HASP Student Payload Application for 2012

Payload Title: ***Student Payload First Flight***		
Payload Class: (check one) ☐ Small x 2 ☐ Large	Institution: Boston University/Georgia Institute of Technology/New Mexico Tech	Submit Date: 16-Dec-2011

Project Abstract

The BUSAT program, in conjunction with development teams from Georgia Institute of Technology (GA Tech) and New Mexico Institute for Mining and Technology (NMT) intends to fly the Satellite Platform Integrated First Flight (SPIFF) aggregate instrument platform to gather baseline data on the fair-weather electric field, monitor the high-altitude magnetic field, and record changes in the structural integrity of a high-altitude scientific instrument. SPIFF will also advance the technology readiness of three student-built instruments as well as a central support module, enabling future development and use in the scientific spaceflight community. Experiments include an Electric Field Mill (EFM), a piezoelectric structural health monitoring sensor array (SHM), and a magnetometer (MAG). The central support module (the "Hub") will interface with peripheral payloads using Space Plug-and-Play (SPA-1) software developed by AFRL. Each team will include a project manager and engineer responsible for overall development. Interface between BUSAT, NMT and GA Tech teams will be the responsibility of each team's project manager. Interfaces require ***two small payload positions*** (referred to herein as **PAYLOAD 1** and **PAYLOAD 2**)with minimal mounting plate modification, ***two analog downlinks*** via EDAC 516 connector and ***one RS 232 data line*** via DB9 connector.

Team Name: ***Student Payload First Flight***		Team or Project Website: N/A
Student Team Leader Contact Information:		Faculty Advisor Contact Information:
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1. INTRODUCTION

Student Payload First Flight (SPIFF) Payload Description: Scientific Objectives, High Level Review of Payload Systems, Statement of Principle of Operation of Experiments
The Student Payload Integrated First Flight (SPIFF) mission seeks to unify diverse scientific instrumentation aboard a high altitude balloon flight for the dual purpose of recording pertinent high-altitude scientific data for university research, and for furthering the impact of current plug and play technologies in scientific remote sensing for extreme environments. The SPIFF mission has three components in ***two payload*** *modules: The Hub and the SHM instrument make up Payload 1 while the EFM is Payload 2.*

2. PROJECT DESCRIPTION

2.1 The Hub

Principal Investigator: Professor Theodore Fritz
Project Manager: Nate Darling
Project Engineer: Christopher Hoffman

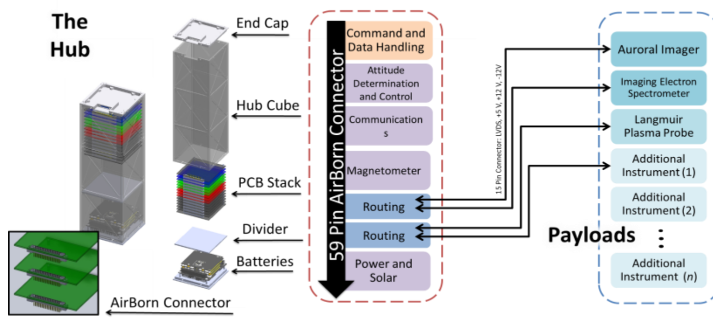


FIGURE (1): The BUSAT Hub showing peripheral payload

The Boston University Student satellite for Applications and Training (BUSAT) program is a grassroots spaceflight hardware development program for students of engineering, physics, astronomy, and computer science. While professional and academic mentorship is essential to the program, ***BUSAT is entirely staffed and directed by students of Boston University and Boston University Academy***. Cooperative efforts by students at Georgia Institute of Technology and New Mexico Institute of Mining and Technology also contribute considerably to the BUSAT effort. The SPIFF mission will serve as a milestone in hardware development and qualification of BUSAT's space weather satellite development project by advancing the technology readiness of its fundamental components. In addition to the scientific mission, the BUSAT and SPIFF missions address the high cost, long development schedule, and challenging interface environment that characterize current space hardware development projects, thereby impeding collaboration efforts and access to space and other hazardous regimes as scientific sampling environments. This is accomplished by compartmentalizing the satellite's diverse instrumentation into 10cm cubic modules and reducing every interface (mechanical, electrical and software) to a common standard, effectively

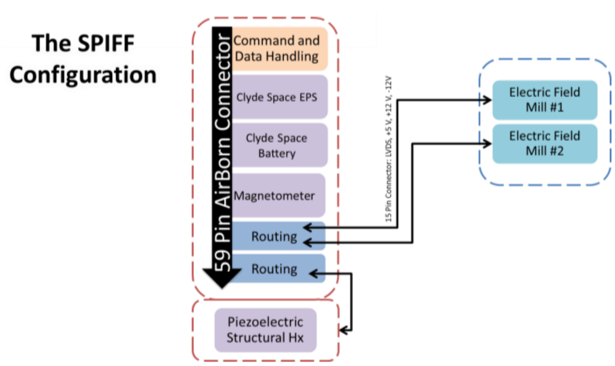


FIGURE (2): The BUSAT Hub configured for the SPIFF / HASP mission allowing a local or remote development team to deliver an instrument that can be integrated and ready for testing in minutes and hours, rather than days or months.

"The Hub" and SPIFF

The mechanical, electrical and software core of the BUSAT satellite is referred to as "the Hub" and comprises all of the subsystems essential to the functions of a scientific satellite mission, including a central single-board computer, electric power supply and batteries, radio, attitude determination and control, a magnetometer, and several routing boards for interface with peripheral scientific subsystems. The Hub is configured for Space Plug-and-Play Architecture (SPA-1) physical layer interfaces with peripheral instrumentation. This allows standardization of interface specifications and drastically simplifies the effort required to connect several instruments quickly with the Hub. Additionally, the structure of the hub allows additional 10cm cubes to be locked into place around it, and is strong enough to withstand the launch environments on a wide variety of vehicles. The Hub will function as the central node of the SPIFF mission, interfacing with the EFM and the SHM via SPA-1.

2.2 Miniature Electric Field Mill (EFM) for volcanic plume research

Principal Investigator: Josef Dufek
Project Manager/Project Engineer: Joshua Mendez
Co-Investigator: John Trostel

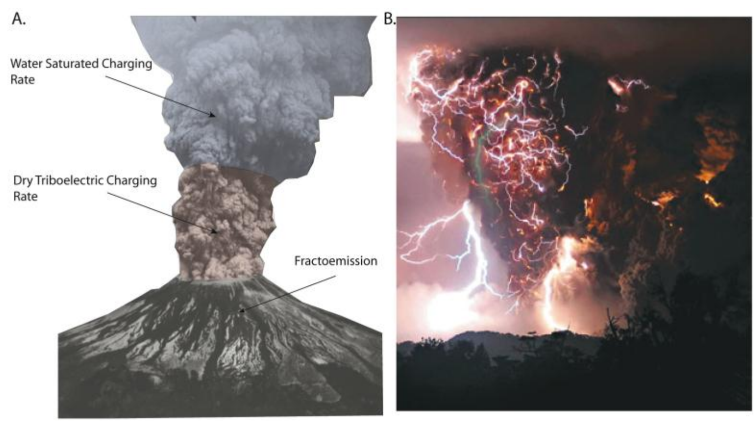


FIGURE (3): Regions of plume electrification B. Strong electrical fields result in the dielectric breakdown of air. Both the static field and lightning can be detected with relatively simple technology

The spectacular electrostatic discharges that occur during eruptions testify to the huge potentials that are generated within plumes as ash becomes charged. Since the production and movement of charged particles are closely coupled to the updrafts in an eruptive column, the electromagnetic signals they produce must reflect the physics of the plume itself. In other words, we hypothesize that the proximal plume dynamics can be inferred from measured electric fields and lightning observations.

