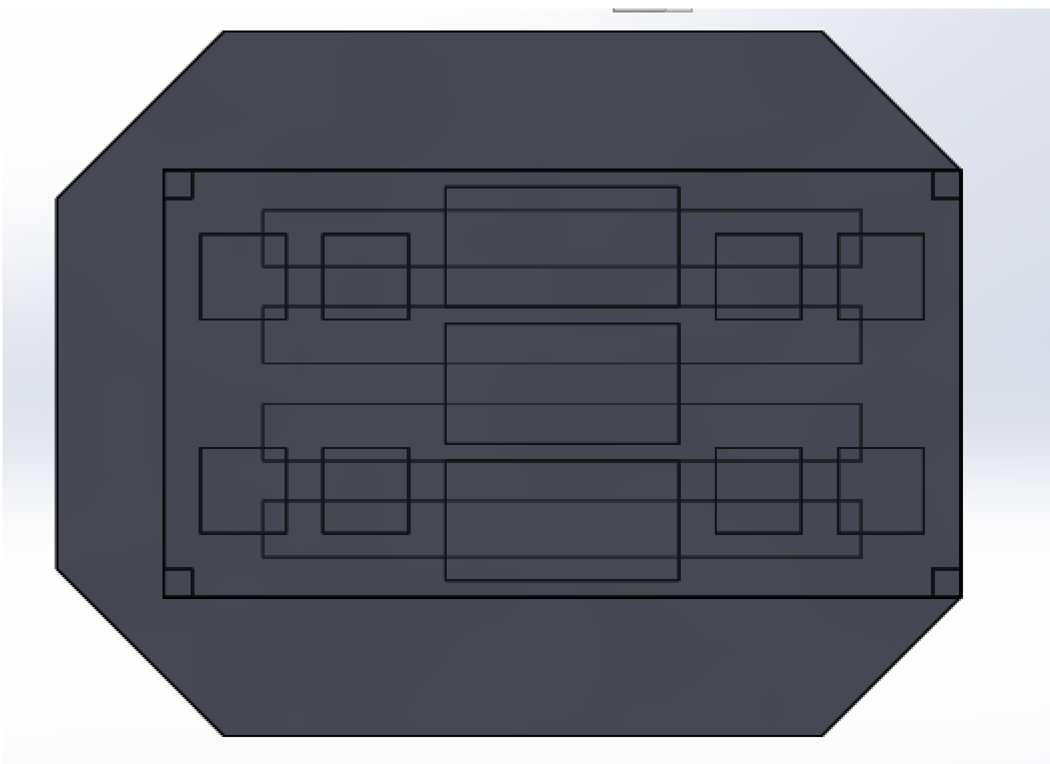

Figure 11: Top-down transparent view of SPACE payload attached to mounting board.

4.4 Payload Footprint

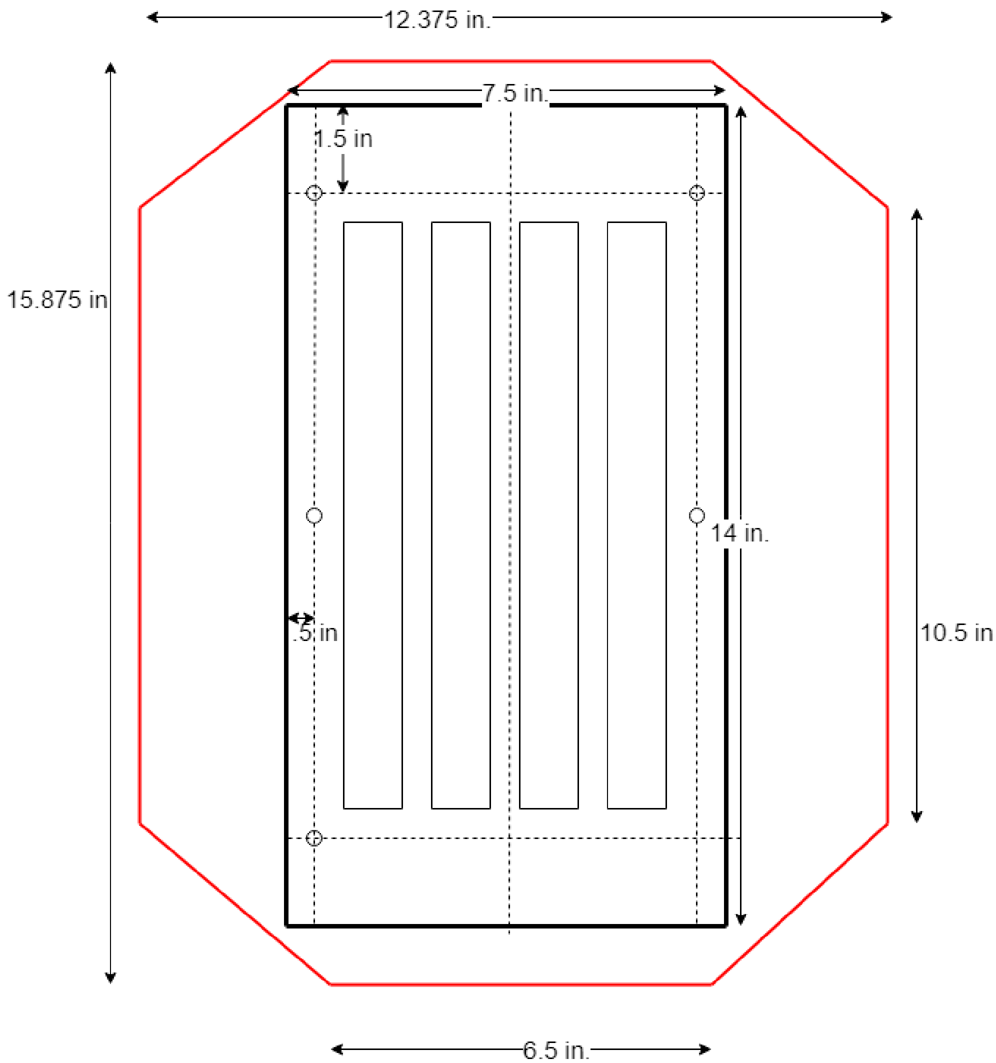

Figure 11: Mounting plate foot print of SPACE payload. Dimensions: 7.5in x 14in. Six #12 machine screws (0.21 inch diameter) with accompanying nut and washer will secure the payload to the mounting plate. In red is shown the inner boundary of the HASP mounting plate keepout area. Location of mounting holes for securing base plate of spacer to HASP plate shown as well.

5.0 References

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