The need to characterize plume dynamics in the near-field was clearly demonstrated when key airways were paralyzed by the eruption of Eyjafjallajökull in 2010. As stated in the International Civil Aviation Working Paper (July, 2011), two important sources of uncertainty in current models are the proximal dynamics of particle sorting and aggregation, which determine how long these remain in a plume. While it is nearly impossible to directly probe the dynamics in a plume, the resulting electrical signals can be measured with relatively simple technologies like field mills (EFM).

Interconnected with Space-Plug-and-Play (SPA-1), we hope to expand this architecture to earth based systems in extreme environments. Our goal is to realize a self-configuring wireless network of EFMs which can be integrated and deployed around a cone within days of the start of activity. Using the technique described by Renno et al [2007], our EFM can measure both the ambient field and the charge on precipitating ash particles. Once deployed, this network will allow us to closely monitor the evolution of the overhead E-field as ash becomes charged and is advected above the volcano. By flying one EFM on HASP, we will be able to test the operation of the instrument as well as our novel implementation of the SPA-1 protocols. Furthermore, the relative simplicity of field mills presents a great introduction to practical electronics and how to use technology to network the physical world. Over the course of the next year we will involve students at the high school level in constructing and testing the field mills.

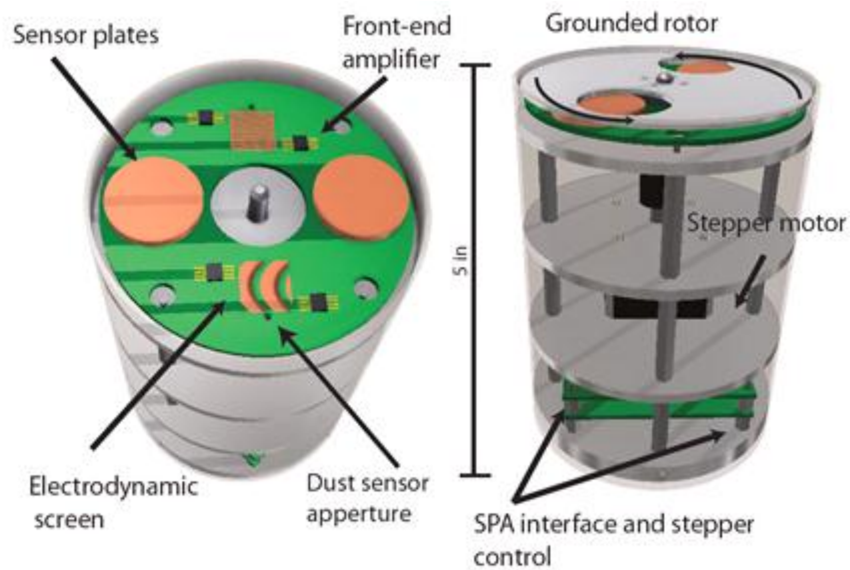


FIGURE (4): The EFM Instrument showing basic PCB and mechanical design

2.3 Structural Health Monitoring: SHM

Principal Investigator: Professor Anders Jorgensen
Project Manager: Jordan Klepper
Project Engineer: Mathew Landavazo

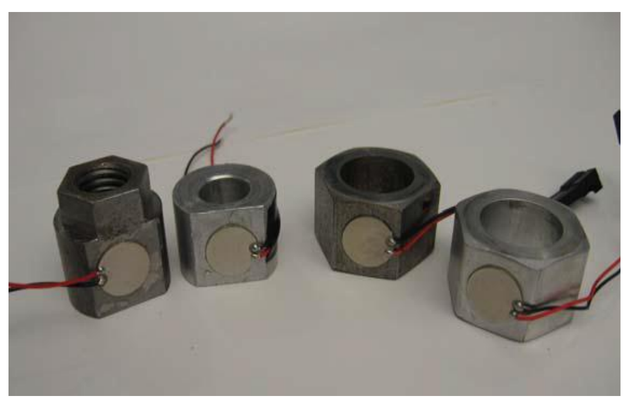


FIGURE (5): Piezoelectric wafer sensor / actuators

The SHM instrument utilizes multiple piezoelectric actuator / sensors to provide onboard structural health monitoring for platforms operating in extreme environments such as low-Earth orbit, near space, and even during delivery and integration stages. In this way the structural integrity of expensive and often one-of-a-kind instrumentation can be monitored to mitigate risk of failure during critical mission phases. Piezoelectric actuator / sensor “wafers” (PZTs) are placed strategically on jointed elements such as bolts (see FIGURE (7)) and driven by an alternating electric field. The resulting mechanical vibration excites the structural element, which in turn transfers back to the PZT, producing an electrical response. Electrical impedance can then be correlated to structural impedance, allowing a baseline structural health response to be measured. Any future change in electrical impedance indicates a change in mechanical impedance and therefore also a change in the structural element such as loosening or plastic deformation.

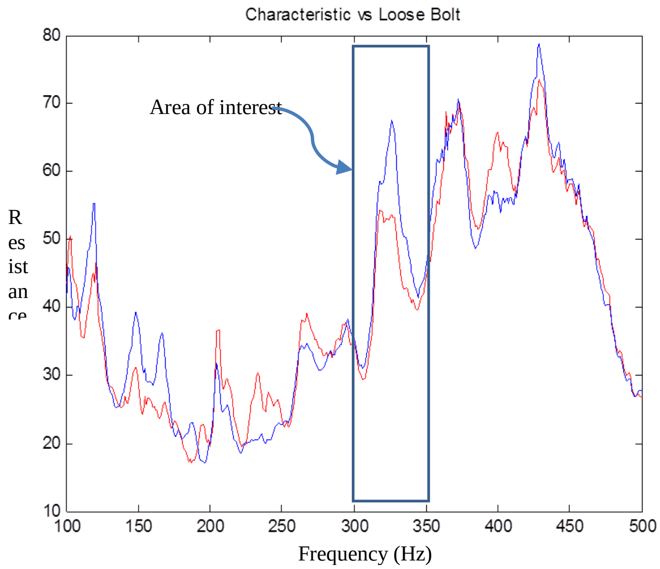


FIGURE (6): Characteristic vibration response (blue) with loose bolt response (red)

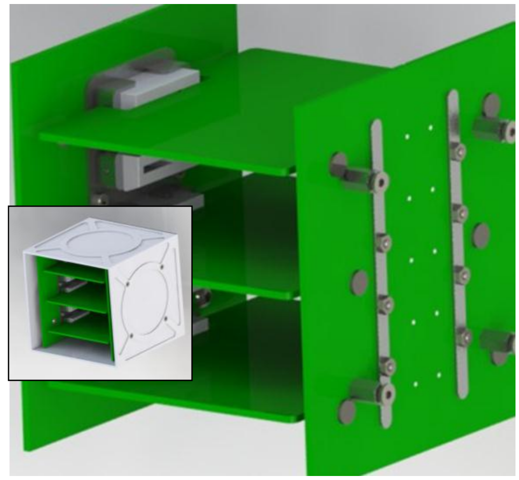


FIGURE (7): SHM printed circuit board configuration showing detail of cube housing and slot connector design.

2.4 Thermal Control Plan

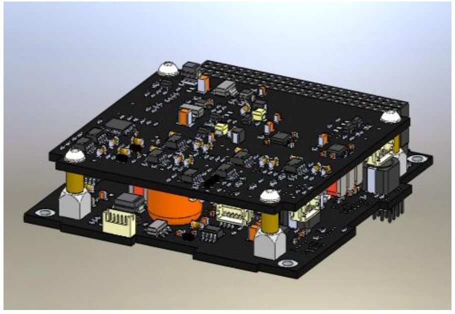


FIGURE (8): Clyde Space FlexUEPS Electronic Power Supply (EPS)

All instruments will be contained within cube elements that conform to the BUSAT standard form factor (although 6063-T6 aluminum will be substituted with lighter prototyping structural materials). This will not afford much insulation or thermal control. Passive thermal control will be provided by a 1" foam housing surrounding the instruments. Additionally, the Clyde Space FleXUEPS includes internal active thermal control that activates at 0˚C. Although the need for more active thermal control is not anticipated, thermal resistors could be used if their use is warranted by thermal / vacuum chamber testing at Boston University.

3. TEAM STRUCTURE AND MANAGEMENT

3.1 Boston University

Theodore Fritz: Principle Investigator (BUSAT)
Theodore Fritz is a Professor in the Astronomy Department at Boston University and member of the BU Center for Space Physics. Dr. Fritz brings rings to the project 40 years of experience in spacecraft and instrument design and will oversee the HUB development effort at BU.

Nathan Darling: Project Manager (BUSAT)
Nathan Darling is a graduate mechanical engineering student studying the vibration and environmental testing of small satellite structures. He has several years of team leadership through outdoor education and has applied much of this experience to the BUSAT effort since beginning work on the project in January, 2011. Nathan will oversee structural design, logistical issues, and act both as the SPIFF Project Manager and as point of contact and coordinator for BU, GA Tech, and NMT.

Christopher Hoffman: Project Engineer (BUSAT)
Christopher Hoffman is a junior electrical engineer at Boston University. As BUSAT's project manager and power systems engineer, Chris designed BUSAT's modular solar panels and electronic power system. Chris will oversee the SPIFF power system development and other electrical aspects of the system.

3.2 Georgia Institute of Technology

Josef Dufek: Principal Investigator (Georgia Institute of Technology)
Josef Dufek is an Assistant Professor of volcanology and multiphase fluid dynamics in the School of Earth and Atmospheric Science at Georgia Tech. Joe Dufek is well known in the geophysics community for his transformative science and innovative computational methods. Dr. Dufek will oversee the development and deployment of the field mill sensor network in the context of volcanic processes.

Joshua Mendez: Co-Investigator (Georgia Institute of Technology)
Josh Mendez is a first year graduate student at Georgia Tech. He worked on both BUSAT I and II as an undergraduate. With experience in embedded systems and analog circuit design, he will lead the construction of the field mill, in addition to a semester-long course on the design of sensor systems for hazardous environments during the spring of 2012. Josh will act as the SPIFF Project Engineer, overseeing the integration of the constituent subsystems.

John Trostel: Co-Investigator (Georgia Tech Research Institute)
John Trostel is the director of the Severe Storms Research Center (SSRC) at the Georgia Tech Research Institute. Working with students at the college and high school levels, he is engaged in developing novel ways to forecast storms, as well as instrumentation.

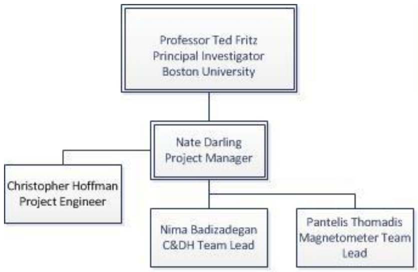
3.3 New Mexico Institute for Mining and Technology

Anders Jorgenson: Principal Investigator
Anders Jorgensen's research interests span a wide range of topics from astronomical instrumentation and techniques through space plasma physics and space weather to sensor networks and machine learning algorithms. Dr. Jorgensen received his PhD in Astronomy from Boston University, and is the Principal Investigator for the SHM instrument.

Jordan Klepper: Project Manager
Jordan Klepper is a senior mechanical engineer at New Mexico Tech. He has recently worked on the development of a plug-and-play Langmuir probe for AFRL. Jordan will oversee the structural design of the SHM system, sensor placement, and structure characterization.

Matthew Landavazo: Project Engineer
Matther Landavazo is a senior electrical engineering student at New Mexico Tech and will oversee electrical development of the SHM. Matt also contributes to the Langmuir Plasma Probe for the BUSAT project.

3. 4 Organizational Chart and Contact Information



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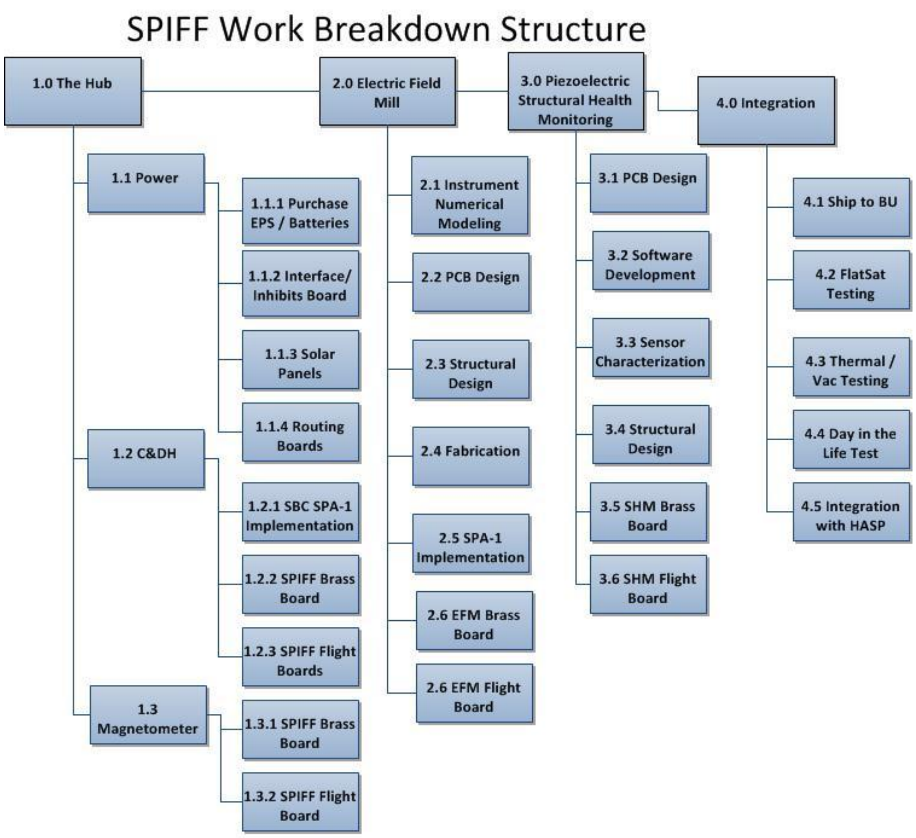
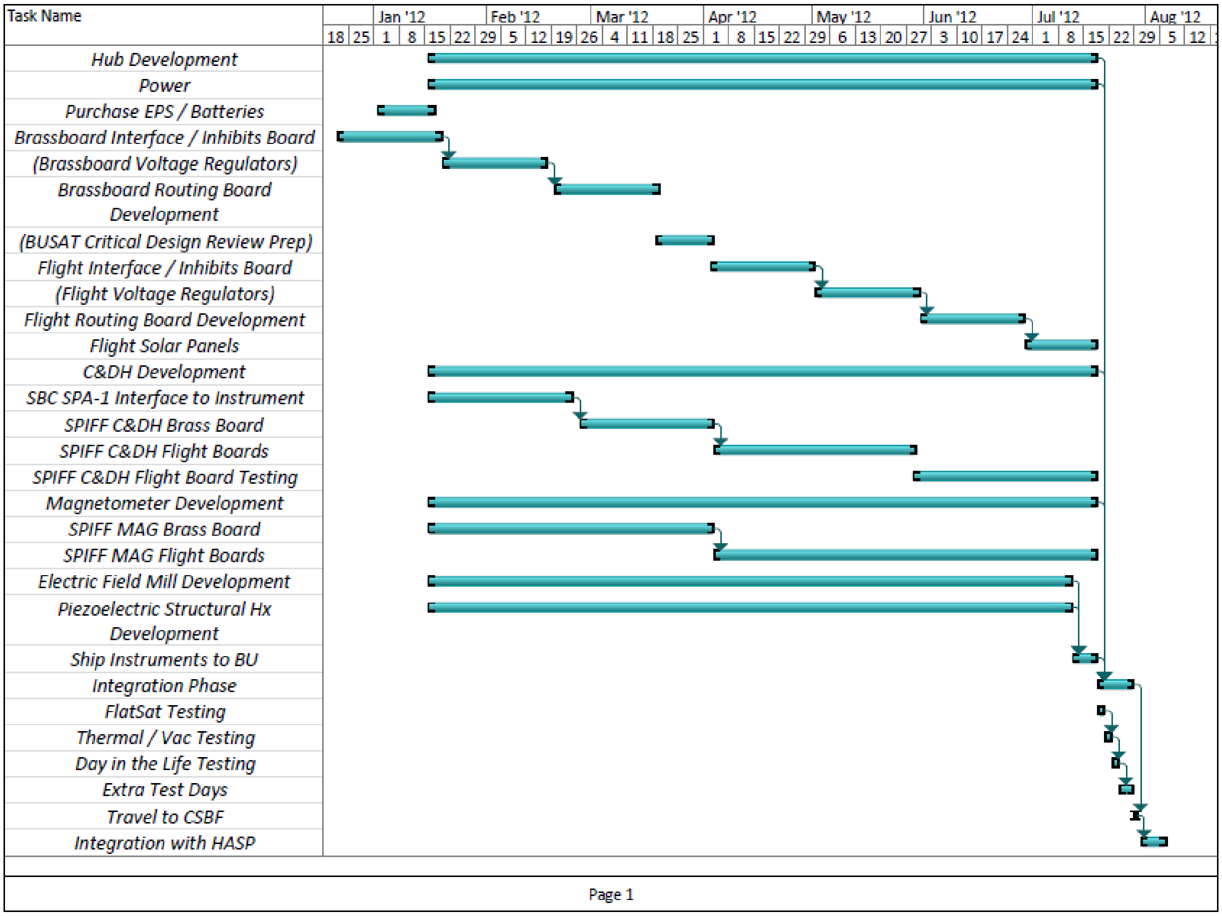
3.5 Work Breakdown Structure



3.6 Scheduling



3.7 Number of Personnel Needed for Integration

The SPIFF instrumentation will require four personnel on site for integration. The BUSAT project manager will coordinate personnel, oversee transportation and logistics, and manage testing and the SPIFF team during integration. The BUSAT project engineer will oversee technical details of testing and integration. One representative from each of the collaborating universities will also be present during this phase.

4. PAYLOAD SPECIFICATIONS

4.0 Configuration and definitions

To correctly assess the performance of the SPA-1 protocol we are requesting two small payloads on the 2012 HASP launch. For simplicity of integration, and to avoid confusion during integration, we are hoping to obtain payloads that share a boom; that is, either payloads 2 and 3, 4 and 8, 1 and 5 or 6 and 7.
In this document we refer to this payload pair as **PAYLOAD 1** and **PLAYLOAD 2**.
Payload 1: Small payload including the HUB and SHM subsystem
Payload 2: Small payload including the EFM subsystem
To implement the SPA-1 functionality we will run a shielded cable between these packages. While we use the SPA protocol to receive and transmit data between the HUB, the EFM and the SHM, the physical layer connection consists of a differential I2C pair (SDA and SDK).

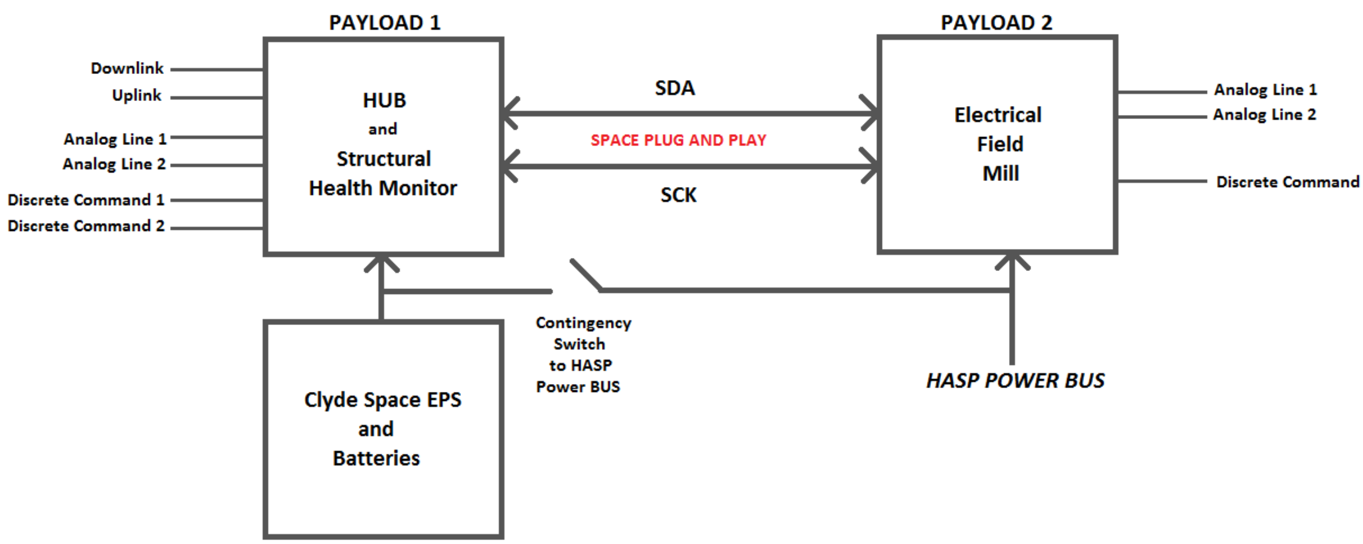


FIGURE (9): Overall system block diagram, showing interconnecting between two small payload packages

4.1 Weight Budget

TOTAL EXPERIMENT MASS: 2308 g
PAYLOAD 1 MASS: 1721 g
PAYLOAD 2 MASS: 587 g

Subsystem: HUB	Item	Quantity	Mass ea. (g)	Total
Structure	External Panels	4	50	200
	Mounting	8	25	200
	Fasteners	18	1	18
PCBs	C&DH Board	1	40	40
	EPS	1	140	140
	Batteries	2	260	520
	Solar panels	6	10	60
	Magnetometer	1	3	3
	Extra boards	2	30	60
TOTAL MASS:				1241

TABLE (1): Mass budget for HUB

Subsystem: EFM	Item	Quantity	Mass ea. (g)	Total
Structure	Sleeve	1	84	84
	Shielding plates	4	48	194
	Stand-offs	12	1.4	16.8
PCBs	Processor board	1	40	40
	Motor driver	1	3	3
	Front-end analog	1	20	20
	Stepper driver	1	130	130
	Fasteners	100	1	100
TOTAL MASS:				587

TABLE (2): Mass budget for EFM

Subsystem: SHM	Item	Quantity	Mass ea. (g)	Total
Structure	External Panels	4	25	100
	Fasteners	8	25	200
	Misc.	1	100	100
PCBs	Processor board	1	40	40
	Piezo Transducers	10	2	20
	Misc.	1	20	20
TOTAL MASS:				480

TABLE (3): Mass budget for SHM

4.2 Mounting Plate Footprint

Payload	Footprint
Payload 1: HUB and SHM	**4.882 in x 4.882 in (12.400 cm x 12.400 cm)**
Payload 2: EFM	**3.500 in x 3.500 in (8.890 cm x 8.890 cm)**

TABLE (4): Mounting footprints
NOTE: See FIGUREs (12) and (14)

4.3 Payload Height:

Payload	Height
Payload 1: HUB and SHM	**11.4 in (29 cm)**
Payload 2: EFM	**4.650 in (11.8 cm)**

TABLE (5): Instrument heights
NOTE: See FIGUREs (10) and (11)

4.4 Power Budget

TOTAL EXPERIMENT POWER: 9.995 Watts
PAYLOAD 1 POWER: 5.89 Watts
PAYLOAD 2 POWER: 3.3 Watts

Subsystem: HUB	Op. Voltage	Current (A)	Power
NanoCDH	3.3	0.500	1.650
FlexUEPS	3.3	0.350	1.155
Honeywell Mag.	12	0.033	0.400
Atmega	3.3	0.300	0.990
TOTAL:			4.195

TABLE (6): Power budget for HUB

Subsystem: EFM	Op. Voltage	Current (A)	Power
Mill Motor	5	0.280	1.400
Processor	3.3	0.500	1.650
MISC	5	0.050	0.250
TOTAL:			3.300

TABLE (7): Power budget for EFM

Subsystem: SHM	Op. Voltage	Current (A)	Power
Piezoelectric Trans.	5	0.010	0.050
Processor	3.3	0.500	1.650
TOTAL:			1.700

TABLE (9): Power budget for SHM

PAYLOAD 2 will draw power directly from the HASP bus, while PAYLOAD 1 will employ a commercial EPS and battery pack for power from Clyde Space. While the total experiment power is a very conservative overestimate that will be reduced by accounting for duty cycle, and confirmed by system testing during the spring 2012 semester, there is a very real possibility that the HUB mission will not have sufficient battery life for a 24-hour balloon flight. The HUB development team has two contingency plans:

Backup Power Supply:
SPIFF will also be capable of switching power supplies when the Clyde Space battery reaches a predetermined depth of discharge. The power supplied via the EDACS 516 connector will be routed through an alternate power regulator in the Hub, and will replace the FlexUEPS in powering the instruments for the remainder of the flight. In this way both the scientific mission and hardware qualification will be achieved.

4.5 Downlink Serial Telemetry Rate

Mode	Rate
Nominal telemetry rate	277 bytes/min

Table (10): Packet description

The digital downlink will only be employed on PAYLOAD 1.

Description	Length
DOWNLINK PACKET	
Starting word	1 byte
System time	4 bytes
Packet ID	2 bytes
Number of payloads	2 bytes
System status	2 bytes
Number of payload packets	2 bytes
Payloads packets	N packets
Checksum	8 bytes
PAYLOAD PACKET	
Instrument code	1 byte
Instrument status	1 byte
Time of packet arrival	4 bytes
Packet length	2 bytes
Data	N bytes
HUB DATA	
Subsystem data	N = 8 bytes
EFM DATA	
Subsystem data	N = 8 bytes
SPH DATA	
Subsystem data	N= 8 bytes

Table (11): Packet description

4.6 Uplink Serial Command Rate

In addition to the downlink, we are requesting uplink capabilities to send commands to the HUB. In other words, we require uplink capabilities for Payload 1 only. Succinctly, we would like to change the configuration of the SPA-1 protocol during flight to test the robustness of the network between Payload 1 and 2. We implement the command format suggested by the integration manual.

List of commands:
1. On/Off (sleep state)
2. Carry out calibration sweep on selected sensor
3. Measure and compare preset bandwidths on selected sensor or all.
4. Measure and compare custom bandwidths on selected sensor or all.
5. Return Latest Measurement Data.

6. Return Auxiliary Measurement (Thermometer and Accelerometer)
We are expecting to send a command **every hour.**

Description	Bits	Byte
Least significant 4 bits of the command checksum	**0-3**	**First**
Student Payload ID	**4-7**	**First**
Command byte	**0-7**	**Second**

Table (12): Two byte command format

4.7 Use of Analog Downlink Channels

PAYLOAD 1:
The Hub (PAYLOAD 1) will monitor raw magnetometer data via the analog downlink channel provided (**channel one**). The BUSAT satellite bus is capable of charging the Clyde Space lithium-ion polymer battery set on orbit using a set of 27 10cm x 10cm solar panels. At just under 60g per panel, cost-benefit analysis of the effect on both weight and power budgets does not justify including all 27 panels. BUSAT proposes instead to use one analog downlink channel (**channel two**) to independently monitor the output of a single, zenith-facing panel to better understand its behavior in space environment.

PAYLOAD 2:
The EFM will use both of the analog downlink channels provided in PAYLOAD 2. **One channel** will be employed to directly monitor the output of the analog front end. While instrument data will be transmitted to ground using the provided downlink on PAYLOAD 1, we implement this feature in the event the SPA-1 link between both payloads fails during flight. As such we will still be able to recuperate the necessary data to assess the operation of the EFM during the high altitude flight.
The **second channel** will be used to monitor the temperature within the field mill during the flight.

4.8 Additional Discrete Commands

PAYLOAD 1:
Preferentially, PAYLOAD 1, housing the HUB, would include two discrete payload lines. The first discrete command will be used as way to change the size of the downlink packet. The second discrete command will be used as a failsafe to power down the system in the event of an emergency.

PAYLOAD 2:
The EFM will use one discrete command channel as a safety feature to deactivate the instrument in the event of an emergency.

4.9 Desired Payload Location and Orientation

We are requesting to have both PAYLOAD 1 and PAYLOAD 2 on the same HASP boom (refer to FIGURE (16)).This will simplify the SPA-1 interconnection that must run between both payloads, as it will avoid potential interference with other experiments. Additionally, we would like to request small payload packages which include additional discrete command lines.

4.10 Description of Integration Procedures

Both the HUB (PAYLOAD 1) and the miniature field mill (PAYLOAD 2) have a bolt hole patterns on their bases (see FIGUREs (10) and (11)) which serves to directly attach the instrument to the mounting plate (see FIGURE s(12) and (14)).

4.11 Request for Waivers

N/A

5. PRELIMINARY DRAWINGS

5.1 Dimensioned Drawings of Payloads

5.1.1 HUB (PAYLOAD 1)

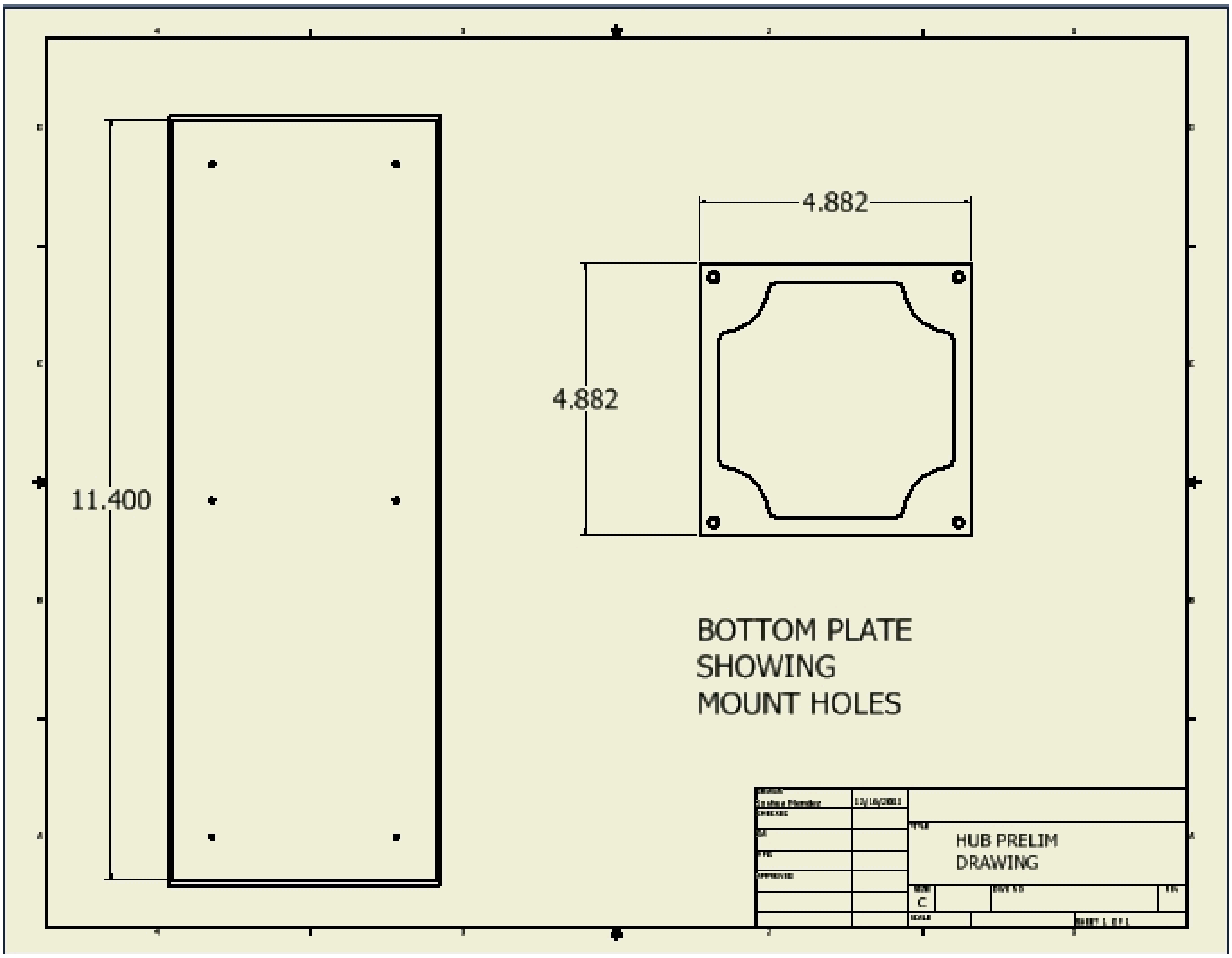


FIGURE (10): Dimensional drawing for the BUSAT HUB

5.1.2 EFM (PAYLOAD 2)

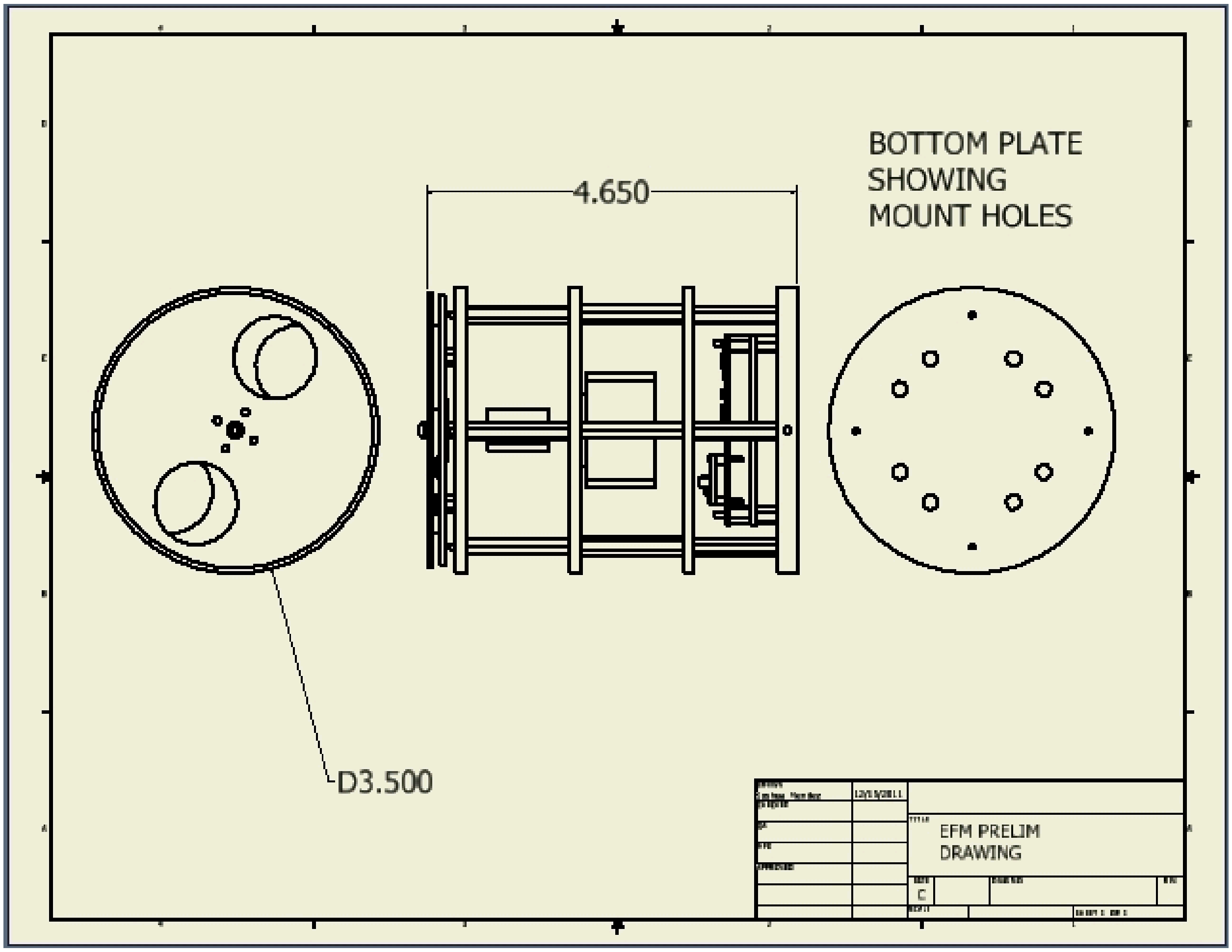


FIGURE (11): Dimensional drawing for the EFM

5.2 Anticipated Modifications of Mounting Plate

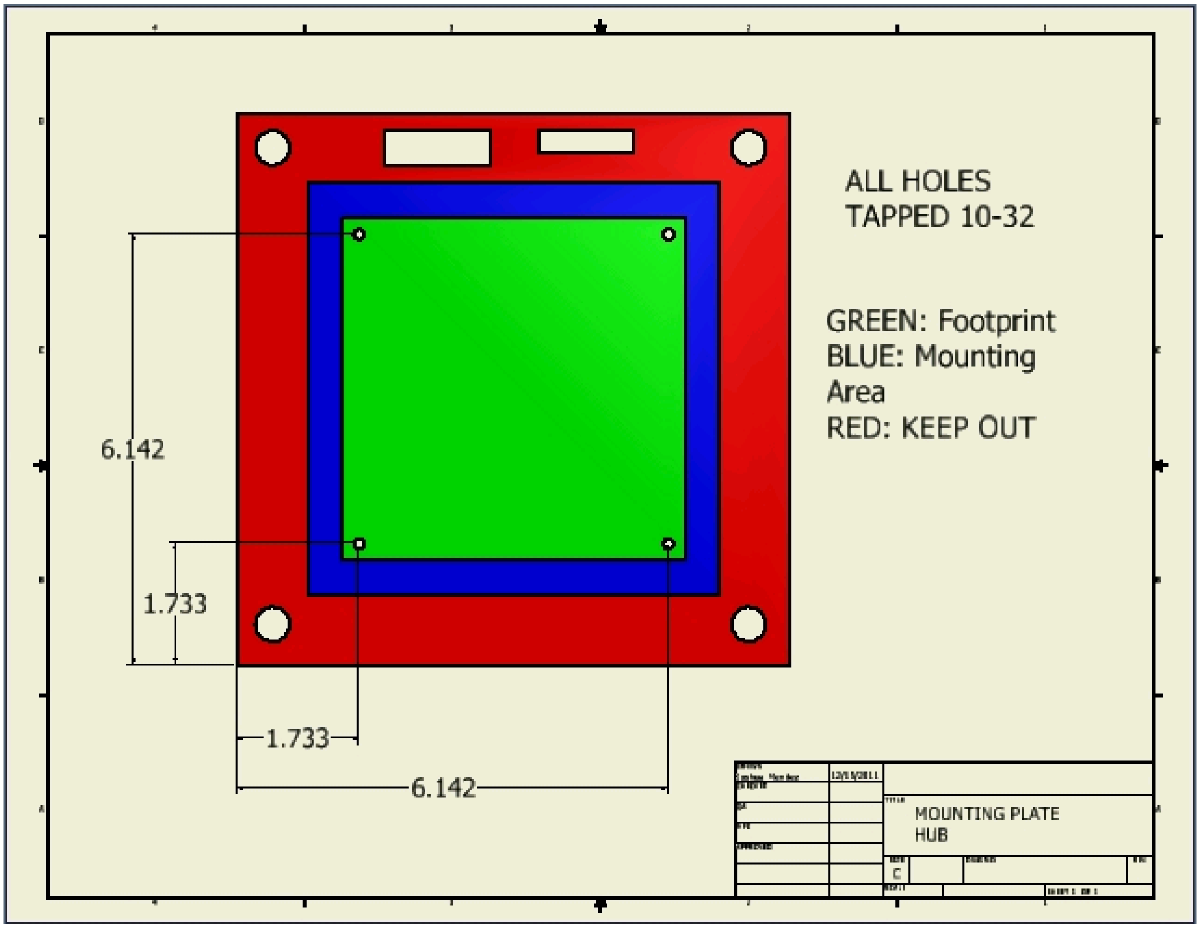


FIGURE (12): Diagram of modified mounting plate for the BUSAT Hub

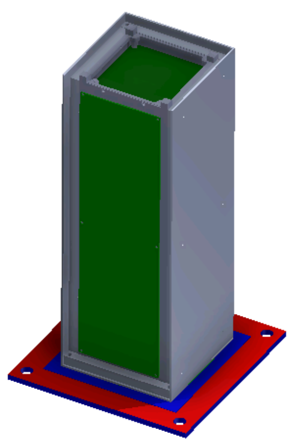


FIGURE (13): CAD rendition of completed HUB mounted on the HASP interface

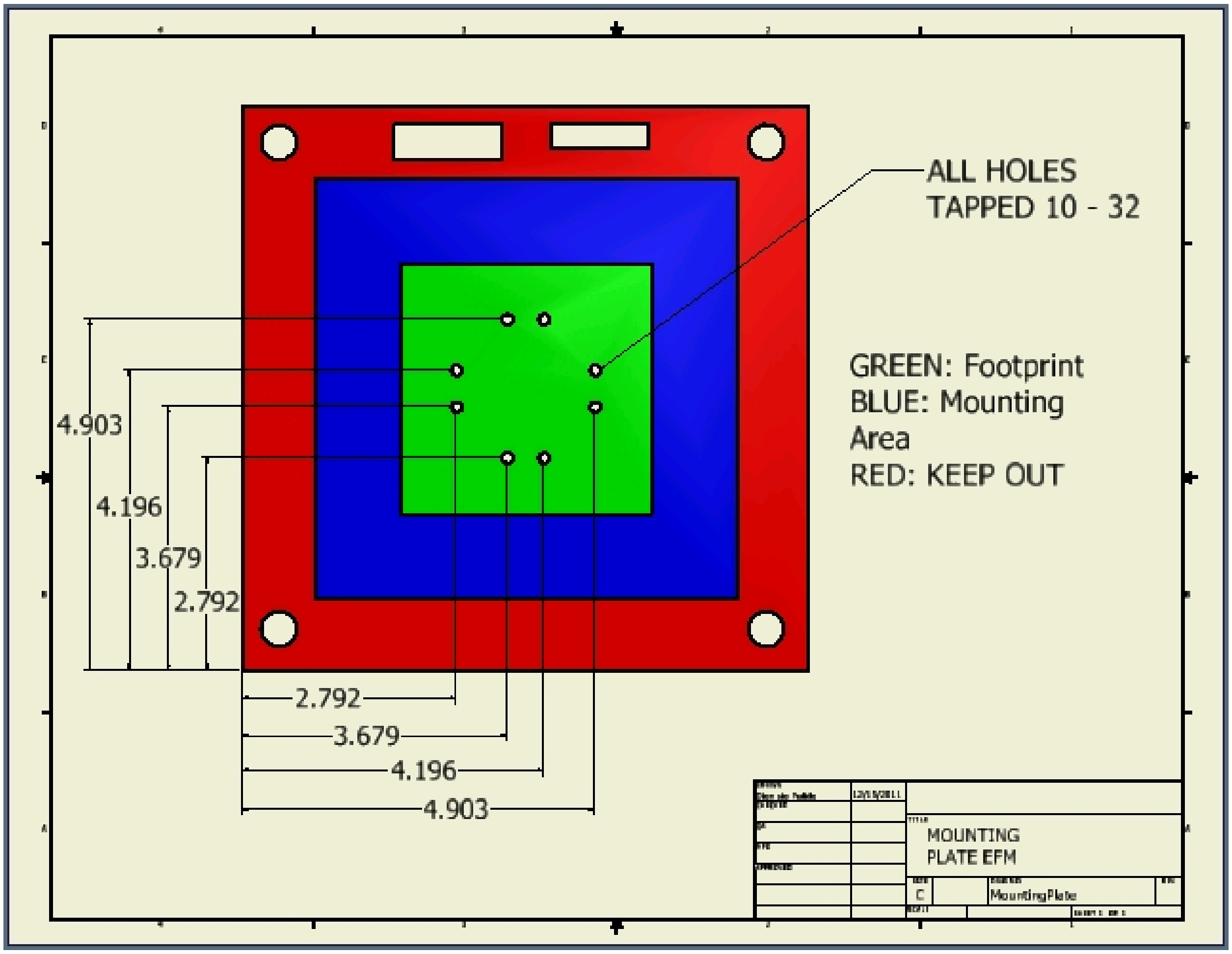


FIGURE (14): Diagram of modified mounting plate for the electrical field mill

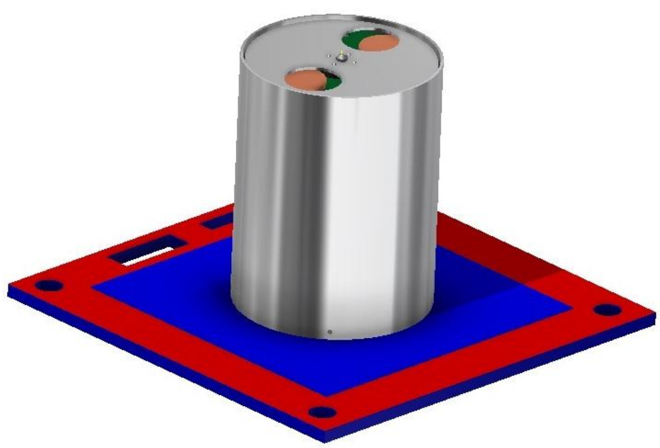


FIGURE (15): CAD rendition of completed field mill mounted on the HASP interface

5.3 Sketches of Mounting Structure

N/A

5.4 Illustrations of Preferred Payload Orientation and Location on HASP

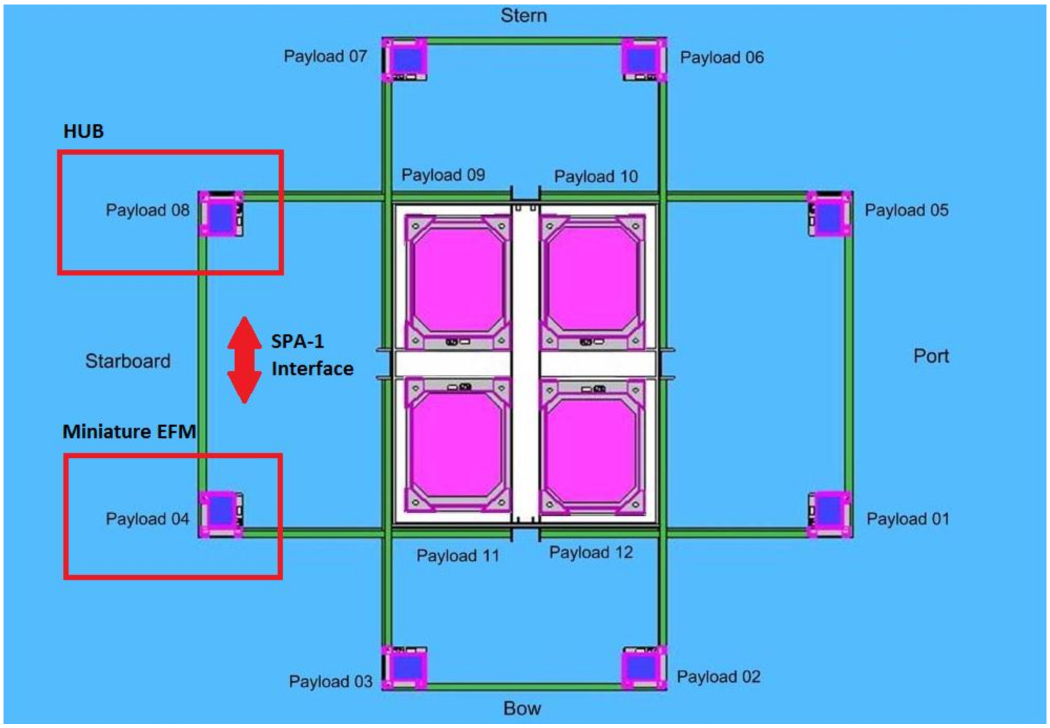


FIGURE (16): Location of the two small pay loads. We require having both payloads on the same boom. In the example above, we show both boxes on the starboard boom.

6. LETTER OF SUPPORT

Boston University

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Boston, Massachusetts 02215

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Fax: 617-353-6463
E-mail: *csp@bu-ast.bu.edu*

13 December 2011

This letter is to confirm the full support of the Center for Space Physics for the proposal "Student Payload First Flight (SPIFF)" submitted to the HASP call for proposals. The Principal Investigator for this proposal is Prof. Ted Fritz, the Project Manager is Nathan Darling, and the Project Engineer is Christopher Hoffman.

Sincerely,

John T. Clarke
Director, Center for Space Physics